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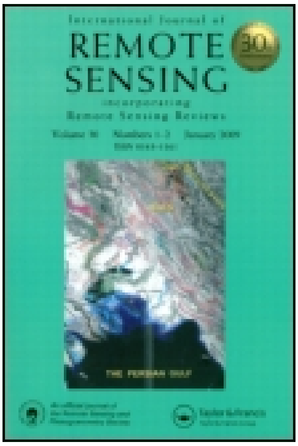

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Variability and trends of mean maximum and mean minimum air temperature in Greece from ground-based observations and NCEP-NCAR reanalysis gridded data

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Variability and trends of mean maximum and mean minimum air temperature in Greece from ground-based observations and NCEP–NCAR reanalysis gridded data

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In this study, the variability and trends of the mean annual and seasonal maximum and minimum surface air temperature in Greece are examined, using monthly data sets of 26 meteorological stations from the Hellenic National Meteorological Service (HNMS) and gridded data from the National Center for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) Reanalysis project for the period 1955–2001. NCEP–NCAR reanalysis data sets are created by assimilating climate observations from different sources, including ships, satellites, ground stations, radiosonde observations and radar. The general purpose of conducting reanalyses is to produce multi-year global state-of-the-art gridded representations of atmospheric states, generated by a constant model and a constant data-assimilation system.

The trends of the mean extreme air temperatures were evaluated, using the Mann–Kendall criterion, and, in the process, factor analysis was applied to both the stations' and the NCEP–NCAR grid points time series. Regarding the mean maximum air temperature, the first main factor, which explains a high percentage of the total variance, presents a statistically significant (CL = 95%) negative trend only during the winter. The first main factor of the mean minimum air temperature manifests a statistically significant (CL = 95%) positive trend during the summer and the year, and a statistically significant (CL = 95%) negative trend in autumn and winter. These findings were compared to the respective ones of the NCEP–NCAR reanalysis data and significant differences in the spatial distribution and temporal variability of the extracted new factors were found. These differences between the two examined data sets could be attributed to topographical factors such orography and land–sea distribution, which could not be represented properly by the reanalysis model.

1. Introduction

The spatial and temporal coverage of surface observations is more sporadic, and large areas of the globe (such as the southern oceans) cannot be reliably analysed

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(Trenberth 1992, Karl *et al*. 1994). The satellite data have a large impact on reanalysis, and a lack of satellite data creates undesirable discontinuities in the long series of analyses, particularly over the complete data void areas in the eastern and oceanic areas of the southern hemisphere and in the stratosphere (Kanamitsu *et al*. 1997). Concerning air temperature, it is not directly accessible from remote-sensing measurements. Satellite-based surface temperature is referred to as skin temperature (Dickinson 1994), depending on the infrared wavelength used for the measurement, spectral dependence of the emissivity, angle at which the measurement is made, state of the surface (roughness, surface type, moisture, vegetation cover, etc.), height of the instrument above the surface and state of the atmosphere above (i.e. atmospheric moisture distribution, amount and geometrical distribution of cloud cover and aerosol). Consequently, a wide range of errors may occur when one tries to measure a single accurate surface skin-temperature measurement from space (Jin 2004). For this reason, in the last decades, reanalysis data sets, made after real time, are widely used in climate studies. The National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) have cooperated in a project (denoted 'Reanalysis') to produce a record of global analyses of atmospheric fields in support of the needs of the research and climate monitoring communities, using a frozen modern global data assimilation system, and a database (from different sources, including ships, satellites, ground stations, radiosonde observations and radar) as complete as possible (Kalnay *et al*. 1996). More specifically, the satellite data used in the NCEP–NCAR Reanalysis project are: (i) operational TOVS (TIROS Operational Vertical Sounder) vertical temperature soundings from NOAA polar orbiters over the ocean, with microwave retrievals excluded between 20° N and 20° S due to rain contamination, (ii) temperature soundings over land only above 100 hPa and (iii) cloud-tracked winds from geostationary satellites (Kistler *et al*. 2001).

Extreme air-temperature values may have negative impacts on energy consumption, tourism and the bioclimatic comfort of human beings (Henderson and Muller 1997, WISE 1999, Subak *et al.* 2000). A number of studies have pointed out the significant effects of extreme temperatures on human health and human life (Katsouyanni *et al.* 1988, Kalkstein 1993, McGregor 2005, Nastos and Matzarakis 2006). Widespread changes in extreme temperatures have been observed over the last 50 years. Cold days, cold nights and frost have become less frequent, while hot days, hot nights and heat waves have become more frequent (IPCC 2007). The role of the atmospheric greenhouse effect in climate change has been analysed by Kondratyev and Varotsos (1995). Although there is quite clear evidence for abrupt changes in climate, the mechanisms driving these changes are less clear, and they are still the subject of very active research. Even if the causes of these changes were known, it seems unlikely that computer models would be able to predict sudden changes (Cracknell and Varotsos 2007).

The maximum air temperature in Athens was first studied several years ago by Aiginitis (1907) and more recently by Flocas and Angouridakis (1979), Bartzokas and Metaxas (1995), Philandras *et al*. (1999) and Founda *et al*. (2004). Respective studies have been also conducted for Greece (Balafoutis and Arseni-Papadimitriou 1992, Nastos 1995, Proedrou *et al.* 1997, Feidas *et al.* 2004, Flocas *et al*. 2005, Nastos and Matzarakis 2008). The study of air-temperature trends in a large region presupposes, on one hand, a dense meteorological stations' network and, on the other hand, long-term data records in order to obtain reliable results. It is well known that in many regions, such as in the Eastern Mediterranean region, there are limited meteorological observations as far as the spatial and temporal distribution is concerned. For this reason, many researchers have analysed data from the NCEP–NCAR reanalysis project

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in order to investigate the climate variability in those regions (Maheras *et al.* 2000, 2001, Flocas *et al*. 2001). Recent studies have also compared NCEP–NCAR gridded data with ground-based measurements of surface air temperature over wider or smaller regions (Rusticucci and Kousky 2002, Flocas *et al*. 2005).

