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ORIGINAL PAPER

Winter mean temperature variability in Turkey associated with the North Atlantic Oscillation

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Abstract Changes and variability in seasonal average mean and monthly mean winter (DJF) air temperature series at 70 stations of Turkey and the circulation types at 500-hPa geopotential height level were investigated to explain atmospheric controls of temperature variations during the extreme (*weak* and *strong*) phases and normal (*negative* and *positive*) phases of the North Atlantic Oscillation (i.e., Ponta Delgada–Reykjavik and the Gibraltar–Reykjavik) indices. During the *positive phases* of the North Atlantic Oscillation indices (NAOIs), northeasterly circulation increased, and thus spatially coherent and significant cold signals dominate over the majority of Turkey. This pattern is closely linked to anomalously low 500-hPa heights over the region of the Icelandic Low, and anomalously high geopotential heights over the regions of the Azores High, the western Mediterranean basin and the Europe, in general including the Balkans and northwest Turkey. Contrarily, during *the negative phases* of the NAOIs, prevailing westerly winds that originate from the subtropical northeast Atlantic increase, and thus spatially coherent and significant warm signals over the Anatolian peninsula appear. This pattern is closely linked to the increased cyclonic activity and associated increased westerly and southwesterly circulation causing warm maritime air advection over the Mediterranean basin toward Turkey.

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1 Introduction

The atmospheric circulation is the principal control that determines the climate variability. Atmospheric circulation and teleconnection patterns can be characterized by using circulation indices, such as the indices developed for El Niño–Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO) or the North Sea–Caspian Pattern (NCP). Among them, the NAO is one of the most important circulation sources for short and/or long-term climatic variability in the North Atlantic, the Europe, and the Mediterranean regions, because of its importance in transporting heat and moisture to these regions or from them.

The NAO is closely connected to the interannual variability of climatic conditions, mainly during winter across wide regions of the North Atlantic Ocean, the North America, the Arctic, the Eurasia and the Mediterranean, including storminess and precipitation, ocean heat content, ocean currents and their related heat transport, and sea ice cover (Wallace et al. 1996; Hurrell and van Loon 1997; Hurrell et al. 2003). The NAO also has a strong effect on the European temperature variability. For instance, Hurrell (1996) revealed that the NAO accounted for 31% of the wintertime interannual variance of the Northern Hemisphere (NH) extratropical temperatures over the second half of the twentieth century. Pozo-Vázquez et al. (2001) revealed that in British Isles and southern Scandinavia, relationship between the NAO and temperatures seemed to be linear to highest degree. Influence of the NAO was greater over the Central Europe in extremely positive phase, but only small changes were in temperatures when the NAOI moderately or extremely negative. Ben-Gai et al. (2001) found high correlations between the winter mode of the NAO and temperature, and sea level pressure (SLP) in

Israel. Werner and Schönwiese (2002) revealed that the NAOI and temperature relationships were approximately linear and most pronounced in winter over Europe. The spatial correlation patterns depicted a correlation decreasing from the northwest to the southeast in winter. Xoplaki (2002) analyzed winter (DJFM) air temperatures over the Mediterranean for the period 1950–1999. She showed that the winter NAO and AO were significantly negative correlated with winter air temperatures over a large area, mainly in the southeastern part including mid-Algeria, Libya and Egypt, southern Italy, Greece, Turkey, Cyprus, and the entire Near East countries. Esteban-Parra et al. (2003) explained that the relationships between extreme temperatures and the NAOI increased only for winter in the Iberian Peninsula; for other seasons, no significant correlations were found. In winter, correlations were significant, positive for maximum temperature, and negative for minimum temperature. Matyasovszky (2003) revealed that "variability over the southern Europe is more complex than over the central and northern Europe, being extremely sensitive to the location of SLP anomaly centers". Hasanean (2004) found that a statistically significant negative relationship between winter temperatures and winter NAOI in Egypt. He also showed that the NAO was more dominant in wintertime temperature than the El Niño-Southern Oscillation (ENSO). Feidas et al. (2004) analyzed winter (JFM) air temperatures in Greece for the period 1955–2001. They found that temperature trends and changes linked to circulation indices, such as the NAOI, Mediterranean Circulation Index (MCI) and Mediterranean Oscillation Index (MOI). They concluded that most appropriate index for understanding temperature variability in Greece was the MCI. On the other hand, their results showed that PD-R NAOI has not an important effect on winter temperature variability.

Changes of the strength and character of correlations between the NAO and the NHTs seem to be modulated by a phase of the solar activity cycle. For solar maximum phases, the NAO and NHTs are positively correlated; however, for solar minimum phases, correlations are not significant or even negative (Gimeno et al. 2003). Some studies showed that the relationship between the NAO and the NH winter surface temperatures (NHTs) are not stationary, changing considerably in time (Pozo-Vázquez et al. 2001; Beranová and Huth 2008). Beranová and Huth (2008) also identified five modes of variability, which affect the surface climate elements in the Europe, using winter monthly mean 500-hPa heights over the Euro-Atlantic sector. Their results showed that the relationships between the modes and the surface climate elements vary in time and space.

A number of studies were also performed for variations and trends in surface air mean temperatures in Turkey. For instance, Türkeş et al. (2002) found slightly increasing trends for annual, winter and spring mean temperatures particularly over the southern regions of Turkey, and slightly decreasing trends for summer and particularly autumn mean temperatures over the continental inner and northern regions for the period 1929–1999. Winter mean temperature series in Turkey are mostly random against any significant secular trend. Tatlı et al. (2005) investigated statistical linkages between monthly mean near-surface temperature series over Turkey and large-scale upper air circulations by using a particular downscaling approach. Their results showed that effects of the large-scale upper air circulations on monthly maximum, minimum, and mean temperatures produce similar patterns in winter, and large-scale circulation features of winter are more effective than other seasons. Recent studies indicated that the NAO is also one of the major atmospheric sources for the spatial and temporal variability of the precipitation conditions in Turkey including significant wet periods and meteorological droughts (Türkeş and Erlat 2003, 2005).

Nevertheless, relationships between winter mean temperatures of Turkey and the NAOIs, and winter temperature changes corresponding to the various phases of the NAOIs and associated upper-air circulations have not been studied yet. Consequently, this study aims to: (a) detect statistical relationships between variability of the winter (December, January, and February) mean and monthly mean air temperature anomaly series of 70 stations in Turkey and variability of the NAOIs during the period 1950–2003; (b) determine the spatial and temporal patterns of the composite temperature anomalies and averages linked to the negative and positive extreme NAOI phases (i.e., *weak* and *strong phases*, respectively), and all negative and positive index years of the NAOIs (i.e., *negative* and *positive phases*, respectively); (c) reveal anomalous circulation patterns and centers of action at 500-hPa geopotential level during the extreme and normal NAOI phases in order to explain the dynamic causes of responses of winter mean air temperatures to the various phases of these atmospheric oscillations.

2 Materials and methods

2.1 Surface and upper-air data

The temperature dataset used in the study was originally developed by Türkeş et al. (2002) for 70 stations of Turkey operated during the period 1929–1999. We have updated the dataset to 2003 for the present study. The dataset consists of monthly mean temperatures recorded at stations of the Turkish State Meteorological Service (TSMS), most of which are principal climatology stations. The 70 stations

