The Relationships between Large-scale Atmospheric Circulation and Surface Climate: a Case Study for Borneo

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In the memory of my loving mother, the late ***Kimbodoh Gampul*** *(1930-1988 A.D), who had inspired and nurtured my intellectual awareness; but unfortunately, had never had the opportunity to see me stepping my feet (literally and proverbially) into university.*

And, for my father, ***Dambul Dumaring****, who is currently fighting for life.*[Note]

Climate is a function of time. It varies; it is subject to fluctuations; it has a history.

Emmanuel Le Roy Ladurie
Times of feast, times of famine, "A history of climate since the year 1000".
(Allen and Unwin, 1972)

[Note] Exactly a week after submitting, and two weeks prior to the oral exam, my father passed away. Obviously I missed the funeral, the least I could have done since I hadn't met him in three years. During his last few difficult months, he had insistently encouraged me to keep going with the research. Whether to stay in UK or simply go home to be with him – it could have been a very difficult decision. However, he made it easier by deciding it for me. Thank you, father.
- *Note added upon submitting the corrected version*

Abstract

The principal aim of this project is to relate the large-scale atmospheric circulation (of Southeast Asian region) to the surface environmental elements of Borneo (especially the local climate). The understanding of the climatic processes that link these two aspects serves as the key theoretical basis. The two most significant synoptic forcings affecting the surface climatic elements of Borneo are the monsoon and the El Niño Southern Oscillation, which are mutually interactive.

Three stages of analyses were involved. Borneo was first divided into six climatic sub-divisions according to similarity in surface climate. The long-term characteristics and trends for the local climate were then evaluated based on these climatic groups. This first stage also included the task to develop daily weather types (WTs) based on precipitation and temperature variability. The second stage was synoptic typing, which attempted to classify the large-scale atmospheric circulation (which consist of both monsoon and ENSO signals) into a few identifiable modes that can explicitly represent physical reality. The final stage was to establish relationships and teleconnections with surface environmental elements: i.e. precipitation and temperature. There are three main typing schemes developed in this thesis – i.e. the surface-based weather types (WTs – 8 types, but only 6 modes are significant in terms of occurrences), and the two synoptic-based circulation types employing: (i) absolute SLP data (combined season); and (ii) SLP anomaly (separate and combined seasons). These CTs, which produce eight circulation types each, have been related to surface environmental elements – precipitation and temperature.

The typing schemes have established reasonably good relationships with the surface climate – and successfully discriminates distinctive patterns of relationships based on seasonal and spatial factors. Generally, the relationships with precipitation were more clearly exhibited than with temperature. Another aim of this study was to examine which one of the large-scale variables (i.e. synoptic indicators or Circulation Types) performs better for estimating the surface climate of Borneo. In general, the synoptic indicators (i.e. ENSO/monsoon indices) were better correlated with temperature anomalies. However, the circulation types establish a much stronger (in terms of amplitude) correlation for precipitation variables.

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Menjunjung Budi[i]

Padi bukit bertampi sudah,
Anak kunyit celah jerami;
Budi sedikit bukannya mudah,
Seberat langit antara bumi.

Hill rice harvested by hand,
Tumeric peeps through rice stalks;
A little kindness I comprehend,
As heavy as the earth and stars[ii].

This project has been extremely challenging. It pushed me, cruelly, to the limit. The journey was totally a new route for me; miles away from my natural 'comfort zone' (my supervisors know what exactly I mean by this). So many times, I had actually been thinking of giving up. Fortunately, it never happened. I couldn't thank enough my principal supervisor, **Prof. Phil Jones**, for never losing his faith in me (and, that was the only reason that had kept me going). I feel very honoured having the opportunity working with a great academic/scientist like Phil. Throughout this project; he has been very supportive with great sense of empathy. He understood my limitations, and acknowledged my individuality (in terms of research approach). He provided me with all the essential ingredients, but allowed me to explore them in my own style. The entire experience has been truly rewarding, as far as learning process is concerned.

Yes, I have so many other people to thank for making this journey possible. But, the journey had been so exhausting – mentally, physically, emotionally and spiritually. By the time I was trying to write this dedication, I could barely think (yes, it's not an exaggeration!). I'm not sure if I could even express my appreciation appropriately. Every name mentioned here, regardless of how irrelevant they may appear to this research, had made a very significant contribution – in his/her own way.

My other supervisory team members (whom I'm indebted to),
Dr. Clare Goodess (Second Supervisor), who had not only offered supervision in terms of academic; but at times, willingly shared some motivational chats. Dr. Grant Bigg (Third Supervisor: Oct 2001 – Oct 2002), a relatively short period perhaps, but his valuable inputs are equally appreciated.

The technical and administrational supports from people in CRU,
Mr. Mike Salmon, he had been extremely helpful with computing-related matter (something I'm most idiot at). For what he had done, failing to mention his name would have been one of my biggest sins in life. Dr. Mick Kelly, for his guidance and advice for all PhD-related issues. Mr. Ian Harris, Mr. David Lister, Dr. Sidup Sirabaha and Dr. Malcom Haylock, who have provided/extracted some of the data used in this project. Mrs. Julie Burgess (who left CRU earlier this year), for all the seemingly 'little' favours, but actually made a huge difference – e.g. imagine how depressing it could be finding the photocopy machine broken down and nobody cares to offer some comforting words! Dr. Effie Kostopoulou, for generously sharing some of her valuable references and thoughts.

Dr. Awang Bugilba (my fellow Malaysian friend), who has prepared the template for my thesis (organising all the figures and tables manually, could have been an endless nightmare!). Lastly but not the least, all my fellow CRUian PhD-mates (especially, but not exclusively): Mansour Al-Mazroui, Stephen Blenkinsop, Mark Hoar, Matt Swan, Carol McSweeny, Abdullah Misnid, Matt Livermore, I Chen, Kate and Marco Salas. Each one of them had offered his/her empathy during one of my many poorly moments. Never underestimate some little favours of this kind, because when it's truly needed, a single word could mean the entire world.

I'm also thankful to these institutions,
University Malaysia of Sabah (for funding my research)
Climatic Research Unit & Dean of Student Office (University of East Anglia)
Malaysian Meteorological Services & Brunei Meteorological Services & Indonesia Meteorological and Geophysical Agency

[i] Menjunjung Budi literally means 'Expression of Gratitude' (in Malay). Pantun (*Pantoum*), a Malay traditional poem equivalent to the Japanese Haiku, is characterized by beautifully simple language but with deep meaning. In Malaysia, reciting pantoum is often regarded as one of the most gracious and classical ways to show an appreciation.
[ii] The translated version serves only as a rough idea of what the pantoum means. Of course, creative writing is highly contextual, and unique to every language and culture. Thus, literary values are often impossible to be transferred from one language to another, without losing its natural elegance, along the process.

Abbreviations

	STATIONS
BMS	Banjarmasin (Kalimantan)
BPN	Balik Papan (Kalimantan)
BRA	Brunei Airport (Brunei)
BRK	Kilana (Brunei)
BRL	Labi (Brunei)
BRS	Seria (Brunei)
BTK	Buntok (Brunei)
BTU	Bintulu (Sarawak)
KBA	Kota Baru (Kalimantan)
KCH	Kuching (Sarawak)
KDT	Kudat (Sabah)
KK	Kota Kinabalu (Sabah)
KPG	Ketapang (Kalimantan)
LBN	Labuan (Sabah)
LIM	Long Iram (Kalimantan)
MAN	Muara Ancalung (Kalimantan)
MIR	Miri (Sarawak)
MTW	Muaratewe (Kalimantan)
NGA	Nanga Pinoh (Kalimantan)
PBN	Pengkalan Bun (Kalimantan)
PRYA	Plangkaraya (Kalimantan)
PTK	Pontianak (Kalimantan)
SAM	Sri Aman (Sarawak)
SBU	Sibu (Sarawak)
SDK	Sandakan (Sabah)
SMD	Samarinda (Kalimantan)
TRK	Tarakan (Kalimantan)
TSR	Tanjung Selor (Kalimantan)
TWU	Tawau (Sabah)
	CLIMATIC INDICES/VARIABLES
AIRI	All Indian Rainfal Index
CI	Convection Index (1 & 2)
DTR	Diurnal Temperature Range
DU	Difference Index
IOI	Indian Ocean Index
MH	Monsoon Hadley Circulation Index
MSLP	Mean Sea Level Pressure
RD	R Dambul Borneo Monsoon Index (1 & 2)
RM	Regional Monsoon Index (1, 2 & 3)
SLP	Sea Level Pressure
SST	Sea Surface Temperature
SSTA	Sea Surface Temperature Anomaly
SOI	Southern Oscillation Index
T-max	Maximum Temperature

T-mean	Mean Temperature
T-min	Minimum Temperature
TSP	Total Suspended Particulates
UMI	Unified Monsoon Index
WYI	Webstar and Yang Monsoon Index
	AGENCIES
APN	Asia-Pacific Network for Global Change Research
BMS	Brunei Meteorological Services
CDC	Climatic Diagnostic Centre
CESRC	Climate Environment System Research Center
COADS	Comprehensive Ocean-Atmosphere Data Set
CRU	Climatic Research Unit
ECMWF	European Centre for Medium Range Weather Forecasts
IMGA	Indonesia Meteorological and Geophysical Agency
IRI	International Research Institute for Climate Prediction
JISAO	Joint Institute for the Study of Atmosphere and Ocean
MMS	Malaysia Meteorological Services
NCEP	National Centers for Environmental Prediction
NCAR	National Center for Atmospheric Research
	STATISTICAL TECHNIQUES
ANOVA	Analysis of Variance
CA	Cluster Analysis
KCA	K-Means Clustering Analysis
PC	Principal Component
PCA	Principal Component Analysis
	GENERAL
A1	Sepilok Climatic Group (for Borneo)
A2	Sepanggar Climatic Group (for Borneo)
B1	Samarahan Climatic Group (for Borneo)
B2	Sambas Climatic Group (for Borneo)
C1	Sintang Climatic Group (for Borneo)
C2	Selor Climatic Group (for Borneo)
CT	Circulation Type (Absoulte SLP)
CT1	Circulation Type (SLP Anomaly – Separate Season)
CT2	Circulation Type (SLP Anomaly – Combined Season)
CW	Cool Weather (Weather Type)
Cwet	Central Wet (Weather Type)
ENSO	El Niño Southern Oscillation
Ewet	Eastern Wet (Weather Type)
HW	Hot Weather (Weather Type)
ITCZ	Inter-Tropical Convergence Zone
NE	Northeast
NEM	Northeast Monsoon
NET	Northeast Monsoon Transition
NW	Normal Weather (Weather Type)
QBO	Quasi Biennial Oscillation

SE	Southeast
SEA	Southeast Asia
SEAM	Southeast Asia Monsoon
SW	Southwest
SWM	Southwest Monsoon
SWT	Southwest Monsoon Transition
WT	Weather Type
Wwet	Western Wet (Weather Type)

Chapter 1
Introduction to the Issue and the Case Study

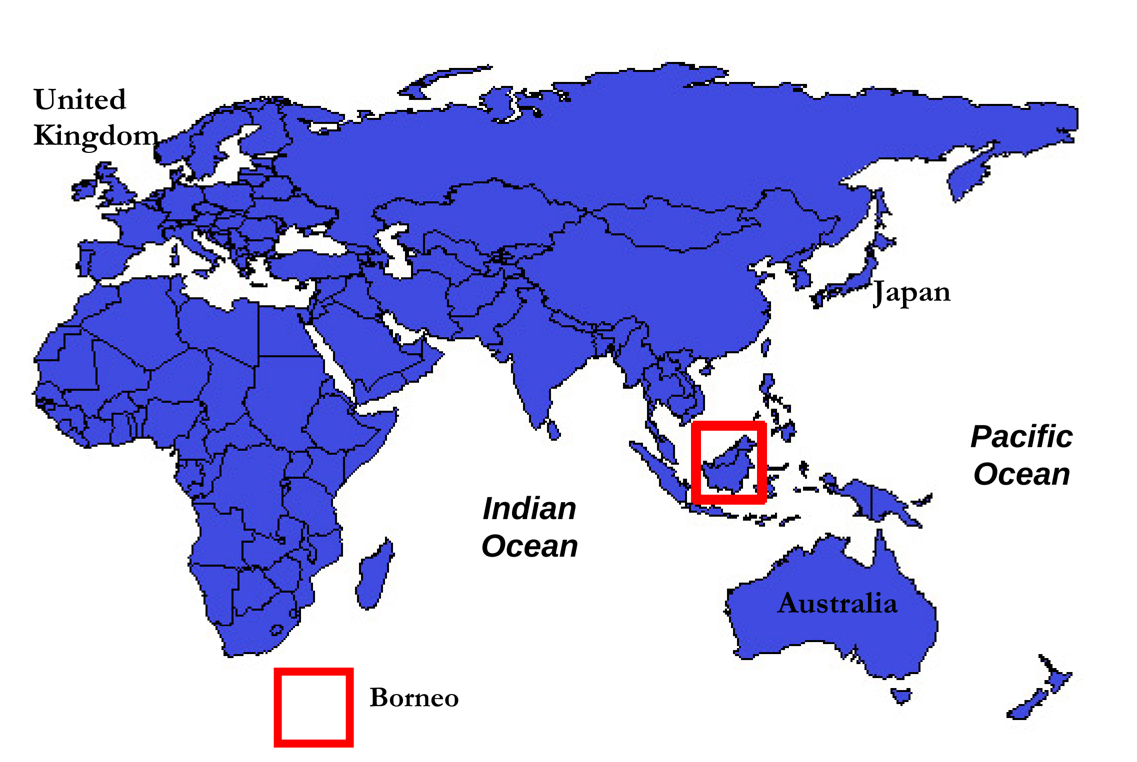


Figure 1.1: The location of Borneo

1.1 Introduction

The main aim of this research is to develop a systematic procedure that could improve the understanding of local and synoptic climatic elements in the chosen case study, the Borneo island (see Figure 1.1). Understanding the climatic processes that link the large-scale circulation and the local climate of the selected region is a required basic step towards this aim. This chapter introduces the thesis structure – (i) the background of the issue and case study; (ii) the aims and approaches applied in this project; and (iii) the outline of all chapters presented in this thesis.

1.2 Background

The primary source of tropical rainfall is the inter-tropical convergence zone (ITCZ) (Behrend, 1987). Moisture from the low-level convergence of trade winds is subject to a large seasonal march in the monsoon region of Southeast Asia (between 25°N and 15°S). The three principal origins of the large-scale atmospheric circulation that influence this large region are: the Indian Ocean (westerly relative to Borneo), the Asian continent (northerly) and the Pacific Ocean (easterly). These synoptic atmospheric features are translated into two climatic modes: the monsoon and the El Niño Southern Oscillation (ENSO) (Quah, 1988; Sirabaha, 1998, 2004), which are mutually interactive in nature. In terms of occurrence and effect, the seasonal monsoon is more constant and predictable. ENSO, on the other hand, is a more complicated phenomenon, fluctuating between two climatic phases on a semi-regular timescale of 3-7 years (Allan et al., 1996).

The effects of the Asiatic-monsoonal flow on surface climate, in general, are not identical across the region (Das, 1962). The western part of Borneo (South Asia i.e. India) is more influenced by the summer monsoon and the northern part (East Asian region i.e. China) by the winter monsoon. However, Borneo itself is subject to the influences of both monsoons: the winter and summer monsoons. These two monsoons are locally known as the Northeast and Southwest Monsoons, respectively. This local Southeast Asian monsoon (which directly influences Borneo) is part of the larger Asian monsoon system, which consists of two major components, namely the Indian and the East Asia monsoon (Sham Sani, 1984; Lau and Yang, 1997).

ENSO is arguably the most prominent cause of inter-annual variability in the global atmosphere and it holds the key for long-range predictions (Quah, 1988; Bohn, 2000). However, for the Asian monsoon region, particularly Southeast Asia, which is directly affected by the influential synoptic circulations originating from the Indian Ocean and the Asian continent – the inter-correlation between monsoon and ENSO must be examined thoroughly. Sirabaha (1998) acknowledged, "principally the East Asian Monsoon Winter (the northeast monsoon) plays the major role in shaping or maintaining the rhythm of seasonal climate over Borneo (rightly located in the heart of Southeast Asia)". Past studies on this issue have established that: ENSO and the monsoon are two main synoptic forcings that drive Southeast Asia surface climate (where Borneo is centrally located). The relationship between the Asian monsoon and ENSO phenomena, with respect to the southeast Asian region, has been better understood from the works of Caesar (2002) and Sirabaha (1998, 2004) – which will be the main references for the theoretical framework of this project.

What is the significance of this research? It could serve as the key to a better understanding of the climate (especially the seasonal cycle) in Borneo. This is crucially important because of the agrarian economies of the region (Sirabaha, 1998; WWF, 1998; Yearbook of Statistic, Malaysia, 2004). Agricultural outputs are severely affected if there is any major displacement of the monsoon rains, or if ENSO events occur (which can either prolong the dry season or intensify the rainy period). For instance, the monetary losses attributed to the El Niño 1997/98 for Southeast Asia (including Borneo) were estimated at US$1.38 billion (WWF, 1998).

1.3 Aims and approaches

The core aim of this research is to investigate a more meaningful association between the large-scale atmospheric circulation and the surface climate in Borneo. This requires improved understanding of the significant characteristics and features of the large-scale circulation that influences the region (Southeast Asia in general) – namely the Asiatic monsoon and ENSO phenomena are the two main synoptic features. There are very few studies that have been carried out on the specific effects of monsoon and ENSO on the southeast Asian region. Up to this date, only Caesar (2002) and Sirabaha (1998, 2004) have provided the most comprehensive knowledge on the mutual interaction between these two synoptic forces – with respect to the southeast Asian region. What are the motivations behind this proposed research?

- The scientific challenge – the complexity of tropical climate, especially with regards to the Asian monsoons and ENSO (El Ninõ Southern Oscillation), both in terms of their mutual interaction and their remote teleconnection-effect on local climate.
- Gap in current knowledge exists. The lack of a thorough understanding of climatic variability and seasonal fluctuation in the Southeast Asian region, especially when it comes to higher spatial resolution (e.g. for Borneo or other sub-region of Southeast Asia).

It is clear that the ultimate aim of this project is: establishing empirical relationships between large-scale atmospheric circulation and the surface climate. In order to achieve this, some key elements of the Borneo and Southeast Asia climate need first to be identified and analysed. The more specific objectives (which collectively form the core component of this thesis) are outlined below:

- To identify characteristics of the local climate by analysing station-based precipitation/temperature trends and patterns.
- To investigate the mutual-interaction between the monsoon and the ENSO.
- To establish a relationship between surface climate and the large-scale circulation.
- To examine the effect of the monsoon, the ENSO and “the two in combination” on the local climate and large-scale circulation.

What are the main foundations on which to base the framework of this research? Firstly, the determination of the seasonal cycle (based on rainfall data) and climatic division of Borneo. This will clearly outline of the characteristics for surface climate in each of the defined temporal seasons and spatial climatic divisions. This will then be supported by the identification of the underlying processes, which govern the large-scale circulation (namely, the monsoon and ENSO). By employing synoptic typing to integrate the forces from the monsoon and ENSO, a circulation typing scheme will be developed – and this will finally be related to the surface climate of Borneo.

1.4 Thesis contents

This thesis consists of nine chapters, which are divided into four main categories: an introduction of the thesis structure and a summary of earlier studies in the region (Chapters 1 and 2), descriptions of the data and statistical and mathematical methods (Chapter 3), discussions of analyses and results (Chapters 4, 5, 6, 7 and 8); and, finally a conclusion (Chapter 9). The schematic framework for this research is summarised in Figure 1.2.

In Chapter 2, previous studies on the synoptic and local climatology of Borneo are presented with the emphasis on the teleconnections of the monsoon flows and ENSO forces with surface climate of Borneo (i.e. precipitation and temperature). The main controls on the local climate of Borneo – various synoptic forcing that originate from the Indian Ocean, Far East Asian continent (moving through South China Sea) and Pacific Ocean. The local climate of Borneo also has a strong association with the orographic divides and the distinctive distribution of land and sea (see Figure 2.1). Two main synoptic forcings for Borneo (and SEA region in general) is monsoon and ENSO (see Table 1.1 for a comparison). The two main weaknesses from past studies – (a) all analyses were rigidly based on “political boundaries” and this approach simply ignored the need to treat Borneo as a single entity itself; (b) the ultimate focus of the analyses were mostly “describing and explaining the large-scale circulation patterns”. This thesis aims to identify the patterns, and classify them into several specific modes.

Table 1.1: Comparison between the monsoon and ENSO

Aspect	Monsoon	ENSO
Source origin of the forcing	Land mass (Asian continent)	Body mass from ocean (tropical part of Pacific Ocean)
Characteristic fluctuation	Seasonal (intra-annual)	Quasi biennial (inter-annual)
Best physical identification	Precipitation anomaly Land or sea surface temperature and pressure	Sea-surface temperature (SST) Sea-level pressure (SLP)
Atmospheric circulation domain	Observation of pressure differences between 110°E - 160°E	Observation of pressure differences between Tahiti and Darwin
Specific index	E.g. East Asian Summer Monsoon Index (MI) and Indian Monsoon Rainfall Index (IMR)	E.g. Southern Oscillation Index (SOI), Sea Surface Temperature Anomaly (SSTA)

In Chapter 3, all the datasets used in this thesis are described – including the sources, limitations, quality issues and justifications of why these data are selected. Two main types of data are used: large-scale variables (i.e. sea-level pressure grids, various monsoon and ENSO indices) and surface observed variables (i.e. daily precipitation and temperature). The first type of data is mainly obtained from NCEP, while the second are mostly provided by the meteorological services from Malaysia, Brunei and Indonesia. The second part of Chapter 3 provides an introduction to the statistical methods used throughout this project – i.e. descriptive statistics, classification analysis (PCA and K-means Clustering), significance tests (mean, frequency and trends), and correlation. These statistical techniques are discussed in an introductory manner, and each one will be explored in more detail in the individual chapters, where the particular techniques are employed.

In Chapter 4, the first step to understanding the underlying features of local climate of Borneo, is undertaken. There are two main analyses in this chapter: (i) regional classification that aims to divide Borneo into several climatic divisions; and (ii) temporal classification, which identifies and classifies the weather types affecting Borneo. Both classifications are based on surface climate variables – precipitation and temperature[1]. Three main climatic groups have been established to represent Borneo, and each one of the groups is distinguished with different cycles of wet and dry seasons. With regard to the temporal classification, eight weather types (including the normal type with zero anomaly of precipitation/temperature) have been identified.

[1] The other alternatives are humidity and evaporation rate (which are not used in this study)

In Chapter 5, another element of the local climate of Borneo is explored: (i) the long-term fluctuations of time series (for various measures/thresholds of precipitation and temperature); and (ii) the trends in all those time series. In general, it is found that precipitation exhibits no significant trend (in all measures/thresholds); whereas, most of the temperature measures (except for one station – Kuching) show statistically significant warming trends from 1968-2001.

In Chapter 6, the synoptic climatology that is affecting the local climate of Borneo is analysed – by evaluating the readily-established synoptic indicators (monsoon and ENSO indices) and developing a typing scheme based on the large-scale atmospheric circulation (using SLP as the diagnostic variable). This analysis involves several procedures: (i) evaluating the established synoptic indices (associated with the monsoon and ENSO), which are relevant for diagnosis of the local climate of Borneo; (ii) selecting the best currently-available indices or creating better new indices; and (iii) developing a circulation scheme (to be related to the local climate of Borneo) using selected large-scale climatic variables – ideally ones that can detect both the monsoon and ENSO-related modes.

In Chapter 7, the relationships between the circulation typing scheme (established in Chapter 6) and surface climate (i.e. precipitation and temperature) are analysed based on several regular specific features (seasonal, periodic, ENSO phases) and Borneo climatic divisions. For this analysis, six key stations from three main climatic groups – i.e. A1 (Sepilok), A2 (Sepanggar) and B1 (Samarahan)[2] – are selected. The important issues being addressed are: (i) identifying circulation types that are exclusively associated with a particular monsoon season, ENSO phase or climatic group (i.e. individual station); (ii) examining the typing scheme under a multiple climatic condition (i.e. monsoon-ENSO phase), to identify which component has a stronger influence on the occurrences of certain circulation types; (iii) investigating which circulation types are strongly associated with a particular condition of surface climate (e.g. wet, dry, cold and hot days); and (iv) analysing the consistency of the relationships in each one of the set of specific events. The ultimate purpose of this chapter is to determine if there are any strong identifiable patterns (of the relationships) that could possibly be developed for further application (i.e. construction of future climate scenario).

In Chapter 8, two main objectives are set: (i) analysing and comparing the performances of synoptic indicators (i.e. monsoon and ENSO indices) and circulation types in terms of how

[2] Sepilok, Sepanggar and Samarahan are places in Borneo, and chosen to as the references for three of the six sub-groups for the climatic division of Borneo (more details are presented in Chapter 4).

well they are related to surface climate; (ii) investigating the inter-relationships between weather types (Chapter 4), local climate (Chapter 5), synoptic indicators (Chapter 6), and the circulation types (Chapters 6/7). Among the issues this chapter will address are: (i) which are the best individual indices/types (from the numerical synoptic indicators and SLP established circulation types) that are best correlated with the surface climate of Borneo?; and (ii) different combinations of synoptic indicators (i.e. monsoon and ENSO indices) and the newly-established circulation types, which one is related better with surface climate?

In Chapter 9, a summary of the important findings and a comprehensive set of concluding remarks are presented. This chapter covers the conclusions produced from this thesis. The strengths and weaknesses of the approaches used in this study are also assessed. Finally, aspects of possible future work to extend the findings from this research are proposed. The aims and approaches employed in the entire project are summarised in Table 1.2.

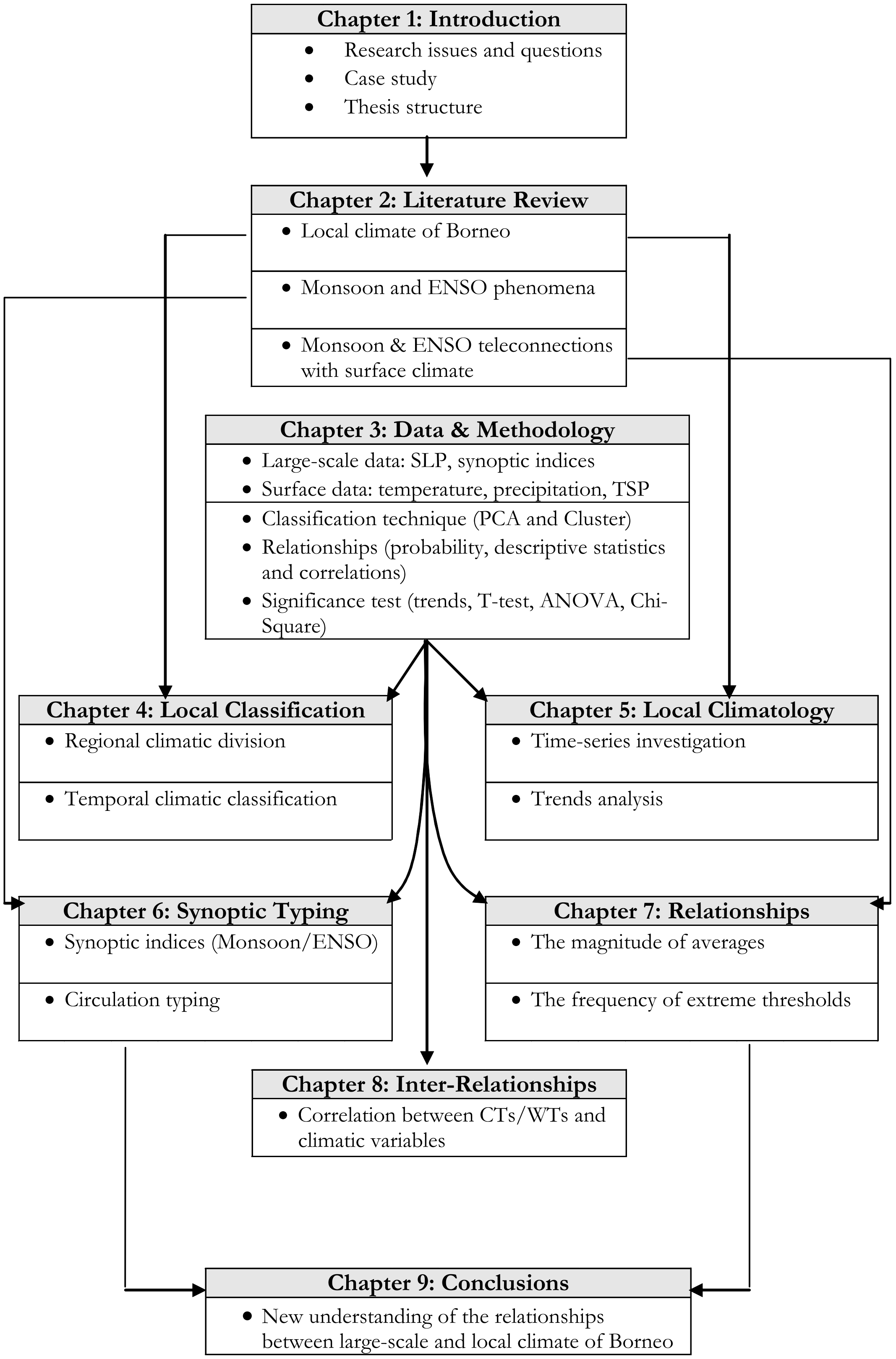


Figure 1.2: A schematic flow of the research organisation

Table 1.2: General overview of the research foundations

The Fundamental Part	Major Consideration	Secondary Consideration
The Issue: To establish and explain the relationship between the large-scale variables and the local attributes.	Reviewing the scientific knowledge of – (i) the interaction between the monsoon flow and the El Niño Southern Oscillation (ENSO) phenomenon for the Southeast Asian region; and (ii) the teleconnections of these two synoptic influences over Borneo: **Chapter 2**.	
The Case Study: Borneo (the largest island in Southeast Asia) and its synoptic domain (30˚N-20˚S; 75˚E-140˚E) – which is under the influence of the Asian Monsoon and ENSO.	To establish a climatic division (regional) for Borneo with clearly identified characteristics (based on local variables – precipitation and temperature): main section in **Chapter 4**. To analyse the trends and patterns of local climate (especially, but not exclusively, the extreme thresholds): **Chapter 5**.	To develop a weather-type catalogue (temporal) for Borneo based on surface variables (i.e. precipitation and temperature): sub section in **Chapter 4.**
The Data: Surface observed data (precipitation, temperature) and NCEP Reanalysis large-scale variable (i.e. sea-level pressure).	Selecting a large-scale variable (i.e. sea-level pressure) to develop the circulation typing scheme: first section of **Chapter 3**. Selecting the key stations (with the most complete data) that could be representative for different region of Borneo: second section of **Chapter 3**.	Selecting several synoptic climatic indicators (that capture the monsoon and ENSO signals), and which are relevant for Borneo: first section of **Chapter 3**.
The Methodology: Using purely quantitative methods to process the data and to produce results; and combination of quantitative and qualitative approaches to interpret the findings.	Analysis of local climate for Borneo (trends and time series) by trends significant test and time-series correlation: **Chapter 5**. Synoptic circulation typing by PCA and K-means Clustering: **Chapter 6**. Investigation of relationships between circulation types and surface climate by descriptive statistics and probability analysis: **Chapter 7**.	Local classification (climatic divisions and daily weather types) by PCA and K-means Clustering: **Chapter 4**.
The Expected Outcome: To establish patterns and characteristics of recognisable relationships between synoptic and local atmospheric variables for Borneo and its synoptic domain.	Explanation and justification of the relationships based on – (i) the physical features of the circulation types; (ii) the identified climatic divisions in Borneo; and (iii) the nature of the relationships under the influences of the Asian monsoon and ENSO forcing: **Chapter 7 and 8**. Identification of the most reliable predictors and the most appropriate predictands: **Chapter 9**.	Putting the findings into a practical context – to improve understanding on the local and synoptic climate of Borneo; thus to serve as a breakthrough for further research, especially but not exclusively, in the construction of future climate scenarios for Borneo: **Chapter 9**.

Chapter 2
Local and Synoptic Climatology of Borneo

2.1 Introduction

This proposed study is based on two hypotheses – (i) surface climate is closely related to the synoptic circulation; and (ii) the variations of these relationships can be estimated and translated into spatial and temporal patterns. As far as tropical regions are concerned, the two research foundations above have been proven 'sound' since the early works of Walker (1918, 1923), whilst several other studies (e.g. Krishna Kumar et al., 1995) have further validated the hypotheses. However, the previous teleconnection studies were mostly undertaken in south Asia (e.g. Parthasarathy, 1984; Kripalani and Kulkarni, 1997, 1999), east Asia (Shi and Zu, 1996), and the tropical part of northern Australia (Drosdowsky and Chambers, 2001). Both Caesar (2002) and Sirabaha (2004) had already shown that very few teleconnection studies have been carried out for southeast Asia (SEA), where Borneo is located. Therefore, this research faces the challenge to seek further and more complete understanding of the underlying physical and dynamic processes, which govern the synoptic-surface relationships in this region.

2.2 The Borneo background

Borneo is a large island in Southeast Asia. It is in fact the third largest island in the world, behind Greenland and New Guinea. The southern two-thirds of Borneo is controlled by Indonesia, and the northern one-third by Malaysia, as can be seen in the map (see Figure 2.1). The Indonesian part is called Kalimantan, which is further divided into four Indonesian provinces. The Malaysian portion is divided into two, the provinces of Sarawak and Sabah. In addition, the tiny oil-rich state of Brunei is wedged between the Malaysian provinces of Sarawak and Sabah.

Source: Extracted from 'The ASEAN Climatic Atlas' (Asean Secretariat, 1982: p. viii)

Figure 2.1: The Borneo main orography feature

This island is latitudinally located within 4.5°S to 7.5°N, and longitudinally lies between 108.5°E and 119°E. It is surrounded by several seas and islands (see Figure 2.2). In the north, the Sulu Sea separates it from the Philippines archipelago. In the east, the Sulawesi Sea (also known as Molucca Sea) serves as the barrier between the Borneo and the Sulawesi (or Molucca) island group. To the south is the Java Sea separating it from Java, whilst the South China Sea and the Natuna Sea lie to the west of Borneo. The orographic features of this Island are no less complicated. The main feature is the so-called "Borneo Highland Belt", which connects two main ranges, namely the Crocker Range (in Sabah – from 200m to 3000m above the sea level) and the Muller Range (middle of Kalimantan – 1500m to 2300m). The mountainous belt extends from the north to the south and clearly divides the island into two sub-regions – the northwest (facing the South China Sea) and the southeast (facing the Sulawesi Sea). This will be, later, useful to explain the differences in surface environmental conditions between meteorological stations located in the west and east coastal areas (see Chapter 7 and 8).

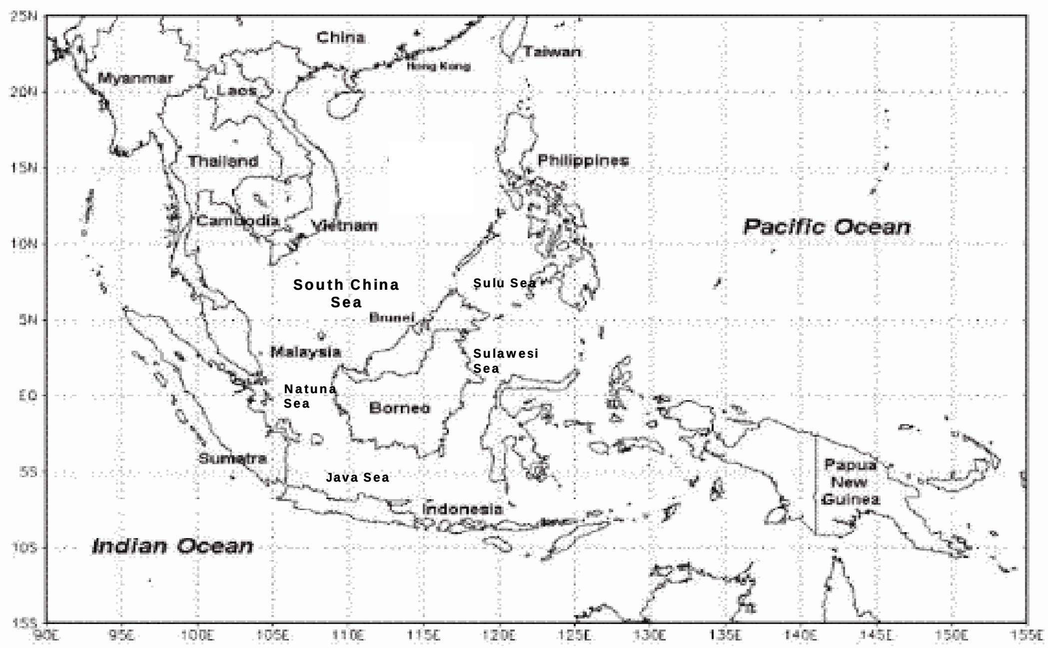


Figure 2.2: Location of Borneo – relative to the Southeast Asia region

Approximately sixteen million people live in Borneo, and most of them are economically involved in agrarian-oriented sectors (e.g. agriculture, fishery, and eco-tourism). About two million live in Sarawak, another 2 million in Sabah, 300,000 in Brunei, and the rest live in Kalimantan. The island's population is quite low, compared to most surrounding areas. For instance, the island of Java, located at the south of Borneo, has over 130 million people, yet it has only one fifth the size of Borneo. The explanation is in the island's geography. Until logging began a few decades ago, the island was completely covered by a dense rainforest. Indeed, more than 70% of the land is still covered by virgin tropical rainforest. For example, 67% of Sarawak (the second most developed province after Brunei) is still covered by forest (Yearbook of Statistics, Sarawak/Sabah, 2004).

2.3 The complexity of monsoon and ENSO

Modern climatology, in general, has put great emphasis on mid-latitude areas, and most of the basic concepts and principles were first tested in temperate regions (Stringer, 1972). Ironically, it is well known that the climatology of tropical regions (in the lower latitudes) is generally under the control of more complicated physical systems (Alaka, 1964). From the academic point of view, this imbalance in our knowledge for this region is inadequate, especially when addressing climatic problems (i.e. forecasting and construction of future scenarios).

The primary source of tropical rainfall is the inter-tropical convergence zone (ITCZ) (Behrend, 1987). Moisture from the low-level convergence of trade winds is subject to a large seasonal march in the monsoon region of Asia (between 25°N and 15°S). Nieuwolt (1977) identified three main origins of large-scale atmospheric circulation that influence this region, namely the Indian Ocean (westerly relative to Borneo), the Asian main land continent (northerly) and the Pacific Ocean (easterly). Specifically, there are two main synoptic circulations for Borneo (and SEA region as a whole) - the monsoon and the El Niño Southern Oscillation (ENSO) (Quah, 1988; Sirabaha, 1998, 2004).

The monsoon is a result of a complex interaction that includes the geographic features (distribution of sea and land), surface topography, and the large-scale force driven by the tropical and mid-latitude circulation (Barry and Perry, 1973; Nieuwolt, 1977). The monsoon over the South East Asian region is popularly known as the South East Asia Monsoon (Cheang, 1993; Kripalani, 1997; Wu and Wang, 2002). For Borneo, Sham Sani (1984) has identified two significant monsoon flows, locally referred as – the Southwest (SW) Monsoon, which occurs during the Northern Hemisphere's summer season, and the Northeast (NE) Monsoon (winter). Ramage (1971) also stressed that Borneo belongs to the equatorial monsoon climate region. Therefore, this island is subject to the convergence of inter-hemispheric air streams, or in the previous paragraph referred as the Inter Tropical Convergence Zone (ITCZ).

While in terms of occurrence and effect, the seasonal monsoon is more common and predictable. ENSO, on the other hand, is a more complicated phenomenon. Why is this so? The complexity lies within the nature of its origin. To begin with, it is important to note that atmosphere and ocean are strongly coupled (Bjerknes, 1969). However, the physical and meteorological linking mechanisms have not been fully established (reviewed by Sirabaha, 1998). At present, climatologists are still developing a reliable means to precisely model the interaction between the atmosphere and ocean components, with regard to ENSO (Goddard et al., 2001). What do these facts tell us about ENSO? This phenomenon, according to Rasmussmen and Carpenter (1982, 1983), is actually a broader concept to link the El Niño/La Niña (the warming/cooling of sea-surface temperatures in the eastern Pacific domain) and the Southern Oscillation (the surface atmospheric circulation). In other words, the ENSO is a manifestation of oceanic and atmospheric changes in the Pacific Ocean (Barnett, 1984; Bigg, 1990; Glantz, 1991).

ENSO fluctuates between two climatic phases on a semi-regular timescale of 3-7 years, and this fluctuation is manifested by the changes in the frequency, magnitude and spatial characteristics of the events (Allan, 2000). This uneven and irregular phenomenon remains something of a mystery and beyond the reach of full understanding. In addition to this complexity, some scientists believe that the monsoon and ENSO are interactive (reviewed by Yasunari, 1990), and from a statistical perspective, there also might be a presence of strong multicollinearity[3] between them (Krishna Kumar et al., 2000). This complexity has made research on teleconnections between the large-scale circulation (monsoon and ENSO) and local climate even more challenging, but still very interesting.

2.4 Local climate – an overview

It is important to note that Asiatic-monsoonal effects on surface climate, in general, are not identical across the region (Das, 1962). For instance, the summer monsoon has stronger effects on the western part of Borneo (south Asia) and the winter monsoon plays more noticeable roles on the eastern part (the more eastern part or east Asia). Interestingly, as pointed out by Sham Sani (1984), the northern part of Borneo (Sabah) is subject to the influences of the NE Monsoon (generally known as the winter monsoon) and the SW Monsoon (summer monsoon). Therefore, both monsoons are equally effective when influencing southeast Asia (Sham Sani, 1984) – even though the intensity and the climatic effects (by each monsoon) might be different (Sirabaha, 1998, 2004).

As far as local climate (i.e. temperature and precipitation) is concerned, Borneo uniquely manifests a certain pattern of its own – in comparison with the surrounding area. This island shares the same type of climate (C type) based on classification of Wyrtki (1975), which had been further expanded by Aldrian (1999, 2001). Apparently, the climate type of the nearby Molluca archipelago is categorized as D, which is significantly different from the C type. The main characteristics of the neighbouring Molluca island (type D) are – (i) the average rainfall in dry season (SW Monsoon) is still high and not much different from the wet season (NE Monsoon); and (ii) the effect of Niño3 variation in summer is insignificant,

[3] In terms of a pure statistical definition, multicollinearity is a case of multiple regression in which the predictor variables are themselves highly correlated. Multicollinearity is a problem that plagues almost all multivariate techniques, such as multiple regression, discriminant function analysis, canonical correlation, and even factor analysis. In particular, when the variables are very highly correlated, the power of these techniques is severely compromised. The context of which it is refereed in this chapter is – the various monsoon and ENSO parameters are highly correlated (between each other) that it is difficult to establish a clear pattern association.

which is totally contrasting to the other types. On the other hand, type C, which characterizes Borneo has a highly anomalous rainfall pattern (i.e. strong seasonality) compared to all other regions.

For the past 50 years, this region (SEA) as a whole generally has not experienced any strong extreme climate change (Manton et al., 2001). However, according to Manton et al. (2001), after a closer investigation of a smaller part of SEA, it was found that Borneo has shown a noticeable extreme trend. The significant extreme trends being observed were – (i) increases of hot temperature extremes; and (ii) decreases of cold temperature extremes. All stations in Borneo (except Kuching) have also shown a significant decrease in the number of rain days. This finding might indicate that there is a special characteristic that locally underlies the climate of this island (compared to the other part of Southeast Asia). Its orographic features and the distinct distribution of land and sea (surrounded by the South China, Natuna, Java, Sulu and Molucca Seas) might explain the above point. As Webster et al. (1992, 1999) noted the distribution of land and ocean could make an important contribution to the seasonally changing characteristics of regional tropical climates. Borneo's unique geography may have served as filters for the synoptic circulation that originates from the Indian Ocean, the Pacific Ocean and the Asian mainland continent. Thus, the large-scale circulation would be altered before its local effect is manifested in the island.

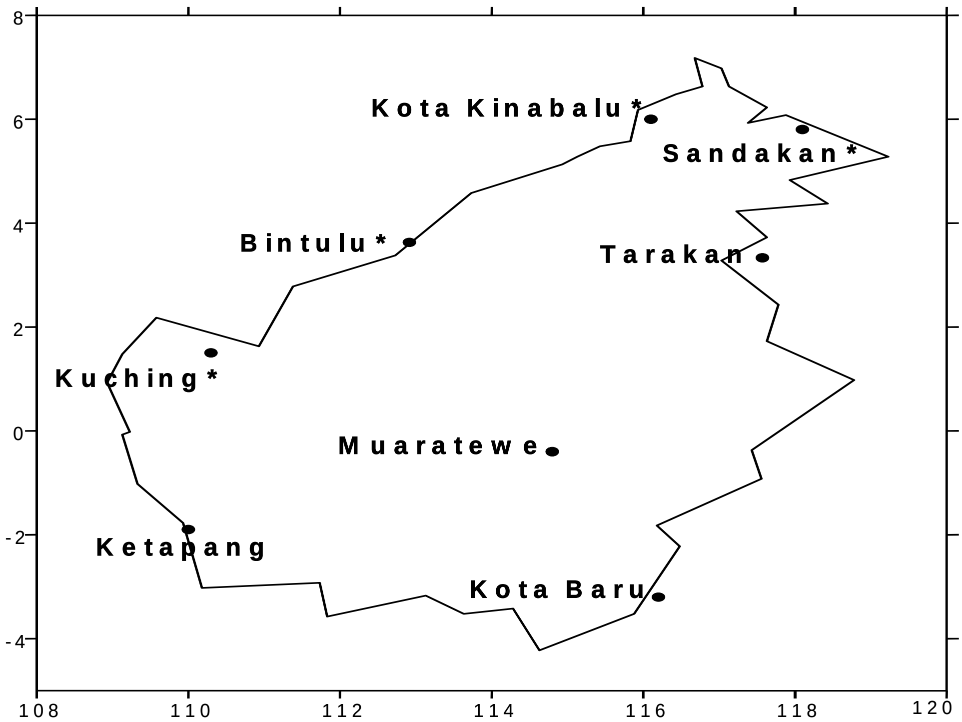


Figure 2.3: Map of Borneo showing eight selected stations in Sabah, Sarawak (Malaysia) and Kalimantan (Indonesia) – for precipitation and temperature patterns
(Stations marked with (*) are plotted for both precipitation and temperature)

The long-term monthly average of total precipitation and daily temperature are shown in Figure 2.4 for four stations (temperatures); and Figure 2.5 for eight stations (precipitation). The locations of stations are shown in Figure 2.3. The plots for precipitation are based on observed data for 41 years – from 1961 to 2001. However, the data used for the Kalimantan stations are comparatively shorter due to lack of observation (see Chapter 3). The plots for the temperature are established using daily observations between 1968 and 2001 (for the mean, maximum and minimum temperature). The results shown here are highly consistent with the general findings of Sham Sani (1984) – using station data for the period 1968-80 in north Borneo (Sabah); and the results from The ASEAN Climatic Atlas (1982) observed data for the period 1951-1975.

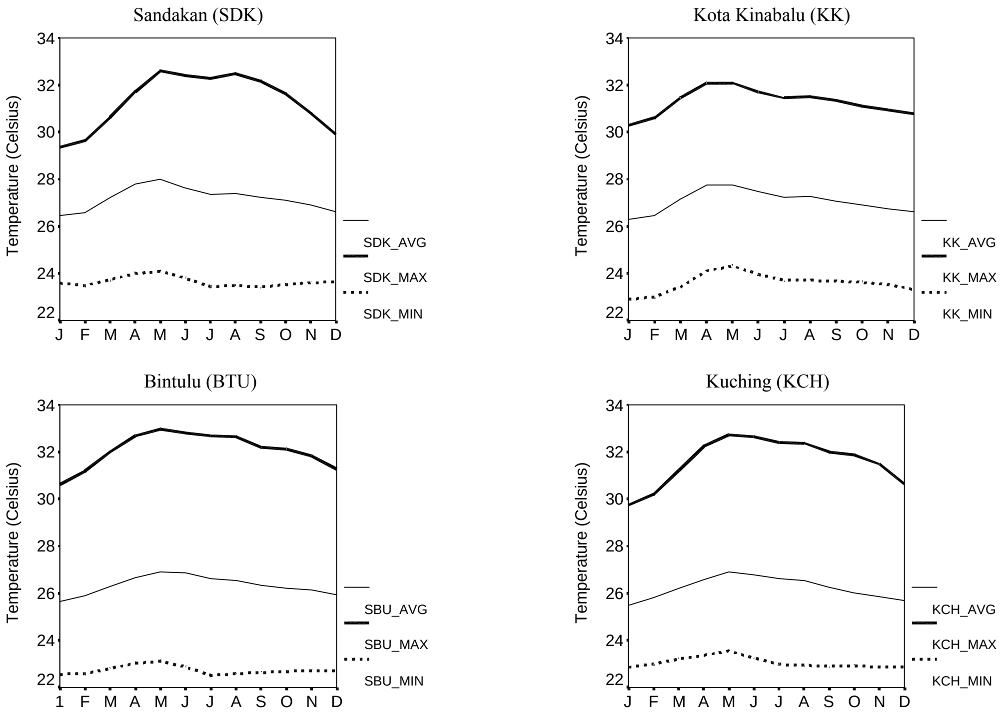


Figure 2.4: Monthly temperature averages (Mean, Maximum and Minimum) at four selected stations (on the period of 1968 – 2001)

2.5 Synoptic characteristic of the large-scale domain

As mentioned earlier, the two most significant synoptic forcings affecting Borneo are the monsoon and the ENSO, which are mutually interactive in nature. Therefore, as far as determining the local climate is concerned, its association with the monsoon and the ENSO is not exclusively independent. Krishna Kumar et al. (1997) put this into perspective by stating: “The forcing represented by the various predictors (including monsoon and ENSO indices) can be objectively delineated and the common variance among them pooled into a set of independent principal components”. Which forcing is stronger? The monsoon could play an active role, as opposed to a passive role, in tropical and global climate variability

(Yasunari, 1990). However, whilst the monsoon influence is seasonally more prominent (Sirabaha, 1998), ENSO normally shapes the climate system on an inter-annual basis (Sirabaha, 2004).

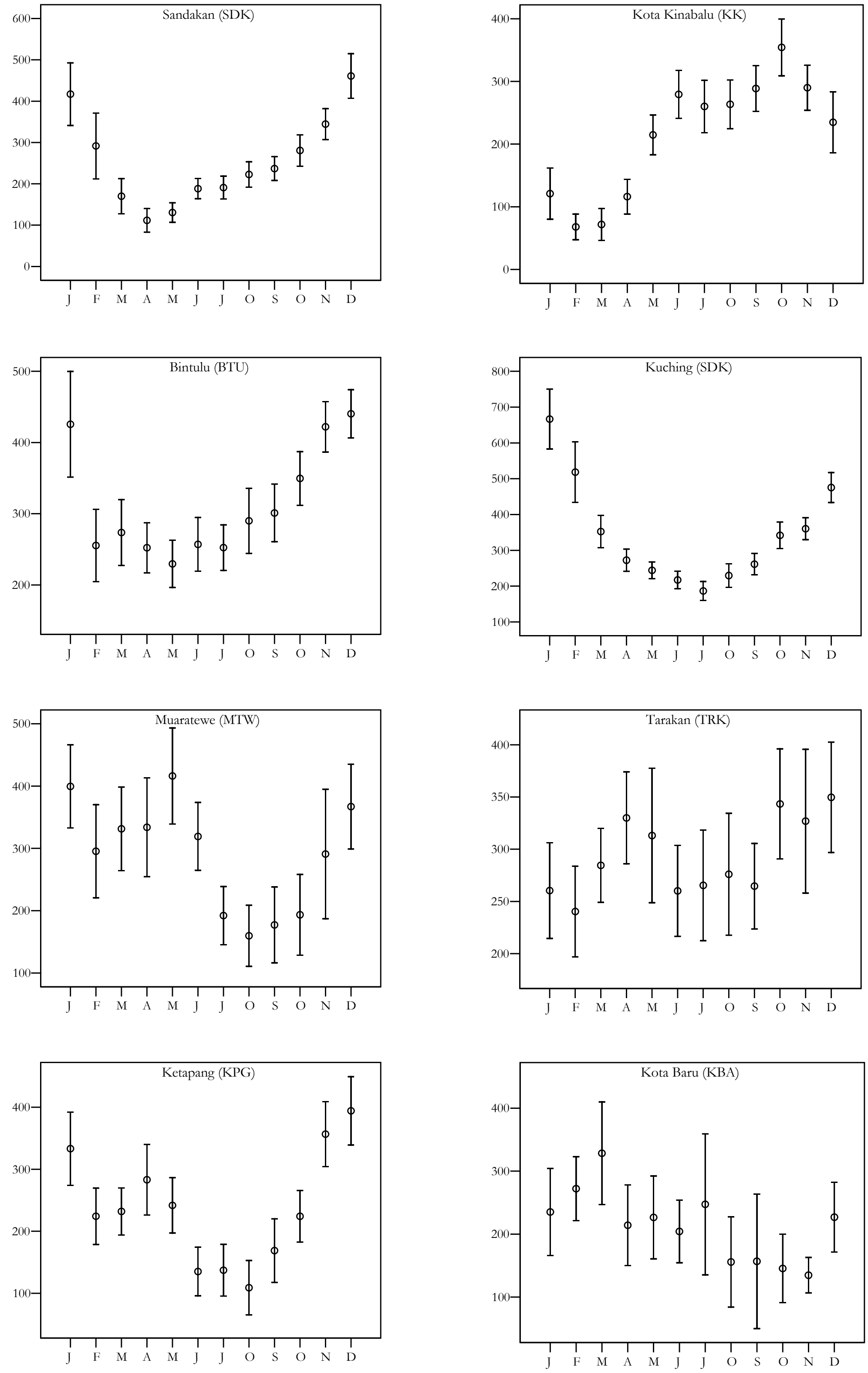


Figure 2.5: Monthly rainfall average (i.e with error bar shown at 95% level of confidence) at eight selected stations in Borneo (based on the period of 1961 – 2001 observed data)

2.5.1 Asian monsoon seasonal cycle

The Asian monsoon is an extremely complex phenomenon, which encompasses variability over a wide range of spatial and temporal scales (Lau et al., 1984). A monsoon is a term from early Arabic called the "Mausin," or "the season of winds." This was in reference to the seasonally shifting winds in the Indian Ocean and surrounding regions, including the Arabian Sea. These winds blow from the southwest during one half of the year and from the northeast during the other. The Asian monsoon, which affects the Indian subcontinent and southeast part of the Asia, is probably the most noted of the monsoons anywhere in the world.

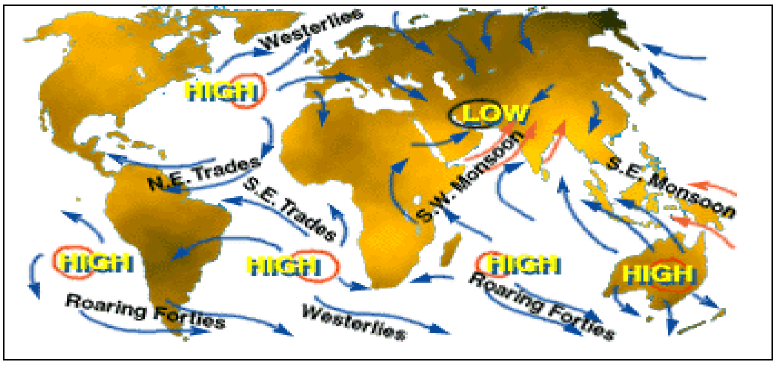
Over the past thirty years, many monsoon studies have been conducted in Asia, related to the summer and the winter monsoon and mainly in the south and east Asian regions (e.g Krishnamurti, 1971; Krishnamurti et al., 1989; Lau and Sheu, 1988; Meehl, 1997; Yasunari, 1990; Matsumoto, 1992; Webster et al., 1992; Slingo and Annamalai et al., 1999). There are seasonal changes, which are particularly noticed as northeast winds, prevailing in the winter in Southeast Asia and southwest winds in the summer. As monsoons have become better understood, the definition now indicates climatic systems anywhere in which the moisture increases dramatically in the warm season.

The Asian monsoon exhibits a clear annual cycle (Ding, 1994; Sirabaha, 2004). A monsoon seasonal change is also characterized by a variety of physical mechanisms, which produce strong seasonal winds, a wet summer and a dry winter. All monsoons share three basic physical mechanisms: differential heating between the land and oceans; Coriolis forces due to the rotation of the Earth; and the role of water which stores and releases energy as it changes from liquid to vapour and back (latent heat) (Ramage, 1971; McGregor and Nieuwolt, 1998). The combined effect of these three mechanisms produces the monsoon's characteristic reversals of high winds and precipitation.

Scientists conclude that the two key ingredients needed to make a monsoon are a hot land mass and a cooler ocean (McGregor and Nieuwolt, 1998; Webster et al., 1998; Slingo et al., 1999). Low-level winds emanating from the Indian Ocean, Australian continent and northwest Pacific Ocean onto the Asian continent during the boreal summer. In contrast, an intense continental anticyclonic flow associated with the cold Siberian high ridging east and southwards onto the subtropical and equatorial Asia, including the maritime continent of Southeast Asia prevails during the boreal winter (Ding, 1994).

Southeast Asian winters are generally considered to be hot and dry, which occur from September to March. The winds from the northeast during the winter months are dry because they have lost their moisture on the Asian land mass. The cold air from the middle of the continent cannot reach the portion of Southeast Asia. The reason for this is that the Himalayas act as a huge wall blocking this cold weather and causing high temperatures. The dry winters come from the fact that moisture comes toward this area is also blocked by the Himalayas. However, there is an exception to this effect. This is the so-called 'maritime continent of Southeast Asia – consisting of Peninsular Malaysia, Borneo and the Indonesian archipelago. As the winds blow toward these areas, they pick up some moisture from South China Sea and other surrounding seas. Therefore, this maritime continent of Southeast Asia receives a majority of its rainfall during these months.

The local SEA monsoon (which directly influences Borneo) is part of the larger Asian monsoon system, which consists of two major components, namely the Indian and the East Asia monsoon (Sham Sani, 1984; Lau and Yang, 1997). The region is associated with mountainous and forested islands, which induce very strong convective activity and characterised by the wet winter monsoon (Kitoh, 1992; Sirabaha, 2004). Malaysia, Singapore, Brunei, Indonesia, Philippines and Papua New Guinea are often referred to as the maritime continent due to the evidence of a strong diurnal cycle in terms of rainfall distribution (Ramage, 1971; Yang and Slingo, 2001). The surrounding waters are warm all through the year and consistent daily heating over the land areas tends to establish local circulations. This produces warm moist air from the sea converging inland and triggering deep atmospheric convection and rainfall during the afternoon (Houze et al., 1981). The two monsoons are locally known as the Southwest Monsoon (summer) and the Northeast Monsoon (winter) (Sham Sani, 1984; Cheang, 1986, 1993a).



Source: Monsoon Online (http://www.met.rdg.ac.uk/)
Figure 2.6: Summer monsoon synoptic feature

Changes in the wind directions occur when the south to north pressure gradient is established during the boreal summer associated with the northward migration of the Intertropical Convergence Zone (ITCZ) from the equator up to 25ºN in India (Asnani, 1993a & 1993b). During July-August, a double monsoon trough develops north and south of the equator in the western Pacific. Disturbances in these troughs bring short but intense spells of rainfall to Malaysia, Borneo, Sumatra and Java (Cheang et al., 1981a, 1981b). During the SW monsoon (summer), the more eastern and southern part of Southeast Asia, such as Indonesia, Borneo, Papua New Guinea and the Philippines are much more influenced by cross equatorial and southeasterly flow emanating from northern Australia (Sirabaha, 2004). The latter is associated with the cold austral winter circulation, which is centred over the Australia continent (Kitoh, 1992).

There are two changes that mark the weakening of the summer monsoon in Southeast Asia around autumn (middle of September). Firstly, the thermal contrast between land and sea decreases, which weakens the circulation (see Figure 2.6). Secondly, the mid-latitude westerlies migrate southward, and eventually more to the south of the Himalayas and disrupt the circulation. The upper-tropospheric easterly jet is then replaced by westerly winds, and the surface pressure gradient from north to south establishes itself extending from Siberia (Sirabaha, 2004). The winter monsoon (Northeast) is characterised by air flow originating from the Siberia (Caesar, 2002; Sirabaha, 2004) and Southeast Asia regions are affected by coherent northeasterly wind flow (Sham Sani, 1984; Nieuwolt, 1977). Precipitation in both west and east Malaysia (which includes Borneo) reaches its maximum during the Northeast Monsoon (boreal winter) (Sham Sani, 1984; Cheang, 1993; Sirabaha, 1998). That is the effect of the northeast wind, which moves across the South China Sea and pick up the moist from the sea.

As far as monsoon mechanisms are concerned, there is still very limited understanding in terms of the timing of the onset and the termination (Tao and Chen, 1987; Lau and Sheu., 1988). Different researchers have used various indicators to define the timing – but the most commonly diagnostic elements are the behaviour of deep convection and the low-level wind circulation. As has been exhibited by the larger Asian monsoon system, these so-called local sub-monsoons are also subject to transition periods (Sirabaha, 2004), which are between April-May and October-November (Sham Sani, 1984). The pre-summer monsoon is the most important transition in terms of monsoonal rainfall predictability in the Southeast Asia (Webster and Yang, 1992). The transition period is a set of abrupt changes that occurs in the atmospheric circulation system marking the end of each monsoon. As far as Borneo is concerned, the pre-summer season (also known here as the monsoon transition) is the driest season (Sirabaha, 1998).

Table 2.1: List of studies on the monsoon onset and offset timing

(a) Summer Monsoon

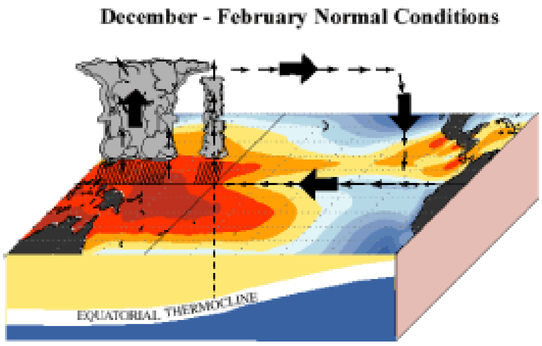
AUTHOR	**INDICATORS (SOUTHWEST MONSOON)**	**ONSET TIME**
Sham Sani (1984); Cheang (1993)	Malaysia's summer monsoon (Northwest) indicated by change in low-level wind direction	Mid May
Lau and Yang (1997); Wu and Zhang (1998); Hsu et al. (1999)	Southeast Asia summer monsoon's initial onset recognized by strong convection and change of prevailing wind over the Indo-China Peninsula and the South China Sea	Early May
Ding et al. (1999)	South China Sea monsoon experiment based on convection activity	Mid May
Kim and Chung (2001); Lim et al. (2002)	Deep convection regions of the South China Sea, Indo-China, Sumatra and West Malaysia	Mid May
Lin Ho and Wang (2002)	South Asia summer monsoon marks by a rapid northward march of the convection centre from west Sumatra to the Adaman Sea along the land bridge between Indonesia and Indo-China	Earliest by late April

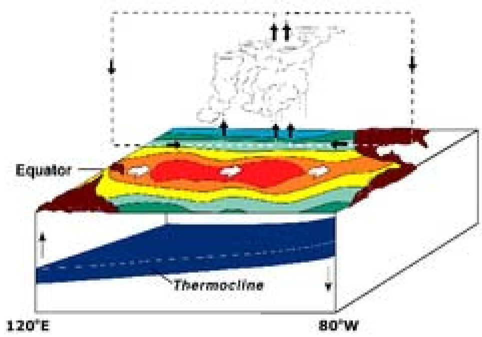
(b) Winter Monsoon

AUTHOR	**INDICATORS (NORTHEAST MONSOON)**	**ONSET TIME**
Ramage (1971)	Centre of convection lies slightly south to the equator	January
Sham Sani (1984)	The change of the low-level wind direction from generally northwards into southwards	November
Chang and Lau (1982) Hsu (1994)	Air flow movement from the anti-cyclonic centre over Mongolia and Siberia in southerly direction	October
Webster and Yang (1992)	Formation of a deep convection centre in the maritime continent of Indonesia/Borneo	September - October
Cheang et al. (1981a) Cheang (1993)	Three major features – large-scale monsoon trough over the South China Sea, cold air within the northerly monsoon current generated from the Asian anti-cyclonic system, and upper level winds from easterly to westerly over southern China	September

2.5.2 ENSO quasi-biennial phenomenon

ENSO, or the El Niño-Southern Oscillation phenomenon, is a system of interactions between the equatorial Pacific Ocean (indicated by sea surface temperature – SST) and the atmosphere above it (indicated by the difference in sea level pressure between Tahiti and Darwin). Throughout the 1960's and 1970's, oceanographers referred to the large-scale warming of the equatorial eastern and central Pacific as El Niño (Allan, 1996, 2000). This anomalous warming was later shown to be associated with anomalies in the upper ocean thermal structure throughout the equatorial Pacific Ocean. At about the same time, scientists realized that the Southern Oscillation is intimately related to the large-scale changes in the tropical Pacific Ocean (Rasmussen and Carpenter, 1982; Glantz, 2001). In brief, the Southern Oscillation represents the variability in the Indo-Pacific Walker circulation in the tropics, and is manifested as a displacement of the convection over the maritime continent, and is associated with large-scale anomalies in the surface wind and sea level pressure throughout the tropical Pacific (and into the Indian Ocean) basins.

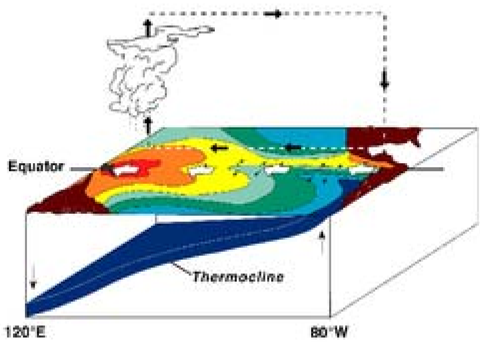




The El Niño

Images obtained from NOAA, Climate Prediction Center

The sea-surface temperature is shaded: blue-cold and orange-warm. The dark arrows indicate the direction of air movement in the atmosphere: upward arrows are associated with clouds and rainfall and downward-pointing arrows are associated with a general lack of rainfall



The La Niña

Figure 2.7: Schematic view of sea surface temperature and tropical rainfall in the equatorial Pacific Ocean during normal, El Niño, and La Niña conditions

It becomes clear by the beginning of the 1980's that the El Niño and Southern Oscillation are intimately related, with the large-scale warming (El Niño) coordinated with a relaxation of the trade winds throughout Pacific Ocean and a displacement of the atmospheric convection into the central Pacific from the maritime continent (Rasmussen and Carpenter, 1982; Sirabaha, 1998). Scientists coined the phrase El Niño/Southern Oscillation (ENSO) to uniquely describe this large-scale, interannual atmosphere/ocean climate phenomenon. Throughout the 1980's, theoretical and modelling studies demonstrated that ENSO (hence, El Niño) is a phenomenon that inherently involves the coupling between the atmosphere and ocean, and that the crucial interactions between these spheres are in the tropical Pacific (see Figure 2.7). The state of the ENSO system fluctuates from year to year. One of the main ways these fluctuations have been observed is through changes in the sea-surface temperature of the equatorial Pacific Ocean. El Niño and La Niña events are opposite states of the ENSO system: El Niño is when the equatorial Pacific is warmer than average, and La Niña is when it is cooler than average (see Figure 2.8).

Once an El Niño or La Niña event develops, it tends to continue for about a year. Changes in the ENSO system in the Pacific Ocean influence the seasonal climate (such as rainfall and temperature patterns) in many parts of the world in a consistent way. In other words, depending on the region and season, some climate conditions are more likely to happen during El Niño events or during La Niña events than at other times. For instance, El Niño forces a positive rainfall anomaly on the west coast of South America (e.g. Peru) (Barnston and Chelliah, 1997), whereas the impact on rainfall in the southeast Asia maritime continent (e.g Indonesia, Peninsular Malaysia and Borneo) is the opposite (Cheang, 1993; Sirabaha, 1998).

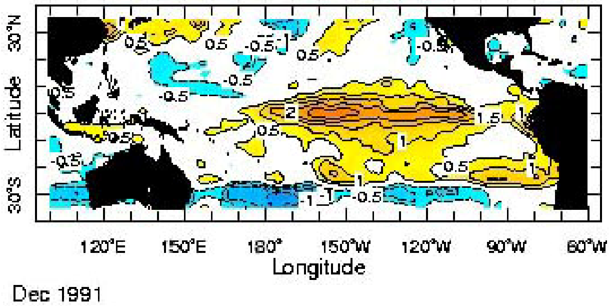


Figure 2.8a: Typical El Niño conditions

Departure of sea surface temperature from the long-term average for an El Niño during December 1991. Yellow shading indicates warmer than average temperatures. Units are degrees. Celsius and contours are drawn at 0.5 degrees C intervals.

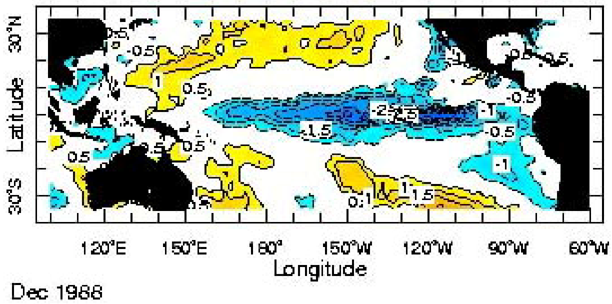


Figure 2.8b: Typical La Niña conditions

Departure of sea surface temperature from the long-term average for a La Niña during December 1988. Blue shading indicates colder than average temperatures. Units are degrees. Celsius and contours are drawn at 0.5 degrees C intervals.

Source: Derived from NCEP official homepage

The term El Niño was first coined more than 500 years ago to describe the unusually warm waters that would occasionally form along the coast of Ecuador and Peru. This phenomenon typically occurred late in the calendar year near Christmas, hence the name El Niño (Spanish for "the boy child", referring to the Christ child) (Glantz, 2001). Today the term El Niño is used to refer to a much broader scale phenomenon associated with unusually warm water that occasionally forms across much of the tropical eastern and central Pacific. The time between successive El Niño events is irregular but they typically tend to recur every 3 to 7 years. La Niña is the counterpart to El Niño and is characterized by cooler than normal SSTs across much of the equatorial eastern and central Pacific. A La Niña event often, but not always, follows an El Niño and vice versa. Once developed, both El Niño and La Niña events tend to last for roughly a year although occasionally they may persist for 18 months or more. El Niño and La Niña are both a normal part of the earth's climate and there is recorded evidence of their having occurred for hundreds and thousands of years. However, as noted by Sirabaha (2004), although this phenomenon has existed thousand of years – its complexity is still fascinating to research and understand.

A number of researchers have pointed out that 'typical ENSO events' do not occur because the characteristics between individual events can be highly varied (Philander, 1989; Caesar, 2002). However, historically speaking El Niño and La Niña events tend to develop during the period of April-June and they also: (i) tend to reach their maximum strength during December-February; (ii) typically persist for 9-12 months, though occasionally persisting for up to 2 years; and (iii) normally recur every 2 to 7 years. An ENSO event that develops before the Northern Hemisphere summer season will normally have its peak amplitude at the end of the calendar year (Miyakoda et al., 1999). On average, ENSO events tend to last between 18 to 24 months and show a characteristic cycle, phase locked to the seasonal cycle (Ramusson and Carpenter, 1982; Philander, 1990; Yasunari, 1985). This is, however, only a simplified generalisation because some events (e.g. 1986-87) are not well phase-locked with the annual cycle (Caesar, 2004).

2.6 ENSO-Monsoon interaction and synoptic-surface teleconnections

In some recent studies, investigators have postulated that an annual cycle forcing of the coupled atmosphere/ocean system is responsible for the irregularity of ENSO events (Jin et al., 1994; Chang et al., 2000; Caesar, 2002; Sirabaha, 2004). In most of those quoted studies, the coupled interannual variability is produced by arbitrarily increasing the annual cycle of a chosen parameter or the coupling strength between the atmosphere and ocean. It has been suggested that, the physical mechanism behind the interaction between the ENSO mode and the seasonal cycle, is based on different physical processes that seem to govern the interannual ENSO mode and the annual cycle (Philander, 1999). It is found that a deepening of the thermocline in the warm phase of ENSO reduces the amplitude of the annual cycle in SST (and vice versa), leading to a phase-locking of ENSO to the seasonal cycle.

2.6.1 Overall picture of the teleconnections

The monsoon seasonal circulations are strongly influenced by the elevated heating that is caused by Tibetan Plateau (during the summer), whilst the Siberian highland plays a similar role in the winter monsoon (Luo and Yanai, 1996). It is worth noting that explaining the monsoon-ENSO relationship is far more complex, because the monsoon itself has its internal variability factors. The monsoon region is mainly between 35°N - 25°S and 30°W - 170°E (Ramage, 1971). This characteristic of large Asian monsoon domain is important to consider when explaining the impact of ENSO over Borneo (Sirabaha, 1998).

Past studies of the association between ENSO and monsoon have largely focused on the Far East Asia region (China) and the South Asian region (India) with less attention paid to the Southeast Asia region (reviewed by Sirabaha, 2004). Numerous studies have been undertaken either on the influences of the Indian summer monsoon on the tropical circulation i.e. ENSO (Krishnamurti, 1971; Krishnamurti and Lau., 1987; Yasunari and Seki, 1992); or the other way around, the impact of ENSO over the Indian monsoon (Shukla and Paolino, 1983). Based on coupled model simulations (e.g. Bacher et al., 1998), it is found that warm (cold) ENSO events are made even warmer (colder) by weak (strong) monsoons. Similarly, warm (cold) ENSO events are weakened by strong (weak) monsoons (Kirtman and Shukla, 2000). This is consistent with the finding by Webster et al. (1998), which concludes that warm ENSO events tend to suppress the monsoon. With respect to the southeast Asian region, ENSO is known to modulate the advance and retreat of the monsoon (Cheng, 1993; Webster et al., 1999).

The central issues (key element) in fully understanding the inter-connection between ENSO and monsoon - are to establish the most appropriate definitions of ENSO and the monsoon themselves – in terms of their onset and termination timing (Sirabaha, 2004). Although a number of studies suggest that the impact of ENSO on the Southeast Asia monsoon, especially in the mainland region (i.e. Thailand, Mynmar, Indochina) are not prominent (Roy and Kaur, 2000; Kriplani and Kulkani, 1997), other studies found that a strong association does exist (Roeplewski and Helpert, 1987, 1989; Bell and Halpert, 1998; Diharto, 1999). In addition, this significant connection is more clearly exhibited over Borneo (Quah, 1988; Sirinada, 1990; Cheang, 1993; Sirabaha, 1998; Tangang, 1999). In this research, the method of defining and setting these elements are based on the works by Caesar (2002) and Sirabaha (2004). More detail about how the definitions are applied is given in the Chapter 6.

2.6.2 Large-scale circulation predictors

Subsequent to studies by Walker (1923) and Walker and Bliss (1932), very little progress was made in long-range forecasting of monsoon rainfall until the early 1980s when several studies (e.g. Yasunari, 1980; Mooley and Parthasarathy, 1983, 1986; Parthasarathy 1984) have re-established the strong links between the monsoon rainfall variability and ENSO using improved and longer data sets. Krishna Kumar et al. (1995) suggested that surface climate variables, which are driven by monsoon forcings, can be associated with 4 main groups of synoptic predictor – namely the regional conditions (surface pressure, thermal fields, 500 hPa ridge, upper tropospheric winds), ENSO indicators (SOI, SLPA at Tahiti and Darwin, SSTA)[4], cross-equatorial flows (over India) and hemispheric conditions (Northern Hemispheric surface air temperature, Eurasian/Himalayan snow cover, QBO of the mean zonal wind of the tropical stratosphere at the height range of 20-30 km).

Those classifications of predictor above are referred to in case studies carried out in India by Mooley and Paolino (1988), Verma and Kamte (1980), Shukla (1984) and Mukherjee et al. (1985). Several studies (Quah, 1988; Sirabaha and Caesar, 2000; Tangang, 2001) were undertaken in Southeast Asia (i.e. Malaysia in particular) and the predictors used were ENSO indices (namely the SSTA, MSLP[5] and SOI observed in the Pacific Ocean). For Malaysian case, the most successful predictor is SOI, in which a strong negative (positive) value of SOI has been associated with the occurrence of El Niño (La Niña) respectively. There are several specific indices used by various researchers to measure the Asian monsoon, some of which are shown in Table 2.2.

Table 2.2: Asian monsoon indices

Author	Climatic variables used to establish indices	Monsoon region
Webster and Yang (1992)	Zonal wind shear between 850 and 200 hPa	Large-scale Asian monsoon
Parthasarathy et al. (1995)	Seasonally averaged rainfall over all Indian sub-divisions from June-September (1871 – 1995)	Indian summer monsoon
Goswami et al. (1999)	Meridional wind shear between 850 and 200 hPa	Large-scale Asian monsoon
Wang and Fan (1999)	Negative outgoing longwave radiation (OLR) anomalies and meridional wind difference at 850 hPa	CI1 for south Asian summer monsoon and CI2 for southeast Asian summer monsoon
Lau et al. (2000)	Meridional/zonal wind difference shear 850 and 200 hPa	South and east Asian monsoon

2.6.3 Influences on Borneo

ENSO is arguably the most prominent cause of inter-annual variability in the global atmosphere and it holds the key for long-range predictions (Quah, 1988; Bohn, 2000). However, for the Asian monsoon region, particularly Southeast Asia, which is directly affected by the influential synoptic circulations originating from the Indian Ocean and Asian continent – the inter-correlation between monsoon and ENSO must be examined thoroughly. Sirabaha (1998) acknowledged, "principally the East Asian Monsoon Winter (the northeast

[4] SOI stands for Southern Oscillation Index; SLPA (Sea-level pressure anomaly); SSTA (Sea surface temperature anomaly).
[5] MSLP stands for mean sea-level pressure.

monsoon) plays the major role in shaping or maintaining the rhythm of seasonal climate over Borneo (rightly located in the heart of Southeast Asia)". A simplified schematic interaction between ENSO, monsoon and local climate can be seen in Figure 2.9. ENSO has the widest domain of action on temporal and spatial basis. It fluctuates within 2-7 years and the action centre covers the area between South American and African continents. The Asian monsoon is based on annual cycle and covers a smaller region (of action centre), which is between the Indian Ocean (west) and the Philippines Sea (east). The intraseasonal variability is characterized by 10-90 day oscillation, which has strongest signals in the tropical Indian and western Pacific Oceans (Wang, 1992). The first known of such synoptic forcing is Madden-Julian Oscillation (MJO), discovered by Madden and Julian in 1971. Julian and Madden (1981) postulated that the South Asia summer monsoon (which mainly affects the South Asia and East Asia regions) is a portion of the global equatorial MJO. However, there is not much study has been made on its effect on the Southeast Asia monsoon. Thus, the focus on this thesis will be mainly aimed to understand the quasi-biennial and seasonal large-scale influences (i.e. the ENSO and SEA monsoon).

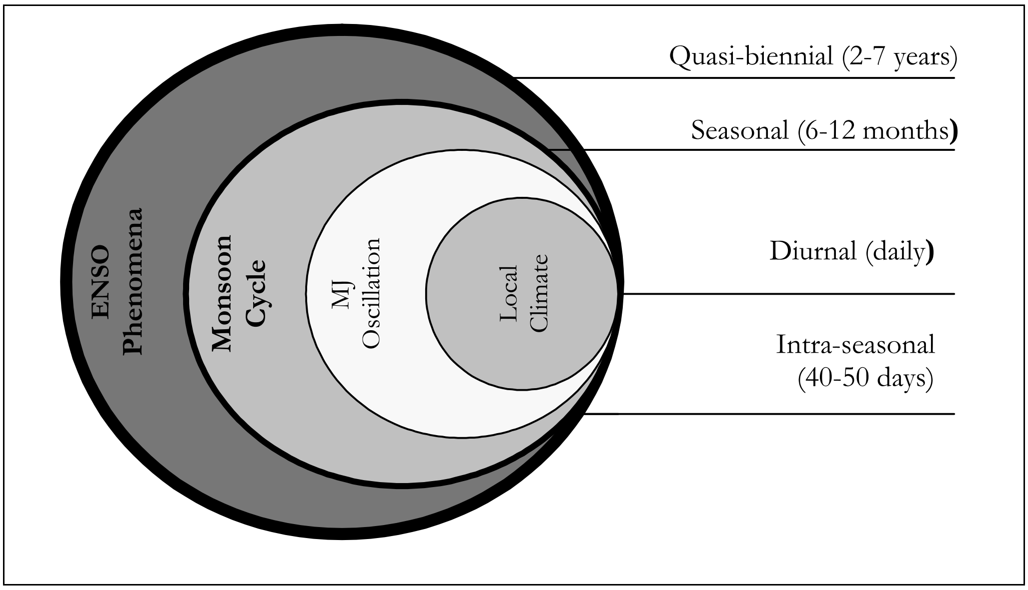


Figure 2.9: Simplified inter-relationships between ENSO, Southeast Asian Monsoon, Intra-Seasonal Forcing (i.e. Madden-Julian Oscillation) and Local Weather (temporal and spatial perspective)

How do these large-scale systems influence the local climatic variability of Borneo? Although a number of studies suggest that the impact of ENSO on the Southeast Asia monsoon, especially in the mainland region (i.e. Thailand, Mynmar, Indochina) are not prominent (Roy and Kaur, 2000; Kriplani and Kulkani, 1997), other studies have found that a strong association does exist (Halpert and Roelewski; 1989; Diharto, 1999). In addition, this significant connection is more clearly exhibited in the Borneo region. Previous researches (Quah, 1988; Cheang, 1993; Tangang, 1999; Sirabaha, 1998) showed that Borneo (as one entity itself) has developed its own teleconnection pattern with these synoptic circulations – and, this specific relationship is different from what has been observed in other parts of the region (the peninsular Malaysia and the southern part of Indonesia).

How different is Borneo? Malaysian rainfall, in general, has strong seasonal characteristics. As had been mentioned earlier, it is under the influence of Asian monsoons, and significantly modulated by the ENSO events on the time-scale of 2-7 years basis (Ooi, 2001). Both Cheang (1993) and Ooi (2001) in their studies on the relationship between ENSO and monsoon rainfall in Malaysia failed to trace any linear trend. However, both of them concluded that East Malaysia (Sabah and Sarawak) is more prone to ENSO influences compared to peninsular Malaysia. On the specific trend of how local climate associated with the ENSO, Cheang (1993) suggested that El Niño (La Niña) was closely related with less (more) rainfall. This is consistent with latest findings by Sirabaha (1998, 2004).

As far as ENSO and monsoon forcing are concerned, Cheang (1993) has produced the most comprehensive overview of the teleconnections with respect to Borneo. The main results, which were based on 12 El Niño and 10 La Niña events from 1951 to 1991, are summarized in Table 2.3. Seven events from a total of twelve El Niño events (1951 – 1991) brought extremely dry years to many stations all over Malaysia, especially in Sarawak and Sabah. For the La Niña events, eight out of the ten events being studied (1951 – 1991) caused extremely wet conditions (Ropelewski and Halpert, 1987; Quah, 1988; Cheang, 1993). This finding seems to be consistent with Behrend (1987), and Rasmussen and Carpenter (1982) who concluded that the SOI (ENSO index) is negatively connected with rainfall anomaly in the southeast Asian region, particularly the maritime continent (i.e. Indonesia and Borneo). In a similar study, Tangang (1999) used empirical orthogonal function (EOF) analysis on rainfall data from twelve stations in Malaysia and concluded that precipitation anomalies in Sabah and Sarawak are mostly affected by the first dominant mode of perturbation (which accounted to 24.3% of the total variance), which was believed to be associated with ENSO signals.

Precipitation anomalies (developed as a monsoon index) can be related to the Southern Oscillation Index (regarded as one of the most prominent ENSO indicators) in the entire tropics. They tend to appear within one 'season' of the "monsoon year" (annual cycle), though the anomaly for each region shows a different seasonal influence from place to place (Yasunari, 1991). Most of the teleconnections occur during the second half of the year, when the Southern Hemisphere circulations (the southeast trade winds) reach their peaks (Behrend, 1987).

Table 2.3: ENSO-Monsoon influences on stations in Borneo (Malaysia)

(a) Sabah (north Borneo)

	EL Niño		La Niña	
	Below Normal	Above Normal	Below Normal	Above Normal
SW Monsoon	1951, 1957, 1965, 1972, 1977, 1982, 1986, 1991	None	None	1955, 1956, 1964, 1970, 1971, 1973, 1975, 1988
NE Monsoon	1965, 1972, 1977, 1982, 1991	1957	1974	1955, 1960, 1970, 1973

(b) Sarawak (west Borneo)

	EL Niño		La Niña	
	Below Normal	Above Normal	Below Normal	Above Normal
SW Monsoon	1963, 1965, 1972, 1977, 1982, 1986	1969	1971	1955, 1956, 1960, 1964, 1970, 1973, 1988
NE Monsoon	1953, 1957, 1963, 1972, 1982, 1986, 1991	None	None	1970, 1975

It is also wise to note that these teleconnections are related differently in winter and summer, and therefore it is necessary to examine the relationships separately for the December – February and June – August periods (Riehl, 1954, 1979). In this research, the time-frame used to differentiate the two monsoons are April-September for the SW Monsoon and October-March for the NE Monsoon. This decision is justified based on two considerations – (i) past literatures (Caesar, 2002; Sirabaha, 1998, 2004); and (ii) long-term time-series analysis (of rainfall data) observed in 27 selected stations from Borneo (see Chapter 4). The comparisons between these two synoptic circulations are summarized in Table 2.4.

Table 2.4: Comparison between monsoon and ENSO

Aspect	Monsoon	ENSO
Source origin of the forcing	Circulation mostly from the land (Asian main-land continent) – NE (Winter) Monsoon; And from the ocean (Indian Ocean) – SW (Summer) Monsoon	Circulation generated from the tropical part of Pacific Ocean
Fluctuation cycle	Seasonal (intra-annual)	Low frequency and quasi biennial (inter-annual)
Best criteria of identification	Precipitation anomaly, Land or sea surface temperature and pressure, geopotential height at 850hPa, 500hPa and 200hPa	Ocean temperature (SST), Sea level pressure (SLP)
Geographic domain	Observation of pressure differences between 110°E - 160°E Domain of action - 35°N - 25°S and 30°W - 170°E.	Observation of pressure differences between Tahiti and Darwin The South Pacific Basin within 180°E – 90°W

Specific index	E.g. East Asian Summer Monsoon Index [MI] (Shi and Zu, 1996) and All Indian Rainfall Index [AIRI] (Parthasarty, 1987) Not widely-accepted indices (only applied for specific region)	E.g. Southern Oscillation Index (SOI), Sea Surface Temperature Anomaly (SSTA) – from various Niño regions (Niño3.4 as the most common to be associated with the southeast Asian) Widely-accepted indices (almost globally applicable)
Manifestation on surface climate	Asian Summer (SW) Monsoon – relatively "dry" season (April – September) Asian Winter (NE) Monsoon – relatively "wet" season (October – March)	El Niño events – negative rainfall anomalies La Niña events – positive rainfall anomalies

2.7 Chapter summary

With regards to the proposed research, there are few studies that have been carried out in Southeast Asia (the main domain of the chosen case study). However, there is a large amount of literature on the ENSO and the Asiatic monsoons – two key phenomena to understand the relationship between large-scale atmospheric circulation and the local surface climate of this tropical region. Previous studies have established several findings:

- ENSO and the monsoon are clearly accepted as the two main synoptic forcings that drive Southeast Asia surface climate (where Borneo is centrally located).
- ENSO parameters have been established and proven to be highly reliable to predict surface climate variables (especially rainfall).
- Several monsoonal-flow indicators have been identified and successfully used to explain rainfall variability in the Asian tropical region.
- The relationship between the Asian monsoon and ENSO phenomena, with respect to the southeast Asian region, is better understood from the works of Caesar (2002) and Sirabaha (1998, 2004)[6].

On the other hand, some incomplete knowledge still needs further exploration and understanding. These, listed below, are the important issues to be addressed in this research, and to a certain extent, might serve as the gaps to be filled;

- The influences forced by the two synoptic circulations (ENSO and monsoon) are not mutually exclusive. The questions of which is more dominant and how they interact with each other is still unclear – especially in terms of modulating or shaping the surface climate on a smaller part of Southeast Asia (e.g. Borneo).

[6] See Section 2.7.1.

- Surface friction (orographic factors) and geographic features (the unique distribution of land and sea) have never been seriously considered in previous studies. For instance, the roles of "local current and sea water flow" around the Molucca Sea (Aldrian and Susanto, 2003); and the presence of the Molucca Isles and the Philippines, which might serve as the "blocking" systems. This could be the key information to explain the variability of Borneo surface climate in terms of spatial (e.g. different parts of Borneo experience different characteristics in seasonality, precipitation pattern, etc).
- The influence (or mutual interaction, rather) of non-climatic factors (i.e. atmospheric pollution) on local climate and large-scale circulation are also not appropriately addressed using the monsoon-ENSO perspective. It is wise to note that the effect of QBO are not confined to atmospheric dynamics only, because it also affects the chemical constituents such as ozone, water vapor and methane (Baldwin et al., 2002). In the case of 1997 El Niño – light southeasterly wind anomalies (originating from Australia) had in fact advected smoke haze towards Malaysia – reducing the amount of incoming solar radiation (Ooi, 2001), and through feed-back mechanisms, convective cloud was suppressed resulting in a reduction of rainfall.
- All analyses were rigidly based on "political boundaries" and this approach simply ignored the need to treat Borneo as one entity itself although findings from several studies suggested this Island is climatically unique (Aldrian, 2001).
- The influences of ENSO and Asiatic monsoons have never been treated as a "unique-combined forcing". In the case of all previous studies – usually one (of these two synoptic forcings) had been treated as the "main force", whilst the other one as only the "disturbing factor". The question is, how to put the statement of Krishna Kumar et al. (2000) – "...***though the predictors can be classified into four different groups based on their known physical linkage with the monsoon (or ENSO), the forcings represented by them are not entirely exclusive to their respective groups***" – into the correct perspective?

2.7.1 Final perspective

The core aim of this research is to investigate a more meaningful association between the large-scale atmospheric circulation and the surface climate in Borneo. This requires deep understanding of the significant characteristics and features of large-scale circulation that influence the region (Southeast Asia in general) – namely the Asiatic monsoon and ENSO phenomena are the two main synoptic features. As has been noted before, there are very few studies that have been carried out on the specific effects of monsoon and ENSO to the southeast Asian region. Up to this date, only Caesar (2002) and Sirabaha (1998, 2004) have provided the most comprehensive knowledge on the mutual interaction between these two synoptic circulations – with respect to the southeast Asian region.

Caesar (2002) and Sirabaha (2004) manage to synthesise the previous literatures on monsoons and ENSO and put them together into a Southeast-Asia perspective. They also redefine the monsoon and ENSO (i.e. phases of development; climatic indicators) based on the region feature. It is then followed by detailed evaluation and discussions of the physical features and the dynamic mechanisms behind these two most prominent climatic phenomena in the universe. They have brought the state of knowledge on synoptic climatology for this region to another level. This research will address its own issues by fully optimizing their works and findings – especially in terms of 'how to define the monsoon and ENSO' and 'what are the unique attributes of these forcing factors on Southeast Asia. The questions are – what is lacking from those two previous studies, and how do they motivate this new research? What are the gaps needed to be filled?

- There is no attempt to generalize the circulations (the monsoon and ENSO) into specific modes (i.e. synoptic typing), which can later be empirically associated with the local climate.
- No exclusive focus is given on how these synoptic circulations influence the local climate on different parts of the region (i.e. spatial variability – e.g. differences between Borneo, Peninsular Malaysia, the Philippines and the Indonesian archipelagos).
- No consideration or investigations have emphasized the non-climatic factors (e.g. regional pollution), which could directly influence the surface environment (thus, modifying the conventional effect induced by the normal atmospheric circulation) or could indirectly contribute to the internal changes/variability within the large-scale circulation itself.
- The three issues mentioned above are the knowledge vacuums that this proposed research is attempting to explore further by – (a) establishing specific circulation types; and (b) investigating their empirical relationships with the local variables of Borneo. Even though both Caesar (2002) and Sirabaha (2004) do analyze the associations between the monsoon-ENSO and certain surface parameters (e.g. precipitation and temperature) – they are mostly general descriptions, and not in a form of empirical relationships (i.e. circulation indices numerically related to precipitation/temperature measures). As far as non-climatic factors are concerned, these two studies do not perform any analysis.

Chapter 3
Research Issues, Data and Methods

3.1 Introduction

In the previous chapter, aspects of the variability of the atmospheric circulation over Southeast Asia with a particular reference to the local climate of Borneo have been introduced. The first part of this chapter explains the issues and the theoretical framework for the entire project based upon the key findings raised in Chapter 2. The second section introduces the data sets used in terms of their sources and specific application in this study. The final sections introduce the statistical analysis techniques that will be used.

3.2 Research Issues

What is the main aim? The core aim of this project is to investigate the relationships between the large-scale circulation of Southeast Asia and the surface environmental conditions in Borneo (especially the local climate and atmospheric pollution). Why is it important? Borneo, like many other parts in Southeast Asia, still depends heavily on primary economic sectors (i.e. agriculture, forestry, eco-tourism) (Yearbook of Statistics, Sarawak/Sabah, 2004). A better understanding of the association between the synoptic circulation and local climate will improve understanding on the seasonal cycle and its influences on human per se (i.e. the surface manifestation). Also, improved scientific understanding of the associations between climatic factors and transboundary atmospheric pollution will be highly beneficial for Borneo, which itself earns a reputation as one of the most prone regions in Southeast Asia to the ASEAN brown haze[7] phenomenon. It is also hoped that the outcome of this project (i.e. the synoptic typing) will facilitate the development of further research on constructing the future climate scenario for Borneo (using downscaling techniques).

- How will these goals be realized? This project outlines three key analyses for achieving a better understanding of the local and synoptic climatology of Borneo:

[7] ASEAN brown haze phenomenon is referred to the repeated occurrences of regional haze in ASEAN (mainly affecting Malaysia, Singapore, Brunei and Indonesia) as a result of the 'slash and burn' activities in Riau, Sumatera and Kalimantan (all are Indonesian provinces).

- To define the seasonal cycle and local climatic divisions for Borneo; and to formally establish the characteristics of these seasons in the spatial climatic divisions.
- To identify the significant/important modes of the large-scale circulation surrounding Borneo; and to classify these modes into a systematic synoptic typing scheme.
- To relate this established synoptic typing scheme with the surface characteristics (local climate and its fluctuation) of Borneo; and to investigate the patterns of these relationships.

What are the challenges for this project? The monsoon cycle and ENSO are two synoptic features that mainly influence the climate variability in Southeast Asia (including Borneo). However, study of climate variability in this region, has received relatively less attention than the neighbouring areas of South and East Asia (Caesar, 2002). Thus, the complete understanding of the large-scale climatic phenomena (especially the interaction between the monsoon and ENSO) that could possibly shape Borneo's surface climate is still very limited. This issue (i.e. missing in previous studies) will be one of the biggest challenges in this project. Although a wide range of literature on this subject (monsoon-ENSO forcing and its relationships with local climate) is available for the South/East Asia regions (e.g. Parthasarathy and Pant, 1984; Shi and Zu, 1996); few studies have been carried out in Borneo. Most studies (Meehl, 1997; Kirpalani and Kukarni, 1997; Sirabaha, 2004) have found that Asian monsoon variability is by no mean uniform across sub-regions of South and East Asia, so it is difficult to transfer results and findings (from other region) to Borneo.

What is the key scientific breakthrough that motivates this research? On a positive note, for the last few years, there have been a number of important studies (i.e. Tangang, 2001; Sirabaha, 1998 and 2004; Caesar, 2002) specifically aimed to help understanding of the monsoon-ENSO interaction and its influences on the surface climate of Southeast Asia. Sirabaha (1998) successfully managed to improve the empirical understanding of the impact of ENSO on inter-annual variability of rainfall in Borneo. Tangang (2001) exclusively focused his attention on remote ENSO forcing and its teleconnections with the local climate of Malaysia (which includes Borneo), especially for precipitation. However, both studies (i.e. Sirabaha, 1998; Tangang, 2001) lacked insightful knowledge on the mutual interaction between ENSO and the monsoon. Caesar (2002) established a deeper understanding of the role of SST anomalies in forcing monsoon variability over Southeast Asia. This significantly enhanced the knowledge on how ENSO and the monsoon mutually shape the local climate patterns (precipitation and temperature) in this region, especially during the boreal winter. Sirabaha (2004) added a new element to what Caesar (2002) had established by investigating the physical mechanisms underlying the impact of ENSO on the climate and weather of Southeast Asia in both seasons (summer and winter). The key outcomes from these studies will be the main basis for this project as far as designing a research theoretical framework and the setting of operational objectives.

3.2.1 Hypothetical foundations

Three hypotheses have been established as the theoretical framework for this research (which are mainly based on the compilation of the main findings presented earlier in the literature review – see Chapter 2). These hypotheses will serve as the foundations to guide the flow of this research; and as the benchmarks in assessing whether these aims have been achieved, in the final stage.

- Borneo experiences systematic surface climate variability subject to temporal and regional scales; and this can be identified and classified using appropriate climate variables (i.e. precipitation and temperature).
- Large-scale circulation (mainly due to the fluctuating interaction of the monsoon and ENSO) is perceived as the main synoptic features that influences the climate variability of Borneo.
- By establishing a circulation-typing scheme (which can capture and integrate the signals of both the monsoon and ENSO), the patterns of relationships between surface environmental condition (for Borneo) and its surrounding synoptic circulation can be investigated.

These three hypotheses (which serve as the theoretical framework of this project) will be explored further, and each one of these hypotheses will be set with specific objectives. The first hypothesis (i) will be analyzed in Chapter 4 and 5. The main objectives are establishment of climatic divisions for Borneo (spatially) and classification of weather types based on precipitation and temperature (temporally).

The second hypothesis (ii) is the main basis for Chapter 6. The core objective is to develop a synoptic typing scheme (using SLP data), which can classify the large-scale circulation surrounding Borneo into several significant modes. The final hypothesis (iii) will be investigated in Chapter 7 and 8. The objectives are to examine and explain the relationships between the circulation types (established in Chapter 6) and the local climate of Borneo. It will also investigate the inter-relationships between the synoptic circulation, local climate and a pollution index.

3.3 Data

There are two main types of data used in this project (i.e. Reanalysis and Observational data), which fall into two categories – (i) large-scale/synoptic climatic data; and (ii) surface climatic data. Both types and categories of data have been subject to rigorous quality control, and have been widely used for scientific studies in climatology. This will be explained in further detailed in the Sections 3.3.1, 3.3.2 and 3.3.3.

3.3.1 Reanalysis Data

The reanalysis data in common use are produced by the National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR) Reanalysis project (NCEP Reanalysis), and the European Centre for Medium Range Weather Forecasts (ECMWF). The reanalysis data chosen for this study are those produced by NCEP. Reanalysis data from this project have been used in previous studies for Southeast Asia (Caesar, 2002; Sirabaha, 2004). The NCEP Reanalysis data are based on the use of a frozen state-of-the-art analysis system, which assimilates past atmospheric data from recent years (Kalnay et al., 1996). The lower boundary of the atmospheric model is fixed by providing historic analyses of sea surface temperature (SST). The complete output data from this project typically has a horizontal resolution of 2.5º X 2.5º latitude/longitude, with a vertical resolution up to 17 levels (Sirabaha, 2004). The goal of the NCEP/NCAR Reanalysis project is to provide the climate research, monitoring, and modelling community with a record of global atmospheric analyses that have been generated from a stable, invariant analysis system. The output variables for the NCEP Reanalysis are classified by Kalnay et al. (1996) into four classes. This classification is based on the degree to which the data are influenced by the observations or by the model.

- (A) The variable is strongly influenced by observed data, and is therefore in the most reliable class (e.g. upper-air temperature, geopotential height, sea-level pressure, zonal and meridional wind components).
- (B) The variable is directly influenced by the observed data, and equally a strong influence from the model (e.g. moisture and surface variables).
- (C) The variable is purely derived from the model fields (e.g. clouds and precipitation).
- (D) A field fixed from climatological values with no dependence on the model (e.g. plant resistance).

This research only uses sea-level pressure (SLP), which is categorized in A. It means that SLP is heavily influenced by the observations, and therefore, is in the most reliable class. Since the land-ocean pressure gradients are important for driving the Asian monsoon system (Caesar, 2002), it is useful to use the mean sea-level pressure fields as the key synoptic indicator to capture the variability of large-scale atmospheric circulation over Borneo. It serves as a guide to 'the contrast'[8] between the Southeast Asian maritime continent (where Borneo is located) and the surrounding oceans (i.e Indian Ocean, where the Southwest Monsoon forcing comes from; and Pacific Ocean, from where the ENSO remote teleconnection originates).

In the recent years, NCEP Reanalyses have been widely used by scientists all over the world (see e.g. Kostopoulou, 2003). The issues pertaining to validation, quality control and reliability test have been explored and studied by many scientists too (e.g. Kalnay et al., 1996; Kistler et al., 2001; Reid et al. 2001; Trenberth et al., 2001). The NCEP Reanalysis SLP data used in this study are daily mean grids which extend from 1960 – 2001 (inclusive); and cover a large area (30˚N-20˚S; 75˚E-140˚E). As a simple test of the data used in this project and its compatibility with the region being studied, a simple validation has been carried out.

Table 3.1: Specific location of each station with its surrounding grid-points

Station	Longitude	Latitude	Nearest 4 grid-points (2.5° X 2.5°)*	Zone
SDK	118.1°E	5.8°N	(117.5E, 5N), (120E, 5N), (117.5E, 7.5N), (120E, 7.5N)	A
TWU	117.9°E	4.3°N	(117.5E, 2.5N), (120E, 2.5N), (117.5E, 5N), (120E, 5N)	B
KDT	116.8°E	6.9°N		
KK	116.1°E	6.0°N		
LBN	115.3°E	5.3°N	(115E, 5N), (117.5E, 5N), (115E, 7.5N), (117.5E, 7.5N)	C
MIR	114.0°E	4.4°N		
BTU	113.0°E	3.2°N	(112.5E, 2.5N), (115E, 2.5N), (112.5E, 5N), (115E, 5N)	D
SBU	111.8°E	2.3°N		
SAM	111.5°E	1.2°N		
KCH	110.3°E	1.5°N	(110E, 0), (112.5E, 0), (110E, 2.5N), (112.5E, 2.5N)	E

** These 4 grids are averaged to produce Zone A, B, C, D and E*

The SLP reanalysis data (obtained from NCEP) have been correlated with observed SLP data from 10 stations in the northern part of Borneo (Sabah and Sarawak)[9]. A normality test is first performed on the SLP data (both the observed and reanalysis) to identify the nature of distribution. The results demonstrate a convincing normal distribution. Therefore, it is decided to use Pearson Correlation method. A theoretical background concerning this

[8] The contrast – is referred to the difference in large-scale atmospheric condition between the Borneo archipelago and its surrounding oceans (Pacific Ocean, Indian Ocean and South China Sea). SLP is deemed to be the best indicator because it is directly associated with the fluctuation of both monsoon and ENSO.

[9] This is performed for the period of 1968-2001 (34 years).

method (the measure is better known as the Pearson's Product Moment Coefficient) is given in Section 3.4.5.

The specific location of each station and with its four closest surrounding grid-points (where the reanalysis SLP data are located) is shown in Table 3.1. The correlation values between the observed SLP at each station with the corresponding average (based on the four surrounding grid points) are summarized in Table 3.2. All are significant at the 99.9% level of confidence. The correlation values are between 0.89 – 0.95, which generally proves that the NCEP reanalysis data for this region are reasonably precise, as far as daily SLP data are concerned.

Table 3.2: The Pearson's Product Moment Coefficient values

	SDK	TWU	KDT	KK	LBN	MIR	BTU	SAM	SBU	KCH
A	0.93									
B		0.95								
C			0.95	0.90	0.91					
D						0.94	0.89			
E								0.94	0.92	0.94

All values are significant at the 99 % level of confidence

3.3.2 Observational data (synoptic indices)

There are several ENSO indices that have been widely used in scientific research, with the most common ones being the Southern Oscillation Index (SOI) and the sea surface temperature (SST) anomalies observed in the Niño regions in the Pacific Ocean. SOI is an inter-annual fluctuation in sea-level pressure across the Pacific, or specifically the normalized pressure difference between two identified sites: i.e. Tahiti and Darwin. The SST anomalies are observed in four Niño regions in the central and eastern Pacific: i.e. Niño-1 + 2 (0˚-10˚S; 60˚W-30˚W), Niño-3 (5˚N-5˚S; 150˚W-90˚W), Niño-3.4 (5˚N-5˚S; 170˚W-120˚W), and Niño-4 (5˚N-5˚S; 160˚E-150˚W).

The Asian monsoon variation on an annual basis is one of the strongest climatic signals in the earth system, which is directly or indirectly linked to other atmospheric-related factors (i.e. surface climate, ENSO, regional/local pollution). It is important to use a representative variable to quantify the variability of this monsoon signal, similar to the establishment of ENSO indices that provide excellent examples of quantifying a complex phenomenon using a single parameter. According to Wang and Fan (1999), the use of concise and meaningful indices to characterize monsoon variability can greatly facilitate empirical studies of the relationship between monsoon variability and lower boundary forcing (i.e. local or regional climatic condition).

3.3.2.1 ENSO Indices

All SST-based (Niño) indices are extracted from the Climatic Diagnostic Centre (CDC) website at this url address: http//www.cdc.noaa.gov/ClimateIndices. This project uses the SST anomalies (as departures from the long-term 1961-1990 mean) as the representation of the oceanic component of ENSO. Of the four original 'Niño regions' (see Figure 3.1), Niño-3 and Niño-4 are typically used to represent the larger-scale ENSO phenomena (Caesar, 2002). However, Barnston and Chelliah (1997) have found that the newly-introduced (in 1996) Niño-3.4 region has a stronger relationship with regard to ENSO teleconnections.

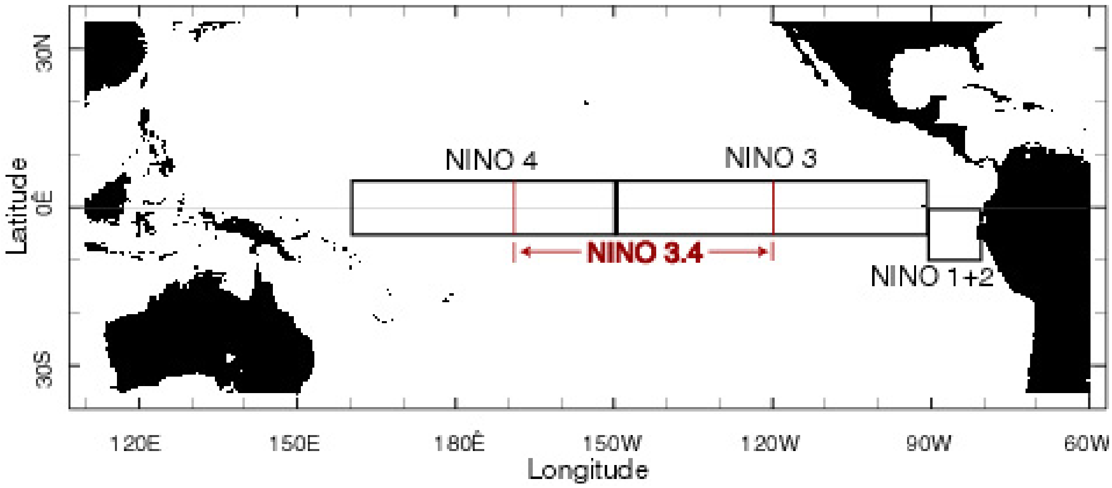


Figure 3.1: The Niño regions
(Source: Caesar, 2002)

The monthly SOI data used in this study are from the Climatic Research Unit (CRU) established record (Ropelewski and Jones, 1987). These data are the normalised pressure difference between Tahiti and Darwin, and they give a representation of the atmospheric component of the ENSO. The data for all ENSO indices used in this study cover the period from 1960 to 2001, to be consistent with the available data for surface climate. Arguably, SOI and Niño-3.4 indices are the most commonly used of the ENSO indicators for climate study in Southeast Asia (e.g. Tangang, 2001; Caesar, 2002; Sirabaha, 2004). However, all five indices will be re-evaluated in this project (Chapter 6), before the best indices will be selected for further analysis (Chapter 7 and Chapter 8).

3.3.2.2 Monsoon indices

The choice of an appropriate index for the Asian monsoon has been a subject of some controversy and received considerable attention in recent years (Webster and Yang, 1992; Parthasarathy et al., 1995; Goswami et al., 1999; Lau et al., 2000). There have been many monsoon indices proposed for climatology studies in Asia (especially the South and East

Asian regions). The most notable monsoon indices are summarized in Appendix A. The debate on the issue of 'choice for monsoon indices' has created some controversy among scientists (e.g. see the commentary article by Goswami and the response by Wang, both in 2000). The monsoon is an extremely complex phenomenon because it varies from year to year and the effect is not spatially uniform. Both Goswami (2000) and Wang (2000) have pointed out a large element of subjectivity on this issue, which includes:

- Making the decision of what type of climatic variables that will best represent the monsoon (i.e. sea-level pressure, precipitation, zonal and meridional winds, etc). Each one of these variables is correlated differently (in terms of strength and orientation) with the surface climate (Goswami, 2000).
- The process of selecting the best region to capture the monsoon signals (i.e. heating centre, anomalous area for a particular atmospheric parameter – e.g. SLP). This involves some conceptual questions – i.e. whether the signal (captured in the selected region) is truly uniform and the largest available.

The eventual choice will be heavily dependent on the area chosen and the purposes of the study. This is because the effect of broad-scale monsoon indices is not uniform across the Asian region. Thus, for more precise relationships (between monsoon indices and other atmospheric-related factors) – the monsoon indices must be 'localized' to suit a specific area of study. This project will evaluate six of the most commonly-used monsoon indices (for climatology studies in Asia) and compare the performances (of these six selected indices) with newly-established indices (especially created to suit the area of study in this project – i.e. Borneo). The six selected indices are described below, and the sources/observations summarized in Table 3.3 and described in turn.

- All-India Rainfall Index (AIRI – Parthasarathy et al., 1995): An all-India summer monsoon rainfall series for the instrumental period of 1844-1991 has been constructed using a progressively increasing station density to 1870, which is then fixed thereafter at a uniformly distributed thirty six stations. The interesting outcome of this study is that a reliable estimate of summer monsoon rainfall over India can be obtained using only these thirty-six observations. The statistical scheme accounts for the increasing variance contributed to the all-India series by the decreased number of stations during the period 1844-1870.
- Indian Ocean Index (IOI): Index values are the average of SST anomalies over 30˚N-30˚S, 46˚E-100˚E with the exclusion of the grid points corresponding to the Red Sea (see Figure 3.2). Anomalies are calculated with respect to the period of 1950-79. The SST data used for 1856-1997 are from the Comprehensive Ocean-Atmosphere Data

Set (COADS)[10] and values for 1998-2002 are from the National Centers for Environmental Prediction real-time marine data (not the NCEP/NCAR reanalysis).

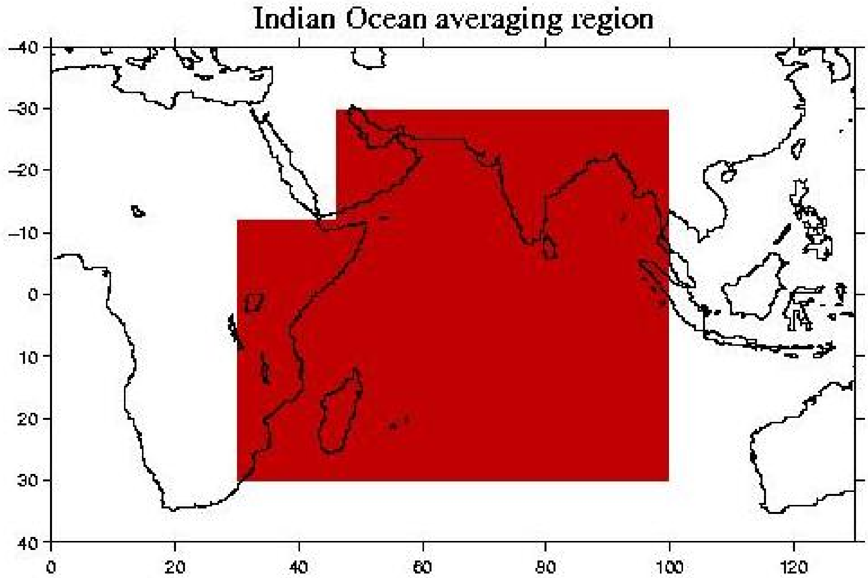


Figure 3.2: The SST averaging region for Indian Ocean Index

- The Unified Monsoon Index (UMI1 and UMI2 – Lu and Chan, 1999): UMI1 and UMI2 are defined based on the meridional winds at 1000 and 200 hPa. UM1 is the difference between meridional winds at 1000 hPa and 200 hPa. UM2 is the monthly average of merdional wind component at 200 hPa. All calculations are over the region of South China Sea (2.5˚N-22.5˚N, 102.5˚E-122.5˚E)
- The Regional Monsoon Index (RM – Lau et al., 2000): There are two Regional Monsoon indices (i.e. RM1 and RM2) introduced by Lau et al. (2000), which are based on time-mean meridional and zonal wind at 850 and 200 hPa. The one used in this project is the Regional Monsoon Index 2 (RM2) that is identified as more suitable for East and Southeast Asia (Lau et al., 2000). RM2 is the time-mean zonal wind at 200 hPa between the regions of 40˚N-50˚N; 110˚E-150˚E and 25˚N-32.5˚N; 110˚E-150˚E.
- Webster and Yang Monsoon Index (WYI – Webster and Yang, 1992): WYI is the time-mean zonal wind shear between 850 and 200 hPa, and being averaged over the region of 0˚-20˚N; 40˚E-110˚E.

[10] The COADS data exhibits a spurious jump at the onset of World War II as the mix of measurements in the COADS changed from bucket to engine-intake values (Folland and Parker, 1995). The removal of the global mean also removes some of the trend.

Table 3.3: The sources of monsoon indices and the data details

Index	Source	Observation	Data Range
AIRI	http://iridl.ldeo.columbia.edu/SOURCES/ International Research Institute for Climate Prediction (IRI)	Seasonal values (available only for the summer monsoon)	1960 – 1995
IOI	http://tao.atmos.washington.edu/data_sets/ Joint Institute for the Study of Atmosphere and Ocean (JISAO)	Monthly (for summer and winter monsoon)	1960 – 2001
UM1 & UM2	http://ncc.cma.gov.cn/apn/monitoring/ Asia-Pacific Network for Global Change Research (APN)	Monthly (for summer and winter monsoon)	1960 – 1997
RM2	Kyung Jin[11] Climate Environment System Research Center (CESRC)	Seasonal values (for summer monsoon only)	1960 – 2001
WYI		Seasonal values (for summer monsoon only)	1960 – 2001

3.3.3 Observational data (surface variables)

The meteorological station data used in this project have been received from Malaysia Meteorological Service (MMS), Brunei Meteorological Service (BMS), Indonesia Meteorological and Geophysical Agency (IMGA) and data available from Climatic Research Unit archive (CRU). Some precipitation data (monthly totals) are available back to the early 1900s. However, most of the data used in this study are those recorded from 1960 – 2001 in order to retain the highest quality data. The data have been subject to a high standard of quality control together with homogenization aspects (Sirabaha, 2004). Over the past few decades, several studies on climatology of Southeast Asia have utilized these data (e.g. Cheang, 1993; Kulkarni and Kriplani, 1997, Quah, 1998; Manton et al., 2001; Tangang, 2001; Caesar, 2002; Sirabaha, 1998, 2004).

The Indonesian data were mostly derived from the records available at the Climatic Research Unit (CRU), University of East Anglia, although there were some data that are obtained from IMGA. The Malaysia and Brunei data were provided directly by the meteorological services in both countries (daily observation); and extended with the records available in CRU for observations before 1968 (monthly totals only). Forty-two stations were initially selected (see Appendix B), which include ten stations from Malaysia, four from Brunei and twenty-eight from Indonesia. However, upon assessing the quality of the data, it was decided that not all forty-two stations were suitable for this project. There are

[11] These data are personally provided by Mr. Jin, a climatology scientist at School of Earth and Environmental Science, Climate Environment System Research Center, Seoul National University, Building 56, Room 527, Sinlim-Dong, Kwanwak-Ku, Seoul, Korea, 151-742 Tel : +82-2-880-6897 Fax: +82-2-885-7357.

two main problems associated with all the omitted stations – (i) a large number of missing values; and (ii) non-availability of daily observation.

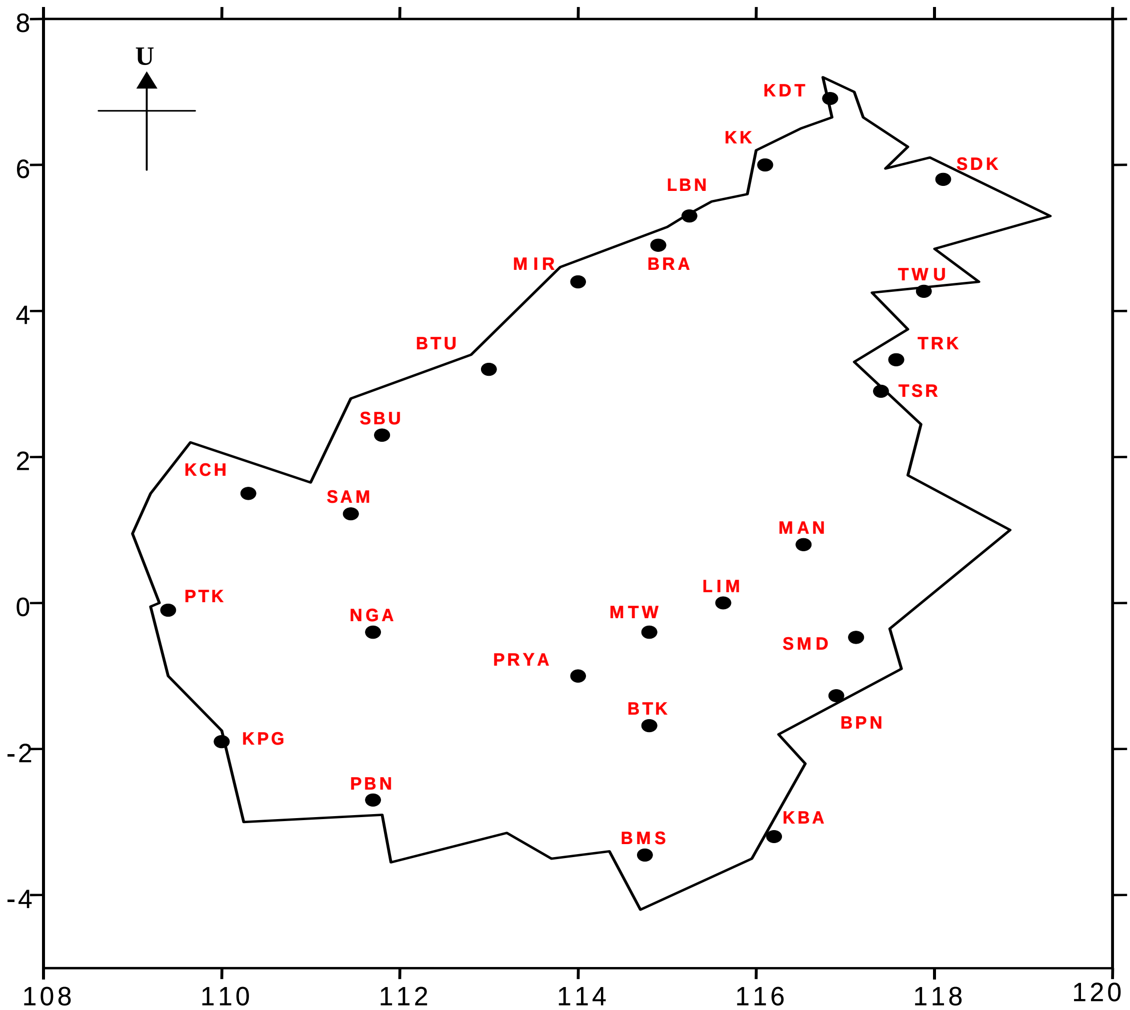


Figure 3.3: Borneo 29 selected stations
[BRL, BRS and BRK are not shown in this map because their locations are too close with BRA]

In this project, the surface data are used for four major purposes: (i) to establish the climatic divisions of Borneo based on monthly precipitation totals – Chapter 4; (ii) to investigate the trends and plot the time-series for precipitation/temperature variables (monthly data) – Chapter 5; (iii) to evaluate the relationships between the circulation types and precipitation/temperature (daily data) – Chapters 6 and 7; and (iv) to examine the inter-correlation between climatic factors (i.e. surface and synoptic) and non-climatic factors (i.e. pollution) – Chapter 8. Each one of these analyses is required to meet a particular degree of quality in the data (depending on the purposes of the analyses). Thus, different sets of stations are used in all four analyses. In establishing the climatic division of Borneo and analyzing the trends, 27 stations have been selected (see Table 3.4 and Figure 3.3). For the relationship analysis (with circulation types), which requires daily observations for both precipitation and temperature, only 6 key stations have been selected from the original 29 (i.e. SDK, KK, MIR, BTU, SBU and KCH). In analyzing the inter-correlation between climatic and non-climatic factors, which involves a pollution variable (observed on a daily basis), 4 stations have been chosen (i.e. TWU, LBN, SBU and BTU). Further justifications for the selection are provided in each chapter related to the analysis.

Table 3.4: The locations of the 29 selected stations for the analysis

Station	Province	Abbreviation	Longitude	Latitude
Sandakan	Sabah (Malaysia)	SDK	118.1 ˚E	5.8 ˚N
Kota Kinabalu	Sabah (Malaysia)	KK	116.1 ˚E	6.0 ˚N
Tawau	Sabah (Malaysia)	TWU	117.9 ˚E	4.3 ˚N
Kudat	Sabah (Malaysia)	KDT	116.8 ˚E	6.9 ˚N
Labuan	Sabah (Malaysia)	LBN	115.3 ˚E	5.3 ˚N
Kuching	Sarawak (Malaysia)	KCH	110.3 ˚E	1.5 ˚N
Sri Aman	Sarawak (Malaysia)	SAM	111.5 ˚E	1.2 ˚N
Miri	Sarawak (Malaysia)	MIR	114.0 ˚E	4.4 ˚N
Sibu	Sarawak (Malaysia)	SBU	111.8 ˚E	2.3 ˚N
Bintulu	Sarawak (Malaysia)	BTU	113.0 ˚E	3.2 ˚N
Seria	Brunei	BRS	114.3 ˚E	4.6 ˚N
Labi	Brunei	BRL	114.5 ˚E	4.5 ˚N
Kilanas	Brunei	BRK	114.8 ˚E	4.9 ˚N
Brunei Airport	Brunei	BRA	114.9 ˚E	4.9 ˚N
Kota Bharu	Kalimantan (Indonesia)	KBA	116.2 ˚E	3.2 ˚S
Muaratewe	Kalimantan (Indonesia)	MTW	114.8 ˚E	0.4 ˚S
Nanga Pinoh	Kalimantan (Indonesia)	NGA	111.7 ˚E	0.4 ˚S
Pengkalan Bun	Kalimantan (Indonesia)	PBN	111.7 ˚E	2.7 ˚S
Pontianak	Kalimantan (Indonesia)	PTK	109.4 ˚E	0.1 ˚S
Tanjung Selor	Kalimantan (Indonesia)	TSR	117.4 ˚E	2.9 ˚N
Tarakan	Kalimantan (Indonesia)	TRK	117.9 ˚E	3.3 ˚N
Muara Ancalung	Kalimantan (Indonesia)	MAN	116.9 ˚E	0.8 ˚N
Buntok	Kalimantan (Indonesia)	BTK	114.8 ˚E	1.7 ˚S
Ketapang	Kalimantan (Indonesia)	KPG	110.0 ˚E	1.9 ˚S
Banjarmasin	Kalimantan (Indonesia)	BMS	114.8 ˚E	3.5 ˚S
Long Iram	Kalimantan (Indonesia)	LIM	115.6 ˚E	0.0 ˚
Balik Papan	Kalimantan (Indonesia)	BPN	116.9 ˚E	1.3 ˚S
Plangkaraya	Kalimantan (Indonesia)	PRYA	114.0 ˚E	1.0 ˚S
Samarinda	Kalimantan (Indonesia)	SMD	117.1 ˚E	0.5 ˚S

The main criteria being considered in selecting the appropriate stations are – (i) the geographical representation (as far as possible, the selected stations should geographically represent Borneo); (ii) the quality of data (minimizing or avoiding if possible, the use of data with high numbers of missing values); (iii) the period of observation (certain analyses require longer periods, and are not appropriately undertaken with only a few cases); and (iv) the availability of daily/monthly observations for both precipitation and temperature variables (depending on the purposes of the analysis). Each one of these criteria will be explained further in the analysis chapters (putting the justification into a clearer perspective with regard to the specific analyses to be undertaken).

3.4 Statistical methods

The statistical methods used in this project can be grouped into four categories – in terms of their main aims. They are – (i) classification (i.e. Principal Component Analysis and Cluster Analysis); (ii) relationships (i.e. descriptive statistics, probability analysis, correlation); (iii) significance tests (Student T-test, ANOVA F-test, Chi Square test); (iv) trends analysis and time-series plotting (trend significance test, long-term averages). Outline descriptions of the important concepts in each one of the statistical techniques used in all four categories are provided in the next section. A brief introduction is given here, with more detailed explanation of how each method was used given in the related analyses chapters (Chapter 4 – Chapter 8).

3.4.1 Principal Component Analysis (PCA)

PCA is designed to capture the variance in a dataset in terms of Principal components[12]. The main purpose is to reduce the dimensionality of the data to summarize the most important (i.e. defining) parts whilst simultaneously filtering out noise. Hotelling first introduced PCA in 1933, and developed further in 1936. This technique has been commonly used to identify the main large-scale atmospheric circulation patterns (e.g. Caesar, 2002; Kostopoulou, 2003; Sirabaha, 2004), sea surface temperature (e.g. Kawamura, 1988), and precipitation fields (e.g. Tangang, 1999).

PCA is also often used to capture the cluster structure (just using the first few PCs) prior to cluster analysis (e.g. before performing K-Means[13] clustering to determine a good value for K). As a data reduction technique, PCA aims to reduce a dataset containing a large number of variables into one with relatively few variables, whilst still retaining a high proportion of the variability of the original data set. Each component is a linear combination of all p variables. The first component accounts for the largest possible amount of variance. The second component, formed from the variance remaining after that associated with the first component, accounts for the second largest amount of variance (a similar description follows subsequent components). The principal components are extracted with the restriction that they are orthogonal. Geometrically they may be viewed as dimensions in p-dimensional space where each dimension is perpendicular to each one of the other dimensions.

[12] **Principal Components:** A set of variables that define a projection that encapsulates the maximum amount of variation in a dataset and is orthogonal (and therefore uncorrelated) to the next principal component of the same dataset.

[13] K-Means clustering will be described more detailed in Section 3.4.2.

Principal component analysis (PCA) is used in this project to achieve two main purposes: (i) identifying significant spatial and temporal modes from surface climate (i.e. precipitation and temperature) variability of Borneo (Chapter 4); (ii) extracting characteristic spatial modes of SLP variability from the daily NCEP data (Chapter 6). The actual process of performing the PCA and the decisions taken at the various steps is covered in more detailed in the analysis chapter (Chapters 5 and 7). This section will present a brief introduction to PCA. Sirabaha (2004) provides these good summaries of the basic PCA equations (originally adapted from Richman, 1986):

PCA operates on an N x n data matrix of $Z = \{Z_{ij} : i = 1, 2…. N; j = 1,2….. n\}$, where the i indexes cases (observations), and j indexes variables. Z_{ij} denotes the variable value of some physical field for every i and j.

$$Z_{ij} = \sum f_{im}a^{T}_{mj} \quad i= 1, …..N; i= 1, …..n; m= 1, …..r; r \leq n \tag{1}$$

Where f_{im} is the r-th principal component score for the I-th individual case and a_{mj} is the the r-th principal component loading on the j-th variable. In matrix form, equation (1) becomes:

$$Z = FA^{T} \tag{2}$$

The PC scores and loadings can be defined as:

$$R \equiv Z^{T}Z \text{ (n x n) – the data correlation matrix} \tag{3}$$

$$\Phi \equiv F^{T}F \text{ (r x r) – the PC score correlation matrix} \tag{4}$$

$$S \equiv Z^{T}F \text{ (n x r) – the PC primary structure matrix} \tag{5}$$

Since $Z^{T} = AF^{T}$ can be substituted in (5);

$$Z^{T}F = AF^{T}F \tag{6}$$

$$S = A\Phi \tag{7}$$

which is the alternative solution of the PC primary structure matrix (5) that represents the correlations between the PCs and the variables. The equations (3), (4) and (5) are used to define the PCA in terms of the correlation matrix (R): $R = Z^{T}Z = AF^{T}FA^{T}$.

$$R = A\Phi A^{T} \tag{8}$$

This relationship (8) is the fundamental PC equation in terms of the correlation matrix and is a combination of A (the PC primary pattern matrix) and AΦ (the PC primary structure matrix). In the initial solution, $\Phi = I_r$, therefore $A = A\Phi$ and both are referred to as PC loadings.

In climatology, PCA is considered an automated technique for classification. However, the researcher still needs to make a number of subjective decisions in various stages of the processes (Yarnal, 1984): (i) Mode of decomposition – selecting the data and preparing for matrix of observation; (ii) Dispersion matrix – selecting the orientation of the input analysis; (iii) Rotation – optimizing the interpretability of the established components; and (iv) Number of retained components – finalizing the number of meaningful components (a decision made to suit the aims of the project).

Mode of decomposition: For eigenvector analysis in climatology, there are three main approaches that can be applied: (i) atmospheric field (or climate variable); (ii) time; and, (iii) station. Analysis can be performed in various different modes by varying any two of these attributes and holding the third one fixed (Richhman, 1986). The six possible modes of decomposition are defined as O, P, Q, R and T (Yarnal, 1993), where each one has a different combination of the fixed and varied attributes. The two modes that are most commonly used in synoptic climatology are: (i) the P-mode (climate variables varying over time); and (ii) S-mode (climate variables varying over space). In this thesis, the P-mode is used to classify the daily weather types for Borneo (Chapter 4); and the S-mode is applied to classify the SLP circulation types (over Borneo) and identify the map features for each type (Chapter 6).

Dispersion matrix: According to Yarnal (1993) and Richman (1986), there are three possibilities for the dispersion matrix – based on correlation (relative variations through standardised values), co-variance (analysing the actual magnitude) and cross-products matrix (incorporating information on the mean of each variable and its variation). For an S-mode map-pattern classification (Chapter 7), Yarnal (1993) advises that a correlation matrix should be preferred. A P-mode application generally analyses more than one variable (as has been applied in Chapter 5, where both precipitation and temperature are used). In this case, the data must be standardised so that both variables will have equal weight and avoid statistical biases. Therefore, the correlation matrix is used in all application of PCA in this thesis.

Rotation of PCs: The main purpose of PCA in this project is to derive patterns that are physically interpretable and not just to reduce the dimensions of the data matrix. Therefore, it is useful to rotate the initial PCs to allow a better physical interpretation of all retained

PCs. The unrotated solution typically demonstrates a physically recognisable pattern in the first PC but the orthogonality constraint on the eigenvectors normally does not allow a similar easy interpretation of the second and subsequent PCs. There are various types of rotation available in multivariate analyses (Richman, 1981, 1986; Richman and Lamb, 1985; Jolliffe et al., 2002), and the most popular method is Varimax (which is used in this thesis). This method maximizes the variance of loadings within each component across variables (Kaiser, 1958). It will produce a set of PCs, which is equally strong in physical pattern, but could be different in the percentages of explained variance.

Number of retained components: As far as mathematical and statistical justifications are concerned, there are no simple criteria for determining the optimal number of retained components (Richman, 1986; Jolliffe 1986, 1990). The number of retained components is expected to meet these requirements: (i) it will reduce the ‘noise’ present in the data; and (ii) it will contain a meaningful proportion of the original variance. There are several rules established to guide the selection of an adequate number of components. The two rules used in this thesis are:

Percentage of total variance explained in the original data: The decision as to what percentage of variance should be retained is entirely made by an individual researcher based on his/her prior knowledge about the subject, data and specific aims of the analysis. Most PCA textbooks suggest that 80% to 90% of the variance should be retained (Jolliffe, 1990). However, a lower percentage is sometimes more acceptable and practical because a large number of PCs is undesirable, unmanageable and lacks physical interpretability (Richman and Lamb, 1985).

