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The anomalous low and high temperatures of 2012 over Greece: an explanation from a meteorological and climatological perspective

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Abstract

The year of 2012 is characterized, for Greece, as the hottest one in the available record dating back to 1958, presenting also the widest annual temperature range. During the summer and autumn months, numerous regions in the domain of study experienced record-breaking maximum and minimum temperatures. Conversely, the winter period was particularly cold and January was one of the coldest months in the last 55 yr. The analysis of the cold period indicates that the synoptic conditions resemble the positive phase of the Eastern Mediterranean Pattern (EMP). The predominance of these cool conditions seems to be primarily related to an intense NNW or NNE atmospheric circulation, as a consequence of the positive EMP phase. Moreover, the reduction of the floating sea ice emerged as a key driver to the formation of a low pressure pattern and the reinforcement of the trough south of Scandinavia, which in turn strengthened the Siberia High east of the trough. This reinforcement resulted in a blocking pattern and in the favorable conditions for the EMP formation The atmospheric circulation during the prolonged high-temperature period resembles, respectively, the negative phase of North Sea–Caspian Pattern teleconnection. The observed positive pole, in conjunction with the strong southwestern circulation, results in temperature increases and in the development of a smooth pressure field that contributes to the weakening of the Etesian winds and therefore to calm conditions over the continental areas.

1 Introduction

According to the Met-Office Hadley Center (UK) as well as the Japan Meteorological Agency (JMA), the annual global average surface temperature anomaly for the year of 2012 was +0.14 °C relative to the 1961–2010 mean. This ranks it as the eight highest global temperature anomaly since 1891. During 2012, several parts of the planet, such as western Russia, southeastern Europe, the Arabian Peninsula, eastern and central parts of the USA and Western Australia, witnessed extremely high temperatures.

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Concerning Greece, 2012 is characterized as the hottest year in the record that dates back to 1958, even hotter than 2007 (Tolika et al., 2009) presenting also the wider annual temperature range. The temperature rise initiated in March and the extreme warm conditions lasted until the end of November. In particular, during the summer and autumn months, numerous regions in the domain of study (Greece) experienced record breaking maximum and minimum temperatures. June, July, August and October rank for many stations as the hottest months of the whole period 1958–2012, while for the rest of the months the warm conditions showed an abnormal duration and persistence. Contrarily, the winter period, especially from the end of December 2011 until the end of February 2012, was particularly cold and January was found to be one of the coldest months of the last 55 yr.

Given the particularly rare temperature characteristics of the year 2012 in Greece, this study aims to identify the leading meteorological conditions over the Mediterranean as well as the corresponding large scale atmospheric processes and key synoptic – scale features that possibly contributed in these extreme winter cooling and summer warming.

2 Data and methodology

Daily maximum and minimum temperatures (Tmax and Tmin) for the period December 2011–November 2012, derived from 15 meteorological stations over the Greek region were utilized. Apart from Thessaloniki (available from the meteorological station of the Aristotle University of Thessaloniki), the rest of the data were provided by the National Climatic Data center of NOAA. Long-term (1958–2011) Tmax and Tmin daily timeseries (Hellenic National Meteorological Service) for the selected stations were also utilized. Furthermore, the NCEP/NCAR re-analysis data (Kalnay et al., 1996) were used to compute the monthly mean, the mean monthly climatological and the mean anomaly fields for the period 1958–2011. The data used for the analysis were air temperature and geopotential heights 1000, 850, 500, 200 hPa on a regular $2.5^{\circ} \times 2.5^{\circ}$

global grid (90° N–90° S, 0–357.5° E) at 00:00, 06:00, 12:00 and 18:00 UTC. The 6-hourly sea surface temperatures (SSTs) of the NCEP/NCAR reanalysis 1, available on a Gaussian grid (192 × 94 grid points), covering the globe 88.542° N–88.542° S, 0–358.125° E), were also used in the study.