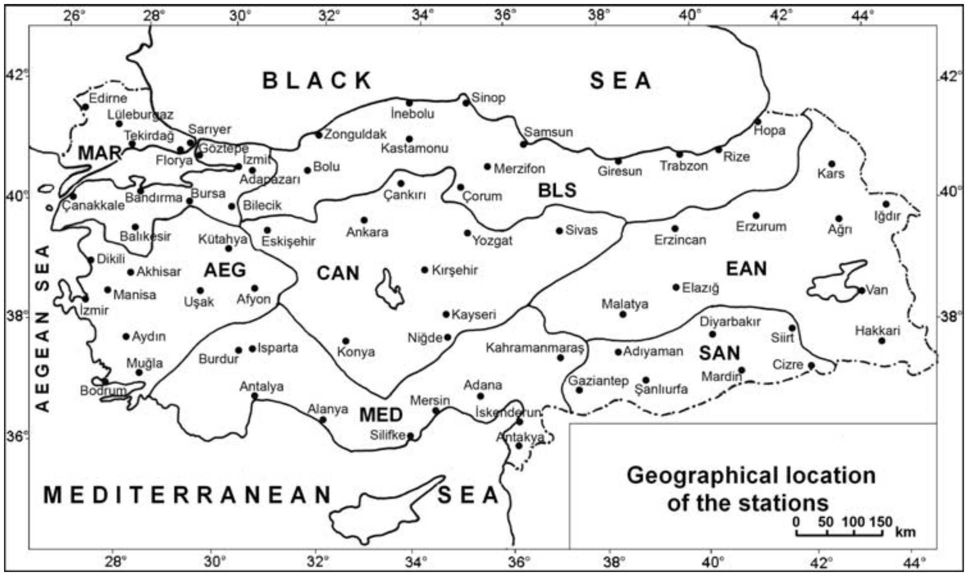

Fig. 1 Spatial distribution of 70 stations over the geographical regions of Turkey. *BLS* Black Sea, *MAR* Marmara, *AEG* Aegean, *MED* Mediterranean, *SAN* Southeastern Anatolia, *CAN* Central Anatolia, *EAN* Eastern Anatolia

mostly having an about 53-year length of record during the period 1950–2003 were selected for the study (Fig. 1). Data quality of temperature series was checked with various controls and homogeneity methods, also making use of a station history file. These stations have the longest and the most homogeneous temperature series (Türkeş et al. 2002). Adequate information on the homogeneity and other time-series characteristics of Turkish temperature data and winter temperature climatology of Turkey can be found in Türkeş et al. (2002) and Türkeş and Erlat (2008), respectively.

The PD-R and G-R NAO monthly and winter indices used in the study were calculated by using the monthly mean SLP series of the Ponta Delgada (PD), Gibraltar (G), and Reykjavik (R) stations, all of which were kindly provided by P. D. Jones. Monthly mean SLP series of the Ponta Delgada, Gibraltar, and Reykjavik stations were normalized for the period 1950–2003 by using monthly averages and standard deviations at each station. Comparison of the NAO indices that were calculated with different normalization periods and approaches is found in Türkeş and Erlat (2005).

500-hPa geopotential height data of the 1958–2003 period was provided by the Data Support Section of the Scientific Computing Division at the NCAR in Boulder, Colorado (http://www.dss.ucar.edu/datasets). We analyzed the 500-hPa geopotential height data of the 231 grid points for a large region between 40°W and 60°E and by 20°N and 70°N.

2.2 Methods of analysis

Pearson's correlation coefficient r was used in order to detect the nature and magnitude of relationships between temperature anomalies and the various NAOIs. The statistical significance of correlation coefficients was checked by a *Student's t test*. By using the two-tailed test of the Student's t distribution, null hypothesis of "absence of any relationship between temperature and the NAOI series" is rejected for large values of $|t|$ with $(N - 2)$ degrees of freedom.

In order to better explain influence of the NAO on air temperatures in Turkey, we used both the negative and the positive extreme phases (i.e., the *weak phase* and *strong phase*, respectively) and all negative and all positive index years (i.e., *negative phase* and *positive phase*, respectively) in the NAO winter indices, the latter group of which can also be named as normal phases. In the approach of this computation, a *weak phase* of the NAO consists of the NAOI anomalies with a value ≤ -1.0, and a *strong phase* of the NAO corresponds to the NAOI anomalies with a value $\geq +1.0$. Composite temperature anomalies and averages corresponding to both *weak* and *strong phases* and *negative* and *positive phases* of the NAO indices were computed for seasonal winter and monthly series of each station.

Composite averages of seasonal and monthly temperatures for both *weak* and *strong phases* and the *negative* and *positive phases* of the NAOIs were compared statistically with long-term average temperatures by using the *Cramer's t_k test*. Significance test of the results is based on the null hypothesis of "there is no significant difference between a composite average of various phases of the NAOIs and the long-term average of the whole period" (Türkeş and Erlat 2005). Test statistic t_k is distributed as the Student's t with the $(N - 2)$ degrees of freedom. The null hypothesis of the test is rejected with the two-tailed test for large values of $|t_k|$. Composite temperature average of a station is considered as warm (cold) 'signal', only if the test statistic of t_k computed for that station is statistically significant.

An analysis for the consistency of temperature anomalies was also performed in order to determine whether the signal of a composite anomaly is dominated by a few large anomalies during a *negative* or a *positive phase* of the NAOI variability or not. This was done with calculation of the percentage of consistent signals (PCS), defined as the percentage of events having values with the same sign as the average of the anomalies (here the composite anomaly).

The significance of difference between the 500-hPa anomaly circulation pattern controlled by the *negative phase* of the NAOI and the 500-hPa anomaly circulation pattern driven by the *positive phase* of the NAOI was checked by the one-tailed *Student's t test* for equality of means with the $(n_1 + n_2 - 2)$ degrees of freedom. The test of significance considers the null hypothesis of "500-hPa anomaly circulation patterns do not differ between the *negative phase* and the *positive phase* of the NAO variability." The *independent samples t test* of the differences between the series of 500-hPa anomalies corresponding the negative and positive index years of the NAO winter index was repeated with both *pooled variance* (equal variances) *t test* and *separate-variance* (equal variances not assumed) *t test*. We used the results of the significance test arising from the *pooled variance t test* for mapping the statistically significant results (Figs. 10c, 11c), because variances of the series are mostly equal, and the resultant *t* statistics from both tests are very similar.

Any signal from the tests of significance performed for all statistical methods used in the present study is taken into consideration if it is significant at the 5% significance level of the *t* distribution, although both 5 and 1% levels of significance are considered for the tests of hypothesis in the study.

3 Results and discussion

3.1 Temporal variability related with the NAO winter indices

A significant negative correlation coefficient is found between year-to-year variability of the NAO winter index and Turkey's normalized winter temperature series (Fig. 2), series of which was calculated by averaging normalized winter temperature series of 70 stations used in the study. Negative correlation coefficients (CCs) between year-to-year variability of station-based temperatures and the NAO winter indices that were found at all stations (Fig. 3a, b) are statistically significant at 52 (47) stations for the PD-R (G-R) NAOI, 22 (19) of which are at the 0.01 level (Table 1). Negative CCs become stronger in central and southwestern regions of Turkey, whereas relationships become weaker over the northern Marmara (MAR), eastern margin of the Eastern Anatolia (EAN), and the Southeastern Anatolia (SAN) region. The large coherent area characterized with negative CCs greater than 0.4 dominates over the sub-regions of Konya and Kırşehir and of Muğla and Aydın in the Central Anatolia (CAN) and the Aegean (AEG) regions, respectively (Fig. 3a, b). According to the monthly results, for both NAO indices, significant correlations are higher in January and February than those in December (Table 2).

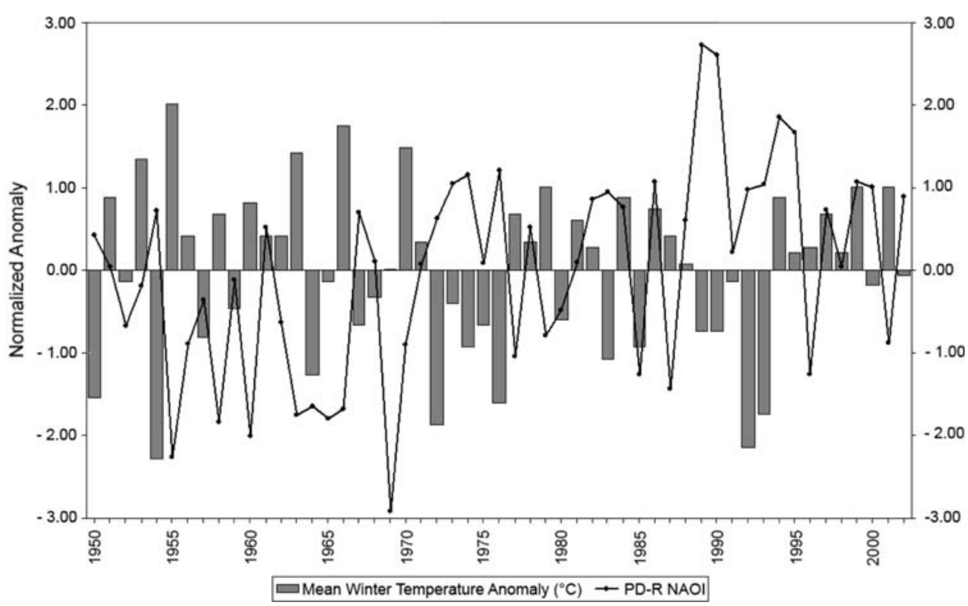

Fig. 2 Inter-annual variations in normalized winter temperatures of entire Turkey and relationship with year-to-year variability of the PD-R NAOI. Negative correlation coefficient (0.39 and 0.37 for the *Pearson's r* and *Spearman's r_s*, respectively) is significant at the 0.01 level of significance