The scree plot: The eigenvalues are plotted against their corresponding PC numbers, and this plot illustrates the rate of change in the magnitude of the eigenvalues against the ordinate number. The first few PCs typically have a higher magnitude of eigenvalues, which is shown by sharper slope in the curve. Theoretically, only PCs with a considerable magnitude of eigenvalues should be retained because it indicates how much variance is explained. In this technique, the maximum number of PCs to retain is at the point where the curve bends – which practically means that the increase of PC numbers will no longer able to add a significant percentage of variance explained.

3.4.2 Cluster analysis

Cluster analysis (CA) is a method for identifying homogeneous subgroups of cases in a population. CA has been widely used for classification purpose in synoptic climatology studies (e.g. Dahni and Ebert 1998; Kidson, 2000). CA seeks to identify a set of groups that both minimize within-group variation and maximize between-group variation. Hierarchical clustering allows users to select a definition of distance, and then choose a linking method to form the clusters, before determining how many clusters best suit the data (Aldendorfer et al., 1984). In K-means clustering the number of clusters is specified in advance, then calculation is applied to assign cases to the K cluster (Kaufman et al., 1990).

Cluster formation: This is the selection procedure for determining how clusters are created, and how the calculations are performed. The first step is to establish of the similarity or distance matrix. This matrix is a table in which the rows and columns are the units of analysis and the cell entries are a measure of similarity or distance for any pair of cases. Every case is initially considered a cluster, and then the two cases with the lowest distance (or highest similarity) are combined into a cluster. The process is repeated, adding cases to existing clusters, creating new clusters, or combining clusters to get to the desired final number of clusters. Euclidean distance is the most common distance measure (and used in this thesis). There are also different measures of inter-observation and inter-cluster distances to use as criteria when merging nearest clusters. The 'nearest neighbour' measure is used in this thesis. In this single linkage method, the distance between two clusters is the distance between their closest neighbouring points.

Hierarchical Cluster Analysis: This type of clustering technique is only appropriate for smaller samples (typically < 250). This technique is used in Chapter 4 as a pre-exploratory analysis to estimate the number of appropriate clusters for Borneo climatic divisions (i.e. prior to the final classification by the K-means clustering method). To accomplish hierarchical clustering, the researcher must specify how distance is defined, how clusters are aggregated (or divided), and how many clusters are needed. It generates all possible clusters of sizes 1...K, but may be used only for relatively small samples. The optimum number of clusters depends on the research purpose. Identifying "typical" types may call for few clusters and identifying "exceptional" types may call for many clusters. Both concepts are applied in this project, where the climatic divisions of Borneo are classified based on a more general grouping (A, B, C) and more specific (A1, A2, B1, B2, etc). In hierarchical clustering, the clusters are nested rather than being mutually exclusive, as is the usual case. That is, in hierarchical clustering, larger clusters may contain smaller clusters.

K-means Cluster Analysis: This type of cluster analysis uses Euclidean distance as its main metric measure. Initial cluster centres are chosen in a first pass of the data, then for each additional iteration (for the observations) based on nearest Euclidean distance to the centroid of the clusters are added. The desired number of clusters must be specified in advance. When performing K-means CA, the cluster centres change at each pass. The process continues until cluster means do not shift more than a given cut-off value or the iteration limit is reached. This type of cluster analysis assumes a large sample (typically more than 200) (Kaufman et al., 1990). K-means CA is very sensitive to outliers. Thus, for all analyses using K-means CA in this project, outliers have been removed, by either standardizing the data, or by converting them into a better measure (i.e. correlation coefficient) prior to the analysis. K-means cluster analysis usually generates different solutions, depending on the sequence of observations in the dataset. However, the application of K-means CA in this project only serves as a complimentary method to the PCA. Therefore, the cluster centre is already pre-determined (using the identified key[14] days by PCA).

3.4.3 Trends analysis

Trend analysis can be used to test different aspects of the shape of the function relating the dependent variable and the independent variable. Trend analysis consists of testing one or more components of trend. These components are tested using specific comparisons. The linear component of trend is used to test whether there is an overall increase (or decrease) in the dependent variable as the independent variable increases. Trends in the data are analysed to determine if the rate of change over the years is significant using the null hypothesis that the slope, ß, of each regression line is equal to zero (Thomas, 1983). The following equations are used:

$$t = (b - \beta)\, s_e^{1-} \times S_x^{-1/2}$$

where,

$$S_x = \Sigma i^2 - [(\Sigma i)^2 * n^{1-}]$$

s_e = the standard error of estimate

By setting the level of significance at 0.05, the null hypothesis will be rejected if $t < -1.96$ or $t > 1.96$. Larson and Schwein (2002)[15] used the same method in analysing the trends for temperature, precipitation and stream flow in the Missouri basin.

3.4.4 Probability

Probabilities are numbers, typically, in the interval from 0 to 1 assigned to "events" whose occurrence or failure to occur is random. Probabilities P(E) are assigned to events *E*

[14] Key days are identified as the representative days for each circulation type. This is based on the thresholds chosen to benchmark the highest (positive) and lowest (negative) scores for all retained components.

[15] Larson, L.W. and Schwein, N.O., undated. Temperature, precipitation and streamflow trends in the Missouri Basin, 1895 to 2001. Unpublished material (corresponding author address: jallwl@aol.com).

according to the probability axioms (Mosteller et al., 1961).The probability that an event *E* occurs given the known occurrence of an event *F* is the conditional probability of *E* given *F*; its numerical value is $P(E \cap F)/P(F)$, where $P(F) \neq 0$. If the conditional probability of *E* given *F* is the same as the ("unconditional") probability of *E*, then *E* and *F* are said to be independent events. That this relation between *E* and *F* is symmetric may be seen more readily by realizing that it is the same as saying $P(E \cap F) = P(E)\ P(F)$. Two crucial concepts in the theory of probability are those of a random variable and of the probability distribution of a random variable (Lipschutz, 1974).

Independent and dependent events: Two events are independent if any given outcome for the first event does not affect the probabilities of any outcome for the second event. Coin tosses are independent events. Two events are dependent if the outcome of the first does affect the second. For instance, the chances of being picked at random to be on a committee is a dependent event because each pick eliminates one person from the pool, changing the probability of being selected for everyone else in the subsequent selections. Mosteller et al. (1961) suggest common ways by which researchers can refer to various types of probability:

- P(A): The probability from 0 to 1.0 that A will occur
- $P(A \cap B)$: The probability of A or B occurring
- P(AB): The probability of A and B both occurring
- P(A|B): The probability of A occurring, given that B has occurred (conditional probability)

The probability analysis used in this thesis is based on percentage, which is explained in detail during the contextual application in the analysis chapters (Chapter 6, 7 and 8).

3.4.5 Correlation

Correlation is a statistical technique meant to measure whether and how strongly pairs of variables are related. As in all statistical techniques, correlation is only appropriate for certain kinds of data. It cannot be used for purely nominal data. The measurement of correlation is expressed as a correlation coefficient (or "r"). These coefficients are normally reported as r = (a value between -1 and +1). If r is positive, it means that both variables move in the same direction. If r is negative it means that as one gets larger, the other gets smaller (or moving in the opposite direction). The square of the coefficient (or r square) is equal to the percent of the variation in one variable that is related to the variation in the other. For example, an r of 0.6 means 36% of the variation is related (0.6 squared =0.36). A correlation value can also show the statistical significance of the relationship. The significance level is an indication of how likely the result may be due to chance in the form of random sampling error. The level of significance is directly influenced by the sample size – the bigger the sample size is, the smaller an r-value is required for the test to be statistically significant.

Pearson Product Moment Correlation: The most common measure of correlation is the Pearson Product Moment Correlation (called Pearson's correlation for short). This correlation is used based on the assumption that the data are normally distributed (parametric). When measured in a population the Pearson Product Moment correlation is represented by the Greek letter rho (ρ). When computed in a sample, the value is usually designated by the "r", and is sometimes called "Pearson's r." The formula for Pearson's correlation is shown below (adapted from Popham, 1967):

r_{xy} = $(\sum xy)/(ns_x s_y)$

where;

$\sum xy$ = Sum of cross products of deviation scores for x and y

s_x = $[\sum(x_1 - x)/n]^{1/2}$

s_y = $[\sum(y_1 - y)/n]^{1/2}$

n = number of pairs

y/x = mean scores for variables x and y

x_1/y_1 = individual scores for variables x and y

A simpler looking formula can be used if the values of x and y are first standardized[16] (converted into z scores) before calculating the Pearson correlation:

r = $(\sum z_x z_y)/n$

where;

z_x = individual scores for variable x (converted into standardized values)

z_y = individual scores for variable y (converted into standardized values)

Spearman Rank Correlation: Spearman's rank correlation has been used to measure and to test for correlation between two random variables in a non-parametric dataset, which is the

[16] It is not easy to compare the covariance of one pair of variables with the covariance of another pair of variables because variables differ in magnitude (mean value) and dispersion (standard deviation). *Standardization* is the process of making variables comparable in magnitude and dispersion: one subtracts the mean from each variable and divides by its standard deviation, giving all variables a mean of 0 and a standard deviation of 1.

method used in this thesis. This method is applied by ranking the values of each variable separately; and ties are treated by averaging the ranks (for the tied values). The r is then computed in exactly the same way as the simple correlation coefficient r. The only difference is that the values of x and y that appear in the formula for r denote the ranks of the individual cases rather than the absolute values of the raw data themselves. The formula for computing Spearman's rank correlation coefficient (Bobko, 2001) is:

$r = 1 - \{6 \sum d^2/[n(n^2 - 1)]\}$

Where,

d = the difference between the values of x and y (corresponding to a pair of observation)

n = the sample size

3.4.6 Student T-test (mean differences)

Student's *t*-test deals with the problems associated with inference between two samples. The calculated mean and standard deviation may deviate from the "actual" mean and standard deviation only by chance (Popham, 1967). For example, it is likely that the true mean of observed precipitation in station A is "close" to the mean calculated from a sample of *N* randomly collected rainfall observations at the particular station. The null hypothesis for all tests is that 'the selected composites[17] averages (for certain conditions – i.e. based on climatic events and circulation types) are not significantly different from the long-term averages (of the entire data)'. The null hypothesis will be rejected if *P* (probability that the mean difference is a result of chance) is "small". A 95% level[18] of significance is used throughout this research, which means that there is only a 5% of probability that the mean difference is observed purely by random chance. It is also worthy to note that the two-tailed t-test is used as no assumption is made about the nature of any bias. The formula of the T-test is:

$t = [M_1 - M_2 - (\mu_1 - \mu_2)]/SD$

where:

$SD = [(S_1^2.n_1 + S_2^2.n_2/DF) . (1/ n_1 + 1/ n_2)]^{1/2}$

and: M_1 and M_2 are the mean of sample 1 and 2 respectively

S_1 and S_2 are the standard deviations of sample 1 and 2

n_1 and n_2 are the sample size of sample 1 and 2

[17] Composite means represent the calculated averages for particular variables in the dataset under certain identified circumstances (e.g. the rainfall average for SDK during Southwest Monsoon for all days that correspond to Circulation Type 1 from 1968-2001).

[18] In a case where the level of confidence is higher than 95% (i.e. 99%), it will be implicitly stated in that particular result.

3.4.7 ANOVA F-test (multiple mean differences)

Analysis of variance (ANOVA) is used to uncover the main and interaction effects of categorical independent variables (called "factors") on an interval dependent variable (Turner et al., 2001). For example, the use of ANOVA to test the significance of differences between the means of precipitation (as the dependant variable) subject to circulation types (as the factor). The key statistic in ANOVA is the F-test which tests if the means of the groups formed by values of the independent variable (or combinations of values for multiple independent variables) are not different enough to have occurred by chance. If the group means do not differ significantly then it is inferred that the independent variable(s) did not have an effect on the dependent variable.

ANOVA focuses on F-tests of significance of differences in group means. For example, in this project, the researcher wants to know if the differences in sample means (i.e. the precipitation averages individually observed for Circulation Types 1, 2, and 3) are different enough to conclude whether the real means do differ among two or more groups. It is important to note that analysis of variance tests the null hypotheses that group means do not differ. It is not a test of differences in variances, but rather assumes relative homogeneity of variances. Thus, some key ANOVA assumptions are that the groups formed by the independent variable(s) are relatively equal in size and have similar variances of the dependent variable ("homogeneity of variances"). One-way ANOVA (which is used in this thesis – Chapter 6, 7 and 8) tests differences in a single interval dependent variables among two, three, or more groups formed by the categories of a single categorical independent variable.

3.4.8 Chi Square test

The chi-square is a non-parametric statistical tests to separate real effects from random variation (Moore, 1995; Agresti, 1996). It can be used on data that have these characteristics: (i) randomly drawn from the population; (ii) reported in raw counts of frequency (not percentages or rates); (iii) measured variables must be independent; (iv) values on independent and dependent variables must be mutually exclusive; an (v) observed frequencies cannot be too small. A chi-square test is any statistical hypothesis test in which the test statistic has a chi-square distribution if the null hypothesis is true. These include:

- Pearson's chi-square test (the method used in this thesis, and will be explained further in the next paragraph).
- General likelihood-ratio test is an alternative procedure to test the hypothesis of no association of columns and rows in nominal-level tabular data. For large samples,

likelihood ratio chi-square will be close in results to Pearson chi-square. Even for smaller samples, it rarely leads to substantively different results.

- Yates' chi-square test is an arbitrary, conservative adjustment to chi-square when applied to tables with one or more cells with frequencies less than five (not used because all data samples have more than five observations in each cell).
- Mantel-Haenszel chi-square test is preferred when testing the significance of linear relationships between two ordinal variables because it is more powerful than Pearson chi-square (not used in this thesis because no ordinal variables are involved).

Pearson's chi-square is by far the most common type of chi-square significance test and is used in this thesis. Scientists commonly interpret a chi-square probability of 0.05 or less as justification for rejecting the null hypothesis that the row variable is unrelated (that is, only randomly related) to the column variable. The chi-square test determines the probability of obtaining the observed results by chance, under a specific hypothesis. It tests independence as well as goodness of fit for a set of data. This statistic is used to test the hypothesis of no association of columns and rows in tabular data (see Table 3.5 for an example). Chi Square can be expressed in mathematical notation by this formula:

$X^2 = \sum [(O-E)^2 / E]$

Where;

O = actual observation (frequency)

E = expected observation (frequency)

The degree of freedom are given by this formula:

df = (r – 1) X (c – 1)

where;

r = number of rows

c = number of columns

Based on the example given in Table 3.5,

$X^2 = 0.5 + 1.67 + 0.07 + 0.20 + 2.50$

$= 4.94$

Table 3.5: Example of calculation for Chi-Square Test

	Type 1	Type 2	Type 3	Type 4	Total
Observed frequency (O)	40	20	16	4	80
Expected frequency (E)	45	15	15	5	80
O - E	-5	5	1	-1	0
$(O-E)^2$	25	25	1	1	52
$(O-E)^2$ / E	0.56	1.67	0.07	0.20	2.50

Using the chi-square table[19], this value of X^2 is significant at 95%. The chi square test is used to test a distribution observed in the field against another distribution determined by a null hypothesis. 95% level of significance is the threshold used throughout this study.

[19] A chi-square table gives a *critical value* based on various df (degree of freedom) values. The calculated chi-square value must be greater than the critical value to reject the null hypothesis (i.e. the row variable is unrelated to the column variable), at the level of significance selected by reading down the appropriate column in the chi-square table, for example, using the 0.05 significance column (which represents 95% degree of confidence).

Chapter 4
Local Climatic Classification: Regional and Temporal

4.1 Introduction

Why is climate classification needed? According to Virmani (1980), there are two basic functions of climate classification. First, to identify, organize and name climatic types in an orderly fashion and formulate a relationship within the population. Second, to serve as a basis for application of technology and policy. Several classification models based on various approaches are found in the literature (e.g. de Martonne, 1926; Koppen, 1936; Hare, 1951; Thornthwaite and Mather, 1955; Gadgil and Iyengar, 1980). To avoid misleading interpretation, it is important to realize that climatic classification is not an objective process, which could rigidly produce a single definitive solution. The result of any classification will differ depending on the choices of variables, methods, and data series. The subjectivity does not mean that a climate classification provides no benefit. As long as the classification process is coherent with the pre-identified aims and purposes, it will be a useful exercise.

Regional classification is an attempt to spatially divide Borneo into several climatic divisions based on distinct surface climatic features. Temporal classification, on the other hand, is to identify the most significant weather features on daily basis – and classify all days into one of the identified modes. For a region like Borneo, where dependency to agrarian economy is still vital, climate classification can be very useful. So far, no research of this kind has been conducted in Malaysia (or Borneo) at any level or scale. Therefore, establishing a specific scheme of climatic divisions and daily weather types will provide a new alternative for policy-makers in Borneo to assist in socio-economic planning. Conventionally, the most common option is to base it on political boundaries – which might not be suitable in most circumstances.

4.2 Regional classification

Regional classification is an attempt to classify Borneo into several climatic divisions using surface climate variable. Several stations in Borneo are selected for this analysis. These stations will be clustered together to form a set of climatic groups (based on similarity in surface characteristics). The only similar works have been undertaken in this region are by Wyrtki (1956) and Aldrian (1999, 2001, 2003). Wyrtki (1956) classified Indonesia into nine climatic regions based on precipitation patterns (using observed data). Aldrian (1999, 2001) made an attempt to improve Wyrtki's classification using data generated by ECMWF[20] Reanalysis. Although these classifications had included Borneo, the spatial resolution was very coarse (i.e. the entire Borneo was classified as D type). Thus, a more specific classification is needed for a better insight of spatial climate characteristics of Borneo.

4.2.1 Data

In developing the regional classification, precipitation is the only surface variable that will be considered. This decision is reasonably acceptable due to the fact that rainfall variation is the most prominent and distinct features for surface climate in Borneo. Twenty key stations (see Table 4.1) have been selected to produce the basic classification. The criteria for choosing these key stations are:

- The selected stations should geographically represent the key areas of Borneo
- The available data for each selected station are at least 8 years for daily observation and at least 10 years for monthly observations (this period is the most reasonable threshold – considering the nature of the data with huge number of missing values)
- A common period (same period of observation for pairs of stations) between Sabah/Sarawak/Brunei and the Indonesian side (Kalimantan) is available
- Missing values (within the range of period for each station) are less than 60% of the entire data
- The first criterion is associated with sufficient data for determining spatial representativeness. The other three criteria are to ensure the correlation matrix between all 20 stations is optimal and statistically reliable.

4.2.2 Methodology

The main technique used to classify the stations into climatic groups is cluster analysis – using the K-mean method. The precipitation data are first transformed into these two measures:

- Annual-cycle of long-term daily precipitation averages (366 days to include the leap year – 29th February)

[20] ECMWF (European Center for Medium-range Weather Forecast)

- Series of monthly precipitation averages for each station (the data period is not identical for all stations – depends on the availability in the original data)

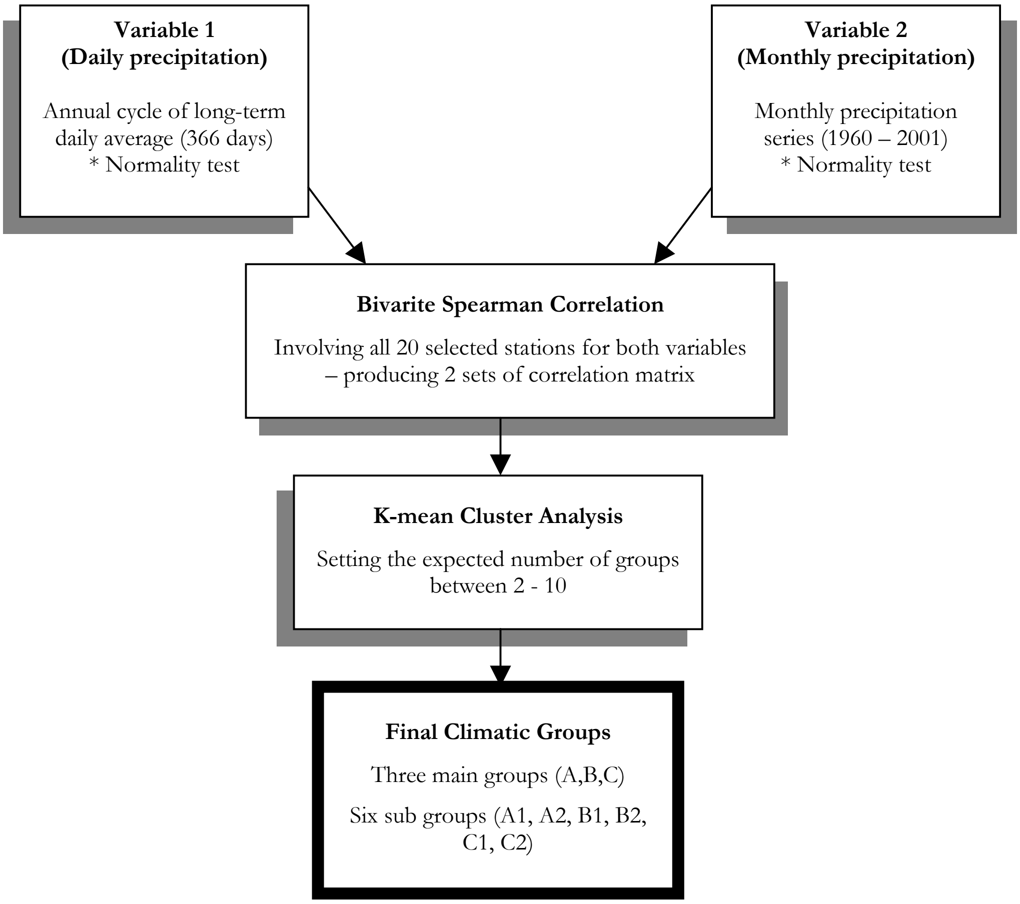


Figure 4.1: Summary of regional classification procedures

The consideration for choosing these two variables is because they are the main features of surface climatic fluctuation in Borneo (Sham Sani, 1984). The long-term daily precipitation averages (representing the seasonal scale) indicate the monsoon variability. The monthly series represents low-frequency climate variability that fluctuates on the time-scale of 3-5 years. This captures the signal of synoptic variability associated with ENSO. By performing bivariate correlation between all the 20 stations (conducted separately for each of the variables above), two sets of correlation matrices will be produced. For the first variable, which is the long-term daily average, a 5-day filter has been applied to enhance the Spearman Correlation coefficient with neighbouring cases. The final step is to assign each station into its respective group. This is done by K-mean clustering technique using the correlation values produced in the previous steps (see Figure 4.1).

4.2.3 Results and discussions

The results of the analysis are summarized in Table 4.2 and Table 4.3. The dendogram for the cluster solution shows that formation of clustered groups is optimal at the '3 Clusters solution' (see Table 4.2) as almost half of the members for each group that formed at this solution remain in similar groups up to the '10 Clusters solution' – the highest expected solution. At this level the following changes are observed – (a) 3 of the 7 original members in Group 1 eventually form another group; (b) 1 of the original 4 members in Group 2; and (c) 5 of the original 8 members in Group 3. The cluster agglomeration scheme (see Table 4.3) has further validated the initial conclusion derived from the dendogram table. The cluster coefficient shows a drastic increment from Stage 17 to the Stage 18 with more than 0.6 units of increases (5.14 to 5.80). This is the indication of where the optimal number of clusters formed (which is 3 main groups in this case). Therefore, based on the assumption that the optimal solution occurs at Stage 17 (refer to the agglomeration schedule – 'Final Cluster'), the retained final cluster solutions are 1 (Group A), 13 (Group B) and 18 (Group C). The initial members of the three main clusters are:

- Group A – KDT, SDK, KK, LBN, TWU, BRA, and MIR (7 stations)
- Group B – BTU, KCH, SBU, SAM, and PTK (5 stations)
- Group C – NGA, PBN, PRYA, MTW, BPN, KBA, SMD, and TRK (8 stations)

In order to refine the classification, so that a more unique feature can be established, each one of the 3 main groups is further divided into 2 sub-groups. This is done by determining the degree of membership stability in the cluster dendogram and by analyzing the clustering steps in the agglomeration schedule. Two main features are evident:

- In terms of membership stability (up to 10 clusters) – (a) SDK, KDT, BRA and MIR are the most stable in group A (therefore are the closest members within the group); (b) BTU, SBU, SAM and KCH are the most stable in group B; and (c) NGA, PBN and PRYA are the only members with high stability in group C.
- In terms of clustering steps – (a) KK, TWU and LBN are the last members formed in group A; (b) PTK for group B; and (c) BPN, MTW, SMD, TRK and KBA for group C.

These observations provide the basis for further separation between the cluster members. Therefore, the final subgroups can be classified as follow (A, B, C – and the most stable sub-group in each group will be further classified as 1 and 2:

GROUP	SUB-GROUP 1 (most stable)	SUB-GROUP 2 (less stable)
A	KDT, BRA, MIR, SDK	KK, TWU, LBN
B	BTU, KCH, SAM, SBU	PTK
C	NGA, PBN, PRYA	BPN, MTW, SMD, TRK, KBA

The K-mean clustering procedure has successfully classified all the 20 selected stations into their respective groups. However, the total number of stations in Borneo with reasonable quality of monthly data is 29. It means that there are another nine unclassified stations. These are not included in the classification process due to unavailability of reliable daily observation. To assign these 9 stations into an appropriate group (from the six established sub-groups), the comparison between normalized[21] annual cycles has been performed. The steps taken are as follow:

- the monthly average for all stations are normalized for the entire series
- the long-term average of the normalized monthly values for each station are calculated
- the composite of normalized monthly values for each sub-group are plotted and then compared with the remaining nine individual unclassified stations
- the comparison based on plots is then empirically validated by performing correlation analysis between normalized monthly precipitation for the individual stations and the composite values[22] for each climatic groups

Based on the annual cycle plot (see Figure 4.5): BRS, BRL and BRL (all stations are in Brunei) have been assigned into sub-group A2; KPG into sub-group B2; BMS into sub-group C1; and the remaining 4 stations (all in Kalimantan – BTK, LIM, MAN and TSR) have been added into sub-group C2. To make this process (i.e. assigning the unclassified stations into their respective group) more objective, a correlation analysis of monthly precipitation time-series between all the identified climatic divisions (A, B, C) and the nine

21 Normalized annual cycle is the monthly average (for 12 months) of normalized precipitation values. Why normalized values are used? It is because the comparison (of annual precipitation patterns/cycle) between the remaining 9 stations and the six climatic groups can be made based on absolute values (i.e. some stations experience heavier rainfall than other stations – although these stations may share similar characteristics in terms of annual cycle and distribution).

22 Composite values are calculated by averaging the normalized values for all stations that form a particular climatic group (e.g. the composite of Sepanggar Climatic Group A1 is based on the average of KK, TWU and LBN).

remaining stations is performed. Table 4.4 summarize the results and the stations are assigned into their respective groups based on the highest value of correlation coefficients.

Table 4.4: Correlation values (for standardised precipitation) between the 9 unclassified stations with each climatic group

	Climatic Group					
Station	A1	A2	B1	B2	C1	C2
BRS	0.71*	0.42	0.51	0.24	0.12	0.16
BRL	0.57*	0.37	0.44	0.22	0.15	0.26
BRK	0.71*	0.43	0.50	0.23	0.12	0.16
KPG	0.25	-0.08	0.47	0.50*	0.45	0.23
BMS	0.15	-0.21	0.49	0.16	0.50*	0.36
BTK	0.16	-0.13	0.43	0.26	0.45	0.50*
LIM	0.07	-0.02	0.24	0.22	0.31	0.47*
MAN	0.18	-0.11	0.29	0.08	0.35	0.47*
TSR	0.16	0.10	0.11	0.05	-0.07	0.21*

Values marked with (*) are the highest and all are statistically significant at the 95% level of confidence

4.2.4 Conclusion

The limitations of this classification are mainly caused by the availability of the basic data. The relative comparisons with some other regions of the world are:

- The comparatively low number of active meteorological stations available in Borneo (the number of stations might be higher if it includes the stations which have been dormant since the 1960s and 1970s). The ratio between station and the region size is 1 station per 25 thousands sq km. This ratio is at least 4 times lower than what is available in England, and three times and lower when compared to Mexico (personal conclusion based on the number of active stations in both countries).
- In terms of geographical location, the stations are not ideally and evenly distributed. For example, Brunei is almost 5 times smaller in size compared to Sabah, but it has four stations, only one station less than the number of stations available in Sabah. Twenty of the stations (or 60%) in Borneo are also located in coastal areas, leaving only 9 stations to represent the interior part of Borneo.

The final regional climatic groups for Borneo are mapped as shown in Figure 4.2. All 29 stations in Borneo have been grouped into their own cluster members. The boundary separating each group does not precisely represent the climatic regions. However, considering the data limitations, it provides a possible visual representation of how the divisions between the different groups of Borneo is divided. Each of the climatic groups has been specially named after a selected place, which is located in its respective region. This will make it easier to discuss or to quote the climatic groups in the latter part of this thesis –

by naming them with a specific reference, instead of the general term as in A1, A2, B1 and the likes. The assigned names for each sub-group are as follows:

- A1 – Sepanggar climatic group (Sepanggar Bay – one of many popular beaches around Kota Kinabalu)
- A2 – Sepilok climatic group (Sepilok is a rehabilitation centre for orang utan, and the main tourist attraction in Sandakan)
- B1 – Samarahan climatic group (Kota Samarahan is one of several small towns near Kuching, i.e. Sarawak's capital city)

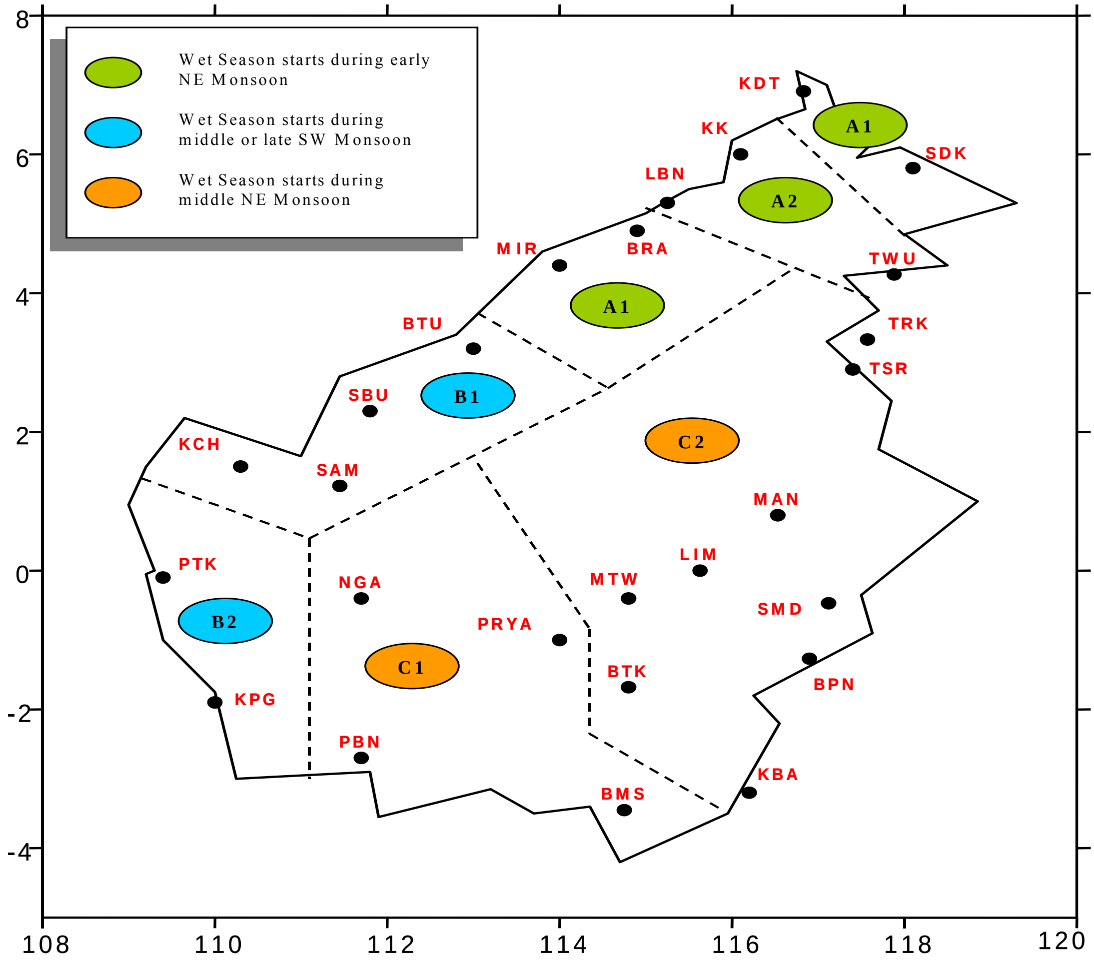


Figure 4.2: Borneo Climatic Classification (the 29 main stations)
*[**BRL**, **BRS** and **BRK** are not shown in this map because their locations are too close with **BRA**]*

- B2 – Sambas climatic group (Sambas is a fishermen's settlement in the most northwestern part of Kalimantan)
- C1 – Sintang climatic group (Sintang is one of very few meteorological stations located in the middle part of Borneo)

- C2 – Selor climatic group (Tanjong Selor is one of the meteorological stations located in the northeastern part of Kalimantan)

The next section discusses the climatic features that characterize each group and sub-group. Four criteria were chosen to establish the characteristics. These are:

- **The duration of the wet season** – This is defined as the consecutive-six-month period with the highest amount of total precipitation. Six months was selected to indicate a complete cycle of a season to be consistent with monsoon fluctuations in the region.
- **The degree of seasonality** – This refers to the ratio of total precipitation between the Northeast Monsoon (October – March) and the Southwest Monsoon (April – September). If the ratio is more than 1.2 but less than 1.5 (which indicates that total precipitation during the Northeast Monsoon are 20%-49% higher), the seasonality is considered moderate. If it is between 1.5 to less than 2.0, it is strong; and a value of more than 2.0 is regarded as very strong.
- **The occurrence of the three wettest and driest months** – This examines, in which monsoon season, the three highest/lowest amounts of precipitation occur.
- **The number of absolute wet months –** identifying how many absolute wet months occur at each station, or the average numbers within each climatic group. Absolute wet month is defined for Borneo by referring to the months where the amount of rainfall is exceeded more than 20% of the monthly average of the entire region (more than 270 mm per-month). This criteria is different from the first one, which is only a relative measurement of the 'wet season'.

The first two criteria serve as the main factors, which best identify the differences between the main groups A, B and C. The other two criteria are considered as secondary that outline the unique features of the subgroups (the first and second variations) – for instance, between A1 and A2. The summary of the characteristics is shown in Table 4.5.

4.3 Temporal classification

4.3.1 Data

Temporal classification for surface climate has never been done before, either in Malaysia, Borneo or Indonesia (although it has been applied in other region – e.g. Christensen and Bryson, 1966). Thus, this part lacks of relevant reference from previous studies. The methodology applied in this section is specially designed for this project. The main aim of this temporal classification is to identify the most important modes that represent daily weather variability over Borneo. This method tries to generalize the question of – "how the spatial pattern of temperature and precipitation changes on daily basis?" In other words, this classification analyzes the distribution of daily weather patterns that characterize Borneo's regional surface climate at the temporal scale. In order to precisely construct the significant modes – a number of stations with complete and overlapping data (in terms of available variables and period of observation) must be chosen to generate the patterns. The selected six stations are:

- KK (Kota Kinabalu) located on the west coast of Sabah
- SDK (Sandakan) located on the east coast of Sabah
- MIR (Miri) located on the northern part of Sarawak
- BTU (Bintulu) and SBU (Sibu), both located in the interior part of Sarawak
- KCH (Kuching) located on the most western part of Sarawak

These stations are selected because they have a complete daily observation for both precipitation and temperature for a reasonably long period of 34 years (1968 – 2001) (see Table 4.1).

4.3.2 Methodology

The method used in this temporal classification is Principal Components Analysis (PCA). The PCA is performed to reduce the dimension of the data, which consist of 34 years of daily observations for two surface variables (precipitation and temperature) in six stations. In this step, PCA will condense the information from these 12 variables into fewer variables, but still represent a large fraction of the original variance in the dataset. Contrary to the regional classification where the number of groups was not known (prior to the classifying process), this is not the case for temporal classification. Using the number of retained components (and the mathematical reasoning behind it – see Chapter 3), it can be objectively determined based on the number of modes that explain a significant amount of the total variances of Borneo daily weather. In the next step, the components scores are used to classify all the days into their respective daily groups.

The criteria used to determine the number of components retained are – (i) the scree plot; and (ii) percentage of variance explained (see Chapter 3 for further explanation of these two criteria). The scree plot from the first step (PCA data reduction) is shown in Figure 4.3, whereas the percentage of variances explained by each component is presented in Table 4.6. Based on these results, 4 components are retained (those successfully describe at least 1 complete variable out of 12, and within the range where the plot bends into a more straight line). The combined 4 components explained 65.3% of the overall variances in the dataset (or almost 8 complete variables out of 12).

Table 4.6: Total of variance explained by the initial and rotated 4 retained components

	Initial Eigenvalues			Rotated Eigenvalues		
PC	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.2	34.9	34.9	3.8	31.8	31.8
2	1.5	12.1	47.0	1.5	12.6	44.4
3	1.2	9.7	56.6	1.4	11.4	55.8
4	1.0	8.7	65.3	1.1	9.5	65.3

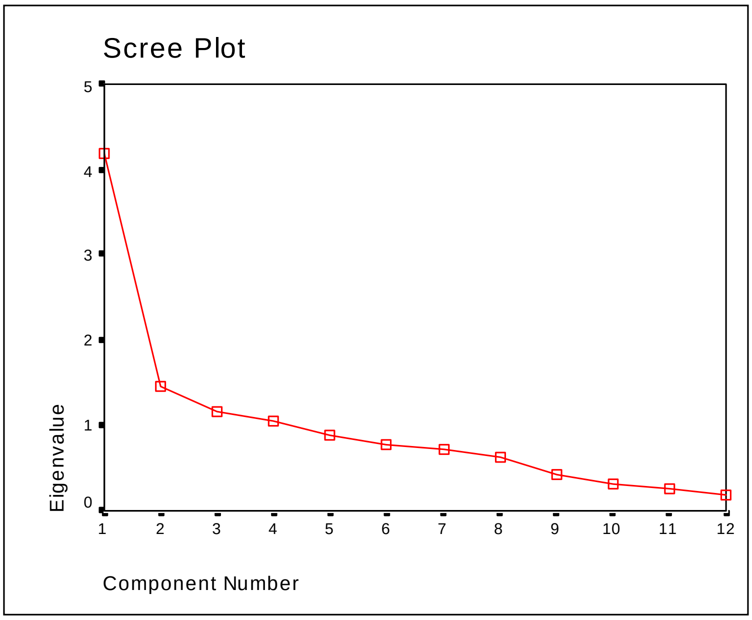


Figure 4.3: Scree plot of the PCA of 12 local climate variables

The 4 retained components were then rotated so that each of them will detect and represent the most prominent variance for a certain individual variable (or a certain group of variables). The assumption behind this rotation is that certain days can be significantly characterized by either temperature or precipitation anomaly (distinguished by climate variables). Similarly, there will also be several groups of days that can be characterized by distinct weather conditions in different parts of Borneo (distinguished by stations). The detail process of how the classification being conducted is summarized in Figure 4.4 and outlined below:

- The 4 retained components will naturally provide 9 significant types of daily weather in Borneo. The first 8 types represent the high negative/positive scores where the thresholds chosen are +1.5 and –1.5. The ninth type is the unclassified days, in which none of the components score above +1.5 or below –1.5. This type is considered as the 'normal day' because the values of all the 12 variables are near to the long-term averages.

- The composites of each type are then created to determine the pattern of variance in precipitation and temperature, and how the variances change between the six stations.

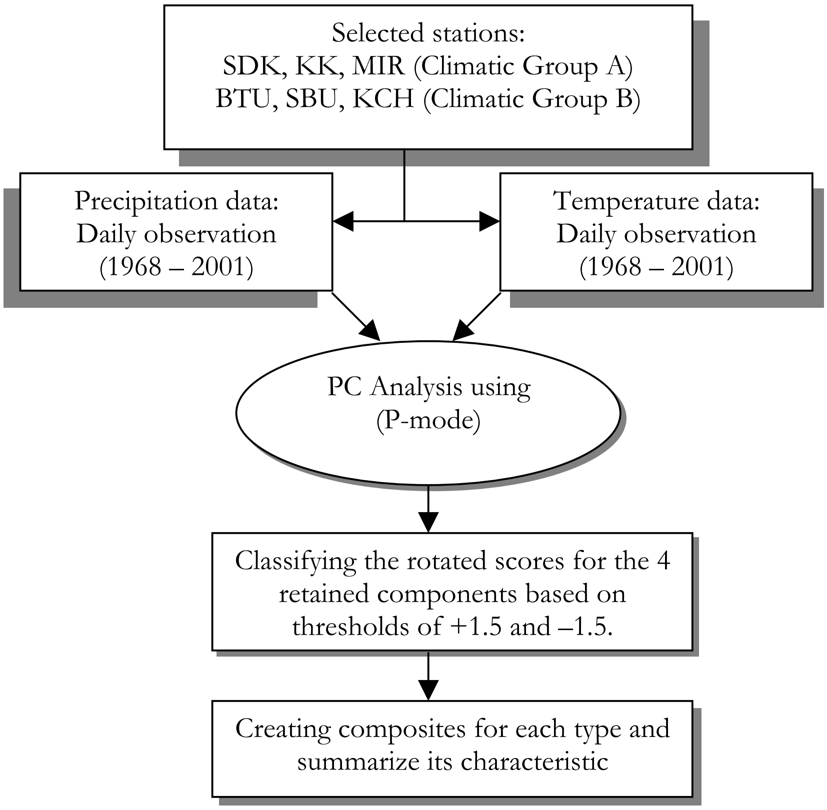


Figure 4.4: Summary of the temporal classifying methodology

4.3.3 Results and discussions

The anomaly composites for each weather type are created based on the types established by PC analysis (Table 4.7 and 4.8). In analyzing these composites, the concepts of 'normal', 'below' (<) and 'above' (>) normal are not used as a loose term, but they are rather defined by specific thresholds. For the precipitation analysis, below normal refers to of at least 50% less than the long-term average (~5 mm). Similarly, the above normal is used to describe a day with 50% more than the average rainfall amount (~15 mm). For the temperature, the thresholds used for significant anomalies are +0.5°C and –0.5°[23]. All the values in between these negative and positive thresholds are considered normal.

Table 4.7a: Precipitation anomaly (mm) in each Weather Type (WT)

WT	*SDK*	*KK*	*MIR*	*BTU*	*SBU*	*KCH*	Distinct Feature
1	-4	-3	-3	-4	-3	-3	All stations are near normal
2	-5	-5	-5	-3	-5	-7	All stations are below normal (but not extreme)
3	-1	-4	2	18	37	40	Clear segregation between Sabah and Sarawak
4	0	34	40	26	2	-2	Positive extreme (> normal) in the central part
5	62	2	-1	0	0	2	Positive extreme (> normal) for east Sabah (SDK)
6	-1	3	0	-3	-3	-1	All stations are near normal
7	-5	36	-4	-9	-9	-11	Only KK shows positive extreme (> normal)
8	-6	-1	17	-4	1	-5	Only MIR shows positive extreme (> normal)

[Blue=wetter; Yellow=drier]

Table 4.7b: Temperature anomaly (°C) in each Weather Type (WT)

WT	*SDK*	*KK*	*MIR*	*BTU*	*SBU*	*KCH*	Distinct Feature
1	0.1	0.1	0.1	0.0	0.1	0.1	All stations are near normal
2	1.3	1.6	1.6	1.7	1.7	1.6	Positive extreme for all stations
3	0.0	0.0	-0.1	-0.2	-0.7	-0.9	SBU and KCH more than normal
4	0.0	-0.5	-0.5	-0.4	-0.4	-0.5	All stations from KK to KCH are below normal
5	-1.0	-0.5	-0.3	-0.2	-0.1	-0.2	All station are within normal, except KK
6	-1.3	-1.6	-1.6	-1.6	-1.5	-1.2	Negative extreme for all stations
7	-0.4	-1.3	-0.6	0.0	0.7	1.1	Negative extreme for KK and positive for KCH
8	2.5	0.3	-0.3	-0.8	-1.3	-0.9	SDK is above normal; SBU/KCH are below normal

[Blue=cooler; Yellow=hotter]

4.3.4 Conclusion

The eight identified modes for daily weather in Borneo are mapped in Figure 4.6 and defined in Table 4.8. The first type (Normal weather) is a day considered to have 'zero variance' or insignificant anomaly for both precipitation and temperature. The other non-zero-variance types can be categorized into three main groups depending on which one of the two variables (temperature/precipitation) strongly characterizes their distinct features.

- Temperature Types: Type 2 (Hot weather) and Type 6 (Cool weather) are mainly characterized by positive or negative temperature anomalies.
- Precipitation Types: Type 3 (Western wet), Type 4 (Central wet) and Type 5 (Eastern wet) are best described by precipitation anomalies.
- Mixed Types: Type 7 (Various weather) and Type 8 (Mixed weather) is a combination of various climatic conditions (temperature/precipitation) throughout the region.

[23] The use of ±0.5ºC as the threshold for significant difference is due to the fact that mean temperature in Borneo does not fluctuate hugely between days, or even between seasons (with average of difference below 1. 5ºC) .

Table 4.8: Summary of the main daily weather types of Borneo

Original PC Score	Weather Type	Specific name	Number of occurrences	% of overall occurrences
Unclassified	Type 1	Normal weather	8712	70.2
PC1 > +1.5	Type 2	Hot weather	753	6.1
PC2 > +1.5	Type 3	Western wet	781	6.3
PC3 > +1.5	Type 4	Central wet	802	6.5
PC4 > +1.5	Type 5	Eastern wet	678	5.5
PC1 < -1.5	Type 6	Cool weather	616	5.0
PC2 < -1.5	Type 7	Various Weather	63	0.5
PC3 < -1.5	No type	Not exists	0	0.0
PC4 < -1.5	Type 8	Mixed Weather	14	0.1

Based on 34-year data 1968-2001 (12419 days)

Type 1 (Normal weather), as expected, dominates the daily weather pattern of Borneo (see Table 4.9). 70.2% of the variance for the 34-year dataset is made of this type, totalling of 8712 days out from the overall of 12419 days. Accepting the fact that these normal days represent the long-term average of weather, it can be concluded that the probability for Borneo daily weather to differ from its normal condition (extreme weather) is only 29.8%. It is also important to note that Type 7 (Various weather) and Type 8 (Mixed weather) contribute only a combined of only 0.6%[24] of the variance. Therefore, from a practical point of view, there are only five really important modes, namely Type 2, Type 3, Type 4, Type 5, and Type 6. These types together comprise 29.2% of the overall variances. The most basic features of all the weather types are listed below:

- Type 1 (Normal weather): Both surface variables (temperature and precipitation) at all stations are within the normal range (≤ ± 4 mm for precipitation and ≤ ± 0.1°C for temperature).
- Type 2 (Hot weather): Precipitation is slightly below normal (4-7 mm/day) and temperature is extremely above normal (anomaly of more than 1.0°C) for all stations.
- Type 3 (Western wet): Precipitation is extremely above normal (anomaly of more than 18mm/day) for the southwestern part of Sarawak, from Bintulu to the far west of Kuching.

[24] Due to extremely low number of occurrences, these two weather types have been omitted from being analyzed further (see Chapter 8).

- Type 4 (Central Wet): Precipitation is extremely above normal (anomaly of more than 25mm/day) for the west coast of Borneo, from Kota Kinabalu and up to Bintulu.
- Type 5 (Eastern wet): Precipitation is extremely above normal (anomaly of more than 60mm/day) only for the east coast of Sabah (Sandakan).
- Type 6 (Cool weather): Temperature is extremely below normal (anomaly of more than 1.0°C) for all stations.
- Type 7 (Various weather): A very distinct mixture of various local conditions for both temperature and precipitation – rainfall is extremely below normal (anomaly of more than 50% less than average) for the southwestern part of Sarawak - from Bintulu up to Kuching; and only the west coast of Sabah (Kota Kinabalu) is above normal (anomaly of more than 35mm/day).
- Type 8 (Mixed weather): Mixture of various local conditions especially for temperature – very hot on the east coast of Sabah (Sandakan) and very cold in the most western part of Sarawak (Kuching); for precipitation, significantly wet for Miri and dry for Sandakan and Kuching.

Table 4.9: Comparison of % occurrences based on period and season

Weather Type	1968-1984 (17 years)	1985-2001 (17 Years)	T-test Significance	Northeast Monsoon	Southwest Monsoon	T-test Significance
Type 1	51	49	NO	49	51	NO
Type 2	29	71	YES	8	92	YES
Type 3	48	52	NO	67	33	YES
Type 4	45	55	NO	50	50	NO
Type 5	52	48	NO	66	34	YES
Type 6	74	26	YES	79	21	YES
Type 7	60	40	NA	30	70	NA
Type 8	36	64	NA	14	86	NA

NA = T-test is not possible due to extremely low number of cases

In further analysis, the probability of occurrence for each type is investigated by varying the seasonal and periodic factors (see Figure 4.6). The percentage of occurrences is compared between the Southwest and Northeast monsoons to determine which weather types are associated to which monsoons. The comparison is also made for two different periods (17-year each): (i) 1968 – 1984; and (ii) 1985 – 2001. This is to examine the consistency of occurrences of each type through time. The result for the comparison is shown in Table 4.9. The percentage values given in the table are the overall percentage of each type based on those two periods and two monsoon seasons. The T-test results are derived from the mean differences for each type based on the two criteria of comparison. How is the T-test conducted?[25]

There is no significant change for Type 1 (Normal weather) whether on a seasonal or a periodic basis (see Table 4.8). This normal type is distributed evenly during NE and SW monsoons; and its frequency of occurrence is consistent throughout the 34-year period. However, for the 7 other types (which contribute to the extreme variations in the local weather of Borneo) – there are prominent differences in percentage of occurrences through times and seasons, which are summarized as below:

- Type 2 (Hot weather): The number of hot days has dropped significantly in 1985-2001 compared to the period of 1968-1984. It is also clear that this type of weather dominates the Southwest Monsoon with 92% of occurrence during this season. The changes in occurrence for Type 2 and Type 6 (as explained below) indicate a warming trend in Borneo.
- Type 3 (Western wet): No significant changes on a periodic basis. However, Type 3 occurs more during the Northeast Monsoon (67%) than the Southwest Monsoon. It means the western part of Borneo (Samarahan climatic group) does experience more wet days during the winter monsoon.
- Type 4 (Central wet): No significant changes, either on a periodic or seasonal basis. In terms of occurrence, this type is the most consistent and not subject to change in times or seasons.
- Type 5 (Eastern wet): No significant changes on a periodic basis. It shares exactly the same nature as in Type 3 on seasonal scale. It occurs mostly during the Northeast Monsoon (66%).
- Type 6 (Cool weather): This type is the mirror of Type 2. In the PC analysis, Type 6 (negative score) and Type 2 (positive score) are derived from the same component (PC1). Therefore, it is expected that Type 6 shows an opposite trend of occurrence compares to Type 2. Its occurrences has decreased significantly from 1968 to 2001, and it also more dominant during the wet season (Northeast Monsoon).

[25] Take Type 1 as an example. T-test is conducted to evaluate if the percentage mean between two periods, 1968-1984 and 1985-2001 is statistically different. Percentages of occurrence during the first period (1968-1984) are calculated for each year. The same calculation is carried out for the second period (1985-2001). T-test is then performed on the percentages of all 17 years for each period. The same method is applied for the two monsoons. However, instead of calculating the percentage of occurrences separately for two periods, the annual percentages are calculated separately based on the two monsoon seasons (for all 34 years).

- Type 7 (Various weather): A slight change on a periodic basis, but is not so prominent. However, it is clear that the probability of occurrence is higher during the dry season (Southwest Monsoon).
- Type 8 (Mixed weather): It shows significant differences both on periodic and seasonal time-scales. However, this trend might not be statistically convincing because the overall number of days (for this type) is comparatively very low (only 14 days). Thus, this low number of cases will hugely increase the possibility that any difference observed may be the result of a pure chance (as opposed to actual variance).

4.4 Chapter summary

Regional classification is an attempt to divide the region into several homogenous groups in terms of long-term average climatic behaviour (e.g. Subrahmanyam, 1956; Meher-Homji, 1980). The result of the regional classification should not be affected by change in times. Temporal classification tries to group each individual day into several identified modes (e.g. Lamb, 1950; Karalis, 1969; Sheridan, 2002). These modes, which will be changing on a daily basis, are described by specific spatial patterns of climatic variables (precipitation and temperature).

Although these two classifications are created from different variables and different methods, they are mutually complimentary to describe the behaviour of local climate in Borneo. Certain types of weather might be more associated with certain groups of climatic divisions. For instance, spatial climatic variation in Samarahan Climatic Group (B1) describes the unique pattern of weather Type 3 (Western wet). Similarly, Type 4 (Central wet) and Type 5 (Eastern wet) are more closely associated with the variance in climate for Sepanggar (A1) and Sepilok (A2) groups. Three main climatic groups (also been refined into six sub-groups) have been established to represent Borneo region (see Table 4.10).

Table 4.10: Regional climatic groups of Borneo

Climatic Group	Main Characteristics
Group A Sepanggar (A1) – Sabah Sepilok (A2) – Sabah and Sarawak	Wet season starts during Southwest Monsoon and peak amplitude (high precipitation) occurs once during the Northwest Monsoon
Group B Samarahan (B1) – Sarawak Sambas (B2) – Kalimantan	Wet season starts during Northeast Monsoon and peak amplitude (high precipitation) occurs once during the Northwest Monsoon
Group C Sintang (C1) – Kalimantan Selor (C2) – Kalimantan	Wet season starts during Northeast Monsoon and peak amplitude (high precipitation) occurs more than once and during both monsoons

With regard to temporal classification, eight local weather types (including the normal type with zero anomaly of precipitation and temperature[26]) have been identified as the main variations of Borneo daily climate (see Table 4.11).

Table 4.11: Daily weather types of Borneo

Weather Type	Unique Feature (subject to anomalies)
Type 1 (Normal weather)	Average temperature and precipitation for all stations Equal number of occurrences when compared between the two periods (1968-1984 and 1985-2001), and the two monsoons (NE and SW Monsoons)
Type 2 (Hot weather)	High temperature for all stations 71% of occurrences are in the second half of the period; and mostly during the SW Monsoon (92%)
Type 3 (Western wet)	High precipitation for B1 (Samarahan Group) No difference between the two periods, but on seasonal basis, more to NE Monsoon (67%)
Type 4 (Central wet)	High precipitation for coastal area from KK to BTU No significant difference on periodic and seasonal basis
Type 5 (Eastern wet)	High precipitation for coastal area of Sabah Mostly occur during the NE Monsoon, but no difference on periodic basis
Type 6 (Cool weather)	Low temperature for all stations 74% of occurrences are in the first half of the period; and mostly during the NE Monsoon (79%)
Type 7 (Various weather)	Various surface conditions at some stations for both temperature and precipitation
Type 8 (Mixed weather)	Various surface conditions at some stations especially for temperature

[26] The first type (Normal weather) is a day considered to have 'zero variance' or insignificant anomaly for both precipitation (< 50% of the long-term average) and temperature (less than ±0.5°C).

Table 4.1: Selected stations for regional climate classification

Station	Name of station	Political region	Daily observations	Monthly observations
TWU	Tawau	Sabah, Malaysia	1979 – 2001 (23 years)	1979 – 2001 (23 years)
SDK	Sandakan	Sabah, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
KDT	Kudat	Sabah, Malaysia	1983 – 2001 (19 years)	1983 – 2001 (19 years)
KK	Kota Kinabalu	Sabah, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
LBN	Labuan	Sabah, Malaysia	1979 – 2001 (23 years)	1979 – 2001 (23 years)
BRA	Brunei Airport	Brunei	1967 – 1999 (23 years)	1967 – 1999 (23 years)
MIR	Miri	Sarawak, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
BTU	Bintulu	Sarawak, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
SBU	Sibu	Sarawak, Malaysia	1968 – 2001 (34 years)	1962 – 2001 (40 years)
SAM	Sri Aman	Sarawak, Malaysia	1983 – 2001 (19 years)	1983 – 2001 (19 years)
KCH	Kuching	Sarawak, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
PTK	Pontianak	Sarawak, Malaysia	1961 – 1990 (30 years)	1960 – 1990 (31 years)
NGA	Ngapinoh	Sarawak, Malaysia	1983 – 1990 (8 years)	1960 – 1975 (16 years)
PBN	Pengkalan Bun	Kalimantan, Indonesia	1972 – 1990 (19 years)	1960 – 1986 (27 years)
PRYA	Pelangkaraya	Kalimantan, Indonesia	1969 – 1990 (22 years)	1969 – 1990 (22 years)
MTW	Muaratewe	Kalimantan, Indonesia	1961 – 1990 (30 years)	1960 – 1986 (27 years)
KBA	Kota Baru	Kalimantan, Indonesia	1962 – 1990 (29 years)	1960 – 1988 (29 years)
BPN	Balik Papan	Kalimantan, Indonesia	1960 – 1990 (31 years)	1960 – 1989 (30 years)
SMD	Samarinda	Kalimantan, Indonesia	1978 – 1990 (13 years)	1978 – 1990 (13 years)
TRK	Tarakan	Kalimantan, Indonesia	1960 – 1970 (11 years)	1960 – 1970 (11 years)

All these stations have both temperature and precipitation variables

Table 4.2: Cluster dendogram table

	Cluster groups for each station in every step of the clustering analysis: based on the number of clusters formed (2 – 10 clusters)								
STATION	10 clusters	9 clusters	8 clusters	7 clusters	6 clusters	5 clusters	4 clusters	3 clusters	2 clusters
1:KDT	1	1	1	1	1	1	1	1	1
2:SDK	1	1	1	1	1	1	1	1	1
3:KK	2	1	1	1	1	1	1	1	1
4:LBN	3	2	2	2	2	1	1	1	1
5:TWU	2	1	1	1	1	1	1	1	1
6:BRA	1	1	1	1	1	1	1	1	1
7:MIR	1	1	1	1	1	1	1	1	1
8:BTU	4	3	3	3	3	2	2	2	2
9:KCH	4	3	3	3	3	2	2	2	2
10:SBU	4	3	3	3	3	2	2	2	2
11:SAM	4	3	3	3	3	2	2	2	2
12:PTK	5	4	4	4	3	2	2	2	2
13:NGA	6	5	5	5	4	3	3	3	2
14:PBN	6	5	5	5	4	3	3	3	2
15:PRYA	6	5	5	5	4	3	3	3	2
16:MTW	7	6	6	6	5	4	3	3	2
17:BPN	8	7	7	5	4	3	3	3	2
18:KBA	9	8	8	7	6	5	4	3	2
19:SMD	10	9	6	6	5	4	3	3	2
20:TRK	10	9	6	6	5	4	3	3	2

Table 4.3: Cluster agglomeration schedule

Stage	Cluster 1	Cluster 2	Distance coefficient	Final Cluster	Stage by stage clustering process – combining the closest and most related
1	6	7	1.42	6	BRA > MIR
2	8	9	1.80	8	BTU > KCH
3	8	11	2.23	8	BTU > KCH > SAM
4	1	6	2.29	1	KDT > BRA > MIR
5	13	14	2.50	13	NGA > PBN
6	3	5	2.54	3	KK > TWU
7	1	2	2.99	1	KDT > BRA > MIR > SDK
8	8	10	3.19	8	BTU > KCH > SAM > SBU
9	19	20	3.34	19	SMD > TRK
10	13	15	3.61	13	NGA > PBN > PRYA
11	1	3	3.86	1	KDT > BRA > MIR > SDK > KK > TWU
12	16	19	3.88	16	MTW > SMD > TRK
13	13	17	4.15	13	NGA > PBN > PRYA > BPN
14	8	12	4.37	8	BTU > KCH > SAM > SBU > PTK
15	1	4	4.52	1	KDT > BRA > MIR > SDK > KK > TWU > LBN
16	13	16	4.83	13	NGA > PBN > PRYA > BPN > MTW > SMD > TRK
17	13	18	5.14 *	13	NGA > PBN > PRYA > BPN > MTW > SMD > TRK > KBA
18	8	13	5.80 *	8	BTU > KCH > SAM > SBU > PTK > NGA > PBN > PRYA > BPN > MTW > SMD > TRK
19	1	8	7.60	1	KDT > BRA > MIR > SDK > KK > TWU > LBN > BTU > KCH > SAM > SBU > PTK > NGA > PBN > PRYA > BPN > MTW > SMD > TRK > KBA

* The two values where the Cluster Distance Coefficient increase drastically from 5.14 to 5.80 (0.66 unit)and this indicate the formation of optimal cluster group (i.e. Cluster 1, 8 and 13).
The complete members of each of the three cluster groups are shaded.

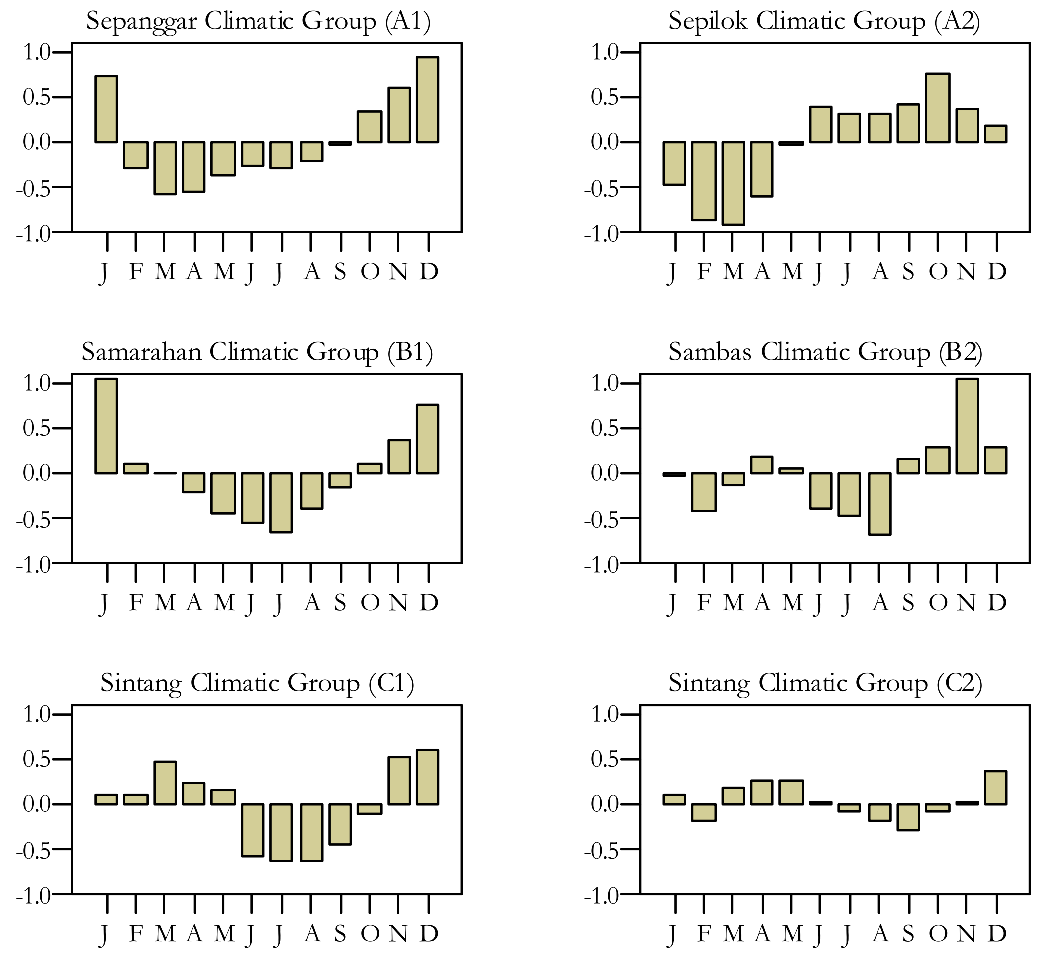


Figure 4.5a: Normalized annual cycle (of precipitation) for six climatic groups in Borneo

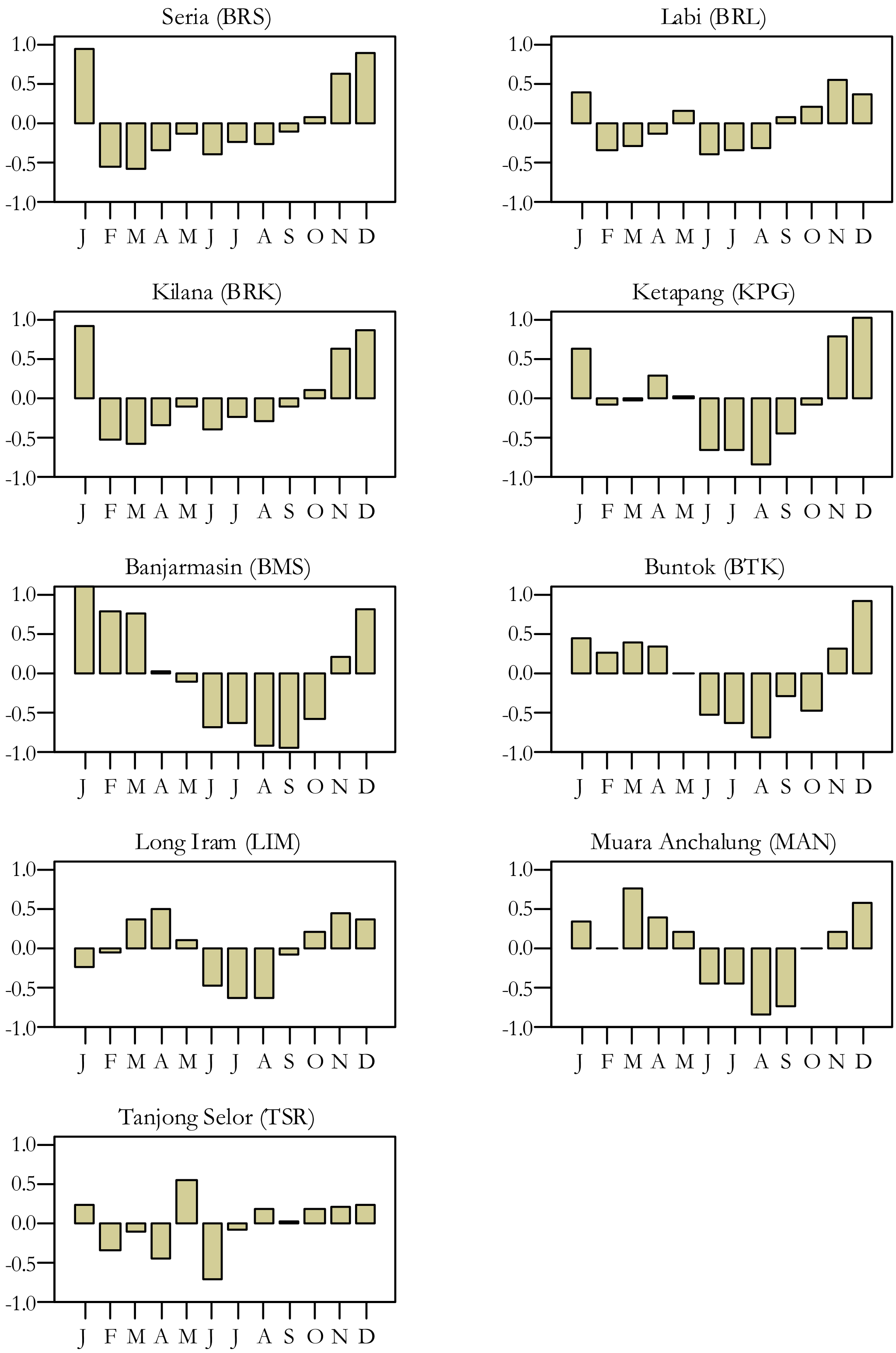


Figure 4.5b: Normalized annual cycle (of precipitation) for nine unclassified stations in Borneo

Table 4.5: Summary of characteristics for each climatic group

	SUMMARY OF UNIQUE FEATURES	MAIN CHARACTERISTICS		SECONDARY CHARACTERISTICS		
	Specific reference for each climatic zone Annual cycle feature and seasonality	Period of Wet Season	Degree of Seasonality	3 Wettest Months	3 Driest Months	Number of Absolute* Wet Months
A1	GA1: Sepanggar Climate Lowest precipitation occurs during monsoon transition from NE to SW; high precipitation in both monsoons Low degree of seasonality	Starts in Jun/Jul (middle SW) and extends up to Nov/Dec (middle NE)	Very weak less than 1.0	Aug – Nov (monsoon transition SW>NE)	Feb – April (monsoon transition NE>SW)	2 – 6 months (occur evenly in both NE and SW)
A2	GA2: Sepilok Climate Lowest precipitation occurs during monsoon transition from NE to SW; higher precipitation during NE Very strong degree of seasonality	Starts in Aug/Sep (late SW) and extends up to Jan/Feb (late/middle NE)	Moderate to very strong 1.2 – 2.5	Oct – Jan (NE)	Mac – May (monsoon transition NE>SW)	3 – 5 months (all occur during the NE)
B1	GB1: Samarahan Climate Lowest precipitation occurs during the late SW; and higher precipitation during NE Strong degree of seasonality	Starts in Oct (early NE) and extends up to Feb/Mac (late NE)	Moderate to strong 1.3 – 1.9	Dec – Feb (NE)	May – Aug (SW)	5 – 7 months (occur mostly during NE)
B2	GB2: Sambas Climate Lowest precipitation occurs during the late SW; peak amplitude of precipitation occurs twice – during SW and NE Moderate degree of seasonality	Starts in Nov (early NE) and extends up to Mac/April (end of NE)	Moderate 1.3 – 1.6	Oct – Jan (NE)	Jun – Aug (SW)	4 – 6 months (occur evenly in both NE and SW)
C1	GC1: Sintang Climate Lowest precipitation occurs during NE; peak amplitude occurs twice – during SW and NE Strong degree of seasonality	Starts in Oct (early NE) and extends up to Feb/Mac (late NE)	Moderate to very strong > 1.3 – 2.0	Dec – Mac (NE)	Jun – Sep (SW)	4 – 6 months (occur mostly during the NE)
C2	GC2: Selor Climate Lowest precipitation occurs during monsoon transition from SW to NE; peak amplitude occurs 3 times – during SW and NE Moderate degree of seasonality	Starts in Nov (early NE) and extends up to Mac/April (end of NE)	Weak to moderate 1.0 – 1.6	Jan – April (NE to early SW)	Jun – Aug (SW)	0 – 6 months (occur evenly in both NE and SW)

** Absolute Wet Months are referred to the actual number of months where the total precipitation is above the long-term average of all 29 combined stations in*

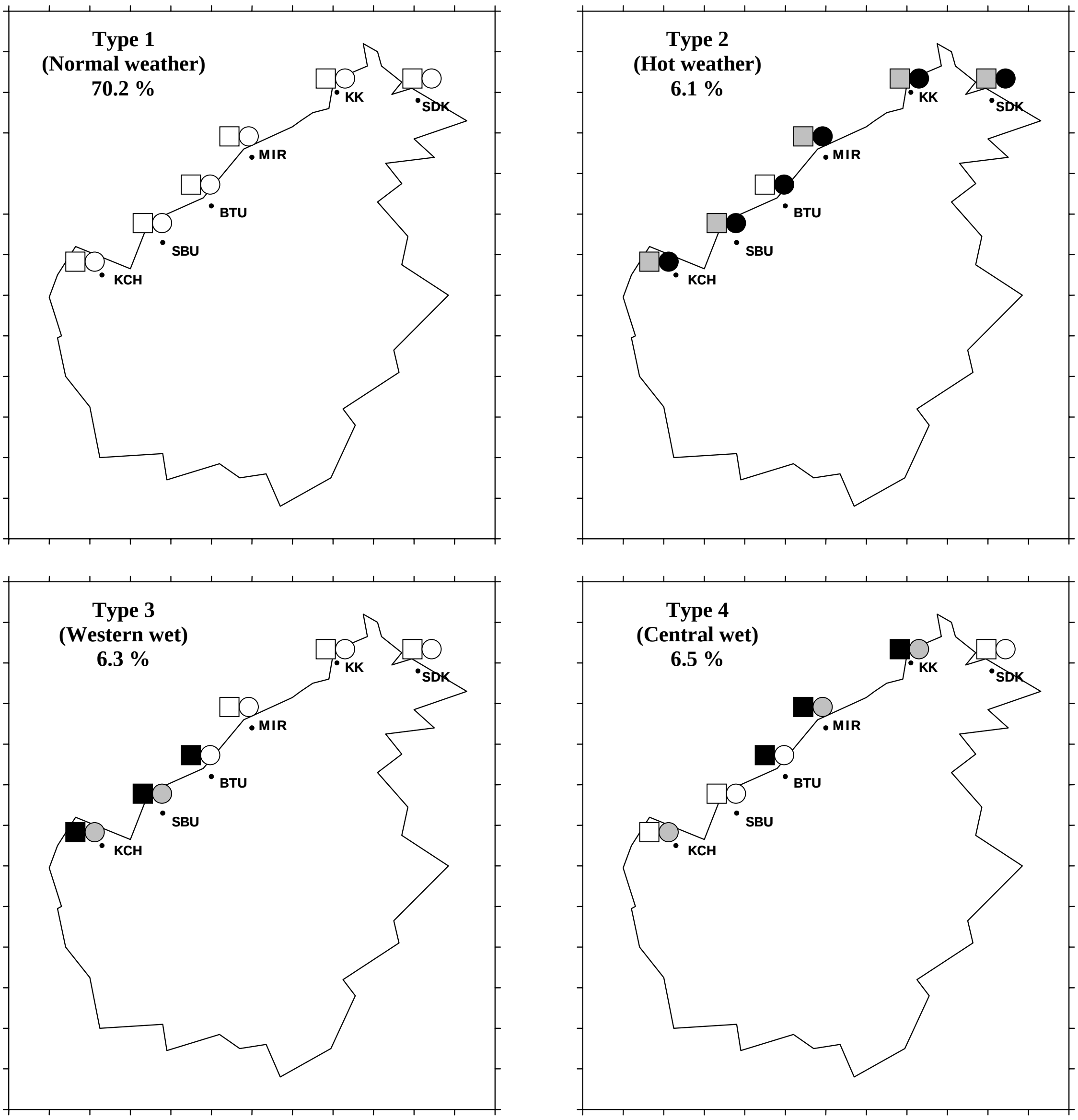
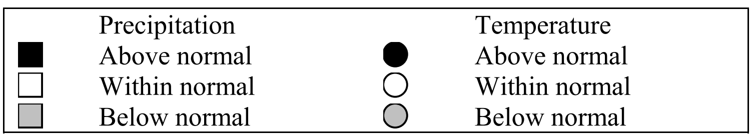


Figure 4.6a: Spatial variation of temperature and precipitation for the eight significant weather types for Borneo [Type 1 – Type 4]
(Percentage indicates the occurrence of the types subject to the overall period)



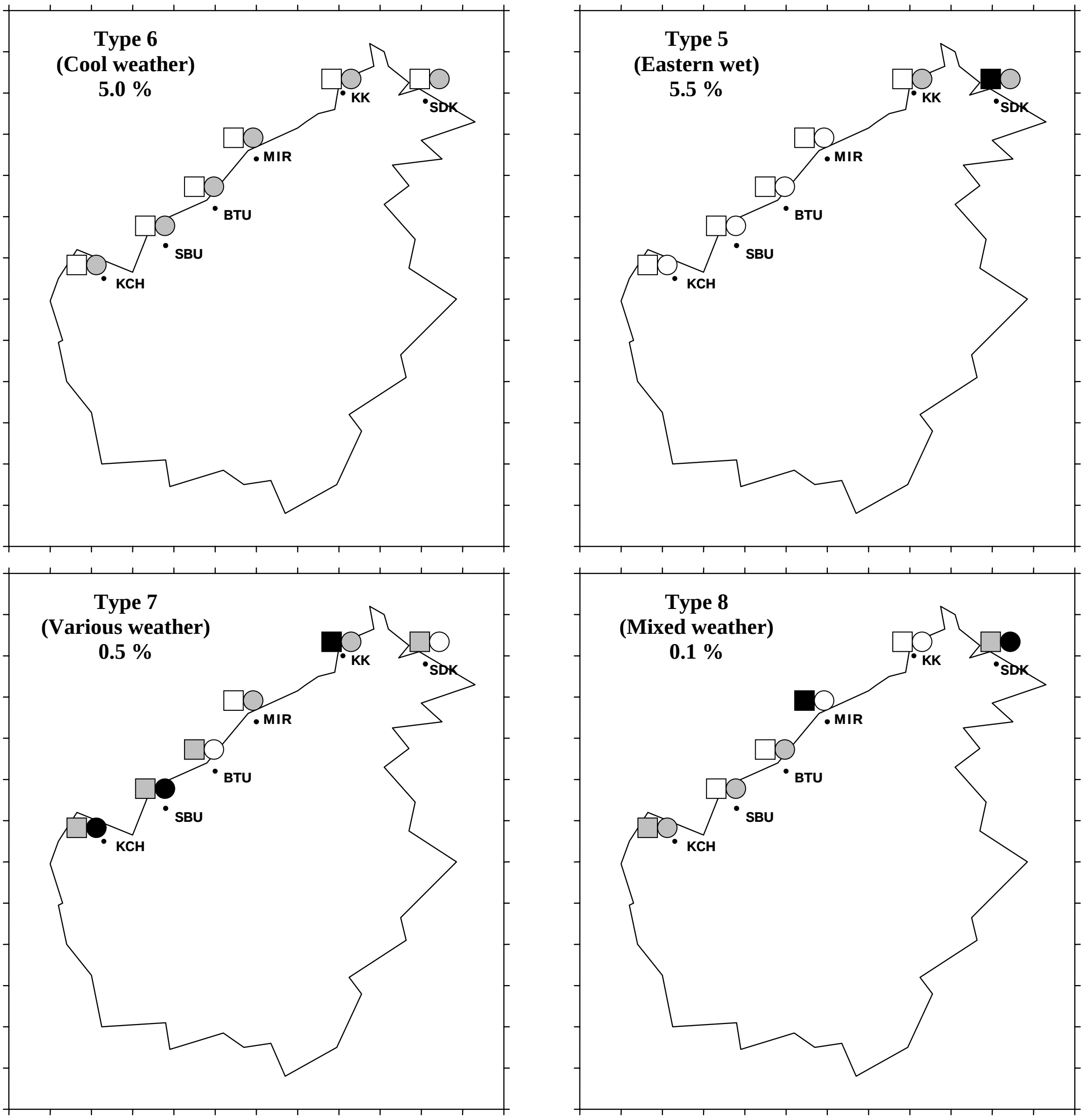
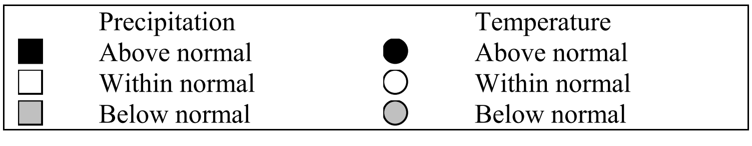
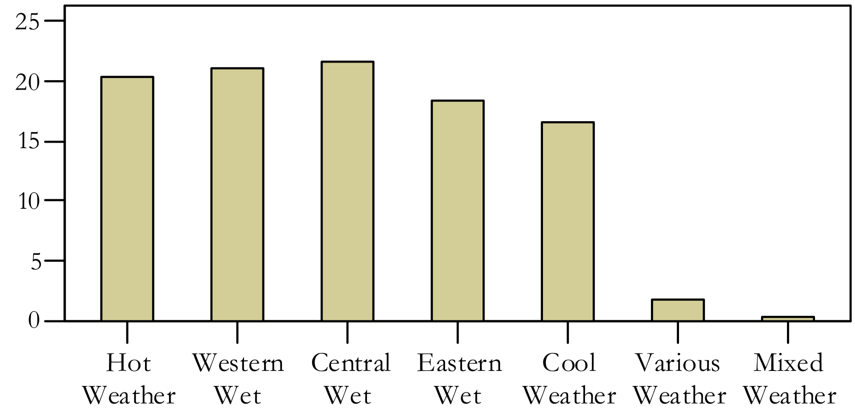


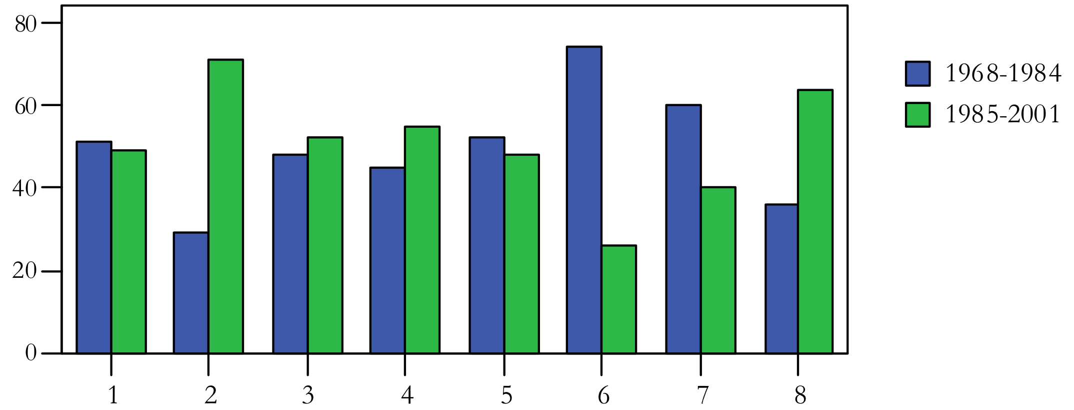
Figure 4.6b: Spatial variation of temperature and precipitation for the eight significant weather types for Borneo [Type 5 – Type 8]
(Percentage indicates the occurrence of the types subject to the overall period)



(a) Overall occurrences
Normal Weather (Type 1) is accounted 72.2% of the days, and is not shown in this plot



(b) Periodic comparison of 17 years (out of 34 years)



(c) Seasonal comparison between NE and SW monsoons

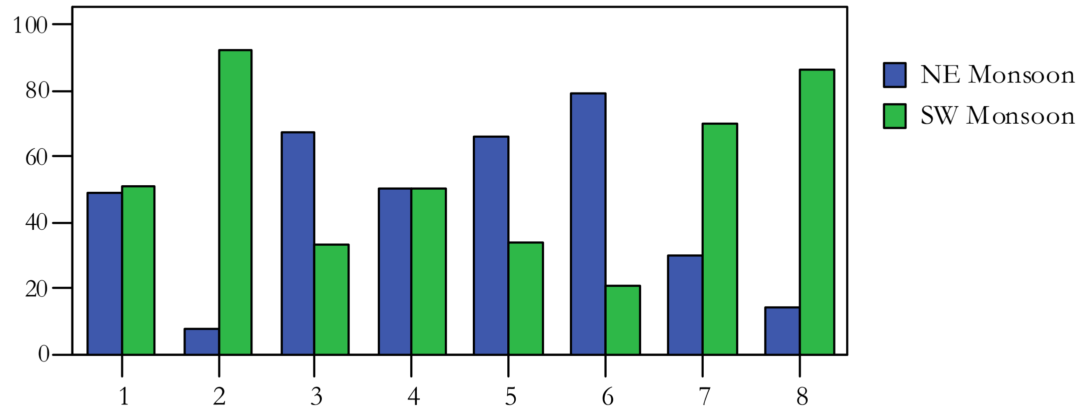


Figure 4.7: Histogram showing the percentage of occurrences for each weather type based on – (a) Overall occurrences; (b) Periodic comparison of 17 years (out of 34 years); and (c) Seasonal comparison between NE and SW monsoons
Weather Types: 1 (Normal Weather), 2 (Hot Weather), 3 (Western Wet), 4 (Central Wet), 5 (Eastern Wet), 6 (Cool Weather), 7 (Various Weather) and 8 (Mixed Weather)

Chapter 5
Trends in Local Climate of Borneo

5.1 Introduction

Analysis of climate trends of the surface climate for Borneo, as clearly outlined in the first chapter, is not the core objective of the thesis. The main aim focuses on the synoptic typing, and analysing the relationship between large-scale circulation (and other synoptic indices) and local climate. However, in order to fully understand the relationships – it is important to establish a general overview of surface temperature and precipitation trends, prior to the circulation typing and relationships with surface variables. Any significant trends will provide a fundamental knowledge of the local climate of Borneo that will assist in structuring the circulation scheme to suit expected key elements in the relationships.

This chapter will also analyse aspects of extreme climate (of the selected climatic variables), namely the magnitude and frequency. The magnitude analysis will investigate the average and intensity of daily observations; whereas, the frequency analysis will examine the occurrences of specific pre-defined events, including extreme days. Five important questions to be addressed are:

- How have temperature and precipitation changed over the past 34 years – both in terms of average magnitude and in the frequency of occurrences for specified events?
- Are any of the trends statistically significant?
- Are there distinct differences evident in some periods within the time series, or differences between the seasons?
- Which of the variables (surface climate) show strong trends; and which of these trends are correlated with each other?
- What are the basic features of trends observed at each station, and is there any similarity/difference between stations from the same/different climatic group?

5.2 Data

Six key stations from Sabah and Sarawak have been chosen to represent the surface climate trends for Borneo. The selected stations are listed below:

- Sandakan (SDK) – Sepilok Climatic Group (A1)
- Kota Kinabalu (KK) – Sepanggar Climatic Group (A2)
- Miri (MIR) – Sepilok Climatic Group (A1)
- Bintulu (BTU) – Samarahan Climatic Group (B1)
- Sibu (SBU) – Samarahan Climatic Group (B1)
- Kuching (KCH) – Samarahan Climatic Group (B1)

What are the main considerations to justify the selection? First, the six chosen stations represent two of the three main regional climatic groups for Borneo i.e. A and B (see Chapter 4). Geographically, they are also all evenly distributed over the northern part of Borneo – where the variance of observed surface climate is the highest (Sham Sani, 1984).

Table 5.1: Variables for precipitation and temperature trends

		Specific Measures	
		Measuring magnitude/intensity (average)	Measuring occurrence/frequency (extreme)
Basic variables	Precipitation	Daily average (mm/day) – all days (AVG) Daily intensity (mm/day) – wet days only (WET)	Wet days (precipitation > 1.0 mm/day) (WET) Heavy rain days (precipitation > 8.0 mm/day)[27] (HVY) 90th percentile of all days (90A) 90th percentile of wet days (90W)
	Temperature	Daily mean (T-mean) Daily maximum (T-max) Daily minimum (T-min) Daily range (DTR) – the difference between T-max and T-min	90th percentile of T-mean (AVG) 90th percentile of T-max (MAX) 10th percentile of T-min (MIN)

The acronyms in parenthesis are the shortening used for the particular measures when discussing the results and summarizing them in figure and tabular form

Second, the stations have the identical quality of data because they are all obtained from the same source – the Malaysian Meteorological Services (MMC), which historically has a better record of climate observation compared to the Indonesian Meteorological and Geophysical Agency (IMGA)[28]. All the selected stations also have exactly the same period of daily observations (1968–2001) for both temperature and precipitation. Thus, these stations maintain the same level of consistency in terms of reliability and homogeneity, which is vital

[27] Heavy rainfall uses “the amount of daily precipitation of more than 8mm” as the threshold. 8mm/day indicates the long-term daily average (composite) of all 29 stations (see Chapter 3) in Borneo.
[28] Based on analysis of all the available data from 42 stations in Borneo (Chapter 3), it is found that the Indonesian parts having more missing values, and with poorer records (especially for daily observations).

especially when analysing the frequency trends of extreme events. Data from the Indonesian part of Borneo are too incomplete (at the daily timescale) to undertake similar analyses.

The specific measures used to investigate temperature and precipitation trends are shown in Table 5.1. Some of these measures are analysed separately for different times of year for comparison between:

- The two monsoons, namely the Northeast Monsoon (October–March) and the Southwest Monsoon (April–September)
- Two 17-year periods, which separates 1968-1984 from1985-2001

5.3 Methodology

5.3.1 Time-series plots (the averages)

Two measures illustrate the precipitation magnitude. These are the long-term average (annual) of daily rainfall and intensity (the ratio between overall amount of rainfall and number of rain days). The daily average provides a general insight for a basic rainfall characteristic throughout the year. As the alternative measure, the intensity serves as a clearer indication of precipitation persistency during the rainy period.

As for temperature, the magnitude measures are represented by the long-term daily average (annual) of four common temperature measures – the mean (T-mean), maximum (T-max), minimum (T-min) and the diurnal temperature range (DTR) (see Table 5.1). Although all four might indicate similar patterns of time-series, it is worth using all of these measures to produce the plots, as they can crosscheck each other. Anomaly values (based on the long-term daily average on monthly basis) are used to plot all the temperature time-series. How are the anomaly values calculated?

$T_A = T_{1,365} - T_{Jan,\ Dec}$

Where,

T_A is the anomaly value

$T_{1,365}$ is the individual daily values for day 1 up to day 365/366 (in a year)

$T_{Jan,\ Dec}$ is the monthly average for each month (January – December)

The plots of time-series (i.e. precipitation and temperature) are created simply by averaging the daily observations[29] for each year, and plotting the values over the 34 or 33 years period. It is a 34-year period for yearly series, but it is only 33 years for seasonal series. In order to

[29] The daily observations are referred to the absolute values (for precipitation) and the calculated anomalies (for temperature).

obtain a precise representation of the Northeast Monsoon (NEM) year, the months that collectively compose the NEM year must be continuous and not necessarily derived from the same calendar year. For example, the 1969 NEM observation consists of October, November and December for the year of 1968; and combined with the January, February and March for the year of 1969. The data series (extended from January 1968 to December 2001) can only produce 33 of NEM years because the first three months in 1968 are counted out due to lack of continuous six NEM months. It means that the year 1968 is considered incomplete and has to be dropped from the seasonal analysis. With such consideration, the NEM year of 1969 is composed of the first three months in 1969 and the last three months of 1968, and the same process applied to the following years.

5.3.2 Time-series plots (the frequencies of specific events)

The time-series for precipitation are plotted for the number of days in four specific events – the wet days, heavy rainfall, 90th percentile of all days and 90th percentile of wet days. The last two events represent extreme measures. The yearly number of wet days and heavy rainfall are plotted for overall annual occurrences (combining two monsoons), and also considered separately on a seasonal basis. This comparison will provide a degree of difference in the patterns of the time-series plots between the two monsoons subject to the yearly overall.

As for the extreme measures, the 90th percentile is calculated using two sets of data: the entire series (all days) and the one that includes only the wet days. Due to the large numbers of dry days in Borneo (40% – 60% depending on stations), it is appropriate to perform the percentile analysis for both cases. The conventional choice uses all days/observations in the data. However, this might not be able to exhibit the actual trend of an extreme measure, especially in a case where a high percentage of dry days occurs. For example, if 60% of the days are dry – a 90th percentile of all days (which supposedly only accounted for 10% of the highest precipitation) is practically measuring the fourth quartiles (25%) of the intended sample. Using the upper 25% as the threshold to measure extreme events is rather too coarse and can easily invite a misleading interpretation.

The plots for temperature time-series are based on these thresholds – 90th percentile of daily average (T-mean) and daily maximum (T-max); and 10th percentile of daily minimum. Instead of the conventional upper percentile to measure extreme, the lower percentile (10th percentile) is chosen for minimum temperature to capture the actual nature of extreme represented by this index. The justification for this decision is simply the fact that the lower the observations of T-min are, the farther they deviate from the daily average (T-mean). Therefore, it is highly logical to assume that the lower bound of T-min observations is better associated with extreme.

Plots for frequency (both in precipitation and temperature) are drawn in a mathematically straightforward manner. The time-series are obtained simply by calculating the absolute occurrences in each year, and the values are plotted over the period of 34 or 33 years[30].

5.3.3 Significance test for trends

The trends are analysed to determine if the rate of change over the years was significant using the null hypothesis that the slope of each regression line is equal to zero. If the regression line is statistically significant at the 95% level of confidence, then the slope is significantly different from zero for this climate measure (thus, the value is also accepted as the change rate). The method used in this analysis is adapted from Johnson (1994) and Larson (undated academic paperwork published in internet). For more details on the method, see Section 3.4.3.

5.3.4 Correlation between time-series plot

Six (seven) key measures for precipitation (temperature) have been used to plot the local climate time-series of Borneo. With so many different climate measures being used to establish the time-series, it is interesting to investigate if there is any significant association between the measures. This analysis will provide insight into how individual climatic indicators influence and interact with each other. Based on the result of a normality test, which reveals that all data are non-parametric, Spearman Correlation has been used to perform the correlation analyses for this part. More details about Spearman's Rank Correlation are given in Chapter 3. Performing correlation analysis on several time-series is basically to investigate whether certain pairs of the climate measures are:

- moving into the same or opposite directions
- having the same or different degree of year-to-year fluctuations

This information can be very helpful to understand the mutual association among the surface climatic measures and how they behave as a group. If the time-series of a particular measure

[30] In order to obtain a precise representation of the Northeast Monsoon (NEM) year, the months that collectively compose the NEM year must be continuous and not necessarily derived from the same calendar year. For example, the 1969 NEM observation consists of October, November and December for the year of 1968; and combined with the January, February and March for the year of 1969. The data series (extended from January 1968 to December 2001) can only produce 33 of NEM years because the first three months in 1968 are counted out due to lack of continuous six NEM months.

is in parallel with another measures (one or more), they can be assumed to move in the same direction with fairly equal degree of change in magnitude/frequency through time. Therefore, they can be used complimentarily to explain certain condition in the climate variability, and therefore can serve as a single indicator to describe or diagnose related changes in local climate.

5.4 Results and discussion

This section presents and discusses the results for these analyses:

- The time-series plots for all the selected measures for precipitation and temperature (annually and seasonally)
- The correlation between the time-series plots for all these measures
- The trends of all selected measures (on annual and seasonal basis)

5.4.1 Precipitation time-series and trends

Daily average and intensity

Daily precipitation average and intensity are expressed in anomalies, and they are shown in Figure 5.1. It is visually clear that there is no clear pattern evident for any of the six stations. The time-series fluctuates throughout the period without showing any distinct pattern. Trend significance has been tested on the trend-lines and none of them is statistically significant. However, in all cases there is one distinct feature that differentiates the two measures. The degree of year-to-year fluctuation for the daily average (anomalies between ±2 mm/day) is weaker than the intensity (up to +5 mm/day for SDK and KCH, and between ±3.5 mm/day for the other stations).

Table 5.2a: Rainfall daily average (mm/day) based on periodic and seasonal time frame for six key stations in Borneo

	1968 – 2001 (34 Years)			1968 – 1984 (17 Years)			1985 – 2001 (17 Years)		
Station	Annual	SWM	NEM	Annual	SWM	NEM	Annual	SWM	NEM
SDK	8.3	5.8	10.7	0.1	0.2	0.2	-0.2	-0.1	-0.2
KK	7.0	7.8	6.2	0	0.1	0	0	-0.1	0.1
MIR	7.5	6.7	8.3	0.1	0	0.3	-0.1	0	-0.2
BTU	10.3	8.7	11.9	0.1	0.3	0	-0.2	-0.3	-0.1
SBU	8.9	7.5	10.3	0.1	0.2	-0.1	-0.1	-0.2	0
KCH	11.3	7.8	14.8	0.2	0	0.4	-0.2	0	-0.4

Values for the overall period (1968 – 2001) are expressed in absolute measurements (mm/day), and values for the two separated periods 1968 – 1984 and 1985 – 2001 are expressed as an anomaly from the overall period

Table 5.2b: Percentage (%) of wet days (rainfall > 1.0mm/day) based on periodic and seasonal time frame for six key stations in Borneo

Station	1968 – 2001 (34 Years)			1968 – 1984 (17 Years)			1985 – 2001 (17 Years)		
	Annual	SWM	NEM	Annual	SWM	NEM	Annual	SWM	NEM
SDK	42	34	50	1	2	1	-1	-1	-1
KK	39	41	37	1	1	0	-1	-1	-1
MIR	44	41	48	2	2	1	-2	-2	-2
BTU	51	46	57	1	1	0	0	-1	-1
SBU	53	46	60	0	1	-2	0	0	1
KCH	57	49	65	0	1	0	0	0	0

Values for the overall period (1968 – 2001) are expressed in absolute percentages (%), and values for the two separated periods 1968 – 1984 and 1985 – 2001 are expressed as percentage differences from the overall period

For the two halves of the data and for the seasonal comparison, the daily average is chosen to consider whether there is a clear difference between the 1968-1984 and 1985-2001 periods; or between the Northeast and Southwest monsoons (see Table 5.2). As clearly shown in the table, the differences are consistently negligible between the two halves, and it is also insignificant on seasonal basis. Each half of the 17-year periods shows less than 0.5 mm/day of difference from the overall average (34 years). And in all stations, the anomalies for the two monsoon seasons are also similar (less than 0.4 mm/day).

Occurrences of specific thresholds

Table 5.3: The time-series and trends for precipitation (specific thresholds)

Specific Thresholds	General Description of the Time series (Fluctuation characteristic)	Trend Test (95 % level of confidence)
Wet days (Precipitation > 1.0 mm/day) Heavy rainfall (Precipitation > 8.0 mm/day) 90^{th} percentile of all days 90^{th} percentile of wet days	All these four measures show the same general feature of time-series. It also seems that there is a 'smoothing effect' on the plots from west to the east.The stations from the most eastern part (SDK and KK – Climatic Group A1/A2) have the most uneven lines indicating a higher degree of year-to-year fluctuation. BTU and MIR (Climatic Group A1), in the central part, have smoother lines compared to eastern stations. However, SBU and KCH (Climatic Group C1), in the most western part, have the smoothest time-series.	Not significant in all cases (Therefore, there is no significant change – either decreasing or increasing)

All the stations share almost the same pattern of time-series for all the measures tested (see Figure 5.2). The general features of the patterns are summarized in Table 5.3. The occurrence of wet days (rainfall > 1mm/day) is chosen to examine the difference in trends between the

1968-1984 and 1985-2001 series; and between the Northeast and Southwest monsoons (see Table 5.2b). Similar to the daily precipitation averages, the frequency (of wet days) also does not show any clear difference, either between the two periods or the two monsoon seasons (see Figure 5.3 for the time series plots). For all stations, the anomalies are extremely small (less than 5%) and the Chi Square test[31] for all cases is not significant, even at the 90% level of confidence.

Correlation between the time-series

For precipitation, four frequency measures (number of days) are used – (a) wet days (more than 1 mm/day); (b) heavy rainfall (more than 8 mm/day); (c) 90th percentile of all days; and (c) 90th percentile of wet days. The results are presented in Table 5.4. For all stations, the number of wet days is highly correlated with the number of heavy rainfall days. At a 99% of significance level, the correlation values for SDK is 0.86, KK (0.86), slightly low in MIR (0.65), BTU (0.78), SBU (0.83) and KCH (0.81). Similarly, the number of extreme days, which measured by two key indicators (90th percentile for all days and for only wet days), also seems to highly correlate with each other. Setting the same level of significance as the above (99%), the correlation coefficients calculated are 0.73 for SDK, KK (0.81), MIR (0.77), BTU (0.71), SBU (0.69) and KCH (0.79).

However, the association between the time series for overall precipitation occurrences (i.e. wet and heavy) and the extremes (90th percentile) varies among stations. The western part of northern Borneo (SBU and KCH) exhibits no strong correlation between these measures from two different categories – the overall and extreme. The correlation coefficients are less than 0.5 for every combination of these measures. The central part of northern Borneo (MIR and BTU) shows a stronger correlation for certain combinations of these measures. Both stations have correlation coefficients higher than 0.70 for the combination of heavy rainfall (HVY) and 90th percentile of all days (90A). However, HVY is not strongly correlated with 90th percentile of wet days (90W) in BTU (0.48); whereas in MIR, the coefficient is higher at 0.73. Thus, in comparison with heavy rainfall (where most values are above 0.70), the wet days in general, are less strongly correlated with the two extreme measures, resulting in lower values of coefficient (0.45 – 0.57). The eastern part (KK and SDK) shows almost similar patterns of correlation as the two stations (MIR and BTU) in the central region do exhibit. The extreme variables is more strongly correlated with the number of heavy-rainfall days (0.64 – 0.77) than with the wet-day count (0.36 – 0.69). The correlation coefficients between

[31] Chi Square is performed to examine whether the differences between the two sets of time-series (i.e. 1968-1984 vs 1985-2001 and NE Monsoon vs SW Monsoon) are statistically significant.

different seasons are shown in Table 5.5. The three measures used to examine the seasonal correlation are the numbers of days for:

- 90^{th} percentile of all days
- 90^{th} percentile of wet days
- Heavy rainfall (more than 8 mm/day)

For all stations (except for KK), there is no strong significant correlation between any particular measure in two different seasons (the Northeast and Southwest monsoons). Among the six selected stations, this seasonal correlation only provides significant values for KK (Kota Kinabalu) – which is, interestingly, the sole member of Climatic Group A2 (Sepanggar Type). All three measures are correlated negatively in different monsoon seasons. The coefficient values are -0.45 (90^{th} percentile of all days), -0.63 (90^{th} percentile of wet days) and -0.39 (the frequency of rainfall more than 8mm/day); all are significant, at least, at the 95% level of confidence.

5.4.2 Temperature time-series and trends

Daily average

Three temperature indicators are analysed: the daily mean temperature (T-mean), daily maximum (T-max), and daily minimum (T-min). Except for KCH, all stations generally exhibit time-series plots that are below zero (negative anomalies) for the first 15 years (up to early 1980s) for all three measures. From the mid-1980s, the temperature averages (for T-mean, T-max and T-min) are starting to increase towards positive anomalies (see Figure 5.4). One of the three measures (T-mean) is plotted for seasonal time-series, and as shown by the plots on the right (in each figure) – the same pattern of increasing trends are observed in both monsoons. There is a clear transition from negative to positive anomalies in the middle of the 1980s. However, as expected, KCH once again, on seasonal basis, is the only station that does not follow this trend.

The time series for T-mean in two separate seasons i.e. the NE and SW monsoons are also plotted (see Figure 5.5). A significance test for trend in the time series has been performed on three of the measures, namely the T-mean (overall), T-mean for the NE and SW monsoons, respectively. Results of the significance test and the increase rate per-decade are summarised in Table 5.6. Except for KCH, the T-mean trends for all the other stations are statistically significant at the 99% level of confidence – and this result applies to both annual and seasonal series. From these results, it can be concluded that from 1968 to 2001, the daily mean temperature has been increasing at a rate of 0.25°C/decade in SDK, KK (0.32°C/decade), MIR (0.20°C/decade), BTU (0.25°C/decade) and SBU (0.21°C/decade).

DTR has also been tested for trend significance. This measure was chosen to simplify the change in temperature variability caused by the combined effect of T-max and T-min. As shown in Table 5.7: SDK, KK, MIR and SBU exhibit significant trends (at the 99% level); and KCH at the 95% level. However, the trend observed in BTU is not statistically significant. The reductions in DTR (for 4 stations) imply a greater warming of T-min compared to T-max (Karl et al., 1993; Jones and Hulme, 1996).

With regards to the change in the difference between the maximum and minimum temperature (DTR), the rates are negatively decreasing for SDK, MIR, SBU, and KCH. The only station with a positive increase is KK (0.23°C/decade). Similar to the case in precipitation, KK once again stands unique relative to all the other stations in northern Borneo. This seems to be consistent with the distinctive characteristics established earlier for Sepanggar Climatic Group (which KK belongs to). This climatic group differs from the other groups especially in terms of seasonality, which means that it has no clear wet and dry seasons (see Chapter 4).

Occurrences of extreme temperature events

Three measures have been chosen to serve as the indication of extremes in temperature. They are: (i) 90th percentile of T-mean (daily mean temperature); (ii) 90th percentile of T-max (daily maximum temperature); and (iii) 10th percentile of T-min (daily minimum temperature). The time series of these three measures are shown in Figure 5.6. The basic trends that can be seen for these measures are – (a) increasing occurrences of 90th percentile for both T-mean and T-max; and (b) a decreasing occurrence of 10th percentile for T-min. It is, however, quite clear that KCH does not share these characteristics with the other five stations. Instead, KCH exhibits trends that contradict the general warming. KCH seems to have lower/higher occurrences of T-min/T-max during the first half of the 34-year period, which means decreasing extreme frequencies for T-mean and T-max; and increasing occurrences for T-min.

Upon testing the statistical significance of the trends (see Table 5.8) – KK, MIR and BTU are all significant (at least within the 95% level of confidence) for the 90th percentile of T-max, both for the annual and seasonal trends. SDK is only significant for the annual trend, and only during the NE monsoon for SBU. On the other hand, KCH shows no significant trend for T-max extreme, neither on an annual nor on a seasonal basis.

The significant trends are all moving in the positive direction – meaning that the occurrence of extreme T-max has been increasing for the past 34 years. The rates in increase are calculated at approximately 5 days per decade for SDK, KK (22/decade), MIR (11/decade), BTU (14/decade) and SBU (7/decade). The only odd trend occurs in KCH. It is decreasing slightly 0.7 day in a decade – but as stated earlier, this trend is statistically not significant.

The trends for the 10th percentile of T-min are moving in the opposite direction and statistically significant for all stations (see Table 5.9). This is to be expected and consistent with the T-max extreme trends described earlier. These trends are also significant when tested separately on the two individual monsoon seasons. In general, this indicates that the extreme trends in T-min are stronger and clearer compared to the T-max. This is because DTR decreases; thus, the trend in T-min are more significant than in T-max. The rates of decrease in number of days are approximately 35 days per decade for SDK, KK (14/decade), MIR (24/decade), BTU (24/decade), SBU (32/decade) and KCH (13/decade).

Correlation between the time series

This analysis evaluates the correlation of the various time series of these measures – (a) three different indicators that measure magnitude (the long-term average of daily mean, maximum and minimum temperatures); (b) three different measures that represents extreme frequency (90^{th} percentile of T-mean/T-max, and 10^{th} percentile of T-min); and (c) three measures in two different monsoon seasons.

The time series of T-mean are highly correlated with T-max and T-min, exhibiting 99% level of confidence for all stations. Correlation coefficients are very high with values between 0.67 – 0.93, with 10 of the 12 values are more than 0.70 (see Table 5.10). However, the correlations between T-max and T-min are not equally strong and significant in all cases. It is significant at 99% level for SDK, KK, MIR and BTU; but only at 95% level for SBU and not significant at all for KCH. The three highest coefficients are observed at BTU (0.71), KK (0.68), and MIR (0.63); whereas the other three stations are less than 0.50.

Using the above result as a guide, the correlation between the frequency trends of T-max and T-min are not analysed further. It is apparent that T-max and T-min are not well correlated. The correlation analysis on frequency time series is only conducted between the 90^{th}

percentile of T-mean, and with both the T-max (90th percentile) and the T-min (10th percentile). All cases are statistically significant at the 99% level of confidence (see Table 5.11). However, in terms of values, the correlation between T-mean and T-max is stronger (compared to T-mean–T-min), with coefficient values of more than 0.70 for all stations except for SDK (0.60). The coefficients calculated for the correlation between T-mean (90th percentile) and T-min (10th percentile) are much lower with three stations (KK, MIR and KCH) have recorded values of less than 0.60. The other three stations have higher values with SDK (0.86), BTU (0.84) and SBU (0.74).

It is worth noting that the correlation for the two pairs (i.e. T-mean–T-max; and T-mean–T-min) are moving in the opposite direction. This is because T-min is warming more than T-max. T-mean–T-max is positively correlated, whereas in T-mean–T-min is negatively related. This means that extreme occurrence in daily mean temperature is positively associated with extreme occurrence in daily maximum. In contrast, the occurrences of extreme in mean temperature is negatively correlated with the extreme in the daily minimum. This distinctive surface climate behaviour consistently supports the earlier findings in the average trends and significance test (see Table 5.10).

The final issue in this correlation analysis is related to the seasonal fluctuation – whether the separate time series during the Northeast and Southwest monsoons (of one particular surface variable) are significantly correlated each other. Three variables are analysed for this purpose: daily temperature average (for T-mean); and two measures for extreme, which are 90th percentile of T-max, and 10th percentile of T-min. The results of the correlation are mixed between stations: depending on which measures are used (see Table 5.12 – with extra attention to the shaded values).

The seasonal correlations for all time series are statistically significant, at least, at the 95% level; with exception for T-max in SDK and SBU. It is also exhibited that for all stations, the strongest correlation is collectively shown by T-min, with values of more than 0.75 except for KK (0.58)[32]. T-mean is the second strongest, with values between 0.50 – 0.70. T-max is comparatively poorer with coefficients between 0.33 – 0.83 (mostly below 0.70). This indicates that the pattern in occurrence of T-min (10th percentile) during the NE monsoon will be most likely to be replicated in the following SW monsoon.

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[32] Manifesting the same unique characteristic (as in the precipitation – see Section 5.4.1), KK once again shows a higher correlation in T-max (0.83) compared to T-min (0.5). This distinctive characteristic further justify why KK has been classified as the sole member of Sepanggar Climatic Group – A1 (see Chapter 4, Section 4.2.3 that outlines the final results of the regional classification for Borneo).

The same case applies to the time series for T-mean – where increasing/decreasing in the annual daily mean temperature during the NE monsoon is more likely to be followed by the same pattern of increasing/decreasing in the following SW monsoon. The time series in the occurrence of extremes (i.e. T-max) also shows the same seasonal association. However, as had been discussed earlier, the strength in T-max seasonal correlation is far less convincing, and there is statistical significance for two stations, namely SDK and SBU. There could be a forecasting potential here, at least on seasonal basis – because some of the measures are correlated significantly between two consecutive seasons (i.e. a tendency of a particular climatic measures to be high/low in the following SW monsoon if it is high/low in the previous NE monsoon).

5.5 Conclusion

Precipitation

The trends for all analyzed measures (either for averages or extremes) do not indicate any significant linear regression trend. This implies that there are no significant changes in the occurrences of extreme, average or intensity of precipitation over the period of 1968 – 2001. This is consistent with Sham Sani (1984), Sirabaha (1998) and Manton et al. (2001).

In terms of trend correlation between the selected frequency variables, three pairs of measures show a high degree of mutual positive influence. There are occurrences of – (i) wet days (>1 mm/day) and heavy rainfall (> 8 mm/day) – WET-HVY; (ii) wet days and 90th percentile of all days – WET-90A; and (iii) 90th percentile of all days and 90th percentile of wet days – 90A-90W.

The increase in the number of wet days will highly influence the increase in the number of heavy rain days and the frequency of occurrence of the 90th percentile (all days – 90A). However, the wet day counts are not correlated convincingly with the frequency of the 90th percentile (wet day – 90W). This suggests that increasing trend merely in number of wet days (> 1mm/day) does not necessarily lead to an increase in extreme events. The coefficient average (composite of all six stations) for each pair of measures is summarized Table 5.13.

There is no evidence of association between rainfall trends during the Southwest Monsoon and the Northeast Monsoon. Therefore, precipitation patterns in terms of magnitude and frequency during a particular NE season should never be treated as an indication of precipitation trends in the following SW season.

Table 5.13: Correlation values for various pairs of measures (precipitation)

Pairing time-series	Composite Average* Correlation Coefficient	Highest	Lowest
WET-HVY	0.80	0.86	0.65
WET-90A	0.50	0.69	0.32
WET-90W	0.38	0.57	0.06
HVY-90A	0.65	0.77	0.43
HVY-90W	0.49	0.73	0.07
90A-90W	0.75	0.81	0.69

** Composite average is the average values for all six stations*

As the sole exception for the above conclusion, KK (the only station from Sepanggar Climatic Group) exhibits a convincing seasonal correlation between certain precipitation measures, namely the 90th percentile (90A) of all days (-0.45) and the 90th percentile (90W) of wet days (-0.63). Thus, these two measures can be used for seasonal forecasting for Sepanggar Climatic Group (i.e. KK) – where the general conclusion is, when the number of days for either 90A and 90W is high during a particular NE monsoon, it is most probably that the frequencies of these measures will also be high in the following SW monsoon.

Regional variability is also not distinctively shown as far as precipitation trends and time series are concerned. The only interesting difference, subject to geographical variations, is that time series are smoother from west to the east. This includes the average measures (daily average and intensity) and those used to measure extreme occurrences (90th percentile). The stations from the most eastern part (SDK and KK) have the most uneven lines indicating a higher degree of year-to-year fluctuation. Time series tend to be smoother for stations in the central part (MIR and BTU); and the stations in the most western part (SBU and KCH) are the smoothest (less year-to-year variability).

Temperature

All the plots of the three temperature averages (daily mean, maximum and minimum) indicate positive increases for the period 1968-2001. However, upon testing the statistical significance of the trends (using two representative measures, namely T-mean and DTR), two stations (KCH and KCH) were not significant. In terms of extreme occurrences, the trends are basically in agreement with the average trends. The frequencies of extreme days in T-max (90th percentile) and T-min (10th percentile) both suggest a warming climate. However, the trend for KCH and SBU are not statistically significant.

Spatial summaries of both average and extreme trends are given in Figure 5.7. It is very clear that weaker trends are observed in the most western stations, which are the members of

Samarahan Climatic Group (B1). In analysing the association between measures, there is a high correlation (mostly above 0.7) between these pairs:

- Between T-mean (daily mean temperature) and – (i) T-max (daily maximum temperature); and (ii) T-min (daily minimum temperature). Both relationships indicate positive correlation.
- Between 90th percentile of T-mean and – (i) 90th percentile of T-max (positive correlation); and (ii) 10th percentile of T-min (negative correlation)

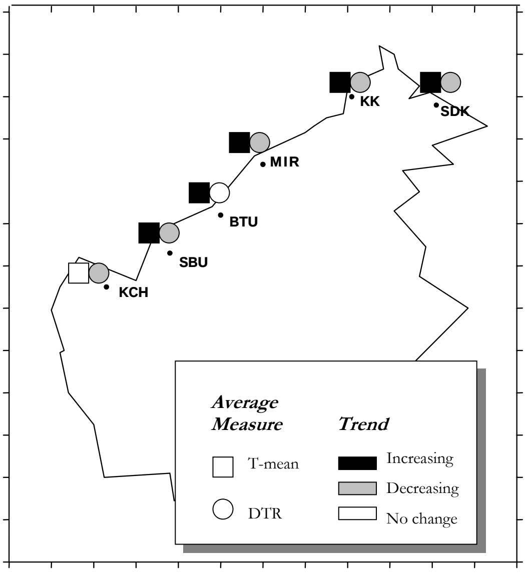


Figure 5.7a: The trends for temperature averages (T-mean and DTR)

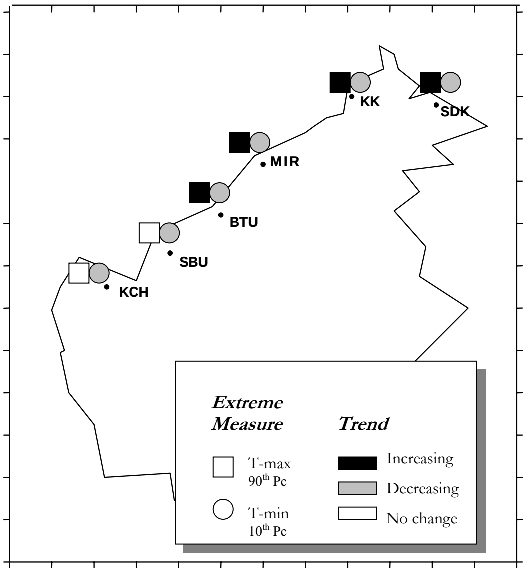


Figure 5.7b: The trends for temperature extremes (T-max and T-min)

The seasonal correlation tested on three extreme measures (namely the 90th percentile for both T-mean and T-max; and 10th percentile for T-min) also show a convincing correlation (above 0.55 at the 99% level) except for T-max in KK and SBU, when both cases are not even statistically significant at the 95% level. Thus, with exception of KK and SBU, these measures can be used as a guide for seasonal forecasting because the significant correlation implies that a high/low number of occurrence for 90th percentile of T-mean in a particular NE monsoon will be followed by the same pattern of occurrences in the number of 90th percentile (T-max) and 10th percentile (T-min).

Comparison between precipitation and temperature variables

In general, the trends for temperature measures are clearer and more interpretable compared to precipitation, especially in terms of changes through time. However, the time series in precipitation have a more distinctive difference between stations (the 'smoothing effect'[33] from the eastern to the western). The stations in the more western part have smoother time-series plots, which imply less year-to-year variability.

The seasonal time series in temperature for all the measures are convincingly correlated between the two monsoons, whereas there is no evidence of association for almost all the measures tested for precipitation. The exception is only for KK (Sepanggar Climatic Group A2), where one particular measure (90^{th} percentile of wet days – 90A) is strongly correlated during the two monsoon seasons. Thus, it can generally be concluded that temperature patterns are more likely to be replicated in the following monsoon season[34], than the precipitation.

[33] The 'smoothing effect' is referred to the observation that stations in the western part (i.e. BTU, SBU, KCH) have smoother plots of time series compared to the stations in the eastern part (i.e. MIR, KK, SDK). This indicates that stations in the western part experience less variability in terms of year-to-year basis.
[34] For example, if the temperature during the NE monsoon tends to be high, it is most likely that the same patterns will be follow the subsequent SW monsoon.

Table 5.4: Correlation matrix between the frequency trends for (a) Wet days (WET > 1.0 mm/day); (b) Heavy rainfall days (HVY > 8 mm/day); (c) 90-percentile of all days (90A); and (d) 90-percentile during wet days (90W)

Sandakan (SDK)	SDKWET	SDKHVY	SDK90A
SDKHVY	0.86**		
SDK90A	0.49**	0.72**	
SDK90W	0.36*	0.65**	0.73**

Kota Kinabalu (KK)	KKWET	KKHVY	KK90A
KKHVY	0.86**		
KK90A	0.69**	0.77**	
KK90W	0.49**	0.64**	0.81*

Miri (MIR)	MIRWET	MIRHVY	MIR90A
MIRHVY	0.65**		
MIR90A	0.48**	0.76**	
MIR90W	0.45*	0.73**	0.77**

Bintulu (BTU)	BTUWET	BTUHVY	BTU90A
BTUHVY	0.78**		
BTU90A	0.56**	0.70**	
BTU90W	0.57**	0.48**	0.71**

Sibu (SBU)	SBUWET	SBUHVY	SBU90A
SBUHVY	0.83**		
SBU90A	0.32*	0.43*	
SBU90W	0.06	0.07	0.69**

Kuching (KCH)	KCHWET	KCHHVY	KCH90A
KCHHVY	0.81**		
KCH90A	0.47*	0.49**	
KCH90W	0.34*	0.34*	0.79**

Correlation coefficients between selected time-series for 34-year period (1968 – 2001) are calculated by Spearman Rank Correlation. Values marked with (*) are significant at the 95% of confidence;, those marked with (**) (significant at 99%) and the unmarked values are not significant.

Table 5.5: Correlation matrix between frequency trends during the Northeast Monsoon and the Southwest Monsoon for selected measures

(i) 90-percentile of ALL precipitation (all days); (ii) 90-percentile of WET precipitation (includes only wet days), and (iii) 90-percentile 8MM precipitation (includes only heavy rainfall)

(a) Climatic Group A (Sepilok and Sepanggar)

	SDKALL	SDKWET	SDK8MM	KKALL	KKWET	KK8MM	MIRALL	MIRWET	MIR8MM
SDKALL	0.04	0.02	0.02						
SDKWET	0.09	0.13*	0.11						
SDK8MM	-0.07	-0.06	0.03						
KKALL				-0.45*	-0.47**	-0.51**			
KKWET				-0.51**	-0.63**	-0.52**			
KK8MM				-0.32*	-0.34*	-0.39*			
MIRALL							-0.26*	-0.28*	-0.28*
MIRWET							-0.14*	-0.18*	-0.14*
MIR8MM							-0.19	-0.22*	-0.11

(b) Climatic Group B (Samarahan)

	BTUALL	BTUWET	BTU8MM	SBUALL	SBUWET	SBU8MM	KCHALL	KCHWET	KCH8MM
BTUALL	-0.28*	-0.29*	-0.11						
BTUWET	-0.08	-0.03	-0.05						
BTU8MM	-0.43*	-0.38*	-0.22*						
SBUALL				0.24*	0.26*	0.01			
SBUWET				0.25*	0.10	0.08			
SBU8MM				0.34*	0.28*	0.10			
KCHALL							0.09	-0.01	0.01
KCHWET							-0.21*	-0.21*	-0.23*
KCH8MM							0.04	0.07	0.01

Correlation coefficients between selected time-series for 34-year period (1968 – 2001) are calculated by Spearman Rank Correlation. Values marked with (*) are significant at the 95% of confidence;, those marked with (**) (significant at 99%) and the unmarked values are not significant. The shaded values represents the correlation values between the two monsoons for the exact same variable

Table 5.6: Significance test for T-mean trends (daily mean temperature) over the period of 1968 – 2001 (34 years) for the overall trends, and over the period of 1969 – 2001 (33 years) for the seasonal trends

STATION	All YEARS	SW MONSOON	NE MONSOON	RATE (°C/year)
SDK	36.05 **	33.36 **	14.67 **	0.026
KK	47.24 **	43.7 **	26.63 **	0.032
MIR	22.81 **	24.29 **	8.89 **	0.020
BTU	39.73 **	48.48 **	14.95 **	0.025
SBU	28.51 **	27.72 **	17.48 **	0.021
KCH	1.12	0.82	0.27	0.004

*t values of Trend Significance Tests ** Sig. at 99% and * Sig. at 95%*

Table 5.7: Significance tests for DTR trends (the difference between daily maximum and minimum temperature) over the period of 1968 – 2001 (34 years)

STATION	All YEARS	RATE (°C/year)
SDK	221.56 **	-0.049
KK	13.97 **	0.023
MIR	7.69 **	-0.013
BTU	3.63	-0.008
SBU	48.42 **	-0.038
KCH	6.65 *	-0.016

*t values of Trend Significance Tests ** Sig. at 99% and * Sig. at 95%*

Table 5.8: Significance test for the occurrence of T-max 90 percentile over the period of 1968 – 2001 (34 years) for the overall trends, and over the period of 1969 – 2001 (33 years) for the seasonal trends

STATION	All YEARS	SW MONSOON	NE MONSOON	RATE (day/year)
SDK	3.08 **	3.95	0.0054	0.52
KK	15.59 **	21.65 **	18.81 **	2.29
MIR	8.46 **	9.08 **	6.22 *	1.11
BTU	34.32 **	33.79 **	14.19 **	1.42
SBU	4.57	0.95	5.41 *	0.68
KCH	0.02	0.0029	0.09	-0.07

*t values of Trend Significance Tests ** Sig. at 99% and * Sig. at 95%*

Table 5.9: Significance test for the occurrence of T-min 10th percentile over the period of 1968 – 2001 (34 years) for the overall trends, and over the period of 1969 – 2001 (33 years) for the seasonal trends

STATION	All YEARS	SW MONSOON	NE MONSOON	RATE (day/year)
SDK	44.18 **	33.04 **	78.21 **	-3.51
KK	8.87 **	5.17 *	18.81 **	-1.40
MIR	55.73 **	49.63 **	33.66 **	-2.40
BTU	45.24 **	39.94 **	32.95 **	-2.38
SBU	52.9 **	43.02 **	80.87 **	-3.15
KCH	19.91 **	9.86 **	11.55 **	-1.29

*t values of Trend Significance Tests ** Sig. at 99% and * Sig. at 95%*

Table 5.10: Correlation matrix between average measures (a) T-MAX temperature (daily maximum temperature); (b) T-MIN temperature (daily minimum), and (c) T-MEAN temperature (daily mean) – correlation is performed on the anomaly values

(a) Climatic Group A (Sepilok and Sepanggar)

	SDKAVG	SDKMAX	KKAVG	KKMAX	MIRAVG	MIRMAX
SDKMAX	0.66**					
SDKMIN	0.93**	0.43*				
KKMAX			0.91**			
KKMIN			0.68**	0.68**		
MIRMAX					0.85**	
MIRMIN					0.77**	0.63**

(b) Climatic Group B (Samarahan)

	BTUAVG	BTUMAX	SBUAVG	SBUMAX	KCHAVG	KCHMAX
BTUMAX	0.87**					
BTUMIN	0.87**	0.71**				
SBUMAX			0.70**			
SBUMIN			0.83**	0.40*		
KCHMAX					0.71**	
KCHMIN					0.67**	0.21*

Correlation coefficients between selected time-series for 34-year period (1968 – 2001) are calculated by Spearman Rank Correlation. Values marked with (*) are significant at the 95% of confidence;, those marked with (**) (significant at 99%) and the unmarked values are not significant.

