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Signatures of the NAO in the atmospheric circulation during wet winter months over the Mediterranean region

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With 9 Figures

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Summary

Positive trend of the North Atlantic Oscillation (NAO) during last several decades was also accompanied by a positive trend of the East Atlantic Western Russia (EAWR) pattern. Decline of the Mediterranean precipitation during the period has also been noted. The precipitation decline over the western part of the region has been linked to the positive trend of the NAO. Explanation for the precipitation decline over the eastern Mediterranean by the role of the EAWR trend has also been suggested. An evaluation of the hypothesis is performed in the current study. A methodology for the determination of the characterizing typical low troposphere circulation during wet-months large-scale correlation-circulation patterns is suggested. The large-scale circulation patterns for three target areas over the northwestern, north-eastern, and southeastern Mediterranean regions are constructed separately for the low and high phase periods of the teleconnection regimes. According to the results, the precipitation decline over the Mediterranean region during the last several decades of the past century may be explained by the positive trend of the EAWR, which in its turn was induced by it that of the NAO. The trends have lead to the changes in the typical for the wet periods of the year low-troposphere circulation regimes associated with a decline in the water vapor transport from Atlantic.

1. Introduction

Weather processes over the Mediterranean region are linked in many ways to those over Eurasia, with its two prominent teleconnection patterns – North Atlantic Oscillation (NAO) and East Atlantic/West Russia (EAWR) (Barnston and Livezey, 1987; Zorita et al., 1992; Jones et al., 1997; Ulbrich et al., 1999; Ulbrich and Christoph, 1999; Panaginatopoulos et al., 2002; Ostermeier et al., 2003). The NAO mode is associated with the meridional oscillation in the sea level pressure (SLP) having its centers of action located in proximity to the Icelandic Low and Azores High (e.g. van Loon and Rogers, 1978; Hurrell and van Loon, 1997; Jones et al., 1997). Though NAO is active throughout the year, it is most pronounced during winter. Positive and negative periods of the NAO are characterized by a specific orientation of the air-flows. During high NAO winters, the westerlies onto Europe are to about 8 ms^{-1} stronger than those during negative NAO months (Hurrell, 1995). A poleward shift of the zonal storm-tracks during the positive NAO years was demonstrated. Vectors of vertically integrated moisture transport for the NAO high and low winters also differ from each other. The difference contributes to quite substantial changes in the weather conditions over west Europe as well as over the northeastern and, especially, western Mediterranean (WM) regions (Hurrell, 1995, 1996; Trigo et al., 2000, 2002b; Tan and Unal, 2003). The NAO-positive periods are associated with wetter than normal weather over west Europe and drier than normal weather in the Mediterranean region. NAO-negative winter periods are characterized by wetter than normal conditions over the western, as well the northern parts of the Mediterranean area.

The second prominent SLP anomaly system in Europe – EAWR (Barnston and Livezey, 1987) – also plays a significant role in determining the weather processes over Europe. In winter, two main anomaly centers, which are located over the Caspian Sea and Western Europe, comprise the EAWR. The EAWR positive and negative periods are associated with specific orientation of the air-flows. During the high EAWR winters, the northerlies onto Europe are predominant over the Baltic Sea area. The northerlies are directed to the area located over and to the E of the Mediterranean region. Positive (negative) phases of the pattern are characterized by the negative (positive) pressure anomalies throughout western and the southwestern Russia, and the positive (negative) pressure anomalies over north-western Europe. During the negative EAWR phases, wetter than normal weather conditions are often observed over a large part of the Mediterranean region. Conversely, during the EAWR positive phases drier than normal conditions are often found over a large part of the region.

2. European teleconnections and the Mediterranean precipitation

Time variation of the running 6-year mean winter (December–February, DJF) NAO and EAWR index values during 1950–2000 is presented in Figs. 1 and 2, respectively. The NAO and EAWR indices values for the graphs are taken from the NOAA Climate Prediction Center (CPC) website http://www.cpc.ncep.noaa.gov/data/teledoc/nao.html as determined according to diagnostic procedure for the identification of teleconnection patterns using the Rotated Principal Component Analysis – RPCA (Barnston and Livezey, 1987) approach. The procedure isolates the primary teleconnection patterns for all months and allows for time series of the amplitudes of the patterns to be constructed. The RPCA technique is being applied at the CPC to monthly mean 700-mb height anomalies. The analysis accounts for variability in the structure and amplitude of the teleconnection patterns associated with the annual cycle of the extratropical atmospheric circulation. It also allows for better continuity of the time series from one month to the next, than if the patterns were calculated based on the data for each month independently. The RPCA procedure is superior to grid-point-based analyses, typically determined from one-point correlation maps, in that the teleconnection pattern is identified based

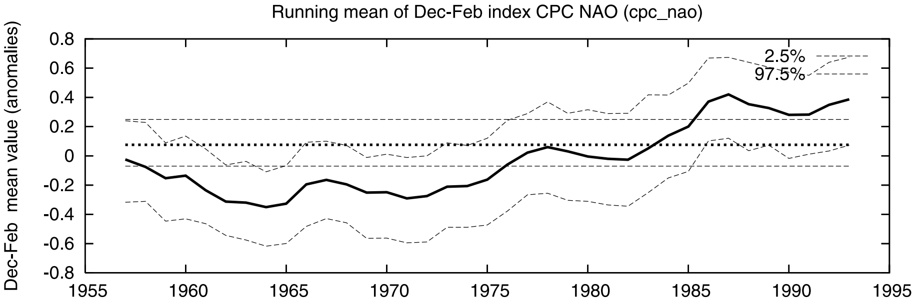


Fig. 1. Time variations of running six-year DJF indices of the NAO from 1950 to 2000

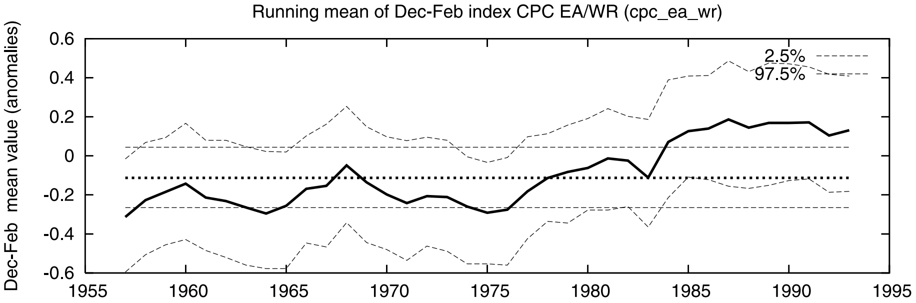


Fig. 2. Same as in Fig. 1 but for EAWR

on the entire flow field, and not just from height anomalies at a few select locations.