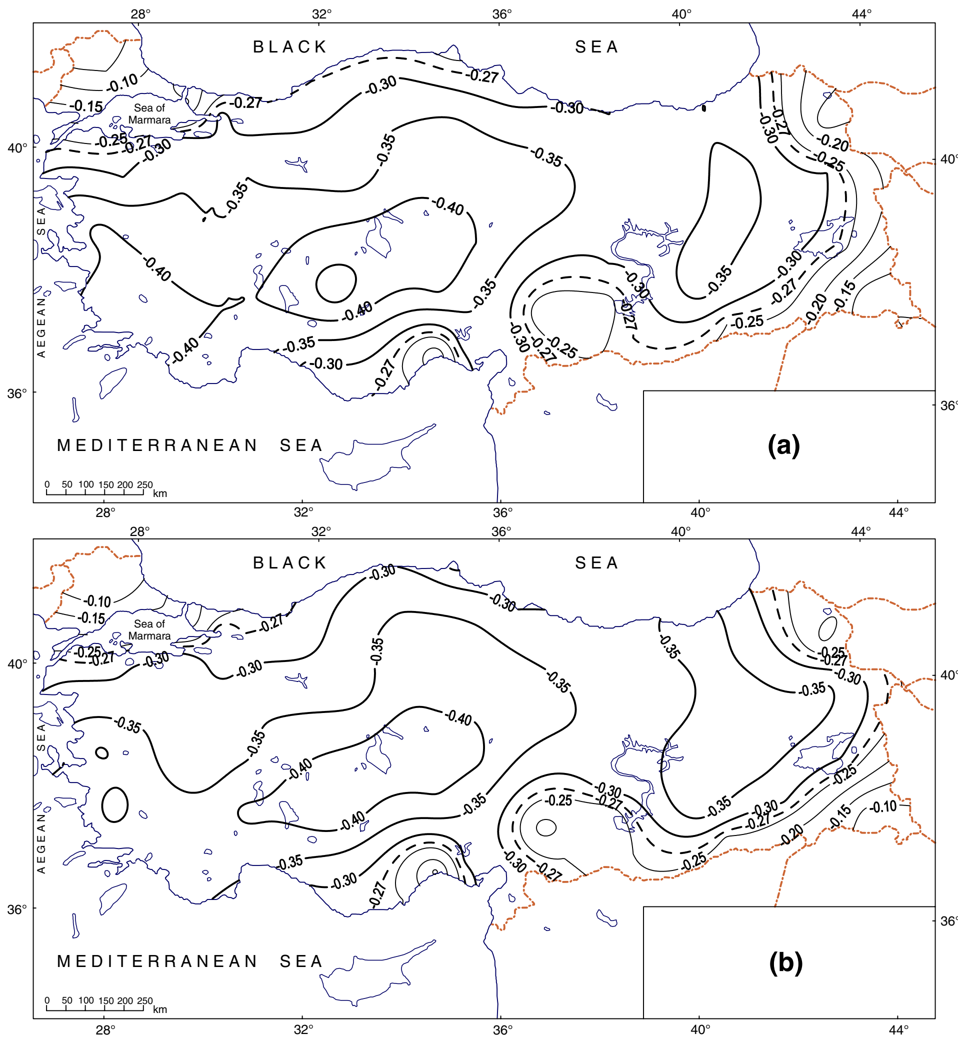

Fig. 3 Geographical distributions of correlation coefficients (CCs) between the G-R NAO winter index and normalized winter temperatures (**a**), and between the PD-R NAO winter index and normalized winter temperatures (**b**) for 70 stations in Turkey (*bold lines* indicate significant CCs at the 0.05 level ($0.35 > r \geq 0.27$) and the 0.01 level ($r \geq 0.35$)

Table 1 Number of stations with significant CCs between two NAO winter indices and normalized winter temperature series, and of significant composite winter temperature averages at 70 stations of Turkey, corresponding to the extreme phases of the NAOIs at the 0.05 and 0.01 levels of significance

Season	G-R NAO						PD-R NAO					
	Pearson's r		Cramer's t_k				Pearson's r		Cramer's t_k			
			Weak		Strong				Weak		Strong	
	5% −	1% −	5% +	1% +	5% −	1% −	5% −	1% −	5% +	1% +	5% −	1% −
Winter	28	19	0	0	22	10	30	22	4	0	0	0
Total	47		0		32		52		4		0	

These statistically significant linkages between winter temperatures and the NAO winter indices suggest that year-to-year variability responses of temperatures are very likely to be characterized with warmer (colder) than long-term average conditions during the low-index (high-index) NAO events.

3.2 Temperature changes during extreme phases of the NAO winter indices

Composite temperature anomalies during the *weak phase* of the G-R NAOI characterized by warmer than long-term average conditions at almost all stations of Turkey, except

Table 2 Number of stations with significant CCs between monthly indices of the NAO and normalized monthly temperature series, and of significant composite temperature averages at 70 stations of Turkey, corresponding to the extreme phases of the NAOIs at the 0.05 and 0.01 levels of significance

Months	G-R NAO						PD-R NAO					
	Pearson's r		Cramer's t_k				Pearson's r		Cramer's t_k			
			Weak		Strong				Weak		Strong	
	5% −	1% −	5% +	1% +	5% −	1% −	5% −	1% −	5% +	1% +	5% −	1% −
December	9	1	1	0	1	0	0	0	1	0	0	0
January	23	33	29	22	27	8	15	12	21	5	0	0
February	15	5	4	1	9	4	15	3	30	3	3	1

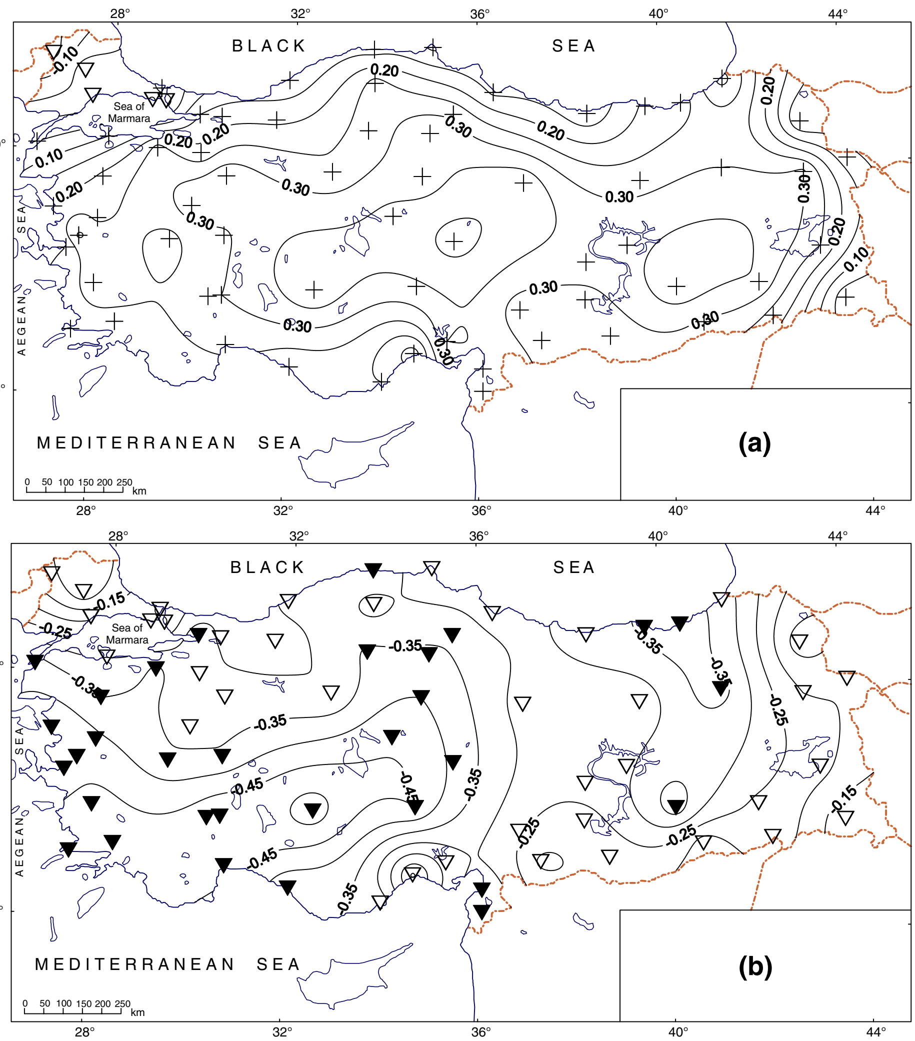

Fig. 4 Geographical distributions of composite normalized temperatures, during the *weak phase* (**a**) and *strong phase* (**b**) of the G-R NAO winter index. Symbol of the *bold plus* (*filled inverse triangle*) shows the significantly warmer (colder) than long-term average mean temperatures at the 0.05 level, according to the *Cramer's t_k test*

a few particularly over northern part of the MAR region (Fig. 4a). However, composite temperatures corresponding to the *weak phase* of the G-R NAOI are not statistically significant (Table 1). Winter temperatures corresponding to the *strong phase* of the G-R NAOI tended to decrease at all stations in comparison with long-term average (Fig. 4b). Colder than long-term average conditions is significant at 32 stations, ten of which are at the 0.01 level of significance. Cold signals are evident mostly in the AEG, Mediterranean (MED) and southwestern part of the

