EXTREME TEMPERATURE EVENTS IN NW GREECE

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INTRODUCTION

Extreme weather events appear to have been recorded more frequently during recent decades, attracting the interest of many researchers all over the world (*Metaxas, D.A. et al.*, 1993; *Domonkos, P.*, 2001; *Founda, D. et al.*, 2004; *Kontogianni, A.V. and A. Bartzokas*, 2005). These events have caused a continuous increase of people's demands for a more accurate, in space and time, weather forecast. Many researchers try to resolve the problem by developing models for a numerical weather prediction while others deal with statistical approaches. In this study we focus on the extreme temperature events in northwestern Greece in winter and summer and we seek for the atmospheric pressure patterns associated or favouring such events using the objective multivariate statistical method Factor Analysis (FA).

DATA COLLECTION AND METHODOLOGY

The dataset used consists of daily values of winter (DJF) minimum and summer (JJA) maximum temperatures recorded at the meteorological station of Ioannina University, located at NW Greece, for the 33-year period 1970-2002. Also, mean sea level pressure values (06:00 and 12:00 UTC) from 40W to 50E and from 30N to 70N, at 629 grid points spaced by 2.5º in latitude and longitude are utilized (ECMWF 40 Years Reanalysis Project).

A winter/summer day is defined as an "extreme temperature day" when its minimum/maximum temperature value belongs to the lower/upper quintile of minimum/maximum temperature distribution (extreme 5%). The two thresholds are: –7.7ºC for winter and +35.8ºC for summer. For these extreme temperature days (approximately 150 for each season) the second dataset is utilized in order to construct daily sea level pressure maps (06:00 for winter and 12:00 UTC for summer) covering E Atlantic, Europe, W Asia and N Africa. Then, FA is applied on the pressure space-series (daily maps), for each season, in order to classify them objectively in groups with discrete and characteristic pressure distribution. Thus, the large scale pressure patterns favouring the appearance of extreme temperatures in NW Greece are objectively revealed. The statistical method of FA is briefly described in the following paragraph.

FA (*Jolliffe, I.T.*, 1986; *Manly, B.F.J.*, 1986) describes a set of p correlated variables X_1, X_2, ..., X_p in terms of a smaller number of new uncorrelated indices, elucidating the relationship between the original p variables. Each of the p initial variables can be expressed as a linear function of m (m<p) factors, i.e. $X_i = a_{i1}F_1 + a_{i2}F_2 + ... + a_{im}F_m$, where F_1, F_2, ..., F_m are the factors and a_{i1}, a_{i2}, ..., a_{im} are the factor loadings which, given that the original time/space series are standardized, express the correlation between the initial variables and the new ones (factors). The number m of the retained factors has to be decided, by using various rules and considering the physical interpretation of the results (*Bartzokas, A. and D.A. Metaxas*, 1993). In the present work, this has been decided based on the 80% threshold of the total variance explained. A widely used process is the "rotation of the axes", which, by maximizing some factor loadings and minimizing some others, succeeds in a better separation among the initial

variables and thus in a better interpretation of the results (*Richman, M.B.*, 1986). In this work, *Varimax* rotation has been applied.

RESULTS AND DISCUSSION

Frequency of extreme temperature events in winter and summer

In winter, the maximum frequency of minimum temperature values below the –7.6ºC threshold appears in the 5-year period 1989-93. This is illustrated in Figures 1a,b per year and per 3-year

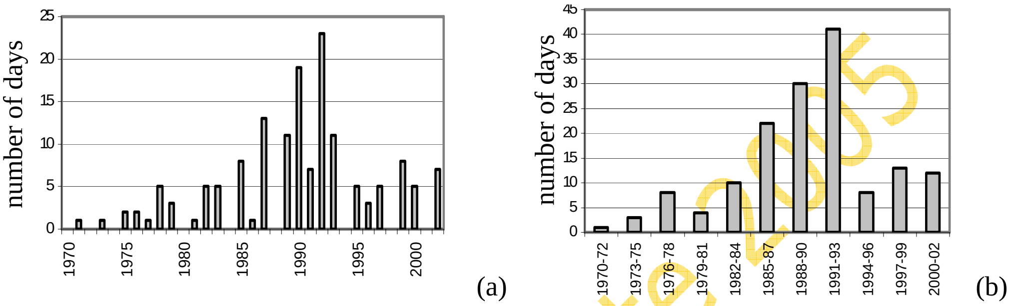

Fig. 1; Frequency of minimum daily temperature values below the threshold of –7.6ºC (a) per year, (b) per 3-year period.

period respectively. It is well known that this period is characterized by a high positive North Atlantic Oscillation (NAO) index (*WMO*, 1998), which means that the subtropical Azores anticyclone and the Icelandic low appear stronger and more extended than usually, modifying the normal weather conditions in Europe. Specifically, the travelling depressions move eastwards at higher latitudes, not affecting Greece and the Mediterranean where high pressure ridges dominate. This situation causes a dry northerly flow over the Balkans, which, along with the cloudless anticyclonic nights, results in very low minimum temperatures in NW Greece. On the contrary, the very low values appearing in the early 1970's must be attributed to the negative NAO index of that period which leads the depression tracks over the Mediterranean. These depressions, when they approach W or NW Greece, apart from the humid weather conditions, also cause mild winters without extremely low minimum temperatures. In general, temperature and rainfall in NW Greece, in winter, appear anti-correlated due to the NW-SE orientation of the Pindus mountain range (*Fotiadi, A.K. et al.*, 1999; *Bartzokas, A. et al.*, 2003).