Significant positive trends of the both NAO and EAWR indices from early 1970s to about 1995 are evident in Figs. 1 and 2. According to the figure the DJF period from 1958 to 1972 has been characterized by relatively low index values whereas the DJF period from 1979 to 1993 DJF was characterized by high NAO and EAWR values.

Also significant trends in the weather conditions have been detected over the Mediterranean region during the period. A number of authors report a rainfall decrease (Trigo et al., 2000, 2002b; Alpert et al., 2003; Alpert, 2004). A weakening of Mediterranean cyclones during the same period has been demonstrated (Corte-Real et al., 1995; Brunetti et al., 2001, 2002; Hurrell and van Loon, 1997). Decrease in the moisture content in the atmospheric masses due to the northward shift of the storm-tracks during the high NAO periods has been suggested as an explanation of the decline in the winter-time precipitation over the WM (Trigo et al., 2000). No explanation of the decrease in intensity of the cyclones over the eastern- and southeastern Mediterranean (EM) regions has been given.

Role of the both NAO and EAWR patterns in controlling precipitation over the EM region has also been demonstrated. Existence of a high positive correlation between the height of the smoothed 1000 hPa in Israel and NAO has been noted by Ben-Gai et al. (2001). High negative correlation between the NAO index and temperature variations in Israel was also detected. No dependency of precipitation in Israel on the NAO has been revealed in this study however. Extreme wet (dry) winter EM months were characterized by the anomaly patterns, that have much in common with those of the positive (negative) EAWR phases (Krichak et al., 2000). Kutiel and Benaroch (2002), Kutiel et al. (2002) and Paz et al. (2003) also demonstrated a dependency between the EM precipitation and a similar to the EAWR dipole pattern with the center located over the east Atlantic and the Caspian Sea areas. Zangvil et al. (2003) suggested an indirect mechanism of the dependency which is represented by an increased frequency of occurrence of 500 hPa troughs oriented from north-east to south-west during the NAO positive months.

The changes in the WM precipitation regimes have been linked to the positive trend of the NAO (Trigo et al., 2000; Alpert et al., 2003). The negative precipitation trend over the eastern Mediterranean region has been explained by the positive EAWR trend. At the same time the EAWR positive periods have been found favorable for an increased precipitation over the south-eastern part of the EM (Krichak et al., 2002, 2004).

The recent past positive trends of the two modes have been jointly contributing the weather and climate developments over Europe. The aim of the current study was to investigate the joint contribution of the two annual modes in controlling the precipitation over the Mediterranean region.

3. Methodology and data

Typical atmospheric circulation patterns that characterize the wet periods over the Mediterranean region are discussed in the study.

In accordance with Figs. 1 and 2 the 1958–1972 and 1979–1993 periods have been chosen to represent the typical low and high NAO and EAWR regimes in the lower troposphere. Since the winter rainfall accounts for about 60% of the annual total over the northern (Trigo et al., 2000; Trigo et al., 1999, 2002b), and for about 100% (due the role of the summer Asian monsoon effects here – over the southeastern Mediterranean region (Alpert et al., 1990; Bedi et al., 1976) the following analysis is restricted by the December–February (DJF) period.

Three target areas located over the north-west and north-east and south-east of the region (Fig. 3) have been selected. The 07°–10° E; 44°–46° N area in Fig. 3 represents the north-western Mediterranean region (NWM). The 37°–40°; 35°–37° target area represents the north-eastern Mediterranean region (NEM). The 35°–37° E; 31°–34° N area represents the southeastern Mediterranean region (SEM).

Data archives for the monthly precipitation and lower tropospheric winds have been adapted for the analysis. The gridded (0.5° lat-long) monthly precipitation data over land available from the Climatic Research Unit (CRU) University of East Anglia (New et al., 2000) for the period from 1901 to 1998. The precipitation data in the archive are those directly interpolated from

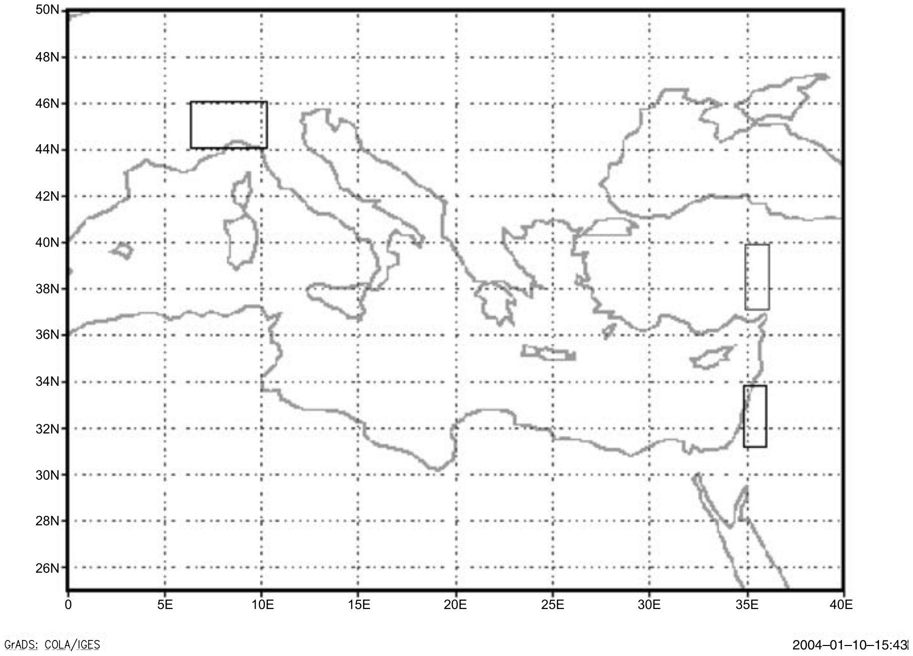


Fig. 3. Positioning of the NWM (7° E–10° E, 44° N–46° N), NEM (35° E–37° E, 37° N–40° N) and SEM (35° E–37° E, 31° N–34° N) target areas