3 Results: meteorological aspects – links with the atmospheric circulation

The investigation of the leading synoptic conditions at the levels of 1000, 850, 500, 200 hPa during the year December 2011–November 2012 and their anomalies, showed that the meteorological causes of the prevailing low Tmax and Tmin (December 2011–March 2012) and the high Tmax and Tmin (April–November 2012) are quite clear and straightforward in some cases, while in others the key drivers to such cooling or warming are more complicated since they could be originated from the synergy of several different atmospheric processes.

3.1 The atmospheric circulation during the cold period of the year 2012

January and February were found to be the coldest months of the period of study. Their main thermal characteristic was not the extreme absolute low temperatures (T_{max} and T_{min}) but the extended duration of cool conditions in most of the stations over the Greek region (Tjanuary, 2012 $< T_{mean} - 2\sigma$). The atmospheric circulation during those two months is generally anticyclonic. More specifically, at the 1000 hPa geopotential level (Fig. 1), positive anomalies are observed over the Atlantic and over eastern Europe and mainly in NW Siberia where the anomalies reach the value of 120 gpm. A NW-SE oriented zone is detected between these two positive anomaly poles; extending from eastern Mediterranean through Greece up to the Scandinavian Peninsula. Another low geopotential anomaly zone covers the whole North America and Greenland. On the other hand, positive anomalies are found at the west of North America, over northern Pacific Ocean, centered over Berig Sea (January) while during February (Fig. 2) this

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positive anomaly zone is replaced by a negative anomaly one (the positive anomalies are abridged to the south).

Regarding the 500 hPa level, the two aforementioned positive anomaly poles (one over the north Atlantic and one over NW Siberia) are also observed in the same locations in January 2012 but there are more reinforced. A negative anomaly zone between these two poles covers Greece once more and the negative anomaly zone of North America and Greenland is more extended to the west (Pacific Ocean) in comparison with the equivalent one of the 1000 hPa. During February, the North America negative anomaly zone is being replaced by positive anomalies, while the negative anomalies in Greenland remain although there are much weaker.

The atmospheric circulation at the two examined levels (1000 and 500 hPa) implies on one hand the reinforcement of the north Atlantic High and on the other hand the even greater strengthening of the Siberian Anticyclone especially over the NW Siberia. This intense strengthening, noted as the greatest since 1979/1980 (TCC News, 2012) redounds to a further reinforcement of the winter monsoon in northeast Asia and a blocking in the atmospheric circulation on its west side, in the Scandinavian region as well as in eastern Europe and eastern Mediterranean. Thus, the low temperatures with extend duration during the winter of 2012 and mainly during the January – February period could be attributed primarily to the aforementioned blocking caused by the extension of the Siberian High itself over the Balkan Peninsula and the northwestern Europe. This blocking situation favored the transfer of cold air masses from Scandinavia and even possible from the North Pole to the south over the Balkans and eastern Mediterranean. Moreover, the detection of negative temperature anomalies in several atmospheric levels (1000, 850, 500 hPa) in the Scandinavia, the Balkans, over Eastern Europe and the Mediterranean, (not shown) comes in agreement with the previous statement.

Yet, another question is raised. Is it a common phenomenon the reinforcement of the Siberian Anticyclone to the northwest and in all the atmospheric levels? It should be highlighted at this point that its extension to the west and southwest (central Europe,

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Balkan Peninsula and eastern Mediterranean) is accompanied at the 500 hPa level with a cyclonic circulation. In other words, a positive vorticity advection (Makrogiannis et al., 1981) is found there. In the case of winter 2012, positive vorticity advection over to southeasten Europe is observed at the 500 hPa level; however, at the surface the pressure is relatively low or with a slack pressure gradient. In addition, the common mean location of the center of the Siberian Anticyclone is found at 50° N and 100° E (Sahsamanoglou et al., 1991), which in our case is found in almost the same location. However, the intense positive anomaly center is detected much further to the north and west (70° N, 62° E).

