Climatology of the impact of atmospheric circulation on surface meteorological conditions over Greece

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Abstract Large-scale atmospheric circulation is a critical factor that controls the surface climatic conditions of a specific region. The scope of this work is to examine this relationship for different climatic regions over Greece and provide a detailed descriptive statistical analysis for multiple parameters related to heat and drought. The atmospheric circulation patterns are provided using a neural network approach and the surface climatic parameters are extracted from 17 surface meteorological stations for a 30-year period. In detail, for each circulation pattern the maximum and minimum temperature, the diurnal temperature range along with the precipitation amount are assessed. The 32 identified regimes describe effectively the large-scale atmospheric circulation and they are found to affect significantly the climatic parameters variability. Interesting statistical aspects are extracted for each climatic region and specific atmospheric circulation patterns are found to be associated with extreme heat and drought in the region. The persistence of atmospheric circulation is examined and associated with unusual episodes. The quantification of the large-scale effect on climatic parameters anomalies is demonstrated and is also discussed in terms of the effect of local topography and urbanization in each site.

Keywords: Atmospheric circulation, climate, temperature, precipitation

1. Introduction

The climatic conditions of a specific area are associated with the interaction of synoptic and local scale flows, which are mainly influenced by topography. These complex interactions need to be thoroughly examined and their effect is observed in the variability and fluctuations of the climatic parameters. Specific areas of interest include the South-eastern Mediterranean (Tzanis et al., 2019), an area which is characterized as a climate change 'hot-spot'. The large-scale atmospheric circulation patterns over Greece have been the subject of multiple studies and the identification of distinct weather types can help towards the understanding of dynamic processes and the forecasting of critical events related with increased temperature and limited precipitation.

The association of synoptic scale flows and surface meteorological conditions can be established through building robust relationships between the weather types using the surface climatic conditions as response variables. Focusing on Greece, Kostopoulou and Jones (2007) has identified atmospheric patterns using the rotated principal components analysis for a time period of 43 years and Kassomenos (2003a, b) examined the weather systems for the second half of the 20th century. The former demonstrated the increased frequency of high-pressure systems in an attempt to explain the increasing maximum temperature during summer. The correlation between local climatic variables and synoptic meteorology has also been used to examine extreme weather conditions such as unusual increased precipitation for a specific area (Houssos et al., 2008). In another study, Philippopoulos and Deligiorgi (2012) identified 32 synoptic weather types, that include six summer, seventeen winter and nine transient season patterns. The authors employed a neural network approach and the optimum self-organizing map configuration is found to reproduce the expected atmospheric circulation patterns with four anticyclonic patterns, six cyclonic, thirteen mixed and eight smooth fields. It should be noted that in some cases winter patterns are also observed during early spring and late autumn and the summer patterns during September and May, in accordance with the meteorological definition of seasons for the geographical area under study.

This work aims to perform an assessment regarding the relationship between circulation patterns and surface meteorological parameters in Greece. It is important to clarify that the connection between the atmospheric circulation and the local weather conditions is based on long-term observations and subsequently, a large database is employed so as to ensure its reliability regarding the results. The association between the identified patterns and the local weather conditions is tested by examining the anomalies of the climatic parameters for each type.

2. Data

Five climatological elements are utilized from 17 meteorological stations located in Greece. In detail, mean daily temperature (Tmean), daily minimum (Tmin) and maximum (Tmax) temperature, diurnal temperature range (Tmax-Tmin) and precipitation (Precp) data are provided from the Global Surface Summary of the Day product of the National Climatic Data Center (NCDC) (Menne et al., 2012). All stations had to meet certain criteria to be selected for the analysis. These criteria, among others, set a critical value of a sufficient number of measurements for the study period (1979-2009). Regarding the climatic region of each station, it should be noted that the Greek climate is categorized as a Mediterranean type of climate with maxima in precipitation during winter and a dry summer period. Nevertheless, the complex topography of Greece induces significant climatic variability even in small distances. Temperature variations are observed due to topographical features such as the distance from the sea, the altitude and local anthropogenic activities (Kalamaras et al., 2019; Philippopoulos et al., 2019). The selected stations are representative of the study area and cover almost all seven climatic zones that share similar climate characteristics (Mamara et al., 2013). Western Greece and the Ionian islands are grouped into the C climatic zone, Northern Greece in the A zone, the Aegean islands in E and F, Crete in G, the mainland of Greece in B and Eastern Greece in the D zone. Table 1 shows the abbreviation of the station, the climatic region and the elevation of all meteorological stations respectively.