Table 5.11: Correlation matrix between frequency variables (a) 90 percentile of T-mean (daily mean); (b) 90 percentile T-max (daily maximum temperature); and (c) 10 percentile of T-min (daily minimum)

	SDKAVG	KKAVG	MIRAVG	BTUAVG	SBUAVG	KCHAVG
SDKMAX	0.60					
SDKMIN	-0.86					
KKMAX		0.83				
KKMIN		-0.57				
MIRMAX			0.85			
MIRMIN			-0.48			
BTUMAX				0.85		
BTUMIN				-0.84		
SBUMAX					0.74	
SBUMIN					-0.74	
KCHMAX						0.82
KCHMIN						-0.58

All values are significant at the 99% level

Table 5.12: Correlation matrix for extreme frequency during the Northeast Monsoon and the Southwest Monsoon for (a) 90 percentile T-mean (daily mean; (b) 90 percentile of T-max (daily maximum temperature); and (c) 10 percentile of T-min (daily minimum)

(a) Climatic Group A (Sepilok and Sepanggar)

	SDKAVG	SDKMAX	SDKMIN	KKAVG	KKMAX	KKMIN	MIRAVG	MIRMAX	MIRMIN
SDKAVG	0.70**	0.47**	-0.71**						
SDKMAX	0.24*	0.33*	-0.20*						
SDKMIN	-0.65**	-0.31*	0.78**						
KKAVG				0.69**	0.70**	-0.62**			
KKMAX				0.72**	0.83**	-0.57**			
KKMIN				-0.27*	-0.39*	0.58**			
MIRAVG							0.69**	0.49**	-0.64**
MIRMAX							0.63**	0.57**	-0.53**
MIRMIN							-0.50**	-0.27*	0.75**

(b) Climatic Group B (Samarahan)

	BTUAVG	BTUMAX	BTUMIN	SBUAVG	SBUMAX	SBUMIN	KCHAVG	KCHMAX	KCHMIN
BTUAVG	0.63**	0.58**	-0.67**						
BTUMAX	0.67**	0.69**	-0.53**						
BTUMIN	-0.63**	-0.62**	0.77**						
SBUAVG				0.61**	0.12	-0.73**			
SBUMAX				0.53**	0.29**	-0.52**			
SBUMIN				-0.48**	0.02	0.89**			
KCHAVG							0.50**	0.41*	-0.57**
KCHMAX							0.50**	0.62**	-0.32*
KCHMIN							-0.37*	-0.13	0.77**

Correlation coefficients between selected time-series for 34-year period (1968 – 2001) are calculated by Spearman Rank Correlation. Values marked with (*) are significant at the 95% of confidence;, those marked with (**) (significant at 99%) and the unmarked values are not significant. The shaded values represent the correlation values between the two monsoons for the exact same variable

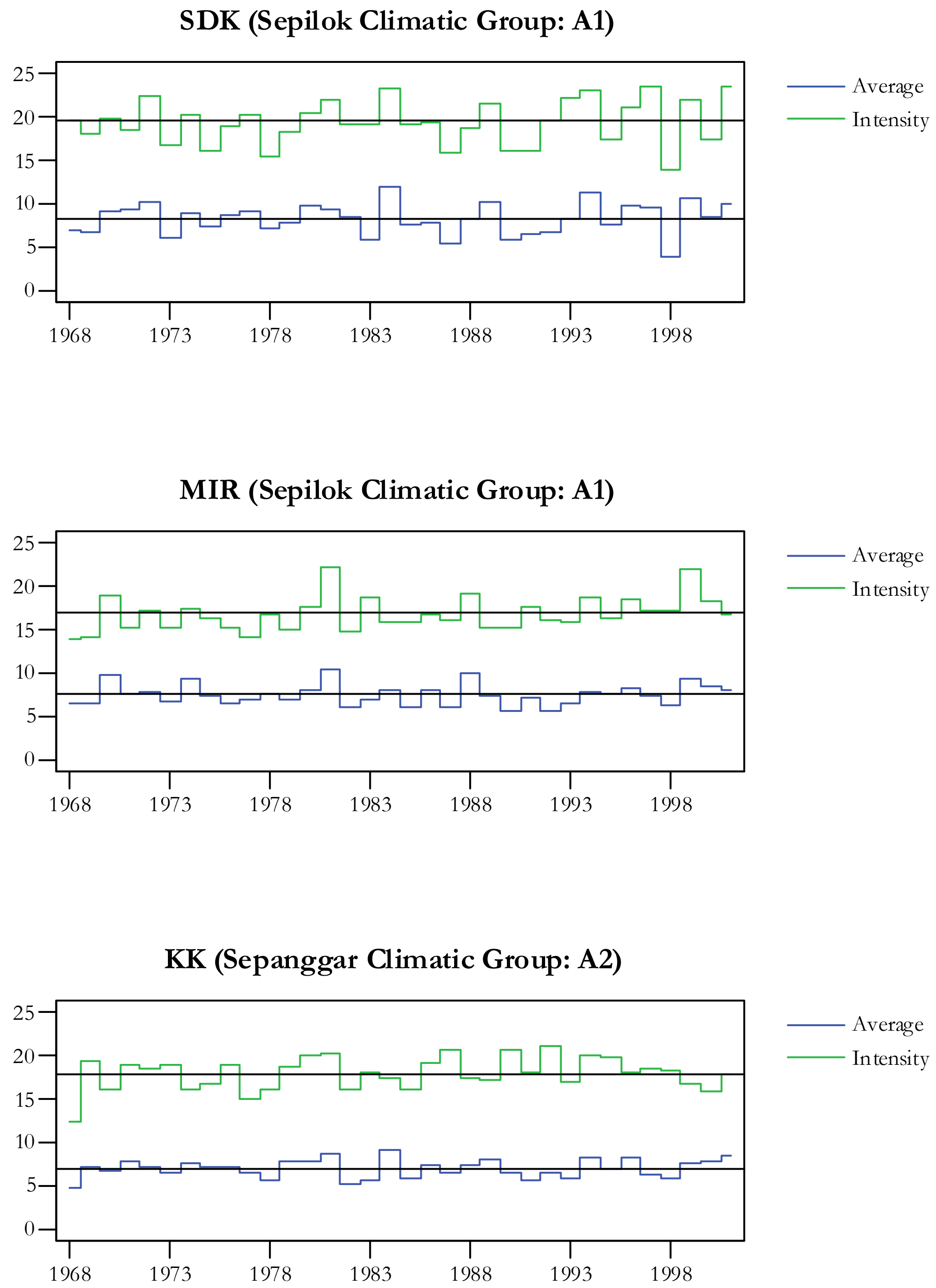
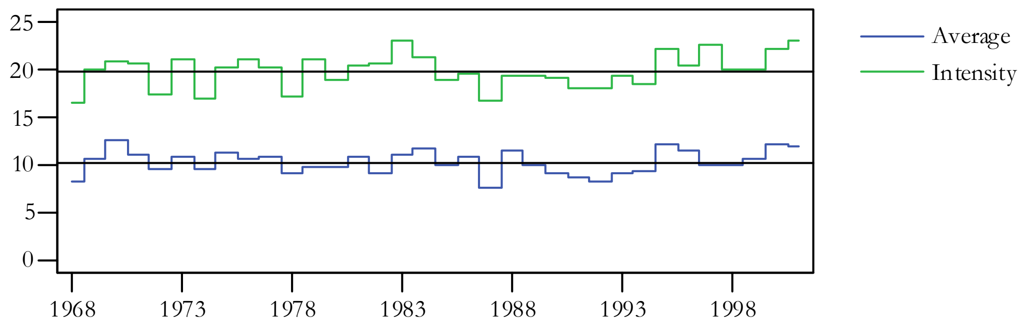
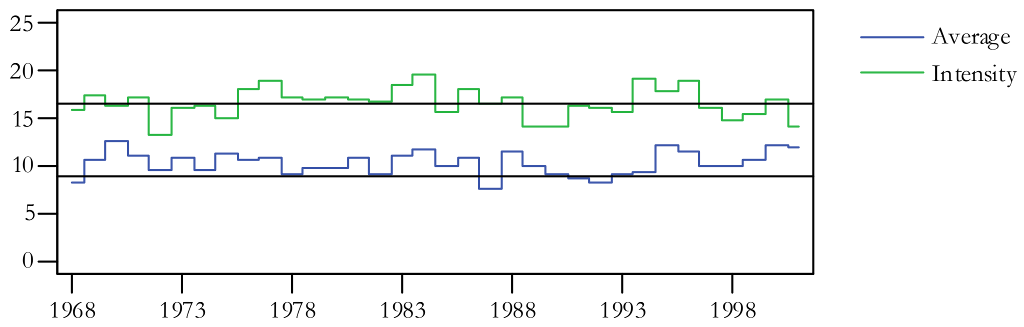


Figure 5.1a: Precipitation time series for average and intensity (Climatic Group A)
Straight lines over the plot indicate the long-term mean

BTU (Samarahan Climatic Group: B1)



SBU (Samarahan Climatic Group: B1)



KCH (Samarahan Climatic Group: B1)

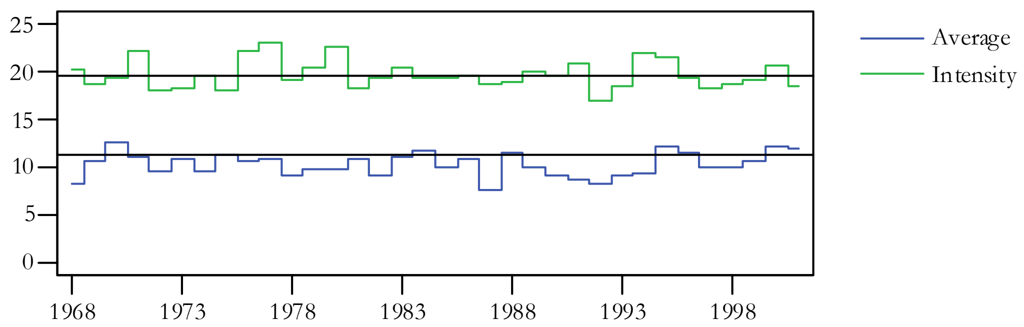
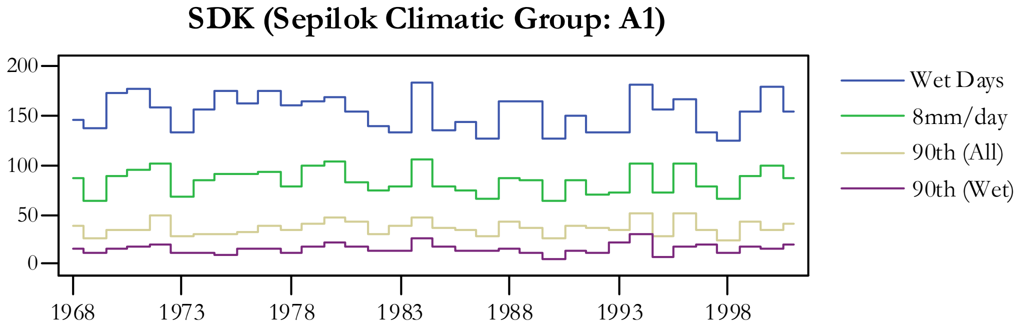
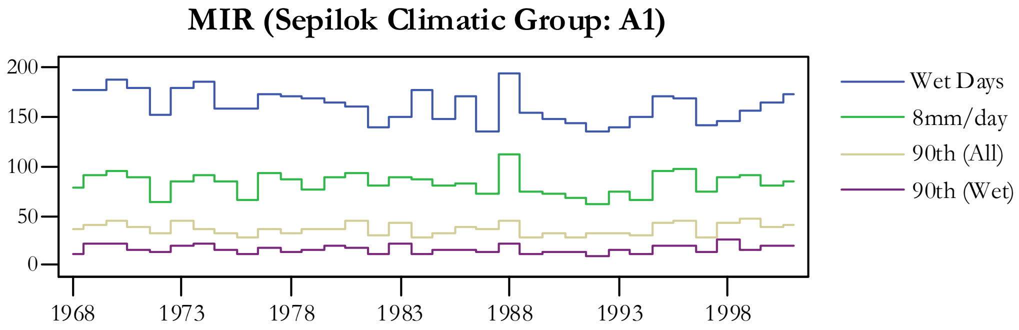


Figure 5.1b: Precipitation time series for average and intensity (Climatic Group B)
Straight lines over the plot indicate the long-term mean





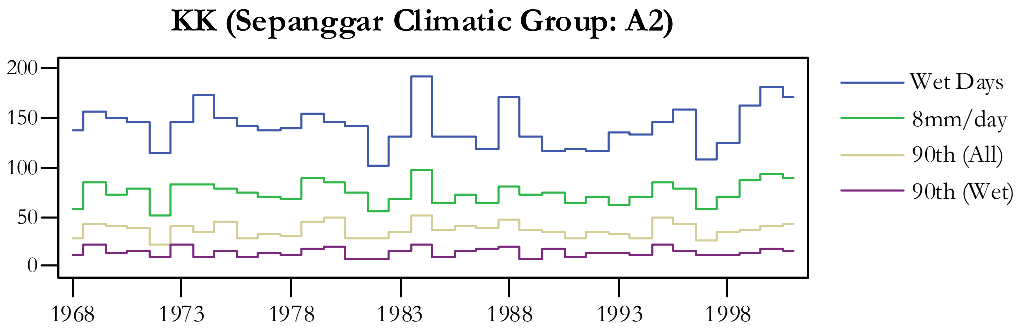


Figure 5.2a: Precipitation time series for frequency (i) wet days; (ii) rainfall of 8mm or more; (iii) 90th percentile of all days; and (iv) 90th percentile of wet days (Climatic Group A)

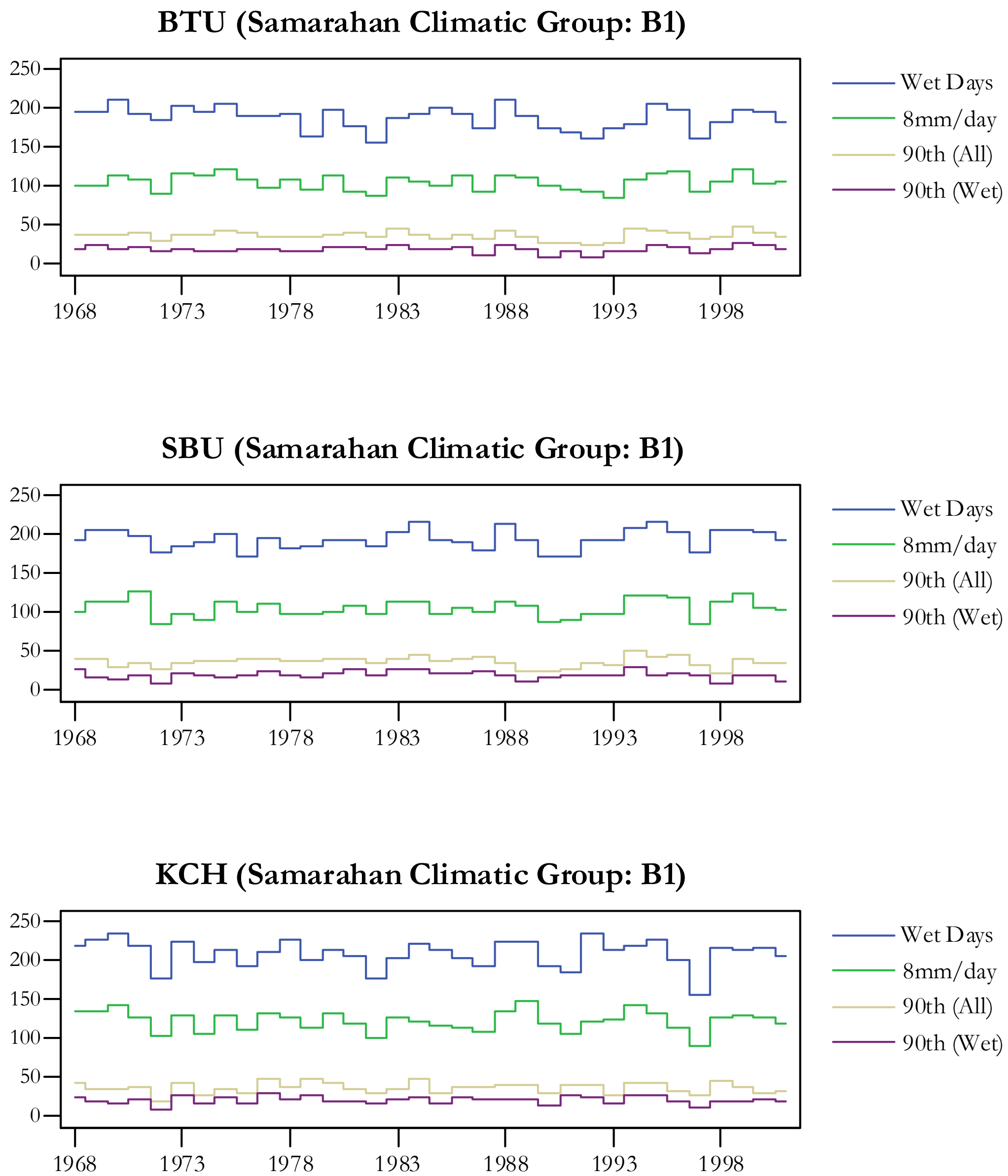
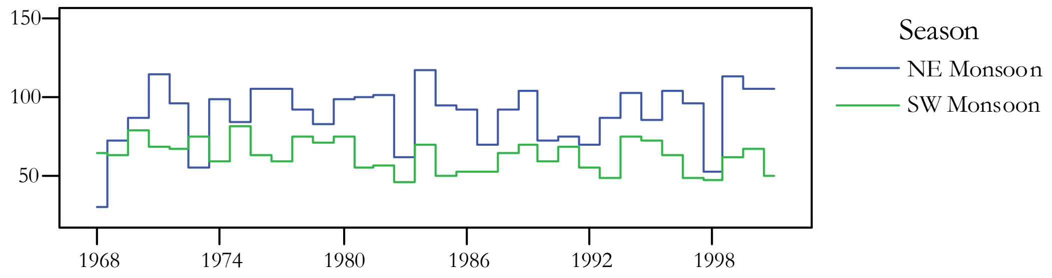
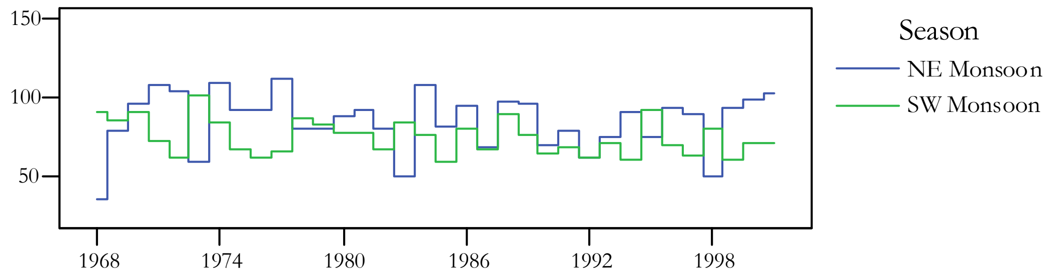


Figure 5.2b: Precipitation time series for frequency (i) wet days; (ii) rainfall of 8mm or more; (iii) 90th percentile of all days; and (iv) 90th percentile of wet days (Climatic Group B)

SDK (Sepilok Climatic Group: A1)



MIR (Sepilok Climatic Group: A1)



KK (Sepanggar Climatic Group: A2)

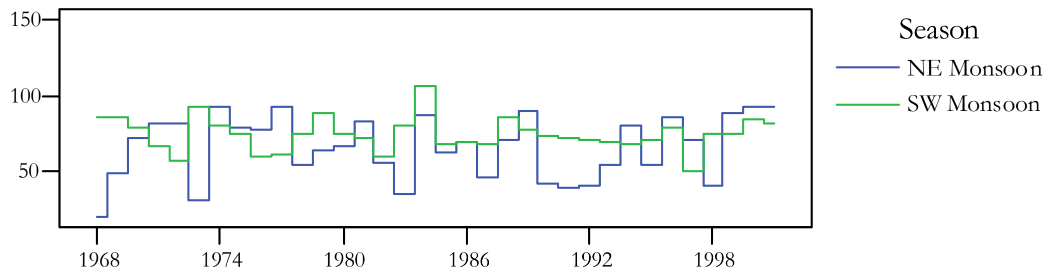
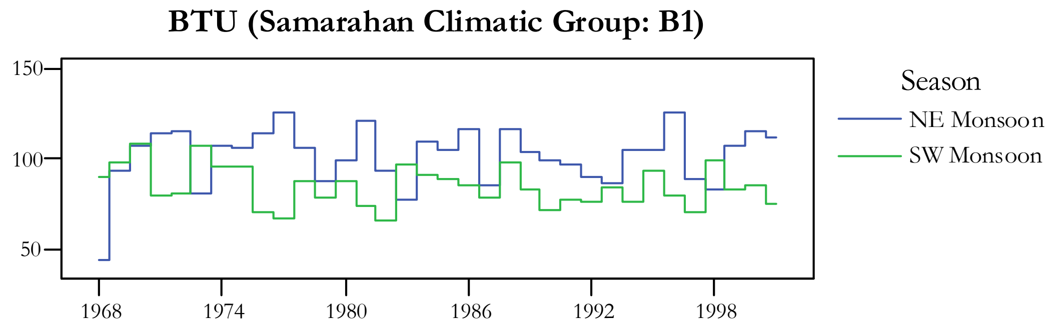
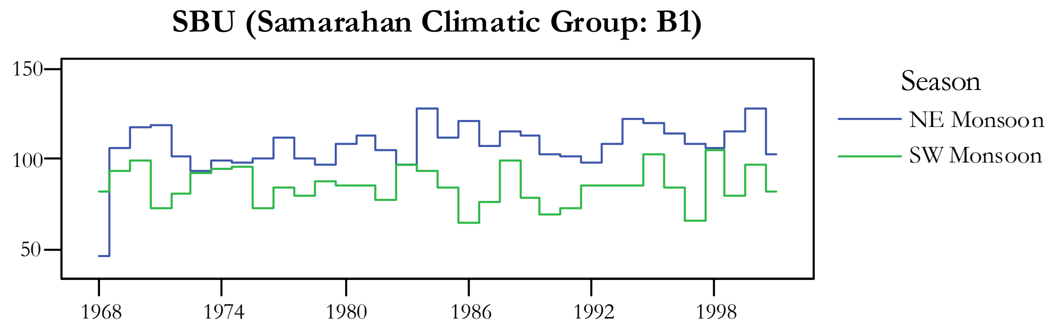


Figure 5.3a: Precipitation time series for number of wet days during the Northeast and Southwest Monsoon (Climatic Group A)





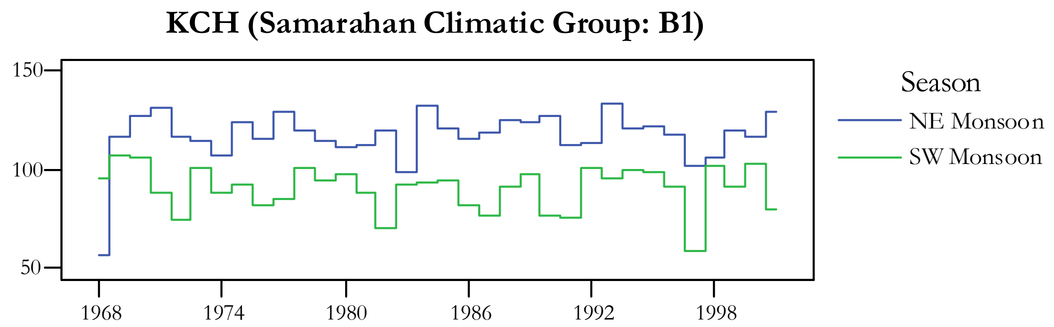
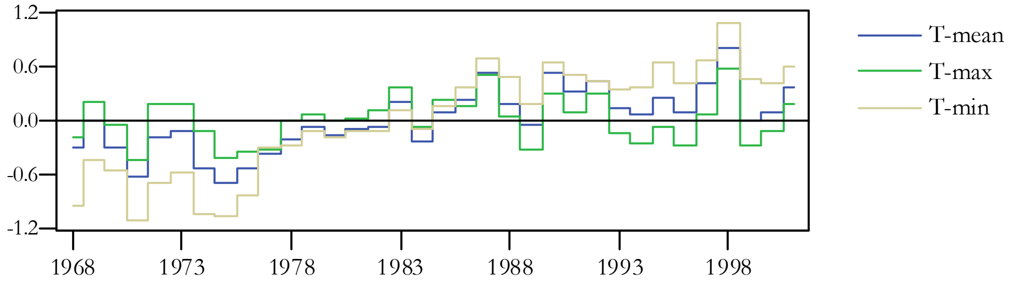
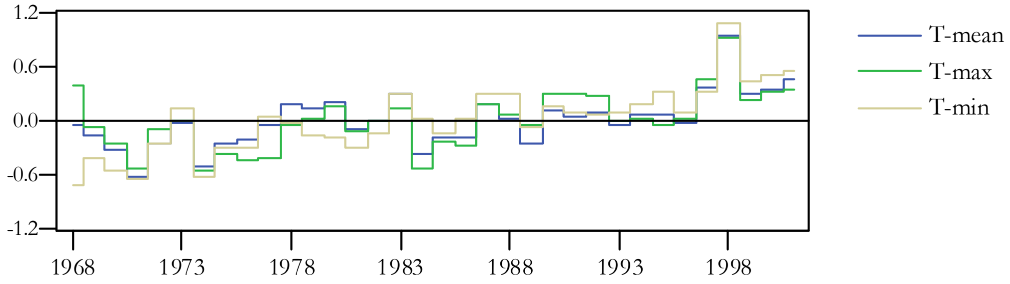


Figure 5.3b: Precipitation time series for number of wet days during the Northeast and Southwest Monsoon (Climatic Group B)

SDK (Sepilok Climatic Group: A1)



MIR (Sepilok Climatic Group: A1)



KK (Sepanggar Climatic Group: A2)

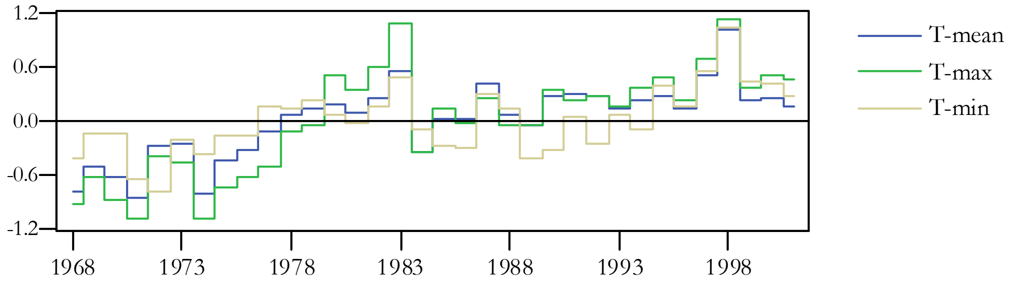


Figure 5.4a: Time series for mean, maximum and minimum temperature (Climatic Group A)
Values are expressed in anomaly (˚C)

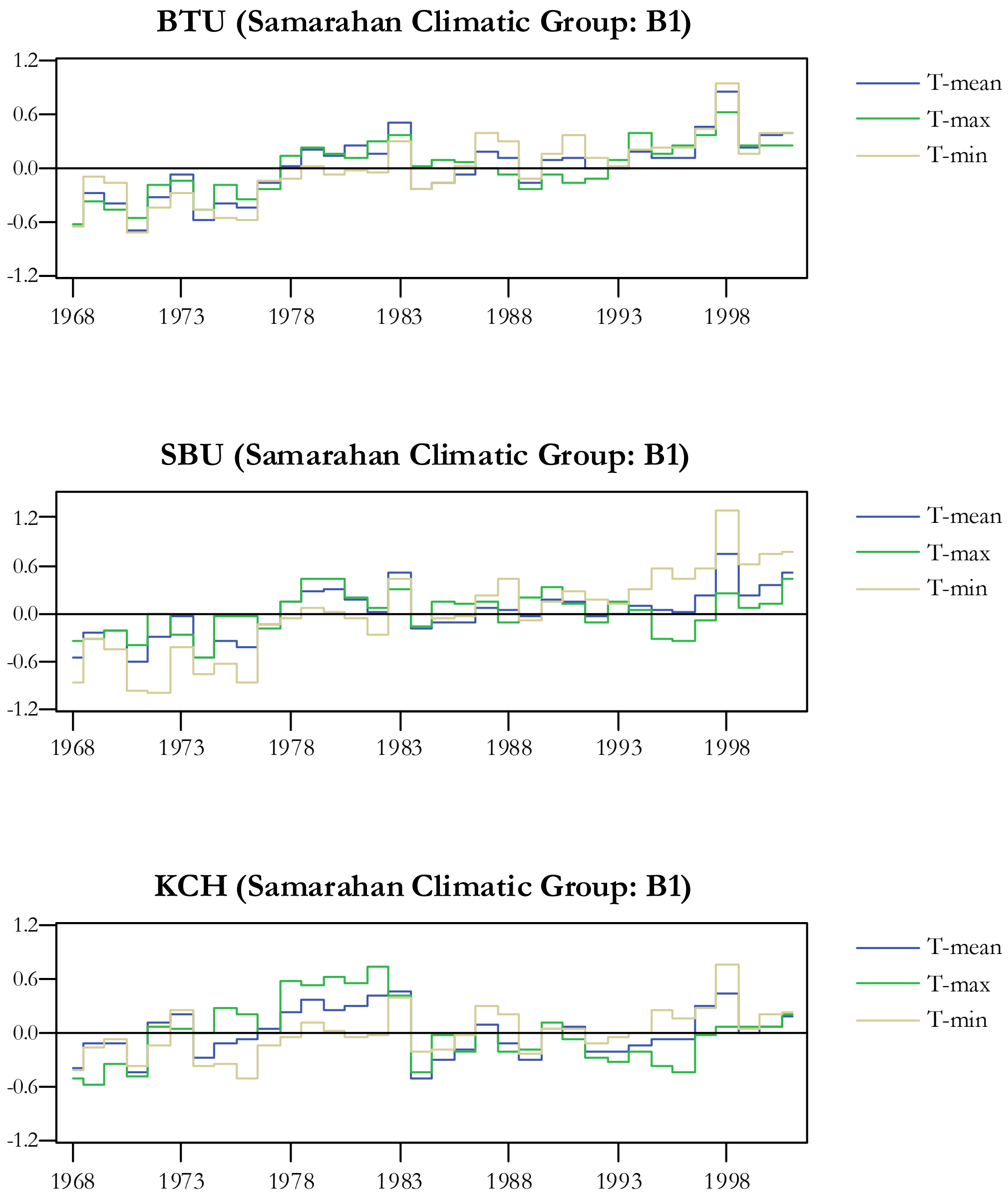


Figure 5.4b: Time series for mean, maximum and minimum temperature (Climatic Group B)
Values are expressed in anomaly (˚C)

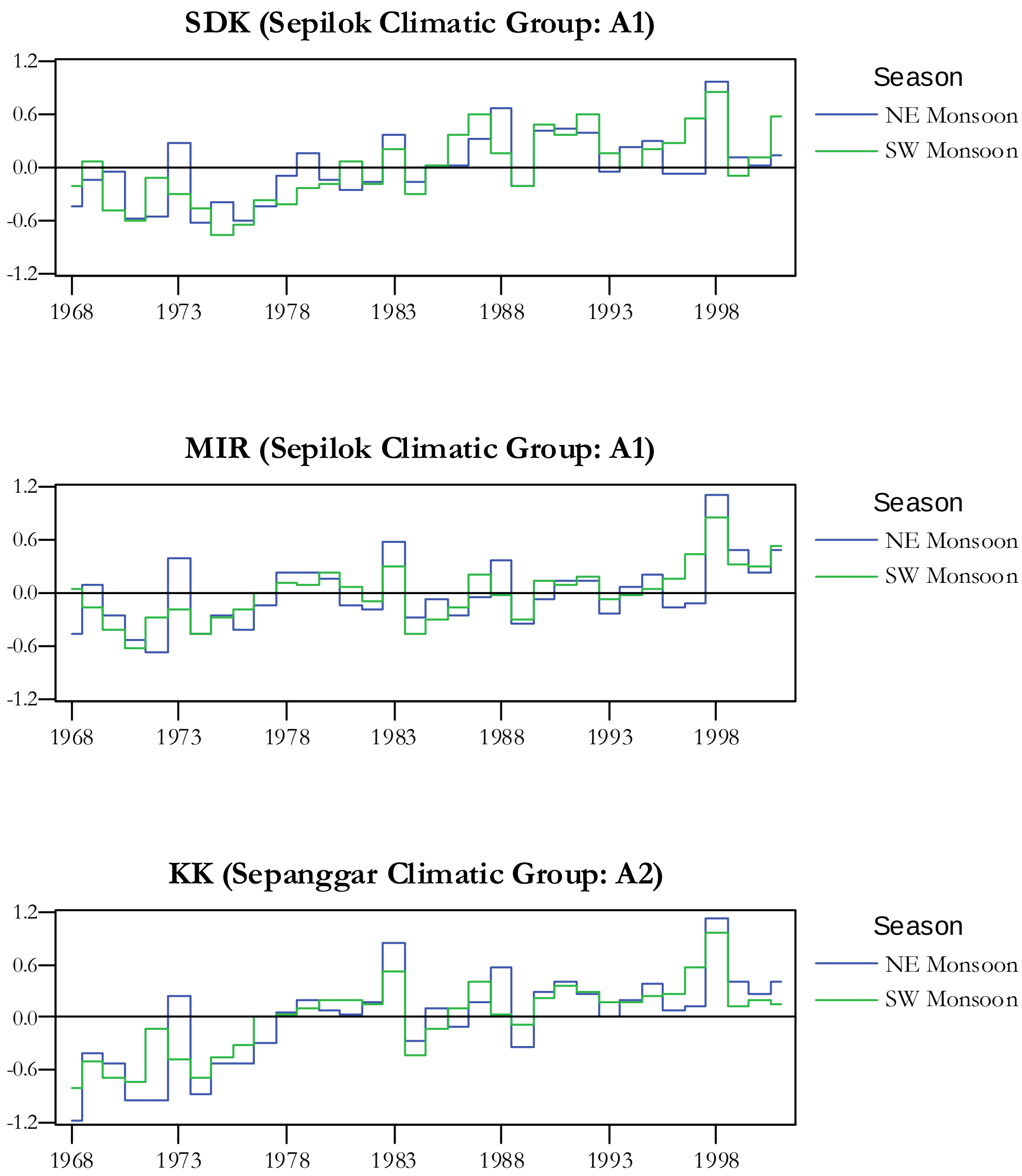
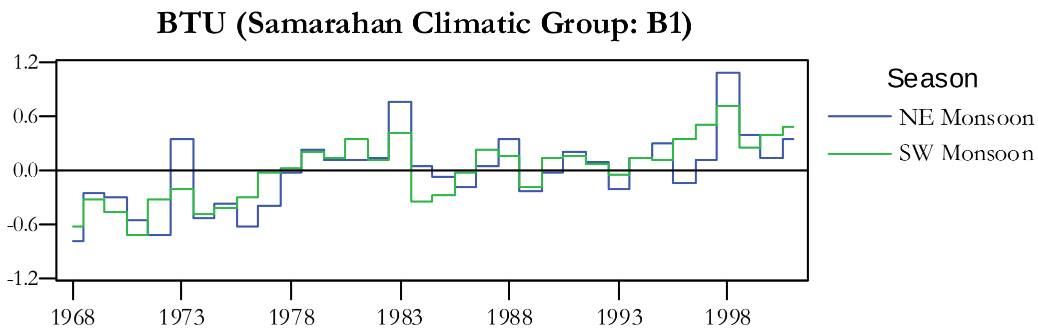
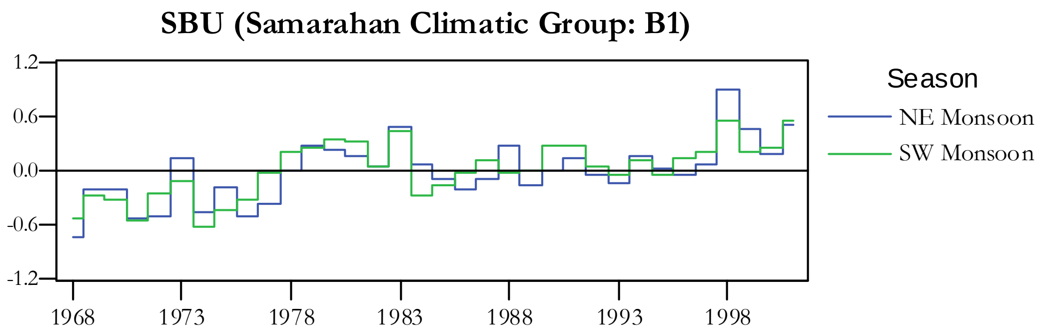


Figure 5.5a: Time series for mean temperature during the Northeast and Southwest monsoon (Climatic Group A)
Values are expressed in anomaly (˚C)





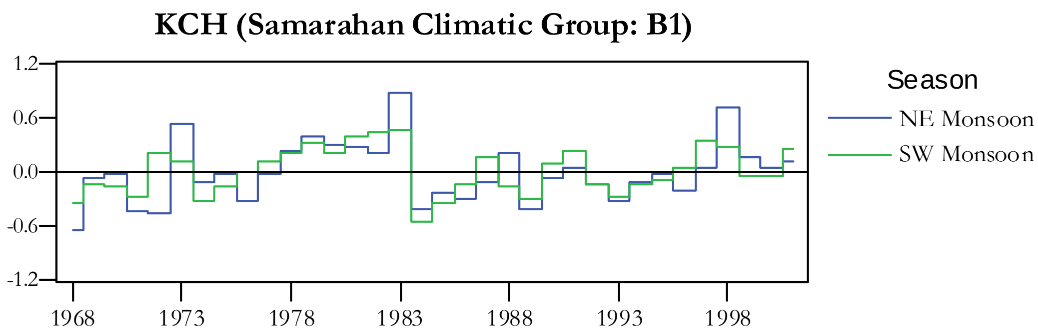
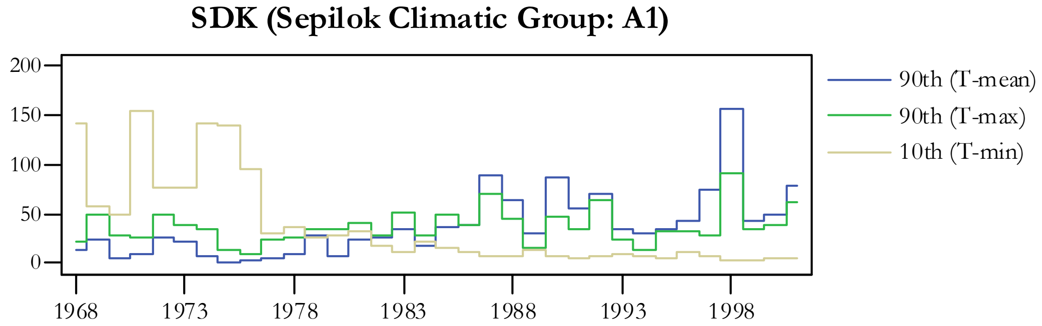
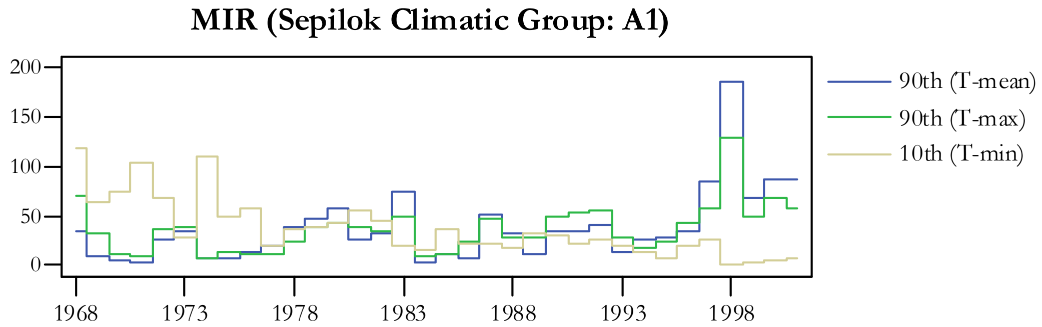


Figure 5.5b: Time series for mean temperature during the Northeast and Southwest monsoon (Climatic Group B)

Values are expressed in anomaly (˚C)





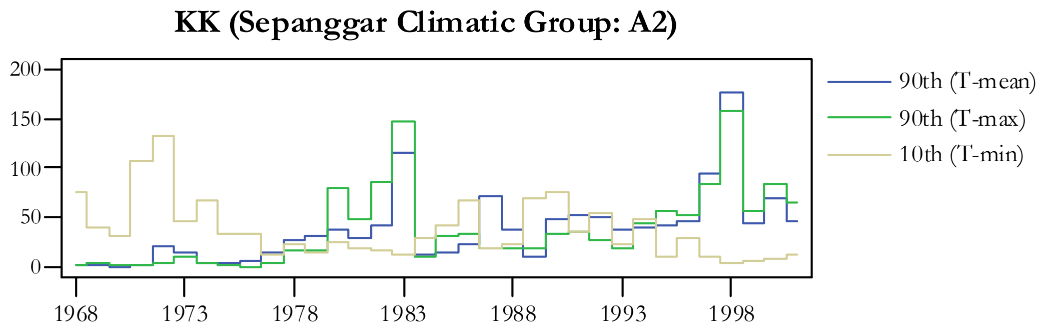
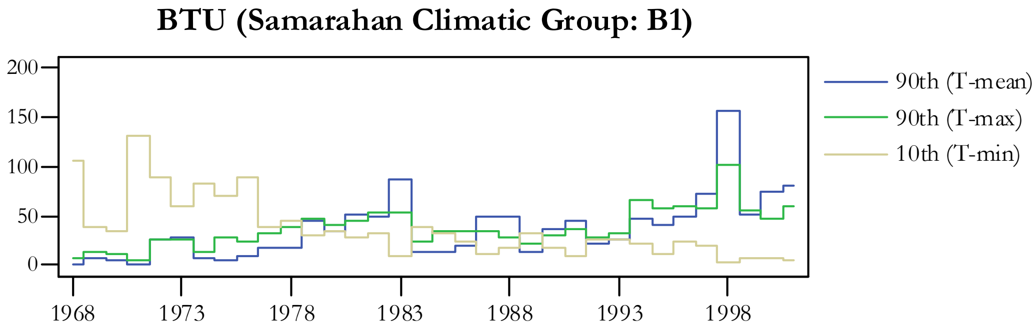
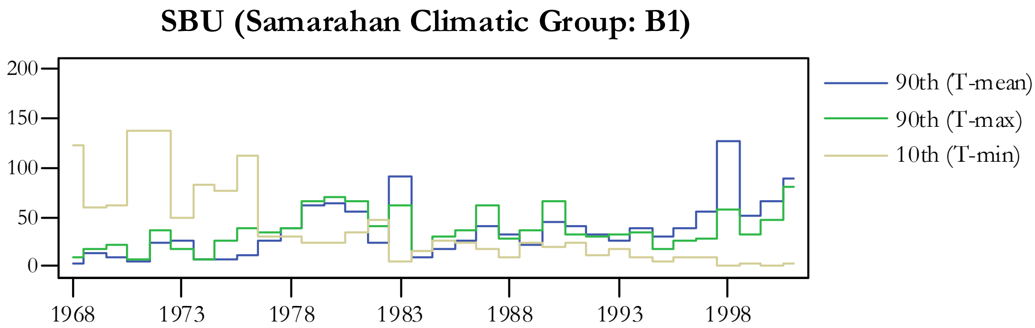


Figure 5.6a: Time series extreme temperature – 90th percentile for T-mean and T-max; 10th percentile for T-min (Climatic Group A)
Values in y-axis are expressed as number of days per-year





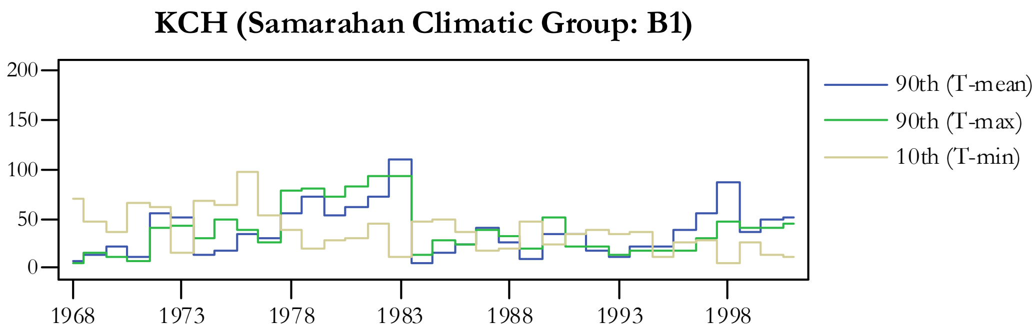


Figure 5.6b: Time series extreme temperature – 90^{th} percentile for T-mean and T-max; 10^{th} percentile for T-min (Climatic Group B)
Values in y-axis are expressed as number of days per-year

Chapter 6
Synoptic Indices and Circulation Typing

6.1 Introduction

There are two principal features of the large-scale circulation in Southeast Asia – namely the low frequency ENSO signals (2-7 years); and the seasonal monsoon modes fluctuating within the annual cycle. The main centre of action for the monsoon is the South China Sea within the area 2.5°-22.5°N and 102.5°E-122.5°E (Lu and Chan, 1999). However, the energy sources to stimulate the monsoonal flows originate from the mainland of the Asian continent (to the north), Indian Ocean (to the west), the Australian continent (to the south) and the western equatorial Pacific (to the east). ENSO, on the other hand, is a synoptic forcing that originates from the Pacific Ocean.

These two forces (i.e. the monsoon and ENSO) form and modulate the climate of Borneo (Sham Sani, 1984; Sirabaha, 1998). Therefore, in order to understand the local climate of Borneo – it is crucial to investigate how these two synoptic forces act and interact in forming large-scale circulation within the Southeast Asian region. Four steps, are undertaken in this thesis to achieve the aim:

- Evaluating the established synoptic indices (associated with the monsoon and ENSO), which are relevant to diagnose the local climate of Borneo.
- Selecting the best currently-available indices or creating better new indices.
- Developing a circulation scheme (to be related to the local climate of Borneo) using selected large-scale climatic variables – ideally ones that can detect both the monsoon and ENSO-related modes.
- Comparing the performance of the two diagnostic approaches – (a) the monsoon and/or ENSO indices (one or two indicators); and (b) the synoptic typing (multiple indicators).

6.2 Synoptic indices

Monsoon and ENSO are the most influential forces modulating surface climate in many part of the world (Nieuwolt, 1977; Das, 1986; Allan et al., 1996) – thus, many studies have been conducted to develop indices for both of these large-scale factors (e.g. Ropelewski and Jones, 1987; Barnston and Chelliah, 1997; Goswami et. al, 1999). The main purpose for such indices is to enable researchers to investigate empirical relationships between these two synoptic phenomena and the local climate of a particular region.

6.2.1 Monsoon

For the south Asian monsoon (also known as the Indian monsoon), which generally emphasizes summer rainfall, Lu and Chan (1999) identify two indices that have been successfully used to measure strong and weak monsoonal events. The first one is the all-Indian rainfall index (AIRI), which uses the precipitation average for June-September in subcontinental India (Krishnamurti, 1985). The other one is known as the WY index and is represented by the zonal wind shear between 850 and 200 hPa over Southeast Asia (Webster and Yang, 1992). Both of these indices have been improved in later work by Parthasarathy et al. (1995), and Goswami et al. (1999), and Wang and Fan (1999), respectively.

According to Lu and Chan (1999), the situation is more complicated in the case of the east and southeast Asia monsoon, which consists of three major airflows – (1) southwesterly flow (part of the Indian monsoon); (2) southeasterly flow (from the southwestern edge of the western Pacific sub-tropical high); and (3) the cross-equatorial flow over the southern part of the South China Sea (adjacent to Borneo). Whilst the summer monsoon is more dominant in the south Asia region (in terms of surface climate teleconnections – i.e. precipitation), the winter monsoon is stronger in the east and southeast Asia region (Lu and Chan, 1999; Lau et al., 2000). The monsoon in this region also shows a very distinctive wind component, which are southerly (northerly) during the boreal summer (winter).

The most well-known and widely accepted monsoon indices are listed in Appendix A. There are three issues/problems to be considered if these indices are to be used for Borneo:

- Most of the indices are specifically developed for either the south or east Asia regions. Ideally, as was pointed out by Wang and Fan (1999), any Asian monsoon index should be associated with the broad-scale flow of the Asian monsoon regions (this includes the Indian continent, Southeast Asia – both the mainland and the maritime continent, and East Asia). However, some researchers (e.g. Tao and Chen, 1987; Ding, 1990 & 1994) stress that local manifestations can be significantly varied when the monsoon components move across different latitudes, land-sea contrast and topography.

- Most of the indices focus on the summer monsoon and they are based on the larger monsoon region (normally it includes both the southern and eastern part of Asia). According to Wu and Chan (1997), while the winter monsoon may be adequately represented by the planetary-scale flow, this may be questionable for the summer monsoon. Apparently, Borneo experiences equally noticeable effects during the winter and summer monsoon (Sham Sani, 1984). Therefore, a more local approach is required to find the best monsoon indices to diagnose the local climate of Borneo.
- All the existing indices are seasonal/annual measures except for the Unified Monsoon Indices by Lu and Chan (1999), which are calculated on a monthly basis for both monsoons. Therefore in most cases, correlation analysis could not be performed on monthly or daily values – thus, this will limit the investigation of the monsoon influences on precipitation/temperature on these time scales.

6.2.2 ENSO

ENSO indices are generally represented by two climatic variables – (a) the sea level pressure; and (b) sea surface temperature (SST). The well-established specific indices are listed in Table 6.1 (see Figure 3.1 in Chapter 3, for the map showing all the Nino regions). Based on the published literature, it is clear that there is a consensus on what the most suitable ENSO indices are for Southeast Asia. In most of the previous studies (Quah, 1988; Cheang, 1993; Tangang, 2001; Caesar, 2002; Sirabaha, 2004), researchers have regarded the SOI (Southern Oscillation Index) and Niño-3.4 (SST anomaly for the Niño-3.4 region) as the best indices to be associated with Southeast Asia surface climate.

Table 6.1: Established ENSO Indices

Index	Climatic Variables	Description	Timescale
SOI	Sea level pressure (SLP)	SLP difference between Tahiti/Darwin	Monthly
Niño 1+2	Sea surface temperature (SST)	SST anomaly at the Niño-1 + 2 region	Monthly
Niño 3	Sea surface temperature (SST)	SST anomaly at the Niño-3 region	Monthly
Niño 3.4	Sea surface temperature (SST)	SST anomaly at the Niño-3.4 region	Monthly
Niño 4	Sea surface temperature (SST)	SST anomaly at the Niño-4 region	Monthly

6.2.3 Evaluation of established monsoon indices

The method used to evaluate the monsoon indices is a simple non-parametric correlation (see Chapter 3). These indices will be correlated with surface variables of Borneo (i.e. precipitation and temperature) and also the well-established ENSO indices. Based on discussion in the earlier part of this chapter and the literature overview on the synoptic climatology of Borneo (Chapter 2), there are two underlying characteristics of the monsoon phenomenon:

- The monsoon modulates the climate of Borneo on a seasonal basis (fluctuating within the 12-month annual cycle).
- The monsoon interacts with the ENSO signal, which is responsible to the occurrence of El Niño or La Niña events.

Using this knowledge, two criteria are identified to measure and justify the suitability of the monsoon indices – prior to the correlation analysis. The criteria are:

- The correlation between the monsoon indices and the surface variables (precipitation and temperature) must be convincing in both seasons (winter and summer monsoon). This serves as an indication of how reliable the indices are in capturing the seasonal variability.
- The correlation between the monsoon indices and ENSO indices (especially SOI and Niño3.4) must be highly significant. This measures the ability of the monsoon indices in phase-locking with the ENSO signals (the most prominent variability on multiyear timescales).

The results of the correlation analysis are shown in Figures 6.1 to 6.3. The following information serves as a guide for all the figures:

- The thresholds of correlation coefficient values at 95% level of significance are 0.30 (for Monsoon-ENSO) and 0.34 (for Monsoon-Surface). The differences in threshold are due to the length of the data series: 42 years (1960-2001) for the monsoon and ENSO indices; and is only 34 years (1968-2001) for precipitation and temperatures.
- Monsoon indices being evaluated are AIRI, RM2, WY, UMI1, UMI2 (see Table 6.1), and IOI (Indian Ocean Index), represented by the mean SST over Indian Ocean region bounded by 20° N–10° S and 50° E–100° E and computed in a 5° X 5° grid using the ship's observations archived by the National Data Centre of the India Meteorological Department (Tourre and White, 1994; 1996). AIRI and WY are only available for the summer (SW) monsoon. Therefore, the correlation values for AIRI and WY during the winter (NE) monsoon are based on the seasonal values for the SW monsoon (i.e. with six month lag).

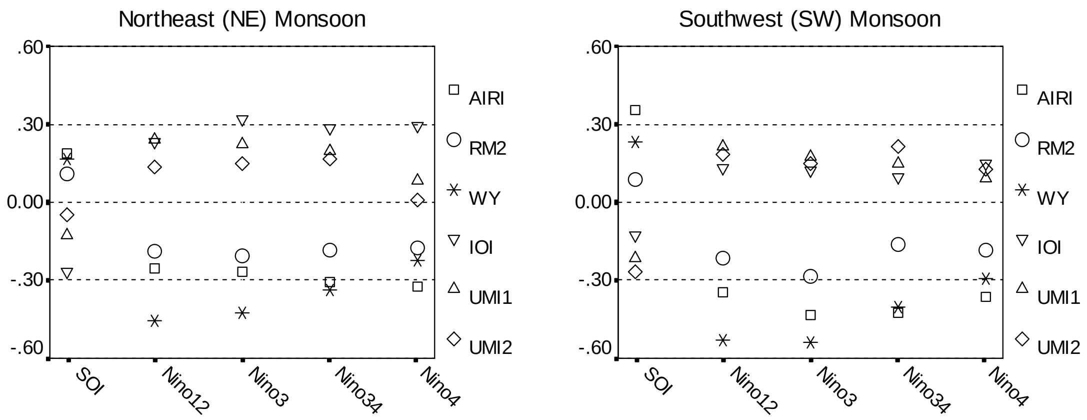


Figure 6.1: Correlation between selected monsoon indices (from previous studies) and well-established ENSO indices for two different monsoons: NE (Northeast/Winter Monsoon) and SW (Southwest/Summer Monsoon)

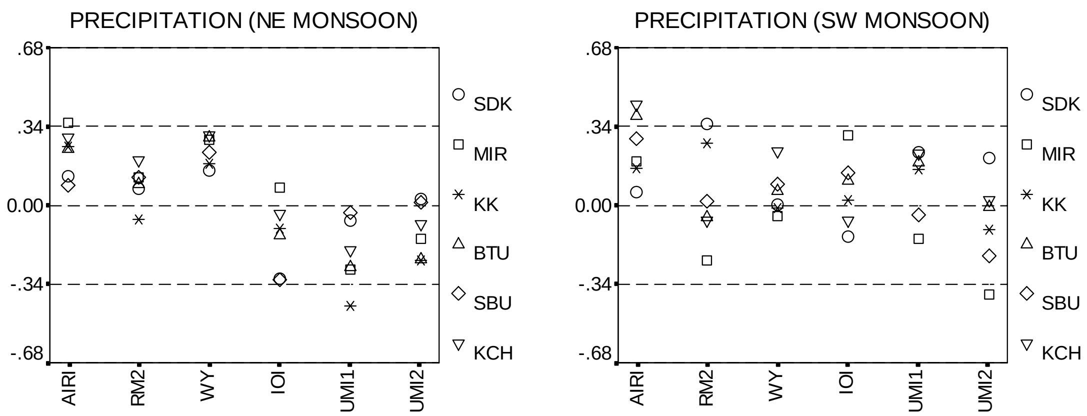


Figure 6.2: Correlation between selected monsoon indices (from previous studies) and precipitation at 6 key stations in Borneo for two different monsoons: NE (Northeast/Winter Monsoon) and SW (Southwest/Summer Monsoon)

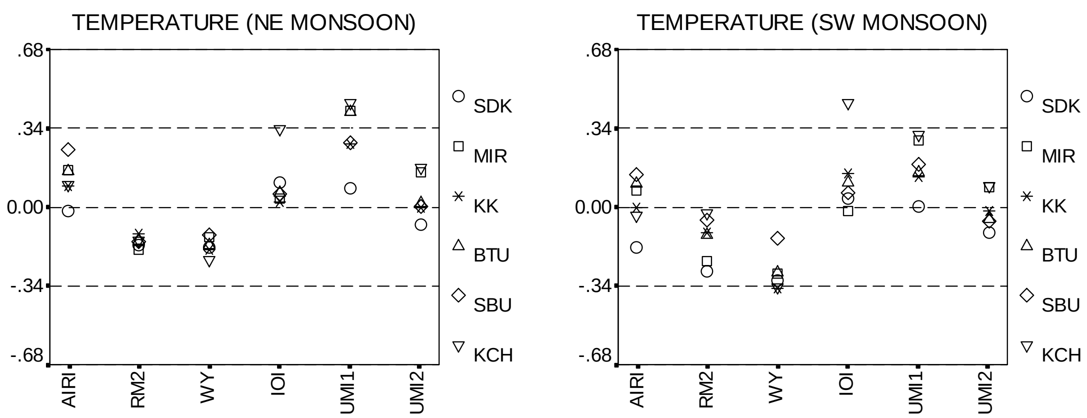


Figure 6.3: Correlation between selected monsoon indices (from previous studies) and temperature anomaly at 6 key stations in Borneo for two different monsoons: NE (Northeast/Winter Monsoon) and SW (Southwest/Summer Monsoon)

ENSO indices are SOI, Niño1+2, Niño3, Niño3.4 and Niño4 (see Table 6.2). Particular attention is given to SOI and Niño3.4, the two indices that are considered most representative of Borneo (see Section 6.2.2). The six key stations in Borneo are SDK (Sandakan – A1 climatic group), MIR (Miri – A1), KK (Kota Kinabalu – A2), BTU (Bintulu – B1), SBU (Sibu – B1) and KCH (Kuching – B1). In general, the chosen monsoon and ENSO indices are poorly correlated. During the winter (Northeast) monsoon, none of the indices are significantly correlated with SOI, and only WY (0.36) is statistically significant during the summer (Southwest) monsoon. As for the Niño3.4, AIRI (-0.31/-0.43) and WY (-0.34/-0.40) are significantly correlated in both seasons (winter/summer). However, all the other indices are statistically not significant.

The correlation between the surface climate of Borneo is also relatively poor. Only UMI1 shows significant correlation with more than one station (MIR, BTU, KCH) for temperature during the winter (Northeast) monsoon. The other indices have a maximum of only two stations significantly correlated in either case with temperature or precipitation. However, none of the indices prove to be reliable for both surface variables (i.e. precipitation average and temperature anomaly) in both seasons (summer and winter).

6.2.4 Creation and evaluation of new monsoon indices

Upon evaluating several established monsoon indices used by previous studies (mostly using zonal and meridional upper wind shear at various gPh levels), none of these indices establish convincing correlations with either the surface climate or the ENSO signals (see Section 6.2.3). In particular, most of the indices fail to establish reasonable teleconnections during the boreal winter – the season that supposedly manifests a stronger monsoon effect for Southeast Asia (as been reviewed by Sham Sani, 1984; Sirabaha, 1998; 2004). Therefore, it is appropriate, indeed essential, to create new indices using a more 'local approach' and focussing the centre of action within the region of Borneo (20°S-30°N; 75°E-140°E) itself. What is the justification for this new choice of so-called 'action centre'?

First, as has been discussed in Chapter 2, the main domain of action for the Southeast Asia Monsoon (SEAM) is between northern Australia and mainland Asia. Although there are various physical mechanisms that force the movement of the SEAM flow, the main source is the meridional thermal contrast between the northern and southern hemispheres (Lu and Chan, 1999). Since Borneo is located right on the equatorial line, the 20°S-30°N latitudinal range is appropriate. The second justification is to ensure consistency with the chosen synoptic window for all analyses in this thesis. Thus, this particular analysis will empirically be more sound when its results are associated with other findings in this research framework.

The synoptic variable used to create the new indices is sea level pressure (SLP). Most of the previous indices are based on upper level wind (at 1000, 850 and 250 hPa). This might be an appropriate approach to establish indices for the broader-scale monsoon region (i.e. the entire continent of South Asia or Far East Asia). However, for a smaller region like Borneo, the lower level wind is considered more effective (Sham Sani, 1973). There are two reasons why SLP is a better choice – (i) to shift the search for monsoon indices into a totally new perspective (so far, there is no established monsoon index based on sea level pressure); and (ii) SLP, being a lower level wind, has two advantages – not only the ability to reflect the large-scale signal, but also to capture the more local influences of geographical layout and land-sea distribution.

The SLP is derived from the gridded reanalysis data for the chosen window (20°S-30°N; 75°E-140°E – regarded as the monsoon action centre for Southeast Asia). Daily observations from 1960-2001 (42 years) with the grid resolution of 2.5° X 2.5° are used (see Chapter 3 for a detailed description of data selection and sources). The two monsoon indices being created are named RD1 and RD2[35].

6.2.5 *The first new index (RD1): SLP differences*

Similar to the basic principle in creating the SOI, RD1 is a simple index using pressure differences between two identified points/areas. The two points identified are – (a) the northern latitude of 30°N; and (b) the southern latitude of 20°S. These are the starting latitudinal lines where the low-level wind changes its direction during the seasonal transition between winter and summer and vice versa (Sham Sani, 1984).

The daily values of RD1 are obtained from the differences between the averages of SLP values along the two latitudinal lines – 30°N and 20°S (27 grid-points of 2.5° X 2.5° in each line between the longitude 75°E-140°E). This can be represented mathematically as:

$$\text{RD1 Index} = \text{AVG}(\text{SLP}^{30°N})_{n=1,27} - \text{AVG}(\text{SLP}^{20°S})_{n=1,27}$$

Where,
$\text{SLP}^{30°N}$ is the averaged SLP values for 27 grid-points along the 30°N (latitude line)
$\text{SLP}^{20°S}$ is the averaged SLP values for 27 grid-points along the 20°S (latitude line)

[35] RD is chosen as the acronym for these new indices – which are the initials of the researcher.

6.2.6 The second new index (RD2): unrotated PC modes

This second index is more complex. RD2 values are obtained from the unrotated PC scores – the product of PCA on the absolute measure of daily SLP from 1960-2001. The basic assumption in this process is that all the daily SLP gridded values at 567 grid points (evenly distributed over the chosen window) – could collectively represent the monsoon mode on any particular day. The problem is, there are too many values to serve as diagnostic indices. PCA aims to reduce these variables and produce fewer significant modes, which should simplify the temporal variability (see Chapter 3, Section 3.4). There are three important processes to achieve this goal using PCA:

- Reducing the 567 grid-point variables into fewer significant modes
- Combining the identified significant modes into one single monsoon index
- Calculating values to represent each day over the time series (these daily observations can then be converted into monthly, seasonally or annual values – depending on need)

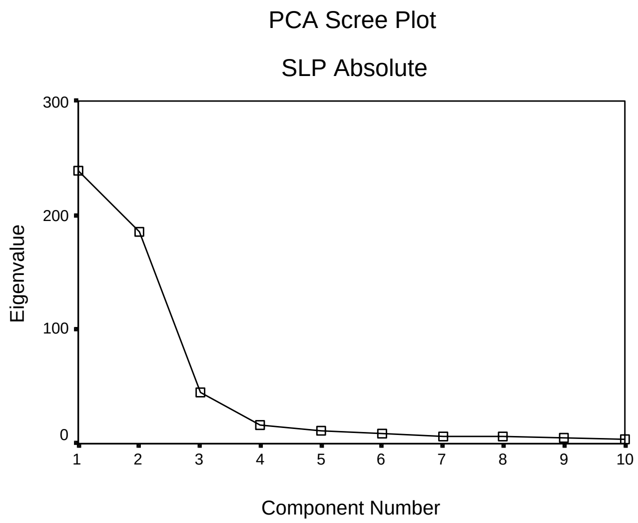


Figure 6.4: Scree Plot of the PCA

The core objectives neither include regionalisation nor map-pattern classification. Therefore, the most appropriate mode of decomposition is the S-mode (Yarnal, 1993). In this case, the PCA serves purely as a reduction process. Upon performing the PCA, it is found that there are four significant components that cumulatively describe a total variance of 86% (see Table 6.2). The criterion used to identify the significant modes is a Scree Plot (Cattell, 1966; Preisendorfer, 1988; Kostopoulou, 2004). The optimum number of PCs that should be retained is where the eigenvalue's plot bends (component number 4 in this case – see Figure 6.4). The detail on PCA is given in Section 3.4.

Table 6.2: Percentage of variance explained by each PCA

	Unrotated Eigenvalues		
Retained PC	Total	% of Variance	% Cumulative
PC 1	239	42	42
PC 2	185	33	75
PC 3	45	8	83
PC 4	17	3	86

Each one of the retained components could, itself, serve as a monsoon index. However, the four components theoretically represent various physical features of the monsoon signals. Therefore, each one of them can only capture a certain fraction of the whole variability in the monsoonal flow. In order to obtain a more holistic and representative index, the calculation of the final value is done by averaging the score of all four retained components – and each component is weighted by its individual percentage of variance explained. The calculation is shown by the mathematical equation below:

$$\text{RD2 Index} = [(PC_1 \bullet V_{\%1}) + (PC_2 \bullet V_{\%2}) + (PC_3 \bullet V_{\%3}) + (PC4_1 \bullet V_{\%4})] /4$$

Where;
PC is the component score of PC1, PC2, PC3 and PC4
$V_{\%}$ is the percentage of variance explained by PC1, PC2, PC3 and PC4 (see Table 6.3)

6.2.7 Evaluation of the new monsoon indices (RD1 and RD2)

The method and justification for evaluating the new indices is exactly the same as in Section 6.3. These new indices will be tested as the basis of correlation performance with two other empirical climatic variables – namely the ENSO indices and the local climate (precipitation and temperature). The monthly/seasonal RD1/RD2 values that have been correlated with ENSO indices are the averaged values of all days in each month/season. These correlations are shown in Figure 6.5 (0.30 is the threshold for statistical significance at the 95% level). The correlations between surface climate (precipitation average and temperature anomaly) is shown in Figures 6.6 and 6.7 respectively (0.34 is the threshold for statistical significance at the 95% level).

In comparison with the previously established indices (Figures 6.1 to 6.3), the correlation results clearly indicate that these two new indices (RD1 and RD2) have shown far better performance (both with respect to local climate and ENSO indices). Based on overall correlation performance, it can be concluded that the best index from the previous indices (i.e. WY) is poorer than the worst of the newly created indices (i.e. RD1).

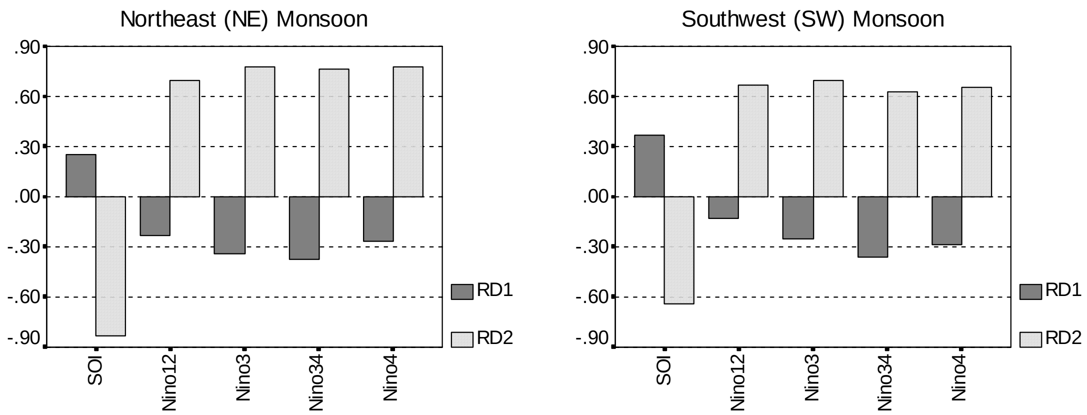


Figure 6.5: Correlation between RD1/RD2 and ENSO indices

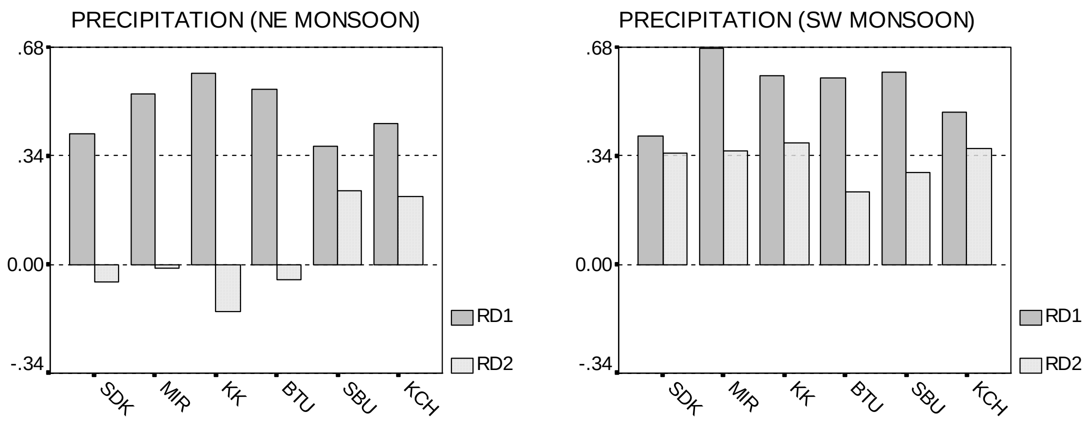


Figure 6.6: Correlation between RD1/RD2 indices and Borneo seasonal precipitation

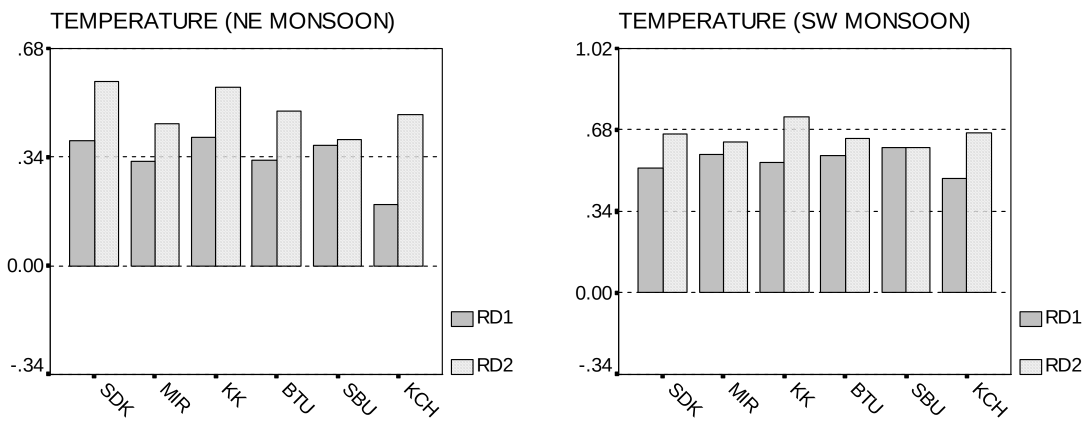


Figure 6.7: Correlation between RD1/RD2 indices and Borneo seasonal temperature anomaly

Of the two indices, RD1 is better correlated with precipitation; whereas RD2 is better correlated with temperature anomaly and the ENSO indices. Both indices also show much better association during the winter (NE) monsoon, as opposed to the previous indices – which are clearly biased to the summer monsoon. The results for RD1 and RD2 are summarised in Tables 6.3 and 6.4. The highest correlation between ENSO indices and the old monsoon indices (during the NE Monsoon) are: SOI – IOI (-0.27), Niño12 – WY (-0.46), Niño3 – WY (-0.42), Niño3.4 – WY (-0.34) and Niño4 – AIRI (-0.33. The highest correlation during the SW Monsoon are: SOI – AIRI (0.36), Niño12 – WY (-0.53), Niño3 – WY (-0.54), Niño3.4 – AIRI (-0.43) and Niño4 – AIRI (-0.36). RD2 proves to perform better than any of these monsoon indices (from previous studies).

Table 6.3: Correlation values for RD1/RD2 during the winter (NE) monsoon

6.3a Correlation coefficients with ENSO indices

	SOI	NIÑO12	NIÑO3	NIÑO34	NIÑO4
RD1	0.24	-0.23	-0.34*	-0.38*	-0.26
RD2	-0.84*	0.70*	0.78*	0.77*	0.78*

6.3b Correlation coefficients with precipitation

	SDK	MIR	KK	BTU	SBU	KCH
RD1	0.41*	0.53*	0.60*	0.55*	0.37*	0.44*
RD2	-0.05	-0.01	-0.15	-0.05	0.23	0.21

6.3c Correlation coefficients with temperature anomalies

	SDK	MIR	KK	BTU	SBU	KCH
RD1	0.39*	0.33	0.40*	0.33	0.38*	0.19
RD2	0.58*	0.45*	0.56*	0.49*	0.40*	0.47*

Values marked with (*) are statistically significant, at least, at the 95% level

Table 6.4: Correlation values for RD1/RD2 during the summer (SW) monsoon

6.4a Correlation coefficients with ENSO indices

	SOI	NIÑO12	NIÑO3	NIÑO34	NIÑO4
RD1	0.37*	-0.13	-0.25	-0.36*	-0.29
RD2	-0.64*	0.67*	0.70*	0.63*	0.66*

6.4b Correlation coefficients with precipitation

	SDK	MIR	KK	BTU	SBU	KCH
RD1	0.40*	0.68*	0.59*	0.58*	0.60*	0.48*
RD2	0.35*	0.35*	0.38*	0.23	0.29	0.36*

6.4c Correlation coefficients with temperature anomalies

	SDK	MIR	KK	BTU	SBU	KCH
RD1	0.52*	0.58*	0.54*	0.57*	0.61*	0.48*
RD2	0.66*	0.63*	0.73*	0.64*	0.61*	0.67*

Values marked with (*) are statistically significant, at least, at the 95% level

These new indices (RD1 and RD2) are also correlated fairly well with some of the previous monsoon indices, particularly the UMI1 and RM2 indices – as shown in Figure 6.8 (0.30 is the threshold for statistical significance at the 95% level).

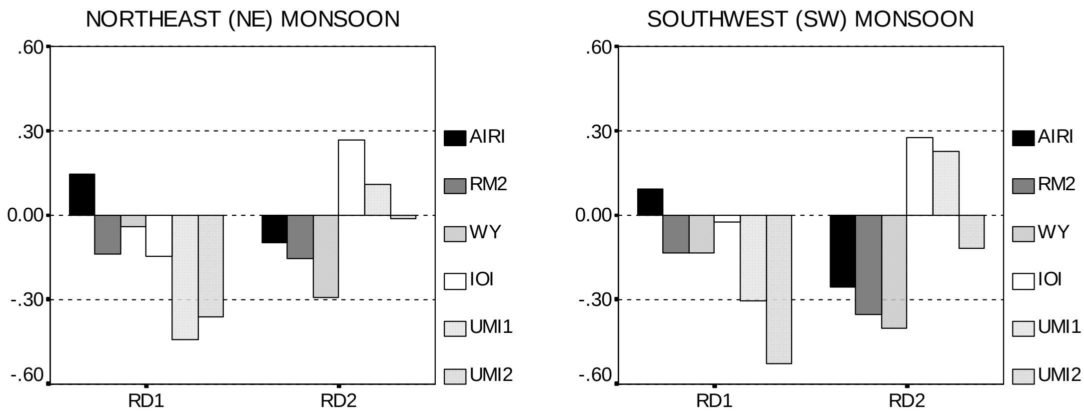


Figure 6.8: Correlation between RD1/RD2 and other monsoon indices

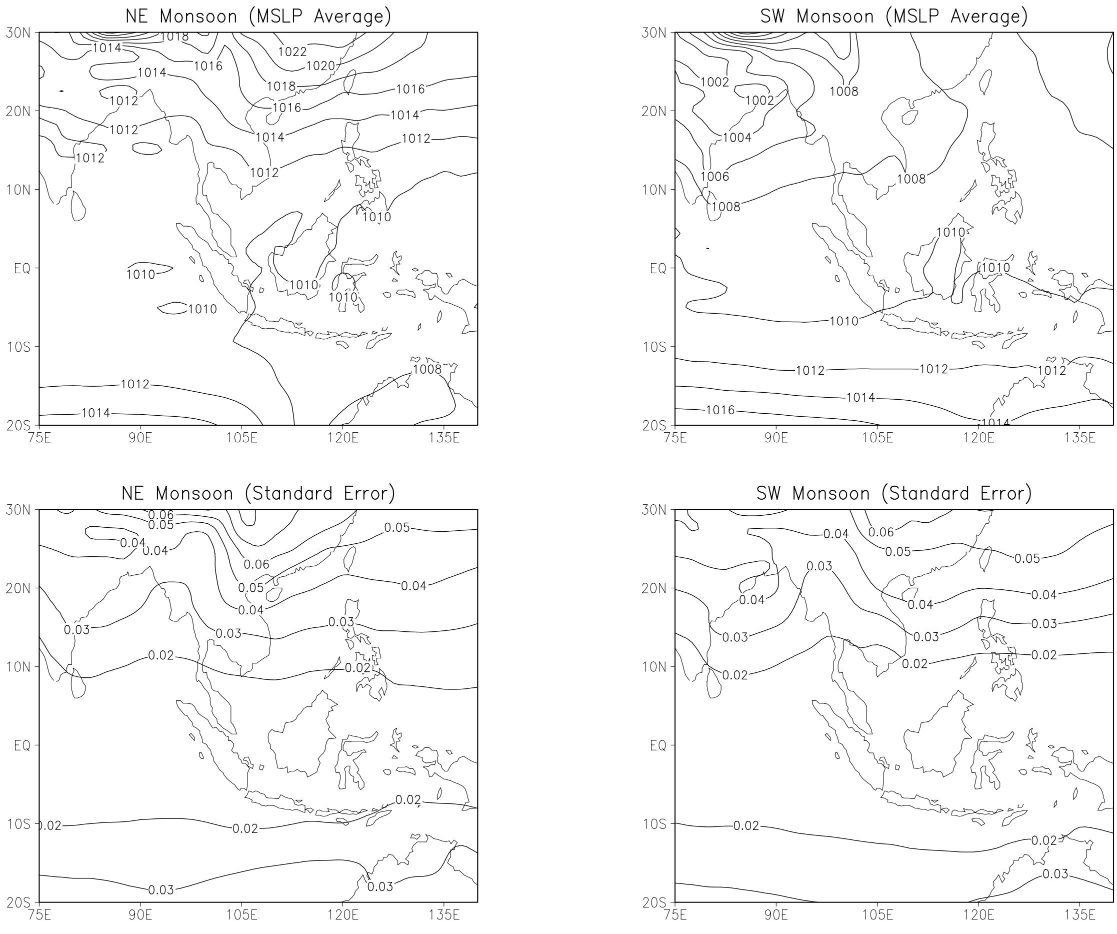


Figure 6.9: SLP averages and the standard error of means during the NE and SW monsoons

The SLP averages for the region (i.e. cross section of 30°N-20°S) during the SW and NE monsoons are shown in Figure 6.9. It exhibits how well the pressures vary between those two points. The advantages of using RD1 and RD2 for Borneo compared to using the previous monsoon indices are:

- The indices are developed using synoptic variables that are closely related to Borneo and with physical association with the region's geographical layout – lower level wind (SLP), instead of the upper level winds at geopotential height 200mb, 850mb and 1000mb.

- The indices are calculated on a daily time-scale, which makes them flexible to be transformed into monthly or seasonal measures, or to be retained as daily observations – depending on the purposes and aims of the analysis.
- The indices are shown to have stronger correlations with both the ENSO indices and local climatic variables (i.e. precipitation magnitude and temperature anomaly).
- The indices also show fairly reasonable correlations with other established monsoon indices – suggesting that the method in developing these new indices is based on a sound theoretical foundation (still in line with the previous studies)

6.2.8 Defining monsoon seasonal cycle for Borneo

Defining the seasonal cycle in tropical regions is quite tricky. Contrary to high and mid-latitude regions, where the 'physical features' of seasonal climate are more visible – seasonal characteristics are harder to observe in low-latitude or equatorial regions. Precipitation occurrences and temperature anomalies are almost evenly distributed throughout the year. As for Borneo, monthly total precipitation is the best criterion to classify the seasonal cycle (Sham Sani, 1984). In this thesis, two main seasons are identified – namely the 'wet season' (six consecutive months with generally highest total rainfall) and the 'dry season' (lowest rainfall). It is important to note that these 'wet' and 'dry' references are used in a loose way. In general, the wet/dry season is a monsoon cycle when Borneo (cumulative amounts of rainfall for all stations) experiences the highest/lowest rainfall. However, there are certain areas in Borneo (i.e. Sepanggar Climatic Group – A2) that experience much lower rainfall during the wet season and vice versa (see Chapter 4).

The main purposes for implicitly defining the monsoon seasonal cycle are – (a) to establish a specific time-frame for referring to the two unique monsoons, which are locally known as the Northeast Monsoon (NE) and Southwest Monsoon (SW); and (b) to set a time-frame where empirical analyses on local climate and the synoptic climatology can be performed in a consistent manner. The definition of the monsoon seasonal cycle for Borneo used in this thesis is based on the works by Sham Sani (1984) and Sirabaha (1998, 2004), and supported by analysing the long-term monthly pattern of precipitation in 29 selected stations in Borneo – see Chapter 4. The final classification for the monsoon seasons is summarised below:

The simplified monsoon cycle (excluding the transition phase):

SEASON	MONTH
Northeast Monsoon (wet season)	October – March
Southwest Monsoon (dry season)	April – September

The complete monsoon cycle (including the transition phase):

SEASON	MONTH
NE Transition	October – 15 November
Northeast Monsoon (NE)	16 November – March
SW Transition	April – 15 May
Southwest Monsoon (SW)	16 May – September

6.2.9 Defining ENSO phases

Over the past few years, many studies have been undertaken in defining ENSO phases – the La Niña (cooling) and El Niño (warming). Although ENSO is a global phenomenon, its effect on local surface climate is varied (Ropelewski and Halpert, 1987; 1996). Researchers have used many different ways to define the events that suit the region and the objectives of their studies (Bohn, 1996; Sirabaha, 1998). The methods that have been applied include the use of single index (i.e. SLP or SST anomalies in the Pacific basin) and multivariate indices (combination of several variables) (Rasmusson and Carpenter, 1982, 1983; Wolter and Timlin, 1993). The most common variables used to define this event are SOI and Niño3.4 (Quah, 1988; Cheang, 1993; Tangang, 2001; Caesar, 2002; Sirabaha, 2004) – where SOI and Niño3.4 represent the atmospheric and ocean components respectively (see Section 6.2.2).

In this study, both SOI and Niño3.4 (monthly values for the period of 1960-2001) are used as a combined multivariate index to define the ENSO phases. The standardised values for both SOI and Niño3.4 are set at certain thresholds and with certain period of persistence. This is to determine if the occurrences of El Niño or La Niña are strong and persistent enough, and to determine the degree of strength for each individual event. Caesar (2002) and Sirabaha (2004) have both argued that ENSO occurrences are normally phase-locked with the monsoon cycle. Therefore, the persistence of the ENSO signals (indicated by SOI and Niño3.4 standardised values) must be evaluated based on the 6-month monsoonal cycle of Borneo – i.e. October – March (NE Monsoon) and April – September (SW Monsoon) (see Section 6.2.7).

The standardisation for SOI and Niño3.4 is done based on monthly long-term averages in order to remove the seasonality effect. If the standardised values for SOI and Niño3.4 both fall between "more than negative 1 and less than positive 1", and these values persist for 6 months within any monsoon cycle – then, that particular season is defined as a 'non-ENSO event' (normal season). This is based on the assumption that only observations below/above the long-term average by more than one unit of standard deviation will be regarded as an extreme (i.e. occurrence of a identified ENSO event). The definitions of each specific ENSO event are summarised in Table 6.5, and the number of ENSO phases and thus identified are shown in Table 6.6.

Table 6.5: Definition of ENSO phases based on standardised values of SOI and Niño3.4

Event	SOI	Niño-3.4	ENSO definition
Condition 1	$x < -1$	$x > 1$	Strong El Niño
Condition 2	$x > 1$	$x < -1$	Strong La Niña
Condition 3	$1 > x > -1$	$x > 1$	Weak El Niño
Condition 4	$1 > x > -1$	$x < -1$	Weak La Niña
Condition 5	$x < -1$	$1 > x > -1$	Weak El Niño
Condition 6	$x > 1$	$1 > x > -1$	Weak La Niña

x values are subject to persistency of 6-consecutive-month, which must be in phase-locked with the NE and SW Monsoons. Normal seasons are those not classified into any of the six conditions above (i.e. where both x values for SOI and Niño-3.4 are 1 > x > -1).

Table 6.6: Number of ENSO phases for the period of 1960-2001 (42 years) – classified based on monsoon season

Event	NE Monsoon	SW Monsoon	Overall
Weak El Niño	6	4	10
Strong El Niño	3	4	7
Weak La Niña	2	6	8
Strong La Niña	6	1	7
Normal Seasons	25	27	52

6.3 Circulation typing

The major purpose of any classification study is to establish a simple and general form of a large amount of information. Synoptic climatology, which aims to simplify the large-scale climatic environment into a few significant types, normally employs atmospheric-circulation as the tool to achieve this aim (Yarnal, 1993; Kostopoulou, 2003). In this thesis, SLP is used as the synoptic variable to establish the circulation typing. The justification for this choice is based on the belief that low-level wind is able to capture the monsoon signal much better than other atmospheric synoptic variables – i.e. upper-level winds (see Chapter 2).

6.3.1 Introduction

In the previous section of this chapter, several synoptic indicators were discussed. These indicators (i.e. monsoon and ENSO indices) have been used to diagnose the surface climate of Southeast Asia. All of these previous indices are exclusively representing either the monsoon or ENSO signals only. This is the main reason why another diagnostic scheme, with different approach, is needed (i.e. circulation typing). Specific studies on circulation typing for the Borneo region have never been undertaken. However, there are quite a number of similar studies conducted in the neighbouring regions: namely, the south Asian region (e.g. Mohapatra et al., 2003), the higher latitudes of the Far East (e.g. Wu, 1992; Chen and Chen, 1997; Liu et al., 2004) and Australia (e.g. Henderson-Sellers and Schubert, 1997; Dahni and Ebert, 1998; Schnur and Lettenmaier, 1998). Therefore, choosing the best synoptic variable is still an issue when it comes to developing a circulation-typing scheme in Southeast Asia.

Ideally, the chosen large-scale variable should be able to combine the climatic effects of the two well-established synoptic forces in this region – i.e. the monsoon and ENSO. How can this kind of large-scale circulation scheme be any advantage compared to the available synoptic indices? The theoretical advantages (which will be evaluated at the end of this chapter) are:

- Circulation typing (which is based on a large-scale climatic variable) can summarise the monsoon and ENSO effects in one empirical scheme.
- As opposed to the synoptic indices, which mainly are based on monthly or seasonal averages, circulation typing can be developed at the daily time-scale.
- Circulation typing can also open the door to constructing future scenarios (which have so far never been undertaken in Southeast Asia) by making use of statistical downscaling techniques.

6.3.2 Data

Sea level pressure (SLP) has been chosen as the large-scale variable to develop the synoptic typing. SLP Reanalysis data are obtained from the NCEP website, and the daily mean observations are used in this thesis. To be consistent with the surface data, which are available from 1960-2001 (monthly) and 1968-2001 (daily), SLP data used for this analysis cover the period 1960-2001 (42 years). Further details and justifications on the data sources and selection can be found in Chapter 3.

6.3.3 Methodology overview

Synoptic classification in this thesis applies an eigenvector-based approach using Principle Component Analysis (PCA) as the statistical method. Daily observations of SLP (1960-

2001), measured as both absolute (to retain seasonality) and anomaly[36] (to remove the seasonal effect) values are processed by PCA to establish an orthogonal and smaller number of significant factors to represent the entire series. The core objective of PCA in this section is to produce a map-pattern classification. To achieve this aim, it is most appropriate to apply S-mode decomposition, and to use the correlation matrix as the dispersion mode (Yarnal, 1993). PCA will initially produce component scores, and by setting certain thresholds, these scores will be then used to determine the so-called key days (representing initial classification types). The final types will be identified based on these key days (initial types) using two different techniques – namely cluster-based and correlation-based methods. In this thesis, four different combinations of data and classifying techniques are used to classify the synoptic circulation, as shown in Table 6.7. The performance of each method will be evaluated at the end of this chapter, to decide which the best is.

Table 6.7: Synoptic Classification – combination of data and techniques

Method	*Data In-put*	*Final Classifying Technique*
Method 1	*SLP absolute values*	*Cluster*
Method 2	*SLP absolute values*	*Correlation*
Method 3	*SLP anomaly values*	*Cluster*
Method 4	*SLP anomaly values*	*Correlation*

6.3.4 Principle Component Analysis (PCA)

The main purpose of the PCA is to establish a map-pattern catalogue – where each day will be classified into one of the generalised map-patterns available in the catalogue. This kind of synoptic typing reduces the dimensionality in the data and regroups the large dimensionality into a few specific modes based on identified spatial variance. The S-mode decomposition and correlation dispersion matrix are being applied to suit this purpose (Yarnal, 1993; Kostopoulou, 2003). The retained/identified significant components are also rotated (using the Varimax approach) to increase the interpretability. Detailed explanations about the PCA procedures and decisions made in each step are provided in the following sections and also in Chapter 3. Figure 6.10 summarises the key steps.

[36] SLP anomalies are calculated subject to long-term daily averages of 366 days in a year (i.e. leap year). The long-term daily averages are based on 1961-1990, which is the standard period introduced by World Meteorological Organisation (WMO).

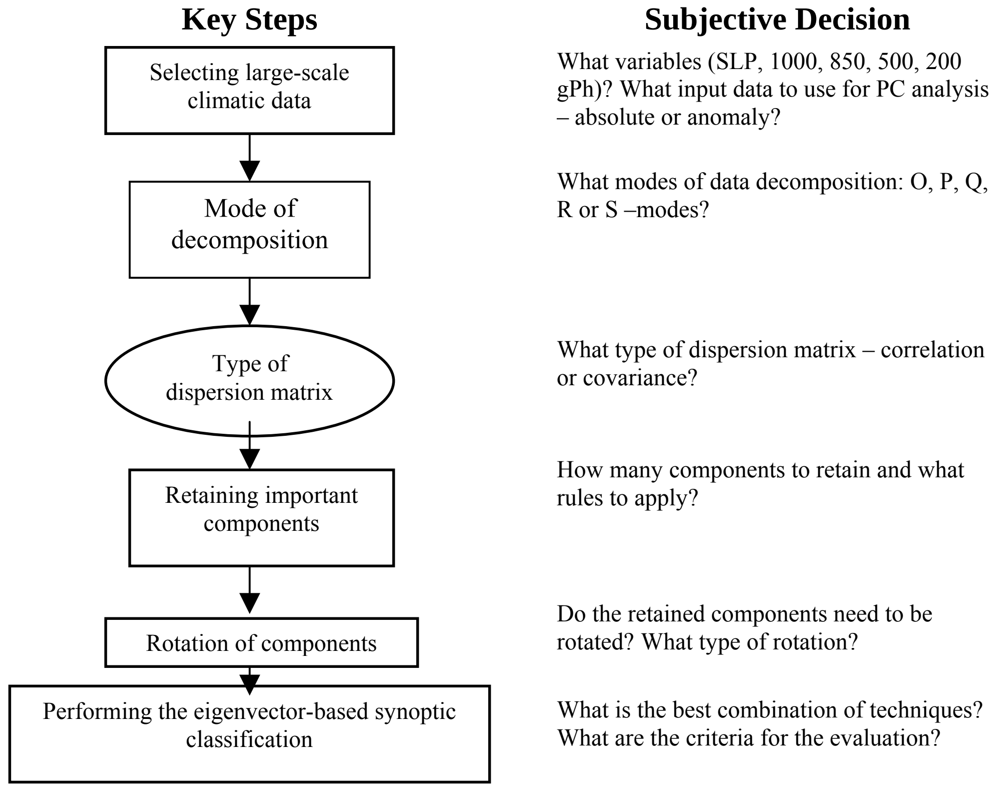


Figure 6.10: Eigenvector-based classification in synoptic climatology – adapted from Yarnal (1993)

6.3.4.1 Retained components

Two criteria are used to determine the number of significant components: these are (i) setting the minimum percentage of variance explained at 80% (Jolliffe, 1990); and (ii) analysing the scree plot, in which the last meaningful component is where the eigenvalue's plot bends (Cattell, 1966). Therefore, the retained components must at least – (i) cumulatively explain 80% of the total variance in the original data; and (ii) include all the significant components identified by the scree plot.

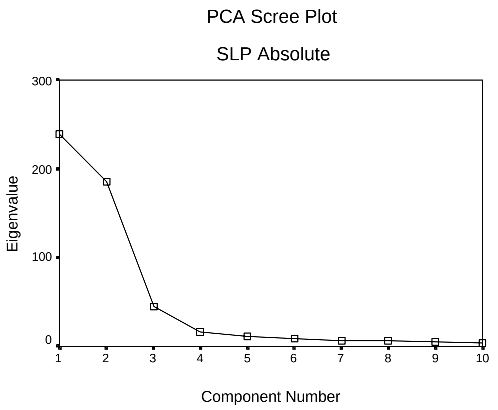


Figure 6.11a: The scree plot for PCA on SLP absolute values

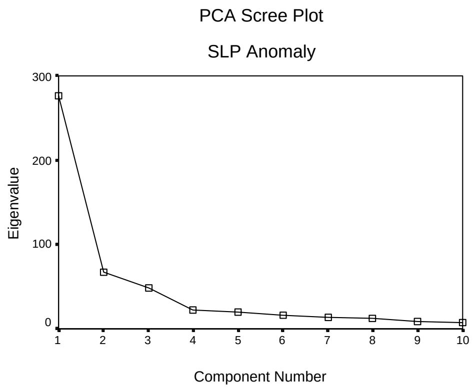


Figure 6.11b: The scree plot for PCA on SLP anomaly values

Two sets of SLP data are used in the PCA – namely the absolute and anomaly values. The anomaly dataset is based on long-term daily average to remove the monsoon seasonality (using the standard period of anomaly for NCEP Reanalysis data: 1961-1990). Based on these two criteria, the absolute data produces four significant components to be retained, which accounted for 86% of the total variance. In contrast, the anomaly data produces a higher number of retained components (six), but a lower percentage of cumulative variance explained (80%).

Table 6.8: Percentage of variance explained by each of the retained components, using SLP absolute values

	Initial Eigenvalues			Rotated Eigenvalues		
PC	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)
1	239	42	42	187	33	33
2	185	33	75	129	23	56
3	45	8	83	97	17	73
4	17	3	86	73	13	86

Table 6.9: Percentage of variance explained by each of the retained components, using SLP anomaly values

	Initial Eigenvalues			Rotated Eigenvalues		
PC	Total	Variance (%)	Cumulative (%)	Total	Variance (%)	Cumulative (%)
1	276	49	49	102	18	18
2	67	12	61	96	17	35
3	49	9	69	82	14	49
4	22	4	73	64	11	61
5	20	4	77	55	10	70
6	16	3	80	51	9	80

Statistically speaking, this means that the absolute data are more effective for compressing the original variance into a smaller number of modes, but with stronger representation of the data actual/original dimension. The scree plots for both types of data values are shown in Figures 6.11a and 6.11b; and the percentages of variance explained are shown in Tables 6.8 and 6.9.

6.3.4.2 Rotation of the components

The technique used to rotate the retained components is Varimax, which is commonly used in many climatology studies (e.g. Caesar, 2002; Kostopoulou, 2003). This rotation maximises the variance explained by each component, without losing the orthogonality of each individual component (Jolliffe et al., 2002). Therefore, whilst the interpretability of the map patterns will be enhanced, all the individual components will still retain their independence. Thus, the final components will each represent different modes of synoptic variability in Southeast Asia.

6.3.4.3 Communalities maps

The relevance of communalities is to indicate the amount of variance in each variable that is accounted for in a particular set of factors/components. Initial communalities are estimates of the variance in each variable accounted by all components or factors. In PCA, this is always equal to 1.0 (for correlation dispersion matrices) or the variance of the variable (for covariance matrices). Extracted communalities are estimates of the actual variance in each variable accounted for by all the components in the final solution. In this PCA, each grid-point is considered as one variable. Therefore, communalities maps will represent the percentage distribution of extracted variance over the entire region from the spatial dimension (for all grid points). Small values indicate that the variables do not fit well with the factor solution, and should possibly be dropped from the analysis or treated as less important. High values in the maps indicate the areas where SLP variance strongly describes the component modes. The communilities maps for the final component solutions (for both the absolute and anomaly data) are shown in Figures 6.13 and 6.14.

The communalities map for the SLP absolute data shows better performance with extracted communalities within the range 80% to 90% over mush of the region; whereas the communalities map for the anomaly data shows some values as low as 60% for certain areas (i.e. the northern part of Australia and the area over the northern Indo-China). However, both approaches (i.e. the absolute and anomaly data) clearly indicate that extraction of variance in all grid-points is reasonably reliable and representative. The lowest extraction is 60% (for the anomaly data), which occupies only a small part of the northern region (see Figure 6.13). What do these communalities maps tell us?

- Very high variances (i.e. 80-90%) are extracted from the central area (especially over the South China Sea and Borneo) – which is regarded as the main centre of action for the Southeast Asian monsoon.
- Relatively low variances are extracted in small area of the most northern and the most southern part of the region (i.e. the mountainous areas of Indo-China and northern Australia). However, these 'low' variances (i.e. 60%) are still reasonably acceptable.

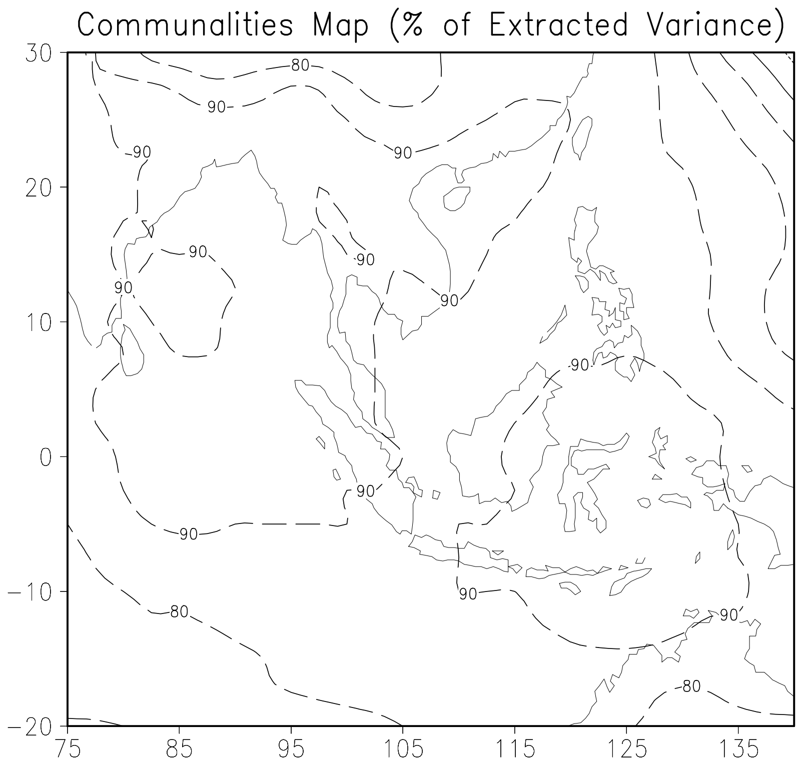


Figure 6.12: Communalities maps indicating the percentage of variance extracted from each grid-point while performing the data reduction analysis (PCA) – SLP absolute values

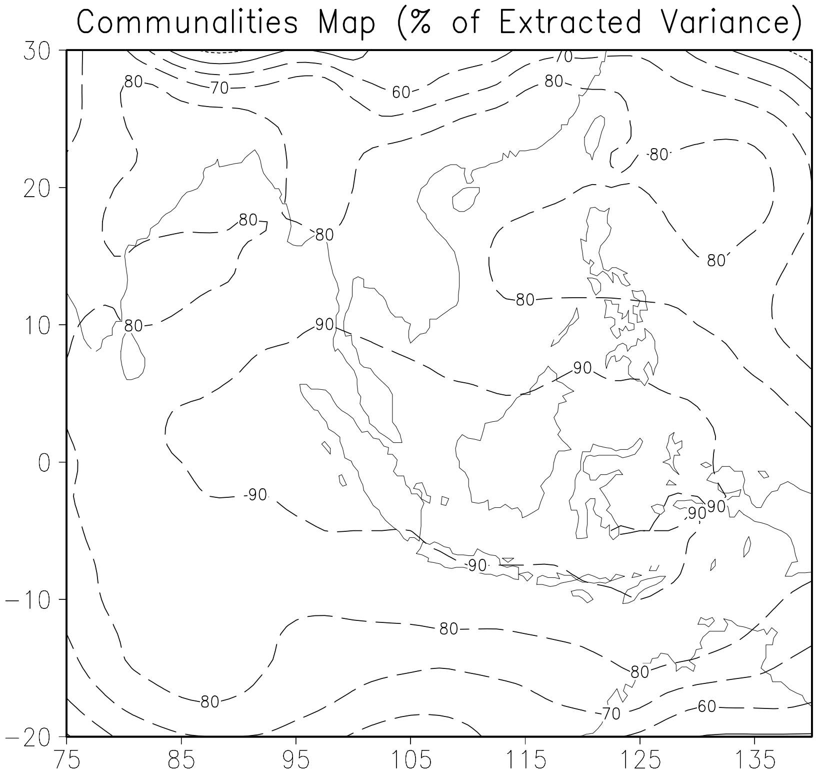


Figure 6.13: Communalities maps indicating the percentage of variance extracted from each grid-point while performing the data reduction analysis (PCA) – SLP anomaly values

6.3.4.4 Loading maps

Loading maps show the correlation of each component with the original variables (in this case, it refers to the 567 grid-points of 2.5°X2.5° within the chosen window). The loadings are standardised between –1 and 1. The values are a measure of the correlation magnitude (between PCs and each grid-point); whereas the signs (positive/negative) indicate the orientation of the association. Grid-points with high loadings represent areas with high variance – for that particular component. Therefore, loading maps could serve as the basic shape of the actual map-pattern catalogues (which will be classified using the components' scores). The loading maps are shown in Figures 6.15 (absolute data) and 6.16 (anomaly data). The physical features[37] for each map are summarised in Tables 6.10 (absolute) and 6.11 (anomaly).

[37] Further analysis on physical features will be explored in Chapter 7. This section is only a brief introduction of the basic physical features of the circulation types.

Table 6.10: Summary of the loading maps (SLP absolute values)

PC (%)	Low Variance (<0.4 and > -0.4)	High +ve Variance (> 0.6)	High -ve Variance (< -0.6)
PC1 33.0%	Along the equatorial latitude (between 10°S-5°N)	Northern part from 10°N northward (mainland Asia)	Northern part of Australia (110°E-140°E; 10°S-20°N)
PC2 22.8%	From the equator (0°) and northward	From 10°S and southward, especially the ocean between Australia and the Indonesian archipelago	No distinctive area with high negative variance
PC3 17.2%	From 15°N and northward; and the south-eastern part - 110°E-140°E; 10°S-20°N (northern of Australia)	Eastern part of Indian Ocean (75°E-105°E; 10°S-10°N	No distinctive area with high negative variance
PC4 12.8%	Western part, within the region of 75°E-115°E; 20°S-30°N	Eastern part, over the Philippines archipelago (120°E-140°E; 5°S-20°N)	No distinctive area with high negative variance

Table 6.11: Summary of the loading maps (SLP anomaly values)

PC (%)	Low Variance (<0.4 and > -0.4)	High +ve Variance (> 0.6)	High -ve Variance (< -0.6)
PC1 18.0%	Western part from 105°E westward and northern part from 10°N northward	The south-eastern part - 110°E-140°E; 10°S-20°N (northern of Australia)	No distinctive area with high negative variance
PC2 17.0%	Eastern part from 100°E eastward and northern part from 10°N northward	Towards south-eastern of Indian Ocean (75°E-105°E; 10°S-20°N)	No distinctive area with high negative variance
PC3 14.5%	From 10°N northward (mainland Asia) and from 5°S southward (northern Australia)	Central part, which includes Peninsular Malaysia, Borneo and the most southern part of South China Sea	No distinctive area with high negative variance
PC4 11.3%	From 100°E eastward (including Borneo, Indonesian and Philippines archipelagos) and from 10°N northward (up to northern Australia)	The north-western part over the Indian subcontinent, within the region of 75°E-95°E; 15°N-30°N	No distinctive area with high negative variance
PC5 9.7%	From 10°N southward; and from 90°E westward (including Indian Ocean, Australia and the entire maritime region of Southeast Asia)	The northern part over Indo-China (95°E-125°E; 10°N-30°N)	No distinctive area with high negative variance
PC6 9.0%	From 10°N southward; and from 115°E westward (including Indian Ocean, Australia, Indo-China and the entire maritime region of Southeast Asia)	The north-eastern part, over the Philippines sea and archipelago (115°E-140°E; 10°N-30°N)	No distinctive area with high negative variance

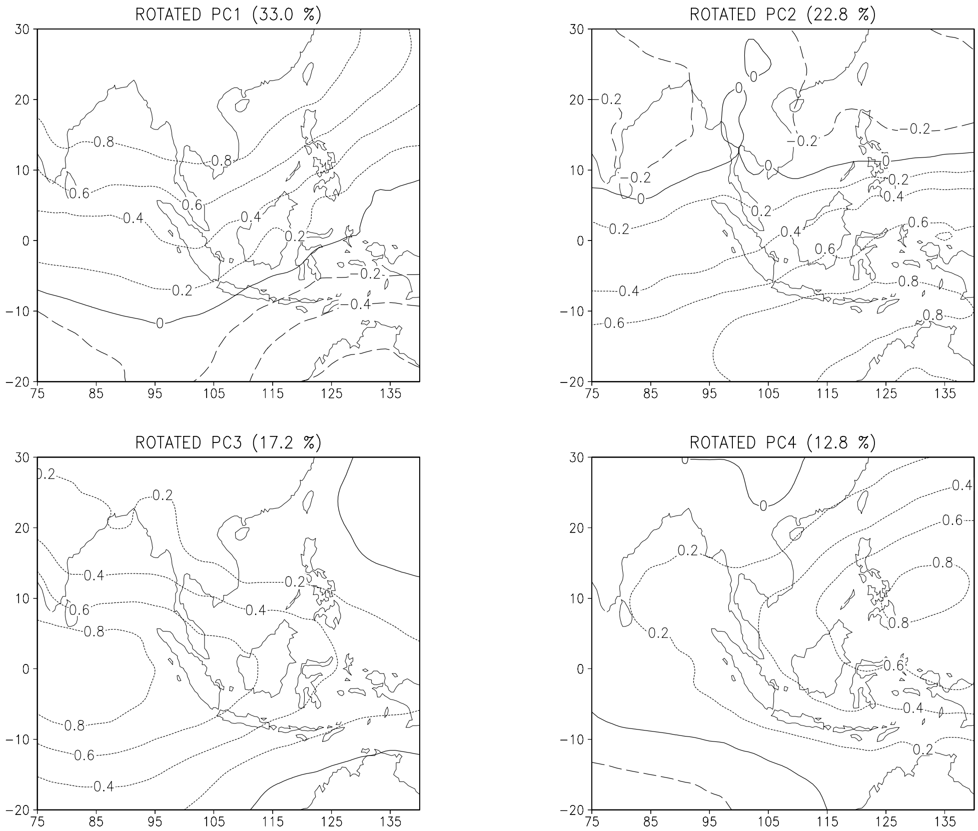


Figure 6.14: Loading maps for the four retained components (SLP absolute values)

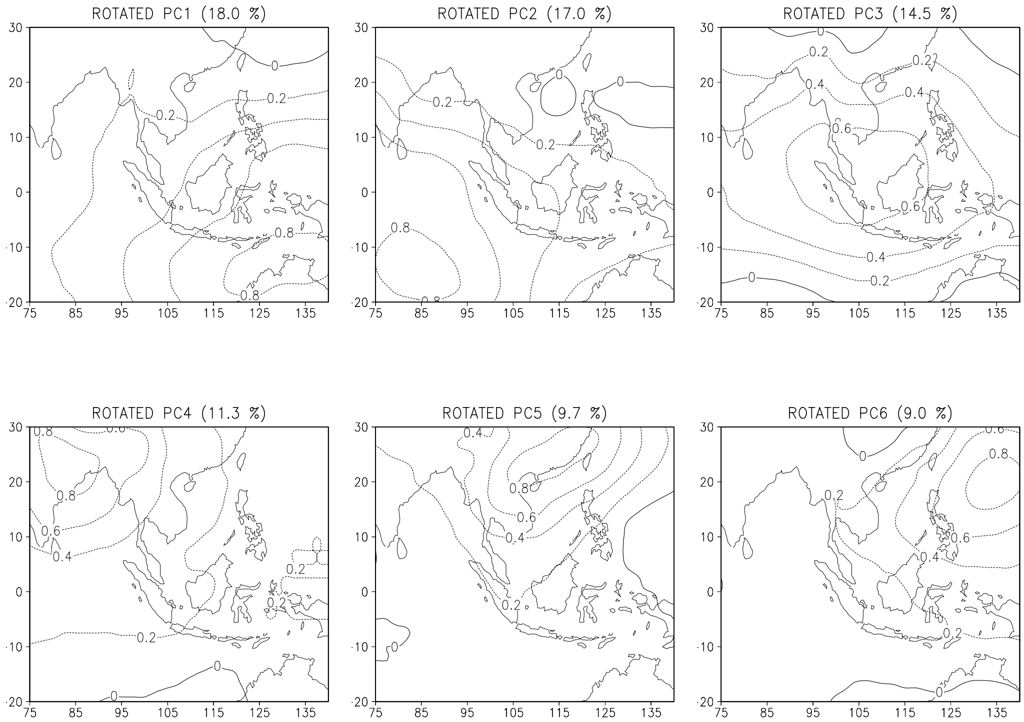


Figure 6.15: Loading maps for the six retained components (SLP anomaly values)

6.3.5 Establishing SLP circulation types

As has been mentioned earlier, SLP circulation types will be established based on four different combinations of data and typing techniques. The combinations are as follow:

- Combination 1: SLP (absolute values) + Classification technique (K-means Cluster)
- Combination 2: SLP (absolute values) + Classification technique (Correlation)
- Combination 3: SLP (anomaly values) + Classification technique (K-means Cluster)
- Combination 4: SLP (anomaly values) + Classification technique (Correlation)

6.3.5.1 Methodology overview

Synoptic types, in this thesis, are classified using the rotated scores from the components produced by PCA. The first step is to identify the key days. This is undertaken by setting the threshold of PC scores[38]. Theoretically, each PC will be able to produce two initial circulation types (i.e. those that exceed/equal the positive threshold value, and those that are equal/below the negative threshold value). A particular day will then be classified according

[38] Four thresholds are tested in this analysis, which are ±1.5, ±2.0, ±2.5 and ±3.0. The final selected threshold is ±2.0 based on the performance (which is explained in Section 6.3.5.2).

to the highest score (in any of the retained PCs), bearing in mind that the score must equal or exceed the chosen threshold. This first step usually will only classify a small number of days in the entire series (i.e. between 15-25%). The days with no component scores equalling or exceeding the thresholds will be regarded as 'unclassified days'.

Using these key days, the next task is to assign all the other unclassified days into one of the established initial types. Composites of the key days will serve as the 'identification' for each of the initial types. In assigning and merging the other unclassified days into these initial types – there are two approaches that can be applied. The first one is known as a 'cluster-based' technique (non-hierarchical cluster), which is a more straightforward approach and does not involve any subjective decision. The key days serve as the cluster centre – and all the unclassified days will be grouped into the nearest cluster centre using the 'between-group linkage' as the method of linking. Detailed explanation of K-means Cluster Analysis (KCA) is provided in Chapter 3.

The second approach is known as a 'correlation-based' technique. The key days will be used to produce composite maps of all the initial types. Then, the unclassified days will be correlated with these maps, and a particular unclassified day will be merged into the initial type that produces the highest positive correlation. However, contrary to the first approach (i.e. cluster-based), this approach involves a subjective decision – i.e. to choose the appropriate threshold for the correlation. Because of this threshold, the correlation-based technique will not be able to reclassify all the unclassified days – whilst this is not a problem for the cluster-based technique. However, this does not necessarily make the cluster-based technique the better approach. The disadvantage of the cluster-based method is the possibility of diluting or weakening the characteristic of the final types – because this technique tends 'to force' all days into one of the identified initial types (which will be tested in the following sections). The use of a threshold in the correlation-based technique can serve as a filter. It will discriminate the 'very weak days' (which cannot be realistically represented by any of the types) from those reasonably 'strong days' (which can cumulatively produce distinctive map patterns). There are numerous steps and subjective decisions involved before the final classification can be made. Figure 6.16 summarises all the important processes.

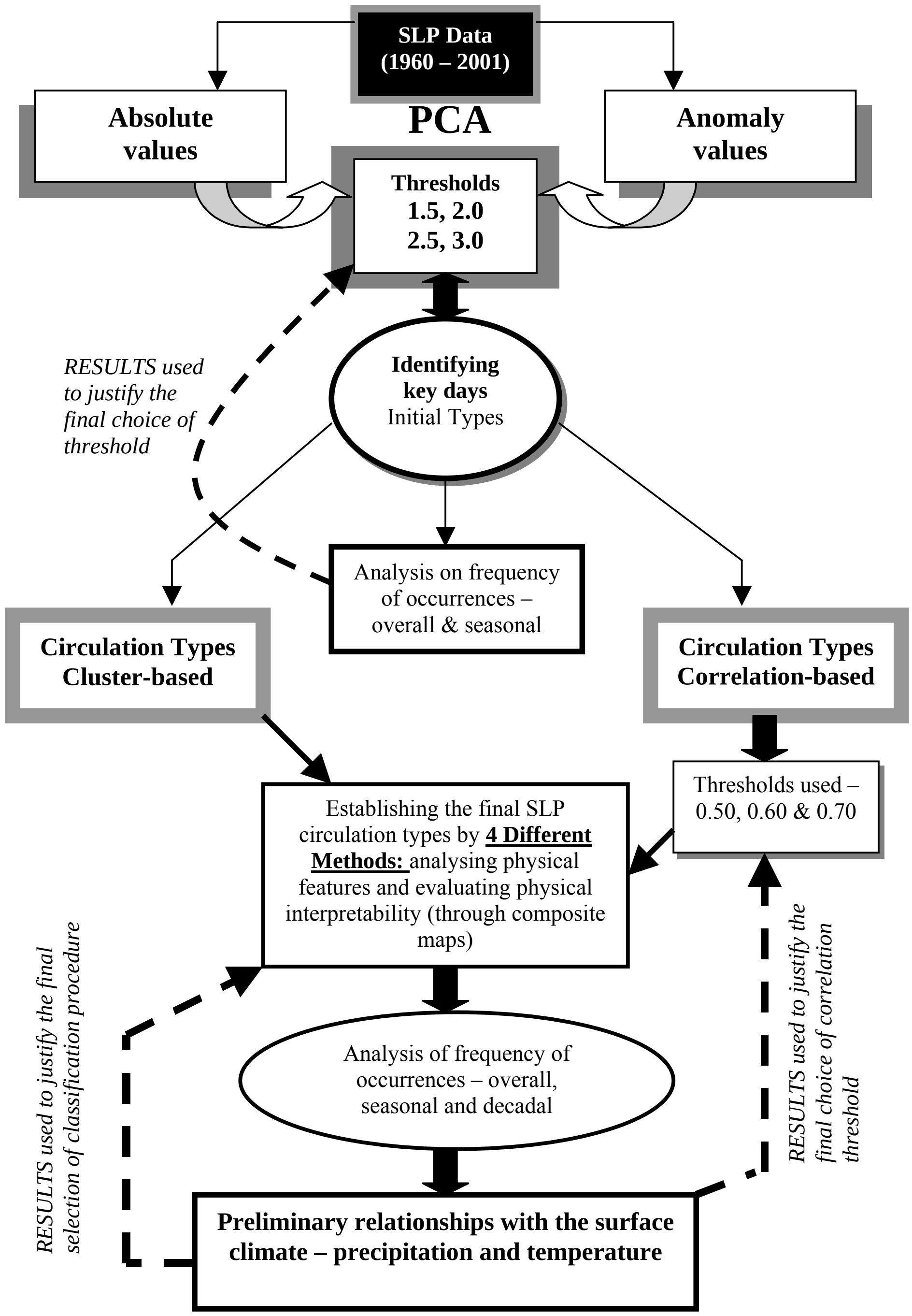


Figure 6.16: Circulation typing methodology overview

Once the final classifications using the correlation and cluster based techniques have been developed, the next step is analysing the types produced by the four different methods (see Table 6.7). These analyses will involve:

- Producing SLP composite maps for all types in each typing scheme, and investigating the physical features and their association with known large-scale circulation patterns in Southeast Asia. This is an evaluation of the physical interpretability.

- Analysing the occurrences of all types through the period of observations (1960-2001) and how the frequencies vary in different seasons (i.e. the Northeast and Southwest monsoons) or under the influence of ENSO phases. This investigates the stability (over time) of the types and their discriminating abilities under various climatic events.
- Evaluating the relationships with surface climate, particularly the magnitude of precipitation and temperature; and also the occurrences of extreme weather. This is to compare the performance of the methods in diagnosing the surface climate.

6.3.5.2 Key days (initial SLP circulation types)

The highest PC scores observed in any of the retained components are used to identify the key days. Four thresholds are used for this initial identification: 1.5, 2.0, 2.5 and 3.0. Tables 6.12 (SLP absolute values) and 6.13 (SLP anomaly values) show the number of key days obtained from different thresholds.

There are no rigid rules in selecting the most appropriate thresholds (Kostopoulou, 2003). However, it is worth noting that key days play a very important role in this eigenvector-based approach to synoptic typing. Key days will be used to develop the so-called initial types. In the next step, these will serve as the 'mould' to reclassify all the other days into one of the initial types. This merging process will eventually produce the final types – thus the mould plays a significant role in determining these final types. Therefore, it is very important to have an optimum number of key days, which should possess very strong individual and unique patterns. Choosing too low thresholds might lead to having a huge number of key days and will dilute the patterns (i.e. weakening the individual characteristic). On the other hand, too high thresholds will result in a very low number of key days – thus, it can become less representative of the actual pattern/signal.

Table 6.12 (SLP absolute values) shows that the 1.5 threshold manages to classify almost half of the days (43.8%) and each type has more than 500 key days. Using the same threshold, Table 6.13 (SLP anomaly values) shows that it manages to classify more than half of the days (55.1%) and each type, yet again, has more than 500 key days. These samples are considered too high because statistically speaking, 40-55% of the entire population could represent the overall average (i.e. the patterns created from these key days will have characteristics that are closely similar to the average). When the threshold is increased to 2.5, the number of key days drops dramatically to only 4.4% (SLP absolute values) and 9.0% (SLP anomaly values). These numbers are considered too small and could possibly lead to the creation of very strong unrealistic patterns/characteristics. Therefore, the final selected threshold is 2.0, which classifies reasonable numbers of key days for both types of data values – i.e. 15.6% and 24.7% for absolute and anomaly values respectively.

Table 6.12: Frequency and percentage of identified key days for each type using different thresholds for the PC scores (SLP absolute values)

	Threshold = 1.5		Threshold = 2.0		Threshold = 2.5		Threshold = 3.0	
TYPE	Day	%	Day	%	Day	%	Day	%
Type 1 (PC1 +ve)	921	6.0	269	1.8	41	0.3	4	0.0
Type 2 (PC2 +ve)	577	3.8	135	0.9	16	0.1	0	0.0
Type 3 (PC3 +ve)	687	4.5	258	1.7	65	0.4	9	0.1
Type 4 (PC4 +ve)	830	5.4	350	2.3	126	0.8	42	0.3
Type 5 (PC1 –ve)	720	4.7	95	0.6	1	0.0	0	0.0
Type 6 (PC2 –ve)	1154	7.5	544	3.5	216	1.4	59	0.4
Type 7 (PC3 –ve)	941	6.1	363	2.4	101	0.7	23	0.1
Type 8 (PC4 –ve)	889	5.8	386	2.5	112	0.7	37	0.2
OVERALL	Day	%	Day	%	Day	%	Day	%
Classified	6719	43.8	2400	15.6	678	4.4	174	1.1
Unclassified	8622	56.2	12941	84.4	14663	95.6	15167	98.9

Table 6.13: Frequency and percentage of identified key days for each type using different thresholds for the PC scores (SLP anomaly values)

	Threshold = 1.5		Threshold = 2.0		Threshold = 2.5		Threshold = 3.0	
TYPE	Day	%	Day	%	Day	%	Day	%
Type 1 (PC1 +ve)	692	4.5	289	1.9	108	0.7	41	0.3
Type 2 (PC2 +ve)	556	3.6	211	1.4	57	0.4	9	0.1
Type 3 (PC3 +ve)	673	4.4	276	1.8	84	0.5	16	0.1
Type 4 (PC4 +ve)	671	4.4	276	1.8	74	0.5	14	0.1
Type 5 (PC5 +ve)	743	4.8	338	2.2	149	1.0	49	0.3
Type 6 (PC6 +ve)	551	3.6	157	1.0	22	0.1	2	0.0
Type 7 (PC1 –ve)	700	4.6	329	2.1	150	1.0	62	0.4
Type 8 (PC2 –ve)	805	5.2	423	2.8	174	1.1	72	0.5
Type 9 (PC3 –ve)	756	4.9	337	2.2	101	0.7	22	0.1
Type 10 (PC4 –ve)	749	4.9	362	2.4	127	0.8	27	0.2
Type 11 (PC5 –ve)	698	4.5	287	1.9	85	0.6	21	0.1
Type 12 (PC6 –ve)	865	5.6	505	3.3	243	1.6	102	0.7
OVERAL	Day	%	Day	%	Day	%	Day	%
Classified	8459	55.1	3790	24.7	1374	9.0	437	2.8
Unclassified	6882	44.9	11551	75.3	13967	91.0	14904	97.2

6.3.5.3 Classified days (by correlation-based and cluster-based techniques)

Cluster-based technique: As has been mentioned earlier, this technique does not involve any subjective decision. Non-hierarchal cluster (i.e. K-means Cluster Analysis – KCA) is applied, where the key days are used as the cluster centres (see Chapter 3 for theoretical background on KCA). For this purpose, KCA applies ‘between-group linkage’ as the linking calculation to assign all the remaining days into the nearest/closest ‘cluster centres’ (or the key days). No threshold is used and thus all the remaining days can be reclassified into one of the initial types. Cluster-based technique could technically be seen as a perfect technique in synoptic typing due to its ability to classify 100% of the observations. However, technical ability is not the only criterion to be considered for the final selection. Table 6.14 (SLP absolute and anomaly) shows the number of days and percentage for each type after the final classification using KCA.

Table 6.14: Frequency and percentage of days for each type after the final classification by the cluster-based technique

Final Type	SLP absolute data		SLP anomaly data	
	Days	%	Days	%
Type 1	1589	10.4	833	5.4
Type 2	1222	8.0	1327	8.7
Type 3	1532	10.0	1636	10.7
Type 4	1817	11.8	1140	7.4
Type 5	2658	17.3	982	6.4
Type 6	2039	13.3	1300	8.5
Type 7	3266	21.3	1187	7.7
Type 8	1218	7.9	1265	8.2
Type 9	NA	NA	1731	11.3
Type 10	NA	NA	1521	9.9
Type 11	NA	NA	1158	7.5
Type 12	NA	NA	1261	8.2

SLP absolute has 8 types – which are produced from the 4 retained PCs; whilst SLP anomaly has 12 types (6 retained PCs). NA – not available.

Correlation-based technique: This technique uses the SLP composites of the key days as the patterns to represent each type or the so-called initial classification scheme. Correlation analysis is then performed between these initial types and all the remaining days i.e. those unclassified in the previous step (see Section 6.3.5.2). These unclassified days will be assigned into one of the initial types based on the maximum values of positive correlation. As has been mentioned earlier, the correlation-based technique involves a subjective decision pertaining to the choice of threshold. Thresholds must be set to ensure that the correlation coefficient is not only significant, but has a reasonably acceptable magnitude. This is important to filter all the under-representative days, which have weak attributes and can possibly dilute the patterns of the final types. Three thresholds are selected and tested in this analysis – 0.5, 0.6 and 0.7. The results are shown in Tables 6.15 and 6.16.

In choosing the appropriate threshold for this correlation, the same considerations are applied as in selecting the threshold to determine the key days. There are no rigid or specific rules. In climatological classification correlation, values within the range 0.5 – 0.7 are typically satisfactory (Yarnal, 1993; Kostopoulou, 2003). However, it is important to realise that using low thresholds may dilute the patterns (i.e. forcing weak days to merge together). On the other hand, using high threshold will increase the number of unclassified days. If there are too few classified days, the synoptic typing might become over-representative; thus making it irrelevant for climate diagnostic purposes. On the other hand, using a low threshold can significantly increase the number of classified days. This will lead to a higher portion of 'weak days' being forced into the classification and might make the classification scheme under-representative; thus, make it less significant.

Table 6.15: Frequency and percentage of days for each type after the final classification by the correlation-based technique (SLP absolute values)

	Threshold 0.5		Threshold 0.6		Threshold 0.7	
TYPE	Days	%	Days	%	Days	%
Type 1	2298	15.0	2288	14.9	1849	12.1
Type 2	1360	8.9	1355	8.8	917	6.0
Type 3	867	5.7	856	5.6	518	3.4
Type 4	979	6.4	971	6.3	633	4.1
Type 5	4072	26.5	4065	26.5	3227	21.0
Type 6	2794	18.2	2785	18.2	2448	16.0
Type 7	2137	13.9	2128	13.9	1821	11.9
Type 8	805	5.2	794	5.2	456	3.0
OVERALL	Days	%	Days	%	Days	%
Classified	15312	99.8	15242	99.4	11869	77.4
Unclassified	29	0.2	99	0.6	3472	22.6

Table 6.16: Frequency and percentage of days for each type after the final classification by correlation-based technique (SLP anomaly)

	Threshold 0.5		Threshold 0.6		Threshold 0.7	
TYPE	Days	%	Days	Type	Days	%
Type 1	634	4.1	491	3.2	364	2.4
Type 2	538	3.5	407	2.7	270	1.8
Type 3	404	2.6	311	2.0	283	1.8
Type 4	1036	6.8	815	5.3	552	3.6
Type 5	1893	12.3	1622	10.6	1110	7.2
Type 6	1148	7.5	984	6.4	433	2.8
Type 7	780	5.1	578	3.8	478	3.1
Type 8	810	5.3	653	4.3	529	3.4
Type 9	531	3.5	405	2.6	351	2.3
Type 10	1197	7.8	1021	6.7	623	4.1
Type 11	1855	12.1	1673	10.9	1055	6.9
Type 12	1368	8.9	1060	6.9	769	5.0
OVERALL	Days	%	Days	Type	Days	%
Classified	12194	79.5	10020	65.3	6817	44.4
Unclassified	3147	20.5	5321	34.7	8524	55.6

For the SLP absolute data, the difference in percentage of classified days between correlation thresholds of 0.5 (99.8%) and 0.6 (99.4%) is not too evident. However, the percentage dramatically drops to only 77.4% when the threshold is increased to 0.7. The decrease in percentage of classified days as the threshold value is increased is more prominent in the SLP anomaly data. It starts with 79.5% for 0.5 as the threshold, and this percentage falls by 14.2% to only 65.2% when 0.6 is used. Upon increasing the threshold up to 0.7, the typing scheme only manages to classify 44.4% of the overall days. Based on this evaluation, it was decided that 0.5 was too low and that the use of 0.7 could make the typing scheme irrelevant due to the high number of unclassified days (i.e. more than 50% for the SLP anomaly data). Therefore, 0.6 is adopted as the correlation threshold. This is consistent with Kostopoulou (2003). Even Frakes and Yarnal (1997) have argued that high thresholds do not always provide the best solution, instead they advise for low thresholds (i.e. between 0.5 – 0.6).

6.3.5.4 Composite maps (physical features of the final SLP circulation types)

When using absolute SLP values as the input data, the composite maps of the key days are found to be highly similar, in terms of pressure patterns, to the corresponding types in the final classification produced by both techniques – i.e. Method 1 (cluster-based) and Method 2 (correlation-based). This can been seen by comparing maps in Figures 6.18 (Method 1) and 6.19 (Method 2) to the key-day maps in Figure 6.17. A similar situation is observed when SLP anomaly values are used (see Figures 6.20, 6.21. and 6.22). The basic patterns shown in the key days are also clearly exhibited in the corresponding types produced by the final classification – i.e. Method 3 (cluster-based) and Method 3 (correlation-based). All combinations of methods show a reasonable and consistent association between the map patterns of the initial types (key days) and the final types. This means that the data values used in the PCA (either absolute or anomaly values) does not affect the performance of the final classification, in terms of identifying the appropriate key days. Both classifying techniques (cluster and correlation) are proven to have similar abilities in assigning the remaining days into their representative modes (i.e. the key days that most likely represent a particular day). Therefore, making a decision on which pairing of data and technique is a better classification scheme based on this aspect is not possible. However, in terms of physical features, the circulation schemes produced by the SLP absolute values (i.e. Methods 1 and 2) have performed better. These two methods successfully establish map-pattern catalogues that are more interpretable. In contrast, the map-patterns that are created using SLP anomaly (i.e. Methods 3 and 4) seem to have lower degree of physical interpretability.

There are three general patterns of large-scale circulation in Borneo, which are mostly dominated by the Southeast Asian monsoon flow. The first one is formation of a strong pressure gradient from the north (over the China-Indochina border) to the south (northern part of Australia). This generates distinct movement of low-level winds in the southward direction. This circulation is usually associated with the mature phase of the winter monsoon (locally known as the Northeast Monsoon). The second synoptic circulation pattern is a reverse pattern of the first one. A strong pressure gradient from the south to the north is formed and generates airflow in the northward direction. This is physically manifested by monsoon flow during the boreal summer (locally known as the Southwest Monsoon). The third significant pattern is a simultaneous formation of high-pressure areas on both sides of the equator, which concentrated at 20º-30ºN in the north and at 15º-20ºS in the south. This generates airflow from both directions (southword and northward) towards the centre of Southeast Asia (i.e. Peninsular Malaysia, Borneo and the Indonesian archipelago). This rather unique synoptic flow represents the inter-monsoon periods, which normally occur around April to mid-May and October to mid-November (see Chapter 3).

The full field maps for all types produced by Methods 1 and 2 can be seen in Figures 6.18 and 6.19 respectively[39]. For both Methods 1 and 2, Type 1, Type 4 and Type 6 are closely associated with the first mode of large-scale circulation in the Southeast Asia (i.e. Northeast Monsoon). Type 5 and Type 7 are physically related to the circulation pattern during the Southwest Monsoon. The other three types, namely Type 2, Type 3 and Type 8 are associated with various states of monsoon airflow during the transitional seasons (i.e. when the heat differences gradually changes from the south-north to north-south due to global seasonal variation). The 12 circulation types produced by Method 3 and Method 4 mostly represent the transitional seasons. There is no distinctive direction of the pressure gradient in either southerly or northerly directions, but rather simultaneous movement of airflows towards the equator in both directions (southerly and northerly).

Table 6.17: Correlation matrices showing the coefficient values between types in the same circulation scheme

(a) Method 1

Type	1	2	3	4	5	6	7	8
1	1.00							
2	-0.33	1.00						
3	0.79	0.20	1.00					
4	0.95*	-0.25	0.76	1.00				
5					1.00			
6					-0.67	1.00		
7					0.66	-0.10	1.00	
8					0.51	0.02	0.55	1.00

(b) Method 2

Type	1	2	3	4	5	6	7	8
1	1.00							
2	-0.14	1.00						
3	0.78	0.36	1.00					
4	0.79	-0.07	0.57	1.00				
5					1.00			
6					-0.65	1.00		
7					0.49	0.12	1.00	
8					0.33	0.19	0.47	1.00

(c) Method 3

Type	1	2	3	4	5	6	7	8	9	10	11	12
1	1.00											
2	0.67	1.00										
3	0.85*	0.90*	1.00									
4	0.80*	0.58	0.68	1.00								
5	0.63	0.31	0.44	0.88*	1.00							
6	0.94*	0.76	0.93*	0.72	0.55	1.00						
7							1.00					
8							0.53	1.00				
9							0.53	0.80*	1.00			
10							0.33	0.73	0.86*	1.00		
11							0.58	0.55	0.76	0.78	1.00	
12							0.13	0.31	0.66	0.56	0.44	1.00

[39] All these composite maps are tested for statistical significance of anomalies and proven to be significant at least at the 95% level of confidence.

(d) Method 4

Type	1	2	3	4	5	6	7	8	9	10	11	12
1	1.00											
2	0.41	1.00										
3	0.65	0.75	1.00									
4	0.80*	0.48	0.63	1.00								
5	0.67	0.27	0.56	0.88*	1.00							
6	0.86*	0.61	0.83	0.66	0.53	1.00						
7							1.00					
8							0.33	1.00				
9							0.19	0.65	1.00			
10							0.07	0.62	0.85*	1.00		
11							0.30	0.51	0.80*	0.84*	1.00	
12							-0.13	0.18	0.67	0.54	0.49	1.00

*Values marked with * indicate a very high correlation (> 0.80), and statistically significant at the 99% level*

It is also found that Method 1 and Method 2 produce types that are less similar and more discriminating. Although the physical patterns of all the circulations types established by Method 3 and Method 4 are still uniquely individual, the similarity between each type is closer (see Figures 6.21 and 6.22). This conclusion is also proven by correlation analyses (see Table 6.17). Using +0.80 as the threshold to indicate a ‘high and strong correlation’, non-parametric correlation analysis has been performed for all the positive and negative types in the same classification scheme. Correlation is only performed between types within the same group of components produced by a particular method – e.g. for Method 1 and Method 2; Type 1, 2, 3 and 4 (established from the positive PC) are correlated with each other, whilst Type 5, 6, 7 and 8 (established from the negative PC) are inter-correlated separately. Method 1 only has two types that are strongly correlated, namely Type 1 and Type 4. None of the types in Method 2 exhibits any strong correlation. However, Method 3 and Method 4 both have 9 types (out of 12) that are highly inter-correlated.

As far as physical features are concerned (see Figure 6.17 – 6.22 for SLP full-field maps; and Figure 6.23 – 6.28 for SLP anomaly maps), distinctive characteristics observed in the final catalogues of all map-patterns (which represent circulation types) are mainly determined by the choice of the original SLP data. The catalogues produced by the absolute SLP data (Method 1 and Method 2) generally exhibit similar map-patterns between the corresponding types (e.g. Type 1 by Method 1 is generally identical with Type 1 by Method 2). The same ‘duplication’ also applies to the two synoptic catalogues established by anomaly SLP data (Method 3 and Method 4). These two approaches show several other similarities and differences, which are summarised in Table 6.18.

Table 6.18: Similarities and differences between the circulation schemes produced by SLP absolute and SLP anomaly

Aspects	Absolute SLP (Methods 1 and 2)	SLP Anomaly (Methods 3 and 4)
Number of circulation types	PCA produces 4 significant components and 8 circulation types.	PCA produces 6 significant components and 12 circulation types.
Association between key days and final types	The map-patterns of key days are strongly duplicated in the map-patterns of the final types.	The map-patterns of key days are also strongly duplicated in the map-patterns of the final types.
Basic patterns	The individual features of all types are more distinctively unique.	The individual features of all types are less distinctive.
Correlation between types	The similarity between types is less evident when the types are inter-correlated.	The similarity between types is empirically more prominent with 9 out of 12 types being highly inter-correlated.
Physical interpretability[40]	All 8 types collectively represent the most common synoptic circulations in Southeast Asia (the surrounding region of Borneo), which is the monsoon cycle – consisting of the mature phase of the monsoon, namely Northeast Monsoon and Southwest Monsoon; and also the transitional phase (or inter-monsoon seasons).	The 12 types are mostly representing only the inter-monsoon seasons (i.e. the formation of high/low pressure at the northern/southern parts at the same time). There is no or less representation of the main seasonal variation of monsoon cycle, which are the NE and SW monsoons.

6.3.6 *Preliminary analysis of the circulation types*

There are four different methods used in this thesis to classify the circulation (see Table 6.19), which are – Method 1 (combination of SLP absolute data and cluster-based technique), Method 2 (absolute and correlation-based), Method 3 (anomaly and cluster-based) and Method 4 (anomaly and correlation-based). This preliminary analysis is mainly to determine which typing scheme has the best performance and will be further analysed in Chapter 8. Two aspects of the circulation types are examined, namely the frequency of occurrence (under various climatic conditions – i.e. different halves of periods, seasons and ENSO influences) and the relationships with surface climate of Borneo. These two aspects will be the main justification in deciding the best method, although the assessment will also include basic statistical results (i.e. variances explained and number of retained components) and physical interpretability into consideration.

Table 6.19: Summary of the classification schemes

Original SLP data	Classification Techniques	Schemes	Number of Circulation Types
Absolute values (86% variance explained by 4 PCs)	Cluster-based	Method 1	8 Types (100% classified)
	Correlation-based	Method 2	8 Types (99.4% classified)
Anomaly values (80% variance explained by 6 PCs)	Cluster-based	Method 3	12 Types (100% classified)
	Correlation-based	Method 4	12 Types (65.3% classified)

[40] A more detailed of the physical interpretability aspect will be explored and discussed in Chapter 7.

6.3.6.1 Occurrences in different periods, seasons and ENSO phases

All the results in this section are tested for statistical significance using a Chi-Square test (see Appendix C for an example of X^2 values for significance test between the two monsoon seasons). The differences in frequency for different periods, seasons and ENSO phases are statistically significant at the 99% level of confidence.

(a) Occurrences in the two halves of period analysed: 1960-1980 and 1981-2001
The following descriptions are based on results shown in Table 6.20 and Figure 6.29. Method 1 shows two unstable types with differences of more than 50% between the two periods, in their occurrence rates. The unstable types are Type 1 (difference of 51%) and Type 2 (100%). Method 3 has three highly unstable types with changes in frequencies up to 141% (Type 1). The other unstable types are Type 4 (137%) and Type 10 (68%). Method 4 shows the highest number of unstable types, which include Type 1 (119%), Type 4 (136%), Type 10 (69%) and Type 12 (58%).

Method 2 is the only classification scheme that produces consistently highly stable circulation types. The highest degrees of changes are observed in Type 2 and Type 3 (both with differences up to 33%). What does this indicate for the performance of a typing scheme? Circulation types produced by Method 2 are the most stable over the period of 1960 to 2001. Therefore, it might be possible to conclude that Method 2 has performed better in this aspect. It is generally accepted (Caesar, 2002; Sirabaha, 1998 and 2004) that the only prominent inter-annual forcing factors (3-7 years) influencing the synoptic circulation in Southeast Asia (which governs the Borneo climate) are due to ENSO phases. It is also known that the frequencies of ENSO phases (i.e. La Niña and El Niño) are almost equally balanced between the two halves of periods – 1960-1980 (21 years) and 1981-2001 (21 years)[41]. The first half has 26 normal seasons[42], 7 El Niño and 9 La Niña seasons. The second half consists of 26 normal seasons, 10 El Niño and 6 La Niña seasons (see Table 6.5). Due to a very high proportion of normal seasons (approximately 62% in both halves of the period), the changes in the circulation types should not be too extreme (i.e. not exceeding 50%) between the two periods (1960-1980 and 1981-2001). This is based on the assumption that ENSO is the only significant factor that can make a difference to the frequency of synoptic circulations between the two periods being compared; and ENSO phases have occurred equally balanced in both halves of period.

[41] The number of La Niña and El Niño events is considerably balanced (Sirabaha, 1998 and 2004; Caesar, 2002), although some studies have argued that certain events in the 1980s were stronger and more extreme (e.g. Goddard and Graham, 1997; Big, 1998; Tangang, 2001).
[42] Each season has six months and represents the monsoon cycle, which is October-March for the Northeast Monsoon and April-September for the Southeast Monsoon.

