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The effect of the North Sea-Caspian pattern (NCP) on winter temperatures in Iran

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With 10 Figures

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Summary

This study attempts to find possible linkages between the NCP index and the winter temperature variability over Iran. The investigation is based on statistical analysis of simple, partial and multiple correlations and also evaluation of composite maps of the extreme NCP index and maps of correlation between atmospheric variables and the temperature time series.

Our results show that the NCP has a strong negative correlation with the winter temperature in Iran. Furthermore, combination of both the NCP and the AO (Arctic Oscillation) indices improve the correlations in all stations, implying both NCP and AO can be considered as major patterns for explaining the Iranian winter temperature variability. The results show that the positive NCP is associated with enhanced precipitation and cloudy conditions, consequently causing below normal temperature over Iran. The anomalies of OLR in this phase are also negative, implying a cloudy sky. For the negative NCP phase these results are completely reversed. The correlation maps indicate that the NCP is negatively/positively correlated with winter Outgoing Longwave Radiation/precipitation over Iran. The results also show that the SLP and GPH patterns are quite different for the positive and negative NCP phases over Iran. During the negative NCP a small cyclone is formed over the Arabian Sea causing a strong easterly towards Iran. During the positive NCP this cyclone is removed. Our results show that for the positive NCP years an upper-level trough is formed over northern Iran and the eastern Mediterranean. For the negative NCP years this trough becomes weak and is located over central European regions. This trough is closely linked with the winter temperature over Iran. This is expressed by a high correlation between 500-hPa geopotential height at this region and Iranian winter temperature.

1. Introduction

Most of Iran, due to its low annual precipitation (about 250 mm), is classified as either arid or semi-arid according to various climate classifications. The two highest mountain systems, the Alborz and the Zagros and two great deserts called Dasht-e Lut and Dasht-e Kavir strikingly affect the temporal and spatial pattern of precipitation and temperature over Iran. Sometimes the precipitation and temperature variabilities are to a great extent linked to larger global systems.

Previous studies indicate that, variations of monthly and seasonal mean temperature, over a large part of the Northern Hemisphere are strongly controlled by the Siberian High (e.g. Gong and Ho, 2002, 2004). As a result, the associated teleconnection patterns should be considered when investigating temperature variability in the Northern Hemisphere. In addition to the Siberian high, there are a variety of factors that influence surface temperature in Northern Hemisphere, including, for example, the North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and North

Sea-Caspian Pattern (NCP). Relationships between surface air temperature (SAT) and AO and NAO indices have been extensively documented over different parts of the globe (Jones et al., 1997; Serreze et al., 1997; Randall et al., 1998; Thompson and Wallace, 1998, 2000; Thompson et al., 2000, 2002; Kryjov, 2002; Wettstein and Mearns, 2002; Buermann et al., 2003; Gong et al., 2004; Hasanean, 2004; Rogers et al., 2004; Ryoo et al., 2004; Casty et al., 2005; Jeong and Ho, 2005; Ghasemi and Khalili, 2006).

Kutiel and Benaroch (2002) defined an atmospheric teleconnection in the 500-hPa geopotential height between the grid points 0°, 55° N; 10° E, 55° N (North Sea) and 50° E, 45° N; 60° E, 45° N (North Caspian Sea) and called it North Sea-Caspian Pattern (NCP). This teleconnection has both positive and negative phases. They showed that, a negative NCP implies an increased counter-clockwise anomaly circulation around the western pole of the NCP (North Sea) and an increased clockwise anomaly circulation around the eastern pole of the NCP (North Caspian Sea). As for the positive NCP the process is reversed. The negative NCP causes an increased westerly anomaly circulation towards central Europe, and an increased easterly anomaly circulation towards Georgia, Armenia and eastern Turkey. This results in an increased southwesterly anomaly circulation towards the Balkans and western Turkey. Similarly, during the positive NCP, the circulation suggests an increased northwesterly circulation towards eastern Europe, and an increased northeasterly circulation towards the Black Sea. This results in an increased northeasterly anomaly circulation towards the Balkans.