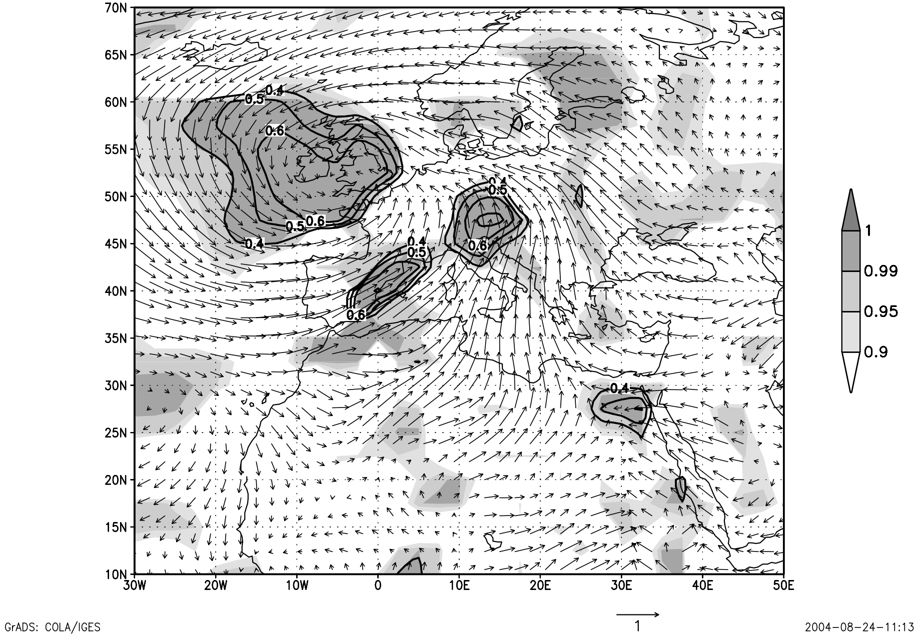
terrestrial station observations. The data archive is considered as the most advanced among those currently existing datasets for climate applications. The wind data used are from the gridded (2.5° lat-long) National Center for Environment Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis Project (Kalnay et al., 1996; Kistler et al., 2001). The NNRP data are derived through a consistent assimilation and forecast model procedure allowing incorporation of all available observation data. Usefulness of the data for the climate analyses over the European region has been widely proven (e.g. Trigo et al., 2002).

The current analysis was based on an evaluation of typical circulation regimes that characterize the low and high NAO-EAWR periods. The following approach has been adapted for the determination of the regimes. Normalized indices of the precipitation over the target area have been calculated. One-dimensional (Press et al., 1997) correlations between the squared (to allow a better fit to the Gaussian distribution) precipitation indices with the *u* and *v* wind field components at 10 m height and 850 hPa isobaric surface have been computed. The correlations were calculated on detrended time series. The fit of the data to the Gaussian distribution was evaluated according to Kolmogorov-Smirnov test (Press et al., 1997). Characterizing the low and high NAO-EAWR wet EM periods circulation patterns have been constructed based on the correlations computed. The wind vectors represent the magnitudes of the winds-precipitation correlations obtained. The isolines and shaded areas in the figures represent the correlations and statistical significances (above 0.90) of the dependencies between relative vorticity at the corresponding surface and precipitation respectively. It is worth noting here that the directions of the typical atmospheric flows in the patterns are reliable only over the areas with sufficiently high level of statistical significance. Over the rest of the areas the patterns provide only approximate information on the directions of the air-mass transport during the wet periods over the target areas. Obtained circulation patterns are discussed in the following section.

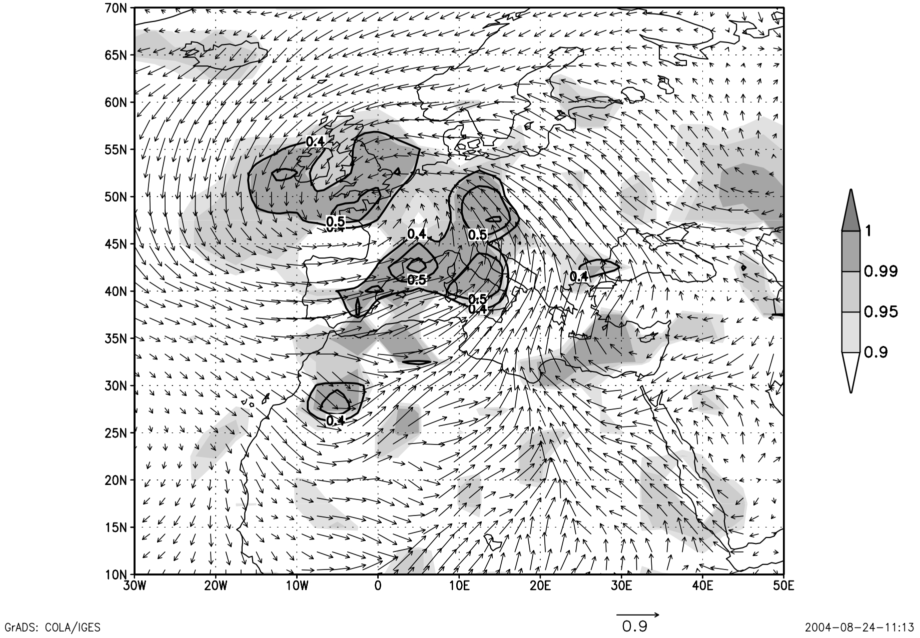
4. Results

4.1 NWM

Circulation patterns that characterize atmospheric circulation near surface (at 10 m height) during the wet NWM periods are given in Fig. 4a, b for the low and high phases of the two (NAO and EAWR) modes respectively. The pattern presenting correlations between the wind components



