CHAPTER 1: INTRODUCTION

There is now unequivocal evidence from direct observations of a warming of the climate system (IPCC, 2007). Despite remaining uncertainties, it is now clear that the upward trend on global averaged temperatures during the 20th century is very likely due to anthropogenic origin; especially changes in the greenhouse gas concentrations (IPCC, 2007). These climatic changes have been recorded in observations of air and ocean temperatures, ice cores, glaciers, and increasing sea levels. With some geographical variations, all their average conditions testify to globally increasing temperatures.

Certainly, one of the arguments of the sceptics against global warming is the spatial inhomogeneity of the changes of the parameters that measure climate change across the world, like temperature (Soon et al., 2003). The largest percentage of the meteorological data, for example, comes from mid-latitude developed countries (Vose et al., 2005). There is a real necessity to gather information from developing countries to complete the picture of the global climate. It is only recently that more extensive climatic information from these regions has been added to the global databases. Among these developing countries, some of them are of great interest for climatologists: countries, for example, that lie at the transition between tropical and extra-tropical climatic conditions. Mexico is one of those countries that encompass a rich variety of climatic regions within its territory.

Mexico is a bridge between tropical and temperature latitudes that reflects a broad distribution of climatic regimes. For instance, are the climatic change patterns similar or they are strongly differing in the southern or northern part of the country? These questions need to be addressed in the climate change context in order to increase our understanding of the variables involved in the climate system. Although rapidly increasing, there is still a lack of studies on climate change in Mexico (Jauregui, 1997). A proper network of stations in terms of data coverage and length is necessary to analyse the climate of these regions. A pre-requisite for reliable results within these climatic studies are long-term and high-quality databases. Fortunately, it has been only recently that several digital databases of climatological data have become available and suitable for different scientific and social studies including climatic research.

Several efforts have been made in Mexico to build a large network of climatological stations across the country. The oldest set of stations to measure meteorological variables began in 1921, just after the end of the Mexican Revolution. In that year the Servicio Meteorológico de México (Mexican Meteorological Service) was created with 600 stations distributed across the country (Metcalfe, 1987). The latest digital datasets contain daily records of the main meteorological parameters. Several mathematical and statistical processes have been applied to different spatial and temporal resolutions in this thesis and the consistency of the results compared.

In this context, the aims of this thesis are:

1. A national appraisal of climatic patterns in México using instrumental data. In particular, daily and monthly (land surface) precipitation and air temperature will be used.
2. Climatic regionalisation of seasonal rainfall and temperature according to their secular variations using Principal Component Analysis (PCA).
3. An assessment of spatial and secular changes of rainfall and temperature extremes during the twentieth century, with special focus on finding the climatic patterns of the last few decades and consistency between local and regional scales. For this purpose, digital instrumental data and up_to_date software to calculate the weather extreme indices have been used.
4. Finally, an exploration of one of the large-scale atmospheric controls which modulate the long-term trends of Mexican climate at both regional and local scales is made, especially those associated with El Niño Southern Oscillation (ENSO) phenomenon.

The main characteristics of the climate of Mexico are addressed in Chapter two. Geographical features are explained in section 2.2. As mentioned above, Mexico is located in the transition between tropical and temperate climates. Therefore, latitude plays a key role in the rich variety of its climatic regimes, and that is fully explained in section 2.2.1. With two large mountain ranges along both coasts and a high central plateau, altitude has a great influence in many regions of Mexico, especially those in the northern part of the country that are affected during the winter by polar fronts, or the line of high-altitude sites within the neovolcanic belt in central Mexico. The orographic influence on climate is found in section 2.2.2. Two great bodies of waters also exert their influence on Mexican climate. Along the east coast, the Gulf of Mexico is a relatively closed basin that modulates the weather. The greatest variations in precipitation here are seen during the Hurricane season (approximately May-Nov). This is most apparent in the peninsula of Yucatan, and its rainfall patterns completely differ from the neighbouring regions. Because of its length and the vast extent the Pacific has larger influence than the Atlantic Ocean; and an enclosed body of water, the Gulf of California acts like a physical barrier to the cold marine currents at those latitudes to regulate what otherwise could be a more varying climatic region in north-western Mexico. Oceanic and continental influences are both addressed in section 2.2.3. Large-scale phenomena are considered in section 2.3. Northern Hemisphere General Circulation, Trade Winds and Subtropical High Pressure Belt are important, but probably the most extensive studied large-atmospheric control is the El Niño Southern Oscillation (ENSO) phenomenon with the key research on ENSO found in this section. Other important resources to understand the climate are: documentary and proxy data; these records aim to extend, back in time, the picture of the climate of Mexico. The different efforts to develop meteorological instrumental measurements are studied in section 2.4. The development of recent digital databases and their limitations are also seen in this section. Documentary and proxy data like historical records are addressed in section 2.5. Finally, some of the most important studies that have been explored about the climate of Mexico are shown in section 2.6. Conclusions are discussed in the last section (2.7) of the Chapter.