It is obvious that a clear answer to the question raised above can not be easily given. However, taking under consideration the intense strengthening of the Siberian High to the northwest and its different altitudinal characteristics, in comparison to this common structure and the blocking conditions that it caused in eastern Europe, the Balkans and eastern Mediterranean, it can be concluded that these are "very abnormal" atmospheric circulation conditions for the whole European region. What is left is to investigate the general atmospheric circulation on a hemispheric or planetary scale that forced these atmospheric circulation conditions and contributed to its great persistence for almost the whole winter period of 2012.

Figure 3 illustrates that during the examined winter period, the SSTs in the equatorial Pacific were below normal mainly in the central part (Nino3 and Nino3.4), while slightly above normal values were observed in the western and eastern parts. These oceanic characteristics indicate the persistence of relatively slighter ENSO – La Nina conditions. Thus, La Nina – like conditions could be associated with a dipole SST anomaly patterns, with positive value in the north and negative ones in the south (TCC New, 2012), observed in the tropical and subtropical Atlantic (Fig. 3). In addition, it can be noted that the SST anomalies found northwards and southwards of the Atlantic tropics as well as the La Nina – like conditions may contribute in the anomalous atmospheric circulation over the north Atlantic and thus could be considered as a key driver to the eastwards shift of wave trains. Finally, the observed reduction of the amount of floating

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sea ice in the Arctic and especially in the Barents Sea and the Kara Sea (Houda et al., 2009; Inone et al., 2012), could have also played an important role in the atmospheric circulation conditions and the strengthening of the Siberian High with height.

3.2 Characteristics of the atmospheric circulation during the warm period of 2012 (April–November)

In contrast to the winter period, exceptional warming conditions occurred in Greece starting by the end of March until the end of November 2012. High maximum and minimum temperatures were observed in particular during summer and autumn (Table 1). Record breaking temperatures were found for June, July, August and October for a great percentage of the stations under study and these months were characterized as the warmest ones of the long term period 1958–2012.

Due to space limitations we could not present the atmospheric circulation maps for all those months. Thus, although all the months of the warm and transitional period are analyzed, we decided to show the most representative ones, regarding July and October.

In the case of June, at the 1000 hPa level, a negative anomaly zone, centered over the British Isles and extending from the south–west to the north–east (from the Gulf of Mexico to the Scandinavian Peninsula and northern Rusia). To the east of this zone, a slack field of almost zero anomalies covers the rest of Europe while to its northwest, an extended positive anomaly zone is found over Greenland up to the North Pole. Also, negative anomalies characterize the whole northern America (Fig. 4). For the previous two-months period (April–May, not shown), it seems that the atmospheric circulation did not differ significantly from that of June apart from the actual magnitude of the negative and positive anomalies. The same was noted for July and August except that in July the negative anomaly field has weakened both in strength and extent, while the positive anomaly field covers a large part of the Eastern Europe and western Siberia.

The analysis of the 500 hPa field is in agreement with the synoptic analysis of the previous paragraph. A strong double-center negative anomaly zone (at the northwest

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the first and the northeast of the British Isles the second) is extended from the Gulf of Mexico to the north Scandinavia in June 2012. At the southeast of this zone, another positive anomaly zone, with its center over the Balkan Peninsula and Greece outspreads from the southwest (Sahara) to the northeast (Black Sea). To the northeast, a positive anomaly zone covers almost the whole of the Siberian region. Positive anomalies are also found over Greenland, covering a large part of north America. As mentioned before, the atmospheric circulation of the previous period of April and May does not present many differences apart from the intensity and the location of the positive and negative anomalies. The 500 hPa pattern of July and August is also similar. More specifically, for July the negative anomaly zone centered over the British Isles is further extended to the north and northeast covering the whole north Siberia and parts of the Artic region. Finally, in August, two negative anomaly poles are detected. The first and most intense one is found at the southwest of the British Isles and the second one which is more extended is observed over the northern Siberia.