In this study, we analyse the annual and seasonal spatial and temporal objective patterns, by means of factor analysis, of mean maximum and mean minimum surface air temperature, from ground-based observations and NCEP–NCAR reanalysis gridded data for Greece, during the long-term period 1955–2001. The goal of this study is to indicate possible inconsistencies between the spatial and temporal patterns of NCEP–NCAR gridded data and ground-based observations, and not to compare gridded station data with the respective NCEP–NCAR gridded data when applied in small regions of Greece, with complex topography and sea-land distribution.

2. Data and analysis

This study analyses the mean maximum and mean minimum surface air temperature in Greece from 26 meteorological stations of the Hellenic National Meteorological Service (HNMS), and from the respective gridded NCEP–NCAR reanalysis data sets, for the period 1955–2001. The NCEP–NCAR data are provided in a Gaussian T62 grid with a resolution of 1.9° latitude × 1.875° longitude. The reanalysis data are model-based data originating from observations from many different sources, including ships, satellites, ground stations, radiosondes and radar. The general purpose of conducting reanalyses is to produce multi-year global state-of-the-art gridded representations of atmospheric states, generated by a constant model and a constant data assimilation system (Kalnay *et al*. 1996).

The geographical distribution of the examined weather stations used in this study together with the respective NCEP–NCAR grid points are shown in figure 1.

The trends of the mean maximum and mean minimum surface air temperature time series were determined using the Mann–Kendall statistical method (Mitchell *et al.* 1966, Sneyers 1975, Chu *et al.* 1994), which was applied on the seasonal and annual time series of each station. According to this criterion, every term x_i ($i = 1, \ldots, N$) is compared to all terms following. If n_i is the number of terms that exceed x_i, then the sum (equation (1)) is computed and, in the process, the statistical term τ (equation (2)) is accessed. Then, this statistical term is compared to $(\tau)_t$ (equation (3)).

$$P = \sum_{i=1}^{N-1} n_1 \tag{1}$$

$$\tau = \frac{4P}{N(N-1)} - 1 \tag{2}$$

$$(\tau)_t = 0 \pm 1.9\sqrt{\frac{4\mathrm{N} + 10}{9\mathrm{N}(N-1)}} \tag{3}$$

where 1.96 is the value for t at the probability point in the Gaussian distribution for 95% significant level and for the two-tailed test.

In order to reduce the number of variables (stations or grid points) and detect structure in the relationships between the different variables, factor analysis (FA, S-mode, Varimax rotation) was applied to the annual and seasonal air temperature of both the

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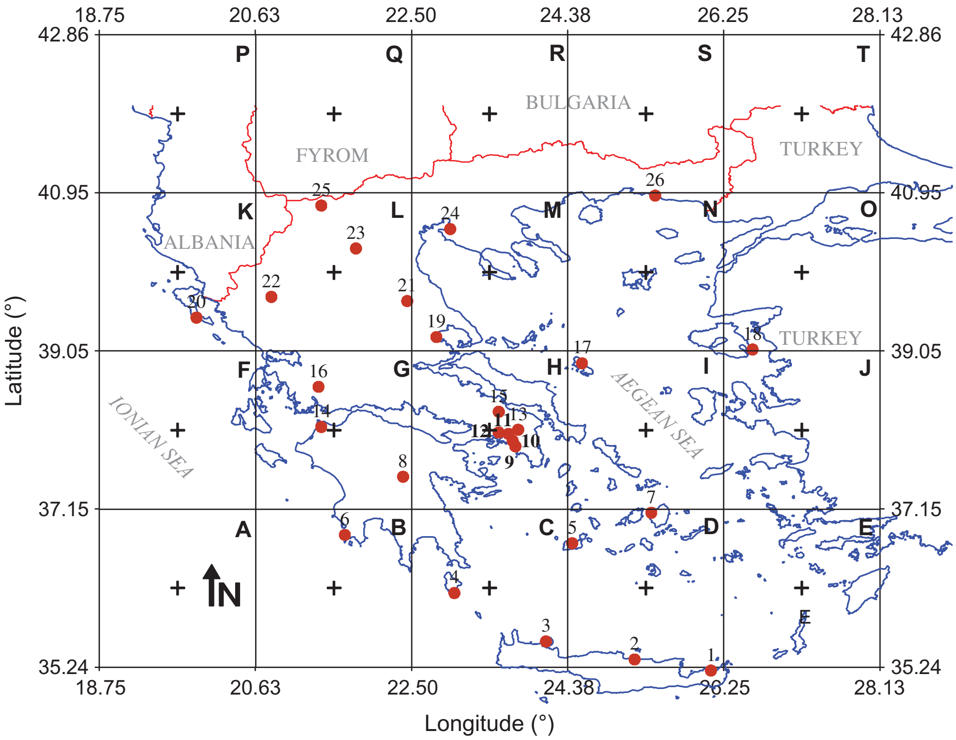

Figure 1. Geographical distribution of the 26 meteorological stations of the Hellenic National Meteorological Service (circle), and the NCEP–NCAR grid points (cross) used in the study.

ground-based and the gridded data from NCEP–NCAR reanalysis. The data should have a bivariate normal distribution for each pair of variables, and observations should be independent. Therefore, each of the p initial variables, X_1, X_2, . . ., X_p, can be expressed as a linear function of m ($m < p$) uncorrelated factors: $X_i = a_{i1}F_1 + a_{i2}F_2 + \cdots + a_{im}\mathrm{F}_\mathrm{m}$, where F_1, F_2, . . ., F_m are the factors and a_{i1}, a_{i2}, . . ., a_{im} are the factor loadings that express the correlation between the factors and the initial variables. The values of each factor are called factor scores and they are presented in standardized form, having zero mean and unit variance (Jolliffe 1986, Manly 1986). The number m of the retained factors has to be decided, by using various rules (eigenvalue ≥ 1, scree plot) and considering the physical interpretation of the results. Another important point of the analysis is the rotation of the axes, which maximizes some factor loadings and minimizes some others and in that way a better separation among the initial variables is achieved. Varimax rotation is generally accepted as the most accurate orthogonal rotation, which maximizes the sum of the variances of the square factor loadings, keeping the factors uncorrelated (Richman 1986).