There are also, a few studies on the NCP effects on climate variability, especially SAT, on the various parts of the European and Asian countries (Kutiel et al., 2002; Gunduz and Ozsoy, 2004, 2006; Kutiel and Türkeş, 2005; Gokturk and Karaca, 2006). A study by Kutiel et al. (2002) pointed out that in all months temperature values in the eastern Mediterranean were significantly higher during the negative NCP as compared with the positive NCP. They also showed that the absolute monthly mean maximum and monthly mean minimum values were obtained during the negative and positive NCP phases, respectively. They showed the main impact of this teleconnection was over the Balkans and the eastern Mediterranean basin.

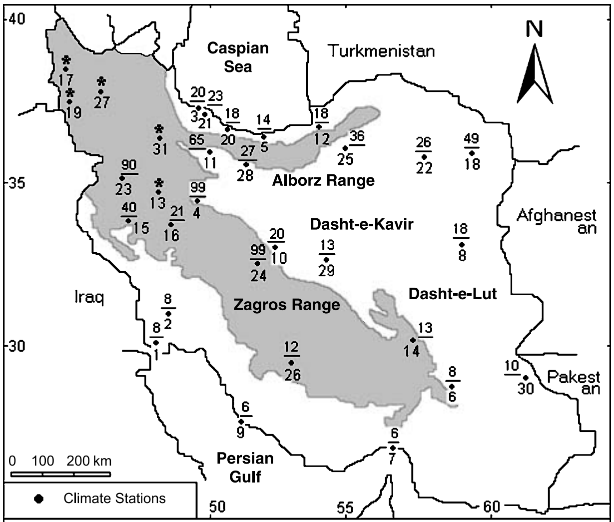
A previous study by Ghasemi and Khalili (2006) showed that variations of the mean winter temperature in Iran are strongly controlled by the Arctic Oscillation (AO). They pointed out that the winter AO index accounts for about 14–46% of the Iranian winter SAT variance. They showed that the probability of below long-term mean temperature during the positive and the negative AO phases are around 70% and 25%, respectively. They also, indicated that, for the negative phase, westerly winds that are originated from the warm Atlantic regions increase over Iran and the positive AO phase would cause northerly winds move towards Iran, allowing continental polar cold air to plunge into Iran.

Apart from a very few studies such as Ghasemi and Khalili (2006) relationships between oceanic-atmospheric indices and temperature variability over Iran have not yet been comprehensively explored. Although, there are no regional indices for the investigation of climate variability in Iran, but because one of the NCPs poles is located over the northern parts of the Caspian Sea (in the north of Iran), the NCP index can be used as a regional index for the investigation of Iranian climate rather than other indices such as NAO and AO.

To a large extent, the present study is a further development of the investigations carried out by Ghasemi and Khalili (2006), aimed at studying the effects of NCP and AO indices, using minimum, maximum and mean winter temperature in the analysis. This study attempts to make advancements in the understanding of the mechanisms of Iran winter SAT variability by directly assessing the relationships between the large-scale atmospheric patterns (i.e. NCP and AO).

1.1 A brief description of the winter temperature in Iran

Topographic features are considered to be the main source of surface air temperature (SAT) variability in Iran. The lowest winter SATs in Iran are centered over the mountainous regions in the northwestern areas and the highest winter SATs are observed in the southern parts. The winter SAT decreases from the southern areas towards the northern regions. On the average, the Persian



1 Abadan	7 Bandar-Abbas	13 Hamadan	19 Oromieh	25 Shahroud
2 Ahvaz	8 Birjand	14 Kerman	20 Ramsar	26 Shiraz
3 Anzali	9 Bushehr	15 Kermanshah	21 Rasht	27 Tabriz
4 Arak	10 Esfahan	16 Khoramabad	22 Sabzevar	28 Tehran
5 Babolsar	11 Ghazvin	17 Khoy	23 Sanandaj	29 Yazd
6 Bam	12 Gorgan	18 Mashhad	24 Shahrekord	30 Zahedan
				31 Zanjan

Fig. 1. Geographical location of climate stations used in this study, showing the station names and the corresponding coefficients of variance (underlined values) for winter. The values marked * are the coefficients of variation above 100%

Gulf and Oman Sea coasts are warmer than the inner regions. The winter temperature difference between the northwestern and the southeastern areas is about 20 °C. It appears that, the northern half of the country is more influenced by the cold polar air masses than the southern half (Ghasemi and Khalili, 2006).