During the next trimester (September, October and November) it should be highlighted that October is the month with the strongest positive temperature Tmax and Tmin anomalies for all the stations of this study. The examination of the atmospheric circulation at the 1000 hPa level for October, showed an extended but weak negative anomaly zone with a center at the southwest of Britain covering the region from the Gulf of Mexico till the north Scandinavia (Fig. 5). Two positive anomaly poles are formed at the west and east of this zone. The first one is over Greenland and the second over the north Siberia extending to the east. Moreover, positive anomalies characterize north America (north to the 50° N parallel) while to the south negative anomalies are observed. It is worth noting that during the previous month (September 2012), the atmospheric circulation was very different in comparison to the October one. A positive anomaly zone oriented from the west to the east, covers the largest part of north Atlantic in the mid-latitudes, while to the north, another negative anomaly zone extends from north America to central Siberia. Regarding November, the atmospheric conditions also differ. A positive anomaly pole is discerned in the middle of north Atlantic at the mid-latitudes between north America and western Europe, a negative anomaly pole between Iceland and Scandinavia and another negative anomaly pole is detected in the Pacific Ocean southern of Alaska.

For the same time period of September–November 2012, the atmospheric circulation at 500 hPa create almost consecutive positive and negative anomalies with some variations concerning the location and the intensity of the anomalies. For October, two significant anomaly poles form over the domain of study (Fig. 5). The first with negative anomalies covers the Baltic and extends from the southwest to the northeast and the second one, with positive anomalies is located over the Caspian Sea. This patterns resembles greatly the negative phase of the North Sea–Caspian Pattern (NCP) teleconnection (Kutiel and Brunetti, 2011) which is responsible for the strong southwest current over the eastern Mediterranean and the Balkans, resulting to intense positive temperature anomalies (Kutiel et al., 2002). In September, the atmospheric conditions differ compared to October due to the fact that the negative pole is shifted to the northwest and extends from west to east covering parts of Greenland. On the other hand the positive pole is shifted to the west over the Black Sea, maintaining the southwest current over the Balkans and Greece. Concerning November, the position of the two poles is also different. The negative pole is located over Great Britain and the anomaly zone extends from south to north (from Algeria to Iceland and even northern) while the positive pole is found over the Black Sea covering almost the whole Europe and the Mediterranean. In each case, the south, southwestern current over Greece and the Balkans is maintained resulting to positive temperature anomalies.

Furthermore, for the warm period from April to November 2012, the analysis of the SSTs (sea surface temperatures) in the equatorial Pacific showed that they were from neutral (April, June and September–November) to above normal (July–August). To the north, at the subtropics of the north Pacific, from June until October, a negative anomaly zone is formed at the west of north America. Further north, at mid-latitudes, from August till October, an extended positive anomaly zone is observed that reaches even

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eastern Siberia. At the north Atlantic region, at mid and high latitudes (30–50° N), another positive anomaly zone can be detected for the time period from May to November.

Finally, a factor that probably plays an important role in the spatial pressure distribution in the Northern Hemisphere and especially in the mid and high latitudes is the Arctic ice coverage. According to the TCCNews (2012), until the beginning of March 2012, an intense decrease of the ice coverage is detected until the mid of August, when a minimum dating back to 1979 is observed. It is worth mentioning that in 2007, when Greece experienced record breaking high temperatures as well (Tolika et al., 2007) during the summer period (June–August), the Arctic ice coverage also presented a minimum. Thus, it seems that there is a strong connection between the arctic ice extend and the atmospheric circulation in the mid and high latitudes and the time and spatial distribution of temperatures in the Greek area. The trigger mechanism that causes this effect should be further examined.

4 Conclusions and Discussion

During the year of 2012 (December 2011–November 2012), extreme temperatures were recorded in Greece, ranking it as the hottest of the last 50 yr. Despite these extreme hot conditions the time distribution of the temperatures was not uniform during the year. Two different periods were detected. The first one, from December 2011 until March 2012, presented low temperatures, especially for January and February (the coldest one of the last 50 yr). The second one, April–November 2012, was characterized by high temperatures in particular for the trimester June–August (the warmest period for many stations of the last 50 yr).

