IL NUOVO CIMENTO Vol. 29 C, N. 1 Gennaio-Febbraio 2006
DOI 10.1393/ncc/i2005-10228-8

Influences of the North Atlantic oscillation on precipitation variability and changes in Turkey(*)

M. Türkeş(1) and E. Erlat(2)

(1) *Department of Geography, Çanakkale Onsekiz Mart University*
Terzioğlu Campus - Çanakkale, Turkey
(2) *Department of Geography, Ege University, Bornova - İzmir, Turkey*

(ricevuto l'1 Settembre 2005)

Summary. — The anomalous circulations at 500-hPa geopotential level during the extreme North Atlantic Oscillation Index (NAOI) phases were investigated in order to explain atmospheric causes of the changes in precipitation of the 78 stations of Turkey during the extreme NAOI phases. We arranged and analysed the 500-hPa height data of the 231 grid points for a large region delimited by the 40°W and 60°E longitudes and by the 20 °N and 70°N latitudes. The main conclusions of the study are as follows: 1) Annual, winter, spring, autumn and partly summer composite precipitation means are mostly characterised by wetter than long-term average conditions during the negative NAOI phase, whereas the positive NAOI responses mostly exhibit drier than long-term average conditions annually and in all seasons except summer. 2) Spatially coherent and statistically significant changes in the precipitation amounts during the extreme NAOI phases are more apparent in the west and mid Turkey. 3) The 500-hPa circulation corresponding to the negative NAOI phase brings above long-term average precipitation to Turkey in winter, spring and autumn and annually, associated with the NAO pattern in which the 500-hPa geopotential level is anomalously high in the area of the Icelandic Low and anomalously low across the regions of the Azores High and the Europe in general. 4) Contrary, the NAO pattern over the North Atlantic and the Europe is responsible for the drier than long-term average precipitation conditions in Turkey during the positive NAOI phase, when the 500-hPa geopotential level is anomalously low over the area of the Icelandic Low and the anomalously high across the subtropical and mid-latitude north-east Atlantic and the Europe regions.

PACS `92.60.Ry` – Climatology.
PACS `92.70.Gt` – Climate dynamics.
PACS `92.60.Bh` – General circulation.
PACS `01.30.Cc` – Conference proceedings.

(*) Paper presented at the Workshop on "Historical Reconstruction of Climate Variability and Change in Mediterranean Regions", Bologna, October 5-6, 2004.

1. – Introduction

The Turkish precipitation, which is considerably variable in time and space, is associated with the location, variation and activity of the atmospheric centres of action throughout the year except in summer over most of Turkey [1-7]. Recent studies indicated that the North Atlantic Oscillation (NAO) is one of the major atmospheric sources for the spatial and temporal variability of the precipitation conditions in Turkey [5, 6], as much as in the Atlantic, Europe and the Mediterranean basin [8-17]. The NAO is defined as a large-scale swaying of atmospheric pressure between the dynamic subtropical anticyclone centred over the Azores region and the mid-latitude cyclone dominated over the Iceland and Greenland region in the North Atlantic [5]. It is associated with the changes in the surface and upper level centres of action, and related surface winds and upper level geostrophic airflows across the large area extending from the north-east (subtropical, mid-latitude and sub-Arctic) Atlantic to the Eastern Europe, the eastern Mediterranean and the northern part of the Arabian Peninsula. This paper was prepared partly based on the authors' recent studies [5, 6] and on new and additional analysis performed in order to reveal upper level atmospheric circulations during the extreme NAOI phases. The aim of the study is as follows: i) To summarize reference information on the synoptic climatology of Turkey in order to understand all aspects of the Turkish precipitation responses to variability of the NAO; ii) to show the spatial and temporal patterns of the composite precipitation anomalies at the 78 stations of Turkey linked to the extreme (negative and positive) NAOI phases during the period 1930-2000; iii) to assess the statistical significance of drier or wetter than long-term average precipitation conditions associated with the extreme NAOI phases; and iv) to reveal anomalous circulation patterns at 500-hPa geopotential level during the extreme NAOI phases in order to explain atmospheric causes of responses of the Turkish precipitation to the extreme NAOI phases. We have used the Ponta Delgada-Reykjavk (PD-R) NAOI in this study, because Türkeş and Erlat [6] have recently found that the PD-R NAOI followed by the Lisbon-Stykkishlmur/Reykjavk (L-S(R)) NAOI is the best NAOI among the three NAOI compared (*i.e.* PD-R, L-S(R) and Gibraltar-Reykjavk), with respect to the ability for controlling variability in winter precipitation series of Turkey.

2. – Data and methods

Türkeş [18, 19, 3] originally developed the precipitation data set used in the present study for 99 stations in the period 1929-1993. We updated the data set for the years 1994 to 2000. The data set consisted of monthly precipitation totals (mm) recorded at the stations of the Turkish State Meteorological Service (TSMS), most of which are principal climatological stations. Detailed information for the meta-data and the homogeneity analyses applied to long-term precipitation series can be found in Türkeş [18, 20]. Precipitation climatology of Turkey and long-term variability, trends and changes in precipitation series were investigated previously by Kadioğlu [21], Türkeş [18, 19, 3, 20] and [4] and Türkeş *et al.* [7]. The 78 stations mostly having an about 70-year length of record were selected for the present study. Spatial distribution of the 78 stations over the rainfall regions is shown in fig. 1.

Annual and seasonal normalized precipitation (500-hPa geopotential height) anomaly series were used in the study. A normalized (standardized) precipitation anomaly A_{sy}

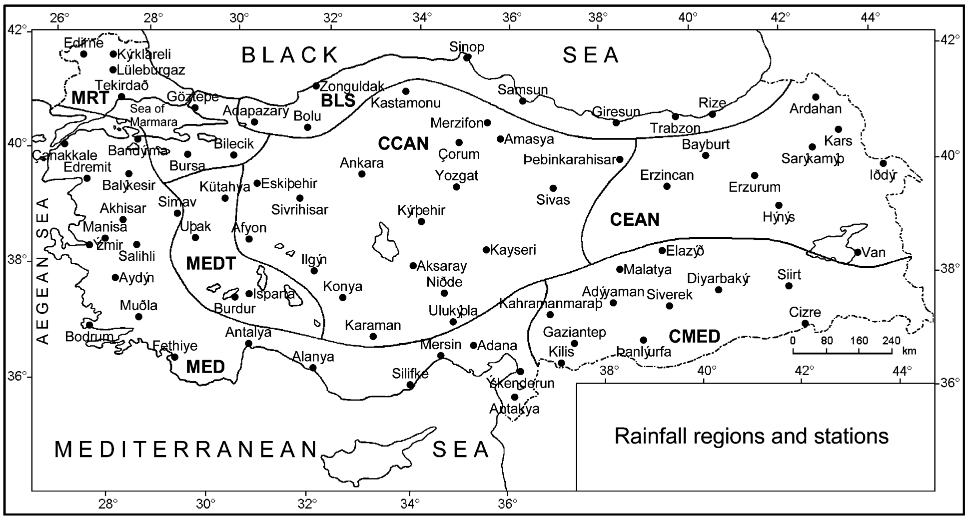


Fig. 1. – Location of the 78 stations over the rainfall regions of Turkey. **BLS**: Black Sea; **MRT**: Marmara Transition; **MED**: Mediterranean; **MEDT**: Mediterranean Transition; **CMED**: Continental Mediterranean; **CCAN**: Continental Central Anatolia; **CEAN**: Continental Eastern Anatolia.