3. Results and discussion

Table 1 shows the trends of the mean maximum and mean minimum surface air temperature at each individual examined meteorological station. Although there are negative trends in the mean maximum air temperature during wintertime and positive trends in summertime, these trends are only statistically significant (CL = 95%) in

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Table 1. Trends (°C/year) of annual and seasonal mean maximum and mean minimum air temperature for the 26 Greek meteorological stations for the period 1955–2001. Statistically significant trends (CL = 95%) are shown in bold.

		Winter		Spring		Summer		Autumn		Year	
	Stations	$T_{\max}$	$T_{\min}$	$T_{\max}$	$T_{\min}$	$T_{\max}$	$T_{\min}$	$T_{\max}$	$T_{\min}$	$T_{\max}$	$T_{\min}$
1	Sitia	**−0.059**	+0.015	**−0.030**	**+0.025**	**−0.022**	**+0.040**	**−0.038**	+0.034	**−0.047**	**+0.029**
2	Heraklion	**−0.054**	+0.001	+0.021	+0.008	**+0.090**	**+0.021**	+0.014	+0.012	+0.016	+0.009
3	Souda	**−0.032**	−0.123	+0.002	**+0.032**	**+0.021**	**+0.057**	−0.003	**+0.043**	−0.004	−0.003
4	Kithira	**−0.025**	+0.620	−0.006	+0.011	+0.011	**+0.026**	−0.007	+0.015	−0.009	+0.014
5	Milos	−0.016	−0.010	+0.008	−0.012	**+0.040**	+0.000	+0.017	−0.013	+0.010	−0.004
6	Methoni	−0.010	**−0.023**	−0.006	**−0.019**	+0.007	−0.005	−0.000	−0.014	−0.003	**−0.017**
7	Naxos	−0.011	**+0.012**	+0.010	**+0.018**	**+0.013**	**+0.024**	+0.007	+0.012	+0.003	**+0.010**
8	Tripoli	−0.003	−0.033	+0.023	−0.015	**+0.036**	**−0.024**	+0.015	**−0.043**	+0.014	**−0.031**
9	Hellinikon	**−0.023**	−0.006	+0.002	−0.005	+0.020	−0.000	−0.011	−0.002	−0.005	−0.005
10	NOA (Nat. Obs. Athens)	+0.004	+0.003	+0.018	+0.014	**+0.048**	+0.020	+0.019	+0.011	**+0.024**	+0.011
11	Philadelphia	**−0.018**	−0.001	−0.003	+0.002	**+0.048**	**+0.030**	+0.006	+0.011	**+0.015**	+0.012
12	Elefsina	−0.014	−0.006	−0.002	+0.000	+0.015	**+0.025**	−0.011	**+0.021**	−0.008	+0.007
13	Tatoi	**−0.031**	+0.016	−0.008	+0.017	**+0.029**	**+0.024**	+0.000	**+0.036**	−0.002	+0.013
14	Araxos	−0.015	−0.012	−0.006	+0.003	−0.005	**+0.018**	−0.012	−0.006	**−0.011**	−0.001
15	Tanagra	**−0.027**	+0.008	+0.003	+0.016	−0.004	**+0.024**	−0.001	+0.009	**−0.014**	**+0.013**
16	Agrinio	−0.010	**−0.035**	+0.004	**−0.035**	−0.008	**−0.025**	−0.018	**−0.035**	−0.006	**−0.035**
17	Skyros	**−0.026**	**−0.025**	−0.001	−0.007	+0.011	+0.006	−0.001	−0.013	−0.006	−0.012
18	Mytilini	−0.015	−0.025	+0.015	−0.005	**+0.023**	+0.012	−0.001	−0.006	+0.004	−0.009
19	Agchialos	−0.006	+0.022	+0.005	**+0.023**	**+0.018**	**+0.026**	+0.006	+0.002	+0.006	**+0.016**
20	Kerkyra	0.000	+0.012	+0.010	**+0.031**	**+0.020**	**+0.057**	+0.002	**+0.031**	+0.006	**+0.030**
21	Larissa	−0.006	−0.001	+0.019	+0.015	+0.006	**+0.022**	+0.003	−0.007	+0.002	+0.005
22	Ioannina	**−0.019**	−0.005	−0.002	−0.006	+0.011	+0.013	−0.020	−0.008	−0.006	−0.001
23	Kozani	−0.002	+0.078	+0.012	+0.018	+0.018	**+0.047**	+0.000	+0.023	+0.005	**+0.020**
24	Mikra	−0.005	+0.025	+0.000	**+0.042**	+0.013	**+0.069**	−0.018	+0.003	−0.003	**+0.045**
25	Florina	−0.004	+0.002	+0.077	+0.021	+0.020	**+0.020**	+0.005	+0.005	+0.004	+0.097
26	Alexandroupolis	−0.003	−0.009	+0.014	+0.009	**+0.018**	+0.017	−0.008	−0.013	+0.003	−0.002