Table 1. Abbreviation, climatic region and elevation of the meteorological stations

Station	Abbr.	Climatic region	Elevation (m)
Aktion	AKT	B	2.10
Alexandroupoli	ALE	A	3.52
Andravida	AND	B	10.10
Helliniko	HEL	C	43.13
Heraklion	HER	F	39.00
Corfu	KER	B	1.13
Lamia	LAM	C	12.46
Larissa	LAR	C	72.72
Limnos	LIM	D	1.90
Methoni	MET	B	51.84
Mitilini	MIT	E	4.22
Naxos	NAX	D	9.00
Rhodes	RHO	E	6.63
Skyros	SKY	D	22.00
Souda	SOU	F	147.64
Thessaloniki	THE	A	1.68
Tripoli	TRI	G	650.57

3. Methodology

To illustrate the relationship between synoptic scale flow and surface climatic conditions, an established classification of atmospheric circulation was used (Philippopoulos and Deligiorgi 2012; Philippopoulos et al. 2014). The classification is focused at the Eastern Mediterranean and Greece and is based on the ERA-Interim Reanalysis dataset, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) (Dee et al., 2011). The Mean Sea Level Pressure and the Geopotential at 500hPa are used for a domain that covers the European area and the zonal and meridional wind components at 10m and at 850hPa, the specific humidity at 700hPa and the air and dew-point temperature at 2m are extracted for a domain centered over Greece. The influence of the large-scale atmospheric circulation is assessed for the subdomain centered in Greece and 32 patterns are identified in total. This study focuses on heat and drought and the impact of each pattern on Tmean, Tmin, Tmax, Tmax-Tmin and Precp observations is studied using the in-situ observations from the selected stations. The effect of atmospheric circulation patterns on the surface climatic conditions is examined using the anomalies, which are calculated from the following equation:

$$\Delta X = \bar{X}_{ij} - \bar{X}_i$$

where X is the examined surface meteorological parameter, $\bar{X}_{ij}$ is the average X parameter value for site i, under the j atmospheric circulation pattern and $\bar{X}_i$ is the X parameter value for site i, averaged over all atmospheric circulation patterns.

4. Results

In Table 2 an overview of the mean values of the climatic parameters is presented for the examined sites. It should be noted that stations within the same climatic region exhibit similar mean values and illustrate the effect of their geographical location.

Table 2. Mean climatic parameter values for each station.

Station	T_{mean}	T_{max}	T_{min}	T_{max}-T_{min}	PRCP
HEL	18.04	22.28	13.96	8.32	0.04
THE	15.27	20.45	10.27	10.18	0.06
ALE	14.54	19.36	9.10	10.26	0.06
KER	17.09	22.10	12.02	10.08	0.12
AKT	17.08	21.00	13.10	7.88	0.10
LAR	15.03	21.43	8.93	12.50	0.05
LIM	15.72	19.49	11.33	8.16	0.05
MIT	17.44	21.31	13.62	7.69	0.06
LAM	16.69	22.08	10.65	11.43	0.06
AND	16.79	21.98	11.46	10.52	0.09
SKY	17.04	19.66	13.82	5.84	0.05
TRI	13.78	19.85	6.93	12.92	0.08
NAX	18.44	20.65	15.62	5.03	0.04
MET	17.91	21.36	13.80	7.56	0.07
SOU	18.07	22.22	14.24	7.97	0.07
RHO	19.24	22.19	16.43	5.75	0.08
HER	18.41	21.93	14.58	7.36	0.05

Regarding the atmospheric circulation patterns, a further grouping of the 32 types is presented in Table 3, based on criteria related to the resulting surface temperature conditions and their seasonal frequencies.

Table 3. Grouping of atmospheric circulation patterns

Atmospheric type	Temperature conditions	Season
1, 9, 17, 18, 25, 26	Warm	Summer
2, 3, 4, 10, 11, 19, 27	Fairly warm	Transient/Summer
5, 6, 7, 12, 13, 14, 16, 23, 24	Fairly cold	Transient/Winter
8, 15, 21, 22, 28, 29, 30, 31, 32	Cold	Winter

The anomalies of the Tmean, Tmax, Tmin, Tmax-Tmin and Precp for characteristic cases and climatic regions are presented in Figure 1, where the influence of each atmospheric pattern is highlighted. Negative/possitive values correspond to cases where the effect of atmospheric circulation leads to lower/higher than the climatological mean for each of the examined parameters.