for a long series of a given station is calculated with

$$A_{sy} = \frac{(P_{sy} - \overline{P}_s)}{\sigma_s}\,, \tag{1}$$

where P_{sy} is the total precipitation amount (mm) for a station s during a year y (or a season); P_s and σ_s are the long-term average and standard deviation of annual (or seasonal) precipitation series for that station, respectively. The NAOI Data used in the study was provided by the Climate Analysis Section of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, USA and Hurrell [8,22]. The seasonal and annual NAO indices were based on the difference of normalized SLP between Ponta Delgada, the Azores and Stykkisholmur/Reykjavik, Iceland since 1865. The 12:00 GMT 500-hPa geopotential height data of the 1958-2002 period was also provided by the Data Support Section of the Scientific Computing Division at the NCAR in Boulder, Colorado [23]. We arranged and analysed the 500-hPa geopotential height data of the 231 grid points for a large region delimited by the 40°W and 60°E longitudes and by the 20°N and 70°N latitudes. This region covers the north Atlantic, the whole Europe, the North Africa, the Mediterranean basin, the Arabian Peninsula, the Middle East and the Caspian basin. In order to objectively determine the nature and magnitude of the precipitation responses in Turkey to the variability of the NAO, both composite normalized precipitation (500-hPa geopotential height) anomalies and the composite precipitation means corresponding to the extreme (negative and positive) NAOI phases were computed for the annual and seasonal series of each station. The composite analysis refers to a "negative" (or weak) NAOI anomaly phase corresponding to the normalized NAO index values ≤ 1.0 and a "positive" (or strong) NAOI anomaly phase corresponding to the normalized index values $\geq +1.0$. A comparison of the composite means corresponding to the extreme NAOI phases with the long-term average precipitation totals was made by means of Cramer's t_k test, based on the null hypothesis of "no significant difference between a composite mean of the negative (positive) NAOI phase and the long-term average of the whole period". Cramer's t_k test [24] was applied previously to detect the wet and dry periods in the regional precipitation series of Turkey [18, 19] and the extreme event signals of the Southern Oscillation and the NAO indices in the station-based precipitation series of Turkey [3, 5, 6]. The long-term average ($\overline{P}$) and standard deviation (σ) of the entire period with N years, and the composite mean ($\overline{P}_k$), of the individual years (P_i) compared with $\overline{P}$ corresponding to negative (positive) NAOI anomaly years are defined as follows, respectively:

$$\overline{P} = \frac{1}{N}\sum_{i=1}^{N} P_i\,, \tag{2}$$

$$\sigma = \left[\sum_{i=1}^{N} \frac{(P_i - \overline{P})}{N}\right]^{1/2}\,, \tag{3}$$

$$\overline{P}_k = \frac{1}{n}\sum_{i=1}^{n} P_i\,. \tag{4}$$

Then, normalized anomaly τ_k and the test statistic t_k are computed by the following formulas:

$$\tau_k = \frac{(\overline{P}_k - \overline{P})}{\sigma}\,, \tag{5}$$

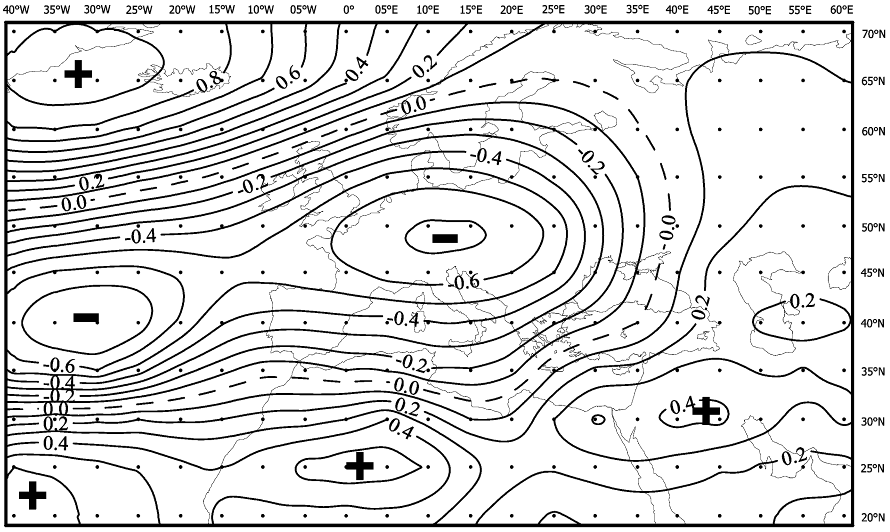
$$t_k = \tau_k \left[\frac{n(N-2)}{N - n - n\tau_k^2}\right]^{1/2}\,. \tag{6}$$

The test statistic t_k is distributed as Student's one with the $N-2$ degrees of freedom. The null hypothesis of the test is rejected with the two-tailed test for large values of $|t_k|$. Any composite precipitation mean of a station is considered as dry (wet) "signal" only if the test statistic of computed t_k for that station is significant at the 0.05 level of significance.

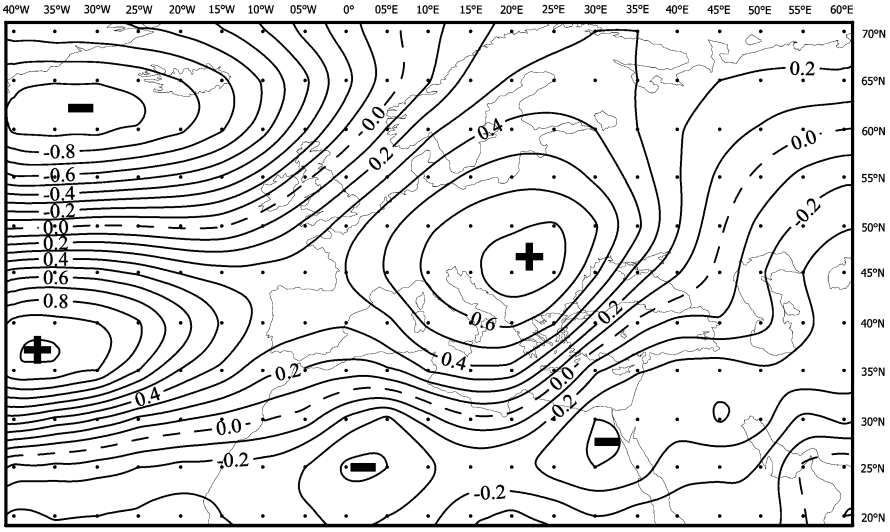
3. – Synoptic climatology of Turkey with emphasis on precipitation

The climate of Turkey, which is characterized mainly by the Mediterranean macroclimate, results from seasonal alternation of the mid-latitude frontal depressions, with the polar air masses, and the subtropical high pressures, with the subsiding maritime tropical and continental tropical air masses. Continental tropical air-streams from the Northern African and the Middle East/Arabian regions dominate particularly throughout summer by causing long-lasting warm and dry conditions over Turkey, except in the Black Sea region and the continental north-eastern part of the Anatolian Peninsula [3, 20, 4]. In winter, a well-known combination of North-eastern Atlantic-originated mid-latitude and

Mediterranean depressions and subtropical dynamic anticyclones from the Azores control the weather and climate in Turkey. In some winter seasons, the very cold, stable and dry high-pressure conditions related with the Siberia anticyclone join this average macro atmospheric circulation pattern over Turkey and its surrounding regions. Main atmospheric controls that characterise the Turkish summer climate are divided into three parts: a) the subtropical Azores anticyclone associated with the Hadley cell circulation in the north-eastern Atlantic and northern Africa along with the southern Mediterranean basin; b) circulation-based north-western extension of the Asiatic Monsoon, which has similar influence on the summer climate of the southern regions of Turkey with the Azores anticyclone; and c) North-eastern Atlantic-originated travelling mid-latitude depressions and upper level troughs. In summer, the north-western extension of the Asiatic Monsoon circulation to the eastern Mediterranean basin and Turkey, which causes very dry and hot conditions over the Middle East region including southern half of Turkey, has overriding importance to effect the anticyclonic Azores circulation associated with the Hadley cell. Turkish precipitation is generally associated with the location, variation and activity of the atmospheric centres of action throughout the year except summer over most of Turkey [1, 3, 7]. Year-to-year variations of winter, spring and autumn precipitation series are closely related with variations of the 700 and 500-hPa geopotential height series at the Göztepe (İstanbul) radiosonde station. In winter, negative CCs that were detected to be significant at the 0.01 level exhibit a widespread spatial coherence over most of Turkey, except the Black Sea rainfall region [3,7]. Kutiel *et al.* [1] also found very similar results for the linkages between monthly precipitation series at seven stations representing the rainfall regime regions of Turkey and monthly mean SLP series at sixteen grid points in the eastern Mediterranean Basin. According to that study, relationships between year-to-year variability of precipitation series in Turkey and regional SLP variability were significant in winter and non-existent in the hot dry Mediterranean summer. The information summarised above should be interpreted as a greater dependence of precipitation occurrence conditions in Turkey on the synoptic and/or regional scale atmospheric circulation in winter. As for the anomaly circulation patterns related with dry or wet conditions in Turkey, Kutiel *et al.* [1] revealed that regional surface pressure patterns linked to dry conditions during the period from November to April show usually positive SLP departures, whereas pressure patterns associated with wet conditions exhibit usually negative SLP departures at all representative stations of the rainfall regions, except Giresun on the eastern coast of the Black Sea region. Unlike those in other rainfall regions, both dry and wet conditions on the eastern BLS sub-region represented by Giresun station are generally associated with the anticyclonic anomaly circulation. Giresun also experienced the lowest number of significant CCs with the gridded SLP series; furthermore, significant CCs were mainly positive and located near the far edges of the study area. Our findings and assessments on the precipitation climatology of Turkey were supported by Tatli [2] in a recent study performed by using a new method for downscaling regional climate processes. Their model results showed that the precipitation regime (both wet and dry periods) of the coastal regions of Turkey (the Mediterranean, Aegean, Marmara, and the western Black Sea) is under the influence of large-scale pressure systems and upper-air circulations. Tatli [2] also pointed out that, particularly in the Black Sea region, in addition to the large-scale processes; the local features (*e.g.*, topography) determine the likelihood and intensity of precipitation.