In order to obtain a clear understanding of the winter temperature in Iran, the coefficient of variation (CV) was calculated for each station (Fig. 1). The CV is a good way to evaluate variability of temperature. It offers an indication of the reliability of the average. A higher CV implies a less reliable average temperature, and the lower CV implies a more dependable average temperature (Hasanean, 2004). The winter CV in the southern stations is much lower than the northwestern stations (Fig. 1). This indicates more stability for the wintertime SAT in the southern stations as compared with the northern stations. As Fig. 1 suggests CV values increase with decreasing mean winter SAT (winter temperature values in western and northwestern Iran are lower than other areas), and with increasing latitude (stations in the north are more variable than stations in the south). This suggests that the winter temperature variability in western and northwestern regions is higher than the other regions. The ranges (differences between maximum and minimum temperature values during the studied period) in these regions are also higher than the other regions (not shown). The above results indicate that, use of the mean winter temperature over the western and northwestern stations of Iran is not sufficient for investigating temperature variability, so in addition to the mean temperature, maximum and minimum winter temperatures should also be considered.

2. Data and methodology

Historical data (winter (JFM) minimum, maximum and mean SAT) used in this study were available from 31 stations throughout Iran for a period extending over 43 years, starting from 1958. The data sets were extracted from Iranian Meteorology Organization (IMO) site (http://www.weather.ir). The geographical distribution of these stations are presented in Fig. 1. The NCP index based on the study by Kutiel et al. (2002), was extracted form the website www.cru.uea.ac.uk/~andrewh/nscp.html. The AO index was found by projecting the Northern Hemisphere SLP EOF1 onto monthly SLP anomalies, extracted from the website http://tao.atmos.washington.edu/ao/.

The Median Sequential Correlation Analyses (MSCA) between the temperature and the NCP index were performed. This method was previously used to identify instabilities and trends in relationships between climate variables and indices (Ghasemi and Khalili, 2006). The correlation between temperature and NCP may not imply a direct relationship since the correlations may be influenced by another index. In this case partial correlations can be used which can check for the strength of the relationship between any two variables once the effects of a third variable has been removed (Nicholls, 1989). In addition to the above-mentioned procedures, multiple correlation was also used to identify the combined relationship between winter temperature, NCP and AO. Partial and multiple correlation coefficients were calculated according to the following formulas, respectively:

$$r^2_{yx_1\cdot x_2} = \frac{(r_{yx_1} - r_{yx_2} r_{x_1x_2})^2}{(1 - r^2_{yx_2})(1 - r^2_{x_1x_2})} \tag{1}$$

and

$$r^2_{y\cdot x_1x_2} = \frac{(r^2_{yx_1} + r^2_{yx_2} - 2r_{yx_1}r_{yx_2}r_{x_1x_2})}{(1 - r^2_{x_1x_2})} \qquad (2)$$

where $r^2_{yx_1\cdot x_2}$ is the correlation coefficient (CC) between y and x_1 with a fixed x_2, $r^2_{y\cdot x_1x_2}$ is the combined relation of x_1 and x_2 with y, r_{yx_1} is the CC between y and x_1 y, r_{yx_2} is the CC between y and x_2, and $r_{x_1\cdot x_2}$ is the CC between x_1 and x_2.

As the next step, for each station, temperature averages were calculated separately for both positive and negative NCP phases. These average values were then compared with the long-term mean temperature for the entire period. To determine if the difference between these values differ significantly from each other, a two-tailed Student's t-test was applied.

In order to understanding the physical mechanisms of SAT variability In Iran, the maps of the sea level pressure (SLP), geopotential height (GPH), Outgoing Long-wave Radiation (OLR) and vector wind which were extracted from NOAA NCEP CPC website were analyzed for January–March. To study the relationship between global fields and the Iranian winter SAT time series, we used correlation maps from http://cdc.noaa.gov/correlation/.