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some stations. During spring and autumn, there are no statistically significant trends except in Sitia, which shows a significant negative trend (CL = 95%). The highest negative trend in mean maximum air temperature is observed in Heraklion during winter, and it is estimated at −0.54°C per decade. On the other hand, the highest positive trend in mean maximum air temperature is again observed in Heraklion (+0.90°C per decade) followed by Philadelphia and National Observatory of Athens (+0.48°C per decade) during summer. Apart from climate change, a physical explanation of the increasing mean maximum air temperature within large cities is the urban heat island (UHI). Heraklion, which is the largest city and capital of Crete and also the fourth-largest city in Greece, has experienced a rapid urbanization due to the increase of the population (>100% during the period 1951–1991). Besides, the Idi mountain range (Psiloritis 2456 m) are orientated perpendicularly to the southern air mass flow, generating the so-called Föhn winds. Coming down from the lee of the mountains, these dry, hot winds have an abrupt effect on the maximum air temperature. As far as the area around the National Observatory of Athens is concerned, it was highly urbanized after World War II up to about 1990, when this effect became stationary. The UHI effect, paradoxically, seems not to influence the winter mean maximum air temperature time series, which present positive trends but which are not statistically significant at 95% CL. This is in agreement with the work of Philandras *et al*. (1999), who studied the urbanization effect on climate variability in Athens and concluded that the urbanization effect in Athens referred mainly to maximum temperature and to the warmer seasons of the year.

The mean minimum air temperature shows statistically significant increasing trends (CL = 95%) in most of the stations during summertime, and statistically significant decreasing trends (CL = 95%) in few stations during wintertime. During spring and autumn, the observed positive trends are not statistically significant, except in some stations. The highest increasing trend in mean minimum air temperature during summertime was found in Kerkyra (+0.57°C per decade).

The increasing trends in summer air temperature could be attributed to the significant positive pressure trend at the south-eastern Mediterranean, the Middle East and Turkey (Feidas *et al.* 2004), linking to less frequent expansion of the low over the south-eastern Mediterranean and therefore a weakening of the Etesian winds resulting in the increase of summer temperatures. The prevailing weather type in summer is that of Etesians winds (periodical winds of the north section). This type is established in Greece, when a North Atlantic anticyclone extended over Europe covering the Balkans is combined with the Indian low over Asia Minor and the Eastern Mediterranean Sea. The blow of Etesians winds transfers polar continental (cP) air masses resulting in a north to north-easterly low-level airflow over Greece, which cools the area (Nastos *et al.* 2002). Besides, Maheras *et al*. (2000) found a decreasing frequency of the weather types, which are responsible for the Etesian winds during the period 1958–1997.

The general cooling trend, although not significant, that occurs in winter over Greece is in accordance with the increasing trend of sea-level pressure over the area, linking to an overall winter cooling in the Balkans (Leroux 1993). Especially, for the eastern Mediterranean, a decrease in cyclonic circulation has been observed since 1960 for winter, which can be connected to a change in the zonal circulation index for the North Atlantic and Europe (Sahsamanoglou and Makrogiannis 1992). The winter cooling over Greece can be attributed to the increased frequency of north-west or north-east continental, dry and cold airflows from northern Europe and western

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Russia. These flows are connected with the increase of the frequency and persistence of anticyclones over the central Mediterranean and Balkans (Maheras *et al*. 1999).

The trends of the annual and seasonal mean maximum and mean minimum air temperature for the 20 grid points from NCEP–NCAR reanalysis data are presented in table 2. Statistically significant positive trends (CL = 95%) of summer mean maximum and minimum air temperature exist in the wider area of Greece. Higher trends of mean maximum air temperature (+0.75°C per decade and 1.00°C per decade for grid points L and G respectively) appear in the continental mountainous regions than in coastal regions and islands (+0.08°C per decade, +0.17°C per decade, +0.25°C per decade for grid points D, I and N respectively), while statistically insignificant trends appear in winter, with an exception of the northern gridded data sets, which present statistically significant negative trends.

In the process, we applied FA to the seasonal and annual air temperature time series derived from both ground-based observations and NCEP–NCAR grid points in order to examine the consistencies between the spatial distribution of the loadings and the temporal variability of the factor scores of the two data sets, extracted by FA. Taking into consideration the coarse resolution of NCEP–NCAR reanalysis data (1.9° latitude × 1.875° longitude), we applied factor analysis to the two examined data sets in order to compare the extracted patterns (which represent the main factors) and not to compare gridded station data with the respective NCEP–NCAR gridded data, an analysis that has been previously carried out by Flocas *et al.* (2005). A number of studies have shown that the NCEP–NCAR data are not sufficient to reproduce characteristic climatological properties due to limitations in model parameterization or non-sufficient data entries. Regarding the surface air temperature, even though there can be good agreements on large scales (Smith *et al*. 2001), it has been shown that, on local scales, there can be many uncertainties in small-scale variations, which are related to topography and to other local parameters (Rusticucci and Kousky 2002).

The total variance of the mean maximum and mean minimum surface air temperature, for both examined data sets, can be explained quite satisfactorily by using two main factors for all the seasons and the year, except the winter where three factors have been returned by the application of FA. As far as the ground-based data are concerned, on a seasonal basis, the total variance of the mean maximum air temperature can be explained from 78% in the summer up to 87% in the winter. Accordingly, the variance in the mean minimum temperature can be explained from 70% in spring up to 85% in winter. On an annual basis, the total variance explained in the mean maximum air temperature is 75%, while in the mean minimum air temperature it is 69%.

When NCEP–NCAR grid points data sets are analysed, the respective explained variances of the air temperature are higher than 85%, which can probably be attributed to the fact that the gridded data are smoothed.

The spatial distributions of the factors loadings extracted by FA, with respect to the ground-based and the gridded data, appear to have significant differences mostly in summer and spring. Figures 2–5 show the spatial distributions of the factor loadings (>0.6) for summer and winter (for brevity, the other seasons are not shown). Significant dissimilarities appear between the factor loadings seasonal patterns of the two examined data sets. In particular, the patterns shown in figures 2 and 3 depict dissimilarities that may be attributed to the land–sea distribution, a factor that is very important in the air-temperature regime during summertime, because of the higher thermal capacity and less conductivity of the sea compared to land. The land–sea distribution is assigned in a more clear way by the air-temperature patterns of the

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Table 2. Trends (°C/year) of annual and seasonal mean maximum and mean minimum air temperature for the 20 grid points (NCEP–NCAR reanalysis data) for the period 1955–2001. Statistically significant trends (CL = 95%) are shown in bold.