Regarding the cold period of December 2011–March 2012, the analysis of the synoptic conditions and their anomaly maps for several geopotential levels resemble to the positive phase of the Eastern Mediterranean Pattern (EMP) as determined by Hatzaki et al. (2007, 2009). They showed that the EMP exhibits a pronounced inter-monthly variation in its location, structure and strength. In winter, the EMP is defined as follows:

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EMP = gpm(25° W, 52.5° N) – gpm(22.5° E, 32.5° E) but during the other seasons the northern pole is shifted eastwards over Great Britain or central Europe. In January the northern and southern poles are located at almost the same positions while in February the southern negative pole has shifted to the southwest. During March, the locations of the poles are completely different. The positive one is detected over the British Isles whereas the negative one is found to the east, north of the Caspian Sea. Therefore the prevalence of low temperature conditions (both Tmax and Tmin) over the Greek region during winter 2012 seems to be mainly associated with the occurrence of an intense NNW or NNE atmospheric circulation over the country, mainly at mid-upper troposphere, due to the positive EMP phase.

At this point, it is imperative to try and identify which are the main factors that contributed to the development of the EMP teleconnection and consequently to the very low winter temperatures in the domain of study. Previous studies have shown (Hoarling et al., 1997; De Weaver and Nigam, 2002; Hurrell et al., 2003; Bulic, 2010) that negative or positive SST anomalies in the tropics (Nino3 or Nino3.4) stimulate a "wave train" which propagates eastwards and could affect the meteorological conditions over the North Atlantic in the region of the north pole of the EMP. The previous analysis provided evidence about the role of several other geographical or dynamical factors in alerting the circulation pattern in the area of interest. Thus, La Nina – like conditions associated with the SST negative anomaly observed in the Pacific tropics and positive SST anomalies in the north Pacific and the North Atlantic may be responsible for the enhanced convective activity over these regions and therefore responsible for wave trains along the Polar Front Jet Stream in the Atlantic. Moreover, the complex relief (orography) of Greenland and Scandinavia in addition to the reduction of the amount of floating sea ice in the artic and especially in the Barents and the Kara Sea play an important role in the location and the range of the circulation patterns. The effect of this reduction of the floating sea ice seems to be the key driver to the low pressure pattern formation and to the reinforcement of the trough at the south of Scandinavia resulting to an even greater strengthening of the Siberia High at the east of the trough. This re-

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inforcement led to the blocking pattern that was described in the previous paragraphs and resulted to the favorable conditions for the formation of the EMP teleconnection.

Concerning the prolonged high temperature period in Greece (April–November 2012), the analysis of the synoptic conditions and their anomaly patterns showed that for April, September, October and November the spatial distribution of the atmospheric circulation resembles the negative phase of the North Sea–Caspian Pattern (NCP) teleconnection, with only some differentiations mainly at its south pole. Conversely, for the time period from May until August, the prevailing situation resembles more with the negative phase of the Eastern Mediterranean Pattern (EMP). For both cases and in all the geopotential level, a southwesterly flow (transfer of air masses from Sahara) is apparent over the Balkan Peninsula and the Greek region, mainly responsible for the high temperatures in our country. As in the case of the low winter temperatures, the prevalence of the two teleconnections (NCP and EMP) is probably due to several different factors (meteorological and geographical) the temporal cascade of which is very difficult to be investigated in comparison to the cool period one. From the previous analysis it was found that the temperatures in the equatorial Pacific were from neutral (April, June and September–November) to above normal (July–August). It is apparent that the temperatures in the Pacific and particularly in the Atlantic play a very important role in the subtropical and high latitude areas. Thus, the notably high temperature anomalies formed at the north Atlantic combined with the high temperatures of the Arctic; northern to Siberia, as well as the continuous decrease of the Arctic ice seems to be responsible for the negative geopotential anomalies in all the atmospheric levels over the northeast Atlantic. This atmospheric pattern contributes to the reinforcement of the length and width of the meanders of the polar jet. It is also possible that the strong convection observed for the same time period in the Pakistan area and in the monsoon area of India, amplifying the thermal low in the regions east of the Mediterranean, could play an important role in the intensity and the location of the jet meanders. The positive geopotential anomaly pole observed over Greece, mainly during summer, with the strong southwesterly flow results not only to the temperature increase but also to the development of a slack pressure field over our country that contributes to the weakening of the Etesian winds and therefore to calm conditions over the continental areas, increasing the unbearable warm sense. Finally, it should be mentioned that other dynamical and geographic factors may have played an important role to these abnormal high temperatures for the time period of April–November but due to lack of data it was not possible to be analyzed at this point.