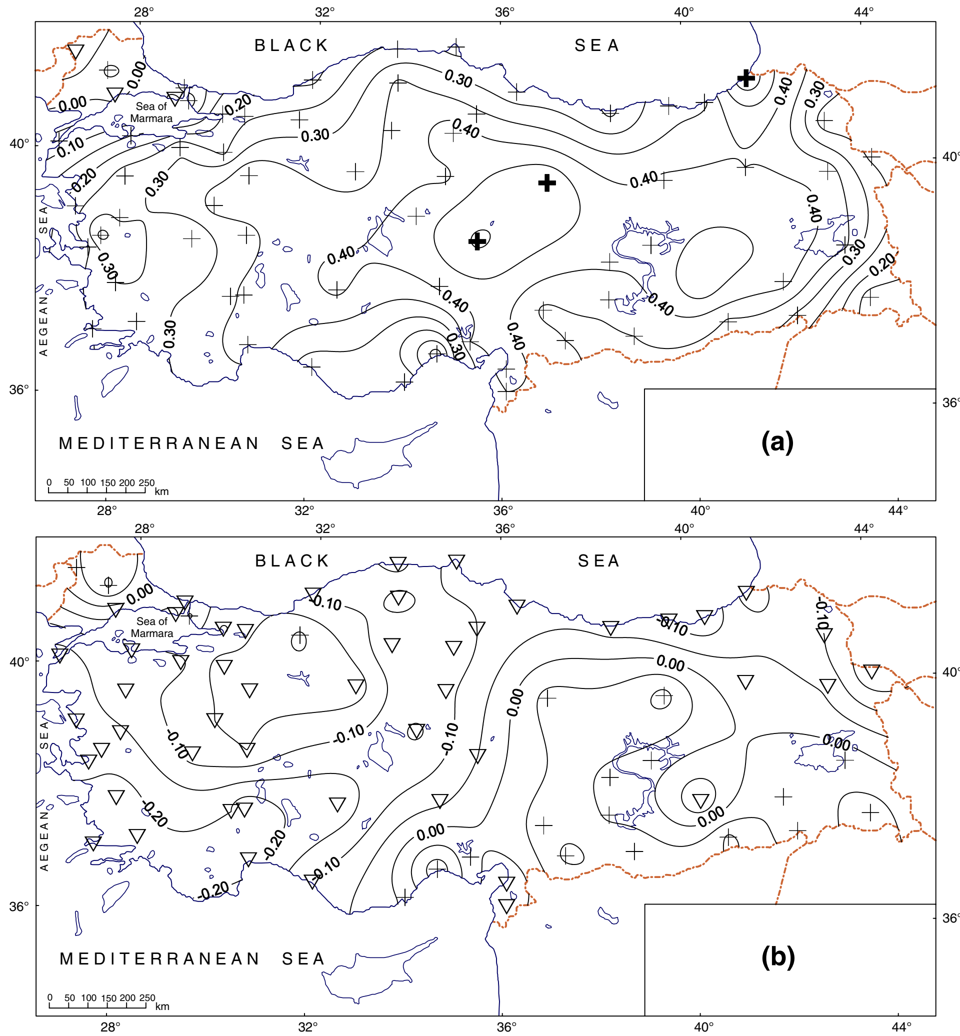

Fig. 5 Geographical distributions of composite normalized temperatures, during the *weak phase* (**a**) and *strong phase* (**b**) of the PD-R NAO winter index. Symbol of the *bold plus* (*filled inverse triangle*) shows the significantly warmer (colder) than long-term average mean temperatures at the 0.05 level, according to the *Cramer's* t_k *test*

CAN, and at a few station of the eastern Black Sea (BLS) sub-region.

Composite temperatures corresponding to the *weak phase* of the PD-R NAOI are qualified by warmer than long-term average conditions at all stations except Edirne and Tekirdağ stations in the European portion of the MAR (i.e., the Thrace sub-region) (Fig. 5a). Nevertheless, increased temperatures are significant only at four stations. Although strong PD-R NAOI responses of 50 stations are explained by a negative composite temperature anomaly (Fig. 5b), colder than long-term average conditions are not significant (Table 1).

Composite temperature anomalies during the *weak* (*strong*) *phases* of the NAOI are characterized by warmer (colder) than long-term average conditions at all stations for winter months. In parallel with the seasonal results of the extreme phases, G-R NAOI has the highest power in ability to represent monthly temperature variability and composite temperature changes in Turkey related with the extreme phases of the NAO variability (Table 2). This situation is most noticeable for the results of the *strong phase* of the G-R NAOI in comparison with the PD-R NAOI.

3.3 Temperature changes during normal phases of the NAO winter indices

3.3.1 Negative and positive phases of the Gibraltar–Reykjavik NAOI

Composite temperature averages corresponding to *negative index years* (i.e., *negative phase*) in the G-R NAO winter index are significantly warmer than long-term averages at 39 stations, eight of which are at the 0.01 level (Table 3). Warm signals in winter are more pronounced for the stations in northern, western, and central regions of Turkey (Fig. 6a). Composite temperature anomalies for the *positive index years* (i.e., *positive phase*) of the G-R NAOI are negative at all stations, except at the station of Hakkari (Fig. 6b). Colder than long-term average conditions is

Table 3 Number of stations with significant composite winter temperature averages corresponding to the *negative* and *positive phases* of the NAO winter indices at 70 stations of Turkey at the 0.05 and 0.01 levels of significance

Season	G-R NAO				PD-R NAO			
	Cramer's t_k				Cramer's t_k			
	Negative phase		Positive phase		Negative phase		Positive phase	
	5% +	1% +	5% −	1% −	5% +	1% +	5% −	1% −
Winter	31	8	34	4	14	49	14	50
Total	39		38		63		64	

significant at 38 stations, four of which are at the 0.01 level of significance (Table 3).

A consistency analysis is performed in order to determine whether the signal of a composite temperature anomaly is dominated by a few large anomalies or not. This is done by applying the percentage of consistent signals (PCS) technique to winter temperature anomalies linked to the negative and positive index years of the G-R and PD-R NAO winter indices (Figs. 7, 9). According to the consistency analysis for the *negative phase* of the G-R NAO winter index, Turkey has an average PCS of 66.4%, and the PCSs greater than 60% indicate a large spatial coherence over most of Turkey except eastern parts of the Eastern and the Southeastern Anatolia regions (Fig. 7a). The spatially coherent area with the maximum PCSs greater than 70% covers most of the Aegean and the CAN regions. This result clearly supports consistency of the warm signals in winter found at the stations particularly in western and central regions of Turkey associated with the *negative phase* of the G-R NAOI (Figs. 6a, 7a).