		Winter		Spring		Summer		Autumn		Year	
	Grid points	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}
1	A	+0.014	+0.015	**+0.015**	+0.011	**+0.028**	**+0.024**	**+0.030**	**+0.026**	**+0.021**	**+0.018**
2	B	+0.013	+0.007	**+0.016**	+0.007	**+0.025**	**+0.017**	**+0.027**	**+0.018**	**+0.019**	**+0.011**
3	C	**+0.023**	−0.010	**+0.057**	−0.006	**+0.072**	−0.002	**+0.046**	−0.005	**+0.048**	**−0.007**
4	D	+0.011	+0.009	+0.010	+0.007	**+0.008**	**+0.010**	+0.013	+0.013	**+0.009**	+0.008
5	E	+0.007	+0.005	+0.010	+0.005	+0.010	**+0.010**	+0.009	+0.007	+0.007	**+0.005**
6	F	+0.013	+0.011	**+0.016**	+0.005	**+0.030**	**+0.019**	**+0.026**	**+0.018**	**+0.020**	**+0.012**
7	G	+0.020	**−0.020**	**+0.060**	−0.005	**+0.100**	+0.003	**+0.051**	+0.000	**+0.056**	**−0.007**
8	H	+0.014	**−0.028**	**+0.055**	−0.010	**+0.076**	**+0.013**	**+0.041**	−0.011	**+0.045**	−0.011
9	I	+0.009	+0.001	+0.007	+0.001	**+0.017**	**+0.012**	+0.011	+0.006	**+0.009**	**+0.003**
10	J	+0.009	+0.001	+0.013	+0.003	**+0.015**	**+0.014**	+0.008	+0.007	**+0.009**	+0.004
11	K	+0.004	+0.001	+0.005	−0.001	+0.021	**+0.017**	+0.011	+0.005	**+0.009**	+0.004
12	L	−0.030	**−0.054**	+0.016	−0.030	**+0.075**	+0.005	+0.022	−0.014	**+0.021**	−0.025
13	M	−0.006	**−0.038**	+0.028	**−0.022**	**+0.056**	**+0.014**	+0.021	−0.021	**+0.023**	**−0.019**
14	N	+0.005	−0.016	+0.048	**−0.009**	**+0.025**	**+0.023**	+0.0190	−0.013	**+0.022**	**−0.006**
15	O	+0.008	−0.015	+0.051	−0.006	+0.016	**+0.019**	+0.017	−0.012	**+0.020**	−0.006
16	P	**−0.034**	**−0.038**	**+0.008**	−0.012	**+0.056**	+0.009	−0.007	−0.014	+0.005	−0.015
17	Q	**−0.052**	**−0.079**	**−0.009**	**−0.029**	**+0.048**	+0.005	−0.012	**−0.028**	−0.007	**−0.035**
18	R	**−0.041**	**−0.081**	**−0.002**	**−0.030**	**+0.040**	−0.000	−0.014	**−0.044**	−0.007	**−0.042**
19	S	**−0.035**	**−0.051**	**+0.029**	−0.015	+0.030	+0.007	−0.007	**−0.035**	+0.001	**−0.027**
20	T	**−0.030**	**−0.032**	**+0.041**	−0.008	+0.027	**+0.018**	−0.001	**−0.025**	+0.006	**−0.015**

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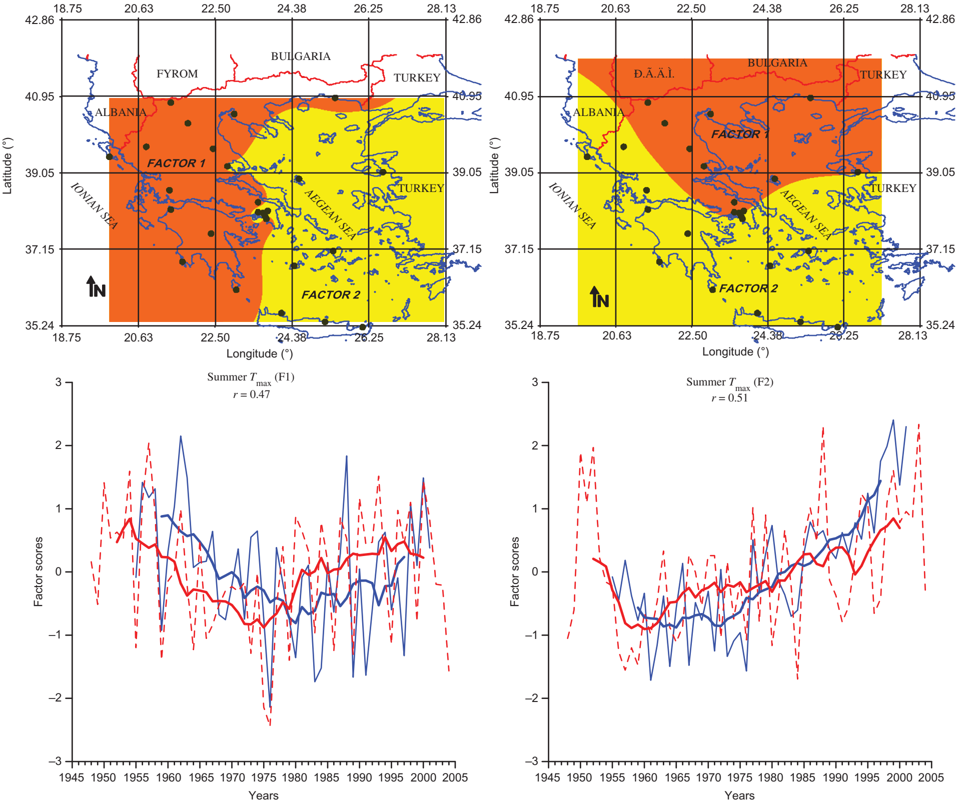