A rich variety of climates occur across Mexico (García, 1988). In order to understand and unveil these (sometimes contrasting) conditions of climate, different mathematical and statistical methods were applied. The best possible data quality is an essential condition for reliable results in climatology. For this reason, the extraction of the data was one of the most important stages in the present study. The whole process of gathering and analysing climatological time-series is reviewed in section 3.2. Only long records of digital instrumental data were used in this thesis. The different databases of daily temperature and precipitation are explained in section 3.2.1. For a station to be selected, its time-series needed to comply with several conditions such as: daily data, at least 30 years of information, less than ten percent of missing values, etc. This selection is explained in detail in section 3.2.2. Amongst the several natural causes that modulate the climate of Mexico, El Niño Southern Oscillation (ENSO) is probably the most extensively studied. In order to test the stability of the relations between the climate and ENSO, three different indices will be used: the Southern Oscillation Index (SOI), El Niño 3.4 and the Multivariate ENSO Index (MEI). The different sources, time-series lengths, characteristics, and other limitations are explained in section 3.2.3.

The selection of the different methods to be applied in the meteorological databases is crucial for the interpretation of the results. These are divided into the consideration of homogeneity, Principal Component Analysis (PCA), extreme weather analysis and regional averages within section 3.3. It has been already mentioned that one of the most important processes in the analysis of climate is the quality of the data. For instance, a few typing errors can severely alter the results. Considerations on homogeneity and urbanisation are found in section 3.3.1. For Mexico, a territory of complex climatic conditions; Principal Component Analysis (PCA) was chosen as an effective method to identify sets of stations (regionalisation) that vary coherently. The general characteristics and limitations of this technique will be discussed in section 3.3.2. Based on the results of PCA, the method used to obtain averages of the different regions is shown in section 3.3.3. For their extraordinary characteristics, and direct impact on society extreme weather indices are an important part of climatic studies. The consideration of these extraordinary events and their definitions for temperature and precipitation are explained in section 3.3.4. Because the analysis of extremes needs high-quality daily data a further refined selection among the rainfall and temperature stations was made in the same section. For different purposes linear and lag-cross correlations are used in the present research and these methods are explained in section 3.3.5. Non-parametric correlation, in particular kendall tau-b is preferred to the Pearson correlation coefficient and its advantages and limitations are described here. Because frequently, local meteorological parameters reflect a delayed response to large-atmospheric controls like ENSO, lag-cross correlations will be used in the present study. The main characteristics of this method are shown in the same section 3.3.5.

Chapter 4 outlines the search for coherent patterns of climatic variations in the networks of the main meteorological variables. PCA is the method selected to unveil these spatially coherent variations. Rotated PCA methods are preferred for their ability to deal with large networks of meteorological variables. The mean temperature and precipitation data have been processed into seasonal periods, i.e., annual, wet (May to October) and dry (November to April). PCA on the precipitation data is studied in section 4.2. Annual totals are analysed in section 4.2.1. A large percentage of the annual precipitation total occurs during the wet season (section 4.2.2); therefore, quite similar PCA regionalisations are expected for annual and wet season rainfalls. A different climatic picture is observed during the dry season in which most of the precipitation falls in winter, especially in the northwestern part of the country. The regionalisation of the dry season is found in section 4.2.3.

The variability of mean temperature increases from the narrow south to the wide territory of northern Mexico. The same PCA orthogonal (varimax) and oblique rotation techniques (promax) that were applied to precipitation are used for seasonal mean temperature. The temperature network (52 stations) is data-sparse when compared with the rainfall database (175 stations), and the time-series length is also shorter (1941-2001). The details of the analysis of annual mean temperature are found in section 4.3.1. Wet season analysis of mean temperature is presented in section 4.3.2. Due to their poor results in regionalisation, an additional analysis was performed using the standard three-monthly periods (DJF, MAM, JJA, and SON). The results of the application of PCA to these periods are shown in section 4.3.3. Because the division of the time-series into three monthly periods does not improve the results; a final attempt (seeking better results) was made applying K-means cluster analysis to the annual totals and wet season and these are discussed in section 4.3.4. The conclusions to chapter 4 are given in detail in section 4.4.

Another important aspect of studies on climate change is extreme events. In the case of precipitation, the network of monthly and daily data allows a comparison at both spatial and temporal scales. Non-parametric correlations using Kendall tau-b are applied to precipitation extreme indices at regional and local scales. In addition, results are divided in two parts using the Tropic of Cancer as a geographical limit in order to test a latitudinal transition of the changes on precipitation extremes.