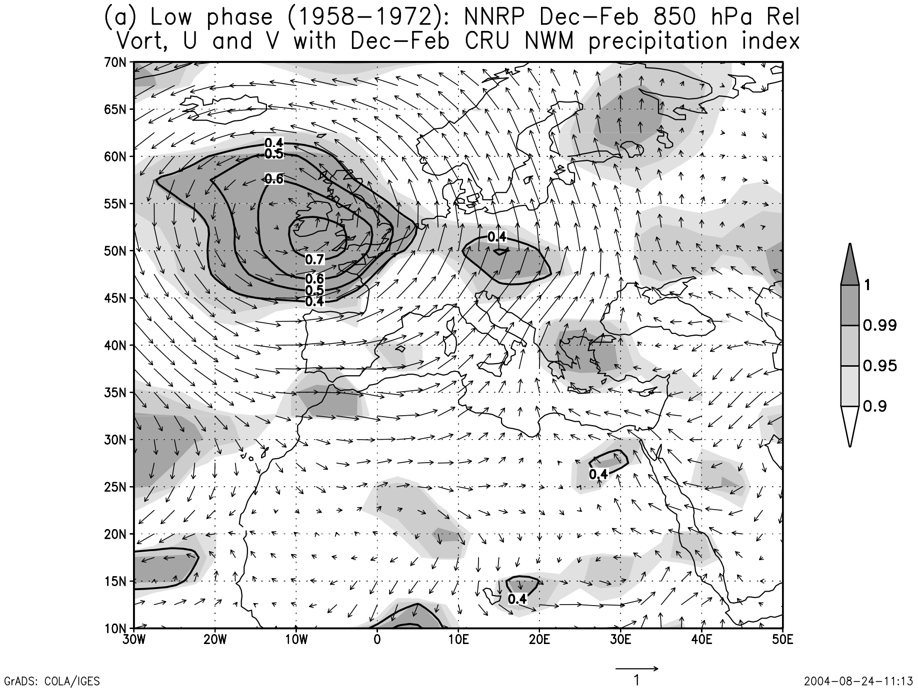
(a) Low phase (1958–1972): NNRP Dec–Feb 10 m Rel Vort, U and V with Dec–Feb CRU NWM precipitation index



(b) High phase (1979–1993): NNRP Dec–Feb 10 m Rel Vort, U and V with Dec–Feb CRU NWM precipitation index

Fig. 4. Correlations between precipitation index over the NWM target area and the *u*, *v* wind components at 10 m height, during DJF months for (**a**) low six-year mean NAO/EAWR; (**b**) high six-year mean NAO/EAWR

at 10 h and the NWM precipitation reveals existence of a cyclonic center located over the eastern Atlantic during the wet periods over the target area. The pattern repeats results the earlier synoptic analyses for the region (Jansa et al., 2000, 2001). A difference between the two pictures (Fig. 4a, b) may be noted. On the pattern for the low phase period (Fig. 4a) the vortex is located about 500 km to the north-west of its location during the high phase DJF's (Fig. 4b). Similar correlation-circulation patterns characterize correlations between the NWM precipitation and winds at 850 hPa (Fig. 5a, b). The cyclone vortex over eastern Atlantic is also found in the patterns. As in the case of the near surface circulation patterns (Fig. 4a, b) on the 850 hPa



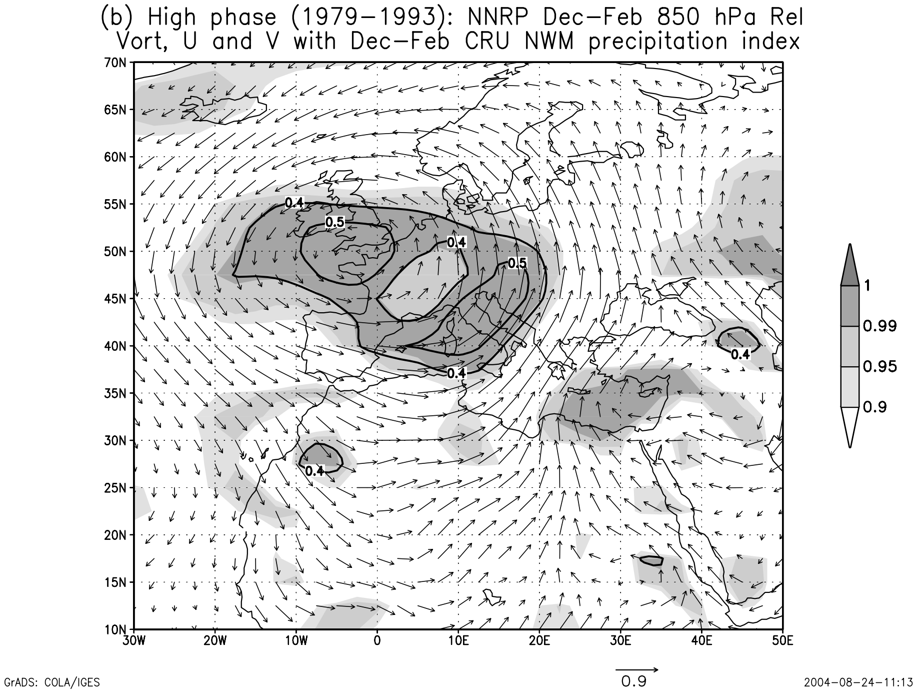
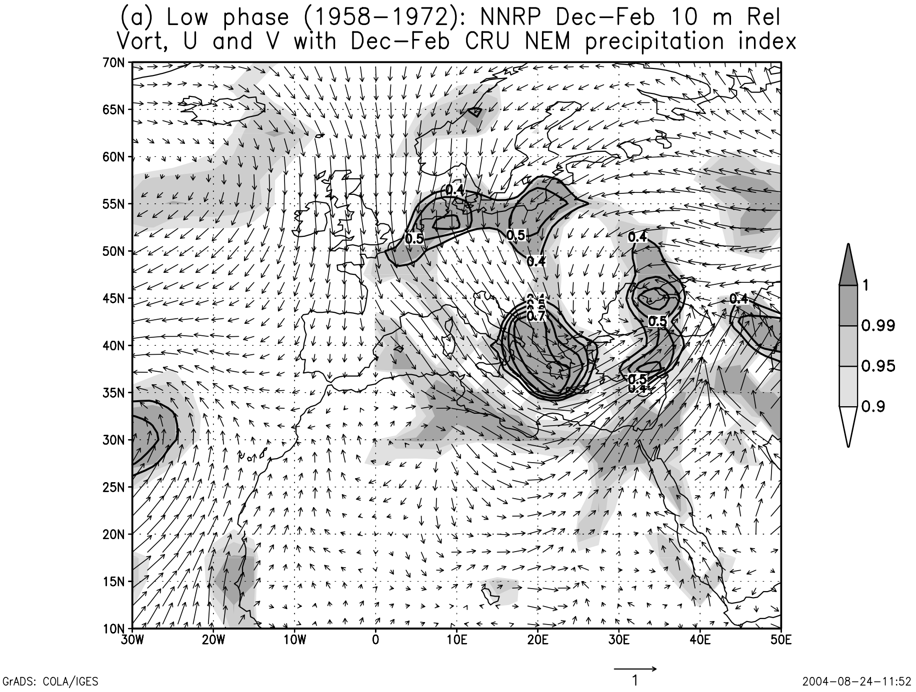