Figure 2. Spatial distribution of the factor loadings, for the summer T_{max}, based on factor analysis, which was applied in the ground-based stations (upper-left panel) and in the NCEP–NCAR grid points (upper-right panel). Time series of the factor scores (continuous blue line: stations; dotted red line: grid points), of the first factor (lower-left panel), and the second factor (lower right panel), along with a nine-year moving average.

ground-based observations. Additionally, the seasonal time series of the factor scores of the main factors extracted by FA also show differences. More specifically, on one hand, regarding the mean maximum air temperature, the highest correlation between the factor scores time series of the first main factors appears in winter ($r = 0.78$) and the lowest correlation appears in summer ($r = 0.47$); on the other hand, the correlation between the factor scores time series of the second main factors is highest in autumn ($r = 0.81$) and lowest in spring (not shown). Regarding the mean minimum air temperature, high correlations appear between the factor scores time series of the second ($r = 0.73$) and the third ($r = 0.72$) main factors in winter and of the first ($r = 0.81$) and the second (0.77) main factors in autumn. It is obvious from figures 2–5 that the spatial divergence between NCEP–NCAR gridded data and ground-based observations leads to temporal differences shown in the respective diagrams of the figures.

Even if spatial patterns (interpreting the air-temperature variability within great areas), derived from ground-based observations or NCEP–NCAR gridded data, are compared, instead of comparing gridded station data to respective NCEP–NCAR gridded data (Flocas *et al*. 2005), dissimilarities will appear. These findings confirm the assumption that, on a local scale, the annual and seasonal mean maximum and mean

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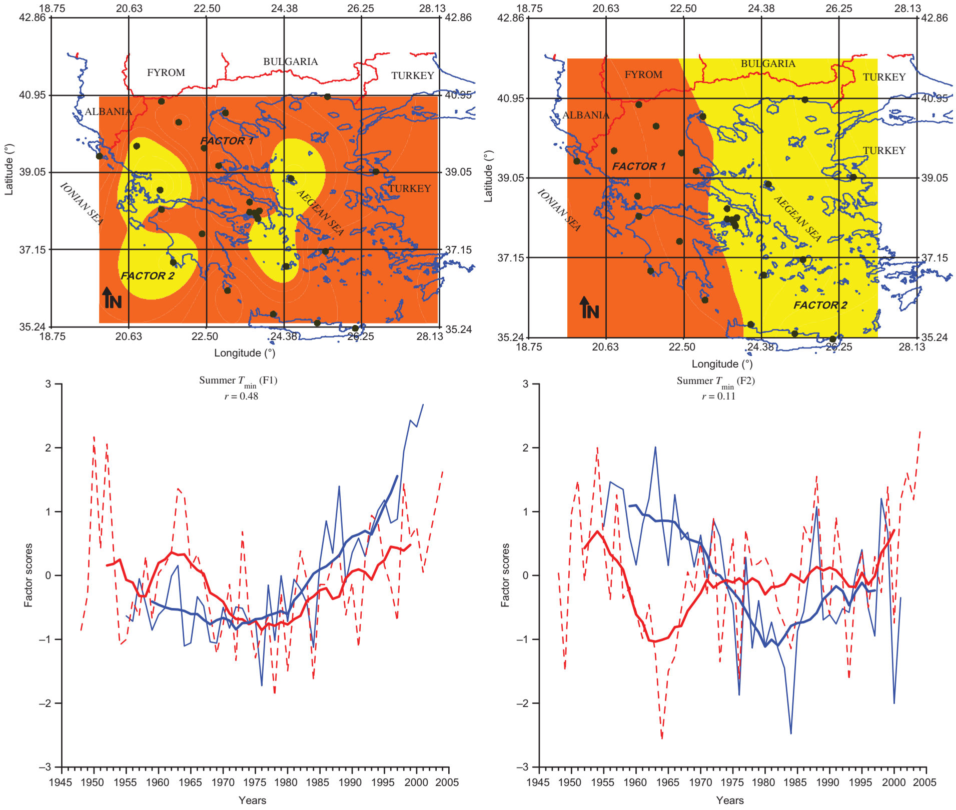

Figure 3. As figure 2, but for the summer $T_{\min}$.

minimum air temperatures derived from the NCEP–NCAR reanalysis grid points present significant divergences from the respective time series of ground-based observations. Nevertheless, the mean composite ground-based observations (averaged over the Greek area) were statistically significantly (CL = 95%) correlated to the mean composite NCEP–NCAR gridded data (average of A–O grid points; figure 1), on an annual and seasonal basis. The correlations appeared to be slightly higher with respect to mean minimum air temperature (from 0.88 in spring to 0.95 in autumn) than mean maximum air temperature (from 0.80 in autumn to 0.86 in winter). Besides, the NCEP–NCAR data underestimated the mean maximum air temperature by about 2°C in both summer and winter, while they overestimated the mean minimum air temperature in summer (by about 0.5°C) and in winter (by about 1.0°C), as depicted in figure 6. Similar patterns appeared in spring and autumn (not shown).