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Table 1. Ranking classification of the months of the warm and transitional period of 2012 according to their mean Tmax and Tmin temperatures in each station under study. The comparison was made with the T_{max} and T_{min} temperatures of the long term period 1958–2012.

	Apr		May		Jun		Jul		Aug		Sep		Oct		Nov	
	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}
Alexandroupoli	+8	+5	+12	+6	+1	+2	+1	+1	+2	+2	+3	+1	+1	+2	+6	+5
Heraklio	+5	+10	+14	+26	+19	+4	+3	+2	+8	+2	+7	+9	+7	+3	+13	+1
Thessaloniki	+10	+10	+12	+12	+1	+2	+1	+1	+2	+5	+5	+4	+1	+2	+4	+2
Kalamata	+10	+12	+19	−18	+2	+6	+1	+3	+1	+13	+8	+13	+3	+9	+12	+13
Kerkyra	+11	+3	+18	+12	+2	+6	+1	+1	+1	+4	+7	+7	+1	+3	+1	+8
Kozani	+22	+20	− 23	−23	+1	+14	+1	+10	+3	+24	+8	+22	+5	+5	+18	+14
Larissa	+14	+8	+28	+18	+1	+9	+1	+2	+1	+10	+6	+13	+4	+11	+9	+6
Mytilini	+10	+12	+19	+13	+2	+2	+1	+1	+5	+2	+4	+10	+1	+5	+5	+7
Naxos	+1	+2	+8	+2	+6	+3	+4	+2	+3	+2	+10	+6	+3	+2	+11	+2
Rodos	+12	−25	− 25	+29	+4	+7	+1	+3	+1	+1	+7	+23	+5	+15	+6	+11
Samos	+9	+2	+27	+8	+1	+1	+2	+1	+5	+1	+4	+12	+4	+4	+5	+6
Skyros	+7	+9	+12	+20	+4	+6	+3	+2	+3	+5	+6	+15	+3	+4	+14	+4
Souda	+4	+17	+16	+19	+3	+7	+1	+2	+3	+4	+4	+11	+5	+7	+15	+6

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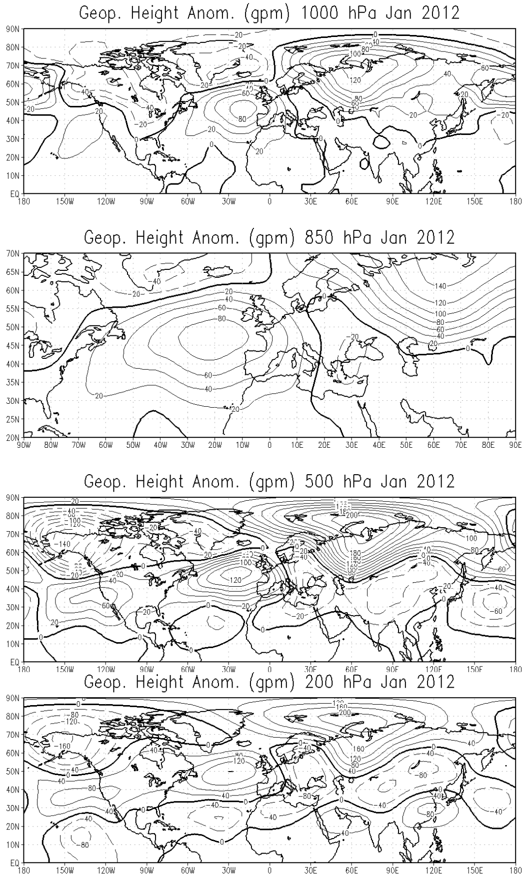

Fig. 1. Mean anomaly field for January 2012, (with respect to the long term 1958–2011 January mean field) for different levels (1000, 850, 500 and 200 hPa).