However, with respect to the *positive phase* of the G-R NAO winter index, the PCSs greater than 60% show a smaller spatial coherence over Turkey compared with the *negative phase*, consisting of coastal western regions, the CAN and the BLS regions along with eastern MAR and

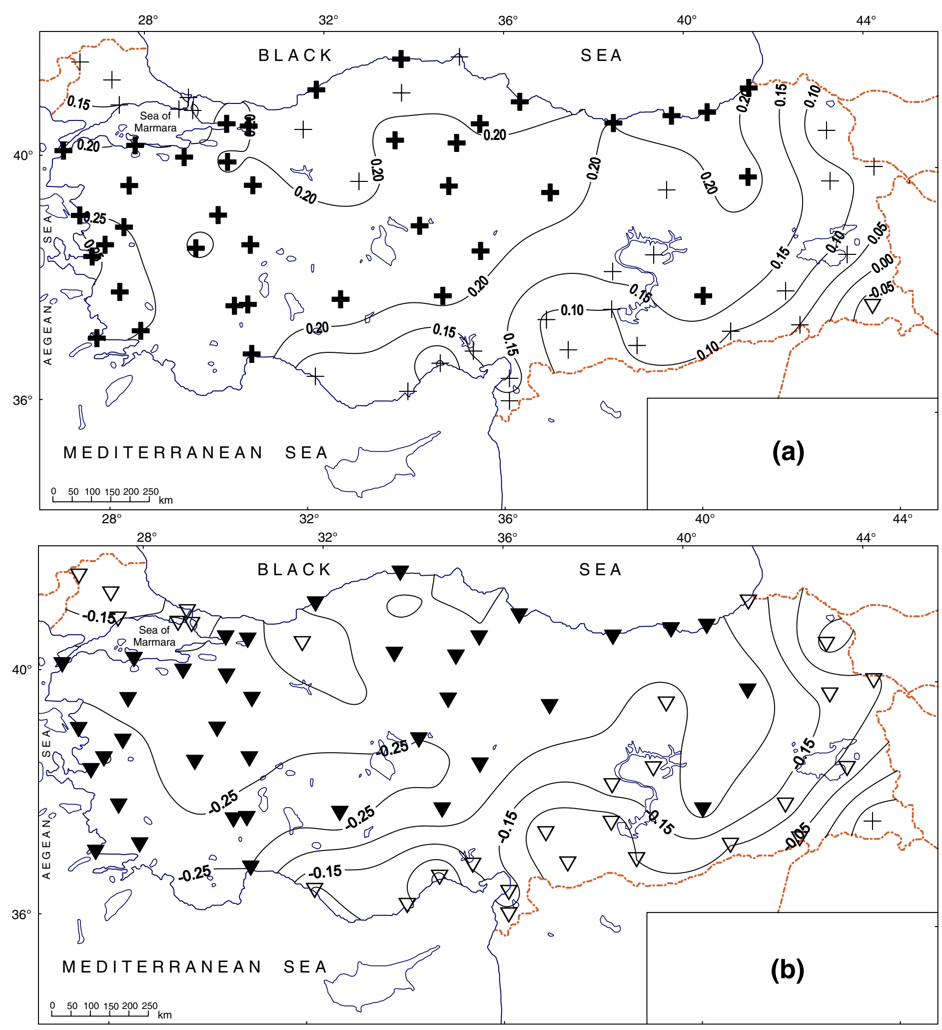

Fig. 6 Geographical distributions of composite normalized temperatures, during the *negative phase* (**a**) and the *positive phase* (**b**) of the G-R NAO winter index. Symbol of the *bold plus* (*filled inverse triangle*) shows the significantly warmer (colder) than long-term average mean temperatures at the 0.05 level, according to the *Cramer's t_k test*

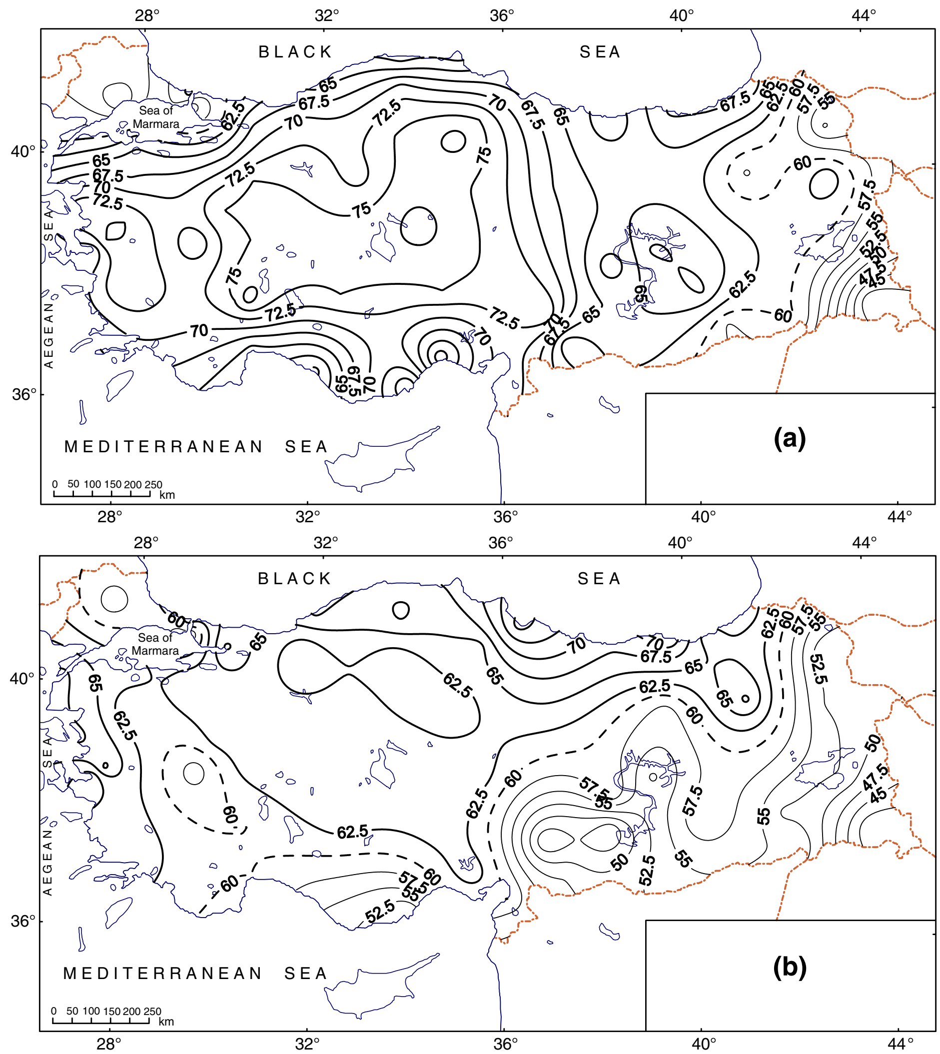

Fig. 7 Geographical distributions of percentages of the consistent signals (PCSs), for the *negative phase* (**a**) and the *positive phase* (**b**) of the G-R NAO winter index

northern part of the EAN region (Fig. 7b). Country average of the station-based PCSs is 60.6% for the *positive phase* of the G-R NAO winter index.

3.3.2 Negative and positive phases of the Ponta Delgada–Reykjavik NAOI

Influence of the *negative phase* of the PD-R NAO winter index are explained by a marked composite positive anomaly at almost all stations of Turkey, except few in the Thrace sub-region and the EAN region (Fig. 8a). Composite averages are significantly warmer than long-term averages at 63 stations, 49 of which are at the 0.01 level (Table 3). Composite temperature anomalies corresponding to the *positive phase* of the PD-R NAOI are negative at all stations. Decreased temperatures are significant at 64 stations, 50 of which are at the 0.01 level of significance (Fig. 8b).

Effects of *negative phase* and *positive phase* of the winter NAOIs on winter temperature variations are most pronounced for western, central and northern regions of Turkey, which are most vulnerable to direct influences of the westerly and northwesterly large-scale weather systems (e.g., travelling mid-latitude cyclones and anticyclones) during the cold season. With respect to controls of the NAO variability on the Turkish mean temperatures, it should be underlined here that the *negative* and *positive phases* of the PD-R and G-R NAOIs have a clear advantage over the *extreme phases* of the same NAO indices for explaining the changes and variability in winter temperature series over Turkey.