Table 6.20: Overall frequencies of types and their changes over the periods of 1960-1980 and 1981-2001

Method 1	Overall		1960-1980		1981-2001		Ratio of differences
TYPE	Days	%	Days	%	Days	%	
Type 1	1589	10.4	632	8.2	957	12.5	-51
Type 2	1222	8.0	408	5.3	814	10.6	-100
Type 3	1532	10.0	691	9.0	841	11.0	-22
Type 4	1817	11.8	868	11.3	949	12.4	-9
Type 5	2658	17.3	1512	19.7	1146	14.9	24
Type 6	2039	13.3	1211	15.8	828	10.8	32
Type 7	3266	21.3	1780	23.2	1486	19.4	17
Type 8	1218	7.9	569	7.4	649	8.5	-14
Total	15341	100	7671	100	7670	100	0

Method 2	Overall		1960-1980		1981-2001		Ratio of differences
TYPE	Days	%	Days	%	Days	%	
Type 1	2288	15.0	1029	13.5	1259	16.5	-22
Type 2	1355	8.9	583	7.6	772	10.1	-33
Type 3	856	5.6	368	4.8	488	6.4	-33
Type 4	971	6.4	452	5.9	519	6.8	-15
Type 5	4065	26.7	2127	27.9	1938	25.4	9
Type 6	2785	18.3	1545	20.3	1240	16.3	20
Type 7	2128	14.0	1150	15.1	978	12.8	15
Type 8	794	5.2	370	4.9	424	5.6	-15
Total	15242	100	7624	100	7618	100	0

Method 3	Overall		1960-1980		1981-2001		Ratio of differences
TYPE	Days	%	Days	%	Days	%	
Type 1	833	5.4	244	3.2	589	7.7	-141
Type 2	1327	8.7	544	7.1	783	10.2	-44
Type 3	1636	10.7	743	9.7	893	11.6	-20
Type 4	1140	7.4	338	4.4	802	10.5	-137
Type 5	982	6.4	448	5.8	534	7.0	-19
Type 6	1300	8.5	661	8.6	639	8.3	3
Type 7	1187	7.7	663	8.6	524	6.8	21
Type 8	1265	8.2	710	9.3	555	7.2	22
Type 9	1731	11.3	877	11.4	854	11.1	3
Type 10	1521	9.9	1151	15.0	370	4.8	68
Type 11	1158	7.5	731	9.5	427	5.6	42
Type 12	1261	8.2	561	7.3	700	9.1	-25
Total	15341	100	7671	100	7670	100	0

Method 4	Overall		1960-1980		1981-2001		Ratio of differences
TYPE	Days	%	Days	%	Days	%	
Type 1	491	4.9	155	3.1	336	6.7	-119
Type 2	407	4.1	186	3.7	221	4.4	-20
Type 3	311	3.1	152	3.0	159	3.2	-5
Type 4	815	8.1	244	4.9	571	11.4	-136
Type 5	1622	16.2	760	15.1	862	17.3	-14
Type 6	984	9.8	577	11.5	407	8.2	29
Type 7	578	5.8	307	6.1	271	5.4	11
Type 8	653	6.5	311	6.2	342	6.9	-11
Type 9	405	4.0	179	3.6	226	4.5	-27
Type 10	1021	10.2	780	15.5	241	4.8	69
Type 11	1673	16.7	966	19.2	707	14.2	26
Type 12	1060	10.6	413	8.2	647	13.0	-58
Total	10020	100	5030	100	4990	100	0

Ratio of differences = [(% 1960-1980) – (% 1981-2001)] / (% 1960-1980

(b) Occurrences during the different seasons: NE Monsoon and SW Monsoon

Discussion in this section is based on Figure 6.30 and 6.32. In general, Method 1 and Method 2 show a better discrimination of the so-called 'dominant types' (i.e. those that are exclusively associated with certain seasons) in the two different monsoons. In Method 1, the most dominant types during the NE monsoon are Type 1, Type 3, Type 4 and Type 6, which each one of them contributes at least 15% of overall occurrences (and, a combined percentage of more than 80%). During the SW Monsoon, Type 2 (~15%), Type 5 (~35%) and Type 7 (~35%) lead the role as the dominant types.

Method 2 has made this discrimination even clearer. During the NE monsoon season, there are two very dominant types, which are Type 1 and Type 6 (with a combined occurrence of ~65%). Interestingly, about 50% of circulation types during the SW monsoon are dominated by only one type, namely Type 5. The other types with high frequencies (but less dominant) during this season are Type 2 (~15%) and Type 7 (~20%). It is clearly evident that both Method 1 and Method 2 have managed to establish two sets of circulation types that exclusively dominate the two different seasons. They are Type 1, Type 3, Type 4 and Type 6 for NE Monsoon; and Type 2, Type 5 and Type 7 for SW Monsoon. It is also worth observing that 'the mirror pairs'[43] have always shown an anomaly effect in terms of frequency – e.g. Type 1 and Type 6 are dominant in NE Monsoon; whilst their mirrors, Type 5 and Type 2 respectively, are more frequent during the SW Monsoon.

These so-called dominant types are less obvious and not as clearly discriminated in Method 3 and Method 4 (see Figure 6.32). In fact, it can be generally concluded that there is no systematic pattern (in terms of seasonal frequency distribution) shown in either of the methods. Although there are visible differences between the two seasons, the differences are not strong enough to indicate the existence of any dominating types in one particular season. In Method 3 for instance, Type 9 (~11%) exhibits the highest occurrences during the NE monsoon. However, it also has a relatively high occurrence during the SW monsoon (~11%, the second highest). Type 3 is the strongest during the SW monsoon with a frequency of ~13%, and this same type also shows some of the highest occurrences during the NE monsoon (~8%).

Method 4 also shows the similar patterns as in Method 3, which are quite randomly uncharacteristic. For example, Type 5 (~18%) and Type 11 (~19%) are two types with the highest frequencies during the NE monsoon. However, these two types are also among the three types with the highest percentages of occurrences during the opposite season. Similarly, Type 2, Type 3 and Type 9 are all sharing a very low percentage of occurrences in both seasons. Therefore, it can be concluded that these two classification schemes (i.e.

[43] Mirror pairs are referred to the two pairing types that share the same PC factor – e.g. Type 1 (positive PC score) and Type 5 (negative PC score) are a MIRROR TYPE because both types are created from the same component (i.e. PC1) – see Table 6.12 and 6.13 (Section 6.3.5.2).

Method 3 and Method 4) have failed to establish any convincing association between the circulation types and the monsoon seasonal modes.

(b) Occurrences during different ENSO phases: El Niño and La Niña

The following descriptions are based on Figures 6.31 and 6.33. The time series for this analysis consist of 42 years and 84 seasons (evenly divided between the NE and SW monsoons). During this period, there are 17 seasons identified as El Niño and 15 seasons of La Niña. 9 of the 17 El Niño seasons and 8 of the 15 La Niña seasons occur during the NE monsoon (refer to Section 6.2.8 and Table 6.6). During this 42-year period, strong El Niño and strong La Niña events each occur seven times. The main purpose of analysing the occurrences of the types during the two separate ENSO phases is to investigate if the typing schemes have the ability to detect these two low-frequency circulation modes. How can this detection be confirmed? There are two indicators:

- The existence of clear dominating types during a particular ENSO phases (specific types are exclusively associated with certain ENSO phase – either El Niño or La Niña). The rational is to differentiate the circulation distribution between the two different ENSO phases.
- The existence of general ENSO types (one or more), which are specifically associated with ENSO occurrence (both El Niño and La Niña). The rational is to differentiate the circulation distribution between ENSO years and the normal years.

The first investigation is to compare the occurrences of type in the two different ENSO phases – El Niño and La Niña (see Figure 6.31). Method 1 shows Type 4 (~20%) as the dominant type in the El Niño seasons; whilst, Type 6 (~24%) and Type 7 (~27%) are more frequent during La Niña. Method 2 is less discriminating than Method 1, where Type 5 occurs with the highest percentage (~25%) in both events – i.e. during El Niño and La Niña. Method 3 exhibits the clearest discrimination – with Type 1, Type 2, Type 3 and Type 6 (combined percentage of more than 47%) dominating El Niño phases; and three other different types (i.e. Type 7, Type 8 and Type 9) providing more than 45% of the combined occurrences during the La Niña years. Method 4 shows a substle distribution of frequency between the two ENSO phases. Type 5 and Type 11 become the two highest frequencies in both El Niño and La Niña events (with a combined percentage of more than 32% in each case). Based on comparison with the two ENSO phases (without taking into consideration the overall comparison with the normal years) – it is concluded that only Method 3 has a reasonable discriminating ability (i.e. establishing an exclusive association between circulation types and specific ENSO phases).

The second investigation analyses the circulation frequencies (during the ENSO phases) subject to the overall occurrences. This is equally important in evaluating the performance of the typing schemes because it can clearly discriminate which type (or types) are generally associated with normal, El Niño or La Niña years (see Figure 6.33). Method 1 and Method 2 do not exhibit any specific types that are strongly associated with normal years. The percentages of occurrences for all types during the normal years (in both methods) are mostly around 58-65%, which are considered within random probability[44]. However, differences in frequency distribution are still evident when it comes to comparing the two different ENSO phases. In Method 1, the frequencies of Type 2 and Type 4 are 10% higher than the random or expected probability (during El Niño); and during La Niña, Type 6 is approximately 10% higher than expected by random occurrence. This discriminating pattern is apparently less visible in Method 2. Only Type 4 has shown a clear deviation from the random distribution (during El Niño) – with a percentage of more than 35% (17% above the expected value). No particular type can be specifically associated with La Niña events in Method 2.

Method 3 and Method 4 exhibit very clear differences between the types (in terms of occurrences distribution) during the normal, El Niño and La Niña years. In both methods, Type 1 accounts for only ~46% (16% below the random probability) during the normal years/seasons, and less than 5% (15% below the random probability) during the La Niña years. Therefore, the frequency of Type 1 during the El Niño seasons is approximately 50%, which exceeds random probability by more than 30%. In this case, Type 1 can be strongly regarded as “the El Niño type”. Type 7 also shows a very distinctive character as ‘the La Niña type’ with an occurrence of approximately 35% during this event. This figure has clearly exceeded the random probability by more than 15%. In general, Method 3 and Method 4 (two classification schemes that are based on SLP anomaly) have proven to be more effective in capturing the inter-annual fluctuations (ENSO phases). Method 1 and Method 2 (although not as clear as Method 3 and Method 4) have also managed to discriminate these low-frequency synoptic modes but to a lesser degree. However, the actual ability of each scheme will be further analysed in Chapter 8 pertaining to the ENSO phases by investigating the extreme influences of strong and weak events.

[44] The random probability for normal seasons/years is 62%, which is based on the ratio of 32 (ENSO seasons) to 84 (overall seasons). It means that if the occurrences are distributed randomly the expected percentage for ENSO seasons should be 19% each (38% equally divided into two: for El Niño and La Niña).

6.3.6.2 Relationships with local climate

This section investigates the most important element in making the decision of which is the best classification scheme. The core aim of the thesis is to establish relationships between the large-scale circulation (of Southeast Asia) and the surface climate of Borneo. Therefore, a classification scheme with the best performance in linking these relationships will be the most preferable. The results in this section are tested for statistical significance with either Chi-Square (for frequency) or ANOVA F-test (for magnitude), and all of them are statistically significant at the 99% level of confidence (see Appendix C). In this preliminary analysis, two surface variables have been chosen to be explored further – (i) average precipitation; and (ii) seasonal temperature anomaly. The analyses will be performed on three key climatic groups of Borneo, namely the Sepilok Climate group (A1) that comprises of Sandakan, Kudat and Miri; Sepanggar Climate (A2 – Kota Kinabalu, Tawau and Labuan), and finally the Samarahan Climate group (B1 – Bintulu, Sibu and Kuching). There are two main issues to be addressed:

- Are there any distinguishable differences (and, to what extent – weak or strong) in the relationships between certain circulation types and specific surface variables?
- What is the pattern of the distinctive relationships (if there is any), and is this pattern recognisable (i.e. seasonally/regionally distinctive)?

(a) Precipitation average – see Table 6.21[45] and Figure 6.34

Method 1 identifies Type 1 as the wet type and Type 5 (as the dry type) for both Sepilok (A1) and Samarahan (B1) climate groups. The wet and dry types for Sepanggar Climate (A2) are Type 8 and Type 4 respectively. Method 2 produces exactly the same wet and dry types (as in Method 1) for all climate groups except for the dry type in the Sepilok Climate group, which is Type 5 instead of Type 4. Generally, both methods show good skill in producing circulation types that can clearly identify the wet and dry days. However, in terms of predictability – Method 2 has a more distinguished pattern. As been shown in Table 6.24, based on 95% confidence interval (CI) for the mean[46], Method 2 has wet and dry types that are more recognisable when compared to the total precipitation average. For example: in Sepanggar Climate (A2), the CI mean for wet type is 11.6-15.4 mm/day and 1.2-2.7 mm/day for dry type. Those intervals are far removed from the total precipitation mean where the lower and upper bounds stand at 6.7 and 7.3 mm/day respectively. On the other hand, CI

[45] See Appendix D for a simplified summary for wet and dry types based on individual stations.

[46] CI mean for each climatic group (i.e. A, B and C) are based on the composite means for all stations in the particular group (e.g. for Samarahan Group, three stations are used to form the composite that are BTU, SBU and KCH). The values are given in a range form (e.g. 10.4-13.1 mm/day), which indicates the lowest (10.4) and highest (13.1) values.

means for Method 1 that are associated with wet and dry types are closer to the lower and upper bounds of the overall precipitation mean, which are 10.4-13.1 mm/day for wet type and 2.8-4.1 mm/day (dry type).

Table 6.21: 95% mean confidence interval (daily precipitation – mm/day) for three climatic regions in Borneo (A1, A2 and B1)

Method 1	Sepilok Climate (A1)		Sepanggar Climate (A2)		Samarahan Climate (B1)	
Type	Lower	Upper	Lower	Upper	Lower	Upper
1	11.8**	13.8**	4.9	6.6	14.7**	16.5**
2	6.3	7.6	7.4	9.6	8.3	9.7
3	7.7	9.1	7.2	9.2	9.9	11.3
4	6.2	7.5	2.8	4.1	11.0	12.5
5	5.2*	6.1*	6.7	8.2	5.8*	6.7*
6	8.4	10.0	4.1*	5.3*	10.7	12.2
7	6.0	6.9	7.0	8.5	8.7	9.6
8	8.1	9.7	10.4**	13.1**	8.1	9.6

Method 2	Sepilok Climate (A1)		Sepanggar Climate (A2)		Samarahan Climate (B1)	
Type	Lower	Upper	Lower	Upper	Lower	Upper
1	11.1**	12.6**	6.4	8.0	13.7**	15.1**
2	6.7	8.1	7.8	10.2	8.4	9.7
3	9.1	11.4	8.5	11.4	9.3	11.0
4	3.5*	4.8*	1.2*	2.7*	9.4	11.2
5	5.7	6.5	7.4	8.7	6.9*	7.6*
6	8.3	9.7	3.3	4.2	11.3	12.6
7	5.5	6.5	5.7	7.3	8.7	9.7
8	8.3	10.1	11.6**	15.4**	8.6	10.6

Method 3	Sepilok Climate (A1)		Sepanggar Climate (A2)		Samarahan Climate (B1)	
Type	Lower	Upper	Lower	Upper	Lower	Upper
1	4.8*	6.3*	3.2*	4.8*	9.2	11.0
2	6.1	7.4	6.0	7.9	7.3*	8.6*
3	7.0	8.3	6.8	8.9	9.8	11.2
4	7.7	9.4	6.0	8.3	11.1	12.8
5	9.9**	12.3**	5.7	8.3	12.6**	14.8**
6	7.2	8.7	6.1	8.5	10.4	12.0
7	9.6	11.6	7.7**	10.1**	9.8	11.4
8	7.8	9.8	7.0	9.3	11.0	12.8
9	6.8	8.1	5.7	7.4	8.2	9.5
10	6.4	7.9	5.7	8.0	8.5	10.1
11	5.7	7.6	3.6	5.2	8.0	9.8
12	5.9	7.3	6.5	8.4	7.0	8.4

Method 4	Sepilok Climate (A1)		Sepanggar Climate (A2)		Samarahan Climate (B1)	
Type	Lower	Upper	Lower	Upper	Lower	Upper
1	3.7*	5.4*	1.7*	3.5*	8.5	11.0
2	5.8	8.3	7.7**	11.8**	5.3*	7.3*
3	6.1	9.1	6.6	12.2	7.7	10.7
4	7.9	9.9	5.9	8.6	10.8	13.0
5	9.9	11.6	6.4	8.4	13.2**	15.0**
6	6.8	8.6	6.1	8.8	9.7	11.6
7	10.2**	13.1**	6.5	10.2	9.6	12.1
8	8.3	11.5	7.2	10.4	11.1	13.4
9	6.0	9.0	4.7	8.3	7.6	10.6
10	6.4	8.3	5.2	7.9	7.9	9.7
11	5.8	7.3	3.7	5.1	8.3	9.6
12	5.9	7.4	6.8	8.9	6.6	8.0

*CI means are measured based on SLP circulation types (** the wettest type; * the driest type)*

Method 3 and Method 4 generally show a more random pattern in terms of identifying the so-called wet and dry types (see Table 6.21 and Figure 6.34). Both methods identify Type 1 as the dry type for A1 and A2, and Type 2 as the dry type for B1. However, Method 3 and Method 4 individually recognise different types for the wet types in all three climate groups, except for B1 (where both methods have recognised Type 5 as the wet type). It is also evident that the margin between the lower and upper bounds (based on 95% confidence interval for mean) is relatively much wider in these two methods, compared to Method 1 or Method 2. This indicates that the relationships shown by Method 1 and Method 2 (using SLP absolute data) are statistically more reliable (in terms of discriminating) than those observed in Method 3 and Method 4 (using SLP anomaly data).

(b) Seasonal temperature anomaly – see Table 6.22[47] and Figure 6.35

In general, Method 1 has three hot types (associated with positive anomaly), namely Type 4, Type 5 and Type 8. It also produces three cold types (negative anomaly), which are Type 1, Type 6 and Type 7. However, all the anomalies are less than 0.2ºC. In terms of discriminating ability, Method 1 is not considered to have a reasonably good performance because there are too many types (6 out of 8) associated with positive or negative anomalies; but none of them are really strong[48]. Method 2 shows a much better performance. In this method, Type 4 is clearly associated with hot temperatures (high positive anomaly of up to 0.4ºC) and Type 6 generally is related to lower temperature (with negative anomaly up to 0.1ºC). The 95% confidence interval for means of the hottest and coldest types, generally deviate further from the seasonal average (i.e. zero anomaly).

Table 6.22: 95% mean confidence interval (temperature anomaly – °C) for three climatic regions in Borneo (A1, A2 and B1)

Method 1	Sepilok Climate (A1)		Sepanggar Climate (A2)		Samarahan Climate (B1)	
Type	Lower	Upper	Lower	Upper	Lower	Upper
1	-0.11	-0.03	-0.10	-0.01	-0.12	-0.05
2	-0.05	0.03	-0.03	0.07	-0.09	0.01
3	-0.03	0.05	0.01	0.10	-0.09	-0.01
4	0.09**	0.16**	0.12**	0.21**	0.09	0.17
5	0.07	0.14	0.07	0.15	0.10**	0.18**
6	-0.15*	-0.09*	-0.20*	-0.12*	-0.10	-0.03
7	-0.10	-0.04	-0.15	-0.08	-0.12*	-0.06*
8	0.04	0.13	0.01	0.13	0.06	0.16

Method 2	Sepilok Climate (A1)		Sepanggar Climate (A2)		Samarahan Climate (B1)	
Type	Lower	Upper	Lower	Upper	Lower	Upper
1	-0.04	0.02	-0.04	0.04	-0.07	-0.02
2	-0.02	0.06	-0.02	0.09	-0.06	0.04
3	-0.10	0.00	-0.10	0.03	-0.13*	-0.02*
4	0.19**	0.30**	0.25**	0.38**	0.18**	0.29**
5	0.00	0.05	0.00	0.07	0.01	0.07
6	-0.14*	-0.08*	-0.16*	-0.09*	-0.09	-0.03
7	-0.05	0.02	-0.09	0.00	-0.07	0.00
8	0.00	0.11	-0.08	0.07	0.02	0.14

[47] See Appendix F for a simplified summary for cold and hot types based on individual stations.

[48] Statistically, it is not a problem to have these differences from several circulation types. However, for the purpose of establishing an easily-interpreted relationship – a typing scheme that can associate only few specific circulation type (one or two) with high differences in negative and positive anomalies is considered better in terms of performance.

Method 3	Sepilok Climate (A1)		Sepanggar Climate (A2)		Samarahan Climate (B1)	
Type	Lower	Upper	Lower	Upper	Lower	Upper
1	0.26**	0.36**	0.35**	0.47**	0.17	0.28
2	0.05	0.13	0.11	0.20	0.09	0.18
3	-0.16	-0.09	-0.20	-0.11	-0.25	-0.17
4	-0.04	0.04	0.02	0.12	-0.12	-0.04
5	-0.20	-0.11	-0.27	-0.16	-0.28	-0.18
6	-0.09	0.00	-0.11	0.00	-0.05	0.04
7	-0.36*	-0.27*	-0.49*	-0.37*	-0.32*	-0.23*
8	-0.16	-0.08	-0.25	-0.13	-0.18	-0.08
9	0.12	0.19	0.14	0.23	0.20**	0.28**
10	-0.11	-0.02	-0.12	0.00	-0.04	0.06
11	0.12	0.21	0.12	0.24	0.15	0.25
12	0.12	0.20	0.12	0.23	0.11	0.21

Method 4	Sepilok Climate (A1)		Sepanggar Climate (A2)		Samarahan Climate (B1)	
Type	Lower	Upper	Lower	Upper	Lower	Upper
1	0.39**	0.51**	0.53**	0.68**	0.29	0.44
2	0.08	0.23	0.02	0.22	0.16	0.34
3	-0.40	-0.23	-0.48	-0.26	-0.53*	-0.36*
4	-0.03	0.07	0.02	0.14	-0.15	-0.05
5	-0.17	-0.09	-0.23	-0.14	-0.25	-0.17
6	-0.15	-0.04	-0.21	-0.08	-0.12	-0.01
7	-0.53*	-0.40*	-0.61*	-0.45*	-0.39	-0.27
8	-0.20	-0.08	-0.24	-0.09	-0.17	-0.04
9	0.28	0.43	0.34	0.52	0.42**	0.57**
10	-0.12	0.00	-0.11	0.03	0.01	0.14
11	0.15	0.23	0.16	0.25	0.13	0.22
12	0.12	0.22	0.14	0.26	0.12	0.23

*CI means are measured based on SLP circulation types (** the hottest type; * the coldest type)*

Method 3 and Method 4 exhibit the same problem as in Method 1: there are too many (more than two types) being associated with either higher or lower temperature (see Figure 6.35). This again, could lead into a difficulty in interpretation. Both methods identify four circulation types that are associated with positive anomalies – Type 1, Type 9, Type 11 and Type 12. These two methods also share the same four cold types, which are Type 3, Type 5, Type 7 and Type 8. Although these extreme circulations (the so-called 'cold' and 'hot' types) produced by Method 3 and Method 4, show a higher degree of deviation from the average (mostly between 0.2-0.4ºC) compared to first two methods; they collectively fail to establish a more exclusive association between a particular circulation and certain surface conditions (in terms of temperature anomaly). As a result, the pattern of association is less distinguishable and predictable. Therefore, it can be concluded that Method 2 remains as the best circulation scheme with regards to relationships with local temperature over Borneo.

6.3.7 Analysing the performance of each method

All the methods that have been used to classify the SLP circulation are generally successful in meeting the basic aim of the thesis – to establish a synoptic classification scheme, which can be associated with the surface climate of Borneo. However, each one of the classification schemes has shown different performance skill in various aspects. This section is the most important part of this chapter. It will discuss the statistical, empirical and physical justifications to decide which is the best method to be further analysed in Chapter 7 (detailed analysis on relationships between the circulation types and surface climate). There are four key elements to be considered:

- Physical interpretability – how interpretable are the circulation types produced by each classification scheme in relation with the known synoptic atmospheric flow in Southeast Asia (the large-scale domain that directly influences Borneo)?
- Ability to optimise the original data – how much of the original data has been incorporated in each typing scheme? A higher proportion will indicate that more variations have been captured, thus increasing the ability to explain more precisely the climate variability.
- Ability to discriminate various climatic conditions – how sensitive is the typing scheme when tested on different climatic events? A clearer discrimination between 'competing climatic events'[49] will prove that the typing scheme really has the ability to detect the climate variations.
- Ability to establish recognisable relationships with surface climate – how strong are the relationships between circulation types and surface climatic variables? If a highly distinguishable association is found, the typing scheme can be considered as a reliable diagnostic tool for surface climate.

6.3.7.1 Physical interpretability[50]

The best physical interpretabilities are shown in the map-patterns produced by Method 1 and Method 2 (see Figures 6.18 and 6.19). Each of these methods produces a similar set of eight circulation types, which can be easily associated with the known large-scale circulation in Southeast Asia. Type 1, Type 4 and Type 6 are associated with the Northeast Monsoon (southerly airflow), Type 5 and Type 7 represent the Southwest Monsoon (northerly airflow), and three other types (Type 2, Type 3 and Type 8) are associated with various state of monsoon transition (the less dominating modes compared to the 'mature' monsoon – i.e. the NE and SW monsoons).

Physical features of the map-patterns produced by Method 3 and Method 4 are less representative of the overall characteristics of Southeast Asia synoptic airflow. All of the 12

[49] "Competing climatic events" are referred to two different events that should, theoretically, manifest different climatic conditions (i.e. SW and NE monsoons; or El Nino and La Nina phases). Thus, a reasonably good typing scheme should be able to differentiate these two different climatic events.
[50] This aspects will be assessed and described in more detailed in Chapter 7.

types share a similar basic pattern[51] (see Figures 6.21 and 6.22), which is a formation of pressure gradient either towards the equator (the maritime region of Southeast Asia – including Borneo) or to the eastern part of the Philippines archipelago. This feature is normally associated with the inter-monsoon transitions, but is not representative enough for the mature monsoons (i.e. Northeast and Southwest Monsoon).

6.3.7.2 Ability to optimise the original data

Method 1 and Method 2 use absolute SLP values as the original data. Upon performing the PCA, four significant components that explained 86% of the total variance, have been identified. Method 3 and Method 4 are based on SLP anomalies. The PCA for this approach has retained 6 significant components that cumulatively explained 80% of the total variance. Statistically speaking, the component modes captured by Method 1 and Method 2 are stronger compared to those identified by Method 3 and Method 4. Why? It is because the ratio between variance explained and number of component retained is much higher in the first two methods (86:4)[52] than in Method 3/Method 4 (80:6). Judging from the communalities maps (which show the spatial distribution of extracted variance from original data), it was found that the distribution of a high percentage is more even and balanced for Method 1/Method 2 than Method 3/Method 4. The communalities map for the absolute SLP (Method 1/Method 2) shows better performance with extracted variance within the range of 80% and 90% (see Figure 6.12); whereas the communalities map for the SLP anomaly (Method 3/Method 4) shows some values as low as 60% for certain areas (see Figure 6.13).

6.3.7.3 Ability to discriminate various climatic conditions

Chi-square tests have been performed on the frequencies of circulation types in each classification scheme to determine if there are significant differences between types. This test is performed under three different conditions – (i) the overall time-series (1960-2001); (ii) separately for NE and SW Monsoon; and (iii) during the occurrence of ENSO phases. The test results for all classification schemes show that the differences are statistically significant at 99.9% level of confidence in every condition tested. However, the degree of clarity in discriminating various climatic events (as has been discussed in Section 6.3.6.1), for each individual method is not equally convincing.

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[51] Take note that the similarity in basic pattern of the circulation types (apart from being shown in the SLP maps) is also clearly demonstrated with correlation analysis (see Table 6.17).
[52] The four retained components in Method 1 and 2 account for 86% of the total variance. These four retained components are then used to establish eight circulation types.

Method 1 performs fairly reasonably in terms of association with the seasonal cycle. But, it is Method 2 that has the best discriminating ability on a seasonal basis (ability to clearly distinguish the two monsoons). Method 3 and Method 4 have almost totally failed to show any meaningful differences between these two seasons. However these two methods perform better when it comes to discriminating the ENSO phases. Although Method 1 and Method 2 are less convincing (when discriminating ENSO phases), the patterns of occurrences under this synoptic forcing are still prominent and distinguishable. Finally, Method 2 has shown to be the only scheme that produces stable circulation types over the full period of 1960-2001. This conclusion is reached by analysing changes in the circulation frequencies over the two halves of period – 1960-1980 and 1981-2001. It is clear that Method 2 not only has the best ability to discriminate various climatic events, but it also has produced the most stable circulation types over the period of 42 years (1960-2001).

6.3.7.4 Ability to establish strong and recognisable relationship with surface climate

Analysis of variance (ANOVA) has been performed to examine if the magnitude of local climate variables (i.e. precipitation average and temperature anomaly) being associated with each circulation type is significantly different from the total mean (the expected value). Three climate groups have been chosen for this analysis – Sepilok Climate (A1), Sepanggar Climate (A2) and Samarahan Climate (B1). The ANOVA results reveal that all classification schemes are statistically significant at 99.9% level of confidence (as far as relationship with precipitation and temperature anomaly are concerned).

To analyse further detail of the relationships, descriptive statistics are produced to show the values of 95% confidence interval (CI) for means (for precipitation and temperature – related to certain classification schemes). This will provide a better insight of how strong and clear the relationships between certain surface variables and a specific circulation type. How is the strength and clarity of relationships being measured? As has been discussed earlier (see Section 6.3.6.2), the comparison between CI values and the overall average will be the key indicator. Although ANOVA reveals that all classification schemes are statistically acceptable, the degree of differences and how distinguishable the patterns are – can only be investigated by analysing the individual CI values.

Based on this analysis, Method 2 has established the most distinguishable pattern in terms of relationships between the circulation types and surface climate. This classification scheme has been able to clearly identify the wet types (higher precipitation), dry types (lower precipitation), cold types (negative temperature anomaly) and hot types (positive temperature anomaly). Although the ability to identify these so-called ‘dominant types’ is also shown by Method 1, Method 3 and Method 4 – it is not as clear as in Method 2. These three methods have managed to establish wet, dry, cold and hot types – but rather in a looser way. There are too many dominant types and less discrimination from the ‘normal types’.

6.3.8 Conclusion (Circulation Typing)

Based on the evaluations carried out in the previous sections, each classification scheme seems to have its own advantages and disadvantages. It is found that a particular scheme appears better when assessed under certain criteria; and another scheme outperforms it under different criteria. The question is – how to evaluate these advantages and disadvantages and use the evaluation to determine which method is the best?

Firstly, to evaluate the results derived from different measures of original data (absolute and anomaly values). It is concluded that absolute SLP produces a typing scheme with lower number of circulation types but with stronger modes. This is determined by the percentage of variance explained (in the PCA final solution) and how the extracted variances were spatially distributed. In this aspect, Method 1 and Method 2 (absolute SLP) clearly have shown greater advantages over Method 3 and Method 4 (SLP anomaly) because these two methods explained higher variance with less number of PCs (Methods 1 and 2: 4 PCs explain 86% of the total variance; Methods 3 and 4: 6 PCs explain 80% of the total variance).

Secondly, to examine the effect of using different classification techniques (cluster-based and correlation-based) in the second stage of the synoptic typing – i.e. to assign the remaining unclassified days into the identified key days. The choice of classifying techniques will influence the percentage of classified days, but will not make any significant difference to the map-patterns. There is no clear advantage with regards to this choice. Both techniques have their own weaknesses – the correlation-based technique is not able to classify all days (e.g. Method 3 classify only 65.3% of the available days), whilst the cluster technique tends to dilute the type’s unique characteristics (not physically, but empirically – i.e. association with monsoon, ENSO and surface climate).

Thirdly, to investigate the individual performance of each combination – Method 1 (absolute-cluster), Method 2 (absolute-correlation), Method 3 (anomaly-cluster) and Method 4 (anomaly-correlation). It is found that Method 1 and Method 2 produce circulation modes that are better associated with the seasonal cycle (the monsoon); while Method 3 and

Method 4 are better associated with ENSO forcing. However, in terms of relationship with surface climate, Method 2 shows the best performance for both local variables being tested (i.e. precipitation average and temperature anomaly). Based on these three levels of evaluation, it has been decided that Method 2 is the best classification scheme with the most satisfactory combined results (in all criteria).

6.4 Reclassification using anomaly data and separate monsoon seasons

In the previous section, SLP absolute data (Methods 1 and 2) are used as the initial input data (for the PC analysis). The other two methods (Methods 3 and 4) employ SLP anomaly data without separating into the two different monsoons (i.e. the Northeast and Southwest Monsoons). This section attempts to evaluate three new alternatives to classifying the synoptic circulation. These are:

- SLP anomaly (as input data) with PCA performed based on a single season for NE Monsoon
- SLP anomaly (as input data) with PCA performed based on a single season for SW Monsoon
- SLP anomaly (as input data) with PCA performed including both seasons

The data used for this reclassification are similar to those used in Section 6.3, which are the SLP Reanalysis data obtained from NCEP. Daily mean anomaly[1] observations are used, which cover the period 1960-2001 (42 years).

6.4.1 Methodology overview

As in the previous section, the classification procedures here employ an eigenvector-based approach using Principal Component Analysis (PCA). See the discussion with Figures 6.9 and 6.12 for an overview of the methodology employed in this section. Daily observations of SLP (1960-2001), measured in anomaly[53] values (to remove the seasonal effect) are processed by PCA to establish an orthogonal and smaller number of significant factors. The retained components are then rotated (using the Varimax approach) to increase the interpretability. PCA will initially produce component scores, and by setting 2.0 as the threshold[54], these scores will be used to identify the key days (representing initial

[53] SLP anomalies are calculated subject to long-term daily averages of 366 days in a year (i.e. including leap days). The long-term daily averages are based on 1961-1990, which is the standard period introduced by World Meteorological Organisation (WMO).
[54] This value has been tested in Section 6.3.5.2.

classification types). The final types will be determined using the correlation technique with the threshold of 0.6[55].

6.4.2 Retained components

Two criteria are used to determine the number of significant components, previously described in Section 6.3.4.1. These criteria are based on (i) looking at where the eigenvalue's plot bends in the scree plots; and (ii) percentage of variance explained (set at 70% minimum for this case).

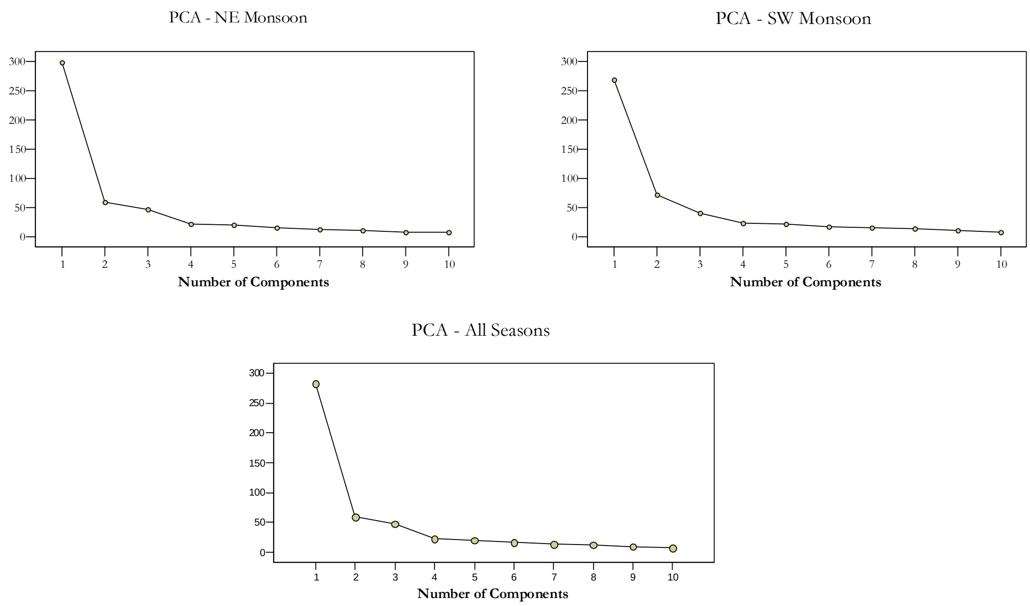


Figure 6.29: The scree plots for PCA (using SLP anomaly values) based on NE and SW monsoons; and all seasons

By observing the three scree plots (Figure 6.29), it is clear that the eigenvalue's plot (in all cases) bends at component number four. Upon analysing the percentage of variance (see Tables 6.23, 6.24 and 6.25), it is also evident that each case is able to achieve at least 70% of total variance explained by retaining four components. It is 74.8% for NE Monsoon, 71.1% for SW Monsoon and 72.6% for All Seasons. Thus, it was decided that four components would be retained in all cases. The communalities maps in Figure 6.30 show the spatial distributions of the explained variances. The highest values (more than 80%) are found in the areas between 10ºN and 10ºS, where Borneo is located.

[55] This value has been tested in Section 6.3.5.3.

Table 6.23: Percentage of variance explained by the retained components (NE Monsoon)

	Initial Values			Rotated Values		
PC	Eigenvalues	Variance (%)	Cumulative %	Eigenvalues	Variance (%)	Cumulative %
1	297.7	52.5	52.5	158.3	27.9	27.9
2	58.6	10.3	62.8	121.4	21.4	49.3
3	46.6	8.2	71.1	90.4	15.9	65.3
4	21.5	3.8	74.8	54.2	9.6	74.8

Table 6.24: Percentage of variance explained by the retained components (SW Monsoon)

	Initial Values			Rotated Values		
PC	Eigenvalues	Variance (%)	Cumulative %	Eigenvalues	Variance (%)	Cumulative %
1	268.4	47.3	47.3	129.9	22.9	22.9
2	71.1	12.5	59.9	125.7	22.2	45.1
3	40.2	7.1	67.0	83.7	14.8	59.9
4	23.6	4.2	71.1	63.9	11.3	71.1

Table 6.25: Percentage of variance explained by the retained components (All Seasons)

	Initial Values			Rotated Values		
PC	Eigenvalues	Variance (%)	Cumulative %	Eigenvalues	Variance (%)	Cumulative %
1	281.9	49.7	49.7	144.1	25.4	25.4
2	59.4	10.5	60.2	115.4	20.4	45.8
3	47.7	8.4	68.6	89.9	15.9	61.6
4	22.7	4.0	72.6	62.2	11.0	72.6

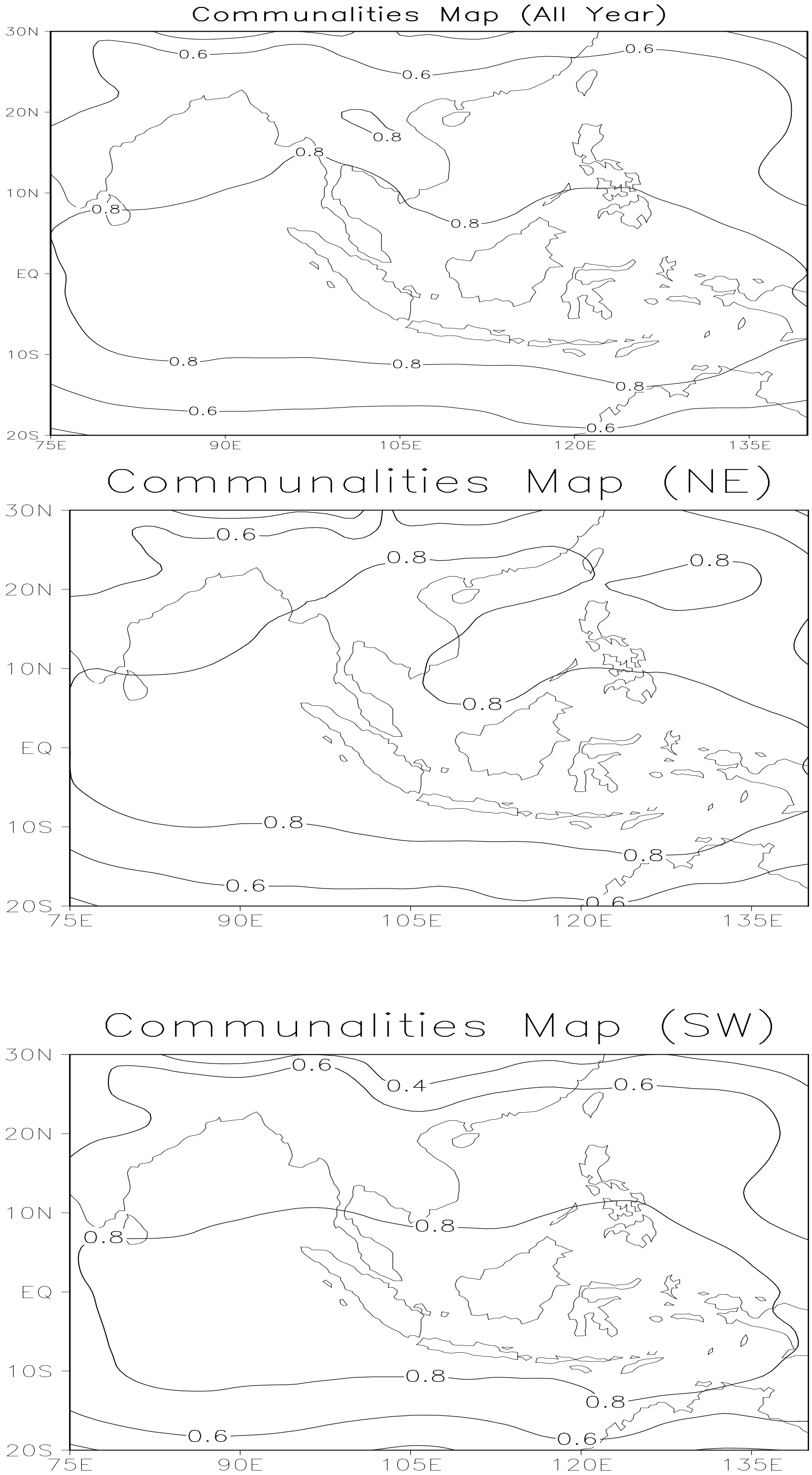


Figure 6.30: The communalities maps for – all seasons, NE and SW monsoons

6.4.3 Loading maps

Loading maps show the correlation of each component with each one of the 567 grid-points (with the size of 2.5° X 2.5° latitude/longitude). The loadings are standardised between –1 and +1. These values are the measure of the correlation magnitude (between each PC and each grid-point). Loading maps serve as the basic shape of the actual map-pattern catalogues. The loading maps are shown in Figures 6.42 (NE Monsoon), 6.43 (SW Monsoon) and 6.44 (All Seasons). The patterns of low and high values for each component, for all three different seasons, are strikingly similar. The general description of the features[56] for each map are summarised in Table 6.26.

Table 6.26: Summary of the loading maps

PC	Low Variance (<0.4)	High Variance (> 0.6)
PC1	The northern part (north of 20°N), towards the northeast region (from 10°N northward) and the southeast region from 120°E eastward.	The southwest part, from 15°N southward, and 100°E westward.
PC2	Generally, a large area of low variance which covers the northeast, northwest and southwest regions (from 105°E westward and 10°N northward).	The southeast region, from 120°E eastward and 10°N southward.
PC3	The southern region, from 10°N southward.	The northern region, from 15°N northward.
PC4	Western part, within the region of 75°E-115°E; 20°S-30°N.	Eastern part, over the Philippines archipelago (120°E-140°E; 5°S-20°N)

PC1 has very high values (more than 0.8) over the Indian Ocean and considerably lower values (below 0.2) over the Indo-China sub-continent. PC2 has significantly high values over the northern Australia and low values over all other areas. PC3 shows high values of more than 0.6 and up to 0.8 over the Indo-China region, and extremely low values in the southern part, especially south of 5°N (below 0.2). PC4 distinctively exhibits very high values (more than 0.6 and up to 0.8) over the Philippines archipelago.

[56] Further analysis on physical features will be explored in Chapter 7. This section is only a brief introduction of the basic physical features of the circulation types.

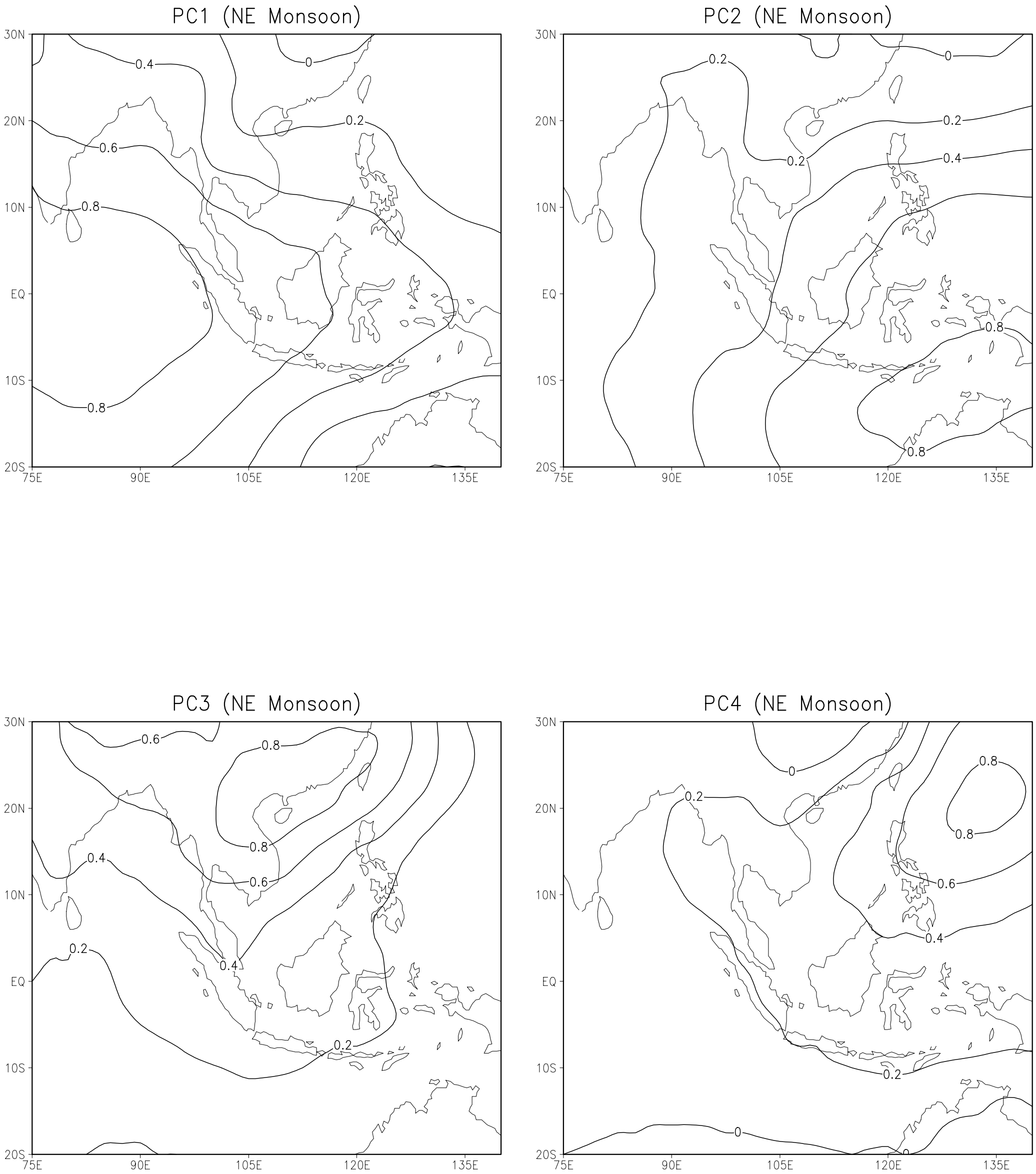


Figure 6.31: Loading maps for the four retained components (NE Monsoon)

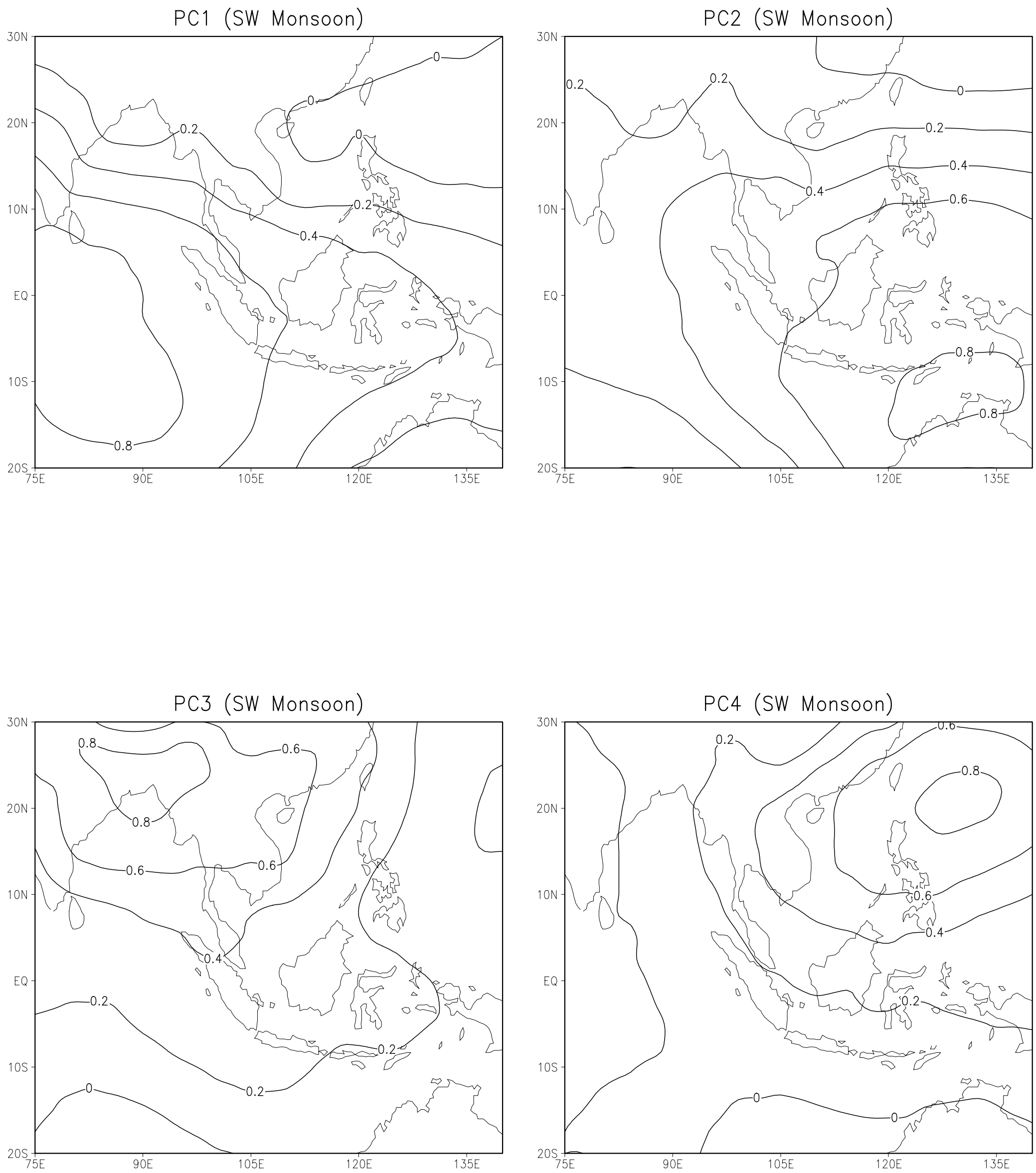


Figure 6.32: Loading maps for the four retained components (SW Monsoon)

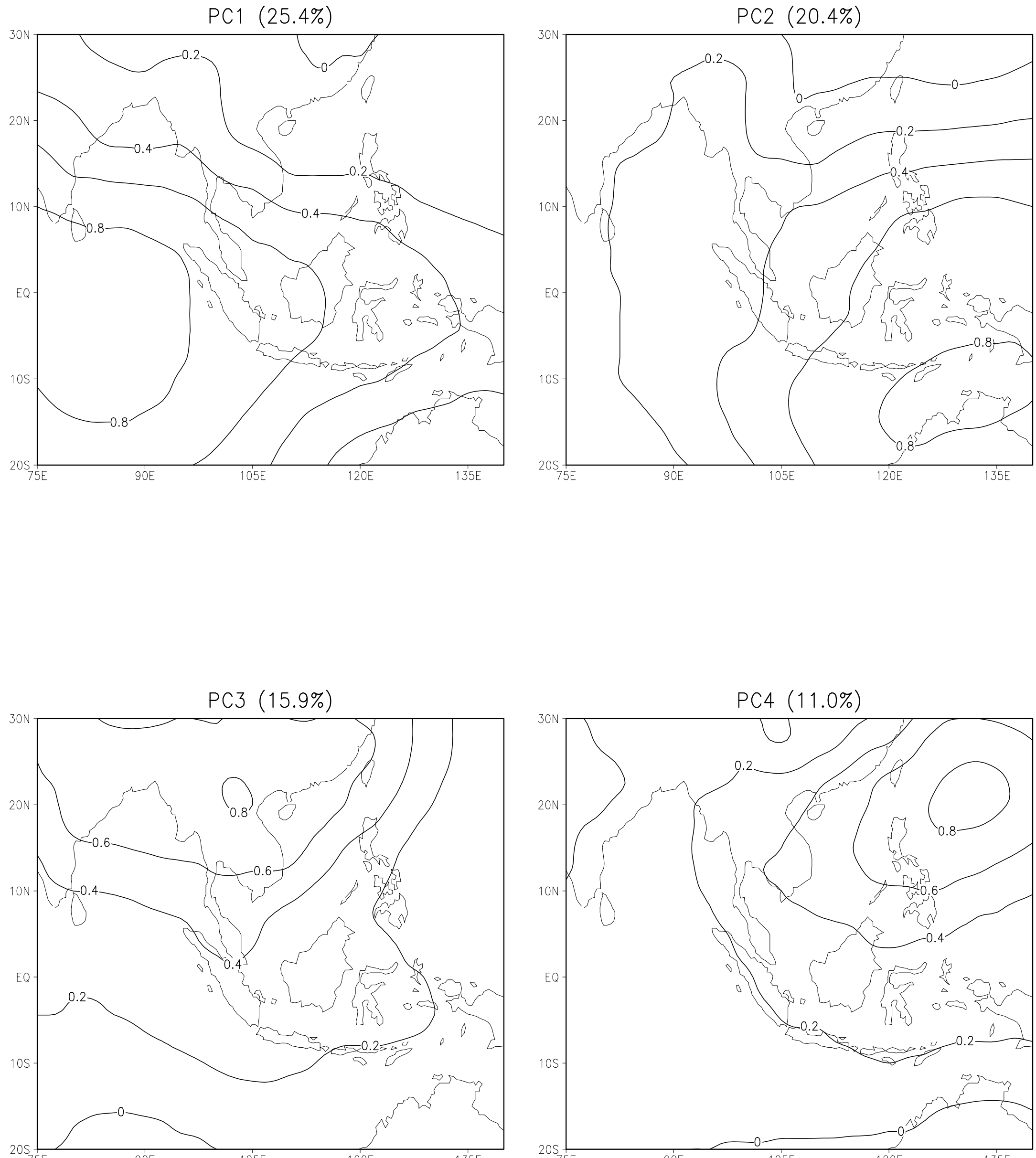


Figure 6.33: Loading maps for the four retained components (All Seasons)

6.4.4 Establishing SLP circulation types

As has been mentioned earlier, the circulation types in this section will be classified based on three different procedures. Daily MSLP anomaly data are used in all cases, but each one is processed by PCA in a different manner: based on separate seasons (i.e. NE and SW monsoons) and by combining both monsoon seasons. The key days are identified by setting the threshold of PC scores at ±2.0. Naturally, each PC will be able to produce two initial circulation types (i.e. those that exceed/equal the positive threshold value, and those that are equal/below the negative threshold value). Composites of the key days will serve as the 'identification' for each of the initial types. All the other unclassified days are then assigned into one of these 'key types' using the correlation technique (see Section 6.3.5.3 for more details on the method). The threshold set for the correlation is 0.6. The numbers and percentages of classified days for each type are shown in Tables 6.27, 6.28 and 6.29. For the NE Monsoon, a total of 5361 days (70%) are classified, 4891 days (63.6%) for the SW Monsoon and 10915 days (71.1%) for both seasons, in the combined analysis. In these Tables, the number of finally classified days is the difference between the total number of days and those left unclassified. Statistically, the differences between each of the different methods are less notable (1 – 7%) in terms of the ability to classify all available days.

Table 6.27: Percentage of classified days for each type (NE Monsoon)

	Key Days		Final Classification	
Type	N	%	N	%
1	364	1.9	379	5.0
2	439	2.2	356	4.7
3	408	2.1	1328	17.3
4	344	1.4	561	7.3
5	455	2.2	442	5.8
6	368	2.2	361	4.7
7	444	1.9	1329	17.4
8	462	3.1	605	7.9
Unclassified	4371	83.0	2294	30.0
Total	7655	100	7655	100

Table 6.28: Percentage of classified days for each type (SW Monsoon)

	Key Days		Final Classification	
Type	N	%	N	%
1	397	1.9	343	4.5
2	398	1.9	353	4.6
3	392	1.8	713	9.3
4	359	1.5	841	10.9
5	438	2.6	540	7.0
6	431	2.2	375	4.9
7	440	2.3	711	9.3
8	487	2.8	1015	13.2
Unclassified	4344	83.0	2795	36.4
Total	7686	100	7686	100

Table 6.29: Percentage of classified days for each type (All Seasons)

	Key Days		Final Classification	
Type	N	%	N	%
1	865	5.6	1108	7.2
2	867	5.7	1115	7.3
3	937	6.1	2045	13.3
4	765	5.0	1472	9.6
5	764	5.0	1081	7.0
6	678	4.4	876	5.7
7	749	4.9	1768	11.5
8	792	5.2	1450	9.5
Unclassified	8924	58.2	4426	28.9
Total	15341	100	15341	100

6.3.5 Composite maps

It was found earlier that the loading maps for the three different methods exhibit very similar patterns. The same similarity is also shown in the composite maps for both the anomaly and absolute SLP (i.e. the latter being the full field). This can be observed in Figures 6.45a-b (NE Monsoon), 6.46a-b (SW Monsoon) and 6.47a-b (All Seasons). This indicates that each set of the eight circulation types (produced by three different methods of PCA) corresponds with each other. For example, Type 1 for the NE Monsoon has almost the same features and characteristics as the Type 1 established for the SW Monsoon and that for All Seasons.

6.4.6 Frequency analysis

Prior to the relationship analysis, the established circulation types are first evaluated in terms of occurrences. This will help to understand the key characteristics of each circulation pattern and how it behaves under the various known climatic forcings (i.e. the monsoon and ENSO) in the Southeast Asia region. These frequency analyses will attempt to look at these issues:

- How the circulation types are generally distributed (i.e. which ones have higher and lower frequencies)?
- How stable the circulation types are, in terms of their frequency distribution throughout the study period (1960-2001)?
- Which types are commonly associated with a particular monsoon season or ENSO event?

- Between the two newly introduced methods (hereafter referred to as CT1 and CT2)[57], which one produces a classification scheme that is more stable (i.e. the occurrences fluctuate less over the study period) and is more consistent (having a distinctively recognisable pattern of association with monsoon and ENSO)?

The frequency distribution for both methods is not distinctively different from each other (see Figure 6.34a-d) which may indicate that the two different methods are generally able to produce a similar classification scheme. For CT1 (i.e. separate season), the two highest occurrences are exhibited by Types 3 and 7, with both recording 19.9%. Similarly for CT2 (i.e. combined season), Types 3 and 7 exhibit the highest frequencies, with 18.7% and 16.2% respectively. Types 1, 2, 5 and 6 show relatively fewer occurrences for both CT1 and CT2. However, the degree of discrimination (i.e. in terms of assigning the highest number of days to each circulation type) is much clearer in CT1. For instance, Type 3 and 7 both have 19.9%; whereas the two lowest percentages (Types 2 and 6) are only assigned with 7.0% and 6.9% of days. In CT2, this kind of discrimination is less obvious with less of contrast between the highest and lowest occurring types. The two highest frequencies are 16.2% and 18.7%; whereas the lowest two are 8.0% and 9.9% (see Table 6.27b).

The changes in the frequency over the 42-year period of study are not really evident in most of the circulation patterns, except for Types 1 and 7. Interestingly, this distinctive trend is observed in both CT1 and CT2. For CT1, the occurrence of Type 1 is increases over the 42 years. In the first decade (1960-1969), Type 1 only contributes 3.9% of the overall percentage. The next three decades exhibit some noticeable increases – from 6.7% (in the 70s) to 8.7% (in the 90s). Type 7, on the other hand, shows a significant decrease – from as high as 37% in the first decade (60s) to only 13.3% during the 90s. The same trends of increase and reduction are observed in CT2 for Type 1 and Type 7. However, it occurs at a slightly different rate (see Table 6.27b).

In terms of association with monsoon seasons, CT1 and CT2 once again exhibit a quite similar behaviour (see Table 6.28a). For both CT1 and CT2, Types 4 and 8 are strongly associated with SW Monsoon and exhibit relatively high percentages of occurrences. Type 7, also in both CT1 and CT2, shows a comparatively higher frequency during the NE Monsoon. Types 1, 5 and 6 can be safely considered as having almost an equal frequency distribution in both monsoons for the two methods. However, Types 2 and 3 are a little

[57] CT1 is the first method where the PCA is performed separately for NE and SW monsoons. CT2 is the alternative method, where the PCA is conducted without separating the two monsoon seasons.

harder to understand. For CT1, Type 3 has a higher frequency (24.8% vs 14.6%) during the NE Monsoon – but this characteristic is not shown by CT2 (19.4% vs 18.0%). Similarly for CT2, Type 2 occurs more frequently (12.8% vs 7.4%) during the NE Monsoon – but the frequency is almost equally distributed in CT1 (6.6% vs 7.2%).

The associations with ENSO events are also relatively similar between CT1 and CT2 (see Table 6.28b). This further serves as an indication that methods CT1 and CT2 produce a set of circulation patterns, which are highly similar (although the PCA is employed differently in each case[58]). In both methods, the high frequencies of Types 4 and 7 are associated with the La Niña years. Type 2 is strongly related to high percentage of occurrences during the El Niño years. Types 1, 3, 5, 6 and 8 are less associated with ENSO events based on the evidence that the frequencies of these types are not distinctively different during the ENSO and non-ENSO events. It is clear that, in both cases (CT1 and CT2, see Table 6.28), the associations between circulation patterns and ENSO events are more consistent, particularly compared to their associations with monsoon seasons.

Table 6.27: Decadal change in the circulation types

a. Circulation Type (Separate Season)

	All Years (1960-2001)		Decadal change in frequency (%)			
CT1	N Days	%	1960-69	1970-79	1980-89	1990-99
1	722	7.0	3.9	6.7	8.9	8.7
2	709	6.9	5.3	5.4	8.5	9.2
3	2041	19.9	11.4	20.3	23.7	23.5
4	1402	13.7	15.1	16.7	12.4	11.8
5	982	9.6	9.6	9.2	10.5	8.6
6	736	7.2	5.1	8.9	6.5	7.3
7	2040	19.9	37.0	18.3	12.5	13.3
8	1620	15.8	12.7	14.5	17.1	17.6

b. Circulation Type (Combined Season)

	All Years (1960-2001)		Decadal change in frequency (%)			
CT2	N Days	%	1960-69	1970-79	1980-89	1990-99
1	1108	10.2	6.2	9.2	11.6	14.4
2	1115	10.2	7.1	7.5	12.6	15.0
3	2045	18.7	8.2	18.8	23.6	23.2
4	1472	13.5	16.9	15.9	11.6	11.3
5	1081	9.9	11.6	10.0	9.1	7.8
6	876	8.0	7.9	10.9	6.9	5.5
7	1768	16.2	30.6	15.8	10.4	9.1
8	1450	13.3	11.5	11.9	14.2	13.7

[58] See Section 6.4 for the differences.

Table 6.28: Frequency of the circulation types based on monsoon cycle and ENSO events

a. Circulation Type (Separate Season)

	Monsoon Seasons		ENSO Events		
CT1	NEM	SWM	NORMAL	ELNINO	LANINA
1	7.1	7.0	7.1	8.4	5.1
2	6.6	7.2	5.5	15.0	2.5
3	24.8	14.6	20.6	16.3	21.6
4	10.5	17.2	13.1	11.6	18.2
5	8.2	11.0	10.0	8.6	9.3
6	6.7	7.7	7.0	2.1	13.5
7	24.8	14.5	20.2	21.9	16.4
8	11.3	20.8	16.4	16.0	13.4

b. Circulation Type (Combined Season)

	Monsoon Seasons		ENSO Events		
CT2	NEM	SWM	NORMAL	ELNINO	LANINA
1	9.4	11.0	10.5	12.4	6.4
2	12.8	7.4	7.6	25.2	2.2
3	19.4	18.0	19.5	17.2	17.9
4	10.2	17.0	13.3	11.3	16.4
5	10.6	9.2	10.4	5.6	13.1
6	9.7	6.3	7.5	1.3	17.3
7	18.0	14.2	16.8	15.7	14.5
8	9.9	16.9	14.3	11.2	12.1

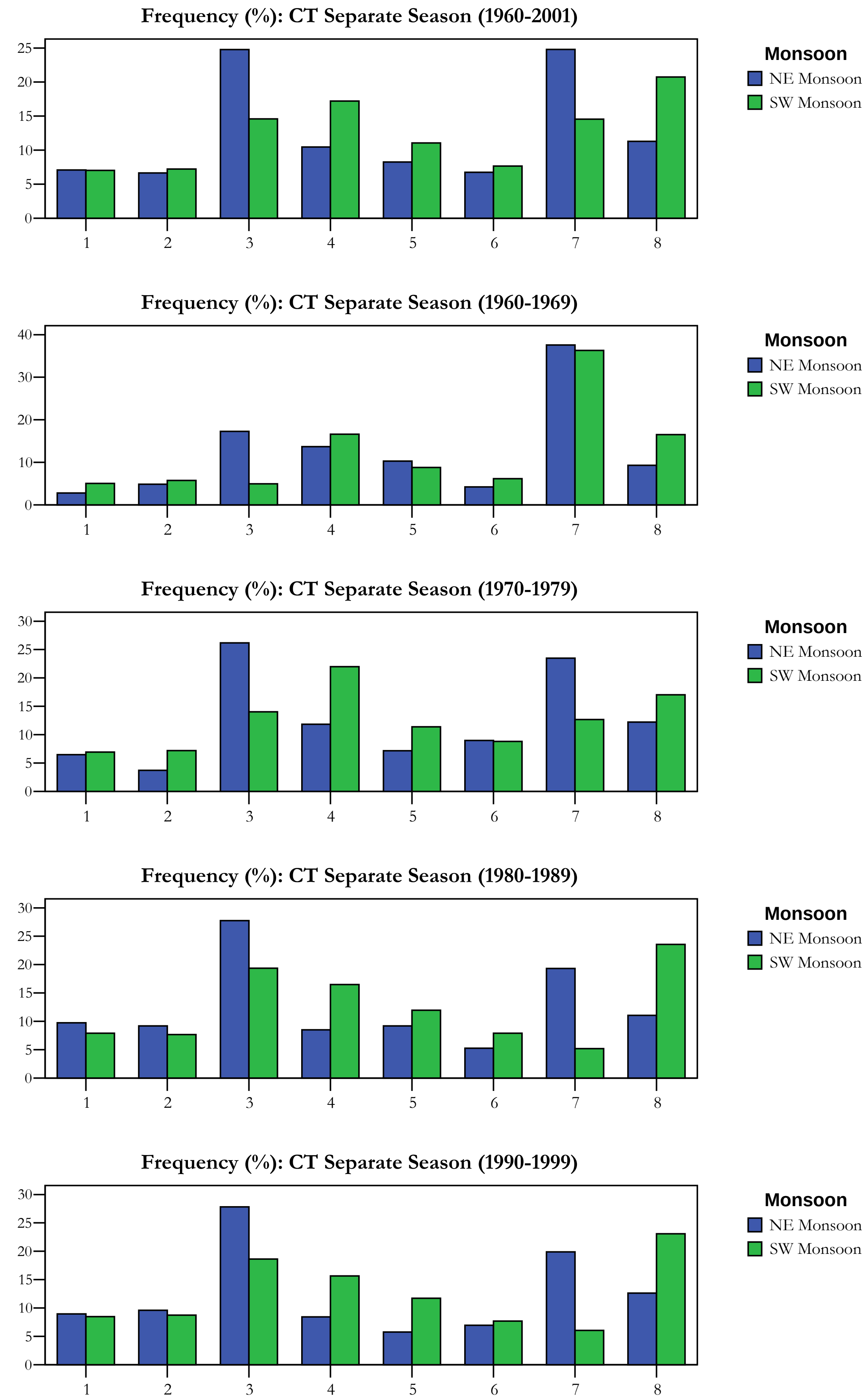


Figure 6.34a: Overall and decadal changes in frequency (for CT1) based on monsoon cycle

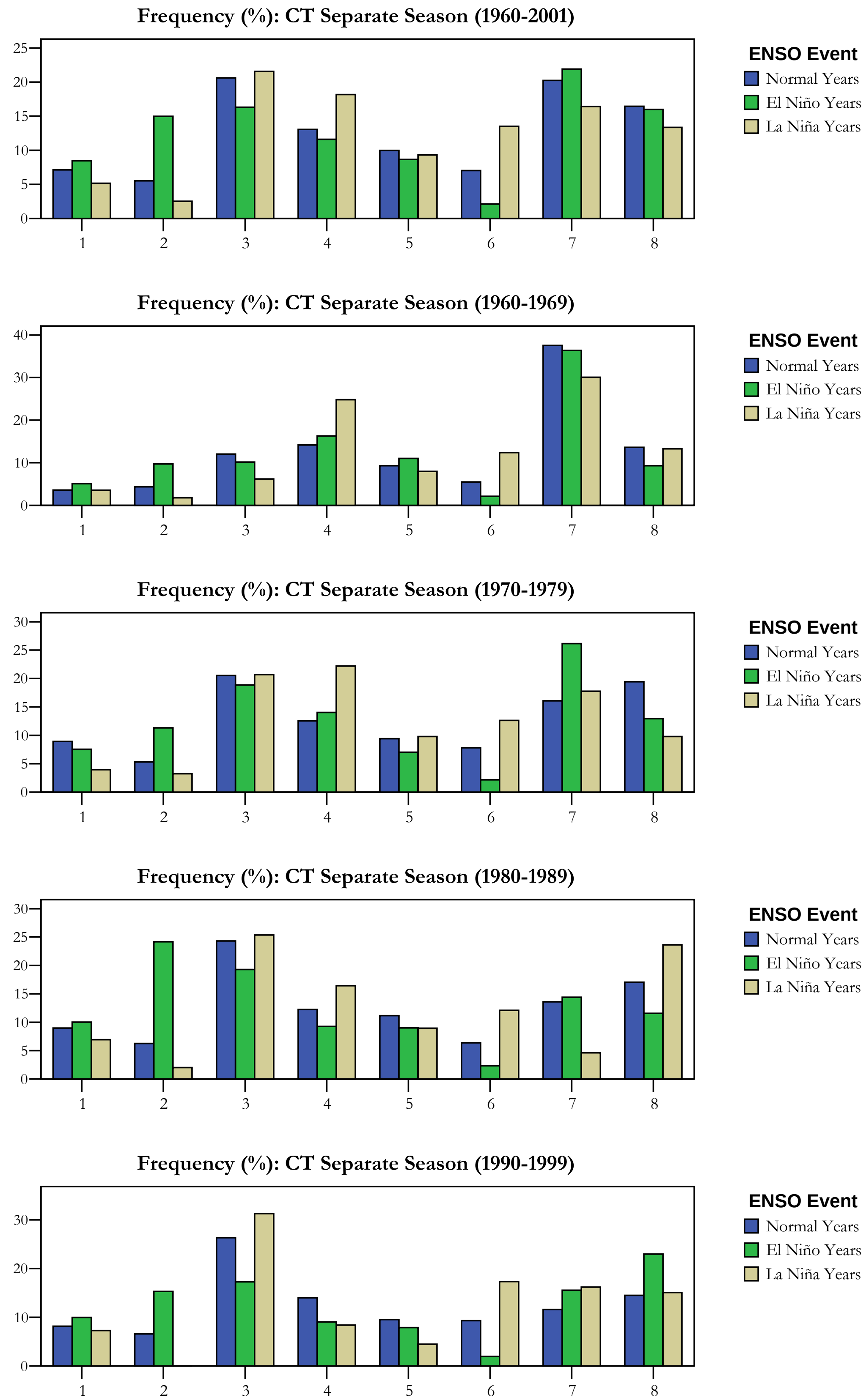


Figure 6.34b: Overall and decadal changes in frequency (for CT1) based on ENSO events

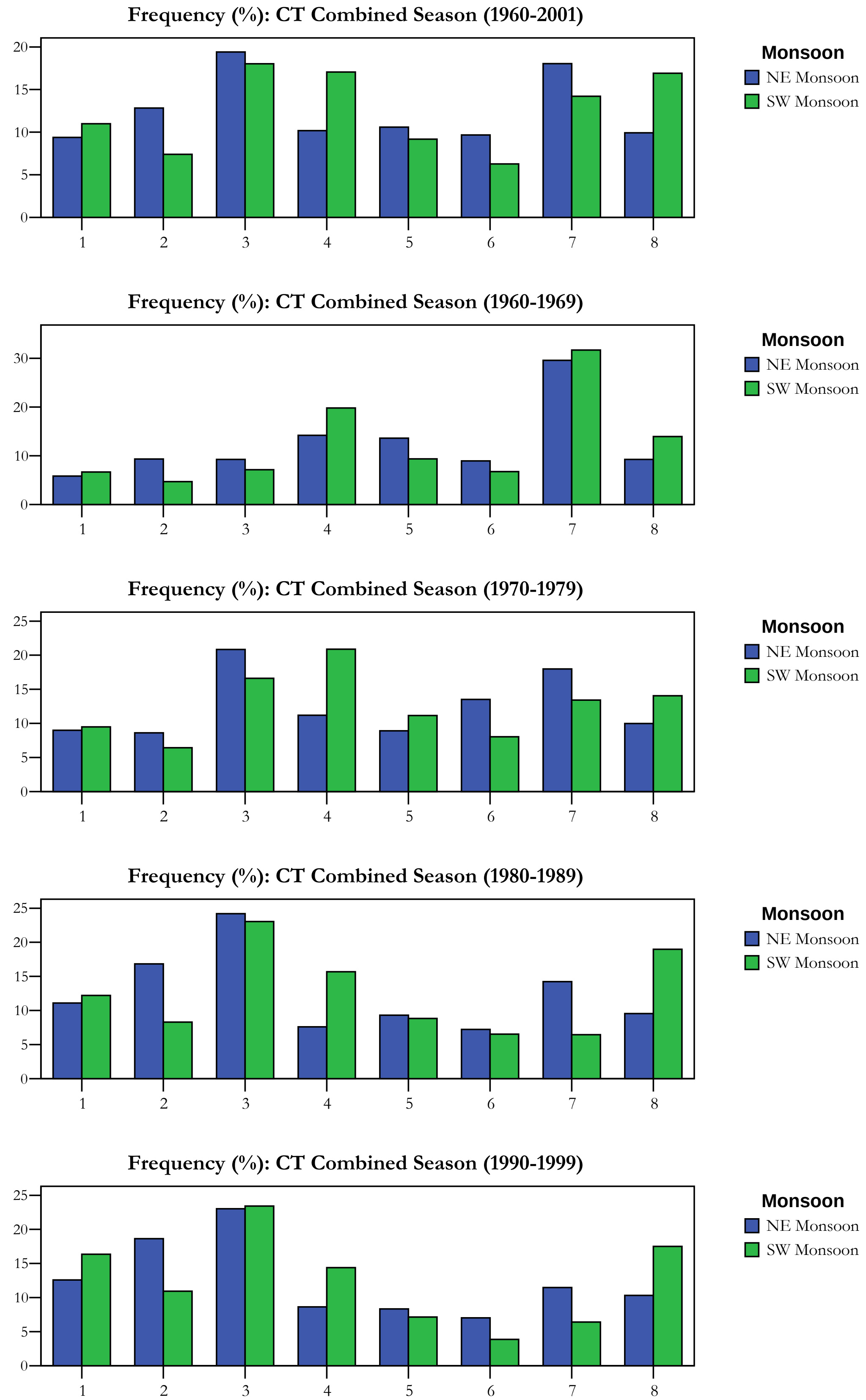


Figure 6.34c: Overall and decadal changes in frequency (for CT2) based on monsoon cycle

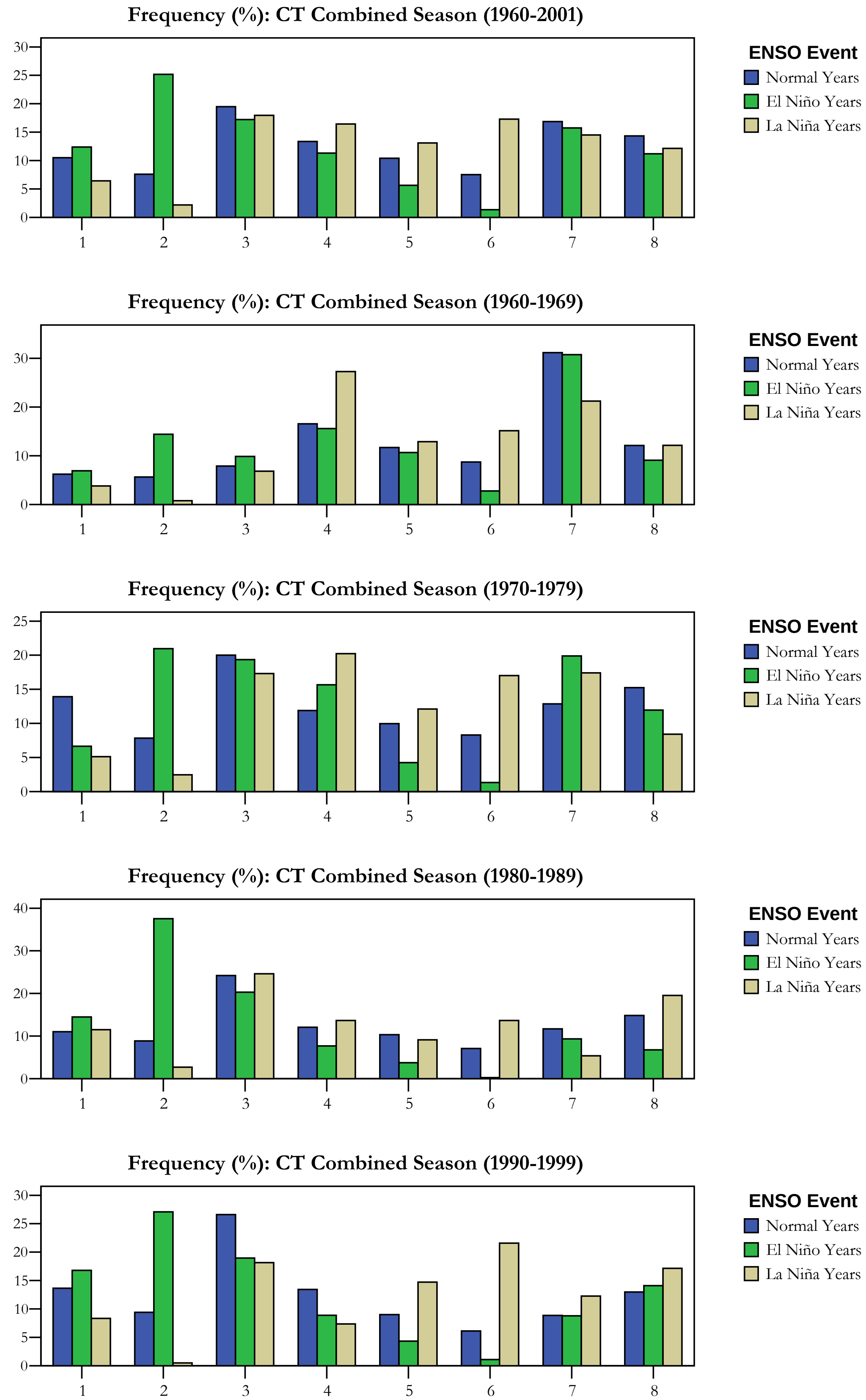


Figure 6.34d: Overall and decadal changes in frequency (for CT2) based on ENSO events

6.4.7 Correlation between circulation types

Two different methods have been employed to produce the new typing schemes, referred to as CT1 (PCA is independently performed on each of the two separate seasons), and CT2 (combining the two seasons). Analysis of the map patterns (see Section 6.4.5) implicitly suggests that the eight final types classified by the two different schemes correspond with each other. For instance, Type 8 that is established for CT1 (both the NE and SW monsoons) is strikingly similar with the Type 8 produced by CT2. The loading maps (which show the spatial distribution of high variance for each component) for the three different PCAs, namely the NE and SW methods (CT1) and the all-seasons method (CT2) are also almost identical (see Figures 6.42, 6.43 and 6.44). These results lead to the question: do the eight circulation types produced by the three different PCAs generally represent the same synoptic circulations?

The speculation should become clearer after performing the frequency analysis (see Section 6.4.6). Here, it was shown that the corresponding types (from CT1 and CT2) share similar distributions of occurrences when assessed under various situations (i.e. the monsoon cycle, ENSO events and changing in trend over the 42-year study period). To conclusively affirm this finding, a Spearmen-Rank correlation analysis is performed on these three different techniques[59]. The results are shown in Table 6.29a-c. It is very evident that the corresponding pair (e.g. Type 8 for both CT1 and CT2) shows the highest value of correlation – confirming the above suggestion that the two new typing schemes essentially represent the same synoptic modes. The correlation values (of the corresponding pairs) between CT1 (for both SW and NE monsoons) and CT2 are very high, where 0.85 is the lowest and 0.99 the highest. However, the correlation values between CT1_SW (typing scheme with separate SWM season) and CT1_NE (the NEM season) are comparatively lower, from 0.64 up to 0.93. Interestingly, the corresponding positive and negative phases of PCs also show very high correlations, but in the opposite direction (negative). For example, CT1's Type 8 (produced from the lowest negative scores of PC4) is negatively correlated with CT2's Type 4 (produced from the highest positive scores of PC4). This serves as another strong indicator that the two different methods, indeed, produce a similar typing scheme.

[59] The correlation is performed by creating the composites for each one of the 8 circulation types (produced by the three PCAs). These composites are, then, correlated between each other using the Spearman Rank technique.

Table 6.29: Rank correlation values between the composites of circulation types established by three different methods

(a) Northeast Monsoon CT1_NE – All Years CT2

	CT2_1	CT2_2	CT2_3	CT2_4	CT2_5	CT2_6	CT2_7	CT2_8
CT1_NE1	**0.85**	-0.39	0.11	-0.37	-0.75	0.48	-0.20	0.42
CT1_NE2	-0.25	**0.97**	-0.43	-0.14	0.21	-0.92	0.46	0.08
CT1_NE3	-0.26	-0.47	**0.96**	0.35	0.35	0.45	-0.94	-0.49
CT1_NE4	-0.47	-0.11	0.16	**0.87**	0.36	0.00	-0.16	-0.84
CT1_NE5	-0.96	0.25	0.23	0.47	**0.95**	-0.30	-0.11	-0.56
CT1_NE6	0.45	-0.88	0.48	-0.11	-0.31	**0.94**	-0.54	0.15
CT1_NE7	0.26	0.47	-0.95	-0.38	-0.35	-0.45	**0.97**	0.54
CT1_NE8	0.70	-0.04	-0.34	-0.85	-0.63	0.12	0.31	**0.94**

(b) Southwest Monsoon CT1_SW – All Years CT2

	CT2_1	CT2_2	CT2_3	CT2_4	CT2_5	CT2_6	CT2_7	CT2_8
CT1_SW1	**0.93**	-0.21	-0.34	-0.63	-0.91	0.25	0.21	0.73
CT1_SW2	-0.28	**0.90**	-0.27	-0.10	0.22	-0.91	0.30	-0.01
CT1_SW3	-0.17	-0.44	**0.98**	0.15	0.29	0.45	-0.96	-0.32
CT1_SW4	-0.61	-0.25	0.49	**0.91**	0.60	0.19	-0.47	-0.91
CT1_SW5	-0.84	-0.02	0.60	0.62	**0.89**	0.01	-0.51	-0.74
CT1_SW6	0.32	-0.86	0.33	0.06	-0.19	**0.94**	-0.35	0.05
CT1_SW7	-0.03	0.38	-0.89	0.03	-0.11	-0.41	**0.92**	0.13
CT1_SW8	0.68	0.15	-0.45	-0.92	-0.61	-0.05	0.44	**0.99**

(c) Southwest Monsoon CT1_SW – Northeast Monsoon CT1_NE

	CT1_NE1	CT1_NE2	CT1_NE3	CT1_NE4	CT1_NE5	CT1_NE6	CT1_NE7	CT1_NE8
CT1_SW1	**0.64**	-0.24	-0.34	-0.56	-0.83	0.38	0.34	0.79
CT1_SW2	-0.44	**0.83**	-0.33	0.03	0.33	-0.78	0.30	-0.14
CT1_SW3	0.18	-0.43	**0.92**	0.09	0.15	0.53	-0.92	-0.26
CT1_SW4	-0.29	-0.20	0.58	**0.77**	0.50	0.05	-0.60	-0.85
CT1_SW5	-0.46	0.06	0.61	0.48	**0.77**	-0.11	-0.61	-0.76
CT1_SW6	0.53	-0.79	0.37	-0.07	-0.35	**0.83**	-0.34	0.16
CT1_SW7	-0.30	0.37	-0.81	0.09	0.01	-0.56	**0.82**	0.06
CT1_SW8	0.39	0.14	-0.53	-0.83	-0.55	0.07	0.57	**0.93**

** Shaded and bolded values indicate the highest positive correlation for each pair*

6.4.8 New classification schemes (CT1 & CT2): the summary

In general, it is found that the two methods (CT1 and CT2) that produce the two typing schemes are almost identical. This conclusion is not only proven by the correlation analysis (see Section 6.4.7), but is also established by evaluating the characteristics observed in the map patterns (see Figures 6.42 – 6.47). The summary of the frequency distributions and the types associations with the monsoon and ENSO is given in Table 6.30.

Based on the overall frequency, Types 3 and 7 are considered the most prominent modes of large-scale circulation in the Southeast Asia region. Types 2, 3 and 7 are associated with the Northeast Monsoon (October-March); and Types 4 and 8 are linked to the Southwest Monsoon (April-September). Type 2 (5) is positively (negatively) associated with El Niño. In contrast, Types 4 and 8 (1) are positively (negatively) related to La Niña. Of all the eight types, only Types 1 (7) exhibits an increasing (decreasing) trend in terms of occurrences.

Table 6.30: The high and low frequency of occurrences based on various conditions

	Overall		Monsoon		ENSO		Decadal
Type	CT1	CT2	NEM	SWM	El Niño	La Niña	Trend
1						Low	Increase
2	Low		High, CT2 *		High		
3	High	High	High, CT1*				
4				High		High	
5		Low			Low		
6	Low	Low					
7	High	High	High			High	Decrease
8				High			

Other than those indicated by (*), all are applied for both CT1 and CT2

6.5 Chapter summary

The synoptic indicators evaluated in this chapter consist of five ENSO indices and eight for monsoon (including the two newly established indices – RD1 and RD2). With regard to the teleconnections with surface climate elements, the best indices for ENSO are SOI and Niño-3.4. This is consistent with the findings of Sirabaha (1998, 2004) and Tangang (2001). As for the monsoon, the newly-established indices have convincingly outperformed the older indices introduced by previous studies (see Section 6.2.7). This is attributed to the fact that the new indices are specifically optimised for Borneo. In other words, these indices are localised, so that it will only capture the monsoon signals that are closely associated with Borneo itself. The synoptic indicators that are selected for further analysis in Chapter 8 (inter-relationships with various factors/variables) are: SOI, Niño-3.4, IOI, UM1, UM2, RD1 and RD2.

There are four classification schemes (using absolute SLP data and combining the monsoon seasons) that have been evaluated, and each one has its own advantages and disadvantages. The identified best scheme is Method 2, which uses absolute SLP values as its data input, and applies a correlation-based technique in the second stage of the classification (assigning the remaining days into their initial key types). The selection is based on its advantage in terms of physical interpretability and ability – (i) to optimise the original data based on the spatial distribution of communalities; (ii) to discriminate various climatic factors; and (iii) to establish recognisable relationships with surface climate (see Section 6.3.7).

Two classification schemes based on SLP anomaly data are also assessed in this chapter. CT1 is established by separating the two monsoon seasons; and CT2 is created by combining the two seasons. Based on frequency and correlation analyses, the eight circulation types produced by CT1 and CT2 do exhibit similar characteristic. Thus, it is reasonable to conclude that either combining or separating the two monsoons is not really an important issue. Some types are shown to be more frequent in one monsoon or the other, but they are still evident in a combined seasonal analysis.

The circulation types established by this two different methods (in terms of data input) will be further analysed in Chapter 7 (relationships with local climate), which will include:

- Detailed analysis of the occurrences of types under various climatic events (including strong and weak ENSO phases; and monsoon transitions) and the combination of different events (i.e. El Niño-SW Monsoon, La Niña-SW Monsoon, etc).
- Detailed analysis of relationships between the circulation types and all surface variables (i.e. average magnitude and frequencies of extreme).
- Detailed analysis of six individual stations in Borneo (Sandakan, Kota Kinabalu, Miri, Bintulu, Sibu and Kuching)

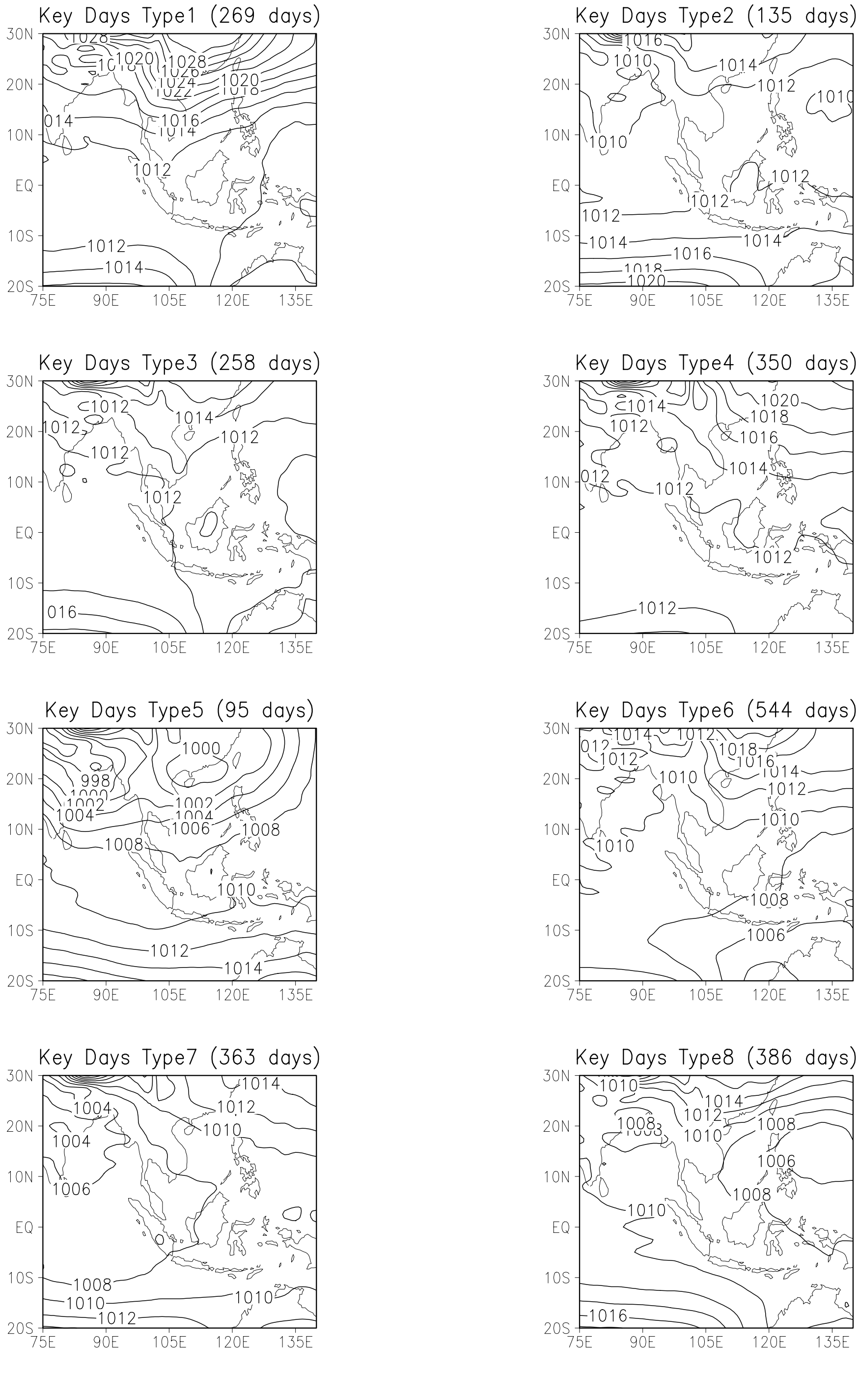


Figure 6.17: SLP maps (full field) for the keyday composites – using SLP absolute data as the original source for PCA

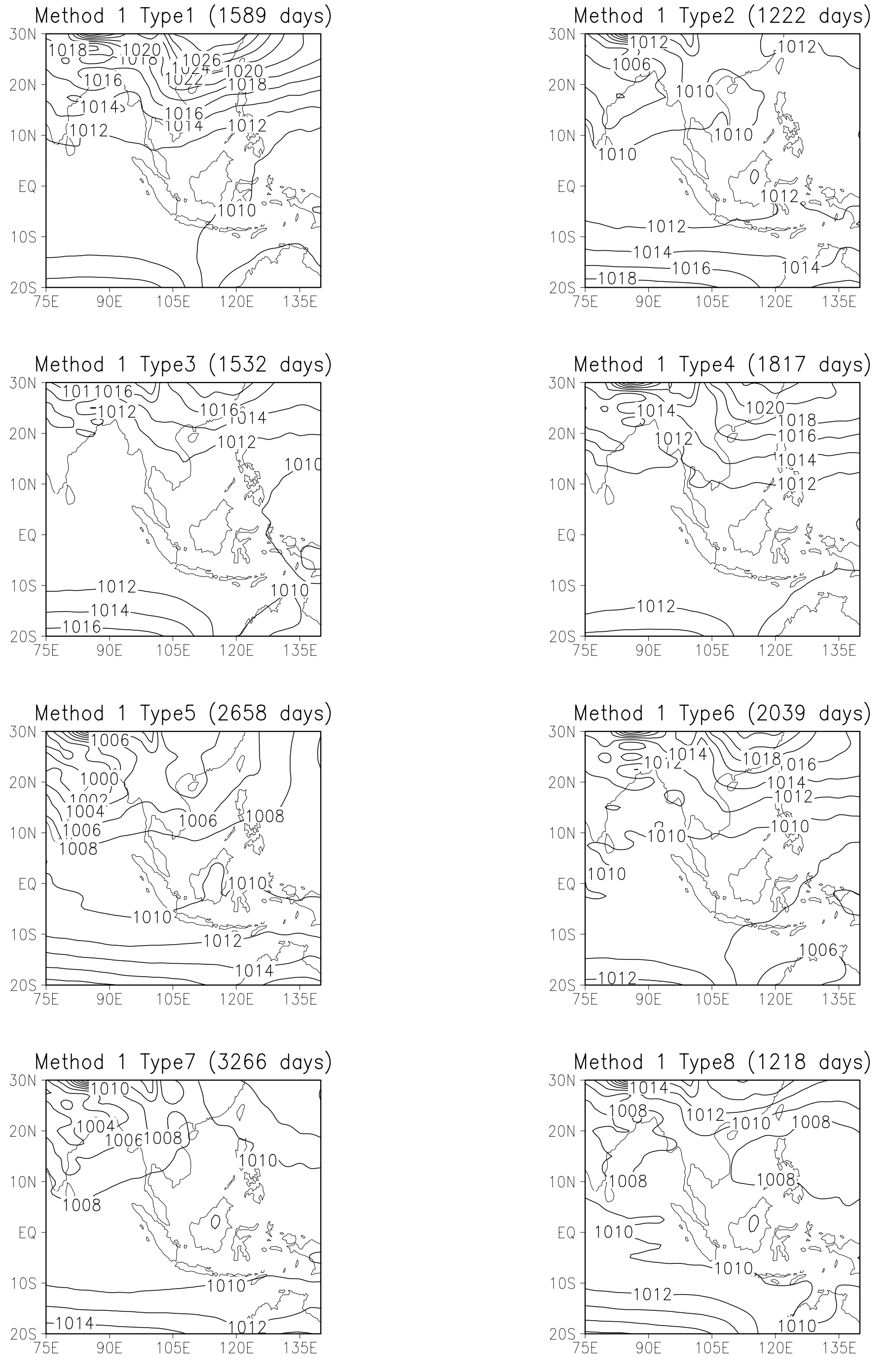


Figure 6.18: SLP maps (full field) for the composites of each type using Method 1 (Absolute-Cluster technique)

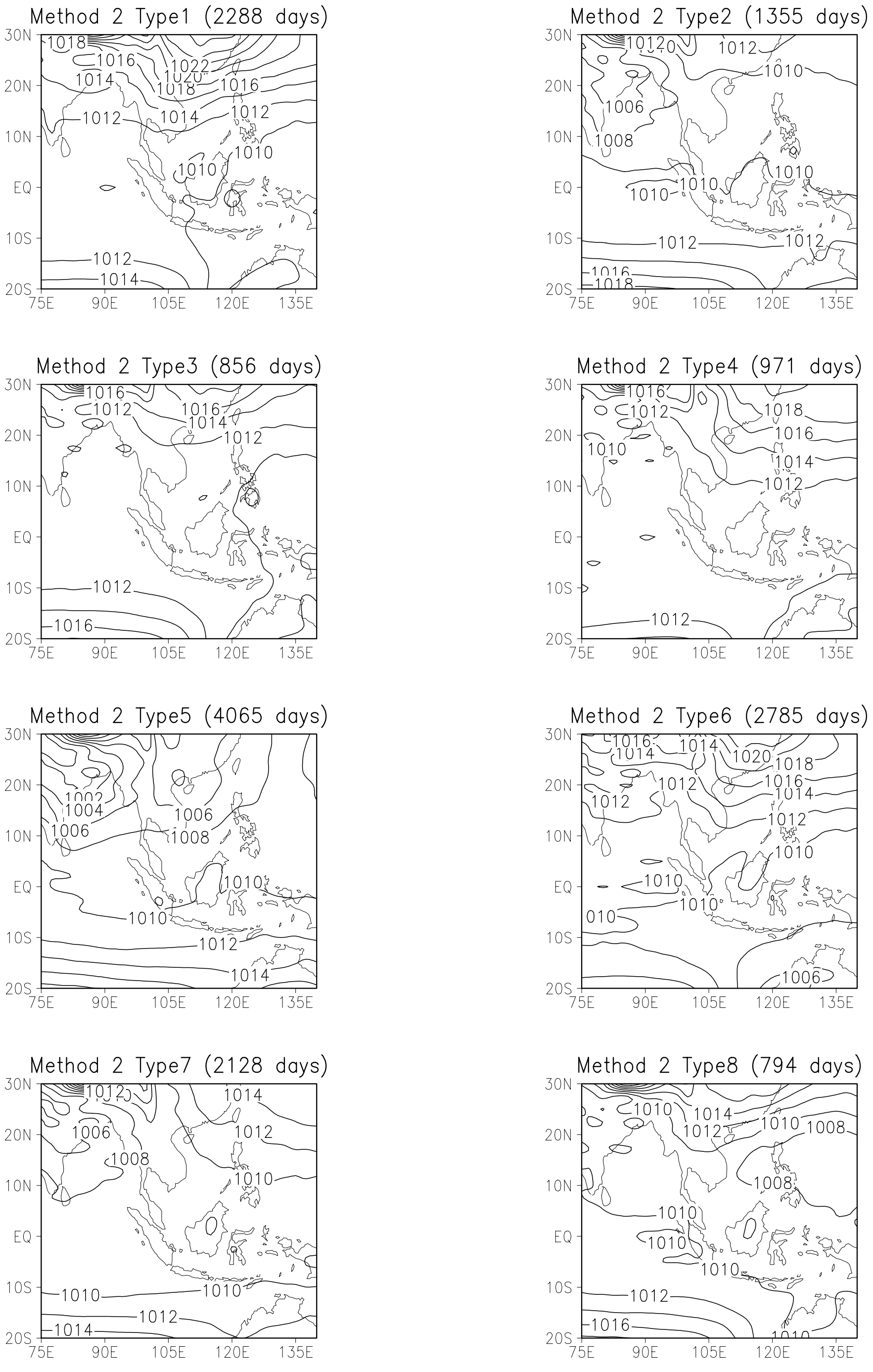


Figure 6.19: SLP maps (full field) for the composites of each type using Method 2 (Absolute-Correlation technique)

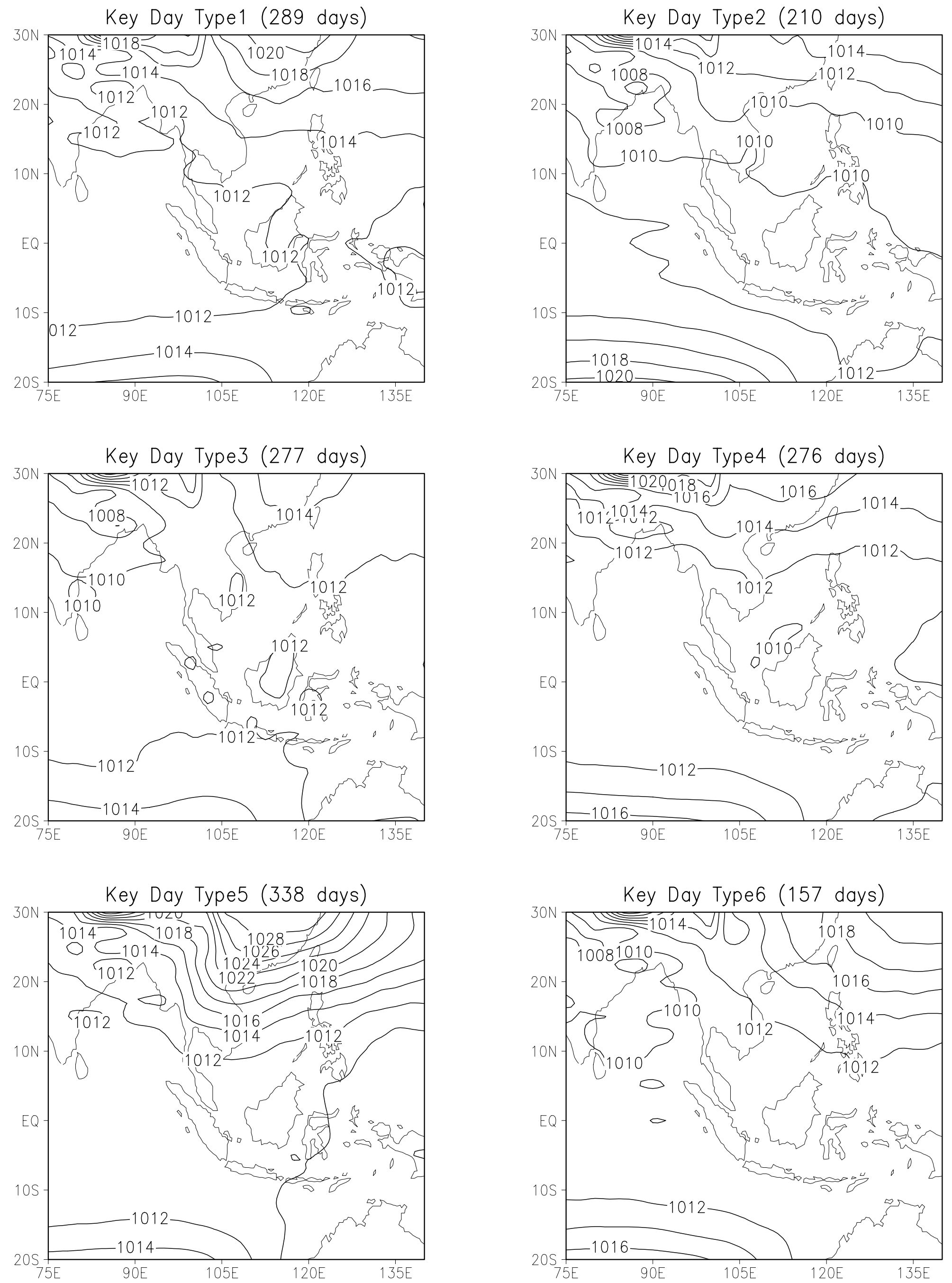


Figure 6.20a: SLP maps (full field) for the keyday composites – using SLP anomaly data as the original source for PCA

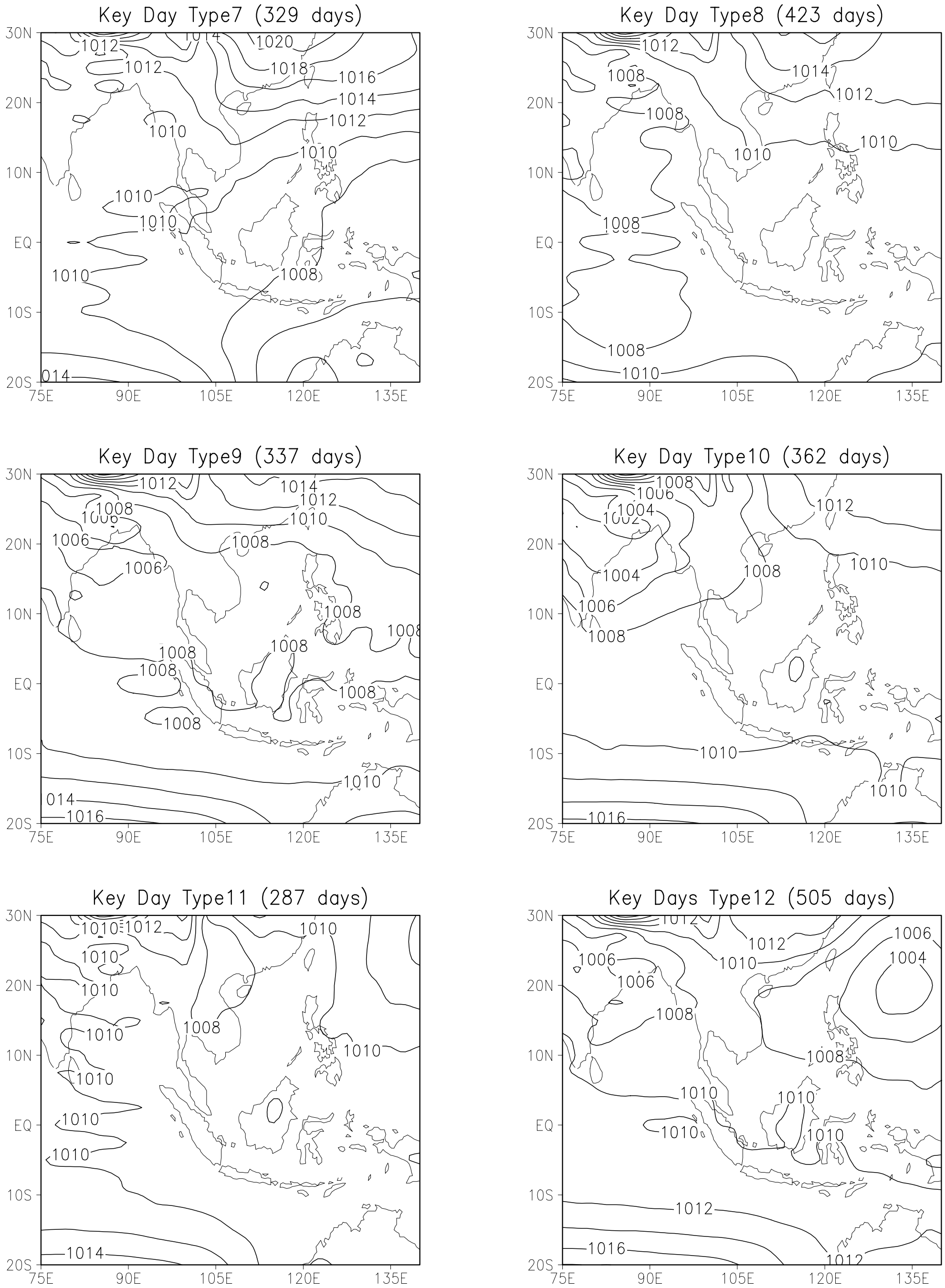


Figure 6.20b: SLP maps (full field) for the keyday composites – using SLP anomaly data as the original source for PCA

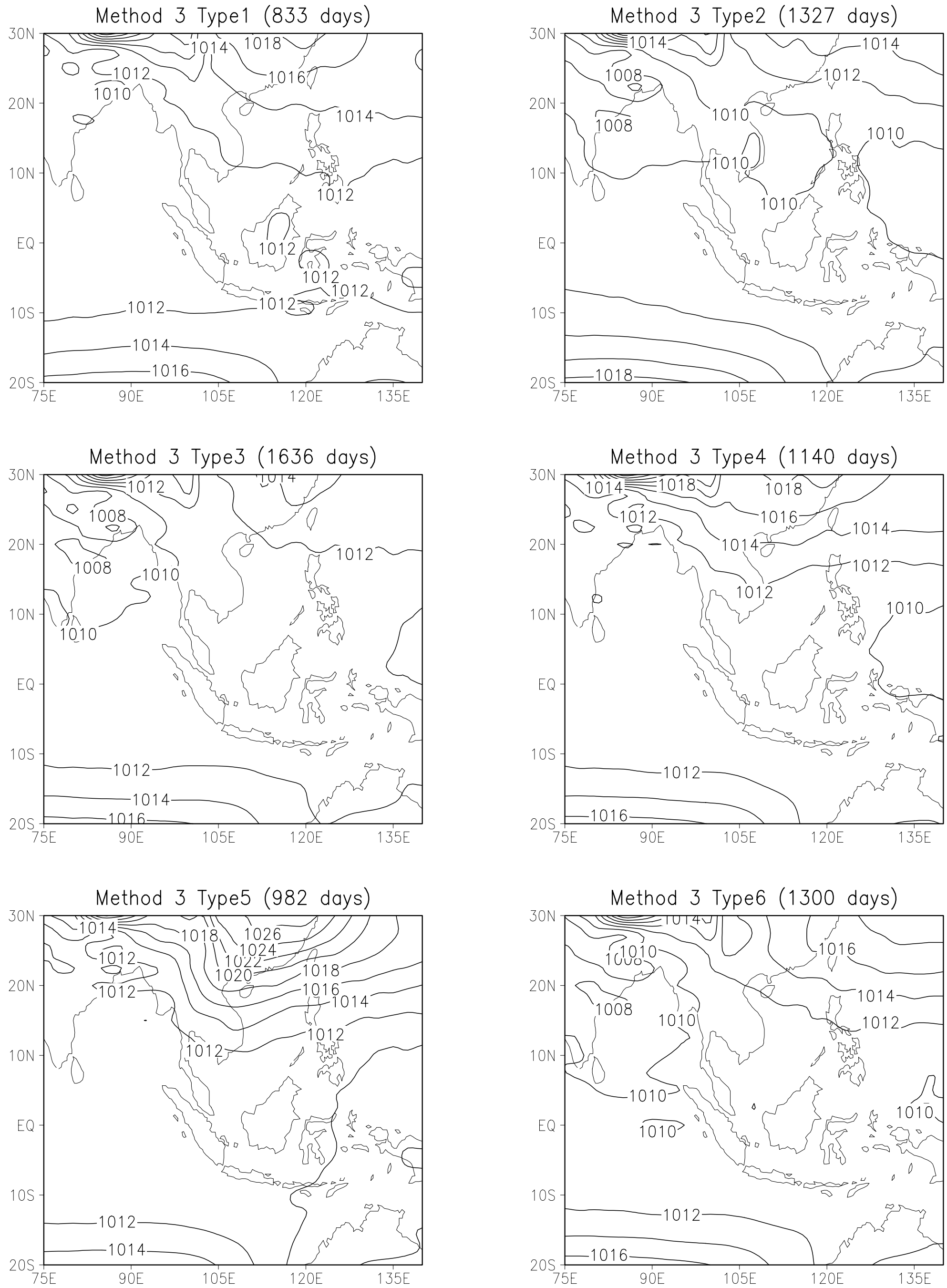


Figure 6.21a: SLP maps (full field) for the composites of each type using Method 3 (Anomaly-Cluster technique)

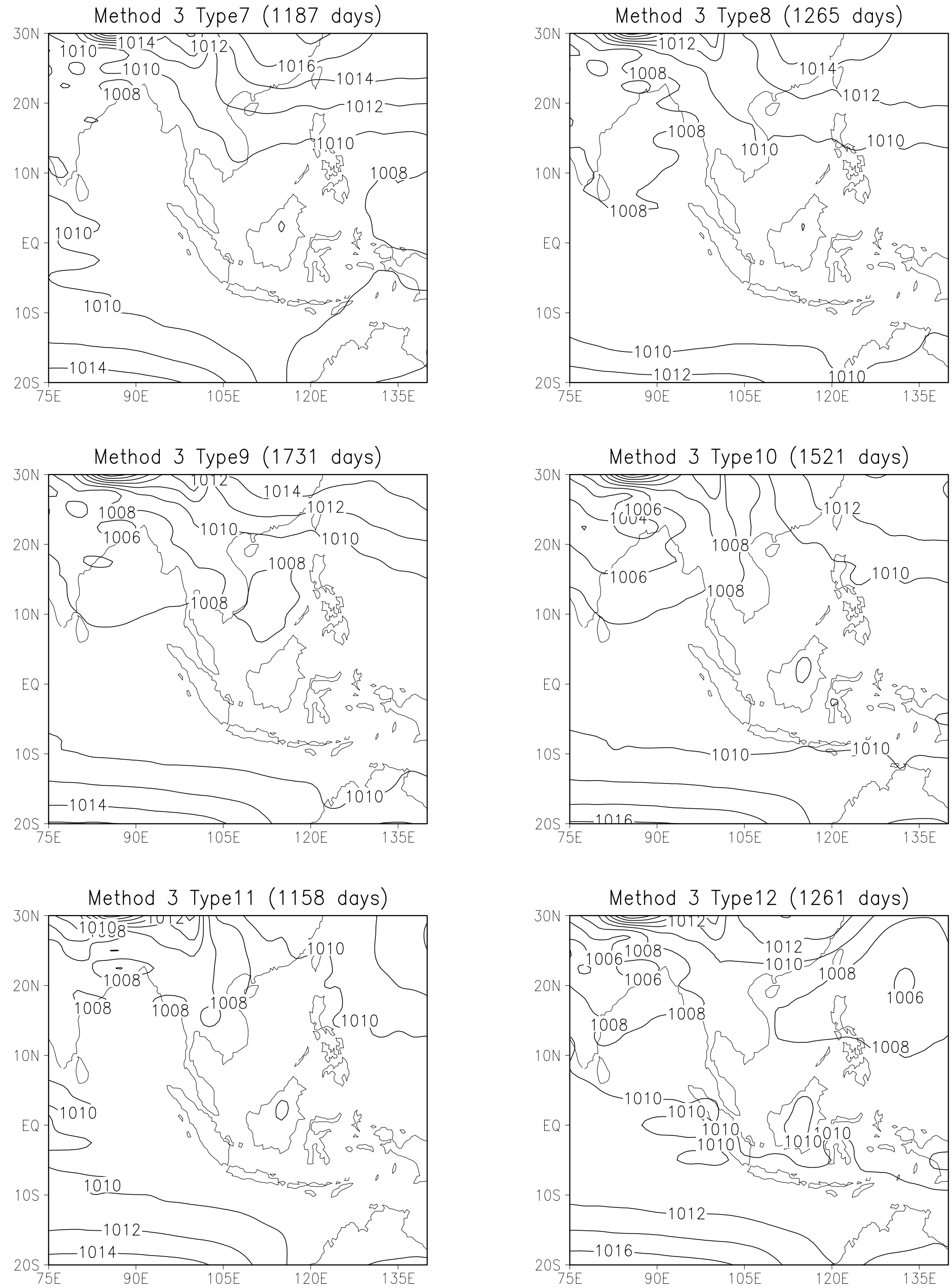


Figure 6.21b: SLP maps (full field) for the composites of each type using Method 3 (Anomaly-Cluster technique)

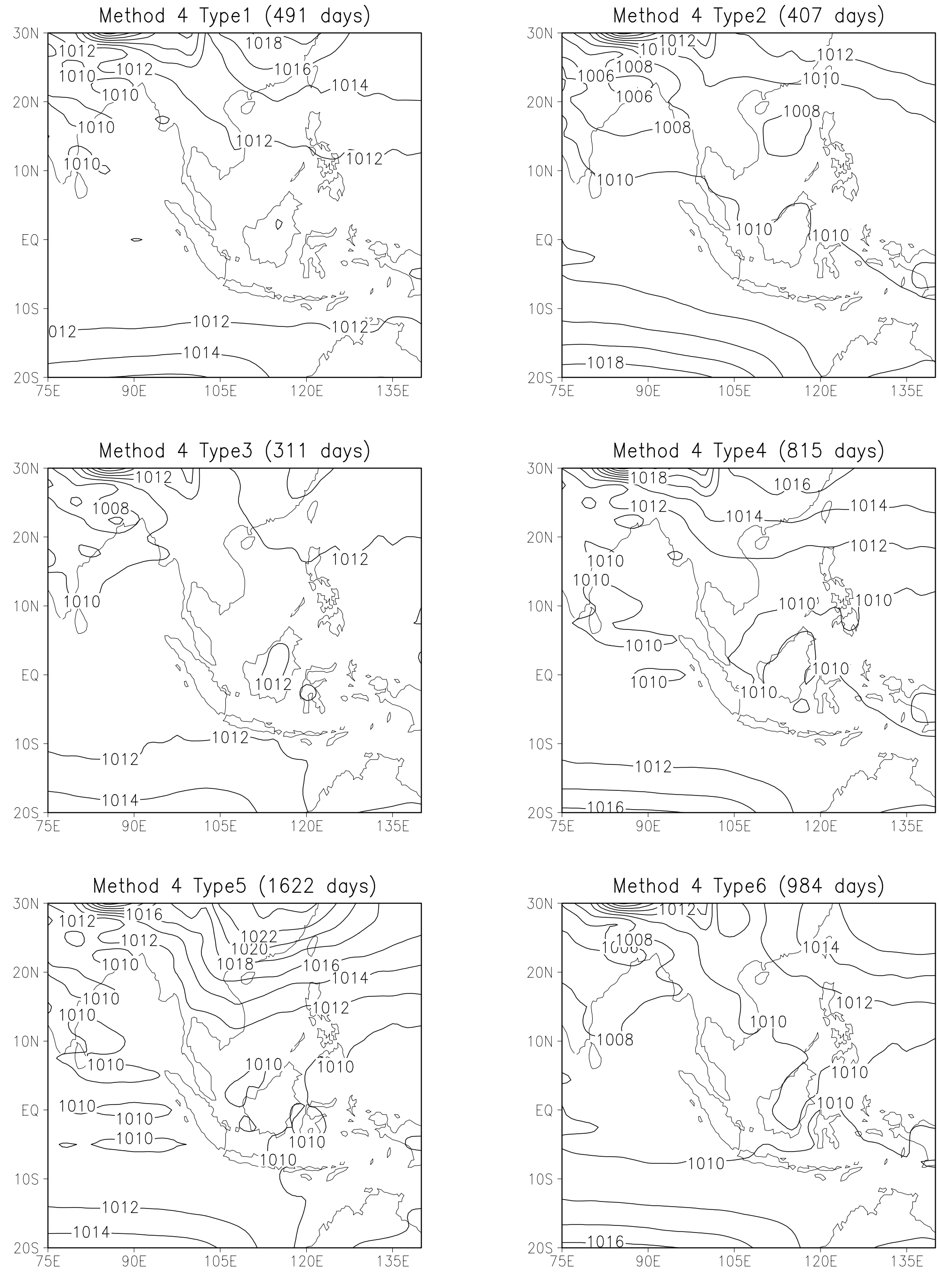


Figure 6.22a: SLP maps (full field) for the composites of each type using Method 4 (Anomaly-Correlation technique)

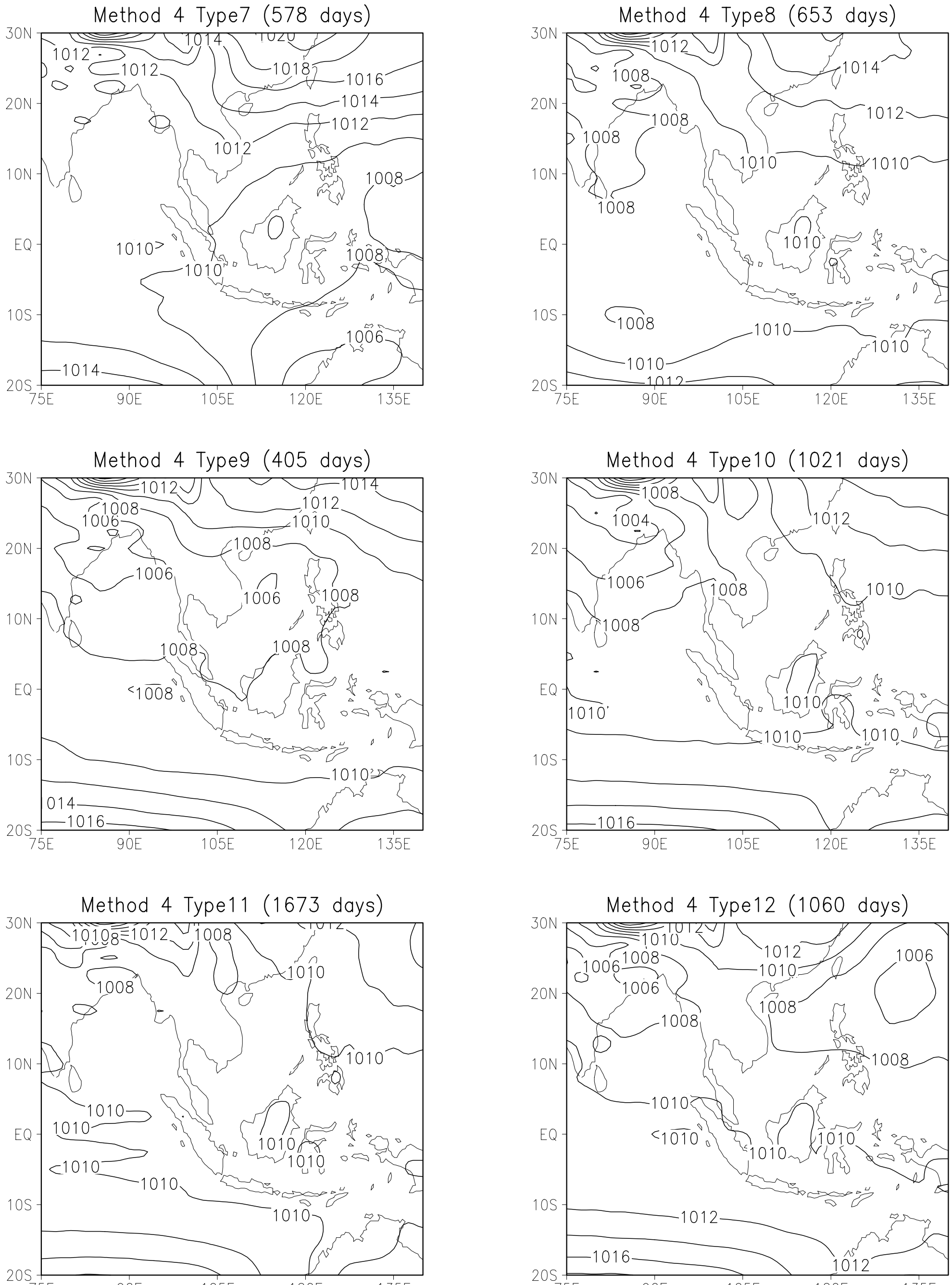


Figure 6.22b: SLP maps (full field) for the composites of each type using Method 4 (Anomaly-Correlation technique)

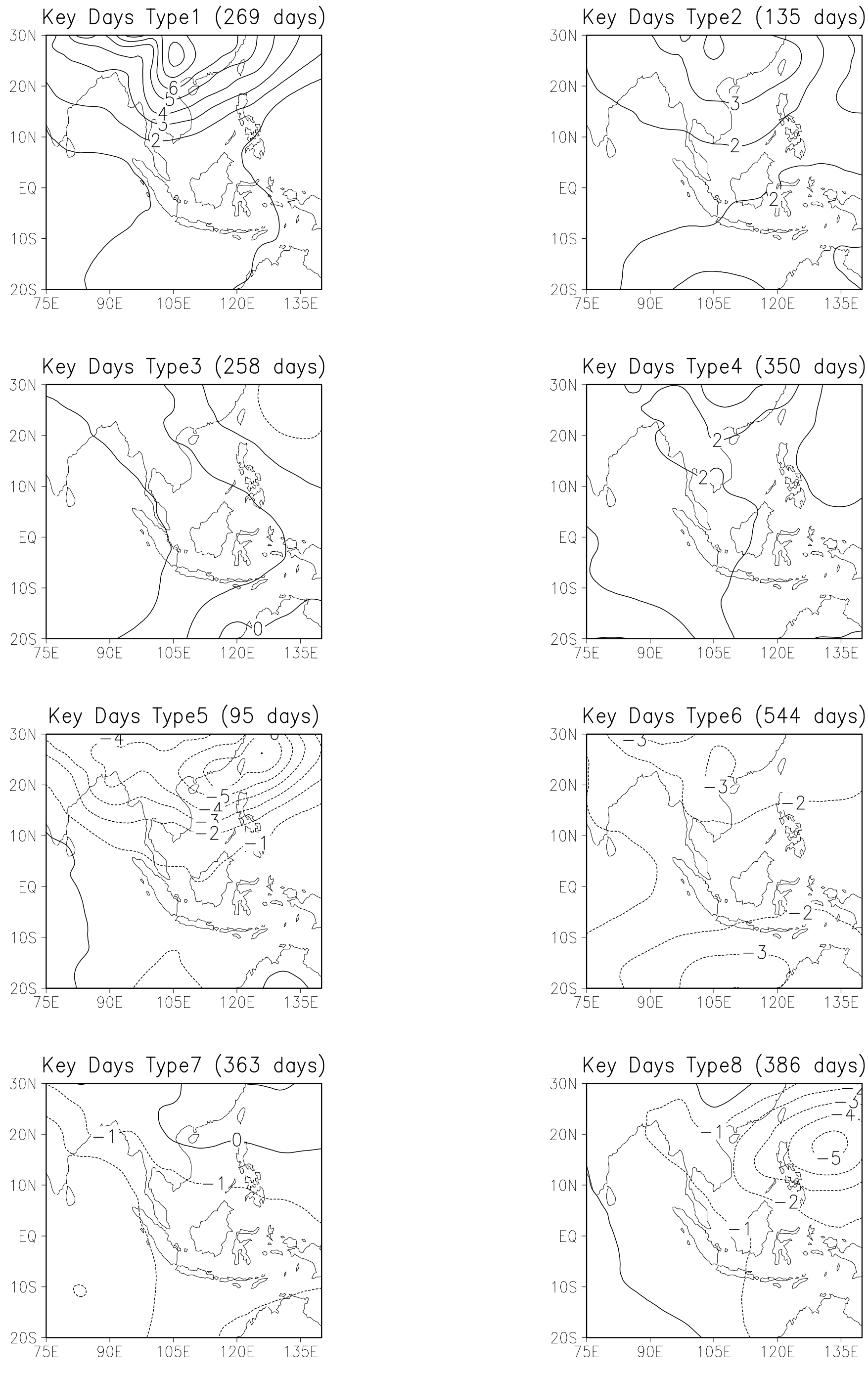


Figure 6.23: SLP maps (anomaly mb) for the keyday composites – using SLP absolute data as the original source for PCA

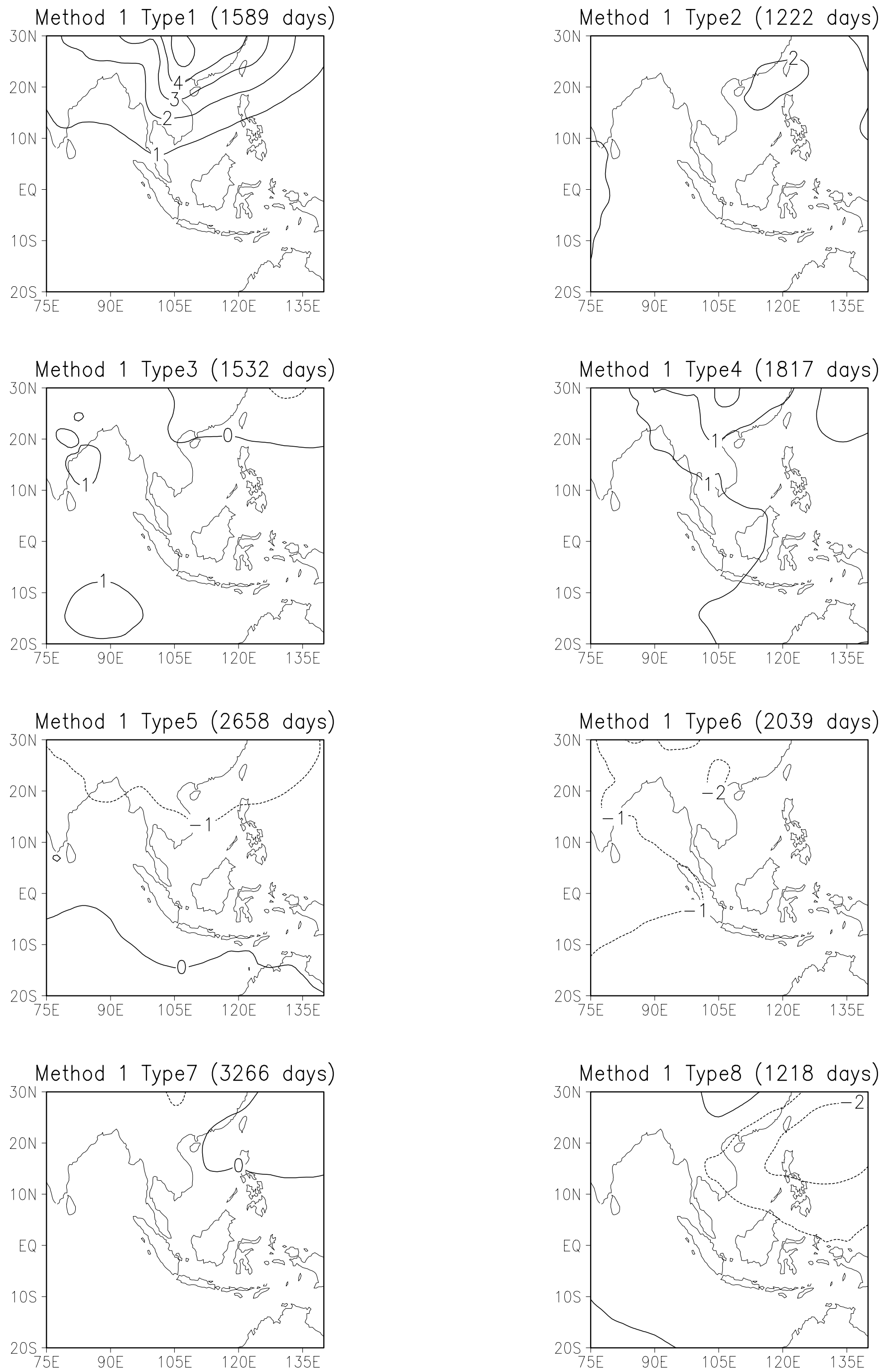


Figure 6.24: SLP maps (anomaly mb) for the composites of each type using Method 1 (Absolute-Cluster technique)