(a) Negative phase of the NAO annual index

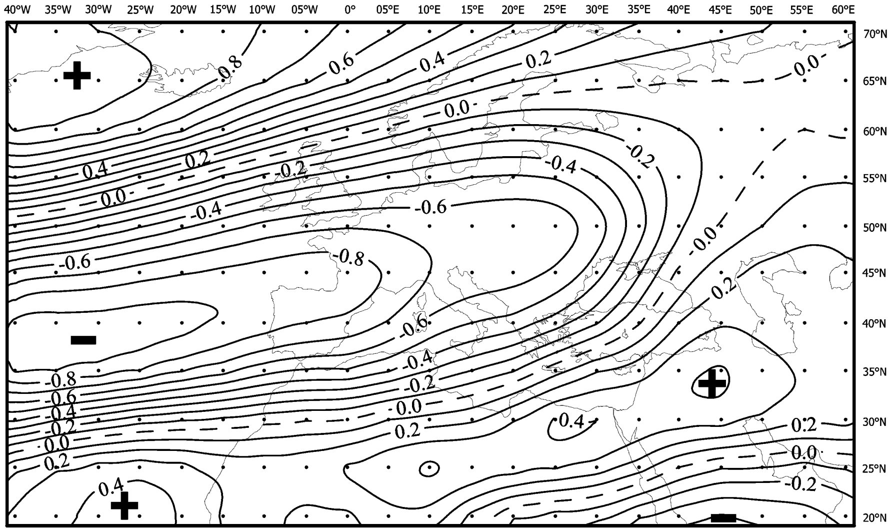


(b) Positive phase of the NAO annual index

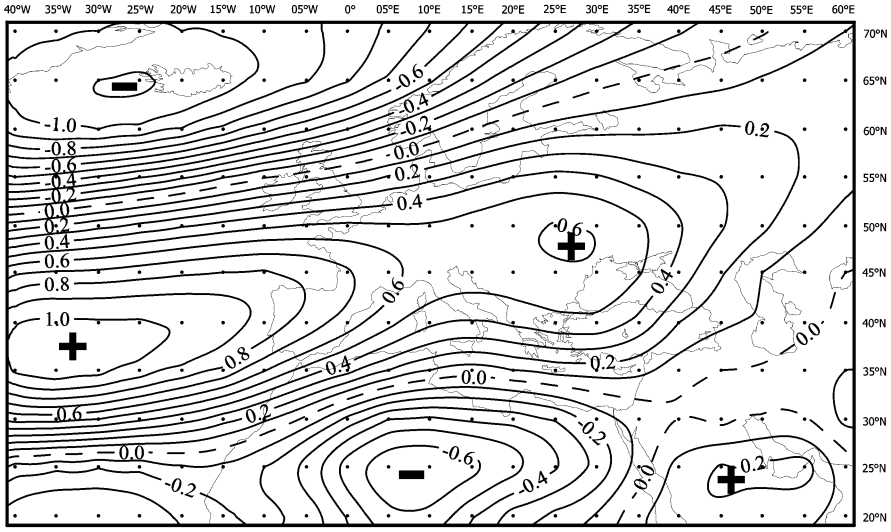
Fig. 2. – Composite annual 500-hPa geopotential height anomalies corresponding to (a) the negative and (b) the positive phases of the NAO annual index.

4. – Results of the analysis

4·1. *500-hPa level circulations linked to the extreme NAOI phases.* – The NAO is associated with the changes in the surface and upper level centres of action, and related surface winds and upper level geostrophic airflows across the large area extending from the mid-north-east (subtropical, mid-latitude and sub-Arctic) Atlantic to the Eastern Europe, the eastern Mediterranean and the northern part of the Arabian Peninsula. When the NAO is in its extreme phases, both the Icelandic Low and the Azores High are



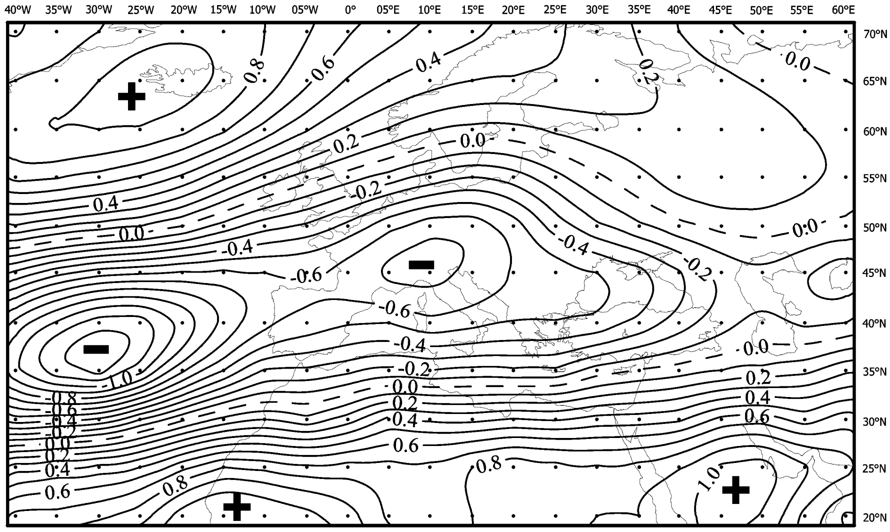
(a) Negative phase of the NAO winter index



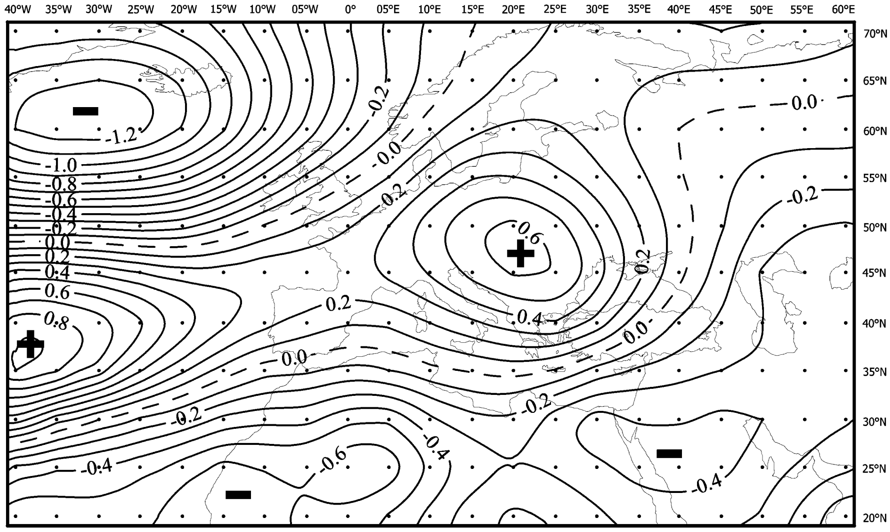
(b) Positive phase of the NAO winter index