As for the consistency of composite temperature anomalies occurred during the PD-R NAOI phases, as it can be expected from the results of composite analysis, majority of Turkey with the exceptions of northern Marmara sub-region and south-eastern corner of the Eastern Anatolia region are characterized with a pattern of spatially coherent PCSs greater than 60% for the *negative phase* of the PD-R NAOI (Fig. 9a). Turkey has a greater country average during this event with a PCS of

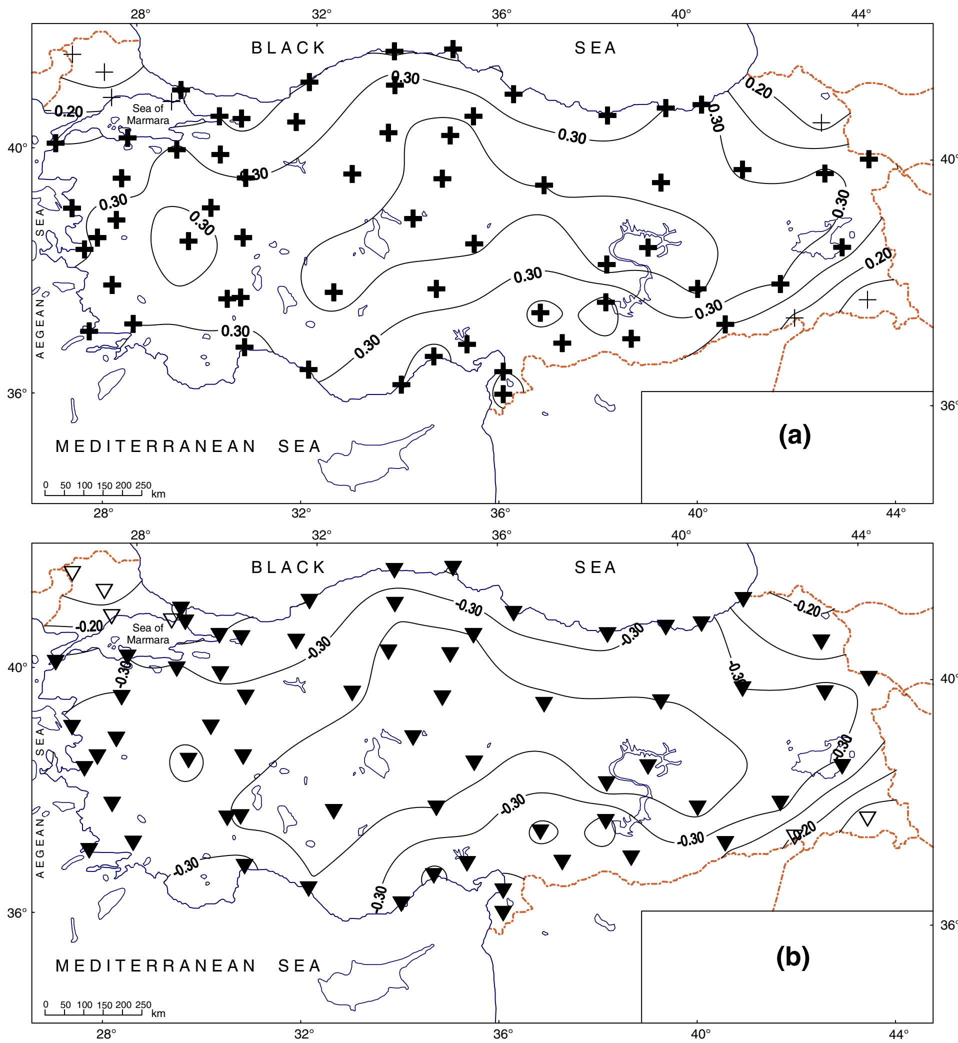

Fig. 8 Geographical distributions of composite normalized temperatures, during the *negative phase* (**a**) and the *positive phase* (**b**) of the PD-R NAO winter index. Symbol of the *bold plus* (*filled inverse triangle*) shows the significantly warmer (colder) than long-term average mean temperatures at the 0.05 level, according to the *Cramer's* t_k *test*

72.3%. The PCSs greater than 75% exhibit a large spatial coherence over the EAN, CAN and the Aegean regions of Turkey, with the areas of maximum PCSs greater than 80% dominated over the CAN region and the inner sub-region of the Aegean region (Fig. 9a). These results also statistically prove that the warm signals associated with the *negative phase* of the PD-R NAOI are not random over most of Turkey.

On the other hand, as in the PCSs for the *negative phase* of the PD-R NAOI, values of the PCSs calculated for the *positive phase* of the PD-R NAO winter index are also generally greater than the PCSs for the *positive phase* of the G-R NAO winter index (Figs. 7b, 9b). Country average of the station-based PCSs is 66% for the *positive phase* of the PD-R NAO winter index. Spatially coherent area with the PCSs of about 65% to some over 70% is characteristic for most of the country with the exceptions of the northern Marmara sub-region, Southeastern Anatolia region and eastern half of the Eastern Anatolia region (Fig. 9b).

Composite positive and negative monthly temperature anomalies corresponding to *negative* and *positive phases* in the monthly PD-R NAOIs are generally similar to, or stronger than, those in extreme phases of the same indices. For instance, composite temperature anomalies corresponding to *negative* (*positive*) *phase* in the PD-R NAOI in February are positive (negative) at all stations, and composite averages warmer (colder) than long-term averages are significant at 51 (52) stations, 7 of which are at the 0.01 level (Table 4).

3.4 500-hPa level circulations during the normal phases of the NAOI

In this section, we have only displayed and discussed the maps of anomalous mean circulations at the 500-hPa level corresponding to the normal phases (*negative phase* and the *positive phase*) of the NAO winter indices, although we prepared the maps of anomalous mean 500-hPa level circulations for the extreme phases of the NAO indices. This

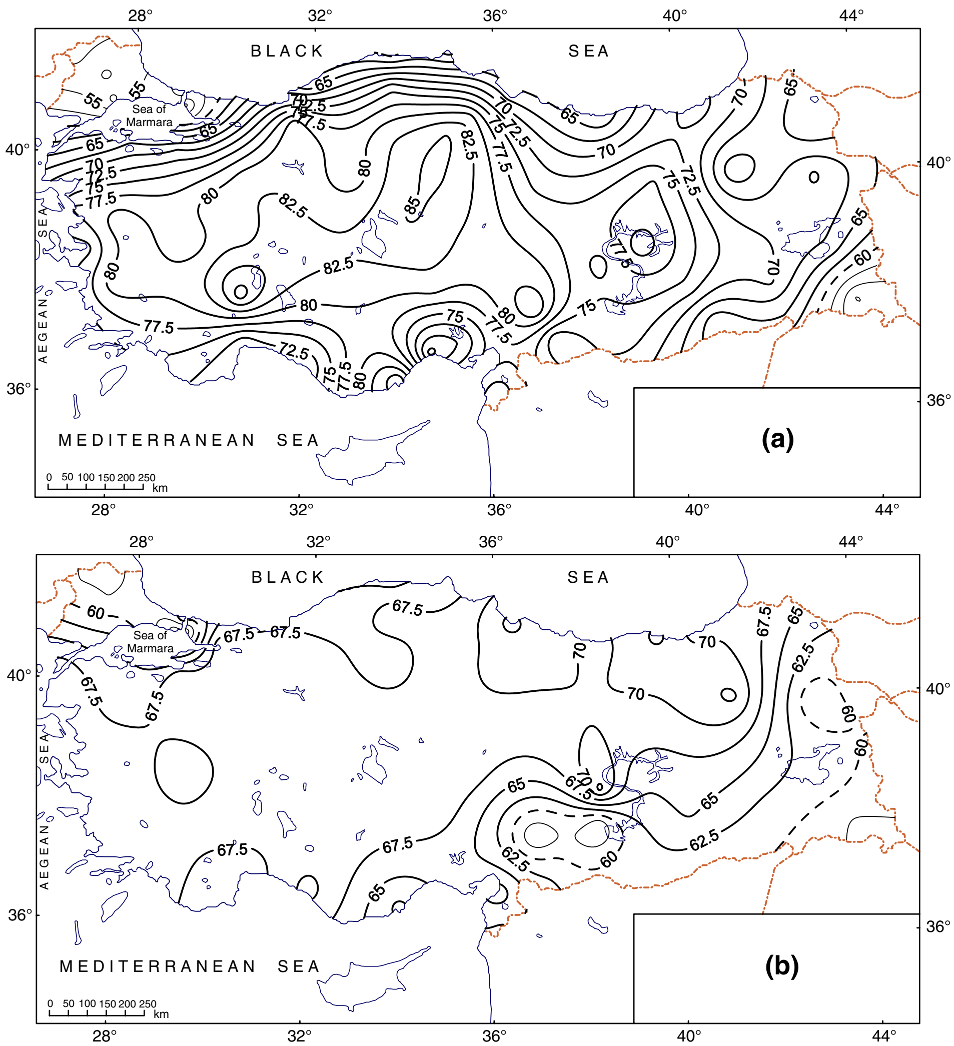

Fig. 9 Geographical distributions of percentages of the consistent signals (PCSs), for the *negative phase* (**a**) and the *positive phase* (**b**) of the PD-R NAO winter index

Table 4 Number of stations with significant composite monthly temperature averages corresponding to the *negative* and *positive phases* of the NAO monthly indices at 70 stations of Turkey at the 0.05 and 0.01 levels of significance

Months	G-R NAO Cramer's t_k				PD-R NAO Cramer's t_k			
	Negative phase		Positive phase		Negative phase		Positive phase	
	5% +	1% +	5% −	1% −	5% +	1% +	5% −	1% −
December	8	0	9	0	2	0	2	0
January	35	1	36	1	26	9	25	10
February	3	1	3	1	44	7	45	7

is mainly because composite temperature signals occurred during the *negative* and *positive phases* of the PD-R and the G-R NAO winter indices are markedly greater and have a larger and stronger spatial coherence over Turkey than those related with the *weak* and *strong phases* of both NAO winter indices. In the maps of anomalous mean circulations at the 500-hPa level corresponding to the *negative* and *positive phases* of the NAO winter indices, centers characterized with positive departures of the normalized 500-hPa geopotential heights represent the anticyclonic anomaly circulation, while centers of negative departures represent the cyclonic anomaly circulation.