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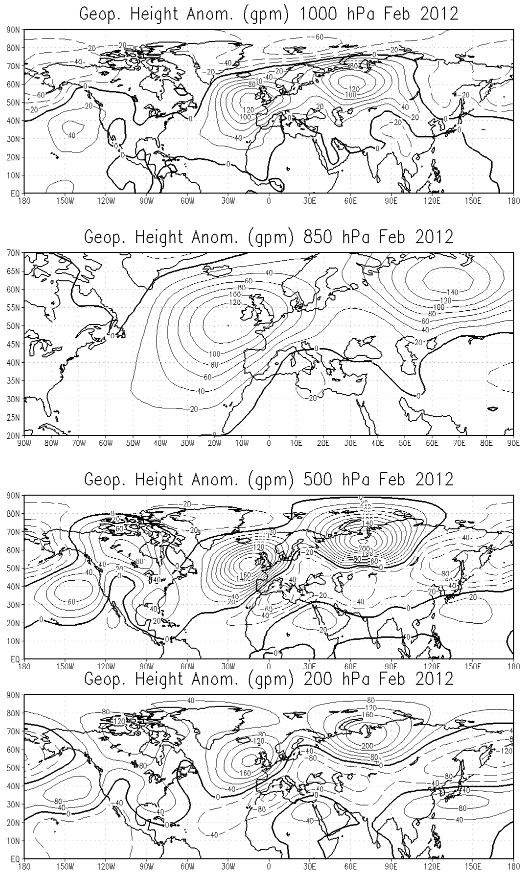

Fig. 2. As Fig. 1 but for February 2012.

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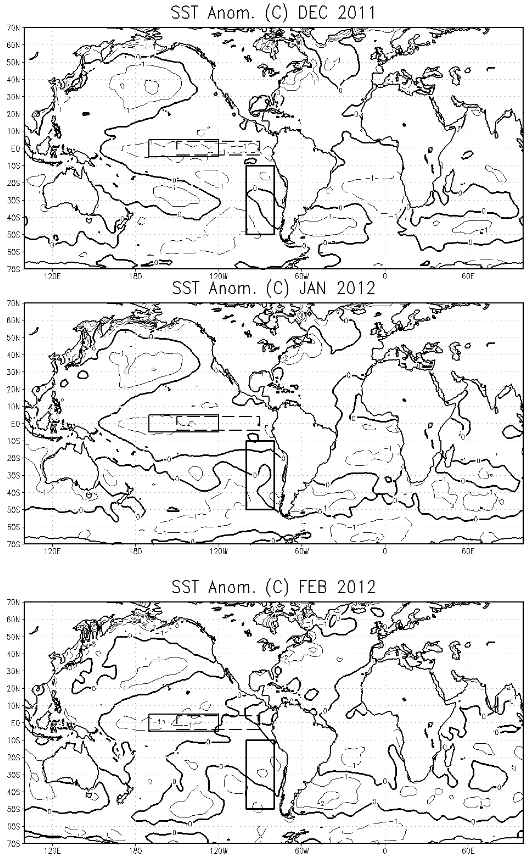

Fig. 3. Monthly mean SST anomalies (°C) December 2011, January 2012 and February 2012 relative to their equivalent long-term mean of 1958–2011 (negative values are indicated by dashed contours). The three boxes depicted in are: Nino 3 (long dashed frame): 4° S–4° N, 150–90° W, Nino3.4 (solid frame): 5° S–5° N, 170–120° W, SE Pacific (bold solid frame): 50–10° S, 100–80° W.