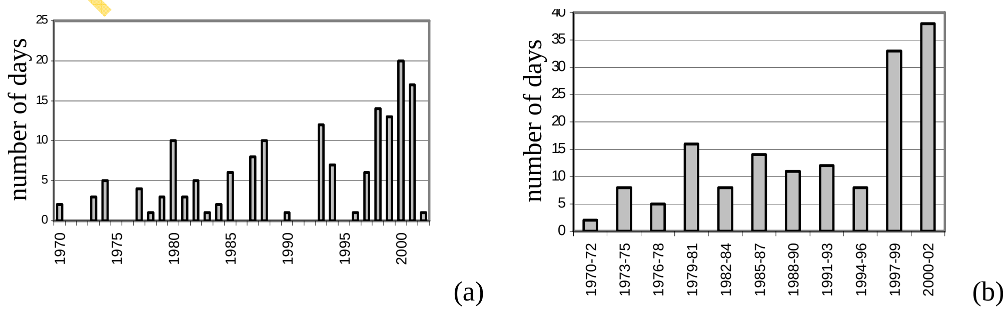

Fig. 2; Frequency of maximum daily temperature values above the threshold of 35.8ºC *(a) per year, (b) per 3-year period.*

In summer (Figures 2a,b), the maximum frequency of maximum temperatures in the upper quintile (T_{max} > 35.8ºC) emerges during the last decade, in agreement with the general warming trend in the eastern Mediterranean (*Lolis, C.J. et al.,* 2002).

Factor Analysis on the winter daily maps

FA for winter reveals that the 149 days can be grouped in 4 factors explaining 80% of the total variance. This means that the main pressure patterns, which are responsible for the extremely low air temperatures in NW Greece during winter, are 4 only.

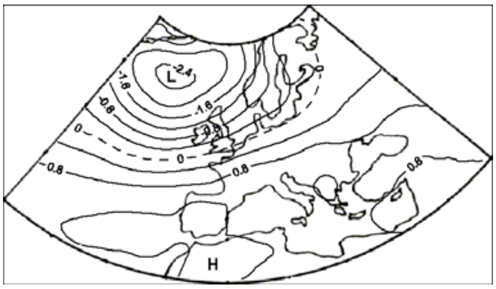

Fig. 3; Factor 1. Pressure (scores) pattern.

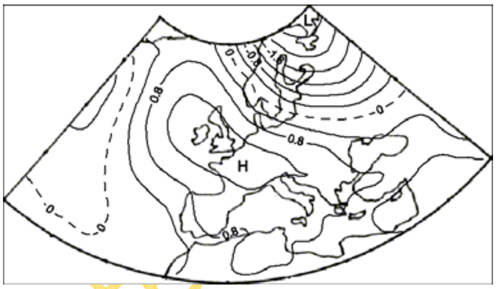

Fig. 4; Factor 2. Pressure (scores) pattern.

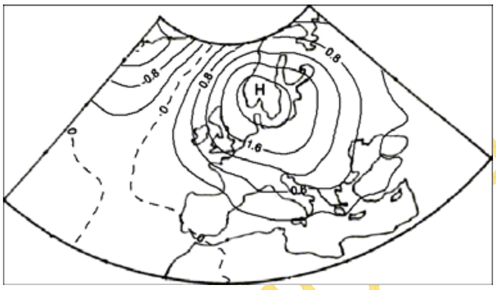

Fig. 5; Factor 3. Pressure (scores) pattern.

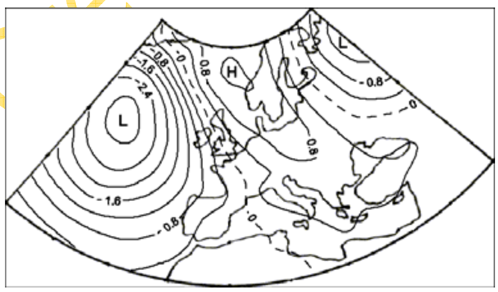

Fig. 6; Factor 4. Pressure (scores) pattern.

Factor 1 is the strongest explaining 30% of the total variance and comprising (loadings above 0.65) 54 days with an average minimum temperature –8.8ºC. The factor scores space-series are presented standardized (unit variance and zero mean) in Figure 3. In fact, the isopleths represent isobars and they exhibit a characteristic high positive NAO index situation. Namely, a deep Icelandic low (2 standard deviations lower than the spatial average) and an extension of the Azores anticyclone over the whole Mediterranean, obviously causing clear night conditions favouring low temperatures during early morning hours. Factor 2 (22%, 27 days, T_{min} = –8.7ºC) presents an anticyclone centred over northwest Europe and extended up to the Balkans (Fig. 4) causing clear nights as well as dry northerly flow over Greece. In Factor 3 (19%, 22 days, T_{min} = –8.8ºC) the position of the anticyclone favours a northeasterly flow over NW Greece, which transfers very cold air masses from eastern continental Europe (Fig. 5). Finally, Factor 4 (9%, 3 days, T_{min} = –8.1ºC) is the weakest one and presents a very rare situation; an extended high pressure system predominating over northern Europe, the Balkans and the eastern Mediterranean, causing clear and windless days and nights (Fig. 6).

