Relationships between winter circulation patterns and temperature and precipitation over Greece

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1. Introduction

The peculiar climate throughout the Mediterranean Sea has created a discrete climate type, which according to Köppen is characterised by mild and moist winters, hot and dry summers and a high percentage of sunshine. The geographical location of the Mediterranean basin allows both mid-latitude and equatorial driving forces to affect the local climate, while prominent orography along with the land-sea interactions complicates the climatic status. Attempts have been made to classify the weather conditions of the region (Livadas, 1962; Maheras, 1979; Maheras *et al.*, 2000) and in some cases the assigned modes are interrelated with surface climatic element regimes (Corte-Real *et al.*, 1995; Goodess and Palutikof, 1998; Maheras *et al.*, 1999). Global climate change, extreme events and natural hazards caused by severe weather have motivated numerous studies. These have examined changes in large-scale circulation or teleconnections with local climate (Moses *et al.*, 1987; Zorita *et al*, 1992) particularly with respect to possible changes in frequency/occurrence of climate extremes. The increasing magnitude, frequency and persistence of extremes have significant implications for a number of natural, economic and social sectors (Jones and Reid, 2001; IPCC, 2001). Here an analysis of surface climate and circulation relationships is discussed and circulation types associated with extreme climate are investigated. An automated classification technique has been developed to represent the dominant circulation patterns in winter, over the study region. Utilising observed station data from the Greek peninsula the dominant temperature and precipitation regimes, accompanying each circulation scheme, are revealed. Trends of the occurrence of circulation patterns are studied to identify significant changes associated with extreme climate event variability.

2. Study region and Data

In the present study a map pattern classification is attempted. An automated approach is employed utilising gridded data. Figure 1 shows the study area delineated by a box with crosses signifying the grid points used in the analysis. Reanalysis daily data from the NCEP/NCAR (Kalnay *et al.*, 1996) have been used for a 43-yr period spanning from 1958 to 2000.

In order to study temperature and precipitation regimes in Greece, daily surface temperature (maximum and minimum) and precipitation records have been collected from 21 meteorological stations distributed evenly over Greece, the locations of which are shown in Figure 2. Daily observational data are available for the same temporal resolution of 43 years.

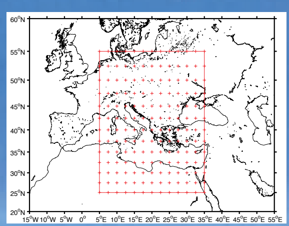

Figure 1. A grid of 169 points used in the automated classification scheme. Fine resolution every 2.5° separates the grids in a study window extended from 5–35E and 25–55N.

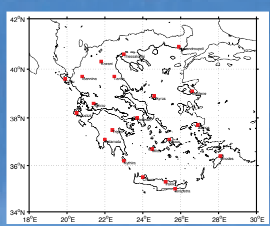

Figure 2. Locations of Greek meteorological sites used in this study. All the stations have complete homogeneous data series for the period 01/01/1958-31/12/2000

3. Analysis Methods

To reduce the size of the original multidimensional data a map-pattern classification using Rotated Principal Component Analysis (RPCA) was employed. At the 500 and 850hPa level, 7 and 5 PCs have been retained, respectively explaining 93.8% and 91.3% of the total variance. For Sea Level Pressure (SLP) 5 PCs were retained explaining 89.6% of the total variance. In Figure 3 loading plots of the latter are given, representing the correlation rank among the grid points. Rotated PCs allow physical interpretation of the patterns, as they are related to large-scale circulation features (Richman, 1986). PC1 seems to be associated with the Azores High, while PC2 relates to a low centre over Cyprus. PC3 is possibly connected to a central European High spreading to study region. PC4 shows a ridge deriving from the Siberian High and in PC5 an anticyclone situated over the Balkan Peninsula dominates the study region.

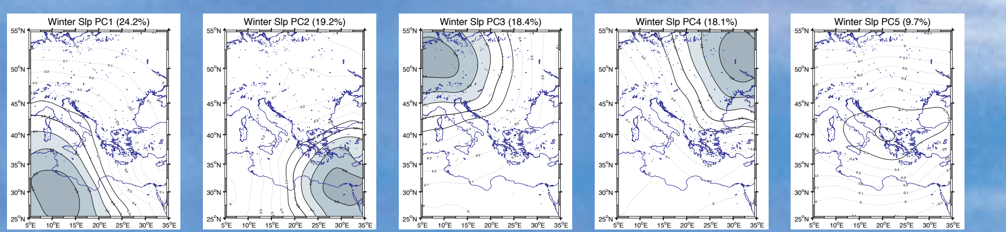

Figure 3: Patterns of surface pressure PCs loadings. The five retained components account for 89.6% of the total variance. Dashed lines: loading less than 0.5, solid lines: loadings greater than 0.5 and shaded areas for loadings over 0.7. Values in brackets represent the explained variance in each component