Fig. 3. – As in fig. 2 (a) and (b), but for winter.

well developed during cool/cold period of the year, especially in winter. Anomalous mean circulations at the 500-hPa geopotential height level corresponding to the extreme NAOI phases clearly prove this situation (figs. 2 to 6). In these maps, centres characterized with positive values of the normalized 500-hPa geopotential heights represent the anticyclonic anomaly circulation, while centres of negative geopotential height anomalies represent the cyclonic anomaly circulation. The cyclonic (anticyclonic) anomaly circulation is supposed to have similar climatologic controls and/or influences on surface conditions with the upper level atmospheric lows and troughs (highs and ridges). Negative phase of the NAO indicates stronger-than-average westerly and south-westerly (*i.e.* western sector



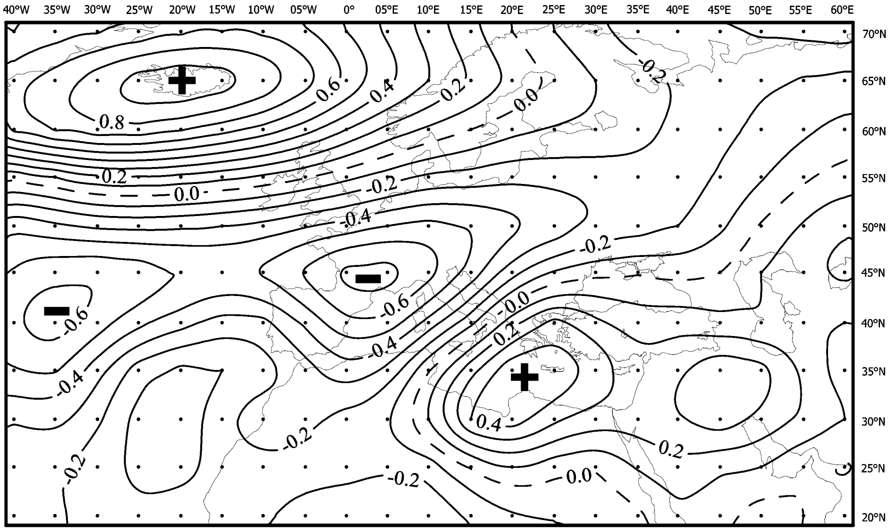
(a) Negative phase of the NAO spring index



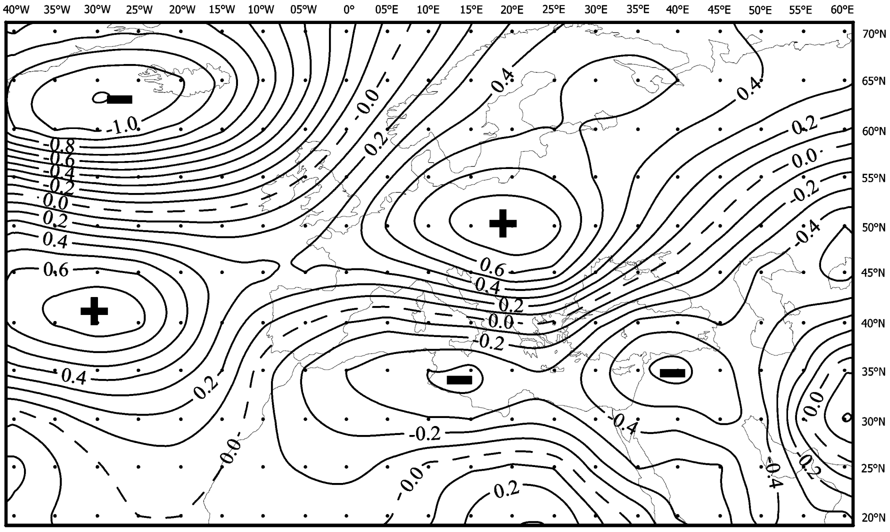
(b) Positive phase of the NAO spring index

Fig. 4. – As in fig. 2 (a) and (b), but for spring.

in general) circulation over the subtropical north-east Atlantic, the north Africa and the Mediterranean basin towards Turkey, and the stronger-than-average north-easterly circulation across Scandinavia and the mid-latitude and sub-Arctic north-east Atlantic particularly in winter, spring and annually. Both prevailing upper atmospheric flows are associated with the anomalous circulation patterns characterized with the anticyclonic anomaly centres over the area of the dynamic-originated Icelandic Low and the area of the thermally-driven Hadley cell circulation in the mid-west and north Africa and the Middle East, and with the cyclonic anomaly centres over the Azores and the Western and Central Europe (figs. 2a, 3a, 4a).



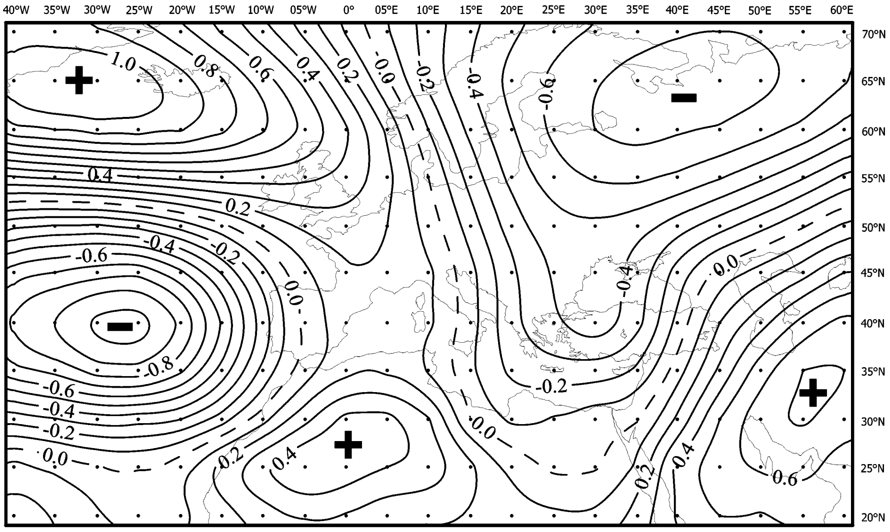
(a) Negative phase of the NAO summer index



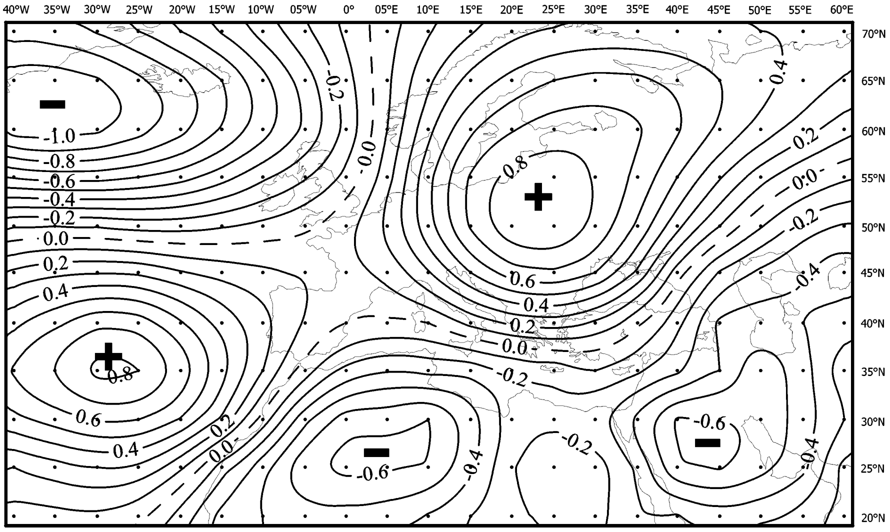
(b) Positive phase of the NAO summer index

Fig. 5. – As in fig. 2 (a) and (b), but for summer.