Factor Analysis on the summer daily maps

FA for summer reveals that the 152 days can be grouped in 5 factors explaining 81% of the total variance. This means that there are 5 main pressure patterns (Figures 7-11), which are responsible for the extremely high air temperatures in NW Greece during summer (heat waves).

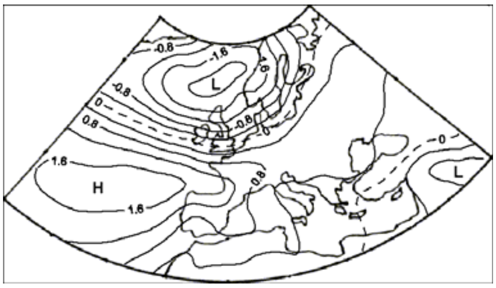

Fig. 7; Factor 1. Pressure (scores) pattern.

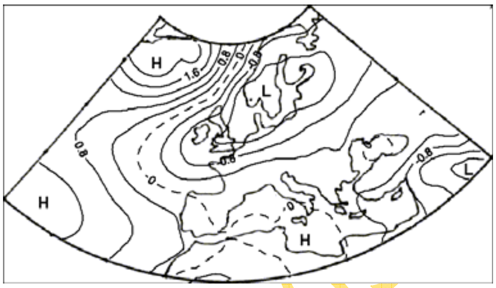

Fig. 8; Factor 2. Pressure (scores) pattern.

Fig. 9; Factor 3. Pressure (scores) pattern.

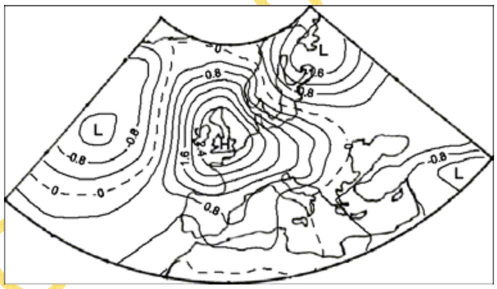

Fig. 10; Factor 4. Pressure (scores) pattern.

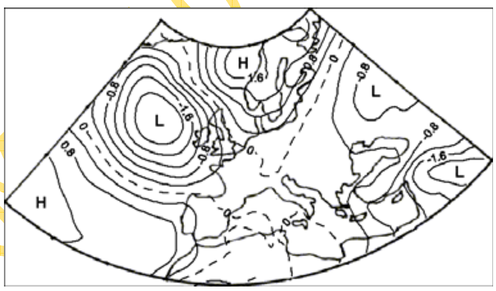

Fig. 11; Factor 5. Pressure (scores) pattern.

In Factor 1 (28%, 48 days, T_{max}=37.1ºC) the pressure gradient over Greece is weak because the Azores anticyclone is not extended sufficiently over the central and eastern Mediterranean and because the SW Asia thermal low is not deep enough. This situation implies very weak northerly winds (Etesian winds) or no winds at all over Greece and thus, because of the lack of this "ventilation mechanism", very high maximum temperatures are recorded. In Factors 2 (20%, 23 days, T_{max}=37.4ºC) and 3 (15%, 11 days, T_{max}=37.9ºC), apart from the weak pressure gradient, it is also seen that the pressure pattern, presenting relatively high values over north Africa and the central Mediterranean, favours a transfer of the warm African air masses over Greece. In Factor 4 (10%, 3 days, T_{max}=37.2ºC), a rare case, a trough appears in the Ionian Sea, modifying the northerly Etesian winds by adding an easterly katabatic component due to Pindus mountain range and thus warming NW Greece. Finally, in Factor 5

(9%, 7 days, T_{max}=37.1ºC), Greece is found in a barometric col, which is responsible for an almost complete lack of winds in the Balkans.

CONCLUSIONS

In this work, the extreme temperature events over NW Greece were studied. It was found that, extremely low minimum temperatures in winter are controlled by the North Atlantic Oscillation. Namely, winters characterized by high NAO index, are very cold in NW Greece and vice versa. In summer, the highest temperatures were found during the recent decades when the global warming is evident in the eastern Mediterranean too. The study on the atmospheric pressure distribution related with the above extreme temperature events revealed that the pressure patterns are classified in 4 groups in winter and 5 in summer. In winter, a blocking anticyclone may result either in cloudless nights or/and in a northeasterly flow advecting cold air masses from eastern continental Europe and causing very low early morning temperatures. In summer, the anticyclone is either located over NW Africa, transferring warm air masses from the Sahara desert, or it is located over Greece causing sunshine and very low Etesian winds or no winds at all, conditions obviously related to heat waves.

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