The introduction to Chapter 5 and general considerations on precipitation extremes are detailed in section 5.1. In order to simplify the evaluation of the results, the precipitation indices have been divided in two different groups: one that measures depth (mm) or intensity (mm/day) and the other that calculates the frequency (number of cases). All these indices are evaluated separately, beginning with a classification according to the level of statistical significance (i.e., at 1% or 5%). Finally, how these climatic changes are occurring geographically, i.e., are they basically occurring in the southern part of Mexico or they are more drastic in the north of the country? All these details are explained in section 5.2.1. In order to check the consistency in the precipitation patterns, a linear trend is applied among the stations with the most important results (correlations) in section 5.2.2. General conclusions on precipitation extreme indices are evaluated in section 5.3.

According to instrumental records, the year 2005 (with 1998) had the warmest global average surface temperature (Osborn and Briffa, 2006). Mean temperatures have been studied extensively but less research has been made on extreme temperatures at a global scale. This situation is changing rapidly, see the recent study of Alexander et al. (2006). Nevertheless, there is a lack of studies on extreme temperatures in developing countries.

Chapter 6 aims to deal with this necessity in Mexico calculating the extreme temperature indices using a network of 26 stations that contain daily data from 1941 to 2001.

Based on daily data, extreme temperature indices (defined in section 3.3.4) are calculated for each station. Linear correlations are estimated for these indices using Kendall tau-b. In order to facilitate their evaluation, the extreme temperature indices have been classified into three different groups: one group deals with those indices expressed in absolute temperature; the indices that count the frequency a temperature exceeds a set limit in °C and the final groups measure the frequency with which the temperature surpasses a limit based on a percentile measure. The trend correlations are separated according to their levels of statistical significance (at 5% or 1% level), and also their tendency towards warming or cooling conditions. In addition, these correlations are evaluated geographically as to whether they are located south or north of the Tropic of Cancer in order to find any spatial pattern in these climatic changes. All these analyses are detailed in section 6.2.1. An analysis of linear trends on the temperature stations of with the most important correlations is applied in section 6.2.2. Conclusions and general remarks related to the analyses performed in this chapter are addressed in section 6.3.

Although, as mentioned earlier anthropogenic causes are increasing their influence on climate, natural variability is, however, still the greatest force on the climate system. Among the most important of the large-scale atmospheric controls, the El Niño-Southern Oscillation (ENSO) phenomenon plays a key role in the climate of Mexico. Its impact on rainfall has been extensively studied at both regional (Magaña et al., 2003; Englehart and Douglas, 2002; Giannini et al., 2001; Cavazos, 1999; Magaña et al., 1997; Cavazos and Hastenrath, 1990) and local scales (Alexander et al., 2006; Aguilar et al., 2005). Fewer studies have been made on temperature (Alexander et al., 2006; Aguilar et al., 2005; Englehart and Douglas, 2004). The relationships between three different ENSO indices and the regional monthly precipitation averages and daily data of rainfall and temperature are explored using non-parametric and lag cross correlations. The results of these correlations will allow a comparison of the results at different spatial and temporal scales.

A general introduction to the databases of rainfall and temperature and the ENSO indices, and also the methods applied in chapter 7 is detailed in section 7.1. The next three sections of the chapter 7 address the results of correlating the three different ENSO indices with regional precipitation averages and daily rainfall and temperature data: the Southern Oscillation Index (SOI) is used in section 7.2, El Niño 3.4 index in section 7.3, and the Multivariate El Niño Index (MEI) in section 7.4. Non-parametric correlations for SOI are applied in section 7.2.1. Regional precipitation averages are correlated with SOI and with daily data in the form of extreme rainfall and temperature indices. Regional and local relationships of the results are established at the final of this section. In order to test delayed responses of the meteorological variables to the ENSO modulation, lag cross-correlations are analysed in section 7.2.2. The time-series of regional precipitation averages are correlated with the SOI index. The lag correlations of SOI and extreme rainfall and temperature indices are detailed also in this section. The same structure is applied in sections 7.3 and 7.4. For instance linear correlations of El Niño 3.4 with the regional precipitation averages and the extreme weather indices are explained in section 7.3.1, and lag cross-correlations of El Niño 3.4 index with the same variables are addressed in section 7.3.2. The same distribution of the MEI results is presented in section 7.4. Contrasting results at local and regional scales using the different ENSO indices are detailed in section 7.5. General conclusions and remarks of the modulation of the ENSO to the climate of Mexico are addressed in this last section of chapter 7.

Chapter 8 summarises the final conclusions of this thesis. The main topics addressed in this thesis are: the construction of a high-quality and long-term network of precipitation and temperature data, the regionalisation of meteorological stations varying coherently, the analysis of extreme weather indices and the ENSO modulation. The main findings of the thesis are presented in section 8.1. The most important goals per topic are presented in detail; and also general remarks and additional considerations of these research areas of climate change in Mexico are discussed in this section. Finally, further study on the topics evaluated in this thesis and new questions posed by the present research are addressed in section 8.2.