3.4.1 500-hPa level circulation patterns linked to the G-R NAO winter variability

The pattern of composite 500-hPa geopotential height anomalies for the *negative phase* of the G-R NAO indicates stronger-than-average westerly and southwesterly circulation over the subtropical northeast Atlantic, the North Africa and the Mediterranean basin toward Turkey, and increased easterly and northeasterly circulation across Scandinavia, and mid-latitude and sub-polar northeast Atlantic in winter (Fig. 10a, c). Both prevailing upper atmospheric flows are associated with the anomalous circulation patterns characterized with the anticyclonic anomaly centers over the area of the dynamic-originated Icelandic Low and the mid and northeast Africa, and with the deep cyclonic anomaly center over the Azores, the Western and Central Europe regions. Significantly warmer than long-term average conditions in northern, western, and continental central regions of Turkey occurred during the *negative phase* of the G-R NAO (Fig. 6a) are very likely linked to these increased westerly and southwesterly circulation from the sub-tropical northeast Atlantic via the North Africa and the Mediterranean basin to Turkey (Fig. 10a, c).

Contrary, the *positive phase* of the G-R NAO produces increased westerlies over the mid-latitudes, Scandinavia and the sub-polar regions, and increased northerly circulation over the Black Sea and northwest Turkey and northeasterly flows from the Balkans and central Mediterranean basin to the subtropical Atlantic (Fig. 10b, c). This NAO pattern is associated with anomalously low 500-hPa heights over the region of the Icelandic Low, and anomalously high 500-hPa heights centered over a large region including the Azores region, the Iberian Peninsula, northeastern Atlantic off the Western Europe, the Western and Central Europe along with the western Mediterranean basin and the Balkans (Fig. 10b, c). This large region characterized by increased westerly circulation at the north and northeasterly circulation at the south are related with the strong geopotential anomaly gradient across the margins of the cyclonic and anticyclonic anomaly centers described above (Fig. 10b). By considering this upper-air anomaly circulation patterns, it is clearly seen that the spatially coherent cold signals over the northern, western, and central regions of the Anatolian Peninsula (Figs. 4b, 6b) are closely related with the increased northerly air flows just over the same regions of Turkey, arising from a marked anomaly gradient over eastern part of the anticyclonic anomaly center (Fig. 10b). According to the *Student's t test,* these evident changes between the large centers of 500-hPa anomaly circulation pattern (i.e., mid-troposphere anomalous centers of actions and their circulation characteristics) controlled by the *negative phase* of the G-R NAO variability and the large centers of 500-hPa anomaly circulation pattern controlled by the *positive phase* of the G-R NAO variability are statistically significant over the regions discussed above paragraphs (Fig. 10c).

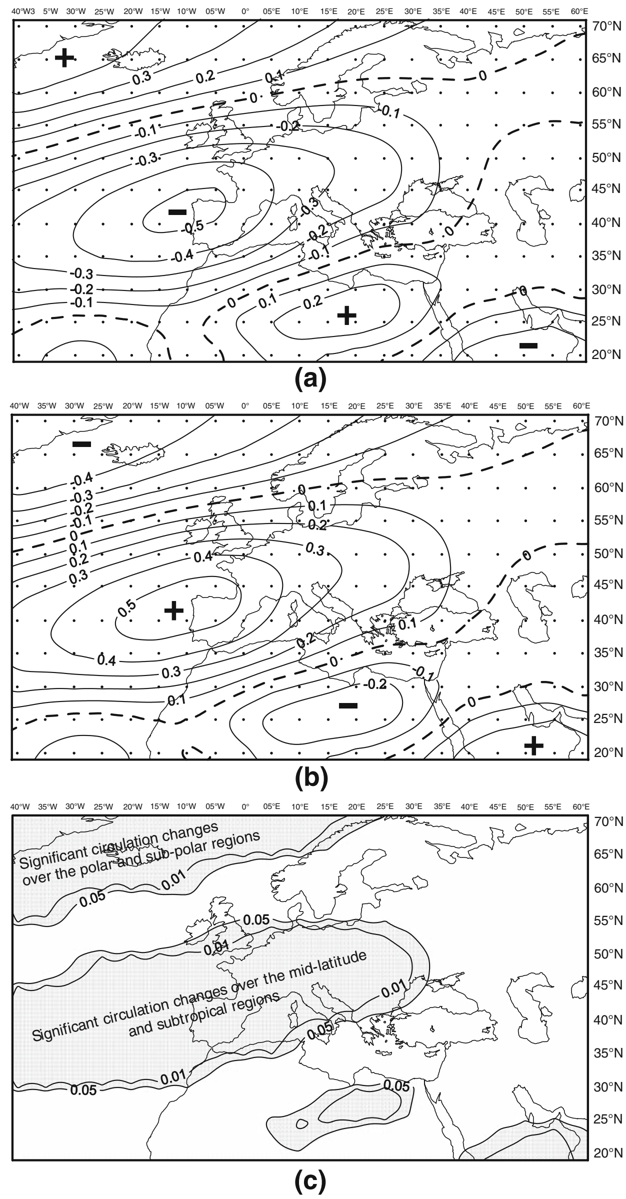

Fig. 10 Geographical distributions of composite winter 500-hPa geopotential height anomalies during the *negative phase* (**a**) and the *positive phase* (**b**) of the G-R NAO winter index, and of the areas accompanied by significant circulation changes at the 500-hPa standard pressure level between the *negative phase* and the *positive phase* of the G-R NAO winter index (**c**). *The dotted regions* display statistically significant differences among the 500-hPa geopotential height anomalies occurred during the *negative* and the *positive phases*, according to the *Student's t test* for equality of means

3.4.2 500-hPa level circulation patterns linked to the PD-R NAO winter variability

As in the *negative phase* of the G-R NAOI, 500-hPa circulation corresponding to the *negative phase* of the PD-R

NAOI is responsible for the statistically significant and spatially coherent warm signals over most of Turkey (Fig. 8a), associated with the NAO pattern, in which the 500-hPa level is anomalously high in the region of the Icelandic Low and anomalously low across the regions of the Azores High, the western Mediterranean basin and the Europe in general (Fig. 11a). It is also considered based on the anomaly pattern that the warm signals dominated over Turkey during the *negative phase* of the PD-R NAO (Fig. 8a) are very likely associated with the increased circulation of roughly westerly flows carrying warm maritime air masses from the sub-tropical north-east Atlantic and the Mediterranean basin to the Balkans and Turkey (Fig. 11a).

On the other hand, the NAO pattern over the North Atlantic and the Europe, when the 500-hPa level is anomalously low over the area of the Icelandic Low and the anomalously high across east of the subtropical and the mid-latitude Atlantic (Fig. 11b) produces well-described and significant cold anomalies over the majority of Turkey except the Thrace sub-region and a small area at the southeast corner of the country during the *positive phase* of the PD-R NAOI (Fig. 8b). These strong and spatially coherent cold signals over Turkey are very likely explained by existing of a strong geopotential anomaly gradient and associated increased northeasterly circulation over the Balkans, Black Sea, and Turkey (Fig. 11b). As being seen among the phases of the G-R NAO variability, it is clearly seen that the apparent large-scale changes in the mid-troposphere anomalous centers of actions and associated circulation characteristics occur during the *negative* and *positive phases* of the PD-R NAO winter variability. These described changes discussed above paragraphs between the large centers of 500-hPa anomaly circulation pattern driven by the *negative phase* of the PD-R NAOI and the large centers of 500-hPa anomaly circulation pattern driven by the *positive phase* of the PD-R NAOI are statistically significant mainly over three large regions: polar and sub-polar, mid-latitude and subtropical and subtropical and tropical regions (Fig. 11c). Another interesting point is that significant circulation change over the large belt extending from the subtropical/tropical northeast Atlantic to the Middle East between the *negative phase* and *positive phase* of the PD-R NAO winter index (Fig. 11c) does not appear among the same phases of the G-R NAO winter index, except in a smaller significant area (Fig. 10c).