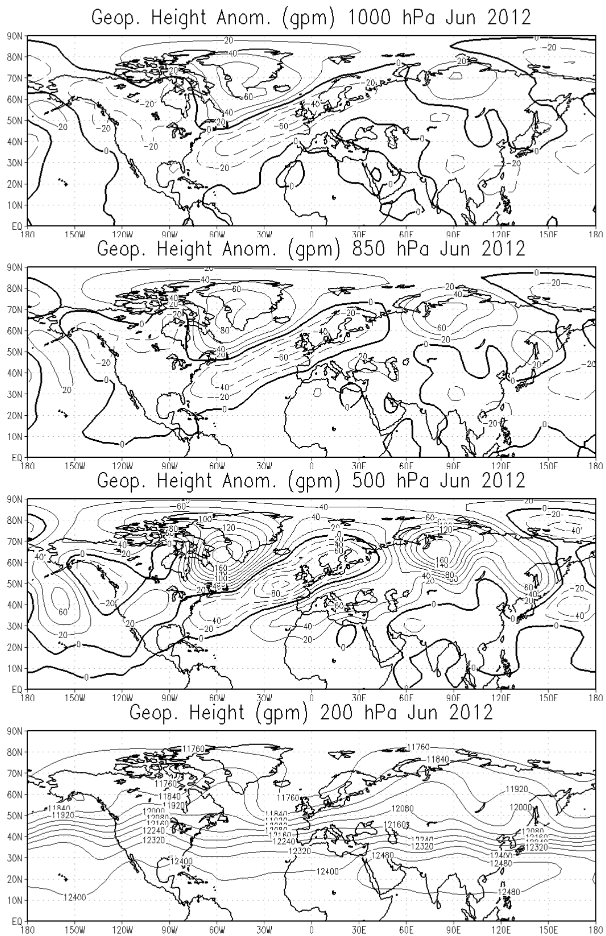

Fig. 4. As Fig. 1 but for June 2012.

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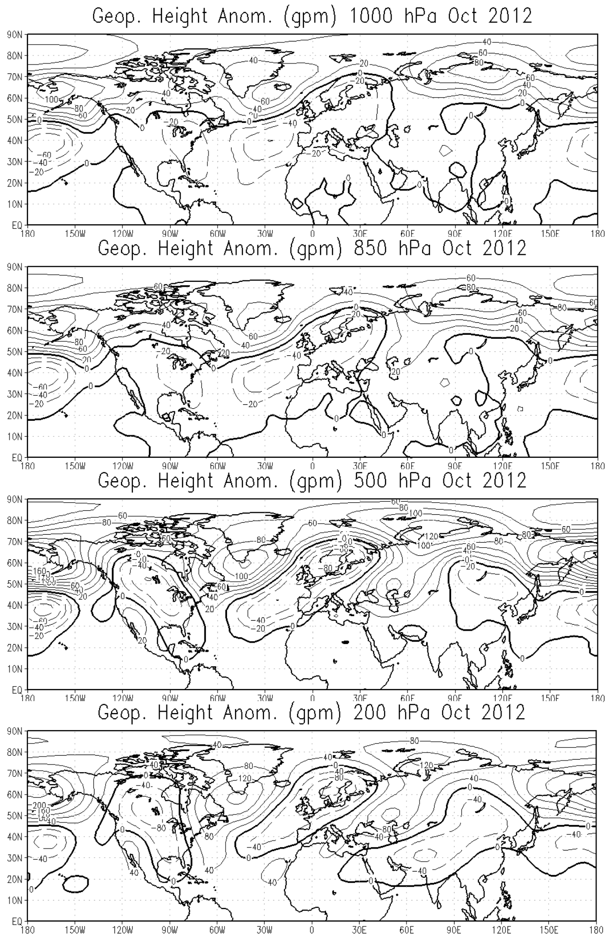

Fig. 5. As Fig. 1 but for October 2012.

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The anomalous low and high temperatures over Greece

K. Tolika et al.

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