Contrary, the positive phase of the NAO shows the increased westerlies over the mid-latitudes and Scandinavia and increased easterly and north-easterly (*i.e.* eastern sector in general) circulation over a large conveyer zone from Turkey to the subtropical Atlantic via the Mediterranean basin and the North Africa. This NAO pattern is associated with anomalously low 500-hPa geopotential heights over the region of the Icelandic Low and the anomalously high geopotential heights centred across the subtropical east Atlantic-the Iberian Peninsula and the Eastern Europe-the Balkans regions in winter, spring and annually (figs. 2b, 3b, 4b). These large regions of the increased westerly and north-easterly circulations are related with the strong 500-hPa geopotential anomaly gradient



(a) Negative phase of the NAO autumn index



(b) Positive phase of the NAO autumn index

Fig. 6. – As in fig. 2 (a) and (b), but for autumn.

across the margins of the cyclonic and anticyclonic anomaly centres described above. Anomalous 500-hPa circulation maps are also characterized with the positive departures and centres over the mid-north Africa and the Middle East for the negative phase of the NAO and with the negative and positive anomaly centres over the mid-north Africa, the Middle East and the Arabian Peninsula for the positive phase of the NAO (figs. 2, 3, 4). On the other hand, the anomalous 500-hPa circulation patterns in summer and autumn are somewhat different and more complex compared with winter, spring and annual patterns, in terms of the place, intensity and the number of the anomaly centres (figs. 5, 6). In summer, negative phase of the NAO indicates increased easterly/north-easterly circulation over the north-east Atlantic and the Northern Europe associated with the anticyclonic anomaly centre over the area of the Icelandic Low and the cyclonic anomaly centres over the mid-north-east Atlantic and the Western Europe (fig. 5a). This phase also controls the increased south-westerly flows over the middle Mediterranean basin and the Balkans. The south-westerly anomaly circulation over this region is closely related with the cyclonic anomaly centre just over the Western Europe and the anticyclonic anomaly centre over the mid-eastern Mediterranean. On the other hand, positive phase of the NAO indicates increased easterly and north-easterly circulation across a large region of the northern Mediterranean/southern Europe, Balkans, the north-west Turkey and the Black Sea (fig. 5b). This pattern is closely related with a well-developed positive anomaly centre over the Central Europe and the negative anomaly centres over the middle Mediterranean and the eastern Mediterranean/Middle East regions (fig. 5b). Autumn, in addition to the apparent anomaly centres over the areas of the Icelandic Low and the Azores High, is the only season that is characterized by well-described and large-scale anomaly centres occurred in both extreme phases of the NAO, in comparison with other seasons. It is very striking to see the existence of a negative anomaly centre over northern Russia and the Eastern Europe, and an associated trough extending from that centre to Turkey (fig. 6a). This only widespread and apparent anomaly pattern is well developed independently of the recognized anomaly centre over the Azores region of the Atlantic Ocean during the negative phase of the NAO. Increased northerly and north-easterly anomaly circulation dominated over Turkey during the positive NAO phase is evident. This anomalous circulation is associated with the strong anticyclonic anomaly centre over the Central and Eastern Europe, and the cyclonic anomaly centres develop over the mid-north Africa and the Arabian Peninsula (fig. 6b).

4˙2. *Influence of the extreme NAO phases on annual precipitation.* – Composite normalized annual precipitation is characterised with a positive anomaly at 58 stations out of total 78 stations used in the study, except some stations over the BLS, the CMED and the CEAN rainfall regions during the negative annual NAOI phase (fig. 7a). Same results were also found for the differences between the composite annual precipitation means corresponding to the negative annual NAOI phase and the long-term precipitation averages. Cramer's t_k test shows the composite precipitation means corresponding to the negative NAOI phase are significantly wet in comparison with the long-term precipitation averages at 14 stations (fig. 7a). These stations with the significant wetter than long-term average conditions (in short, wet signals) are mostly located over the MRT region, Aegean sub-region of the MED region and the MEDT region of the western Turkey.

Composite normalized annual precipitation computed for the positive annual NAOI phase indicates negative anomalies at 67 stations of Turkey, except some stations in the CEAN and the CMED regions (fig. 7b). Composite negative anomalies are generally much stronger at the stations of the north-western part of the country. According to Cramer's t_k test, drier than long-term average conditions are significant at 19 stations. The positive NAOI signals are evident in the MRT, MED and MEDT regions of Turkey (fig. 7b). It is very clear now that the anomalous 500-hPa circulations corresponding to the negative NAOI phase brings above long-term average precipitation to Turkey. In this NAO pattern, 500-hPa geopotential level is anomalously high in the area of the Icelandic Low and anomalously low across the regions of the Azores High and the Western and Central Europe (fig. 2a). Contrary, the NAO pattern over the Atlantic and the Europe brings below long-term average precipitation to Turkey in the positive NAOI phase when the 500-hPa geopotential level is anomalously low over the area of the Icelandic Low and

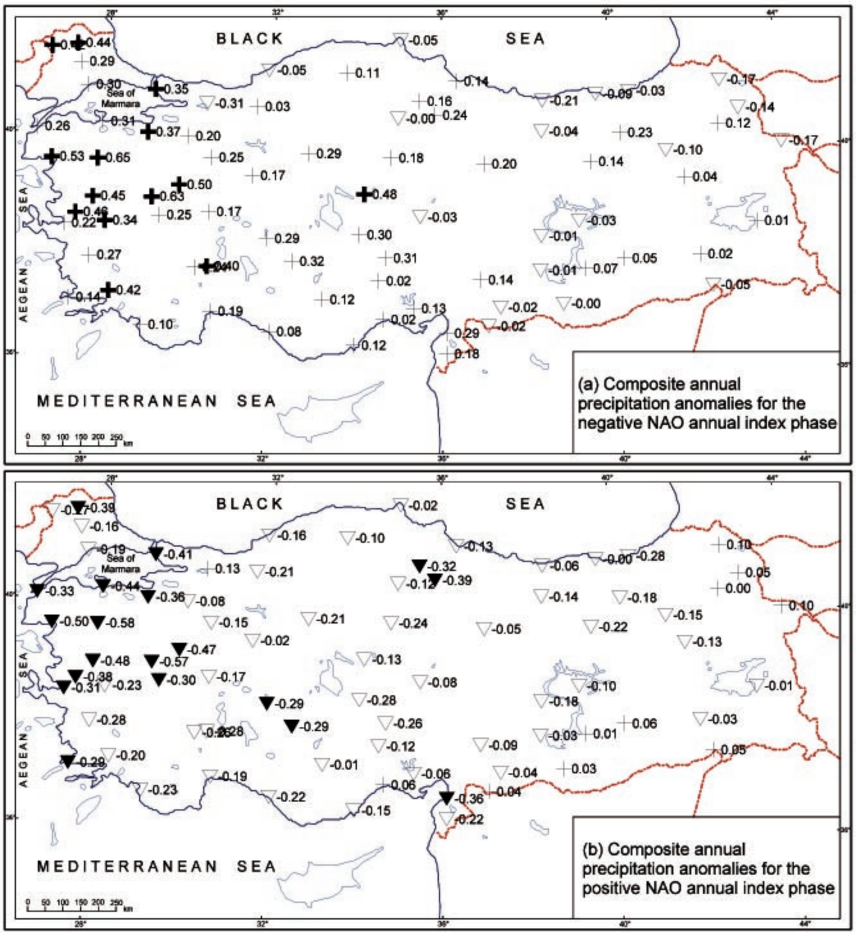


Fig. 7. – Spatial distribution of the composite normalized precipitation anomalies of the 78 stations in Turkey; (a) during the negative and (b) the positive NAO annual index phases (bold plus symbols (filled inverse triangles) indicate the significant wetter (drier) than long-term average precipitation conditions at the 0.05 level, according to Cramer's test) (re-plotted from Türkeş and Erlat [5]).

anomalously high across the subtropical and mid-latitude east Atlantic and the Eastern Europe-the Balkans regions (fig. 2b). Particularly the anomalous south-westerly (north-easterly) circulation related with the cyclonic anomaly (anomalous blocking activity) over the Western and Central Europe (the Eastern Europe-the Balkans) during the negative (positive) NAOI phase controls the wet (dry) signals in the western part of Turkey.