4. Conclusions

The analysis that was performed in the time series of the mean maximum and mean minimum surface air temperature, using data sets from 26 Greek meteorological stations and respective NCEP–NCAR reanalysis gridded data, showed seasonal differences in the spatial and temporal distributions for the main factors (patterns) extracted by the application of factor analysis. The inconsistencies appeared mostly

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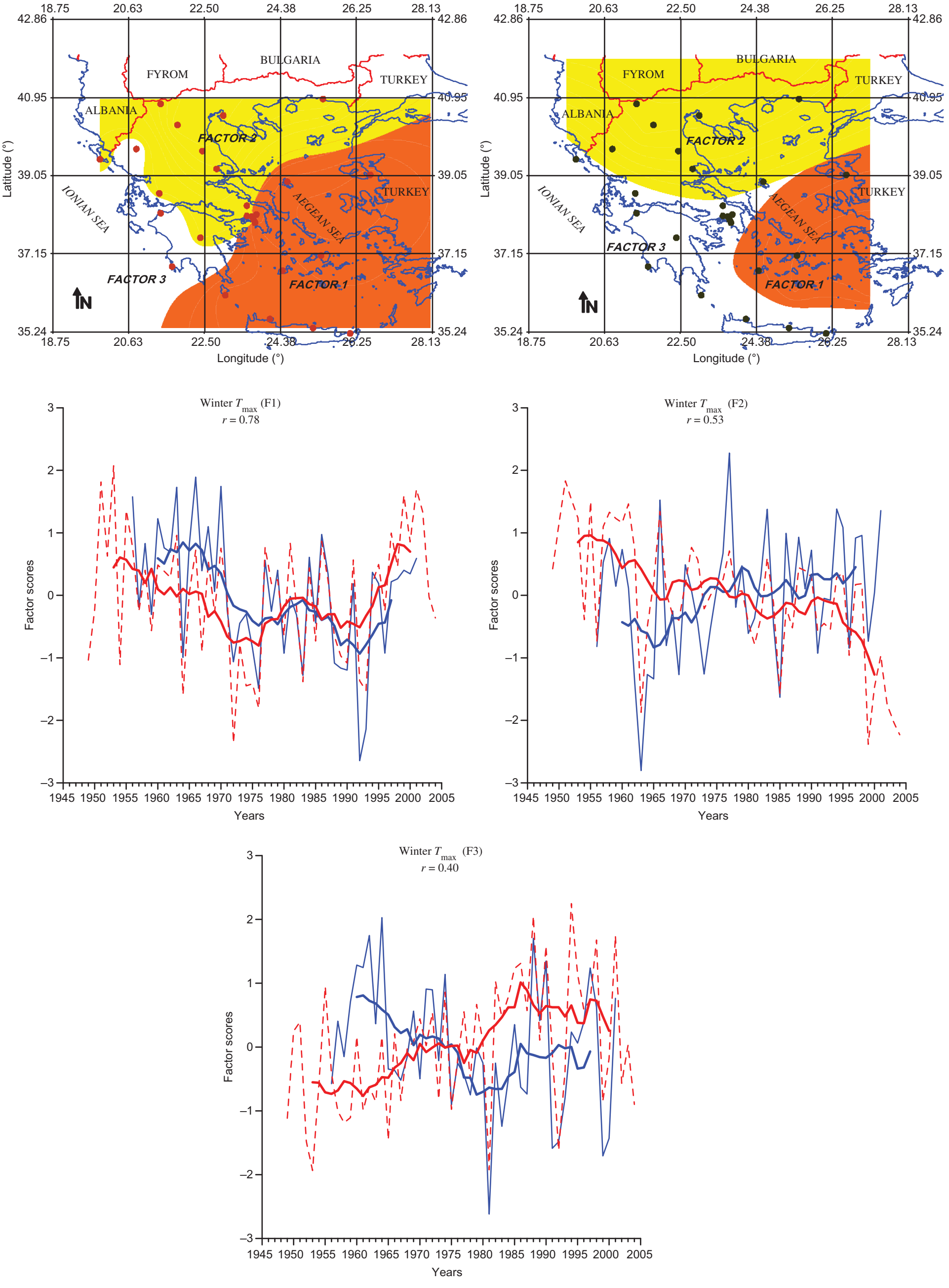

Figure 4. As figure 2, but for the winter $T_{\max}$.

during spring and summer. During winter and autumn, the temporal variability of the NCEP–NCAR gridded data coincides with the variability of the ground-based measurements, better over sea (Aegean Sea, Ionian Sea) than over central continental regions of Greece. This observed divergence is attributed mainly to factors such