3. Results and discussion

3.1 Relationships between the NCP and winter temperature

To identify the strength of the relationships between the NCP and Iranian winter SAT, the sequential correlation coefficient (SCC) between these two factors were computed for each station. Figure 2a shows the SCC between the winter minimum temperature and the NCP index. Apart from a few exceptions, (Birjand (8)[1], Kerman (14), Mashhad (18) and Zahedan (30)) a strong significant (at the 5% level) negative correlation between the minimum winter temperature and the NCP was found for all stations. The northwestern region exhibited the highest correlation (significant at the 1% level), a result suggesting that SAT in this region is more closely attuned to fluctuations in the NCP index. This area is the nearest region of Iran to one of the NCP poles (north Caspian Sea pole).

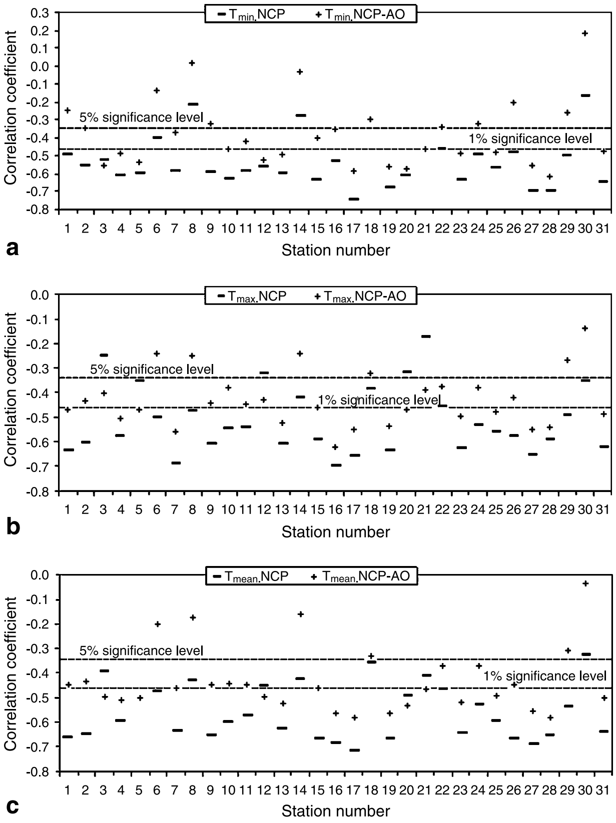


Fig. 2. The sequential simple (marked −) and partial correlation coefficients (marked +) with 25-year periods between the minimum (**a**), maximum (**b**) and mean (**c**) winter temperatures and the winter NCP index. Significance level for 5% is −0.34 and for 1% is −0.46

Apart from Anzali (3), Rasht (21), Ramsar (20) and Gorgan (12), located over the Caspian Sea coast, the SCCs for the maximum temperature were also significant for all studied stations, varying from −0.35 to −0.70 (Fig. 2b). Except for one station (Zahedan (30)), a statistically significant negative relationship was found between mean winter temperature and the NCP index (Fig. 2c). So a positive NCP was related to a decrease in the winter temperature and a negative NCP was related to an increase in the winter SAT. Significant correlations (at the 5% level), were in the range of −0.35 to −0.72, indicating that roughly 12–52% of the winter variance in the mean temperature pattern is associated with NCP forcing. Similarly for the minimum and maximum temperatures these values were in the range of 16–56%, and 12–49%, respectively.

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[1] The station number in Fig. 1.

Table 1. Shift in the minimum, maximum and mean winter temperatures during the positive and the negative NCP phases and the difference between the temperatures during these two phases. Tp and Tn are the average temperature during the positive and the negative phases, respectively, and Ta is the long-term mean of winter temperature. Bolded values are insignificant at 5% level