4˙3. *Influence of the extreme NAO phases on winter precipitation.* – Coherent large-scale and marked changes are found in the winter precipitation of Turkey during the extreme winter NAOI phases: winter precipitation tended to increase at the negative winter NAOI phase, while it tended to decrease at the positive winter NAOI phase. Composite precipitation anomalies corresponding to the negative NAOI phase are positive at all stations, except the stations of Trabzon, Sinop and Karaman. Cramer's t_k

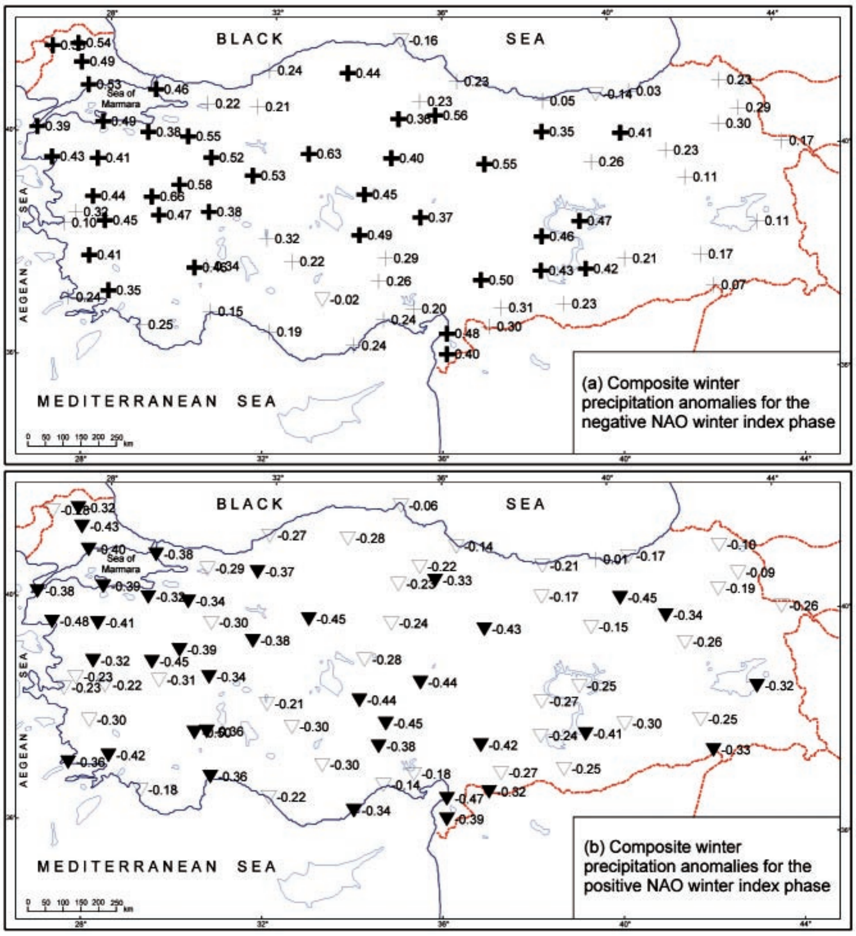


Fig. 8. – As in fig. 7 (a) and (b), but for winter.

test revealed that the wet conditions are significant at 40 stations, 19 of which are at the 0.01 level (fig. 8a). Coherent regions with the increased precipitation signals dominate mainly over the Aegean part and the gulf of İskenderun of the MED region, and the MRT, MEDT, CMED and the mid-north CCAN regions. Non-significant wet and some dry responses are found for the stations on some part of the Mediterranean belt, the CMED and the BLS regions, and the southern and eastern parts of the CEAN region (fig. 8a). The positive winter NAOI responses in winter precipitation are explained by a marked composite negative anomaly at all stations of Turkey except Trabzon on the eastern Black Sea coast (fig. 8b). Composite precipitation means are significantly below long-term average at 38 stations, 12 of which are at the 0.01 level. Dry signals in winter are much more pronounced for the stations in the north-western and middle regions of Turkey. The south-westerly circulation during the negative NAOI phase across the subtropical north-east Atlantic, the North Africa and the Mediterranean basin including Turkey, which is controlled by the anticyclonic anomaly centre in the area of the Icelandic Low and by the cyclonic anomaly centre extending from the Azores to the Eastern

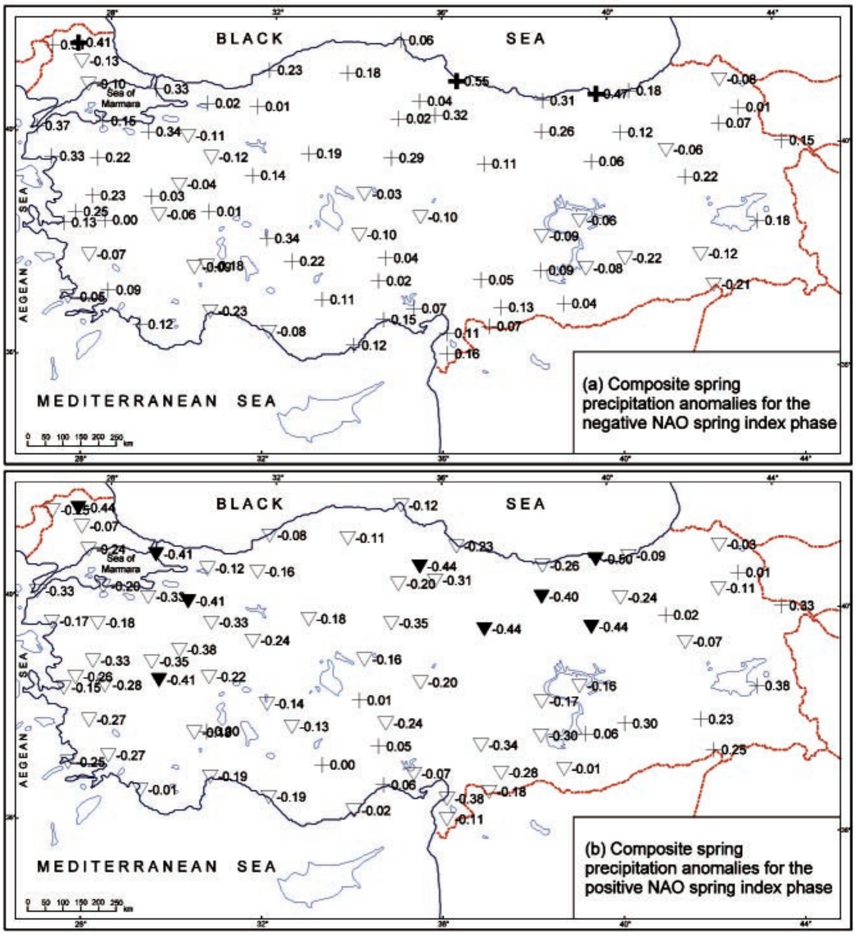


Fig. 9. – As in fig. 7 (a) and (b), but for spring.

Europe (fig. 3a), results mostly in wet conditions and signals in Turkey (fig. 9b). On the other hand, the north-easterly circulation pattern during the positive NAOI phase over Turkey (fig. 3b) results mostly in dry conditions and signals in Turkey (fig. 8b). This circulation is associated with the cyclonic anomaly centres over the region of the Icelandic Low and the North Africa, and the anticyclonic anomaly centre across the subtropical north-east Atlantic-the Iberian Peninsula and the Eastern Europe-the Balkans regions (fig. 3b). The winter correlation coefficients and precipitation anomalies stronger than other seasons in Turkey are explained by the increased pressure differences between the large-scale centres of action in the North Atlantic (the Azores High-Icelandic Low pressure gradient) in this season. It can also be attributed to the fact that precipitation occurrence conditions of Turkey in winter are controlled mainly by the Icelandic and the Mediterranean-originated frontal depressions associated with the humid air streams from the north-east Atlantic [18, 3, 7].