Composites illustrating the mean patterns of the two geopotential height fields (500 and 850 hPa) and SLP were constructed to represent each circulation type for each level. A maximum and a minimum threshold were determined, and PC-scores greater/equal to the maximum threshold (or less/equal to the minimum threshold) were collected along with their respective dates. The days constituting every pattern (determined from the max/min thresholds) were the key criteria to detect circulation patterns. These days were selected together with their corresponding pressure or geopotential height data from the original NCEP files, the values were then averaged and composite maps were drawn.

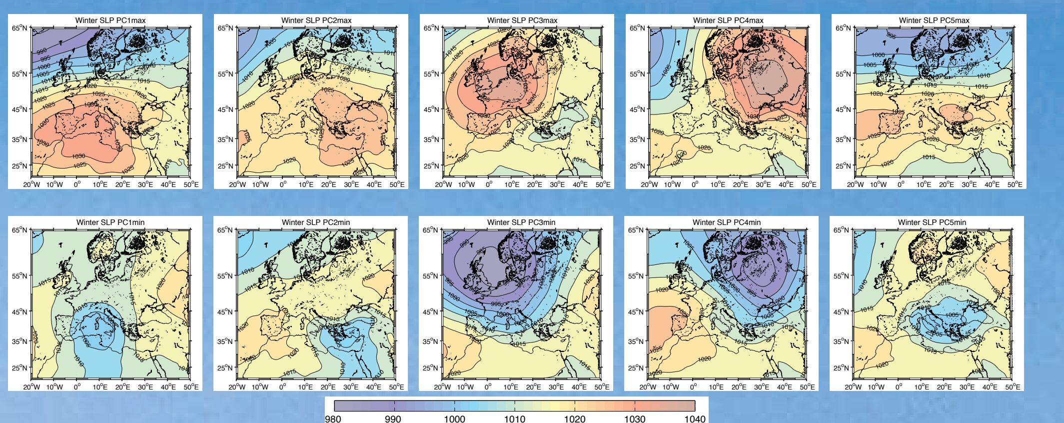

Figure 4: Surface pressure fields for the ten circulation patterns as they derived from RPCA. The contour interval is 5hPa

The first five plots of Figure 4 correspond to the positive phases of the five PCs and are associated with anticyclonic centres located around the study area. In conjunction with these the second five represent the negative phases of the PCs. These represent cyclonic centres, which are located around the Mediterranean basin and affect the study region. These driving forces may be related with areas of local cyclogenesis, or troughs deriving from deeper low-pressure cells from northern latitudes, which expand into the eastern Mediterranean. In Table I a brief interpretation of these patterns is given.

Table I: Interpretation of surface winter patterns, which affect the climate in Eastern Mediterranean

Positive Phases / Anticyclonic centres		Negative Phases / Cyclonic centres	
$PC1_{max}$	Extensive Azores High. Deep Icelandic Low in the north with westerlies dominating over the British Isles and western Europe.	$PC1_{min}$	A Low extended from NW Africa and centred over the central Mediterranean is the main feature in this pattern.
$PC2_{max}$	High pressure throughout Eastern Mediterranean. SSW flow deriving from N. Africa, related to fair weather, affects the study area.	$PC2_{min}$	A Low centre is located in the easternmost Mediterranean. It is possibly related to frontal depressions generated over secondary cyclogenesis areas.
$PC3_{max}$	A strong High located SE of Britain causes meridional flow over Eastern Europe. It coexists with a secondary regional Low affecting Greece.	$PC3_{min}$	An enhanced, deep Low is located between the British Isles and the Scandinavia Peninsula with a trough oriented towards Italy and Greece.
$PC4_{max}$	Siberian High is the principal centre. Affects high latitudes and expands to the south reaching the Mediterranean.	$PC4_{min}$	A strong, deep Low originated in an eastern position with the trough-axis extended over Greece.
$PC5_{max}$	A local High affects the Balkan Peninsula. Westerly flow dominates the mid-latitudes and the Azores High expands over the Iberian Peninsula.	$PC5_{min}$	An extended regional low-pressure centre is located over the Eastern Mediterranean. The weather is affected by local climate characteristics.