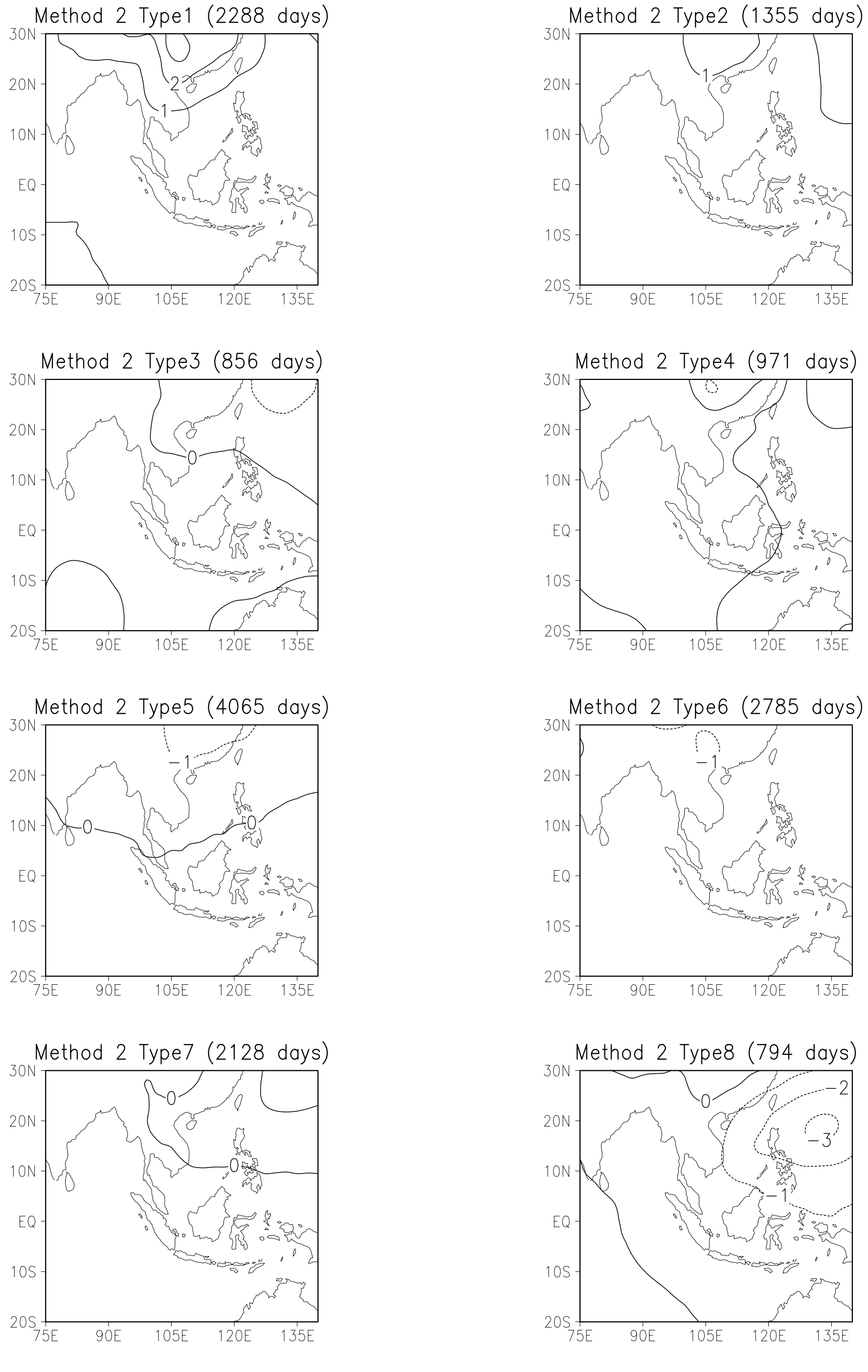


Figure 6.25: SLP maps (anomaly mb) for the composites of each type using Method 2 (Absolute-Correlation technique)

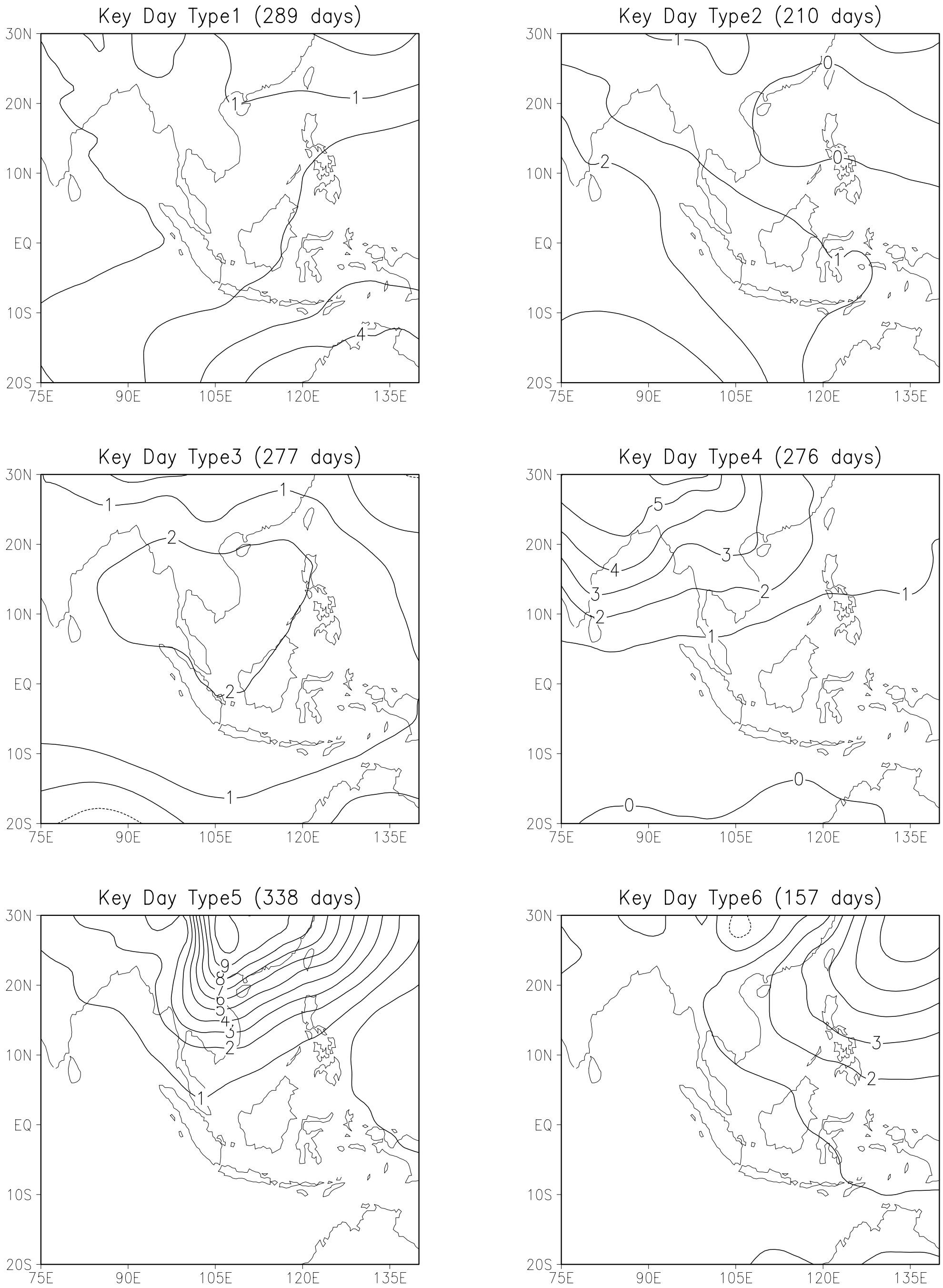


Figure 6.26a: SLP maps (anomaly mb) for the keyday composites – using SLP anomaly data as the original source for PCA

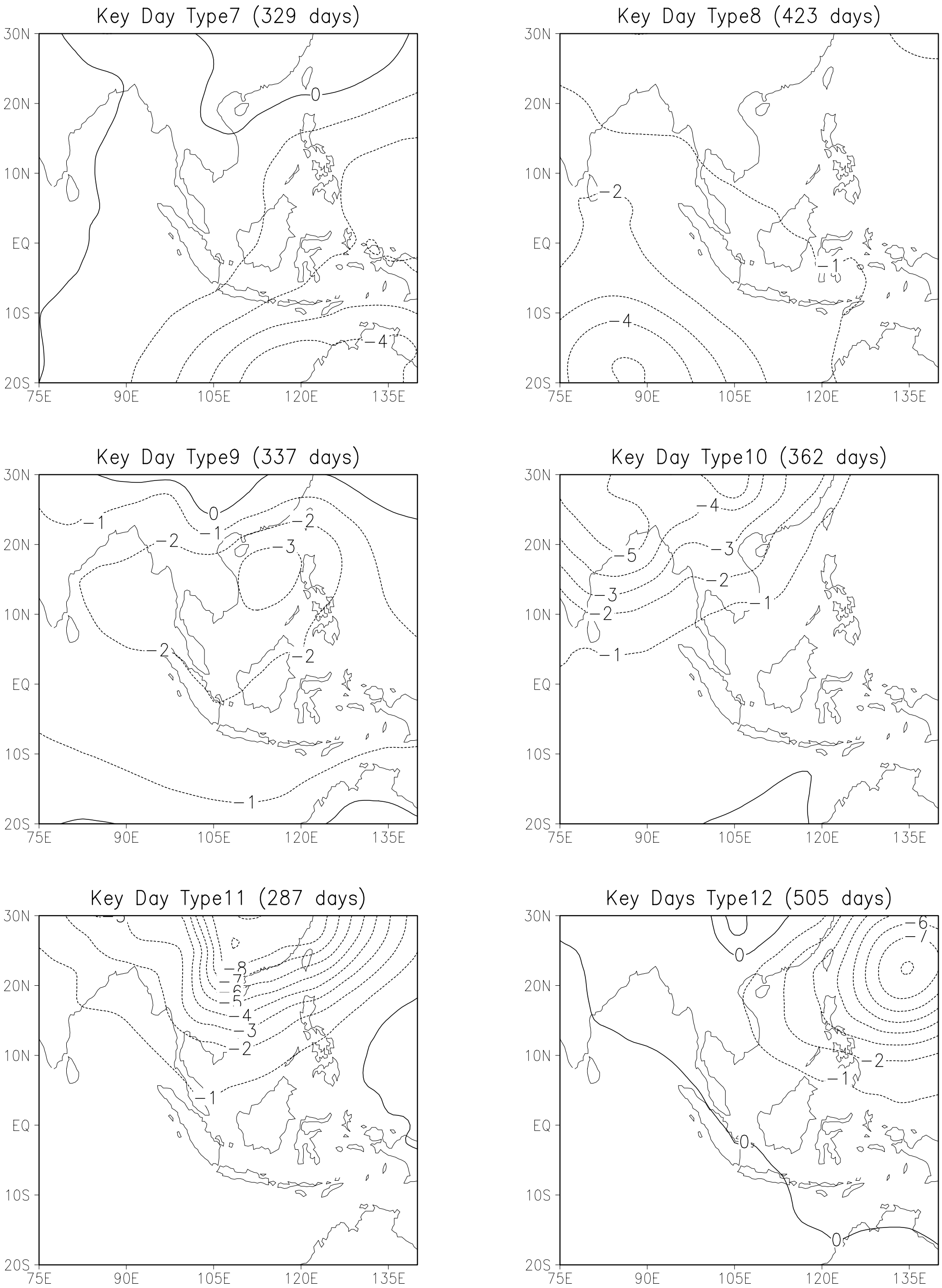


Figure 6.26b: SLP maps (anomaly mb) for the keyday composites – using SLP anomaly data as the original source for PCA

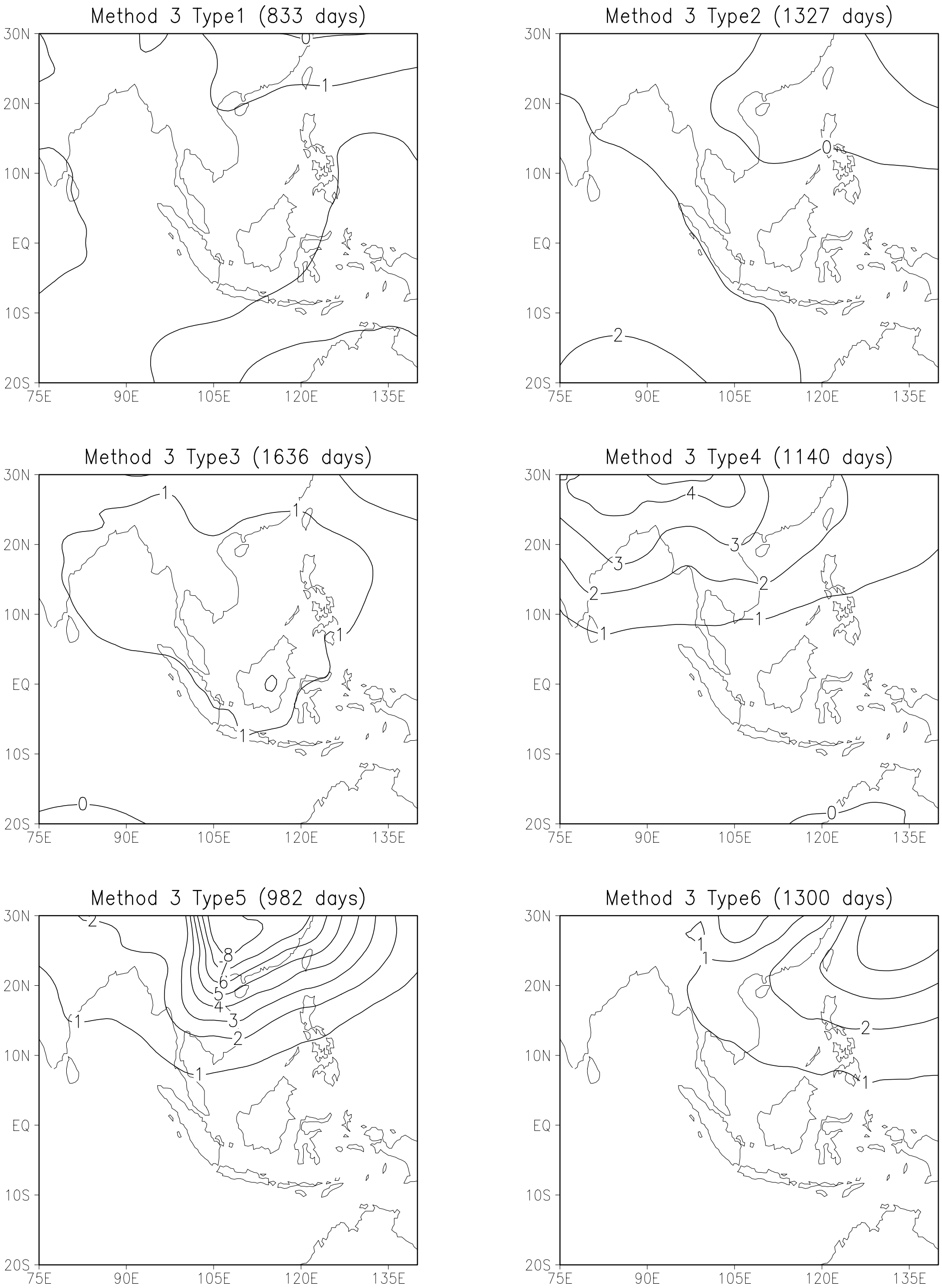


Figure 6.27a: SLP maps (anomaly mb) for the composites of each type using Method 3 (Anomaly-Correlation technique)

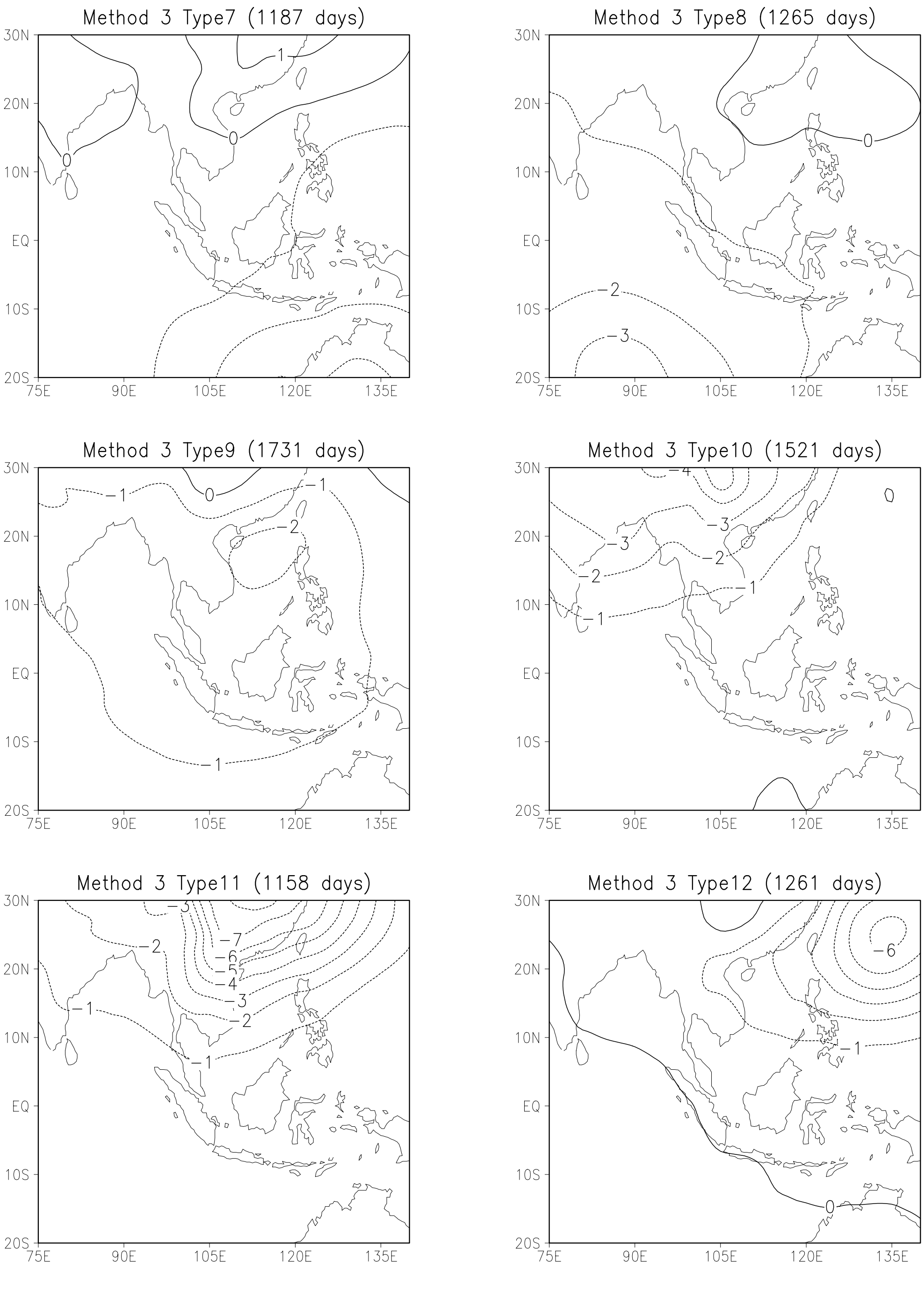


Figure 6.27b: SLP maps (anomaly mb) for the composites of each type using Method 3 (Anomaly-Correlation technique)

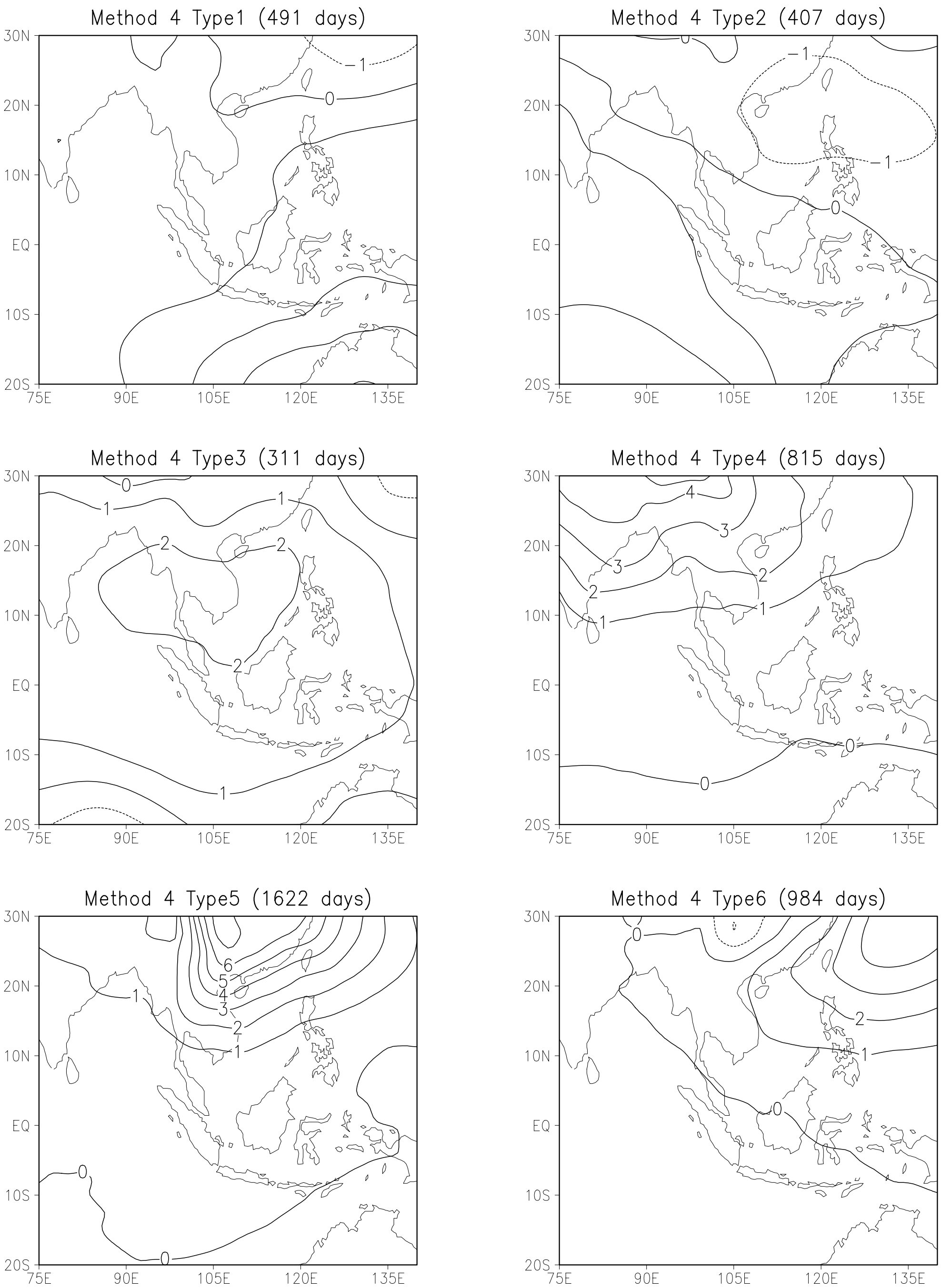


Figure 6.28a: SLP maps (anomaly mb) for the composites of each type using Method 4 (Anomaly-Correlation technique)

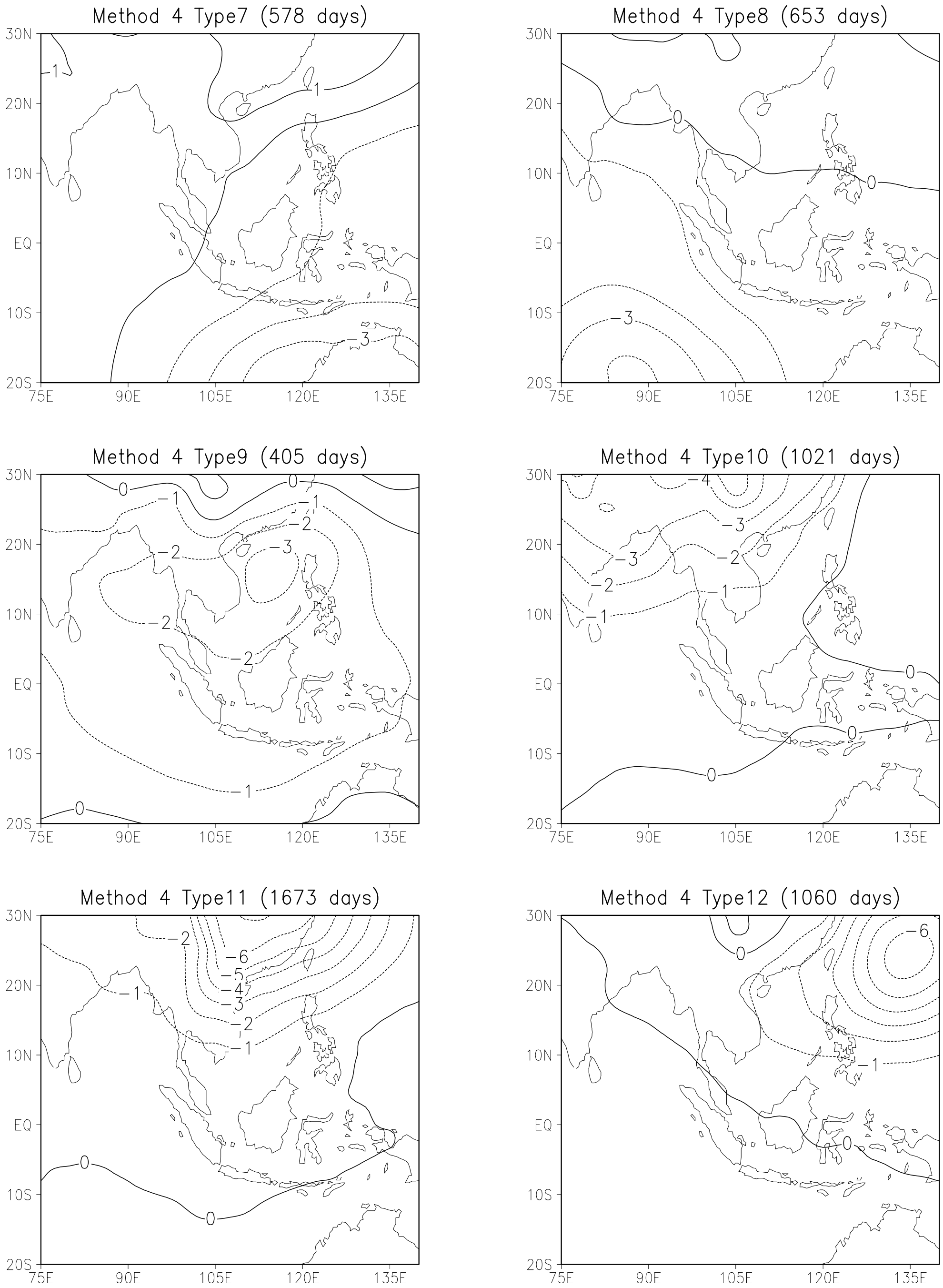


Figure 6.28b: SLP maps (anomaly mb) for the composites of each type using Method 4 (Anomaly-Correlation technique)

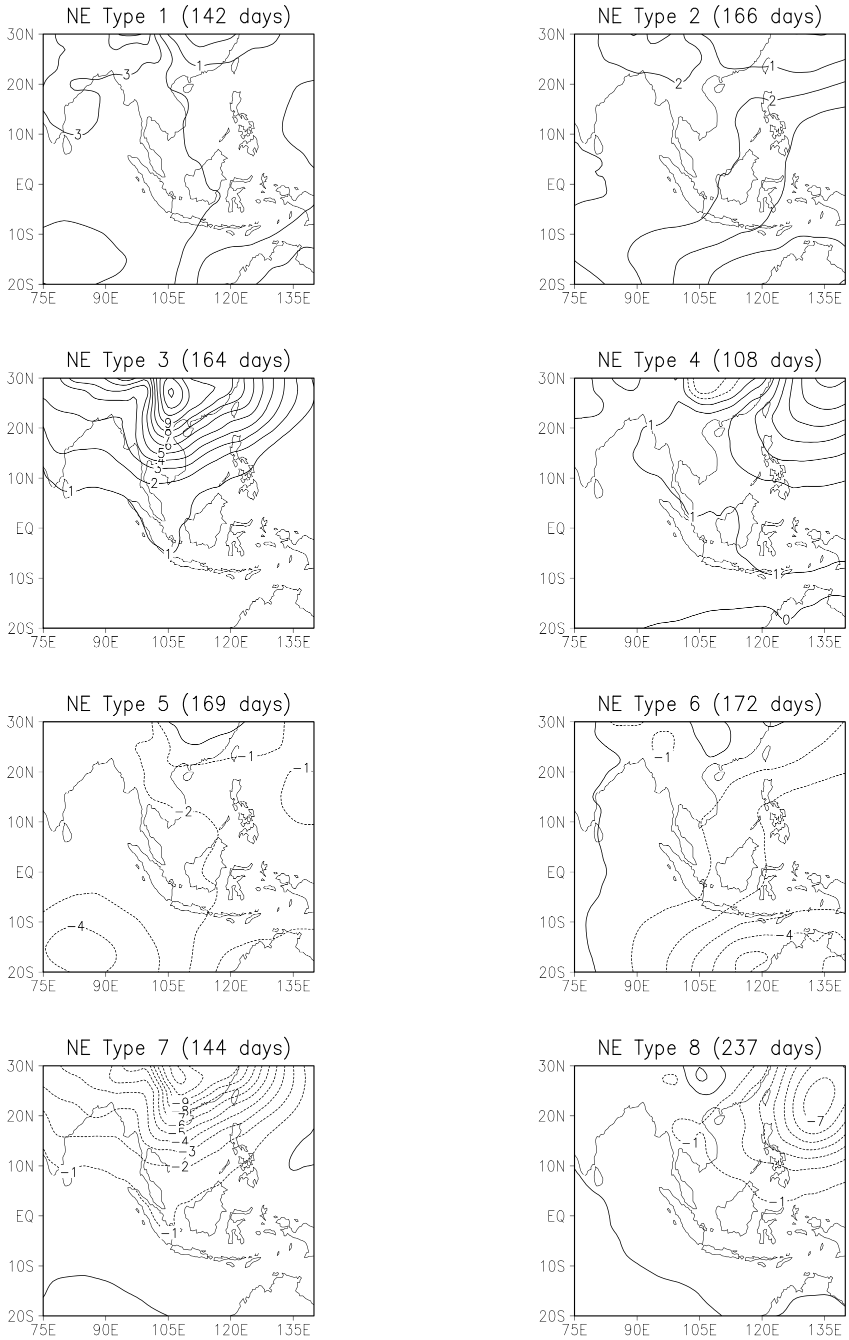


Figure 6.35a: SLP maps (anomaly) for the key composites – NE Monsoon (CT1)

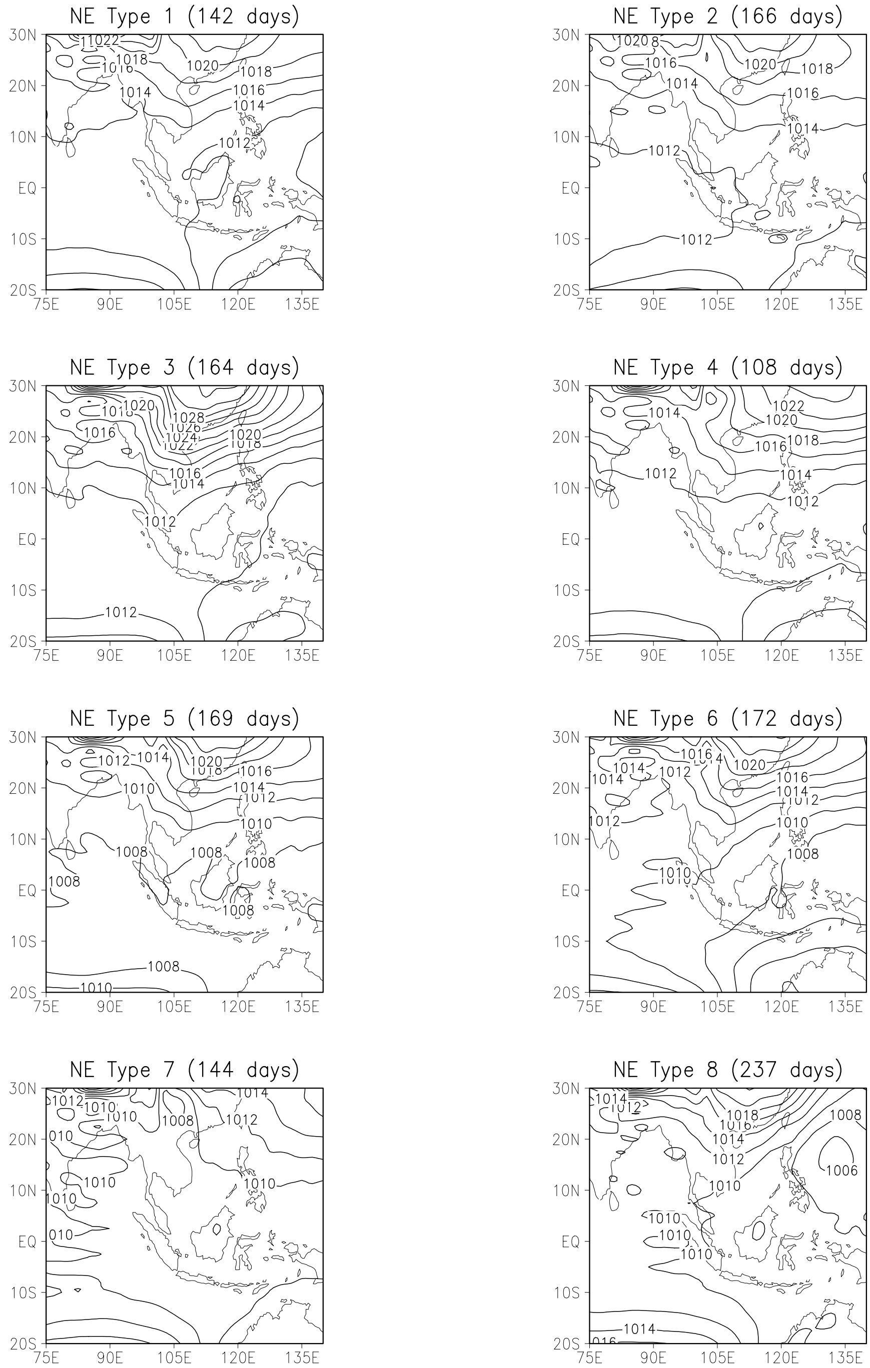


Figure 6.35b: SLP maps (full-field) for the key composites – NE Monsoon (CT1)

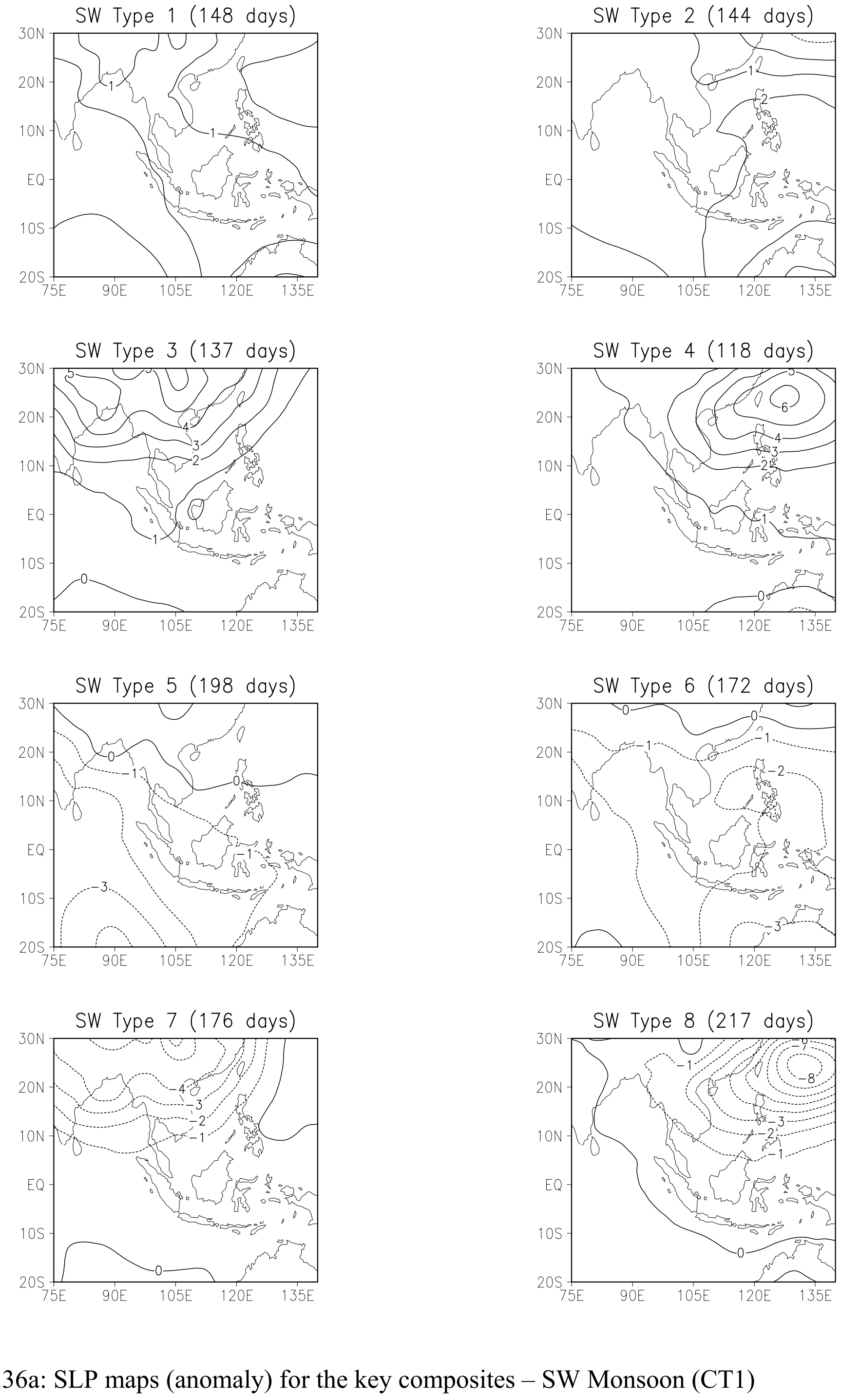


Figure 6.36a: SLP maps (anomaly) for the key composites – SW Monsoon (CT1)

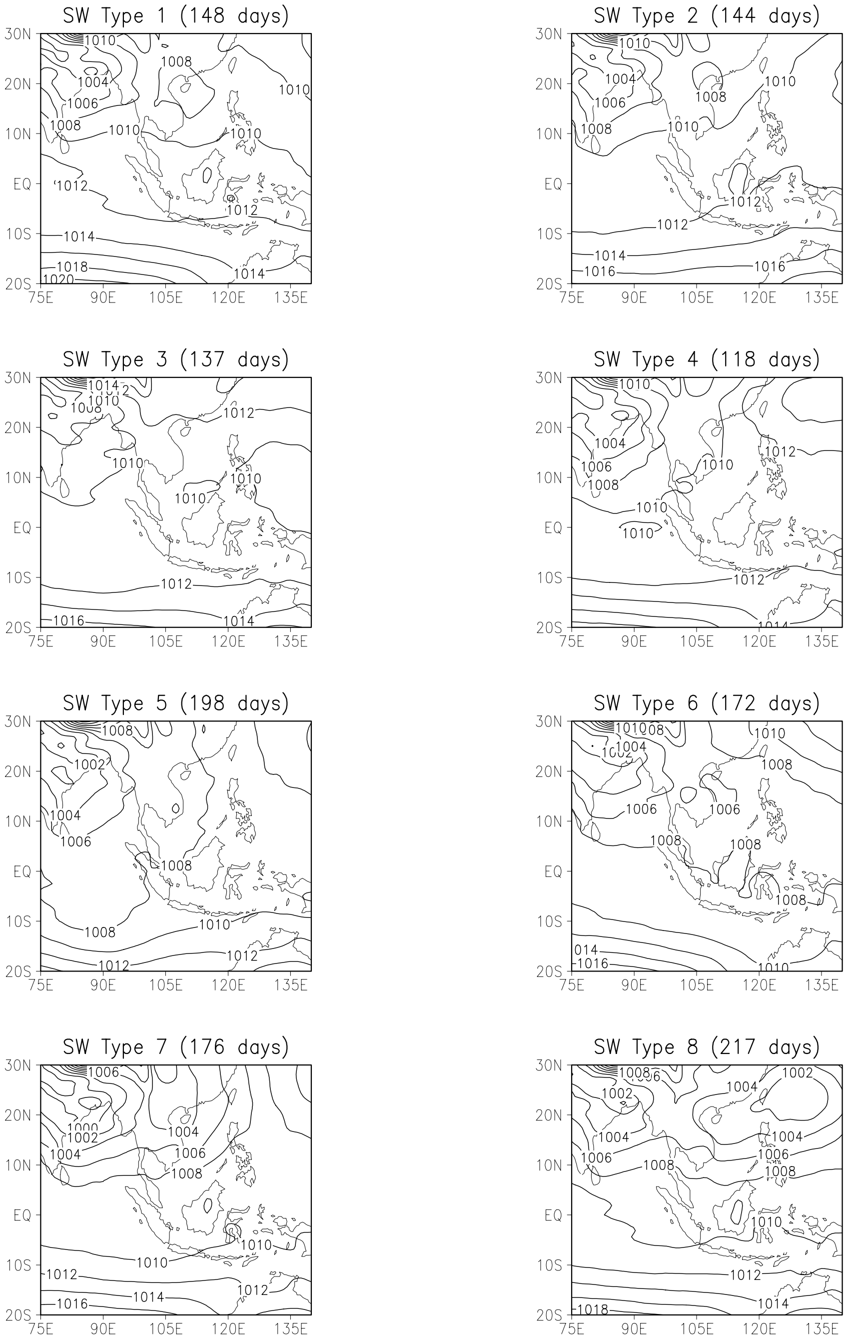


Figure 6.36b: SLP maps (full-field) for the key composites – SW Monsoon (CT1)

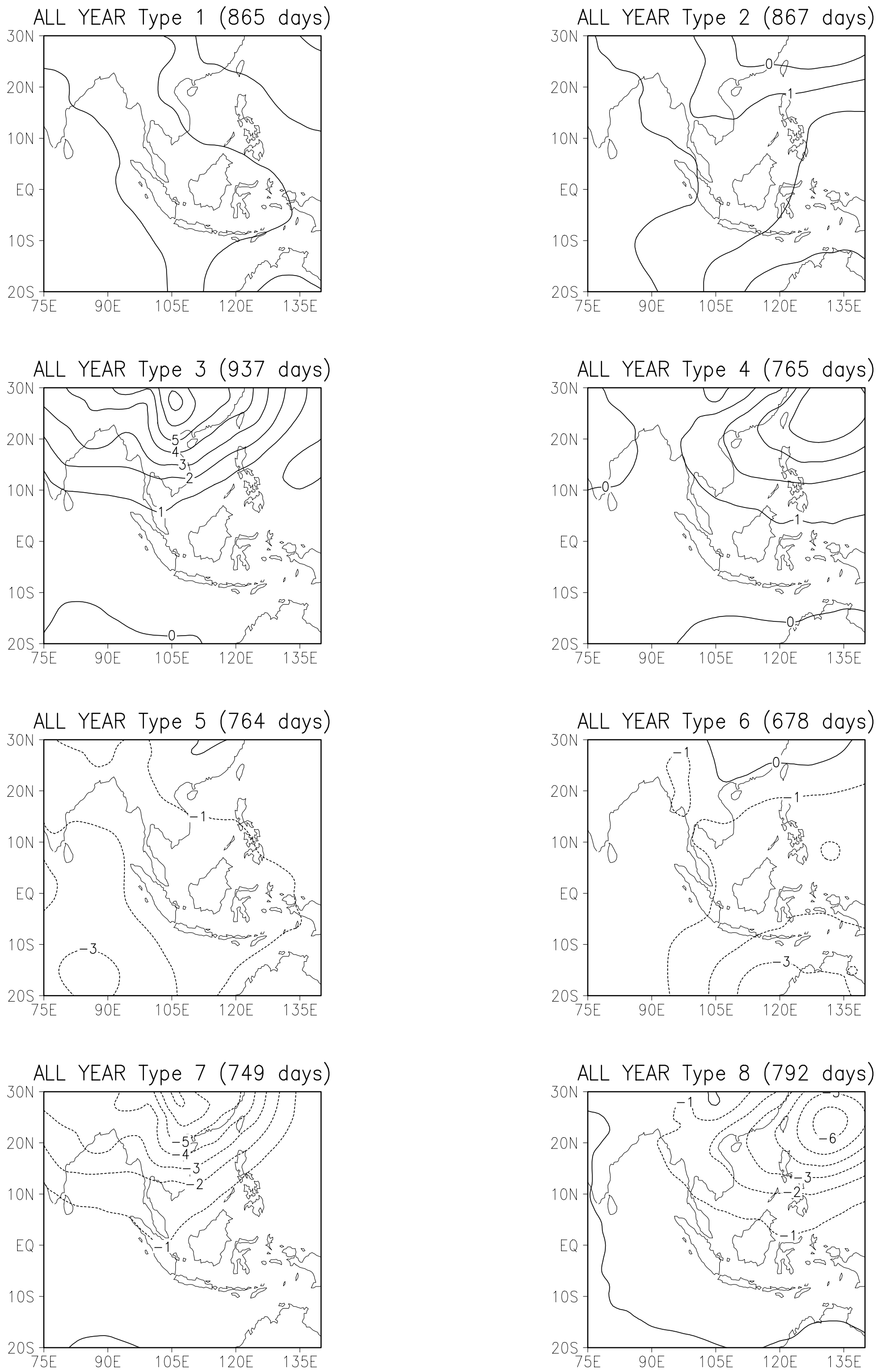


Figure 6.37a: SLP maps (anomaly) for the key composites – All Seasons (CT2)

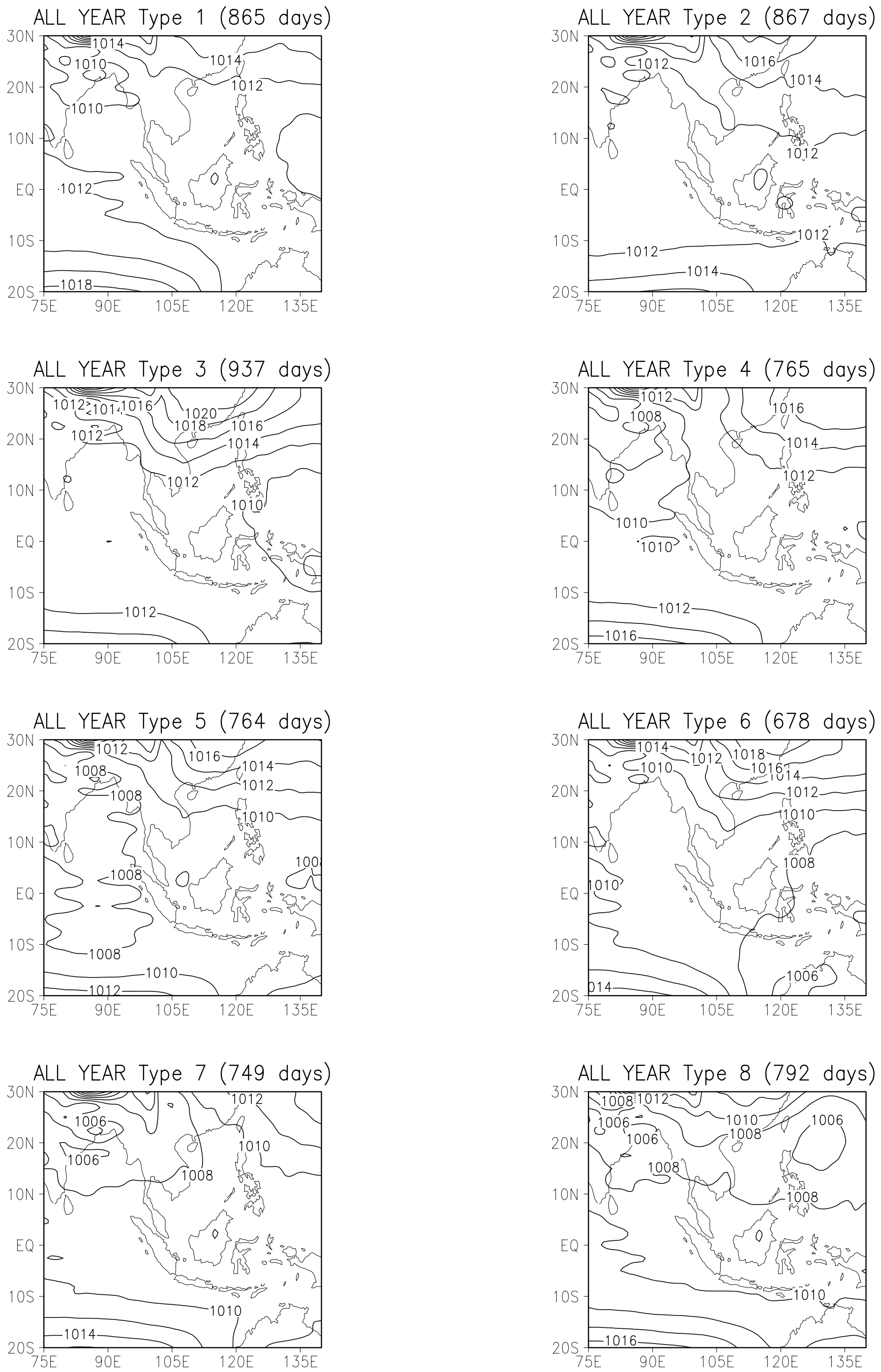


Figure 6.37b: SLP maps (full-field) for the key composites – All Seasons (CT2)

Chapter 7
Relationships between Circulation Types and Surface Climate

7.1 Introduction

Four different circulation-typing schemes have been tested and evaluated in the previous chapter. Based on the chosen criteria of justification (see Section 6.2.1, Chapter 6), Method 2 (absolute SLP data + correlation-based technique) has been selected to be the best scheme. Chapter 7 will further analyse this selected typing scheme and focus on two main aspects:

- The probability of occurrences (for all eight significant types identified by the scheme), the stability over time and the distribution of occurrences under the influences of different climatic events.
- The relationships between the circulation types and the surface climate of Borneo (which includes both average and extreme measures) based on the overall period, the comparison between two halves of period (1968-1984 and 1985-2001), and under the influences of various climatic events.

The main issues to be addressed are:

- Which circulation types are exclusively associated with a particular monsoon season or a particular ENSO phase, and the stability of these associations through time?
- If the circulation types are examined under a multiple climatic condition (i.e. monsoon-ENSO phase), which of the climatic events force stronger influences on the occurrences of the circulation types?
- Which circulation types are strongly associated with a particular condition of surface climate (e.g. wet and dry weather, cold and hot conditions, high frequencies of extreme precipitation and temperature, etc)?
- How stable are the associations (with surface climate) through time (i.e. comparing two halves of period – 1968-1984 and 1985-2001)?

- Are there any spatially distinguished patterns in the relationships, which are uniquely manifest in different climatic divisions (A1, A2 and B1)?
- Which circulation types are exclusively associated with a particular monsoon season or a particular ENSO phase with regard to specific relationships with surface climate (e.g. which types are associated with heavy rainfall during the SW/NE monsoon)?
- How consistent are the associations (between circulation types and a specific surface climate) under the common climatic variations of Borneo – monsoon cycle and ENSO phases?
- Which surface variables establish the strongest relationships with the typing scheme, and under what circumstances (in terms of monsoon cycle and ENSO phases)?
- Are there any strong identifiable patterns to the relationships, which could possibly be developed (in further studies) to relate the circulation types and surface climate more precisely?

7.2 Description of the data

There two types of data used in this analysis – (i) NCEP Reanalysis (SLP); and (ii) Observational precipitation and temperature in Borneo. The detailed background of these data is given in Chapter 3. This chapter will only provide a brief introduction of the data and how they are specifically used for this analysis.

Table 7.1: The finalised typing scheme (Method 2): number of days and percentage of each type based on the period of 1968 – 2001

	1968 – 1984 (17 years)		**1985 – 2001 (17 Years)**		**1968 – 2001 (34 years)**	
Circulation	N of Days	%	N of Days	%	N of Days	%
Type 1	930	15.1	1012	16.4	1942	15.7
Type 2	511	8.3	645	10.5	1156	9.4
Type 3	303	4.9	425	6.9	728	5.9
Type 4	392	6.3	395	6.4	787	6.4
Type 5	1633	26.4	1554	25.2	3187	25.8
Type 6	1188	19.2	1035	16.8	2223	18.0
Type 7	916	14.8	750	12.2	1666	13.5
Type 8	306	5.0	349	5.7	655	5.3
Unclassified	31	0.5	44	0.7	75	0.6
Total	6179	100.0	6165	100.0	12344	100

This table corresponds to Table 6.18 (Chapter 6)

7.2.1 Circulation typing scheme (synoptic variable)

In Chapter 6, the analysis on the circulation types was based on the period of 42 years (1960-2001). However, to be consistent with the surface daily data, which is only available for 34 years (1968-2001), the analysis in Chapter 7 will follow this time-frame. Therefore, the analysis in this chapter (using occurrences of the circulation types) is slightly different and more specific compared to what has been presented in Chapter 6 (i.e. using time-frame of 1960-2001). There are eight significant circulation types (in the finalised typing scheme – Method 2), which cumulatively classify 99.4% of the original data (1960-2001). The new overall percentage (and number of days) being classified in each type based on 1968-2001 (34 years) is shown in Table 7.1. The cumulative percentage (of classified days) is 99.4%, only 0.1% less than the original data.

7.2.2 Precipitation and temperature (surface variables)

Six key surface stations in Borneo are selected for this analysis. These stations are Sandakan (SDK) and Miri (MIR), which are both in Sepilok Climatic Group (A1); Kota Kinabalu (KK), which represents Sepanggar Climatic Group (A2); Bintulu (BTU), Sibu (SBU) and Kuching (KCH), which are all members of Samarahan Climatic Group (B1). The principal justification in selecting these six stations is data availability (see Chapter 3). These stations (which are all located in East Malaysia) have the longest available daily data for both temperature and precipitation (1968-2001).

Table 7.2: The selected surface climate variables

	Precipitation	**Temperature**
Magnitude (average)	Daily rainfall (mm/day) Intensity (mm/day)	Mean temperature (T-mean) (ºC) Maximum temperature (T-max) (ºC) Minimum temperature (T-min) (ºC)
Frequency (extreme)	Wet day (rainfall > 1mm/day) Heavy[60] rain (rainfall > 8 mm/day) 90^{th} percentile of precipitation (all days)	90^{th} percentile of T-mean 90^{th} percentile of T-max 10^{th} percentile of T-min

There are hardly any stations in the Indonesian part of Borneo (Kalimantan) that are able to provide up to 30-year period of complete daily observations. These Indonesian stations have, therefore, been omitted from this analysis because the quality of the data is severely hampered by a large number of missing values. The evaluation of relationships in this chapter focuses not only on average values, but also involves frequency analysis (especially for extreme variables). From a statistical viewpoint, any analysis with regard to extreme occurrences can be significantly affected by missing observations. Two main variables for

[60] Heavy rainfall is set at 8 mm/day, which signifies a daily rainfall total of equal to or more than the composite average of all 29 stations in Borneo (refer to Chapter 3 and 4). The term 'heavy' is used in a loose way, which serves as an indication of 'physically significant rainfall' to differentiate the occurrences of less significant rainfall (< 8 mm/day for Borneo standard, in terms of human and environment sensitivity).

surface climate are analysed: precipitation and temperature. The analysis investigates both the magnitude and frequency, and each one of these aspects is represented by several sub-variables with more specific measures. These sub-variables are summarised in Table 7.2. The details on how each of these variables has been created are provided in Chapter 4.

7.3 Description of the methodology

As has been mentioned earlier, there are two types of measures in the data that are investigated, namely the magnitude (averages) and frequency (occurrences). All the analyses on magnitude are undertaken based on anomaly values. The original observations for both temperature and precipitation (absolute values) are first converted into 'anomalies'[61]. The average values for each circulation type are then calculated based on these anomaly values (averaging the values for all days of each type). The anomaly composites do not only show which types are strongly associated with certain weather conditions (i.e. dry, wet, cold and hot); but also easily distinguish which of them are above or below normal. In other words, the relationships are not only identified in terms of 'how are they related', but also 'how strongly are they related' and 'in which direction (negative/positive)'.

Ratio analysis[62] is used to evaluate the frequency of the circulation types and their relationships with surface extreme variables. Table 7.3 is a typical example of cross-tabulation table that shows how the ratio is calculated. The climatic events can be varied based on monsoon cycles, ENSO phases or different periods (i.e. two halves of periods – 1968-1984; 1985-2001). The 'count' represents the actual observation of the number of extreme days in precipitation (90th percentile). The 'expected count' is the hypothetical number of extreme days under the assumption that the occurrences of 90th percentile days in each type and all seasons should follow the statistical rule of random distribution.

The residual (difference between the 'actual' and 'expected' counts) is calculated by this simple equation: **Residual = Count – Expected Count**. However, the residual is not a valid measure to show the actual degree of discrimination because each one of the circulation

[61] Anomaly values for precipitation and temperature are calculated based on monthly averages and seasonal average respectively. This means that the temperature anomaly is based on a long-term monthly average (e.g. daily temperature on 1st January 1968 minus the average of all days in January); and the precipitation anomaly is based on a long-term seasonal average (e.g. daily rainfall on 1st January 1968 – average of all days in NE Monsoon). It is clearly indicated (see Chapter 4) that the variation in precipitation is only notable on seasonal basis.

[62] Ratio analysis in this chapter is used to measure the probability for 'a particular weather condition' (surface variables) to occur when a particular circulation dominates the day. Why is 'ratio' being analysed, instead of the number of absolute occurrence? The absolute occurrence is dependant on the overall number of days in each circulation type (which is extremely variable from one type to another type). For example, Type 5 comprises 25.8% of the overall days. Therefore, it is highly probable that the greatest number of 'absolute occurrence' (for any investigated surface variables) will always fall into Type 5. Similarly, Type 8 (which only has 5.3% of the overall days) will statistically always have the lowest number of occurrences.

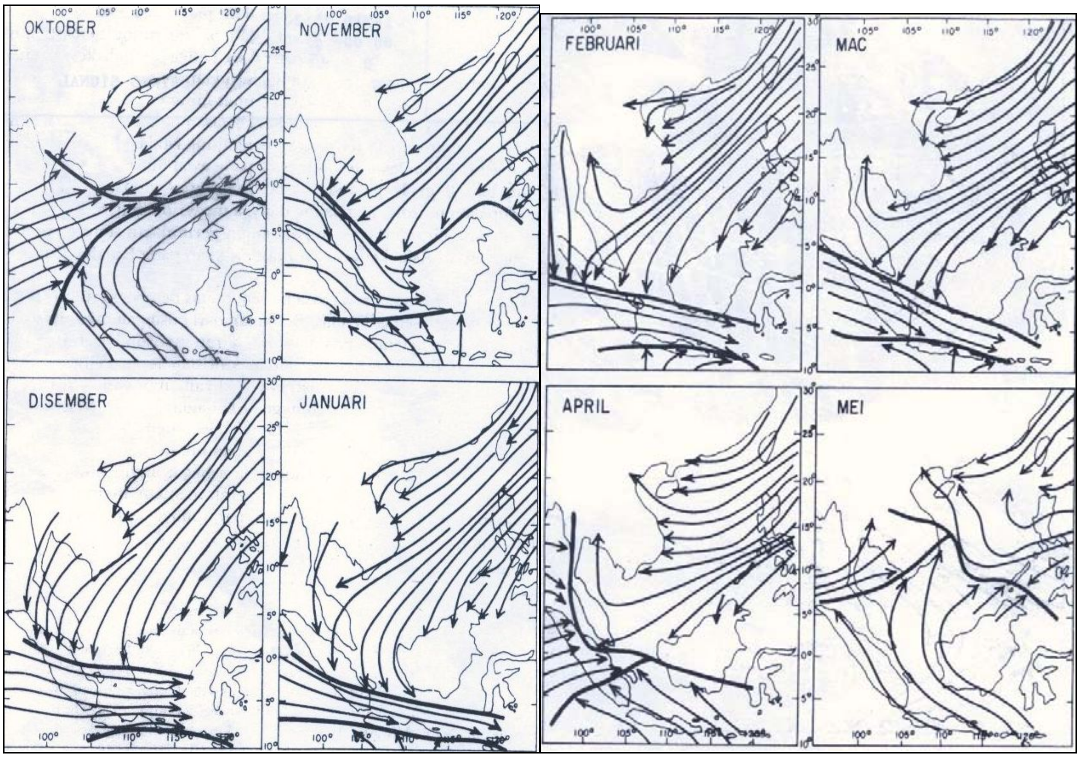
types has different values of 'expected count'. Therefore, to obtain a more meaningful deviation (from the expected average) for each type, this residual must be divided by the expected count. This will give the 'ratio' values, which represent the probability of occurrences for each type. As the equation above clearly reveals, the initial amount of the 'expected count' will significantly influence the value of the residual. If this statistical bias is not standardised, the calculation will not be able to measure the 'real comparable deviation' that is shown by each circulation type. Therefore, the improved measure to distinguish each circulation type (subject to the normal expected condition) is by evaluating the 'ratio', which is calculated by the equation below: **Ratio = Residual/Expected Count**.

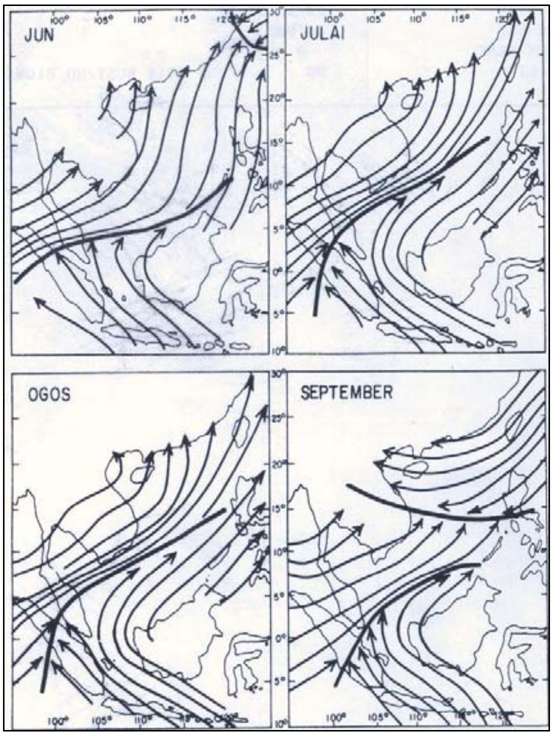
Table 7.3: Cross-tabulation for SDK 90-percentile of precipitation (e.g. under the combination of Circulation Type * Monsoon Cycle)

Climatic Events	Calculation	Circulation Types							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
NE Transition	Expected Count	58.1	14.5	47.2	3.2	0.2	4.3	18.2	47.2
	Residual	6.9	-4.5	2.8	-3.2	0.8	-0.3	-7.2	4.8
	Ratio	**0.12**	**-0.31**	**0.06**	**-1.00**	**4.00**	**-0.07**	**-0.40**	**0.10**
NE Monsoon	Expected Count	182.8	1.3	25.1	75.9	0	272.2	18.2	9.5
	Residual	57.2	-1.3	-4.1	-46.9	0	7.8	-10.2	-2.5
	Ratio	**0.31**	**-1.00**	**-0.16**	**-0.62**	**0.00**	**0.03**	**-0.56**	**-0.26**
SW Transition	Expected Count	1.5	6.3	1.5	6.4	4.7	2.1	38.8	0.8
	Residual	-0.5	6.7	-1.5	-2.4	-1.7	0.9	-0.8	-0.8
	Ratio	**-0.33**	**1.06**	**-1.00**	**-0.38**	**-0.36**	**0.43**	**-0.02**	**-1.00**
SW Monsoon	Expected Count	0	74.5	9.5	0.9	260.8	0	37.2	15.1
	Residual	0	8.5	1.5	-0.9	-5.8	0	-10.2	6.9
	Ratio	**0.00**	**0.11**	**0.16**	**-1.00**	**-0.02**	**0.00**	**-0.27**	**0.46**

7.4 The physical features of the circulation types (CTs)

Eight SLP circulation types that have been established in Chapter 7 are used in this analysis. The method used to produce these circulation types is PCA with S-mode, which concerns one variable (usually surface pressure or geopotential height) varying over space (Yarnal, 1993). The physical features are identified in the previous analysis (see Chapter 6). The direction of low-level winds (either southwesterly or northeasterly) for each circulation type are characterized by the dominant monsoon for that particular circulation. The positions of the ITCZ are estimated based on the Borneo large-scale circulation scheme introduced by Sham Sani (1984). The monthly occurrences for each type are identified and the dominant months are then compared to the scheme that summarises the long-term monthly patterns of the typical atmospheric circulation and surface wind over Borneo (see Figure 7.1a and Table 7.4). This will determine the theoretically most probable location for the ITCZ in each one of the individual circulation types.





These maps are extracted from Sham Sani (1984), which show how the low-level winds change their directions within the Southeast Asian region (on monthly basis). These changes are due to the shifting in pressure gradient between the northern and southern hemispheres. The thick lines show where the two low level winds (i.e. south-westerly and north-easterly directions) meet. It also indicates where the location of the ITCZ. Although this scheme is a generalization (i.e. the actual location of ITCZ changes from time to time, this maps are drawn based on long-term composite averages, and should represent the basic important modes of SEA synoptic circulation.

Figure 7.1a: The location of boundaries for large-scale atmospheric circulation and the patterns of low-level wind in the southeast Asian region (January – December)

Why is it important to identify the positions of ITCZ? All six key stations used in this analysis are located approximately between 0˚-6˚N. The positions of ITCZ over Borneo, which will be dynamically changing between seasons (Sirabaha, 2004), will directly influence the surface climate especially precipitation (Riehl, 1954; Nieuwolt, 1977). Thus, identification of ITCZ position for each circulation type will help to understand the predicted rainfall distribution in Borneo (Ooi and Cheang, 1991; Lau and Yang, 1997). The direction of the monsoonal flow also influences the surface climate; thus, the identification of whether a particular circulation is more southwesterly or northeasterly (in terms of flow) is important to understand how it may affect precipitation and temperature of Borneo. The summary of characteristics for all eight types is given in Table 7.5.

Table 7.4: Frequency of occurrences for circulation types on monthly basis

	Type 1		Type 2		Type 3		Type 4		Type 5		Type 6		Type 7		Type 8	
Month	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
1	259	13	0	0	34	5	49	6	0	0	692	31	8	0	12	2
2	95	5	0	0	41	6	146	19	0	0	662	30	11	1	0	0
3	74	4	8	1	56	8	374	48	0	0	403	18	106	6	1	0
4	35	2	67	6	36	5	152	19	35	1	50	2	605	36	13	2
5	1	0	208	18	3	0	2	0	333	10	0	0	495	30	9	1
6	0	0	57	5	13	2	6	1	832	26	0	0	108	6	4	1
7	0	0	45	4	14	2	5	1	931	29	0	0	36	2	22	3
8	0	0	155	13	26	4	0	0	802	25	0	0	30	2	41	6
9	0	0	497	43	57	8	0	0	252	8	0	0	102	6	109	17
10	186	10	108	9	279	38	13	2	2	0	7	0	123	7	333	51
11	641	33	11	1	143	20	22	3	0	0	76	3	37	2	90	14
12	651	34	0	0	26	4	18	2	0	0	333	15	5	0	21	3
Total	1942	100	1156	100	728	100	787	100	3187	100	2223	100	1666	100	655	100

The shaded values indicate the two months with the highest percentage of occurrences (these two months, in all types, give a combined of between 55% and 67% of the total occurrences)

Table 7.5: Physical features of circulation types

CT	Monsoon Seasons (associated with)	Physical Features
Type 1	NEM (Nov – Dec)	Late transition of pressure gradient between the northern and southern hemispheres. Low pressure starts to develop at the northern part of SEA (i.e. Indo-China), and pressure is gradually increasing in Australia. The main direction of low-level winds is northeasterly, and ITCZ moves between 5ºS – 10ºN over Borneo.
Type 2	NET (Sept)	Early transition of pressure gradient between the northern and southern hemispheres. high pressure starts to develop in Australia, and pressure is gradually decreasing at the northern part of SEA (i.e. Indo-China). The main direction of low-level winds is mixed between southwesterly and northeasterly. ITCZ is located at either below 0ºS, or above 5ºN over Borneo.
Type 3	NET (Oct – Nov)	Late transition of pressure gradient between the northern and southern hemispheres. Low pressure starts to develop at the northern part of SEA (i.e. Indo-China), and pressure is gradually increasing in Australia. The main direction of low-level winds is northeasterly and ITCZ is mostly between 5ºN – 10ºN over Borneo.
Type 4	SWT (Mac – April)	Early transition of pressure gradient between the northern and southern hemispheres. Low pressure starts to develop in Australia, and pressure is gradually increasing at the northern part of SEA (i.e. Indo-China). The main direction of low-level winds is southwesterly and ITCZ is mostly within 0º over Borneo.
Type 5	SWM (June – July)	Mature form of the winter monsoon. Low pressure at the northern part of SEA (i.e. Indo-China and north Philippines). The main direction of low-level winds is southwesterly and ITCZ is mostly above 5ºN over Borneo.

Type 6	NEM (Jan – Feb)	Mature form of the summer monsoon. Low pressure in Australia. The main direction of low-level winds is northeasterly and ITCZ is mostly below 5ºS Borneo.
Type 7	SWT (April – May)	Early transition of pressure gradient between the northern and southern hemispheres. Low pressure starts to develop in Australia, and pressure is gradually increasing at the northern part of SEA (i.e. Indo-China). The main direction of low-level winds is southwesterly and ITCZ is either below 0ºS, or above 5ºN over Borneo.
Type 8	NET (Sept – Oct)	Early transition of pressure gradient between the northern and southern hemispheres. Low pressure starts to develop at the northern part of SEA (i.e. Indo-China), and pressure is gradually increasing in Australia. The main direction of low-level winds is northeasterly and ITCZ is mostly above 5ºN over Borneo.

Established by comparing the frequency (see Table 7.4) and the schematic maps of low-level winds (see Figure 7.1a) for SEA by Sham Sani (1984).

7.5 Circulation types (CT): frequency analysis

The analyses in this section are purely focussed on addressing the first two main issues (see Section 7.1). Before investigating the relationships with surface climate (the next section), it is useful to examine the frequency of the circulation types themselves under various circumstances (i.e. different climatic events and periods). Thus, the researcher can identify the initial distribution patterns of the circulation types per se, and whether these initial distributions are characteristically associated in a certain way with the relationships with surface climate. For instance, if a particular type has a high frequency of occurrence during the wet monsoon (NE Monsoon); in the relationship analysis, it will be interesting to investigate whether this type will also be associated with heavy precipitation.

7.5.1 Frequency based on different climatic events (persistency)

Monsoon cycle

Type 1 is strongly associated with NE Monsoon, where a positive ratio of 0.99 is observed. This type is also correlated to NE Transition with a reasonably strong value of ratio, which is almost as high as 0.91. Excepting Type 1, the other types are positively associated with only one specific season within the monsoon cycle. Type 2 is associated with SW Monsoon (1.00), Type 3 with NE Transition (3.15), Type 4 with NE Monsoon (1.03), Type 5 with SW Monsoon (1.54), Type 6 with NE Monsoon (1.58), Type 7 with SW Transition (3.63), and finally Type 8 is associated with NE Transition (3.61). It is also found that in most cases when the frequency of a particular type is very high during a certain monsoon season, its frequency is also notably very low during other seasons. This means that there are certain types, which are positively and negatively associated with different climatic events/seasons (see Table 7.6).

ENSO phases

Weak El Niño phases are not clearly associated with any circulation types. Strong El Niño phases, however, are notably associated with Type 2 (0.5) and Type 4 (1.50). Weak La Niña years are strongly related to Type 5 (0.45) and Type 7 (0.62); whereas, the strong La Niña seasons are clearly associated with Type 1 (0.68) and Type 6 (1.03). Type 8 and Type 3 are not associated with any particular ENSO phases. Similar to what has been observed in the monsoon cycle, there are also certain types that show extremely high probability of occurrence (positive ratio) in a specific ENSO phase, and at the same time show a very low probability (negative ratio) for the other phases (see Table 7.6).

Table 7.6: Summary of characteristics for each circulation type based on monsoon cycles and ENSO phases

Type	High Probability of Occurrence (Positive Probability)	Low Probability of Occurrence (Negative Probability)
1	Monsoon cycle: NE Monsoon ENSO phase: Strong La Niña	Monsoon cycle: SW Monsoon ENSO phase: Weak La Niña
2	Monsoon cycle: SW Monsoon ENSO phase: Strong El Niño	Monsoon cycle: NE Monsoon ENSO phase: Strong La Niña
3	Monsoon cycle: NE Transition ENSO phase: No particular event	Monsoon cycle: No particular season ENSO phase: No particular event
4	Monsoon cycle: NE Monsoon ENSO phase: Strong El Niño	Monsoon cycle: SW Monsoon ENSO phase: No particular event
5	Monsoon cycle: SW Monsoon ENSO phase: Weak La Niña	Monsoon cycle: NE Transition and NE Monsoon ENSO phase: Strong La Niña
6	Monsoon cycle: NE Monsoon ENSO phase: Strong La Niña	Monsoon cycle: SW Monsoon ENSO phase: No particular event
7	Monsoon cycle: SW Transition ENSO phase: Weak La Niña	Monsoon cycle: NE Monsoon ENSO phase: No particular event
8	Monsoon cycle: NE Transition ENSO phase: No particular event	Monsoon cycle: No particular season ENSO phase: No particular event

Based on the summary of the characteristics for each circulation subject to the monsoon cycle and ENSO phases (shown in Table 7.6), four interesting facts have been observed:

- Type 3 and Type 8 appear to be similar and exclusively associated with only NE Transition, and no influence from ENSO phases.
- Type 1 and Type 5 are quite similar in a different way. While Type 1 is clearly related to the NE Monsoon and strong La Niña phases, Type 5 is associated with SW Monsoon and weak La Niña phases.

- Type 2 is significantly associated with SW Monsoon (the ‘dry season’) and strong El Niño phases (which are also known as ‘dry years’). Similarly, Type 6 is associated with NE Monsoon (the ‘wet season’) and strong La Niña phases (the ‘wet years’).
- Type 4 and Type 7, on the other hand, are opposites of Type 2 and Type 6. Type 4 is uncharacteristically associated with the wet season (NE Monsoon) and the dry years (strong El Niño); whereas Type 7 shows exactly the opposite association (dry season and wet years).

7.5.2 Frequency based on different periods (consistency)

Monsoon cycle

Figure 7.1b (i.e. the first three figures) show the pattern of associations between the circulation types and the monsoon seasons is very similar for both halves of the available data (i.e. 1968-1984 and 1985-2001). This clearly indicates that the occurrences of each circulation are mainly governed by the monsoon cycle; and this systematic association is stable through time (or, at least it is consistent within the 34-year time-frame available for this study).

ENSO phases

Under the influence of ENSO phases, the occurrences of the circulation types are not as stable as they are compared to the association with the monsoon cycle (see the last three figures in Figure 7.1b). When comparing the two periods (i.e. 1968-1984 and 1985-2001), there are certain types that have failed to maintain their association with a particular ENSO phase. For example, Type 2 is overall associated with high occurrence during the strong El Niño phases. However, Type 2 has not shown any highly notable occurrence during the strong El Niño phases for the period of 1968-1984 (with 3 strong El Niño phases being recorded); although it does show a strong association during the second half (i.e. 1985-2001, also has three strong El Niño phases). Types 5 and 7 also show a similar instability between those two periods. These two types have a high frequency of occurrences during the weak La Niña years for the period 1968-1984. However, there is no strong association with La Niña years during the second half of the period (1985-2001). This is despite the fact that both halves of periods have almost the same number of weak La Niña phases (four and three occurrences respectively).

However, a reasonably high consistency is observed for Type 1, Type 2, Type 4, Type 6 and Type 8. As has been mentioned in Section 7.5.1, Type 2 and Type 8 are exclusively not associated with any of the ENSO phases; and this 'no association' characteristic is maintained in both halves of the period. Type 1 (associated with strong La Niña), Type 4 (strong El Niño) and Type 6 (strong La Niña) also consistently show the predicted associations through time.

7.5.3 Comparison between monsoon and ENSO (the degree of influence)

As mentioned in Chapter 7, the final typing scheme to be used in this thesis must have the ability to capture both signals from the seasonal variation (monsoon) and the low-frequency variation (ENSO). Initial analyses on the chosen typing scheme (Method 2) indicate that this requirement has been met. The interesting question is – which one of those two synoptic forcings has the greater influence on the circulation (in terms of occurrence)? Or, do they play an equally significant role?

The probability of occurrence (using ratios) for each type under the influence of ENSO phases is analysed separately based on the monsoon cycle (see Figure 7.2). The purpose here is to evaluate if the association between certain monsoon seasons and a particular circulation will change under the influence of different ENSO phases (i.e. the monsoon variable is kept constant and the ENSO variable is varied). If the association changes, then it can be concluded that ENSO plays a larger role than the monsoon. Based on Figure 7.2, it is clearly evident that the 'monsoon-circulation associations' remain consistent in terms of pattern. For example, during the Northeast Transition, Type 1, Type 3 and Type 8 maintain their high positive occurrences (subject to the 'expected' occurrence) regardless of what the ENSO phase is. The same case is observed during the Northeast Monsoon, Southwest Transition and Southwest Monsoon. Therefore, it can be concluded that the circulation distributions are mainly controlled by the monsoon cycle. Although there is a tendency for the circulation to be influenced by ENSO phases, it is only limited to adjusting the magnitude (but, not the pattern) of the occurrences[63]. The monsoon is clearly the stronger factor in determining the pattern of the distribution (i.e. how the circulation occurrences associated with the typing scheme).

[63] ENSO phases to a certain extent have managed to influence the magnitude of the pattern. For example, Type 1 intensifies the probability of positive occurrences during the Northeast Transition when it is concurrent with the El Niño years.

7.6 Relationships with precipitation

The relationships between Circulation Type (CT) and the local precipitation of Borneo are analysed using both magnitude and extreme variables. Both types of variables (i.e. magnitude and extreme) are analysed in separate sections to make the comparison easier. The specific precipitation measures used are given in Table 7.7.

Precipitation magnitudes (both the average and intensity) are expressed as seasonal anomalies. The anomaly values are calculated based on the seasonal average. The formula used is simplified below:

$$SA = D_{\text{Oct-Marc, Apr-Sept}} - M_{\text{NE, SW}}$$

where;

SA is Seasonal Anomaly

D is Daily Value

(October-March is Northeast Monsoon; and, April-September is Southwest Monsoon)

M is Seasonal Daily Average

(NE for Northeast Monsoon; and SW for Southwest Monsoon)

Table 7.7 Surface variables for precipitation

Variables	Specific Measures
Magnitude	Daily average (mm/day) (P_{avg})
	Intensity (mm/day) – precipitation average (P_{int})
Extreme	Number of rain days (precipitation of more than 1mm) (P_{wet})
	Number of heavy rain[64] (precipitation of more than 8 mm) (P_{8mm})
	90^{th} percentile of precipitation (P_{90th})

Extreme measures are shown in the form of ratios, between the expected values due to random occasion and the actual values observed under the various different circumstances[65] being analysed. The calculation is similar to the method described in Section 7.3.

7.6.1 Magnitude/average measures

General relationships

Generally, precipitation averages show stronger and clearer relationships with the Circulation Type compared to precipitation intensity. Using precipitation average as the surface variable, the results show that all stations (except KK) experience positive anomalies

[64] Heavy rain is defined as precipitation exceeding the composite average of all stations in Borneo (which is 8mm – refer to Chapter 4).

[65] These 'different circumstances' can be subjected to the circulation types only, or with the combined influences of selected climatic events (either with the monsoon cycle or ENSO phases).

during the occurrences of Type 1. KK (the only station in the Sepanggar type), experiences positive anomalies during the occurrence of Type 3 and Type 8. The negative anomalies are mainly associated with Type 4 and 6. In general, it is quite evident that Type 1 and 3 can be identified as the 'Wet Type', whereas Type 4 and 8 are the strong 'Dry Type'.

The relationships are less identifiable with the precipitation intensity. There are several dominant types for both positive and negative anomalies. Although it can be generalised that Type 2 and 6 are quite identifiable as the Wet Type; and Type 4, 7 and 8 as the Dry Type – the relationship is less visibly discriminated compared to precipitation averages. The graphical view of the relationships can be seen in Figure 7.3; and they are summarised in Table 7.8.

Table 7.8: The dominant types (positive and negative anomalies) for precipitation magnitudes

	Daily Average		Intensity	
Station	+ve Anomaly	-ve Anomaly	+ve Anomaly	-ve Anomaly
SDK (A1)	1	4,7	6	4,7,8
MIR (A1)	1, 3,8	4,6	2,3	4,6
KK (A2)	3,8	4,6	2,3,8	4,6,7
BTU (B1)	1	8	4	8
SBU (B1)	1	4	N/A	4
KCH (B1)	1	3, 8	6	3,8

Each type will only be identified as describing positive/negative anomalies if the absolute values deviate from the average by more than ± 1.5 mm; N/A = Identifiable types do not occur

Relationships based on climatic group

There are six stations used in this analysis, which are grouped into Sepilok Climatic Group (A1: SDK, MIR), Sepanggar Climatic Group (A2: KK), and Samarahan Climatic Group (B1: BTU, SBU, KCH) (see Figure 4.5 in Chapter 4). A1 stations are located in the eastern part of Sabah (SDK) and Sarawak (MIR), A2 is in the central part of Sabah (rightly in the middle of the two A1 stations), and B1 is in the western part of Sarawak. Analysing the relationships spatially (see Table 7.8), it can be generally concluded that both Sepilok (A1) and Samarahan (B1) climatic groups exhibit similar relationships between Circulation Types and precipitation average/intensity. All stations in the Sepilok and Samarahan climatic groups (SDK, MIR, BTU, SBU, KCH) experience positive anomalies during the occurrences of Types 1, 2 and 6. KK (the only station in the Sepanggar type) shows positive anomalies during the occurrence of Types 3 and Type 8.

In general, the relationships between Circulation Types and the magnitude variables of precipitation do show some sort of meaningful spatial pattern. For example, the negative anomalies are spatially characterised by the discrimination between the eastern and western stations. The negative anomalies are associated with Types 4, 6 and 7 for the eastern stations (MIR, KK, SDK); whereas, the western stations (BTU, SBU, KCH) are collectively associated with Types 3, 4 and 8.

Relationships based on two different periods

The data are divided into two sets of 17-year periods, which are 1968-1984 and 1985-2001. The relationships between Circulation Types and precipitation average/intensity are analysed and compared between these two periods. The changes can be seen in Figure 7.3a and 7.3b for precipitation average and intensity, respectively. The directions of the changes (positive/negative) are simplified in Table 7.9 below.

Table 7.9: Precipitation magnitudes and the change throughout two halves of period

Daily Precipitation

Station	1	2	3	4	5	6	7	8
SDK (A1)	O	O	O	O	O	O	O	O
MIR (A1)	O	O	O	O	O	O	O	O
KK (A2)	O	O	O	O	O	O	O	O
BTU (B1)	O	O	O	O	O	O	O	O
SBU (B1)	O	O	O	O	O	O	O	O
KCH (B1)	O	O	O	O	O	O	O	O

Precipitation Intensity

Station	1	2	3	4	5	6	7	8
SDK (A1)	W	O	O	O	W	O	O	W
MIR (A1)	O	O	O	O	O	O	O	O
KK (A2)	O	O	O	O	W	O	W	O
BTU (B1)	O	O	O	O	O	O	O	O
SBU (B1)	O	O	W	W	W	O	O	O
KCH (B1)	W	O	O	O	W	W	O	O

O = orientation of the anomalies remain unchanged between the two periods, 1968-1984 and 1985-2001; W = a change from positive to negative anomalies; + = a change from negative to positive anomalies

In general, the associations between precipitation averages and Circulation Types are consistent between the two periods for all types. The only slight exception is for BTU (B1), which experiences a positive anomaly for Type 3 in 1968-1984; and a negative anomaly during the second half (1985-2001). Precipitation intensity, in contrast, shows a much bigger inconsistency. Between the two halves of periods, there are several changes of the orientation of the relationships in certain types. The most notable changes are:

- From positive to negative anomaly in Type 1 for SDK (A1) and KCH (B1)
- From positive to negative anomaly in Type 3 and Type 4 for SBU (B1)
- From positive to negative anomaly in Type 5 all stations except for MIR (A1) and BTU (B1)
- From positive to negative anomaly in Type 6 for KCH (B1)
- From positive to negative anomaly in Type 7 for KK (A2)

- From positive to negative anomaly in Type 8 for SDK (A1)

Interestingly, all the changes are from negative to positive anomaly. This leads to the possibility that the relationship itself might not have changed, but it is simply caused by the increasing trend in precipitation intensity. However, upon checking the intensity trend (Chapter 5) – there is no proof of a significant increase/decrease between the two periods. Therefore, it can be concluded that the Circulation Types are consistently associated with the precipitation average through time; the pattern/orientation of the relationships are not consistently maintained with precipitation intensity.

Relationships based on monsoon cycle

In the previous section, it is proven that there are identifiable patterns of relationships between Circulation Types and precipitation magnitudes (i.e. certain types are negatively/positively associated with precipitation average and intensity). The next question to address is – are the same relationships maintained in different seasons, or are there any particular types that are exclusively associated with a particular season? Four different seasons based on the monsoon cycle have been identified for this analysis (see Chapter 6), which are Northeast Transition (October – 15 November), Northeast Monsoon (16 November – March), Southwest Transition (April – 15 May), and Southwest Monsoon (16 May – September). The relationships are shown in Figure 7.4, and simplified in Table 7.10.

Table 7.10: The relationships for precipitation magnitudes based on monsoon cycle

Daily Precipitation

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	NA	4,7	1	4,7	NA	5,3	3,8	NA	2,6
MIR	3,1	NA	8	4	3	8	2	NA	5,6,7
KK	8,3	NA	8	4	NA	6,8	8,3	NA	1,2,5,7
BTU	4	6	8,1	4	NA	8,1	NA	NA	2,3,5,7
SBU	4	8	1	3	1,4	8	NA	8	2,5,6,7
KCH	NA	7,8	8,1	3	NA	NA	NA	NA	2,4,5,6

Precipitation Intensity

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	NA	4	3	8,4	6	3,8	8	7	1,2,5
MIR	NA	NA	3	4	3	8	2	NA	1,5,6,7
KK	8,5	4	8	4,7	NA	3,6	NA	NA	1,2
BTU	4	6	7	4	NA	8,1	NA	NA	2,3,5
SBU	NA	8	NA	NA	3	8	NA	NA	3,8
KCH	NA	7,4	8	7	1	NA	NA	3	2,5,6

Each type will only be identified as describing positive/negative anomalies if the absolute values deviate from the average by more than ± 1.5 mm; N/A = Identifiable types do not occur

In general, during the Northeast Transition two dominant types are found – Type 4 and 8 – which uncharacteristically produce negative and positive anomalies of different forms depending on the stations. For example, Type 8 is associated with a positive anomaly in KK, while it is a negative anomaly in SBU and KCH. The characteristic is more systematic during the Northeast Monsoon, where Type 1/8 (average) and Type 3/8 (intensity) are clearly associated with positive anomalies. Similarly, Type 3/4 (average) and Type 4/7 (intensity) are strongly associated with negative anomalies. During the Southwest Monsoon, there is no strong association between precipitation magnitudes (both average/intensity) and any of the circulation types. However, Types 2 and 8 seems to be positively related with the two most eastern stations, namely KK (A2) and SDK (A1). During the Southwest Transition, the dominating circulation is Type 8 (negative anomaly), but there is no dominant type for the positive anomaly.

The Northwest monsoon cycle (October-March), in general, is much better defined by the synoptic circulation (compared to Southwest monsoon cycle) as far as precipitation magnitudes are concerned. Type 3, 4 and 8 are clearly dominating this season. On the other hand, during its reverse monsoon (April – September), the relationships between the precipitation magnitudes and synoptic circulations produce a much less recognised pattern. The relationships are summarised as in Table 7.11.

Table 7.11: Summary of relationship during each monsoon season

Monsoon Cycle	Circulation Types		How clear the pattern is?
	Positive Anomaly	Negative Anomaly	
Northeast Transition	Type 4	Type 8	Not clear
Northeast Monsoon	Type 3, 8	Type 4	Clear
Southwest Transition	NA	Type 3, 8	Not Clear
Southwest Monsoon	NA	NA	NA

NA = Identifiable pattern do not occur (except for one/two individual stations)

Relationships based on ENSO phases

There are also four different ENSO phases that have been identified for this analysis (see Chapter 7), which are Weak El Niño (WEL), Strong El Niño (SEL), Weak La Niña (WLA) and Strong La Niña (SLA). Between the two precipitation variables (average and intensity) – none has exhibited a stronger pattern of relationships. This can be seen in Figure 7.5 and Table 7.12.

Both variables (averages and intensities) equally have advantages and disadvantages. The relationships with precipitation average are more clearly shown during the strong El Niño; whereas during the strong La Niña, the intensity produces a clearer pattern of relationships.

Both variables, however, have failed to establish good relationships with circulation types during the weak El Niño and La Niña phases. There are certain types that can be associated with positive/negative anomalies of precipitation magnitudes (i.e. average and intensity) during these weak ENSO phases, but the associations are not as clear as during the strong ENSO years. Using precipitation average/intensity as the surface predictand variables, the relationships are best summarised as in Table 7.13.

Table 7.12: The relationships for precipitation magnitudes based on ENSO phases

Daily Precipitation

Station	WEL +ve	-ve	SEL +ve	-ve	WLA +ve	-ve	SLA +ve	-ve	Non Sig.
SDK	8	4,6	NA	6,4	3,1	8	3	4	2,5,7
MIR	NA	4,6	NA	6,4	8	NA	3	4	1,2,5,7
KK	8	4	NA	4,6	1,8	NA	8	4	2,5,7
BTU	NA	6,3	1	4,6	8,5	NA	1	4	2,7
SBU	4	6	1	8	2	8	2	4	3,7
KCH	7	8	NA	8	NA	NA	5,2	NA	1,3,5,6

Precipitation Intensity

Station	WEL +ve	-ve	SEL +ve	-ve	WLA +ve	-ve	SLA +ve	-ve	Non Sig.
SDK	2,8	6,4	7,5	6,4	4,3	8	3	8,5	1
MIR	2	4	8	4,6	8	NA	8	NA	1,3,5,7
KK	8	4	3,2	4,6	4	NA	8	4	1,5,7
BTU	NA	3,8	1	6,4	6,5	4,2	1	4	7
SBU	2,4	NA	1,3	8	NA	3,8	NA	5	6,7
KCH	7,1	3,4	4	8,5	NA	1,4	1,2	7,3	6

Each type will only be identified as describing positive/negative anomalies if the absolute values deviate from the average by more than ± 1.5 mm; N/A = Identifiable types do not occur

Table 7.13: Summary of relationship during each specific ENSO phase

ENSO phases	Circulation Types		Degree of relationships (How clear the pattern is?)
	Positive Anomaly	Negative Anomaly	
Weak El Niño	Type 2, 8	Type 3, 4	Not clear
Strong El Niño	Type 1, 3	Type 4, 8	Clear
Weak La Niña	NA	NA	NA
Strong La Niña	Type 3, 8	Type 4	Clear

NA = Identifiable patterns do not occur (except for one/two individual stations)

7.6.2 Extreme measures

General relationships

The graphical view of the relationships can be seen in Figure 7.6; and they are summarised in Table 7.14. For extreme variables, all three selected measures appear to exhibit a consistent pattern of relationships. It can be easily simplified that Type 1 and 8 are associated with positive anomalies (higher probability of extreme occurrences); whereas Type 4 and Type 5 are directly related with negative anomalies (lower probability of extreme occurrences).

Table 7.14: The dominant types (positive and negative anomalies) for precipitation extremes

	Rain Days (> 1mm)		Heavy Rain (> 8mm)		90th Percentile	
Station	+ve Ano.	-ve Ano.	+ve Ano.	-ve Ano.	+ve Ano.	-ve Ano.
SDK (A1)	1	4	1	4,7	1	4,7
MIR (A1)	1	4	1,3,8	4	1,3,8	4
KK (A2)	8	4	3,8	4,6	2,3,8	4,6
BTU (B1)	1	NA	1	5	1	5
SBU (B1)	1	NA	1	NA	1	NA
KCH (B1)	1	NA	1	5	1,6	5

Each type will only be identified as describing positive/negative anomalies if the probability of occurrences deviate from the average by more than ± 0.25 (25%); N/A = Identifiable types do not occur

Relationships based on climatic group

Interestingly, as mentioned in the previous section, all three selected extreme variables show a similar pattern of relationships with the circulation types (see Table 7.14). For all stations in Sepilok (A1) and Samarahan (B1) climatic groups, Type 1 best describes the effect of positive anomalies (with an increase of between 26-57%). For KK (the only station in Sepanggar Group – A2), the positive anomaly is exclusively associated with Type 8 (46-105%). This is a very clear discrimination between Climate Group A1/B1 and A2 (see Figure 4.5 in Chapter 4 for the map of the climatic divisions of Borneo) . However, the pattern changes slightly with respect to the negative anomalies. When the three stations in the eastern part (relatively) of Borneo (MIR, KK, SDK) have the negative anomalies, they are exhibited by Type 4 (with a decrease of between 32-60%). The next most geographically western stations (SBU, BTU, KCH) experience negative anomalies during the occurrence of Type 5 (15-45%).

Relationships based on two different periods

The patterns of changes are shown in Figure 7.5 and summarised in Table 7.15. Once again, these three extreme variables exhibit highly consistent patterns of relationships, when they are analysed through time. The relationships between each of the selected measures and circulation types have only minimally changed between the periods 1968-1984 and 1985-2001 (i.e. each half is equally divided into 17 years).

Table 7.15: Precipitation magnitudes and the changes throughout two halves of period

Number of Rain Days (> 1mm)

Station	1	2	3	4	5	6	7	8
SDK (A1)	O	O	O	O	O	O	O	O
MIR (A1)	O	O	O	O	O	O	O	O
KK (A2)	O	O	O	O	O	O	O	O
BTU (B1)	O	O	O	O	O	O	O	O
SBU (B1)	O	O	O	O	O	O	O	O
KCH (B1)	O	O	O	O	O	O	O	O

Number of Heavy Rain (> 8mm)

Station	1	2	3	4	5	6	7	8
SDK (A1)	O	O	O	O	O	O	O	O
MIR (A1)	O	O	O	O	O	O	O	O
KK (A2)	W	O	O	O	O	O	O	O
BTU (B1)	O	O	W	O	O	O	O	O
SBU (B1)	O	O	O	O	O	O	O	O
KCH (B1)	O	O	W	O	O	O	O	O

90th Percentile of Precipitation

Station	1	2	3	4	5	6	7	8
SDK (A1)	O	O	O	O	O	O	O	O
MIR (A1)	O	O	O	O	O	O	O	O
KK (A2)	W	O	O	O	O	O	O	O
BTU (B1)	O	O	O	O	O	O	O	O
SBU (B1)	O	O	W	O	O	O	O	O
KCH (B1)	O	O	O	O	O	O	O	O

O = orientation of the anomalies remain unchanged between the two periods 1968-1984 and 1985-2001; W = a change from positive to negative anomalies; + = a change from negative to positive anomalies

There is no change (i.e. from positive to negative anomalies, vice versa) for the first variable, the ‘number of rain days’ (P_{wet}). However, there are five very minimal changes (combined) in the other two variables – i.e. ‘number of heavy rain days’ (P_{8mm}) and the ‘90th percentile of precipitation’ (P_{90th}). The changes involve Type 1 for KK (in both variables), and the changes in Type 3 for BTU/KCH (for P_{8mm}), and SBU for P_{90th}. In general, it can be concluded that the patterns of relationships are highly consistent through the 34-years period (1968-2001).

Relationships based on monsoon cycle

The graphical view of the relationships can be seen in Figure 7.7; and they are summarised in Table 7.16. Northeast Transition (NET) is not defined very well in two of the selected extreme variables – i.e. the number of rain days (P_{wet}) and 90th percentile (P_{90th}). Only one of the variables (i.e. P_{8mm}) manages to produce a meaningful association with the circulation types, where Type 4 is generally related with positive anomalies, and Type 6 for negative anomalies. During the Northeast Monsoon (NEM), all three variables show a clear pattern of similar relationships. Type 1 and Type 8 are associated with positive anomalies; whereas the negative anomalies are shown in Type 2 and Type 4.

The Southwest Transition (SWT) also exhibits a strong pattern of relationships in two variables (i.e. P_{8mm} and P_{90th}), and a reasonable association for the other variable (i.e. P_{wet}). Types 2 and Type 4 are best described by the occurrences of positive anomalies; and, Types 5 and 8 as the negative anomalies. The relationships during the Southwest Monsoon (SWM) are not well defined, particularly for the negative anomalies. However, all three variables do exhibit a clear association for the positive anomalies (especially for number of rain days and heavy rainfall). The significant types for Southwest Monsoon are Types 4, 8 and 7.

Table 7.16 The relationships for precipitation extremes based on monsoon cycle

Number of Rain Days (>1 mm

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	NA	NA	1	2,4	1	5	3	NA	6,7,8
MIR	NA	NA	8,1	4,2	NA	8,2	7	4	3,5
KK	NA	4,2	8,1	4,2	3	4	8	4	5,67
BTU	NA	NA	8	2	NA	5	4	NA	1,3,6,7
SBU	4	NA	8	2	NA	NA	7	NA	1,3,5,6
KCH	NA	NA	8,1	3	NA	NA	NA	4	2,5,6,7

Heavy Rain (> 8mm)

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	NA	4	NA	2,4	2	3,8	8	4	1,5,6,7
MIR	NA	7	8,1	2,4	3	8,2	4	NA	5,6
KK	NA	6,4	8	4,2	2,5	3,6	8	NA	1,7
BTU	4	6	8,1	4,2	4	1,8	4	NA	3,5,7
SBU	4	6	8	NA	4	8,5	4,2	8	1,3,7
KCH	2,6	7	8	7,3	8	1	7,2	4,8	5

90th Percentile Precipitation

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	6	NA	1	2,4	6,2	5	3,8	NA	7
MIR	NA	NA	8,1	4,2	NA	8,2	NA	NA	3,5,6,7
KK	NA	2	8	4	5	8,6	8	4	1,3,7
BTU	4	6	8	2	3	8,5	4	NA	1,7
SBU	4	NA	NA	2	1	8,5	4,7	NA	3,6
KCH	NA	NA	NA	3	NA	NA	NA	4	1,2,5-8

Each type will only be identified as describing positive/negative anomalies if the probability of occurrences deviate from the average by more than ± 0.25 (25%); N/A = Identifiable types do not occur

Relationships based on ENSO phases

The relationships during the ENSO phases are quite clearly exhibited for these extreme measures compared to the precipitation magnitudes (i.e. average and intensity). The graphical view of the relationships can be seen in Figure 7.8; and they are summarised in Table 7.17.

Table 7.17: The relationships for precipitation extremes based on ENSO phases

Number of Rain Days

Station	WEL +ve	WEL -ve	SEL +ve	SEL -ve	WLA +ve	WLA -ve	SLA +ve	SLA -ve	Non Sig.
SDK	1,8	7,4	1	4	1	5	1	2,4	3,6
MIR	1,7	4,6	1	4	1	4,5	1,8	4,5	2,3
KK	8,5	4	8,3	4,6	2,1	4	8	4	7
BTU	1	5	2	NA	1	NA	1	5	3,4,6-8
SBU	1	5	1	5	2	8	1	4,5	3,6,7
KCH	1	5	1,6	2,5	1,4	NA	1	4,5	3,7,8

Heavy Rain (> 8 mm)

Station	WEL +ve	WEL -ve	SEL +ve	SEL -ve	WLA +ve	WLA -ve	SLA +ve	SLA -ve	Non Sig.
SDK	1	2,7	1	4	1,6	2	1	2,4	3,5,8
MIR	NA	4	1	4,6	8	4	3	4,5	2,7
KK	8	4	8,3	4,6	1,8	4,6	1	5	2,7
BTU	1	NA	1	4	6	2	1	5	3,7,8
SBU	8,4	5	1	5	1,2	8	1	5	3,7
KCH	1	NA	1,3	2,8	1,3	5	1	5	4,6,7

90th Percentile Precipitation

Station	WEL +ve	WEL -ve	SEL +ve	SEL -ve	WLA +ve	WLA -ve	SLA +ve	SLA -ve	Non Sig.
SDK	8,1	4,7	8,1	4	1,3	8	1	4,7	2,5,6
MIR	1	4	3,5	4,6	1	5	3	4	2,7,8
KK	8	4,6	8,4	5	8	4,6	8,5	4	1,2,3,7
BTU	2,1	5	1	6	6	2,4	1	4	3,7,8
SBU	4,1	5	1	8	4,2	8,3	2	4,5	6,7
KCH	1	5,8	1	8	6	NA	NA	5	2,3,4,7

Each type will only be identified as describing positive/negative anomalies if the probability of occurrences deviate from the average by more than ± 0.25 (25%); N/A = Identifiable types do not occur

Using these extreme measures (i.e. number of rain days, heavy rainfall days and 90th percentile) as the surface predictand variables, the relationships are best summarised in Table 7.18.

Table 7.18: Summary of the relationships during each specific ENSO phase

ENSO phases	Circulation Types Positive Anomaly	Negative Anomaly	Degree of relationships (How clear the pattern is?)
Weak El Niño	Type 1, 8	Type 4, 5	Clear
Strong El Niño	Type 1, 8	Type 4, 8	Clear
Weak La Niña	Type 1, 6, 8	Type 4, 5	Clear
Strong La Niña	Type 1, 8	Type 4, 5	Clear

NA = Identifiable patterns do not occur (except for one/two individual stations)

7.6.3 Summary of relationships with precipitation

The significant characteristics shown by each type are summarized in Appendix F. The most prominent relationships established for each type are listed below:

- Type 1 is associated with positive anomalies (in both extreme and magnitude variables) during the Northeast monsoon (NEM) and strong El Niño years (SEL). This is much stronger in Sepilok and Samarahan climatic groups (A1 and B1).
- Type 2 is exclusively associated with Samarahan climatic group (B1). This type particularly shows good relationships with extreme variables, which exhibit positive anomalies during the summer monsoon (SWM), and negative anomalies during the winter monsoon (NEM).
- Type 3 shows a good relationship with magnitude variables (average and intensity). However, the effect is different between Sepilok climate (A1 – positive anomalies) and Samarahan climate (B1 – negative anomalies).
- Type 4 seems to distinctively discriminate B1 from A1/A2. This circulation type shows negative anomalies in A1/A2 during the mature monsoon (NEM). However, it shows positive anomalies in B1 (except KCH) during the transition in both monsoons (NET and SWT). This type too shows clear negative anomalies at all stations during the strong La Niña years, and during the weak El Niño (for stations in A1 and A2).
- Type 5 shows no important relationships based on monsoon cycle. It however exhibits clear negative anomalies for extreme variables (number of rain days) in all stations during the strong La Niña.
- Type 6 is exclusively associated with negative anomalies, especially for magnitude variables (average/intensity) in A1 and A2 during the strong El Niño years (SEL).
- Type 7 exhibits a specific discriminating ability for the most western station, which is KCH (Samarahan climatic group – B1). This type is associated with negative anomalies in all monsoon seasons for one particular extreme variable (i.e. the occurrence of heavy rainfall). It is also associated with positive anomalies for both magnitude variables during the weak El Niño years.
- Type 8 produces the most distinguished relationships. It shows positive anomalies in all variables during the winter monsoon (NEM), and negative anomalies during the summer transition monsoon (SWT). These two distinctive relationships are equally strong in all stations. It also shows unique discrimination between stations in A1/A2 and B1 during the strong El Niño years in two variables – precipitation intensity and the occurrence of extreme days (90^{th} percentile). It is a positive anomaly in A1/A2, and a negative anomaly in B1.

There are several other notable observations from this study, which are not exclusively associated with individual types:

- Generally, the magnitude variables (i.e. daily average and intensity) are identified more easily and clearer than the extreme variables (i.e. rain days, heavy rainfall, and 90th percentile).
- The monsoon cycle can discriminate a different type (or a combination of types) that is visibly more unique than the ENSO phase. Thus, it can be concluded that the relationships are more strongly established based on monsoon seasons than ENSO years. For example: for the occurrence of heavy precipitation (> 8mm/day), the positive anomaly in each monsoon season is not similar, which is – Type 4 for NET, Type 8 (NEM), Type 2/4 (SWT), and Type 4/8 (SWM). For the same variable, positive anomalies are mainly related to Type 1 in all ENSO phases (i.e. WEL, SEL, WLA and SLA).
- Within the monsoon cycle, the weakest relationships (i.e. very few types show absolute anomalies > ± 1.5 mm or probability anomaly > ± 0.25) are observed during the mature Southwest monsoon (SWM) and the transition of Northeast Monsoon (NET). This season covers the period between the middle of May and middle of November (inclusive). Similarly, the weak El Niño (WEL) and weak La Niña (WLA) do exhibit relationships based on ENSO phases, but they are much weaker.
- The relationships are highly consistent through time. The patterns of relationships remain unchanged significantly between the two compared 17-year periods (i.e. 1968-1984 and 1985-2001).
- The climatic divisions (Sepilok – A1, Sepanggar – A2, and Samarahan – B1) do serve as a useful guide to analyze the relationships. The six key stations used in this analyses show different patterns and orientation of relationships depending on the geographical location. In most cases, A1 will combine with either A2 or B1 to manifest certain patterns of relationships. The combination of A2 and B1 is rarely exhibited in the relationships.
- KCH (B1), as an individual station, has shown a unique characteristic of its own. Type 7 exclusively explains the distinctive relationships, which are only observed at this station. Of all the six key stations used in the analyses, KCH is the most western in terms of location

7.7 Relationships with temperature

The methods used in investigating the relationships are similar to those used in the precipitation. Relationships with the magnitude variables are analysed based on the anomalies values (positive or negative); whereas relationships with the extreme variables are analysed based on the ratio between the expected and the actual occurrences (see Section 7.3).

7.7.1 Magnitude measures

The magnitude variables used here are the three conventional measures for temperature, which includes the mean, maximum and minimum. All values are expressed as anomalies (see Chapter 4 for details of the procedure in calculating the temperature anomalies).

General relationships

Figure 7.9 provides a graphical view on the relationships. For T-mean (see Figure 7.9a), Types 4 and 8 are generally associated with positive anomalies (hot days). The negative anomalies (cold days) are mainly attributed to Type 3 and 6. For T-max (see Figure 7.9b), Types 4 and 8 are also associated with positive anomalies. However, cold days are associated with Types 1 and 3. The associations are slightly different for T-min (see Figure 7.9b). Types 2 and 4 are associated with positive anomalies; whereas, Types 3 and 6 characteristically appear to be related to the cold nights. All other types, which are not mentioned (See Table 7.19), show no significant anomalies (deviation from the mean is below ±0.1°C).

Table 7.19: The dominant types (positive and negative anomalies) for temperature magnitudes

	T-mean		T-max		T-min	
Station	+ve Ano.	-ve Ano.	+ve Ano.	-ve Ano.	+ve Ano.	-ve Ano.
SDK (A1)	4	6	4, 8	1,6,7	2,4	6
MIR (A1)	4	3	4	3,8	4	6
KK (A2)	4	6	4	3,7	4	NA
BTU (B1)	4, 8	6	4	1,2,7	2,4	NA
SBU (B1)	4	6	4,5,8	6,8	4	6
KCH (B1)	4	NA	8	1	4	NA

Each type will only be identified as describing positive/negative anomalies if the absolute values deviate from the average by more than ± 0.1 °C; N/A = Identifiable types do not occur

In general, circulation types (associated with cold and hot days) are clearly discriminated as far as associations with temperature magnitudes are concerned. Although the relationships show some differences in each one of the measures (T-mean, T-max and T-min), a significant common characteristic is also exhibited. Type 4 appears to be the hot type and Type 3 is the cold type (in all variables).

Relationships based on climatic group

The relationships between circulation types and all three selected variables (i.e. T-mean, T-max and T-min) are consistent for each station (see Table 7.19). The only exception is for Type 8. For T-mean (see Figure 7.9a), Type 8 is highly associated with positive anomalies in the most eastern (SDK) and the most western (SBU, KCH) stations. However, there is no meaningful relationship for the geographically-central stations (KK, MIR, BTU). The same pattern of associations is also exhibited for T-max.

For T-min (see Figure 7.9b), Type 8 shows the characteristic of hot type in three of the most eastern stations (SDK, KK, MIR) – the A1 and A2 climatic groups. There is no significant relationship (deviation from the mean is below ±0.1°C) for the other three most western stations (BTU, SBU, KCH) – Climatic Group B1.

Relationships based on two different periods

The relationships change from negative anomalies (in all types) during the period of 1968-1984 into positive anomalies in the second half of the period (1985-2001). This dramatic change occurs for all selected variables (T-mean, T-max and T-min). However, this change does not represent any actual fluctuation of the relationship – but rather as the result of the increases in temperature between the two periods (see Chapter 5). The graphical view of the relationships can be seen in Figure 7.9; and they are summarised in Table 7.20.

Except for the most western station (KCH), there has been a significant increasing trend in temperature for all other stations over the period of 1968-2001. Therefore, the relationships between circulation type and surface temperatures have also automatically changed during those two periods. Based on analysis of the absolute values for each circulation types in those two periods, the relationships have consistently remained in the same pattern and orientation. For example, in T-mean (see Figure 7.9a): Type 6 shows negative anomalies during the first period (1968-1984). In the second half of the period (1985-2001), Type 6 shows a reverse value of positive anomalies. However, in both periods – Type 6 remains as the coldest type (compared to other types). Thus, the change in the absolute values does not reflect the change in the actual pattern and orientation of the relationship. The change is merely as a result of the statistical procedure (in calculating the anomalies), and does not reflect any actual variability in the relationships. If the temperature anomaly of those two periods had been calculated separately based on the sub period[66], the relationships would have been similar in both periods.

Table 7.20: Temperature magnitudes and the changes through two halves of period

Mean Temperature

Station	1	2	3	4	5	6	7	8
SDK (A1)	+	+	+	O	+	+	+	+
MIR (A1)	+	+	+	O	+	+	+	+
KK (A2)	+	+	+	O	+	+	+	+
BTU (B1)	+	+	+	O	+	+	+	+
SBU (B1)	+	+	+	O	+	+	+	+
KCH (B1)	O	O	O	O	O	O	O	O

Maximum Temperature

Station	1	2	3	4	5	6	7	8
SDK (A1)	O	+	O	O	O	O	O	O
MIR (A1)	+	+	O	O	+	+	+	W
KK (A2)	+	+	+	O	+	+	+	W
BTU (B1)	+	+	+	O	+	+	+	
SBU (B1)	O		+	O	O	+	O	O
KCH (B1)	O	W	W	W	O	W	W	O

Minimum Temperature

Station	1	2	3	4	5	6	7	8
SDK (A1)	+	+	+	+	+	+	+	+
MIR (A1)	+	+	+	+	+	+	+	+
KK (A2)	+	+	+	+	+	+	+	+
BTU (B1)	+	+	+	O	+	+	+	+
SBU (B1)	+	+	+	+	+	+	+	+
KCH (B1)	+	+	+	O	+	+	+	+

O = orientation of the anomalies remain unchanged between the two periods 1968-1984 and 1985-2001; W = a change from positive to negative anomalies; + = a change from negative to positive anomalies

Relationships based on monsoon cycle

Table 7.21 summarizes the relationships, while Figure 7.10 provides graphical view of the relationships. Positive anomalies are more clearly discriminated than the negative anomalies in the circulation types – during the mature monsoons (Northeast and Southwest monsoons). However, positive and negative anomalies are both equally discriminated during the monsoon transitions (Northeast and Southwest transitions). During the Northeast Transition (NET), Type 4 and 8 are associated with positive anomalies and Type 6 is mainly related with negative anomalies. However, there is a slight exception for T-max. Type 2 and 8 are hot type (positive anomalies), while Type 4 (which exhibits positive anomalies in T-mean and T-min) shows negative anomalies.

During the Northeast Monsoon (NEM), the dominant hot types are Type 4 and 7 (in all three temperature measures). However, negative anomalies are not clearly exhibited in T-mean

[66] Sub period is referred to the two halves: 1968-1984 and 1985-2001. The temperature anomalies are calculated based on the long-term average of the entire data (1968-2001). Had it be calculated based on the sub-period (e.g. the anomaly for 1968-1984 is calculated purely based on this period, and so is for the other sub-period) – the relationships would be consistent between the two periods.

(see Figure 7.10a) and T-min (see Figure 7.10b). Only T-max (see Figure 7.10c) shows a quite clear cold type, which is Type 8. During the Southwest Transition (SWT), Types 4, 5 and 8 are associated with positive anomalies, in which Type 8 shows the strongest relationship. Type 3 and 6 exhibit the impact of negative anomalies, with both types showing an equal degree of discrimination. The weakest associations are shown during the Southwest Monsoon (SWM). In general, Type 8 shows the characteristic of positive anomalies. Type 3 and 7 are both more into negative anomalies. However, the relationships for negative anomalies are only exhibited clearly in T-max, and less evident for both T-mean and T-min.

Table 7.21: The relationships with temperature magnitudes based on monsoon cycle

Mean Temperature

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	2	6	4,7	NA	8	6	8	7	1,3,5
MIR	4,7	NA	4,7	8,3	NA	6,3	NA	7,3	1,2,5
KK	2	6	4,7	NA	8	3,1	NA	NA	5
BTU	4	6	4,7	NA	4	3	NA	NA	1,2,5,8
SBU	8	2	4	NA	8	3,1	8	7,3	5,6
KCH	4	NA	4	8	NA	3,2	8	7	1,5,6

Maximum Temperature

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	8,2	4	7,4	NA	8	6	8	7	1,3,5
MIR	7,2	NA	4	8	4	3	NA	7,3	1,5,6
KK	4,2	NA	4	8	4	3	NA	7,8	5,6
BTU	NA	6	7,4	8	2	3	8	7	1,5
SBU	8	4,6	4,7	NA	5	1,3	8	7	2
KCH	8	4,6	7	1	5	3,4	8	7	2

Minimum Temperature

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	NA	6	4,7	NA	8	NA	8	NA	1,2,3,5
MIR	4	6	4,7	3	8	5,3	8	NA	1,2
KK	NA	6	8,7	NA	8	1,6	NA	NA	2,3,4,5
BTU	4	6	4,7	NA	8,4	6,3	NA	NA	1,2,5
SBU	4	6	4,7	NA	8	5,6	2	3	1
KCH	4	6	4	NA	8	3,1	NA	3	5,7

Each type will only be identified as describing positive/negative anomalies if the probability of occurrences deviate from the average by more than ± 0.25 (25%); N/A = Identifiable types do not occur

Relationships based on ENSO phases

The graphical view of the relationships can be seen in Figure 7.11; and they are summarised in Table 7.22. In general, during El Niño years, the relationships with positive anomalies are more clearly discriminated. This means that warm ENSO phases can be identified with a clear occurrence of hot types. However, different circulation types exhibit the significant positive anomalies during the different categories of the warm ENSO years: namely between the weak (WEL) and strong (SEL) El Niño phases.

Table 7.22: The relationships with temperature magnitudes based on ENSO phases

Mean Temperature

	WEL		SEL		WLA		SLA		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	7	NA	6,4	NA	NA	4	NA	5,2	1,3,8
MIR	4	NA	4,6	NA	NA	4	NA	5,2	1,3,7,8
KK	4	NA	4,6	NA	NA	7,1	NA	6,2	3,5,8
BTU	4	NA	4,6	NA	NA	2,3	NA	5,6	1,7
SBU	NA	NA	6,4	NA	NA	2,3	NA	2,5	1,7,8
KCH	NA	2	4,6	NA	NA	3,2	NA	2	1,5,7,8

Maximum Temperature

	WEL		SEL		WLA		SLA		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	8	NA	4,6	NA	8	4,7	NA	5,7	1,2,3
MIR	4	NA	6,4	NA	NA	2,3	NA	6,5	1,7,8
KK	4	NA	4,6	NA	NA	7,4	NA	6,2	1,3,5,8
BTU	4	NA	6,4	NA	NA	2,3	NA	NA	1,5,7,8
SBU	NA	NA	4,6	3	NA	2	4	1	5,7,8
KCH	NA	2,7	4,6	NA	8	2,3	8,5	1	NA

Minimum Temperature

	WEL		SEL		WLA		SLA		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	NA	NA	6,3	NA	NA	5,3	NA	5,3	1,2,4,7,8
MIR	4	NA	4,6	NA	NA	5	NA	5,4	1-3,7,8
KK	NA	NA	4,6	NA	NA	4,1	3	5	2,7,8
BTU	NA	NA	4,6	NA	NA	5,2	NA	5,2	1,3,7,8
SBU	NA	NA	4,6	5	NA	5,7	NA	5,7	1,2,3,8
KCH	6	NA	4,6	NA	NA	3	NA	2,3	1,5,7,8

Each type will only be identified as describing positive/negative anomalies if the probability of occurrences deviate from the average by more than ±0.1 ℃; N/A = Identifiable types do not occur

During La Niña years, the associations with negative anomalies are better exhibited, which means that cold types are more clearly discriminated during the cold ENSO phases. Similar as been shown during the El Niño years, different circulation types are associated with significant negative anomalies between the weak (WLA) and strong (SLA) La Niña phases. For the WEL events, Type 4 is identified as the hot type (positive anomalies). However, this relationship is only clearly exhibited in the T-mean (see Figure 7.11a) and T-max (see Figure 7.11b) measures. It is less significant in T-min (see Figure 7.11c). For the SEL events, Types 4 and 6 are equally strong in associating with positive anomalies in all three temperature measures (T-mean, T-max, T-min).

The WLA events generally show that Types 2, 3, 4, 7 and 5 (depending on stations) are attributed to the occurrence of negative anomalies. Type 4 and 7 are the dominant cold types in T-mean; Types 2 and 3 in T-max; and Type 5 seems to exclusively associated with T-min.

During the SLA events, Type 5 seems to be the most dominant cold type in all the temperature measures (T-mean, T-max, T-min). However, Types 2 and 6 also exhibit a strong degree of association with negative anomalies in certain stations (especially those in the central part: KK, BTU, SBU).

7.7.2 Extreme measures

The thresholds used are:

- 90pc T-mean = 90th percentile of mean temperature
- 90pc T-max = 90th percentile of maximum temperature
- 10pc T-min = 10th percentile of minimum temperature

General relationships

The graphical view of the relationships can be seen in Figure 7.12; and they are summarised in Table 7.23. Each one of the three extreme variables significantly discriminates the positive and negative anomalies with different types of circulation. This is the basic difference between the relationships exhibited in the magnitude variables (where the same types tend to show similar impact) and in the extreme variables (where each one behaves uniquely).

Table 7.23: The dominant types (positive and negative anomalies) for temperature magnitudes

	90th Pc. T-mean		90th Pc. T-max		10th Pc. T-min	
Station	+ve Ano.	-ve Ano.	+ve Ano.	-ve Ano.	+ve Ano.	-ve Ano.
SDK (A1)	6,7	4,8	5,8	6,7	6	1,2
MIR (A1)	1,6	4,5	4	3,8	6	1,2
KK (A2)	1,6	4	4	8	6	2,6
BTU (B1)	1,6	4,5	4,5	1,7	6	4,8
SBU (B1)	1,6,7	4,5,8	4,5	6,7	6	1,7
KCH (B1)	1,6	4,5,8	4	7	5,6	1,4

Each type will only be identified as describing positive/negative anomalies if the probability of occurrences deviate from the average by more than ± 0.25 (25%); N/A = Identifiable types do not occur

For 90pc T-mean, Type 1/6 are clearly the dominant types for positive anomalies; and Type 4/5 are the strongest types for negative anomalies. In 90pc T-max, Type 4/5 are associated with positive anomalies; whereas Type 1/6/7 are associated with negative anomalies. For 10pc T-min, Type 6 is visibly dominant for positive anomalies, and Type 1/2 are the dominant type for negative anomalies, although Type 4 also significantly exhibits the same associations in all stations within the Samarahan Climatic Group (B1).

Relationships based on climatic group

See Figure 7.12 and Table 7.23 for the description of results in this section. In all three variables (90pc T-mean, 90pc T-max and 10pc T-min), the associations between certain circulation types and the anomaly (whether positive or negative) are similar and consistent in all stations. However, there is one exception for the negative anomalies in 90pc T-max. Type 1 and 6 are associated with the most eastern (SDK) and most western (BTU, SBU, KCH) stations; and Type 3 is exclusively for the central stations (KK, MIR).

Relationships based on two different periods

As opposed to the temperature magnitude (where the relationships change over time – see Section 7.7.2), the relationships between the extreme variables do appear to be consistent between the two halves of the period. This conclusively suggests that the relationships between the circulation types and the occurrences of extreme temperature retain the stability for the period of 1968 to 2001. The graphical view of the relationships can be seen in Figure 7.12; and they are summarised in Table 7.24.

Table 7.24: Temperature extremes and the changes through two halves of period

90th Percentile Mean Temperature

Station	1	2	3	4	5	6	7	8
SDK (A1)	O	O	+	O	O	O	O	O
MIR (A1)	O	O	O	O	O	O	O	W
KK (A2)	O	O	O	O	O	O	+	+
BTU (B1)	O	O	O	O	O	O	O	W
SBU (B1)	O	O	O	O	O	O	O	O
KCH (B1)	O	O	O	O	O	O	O	O

90th Percentile Maximum Temperature

Station	1	2	3	4	5	6	7	8
SDK (A1)	W	+	+	+	O	O	O	O
MIR (A1)	W	O	O	O	O	O	O	O
KK (A2)	W	O	O	O	+	O	O	O
BTU (B1)	O	O	O	O	O	O	O	O
SBU (B1)	O	W	O	O	O	+	O	W
KCH (B1)	O	W	O	O	O	O	O	W

10th Percentile Minimum Temperature

Station	1	2	3	4	5	6	7	8
SDK (A1)	O	O	+	O	W	O	O	O
MIR (A1)	O	O	O	+	W	O	O	O
KK (A2)	+	O	O	O	+	O	O	O
BTU (B1)	O	+	O	O	W	O	O	O
SBU (B1)	O	O	O	O	W	O	O	O
KCH (B1)	O	+	+	O	O	W	O	+

O = orientation of the anomalies remain unchanged between the two periods 1968-1984 and 1985-2001; W = a change from positive to negative anomalies; + = a change from negative to positive anomalies

Relationships based on monsoon cycle

Figure 7.13 provides a graphical view of these relationships. There are two distinctive observations worthy of note. The first observation is that both 90pc T-mean (see Figure 7.13a) and 90pc T-max (see Figure 7.13b) show almost the same identical types, which are associated with negative/positive anomalies in all seasons. During the winter monsoon (NET and NEM: October – March), Types 2, 4, 7 and 8 are associated with positive anomalies; and Types 1, 2, 4 and 8 are associated with negative anomalies[67]. During the summer monsoon (SWT and SWM: April – September), Types 4 and 8 are strongly associated with positive anomalies; whereas Types 3, 6 and 7 are associated with negative anomalies. There is no one particular type, which is associated with both positive/negative anomalies – as has been shown during the winter monsoon.

The second distinctive observation is that the 10pc T-min (see Figure 7.13c) shows a totally different pattern of relationships compared to what has been observed in 90pc T-mean and 90pc T-max. This difference is anticipated because these variables measure the temperature extremes in different ways. 10pc T-min represents the bottom 10th percentile of temperature occurrences, which measures the coldest temperature. On the other hand, 90pc T-mean and T-max represent the upper 90th percentile of temperature occurrences, which measures the hottest temperature (see Chapter 5 under Section 5.3.2 for further justification on this choice). During the winter monsoon (NET and NEM: October – March), Types 3 and 6 are associated with positive anomalies; and Types 2, 4, 7 and 8 are associated with negative anomalies. During the summer monsoon (SWT and SWM: April – September), Types 3 and 5 are associated with positive anomalies; while, Types 2, 4, 7 and 8 are associated with negative anomalies.

Other than these two major observations, it is important to note that a clear relationship is less visible (especially for positive anomalies) during the Southwest Monsoon (May – August). This is particularly obvious for all the stations under Samarahan Climatic Group (B1), which is BTU, SBU and KCH.

[67] Types 2, 4 and 8 describe both the positive and negative anomalies depending on the stations. For example, using the 90pc T-mean variable, Type 4 exhibits positive anomalies for all stations in Climatic Group A1 and A2 (i.e. SDK, MIR, KK). However, this same type exhibits negative anomalies in Climatic Group B1 (i.e. BTU, SBU, KCH).

Table 7.25: The relationships with temperature extremes based on the monsoon cycle

90th Percentile Mean Temperature

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	7	4,6	4	2	8	6,3	8	7	1,3,5
MIR	7	6	4	8	4	1,6	4	7	2,3,5
KK	8	1,4	4,7	6	4	3,6	4	7	2,5
BTU	4,7	1	4,7	8,1	8,4	1,6	4	7	2,3,5
SBU	8,7	4	2,4	NA	8	6	NA	7	1,3,5
KCH	4,7	6,1	4	2	8	3	NA	7,4	5

90th Percentile Maximum Temperature

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	8	4,6	2,8	NA	2,8	1,6	8	7	3,5
MIR	7, 2	8	4	2,8	4	6	4	3,7	1,5
KK	4	6	4	3	1,4	5,6	4	NA	2,7,8
BTU	7	NA	2,4	8	4,2	6,1	4,8	7,3	1,5
SBU	4	6	2	NA	8	1,3	4	7	1,5
KCH	NA	4	2	8	5	3,6	NA	4,7	1

10th Percentile Minimum Temperature

	NET		NEM		SWT		SWM		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	6	4	NA	2,7	3	1,8	NA	4	5
MIR	6	4	3	8	5,1	2	NA	4	7
KK	6	7,3	NA	2,8	1,4	2	3	4	5
BTU	6,4	1	3	2,7	3,5	8	NA	7	NA
SBU	6	8,4	3	2,7	5	8	3	4,8	1
KCH	6	4	3,6	4,1	3	8,1	NA	4,7	2,5

Each type will only be identified as describing positive/negative anomalies if the probability of occurrences deviate from the average by more than ±0.25 (25%); N/A = Identifiable types do not occur

Relationships based on ENSO phases

Figure 7.14 provides a graphical view of the relationships. Interestingly, the same observations as in monsoon cycle are also evident when analysing the relationships based on ENSO phases. Both the 90pc T-mean (see Figure 7.14a) and 90pc T-max (see Figure 7.14b) variables show almost the same identical types, which are specifically associated with negative/positive anomalies in each category of ENSO phases. Similarly, the 10pc T-min (see Figure 7.14c) shows a unique pattern of relationships compared to those two extreme variables[68].

For the first two variables (90pc T-mean and 90pc T-max) during the El Niño years, Types 4/5 (weak events) and Types 4/6 (strong events) are associated with positive anomalies. Type 6/7/8 (weak events) and Type 7/8 are associated with negative anomalies. In the years

[68] For a detailed justification on this difference, please refer to the explanation in Section 7.7.2 under the subtitle *'Relationships based on monsoon cycle'*.

of La Niña, Types 6/8 (weak events) and Types 3/4/8 (strong events) characteristically show clear positive anomalies. For the negative anomalies, they are exhibited in Types 4/6/8 for the weak events, and Types 2/5/8 for the strong events.

Table 7.26: The relationships with temperature extremes based on ENSO phases

90th Percentile Maximum Temperature

	WEL		SEL		WLA		SLA		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	NA	NA	6	NA	8	NA	3	2,5	1,2,4,7
MIR	4	8	4	NA	8,4	NA	3	4,2	1,5,7
KK	5	3	4	8	6,8	5,7	8,3	2,5	1
BTU	5	8,7	4,6	7	3,4	2	3,8	2,5	1
SBU	5	6,1	4,6	7,8	6,8	7	3,8	2,5	NA
KCH	5	2,7	4	7	8	2	8,3	2	1,6

90th Percentile Maximum Temperature

	WEL		SEL		WLA		SLA		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	5	6,3	4	1,7	8	4,7	8	5,4	2
MIR	4	8,7	6,4	7	6	NA	3	2,4	1,5
KK	4	7,3	4,6	5,7	6,1	5	3,8	2,5	NA
BTU	2,5	8,6	4,6	7	NA	3,1	2,5	8,6	NA
SBU	4	7	4,6	7	4,6	NA	4	NA	1-3,5,8
KCH	4	2,7	4	8	4	7,2	4	8	1,3,5,6

10th Percentile Minimum Temperature

	WEL		SEL		WLA		SLA		Non
Station	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	Sig.
SDK	6,4	3	5	8,3	5	8,4	5	3	1,2,7
MIR	6	2,1	5	1,8	3	NA	4	3	7
KK	6	2	7,5	3,1	1	2,5	6	3,7	4,8
BTU	3	7,4	5	6,8	3	4	5	8,3	1,2
SBU	3,6	4,7	5	8,3	5,7	6,4	5	8,3	1,2
KCH	8,5	1,4	2,3	6	6	4,1	2,5	3,8	7

Each type will only be identified as describing positive/negative anomalies if the probability of occurrences deviate from the average by more than ± 0.25 (25%); N/A = Identifiable types do not occur

The 10pc T-min variable shows a clearer discrimination, where different types of circulation are distinctively associated with positive/negative anomalies between each category of ENSO phases. During the El Niños, Types 3/6 seem to be dominant for positive anomalies; and Type 2/4 for the negative anomalies. During the strong El Niño years, Types 2/5 have positive anomalies; while Types 3/6/8 have negative anomalies. For La Niña years, the weak events are discriminated by Types 3/5 (positive anomalies) and Types 6/4 (negative anomalies). The strong events are represented by Types 2/5 (positive anomalies) and Types 3/8 (negative anomalies).

7.7.3 Summary of relationships with temperature

The significant characteristics shown by each type are summarized in Appendix G. The most important relationships established in each type are listed below:

- Type 1 does not show any significant relationships with any of the temperature variables.
- Type 2 exhibits positive anomalies in magnitude variables (mean and maximum temperature) during the Northeast monsoon transition (NET) in A1 and A2 climatic groups. It also shows positive anomalies in B1 for extreme variables during the mature phase of Northeast monsoon (NEM). As for ENSO phases, negative anomalies are experienced by all stations during the strong La Niña years (SLA) for mean temperature (both the average and extreme measures).
- Based on the monsoon cycle, Type 3 is exclusively associated with minimum temperature in B1 climatic group. This gives positive anomalies for 10^{th} percentile of minimum temperature during the winter monsoon (NEM). During the summer monsoon (SWM), it gives negative anomalies for minimum temperature average. Negative anomalies are also observed for all stations (for 10^{th} percentile of minimum temperature) during the occurrences of strong La Niña (SLA).
- Type 4 shows high positive anomalies for all stations for magnitude variables (especially mean and maximum temperature) during the Northeast monsoon (NEM) and the weak El Niño (WEL).
- Type 5, in general, is one of the less significant types. This type shows no important association with surface climate based on monsoon cycle. However, it exhibits negative anomalies in minimum temperature (for all stations) and mean temperature (exclusively for A1) during the strong La Niña years (SLA).
- Type 6 seems to have a unique association with minimum temperature during the transition phase of Northeast monsoon (NET), giving positive anomalies for the magnitude variable (i.e. minimum temperature average) and negative anomalies for the extreme (i.e. 10^{th} percentile of minimum temperature).
- Type 7 is highly discriminating between the two mature phases of monsoon – namely, the Northeast monsoon (winter) and Southwest monsoon (summer). It gives positive anomalies for all stations for magnitude variables (i.e. the mean, maximum and minimum temperature average) during the Northeast monsoon; and negative anomalies during the Southwest monsoon. It also shows significant negative anomalies for extreme variables (i.e. 90^{th} percentile of mean/maximum temperature) during the strong El Niño years.

- Type 8, similarly as has been observed for precipitation variables, shows more complex relationships with various conditions. It gives several significant relationships with different variables in various climatic events/seasons. The most notable relationships are: (i) positive anomalies for magnitude variables (mean and maximum temperature) in the most eastern station (SDK) and the most western ones (SBU/KCH) during the monsoon transition – both the summer and winter monsoons (SWT and NET); (ii) positive anomalies for all stations during the La Niña years (both weak and strong events) for one particular extreme variable (i.e. 90^{th} percentile of mean temperature).

There are several other notable findings from this study, which are not exclusively associated with individual types. They are discussed here in turn.

- Generally, the monsoon seasons can identify clear and strong relationships with both types of variables – (i) the magnitude variables (i.e. the daily averages of mean, maximum and minimum temperatures); and, the extreme variables (90^{th} percentile of mean and maximum temperature, and 10^{th} percentile of minimum temperature). However, the relationships identified under the influence of ENSO phases are only clear for the extreme variables.
- Relationships exhibited based on ENSO phases appear to be more consistent in all stations, and have a minimal difference in terms of spatial distribution. For example, Type 2 gives negative anomaly for 90^{th} percentile of T-mean in all stations during the strong La Niña years. Similarly, Type 4 gives positive anomaly for both T-mean and T-max during the El Niño years in all stations. In contrast, the relationships exhibited based on monsoon cycle are more variable between stations and climatic groups. For example, during the Northeast Transition, Type 2 gives positive anomalies for T-mean and T-max for all stations in A1 and A2 climatic groups. While during the Northeast Monsoon, Type 2 gives negative anomalies for 10^{th} percentile T-min.
- Based on monsoon seasons, all variables (i.e. the magnitudes and extremes) are equally good in establishing relationships with the circulation types. Certain types are clearly and specifically associated with particular climatic groups and monsoon seasons – thus making it easier to establish a pattern with recognisable characteristics. However, for ENSO phases, only the extreme variables are good enough to establish a recognisable pattern of relationships. The circulation types are not able to clearly discriminate the relationships established by magnitude variables (i.e. the mean, maximum and minimum temperature averages).

7.8 Relationship analysis (with the de-seasoned reclassification)

This section will examine the relationships between the circulation types (i.e. CT1 and CT2) [69]and the surface climate of Borneo. Some thorough and detailed analyses[70] on the synoptic-surface relationships have been conducted in the previous sections (see Sections 7.6 and 7.7). By considering the results derived from those analyses, only a few surface variables will be selected for this section, which are deemed to be most likely providing the more reliable patterns of relationships. This selective approach will enable a clearer and more focused comparison with the previous methods (Methods 1, 2, 3 and 4). The chosen variables for the newly established typing scheme (CT1 and CT2) are:

- Precipitation – the seasonal anomaly (mm/day), the number of wet days (rainfall of more than 1mm/day) and the 90th percentile (for extreme measure).
- Temperature – the T-mean (mean temperature) anomaly, the 90th percentile of T-max (maximum temperature) and the 10th percentile of T-min (minimum temperature).