	Station	Tp−Ta	Tn−Ta	Tp−Tn	Station	Tp−Ta	Tn−Ta	Tp−Tn
Min	Hamadan	**−1.8**	2.2	4.0	Tabriz	−1.9	1.8	3.7
Max		−2.0	2.5	4.5		−2.0	2.1	4.1
Ave		−1.9	2.4	4.3		−1.9	1.9	3.9
Min	Ahvaz	**−0.6**	0.6	1.3	Gorgan	−1.1	1.1	2.2
Max		−1.2	1.0	2.2		**−1.0**	**1.2**	2.1
Ave		−0.9	0.8	1.8		−1.1	1.1	2.2
Min	Abadan	−0.9	**0.6**	1.5	Yazd	−07	0.7	1.4
Max		−1.3	1.0	2.3		−1.3	0.8	2.1
Ave		−1.1	0.8	1.9		−1.0	0.8	1.8
Min	Esfahan	−1.0	0.8	1.8	Sabzevar	**−1.0**	**0.8**	1.8
Max		−1.3	1.1	2.4		−1.6	1.3	2.9
Ave		−1.2	1.0	2.1		−1.3	1.1	2.4
Min	Khoram abad	−1.1	**0.8**	1.9	Shahrekord	−1.2	1.2	2.4
Max		−1.5	1.7	3.2		−1.7	1.7	3.5
Ave		−1.3	1.2	2.5		−1.5	1.5	2.9
Min	Oromieh	−2.1	1.7	3.8	Arak	−2.1	2.0	4.1
Max		−2.0	1.9	3.9		−2.2	2.3	4.5
Ave		−2.0	1.8	3.9		−2.2	2.1	4.3
Min	Shiraz	**−0.6**	**0.5**	1.1	Birjand	**−0.5**	**0.3**	**0.8**
Max		−1.3	0.9	2.2		−1.3	**0.8**	2.1
Ave		−1.0	0.7	1.7		−0.9	**0.5**	1.4
Min	Tehran	−1.3	1.3	2.7	Zanjan	−2.1	1.8	3.9
Max		−1.5	1.6	3.1		−2.1	2.1	4.2
Ave		−1.4	1.4	2.9		−2.1	1.9	4.1
Min	Zahedan	**−0.3**	**0.0**	**0.3**	Bam	−0.8	**0.4**	1.2
Max		−0.9	**0.5**	1.4		−1.2	**0.7**	1.8
Ave		**−0.6**	**0.2**	0.9		−1.0	**0.5**	1.5
Min	Babolsar	−0.8	0.9	1.8	Rasht	−1.4	1.2	2.6
Max		−0.8	0.9	1.7		**−1.0**	**1.0**	2.0
Ave		−0.8	0.9	1.7		−1.2	1.1	2.3
Min	Bandar abbas	−0.8	**0.5**	1.3	Kerman	**−0.5**	**0.2**	**0.7**
Max		−1.1	0.8	1.9		−1.0	**0.5**	1.5
Ave		−0.9	**0.6**	1.5		−07	**0.4**	1.1
Min	Anzali	−1.0	1.1	2.2	Ramsar	−1.1	1.2	2.2
Max		**−0.8**	**0.8**	1.6		**−0.8**	**0.9**	1.6
Ave		**−0.9**	1.0	1.9		−0.9	1.0	1.9
Min	Bushehr	−0.9	0.5	1.4	Ghazvin	−1.6	1.3	2.9
Max		−1.1	0.8	2.0		−1.7	1.8	3.5
Ave		−1.0	0.7	1.7		−1.6	1.6	3.2
Min	Kermanshah	−1.3	1.0	2.3	Khoy	−2.6	1.8	4.5
Max		−1.7	1.7	3.4		−2.1	2.3	4.4
Ave		−1.5	1.4	2.8		−2.4	2.1	4.4
Min	Mashhad	**−1.1**	**0.8**	1.9	Sanandaj	−2.0	1.5	3.5
Max		−1.7	**1.3**	3.0		−2.4	2.2	4.6
Ave		**−1.4**	**1.1**	2.5		−2.2	1.9	4.0
Min	Shahroud	−1.0	1.0	2.0				
Max		−1.5	1.5	3.0				
Ave		−1.2	1.2	2.5				

3.2 Extreme NCP phases

The results presented in the previous section indicated the existence of statistically significant dependence of winter NCP upon the winter SAT. Connections between the NCP and winter SAT are further analyzed in this section. In order to evaluate the shifts in the winter SAT for individual stations, the long term mean temperature value was compared with values of the negative and the positive phases of NCP. Table 1 shows the shift in the minimum, the maximum and the mean winter SAT during the positive and the negative NCP phases.