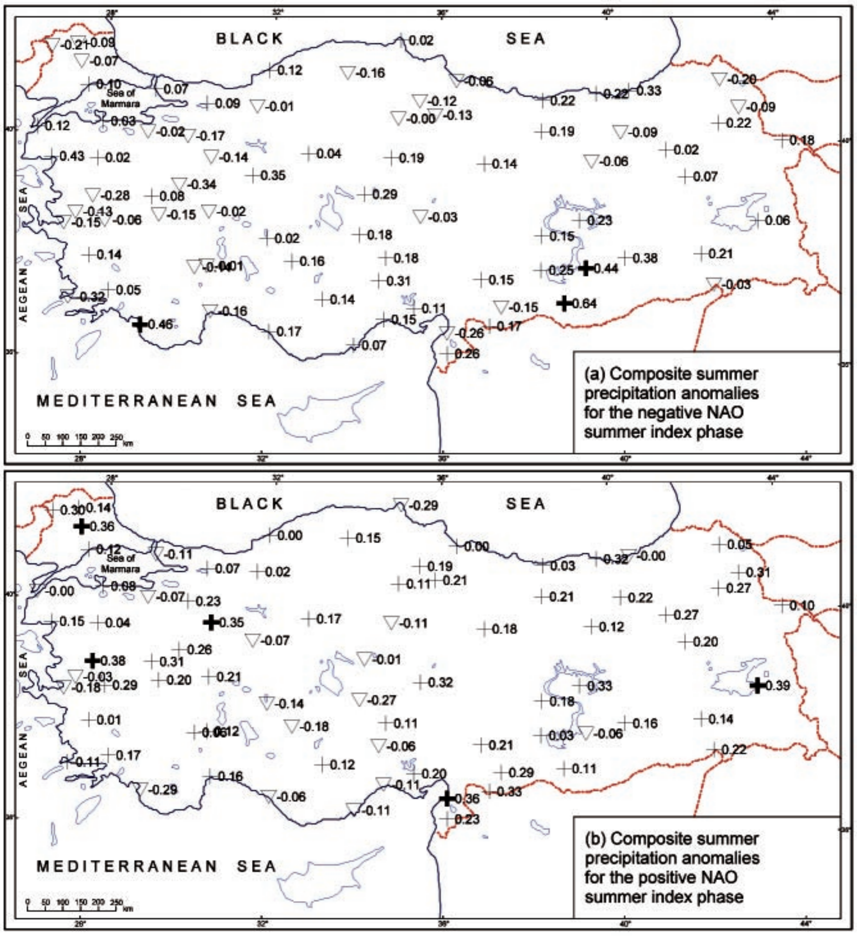


Fig. 10. – As in fig. 7 (a) and (b), but for summer.

4·4. *Influence of the extreme NAO phases on spring precipitation.* – Spring precipitation corresponding to the negative NAOI phase tended to increase at the 55 stations in comparison with the long-term average (fig. 9a). Nevertheless, wetter than long-term average conditions are significant only at the stations of Kirklareli in the northern MRT and Trabzon and Samsun on the Black Sea coast. For the positive NAOI phase, drier than long-term average conditions are significant at the nine stations, although composite precipitation anomalies are mostly negative in Turkey, except at some stations of the CMED, CCAN and CEAN regions (fig. 9b). It seems that relatively wet (dry) conditions in Turkey during the negative (positive) phase of the NAO spring index are related with the cyclonic (anticyclonic) anomaly circulation over the South and Central Europe (fig. 4a, 4b), although influences of the anomalous 500-hPa circulation patterns for the extreme NAOI phases are getting weaker in spring compared with those in winter and autumn, due to the effects of the sub-regional and/or local physical geographic and meteorological factors. Sub-regional and/or local factors may diminish the real effects of the synoptic- or regional-scale atmospheric circulation mechanisms.

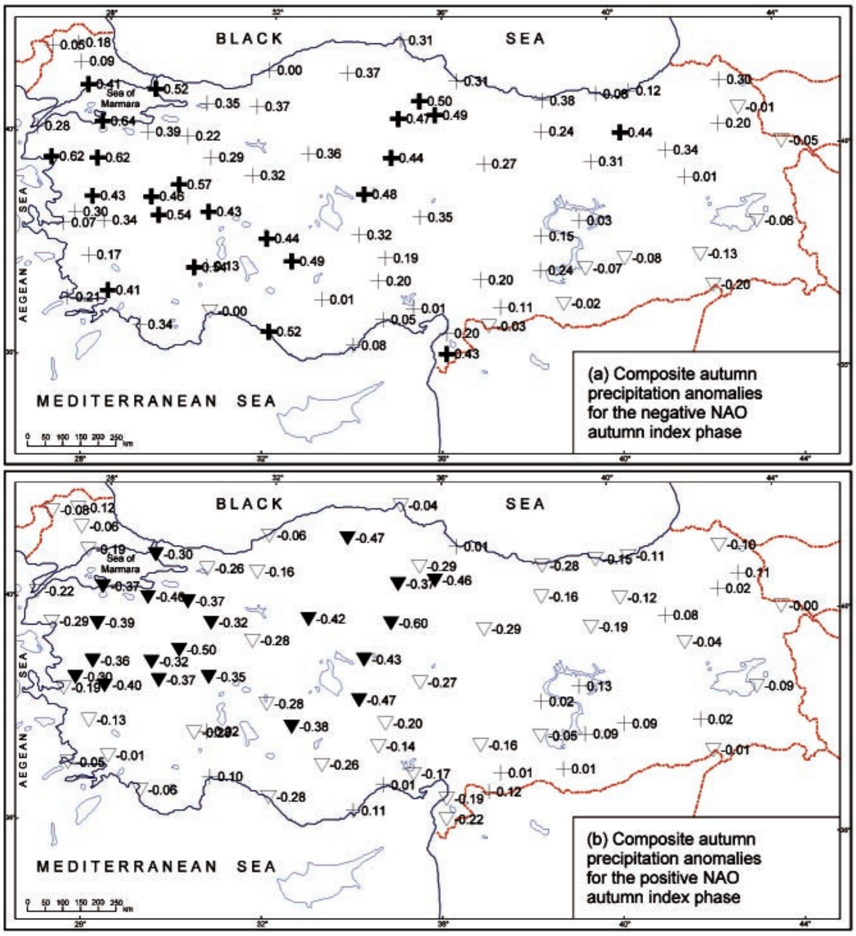


Fig. 11. – As in fig. 7 (a) and (b), but for autumn.

4·5. *Influence of the extreme NAO phases on summer precipitation.* – The negative NAOI responses of the 46 stations are explained by a composite positive precipitation anomaly (fig. 10a). However, the majority of wetter than long-term average precipitation conditions except the stations of Fethiye and Şanliurfa-Siverek in the south-west and south-east of Anatolian Peninsula, respectively, are not significant. The clear opposition determined between the signs of the composite precipitation anomalies and the extreme NAOI anomaly phases for other seasons almost disappears in summer. Composite precipitation anomalies corresponding to the positive NAOI phase are characterised by a positive anomaly at 58 stations (fig.10b). Increased composite summer precipitation is significant only at the stations of Lüleburgaz, Akhisar, İskenderun, Eskişehir and Van, all of which are distributed over the different regions of Turkey without showing any spatial coherence or geographical relationship. As for the much more weaker and complex correlation and anomaly patterns in spring and summer, the considerable contributions of the local convective and the orographic rains in addition to the frontal rains, and the high inter-annual variability particularly in summer are considered as the main factors that cause weakening of the associations between the precipitation and the NAOI. Atmospheric control mechanism in summer differs considerably from that of other seasons [1, 3, 7, 5]: summer dryness arising from the large-scale regional climate (*i.e.*, the Mediterranean macro-climate), which is controlled by both the mid-latitude and north African-Asiatic tropical (*e.g.*, Monsoon low) pressure systems, affects most of the country in this season, except the Black Sea coastal area and the north-eastern Anatolia. Local and/or sub-regional physical geographic factors, such as topography, exposure and continentality, and associated meteorological events (*e.g.*, local convective showers/thunderstorms, orographic rains, etc.) also diminish real effects of the regional atmospheric control mechanisms over Turkey in summer. In spite of the above assessments, it is very likely that wet conditions in summer at many stations of Turkey during the positive NAOI phase (fig. 10b) are controlled by north-easterly circulation particularly in the north-western Turkey. This pattern is associated with a well-developed positive anomaly centre over the Central Europe and the negative anomaly centres over south of Turkey and the middle and eastern Mediterranean/Mesopotamia regions (fig. 5b). The cyclonic circulation over these regions may cause local convective showers and thunderstorms during the positive NAOI phase, which is not expected in terms of the recognized and/or expected climatological influence of the NAOI responses in the Turkish precipitation compared with other seasons.