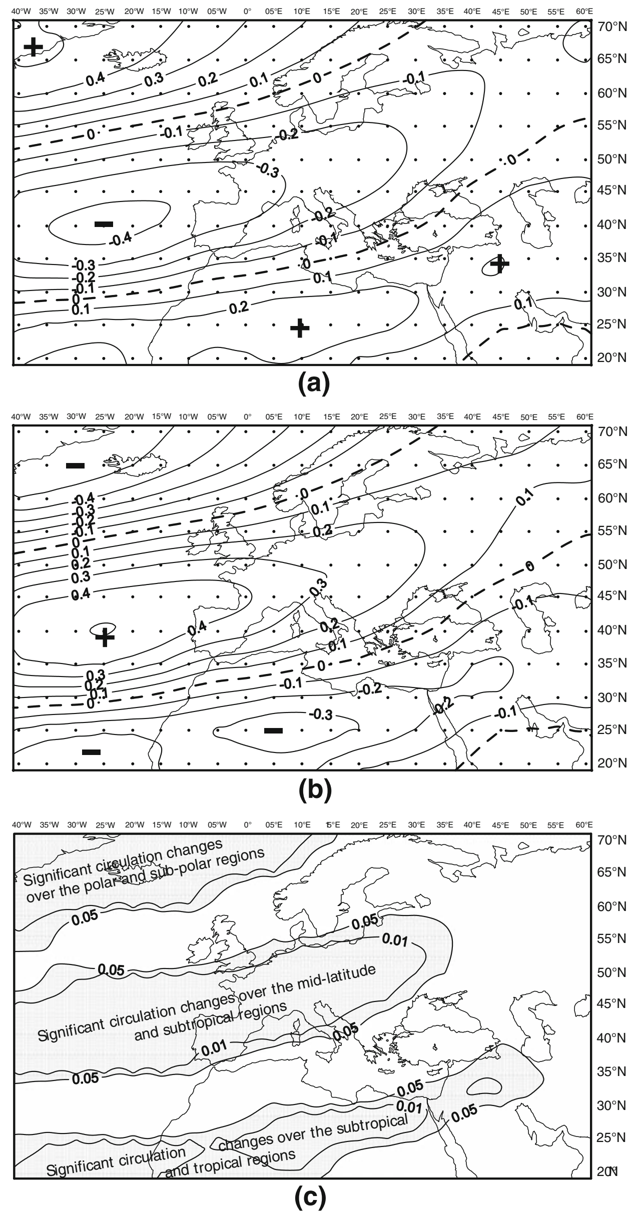

Fig. 11 Geographical distributions of composite winter 500-hPa geopotential height anomalies during the *negative phase* (**a**) and the *positive phase* (**b**) of the PD-R NAO winter index, and of the areas accompanied by significant circulation changes at the 500-hPa standard pressure level between the *negative phase* and the *positive phase* of the PD-R NAO winter index (**c**). *The dotted regions* display statistically significant differences among the 500-hPa geopotential height anomalies occurred during the *negative* and the *positive phases*, according to the *Student's t test* for equality of means

4 Summary and conclusions

In this study, meteorological and climatological relationships between variability of the winter mean and monthly mean temperature anomaly series of 70 stations in Turkey and variability of the NAOIs during the period 1950–2003 were investigated. The following conclusions can be drawn.

1. Correlation analysis revealed a negative relationship between year-to-year variability of the Turkish winter temperatures and the NAO winter indices at almost all stations. Significant CCs were detected at 52 (47) of

70 stations for the PD-R (G-R) NAOI. On the other hand, CC between the country average of normalized winter mean temperatures and the NAOIs is of −0.37 for the G-R NOAI and of −0.39 for the PD-R NAOI. This result reveals a good agreement with the correlation results between winter NAOIs and the winter mean temperatures of Greece as a whole (Feidas et al. 2004).

2. Winter composite temperatures mostly increased during the *weak phases* of the NAOIs and decreased during the *strong phases* of the NAOIs. Increased temperature conditions are not significant during the *weak phase*. On the other hand, negative anomalies are greater particularly during the *strong phase* of the G-R NAOI compared with the *strong phase* of the PD-R NAOI. Most of the cold signals during the *strong phase* of the G-R NAOI are found in the western and central regions of the Anatolian Peninsula. These results mostly coincide with the study carried out by Pozo-Vázquez et al. (2001), indicating the relationship between the NAO and temperatures has different characteristics in different parts of the Europe, especially in the case of weak phase. Our results are also in a good agreement with the study by Castro-Diez et al. (2002) on the linkages between the NAO and winter temperature variability in the southern Europe. Their studies indicated that influence of the NAO on temperature variability over the southern Europe is much more complex than those over the Central and Northern Europe, being closely sensitive to the location of the SLP anomaly centers.
3. Because Turkey is also less influenced by the extreme NAOI variability especially during extremely negative events, we further investigated the likely influences of the normal phases of the NAO winter indices on temperature variability in Turkey. In this frame, we found that winter temperature signals associated with the *normal phases* of the NAO indices are significantly stronger than those computed for the *extreme phases* of the NAOIs, and have a much larger spatial coherence over Turkey. Significantly, increased and decreased temperature conditions are more evident for the *negative* and *positive phases* of the PD-R NAO variability. For instance, warmer (colder) than long-term average conditions occurred during the *negative phase* (*positive phase*) of the PD-R NAOI is statistically significant at 63 (64) stations, 49 (50) of which are at the 0.01 level of significance, while statistically significant warm (cold) signals related with the *negative phase* (*positive phase*) of the G-R NAOI are detected at 39 (38) stations, 8 (4) of which are at the 0.01 level.
4. In parallel with the significant and spatially coherent temperature signals of the normal phases of the PD-R NAOI, percentages of the consistent signals for the *positive* and particularly the *negative phases* of the PD-R NAOI exhibit the largest spatial distribution with the greatest PCS values over Turkey in comparison with the PCSs for the normal phases of the G-R NAOI. During the *negative phase* of the PD-R NAOI, Turkey also has the greatest country average PCS with a value of 72.3%, and the PCSs greater than 75% have a large spatial coherence over the Eastern Anatolia, Central Anatolia and the Aegean regions of Turkey.
5. Spatially coherent and significantly higher temperatures occurred during the *negative phases* of both NAO winter indices over most of Turkey are very likely linked to the increased cyclonic activity and associated increased westerly and southwesterly circulation producing warm air advection over the Mediterranean basin toward Turkey. Patterns of the *positive phases* of the NAO variability are associated with anomalously low 500-hPa heights distributed over the region of the Icelandic Low, and anomalously high 500-hPa heights centered across the subtropical northeast Atlantic, the western Mediterranean basin and the Europe in general. Spatially coherent cold signals over the majority of the Anatolia Peninsula are very likely linked to the increased northerly and northeasterly airflows over the Black Sea, Balkans, and northwest Turkey, causing a cold air advection from the Eastern Europe and the Russian plains to Turkey and the central Mediterranean basin.
6. The results of correlation, composite average, and PCS analyses clearly revealed that the *normal phases* of the PD-R NAO winter index accounts the best for spatial and temporal patterns of winter temperature changes and variability in Turkey in comparison with the *normal phases* of the G-R NAOIs.
7. We also realized, based on comparisons of our results with the previous findings by Kutiel et al. (2002) and Kutiel and Türkeş (2005), and more recently by Türkeş and Erlat (2008), that *extreme phases* of the North Sea–Caspian Pattern Index (NCPI) and the Arctic Oscillation Index (AOI) are more capable than the *extreme phases* of both NAOIs for explaining the nature and magnitude of corresponding year-to-year variability and composite changes in winter mean temperatures in Turkey. This could be attributed to the fact that both the NCP and the AO teleconnections represent atmospheric oscillation patterns sourced and originated from further northern latitudes. Particularly, the NCP represents eastern regions over the Caspian Sea and its surrounding regions that are also linked the thermally originated semi-permanent Asiatic pressure centers (i.e., very likely the Siberian high in winter, and the Asiatic low (monsoon) in summer).

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