Fig. 5. Same as in Fig. 4 but for the wind *u*, *v* components at 850 hPa surface

patterns the vortex is found located much (about 1000 km) further to the east during the high teleconnection phase (Fig. 5b) than during the low phase (Fig. 5a). Large areas with statistically significant correlations between the relative vorticity and the DJF precipitation prove the reliability of the obtained correlations. It may be noted that the statistical significance of the correlation dependencies in the area of the composite Atlantic cyclone is higher (up to 0.7 on Fig. 5a) on the patterns for the low phase than on those for the high one. The fact may be explained by the earlier noted (Corte-Real et al., 1995; Brunetti et al., 2001, 2002; Hurrell and van Loon, 1997) weakening of the cyclones during the NAO high periods.

4.2 NEM

Calculated at the 10 m height surface NEM DJF circulation patterns are presented in Fig. 6a, b for the low and high phase periods respectively. According to the pictures, during the both teleconnection regimes the wet NEM DJF periods are characterized by the existence of a lower troposphere counterclockwise circulation centered over north of the EM region. A significant difference between the quite similar obtained patterns for the low and high teleconnection regimes may be noted. An air-mass inflow to the NEM area from the eastern Atlantic may be noted in the pattern for the low phase regime (Fig. 6a). On the pattern for the high phase however almost no inflow of the air-masses from the Atlantic is


(a) Low phase (1958–1972): NNRP Dec–Feb 10 m Rel Vort, U and V with Dec–Feb CRU NEM precipitation index

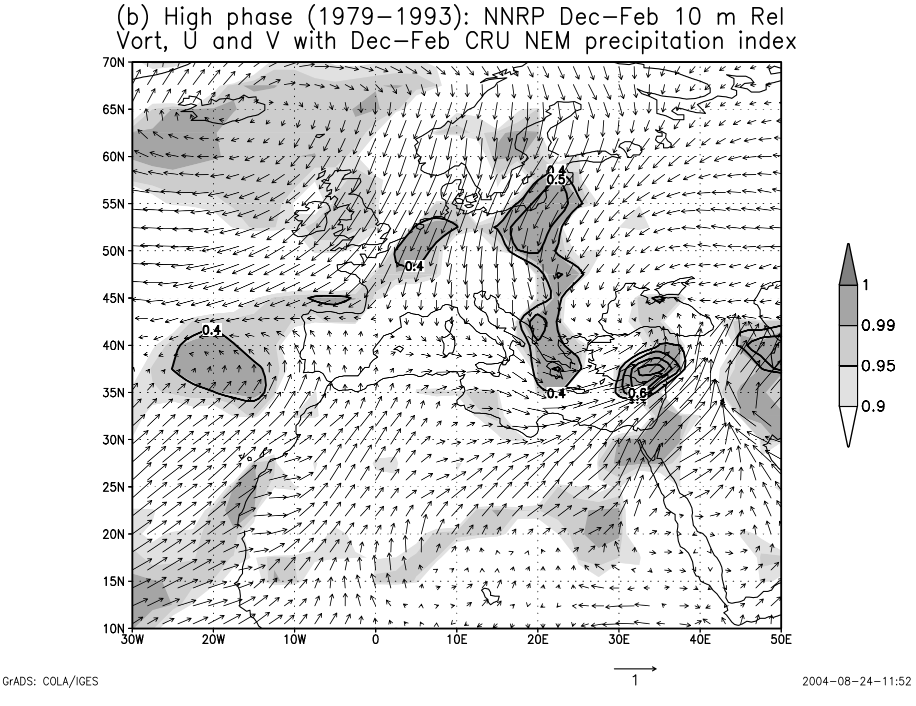
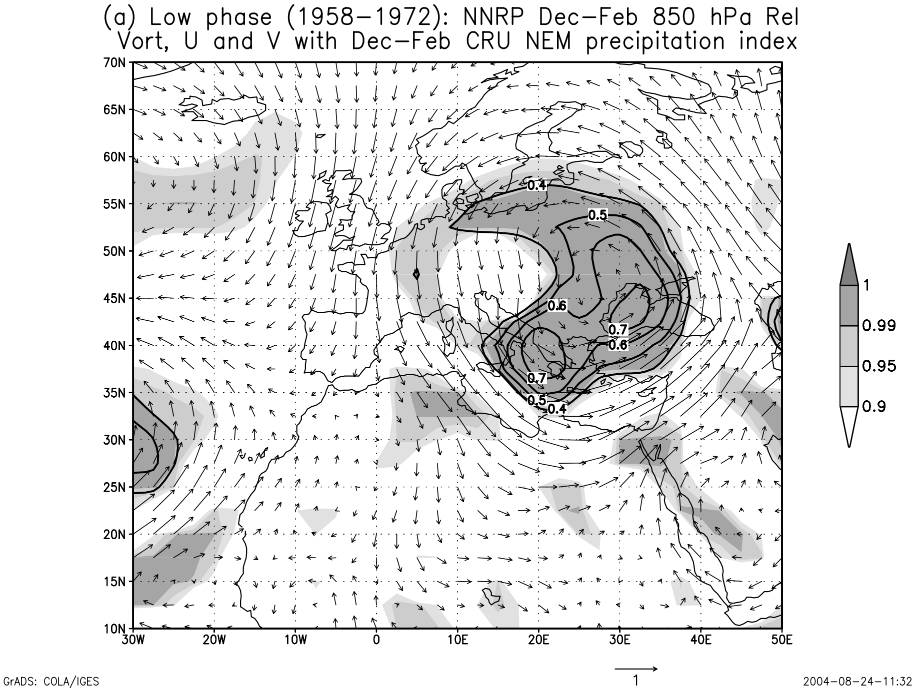