Apart from a few stations, the shifts in the minimum and maximum winter temperature values (T_{min}–$T_{ave\text{-}min}$ and T_{max}–$T_{ave\text{-}max}$) were significant at the 5% level during the positive and negative phases (Table 1). It seems that the NCP effects on the winter SAT increases from the southeastern parts of the country to the northwestern parts. Except for Kerman (14), Birjand (8) and Zahedan (30) the difference between the minimum winter SAT in the two NCP phases were considerable and above 1.1 °C (significant at the 1% level) in all stations. This difference is above 3.5 °C in the western and the northwestern parts. The largest difference is about 4.5 °C (−6.4 °C during the positive NCP phase and −1.9 °C during the negative phase), observed in Khoy (17). The difference between the winter maximum SAT during the positive and the negative phases ($T_{max\text{-}p}$–$T_{max\text{-}n}$) were also significant in all stations, varying between 1.4 and 4.6 °C (Table 1).

The shifts in the winter mean SAT values during the positive and negative NCP phases were significant (at the 5% level) for most stations (Table 1). These shifts ranged form −0.6 to −2.4 °C and 0.2 to 2.4 °C during positive and negative NCP phases, respectively. The difference between the two NCP phases was also significant at the 1% level for all stations studied. The largest difference was for the mountainous areas in the western and the northwestern parts, varying between 2.8 and 4.4 °C. This reveals a high sensitivity of the mean SAT to the NCP phases, in these regions. The sensitivity of the climate in these regions to the teleconnection patterns such as ENSO, NAO and AO have been shown in previous studies (Ghasemi, 2003; Ghasemi and Khalili, 2006). The reason that the maximum impact of these phenomena has been found at the western and the northwestern areas is related to the physical geography of Iranian Plateau. The western and the northwestern regions of Iran are geographically recognized as high regions. These high regions block the westerlies and airmasses that move into Iran from the Atlantic Ocean and higher latitudes.

A list of the distribution of the coldest and warmest winter SATs for various stations is given in Table 2. Apart from a few exceptions, all of the hottest winters occurred during the negative NCP phase. The largest difference between the winter temperature in the negative phase and in the long-term mean temperature was obtained for Ghazvin (11) and Zanjan (31), 5.1 °C. The smallest difference was obtained for Shiraz, 1.4 °C. Similarly, all of the coldest winters occurred during the positive phase. The largest difference between the winter temperature in the positive phase and in the long-term mean temperature was observed for Arak (4), 8 °C, and the smallest difference was found for Kerman and Bushehr (9), 2.3 °C.

As Table 2 shows, except for two stations, the difference between winter temperature in the positive phase and in the long-term mean was higher than the corresponding values for the negative phase. The temperature difference between the two phases (the negative minus positive) was considerable in all stations studied, varying between 3.9 °C in Shiraz (26) and 13 °C in Arak (4). In general, these differences were stronger and more detectable than the results by Kutiel et al. (2002) for Israel, Turkey and Greece temperature regimes.

3.3 Relationship between the winter NCP and AO indices

The El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO) are the major teleconnection patterns which account for a significant portion of climate variability over different parts of the globe. Ghasemi and Khalili (2006) did not find any relationship between the ENSO and Iranian winter temperature. Kutiel and Benaroch (2002) have shown that both the NAO and the NCP teleconnections behave almost independently.

Table 2. Hottest, coldest and long-term mean winter temperatures in each station and the difference between hottest and coldest values. N or P indicates weather the year belonged to the negative and positive phases, respectively