4. Surface temperature and precipitation patterns over Greece

To determine the influence of these patterns on local climate, spatial distribution plots of five climatic variables (Tmean, Tmax, Tmin, DTR and Precipitation) were drawn with respect to each circulation pattern. To avoid biases caused by using the observed station data, anomaly data were used instead. The calculated anomalies were plotted to represent the spatial distribution of anomaly fields associated with each circulation pattern. Those related to dry/wet conditions or warm/cold invasions were, therefore, detected.

For example, PC1max-pattern is related to N/NE circulation over the study area and is associated with cold spells across the central Greek area, where negative anomalies of -4°C for Tmean and as large as -6.5°C for Tmin have been detected. Figure 5 illustrates the temperature fields along with that for DTR, which shows significant positive anomalies up to 5°C, likely, occurring due to the extreme low Tmin. This pattern was particularly active in 1983, 1992 and 1993. Another characteristic of this pattern is the absence of precipitation, providing evidence that this flow is partially responsible for the drought period, which occurred in the study region at the beginning of the nineties. The extension of the European high, which is shown by the PC3max pattern, involves cold air invasions especially in northern Greece. Significant decreases were observed in daily Tmax giving anomalies of –5.5°C. The cold spell is well detected in the Tmean and Tmin anomalies as well (Figure 6), where negative anomalies of –4°C have been observed.

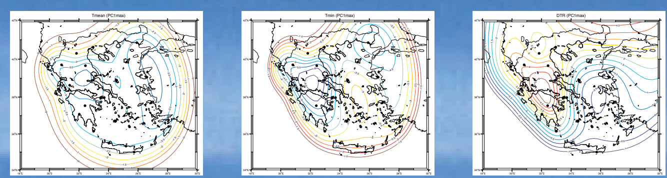

Figure 5: Temperature anomaly fields for Tmean, Tmin and DTR as they respond to the PC1max circulation pattern.

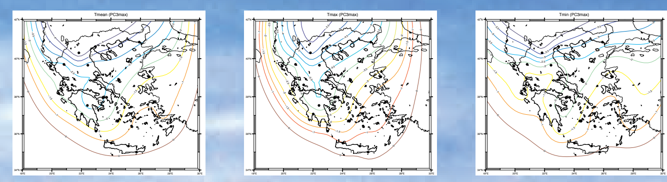

Figure 6: Temperature anomaly fields for Tmean, Tmax and Tmin as a result of PC3max circulation pattern. The cold invasions in north Greece are evident in all three variables.

5. Frequency and Trends of circulation patterns

Inspection of the frequency and persistence of the derived circulation patterns was undertaken. The percentage of each pattern occurrence per year was calculated and linear regression coefficients were estimated for the 43yr-study period. Table II summarises the observed trends (positive and negative; see Figure 7) along with their statistical significance. In the recent 43 years, two circulation patterns show particularly significant positive trends during winter in the domain of Eastern Mediterranean. The first (PC1max) is associated with high-pressure circulation over the western part of the Mediterranean Sea, producing dry and cold weather. The second scheme (PC5min) is related to a regional cyclonic centre, responsible for wet conditions especially in the western mountains of Greece.

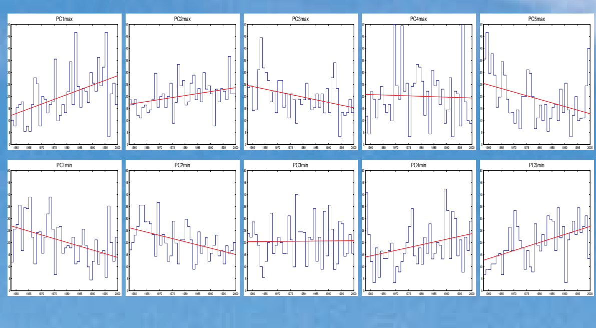

Figure 7: Positive and negative trends in the percentage of occurrence of each circulation pattern for the 43-yr study period.

Table II: Change (%) in frequency for each circulation pattern. Positive sign: increase, negative: decrease, ** significant at 1% and * significant at 5% level of confidence

Mode	B	Mode	B
$PC1_{max}$	+4%**	$PC1_{min}$	-3%**
$PC2_{max}$	+2%*	$PC2_{min}$	-3%**
$PC3_{max}$	-2%**	$PC3_{min}$	+0.1%
$PC4_{max}$	-0.3%	$PC4_{min}$	+2%*
$PC5_{max}$	-3%**	$PC5_{min}$	+3%**

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