(b) High phase (1979–1993): NNRP Dec–Feb 10 m Rel Vort, U and V with Dec–Feb CRU NEM precipitation index

Fig. 6. Same as in Fig. 4 but for the NEM target area

found in Fig. 6b. The pattern here is characterized by advection of the air-masses from central Europe to the EM region.

Similar composite circulation patterns characterize the 850 hPa wind-precipitation relationships (Fig. 7a, b). During the both teleconnection phases the averaged wet NEM periods are characterized by the existence of a low troposphere cyclone centered over the Black Sea. The main difference between the two patterns may be indicated – no inflow of the air masses from the Atlantics characterizes the high phase pattern (Fig. 7b) whereas the inflow does take place during the low phase DJF's (Fig. 7a).


(a) Low phase (1958–1972): NNRP Dec–Feb 850 hPa Rel Vort, U and V with Dec–Feb CRU NEM precipitation index

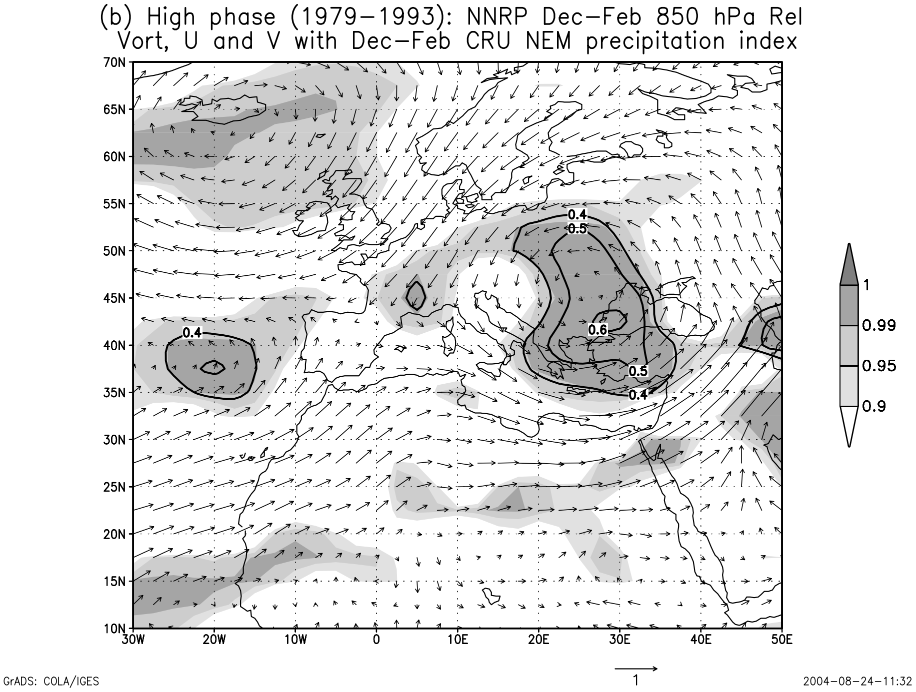
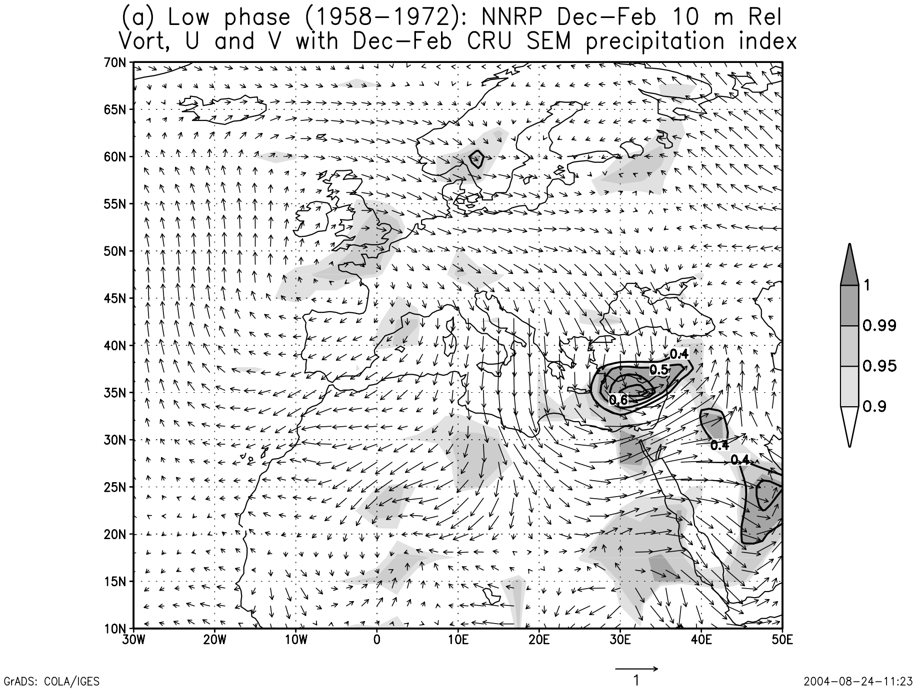

(b) High phase (1979–1993): NNRP Dec–Feb 850 hPa Rel Vort, U and V with Dec–Feb CRU NEM precipitation index