Similar to the analyses that have been conducted in Sections 7.6 and 7.7, the relationships will be investigated for all six key stations (i.e. SDK, MIR, KK, BTU, SBU and KCH). The analyses will be subjected to these key issues:

- Which types are strongly related with certain conditions of precipitation and temperature?[71]
- How the relationships change over time? Are they temporally dependant or have they remained consistent throughout the study period (1968-2001)?[72]
- How do the relationships vary over space? Are they spatially different between the six key stations?
- How the relationships 'behave' under the influences of different phases of the monsoon cycle?

7.8.1 Precipitation

In general, Types 3, 4, 5 and 6 are associated with positive anomalies (wet types); whereas Types 1, 2, 7 and 8 (dry types) exhibit considerable values of negative anomalies (see Figures 7.15a and 7.15b). This applies for both methods, CT1 and CT2. Of the four wet

[69] See Chapter 6, Section 6.4,

[70] These analyses are conducted on the circulation types produced by Methods 1 and 2 (which use the absolute SLP data as the PCA input); Methods 3 and 4 (which use the deseasonised SLP data, but combining the monsoon seasons).

[71] Circulation types that are significantly associated with positive anomalies of precipitation are referred as 'wet types'; and those related with negative anomalies are regarded as 'dry types'. A rather similar way of making the reference goes for temperature – i.e. positive anomalies (hot types) and negative anomalies (cold types).

[72] The analysis for this part will be conducted on two independent sets for different periods. The original data (1968-2001) will be equally divided into two halves – i.e. 1968-1984 and 1985-2001 (see Sections 7.1).

types, the strongest are Types 3 and 6 with anomaly values exceeding 3.0 mm/day (both in CT1 and CT2). For the dry types, the most representative are Types 2 and 7 for CT1 (separate season); and Types 1 and 2 for CT2 (combined seasons). The relationships are fairly consistent over the 34-year period of study. The pattern of relationships between the two halves (of 17 years each) barely differs. For both CT1 and CT2, all circulation types maintain the initial state of their relationships (with precipitation average) throughout the period. The only exception is Type 5, where it shows an obvious change in terms of the strength of the relationship. In both cases (CT1 and CT2), Type 5 exhibits strong association with positive anomalies during the first half of the period (1968-1984). However, this association is significantly weakened in the second half (1985-2001).

Other interesting questions relate to the several circulation patterns identified as wet or dry types:

- In which monsoon phases do they exhibit stronger and clearer relationships?
- What specific types (with a strong emphasis on the pattern of relationships) are uniquely associated with any of the six individual stations in Borneo (SDK, MIR, KK, BTU, SBU and KCH)?
- Is there any difference (in terms of strength, distribution and sign of the relationships) between the average and extreme variables?

In addressing all the three key questions above, analyses for each individual station has been performed for three variables: precipitation average, number of wet days and the extreme indicator, which is the 90th percentile of precipitation (see Figures 7.16a-c for CT1, and 7.17a-c for CT2). The results are summarised in Table 7.27 below. Sub-tables a, b and c are for CT1 (separate season); and sub-tables d, e and f are for CT2 (combined season).

In CT1, Type 1 exhibits negative anomalies for all three precipitation variables. Thus, it can be regarded as the dry type. The relationship is shown strongly during the SW monsoon, especially for stations BTU, SBU and KCH, which share the same climate division, the Samarahan Climatic Group (B1).[73] The same association is observed for CT2 for Type 1. However, more stations are included (i.e. including the A group – Sepilok and Sepanggar Climatic Groups) especially for the extreme variables (i.e. the 90th percentile and wet days). For CT1, Type 2 is also associated with negative anomalies (dry type), but it is only shown during the NE monsoon and it includes all stations. However, in CT2, Type 2 only shows the relationships for the stations from A1 (Sepanggar) and A2 (Sepilok) climatic groups.

[73] See Chapter 4 for further details of the regional classification of local climate in Borneo.

Types 3, 4 and 5 (individually) exhibit the same pattern of relationships for both classification schemes (CT1 and CT2). Type 3 is associated with wet days, and the association is generally stronger during the SW monsoon at the three stations in the most western part of Borneo (BTU, SBU and KCH). Type 4 is also a wet type and effectively shows its relationship during the SW transition and its mature phase of monsoon. For the average variable, it is applicable for all stations. However, the relationship is only prominent in two stations (i.e. BTU and SBU) for the extreme variables (number of wet days and 90th percentile). Type 5 shows strong positive anomalies for all stations in Samarahan Climatic Group (B1 – BTU, SBU and KCH) during the SW monsoon.

Type 7 is a dry type (negative anomalies), and strongly shows during the SW transitional monsoon and the mature phase at all stations. However, for CT2 – the spatial distribution for all stations is less clearly visible. Similar to Type 7, Type 8 is also deemed as a dry type with strong negative anomalies. This relationship is most clear during the SW monsoon, and the degree of association is relatively stronger than Type 7.

Table 7.27: Relationships with precipitation

a. CT1 (Separate Season) – Precipitation (Average)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1		X			X	X				X	X	X
2		X	X	X			X	X	X	X	X	X
3	X			X			X			X	X	X
4	X					X	X	X	X	X	X	X
5	X					X				X	X	X
6	X		X				X	X	X			
7		X			X	X		X	X	X	X	
8		X			X	X		X	X	X	X	

b. CT1 (Separate Season) – Precipitation (90th percentile)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1		X				X				X	X	X
2		X		X			X	X	X			
3	X					X		X	X	X	X	X
4	X			X		X				X	X	
5	X					X				X	X	X
6	X			X		X	X	X	X			
7		X			X	X		X		X	X	X
8		X				X		X	X	X	X	X

c. CT1 (Separate Season) – Precipitation (Wet Days)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1		X			X	X				X	X	X
2		X			X	X	X	X	X	X	X	X
3	X		X	X	X	X	X	X	X	X	X	X
4	X					X		X	X	X	X	X
5	X			X			X	X	X	X	X	X
6	X			X			X	X	X	X		
7		X			X	X	X	X	X	X	X	X
8		X				X		X	X	X	X	X

d. CT2 (Combined Season) – Precipitation (Average)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1		X			X	X		X		X	X	X
2		X		X			X	X	X	X		
3	X			X	X	X			X	X	X	X
4	X					X	X	X	X	X	X	X
5	X					X		X	X	X	X	X
6	X					X	X	X	X			
7		X			X	X		X	X	X	X	X
8		X				X			X		X	X

e. CT2 (Combined Season) – Precipitation (90th percentile)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1		X				X				X	X	X
2		X		X			X	X	X			
3	X			X		X		X	X	X	X	X
4	X				X	X				X	X	
5	X					X				X	X	X
6	X		X	X	X	X		X	X			
7		X				X		X	X	X	X	X
8		X				X		X	X	X	X	X

f. CT2 (Combined Season) – Precipitation (Wet Days)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1		X				X		X	X	X	X	X
2		X		X	X		X	X	X	X		
3	X		X	X	X	X		X	X	X	X	X
4	X					X		X	X	X	X	X
5	X					X				X	X	X
6	X		X	X	X		X	X	X			
7		X				X		X	X	X	X	X
8		X				X		X	X	X	X	X

7.8.2 Temperature

Generally, Types 2, 7 and 8 are associated with positive anomalies (hot types), whereas Types 3, 4 and 6 are characterised by negative anomalies, and are thus known as the cold types (see Figures 7.18a and 7.18b). Types 1 and 5 do not show any strong association either with negative or positive anomalies. Of the three hot types, the strongest is Type 2 with values exceeding 0.2°C (both in CT1 and CT2). For the cold types, the strongest is Type 6 (i.e. with anomaly values of less than -0.2°C). All the descriptions above are applied for both methods, CT1 and CT2.

The relationships are fairly consistent over the 34-year period of study. The pattern of relationships between the two halves (of 17 years each) barely differs. For both CT1 and CT2, all circulation types maintain the initial state of their relationships (with precipitation average) throughout the period. As can be observed, the anomaly values are different between the first (1968-1984) and the second (1985-2001) halves. However, it must be noted that there is an increasing trend of temperature in Borneo over the last 34 years (see Chapter 5). Thus, even if the values differ slightly, it does not mean that the patterns of relationship have changed. To evaluate if the relationships have been consistent or not, it is more precisely done by comparing which types have the higher/lower temperature values for each period. For instance, if some particular types consistently have the lowest values in both compared periods – then it is justified to conclude that the same patterns of relationships have been maintained. It is evident that, by analysing the distribution of anomalies in Figures 7.18a-b, Types 3, 4 and 6 remain to be associated with lower values; and Types 2, 7 and 8 persistently exhibit high temperature anomalies.

For further investigation on these identified hot and cold types, the same issues (as have been discussed for the precipitation) are to be answered: (i) which monsoon phases exhibit the relationships stronger and clearer?; (ii) what specific types (with a strong pattern of relationships) are uniquely associated with any of the six individual stations in Borneo?; and (iii) is there any difference (in terms of strength, distribution and orientation of the relationships) between the average and extreme variables? Questions number (ii) and (iii) are the simplest cases for temperature. Generally, all the identified relationships are equally exhibited at all stations, with little distinctive differences, in contrast to what had been shown for precipitation. There are also no obvious differences, in terms of strength and distribution, between the average and extreme variables.

As for the issue number (i), it can be generalised that the relationships with T-mean temperature average and T-max 90th percentile (the extreme measure) are strongly exhibited during the SW transition and monsoon. The relationships are less evident during the Northeast monsoon. However, for the second extreme variable (T-min 10th percentile), the associations are more strongly exhibited during the NE transition and monsoon. The variability on seasonal basis is the only strong factor affecting the temperature relationships. Spatial variability is not as clear as had been shown by the precipitation relationships. This is attributed to the fact that the degree of variability (both seasonally and regionally) for temperature in Borneo is much lower compared to precipitation (see Chapter 5).

Table 7.28: Relationships with temperature

a. CT1 (Separate Season) – Temperature (T-mean Average)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1	X					X	X	X	X	X	X	X
2	X		X	X			X	X	X	X	X	X
3		X				X	X	X	X	X	X	X
4		X				X	X	X	X	X	X	X
5		X				X	X	X	X	X	X	X
6		X	X	X			X	X	X	X	X	X
7	X					X		X	X	X	X	X
8	X					X	X	X	X	X	X	X

b. CT1 (Separate Season) – Temperature (T-max 90th percentile)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1		X			X				X	X	X	X
2	X			X	X	X	X	X	X	X	X	X
3		X	X	X	X	X				X	X	X
4		X	X	X	X	X	X				X	X
5	X			X	X					X	X	X
6		X			X	X	X	X	X	X	X	X
7	X					X	X	X	X	X	X	X
8	X					X	X	X		X	X	X

c. CT1 (Separate Season) – Temperature (T-min 10th percentile)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1	X		X	X					X	X		
2		X		X			X	X	X	X	X	X
3		X			X		X	X		X	X	X
4	X		X				X		X	X		
5		X		X			X	X	X	X	X	X
6	X		X	X			X	X	X	X	X	X
7	X				X		X	X	X	X	X	X
8		X			X		X			X	X	

d. CT2 (Combined Season) – Temperature (T-mean Average)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1	X					X	X	X	X	X	X	X
2	X		X	X	X	X	X	X	X	X	X	X
3		X		X		X		X	X	X	X	X
4		X				X	X	X	X	X	X	X
5		X				X	X	X	X	X	X	X
6		X	X	X	X	X	X	X	X	X	X	X
7	X					X		X	X	X	X	X
8	X					X		X	X	X	X	X

e. CT2 (Combined Season) – Temperature (T-max 90th percentile)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1	X					X	X			X	X	X
2	X				X		X	X	X	X		X
3		X	X	X	X	X	X			X	X	X
4		X			X	X					X	X
5		X				X	X	X	X	X	X	X
6		X	X	X	X		X	X	X	X	X	
7	X					X	X	X	X	X	X	X
8	X					X	X	X	X	X	X	X

f. CT2 (Combined Season) – Temperature (T-min 10th percentile)

	Anomaly		Monsoon Phases				Stations					
Type	+ve	-ve	NET	NEM	SWT	SWM	SDK	MIR	KK	BTU	SBU	KCH
1	X				X		X	X	X	X	X	X
2		X	X	X	X		X	X	X	X	X	X
3		X			X		X	X		X	X	X
4	X		X				X		X	X	X	X
5		X		X		X	X	X	X	X	X	X
6	X			X			X	X	X	X	X	X
7	X				X		X	X		X	X	X
8		X	X				X				X	X

7.8.3 Physical interpretation

Borneo is located in the centre of the Southeast Asia (SEA) region. It is surrounded by several seas (namely the South China, Sulu, Molluco and Java Seas); and by a large number of islands (i.e. the Philippines and Indonesian archipelagos). The surrounding atmospheric circulation brings different impacts to the local climate of Borneo – depending on where they come from. Nieuwolt (1977) identified three main origins of large-scale factors that influence this region, namely the Indian Ocean (westerly relative to Borneo), the Asian main land continent (northerly) and the Pacific Ocean (easterly). Specifically, there are two main synoptic circulations for Borneo (and SEA region as a whole) - the monsoon and the ENSO phenomenon (Quah, 1988; Sirabaha, 1998, 2004). The section will attempt to relate this identified synoptic forces with the eight established circulation types, and to physically justify why a particular circulation type brings a certain type of impact to the local climate (i.e. wet, dry, cold and hot – see Table 7.30). The interpretation is ilustrated using one selected day of each circulation types (as an example), which shows the direction of the actual wind flow[74]. However, in a bigger context – the interpretation also considers the basic patterns derived from the composite maps (for each circulation type)[75].

Table 7.30: Summary of characteristics for CT1 & CT2 (frequency and relationship)

Type	Dominant season*	ENSO ElNino	LaNina	Precip.	Temp.	Spatial distribution**
1	-		Low	Dry	Hot	B1 (Samarahan)
2	NEM	High		Dry	Hot	A1 (Sepilok), A2 (Sepanggar)
3	NEM			Wet	Cold	All stations
4	SWM		High	Wet	Cold	All stations
5	-	Low		Wet	Cold	All stations (stronger in B1)
6	-			Wet	Cold	A1 and A2
7	NEM		High	Dry	Hot	Central (KK, MIR, BTU)
8	SWM			Dry	Hot	Central (KK, MIR, BTU)

** Sign (-) indicates that the type occurs evenly in both monsoons*
*** For temperature, the impacts are relevant for all stations in most cases*

Type 1 is associated with dry and hot conditions, especially in the western part of Borneo – the Samarahan Climatic Group (B1 – BTU, SBU and KCH). This type occurs equally strongly through both monsoon seasons (see Figure 7.2a). It is characterised by low pressure in the northeast part of this region, especially near the northern Philippines. This moves the dry air[76] from the Indonesian maritime region towards the Philippines along the southwest direction. Thus, it reduces precipitation over Borneo – especially the western part (the first to be affected).

Type 2 is also dry and hot (see Figure 7.2b); but mostly occurs during the NE monsoon. The main atmospheric flow originates from the northern part of the Pacific Ocean. It moves to Borneo, crossing the Philippines archipelago (over which, most of the moisture is converted into rainfall), towards the low pressure area, established to the north of the Peninsular

[74] Calculated based on the u-wind and v-wind components (i.e. data derived from the NCEP website for the period of 1968-2001).
[75] See Figures 7.45, 7.46 and 7.47.
[76] This air originally carries moist from the Indian Ocean, but gets condensed (and normally produces heavy rainfall in the west coast of Sumatra) while the air crossed this Indonesian island.

Malaysia. As opposed to the Type 1, Type 2 influences more strongly the eastern and central part of Borneo, the Sepilok (A1) and Sepanggar (A2) climatic groups. This is easily understood, as the two dry circulations (Types 1 and 2) originate from the opposite directions (South Indian Ocean/North Pacific Ocean).

Type 3 is wet and cold (see Figure 7.2c); and also prominent during the Northeast monsoon. This type is characterised by the creation of high pressure areas over the main Asian land continent (between 15°N-30°N), and the establishment of low pressure over the northern part of Australia. Thus, the existing pressure gradient stimulates a strong circulation of flow from the northeast. This flow will cross the South China Sea (and absorb moisture along the way) before it finally reaches Borneo, and brings heavy precipitation to all the areas facing the South China Sea. Therefore, the local impact of Type 3 is equally exhibited at all key stations (all of which are located in this area).

Types 4 and 6 (see Figures 7.21d & 7.21f) are quite similar to Type 3 in terms of general circulation and impact on the local climate (wet and cold). Type 4 occurs mainly during the Southwest monsoon, whereas the frequency of Type 6 is equally distributed between the two monsoons. The synoptic flow (for both cases) originates from the main Asian land continent due to pressure differences between the Asian mainland and the Australian continent. However, the pressure gradient is much lower for Type 4 – thus relatively weakening the circulation. As can be seen in Figures 7.15a-b/7.18a-b (the relationships with precipitation/temperature), it is clear that Types 3 and 6 show stronger associations with the surface variables.

Although Type 5 (see Figure 7.2e) can be loosely regarded as a wet and cold type – the pattern of relationship is barely visible. There are several locations where distinctive pressure anomalies are established. Two relatively low pressure areas are created. The first one is in the northwest, over the Indian subcontinent, while the second one is in the southwest, over the Indian Ocean (to the west of the Sumatra). Two relatively high pressures are also formed – at the west coast of the Australian continent, and over Mongolia in the Asian mainland. This type is characterised by a rather ‘complicated and chaotic’ distribution of pressure within the Southeast Asia region. Thus, it is safe to assume that the atmospheric flows do dynamically change over time. This is the reason why there is no specific pattern of relationships is detected with surface climate.

Types 7 and 8 share several similarities in terms of features (see Figures 7.21g and 7.21h). Both are wet and cold types; and exhibit strong relationships with the three central stations

(KK, MIR and BTU). The difference is that Type 7 occurs more frequently during the Northeast monsoon; whilst Type 8 is most common in the Southwest monsoon. The general distribution of pressure is – relatively high in the northern and southern areas (above 15°N and 10°S), and much lower pressures occupy the middle areas, between 15°N-10°S. Type 7 also establishes some relatively low pressure areas along the longitude at 75°-85°E, to the west of Borneo. The large-scale atmospheric flows, which should be normally crossing Borneo in the northeast-southwest direction, are now redirected into the westerly direction. Thus, the moist air flows (from the South China Sea) are now diverted from going into Borneo. The case for Type 8 (which is more frequent during the SW monsoon) is slightly different. There is a creation of cyclonic low pressure over the Philippines, somewhere between 15°-30°N. This induces strong air movement from the southwest direction. This atmospheric flow is 'dried' while crossing the Indonesian maritime islands (Sumatra, Java, Belitung) before it eventually moves over Borneo. This flow might still carry some moisture (evaporated from Java and Natuna seas) when it first reaches Borneo (starting over the western part), but it tends to get drier as it moves further north. Therefore, Type 7 does show its 'drying and warming' effect more strongly at the stations located in the central and eastern part of Borneo (i.e. BTU, MIR, KK), and not so evident in KCH and SBU (the more westerly stations).

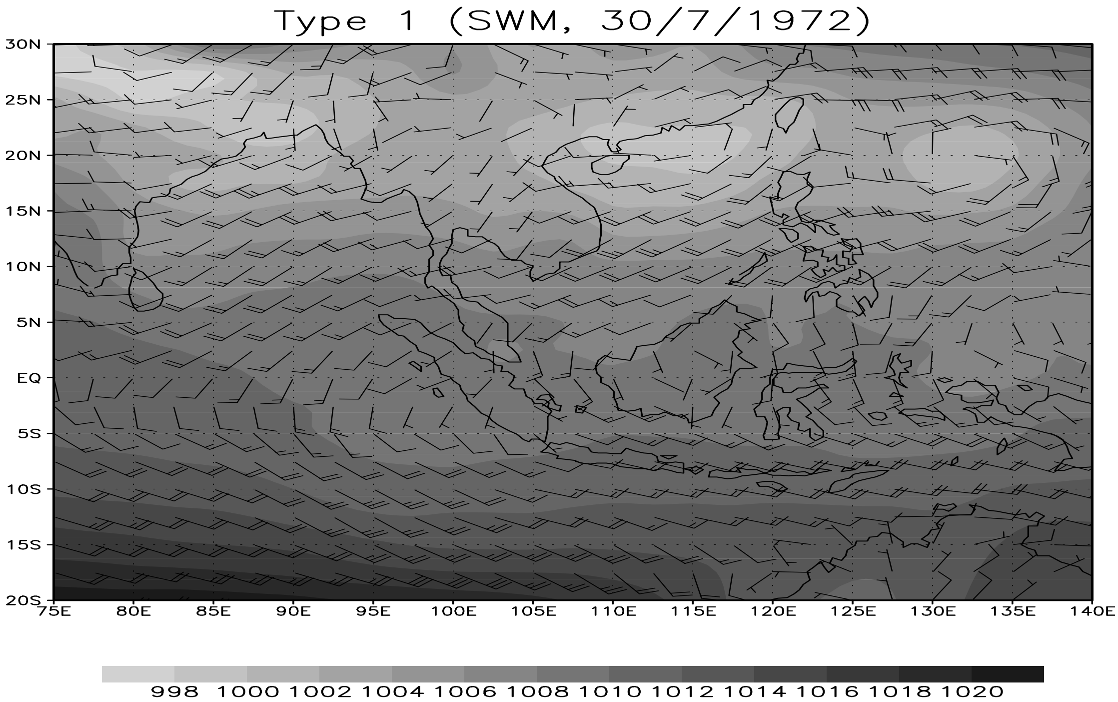


Figure 7.2a: Type 1 (Dry and Hot)

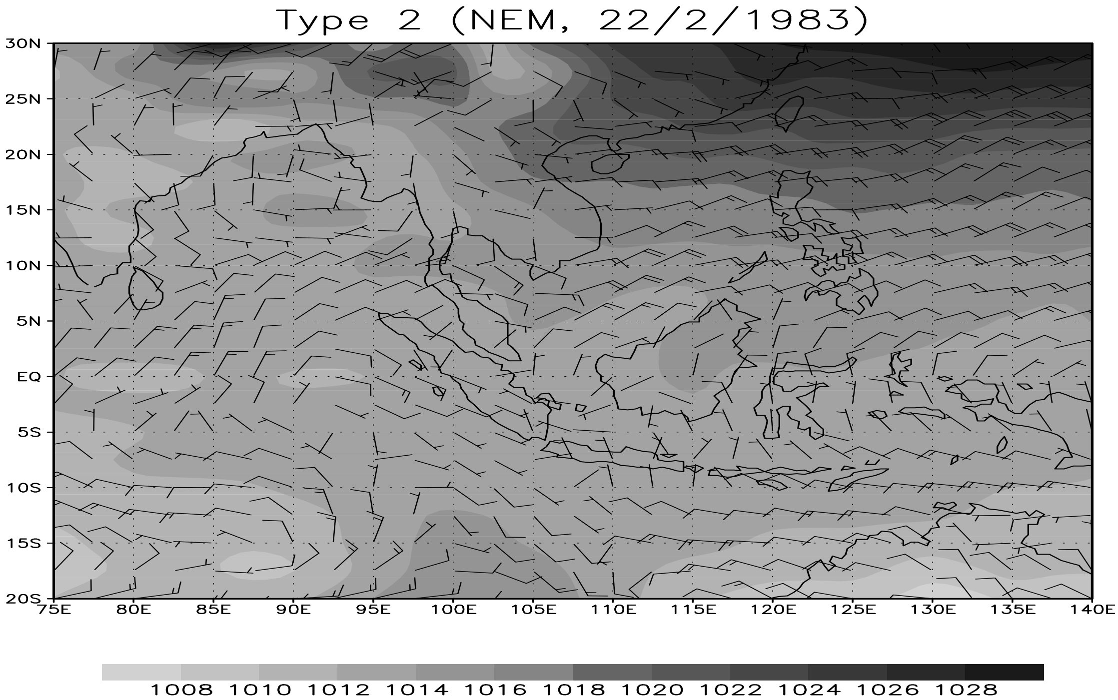


Figure 7.2b: Type 2 (Dry and Hot)

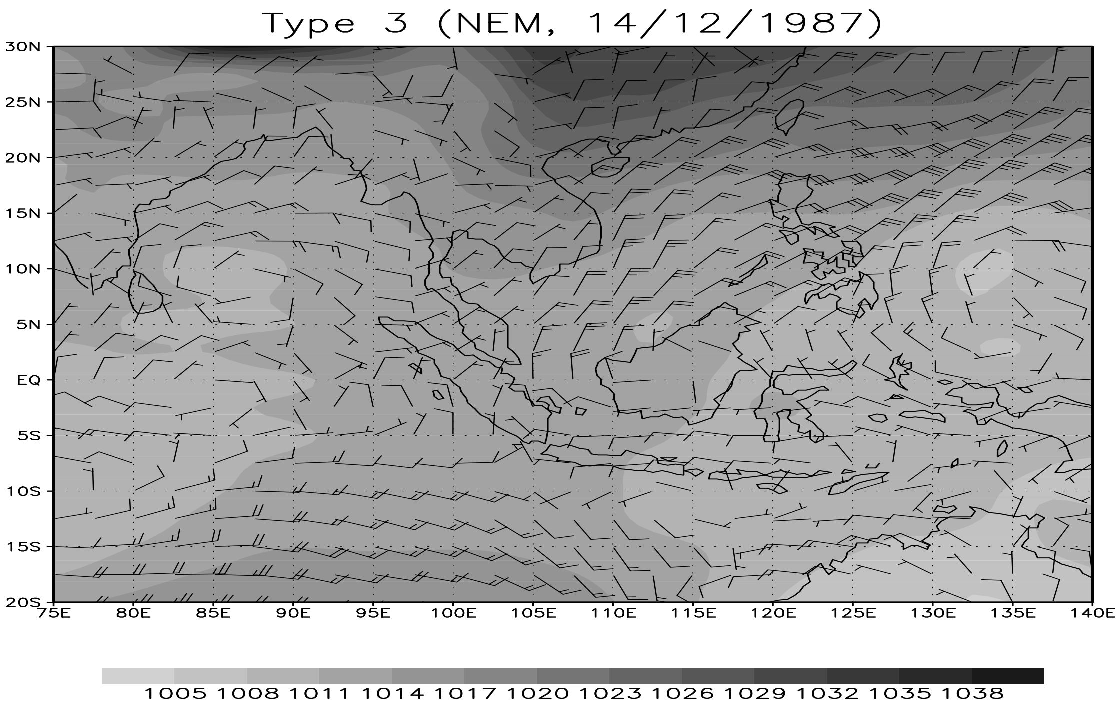


Figure 7.2c: Type 3 (Wet and Cold)

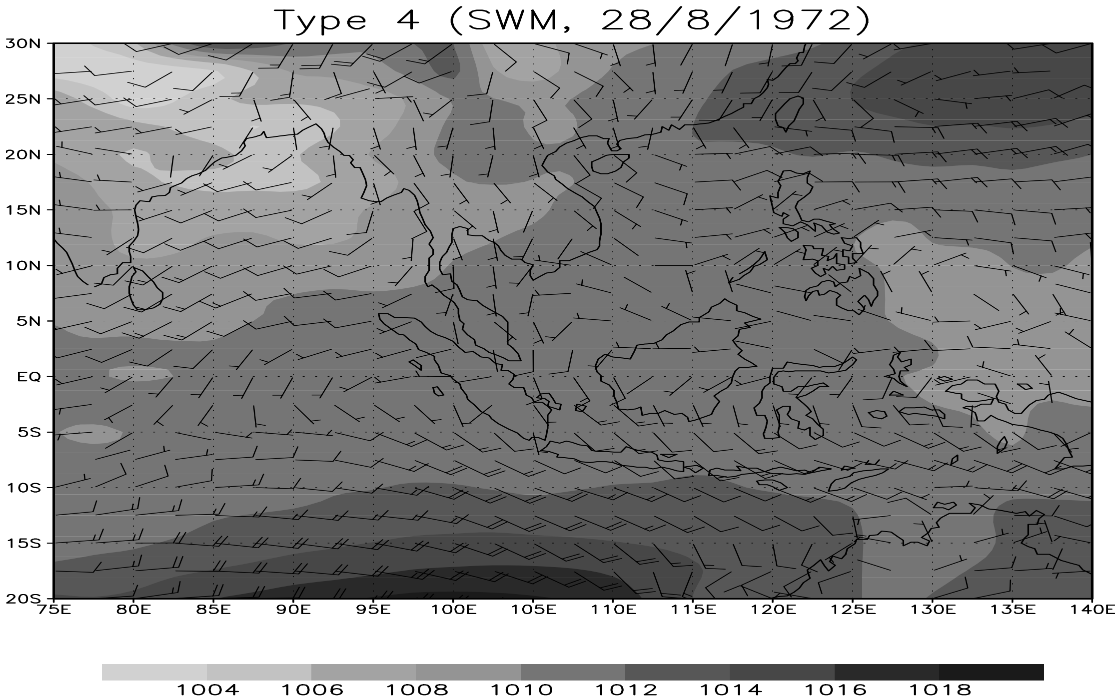


Figure 7.2d: Type 4 (Wet and Cold)

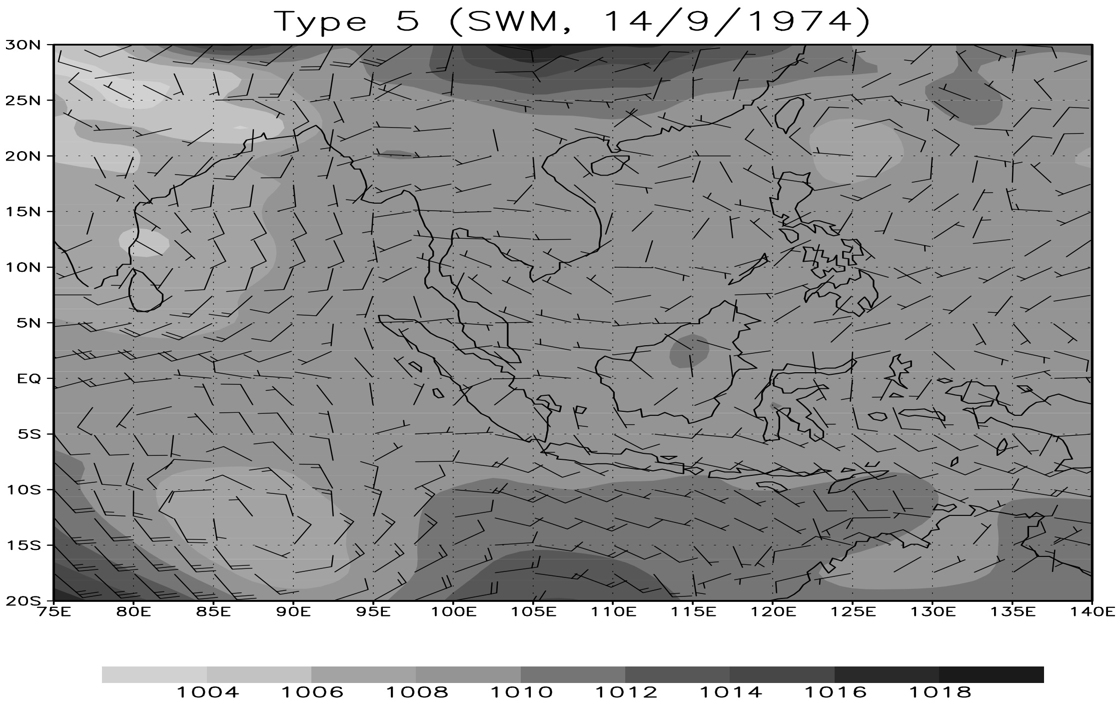


Figure 7.2e: Type 5 (Wet and Cold)

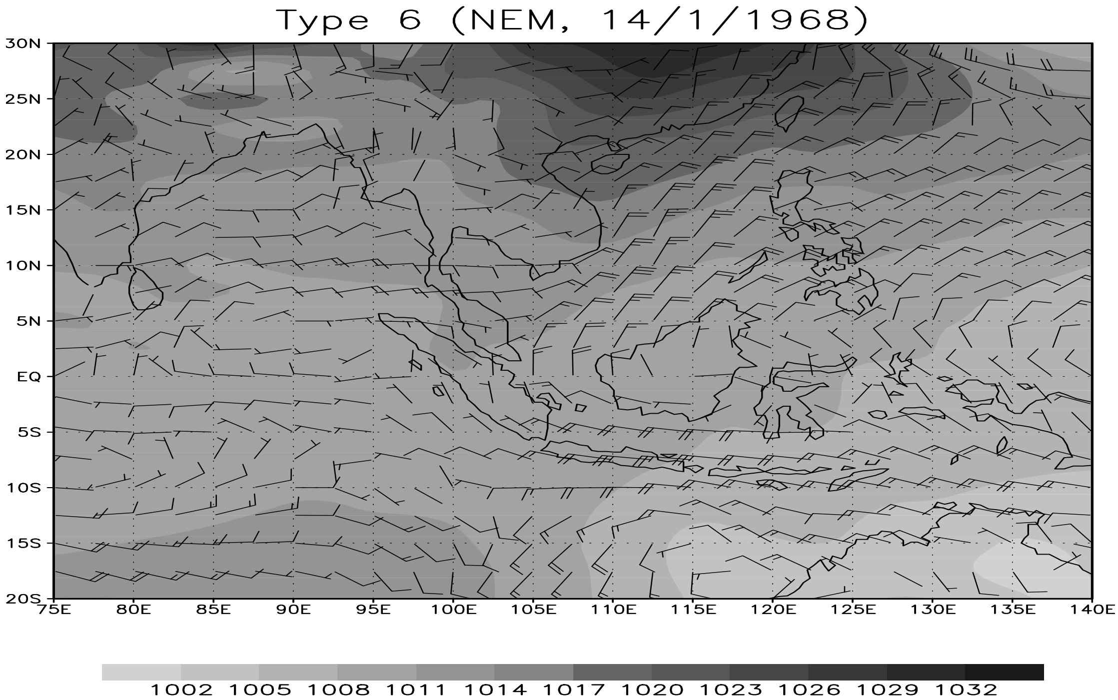


Figure 7.2f: Type 6 (Wet and Cold)

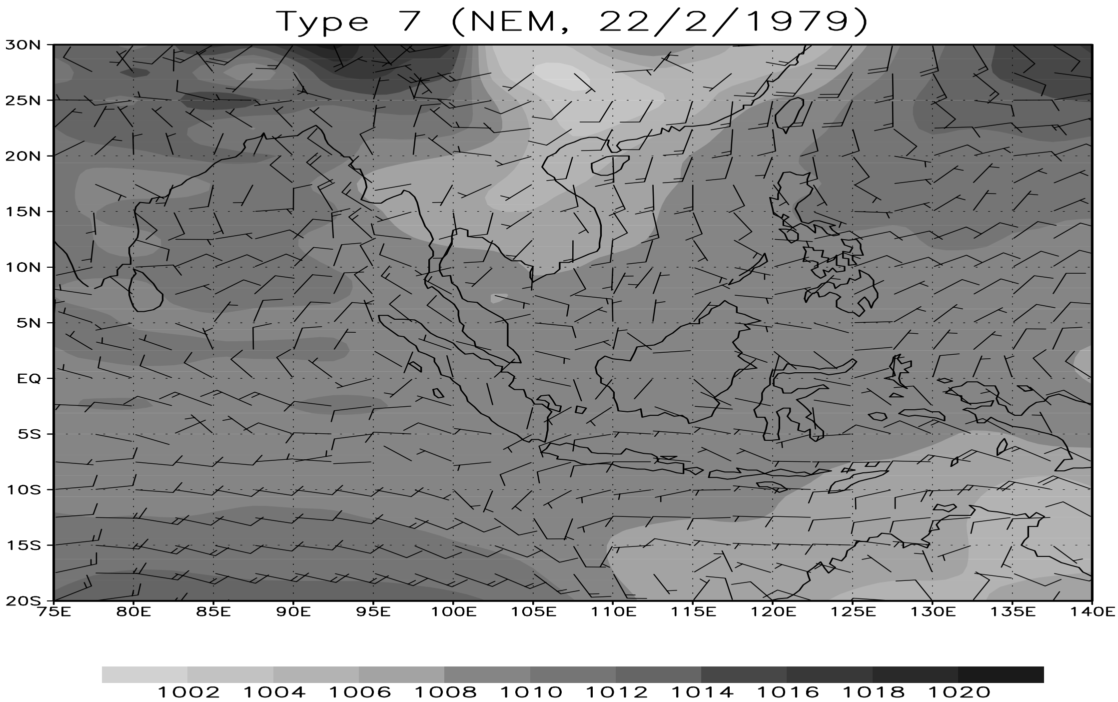


Figure 7.2g: Type 7 (Dry and Hot)

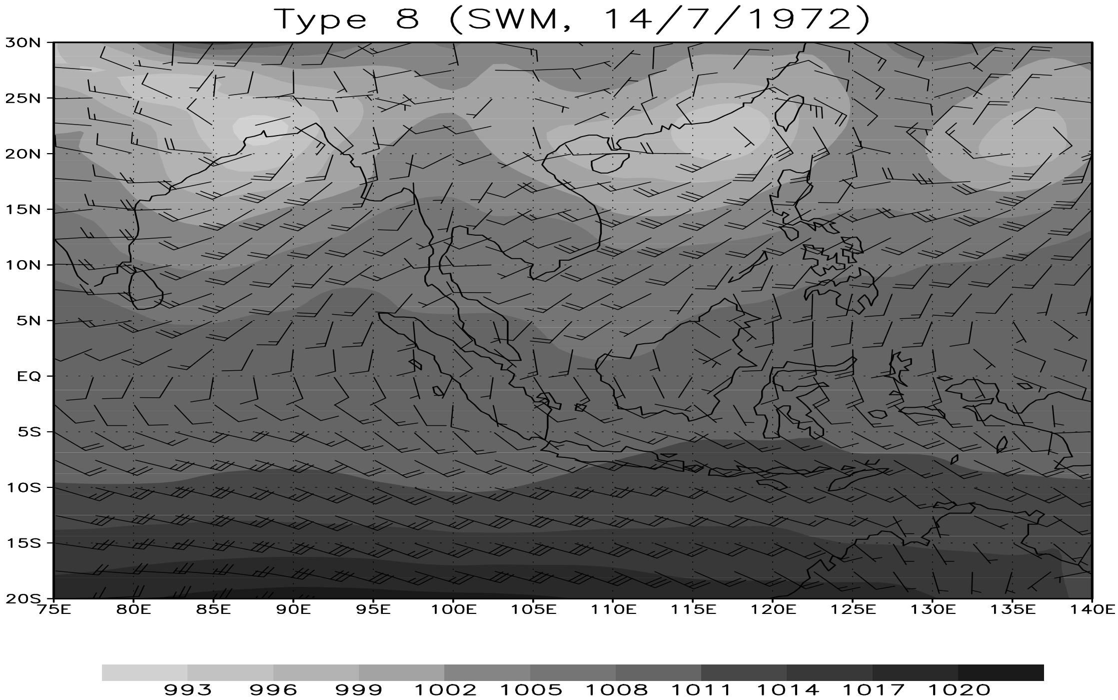


Figure 7.2h: Type 8 (Dry and Hot)

7.9 Conclusions

There are several key findings derived from this analysis, which directly addresses the most important issue pertaining to the synoptic typing scheme: the relationships between the circulation types and the surface climate (this includes both average and extreme measures). These relationships are analysed subject to the established local climatic divisions, the comparison between the two halves of period (1968-1984 and 1985-2001), and by investigating the similarities/differences under the influences of various climatic factors (i.e. monsoon and ENSO). This conclusion will be divided into three parts: (i) a discussion of the findings based on Method2 (using absolute SLP data); (ii) the results derived from methods CT1 and CT2 (using SLP anomaly data); (iii) a comparison of findings from Method2, CT1 and CT2.

Part (i) Method2

The pairing type of 1/5 (originally from the mirror pair of PC1 +ve and PC1 -ve) are the most insignificant in establishing relationships. These types do not exhibit any discriminating patterns, especially for anomalous precipitation. Both types are the mature phases of the monsoon cycle. Type 1 represents the NEM (Nov-Dec), while Type 5 is associated with SWM (Jun-July). These two circulation patterns are characterized by stable monsoonal flow. The low-level winds are either from the northeasterly (i.e. from the mainland Asian continent) or southwesterly (i.e. from the Indian Ocean) directions. These two circulation patterns typically do not contribute much to the formation of ITCZ (Sham Sani, 1984); thus, convective precipitation is less likely to occur. On the other hand, the paired types of 4/8 (created originally from PC4 positive/negative ‘mirror’ types) are the most significant in establishing relationships. These two circulation types are associated with the transitional monsoon. Types 4 and 8 represent the SW (April-May) and NE (Sept-Oct) monsoon transitional seasons, respectively. The two phases are characterized by dynamic changes in large-scale atmospheric flow over Southest Asia from northerly to southerly, and vice versa. During this period, the location of ITCZ moves dynamically up and down between 0°S - 5°N, and results in anomalous precipitation but with high degree of variability.

Generally, the relationships with precipitation are more clearly shown than with temperature. The key circulation types that identify temperature anomalies are: Type 4 (associated with hot days) and Type 6 (cool days). The important circulation types that identify precipitation anomalies are: Types 1 and 3 (associated with wet days) and Types 4 and 6 (dry days). Type 8 exhibits a different influence depends on the climatic groups. It is associated with dry days in B1 (Samarahan Climatic Group) and wet days for A2 (Sepanggar Climatic Group). It is also found that the monsoon cycle influences the changes in relationships much stronger, than the fluctuation in ENSO phases. What does this mean? Although this typing scheme should be able to integrate both the monsoon and ENSO forcings into each of the circulation types; it is evident that the classification captures the monsoon signal much better than that due to ENSO.

The relationships with average measures (e.g. daily precipitation average and intensity) are much more clearly distinguished between different monsoon seasons. However, extreme variables (i.e. 90^{th} percentile of precipitation and temperature) are better discriminated using ENSO years. The variability of the relationships between different stations (or climatic divisions) is also much stronger using the monsoon cycle as the basis i.e. each climatic group (or individual station) establishes its own unique pattern of relationship for a particular surface climate. However, when using ENSO phases as the basis to analyse the relationships – the patterns are more homogenous (for almost all cases, the general relationships are much more similar between stations or climatic divisions).

It has been decided in this research to classify the monsoon cycle and ENSO phases into a more specific classification (e.g. separating the ‘mature monsoon’ from its transitional season; and, reclassifying El Niño/La Niña years into 'strong' and 'weak'). This decision proved to be justified because each specific phase has shown significant differences. Monsoon and ENSO have been regarded as the most influential large-scale phenomena, which directly affect the surface climate of Southeast Asia (including Borneo). The established relationships with eleven surface climatic elements (5 for precipitation; and 6 for temperature) show that the monsoon season is a more dominant factor, compared to ENSO.

Among the criteria for a "good and useful" typing scheme is having consistency and clarity in discriminating the relationships; and this has been well achieved. The physical interpretability has also been generally identified and described by relating the circulation patterns to the most common large-scale atmospheric modes in the SEA region (i.e. seasonal changes in the monsoon flow). Thus, it can be concluded that the selected typing method (Method 2 from evaluation made in Chapter 6) is justified and has performed well.

Part (ii) Method CT1 and CT2

In general, CT1 (separating the monsoon) and CT2 (combining the monsoon) do not show much difference with regard to their relationships with local climate. The corresponding types for each method exhibit almost identical associations with the selected precipitation and temperature variables. For the precipitation anomaly (average measure), Types 3, 4, 5 and 6 are linked with positive anomalies, thus making them wet types. Interestingly, the 'mirror components'[77] of these four types, which are Types 1, 2, 7 and 8 are associated with negative anomalies (the dry types). The same pattern is established with the temperature variable (T-mean average). Types 1, 2, 7 and 8 show positive anomalies (hot types); and their mirror components (Types 3, 4, 5 and 6) exhibit the opposite (cold types).

Three types (2, 3 and 7) are linked with higher occurrences during the NE monsoon. Two other types (4, 8) occur more often during the SW monsoon. However, the frequencies for Types 1, 5 and 6 are equally distributed between the two monsoons. Type 4 and 7 are also more associated with the La Niña years, whilst Type 2 tends to occur during the El Niño years. In terms of spatial pattern (of the relationship), for temperature (both the average and extreme variables) the relationships exhibit the same strength at all stations, for almost all cases. This is, however, not the case for precipitation. Type 1 is exclusively associated with the Samarahan Climatic Group (B1). Types 2 and 6 are more clearly associated with the

[77] Mirror components are referred to two pairing types (i.e. represent the positive and negative scores) that are derived from the same PCs. For example; if four PCs are retained – eight types will be established, where Types 1 and 5 are the mirror components for PC1, Types 2/6 for PC2, and so forth.

Sepilok (A1) and Sepanggar (A2) climatic groups. The relationships for Types 3, 4 and 5 are reasonably clear at all stations; although they (in terms of degree) are slightly more biased to the Samarahan Climatic Group (B1). Finally, Types 7 and 8 are more clearly linked with the three central stations (namely, KK, MIR and BTU).

The relationships in all cases are physically well justified, as they can be explained by describing the flow pattern of the large-scale atmospheric circulations in the Southeast Asia region. These circulations mainly originate from the three main sources are: the Indian Ocean, Pacific Ocean and the Asian mainland continent.

Part (iii) Comparisons between Method2 and Methods CT1/CT2

These two methods have been developed from the same set of data (MSLP, 1960-2001). However, the procedures how the initial components (PC) have been created are quite different. Method2 is chosen as the best, from four other tested methods (see Chapter 6) – which all employ either one of: absolute SLP data for PC input or combining the two monsoon seasons while performing the PCA. The new methods (CT1/CT2), on the other hand, use SLP anomaly data as PC input. One of these methods is additionally tested by separating the two seasons (CT1); and the other one (CT2) by combining the two seasons.

All three methods (Method1, CT1, and CT2) produce the same number of 4 significant components, which eventually leads to the final eight circulation types. There are many similarities, but some differences between the Method2 and CT1/CT2 are also observed. The similarities are:

- Both typing schemes have successfully managed to establish distinctive patterns of relationships with surface variables. In both cases, wet, dry, hot and cold types have been clearly identified.
- Certain types are more strongly associated with a particular region in Borneo. Thus, the ability for spatial discrimination has been clearly shown in both cases.
- In comparing precipitation and temperature variables (for both methods), it is also worth noting that the relationships with precipitation are better (in terms of the signal strength); and the associations with temperature are less discriminating in terms of spatial signal. Interestingly, these similar patterns are observed with both schemes.

The differences are:

- The circulation types established in Method2 are very biased to the monsoon signal, to the extent that each type is specifically assigned to one monsoon season; and in some cases, the types only occur during a particular monsoon phase. Thus, for Method2, the relationships are much clearer when tested in different monsoon seasons; compared to different ENSO events. In methods CT1/CT2, there are only five circulation types that can be exclusively assigned into a particular monsoon season. However, the discrimination is not as extreme as in Method2. The other three types are considered as 'non-monsoon' and may represent other long-term variability signals in the region (such as ENSO). The relationship in CT1/CT2 is not tested separately for ENSO variables – because testing it under the monsoon cycle would still allow the ENSO signals to be included (and not diluted by strong monsoon influences as in Method2).
- Related to the first issue, the physical justification for the circulation types established by Method2 are mainly based on the changing flows between the NE/SW monsoons and their transition seasons. Thus, in explaining the surface climate (as associated with the synoptic circulation) – the description is mainly focussed on the ITCZ mechanism. This is the only clear physical process that determines the amount of precipitation in Borneo, in a case where the types are rigidly made to represent one specific monsoon season. This, however, is not applied in CT1/CT2. The eight circulation types in this case are regarded as the 'summary' of all the important synoptic modes in the area. This results from the quasi-biennial forces (i.e. ENSO), the annual fluctuations (i.e. monsoon) or the intra-seasonal variability (i.e. MJO). Although, some of the types are associated with certain phases of the monsoon or certain conditions of ENSO, these associations are not entirely exclusive.

Which of the two procedures is better? Depending on the objective and aim, both procedures offer advantages and disadvantages. If the aim is to establish a circulation scheme that can specifically identify the synoptic mode of each monsoon phase (and significantly eliminate other synoptic signals, including that due to ENSO) – Method2 has an advantage over CT1/CT2. However, if the aim is to develop a more neutral scheme, which 'summarises' all the important synoptic modes without being biased only to the seasonal features (i.e. the monsoon), then CT1/CT2 is probably the better method.

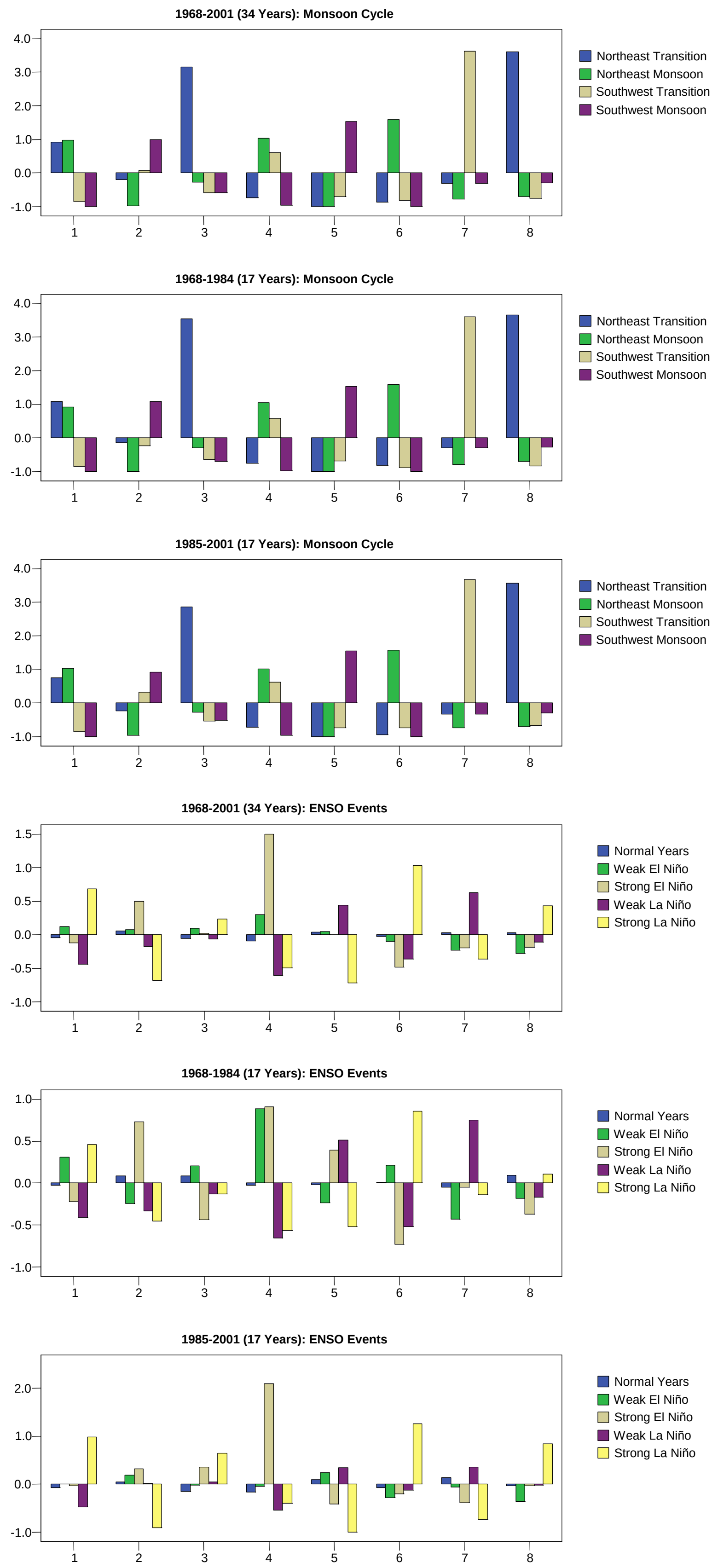


Figure 7.1b: Frequency of occurrences (expressed in ratio probability) for each circulation type based on monsoon cycle and ENSO phases (analysed separately for two periods: 1968-1984 and 1985-2001)

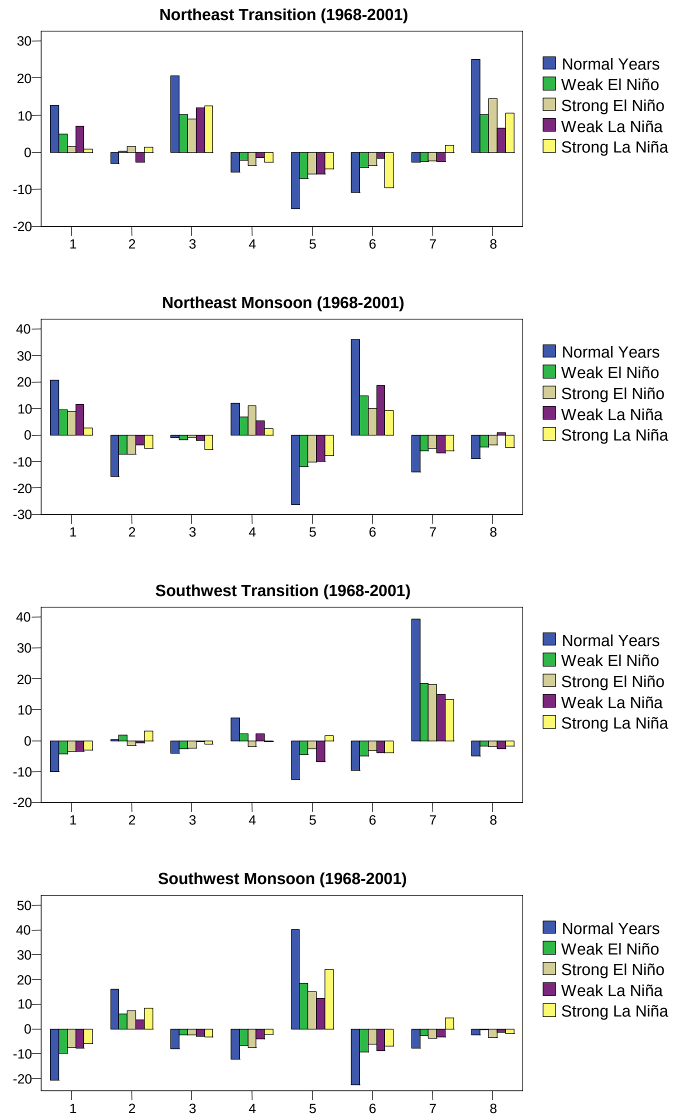


Figure 7.2: Frequency of occurrences (expressed in ratio probability) for each circulation type based on combined influence of monsoon and ENSO (analysed separately for two periods:1968-1984 and 1985-2001)

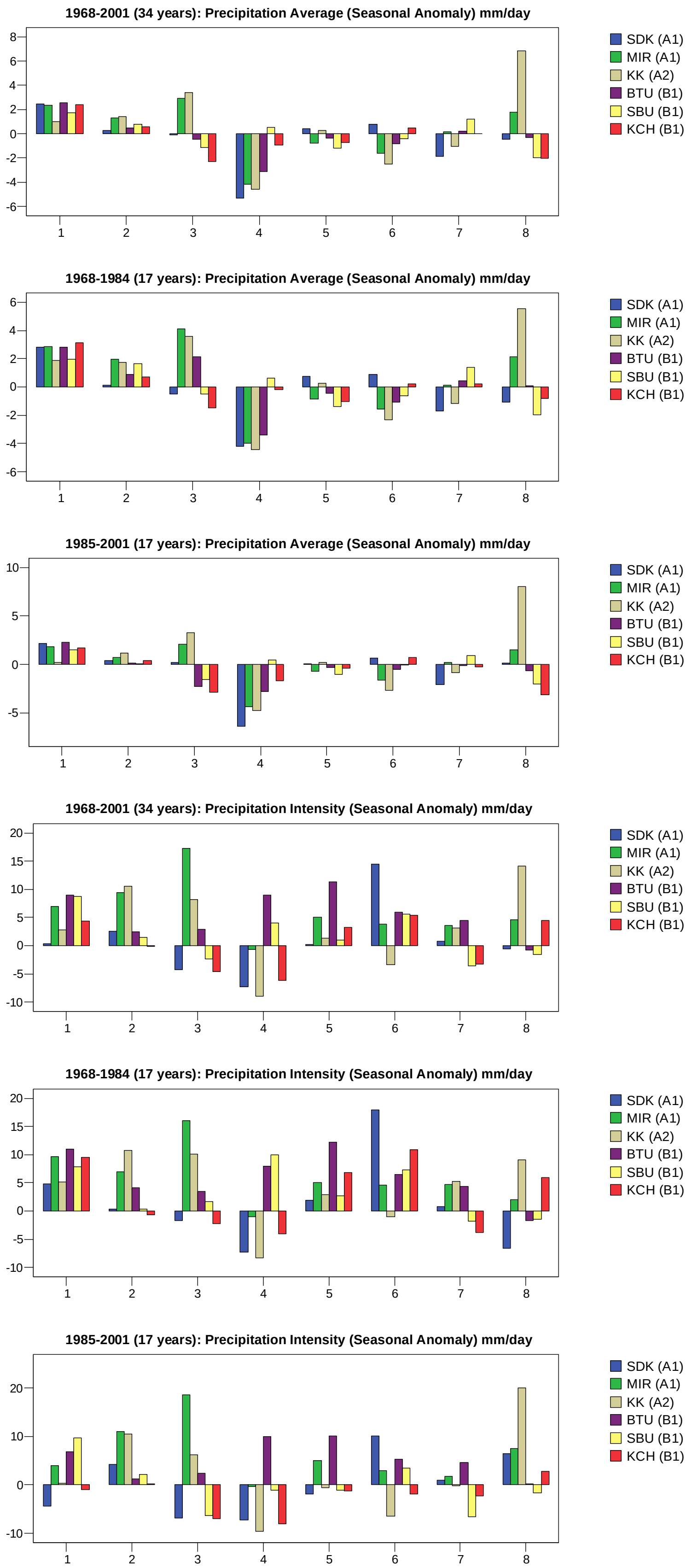


Figure 7.3: Relationships with circulation types based on two halves of period (1968-1984 and 1985-2001) for precipitation average and intensity

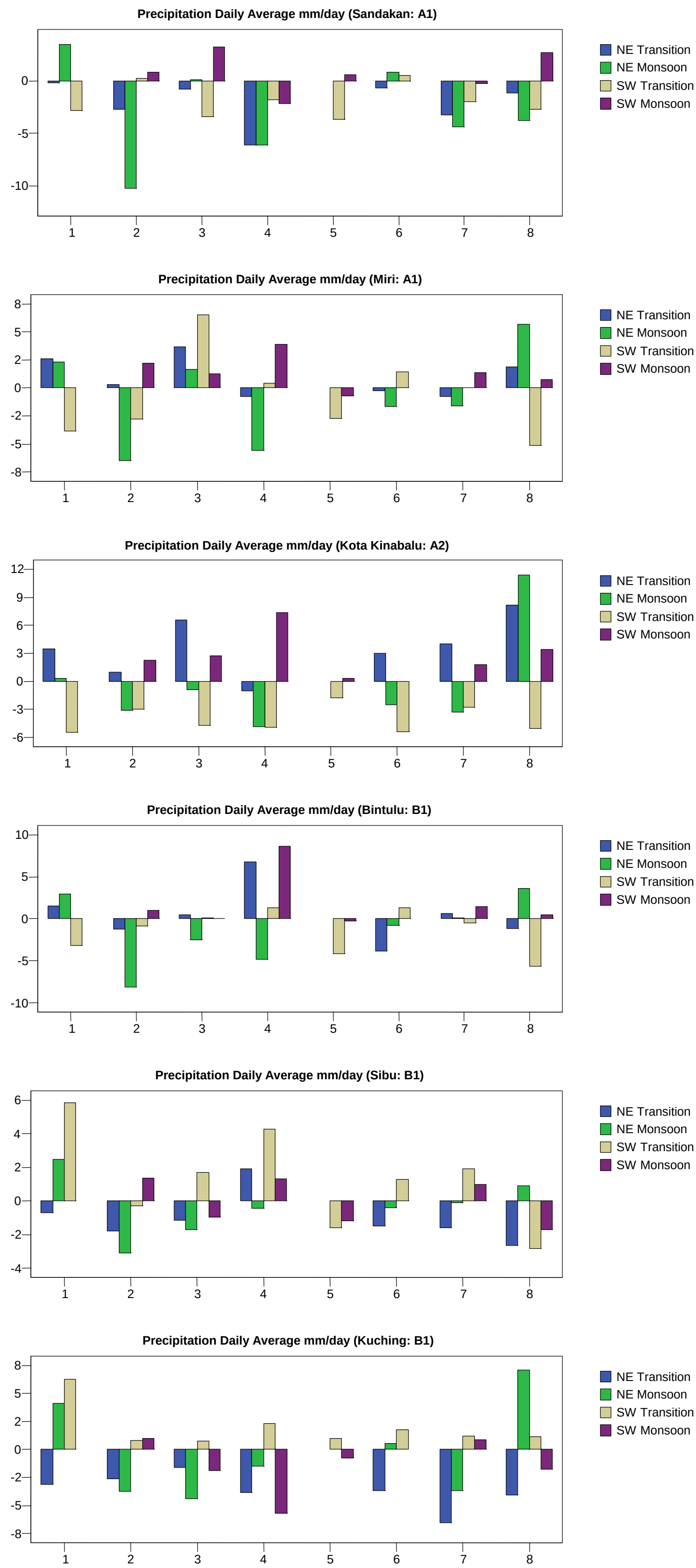


Figure 7.4a: Relationships between circulation types and precipitation average based on different monsoon seasons

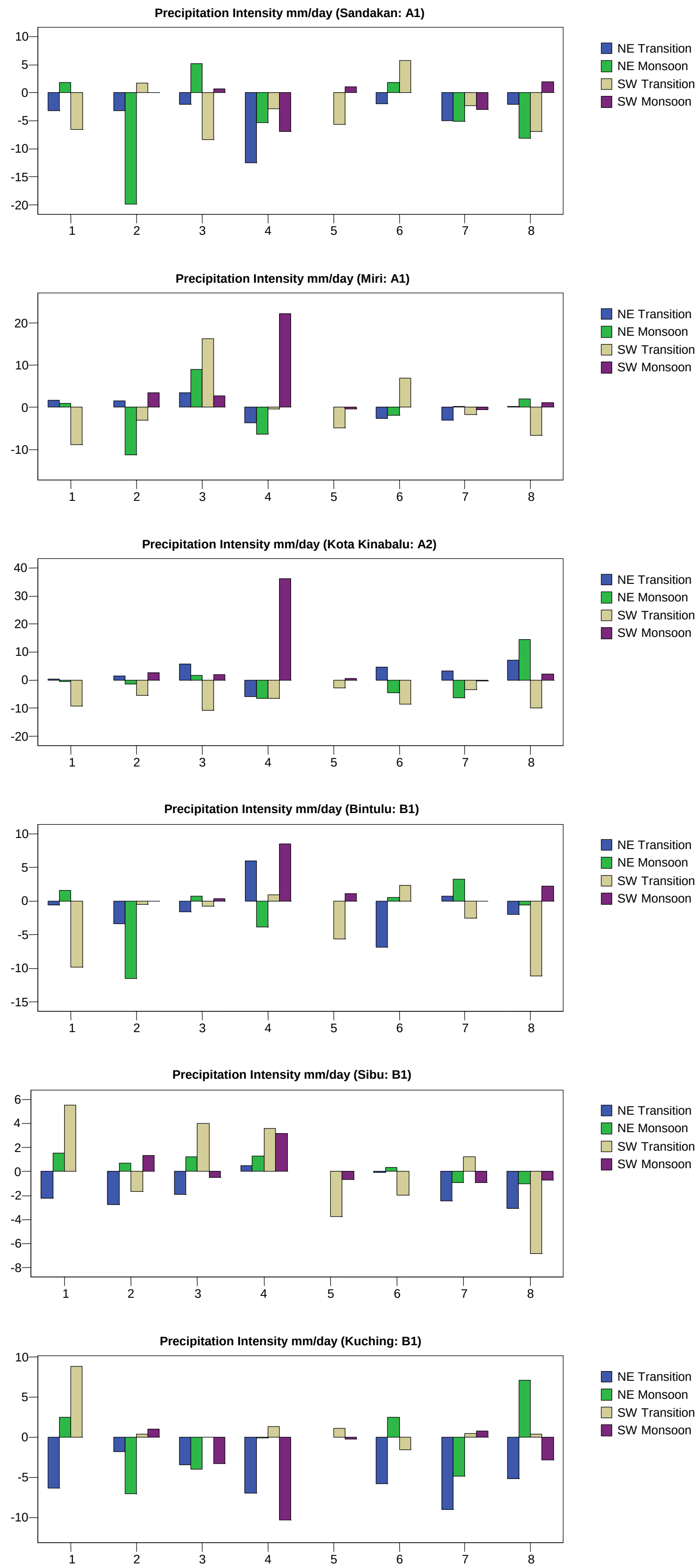


Figure 7.4b: Relationships between circulation types and precipitation intensity based on different monsoon seasons

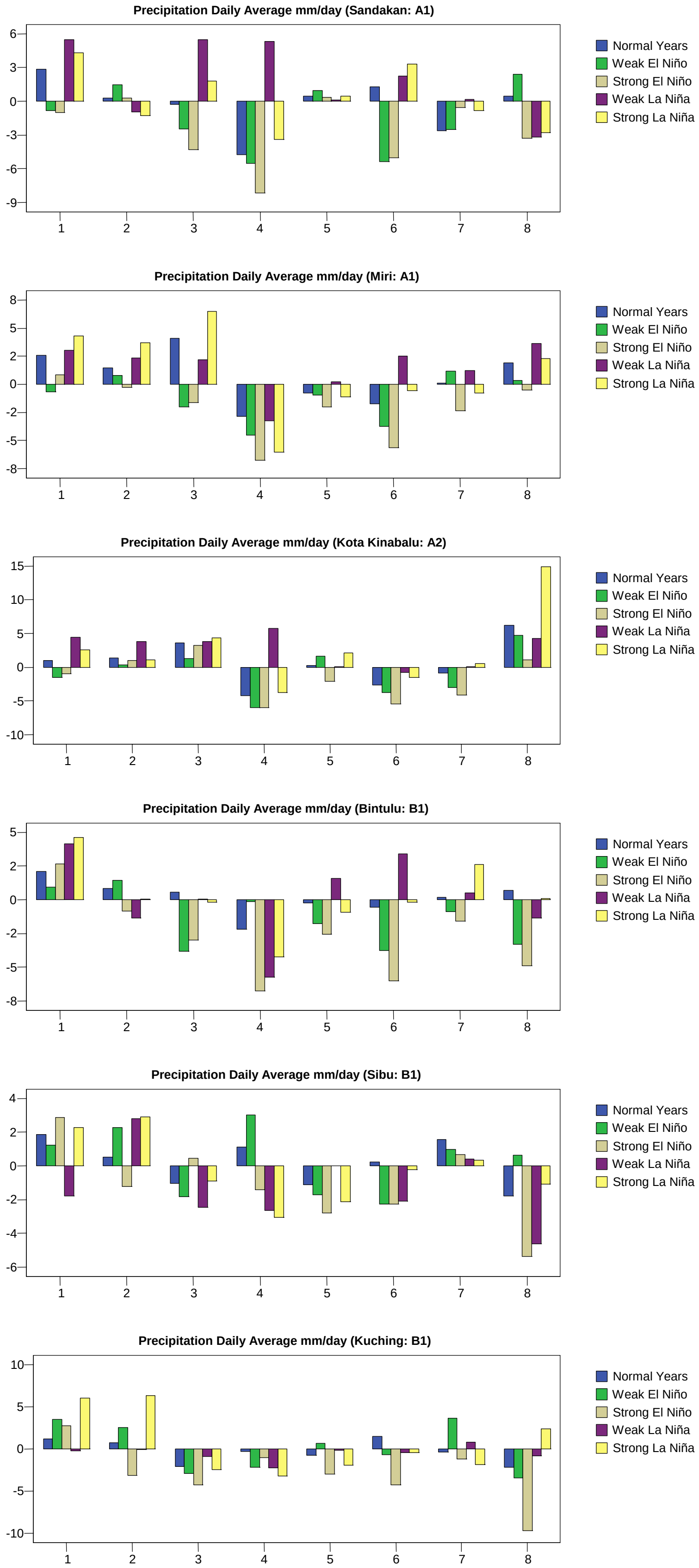


Figure 7.5a: Relationships between circulation types and precipitation average based on different ENSO phases

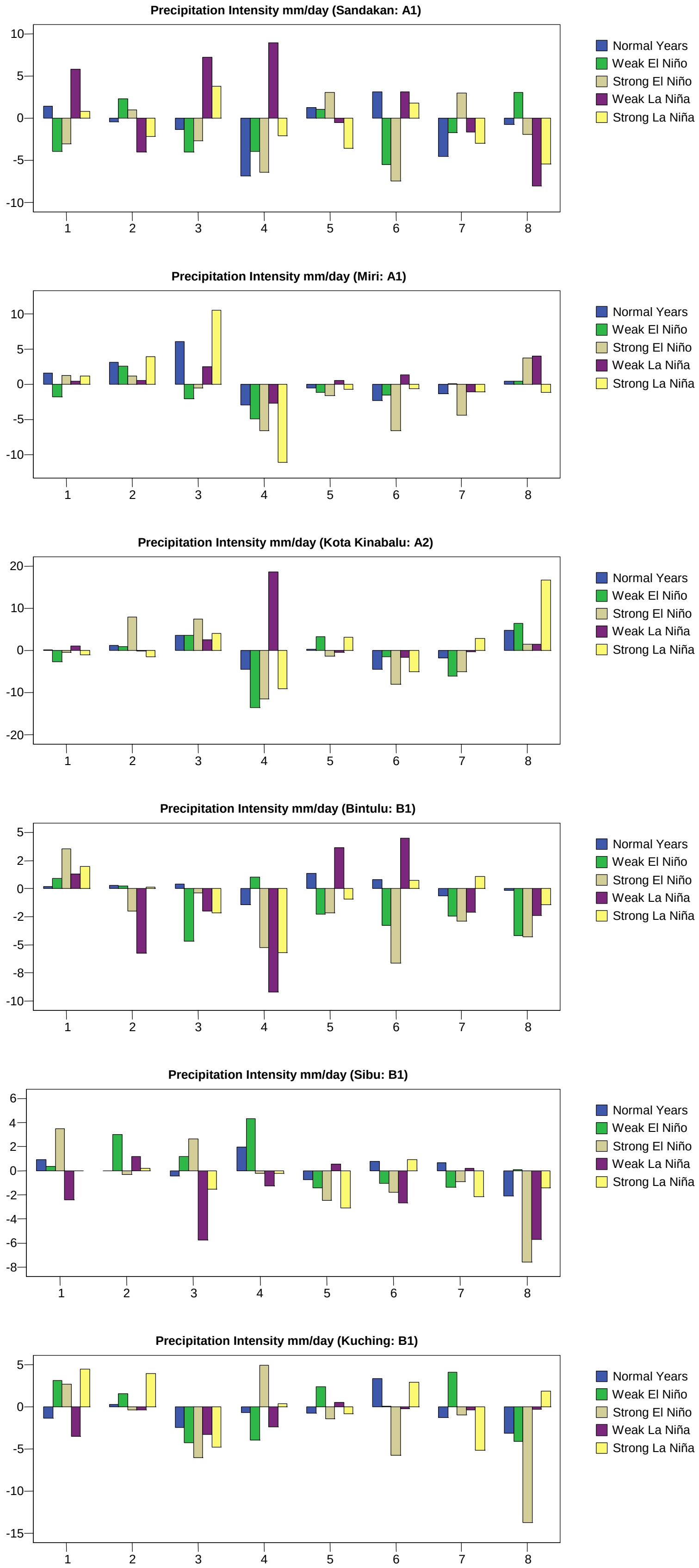


Figure 7.5b: Relationships between circulation types and precipitation intensity based on different ENSO phases

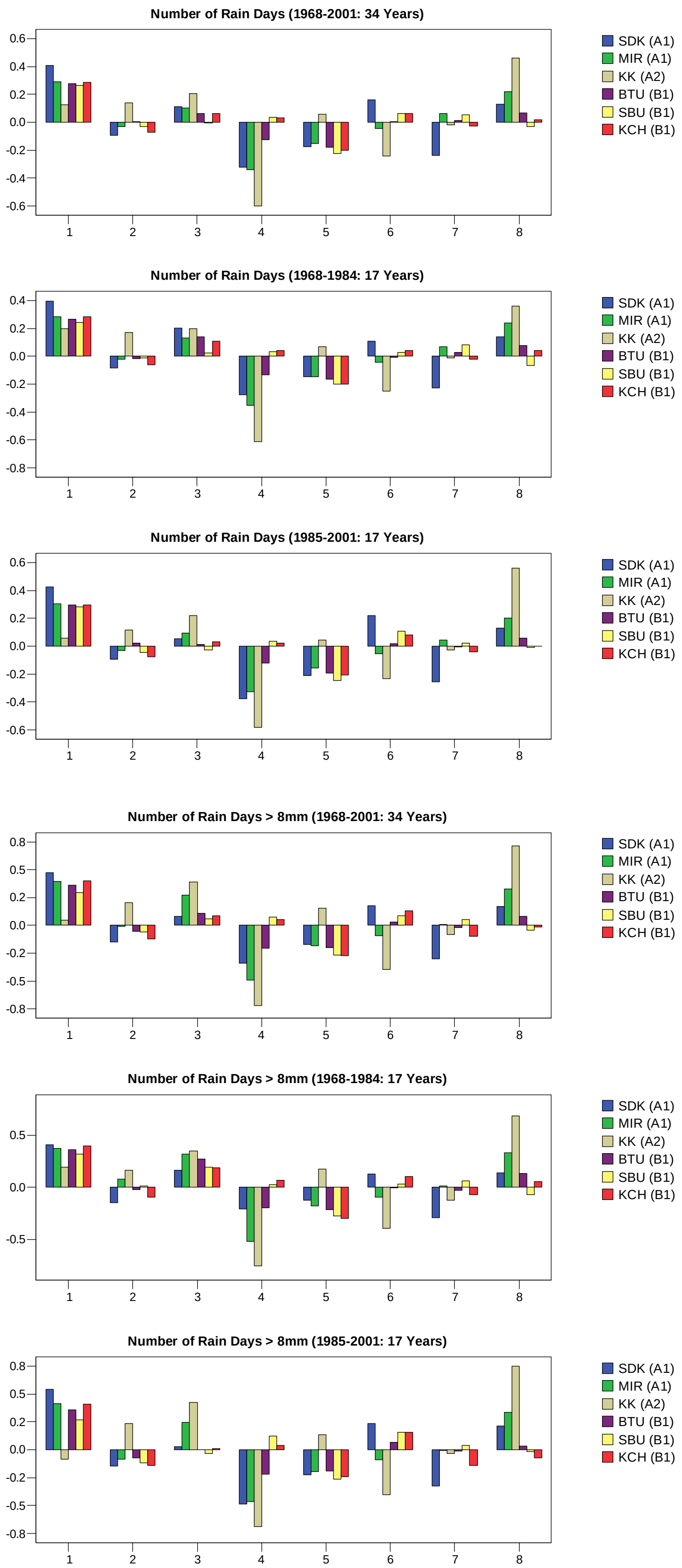


Figure 7.6a: Relationships with circulation types based on two halves of period (1968-1984 and 1985-2001) for number of rain days (> 1mm) and rainfall of more than 8mm

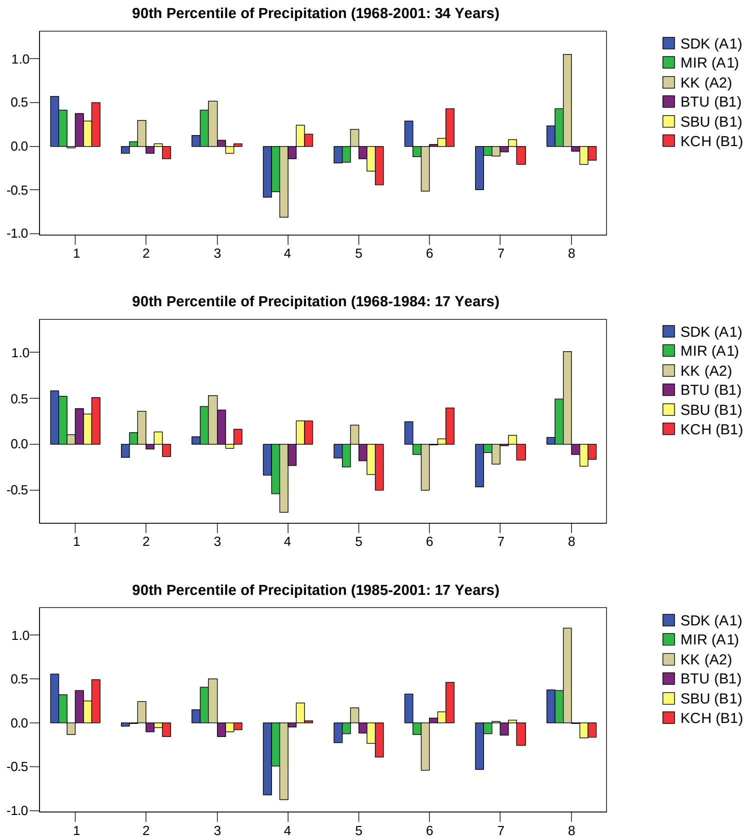


Figure 7.6b: Relationships with circulation types based on two halves of period (1968-1984 and 1985-2001) for 90th percentile of precipitation

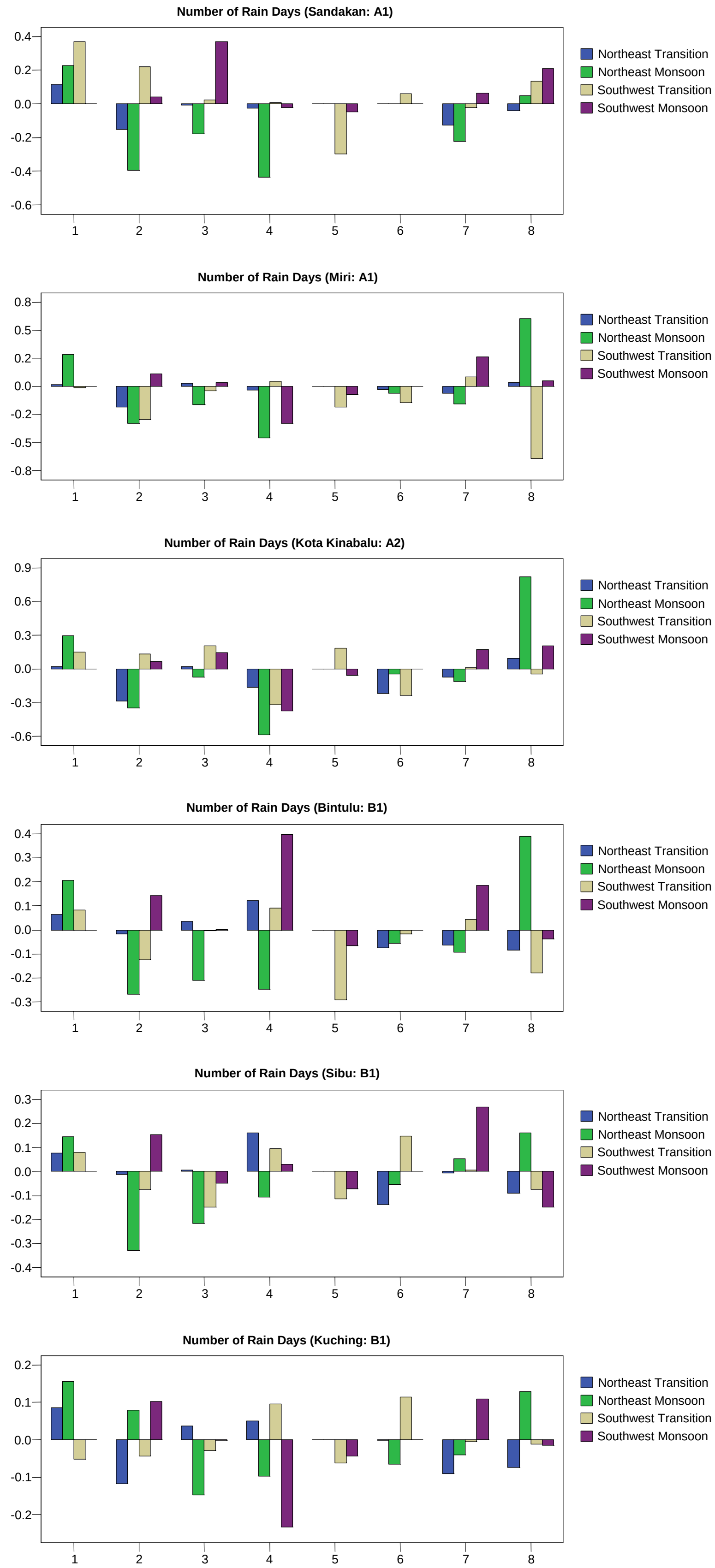


Figure 7.7a: Relationships between circulation types and number of rain days based on different monsoon seasons

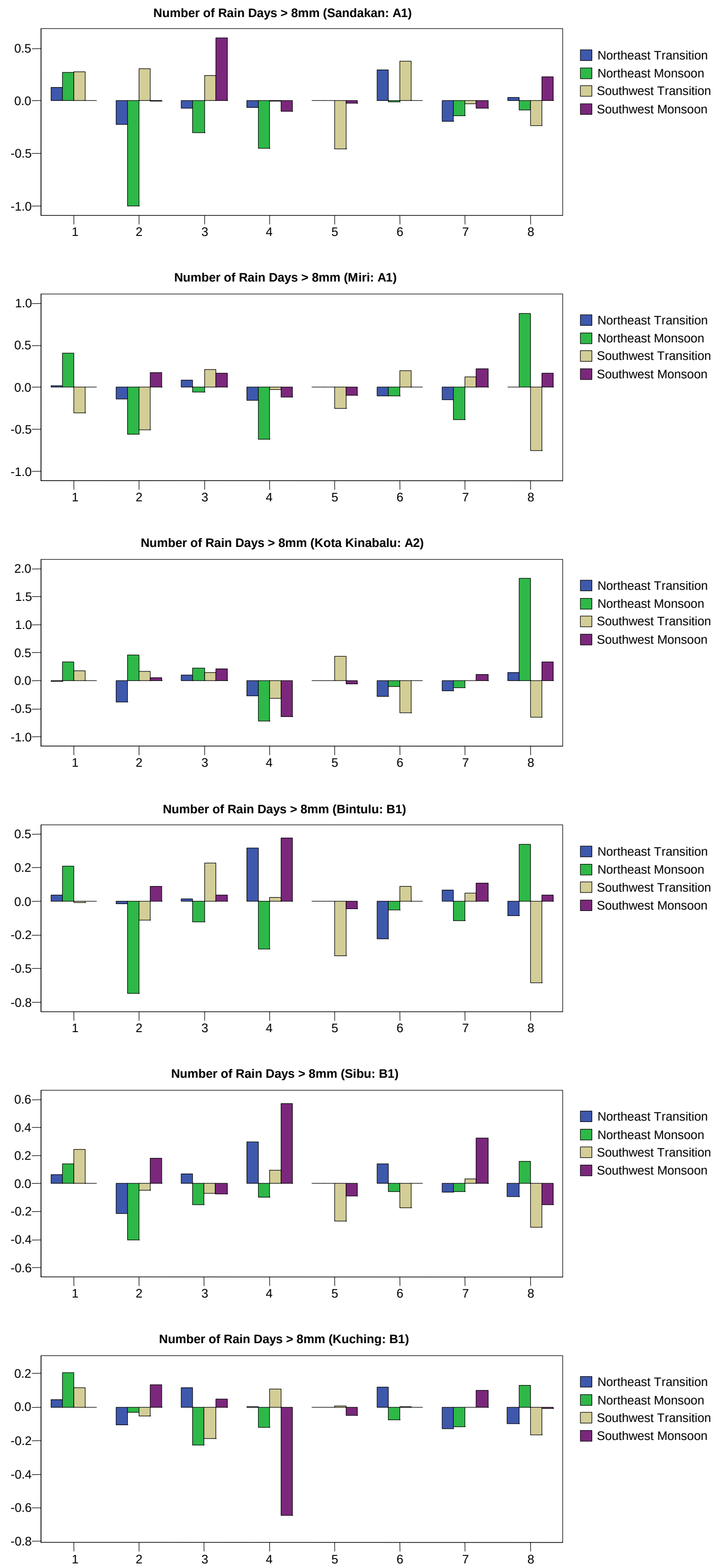


Figure 7.7b: Relationships between circulation types and number of heavy rain days based on different monsoon seasons

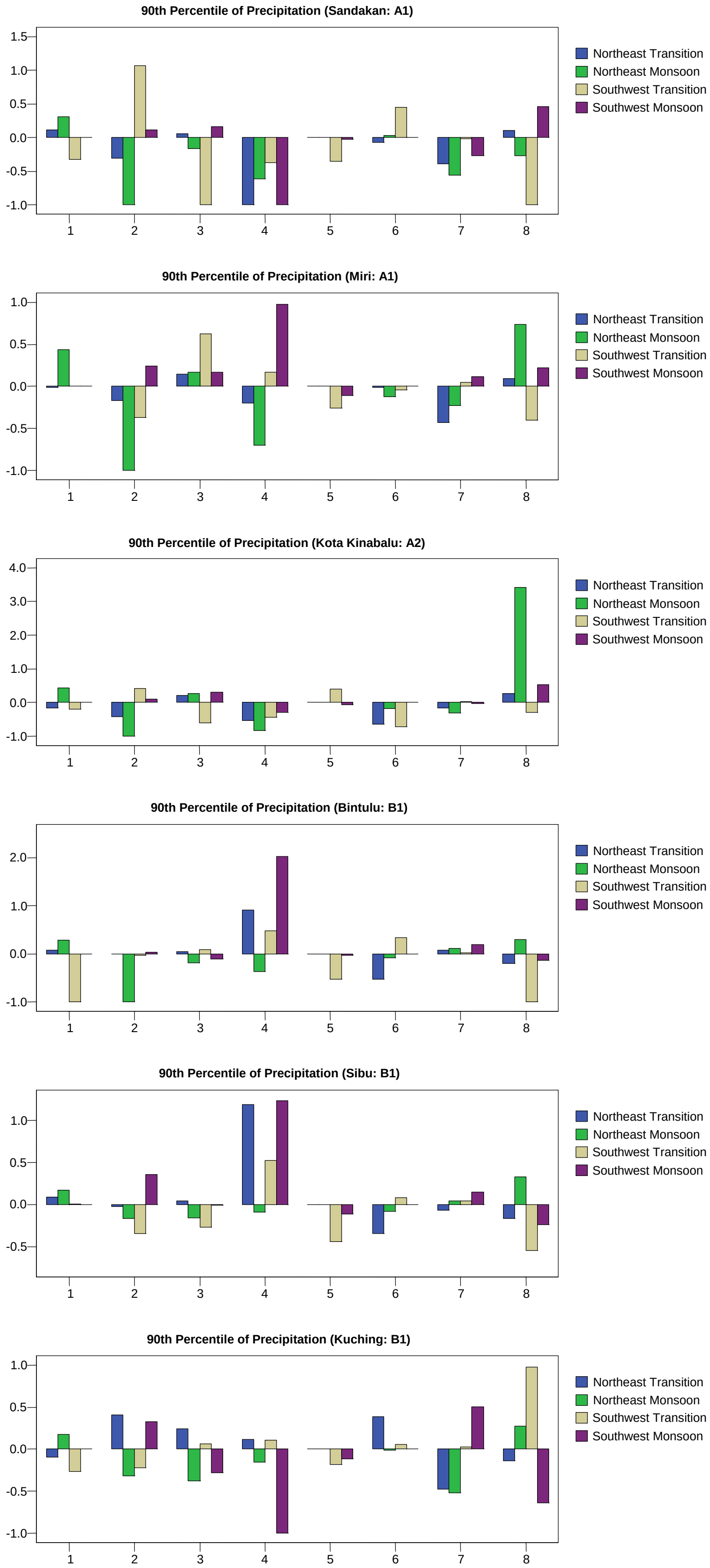


Figure 7.7c: Relationships between circulation types and 90th percentile of precipitation based on different monsoon seasons

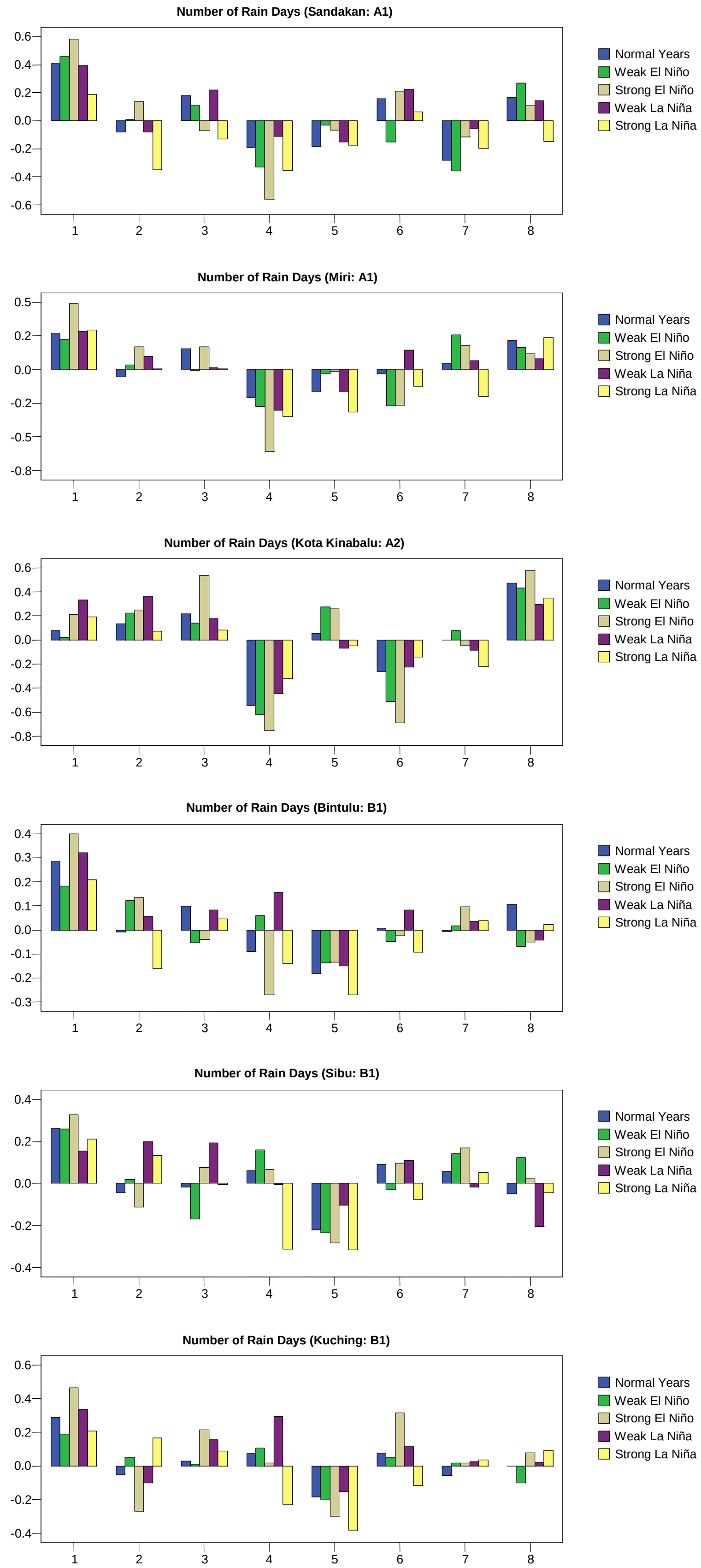


Figure 7.8a: Relationships between circulation types and number of rain days based on different ENSO phases

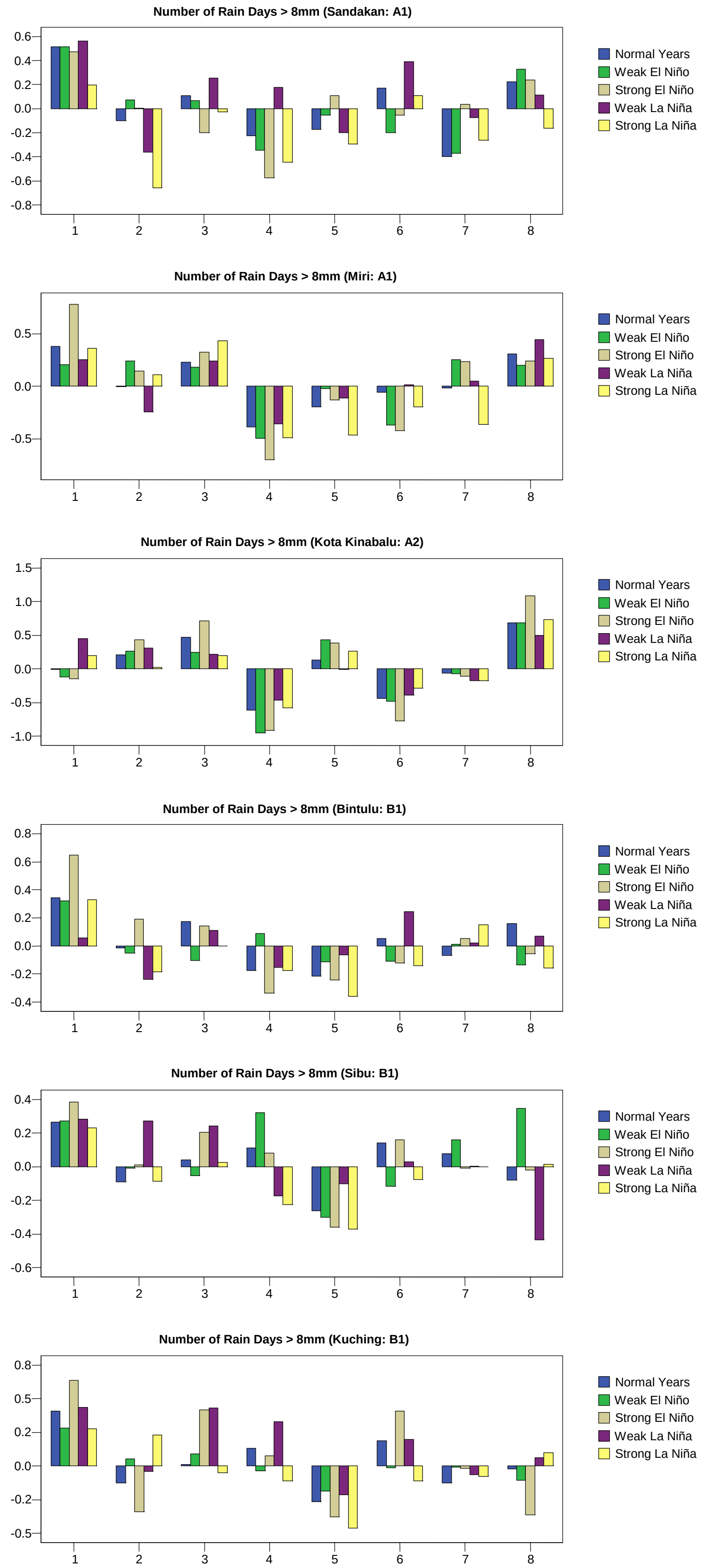


Figure 7.8b: Relationships between circulation types and number of heavy rain days based on different ENSO phases

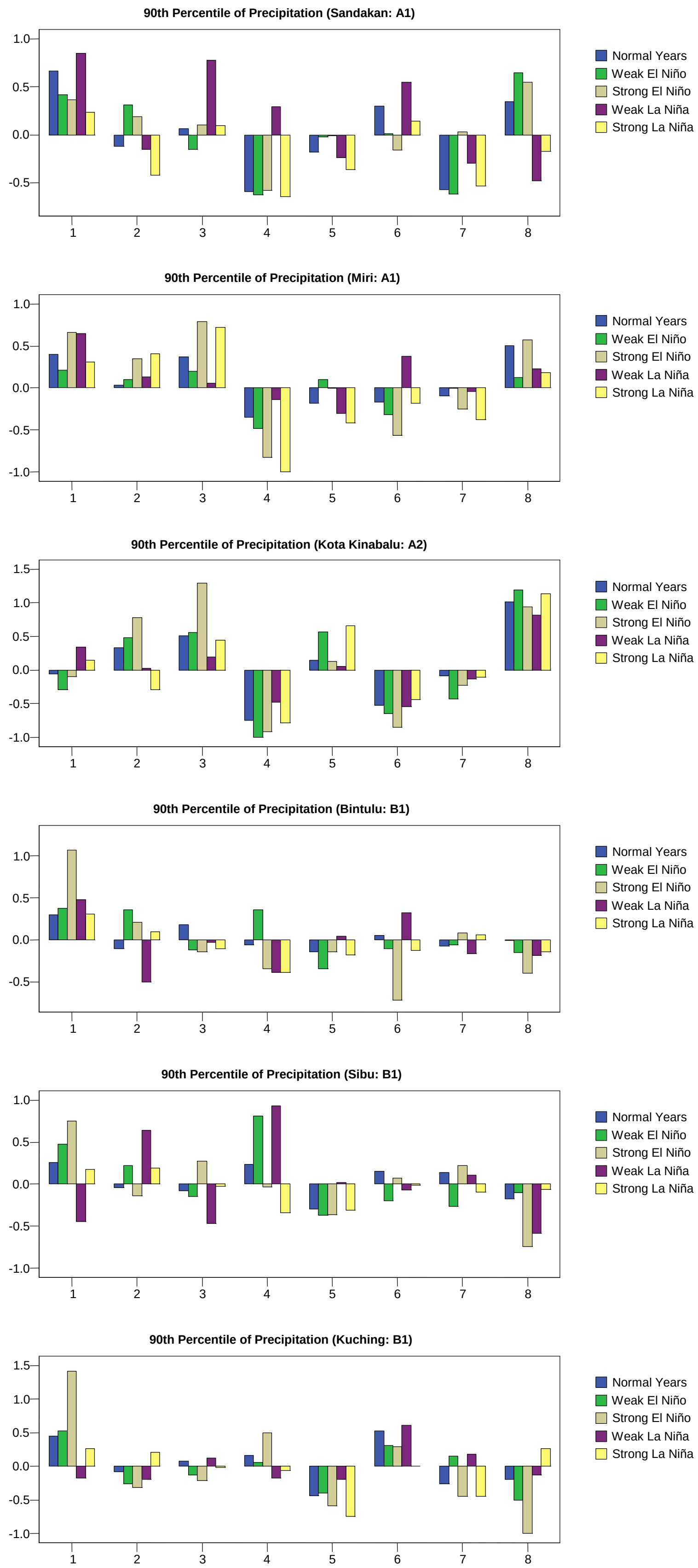


Figure 7.8c: Relationships between circulation types and 90th percentile of precipitation based on different ENSO phases

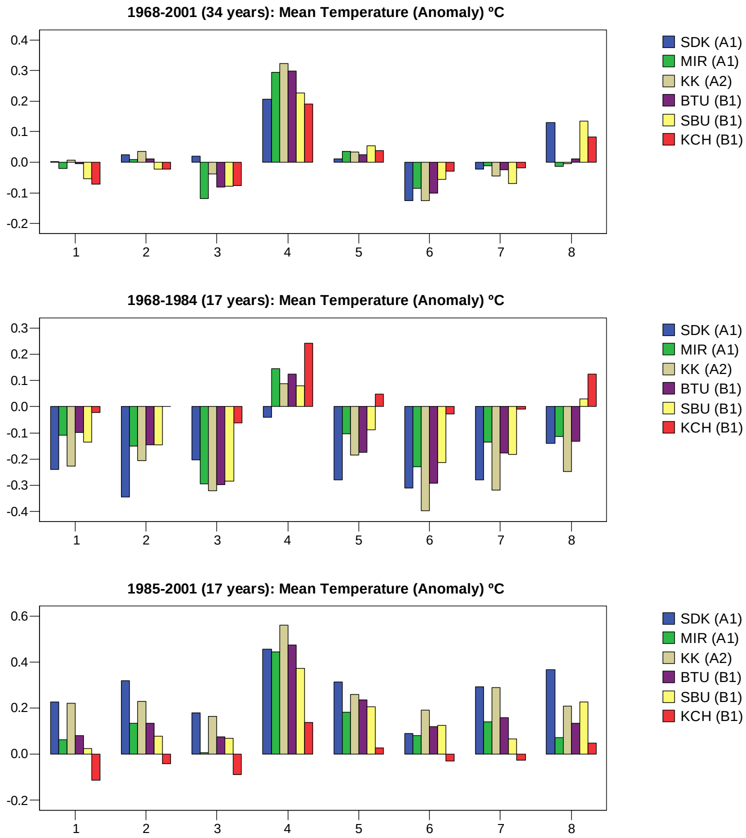


Figure 7.9a: Relationships with circulation types based on two halves of period (1968-1984 and 1985-2001) for mean temperature

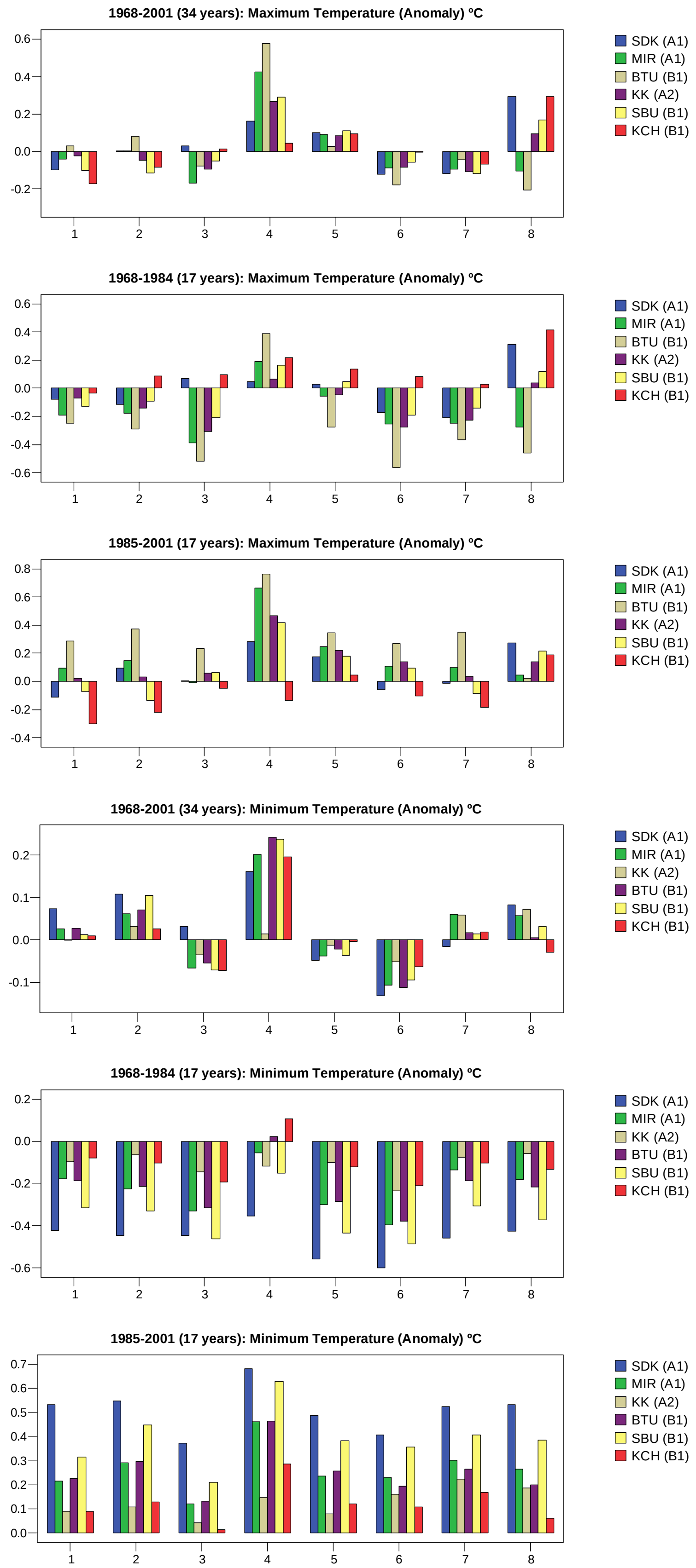


Figure 7.9b: Relationships with circulation types based on two halves of period (1968-1984 and 1985-2001) for maximum temperature and minimum temperature

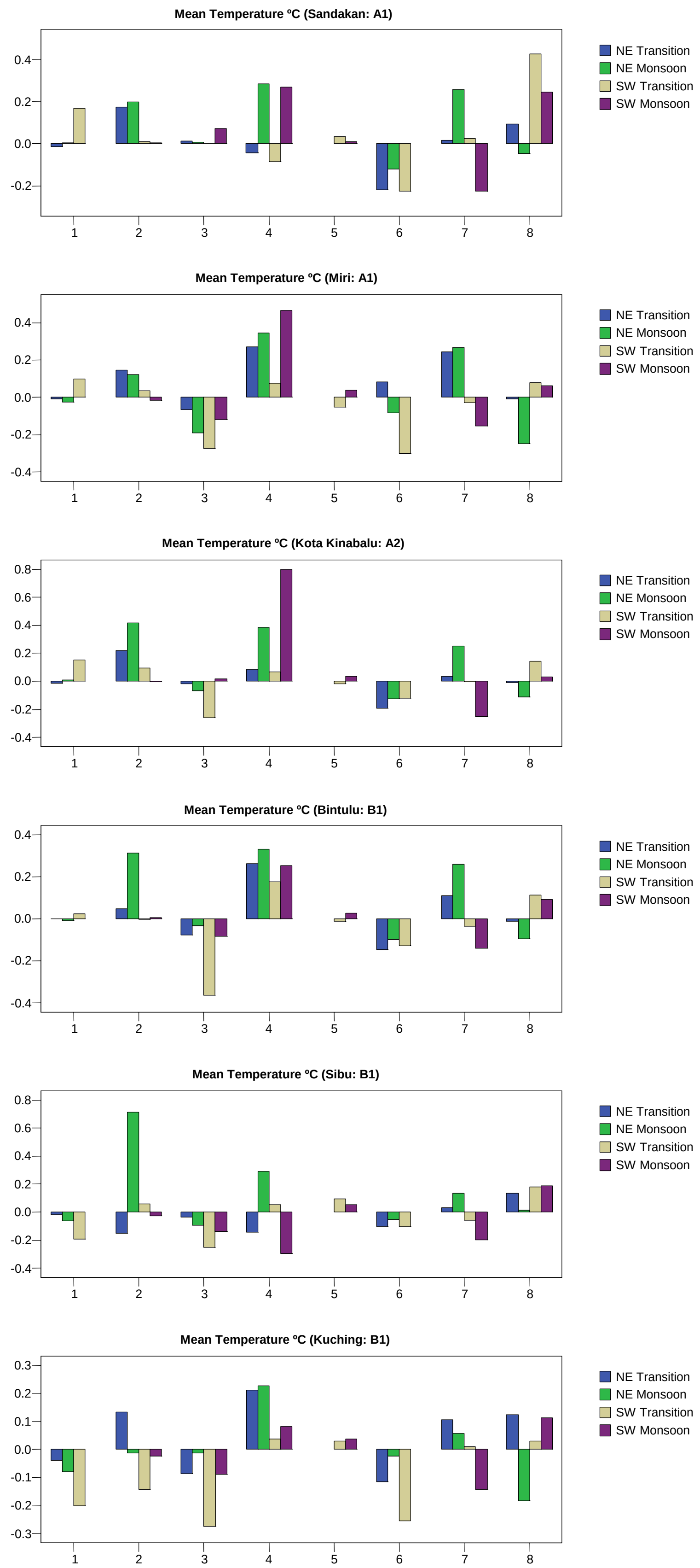


Figure 7.10a: Relationships between circulation types and mean temperature based on different monsoon seasons

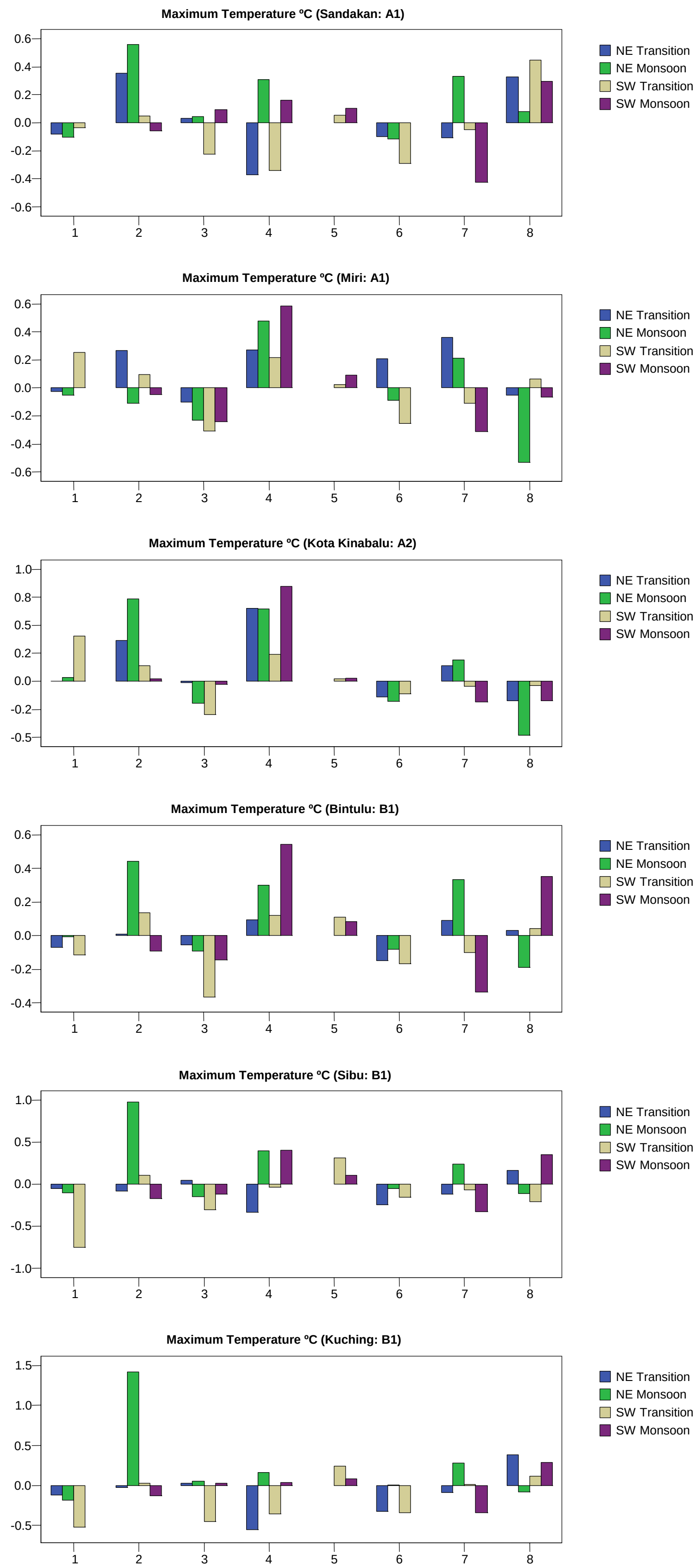


Figure 7.10b: Relationships between circulation types and maximum temperature based on different monsoon seasons

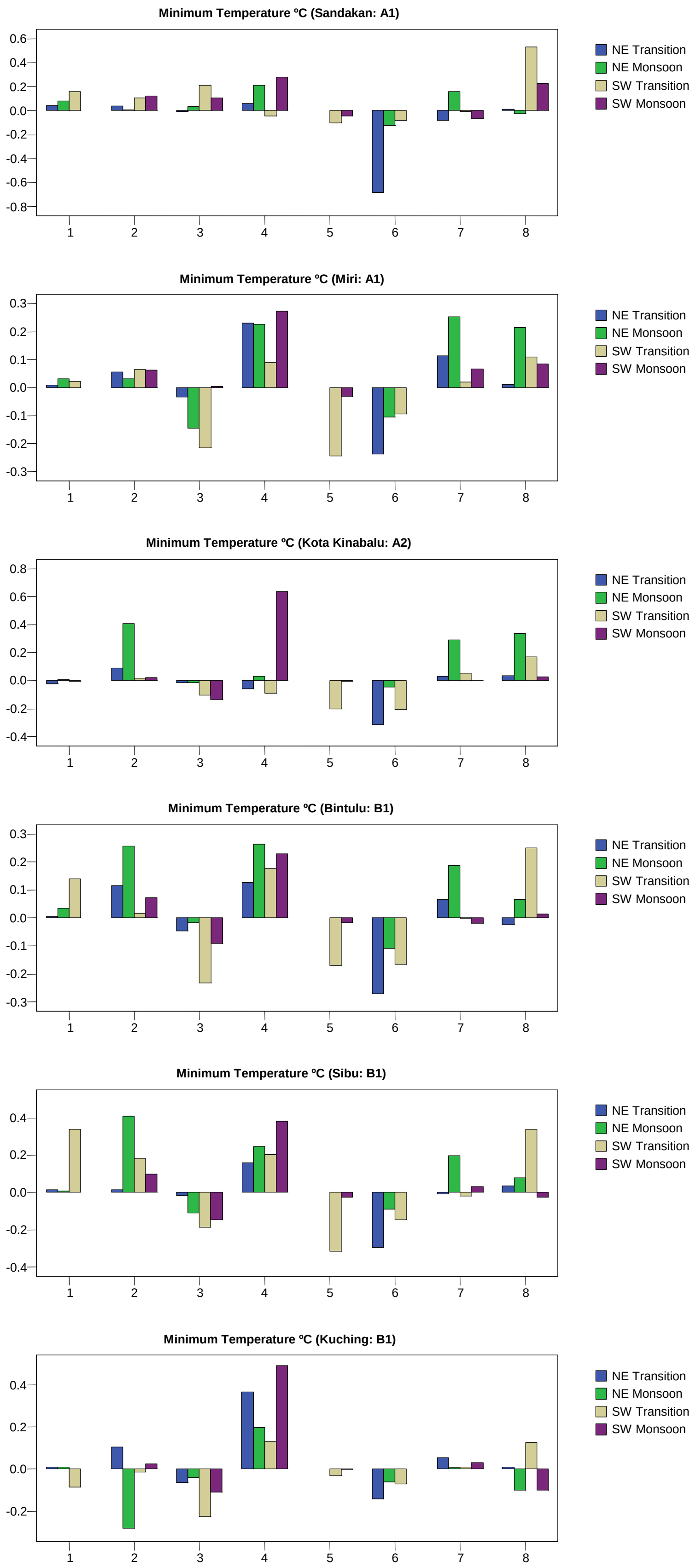


Figure 7.10c: Relationships between circulation types and minimum temperature based on different monsoon seasons

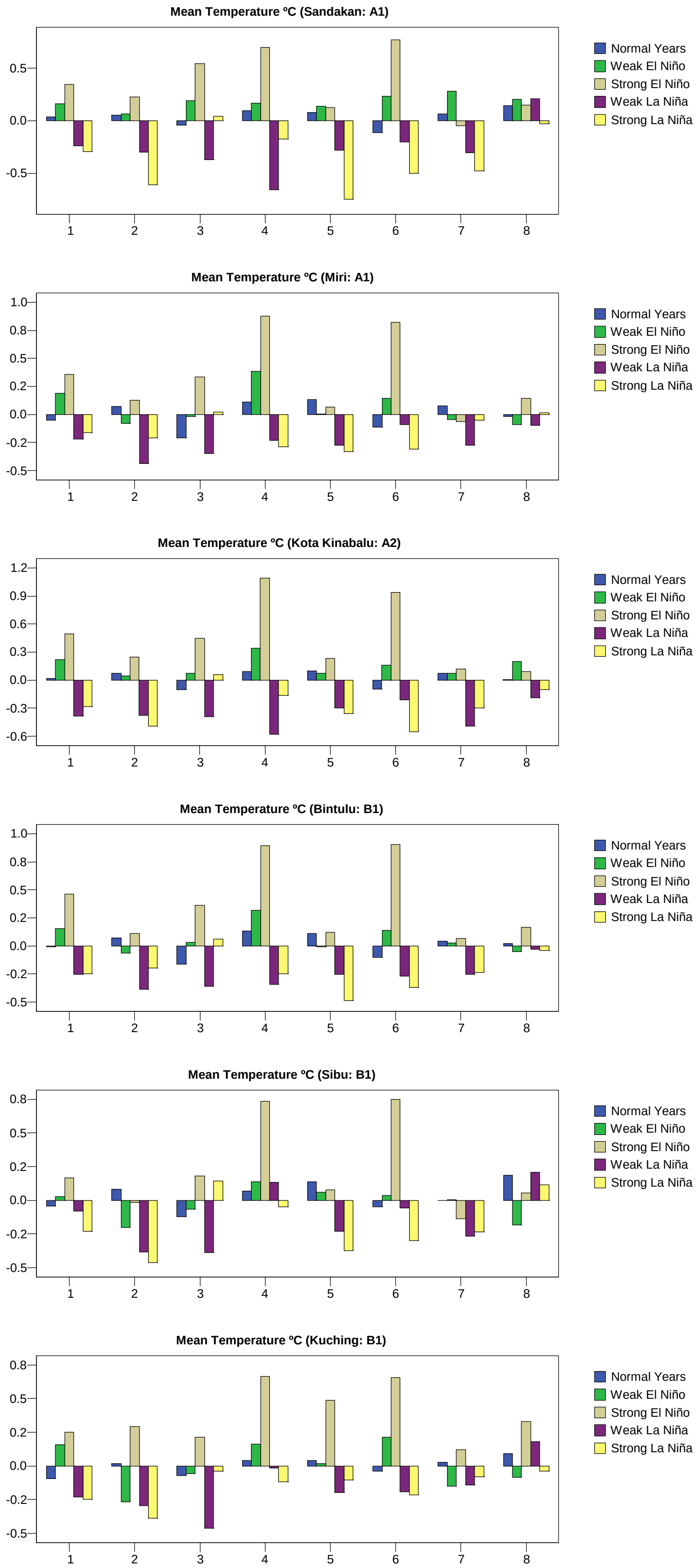


Figure 7.11a: Relationships between circulation types and mean temperature based on different ENSO phases

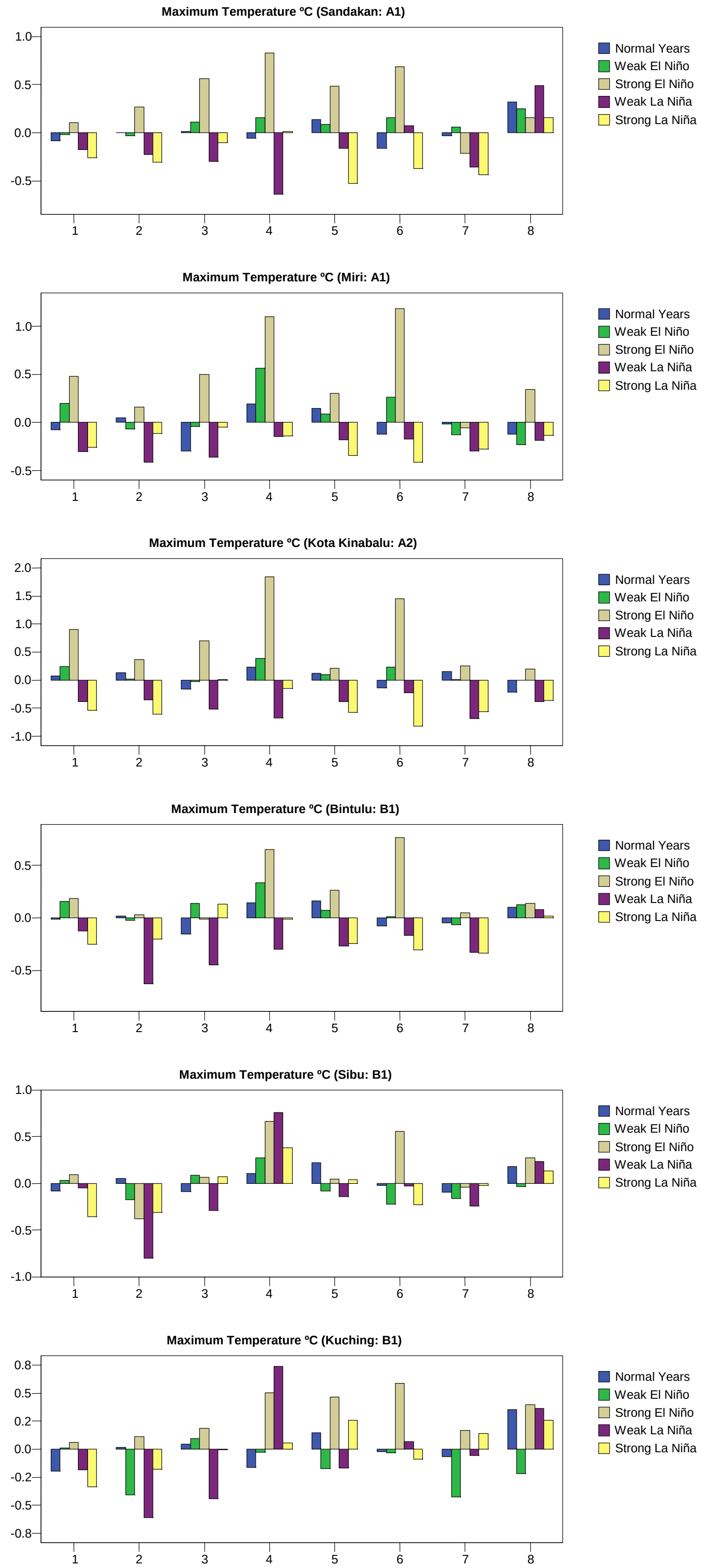


Figure 7.11b: Relationships between circulation types and maximum temperature based on different ENSO phases

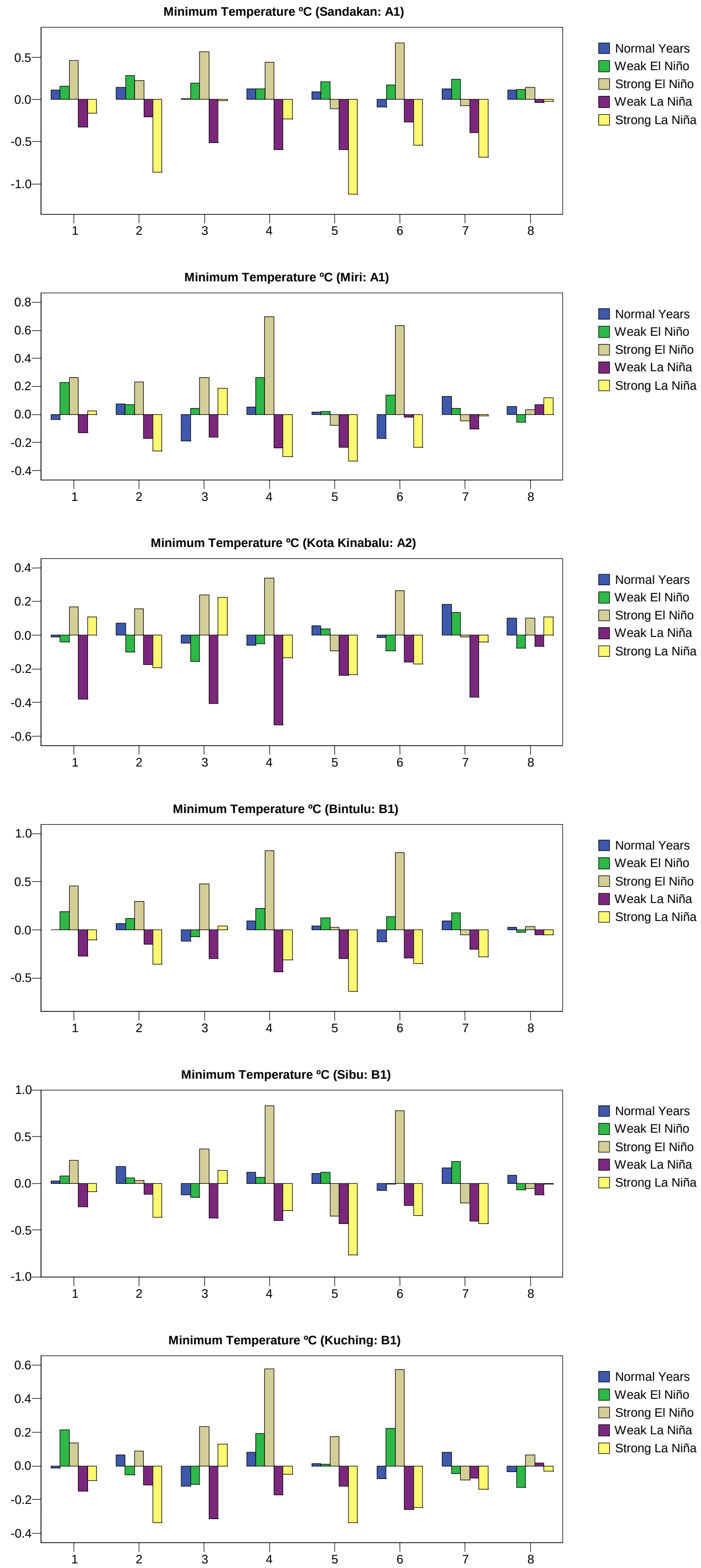


Figure 7.11c: Relationships between circulation types and minimum temperature based on different ENSO phases

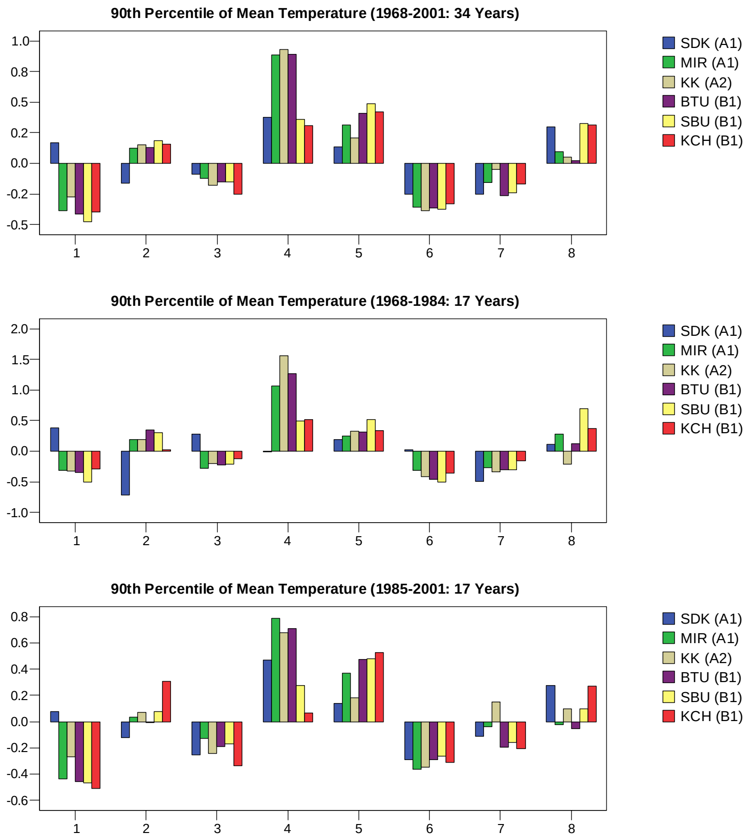


Figure 7.12a: Relationships with circulation types based on two halves of period (1968-1984 and 1985-2001) for 90th percentile of mean temperature

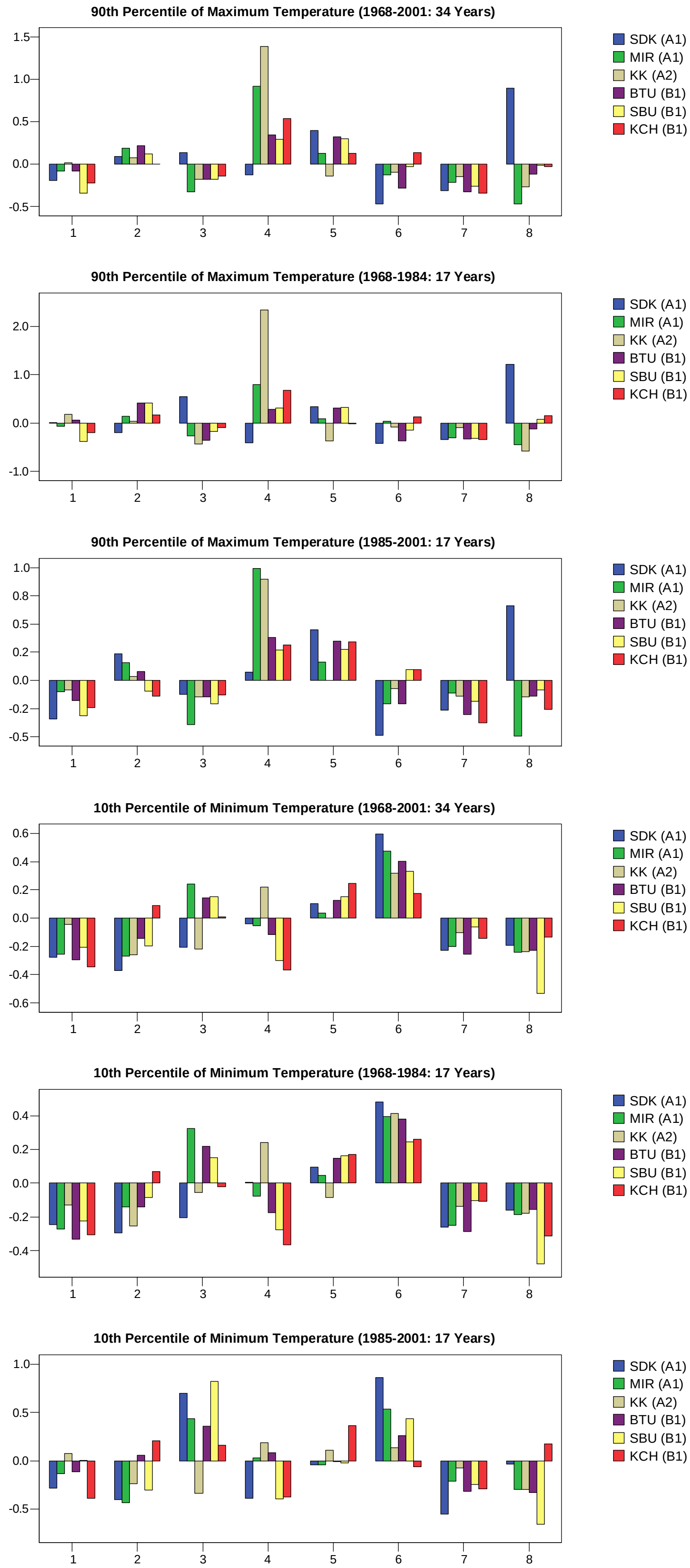


Figure 7.12b: Relationships with circulation types based on two halves of period (1968-1984 and 1985-2001) for 90th percentile of maximum temperature and 10th percentile of minimum temperature