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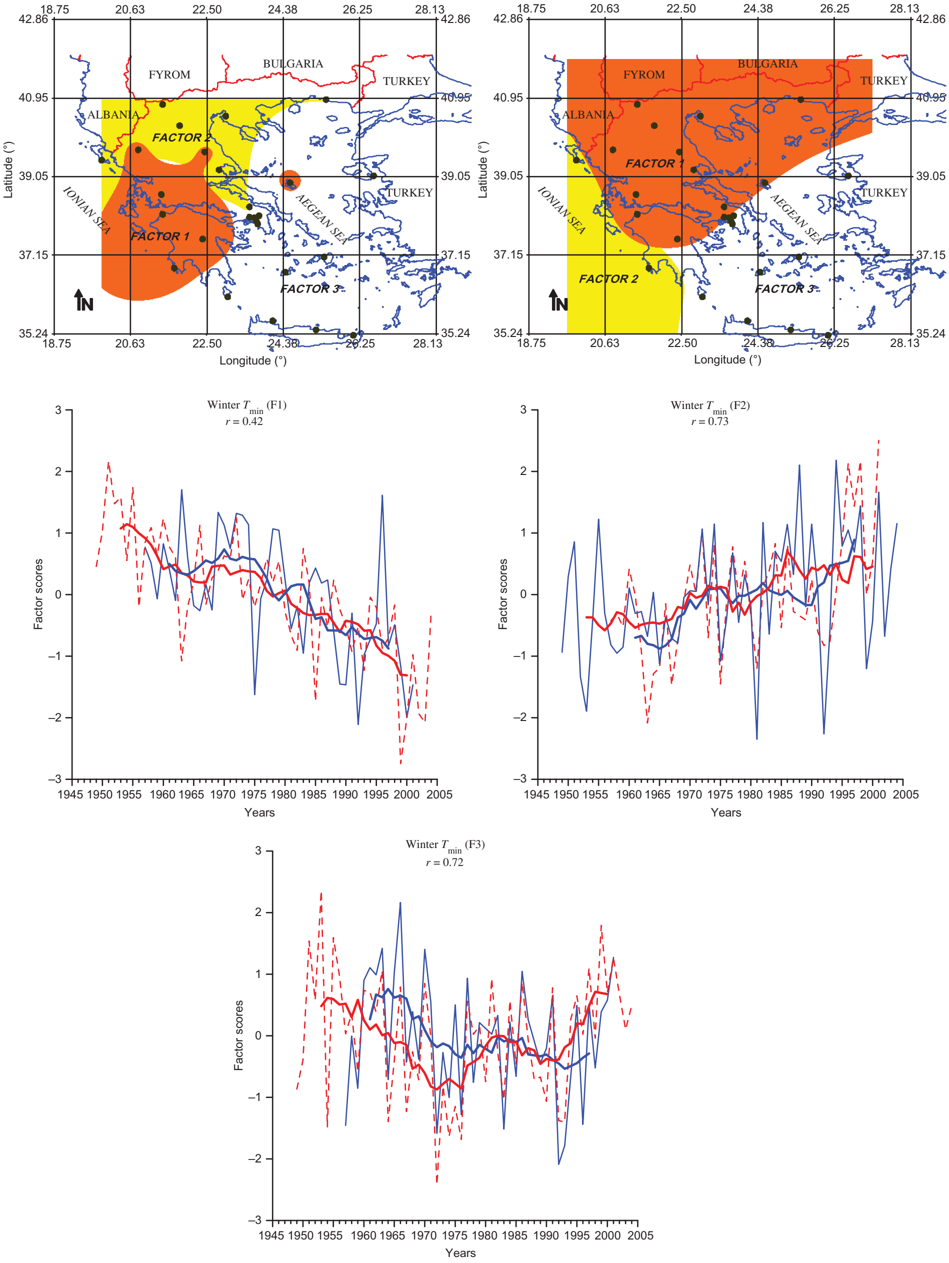

Figure 5. As figure 2, but for the winter T_{min}.

as the land–sea distribution and the topography. Given that, Greece is a country with a wide climatic variability due to its complex topography, successive and high mountain ranges and also multifarious and long coastlines, the NCEP–NCAR reanalysis gridded data should be applied taking into consideration the limitations that appeared due to aforementioned factors, which could not be represented properly by the reanalysis model. On the other hand, when mean composite ground-based and

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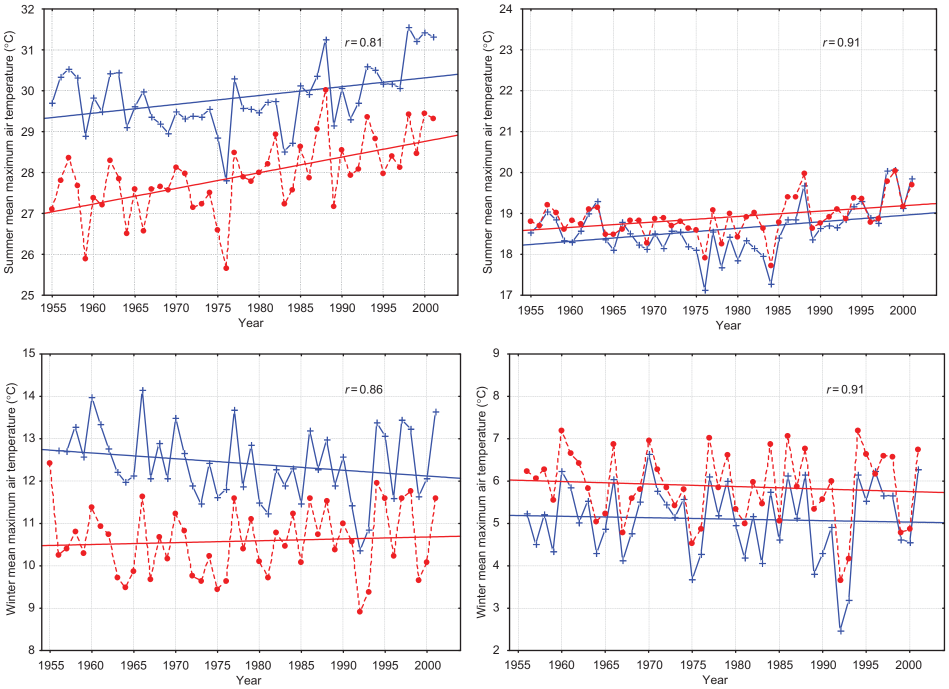

Figure 6. Time series of mean maximum (left graphs) and mean minimum (right graphs) air temperature from mean composite ground-based (blue line) and NCEP-NCAR gridded (red line) data for the Greek region, during summer (upper graphs) and winter (lower graphs).

NCEP–NCAR gridded data were taken into consideration for the whole of the Greek region, high correlations between the two examined data sets appeared on an annual and seasonal basis. It was shown that the mean composite NCEP–NCAR data underestimated the mean maximum air temperature and overestimated the mean minimum air temperature.

As far as the trends of the ground-based observation time series are concerned, statistically significant (CL = 95%) negative trends in mean maximum and mean minimum surface air temperatures were observed during the winter while significant positive trends in both parameters examined appeared during summer. On the other hand, the gridded time series (NCEP–NCAR reanalysis data) present significant positive trends (CL = 95%) of summer mean maximum and minimum air temperature within the wider area of Greece, while statistically insignificant trends appear in winter, with the exception of the northern gridded data sets, which present statistically significant negative trends.

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