Fig. 7. Same as in Fig. 5 but for the NEM target area

4.3 SEM

Circulation patterns that characterize atmospheric circulation near surface (at 10 m height) during the wet SEM periods are given in Fig. 8a, b for the low and high phases of the two (NAO and EAWR) modes respectively. The patterns presenting correlations between the wind components at 10 h and the SEM precipitation reveal existence of a cyclonic center located over the northeastern Mediterranean during the wet periods over the target area. The patterns illustrate a known fact that the main part of the precipitation in the SEM is associated with the activity of Cyprus cyclones (Krichak et al., 2004). The near surface circulation patterns in Fig. 8a, b are almost identical to each other. More noticeable differences


(a) Low phase (1958–1972): NNRP Dec–Feb 10 m Rel Vort, U and V with Dec–Feb CRU SEM precipitation index

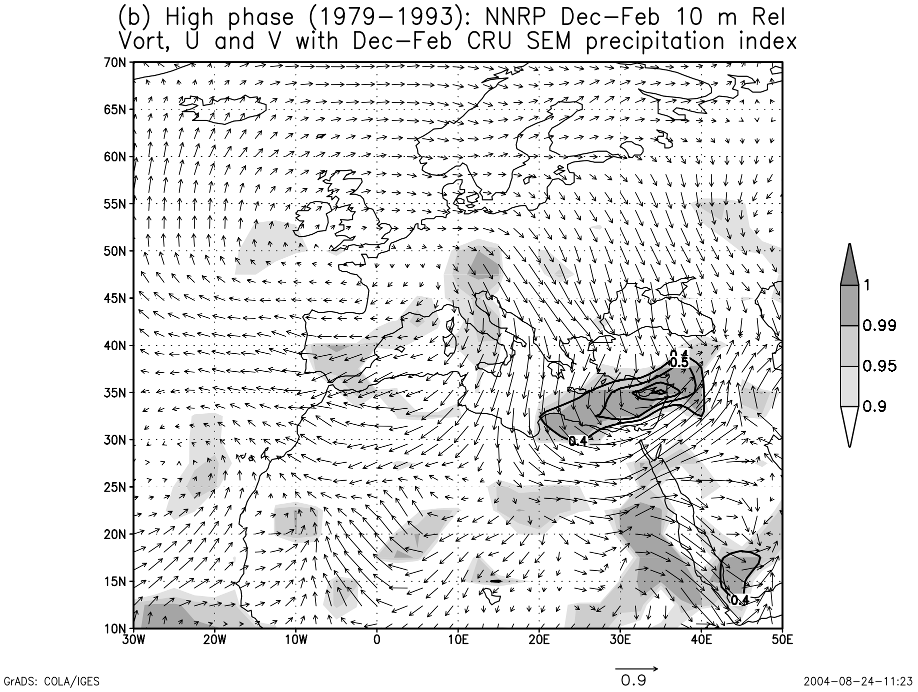
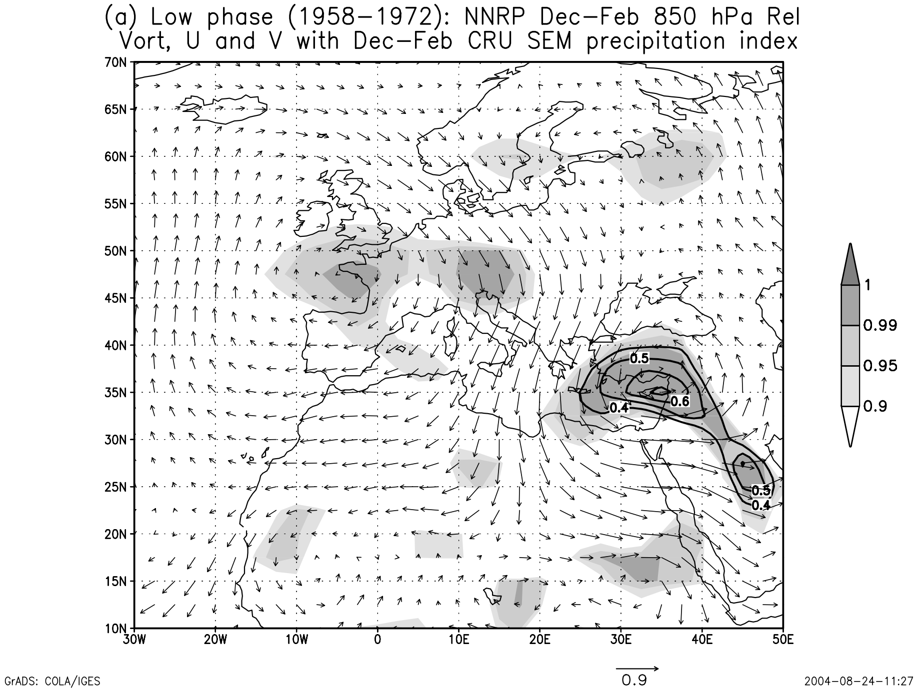

(b) High phase (1979–1993): NNRP Dec–Feb 10 m Rel Vort, U and V with Dec–Feb CRU SEM precipitation index

Fig. 8. Same as in Fig. 4, but for the SEM target area


(a) Low phase (1958–1972): NNRP Dec–Feb 850 hPa Rel Vort, U and V with Dec–Feb CRU SEM precipitation index