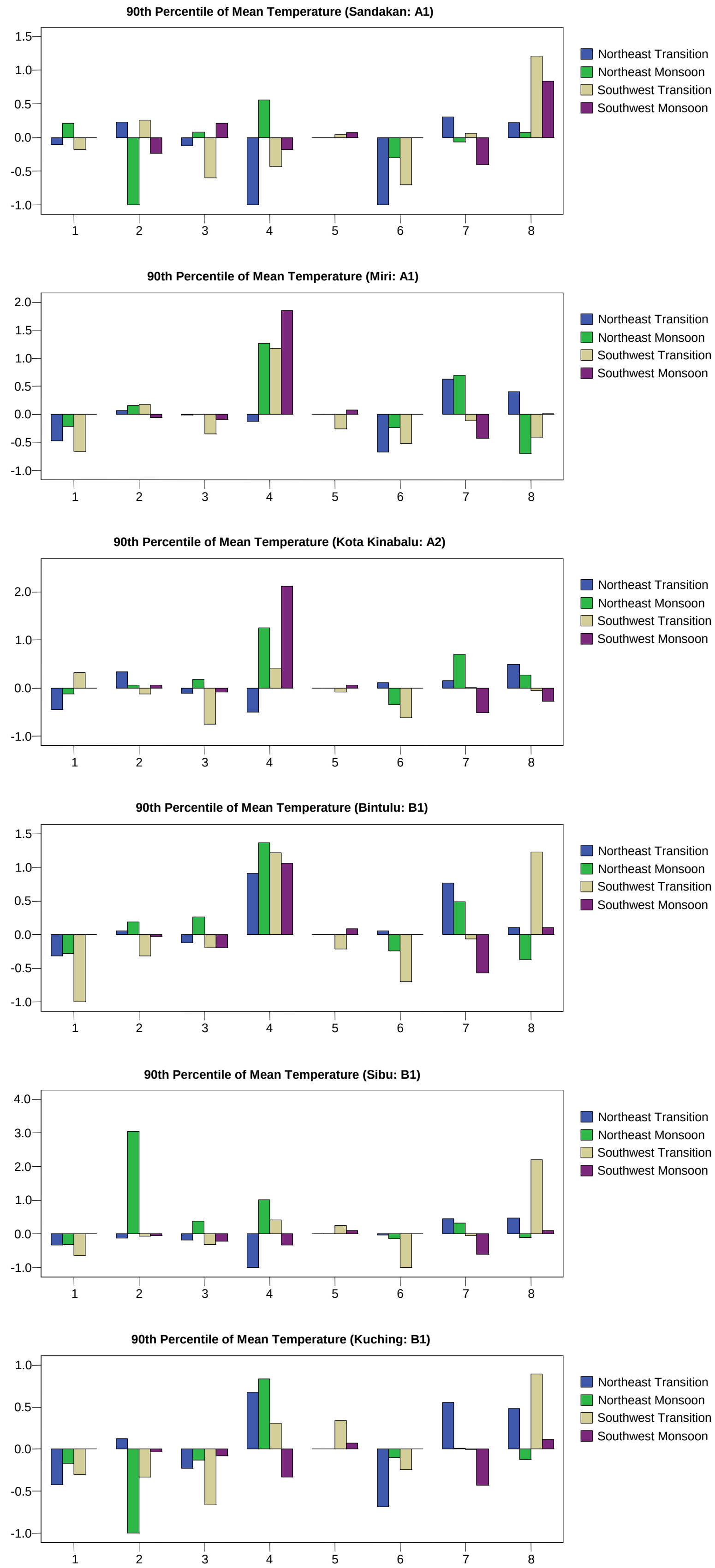


Figure 7.13a: Relationships between circulation types and 90th percentile of mean temperature based on different monsoon seasons

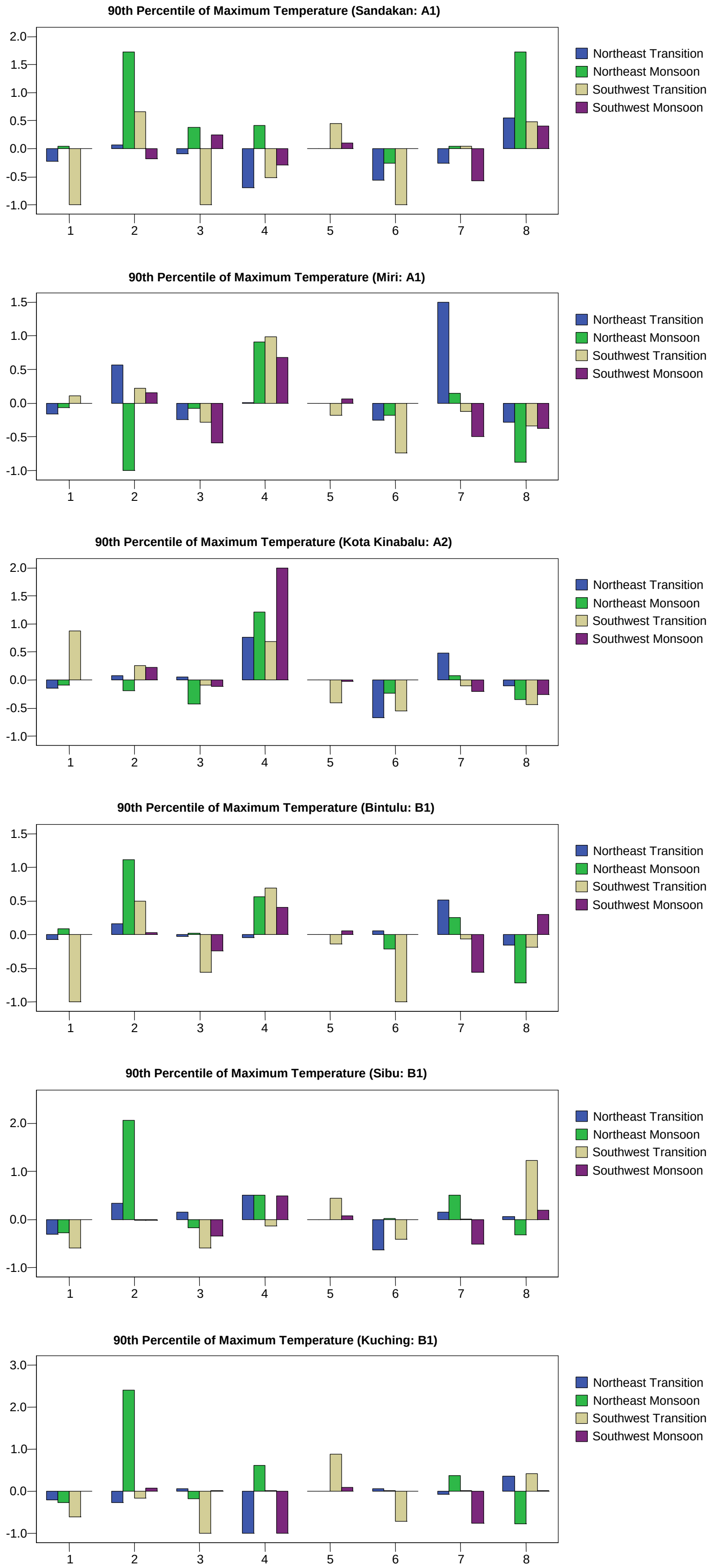


Figure 7.13b: Relationships between circulation types and 90th percentile of maximum temperature based on different monsoon seasons

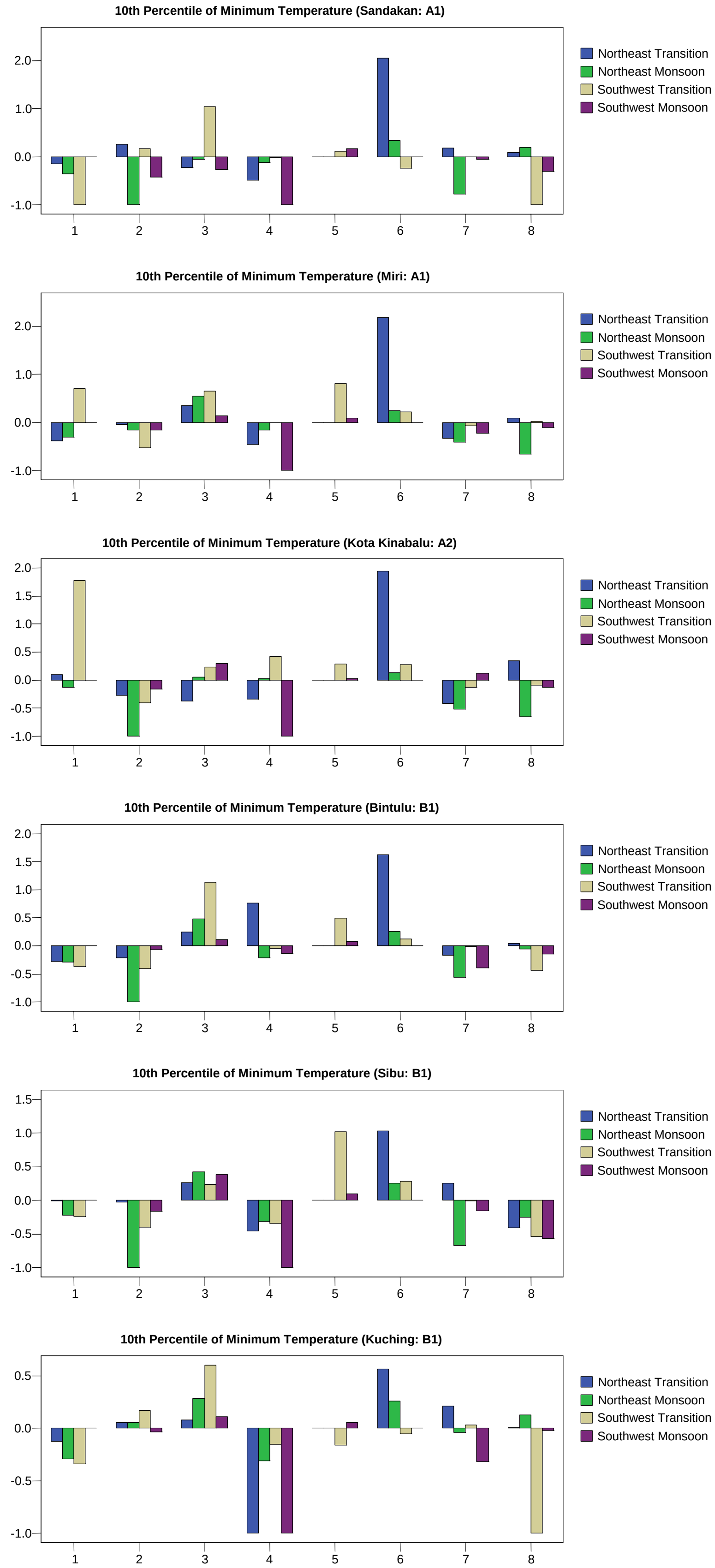


Figure 7.13c: Relationships between circulation types and 10th percentile of minimum temperature based on different monsoon seasons

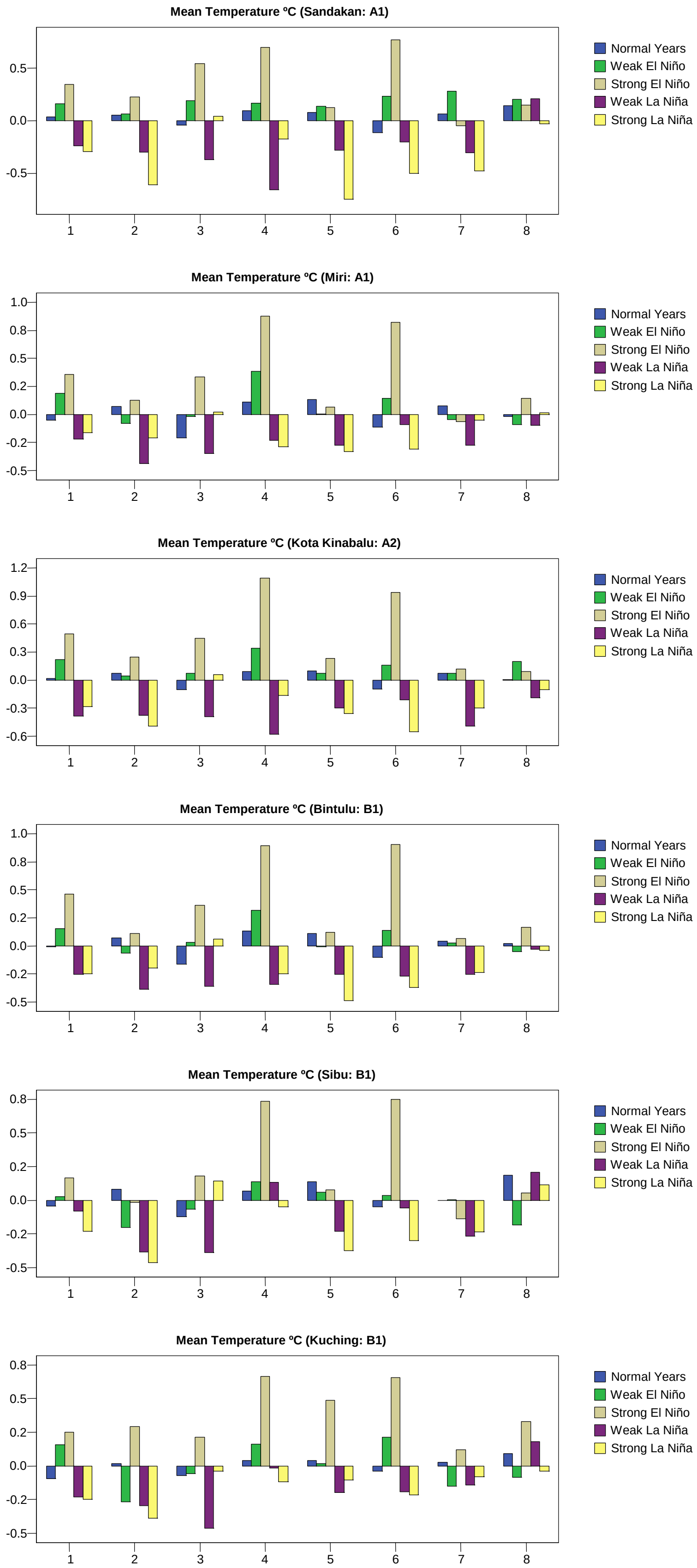


Figure 7.14a: Relationships between circulation types and 90th percentile of mean temperature based on different ENSO phases

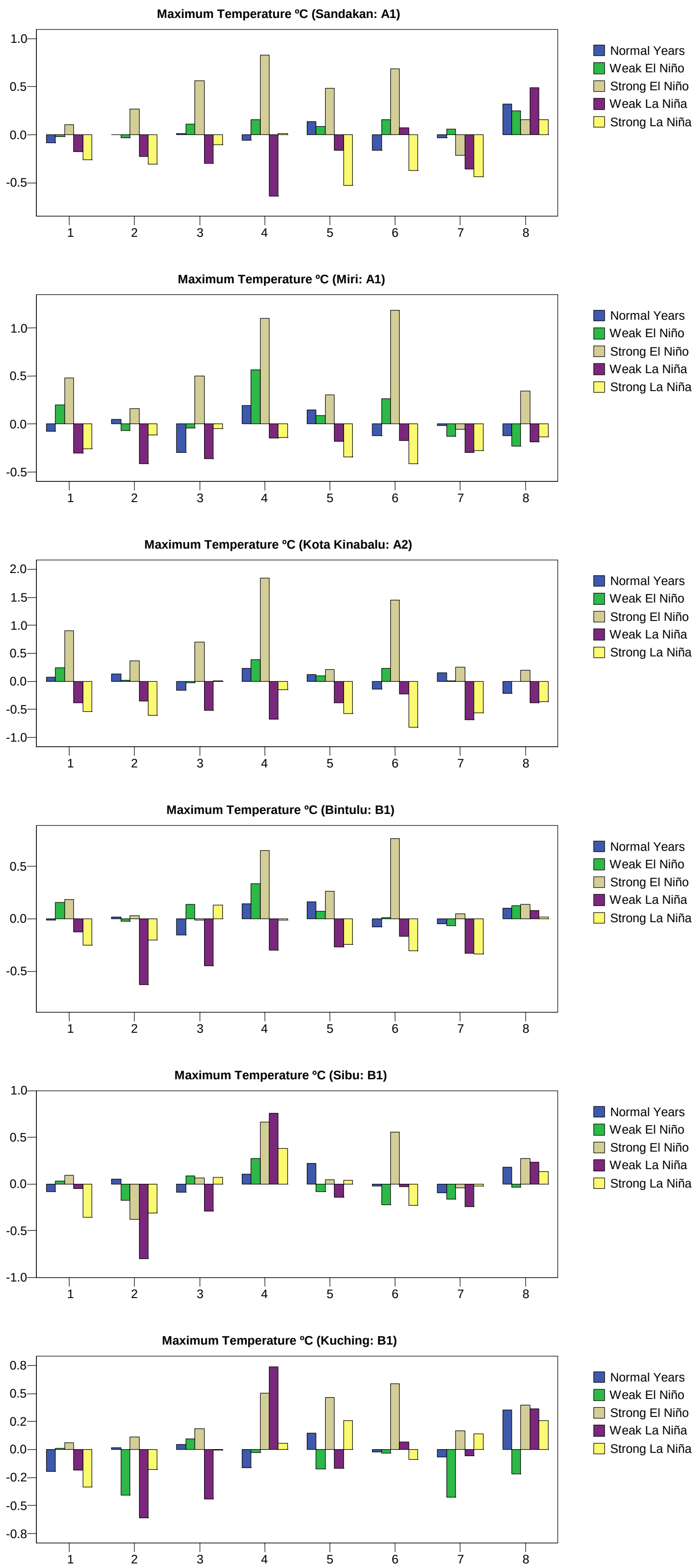


Figure 7.14b: Relationships between circulation types and 90th percentile of maximum temperature based on different ENSO phases

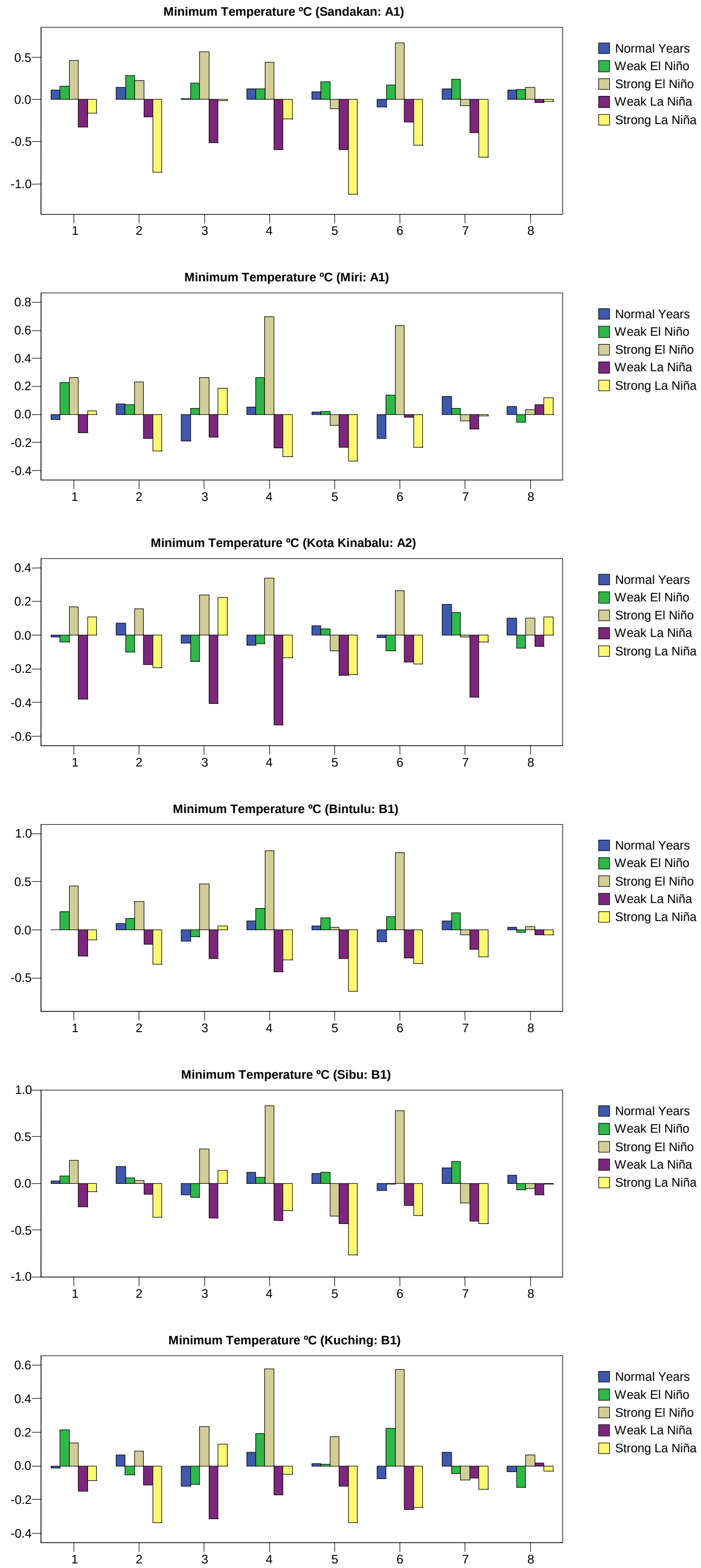


Figure 7.14c: Relationships between circulation types and 10th percentile of minimum temperature based on different ENSO phases

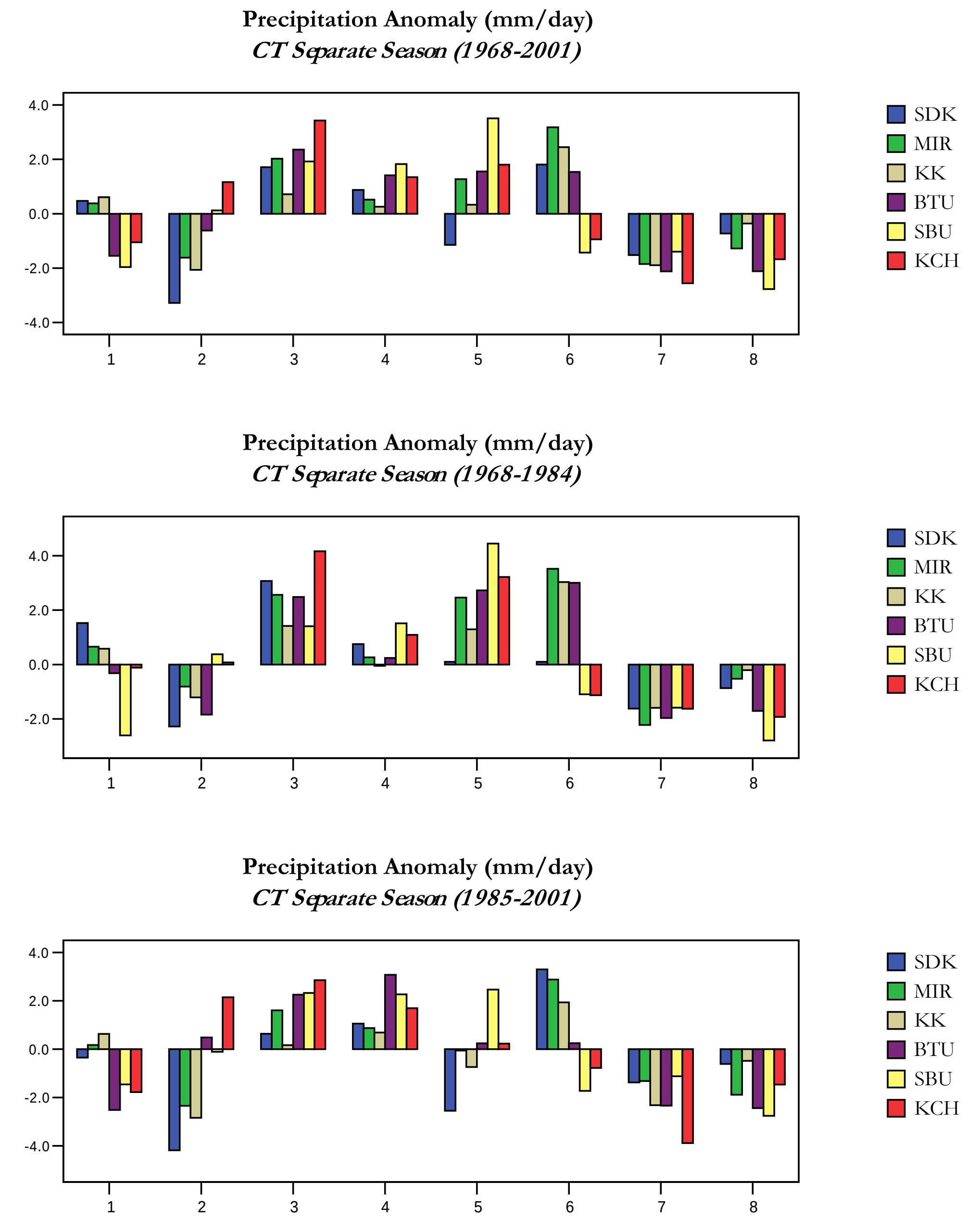


Figure 7.15a: Relationships with precipitation anomaly (CT1)

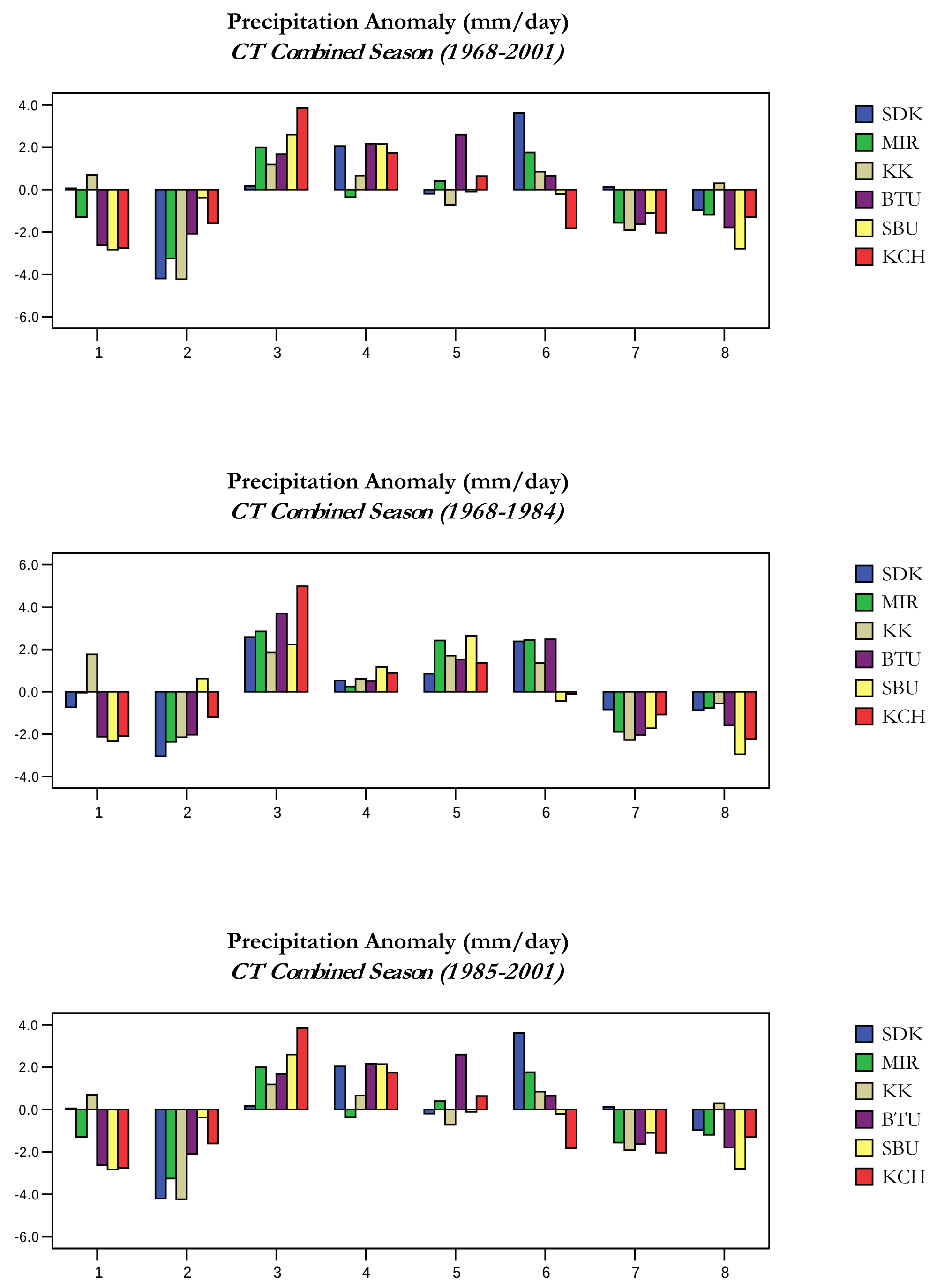


Figure 7.15b: Relationships with precipitation anomaly (CT2)

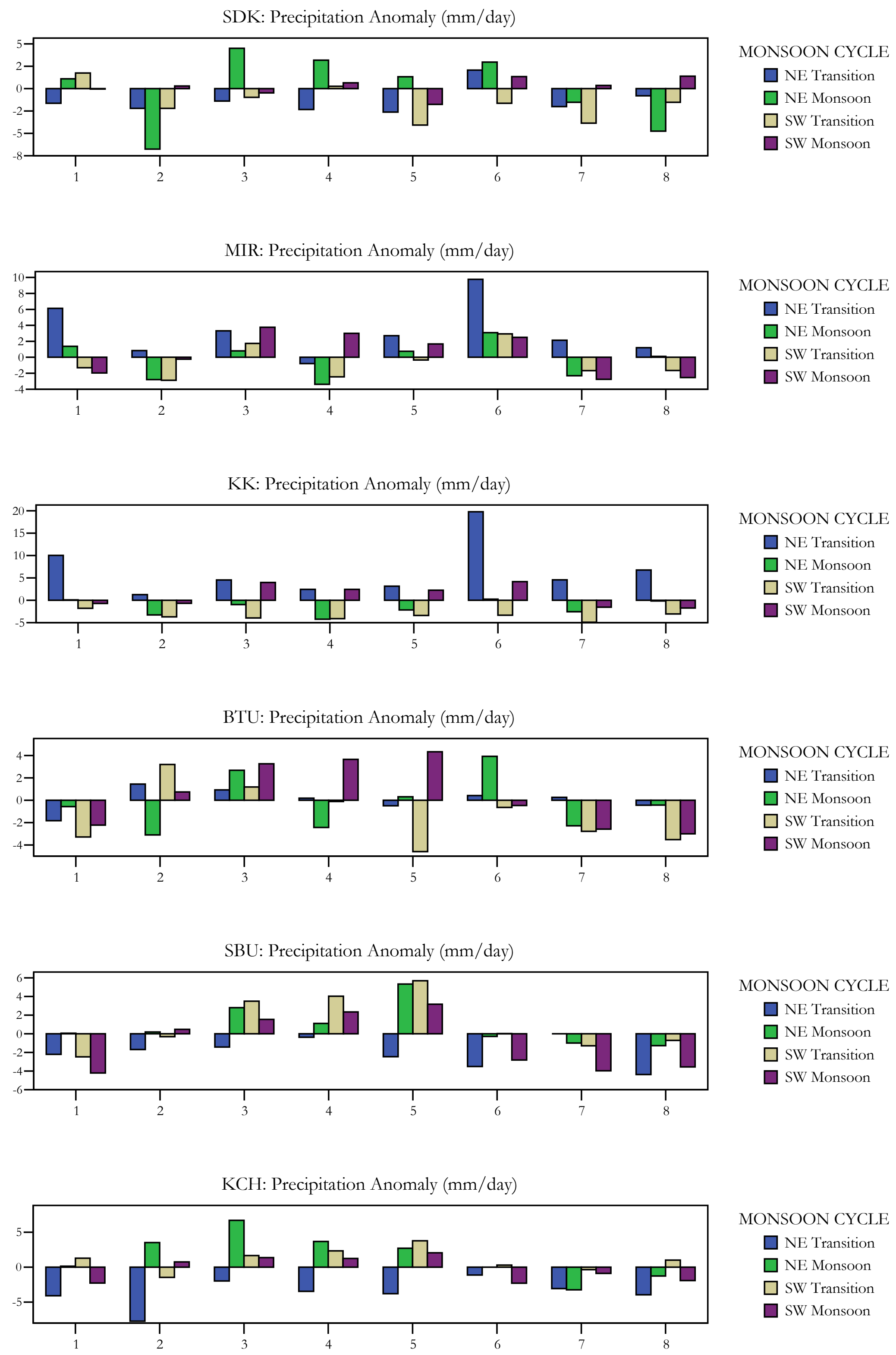


Figure 7.16a: Relationships with precipitation anomaly based on monsoon cycle (CT1)

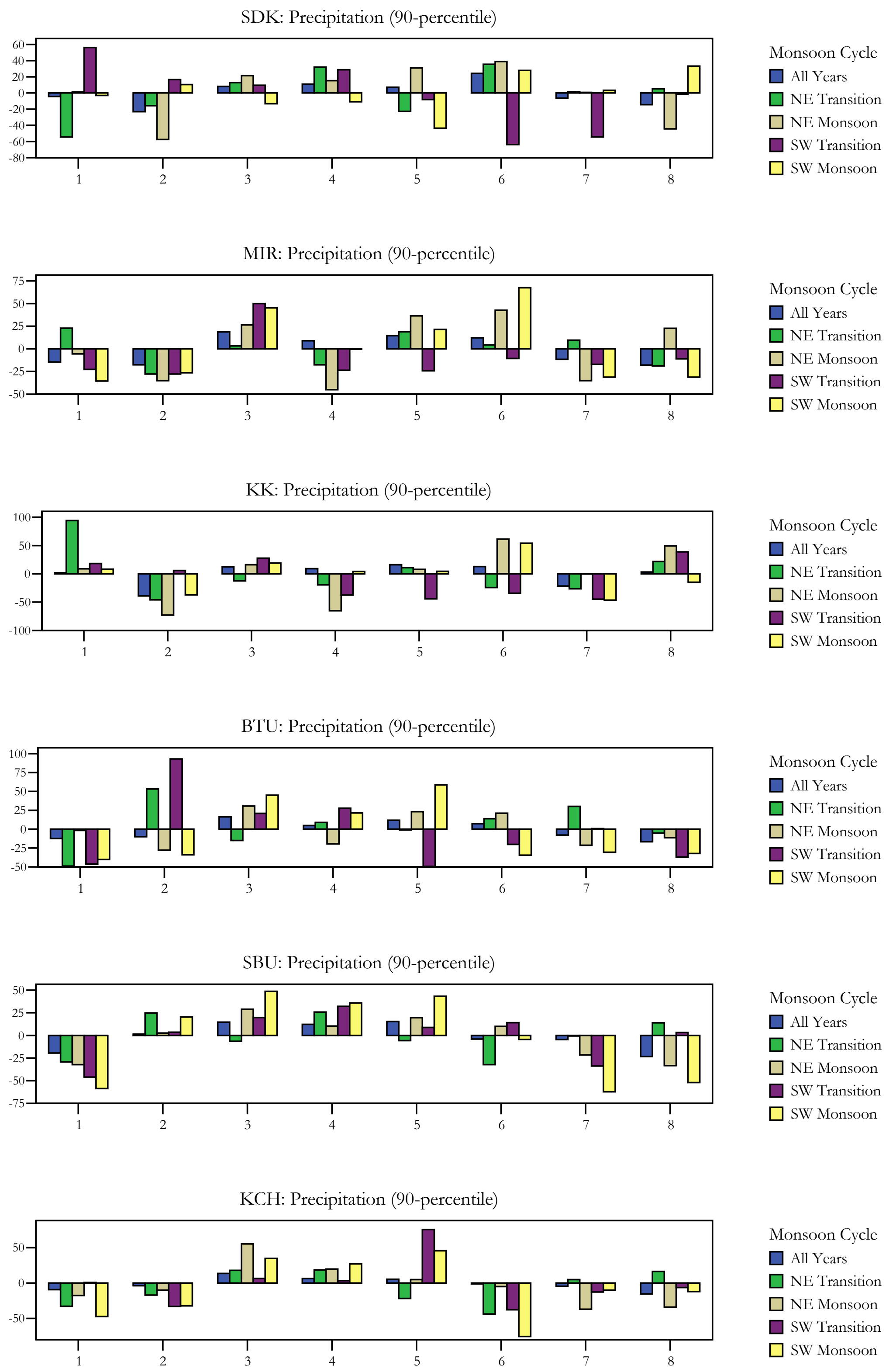


Figure 7.16b: Relationships with 90th percentile of precipitation based on monsoon cycle (CT1)

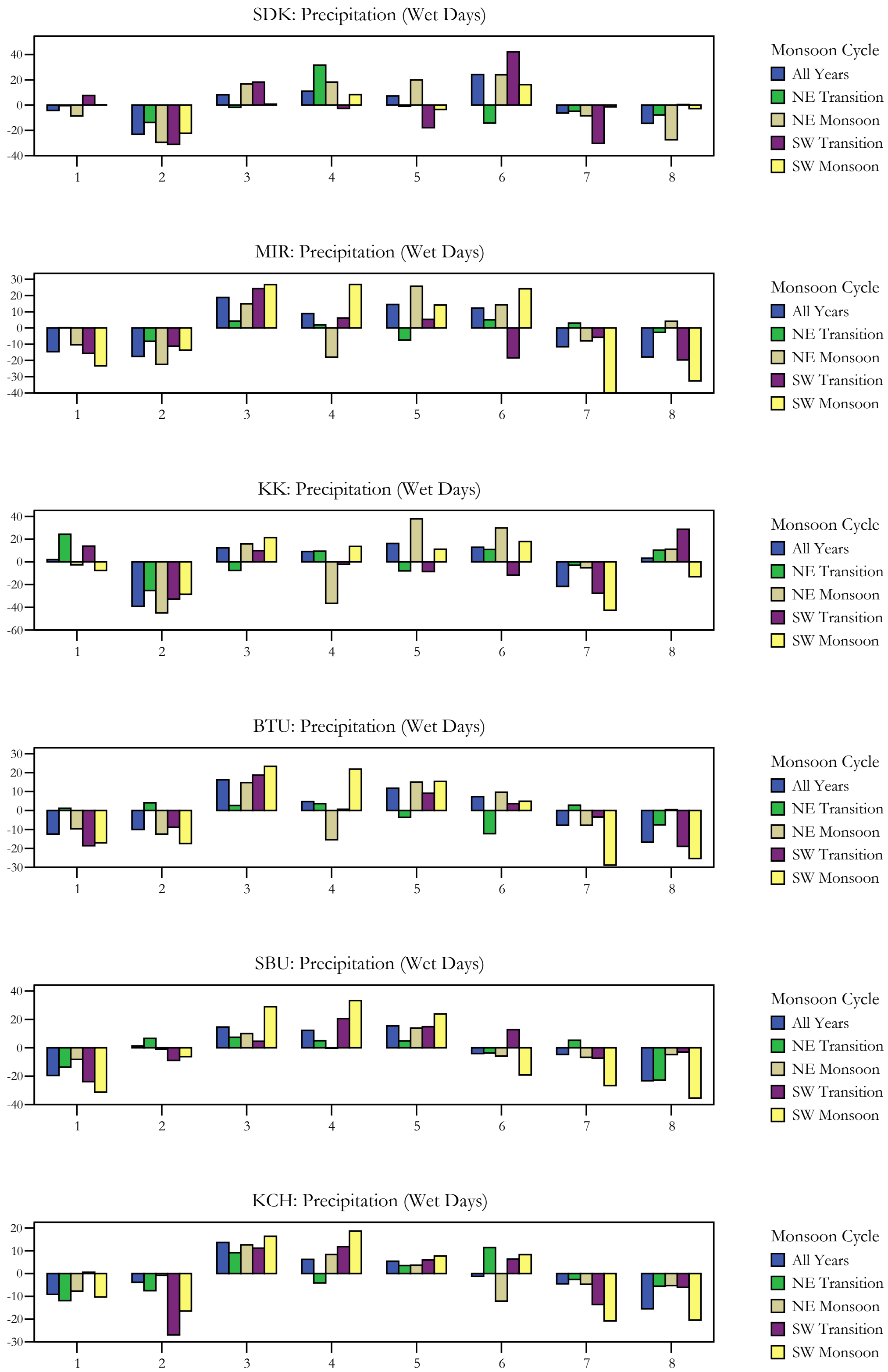


Figure 7.16c: Relationships with number of wet days based on monsoon cycle (CT1)

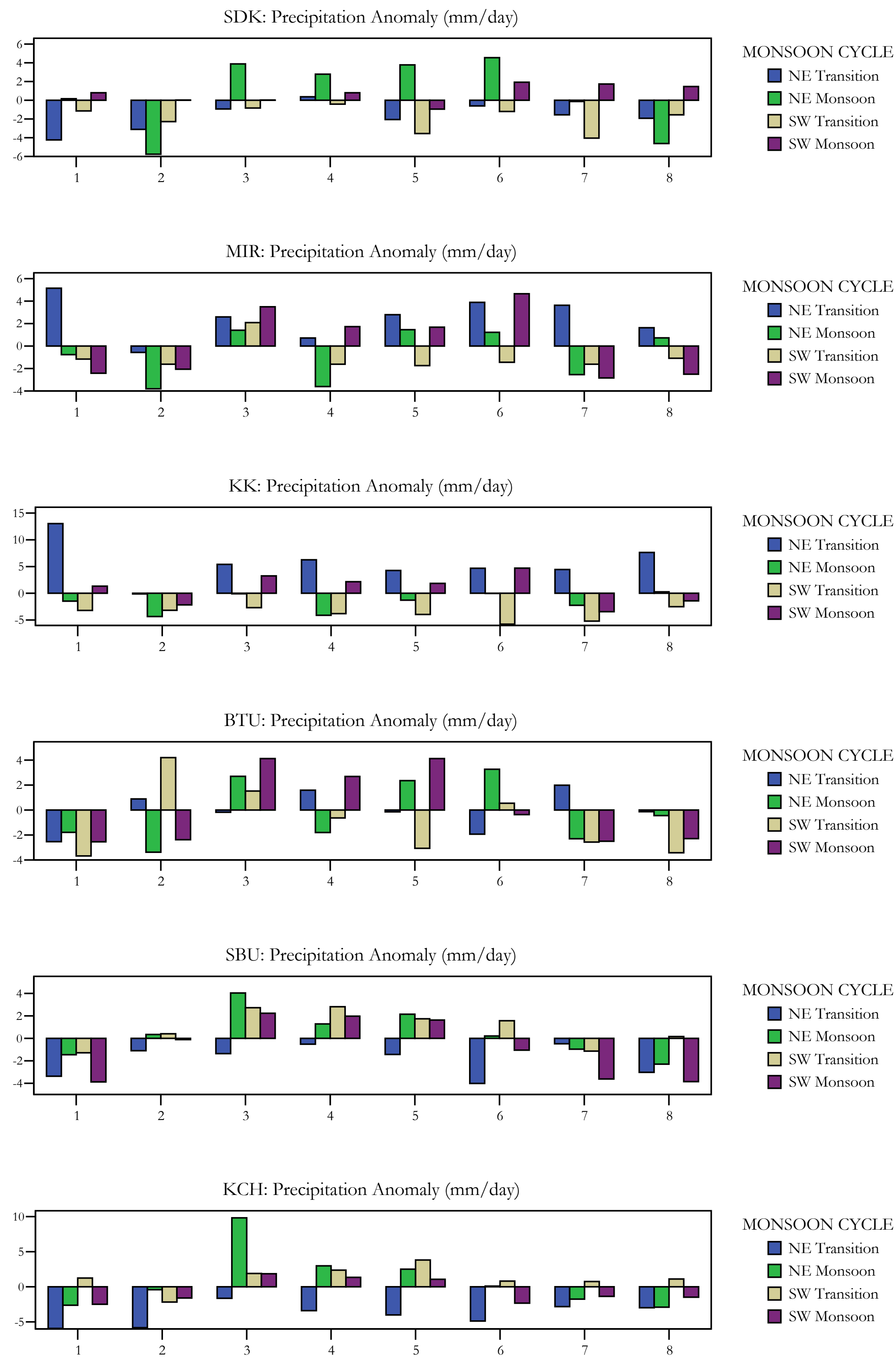


Figure 7.17a: Relationships with precipitation anomaly based on monsoon cycle CT2

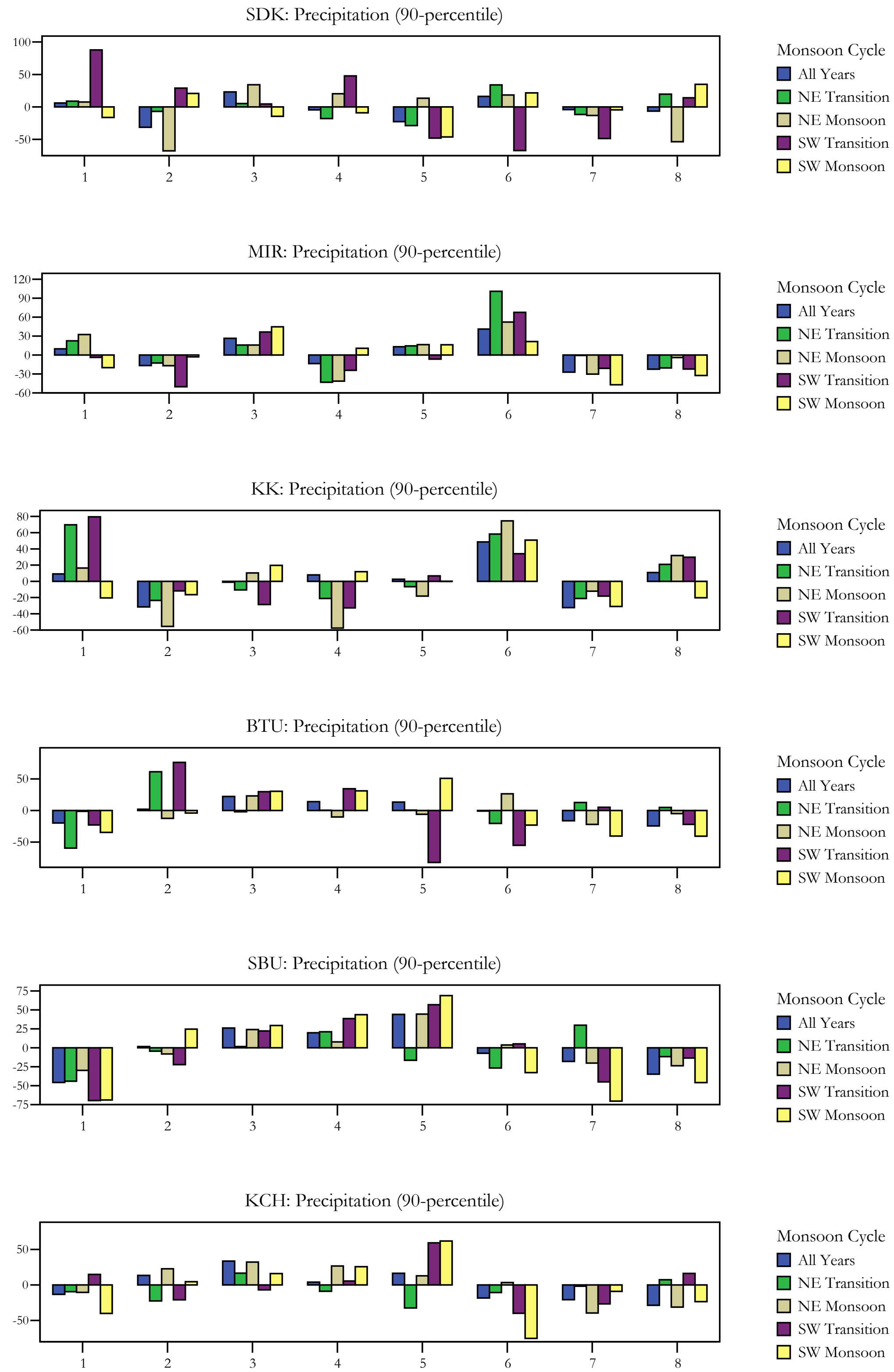


Figure 7.17b: Relationships with 90th percentile of precipitation based on monsoon cycle (CT2)

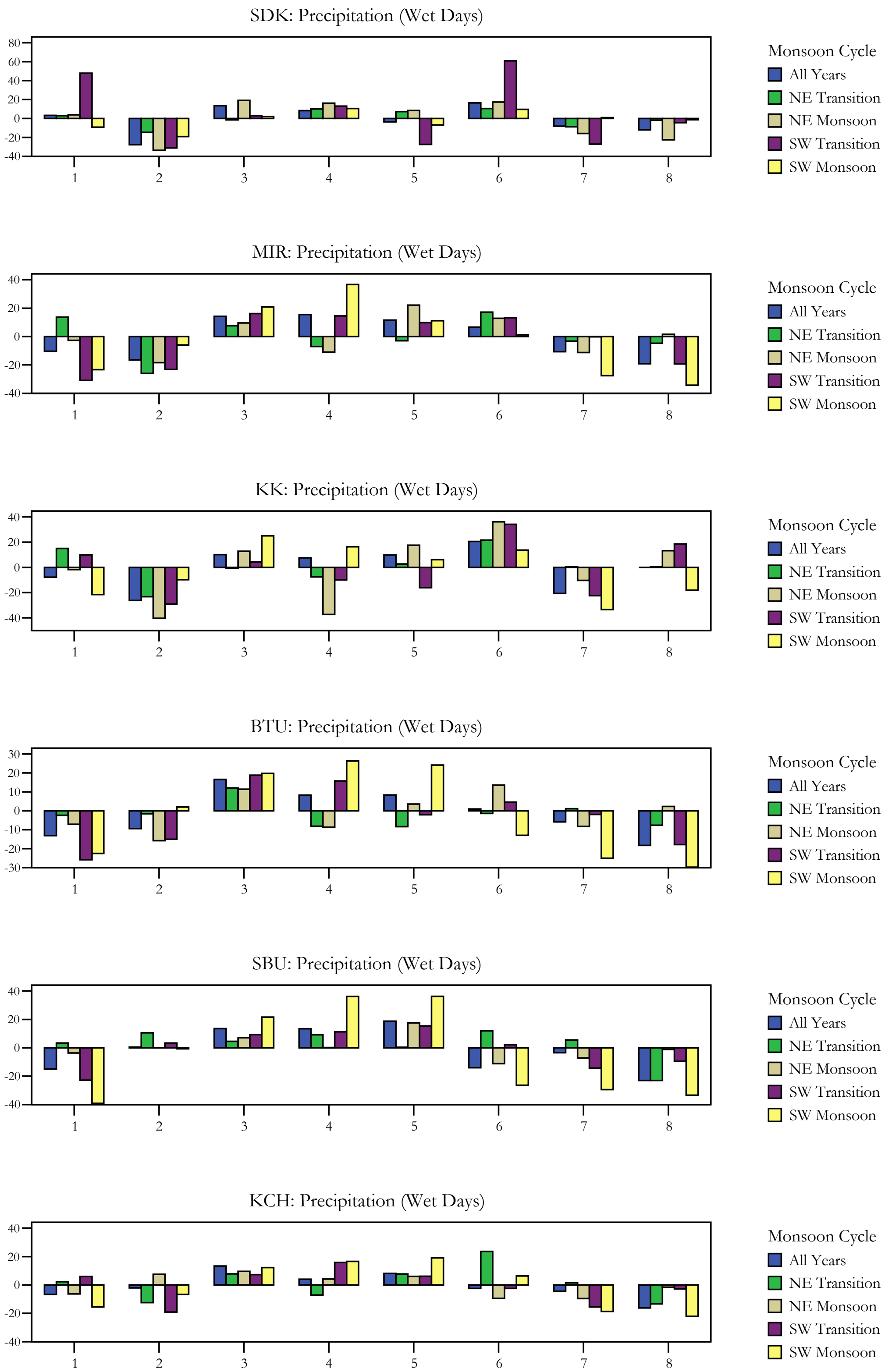
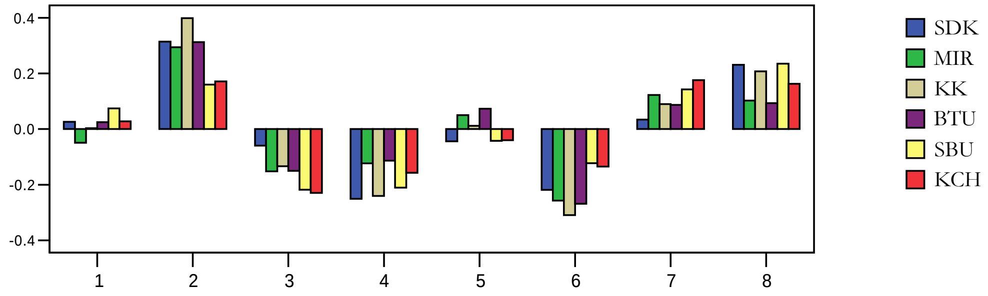
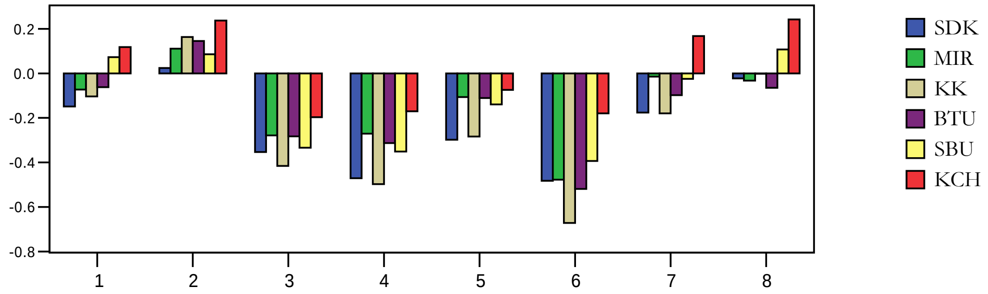


Figure 7.17c: Relationships with number of wet days based on monsoon cycle (CT2)

Temperature (T-Mean) Anomaly (°C)
CT Separate Season (1968-2001)



Temperature (T-Mean) Anomaly (°C)
CT Separate Season (1968-1984)



Temperature (T-Mean) Anomaly (°C)
CT Separate Season (1985-2001)

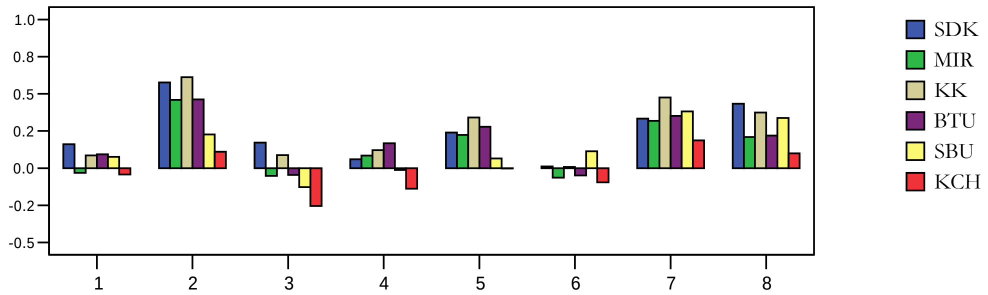
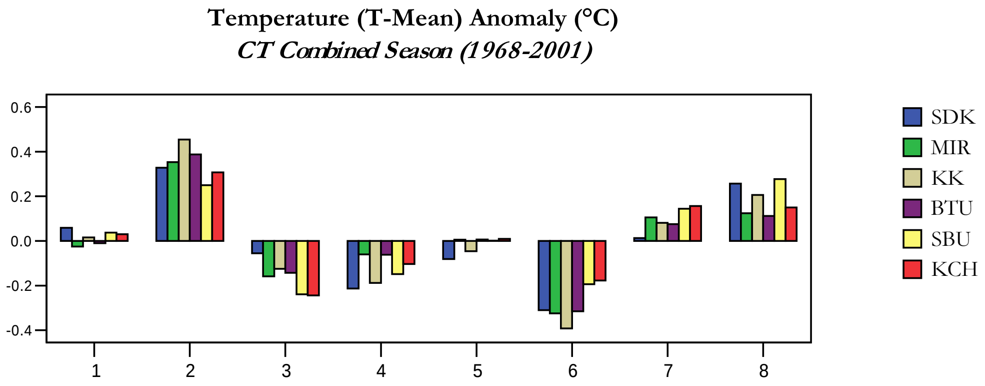
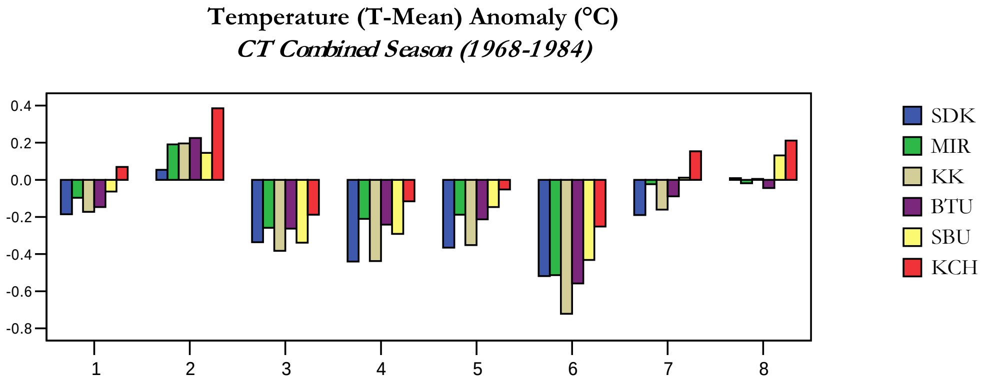


Figure 7.18a: Relationships with T-mean temperature anomaly (CT1)





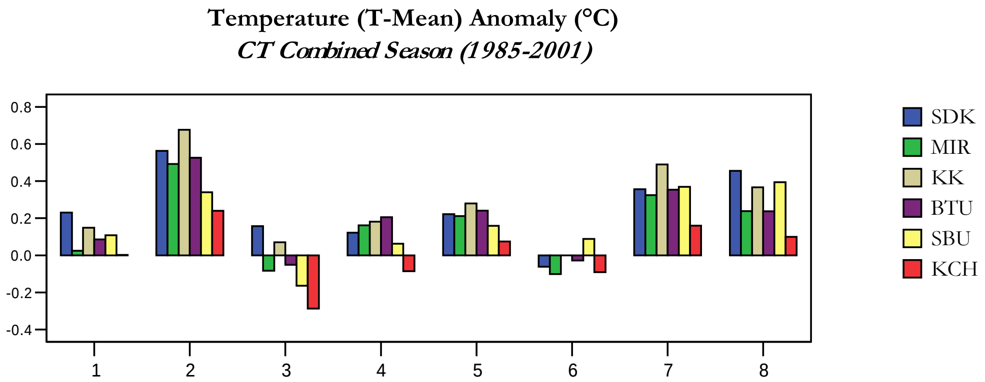


Figure 7.18b: Relationships with T-mean temperature anomaly (CT2)

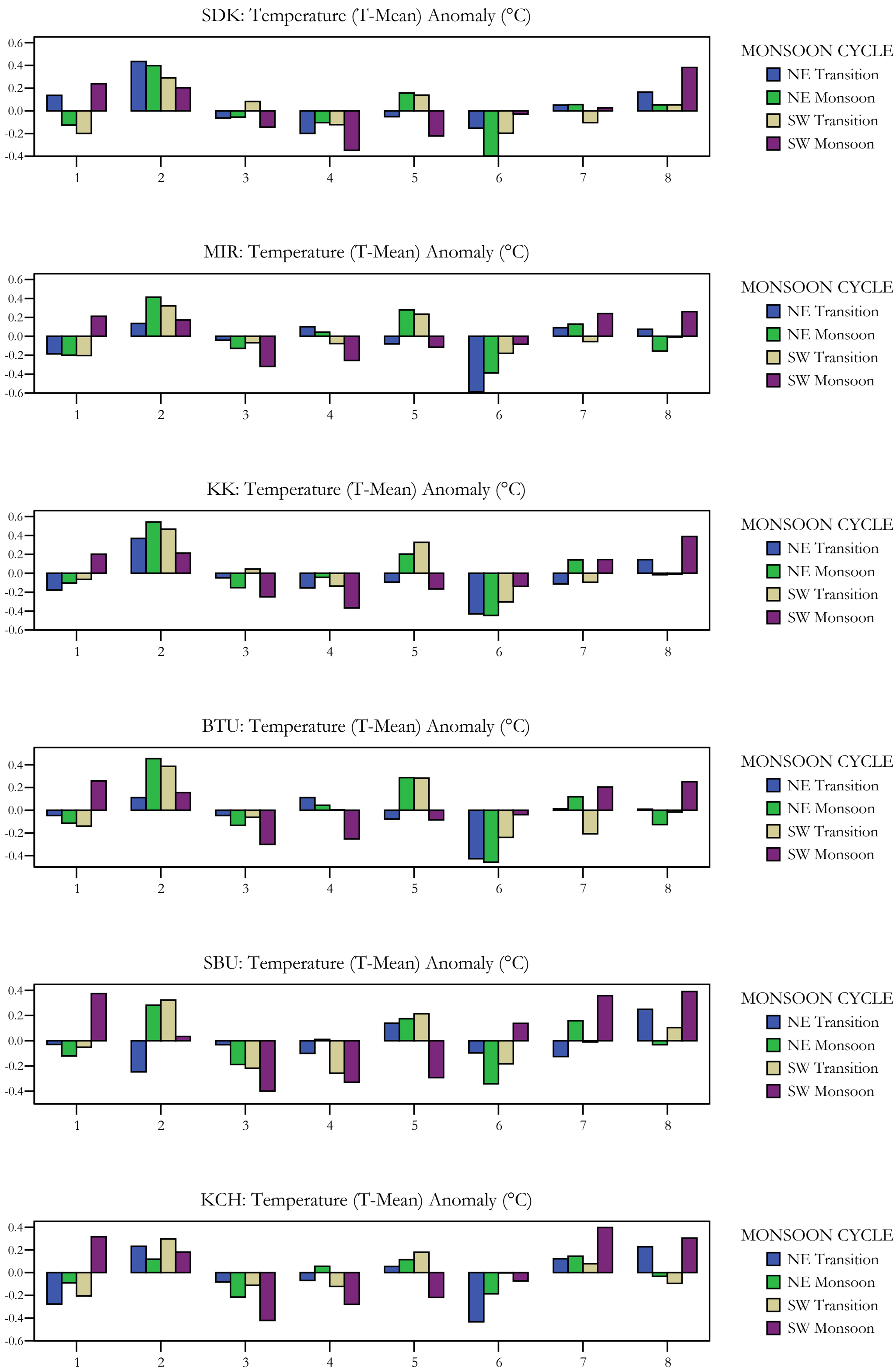


Figure 7.19a: Relationships with T-mean temperature anomaly based on monsoon season (CT1)

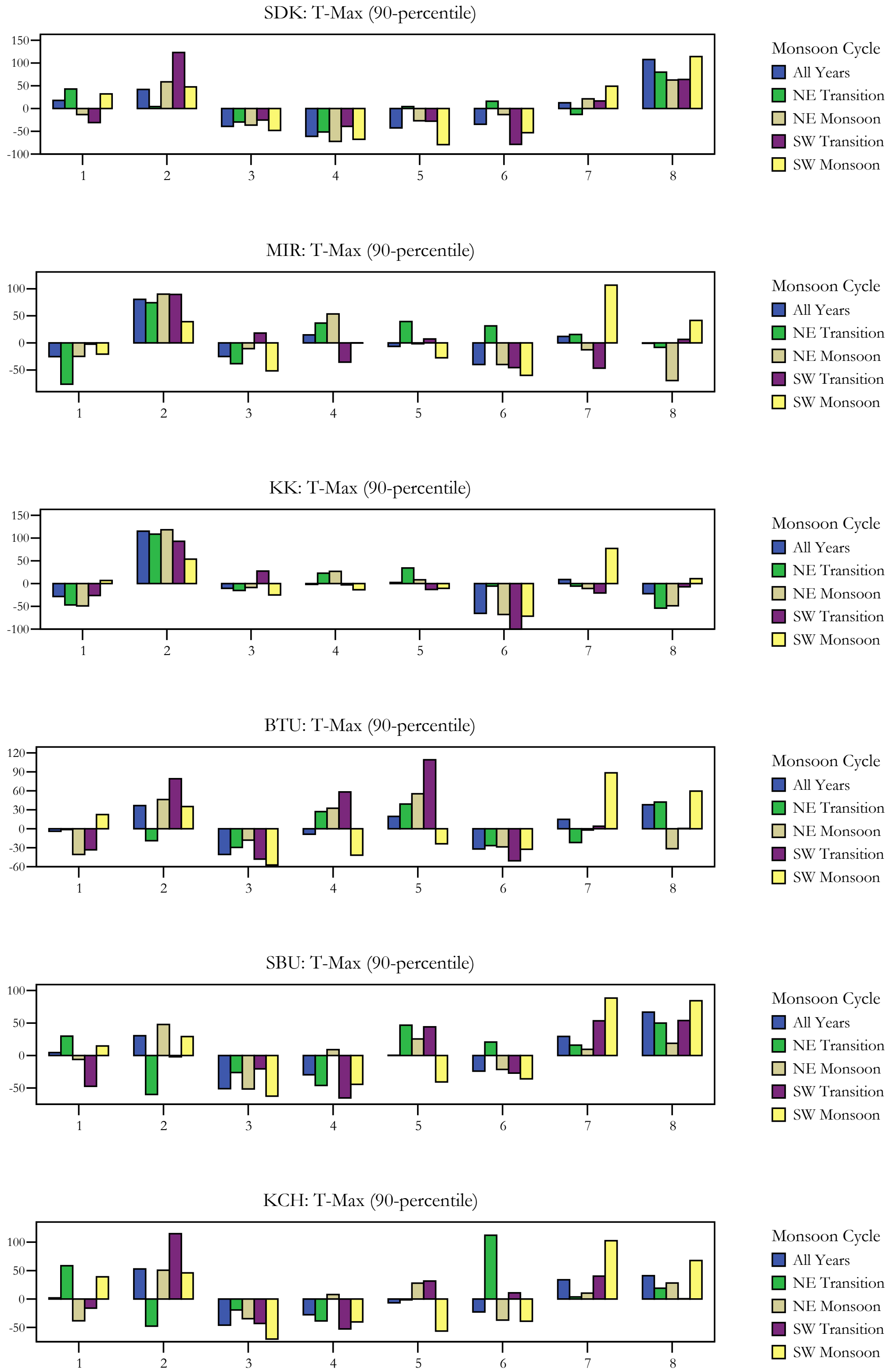


Figure 7.19b: Relationships with 90th percentile of T-max based on monsoon season (CT1)

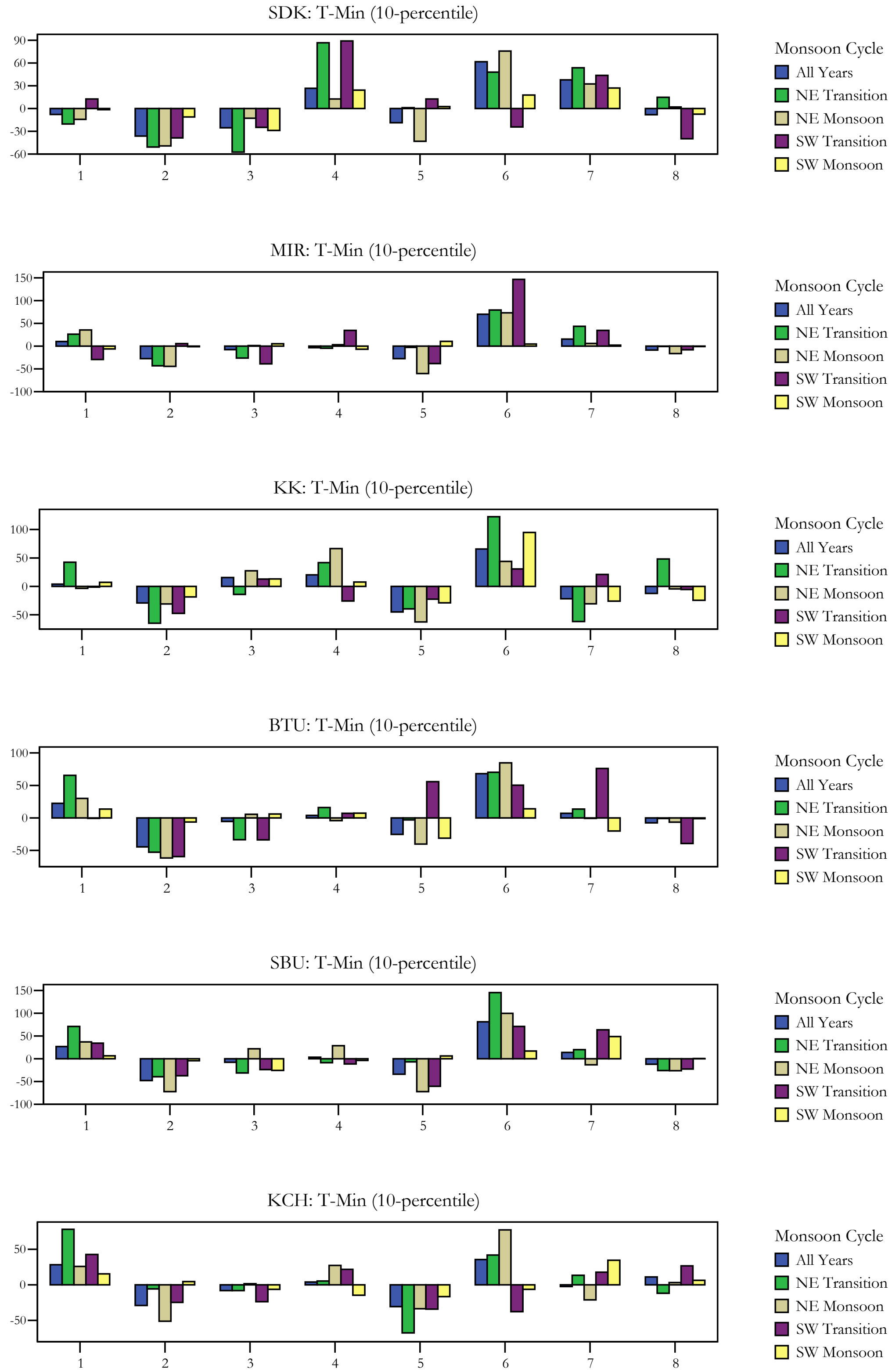


Figure 7.19c: Relationships with 10th percentile of T-min based on monsoon season (CT1)

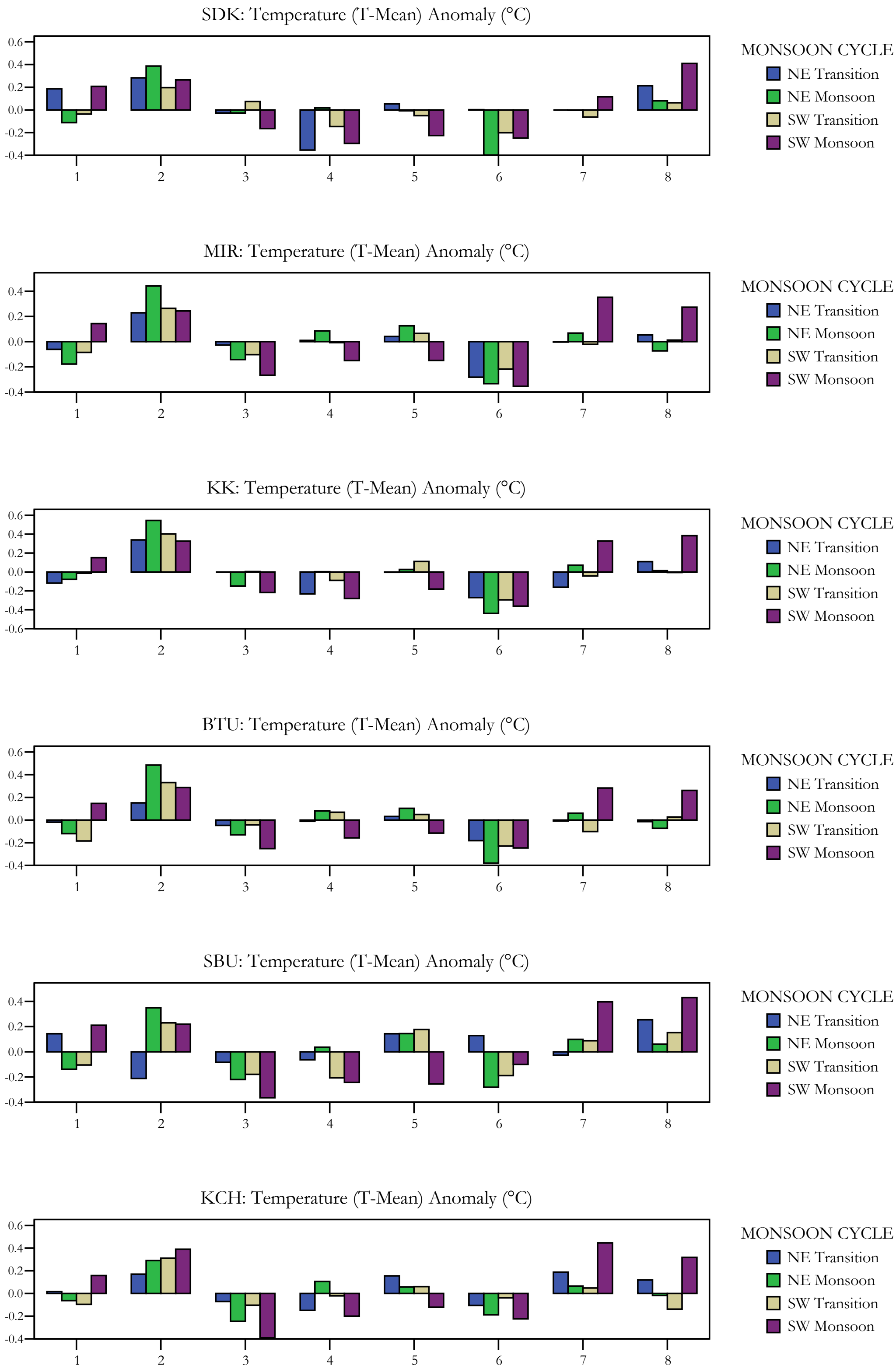


Figure 7.20a: Relationships with T-mean temperature anomaly based on monsoon cycle (CT2)

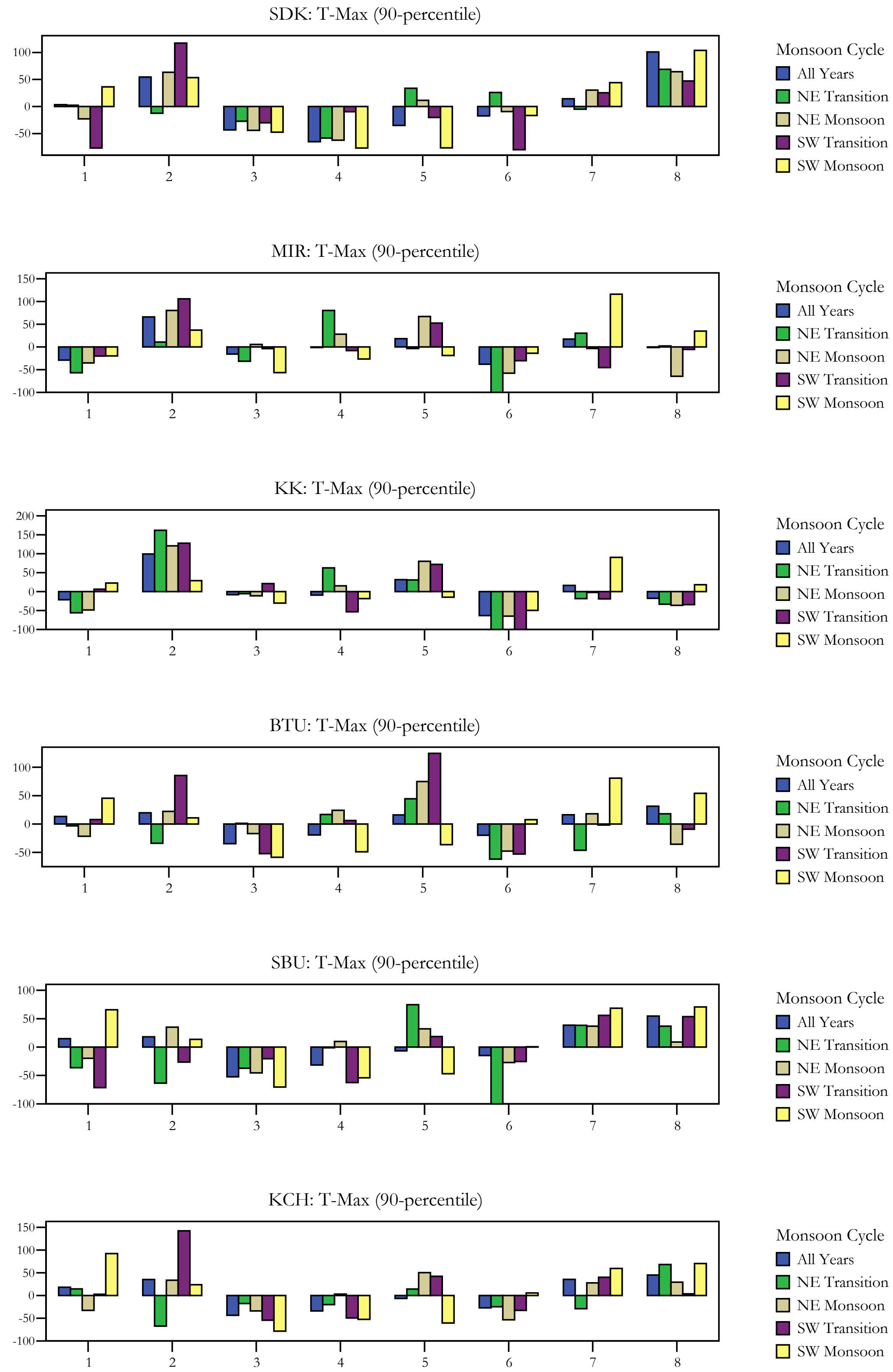


Figure 7.20b: Relationships with 90th percentile of T-max based on monsoon cycle (CT2)

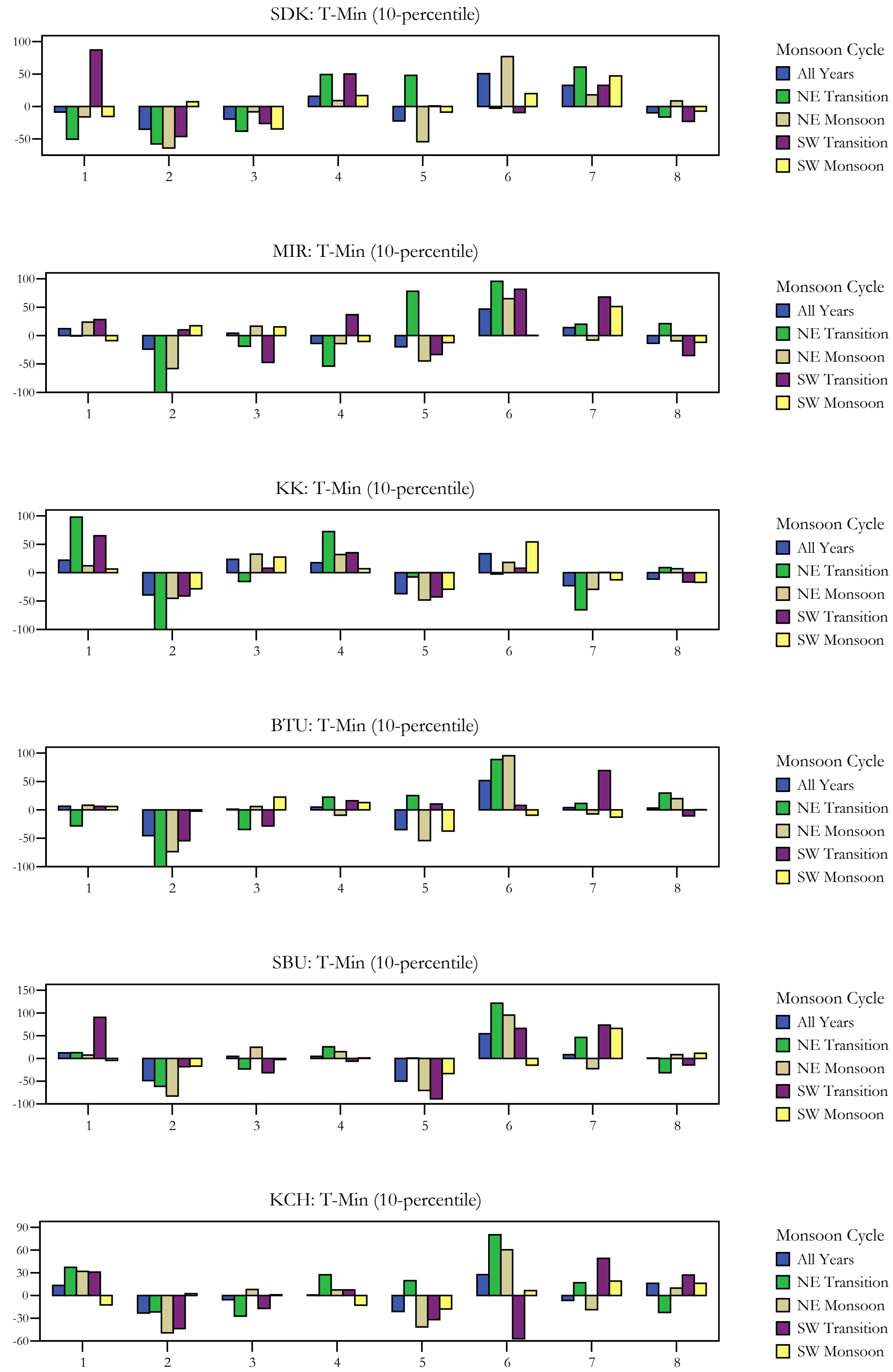


Figure 7.20c: Relationships with 10th percentile of T-min based on monsoon cycle (CT2)

Chapter 8
Correlation and relationship analyses between large-scale and surface climatic indicators

8.1 Introduction

In Chapter 6 (Section 6.2), the associations between selected synoptic indicators (capturing ENSO and monsoon signals) and surface climate have been investigated, where several indices are identified as relevant to Borneo. In Chapter 7, the relationships between Circulation Types (CTs) and surface variables have also been individually analyzed in detail. However, the characteristics and patterns of these two different sets of relationships have yet analyzed for comparison. One of the main aims of this study is to examine which one of the large-scale variables (i.e. synoptic indicators or Circulation Types) performs better in relating the surface climate of Borneo. Synoptic indicators are comprised of several numerical indices, which originally capture various ENSO and monsoon conditions using large-scale variables – such as SLP, SST and geopotential height. CTs (in this research) are the synoptic classification of the sea level pressure (SLP) based on eight significant identified modes (through PC analysis)[78]. CTs can be regarded as a specific index (a form of typing but not absolute numerical values) to simplify the combined effect generated by monsoon and ENSO variability. Both of these two synoptic variables equally represent the large-scale atmospheric circulation surrounding the Borneo region. Therefore, some similarities can be expected from these two different sets of large-scale indicators when being related to surface variables. This chapter will analyze the comparison between these relationships. The main issues to be addressed in this chapter are:

- Which is/are the best individual indices/types (from the numerical synoptic indicators and SLP established circulation types) that are best correlated with the surface climate of Borneo?
- Between those two categories of large-scale variables (synoptic indicator and circulation typing), which performs better in establishing relationships/correlation with surface climate?

[78] Two finalised methods are assessed in this chapter, which are: Method2 and CT1/CT2 (see Chapter 6, Sections 6.3 and 6.4).

- Are the relationships and correlation influenced by the monsoon cycle, and how they are different in each season?

8.2 Selected variables

There are three types of variables used in this analysis – (i) synoptic variables (ENSO and monsoon indices); (iii) the frequency of circulation types (integrating the ENSO and monsoon signals); and (ii) surface variables (precipitation and temperature). Each category will be described in the next section, in terms of the specific indices/variables/ measures used and their period of observations.

8.2.1 Synoptic indicators (ENSO and Monsoon)

There are seven specific indices used for this analysis, which capture the ENSO and monsoon signals. The selection of these seven indices (two for ENSO, and five for monsoon), which serve as the best indicators for Borneo, is based on the previous analysis in Chapter 6 (see Section 6.2): Southern Oscillation Index (SOI) and the SST anomaly at NIÑO3.4 are chosen for ENSO, and these indices have been proven the best in previous studies (Sirabaha, 1998; Sirabaha, 2004; Tanggang, 2001). Monsoon is represented by five indices from various studies and methods of calculation. Two of the five monsoon indices (i.e. RD1 and RD2) are newly created in order to establish unique indices specifically for Borneo. Table 8.1 shows all the synoptic indicators used.

Table 8.1: Synoptic Indices

Indices	Climatic mode being captured	Original variables used to create the indices	Observation	Status
SOI	ENSO	SLP (between Tahiti and Darwin)	Monthly	Established
NIÑO3.4	ENSO	SST anomaly in Niño3.4 region (Pacific Ocean basin)	Monthly	Established
IOI	Monsoon	SST anomaly in Indian Ocean	Monthly	Established
UM1	Monsoon	Meridional wind component at 1000 hPa and 200 hPa	Monthly (summer only)	Established
UM2	Monsoon	Meridional wind component at 1000 hPa	Monthly (summer only)	Established
RD1	Monsoon	SLP differences between two points/areas	Daily/Monthly	Newly created
RD2	Monsoon	SLP identified modes by unrotated PCA	Daily/Monthly	Newly created

8.2.2 Synoptic typing

Eight SLP circulation types (i.e. based on Method2 and CT1/CT2) that have been established in Chapter 7 are used in this analysis. The summary of characteristics for all eight types is given in Table 8.2. The physical features are identified in previous analysis (see Chapter 6) and had been discussed further in Chapter 7. In terms of weather types (WTs), 8 main modes have been identified for Borneo based on the variation of precipitation and temperature (see Chapter 4). However, only 6 of the 8 weather types (WTs) are used in this analysis. The two types being omitted are, 'Various Weather' (originally from PC2 negative) and 'Mixed Weather' (originally from PC4 positive). Both types have a very small number of cases/days (less than 65 days for the period of 1968-2001) – indicating that these types are not very important for describing Borneo weather variations. It is also not statistically appropriate to include these two types in this correlation analysis considering the low number of frequency. Table 8.3 shows the six important weather types of Borneo.

Table 8.2: Summary of physical characteristics of the Circulation Types (CTs)

The 'seasoned' scheme (absolute)			The 'de-seasoned' scheme (anomaly)		
Method2	Surface Relationships	Climatic events most associated with	CT1/CT2	Surface Relationships	Climatic events most associated with
Type 1	Wet & Cold (all)	NE Monsoon Strong La Niña	Type 1	Dry & Hot (B1)	NA
Type 2	Wet (central)	SW/NE Transition Strong El Niño	Type 2	Dry & Hot (A1)	NE Monsoon El Niño
Type 3	Wet (central) Dry & Hot (western)	NE Transition	Type 3	Wet & Cold (all)	NE Monsoon
Type 4	Dry & Hot (eastern/central)	SW Transition Strong El Niño	Type 4	Wet & Cold (all)	SW Monsoon La Niña
Type 5	NA	SW Monsoon Weak La Niña	Type 5	Wet & Cold (all)	NA
Type 6	Dry & Cold (central)	NE Monsoon Weak La Niña	Type 6	Wet & Cold (A1/A2)	NA
Type 7	Wet (A1)	SW Transition Weak La Niña	Type 7	Dry & Hot (central)	NE Monsoon La Niña
Type 8	NA	NE Transition	Type 8	Dry & Hot (central)	SW Monsoon

(See Chapter 7 for more details) NA =distinctive pattern of relationship is not available

Table 8.3: Summary of physical characteristics of the Weather Type (WTs)

WT	Name of reference	Main Physical Features	Seasons and Variables most associated with
NW	Normal Weather	Temperature and precipitation are close to normal in all six key stations	All Seasons
HW	Hot Weather	Temperature is positive anomaly in all six key stations	SW Monsoon/Transition Temperature
CW	Cool Weather	Temperature is negative anomaly in all six key stations	NE Monsoon Temperature
Wwet	Western Wet	Precipitation is positive anomaly in the eastern station (SBU, KCH)	NE Monsoon/SW Transition Precipitation
Cwet	Central Wet	Precipitation is positive anomaly in the stations centrally located (KK, MIR, BTU)	NE Transition/SW Monsoon Precipitation
Ewet	Eastern Wet	Precipitation is positive anomaly in the western stations (SDK)	NE Transition/Monsoon Precipitation

Various Weather and Mixed Weather are two other weather types for Borneo, but have been omitted for this analysis due to extremely low occurrences (i.e. consist of only 63 and 14 days respectively) (see Chapter 4)

8.2.3 *Surface variables*

Variables for surface climate (i.e. precipitation and temperature) include both the average and extreme measures. Four selected measures have been use in each one of the surface variables. Table 8.4 summarizes all the variables and measures used.

Table 8.4: Surface variables

Precipitation	Temperature
(i) Average Precipitation average Precipitation intensity	(i) Average Mean temperatures (T-mean)* Maximum temperature (T-max) Minimum temperature (T-min) Temperature Range (DTR) T-max – T-min
(ii) Extreme Number of rain days* 90^{th} percentile of precipitation*	(ii) Extreme 90^{th} percentile T-max* 10^{th} percentile T-min

** Correlation with CT1/CT2 only include these variables*

8.3 Methodology

Before performing the analyses, the measures for all variables are first transformed into a standard measure to create common ground. CT is based on occurrences, while other variables (i.e. ENSO/monsoon indices and surface climate) are observed averages. The correlation for CT will be based on the monthly frequency/counts for each type. Some of variables are observed on a daily basis, and some measures are recorded monthly. There are also certain variables that are only available during certain seasons. For example, UM1 and

UM2 are exclusively used to measure monsoon index during the summer season, which is the Southwest monsoon (April – September). To accommodate these two limitations, it was decided that the correlation analysis would be performed:

- based on monthly values
- based on monsoon cycle[79] (correlations are performed separately for each season)

All sets of data are evaluated with parametric tests to investigate the normality of distribution (either parametric or non-parametric – to ensure the use of suitable correlation techniques). Two main statistical tools used in this chapter are correlation (Spearman's Rank Technique) and T-test (to evaluate the significance value for the descriptive analysis). Correlation analysis will evaluate if the two sets of variables are moving in the same/opposite directions through time. The coefficient values will determine if the association is significant or not. Descriptive analysis (analyzing the 'long-term average'[80] attributed to certain conditions) is to investigate relationships between two variables. It will evaluate if the occurrences of one particular factor (variable) directly affects the outcome of another variable (in terms of magnitude). ANOVA F-test will then be performed to verify if the mean differences are statistically significant. Thus, correlation analysis is to examine the direction of the association. On the other hand, the so-called 'relationship analysis' is to quantify the magnitude of the association. Detailed explanations about these statistical methods are given in Chapter 3. A specific description of how they are used in this chapter is given in the next sub-sections.

8.3.1 Correlation

The data for surface variables and the Circulation Types (CTs) are available for the period of 1968-2001 (equivalent to 408 valid cases for each monsoon season). Thus, a higher threshold of significance value is chosen (99% instead of 95%). The data pairs being correlated are summarized in Table 8.5. Parametric test has to be performed first to determine if the data follow the normal distribution. This will serve as the justification for the use of the Spearman Rank Correlation technique. All the correlation analyses are performed based on monthly values, and conducted, either separately for each monsoon season or using combined season.

[79] The monsoon seasons are divided only into two categories (NE and SW monsoon), where the 'mature' and 'transition' are merged together into one season. The reason is due to the limited number of cases (if it is performed based on four different seasons). This is the same reason why analysis based on ENSO event is not conducted. It is statistically impossible due to the sample size being extremely small.

[80] 'Long-term average' in this context is exclusively referred to the average value for one particular climatic indicator under the classification of other factors/variables over certain periods of time.

Table 8.5: Correlation pairing data/variables

Variable 1	Variable 2	Valid cases (monthly/seasonally)	Lowest threshold[81]
Surface variables (magnitude/extreme)	CT (T1 – T8)	1968-2001	0.18
Surface variables (magnitude/extreme)	Synoptic Indices	1968-2001	0.18

8.4 Correlation with large-scale variables (Method2 – absolute SLP)

8.4.1 Correlation with precipitation

For synoptic indicators (see Table 8.6 and Figure 8.1), the SOI (ENSO index) is positively correlated with A1 (SDK, MIR), A2 (KK) and the most eastern station from B1, which is BTU. The two most western stations in B1 (SBU, KCH) are not significantly correlated. These significant correlations are observed in all four variables for precipitation, which include both the magnitude and extreme measures. However, it is also worthy to note that the significant correlations are mostly observed during the Northeast (NE) monsoon. Only two stations show statistical significance during the Southwest (SW) monsoon, namely MIR (A1) and BTU (B1) – both stations are located in the central part of Borneo (see Chapter 5). Niño3.4, the second ENSO index, is negatively correlated with all variables and for all four stations as for SOI. However, this significant correlation is exclusively for NE monsoon only. There is no statistical significance, at all, observed during the SW monsoon.

Table 8.6: Results for correlation analyses between large-scale variables (Circulation Types and Synoptic Indicators) and precipitation (both in average and extreme measures)

8.8a Precipitation Average

Synoptic	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Variables	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE
SOI	O		O	O	O		O	O				
NIÑO3.4	X		X		X		X					
IOI												
UM1		O								X		X
UM2		O				O				X		X
RD1	O	X					O		O	O	O	O
RD2	X		X		X		X					
T1	O	X	O		O	X	O			O		
T2			O	O	O				O		X	
T3					O				X		X	
T4	X	X	X		X	X	X			O		
T5		O				O				X		X
T6			X		X	X					O	
T7	X	X								O	X	O
T8		O	O		O						X	

[81] Lowest threshold is decided based on the lowest number of cases in a particular station (for a particular variable). When two pairs of variables are correlated, there are several thresholds of significant correlation coefficients depending on the number of cases for each station. The smaller the sample is, the higher the threshold has to be. To simplify (and for more convenience in interpreting the results), the threshold for the entire result (in one diagram) is set at the highest value (i.e. the lowest number of samples).

8.8b Precipitation Intensity

Synoptic	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Variables	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE
SOI	O		O	O	O		O	O		O		
NIÑO3.4	X		X		X		X					
IOI	X											
UM1		O								X		X
UM2		O				O				X		X
RD1	O	X			O		O		O	O	O	O
RD2	X		X		X		X					
T1	O	X	O			X	O		O	O		
T2					O						X	
T3					O				X			
T4	X	X	X		X	X	X			O	X	
T5		O				O				X		X
T6			X		X	X					O	
T7	X	X								O	X	O
T8		O	O		O						X	

8.8c 90th Percentile Precipitation

Synoptic	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Variables	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE
SOI	O		O		O		O	O				
NIÑO3.4	X		X		X							
IOI												
UM1		O				O				X		
UM2		O								X		
RD1	O	X					O		O	O	O	O
RD2	X		X		X							
T1	O	X	O		O	X			O			
T2		O			O		O					
T3					O				X		X	
T4	X	X	X		X	X	X			O		
T5						O						
T6		X	X		X	X					O	X
T7		X								O	X	
T8		O	O		O						X	

8.8d Number of Rain Days

Synoptic	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Variables	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE
SOI	O		O	O	O	O	O	O		O		O
NIÑO3.4	X		X		X		X					
IOI												
UM1		O						X		X		X
UM2		O		X				X		X		X
RD1	O	X						O			O	O
RD2			X				X			O	O	
T1	O	X	O		O	X	O		O			
T2					O							
T3					O							
T4	X	X	X			X	X		X		X	
T5						O		X		X		X
T6			X				X					
T7		X				X				O		O
T8			O		O		O					

O = significant positive correlation; X = significant negative correlation (at 95% level of confidence); NE = Northeast Monsoon (October – March); SW = Southwest Monsoon (April – September)

For the monsoon indices, the three readily established indices (IOI, UM1 and UM2) collectively perform very poorly, as for each one of the variables, there are less than three stations significantly correlated with. Only UM2 consistently shows a significant correlation for at least 3-4 stations in all variables. However, it does not preserve the consistency over one particular station or climatic group (for example, it is significant for A1 for certain variables, and either for A2 or B1 in other variables), which makes it less useful for climate prediction. The newly created monsoon indices (RD1 and RD2) prove to be better correlated with the Borneo precipitation. RD1 is negatively correlated with the magnitude variables (average and intensity) in A1 and A2 stations (SDK, MIR, KK). For all the B1 stations (BTU, SBU, KCH), RD1 is positively correlated (see Table 8.6a and 8.8b). These significant correlations are observed in both seasons – NE and SW monsoons. RD2, on the other hand, is negatively correlated in A1 and A2 stations only, and its association is exclusively for NE monsoon.

For Circulation Types (see Table 8.6 and Figure 8.1), the correlation is found to have a better pattern. There are four important CTs, which are significantly correlated with precipitation in a systematic way (observed in a particular climatic group or monsoon seasons). Type 1 is associated with A1 and A2 with a positive correlation during the NE monsoon, and a negative correlation during the opposite season (SW monsoon). Type 4 is negatively correlated with all precipitation variables for all climatic groups – A1, A2, and B1. There is only one exception for one of the extreme variables (90^{th} percentile of precipitation), where only stations in A1 and A2 are significantly correlated. Type 5 shows a unique correlation with the two most western stations (SBU and KCH). Both stations are negatively correlated during the NE monsoon for all variables. Type 6 is exclusively related to Sepanggar Climatic Group (A2). Three of the four precipitation variables (excluding the number of rain days) are negatively correlated with the occurrence of Type 6 in both monsoon seasons. In general, magnitude variables (average and intensity) are better correlated with the circulation types, compared to extreme variables (especially 90^{th} percentile of precipitation, which are poorly correlated with any circulation type).

8.4.2 Correlation with temperature

For synoptic indicators (see Table 8.7 and Figure 8.2), both ENSO indices (SOI and Niño3.4) show significant correlation at all stations for the mean temperature average (T-mean). SOI is negatively correlated in both seasons, and Niño3.4 is in the positive direction. However, both indices fail to establish any meaningful[82] correlation with the other three variables (i.e. DTR, 90^{th} percentile T-max, and 10^{th} percentile of T-min). The chosen monsoon indices are poorly correlated with all temperature variables, especially for IOI, UM1 and UM2. However, RD1 and RD2 show a better performance. For T-mean, RD2 is positively correlated with both seasons in all stations except for the two most western ones

[82] The term 'meaningful correlation' is used to describe the observation of several significant correlations (and not only one or two that are scattered uncharacteristically), that could establish an interpretable pattern. For example, it must consist of observations of few significant correlations (for a particular variable) in a systemic way – whether they are specifically maintained in certain groups of stations or consistently exhibited in certain seasons.

(SBU and KCH). For temperature range (DTR), RD1 is negatively correlated in both seasons for all stations in A1 and B1. None of the synoptic indicators (either ENSO or monsoon indices) has successfully established a meaningful (interpretable) correlation for any of the two chosen extreme variables (90th percentile of T-max, 10th percentile of T-min).

For Circulation Types (see Table 8.7 and Figure 8.2), two variables (90th percentile of T-max, and T-mean average) are not significantly correlated with any of the types. Only DTR and 10th percentile of T-min exhibit significant correlation. Four circulation types manage to describe a meaningful pattern (of the correlation) for DTR:

- Type 4 exhibits negative correlation during the SW monsoon for A2.
- Type 5 is positively correlated with B1 during the SW monsoon.
- Type 7 is also correlated with all stations in B1, but negatively during the SW monsoon, and positively during the NE monsoon.
- Type 8 shows positive correlation, also in B1, during the NE monsoon.

Table 8.7: Results for correlation analyses between large-scale variables (Circulation Types and Synoptic Indicators) and temperature (both in average and extreme measures)

8.9a Temperature Average (T-mean)

Synoptic	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Variables	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE
SOI	X	X	X	X	X	X	X	X	X	X	X	X
NIÑO3.4	O	O	O	O	O	O	O	O	O	O	O	O
IOI											O	
UM1												
UM2												
RD1												
RD2	O	O	O		O	O	O	O			O	
T1												
T2												
T3												
T4												
T5												
T6	X											
T7												
T8												

8.9b Temperature Range (DTR = T-max – T-min)

Synoptic	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Variables	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE
SOI					X	X						
NIÑO3.4			O		O							
IOI												
UM1		O		O				O		O		O
UM2		O		O				O		O		O
RD1	X	X	X	X			X	X	X	X	X	X
RD2					O		X					
T1		X	X					X				
T2	O						O		O	X	O	
T3	O						O		O		O	
T4		X	O	X	O		X	X				
T5		O		O				O		O		O
T6	X	X		X			X		X		X	
T7	O	X		X			O	X	O	X	O	X
T8	O						O		O		O	

8.9c 90th Percentile of Maximum Temperature (T-max)

Synoptic	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Variables	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE
SOI			X					X		X		
NIÑO3.4		O	O	O	O			O		O		
IOI												
UM1		O						O				
UM2		O						O				
RD1	X											
RD2			O		O							
T1												
T2	O											
T3												
T4	X											
T5												
T6	X	X										
T7		X		X				X				X
T8	O	O						O		O		O

8.9d 10th Percentile of Minimum Temperature (T-min)

Synoptic	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Variables	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE	SW	NE
SOI	O	O										
NIÑO3.4	X	X					X				X	
IOI												
UM1												
UM2												
RD1												
RD2	X	X				X						
T1	X		X				X		X		X	
T2					X							
T3												
T4					O							
T5												
T6	O		O		O		O		O		O	
T7												
T8		O	O		O						X	

O = significant positive correlation; X = significant negative correlation (at 95% level of confidence); NE = Northeast Monsoon (October – March); SW = Southwest Monsoon (April – September)

It is worthy to note that the A1 climatic group (SDK and MIR) has no significant correlation between the circulation types and the DTR in any season. However, stations from Sepilok Climatic Group (A1) exhibit significant correlation with 10th percentile for T-min. The two significant types associated with this variable are:

- Type 1 is negatively correlated with A1 and B1 during the NE monsoon.
- Type 6 is also negatively correlated during the NE monsoon, but for all six key stations (A1, A2 and B1).

8.4.3 *Discussion of the results*

There are eight specific variables (see Figure 8.1 and 8.3) that consistently show high values of correlation coefficient ($r \geq \pm 0.4$), which are SOI/Niño3.4 (ENSO indices), RD1/RD2 (monsoon indices) and Type 1/4/5/8 (Circulation Types). The ENSO indices are correlated with precipitation at all stations in A1 and A2 climatic group, but not in B1. This is consistent with previous studies that find stations in western part of Borneo (BTU, SBU and KCH – B1 group) are not correlated well with ENSO indices (Quah, 1988; Cheang, 1993;

Sirabaha, 1998; Tangang, 2001). These two chosen ENSO indices, however, are strongly correlated with temperature anomaly at all six key stations.

RD1 and RD2, the newly created indices, are the best monsoon indices. These indices are strongly correlated in all precipitation variables (for all stations and seasons). For temperature, RD1 is significantly correlated with DTR in all stations. The same case applies to RD2, but with a different variable, the temperature anomaly. The creation of the RD2 index is similar with the method used for SOI (see Chapter 6, Section 6.4.1) – which is by calculating the difference of surface pressure between two points (or areas for RD2). Thus, it is anticipated that this index effectively captures the signal of the same variable (i.e. temperature anomaly) as SOI does[83].

Types 1, 4, 5, and 8 are the best circulation types, which are significantly correlated with surface temperature and precipitation. All stations indicates strong significant correlations for precipitation variables (at least one of the four chosen variables). However, stations from the A1 climatic group (SDK, MIR) are not described by any significant correlation for temperature variables. Type 7 is best correlated with the temperature variables (but not with any stations in A1). This association is highly consistent with the result of analysis in the previous chapter (see Section 8.6). Type 7 has been identified as the typical 'temperature type'[84], which produces a higher probability of hot days during the Northeast monsoon, and cold days during the Southwest monsoon. Type 4 is the strongest type for explaining correlation significance for precipitation. This also further validates the results from the previous chapter (see Section 7.5), where Type 4 has been strongly classified as 'precipitation type'[85]. Type 4 exhibits a high negative anomaly with precipitation during the Northeast monsoon and positive anomaly during the Southwest monsoon. Type 4 also has a special characteristic of having the Inter-tropical Convergence Zone (ITCZ) fluctuating around the 0˚ latitude (see Table 8.3). The ITCZ is one of the main sources for precipitation in the tropics (Niewolt, 1977; McGregor and Nieuwolt, 1998). If this convergence zone shifts around the 0˚ latitude (practically fluctuating between 5˚S-5˚N, where six of the selected stations are located), then anomalous precipitation will be observed at all those stations (i.e. SDK, MIR, KK, BTU, SBU and KCH). This means that a higher degree of difference in terms of rainfall variability between stations, and within an individual station

[83] Refer to Chapter 6 (Section 6.4.3) to see how SOI is correlated with RD1 and RD2.
[84] Temperature type is a reference to a circulation type, which is dominantly associated with significant anomaly in temperature variables (either the magnitude or extreme measures).
[85] Similarly, precipitation type is a reference to a circulation type, which is dominantly associated with significant anomalies in precipitation variables (either the magnitude or extreme measures).

itself. Therefore, it is assumed that Type 4 captures this type of signal (a dynamic fluctuation of rainfall distribution).

In general, the synoptic indicators (i.e. ENSO/monsoon indices) are better correlated with temperature anomalies. However, the circulation types establish a far stronger (in terms of amplitude) correlation for precipitation variables. The logic behind this is the fact that precipitation in Borneo is more strongly influenced by the fluctuation of the monsoon modes, and quite regularly subjected to remote ENSO forcing (Sirabaha, 1998; Ooi, 2001). Both ENSO and monsoon indices are exclusively represented by only one of these two well-known large-scale climatic forcings. Thus, a weaker performance in capturing the precipitation signal is expected. On the other hand, the established Circulation Types represent a more complex variation of the synoptic circulation surrounding the Borneo region (which integrates both ENSO and monsoon circulations). Therefore, its ability to establish a significant association with surface climate (especially precipitation) is more effective.

8.5 Correlation with large-scale variables (CT1/CT2 – SLP anomaly)

The correlation results for each individual circulation types (produced by CT1/CT2) are summarised in Table 8.8 below. Figures 8.3a-c presented the same results in a form of graphic for a better overview. This section will investigate the following issues:

- Which types are best correlated with the ENSO/monsoon indices and the surface variables?
- How do the correlations differ between the CT1 and CT2?
- Do the correlations (with surface variables) show spatial discrimination (among the six key stations or the three climatic groups – A1, A2 and B1)?

Table 8.8: Results for correlation analyses between individual circulation types, ENSO/monsoon indices and surface variables

8.10a ENSO and monsoon indices

Circulation	SOI		Nino3.4		IOI		RD1		RD2	
Type	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
1		X		O					O	
2	X	X	O	O	O	O			O	
3							O	O	O	
4							X	X		
5		O		X					X	
6	O	O	X	X	X	X		O	X	
7							O	O		
8	X						X	X	X	

8.10b Precipitation (Number of wet days)

Circulation	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Type	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
1						X		X				
2	X	X	X	X	X	X	X				X	
3	O		O	O			O	O	O	O	O	O
4					O		O		O			
5				O		O		O		O		
6		O		O								
7						X			O	O	O	O
8							X		X	X	X	X

8.10c Precipitation (90th percentile)

Circulation	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Type	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
1												
2	X	X	X	O	X	X						
3	O		O	X					O	O	O	
4			O		O							
5				X		O			O	O		
6		O										
7						X			O		O	
8							X		X		X	

8.10d Temperature (T-mean average)

Circulation	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Type	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
1						O						
2	O	O	O	O	O	O	O	O		O	O	O
3											X	X
4	X	X	X		X	X	X	X	X			X
5												
6	X	X	X	X	X	X	X	X		X	X	X
7												
8									O			

8.10e Temperature (T-max 90th percentile)

Circulation	SDK (A1)		MIR (A1)		KK (A2)		BTU (B1)		SBU (B1)		KCH (B1)	
Type	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2	CT1	CT2
1												
2	O	O	O	O	O	O	O	O			O	O
3			X	X			X		X		X	X
4	X	X			X							
5												
6		X		X		X		X		X		X
7			X				X	X	X	X	X	
8							O	O	O	O	O	

O = significant positive correlation; X = significant negative correlation (at 95% level of confidence)

8.5.1 Synoptic indices

For both typing schemes, Types 2 and 6 are best correlated with ENSO (SOI and Nino3.4) indices and the IOI monsoon index (see Table 8.8a and Figure 8.3a). The former is positively correlated with Nino3.4, and the later is negatively correlated with SOI and IOI. The strongest coefficients are observed for SOI and Nino3.4 with values exceeding ±0.4. The newly established monsoon indices, RD1 and RD2, are best correlated with Types 3 (positive) and Type 8 (negative). The correlations are exhibited more strongly by RD1 (vs RD2), and clearer in CT1 (vs CT2).

8.5.2 Precipitation

Correlation with precipitation is stronger with the number of wet days compared to the extreme measure, the 90th percentile (see Table 8.8b-c and Figure 8.3b). This is, especially, obvious in CT2, where significant correlations can hardly be seen. Types 2 and 8 are negatively correlated with the rainfall occurrence; where the former is related to the stations in A1/A2 and the latter is linked with stations in B1. Types 3 and 7 are positively correlated with wet day – but mostly relevant only for the stations in the B1 climatic group (i.e. BTU, KCH and KCH).

8.5.3 Temperature

The correlations between both variables (the average and extreme) are similar in both typing schemes CT1/CT2 (see Table 8.8d-e and Figure 8.3c). Types 2 and 6 are most significantly correlated, in all stations except for SBU (B1). This sole station, oddly enough, shows no convincing correlation (either in CT1 or CT2) for any of the types, except for Type 7 (negative) and Type 8 (positive), and this is only for the T-max 90th percentile, the extreme variable. Other stations (SDK, KK, MIR, BTU and KCH) are strongly correlated with Type 2 (positive) and Type 6 (negative) for both variables. Type 3 also exhibits negative correlation at these stations.

8.6 Summary of results and analyses

There were two major aims in this chapter – (a) evaluating the correlations between selected synoptic indicators/Circulation Types and surface variables (average magnitude/extreme occurrence for precipitation and temperature); and, (b) investigating the same relationships/correlations with the de-seasoned typing schemes, CT1 and CT2.

8.6.1 Method2 (circulation types based on seasoned data)

SOI is the best ENSO index for Borneo, especially with regards to surface temperature averages (T-mean). RD1 and RD2 are the best monsoon indices for relations with surface climate. RD1 performs particularly well in correlating with DTR (temperature range). RD2 exhibits stronger relationships with precipitation (both magnitude and extreme) and temperature averages. Types 1, 4, and 8 are the best circulation types for correlations with surface variables (temperature and precipitation in both measures – average and extreme). These three types also exhibit similar correlation values in all monsoon seasons and climatic groups.

In general, the association between the circulation-typing scheme (Method2) and surface variables is better than between synoptic indicators (ENSO/monsoon numerical indices). Three reasons justify this conclusion:

- The CT scheme (i.e. Method2) explains more variation of the surface climate in the relationships. This scheme is associated with more surface variables (all extreme/average measures for precipitation; the average and DTR for temperature). The CT scheme correlations are equally significant and strong in all climatic groups and in both monsoon seasons.
- The CT scheme exhibits a better and clearer pattern of relationships (thus, easier to interpret). For example, Type 1 is more strongly associated with temperature; and Type 4 is more clearly related to precipitation. Climatic groups and monsoon cycles are also clearly discriminated and identified by different sets of types. Type 8/Type 1 are useful to differentiate between different climatic groups (especially between A and B). In contrast, Types 3/5 perform better for distinguishing the relationship patterns between the two monsoon seasons.
- The CT scheme shows a more consistent relationship. Each circulation type is normally correlated with particular surface variables in a very identifiable manner (in terms of direction – either negative or positive). For example, Types 4 and 8 are mostly correlated negatively with the precipitation variables.

8.6.2 CT1/CT2 (circulation types based on de-seasoned data)

The patterns of correlations exhibited by CT1/CT2 (de-seasoned data) are generally similar to those shown in Method2 (using absolute data). The individual circulation types are linked to the surface variables better than the synoptic indicators (i.e. ENSO and monsoon indices). The overall correlation patterns reaffirm what has been established by Method2, which are: (i) ability to explain more variation of the surface climate in the relationships (i.e. several negative and positive correlations that are significantly correlated with different variables); (ii) ability to exhibit a clearer and more easily interpreted pattern of relationships (e.g. Types 2/6 are always negatively/positively correlated with precipitation/temperature) iii) ability to establish consistent relationships (e.g. Types 3/6 consistently show similar patterns of relationship for stations in A1/A2; whereas Types 7/8 are very frequently associated with stations in B1).

These results, again, prove that the circulation types produced in this thesis (with both procedures: Method2 and CT1/CT2) have successfully integrated the various synoptic modes of the Southeast Asian region. Previously used synoptic indicators most represent the ENSO and monsoon signals separately (thus, they are known as ENSO or monsoon indices). In contrast, the individual circulation types summarise these two most important synoptic signals into a single indicator. Therefore, it is easily understood why their correlations with the surface climate are stronger and more significant.

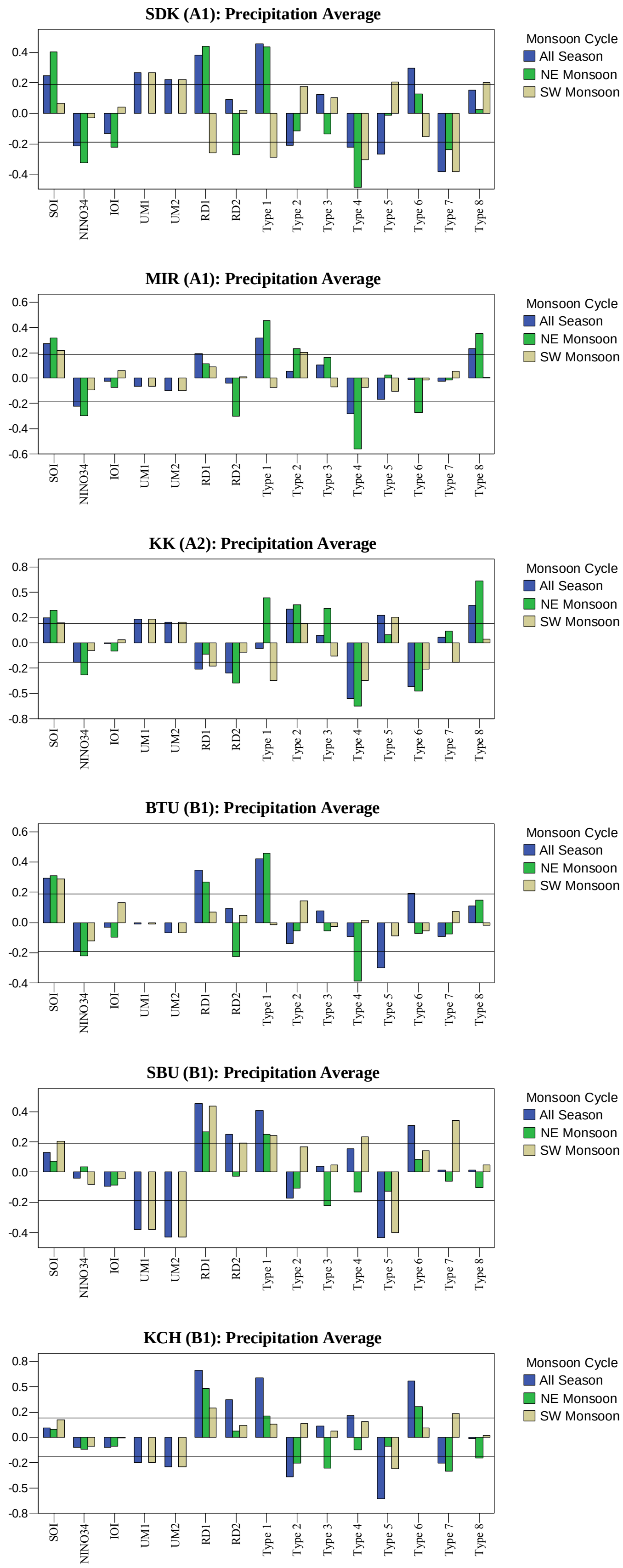


Figure 8.1a: Correlation between precipitation average and Circulation Types (CTs)/Synoptic Indicators (ENSO/monsoon indices) based on monsoon cycle

Lines denote the threshold for significance correlation at the 95% level of confidence

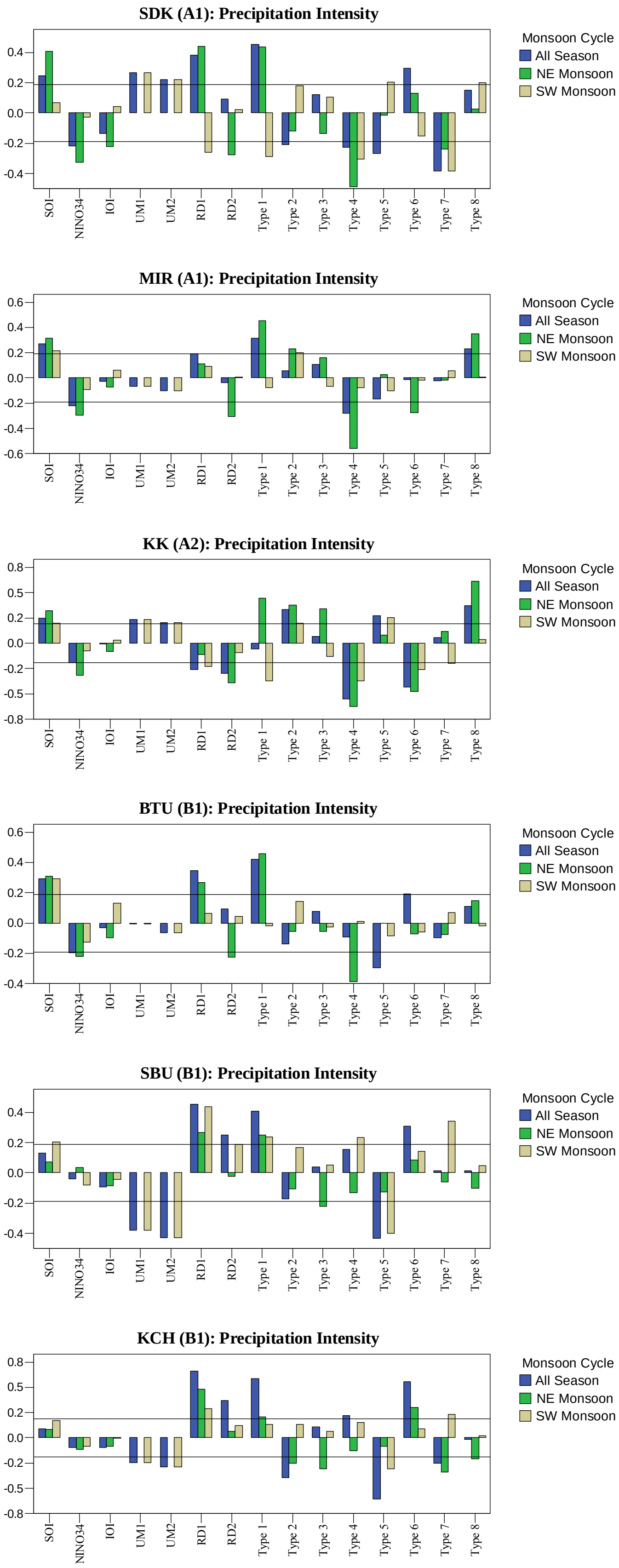


Figure 8.1b: Correlation between precipitation intensity and Circulation Types (CTs)/Synoptic Indicators (ENSO/monsoon indices) based on monsoon cycle

Lines denote the threshold for significance correlation at the 95% level of confidence

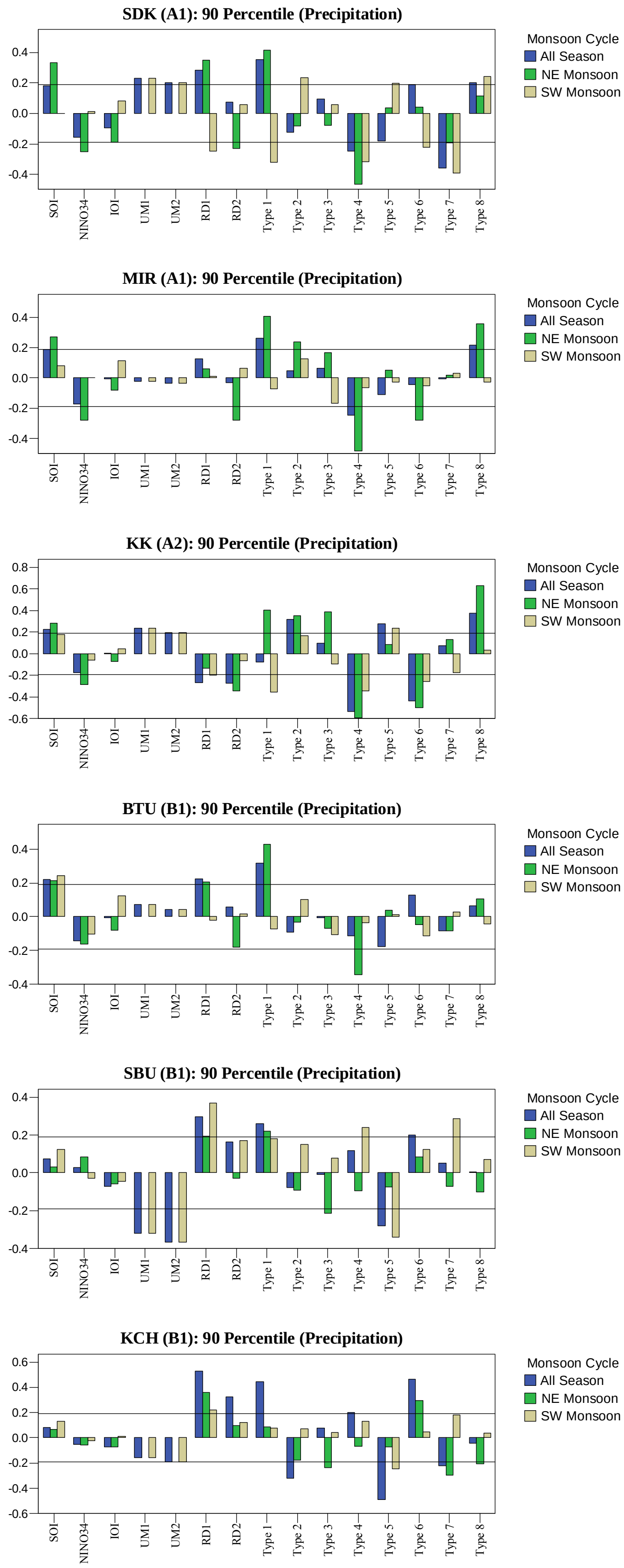


Figure 8.1c: Correlation between 90th percentile precipitation and Circulation Types (CTs)/Synoptic Indicators (ENSO/monsoon indices) based on monsoon cycle

Lines denote the threshold for significance correlation at the 95% level of confidence

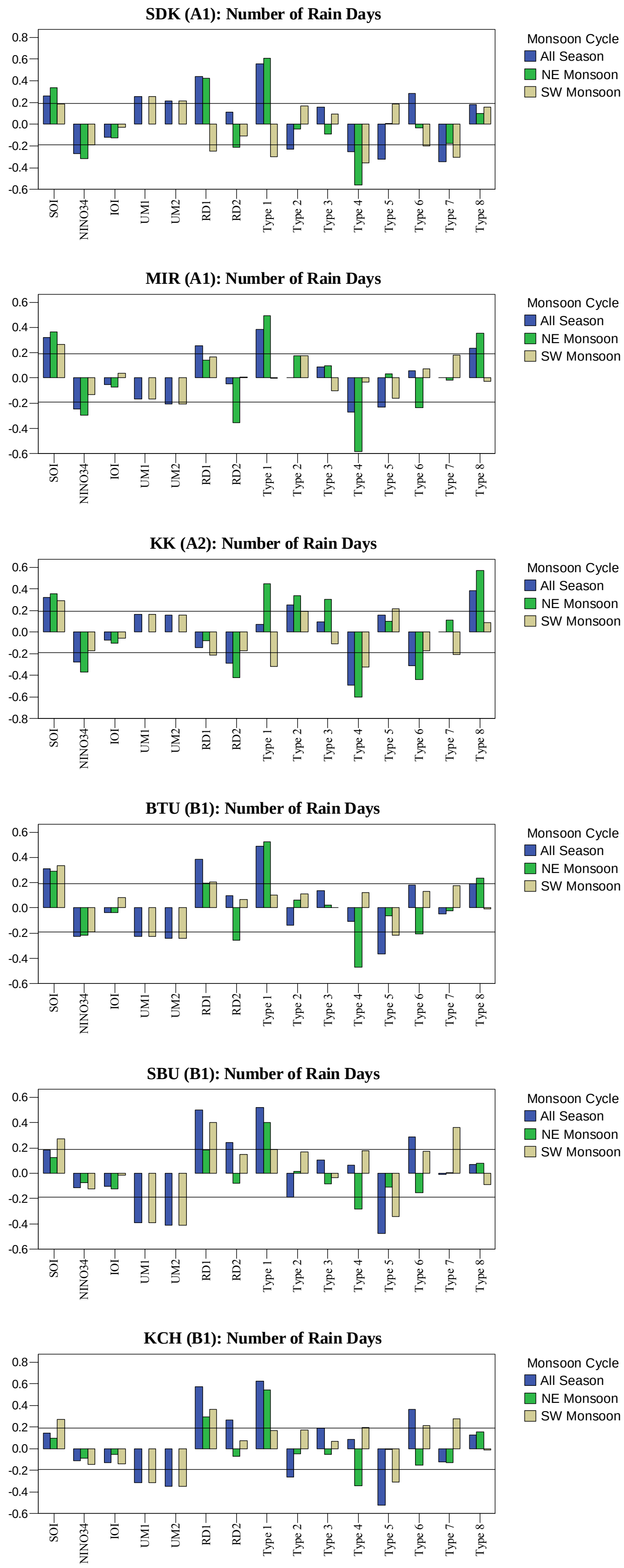


Figure 8.1d: Correlation between number of rain days and Circulation Types (CTs)/Synoptic Indicators (ENSO/monsoon indices) based on monsoon cycle

Lines denote the threshold for significance correlation at the 95% level of confidence

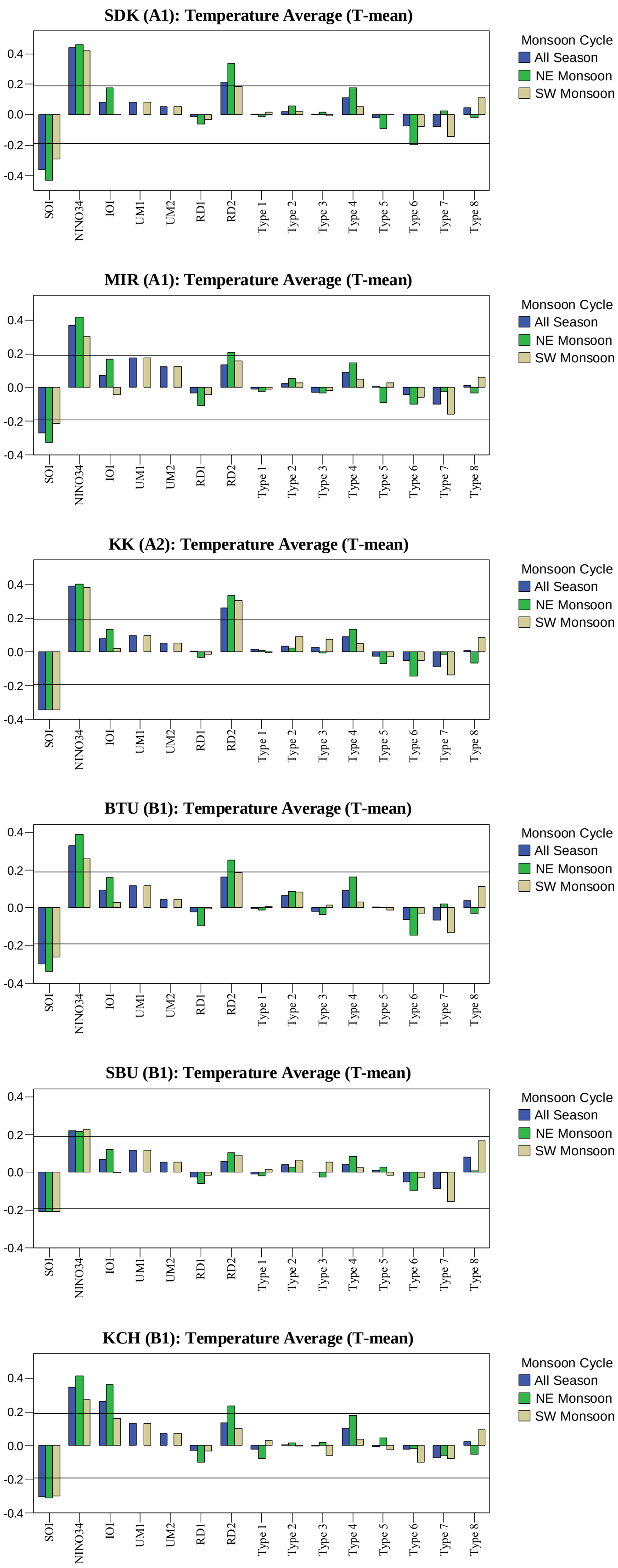


Figure 8.2a: Correlation between mean temperature (T-mean) average and Circulation Types (CTs)/Synoptic Indicators (ENSO/monsoon indices) based on monsoon cycle

Lines denote the threshold for significance correlation at the 95% level of confidence

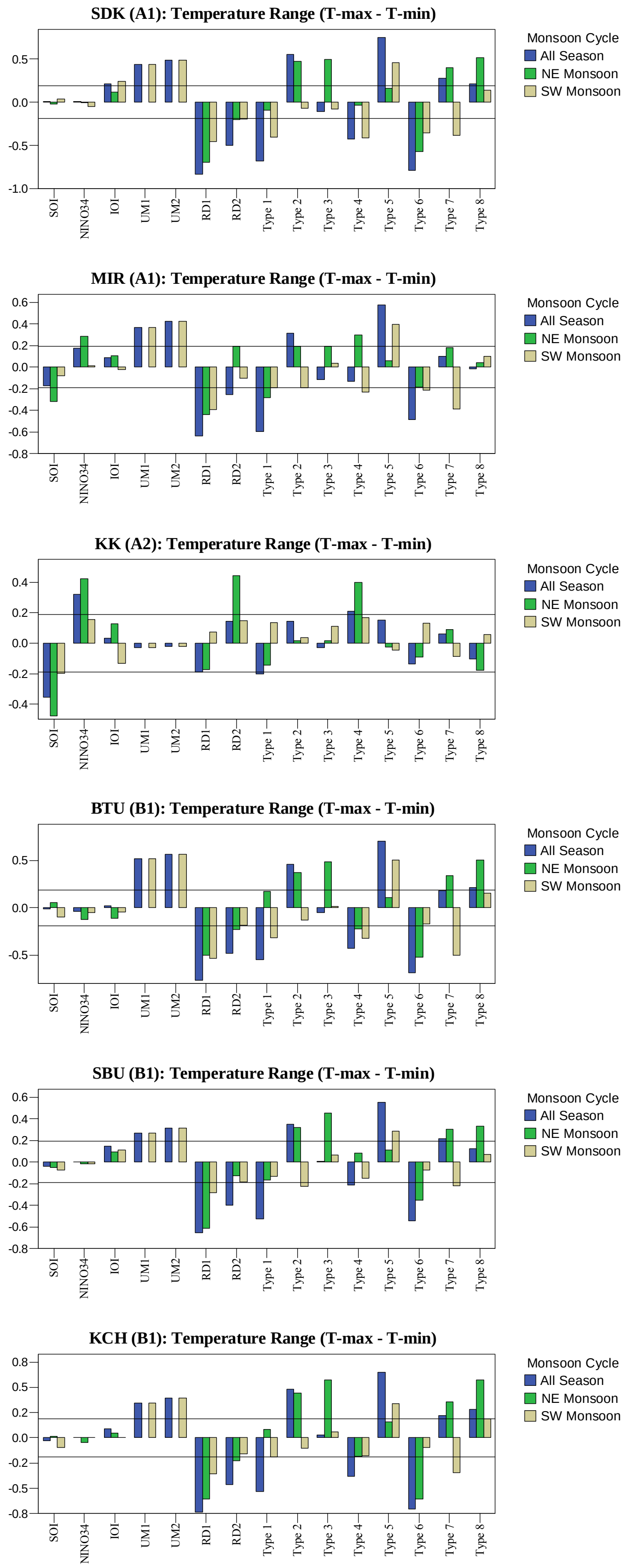


Figure 8.2b: Correlation between daily temperature range (DTR) and Circulation Types (CTs)/Synoptic Indicators (ENSO/monsoon indices) based on monsoon cycle
Lines denote the threshold for significance correlation at the 95% level of confidence

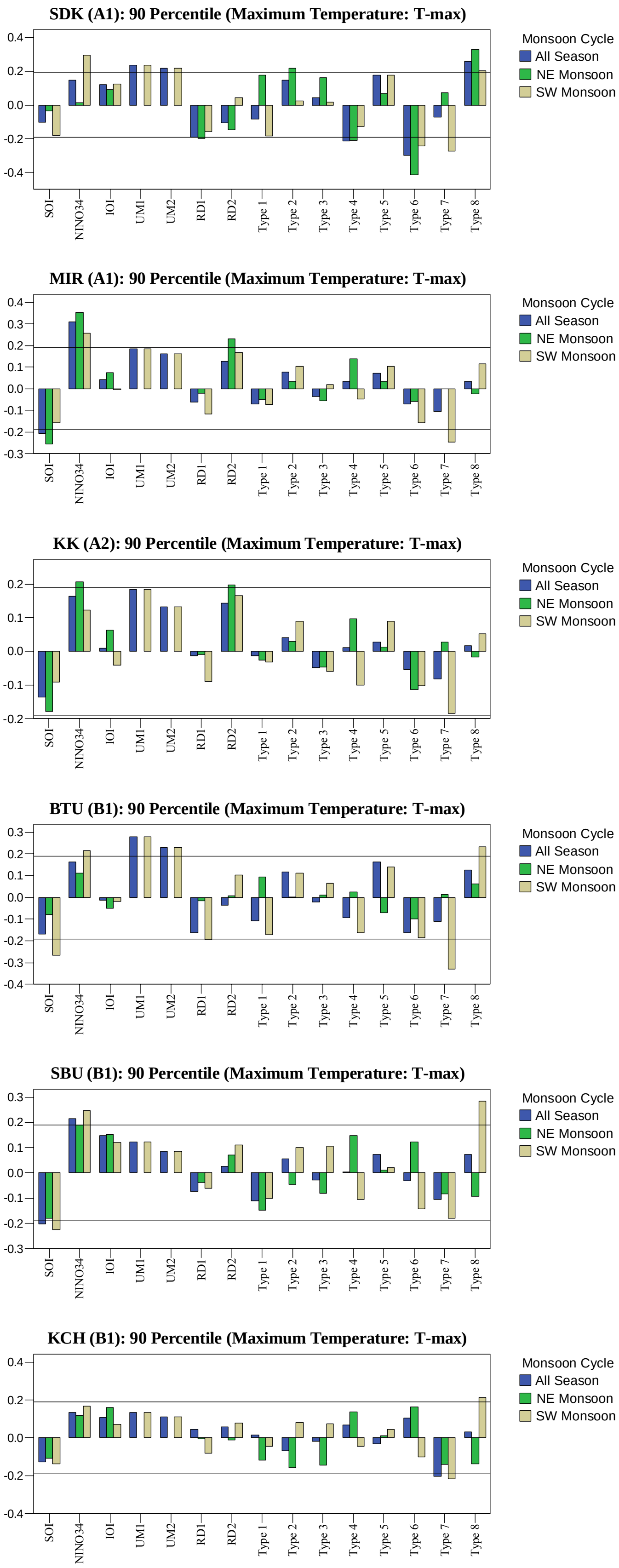


Figure 8.2c: Correlation between 90[th] percentile of maximum temperature (T-max) and Circulation Types (CTs)/Synoptic Indicators (ENSO/monsoon indices) based on monsoon cycle
Lines denote the threshold for significance correlation at the 95% level of confidence

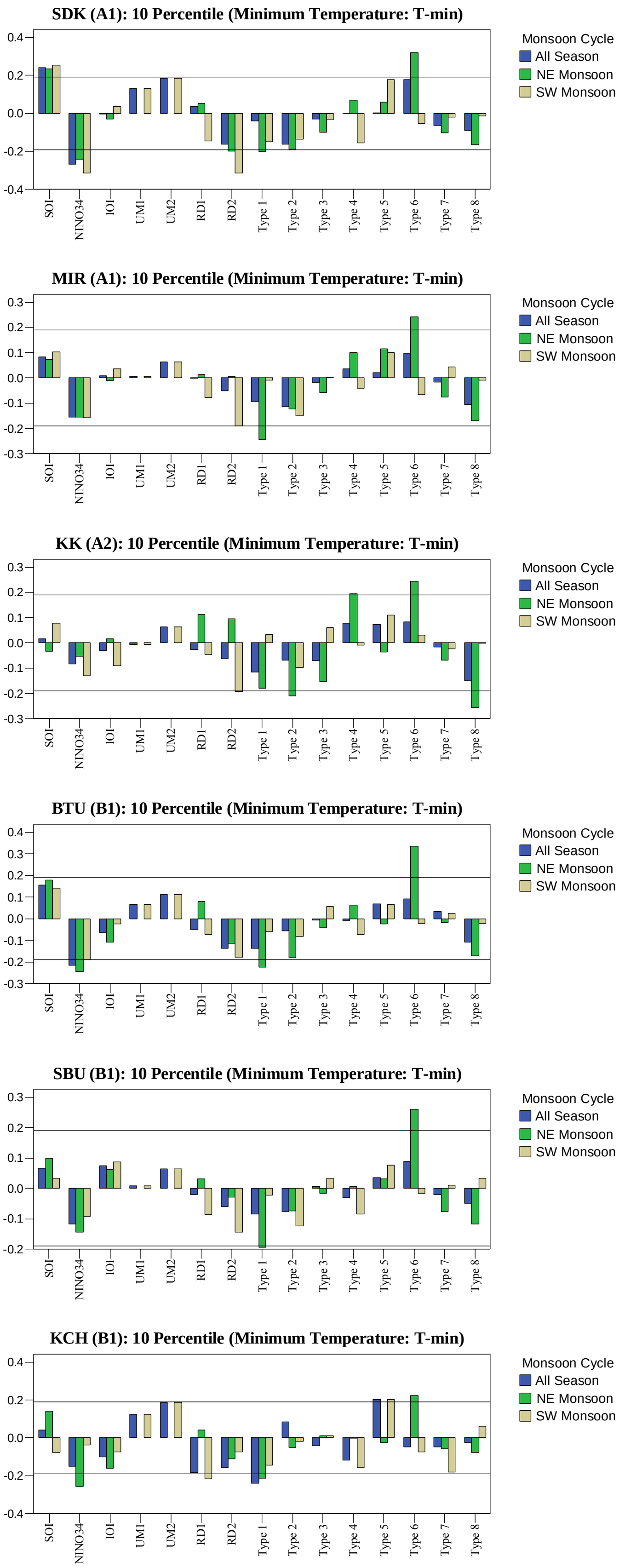
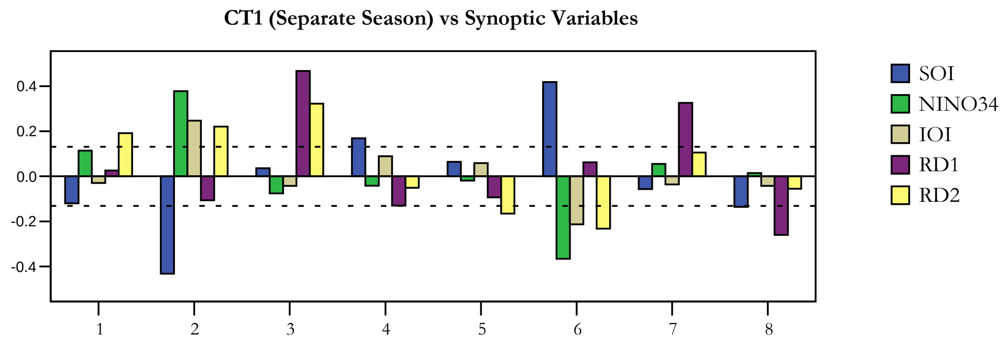


Figure 8.2d: Correlation between 10th percentile of minimum temperature and Circulation Types (CTs)/Synoptic Indicators (ENSO/monsoon indices) based on monsoon cycle
Lines denote the threshold for significance correlation at the 95% level of confidence



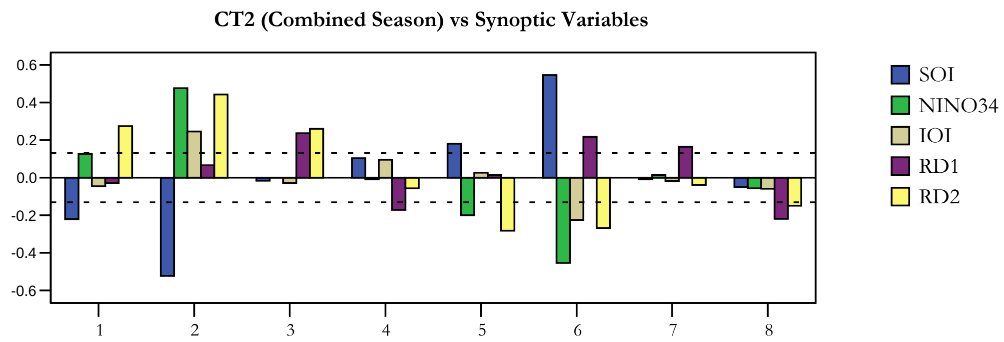
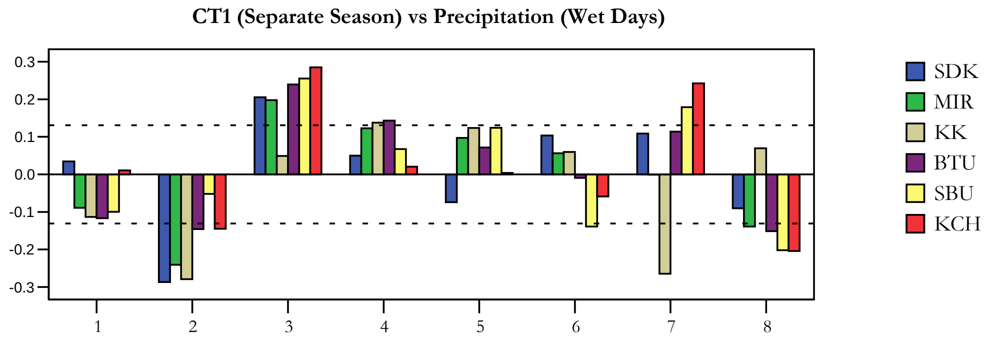
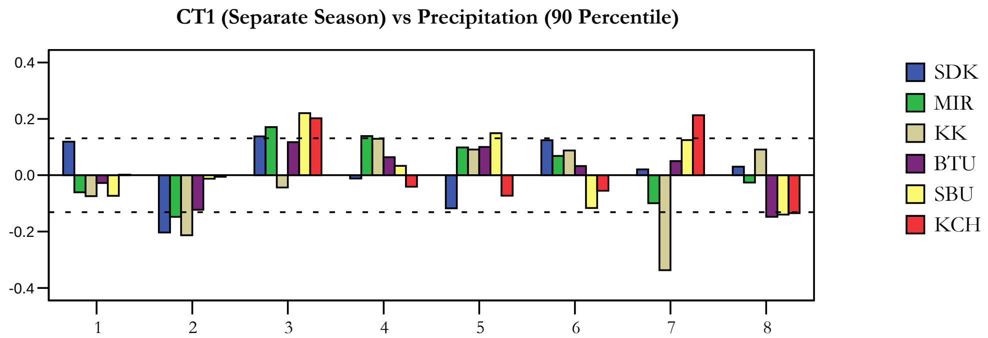
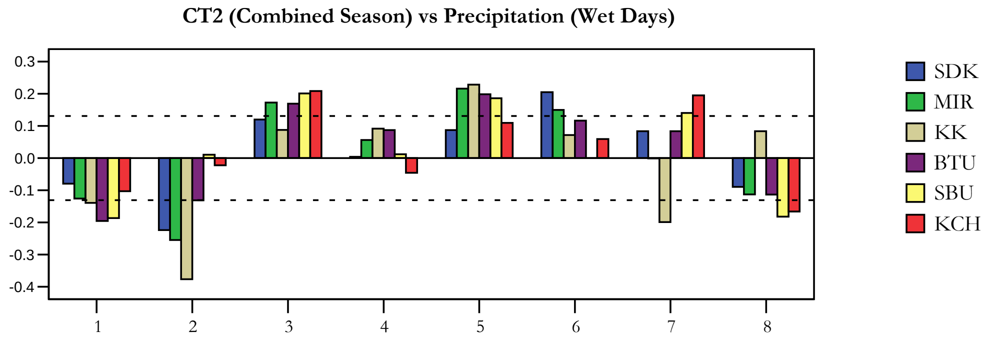


Figure 8.3a: Correlation between CT1/CT2 and Synoptic Indicators (ENSO/monsoon indices)
Lines denote the threshold for significance correlation at the 95% level of confidence







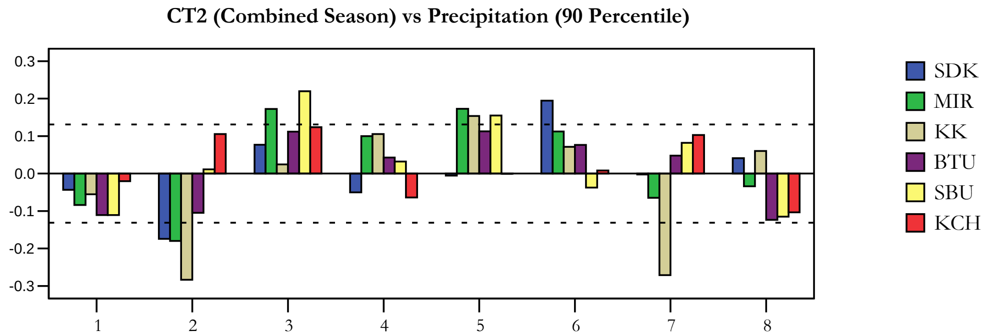


Figure 8.3b: Correlation between CT1/CT2 and Precipitation
Lines denote the threshold for significance correlation at the 95% level of confidence

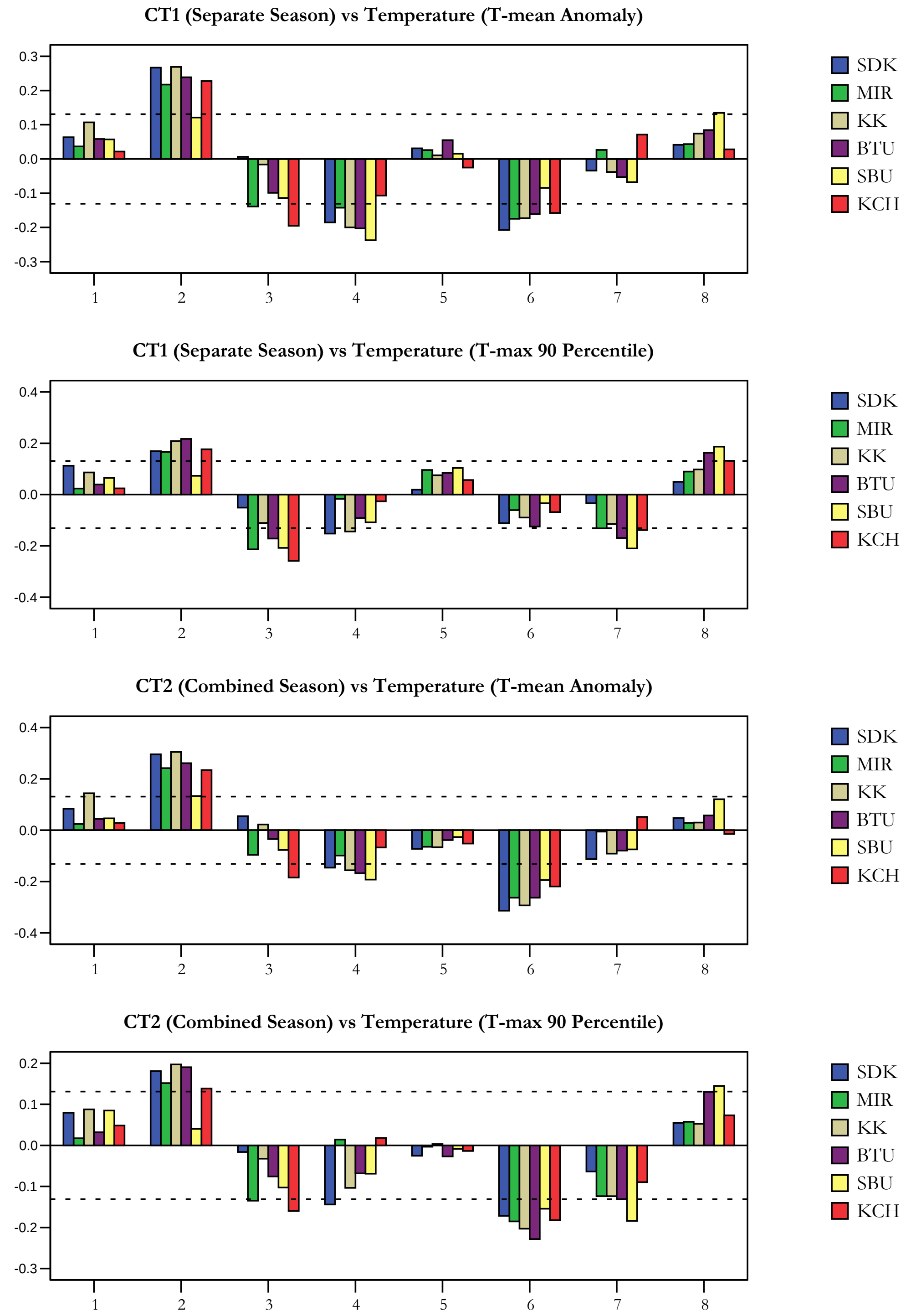


Figure 8.3c: Correlation between CT1/CT2 and Temperature
Lines denote the threshold for significance correlation at the 95% level of confidence

Chapter 9
Summary and Final Conclusions

9.1 Introduction

The principal aim of this thesis has been to relate the large-scale atmospheric circulation (of the Southeast Asian region) to the local climate of Borneo. In achieving this aim, four main tasks have been undertaken: (i) understanding the characteristics of the local climate of Borneo (i.e. the nature of the seasonal cycle and the trends in precipitation/temperature); (ii) understanding of the synoptic circulation within Southeast Asia (i.e. the influences of the monsoon and ENSO); (iii) classifying the important modes of local climate and synoptic typing, and establishing an appropriate typing scheme for each aspect; and (iv) combining both schemes (the regional climatic classification and the synoptic typing) to derive meaningful relationships between the circulation and local climate.