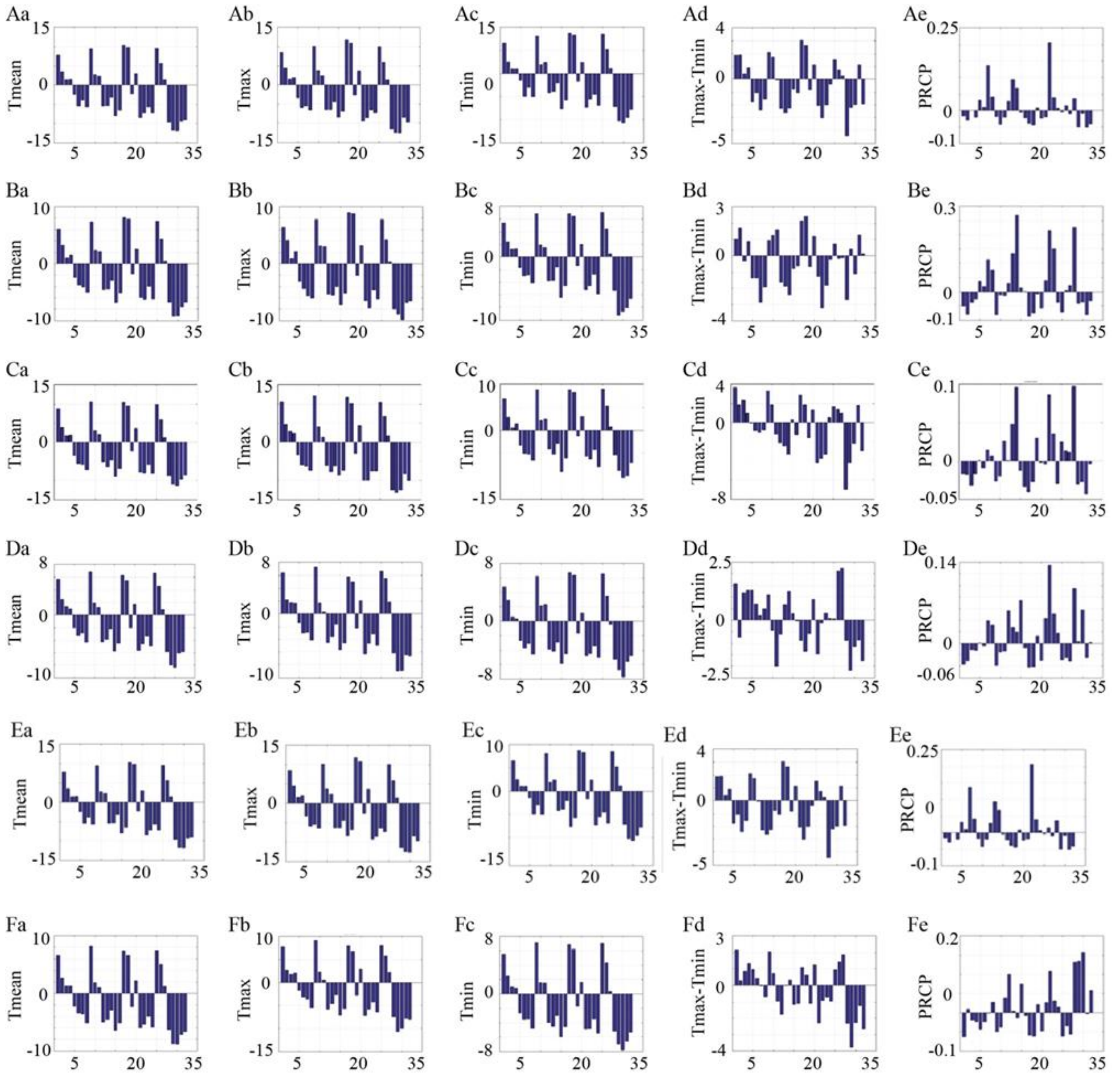

Figure 3. Anomalies of the mean (a), maximum (b) and minimum (c) daily temperature, diurnal temperature range (d) and precipitation (e) for each pattern for characteristic stations for the climatic region A (Alexandrouloli), B (Andravida), C (Larissa), D (Naxos), E (Rhodes) and F (Souda).

A general remark regarding the anomalies for all stations is that positive temperature anomalies are related to negative precipitation anomalies and vice versa.

Focusing on summer and more specifically on the 17th and 18th patterns, which are related with the Etesian winds, the temperature anomalies for the climatic regions of Northern and Western Greece (A and B zones) are higher compared to the Eastern Greece climatic regions (C, D, E and F zones), due to the cooling effect of the northerly flow. The smooth field summer patterns (1, 9, 25 and 26) are generally related with high positive temperature anomalies, especially for the D and F climatic zones (maxima are recorded for these patterns). Regarding the winter atmospheric patterns for all climatic zones the lowest temperature anomalies are related to cyclonic patterns and more specifically with Pattern 5, where a moderate southwesterly flow is observed over Greece (pattern 5) and with pattern 14, which is related to Mediterranean cyclones. On the contrary, the maxima of temperature negative anomalies are related to the winter anticyclonic patterns. In more detail, the 28, 29, 30, 31, 32 patterns exhibit the highest negative anomalies. It should be noted that the 29 and 30 atmospheric patterns are associated with cold outbreaks in Greece and with a north-easterly flow.

Regarding the precipitation results, the circulation patterns that are related with the higher positive anomalies are the 14 and 22 patterns that are associated with cyclonic activity at the west and over Greece and for pattern 28, where a high-pressure centre is located at the north of Greece. It should be noted that the effect of large-scale circulation during spring and autumn (transient periods) follow the results that are observed during winter and summer due to the fact that the climatic conditions for these seasons alternates between the typical patterns observed during winter and summer.

Conclusions

In this paper, we studied the influence of atmospheric circulation patterns as they emerged with the process of self-organising maps, on surface meteorological parameters over the area of Greece. A strong correlation between local conditions and synoptic systems emerged, which controls the surface temperature and precipitation conditions. Each type has an effect of a different magnitude upon the examined parameters but affects the whole region in a uniform way. The results highlight the importance of understanding this relationship for climatological and meteorological forecasting purposes, especially under climate change conditions. Further work is proposed to focus on the drivers of heat and drought events in more detail, focusing on the combined effect of local and synoptic conditions for providing climate information for climate change adaptation and mitigation measures.

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