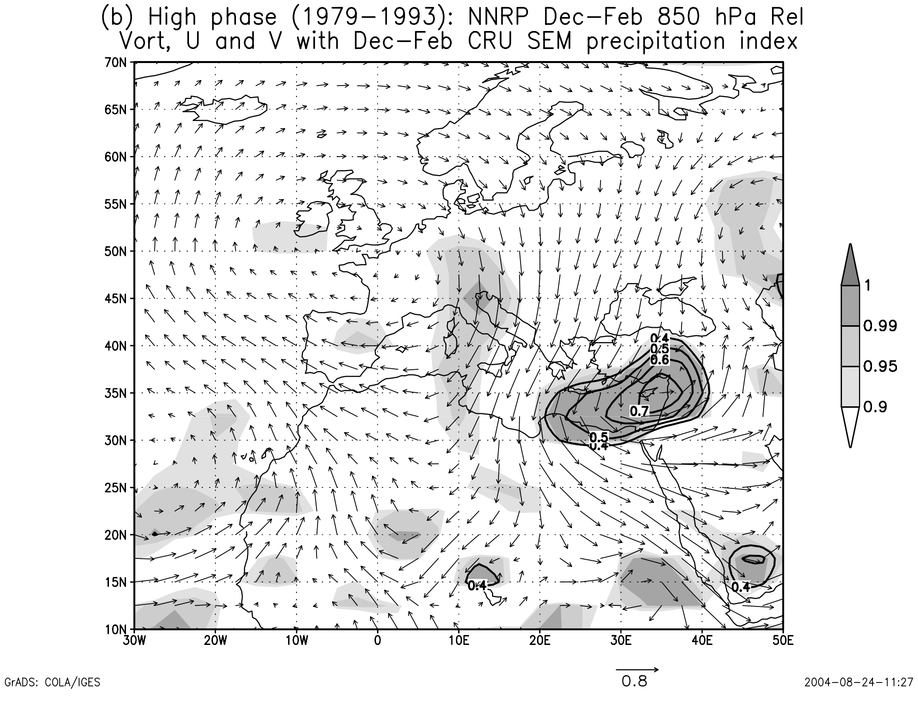

(b) High phase (1979–1993): NNRP Dec–Feb 850 hPa Rel Vort, U and V with Dec–Feb CRU SEM precipitation index

Fig. 9. Same as in Fig. 5, but for the SEM target area

may be found in the 850 hPa patterns obtained for the years with the low and high teleconnection phases (Fig. 9a, b) respectively. As in the case of the 10 m patterns in Fig. 8a, b the 850 hPa patterns reveal the role of the Cyprus cyclones in the SEM precipitation. The typical air-flows to NW of the cyclone however differ significantly on the patterns. During the low phase DJF's the area of the origin of the arriving to the SEM air masses is found located over the eastern Atlantic (Fig. 9a). The direction of the typical air-flow is different on the pattern for the high phase regime (Fig. 9b). Almost no air masses from the Atlantic are transported to the SEM. The northerly north-easterly air-flow characterizes the air-mass transport during the high-phase months.

5. Discussion

In the current study we made an attempt to analyze joint contribution of the NAO and EAWR positive trend in the determining that of precipitation over the northwestern, northeastern and southeastern Mediterranean regions. Rather then estimating relationship between the NAO and EAWR indices and precipitation over the regions of our interest we have searched for predominant atmospheric circulation patterns which characterize the periods with precipitation over specially selected target areas during the winter periods with high and low NAO and EAWR teleconnection regimes (phases). The correlations were used for constructing correlation circulation patterns typical for the periods with precipitation over the target areas. Based on the results of our analysis, in this section we try to determine the individual contribution of the two (NAO and EAWR) regimes and their recent past positive trend to the precipitation over the Mediterranean area.

With the help of the patterns obtained we analyzed the role of the large-scale atmospheric dynamics in controlling monthly mean precipitation over the Mediterranean area. Substantial differences between the circulation patterns for wet months during the high and low phases have been detected. The wet periods over the northwestern Mediterranean are associated with the lower troposphere circulation conditions characterized by a large-scale cyclone vortex positioned to the NW of the target area. During the high phase months the composite vortex is found positioned much further to the southeast (inland) than in the low phase case. The difference may be associated with the stronger westerlies during the high phase months. Consequently, the detected over the NEM area precipitation decline during the last several decades of the past century may be explained by a decrease in the surface evaporation in the individual cyclones due to the positive NAO trend.

A different physical mechanism appears to be linking the positive NAO-EAWR trend with the precipitation decline over the NEM and SEM regions. The low-phase wet DJF EM (both NEM and SEM) months are characterized by the circulation patterns with the north-westerly (i.e. from Atlantics to the EM) air-flow in the lower troposphere. On the contrary, the high phase years are characterized by the northeasterly air-flow in the vicinity of the EM area. The increase of the role of the continental (dry) air masses explains the precipitation decline over the EM during the positive phase periods.

The change in the air-flow direction on the EM circulation patterns appears to be due to the EAWR effects and not due to those of the NAO. The precipitation decline over the EM during the last several decades of the past century resulted from the positive EAWR trend during the period.

Several explanations of the EAWR trend have been suggested. The NAO and EAWR trends could be a representation of more complex nonlinear interactions (Feldstein, 2000). The trend of the EAWR could be caused by the positive trend of the NAO, and the associated with it intensification of the southern NAO center of action due to the global warming effects (Visbeck et al., 2001; Paeth et al., 1999). An eastward shift of the southern NAO positive center (Ulbrich and Christoph, 1999) could be playing a role in the process. A contribution of the ENSO effects has been assumed (Price et al., 1998; van Oldenbrugh, 2003). In was suggested also, that the trend could also be affected by a decline in intensity and eastward shift of the Siberian anticyclone (Panagiotopoulos et al., 2003).

The current results provide explanations for the predominance of positive EAWR situations during the positive NAO periods. The following consideration may be suggested. The periods with the positive NAO regimes are characterized by stronger southwesterly winds over the coastal zone in the mid- and lower troposphere over the NE Atlantic. The stronger southwesterly airflows in their turn lead to more intense air mass transport from the Atlantic area to the northeast. Finally, the effect causes the development of the EAWR type north-northeasterly flow over Scandinavia and the Baltic Sea in the direction of the EM region. In accordance with the explanation suggested formation of positive EAWR patterns may be considered as an indirect consequence of intensification of the northern center of action of the NAO pattern.

It is not known if the NAO are subject to an increased greenhouse gas concentration induced change and if the future climate will be characterized by positive NAO and EAWR regimes (Lionello et al., 2002; Paeth et al., 1999; Visbeck et al., 2001; Benedict et al., 2004; Feldstein, 2003; Franzke et al., 2004). The recent more than 30-y period of the positive trends of the both patterns allows considering the possibility as a highly realistic one. According to results of the current analysis a further precipitation decline over the both western and eastern parts of the Mediterranean area will prevail in the case that the high NAO conditions will be characterizing the future climate over Europe.

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