The data used for these analyses include both large-scale and surface variables, which are in the form of NCEP Reanalysis and observational data. The general overview of all data used is summarized in Table 9.1. In terms of methodology, the statistical methods used can be divided into four categories, which are – (i) classification (i.e. Principal Component Analysis and Cluster Analysis); (ii) relationships (i.e. descriptive statistics, probability analysis, correlation); (iii) significance tests (Student T-test, ANOVA F-test, Chi Square test); (iv) trend analysis and time-series (trend significance test, long-term averages). The flow of the statistical methods applied throughout this thesis is shown in Table 9.2.

Table 9.1: Overview of data used in the thesis

Category	Specific variables	Type
Large-scale	Sea level pressure (SLP)	NCEP Reanalysis
	U and V wind components	NCEP Reanalysis
	ENSO indices	Observational
	Monsoon indices	Observational/NCEP Reanalysis
Surface	Station precipitation/temperature	Observational

Table 9.2: The flow of statistical methods

Analysis Chapter	Specific Tasks	Statistical Techniques
Chapter 4	Regional Classification (climatic divisions)	Correlation (input data) K-means Clustering
	Temporal Classification (weather types)	K-means Clustering
Chapter 5	Time-series analysis	Descriptive (mean)
	Trend analysis	Trend significance test (based on regression)
Chapter 6	Creation of new monsoon indices	PCA
	Evaluation of synoptic indicators (monsoon/ENSO indices)	Correlation (Spearman's Rank)
	Classification of SLP circulation	PCA, K-means Clustering and Correlation
Chapter 7	Frequency analysis for circulation types (CTs)	T-test, Chi-Square and probability analysis
	Relationships between CTs and surface climate	Descriptive (composite average), T-test, ANOVA, Chi-Square and probability analysis
Chapter 8	Inter-relationship analyses between CTs, WTs, ENSO indices and surface climate	Correlation (Spearman's Rank)

9.2 Summary of work presented

9.2.1 The climatology background

Two fundamental elements need to be addressed before the main objective of this thesis (relationship analysis) could be pursued: (i) understanding the synoptic climatology of Southeast Asia; and (ii) understanding the local climate of Borneo.

The two most significant synoptic forcings affecting Borneo are the monsoon and ENSO, which are mutually interactive in nature. Therefore, as far as determining the local climate is concerned, its association with the monsoon and ENSO is not mutually exclusive (Krishna Kumar and Lau, 1997). ENSO parameters have been established and proven to be highly reliable to predict surface climate variables (especially rainfall). Several monsoonal-flow indicators have also been identified and successfully used to explain rainfall variability in the tropical Asian region. The teleconnections, between the Asian monsoon and ENSO phenomena and surface climate, have both been better understood through the works of Caesar (2002) and Sirabaha (1998, 2004) – who have both chosen the larger region of Southeast Asia as in the case study. However, two major gaps (in terms of scientific knowledge) are evident in the analyses. This project intends to fill these gaps, which are: (i) no attempt to generalize the circulation (monsoon and ENSO) into specific modes (i.e. synoptic typing), which can later be empirically associated with the local climate; and (ii) no exclusive emphasis on how these synoptic circulation patterns influence the local climate in smaller parts of the SEA region (i.e. spatial variability – e.g. the differences within Borneo, and between Peninsular Malaysia, the Philippines and Indonesian archipelagos).

According to the classification by Wyrtki (1956) and Aldrian (2001), Borneo is characterized by a highly anomalous rainfall (i.e. a strong degree of seasonality). Thus, this region should experience clear wet (NE Monsoon) and dry (SW Monsoon) seasons. Sham Sani (1984) also identifies this seasonality characteristic. However, this fact has been revisited. Based on the new regional classification undertaken in this thesis (Chapter 4), Borneo has been reclassified into six sub-groups: A1 (Sepilok Climate), A2 (Sepanggar Climate), B1 (Samarahan Climate), B2 (Sambas Climate), C1 (Sintang Climate) and C2 (Selor Climate). Excepting A2, all other climatic divisions exhibit a strong degree of seasonality, where NE and SW monsoons have been identified as the wet and dry seasons, respectively. This is consistent with Wyrtki (1956), Sham Sani (1984) and Aldrian (2001). However, A2 (which consists of KK, LBN and TWU stations) does not share that characteristic. A2 shows its own unique pattern of seasonality. As opposed to the other parts of Borneo, A2 experiences higher precipitation during the NE Monsoon. This difference, however, between the precipitation totals during the two monsoons is not as high as in the other groups – i.e. a much lower degree of seasonality than previously.

Geographically located right over the equator, Borneo is typically not subject to high seasonal variability in terms of temperature. The average difference between the two seasons is less than ± 0.5°C. Interestingly, with regard to the long-term trend, Borneo has experienced a warming trend over the past 50 years (Manton et al., 2001; Sham Sani, 1984). These two studies, however, did not find any significant trend for precipitation. Analyses of trends and time series for precipitation and temperature (Chapter 5) have confirmed the same conclusions. Borneo exhibits no significant trend in precipitation, but a clear warming trend for temperature (increase of T-mean between 0.20 – 0.32°C per-decade). The only exception to this is the one station in the north-western part (i.e. KCH).

9.2.2 The large-scale diagnostic variables

Numerous studies have been undertaken either on the influences of the monsoon or the impact of ENSO over the Southeast Asia, particularly Borneo (Caesar, 2002; Tangang, 2001; Sirabaha, 1998; Quah, 1988). Most of the previous studies have used a single-numerical synoptic indicator (i.e. ENSO/monsoon indices) as the large-scale diagnostic variables. This project introduces a new alternative i.e. synoptic typing, which is the first study of its kind in Southeast Asia. Thus, an analysis must be undertaken to compare the performance (in terms of relationships with surface climate) between the synoptic indicators and circulation (weather) types.

Synoptic indicators

Monsoon and ENSO are the most influential factors modulating surface climate in many parts of the world (Nieuwolt, 1977; Das, 1986; Allan et al., 1996) – thus, many studies have been conducted to develop indices for both of these large-scale factors (e.g. Ropelewski and Jones, 1987; Barnston and Chelliah, 1997; Goswami et. al, 1999). The main purpose for such indices is to enable researchers to investigate empirical relationships between these two synoptic phenomena and the local climate of a particular region.

The monsoon indices (see Table 6.1 in Chapter 6) evaluated here are AIRI, RM2, WY, UMI1, UMI2, and IOI (Indian Ocean Index, representative of the mean SST over Indian Ocean). After evaluating several established monsoon indices used in previous studies (mostly using zonal and meridional upper wind shear at various gPh levels), none of the indices establishes convincing correlations with surface climate. Therefore, new indices (i.e. RD1 and RD2) have been created using a more ‘local approach’ and focussing upon the centres of action within the SEA region (20°S-30°N; 75°E-140°E). The large-scale variable used to create these new indices is SLP.

ENSO, or the El Niño-Southern Oscillation phenomenon, is a system of interactions between the equatorial Pacific Ocean (measure by sea surface temperature – SST) and the atmosphere above it (measure by the difference in sea level pressure between Tahiti and Darwin). The Southern Oscillation represents the variability of the Indo-Pacific Walker circulation in the tropics, and is associated with large-scale anomalies in the surface wind and sea level pressure throughout the tropical Pacific (and into the Indian Ocean) basins. ENSO indices are SOI, Niño1+2, Niño3, Niño3.4 and Niño4 (see Table 6.2 in Chapter 6). In most of the previous studies (Quah, 1988; Boon, 1993; Cheang, 1993; Tangang, 2001; Caesar, 2002; Sirabaha, 1998,2004), researchers have regarded the SOI (Southern Oscillation Index) and the SST-based Niño-3.4 (SST anomaly for the Niño-3.4 region) as the best indices to be associated with Southeast Asian surface climate.

Circulation types

Two sets of typing schemes (Method2 and CT1/CT2), where each one consists of eight circulation types, have been established in this thesis. Method2 (using absolute SLP data and combining the two monsoon seasons) is the best technique selected from three other choices (Method1, Method3 and Method4). CT1 and CT2 have both used SLP anomaly data, with the former employing PCA in separate monsoon seasons and the latter applying it to the combined seasons. In this thesis, it is found that the two different anomaly procedures have produced highly similar circulation types. Thus, CT1 and CT2 are regarded as one method.

The physical features of all circulation types have been identified based on the composite maps. Method2 produces circulation types that are strongly (and almost exclusively) associated with monsoon signals. Thus, it is not surprising that certain types exhibit an extremely high frequency of occurrence during a particular season. CT1 and CT2, on the other hand, establish circulation types that are seasonally independent. Although, there are certain types showing associations with certain phases of the monsoon cycle – the association is not as strong as in Method2. This significant difference is attributed to the fact that CT1/CT2 have employed 'de-seasoned' SLP data.

Method2 – overview of the physical features

The directions of low-level winds (either southwesterly or northeasterly) for each circulation type are characterized by the dominant monsoon for that particular circulation. The positions of the ITCZ are estimated based on the large-scale circulation scheme for Borneo introduced by Sham Sani (1984). Of the eight circulation types, Type 1 is the circulation representing the early phase of the NEM, Type 2 (combination between late SWM and NET), Type 3 (NET), Type 4 (combination of SWT, and late NEM), Type 5 (SWM), Type 6 (NEM), Type 7 (SWT) and Type 8 (NET). In terms of frequency probability, Types 1 and 2 are strongly associated with La Niña and El Niño, respectively.

CT1/CT2 – overview of the physical features

The eight circulation types are physically best described by the origin of the main atmospheric flow – whether it is from the main Asian land continent, the Indian Ocean or the Pacific Ocean. There are only five circulation types that can be exclusively assigned into a particular monsoon season, which are: Types 2 (NEM), 3 (NEM), 4 (SWM), 7 (NEM) and 8 (SWM). Three types are associated with ENSO events, which are: Types 2 (El Niño), 4

(La Niña) and 7 (La Niña). However, it is worth mentioning here that the associations with either the monsoon or ENSO are not as strong as in the Method2.

9.2.3 Relationships with surface variables

Monsoon indices

In comparison with the previously established monsoon indices, the correlation results clearly indicate that the two new indices (RD1/RD2) have shown a much better performance (both with respect to local climate and ENSO indices) than indices used in earlier work. Of the two indices, RD1 is better correlated with precipitation; whereas RD2 is better correlated with temperature anomalies and the ENSO indices. The correlations between these two new indices are significant for all six selected key stations (for both precipitation and mean temperature averages).

ENSO Indices

Particular attention has been given to the SOI and Niño3.4, the two indices that have been widely used for SEA in the previous studies: e.g. Caesar (2004), Tangang (2001) and Sirabaha (1998). These two indicators proved to be the best ENSO diagnostic indices for correlation with the surface climate of Borneo. However, both indices do not exhibit significant correlation (with precipitation) at one station in B1 Climatic Group (i.e. KCH).

Circulation types (CTs)

The patterns of relationships between circulation types and precipitation based on the climatic groups and the seasonal cycle are easily recognized. This is applicable to both cases. For Method2, Types 4 and 8 discriminate the B1 from the A1/A2 climate groups; and Type 3 distinguishes A1 from the other groups. For the monsoon seasons, Types 2 and 8 are exclusively associated with SWM and NEM, respectively. However, temperature variables exhibit a better discrimination for different ENSO phases (which is less distinguishable in precipitation).

For CT1/CT2, the spatial discrimination is particularly obvious in precipitation. Types 1 and 5 are associated with the B1 climatic group, whereas Types 2/6 are better linked with A1 and A2. Types 3 and 4 do not discriminate the stations from each other, however, Type 7 and 8 are strongly related to the centrally located stations (KK, MIR and BTU). The spatial discrimination is minimal for temperature. On a seasonal basis, Types 1, 2 and 3 show stronger relationships during the NE monsoon. Similarly, Type 7 and 8 are more representative of the SW monsoon.

Comparison between synoptic indices and circulation types

Method2: Between the best monsoon indices (i.e. RD1/RD2) and the best ENSO indices (SOI/Niño-3.4), the monsoon indices correlated better with surface climate, especially precipitation. In comparison with CTs, the synoptic indicators (i.e. ENSO/monsoon indices) were generally better correlated with temperature anomalies. However, the circulation types establish a far stronger (in terms of amplitude) correlation for precipitation variables. The explanation for this is that precipitation in Borneo is more strongly influenced by the fluctuation of the monsoon modes, and less regularly subjected to remote ENSO forcing (Sirabaha, 1998; Ooi, 2001). Both ENSO and monsoon indices are exclusively represented by only one of these two well-known large-scale climatic elements. Thus, a weaker performance in capturing the precipitation signal is expected. On the other hand, the circulation types developed here represent a more complex variation of the synoptic circulation surrounding the Borneo region (which integrates both ENSO and monsoon influences). Therefore, their ability to establish a significant association with surface climate (especially precipitation) is more effective.

9.3 Limitations of the study

As in all other scientific studies, this project has faced a number of limitations. The limitations have not necessarily weakened the thesis, in terms of achieving the targeted objectives. However, it is worth mentioning the major ones to acknowledge the problems encountered, and justify the lack of depth/completeness in certain areas. This can also serve as a guide for possible further work in the future. Three main limitations have been identified in this project, and mainly associated with the thesis basic foundation: theoretical basis (i.e. a key element to determine the conceptual framework and set the hypotheses), data issues (i.e. the chosen material to support the analysis) and application of methodology (i.e. technical process to prove the hypotheses and establish a sound basis). Each of these is discussed in turn.

9.3.1 Theoretical basis

There are very few studies that have been conducted that are specifically related to Southeast Asia and Borneo, especially with respect to the large-scale atmospheric circulation (reviewed by Sirabaha, 2004 and Caesar, 2002). Although there are many studies (on local and synoptic climate) which have been undertaken in other part of the tropics or in

Asia (e.g. the South and East Asia – India, China, Japan, etc), these studies are not always comparable to the climatic features in Borneo. So far, no study has been conducted over Southeast Asia that is related to circulation typing.

Studies of the local climate of Borneo have also been very limited, and if there are any, Borneo is mostly treated as a secondary entity in a wider case study. For example, there is a reference to Borneo in works by Cheang (1981b), Tangang (2001) and Quah (1988), but the attention is mainly given to Peninsular Malaysia, and much less weight given to East Malaysia (i.e. Borneo). Aldrian (2001) studied all of Indonesia (i.e. including the province of Kalimantan), and Borneo was treated as one single entity (rather than a region with several divisions and different characteristics). Sham Sani (1984), on the other hand, only focussed on northern part of Borneo (Sabah). The most unique aspect about Borneo is its geographic location. Not only is it exactly on the equator (thus, heavily influenced by the transition of northerly and southerly winds on a seasonal basis), it is also an island and characterised by a maritime climate[86]. These are the unique features that make Borneo less comparable to other regions (e.g. the Indian continent, China, Japan, Indo-China or even Peninsular Malaysia and the Indonesian archipelago).

The lack of a theoretical foundation has made this a pioneer project. This is an exploratory study rather than a pure hypothesis-driven research[87]. This means that many subjective decisions[88] have had to rely on the researcher's experience and instinct. In a case where there are many possible options to take, the researcher has had to perform several 'trial and error' analyses (which is certainly time- and energy-consuming). Thus, to a certain extent, this might have limited the depth of this project, in terms of justification and detailed investigation of certain findings (e.g. the lack of depth in relation between the circulation types with their actual physical features and the direction of atmospheric movement and pressure distribution). This project has adopted an exploratory-oriented[89] approach (albeit, not totally), which seeks to identify only the key patterns and general characteristics (e.g.

[86] This maritime continent of Southeast Asia receives a majority of its rainfall when the low-level winds circulate from the open sea towards the land (i.e. the Northeast Monsoon). As the winds blow toward these areas, they pick up some moisture from South China Sea and other surrounding seas.
[87] See Appendix I for differences between hypothesis-driven and exploratory analyses.
[88] Subjective decisions such as: (i) what type of large-scale variables are best to diagnose the surface climate of Borneo?; (ii) what type of input data is the best for PCA in synoptic typing: absolute or anomaly values?; (iii) how the input data should be processed by PCA – based on monsoon seasonal cycle or the conventional four-season cycle?; (iv) should the mature (SWM, NEM) and transitional monsoons (SWT, NET) be treated separately, or as a combined season?; (v) what are the best specific thresholds for surface variables (especially with regard to extreme measures) to be related/correlated with circulation types? Some of the decisions might be the key contributor to the derived results, and they could have been different (if the specific decisions made were changed).
[89] Exploratory analysis: Statistical or visualisation techniques that attempt to produce a good summary of the data or the patterns (associated with the data). Source: http://hds.essex.ac.uk/g2gp/gis/sect101.asp

what circulation types are associated with particular monsoon or ENSO modes; and which circulation types are related to wet/dry/cold/hot days). Strictly speaking, this research is not necessarily aimed to validate previous findings and theories; but more into opening new ground for further more detailed and thorough scientific studies.

9.3.2 Data issues

There have been three main limitations with regard to the data used in this project: (i) choice – what to use?; (ii) availability – when and what the periods are?; and (iii) quality – how good are they? It has been mentioned earlier that, so far, there have been no studies conducted in Southeast Asia, related to circulation typing and relationships with surface climate. Thus, the choice of large-scale (diagnostic indicator) and surface climate (predicted parameter) variables has been difficult to determine. SLP has been eventually selected as the synoptic variable to establish the circulation typing scheme. This has been based on the theoretical assumption that the monsoon and ENSO signals (the two most prominent large-scale climatic factors in SEA) will be best captured by sea-level pressure. The choice of surface variables has also been tricky. However, precipitation and temperature were finally chosen as the two key variables for the analysis. What are the reasons for this choice? Local climate of Borneo is mainly characterised by precipitation variability (Sirabaha, 1998; Sham Sani, 1984); and temperature is one of the important comfort indices[90] for tropical regions. Both these variables are also the most widely measured.

Data availability has been another limitation faced, especially the observational surface variables (i.e. precipitation and temperature). A total of forty-two stations in Borneo were initially assessed for length and quality. From these forty-two stations, twenty-nine have been chosen to establish the climatic divisions for Borneo. The rest have been omitted from the analysis due to a lack of sufficient daily observations. Also worth noting, only six key stations were selected for the relationship analyses with CTs and WTs: SDK, KK, MIR, BTU, SBU and KCH. All these stations are located in the northern part of Borneo (and within the Malaysian provinces – Sabah/Sarawak). Although the geographical representation is an issue, these are the only stations in Borneo that have daily continuous observations[91]

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90 The comfort index calculates the body's reaction to heat, cold, humidity and wind chill. High temperature and humidity stress the body's ability to cool itself, and low temperature can stress the body's ability to heat itself. Source: http://www.saskschools.ca/~ghuczek/definitioncomfortindex.htm

91 Why it is important for the observations to be daily and continuous? Because the relationship analysis needs to look at both average and extreme measures. Without daily observations, it is almost statistically-impossible to derive reliable modes/patterns from the relationships between the circulation types and surface climate. Missing values (non-continuous observations), on the other hand, will significantly hamper any analysis based on extreme thresholds (i.e. occurrences).

with the same common period (1968-2001) for both precipitation and temperature. These data also have a high degree of homogeneity (constantly monitored by the MMS). Such limitations (being selective of what stations should be used) though, are closely related to quality issues – e.g. homogeneity, missing values, very short period of observation (thus, not enough cases for certain analysis – correlation, significance test, etc), and inconsistency between one source and another (e.g. precipitation data obtained from IMGA for certain stations in Kalimantan are not identical to those available from CRU). To optimise the available data, an initiative has been made to merge data from different sources to extend the period (e.g. the data provided for NGA by IMGA only cover the period 1983-1990, but have been extended to 1906-1990 using the data available in CRU). However, the extension has not always possible for every station due to the quality issues mentioned above. Therefore, the final selection of analysed stations might seem quite biased to the Malaysian part of Borneo – but this limitation is realistically unavoidable. Better quality data could have extended the study spatially, but this data just was not available.

9.3.3 Statistical techniques

Methodological limitations mainly come from the underlying assumptions in some of the statistical techniques used in this thesis. Certain limitations in this section might be related to the problems evident within the input data. Two major questions concerning these issues are: (i) an over simplification or generalisation of the circulation types (PCA aims to simplify the data and only retain those patterns with a certain percentage of the variance); and (ii) the values of correlation coefficient and the degree of strength in the relationship analyses are often incomparable due to low number of cases (both correlation and probability analysis are naturally influenced by the sample size). These limitations, however, do not occur in all analyses using the statistical techniques employed. The specific analyses where these limitations have occurred are discussed next.

Classifying SLP into circulation types by PCA

PCA is generally applied to reduce the dimensionality of a large dataset, and summarise the important modes into several significant components. Although the reduction process is intended to filter out the 'noise' in the dataset, sometimes it could possibly omit certain important modes (which happen to have a very small percentage of variance)[92]. The criterion used for retaining significant components plays a vital role. Ideally, it must be consistent

[92] The assumption made in this thesis has been to identify and retain the important modes based on the percentage of variance explained by the components. In reality, this is not necessarily true. There is a small part of the climate variability, which exists in a very small quantity (in terms of variance) but might have a significant impact to the climate system itself.

with the research objectives and justified by previous studies on similar region (which for this project, unfortunately, there are hardly any, see Section 9.3.1). Another limitation with the use of PCA is the simplification of the circulation modes through composite averages. This is another possible way why certain important signals in the dataset could be masked or ignored.

Thus, without complete understanding of the climatic behaviour (both synoptic and local) for the study area, the use of PCA can sometimes lead to uncertainty with the results. Similar studies conducted (e.g. Halpert et al., 1990; Corte-Real et al., 1999; Goodess and Jones, 2002; Kostopoulou, 2003) in the higher latitude regions (i.e. Europe) are relatively less prone to this so-called PCA limitation. Why is this? Apart from having well-established Lamb (1972) weather types as a reference, there are also many previous studies (e.g. Blasing, 1981; Jones and Kelly, 1982; Davies et al., 1990), which can also be used to determine if the application of PCA has successfully captured all the important modes (by comparing them with the previous established circulation types). In the future, with more studies on synoptic climatology of SEA and improved understanding of the large-scale circulation modes governing the surface climate of Borneo, a better analysis will be possible. Other regions also have much longer periods of data, which enable studies to be conducted on different and independent periods as well, to test long-term consistency of relationship.

Analysing specific climatic events with probability and correlation methods

The datasets used for the relationship analyses are based on a 34-year period (1968-2001) for precipitation and temperature. Sometimes, other stations additionally have shorter observations. Although this seems adequate for the application of these two statistical techniques, the sample sizes are relatively small when analysing the specific events: i.e. ENSO phases and monsoon cycles (NET, NEM, SWT, SWM). The values for the probability and correlation analyses are sometimes incomparable between each one of the circulation types due to a very small number of valid cases. For instance, certain stations (i.e. LBN) have only 10-20% of valid cases from the original 12419 days (1968-2001), and this will only lead to very low number of observations in certain types. Type 8 has as low as 122 of overall valid days, and will lessen further when this small sample size is distributed into four other categories – monsoon cycle and ENSO phases. This problem is only briefly mentioned as it does not influence the results as much as the other limitations (discussed earlier).

9.4 Summary of important findings

Several important findings have been identified in this thesis. These findings can be divided into four main categories in terms of their level of contribution: (i) introducing new methodological schemes, which may typically combine several statistical techniques (in a systematic order); (ii) reconfirming and revalidating currently-existed scientific knowledge; (iii) revisiting and improving the understanding of current knowledge; and (iv) adding new elements to the existing knowledge (which is regarded as one of the key findings for this project).

9.4.1 Introducing new methodological schemes

The classification process (see Chapter 4, Section 4.2) undertaken to divide Borneo into several climatic groups is based on the correlation matrix (for input data) and K-Means Clustering (as the empirical technique in forming the groups). Although the use of the correlation technique and K-Means Clustering is quite common [e.g. Gadgil and Inyengar, 1980; Gadgil et al., 1993 (for cluster) and Aldrian, 1999, 2001 (for correlation)], this application[93] to the surface climate of Borneo has been the first attempt. The three principal groups (i.e. A, B, C) that have been established for Borneo have proved to be very useful throughout the thesis (e.g. investigating the relationships between circulation types and surface climate). Thus, introducing this successful approach is considered to be a new breakthrough for local climate classification specifically for Borneo, and for other SEA region in general.

The statistical procedure used to create the new monsoon index (RD2), which is based on the unrotated solution from the PC analysis is original (Chapter 6, Section 6.2.6). The final index was created by standardizing and averaging the total scores of all retained components (weighting them by their percentages of variance explained). After analysing the reliability of this new index, it was shown that RD2 has outperformed the established monsoon indices (in terms of relating the monsoon teleconnections with Borneo). Thus, the method proves to be successful and the concept can be further developed for other similar purposes (i.e. creating various synoptic indices to diagnose local climate).

In establishing the typing schemes (see Chapter 6), intensive analyses have been undertaken to explore the best procedure to employ with PCA. Two best schemes have been selected at the end of the process (see Chapter 7). However, in reaching this decision, various combinations of procedures have been tested. The inter-changeable variables include: (i)

[93] The approach applied in this thesis is a combination of correlation and cluster methods.

input data for PCA (anomaly/absolute); (ii) time-frame for PCA (separating or combing the seasons); (iii) classifying technique (K-means clustering and correlation); and (iv) the use of many different thresholds for several different purposes[94]. This research had provided a very deep insightful of the advantages and disadvantages of seven different combinations[95] of employing the PCA (i.e. these 7 combinations have yet taken into account the different thresholds used). Such detail had never been explored in previous studies on circulation typing.

9.4.2 Revalidating existing scientific knowledge

This thesis has also validated several previous findings/theories with regard to the climatology of Borneo. The most notable are the seasonal cycle of Borneo, a non-availability of ENSO teleconnections with western part of Sarawak (i.e. KCH) and the warming trend in temperature.

Many previous studies (e.g. Ramage, 1971; Nieuwolt, 1977; Sham Sani, 1984; Ding, 1994) have identified the seasonal cycle of Borneo (and the maritime continent of Southeast Asia in general). The two main seasons are known as the Northeast Monsoon (also regarded as the wet season, concurrent with the boreal winter), and the Southwest Monsoon (also known as dry season and phase-locked with the summer season in the Northern Hemisphere). The analysis conducted in Chapter 4 (see Section 4.2.4) has reaffirmed this established knowledge; and the monsoon cycle has been refined further by clearly distinguishing the transitional (NET/SWT) from the mature (NEM/SWM) phases.

Kuching (KCH), a meteorological station located in Sarawak (in the north-western part of Borneo) exhibits no significant teleconnection with the ENSO signal (Quah, 1988; Cheang, 1993; Sirabaha, 1998). This is rather odd (and, has raised questions and suspicion) because all other stations in Sabah (north-eastern part of Borneo) have shown a strong association with ENSO signals (especially with the SOI and Niño-3.4). However, this 'suspicious' phenomenon has been revalidated by this research. In this thesis, KCH has been found not to be significantly correlated with ENSO, especially with precipitation anomalies (Chapters 7 and 8).

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[94] Among others: (i) Number of retained components – to serve as the best basis to establish the typing scheme; (ii) PC scores – to identify the key days (initial types); and (iii) Correlation coefficients between the composite maps and individual days, to classify all days into its own type.

[95] 1. Absolute (data) + Combined Season (time-frame) + Correlation. 2. Absolute + Combined Season + Cluster. 3. Anomaly (monthly) + Combined Season + Correlation. 4. Anomaly (monthly) + Combined Season + Cluster. 5. Anomaly (daily) + Combined Season + Correlation. 6. Anomaly (daily) + Separate Season (SW) + Correlation. 7. Anomaly (daily) + Separate Season (NE) + Correlation.

Sham Sani (1984) and Manton et al. (2001) also find that Borneo has experienced a warming trend for the last 50 years (using data from 1961 up to 1980, and 1998 respectively). This finding is revisited in this project with a dataset extending to 2001, and the previous trend has been confirmed (Chapter 5, Section 5.4.2).

9.4.3 Revisiting and improving current knowledge

Apart from reaffirming previous findings, this project has also successfully improved the understanding of some other aspects in terms of the local and synoptic climatology of Borneo. The important improvements are related to: (i) identification of a distinctive difference between the transitional and mature monsoons; and (ii) the existence of dwi-seasonality[96] in Borneo.

The transitional monsoon (April – 15 May for Southwest Transition; and October – 15 November for Northeast Transition) has been identified as a different mode from the mature monsoon (16 May – September for Southwest Monsoon; and 16 November – March for Northeast Monsoon). Although the actual period does change based on year-to-year variability (Sham Sani, 1984), making the period implicit and treating it as a separate season in the analysis has tremendously improved the results (especially concerning how precise the relationships are, and what the distinctive behaviours of the atmospheric circulation are under various climatic conditions). It is evident that separating the transitional and mature monsoons (as opposed to the common practice of treating both periods as a single season – e.g. Cheang, 1993; Sirabaha, 1998) has proved to be very useful.

A generalisation that all parts of the SEA maritime continent are subject to a similar degree and pattern of seasonality has also been revisited. Previous studies often make a simplistic assumption that the Northeast Monsoon is generally a wetter season compared to the Southwest Monsoon (e.g. Cheang, 1981b; Sham Sani, 1984; Sirabaha, 1998). Although this assumption is true for most parts of Borneo (and to the larger SEA region in general), the local climate classification (see Chapter 4) reveals that some areas in Borneo are not subject to a strong degree of seasonality. The A2 climatic group (Sepanggar Climate), which consists of Kota Kinabalu (KK), Tawau (TWU) and Labuan (LBN), does not show a clear seasonality. In fact, all stations in the A2 climatic group experience a wetter season during the Southwest Monsoon. In terms of understanding the local climate of Borneo, this is one

[96] Dwi-seasonality is referred to the existence of two different seasonal-cycles in different parts of Borneo. The A1 and B1 climatic groups experience relatively dry (wet) season during the SW (NE) monsoon. Whereas, A2 (which consists of KK – the most important city in the north Borneo) experience the opposite – dry (wet) season during the NE (SW) monsoon.

of the most important findings in this thesis, as it has redefined the entire perception of wet and dry seasons in Borneo.

9.4.4 Adding new elements to the existing knowledge

This section summarizes all the key findings of this thesis, which are the most significant and directly associated with the implicit objectives set, prior to the analysis. There are five major key findings: classification of Borneo into climatic divisions; introduction of new localised monsoon indices; cataloguing the weather types based on the characteristics of surface climate; establishing a synoptic typing scheme based on large-scale circulation; and teleconnections with surface environmental conditions (precipitation and temperature)

Climatic division

Borneo has been divided into six climatic sub-divisions using precipitation and temperature variability as the main criteria. This is more thorough than all previous classifications (Wyrtki, 1956; Aldrian, 1999, 2001), which had simplistically classified Borneo into a single group (and that classification was based only on precipitation patterns). The six identified climatic groups are: A1 (Sepanggar), A2 (Sepilok), B1 (Samarahan), B2 (Sambas), C1 (Sintang) and C2 (Selor). These climatic groups are identified with unique characteristics based on these four aspects: (i) the duration of the wet season; (ii) the degree of seasonality; (iii) the occurrence of the three wettest and driest months; (iv) the number of absolute wet months.

New localised monsoon indices

This project has also introduced two newly-created monsoon indices – RD1 and RD2 (specifically created to suit the local climate of Borneo). The advantages of using these new indices are: (i) the indices are developed using lower level circulation (SLP) which is more closely related to Borneo's physical and geographical layout, instead of the upper level winds at geopotential heights of 200mb, 850mb and 1000mb (as being used in the earlier indices); (ii) the indices are calculated on a daily timescale, which makes them flexible to be transformed into monthly or seasonal measures, depending on the purposes and aims of any analysis; (iii) the indices are shown to have stronger correlations with both the ENSO indices and local climatic variables (i.e. precipitation amout and temperature anomaly); and (iv) the indices exhibit reasonable correlations with other established monsoon indices – suggesting that the method used to develop these new indices has a sound theoretical foundation (i.e. consistent with previous studies).

Weather types (WTs)

In terms of weather types (WTs), 8 main modes have been identified for Borneo based on the variation of precipitation and temperature, including Type 1 (Normal weather), which tends to represent the long-term average of precipitation and temperature anomalies. Type 2 (Hot weather): precipitation is slightly below normal and temperature is extremely high for all stations. Type 3 (Western wet): precipitation is extremely high in the southwestern part of Sarawak. Type 4 (Central wet): precipitation is extremely high for west coast of Borneo, from Kota Kinabalu and up to Bintulu. Type 5 (Eastern wet): High precipitation over the east coast of Sabah (Sandakan). Type 6 (Cool weather): low temperature for all stations. Type 7 (Various weather): a very distinct mixture of various local conditions for both temperature and precipitation (i.e. all stations show various types of weather, and no solid generalisation can be made). Type 8 (Mixed weather): another variation of mixed local conditions, especially for temperature (similar with Type 7, where each station uniquely shows different types of weather – e.g. KCH/BTU both experience an extremely high positive temperature anomaly, whereas SDK exhibits a high negative anomaly).

Circulation types (CTs)

Two sets of typing schemes (comprising eight circulation types each) have been established. The summary of characteristics for each circulation (based on Method2 and CT1/CT2 is given in Table 9.3:

For Method2, the circulation types are very biased to the monsoon signal. In some cases, the types only occur during a particular monsoon phase. In methods CT1/CT2, there are only five circulation types that can be exclusively assigned into a particular monsoon season. Thus, the discrimination is not as extreme as in Method2. The physical justification for the circulation types established by Method2 is mainly based on the changing flows between the NE/SW monsoons and their transitional periods (i.e. special attention on the ITCZ mechanism). In CT1/CT2, however, the eight circulation types are regarded as the ‘summary’ of all the important synoptic modes in the area (which originated from the Asian mainland continent, Indian and Pacific Oceans). Certain types are still associated with specific monsoon and ENSO conditions, but the associations are mutually exclusive.

Table 9.3: General characteristics of the circulation types (occurrences for Method2 and CT1/CT2)

Type	Method2		CT1/CT2	
	High	Low	High	Low
1	Monsoon: NEM ENSO: La Niña	Monsoon: SWM ENSO: La Niña	Monsoon: NA ENSO: NA	Monsoon: NA ENSO: La Niña
2	Monsoon: SWM ENSO: El Niño	Monsoon: NEM ENSO: La Niña	Monsoon: NEM ENSO: NA	Monsoon: SWM ENSO: NA
3	Monsoon: NET ENSO: NA	Monsoon: NA ENSO: NA	Monsoon: NEM ENSO: NA	Monsoon: SWM ENSO: NA
4	Monsoon: NEM ENSO: El Niño	Monsoon: SWM ENSO: NA	Monsoon: SWM ENSO: La Niña	Monsoon: NEM ENSO: NA
5	Monsoon: SWM ENSO: La Niña	Monsoon: NET/M ENSO: La Niña	Monsoon: NA ENSO: NA	Monsoon: NA ENSO: El Niño
6	Monsoon: NEM ENSO: La Niña	Monsoon: SWM ENSO: NA	Monsoon: NA ENSO: NA	Monsoon: NA ENSO: NA
7	Monsoon: SWT ENSO: La Niña	Monsoon: NEM ENSO: NA	Monsoon: NEM ENSO: La Niña	Monsoon: NA ENSO: NA
8	Monsoon: NET ENSO: NA	Monsoon: NA ENSO: NA	Monsoon: SWM ENSO: NA	Monsoon: NEM ENSO: NA

NA indicates that type is not significantly associated with the feature

Relationships with surface climate (i.e. precipitation and temperature)

Part (i): Method1 (absolute SLP data)

The important circulation types that identify precipitation anomalies are: Types 1 and 3 (associated with wet days) and Types 4 and 6 (dry days). Type 8 exhibits a different influence dependant upon the climatic groups. It is associated with dry days in B1 (Samarahan Climatic Group) and wet days for A2 (Sepanggar Climatic Group). Generally, surface climatic elements expressed as averages (i.e. precipitation totals) are more easily identified (with clearer patterns) than the extreme measures (e.g. 90th precipitation). The monsoon cycle can discriminate a different type (or a combination of types) that is visibly more unique than the ENSO phase. Thus, it can be concluded that the relationships are more strongly established based on monsoon seasons than ENSO years. The relationships are highly consistent through time. The patterns of relationships significantly remain unchanged between the two 17-year periods compared (i.e. 1968-1984 and 1985-2001). The climatic divisions (Sepilok – A1, Sepanggar – A2, and Samarahan – B1) have also proved to be a useful guide when analysing the relationships.

The key circulation types that identify temperature anomalies are: Type 4 (associated with hot days) and Type 6 (cool days). The relationships seem to be mostly identical for all variables across the Borneo region (as opposed to the relationships with precipitation, where the patterns are different between each climatic group). There is no distinctive discrimination between different climatic groups. This might be attributed to the fact that the absolute magnitude of temperature variability is relatively low in Borneo (compared to precipitation). Generally, the monsoon seasons are clearly identified and exhibit strong relationships with both types of measures – the averages, and the extremes. Based on monsoon seasons, all variables (i.e. the averages and extremes) are equally good when establishing relationships with the circulation types. On the other hand, the relationships identified under the influence of ENSO events are only clear for the extreme variables and not the averages. However, relationships exhibited based on ENSO phases appear to be more homogenous for all stations, and have a minimal difference in terms of spatial distribution. The relationships established based on monsoon seasons, on the other hand, show different patterns between different parts of Borneo.

Part (ii): CT1/CT2 (SLP anomaly data)

For precipitation, Types 3, 4, 5 and 6 are associated with positive anomalies (wet types); whereas Types 1, 2, 7 and 8 are the dry types. The strongest are Types 3 and 6 with anomaly values exceeding 3.0 mm/day (both in CT1 and CT2). The relationships are fairly consistent over the 34-year period of study. The only exception is Type 5, which exhibits a strong association with positive anomalies during the first half of the period (1968-1984). However, this association is significantly weakened in the second half (1985-2001).

In CT1, Type 1 exhibits negative anomalies during the SW monsoon, especially for the Samarahan Climatic Group (B1). The same association is observed for CT2 for Type 1. However, more stations are included (i.e. including the A group – Sepilok and Sepanggar Climatic Groups) especially for the extreme variables (i.e. 90th percentile and wet days). For CT1, Type 2 is also associated with negative anomalies (dry type), but it is only shown during the NE monsoon and it includes all stations. However, in CT2, Type 2 only shows the relationships for the stations from the A1 (Sepanggar) and A2 (Sepilok) climatic groups. Types 3, 4 and 5 (individually) exhibit the same pattern of relationships for both classification schemes (CT1 and CT2). Types 7 and 8 are dry types with strong negative anomalies, especially for the centrally located stations – KK, MIR and BTU. This relationship is most clear during the SW monsoon, and the degree of association is relatively stronger for Type 8.

For the relationships with temperature, Types 2, 7 and 8 are associated with positive anomalies (hot types), whereas Types 3, 4 and 6 are the cold types. Types 1 and 5 do not show any strong association either with negative or positive anomalies. The strongest hot type is Type 2 with values exceeding 0.2°C. For the cold types, the strongest is Type 6 with anomaly values of less than -0.2°C. Similar to what have been observed in precipitation, the relationships are fairly consistent over the 34-year period of study. Generally, all the identified relationships are equally exhibited at all stations. Thus there is no spatial discrimination in contrast to what had been exhibited for precipitation. There are also no obvious differences, in terms of the strength and distribution, between the average and extreme variables.

T-mean temperature average and T-max 90th percentile (the extreme measure) are strongly exhibited during the SW transition and mature phase of monsoon. For the second extreme variable (T-min 10th percentile), the associations are more strongly exhibited during the NE monsoon (also for both the transition and mature phases). In short, only variability on a seasonal basis is strongly shown in the temperature relationships. Spatial variability does not play a significant factor. This is attributed to the natural features of local climate of Borneo, where temperature varies to a lesser degree (compared to precipitation) in terms of seasonally and regionally.

9.5 Discussions on practical applications and further possible study

This thesis has investigated the large-scale atmospheric processes that influence the climate variability in Borneo by developing a circulation classification scheme (i.e. using SLP) over the region. In order to establish easily-interpretable relationships (between the circulation types and surface climate elements), the local climate of Borneo and the synoptic atmospheric features of Southeast Asia (i.e. monsoon and ENSO forcings) are first assessed. This analysis has used the two main surface variables – precipitation and temperature. To evaluate the performance of the typing scheme (in associating and diagnosing the surface variables), the results are compared with the teleconnections exhibited by numerical synoptic indicators (i.e. the monsoon and ENSO indices). All the relationship and teleconnection analyses are also assessed for comparison between different climatic divisions (in Borneo), different climatic events (i.e. the monsoon cycle and ENSO phases), and their trends over time. The concept and methodology applied in this thesis should provide the basis for further scientific research, and the outcomes derived from this project could be used in various practical applications.

9.5.1 Future studies

There are several areas in which further analyses can be pursued by extending or applying similar concepts and methodologies used in this thesis. For further studies with a pure science-oriented approach, some of the relevant areas are: (i) searching for better or more localised monsoon indices to improve understanding of the monsoon impacts; (ii) using the established circulation types for the construction of future climate scenarios (e.g. applying downscaling techniques); and (iii) further investigation of meaningful relationships between the atmospheric circulation patterns and other physical variables (i.e. humidity, rainfall acidity, occurrences of tropical storms, flood, and drought).

The two new monsoon indices (RD1/RD2) developed here are created using SLP daily data. By applying the same methodological procedure, other localised monsoon indices for Borneo (or other parts of Southeast Asia – e.g. Peninsular Malaysia, the Philippines archipelago, etc) can be created using different large-scale variables, such as 200hPa, 500hPa and 800hPa geopotential heights. The analyses undertaken on the synoptic atmospheric circulation (i.e. typing scheme) can also be extended to the construction of future climate scenarios for Borneo (e.g. Henderson-Sellers and Schubert, 1997; Goodess and Palutikof, 1998). In terms of relationship with surface environmental elements, the circulation types can be further associated with other variables. The circulation types prove to be well related with precipitation and temperature; thus, it is very likely that a similar significant relationship will be established with humidity and the level of acidity in local precipitation – e.g. the studies of Ezcurra (1988) and Farmer et al. (1989).

A relationship between selected socio-economic indicators is another area where the outcome from this thesis can be extended. These kinds of studies have been conducted by other researchers in various chosen cases/regions (e.g. Muller and Tucker, 1986; Hirschboeck, 1987; Dilley, 1992). Within the context of Borneo, suitable socio-economic variables that can possibly be related to either the circulation types (CTs) or weather types (WTs) are crop yields, mortality, frequency of traffic accidents, seasonal forecasting, pollutant index (i.e. TSP) and eco-tourism performance indices.

9.5.2 Practical benefits

The research outcomes also could be used for practical purposes, either through a direct or indirect use of the climatic information presented in this thesis. By introducing two localised monsoon indices (which prove to be effective in diagnosing precipitation anomalies), it helps to improve understanding of the SEA monsoon. In terms of the economy, this is very beneficial because the two key sectors in Borneo (i.e. agriculture and eco-tourism) are highly dependant on climatic factors. The regional climate classification has also increased the understanding of the variability of seasonality within Borneo (i.e. identifying the NE and SW monsoon characteristics according to specific areas). This could provide a new alternative for socio-economic planning in terms of regional identification. As opposed to the traditional approach of using political and administrational boundaries (which is physically not very homogenous), the planning can be structured based on the climatic boundaries. By optimising the synoptic teleconnections derived from this thesis (i.e. the relationships between circulation/weather types and precipitation/temperature), it could assist policy-makers in making some crucial decisions. For example, in the case of the reccurring regional haze (due to the extensive forest burning in Kalimantan), a better understanding on how the synoptic circulation around SEA influences the distribution of pollutant particles is very beneficial. It can also be used to advance preparation of appropriate contingency plans to deal with anticipated problems caused by this transboundary haze.

9.6 Final conclusion

9.6.1 Concluding note

The basic foundation behind this research, as had been strongly stated in the early chapters (1 and 2), is based on the works by Caesar (2002) and Sirabaha (2004). In this final section, it is worth revisiting this foundation through these questions:

- How do the studies by Caesar (2002) and Sirabaha (2004) contribute to this research?
- How does this research add new elements of knowledge to their studies?

Caesar (2002) evaluated ENSO mechanisms and effects on the Southeast Asian region. His assessments on how the ENSO phenomenon really operates in the large-scale climatic system of this region led to the finding (or reaffirmation) of several synoptic modes (associated with ENSO) in this region. The most significant are the cyclonic (anticyclonic) fields over the east Philippines during the La Niña (El Niño) events. Caesar also investigated the physical mechanism of ENSO and its association with the monsoon cycle, where he found that El Niño (La Niña) are responsible for the weakening (strengthening) of the low-level Northeast monsoon.

Addressing the same issue, Sirabaha (2004) took a different approach. Caesar (2002) regarded ENSO as the core subject of his research (i.e. linking it with the monsoon phenomenon). Sirabaha, on the other hand, adopted monsoon as the focus of his investigation, attempting to link it with the ENSO. Sirabaha (2004) re-establish two important findings pertaining to monsoon features. These are the seasonal progression (i.e. understanding the cycle and domains of action), and its general impact on the regional surface climate. Sirabaha (2004) also successfully established the phase-locked relationship between the SEA monsoon and ENSO. With respect to this, he found that the ENSO mechanism could disrupt SEA monsoon flows, which are strongly characterised by the zonal (meridional) circulations of the (Hadley) Walker systems.

This thesis has been primarily aimed at developing a typing scheme that can be related to the surface climate of Borneo (a smaller region within Southeast Asia). In doing so, it is essential to understand the synoptic features of the region, which are heavily influenced by the SEA monsoon and ENSO. The findings of Caesar (2002) and Sirabaha (2004) have contributed to this part of the thesis. The criteria for classifying ENSO events (Caesar, 2002), the linking mechanisms between the monsoon and ENSO (Caesar, 2002; Sirabaha, 2004) and the characteristics of the monsoon cycle (Sirabaha, 2004) – have been used as the foundations for this research. They are particularly channelled into these areas:

- Establishing the monsoon cycle and ENSO events (Chapters 4 and 6)
- Identifying the monsoon/ENSO signals and the physical features associated to them (Chapters 5 and 6)

This thesis, however, has offered new and improved knowledge. The key difference with the earlier studies is the analysis of relationships with surface climate. In both previous studies, the aims were either, focussed purely on the ENSO-monsoon physical mechanism (Caesar, 2002) or assessing the connection between the ENSO/monsoon signals with the surface climate (Sirabaha, 2004). The approach employed in this thesis offers deeper and more insightful assessments of the relationships by looking at a more specific case (i.e. only Borneo, and not the SEA region as a whole). It is also important to note that, this project has also introduced circulation typing schemes (the first such attempt in this region). Each one of the circulation types has implicitly summarised the synoptic modes (those attributed to ENSO and monsoon) into a single indicator. Thus, it offers a new perspective (from what Sirabaha had presented) on how to look at the synoptic-local teleconnections and relationships. In short, this thesis has enhanced the works by Caesar (2002) and Sirabaha (2004) in terms of widening the scope from primarily a simple understanding of the synoptic features (ENSO-monsoon association) into a more specific investigation of synoptic influences on the local climate.

9.6.2 Post-thesis remark

As far as the aims are concerned, all the core objectives outlined for this project have been successfully achieved, which are: (i) to identify the characteristics of local climate (through temporal and regional classification and by analysing the long-term trends and patterns of precipitation/temperature); (ii) to investigate the mutual-interaction between the monsoon and ENSO (by synoptic typing scheme); (iii) to establish a relationship between the large-scale circulation and surface climate.

However, some parts of the analyses and results have some limitations (e.g. data length), which have been mentioned and discussed in this final chapter. The schematic overview of how this project has operated is shown in Figure 9.1 (i.e. Hypothesis → Analysis → Synthesis → Thesis). This diagram is presented to visually simplify the entire work, so that readers can easily revisit the process: how the issues (hypothesis) have been tackled, before reaching the conclusions (thesis) – and what further steps can be expanded from the final outcome.

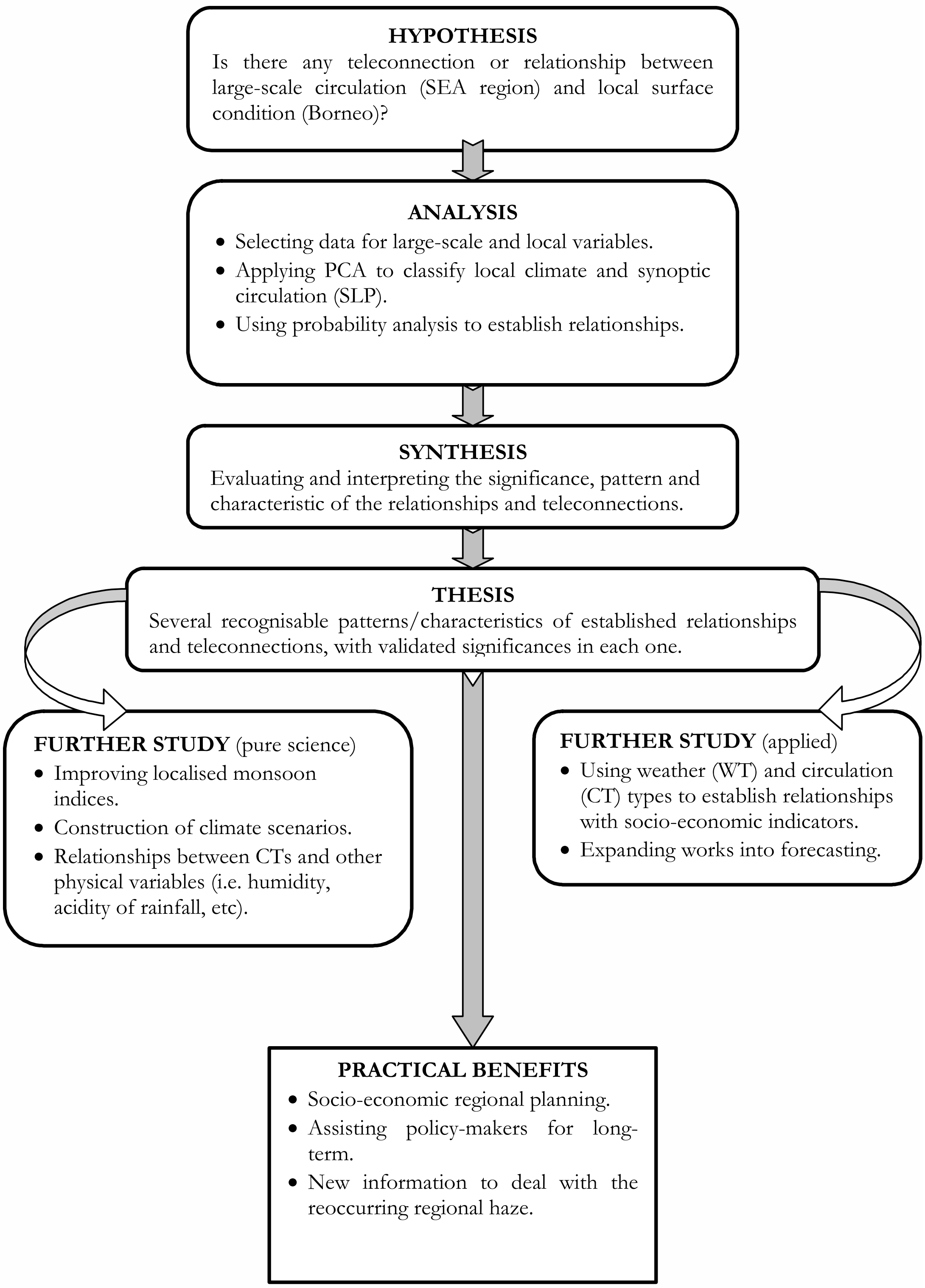

Figure 9.1: Overview of the conceptual framework and outcomes at each level

Bibliography

Agresti, A., 1996. *Introduction to categorical data analysis*. NY: John Wiley and Sons. Discussion on chi-square test p. 231-236.

Alaka, M., 1964. *Problems of Tropical Meteorology (A Survey)*. Geneva, World Meteorological Organization.

Aldenderfer, Mark S. and Roger K. Blashfield, 1984. Cluster Analysis. Thousand Oaks, CA: Sage Publications, *Quantitative Applications in the Social Sciences Series* No. 44.

Aldrian, E. and Susanto, R.D., 2003. ‘Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature’. *International Journal of Climatology*, 23, 1453-1464.

Aldrian, E., 1999. ‘Division of Climate Type in Indonesia Based on Rainfall’ Pattern. *Oceanica – Journal of Marine Science and Technology*, BBPT, 5, 165-171

Aldrian, E., 2001. ‘Pembagian Iklim Indonesia Berdasarkan Pola Curah Hujan dengan Metoda “Double Correlation” (Indonesian Climate Classification Based on Rainfall Pattern Applying Double Correlation Method)’. *Jurnal Sains & Teknologi Modifikasi Cuaca* 2 (No. 1), 2-11.

Allan, R.J., 2000. ‘ENSO and climate variability in the last 150 years’. *El Niño and the Southern Oscillation: Multiscale variability and its impacts on natural ecosystems and society*, Diaz, H.F., and Markgraf, V. (eds), Cambridge University Press.

Allan, R.J., Lindesay, J.A., and Parker, D.E., 1996. ‘El Niño Southern Oscillation and climatic variability’, CSIRO Publishing: Collingwood, Victoria.

Annamalai, H., Slingo, J.M., Sperber, K.R. and Hodges, K., 1999. ‘The mean evolution and variability of the Asian summer monsoon: Comparison of ECMWF and NCEP-NCAR reanalyses’. *Monthly Weather Review*, 127, 1157-1186.

Asnani, G.C., 1993a. ‘Tropical Meteorology’, vol 1, Indian Institute of Tropical Meteorology, Pashan, India.

Asnani, G.C., 1993b. ‘Tropical Meteorology’, vol 2, Indian Institute of Tropical Meteorology, Pashan, India.

Bach, W., 1972. ‘Urban climate, air pollution, and planning’. *Urbanization and Environment, the physical Geography of the City*, Detwyler, T.R. & Marcus, M.G. (eds.). Duxbury Press, p. 69-96.

Bacher, A., Oberhuber, J.M. and Roeckner, E., 1998. ‘ENSO dynamics and seasonal cycle in the tropical Pacific as simulated by the ECHAM4/OPYC3 coupled general circulation model’. *Climate Dynamics*, 14, 431-450.

Baldwin, M.P., Stephenson, D.B., Thompson, D.W.J., Charlton, A.J. and O’Neill, A., 2002. Startosphere-Troposphere Coupling and Extended-Range’. *Weather Forecast. International Symposium of Stratospheric Variations and Climate*, 12-15 November, Kyushi University, Fukuoka, Japan.

Barnett, T.P., 1984. 'Interaction of the monsoon and Pacific trade wind system at interannual time scales. Part II: The tropical band'. *Monthly Weather Review*, 111, 2380-2387.

Barnston, A.G. and Chelliah, M., 1997. 'Documentation of a highly ENSO- related SST region in the equatorial Pacific'. *Atmosphere-Ocean*, 35, no.3, 367-383.

Barry, R. and Perry, A., 1973. Synoptic Climatology Methods and Applications. London, Methuen & Co Ltd.

Behrend, H., 1987. 'Teleconnections of rainfall anomalies and of the Southern Oscillation over the entire tropics and their seasonal dependence'. *Tellus, Series A (Dynamic Meteorology and Oceanography)*, vol.39A, no.2, p.138-51.

Bell, G.D. and Halphert, M.S., 1998. 'Climate assessment for 1997'. *Bulletin of the American Meteorological Society*, 79, S1-s50.

Bigg, G.R., 1990. 'El Niño and the Southern Oscillation', *Weather*, 45, 2-8.

Bigg, G.R., 1995. 'The El Niño event of 1991-1994'. *Weather*, 50, 117-124.

Bjerknes, J., 1969. 'Atmospheric teleconnections from the equatorial Pacific'. *Monthly Weather Review*, 97, 163-172.

Blasing, T.J. 1981. 'Characteristic anomaly patterns of summer sea-level pressure for the Northern Hemisphere'. *Tellus* 33, 428-437.

Bobko, Philip , 2001. Correlation and regression, 2nd edition. Thousand Oaks, CA: Sage Oublications. *Introductory text which includes coverage of range restriction, trivariate correlation.*

Bohn, L., 1996. 'The Impact of The El Niño Southern Oscillation on Interannual Rainfall Variability in South East Africa and The Solomon Islands'. MSc Thesis (University of East Anglia).

Bohn, L., 2000. The Use of Seasonal Forecast. *A paper presented at the Workshop on the Impact of El Niño-La Niña on Southeast Asia*, CERED, IGCN, APNGCR, UEA at Hanoi, Vietnam: 21-23 February 2000.

Caesar, J., 2002. 'The influence of sea surface temperature patterns on the winter monsoon over Southeast Asia'. PhD Thesis, University of East Anglia.

Cattell, R.B., 1966. 'The scree test for the number of factors'. *Multivariate Behavioral Research*, 1, 245-276.

Chang, C.P. and Lau, K.M., 1982. 'Short Term planetary-scale interactions over the tropics and mid-latitudes during northern winter. Part I: Contrasts between active and inactive periods'. *Monthly Weather Review*, 110, 933-946.

Chang, C.P., Zhang, Y.S. and Li, T., 2000. 'Interannual and interdecadal variations of the East Asian summer monsoon and tropical Pacific SSTs'. *Journal of Climate*, 13, 4310-4340.

Cheang, B.K., 1986. 'Short and long range monsoon prediction in southeast Asia'. *Monsoon,* (eds) J.S. Fein and P.L. Stephens (John & Wiley Sons Inc), 579-606.

Cheang, B.K., 1993. 'Interannual Variability of Monsoons in Malaysia and its Relationship with ENSO'. *Proc.Indian Acad.Sci.(Earth Planet Sci.)* 102, 219-239. India.

Cheang, B.K., Lum, K.G., and Radhakirshnan, R., 1981a. 'Oscillation of the Winter Monsoon System'. *Departmental Seminar Paper* 17. Petaling Jaya, Malaysian Meteorological Service.

Cheang, B.K., Yap, K.S., Lum, K.G. and Chang, T.Y., 1981b. 'Variation of Rainfall in Malaysia in Response to the Oscillation of the Summer Monsoon Circulation during Summer Monex'. *Departmental Seminar Paper* 18. Petaling Jaya, Malaysian Meteorological Service.

Chen, T.C. and Chen, J.M., 1997. 'On the relationship between the streamfunction and velocity potential of the Madden-Julian Oscillation'. *Journal of the Atmospheric Sciences*, 54, 679-685.

Christensen, W.I. and Bryson R.A., 1966. 'An investigation of the potential of the component analysis for weather classification'. *Monthly Weather Review*, 94, 697-709.

Corte-Real, J., Xu, H. and Qian, B., D., 1999. 'A weather generator for obtaining daily precipitation scenarios based on circulation patterns'. *Climate Research*, 13, 61-75.

Dahni, R.R. and Ebert, E.E., 1998. 'Automated objective synoptic typing to characterize errors in NWP model QPFs'. *12th Confference on Numerical Weather Prediction*, American Meteorological Society

Das, PK., 1962. Monsoons, Fifth WMO Lecture, WMO No. 613, World Meteorological Organisation, Geneva. 115 pp.

de Martonne, E., 1926. 'Areisme et indices d`aridite'. *Acdemic des Sciences (Paris), Comptes Rendus*, 182 (23), 1395-1396

Diharto, 1999. 'Occurrence of El Niño/La Niña episodes and its impact during the end of 20th century over maritime continent of Indonesia'. *Indonesia Meteorological and Geophysical Agency*.

Dilley, F.B. 1992. 'The statistical relationship between weather-type frequencies and corn (maize) yields in southwestern Pennsylvania'. *Agricultural and Forest Meteorology*.

Ding, Y.H., 1990. 'Build-up, air mass transformation and propagation of Siberian high and its relations to cold surge in east Asia'. *Meteorological Atmospheric Physics*, 44, 281-292.

Ding, Y.H., 1994. 'Monsoon over China'. Kluver Academic Publishers, Dordrecht.

Ding, Z.L., Ren, J.Z., Yang, S.L. and Liu, T.S., 1999. 'Climate Instability during the penultimate glaciation: Evidence from two high resolution loess records, China'. *Journal of Geophysical Research*, 104, 20, 123-20, 132.

Drosdowsky, W. and Chambers, L.E., 2001. 'Near-global sea surface temperature anomalies as predictors of Australian seasonal rainfall'. *Bulletin of American Meteorological Society* 1 April, 1677-1687

Ezcurra, A., Casado, H., Lacaux, J.P. and Garcia, C. 1988. 'Relationships between meteorological situations and acid rain in Spanish Basque country'. *Atmospheric Environment* 22, 2779-2786.

Farmer, G., Davies, T.D., Barthelmie, R.J., Kelly, P.M. and Brimblecombe, P. 1989. 'The control by atmospheric pressure patterns of sulphate concentrations in precipitation at Eskdalemuir, Scotland'. *International Journal of Climatology* 9, 181-189.

Frakes B, Yarnal B. 1997. A procedure for blending manual and correlation-based synoptic classifications. *International Journal of Climatology* **17**: 1381-1396.

Gadgil, S. and Inyengar, R.N., 1980. 'Cluster analysis of rainfall stations of the Indian Peninsula'. Indian Institute of Science, Bangalore, India (unpublished manuscript)

Gadgil, S., Yadumani and Joshi, N.V., 1993. 'Coherant rainfall zones of the Indian region'. *Int. J. Climatol*., 13, 547-566.

Glantz, M.H., 1991. Introduction, in Glantz M.H., Katz R.W. and Nicholls N., (eds) 1991. *Teleconnections linking world wide Climate anomalies*, Cambridge University Press.

Goddard, L. and Graham, N.E., 1997. 'El Niño in the 1990s'. *J. Geophys. Res*., 102, 10423-10426.

Goddard, L., Mason, S.J., Zebiak, S., Ropelewski, C., Basher, R., and Cane, M., 2001. 'Current Approach to Seasonal-To-Interannual Climate Predictions'. *International Journal of Climatology,* 21, 1111-1152.

Goodess, C.M. and Jones, P.D., 2002. 'Links between circulation and changes in the characteristics of Iberian rainfall'. *International Journal of Climatology*, 22, 1593-1615.

Goodess, C.M. and Palutikof, J.P., 1998. 'Development of daily rainfall scenarios for southeast Spain using a circulation-type approach to downscaling'. *International Journal of Climatology*, 18, 1051-1083.

Goswami, B.N, 2000. 'Commentary and analysis'. *Bulletin of the American Meteorological Society*, Vol. 81, No. 4, 821-824

Goswami, B.N., Krishnamurty, V. and Annamalai, H., 1999. 'A broad-scale circulation index for the interannual variability of the Indian summer monsoon', *Quarterly Journal for Royal Meteorological Siciety*, 125, 611-633.

Halpert, M.S. and Ropleweski, C.F., 1992. 'Surface temperature patterns associated with the Southern Oscillation'. *Journal of Climate*, 5, 577-593.

Henderson-Sellers, A. and Schubert, S., 1997. 'A statistical model to down-scale local daily temperature extremes from synoptic-scale atmospheric circulation patterns in the Australian region'. *Climate Dynamics*, 13, 223-234

Hare, F.K., 1951. Climate Classification. Pages 111-134 in London essays in geography, ed. Stamp, L.D. and Wooldrige, S.W. The London School of Economics and Political Science

Hirschboeck, K.K. 1987b. 'Catastrophic flooding and atmospheric circulation anomalies', in L. Mayer and D. Nashn(eds.) *Catastrophic Flooding*, Allen and Unwin, London, 23-56.

Hotelling, H., 1933. 'Analysis of a complex a statistical variables into principal components'. *The Journal of Educational Psychology*, XXIV, 417-441.

Hotelling, H., 1936. 'Simplified calculation of principal components'. *Psychometrika*, 1, 27-35.

Houze, R.A. Geotis, S.G., Marks, F.D, and West, A.K., 1981. 'Winter monsoon convection in the vicinity of North Borneo 1. Structure and time variation of the clouds and precipitation', *Monthly Weather Review*, 109, 1595-1614.

Jin, F.F., Neelin, J.D. and Ghil, M., 1994. 'El Niño on the Devil's staircase: Annual subahrmonic steps to chaos'. *Science*, 264, 70-72.

Jolliffe, I.T., 1986. Principal Components Analysis. Springer-Verlag, 271 pp.

Jolliffe, I.T., 1990. 'Principal component analysis: a beginner's guide-I. Introduction and application'. *Weather*, 45, 375-381.

Jolliffe, I.T., Uddin, M. and Vines, S.K., 2002. 'Simplified EOFs-three alternatives to rotation'. *Climate Research*, 20, 271-279.

Jones, P.D. and Hulme, M., 1996. Calculating regional climatic time series for temperature and precipitation: methods and illustrations. *Journal of Climatology* 16, 361-377.

Jones, P.D. and Kelly, P.M., 1982. 'Principal component analysis at the Lamb Catalogue of Daily Weather Types: Part 1, annual frequencies'. *Journal of Climatology*, 2, 147-157

Julian, P.R. and Madden, R.A. 1981. Comments on a paper by T. Yasunari, A quasi-stationary appearance of 30 to 40 day period in the cloudiness fluctuation during the summer monsoon over India. *J. Meteor Soc. Japan*, 59, 435-437.

Kaiser, H.F., 1958. 'The Varimax criterion for analytic rotations in factor analysis'. *Psychometrica*, 23, 187-200.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Wollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins.,W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R. and Joseph, D., 1996. 'The NCEP/NCAR 40-year reanalysis project'. *Bulletin of the American Meteorological Society*, 77, 437-471.

Karalis, J., 1969. Weather Types in the Greek Region, (in Greek). Ph.D. Thesis, Athens, Greece, 82pp.

Karl, T.R., Jones, P.D., Knight, R.W., Kukla, G., Plummer, N., Razuvayev, V., Gallo, K.P., Lindseay, J., Charlson, R.J. and Peterson, T.C., 1993. 'A new perspective on recent global warming: Asymmetric trends of daily maximum and minimum temperatures'. *Bulletin of the American Mateorological Society*, 74, 1007-1023.

Kaufman, Leonard and Peter J. Rousseeuw, 1990. Finding groups in data: An introduction to cluster analysis, NY: John Wiley & Sons, ISBN: 0471878766.

Kawamura, R., 1988. 'Intraseasonal variability of sea surface temperatures over thetropical western Pacific'. *Journal of the Meteorological Society of Japan*, 66, 1007-1012.

Kidson, J.W. 2000. 'An analysis of New Zealand synoptic types and their use in defining weather regimes'. *International Journal of Climatology*, 20, 299-316

Kim, K.Y. and Chung, C., 2001. 'On the evolution of the annual cycle in the tropical Pacific', *Journal of Climate*, 14, 991-994.

Kirtman, B.P. and Shukla, J., 2000. 'Influence of the Indian summer monsoon on ENSO'. *Quarterly Journal of Royal Meteorological Society*, 12, 213-239.

Kistler, R., Kalnay, E., Collins, W., Saha, W., White, G., Woollen, J., Chelliah, M., Ebisuzaki, W., Kanaitsu, M., Kousky, V., Dool, H., ven den., jenne, R., and Fiorino, M., 2001. 'The NCEP-NCAR 50-Year Reanalysis: Monthly means CD-ROM and documentation'. *Bulletin and the American Meteorological Society*, 82, 246-267.

Kitoh, A., 1992. 'Simulated interannual variations of the Indo-Australian monsoons'. *Journal of the Meteorological Society of Japan*, 70, 563-583.

Kostopoulou, E., 2003. The relationships between atmospheric circulation patterns and surface climate elements in the eastern Mediterranean. University of East Anglia, Ph.D Thesis.

Köppen, W. 1936. 'Das geographische system der climate'. Chapter 3 in: W. Koppen and W. Geiger (eds.) *Handbuch der Klimatologie*, Vol.I, C.G. Borntrager, Berlin, 46pp.

Kripalani, R.H. and Kulkarni, A., 1997. 'Rainfall variability over South-east Asia-connections with Indian monsoon and ENSO extremes: New perspective'. *International Journal Of Climatology*, 17, 1155-1168.

Kripalani, R.H. and Kulkarni, A., 1999. 'Climatology and variability of historical Soviet snow depth data: Some new perspectives in snow-Indian monsoon teleconnections'. *Climate Dynamics*, 15, 475-489.

Krishna Kumar, K., Rupa Kumar, K. and Pant, G.B., 1995. 'Seasonal Forecasting on Indian summer monsoon rainfall'. *Weather*, 50, 12, 449-467.

Krishna Kumar, V. and Lau, K.M., 1997. 'Symmetric instability of monsoon flows'. *Tellus*, 49A, 228-245.

Krishna Kumar, K, Soman, M.K. and Rupa Kumar, K. 2000. Seasonal Forecasting of Indian Summer Monsoon Rainfall: A Review
http://www.tropmet.res.in/~kolli/MOL/Forecasting/frameindex.html

Krishnamurti, T.N. Bedi, H.S. and Subramaniam, M.1989. 'The summer monsoon of 1987'. *Journal of Climate*, 2, 321-340.

Krishnamurti, T.N., 1971. 'Tropical east-west circulations during the northern summer'. *Journal of Atmospheric Science*, 28, 1342-1347.

Lamb, H.H., 1950. 'Types ands spells of weather around the year in the British Isles: annual trends, seasonal structure of the year, singularities'. *Quarterly Journal of the Royal Meteorological Society*, London, 76, 393-438.

Lamb, H.H., 1972. 'British Isles Weather Types and a register of the daily sequence of circulation patterns, 1861-1971'. *Meteorological Office, Geophysical Memoirs* no.116, 85 pp.

Lau, K.M. and Li, M.T., 1984. 'The monsoon of east Asia and its global association – A survey'. *Bulletin of American Meteorological Society*, 65, 114-125.

Lau, K.M. and Sheu, P.J., 1988. 'Annual Cycle, QBO, and SO in Global PPN'. *Journal of Geophysical Research*, 93, 10975-10988.

Lau, K.M. and Yang, S., 1996. 'Seasonal variation, abrupt transition, and intraseasonal variability associated with the Asian summer monsoon in the GLA GCM'. *Journal of Climate*, 9, 965-985.

Lau, K.M. and Yang, S., 1997. 'Climatology and interannual variability of the Southeast Asian summer monsoon'. *Adv. Atmospheric Science*, 14, 141-162.

Lau, K.-M., K.-M. Kim, and S.Yang, 2000. 'Dynamical and boundary forcing characteristics of regional components of the Asian summer monsoon'. *J. Climate*, 13, 2461-2482.

Lim, Y.K., Kim, K.Y. and Lee, H.S., 2002. 'Temporal and spatial evolution of the Asian summer monsoon in the seasonal cycle of synoptic fields'. *Journal of Climate*, 15, 3630-3644.

Lin, H and Wang, B., 2002. 'The Time-space Structure of the Asian-Pacific Summer Monsoon: A Fast annual Cycle View'. *Journal of Climate*, 15, no. 15, 2001-2019.

Lipschutz, S., 1974. Theory and problems of probability. McGraw Hill: Great Britain. 153pp

Liu, Y., Wu, G. and Ren, R. 2004. 'Relationship between the Subtropical Anticyclone and Diabatic'. *Journal of Climate* VOL 17

Lu, E. and Chan, C.L., 1999. 'A unified monsoon index for South China'. *Journal of Climate*, 12, 2375-2385.

Luo, H. and Yanai, M., 1984. The large-scale circulation and heat sources over the Tibetan Plateau and surrounding areas during the early summer of 1979. Part II: heat and moisture budgets'. *Monthly Weather Review*, 112, 966-989.

Madden, R.A. and Julian, P.R. 1971. 'Detectation of a 40-50 day oscillation in the zonal winds in the tropical Pacific'. *J. Atmos. Sci.* 28, 702-708.

Manton, M.J., Della-Marta, P.M., Haylock, M.R., Hennessy, K.J., Nicholls, N., Chambers, L.E., Collins, D.A., Daw, G., Finet, A., Gunawan, D., Inape, K., Isobe, H., Kestin, T.S., Lefale, P.,Leyu, C.H.,Lwin, T., maitrepierre, L., Ouprasitwong, N., Page, C.M., Pahalad, J., Plummer, N., Salinger, M.J., Suppiah, R., Tran, V.L., Trewin, B., Tibig, I. and Yee, D., 2001. 'Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961-1998'. *International Journal of Climatology*, 21, 269-284.

Matsumoto, J., 1992. 'The seasonal changes in Asian and Australian monsoon regions'. *Journal of the Meteorological Society of Japan*, 70, no.1, 127-142.

McGregor, G.R and Nieuwolt, S., 1998. 'Tropical Climatology-Second Edition', John Wiley and Sons Ltd. Chichester, 339.

Meehl, G.A., 1997. 'The south Asian monsoon ad the tropospheric biennial oscillation'. *Journal of Climate*, 10, 1921-1943.

Meher-Homji, V.M., 1980. 'Classification of the semi-arid tropics: climatic and phytogeogrpahic approaches'. *Proceeding of Climatic Classification: A Consultants'*

Meeting 14-16 April 1980 (International Crops Research Institute for the Semi-Arid Tropics), 7-16

Miyakoda, K., Navarra, A. and Ward, M.N., 1999. 'Tropical-wide teleconnection and oscillation. II: The ENSO-monsoon system'. *Quaterly Journal of Royal Metrological Society*, 125, 2937-2963.

Mohapatra, M, Mohanty, UC, and Behera, S., 2003. 'Spatial variability of daily rainfall over Orissa, India, during the Southwest Summer Monsoon season'. *International Journal of Climatology* 23, 1867-1887

Mooley, D.A. and Paolino, Jr. D.A., 1988. A predictive monsoon signal in the surface level thermal field over India. *Mon. Wea. Rev.*, 111, 339 352.

Mooley, D.A. and Parthasarathy, B. and Pant, G.B., 1986. 'Relationships between Indian summer monsoon rainfall and location of the ridge at 500mb level along 75°E'. *J. Climate Appl. Meteorol.*, 25, 640.

Mooley, D.A. and Parthasarathy, B., 1983. 'Fluctuations of All-India summer monsoon rainfall during 1871-1978'. *Climatic Change*, 6, 287-301.

Moore. D.S., 1995. The basic practise of statistics. NY: Freeman and Co.

Mosteller, F., Rourke, R., and Thomas, G., 1961. Probability with Statistical applications. Reading, MA: Addison-Wesley.

Mukherjee, B.K., Indira, K., Reddy, R.S. and Ramana Murty, Bh.V., 1985. 'Quesibiennial oscillation in stratospheric wind and Indian monsoon'. *Mon. Wea. Rev.*, 118, 1421-1430.

Muller, R.A. and Tucker, N.L., 1986. 'Climatic opportunities for the long-range migration of moths', in A.N Sparks (ed.) *Long-range migration of moths of agronomic importance to the United States and Canada: Specific examples of occurrence and synoptic weather patterns conducive to migration*, United States Department of Agriculture, Agricultural Research Service, ARS-43, 61-83.

Niewolt, S., 1977. Tropical climatology – an introduction to the climate of the low latitudes. John Willey & Sons, London.

Ooi, S.H, 2001. 1997-2000 ENSO Impacts on Weather in Malaysia. Unpublished paper presented on a local conference in Malaysia (2001).

Ooi, S.H, and Cheang, B.K., 1991. 'Review of the November 1989 – March 1990 Northeast Monsoon in Malaysia, Part 1: rainfall pattern', *Technical Note No. 47*, Malaysian Meteorological Services

Parthasarathy, B. and Pant, G.B., 1984. 'The spatial and temporal relationships between the Indian summer monsoon rainfall and the southern oscillation'. *Tellus*, 36A, 269-277.

Parthasarathy, B., 1984. 'Interannual and long-term variability of Indian summer monsoon rainfall'. *Proc. Indian Acad. Sci. (Earth Planet.Sci*), 93, 371-385.

Parthasarathy, B., Munot A.A., and Kotawale, D. R., 1995. 'Monthly and seasonal rainfall series for all-India homogenous regions and meteriological sub-divisions: 1871-1994'. Res. Rep. No. RR-065, Indian Institute of Tropical Meoeorology, Pune, India, 113pp.

Philander, S., 1989. 'El Niño and La Niña'. *American Scientist*, 77, no. 5, 451-459.

Philander, S., 1990. El Niño and La Niña', and the Southern Oscillation, Academic Press, 293 pp.

Philander, S., 1999. 'A review of tropical ocean-atmosphere interactions'. *Tellus*, 51A-B, 71-90.

Popham, W.J., 1967. Educational Statistics, use and interpretation, Harper and Row: New York, 429 pp

Preisendorfer, P.W., 1988. Principal Components Analysis in Meteorology and Climatology. Elsevier, 425 pp.

Quah, L.C., 1988. 'ENSO and anti-ENSO Related Precipitation Response over Malaysian Region', *a working paper presented at the WMO/ASCA winter monsoon workshop*, Kuala Lumpur, 27 June-2 July 1988.

Ramage, CS., 1971. Monsoon Meteorology. Academic Press, New York. 296pp.

Rasmusson, E.M. and Carpenter. T.H., 1982. 'Variation in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/E1 Niño'. *Monthly Weather Review*, 110,354-384.

Rasmusson, E.M. and Carpenter. T.H., 1983. 'The relationship between Eastern Equatorial Pacific sea surface temperatures and rainfall over Indian and Sri Lanka'. *Monthly Weather Review*, 111, 517-527.

Reid, P.A., Jones, P.D., Brown, O., Goodess, C.M. and Davies, T.D., 2001. 'Assessments of the reliability of NCEP circulation data and relationships with surface climate by direct comparisons with station based data'. *Climate Research*, 17, 247-261.

Richman, M.B. and Lamb, P.J., 1985. Climate Patterns of 3- and 7-day summer rainfall in the central United States: Some methodological considerations and a regionalization. *Journal of Applied Meteorology*, 24, 1325-1343.

Richman, M.B., 1981. 'Obliquely rotated principal components: an improved meteorological map-typing technique?' *Journal of Applied Meteorology*, 20, 1145-1159.

Richman, M.B., 1986. (Review article) 'Rotation of principal components'. *Journal of Applied Meteorology*, **6**, 293-335.

Riehl, H., 1954. Tropical Meteorology. McGraw-Hill, New York, 392pp.

Riehl, H., 1979. Climate and weather in the tropics. Academic Press, London. 611pp.

Ropelewski, C.F. and Halpert, M.S., 1987. 'Global and regional scale precipitation pattern associated with the El Niño/Southern Oscillation'. *Monthly Weather Review*, 115, 1606-1626.

Ropelewski, C.F. and Halpert, M.S., 1989. 'Precipitation patterns associated with the high index phase of the Southern Oscillation'. *Journal Climate*, 2, 268-284.

Ropelewski, C.F. and Jones, P.D., 1987. 'An extension of the Tahiti-Darwin Southern Oscillation Index'. *Monthly Weather Review*, 115, 2161-2165.

Roy, N.S. and Kaur, S., 2000. ' Climatology of monsoon rains of Myanmar (Burma)', *International Journal of Climatology*, 20, 913-928.

Sankaran, P. and Quah, L.C., 1988. 'Empirical Orthogonal Function Analysis of the Interannual Variability at 850 hPa of the Northeast Monsoon over South East Asia'. *Departmental Seminar Paper 18*. Petaling Jaya, Malaysia Meteorological Service.

Schnur, R. and Lettenmaier D.P., 1998. 'A case study of statistical downscaling in Australia using weather classification by recursive partitioning'. *Journal of Hydrology*, 212-213, 362-379

Sham Sani, 1984. Beberapa Aspek Iklim Negeri Sabah (Several Aspects of Climate in Sabah). Kajian Etnografi Sabah Jilid 8 (Enthnography Study of Sabah Volume 8). Bangi, Malaysia, Universiti Kebangsaan Malaysia – Yayasan Sabah.

Sheridan, S.C., 2002. 'The redevelopment of a weather-type classification scheme for North America'. *International Journal of Climatology*, 22, pp 51-68

Shi, N. and Zhu, Q., 1996. 'An Abrupt Change in the Intensity of the East Asian Summer Monsoon Index and its Relationship with Temperature and Precipitation over East China'. *International Journal of Climatology,* 16, 757-754.

Shukla, J. and Paolina, D.A., 1983. 'The Southern Oscillation and long-range forecasting of the summer monsoon rainfall over India'. *Monthly Weather Review*, 111, 1830-1837.

Shukla, J., 1984. 'Predictability of time averages : Part II. The influence of the boundary forcing', in M.D. Burridge and E. Kallen, Eds., *Problems and Prospects in long and medium range weather forecasting*, Springler – Verlag, London, 155-206.

Sirabaha, S. and Ceaser, J., 2000. Significance of the El Niño Southern Oscillation (ENSO) for Southeast Asia. *A paper presented at the Workshop on the Impact of El Niño-la Niña on Southeast Asia*, CERED, IGCN, APNGCR, UEA at Hanoi, Vietnam: 21-23 February 2000.

Sirabaha, S., 1998. The El Niño Southern Oscillation (ENSO) Impact on Interannual Rainfall Variability in Borneo Island. PhD Thesis, University of East Anglia.

Sirabaha, S., 2004. The Influence of El Niño Southern Oscillation on Climate in Southeast Asia. PhD Thesis, University of East Anglia.

Sirinada, K.U., 1990. 'Rainfall seasonality in Negara Brunei Darussalam'. *Asian Geographer*, 9, 39-52.

Slingo, J.M. and Annamalai, H., 2000. '1997: The El Niño of the century and the response of the Indian summer monsoon'. *Monthly Weather Review*, 128, 1778-1797.

Stringer, E., 1972. Foundations of Climatology An Introduction to Physical, Dynamic, Synoptic and Geographical Climatology. San Francisco, WH Freeman & Co.

Subrahmanyam, V.P., 1956. 'Climatic types of India according to rational classification of Thornthwaite'. *Indian Journal of Meteorology and Geophysics* 7(3), 253

Thomas, J.J., 1983. An introduction to statistical analysis for economists (second edition). Weidenfeld and Nicolson: London, 228-276

Tangang, F., 1999. 'Empirical Orthogonal Function Analysis of Precipitation Anomaly in Malaysia. Malaysian'. *Journal of Analytical Sciences* 5, 155-165. Bangi, Universiti Kebangsaan Malaysia.

Tangang, F, 2001. 'Low Frequency and Quasi-Bienniel Oscillations in the Malaysian Precipitation Anomaly'. *International Journal of Climatology*, 21, 1199-1210

Tao, S.Y. and Chen, L.X., 1987. 'A review of recent research of the East Asian summer monsoon in China', *in Monsoon Meteorology*, Eds: C.P.Chnag and T.N Krishnamurti, Oxford University Press, 60-92.

The ASEAN Climatic Atlas. 1982. ASEAN sub-committee on Climatology, ASEAN Sectretariat.

Thornthwaite, C.W. and Mather, J.R., 1955. 'The moisture balance'. Publications in Climatology, 8, Laboratory of Climatology Centerton, NY, 104 pp.

Tourre, Y. M., and White, W.B., 1994.' ENSO signals in global upper ocean temperature'. *J. Phys. Oceanogr.* 25, 1317-1332.

Tourre, Y. M., and W.B. White, 1996, Evolution of the ENSO signal over the Indo-Pacific domain. *J. Phys. Oceanogr.* 27, 683-696.

Trenberth, K.E. and Hoar, T.J., 1996. 'The 1990-1995 El Niño-Southern Oscillation Event: Longest on record'. *Geophysical Research Letters*, 23, 57-60.

Trenberth, K.E., Stepaniak, D.P., Hurrell, J.W. and Fiorino, M., 2001. 'Quality of Reanalyses in the Tropics'. *Journal of Climate*, 14, 1499-1510.

Turner, J. Rick and Julian Thayer, 2001. Introduction to analysis of variance. Thousand Oaks, CA: Sage Publications.

Verma, R.K. and P.P. Kamte, 1980. 'Statistical technique for long-range forecasting of summer monsoon activity over India'. *Proceedings of Symposium on The Probabilistic and Statistical Methods in Weather Forecasting*, 8-12 September, 1980, Nice, WMO, Geneva, pp. 303-307.

Virmani, S.M., 1980. 'Need, relevance, and objectives of the consultants' meeting on climate classification'. *Proceeding of Climatic Classification: A Consultants' Meeting* 14-16 April 1980 (International Crops Research Institute for the Semi-Arid Tropics) xvii-xx

Walker, G.T. and Bliss, E.W., 1932. 'World Weather V'. *Mem. Royal Meteorology Society*, 4, 53-84.

Walker, G.T., 1918. 'Correlation in seasonal variation of weather'. *Quarterly Journal of Royal Meteo. Soc.*, 44, 223-334.

Walker, G.T., 1923. 'Correlation in seasonal variations of weather. III: A preliminary study of world weather', Mem. Indian Meteorology Department, 24, pp75-131.

Wang, B., 1992. 'An Overview of the Madden-Julian Oscillation and Its Relations to Monsoon and Mid-Latitude Circulation'. *Advances in Atmospheric Sciences*, Vol.9 No.1

Wang, B., and Z. Fan, 1999: 'Choice of South Asian monsoon indices'. *Bull. Amer. Meteor. Soc.* 80, 629-638.

Wang, B., 2000. 'Commentary and analysis'. *Bulletin of the American Meteorological Society*, Vol. 81, No. 4, 821-824

Webster, P.J. and Yang, S., 1992. 'Monsoon and ENSO; selectively interactive system'. *Quarterly Journal of Royal Meteorological Society*, 118, 877-926.

Webster, P.J., Magana, V.O., Palmer, T.N., Shukla, J., Tomas, R.A., Yanai, M and Yasunari, T., 1992. 'Monsoons: Processes, predictability, and the prospects for prediction'. *Journal of Geophysical Research*, 103, 14451-14510.

Webster, P.J., Moore, A.M., Loschinigg, J.P. and Leben, R.R., 1999 'Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997-98'. *Nature*, 401, 356-359.

Wolter, K., and M.S. Timlin, 1993: Monitoring ENSO in COADS with a seasonally adjusted principal component index. *Proc. of the 17th Climate Diagnostics Workshop*, Norman, OK, NOAA/N MC/CAC, NSSL, Oklahoma Clim. Survey, CIMMS and the School of Meteor., Univ. of Oklahoma, 52-57.

Wu, M.C. and Chan, J.C.L. 1997. ' Upper level features associated with winter monsoon surges over South China'. *Monthly Weather Review*, 125, 317-340.

Wu, R. and Wang, B. 2002. 'A contrast of the East Asian summer monsoon-ENSO relationship between 1962-77 and 1978-93', Journal of Climate, 15, 3266-3279.

WWF. 1998. 'Haze damage from 1997 Indonesia forest fires exceeds US$1.3 billion, study shows', website: wwf.org/new/fires/dam.htm, (viewed on 9 April 2005).

Wyrtki, K., l956: The rainfall over the Indonesian waters. Lembaga Meteorologi dan Geofisik, Verhandelingen No. 49, 24 pp.

Wyrtki, K. 1975. "El Niño-the dynamic response of the equatorial Pacific Ocean to atmospheric forcing'. *Journal of Physical Oceanography*, 5, no.4, 572-584.

Yanai, M., Li, C. and Song, Z., 1992. 'Seasonal heating of the Tibetan Plateau and its effects on the evolution of the Asian summer monsoon'. *Journal of the Meteorological Society of Japan*, 70, 319-351.

Yang, G.Y. and Slingo, J., 2001. 'The diurnal cycle in the tropics'. *Monthly Weather Review*, 129, 784-801.

Yarnal, B., 1984. 'A procedure for the classification of synoptic weather maps from gridded atmospheric pressure surface data'. *Computers and Geosciences*, 10, 397-410.

Yarnal, B., 1993. Synoptic Climatology in Environmental Analysis. Belhaven Press, London, 195 pp.

Yasunari, T. and Seki, Y., 1992. ‘Role of the Asian monsoon on the interannual variability of the global climate system’. *Journal of the Meteorological Society of Japan*, 70, 177-189.

Yasunari, T., 1980. ‘A quasi-stationary appearance of 30 to 40 day period in cloudiness fluctuations during the summer monsoon over India’. *Journal of the Meteorological Society of Japan*, 58,225-229.

Yasunari, T., 1985. ‘Zonally propagating modes of the global east-west circulation associated with the Southern Oscillation’. *Journal of the Meteorological Society of Japan*, 65, 81-102.

Yasunari, T., 1990. ‘Impact of Indian Monsoon on the Coupled Atmosphere/Ocean Systems in the Tropical Pacific’. *Meteorology and Atmospheric Physics*, 44, 29-41.

Yasunari, T., 1991. ‘The monsoon year-A new concept of the climatic year in the tropics’. *Bulletin of the American Meteorological Society*, 72, 1331-1338.

Yearbook of Statistics, Malaysia. 2004. Department of Statistics Malaysia, Kuala Lumpur.

Yearbook of Statistics, Sabah. 2004. Department of Statistics Malaysia, Kuala Lumpur.

Yearbook of Statistics, Sarawak. 2004. Department of Statistics Malaysia, Kuala Lumpur.

Appendix A

List of well-established monsoon indices

Author	Index	Climatic variables used to establish indices	Monsoon region	Time-scale & Season
Webster and Yang (1992)	Webster and Yang Monsoon Index (WYI**)	The time-mean zonal wind (U) shear between 850 and 200 hPa (U850 – U200); averaged over south Asia from the equator to 20°N, and from 40°E to 110°E	Large-scale Asian monsoon region and South Asia region (excluding northern Bay of Bengal and a portion of south China)	Seasonal values for Summer Monsoon
Parthasarathy et al. (1995)	All Indian Rainfall Index (AIRI**)	Seasonally averaged rainfall over all Indian sub-divisions from June-September (1871 – 1995)	South Asia region (excluding northern Bay of Bengal and a portion of south China)	Seasonal values for Summer Monsoon
Goswami et al. (1999)	Monsoon Hadley Circulation index (MH)	The time-mean meridional wind (V) difference between 850 and 200 hPa (V850 – V200); averaged over the region of 10°N-30°N and 70°E-110°E	South Asia region (including northern Bay of Bengal and a portion of south China)	Seasonal values for Summer Monsoon
Wang and Fan (1999)	Convection Index (CI1 and CI2) Difference in Zonal (U) Wind (DU2)	CI1: negative outgoing longwave radiation (OLR) anomalies over the region of 10°N-25°N and 70°E-100°E CI1: negative OLR anomalies over the region of 10°N-25°N and 115°E-140°E DU2: meridional (U) wind difference at 850 hPa between region 5°-15°N; 90°E-130°E and region 22.5°-32.5°N; 110°E-140°E	CI1 for south Asian summer; CI2 and DU2 for southeast Asian summer monsoon	Seasonal values for Summer Monsoon
Lu and Chan (1999)	Unified Monsoon Index (UMI1**, UMI2**, UMI3)	UMI1: difference between meridional wind at 1000 hPa and 200 hPa (V1000 – V200) UMI2: the monthly average of meridional wind component at 1000 hPa UMI3: monthly average of meridional wind component at 200 hPa All calculations are over the region of South China Sea (2.5°-22.5°N; 102.5°E-122.5°E)	UMI1, UMI2 and UMI3 mainly for East Asia region	Monthly values for both monsoons (summer and winter)
Lau et al. (2000)	Regional Monsoon Index (RMI1 and RMI2**)	RMI1: the time-mean meridional wind (V) difference between 850 and 200 hPa (V850 – V200); averaged over the region of 10°N-30°N and 70°E-110°E RMI2: the time-mean zonal wind (U) at 200 hPa between region 40°N-50°N; 110°E-150°E and region 25°N-32.5°N; 110°E-150°E	RM1 for South Asia region and RM2 for East and Southeast Asia region	Seasonal values for Summer Monsoon

*Indices marked with ** are chosen in the comparison analysis in Section 6.3*

Appendix B

42 stations in Borneo for surface variables (precipitation and temperature)

This is the list of 42 original stations in Borneo, which had been evaluated for the best quality of data. The original range of data is referred to the actual period of available data provided by the authorized organization from each country (i.e. Malaysia, Brunei and Indonesia). The extended period is obtained when these original data were merged with the data available in Climatic Research Unit (CRU). The stations that are marked with (*) have been chosen for this analysis (see Chapter 3, Section 3.3.2). The final 29 selected Key Stations are those marked with (*) and given an abbreviation.

New Data Set (Extended Version) – SABAH and SARAWAK

STATION	Range Of Data Original	Extended	STATUS	SOURCE OF DATA
Kota Kinabalu KK*	1968 – 2001	1947 – 2001	Old entry – being extended	MMS (fieldwork) + CRU Data Set
Kudat KDT*	1983 – 2001	-	Old entry – no modification	MMS (fieldwork)
Labuan LBN*	1978 – 2001	-	Old entry – no modification	MMS (fieldwork)
Sandakan SDK*	1968 – 2001	1879 – 2001	Old entry – being extended	MMS (fieldwork) + CRU Data Set
Tawau TWU*	1979 – 2001	-	Old entry – no modification	MMS (fieldwork)
Merotai	1964 – 1987	-	New entry	CRU Data Set
Imam	1962 – 1987	-	New entry	CRU Data Set
Tiger	1966 – 1987	-	New entry	CRU Data Set
Table	1964 – 1987	-	New entry	CRU Data Set
Sri Aman SAM*	1983 – 2001	-	Old entry – no modification	CRU Data Set
Miri MIR*	1968 - 2001	1916 – 2001	Old entry – being extended	MMS (fieldwork) + CRU Data Set
Sibu SBU*	1968 - 2001	1915 – 2001	Old entry – being extended	MMS (fieldwork) + CRU Data Set
Bintulu BTU*	1968 - 2001	1911 – 2001	Old entry – being extended	MMS (fieldwork) + CRU Data Set
Kuching KCH*	1968 - 2001	1876 – 2001	Old entry – being extended	MMS (fieldwork) + CRU Data Set

New Set of Data (Extended Version) – BRUNEI

STATION	Range Of Data Original	Extended	STATUS	SOURCE OF DATA
Airport BRA*	1970 – 1997	1966 – 2000	Old entry – being extended	BMS + CRU Data Set
Kilana BRL*	1946 – 1990	-	New entry	BMS
Seria BRS*	1946 – 1990	-	New entry	BMS
Labi BRS*	1946 – 1990	-	New entry	BMS

New Set of Data (Extended Version) – KALIMANTAN

STATION	Range Of Data Original	Extended	STATUS	SOURCE OF DATA
Balik Papan BPN*	1960 – 1990	1946 – 2000 (1990)	Old entry – being extended	IMGA + CRU Data Set
Kota Baru KBA*	1962 – 1990	1927 – 1990	Old entry – being extended	IMGA + CRU Data Set
Muara Tewe MTW*	1961 – 1990	1951 – 1990	Old entry – being extended	IMGA + CRU Data Set
Nanga Pinoh NGA*	1983 – 1990	1906 – 1990	Old entry – being extended	IMGA + CRU Data Set
Palangaka Raya PRYA*	1969 – 1990	-	Old entry – no modification	IMGA
Paloh	1986 – 1990	-	Old entry – no modification	IMGA
Pangkalan Bun PBN*	1972 – 1990	1906 – 2000 (1985)	Old entry – being extended	IMGA + CRU Data Set
Pontianak PTK*	1961 – 1990	1879 – 1991	Old entry – being extended	IMGA + CRU Data Set
Samarinda SMD*	1978 – 1990	1904 – 1990	Old entry – being extended	IMGA + CRU Data Set
Sintang	1980 – 1990	-	Old entry – no modification	IMGA
Tarakan TRK*	1961 – 1970	1911 – 1991 (1990)	Old entry – being extended	IMGA + CRU Data Set
Tanjung Selor TSR*	1961 – 1976	1893 – 1976	Old entry – being extended	IMGA + CRU Data Set
Banjar Masin BMS*	1951 – 1999 (1988)	-	New entry	CRU Data Set
Barabai	1879 – 1975	-	New entry	CRU Data Set
Buntok BTK*	1881 – 1975	-	New entry	CRU Data Set
Ketapang KPG*	1904 – 1998 (1991)	-	New entry	CRU Data Set
Long Iram LIM*	1960 – 1975	-	New entry	CRU Data Set
Marta Pura	1914 – 1975	-	New entry	CRU Data Set
Muara Ancalung MAN*	1927 – 1975	-	New entry	CRU Data Set
Muara Pundak	1906 – 1975	-	New entry	CRU Data Set
Ngabang	1909 – 1975	-	New entry	CRU Data Set
Sampit	1902 – 1973	-	New entry	CRU Data Set
Singkawang	1879 – 1989	-	New entry	CRU Data Set
Tanjung Redep	1908 – 1975	-	New entry	CRU Data Set

Appendix C

Statistical performances (significance test) for each classification scheme evaluated based on frequency and mean differences

(a) Chi Square test for circulation occurrences by different classification schemes*

		Chi Square test: X^2 values are all significant at the 99% level of confidence		
Method	Classification Scheme	Overall	NE Monsoon	SW Monsoon
Method 1	Cluster-Absolute	1888	4130	7590
Method 2	Correlation-Absolute	7067	8974	16948
Method 3	Cluster-Anomaly	566	154	826
Method 4	Correlation-Anomaly	17682	8485	9687

(b) Chi Square test for extreme measures in precipitation and temperature for each station by different classification schemes*

	Chi Square test: X^2 values are all significant at the 99% level of confidence							
	Frequency (90th percentile of precipitation)				Frequency (90th percentile of T-mean temperature)			
STATION	Method 1	Method 2	Method 3	Method 4	Method 1	Method 2	Method 3	Method 4
SDK (Climate Group A1)	190	186	47	52	110	64	138	175
MIR (Climate Group A1)	67	107	68	80	141	180	211	191
BTU (Climate Group A1)	49	43	48	44	199	215	236	226
KK (Climate Group A2)	169	253	58	80	125	154	239	215
SBU (Climate Group B1)	76	59	68	79	236	204	305	333
KCH (Climate Group B1)	237	186	58	92	175	155	220	254

*(c) Analysis of variance (ANOVA)** for precipitation and temperature for each station by different classification schemes*

	Analysis of variance (testing mean differences): F values are all significant at the 99% level of confidence							
	Precipitation Daily Average (mm/day)				Temperature Anomaly (T-mean)			
STATION	Method 1	Method 2	Method 3	Method 4	Method 1	Method 2	Method 3	Method 4
SDK (Climate Group A1)	45.9	7.5	37.0	7.6	20.5	40.3	13.3	47.0
MIR (Climate Group A1)	16.0	9.8	22.9	10.3	18.7	48.6	18.3	50.3
BTU (Climate Group A1)	15.8	6.9	14.9	7.5	21.2	46.4	16.8	45.3
KK (Climate Group A2)	27.0	5.6	36.7	6.6	28.4	67.8	19.4	63.2
SBU (Climate Group B1)	26.4	11.5	20.0	11.1	26.0	57.1	12.4	53.6
KCH (Climate Group B1)	65.6	10.6	45.9	13.3	21.1	43.8	7.7	38.9

** Chi Square tests are conducted by comparing the annual frequencies of each circulation type within the compared events/methods over the period of 1968-2001*
*** ANOVA is performed by comparing the precipitation/temperature annual means for each circulation type within the compared methods over the period of 1968-2001*

All values are significant at the 99% level of confidence. In a case where the number of cases (N) are equal for all tested variables, the values (i.e. X^2 and F) themselves should naturally indicate the degree of difference. The bigger the value is, the higher the degree of difference is (Popham, 1967), thus it could implicitly indicates 'a more obvious' (stronger) relationship.

Appendix D

Tables showing the FIRST TWO STRONGEST types, which produce wetter or drier days (compared to the overall average of daily precipitation) in different seasons and using different combinations of data and classification methods.

(a) Relationships with precipitation: Cluster-Absolute circulation types (Method 1)

	NE MONSOON (OCTOBER – MARCH)		SW MONSOON (APRIL – SEPTEMBER)	
STATION	WET TYPE	DRY TYPE	WET TYPE	DRY TYPE
SDK (A1)	1 (46%); 6 (4%)	7 (43%); 4 (25%)	8 (45%), 2 (11%)	6 (33%); 7 (22%)
MIR (A1)	8 (35%); 1 (21%)	4 (29%); 7 (15%)	7 (21%); 8 (6%)	5 (28%); 3 (10%)
KK (A2)	8 (140%); 3 (40%)	4 (45%); 6 (23%)	2 (12%); 8 (11%)	6 (76%); 4 (50%)
BTU (B1)	1 (19%); 3 (2%)	7 (15%); 4 (15%)	4 (25%); 1 (17%)	6 (62%); 5 (19%)
SBU (B1)	1 (21%); 4 (2%)	2 (29%); 8 (21%)	4 (32%); 6 (28%)	5 (28%); 8 (23%)
KCH (B1)	1 (37%); 4 (5%)	2 (37%); 7 (27%)	3 (16%); 2 (15%)	5 (19%); 8 (8%)

(b) Relationships with precipitation: Correlation-Absolute circulation types (Method 2)

	NE MONSOON (OCTOBER – MARCH)		SW MONSOON (APRIL – SEPTEMBER)	
STATION	WET TYPE	DRY TYPE	WET TYPE	DRY TYPE
SDK (A1)	5 (107%); 1 (23%)	4 (58%); 7 (36%)	8 (36%); 2 (11%)	4 (36%); 1 (34%)
MIR (A1)	5 (173%); 3 (36%)	4 (65%); 6 (20%)	3 (38%); 2 (22%)	1 (30%); 5 (12%)
KK (A2)	8 (139%); 3 (64%)	4 (58%); 6 (40%)	8 (33%); 2 (19%)	6 (73%); 4 (53%)
BTU (B1)	5 (181%); 1 (22%)	4 (36%); 2 (15%)	1 (46%); 2 (9%)	4 (22%); 5 (4%)
SBU (B1)	1 (17%); NA	5 (57%); 8 (20%)	4 (50%); 1 (48%)	8 (24%); 5 (16%)
KCH (B1)	5 (35%); 1 (16%)	7 (35%); 2 (18%)	1 (26%); 4 (20%)	8 (19%); 3 (16%)

(c) Relationships with precipitation: Cluster-Anomaly circulation types (Method 3)

	NE MONSOON (OCTOBER – MARCH)		SW MONSOON (APRIL – SEPTEMBER)	
STATION	WET TYPE	DRY TYPE	WET TYPE	DRY TYPE
SDK (A1)	5 (45%); 7 (34%)	1 (44%); 12 (30%)	7 (16%); 5 (14%)	8 (29%); 1 (27%)
MIR (A1)	7 (21%); 5 (18%)	1 (32%); 11 (30%)	7 (52%); 5 (50%)	11 (46%); 2 (41%)
KK (A2)	12 (48%); 9 (20%)	1 (48%); 11 (28%)	7 (39%); 8 (23%)	11 (47%); 1 (30%)
BTU (B1)	8 (22%); 5 (14%)	1 (17%); 2 (14%)	6 (32%); 7 (29%)	2 (37%); 12 (31%)
SBU (B1)	4 (21%); 5 (21%)	12 (20%); 11 (17%)	5 (40%); 8 (40%)	12 (38%); 2 (37%)
KCH (B1)	5 (46%); 4 (14%)	10 (27%); 11 (22%)	8 (24%); 5 (22%)	11 (28%); 12 (28%)

(d) Relationships with precipitation: Correlation-Anomaly circulation types (Method 4)

	NE MONSOON (OCTOBER – MARCH)		SW MONSOON (APRIL – SEPTEMBER)	
STATION	WET TYPE	DRY TYPE	WET TYPE	DRY TYPE
SDK (A1)	8 (38%); 7 (36%)	1 (61%); 3 (52%)	7 (33%); 3 (29%)	8 (30%); 1 (27%)
MIR (A1)	8 (42%); 4 (29%)	1 (48%); 6 (44%)	5 (47%); 8 (28%)	10 (43%); 2 (40%)
KK (A2)	2 (98%); 12 (58%)	1 (61%); 6 (30%)	7 (45%); 8 (35%)	1 (60%); 11 (44%)
BTU (B1)	5 (21%); 4 (14%)	2 (26%); 1 (25%)	8 (48%); 5 (33%)	12 (42%); 9 (41%)
SBU (B1)	9 (26%); 4 (26%)	2 (32%); 3 (30%)	4 (43%); 8 (38%)	2 (67%); 12 (40%)
KCH (B1)	5 (45%); 9 (19%)	2 (31%); 3 (19%)	5 (33%); 8 (30%)	2 (31%); 12 (27%)

Numbers in parenthesis indicate the percentage of deviation from the overall mean
NA indicates the second strongest type is not available because all the other types are above/below the normal

Appendix E

Tables showing the FIRST TWO STRONGEST types, which produce hotter or cooler days (i.e. positive or negative temperature anomaly) in different seasons and using different combinations of data and classification methods

(a) Relationships with temperature anomaly: Cluster-Absolute circulation types (Method 1)

	NE MONSOON (OCTOBER – MARCH)		SW MONSOON (APRIL – SEPTEMBER)	
STATION	HOT TYPE	COOL TYPE	HOT TYPE	COOL TYPE
SDK (A1)	7 (18%); 4 (13%)	6 (15%); 1 (7%)	8 (20%); 5 (8%)	7 (11%); 6 (3%)
MIR (A1)	7 (23%); 4 (15%)	6 (11%); 1 (4%)	5 (12%); 8 (10%)	6 (27%); 7 (10%)
KK (A2)	2 (20%); 4 (18%)	6 (17%); 8 (6%)	8 (20%); 6 (15%)	7 (14%); NA
BTU (B1)	7 (19%); 4 (17%)	6 (13%); 1 (4%)	4 (14%); 8 (12%)	7 (11%); 3 (9%)
SBU (B1)	7 (19%); 8 (15%)	1 (11%); 1 (4%)	8 (21%); 5 (18%)	7 (13%); 3 (12%)
KCH (B1)	2 (20%); 4 (12%)	1 (12%); 3 (3%)	5 (15%); 4 (13%)	3 (16%); 6 (12%)

(b) Relationships with temperature anomaly: Correlation-Absolute circulation types (Method 2)

	NE MONSOON (OCTOBER – MARCH)		SW MONSOON (APRIL – SEPTEMBER)	
STATION	HOT TYPE	COOL TYPE	HOT TYPE	COOL TYPE
SDK (A1)	4 (27%); 2 (18%)	6 (12%); 5 (9%)	8 (27%); 3 (6%)	6 (26%); 1 (12%)
MIR (A1)	4 (34%); 7 (26%)	5 (80%); 3 (11%)	4 (11%); 8 (6%)	6 (30%); 3 (16%)
KK (A2)	4 (37%); 2 (24%)	6 (13%); 5 (6%)	4 (10%); 8 (4%)	1 (23%); 6 (12%)
BTU (B1)	5 (38%); 4 (33%)	6 (10%); 3 (6%)	4 (15%); 8 (10%)	3 (15%); 6 (14%)
SBU (B1)	5 (49%); 4 (27%)	2 (8%); 3 (6%)	8 (19%); 5 (5%)	1 (23%); 3 (17%)
KCH (B1)	5 (47%); 4 (23%)	1 (7%); 3 (6%)	8 (10%); 5 (4%)	6 (24%); 1 (23%)

(c) Relationships with temperature anomaly: Cluster-Anomaly circulation types (Method 3)

	NE MONSOON (OCTOBER – MARCH)		SW MONSOON (APRIL – SEPTEMBER)	
STATION	HOT TYPE	COOL TYPE	HOT TYPE	COOL TYPE
SDK (A1)	1 (38%); 9 (17%)	7 (41%); 5 (9%)	12 (36%); 11 (26%)	5 (23%); 7 (18%)
MIR (A1)	1 (37%); 11 (19%)	7 (33%); 12 (15%)	11 (25%); 12 (25%)	5 (32%); 7 (31%)
KK (A2)	1 (47%); 9 (19%)	7 (50%); 5 (17%)	12 (34%); 1 (29%)	7 (34%); 5 (28%)
BTU (B1)	1 (38%); 11 (20%)	7 (27%); 3 (16%)	9 (25%); 12 (23%)	7 (30%); 5 (29%)
SBU (B1)	9 (25%); 11 (20%)	7 (27%); 3 (22%)	12 (38%); 9 (36%)	5 (38%); 8 (26%)
KCH (B1)	1 (26%); 11 (17%)	7 (21%); 5 (19%)	9 (31%); 11 (30%)	7 (30%); 8 (27%)

(d) Relationships with temperature anomaly: Correlation-Anomaly circulation types (Method 4)

	NE MONSOON (OCTOBER – MARCH)		SW MONSOON (APRIL – SEPTEMBER)	
STATION	HOT TYPE	COOL TYPE	HOT TYPE	COOL TYPE
SDK (A1)	1 (52%); 9 (43%)	7 (56%); 8 (11%)	12 (37%); 9 (27%)	3 (35%); 7 (28%)
MIR (A1)	9 (50%); 1 (49%)	7 (51%); 3 (37%)	1 (37%); 9 (30%)	3 (44%); 7 (32%)
KK (A2)	1 (67%); 9 (52%)	7 (58%); 3 (33%)	1 (43%); 9 (37%)	7 (42%); 3 (39%)
BTU (A1)	1 (48%); 9 (40%)	7 (48%); 3 (37%)	9 (48%); 1 (40%)	3 (47%); 7 (27%)
SBU (B1)	9 (54%); 1 (31%)	3 (37%); 7 (36%)	9 (68%); 2 (52%)	3 (61%); 5 (31%)
KCH (B1)	1 (29%); 11 (16%)	3 (22%); 7 (22%)	9 (59%); 1 (38%)	3 (50%); 7 (28%)

Numbers in parenthesis indicate the percentage of deviation from the overall mean
NA indicates the second strongest type is not available because all the other types are above/below the normal

Appendix F

Summary of relationships between circulation types and precipitation

Type	Frequency of Occurrences: Monsoon High	Monsoon Low	ENSO High	ENSO Low	Relationships during the monsoon cycle (NET, NEM, SWT, SWM) – which stations? Positive Anomaly	Negative Anomaly	Relationships during the ENSO phases (WEL, SEL, WLA, SLA) – which stations? Positive Anomaly	Negative Anomaly
1	NET NEM	SW	SLA	WLA	P_{8mm} /NEM/A1,A2 P_{90th} /NEM/A1 P_{avg}/NEM/A1,B1	NA	All variables SEL/B1	NA
2	SW	NEM	SEL	SLA	P_{8mm}/SWM/B1	All extreme variables NEM/B1	P_{avg}/SLA/B1	NA
3	NEM	-	-	-	P_{int}/NEM/A1	P_{avg}/NEM/B1	P_{avg}/SLA/A1	
4	NEM	SWM	SEL	-	P_{avg}, P_{8mm}, P_{90th}/NET/B1 (except KCH) P_{8mm}/SWT/B1 (except KCH)	All variables NEM/A1,A2 P_{8mm}, P_{90th}, P_{wet}/SWM/KCH	NA	P_{avg}, P_{wet}, P_{90th}/SLA/ all stations P_{avg}, P_{wet}, P_{90th} /WEL/A1,A2
5	SWM	NET NEM	WLA	SLA	NA	NA	NA	P_{wet}, P_{8mm}/SLA/ all stations P_{wet}/WLA/A1
6	NEM	SWM	WLA	SLA	NA	P_{8mm}/NET/A2, B1(except KCH)	NA	P_{avg}, P_{int}/SEL/A1,A2
7	SWT	NEM	WLA	-	NA	P_{8mm}/all seasons/KCH	P_{avg}, P_{int}/WEL/KCH	NA
8	NEM	-	-	-	All variables NEM/all stations*	P_{avg}, P_{int}, P_{8mm}, P_{90th}/SWT/KK, MIR, BTU, SBU (except SDK)	P_{int}, P_{90th} /SEL/A1,A2	P_{int}, P_{90th}/SEL/B1

Magnitude variables: P_{avg} (Precipitation Average), P_{int} (Precipitation Intensity); Extreme variables: P_{wet} (Rain Days), P_{8mm} (Heavy Rainfall), P_{90th} (90^{th} Percentile); Monsoon cycle: NET (Northeast Transition), NEM (Northeast Monsoon), SWT (Southwest Transition), SWM (Southwest Monsoon); ENSO years: WEL (Weak El Niño), SEL (Strong El Niño), WLA (Weak La Niña), SLA (Strong La Niña); NA = Does not occur

Appendix G

Summary of relationships between circulation types and temperature variables

	Frequency of Occurrences Monsoon		ENSO		Relationships during the monsoon cycle (NET, NEM, SWT, SWM) – which stations?		Relationships during the ENSO phases (WEL, SEL, WLA, SLA) – which stations?	
Type	High	Low	High	Low	Positive Anomaly	Negative Anomaly	Positive Anomaly	Negative Anomaly
1	NET NEM	SW	SLA	WLA	NA	NA	NA	NA
2	SW	NEM	SEL	SLA	T_{avg}, T_{max}/NET/A1,A2 T_{90avg}/NEM/B1	T_{10min}/NEM/B1	NA	T_{90avg}/SLA/all stations T_{avg}/SLA/all stations
3	NEM	-	-	-	T_{10min} /NEM/MIR, B1	T_{min}/SWM/B1	NA	T_{10min}/SLA/all sttaions
4	NEM	SWM	SEL	-	T_{avg}, T_{max}, T_{min}/NEM/all stations T_{90avg}, T_{90max}/SWT/KK, MIR, BTU	T_{10min}/SWM/all stations (exc. BTU)	T_{avg}, T_{max}/WEL/all stations	NA
5	SWM	NET NEM	WLA	SLA	NA	NA	T_{90avg}/WLA/A1, B1	T_{min}/SLA/all stations T_{avg}/SLA/A1
6	NEM	SWM	WLA	SLA	T_{10min}/NET/all stations	T_{min}/NET/all stations	All variables (exc. T_{10min})/SEL/all stations	NA
7	SWT	NEM	WLA	-	T_{90avg}/NET/all stations T_{avg}, T_{max}, T_{min}/NEM/all stations	T_{90avg}/SWM/all stations T_{avg}, T_{max}/SWM/all stations	NA	T_{90avg}/SEL/B1 T_{90max}/SEL/all stations
8	NEM	-	-	-	T_{10min} /SWT/all T_{avg}/SWT/SDK,SBU,KCH T_{max}/NET/SDK,SBU,KCH	T_{max}/NEM/MIR, BTU T_{10min} /SWT/B1	T_{90avg}/WLA/all stations T_{90avg}/SLA/A1,B1	T_{10min} /SEL/A1,A2 T_{10min} /SLA/B1

Magnitude variables: T_{avg} (Mean Temperature), T_{max} (Maximum Temperature), T_{min} (Minimum Temperature); Extreme variables: T_{90avg} (90^{th} Percentile of Mean Temperature), T_{90max} (90^{th} Percentile of Maximum Temperature), T_{10min} (10^{th} Percentile of Minimum Temperature),; Monsoon cycle: NET (Northeast Transition), NEM (Northeast Monsoon), SWT (Southwest Transition), SWM (Southwest Monsoon); ENSO years: WEL (Weak El Niño), SEL (Strong El Niño), WLA (Weak La Niña), SLA (Strong La Niña); NA = Does not occur

Appendix H

Hypothesis-driven analysis, exploratory analysis, and their major characteristics

Hypothesis-driven study	Exploratory study
Motivating question: "Can I reject the null hypothesis that precipitation in Borneo is unrelated to a large-scale circulation in Southeast Asia?"	Motivating question: "How can I optimally explain or describe the variation in the teleconnections between large-scale atmospheric circulation and the local climate of Borneo?"
The approach is objective.	The approach is more subjective.
Sites must be representative of universe: random, stratified random, regular placement.	Sites can be "encountered" or subjectively located.
Analyses must be planned based on a priori (i.e. sound theoretical background).	"Data mining" is permissible (i.e. post-hoc analyses, explanations, hypotheses).
The p-values are meaningful.	The p-values are only a rough guide.
Stepwise: techniques are not valid without cross-validation.	Stepwise: techniques (e.g. forward selection) are valid and useful without being subjected to rigid cross-validation and justification.

Extracted and adapted from: http://ordination.okstate.edu/motivate.htm

True **knowledge** exists in knowing
that you know nothing.

Socrates
(Ancient Greek Philosopher, 470 BC-399 BC)