4˙6. *Influence of the extreme NAO phases on autumn precipitation.* – Autumn NAOI responses are weaker than those in winter precipitation, and greater than those in spring and summer precipitation. Composite precipitation anomalies during the negative NAOI phase are found to be positive at 69 stations of Turkey, except some stations mainly located in the southern CMED and the eastern CEAN regions (fig. 11a). Composite precipitation means that wetter than long-term average conditions are significant at 22 stations. Wet signals are evident mostly in the MRT, MEDT and MED regions, and the middle and north-eastern parts of the CCAN region (fig. 11a). Autumn precipitation tended to decrease during the positive autumn NAOI phase over most of Turkey, except 16 stations mainly located in the CMED region and the north-eastern part of the Anatolian Peninsula (fig. 11b). Significant dry conditions show up at 21 stations. Wet conditions and signals in autumn during the negative NAOI phase (fig. 11a) are explained by an anomalous 500-hPa trough structure over Turkey, which is associated with a cyclonic anomaly centre over the northern Russia and the Eastern Europe (fig. 6a). On the other hand, a north-easterly anomaly circulation mainly associated with the strong anticyclonic anomaly centre over the Central and Eastern Europe (fig. 6b) controls dry conditions and signals during the positive NAOI phase (fig. 11b).

5. – Conclusions

1) When the NAO is in its extreme phases, both the Icelandic Low and the Azores High are well developed during cool/cold period of the year, especially in winter. Negative phase of the NAO indicates stronger-than-average westerly and south-westerly circulation over the subtropical north-east Atlantic, the North Africa and the Mediterranean basin towards Turkey, and the stronger-than-average north-easterly circulation across Scandinavia and the mid-latitude and sub-Arctic north-east Atlantic particularly in winter, spring and annually. Contrary, the positive phase of the NAO shows the increased westerlies over the mid-latitudes and Scandinavia and increased easterly and north-easterly circulation over a large conveyer zone from Turkey to the subtropical Atlantic via the Mediterranean basin and the North Africa.

2) In summer, negative phase of the NAO indicates increased easterly/north-easterly circulation over the Northern Europe and the north-east Atlantic associated with the anticyclonic anomaly centre over the area of the Icelandic Low and the cyclonic anomaly centres over the mid-north-east Atlantic and the Western Europe. On the other hand, positive phase of the NAO indicates increased easterly and north-easterly circulation across a large region of the northern Mediterranean/southern Europe, the Balkans, the north-west Turkey and the Black Sea. Autumn, in addition to the apparent anomaly centres over the areas of the Icelandic Low and the Azores High, is the only season that is characterized by well-described and large-scale anomaly centres occurred in both extreme phases of the NAO, in comparison with other seasons. A negative anomaly centre is evident over north of Russia and the Eastern Europe, and an associated trough is extending from that centre to Turkey.

3) Composite analysis exhibited an apparent opposite anomaly pattern at most stations of Turkey, except in summer, between the negative and positive NAOI phases [5]. Annual, winter, spring, autumn and partly summer composite precipitation means tended to increase during the negative NAOI phase, whereas the composite precipitation means tended to decrease during the positive NAOI phase annually and in all seasons except summer. The extreme NAOI responses, however, show some inter-regional differences at the same phase in terms of the magnitude and partly the sign of the composite precipitation anomalies and means. Autumn and particularly winter precipitation responses to the negative (positive) NAOI anomaly phase are characterised by the significant wet (dry) signals at most stations of the western and middle regions of Turkey.

4) The 500-hPa circulation corresponding to the negative NAOI phase brings above long-term average precipitation to Turkey in winter, spring and autumn and annually. This circulation is associated with the NAO pattern in which the 500-hPa geopotential level is anomalously high in the area of the Icelandic Low and anomalously low across the regions of the Azores High and Europe in general. Contrary, the NAO pattern over the North Atlantic and Europe is responsible for the drier than long-term average precipitation conditions in Turkey during the positive NAOI phase, when the 500-hPa geopotential level is anomalously low over the area of the Icelandic Low and anomalously high across the subtropical and mid-latitude north-east Atlantic and the European regions.

* * *

The authors would like to thank the Climate Analysis Section and the Data Support Section of the NCAR (Boulder, Colorado, USA) and James W. Hurrell (1995) for providing the NAO Index Data and the 500-hPa geopotential height data. We would also like to thank the organizers of the US-Italy Workshop on "Historical Reconstruction of Climate Variability and Change in the Mediterranean Regions", held at Bologna, Italy, October 5-6, 2004.

REFERENCES

[1] Kutiel H., Hirsch-Eshkol Tr. and Türkeş M., *Theor. Appl. Climatol.*, **69** (2001) 39.
[2] Tatli H., Dalfes H. N. and Menteş S., *Int. J. Climatol.*, **24** (2004) 161.
[3] Türkeş M., *Int. J. Climatol.*, **18** (1998) 649-680.
[4] Türkeş M., in *Mediterranean Climate—Variability and Trends*, edited by H. J. Bolle (Springer Verlag, Heidelberg) 2003, pp. 181-213.
[5] Türkeş M. and Erlat E., *Int. J. Climatol.*, **23** (2003) 1771.
[6] Türkeş M. and Erlat E., *Theor. Appl. Climatol.***81** (2005) 45.

[7] Türkeş M., Smer U. M. and Kiliç G. *Clim. Res.*, **21** (2002) 59.

[8] Hurrell J. W., *Science*, **269** (1995) 676.

[9] Hurrell J. W. and Van Loon H., *Climatic Change*, **36** (1997) 301.

[10] Rodo X., Baert E. and Comin F. A., *Clim. Dyn.*, **13** (1997) 275.

[11] Serreze M. C., Carse F., Barry R. G. and Rogers J. C., *J. Clim.*, **10** (1997) 453.

[12] Kapala A., Machel H. and Flohn H., *Int. J. Climatol.*, **18** (1998) 23.

[13] Wibig J. *Int. J. Climatol.*, **19** (1999) 253.

[14] Camuffo D., Secco C., Brimblecombe P. and Martin-Vide J., *Climatic Change*, **46** (2000) 209.

[15] Cullen H. M. and DeMenocal P. B., *Int. J. Climatol.*, **20** (2000) 853.

[16] Delitale A. M. S., Cesari D., Chessa P. A. and Ward M. N., *Int. J. Climatol.*, **20** (2000) 519.

[17] Ben-Gai T., Bitan A., Manes A., Alpert P. and Kushnir Y., *Theor. Appl. Climatol.*, **69** (2001) 171.

[18] Türkeş M. *Int. J. Climatol.*, **16** (1996) 1057.

[19] Türkeş M., in *Climate Variability and Climate Change Vulnerability and Adaptation, Proceedings of the Regional Workshop in 1995*, edited by I. Nemešová (Praha) 1996, pp. 114-126.

[20] Türkeş M., *Turkish J. Eng. Environ. Sci.*, **23** (1999) 363.

[21] Kadioğlu M., *Int. J. Climatol.*, **20** (2000) 1743.

[22] `http://www.cgd.ucar.edu/ jhurrell/nao.html`. The NAO Index Data. The Climate Analysis Section of the NCAR (Boulder, Colorado, USA) and Hurrell (1995).

[23] `http://www.dss.ucar.edu/datasets`. Geopotential Height Data. The Data Support Section of the NCAR (Boulder, Colorado, USA).

[24] WMO Climatic Change. World Meteorological Organization (WMO), Technical Note, No. 79, Geneva (1966).