Station	Hottest Coldest long-term mean	Difference	Year	Station	Hottest Coldest long-term mean	Difference	Year
Abadan	17.7 12.8 15.5	4.8	1963 1992 (P)	Khoy	6.3 −5.6 1.3	12.0	1966 (N) 1972 (P)
Ahvaz	16.9 12.7 15.1	4.2	1994 1992 (P)	Mashhad	8.2 −3.2 4.3	11.4	1966 (N) 1972 (P)
Anzali	10.3 3.0 7.6	7.3	1966 (N) 1972 (P)	Oromieh	4.8 −5.4 0.9	10.2	1966 (N) 1972 (P)
Arak	7.9 −5.2 2.8	13.0	1963 1989 (P)	Ramsar	10.7 3.9 7.7	6.8	1966 (N) 1972 (P)
Babolsar	11.2 5.2 8.6	6.0	1966 (N) 1972 (P)	Rasht	10.6 1.2 7.4	9.3	1966 (N) 1972 (P)
Bam	16.5 10.9 14.0	5.6	1966 (N) 1972 (P)	Sabzevar	9.6 1.7 6.7	7.9	1966 (N) 1972 (P)
Bandar abbas	22.1 17.0 19.9	5.2	1962 (N) 1992 (P)	Sanandaj	5.7 −2.3 2.6	8.0	1999 (N) 1989 (P)
Birjand	10.4 4.7 7.4	5.7	1963 1989 (P)	Shahre kord	5.6 −2.6 2.0	8.2	1963 1972 (P)
Bushehr	18.2 14.1 16.4	4.1	1962 (N) 1992 (P)	Shahroud	7.6 0.8 4.4	6.8	1958 (N) 1972 (P)
Esfahan	8.8 3.0 6.6	5.8	1963 1972 (P)	Shiraz	10.1 6.1 8.7	3.9	1999 (N) 1992 (P)
Ghazvin	8.6 −0.6 3.5	9.2	1966 (N) 1989 (P)	Tabriz	4.8 −4.9 1.1	9.7	1966 (N) 1972 (P)
Gorgan	12.3 4.7 8.9	7.6	1958 (N) 1972 (P)	Tehran	9.6 1.7 6.4	7.9	1966 (N) 1972 (P)
Hamadan	4.6 −6.0 −0.1	10.6	1963 1992 (P)	Yazd	11.1 5.6 9.2	5.4	1966 (N) 1972 (P)
Kerman	9.1 5.0 7.3	4.1	1981 1972 (P)	Zahedan	12.4 7.7 10.4	4.7	1958 (N) 1972 (P)
Kermanshah	6.9 −0.6 4.3	7.4	1963 1989 (P)	Zanjan	5.4 −5.1 0.3	10.5	1966 (N) 1989 (P)
Khoram abad	11.6 3.5 7.7	8.1	1966 (N) 1992 (P)				

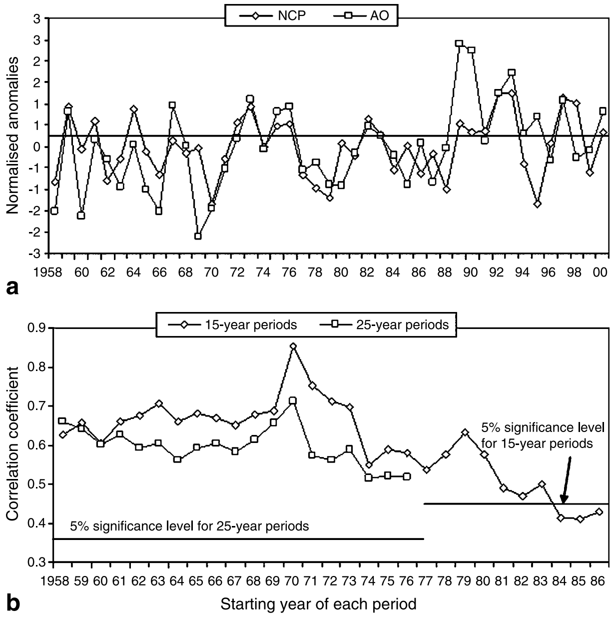

Fig. 3. The fluctuations of the standardized anomalies for both winters NCP and AO indices for the period 1958–2000 (**a**) and the sequential correlation coefficients with 25- and 15-year periods between the winter NCP and the winter AO (**b**)

Ghasemi and Khalili (2006) also indicated that, Arctic Oscillation (AO) is a major teleconnection pattern which accounts for a significant portion of winter SAT variability over Iran. In this section the simultaneous effects between the AO and the NCP indices are investigated.

Since both of the NCP and the AO phenomena occur in the Northern Hemisphere, it is expected that these two phenomena would interact with each other. So the statistical significance of such a relationship is investigated. Figure 3a displays the fluctuations of the standardized anomalies for both NCP and AO indices for the period 1958–2000. When the winter NCP was positive or negative the winter AO was also positive or negative, for about 81% of the years of the study period. Also, for 11 out of 24 extreme years (the positive and the negative extremes) of the winter NCP, the winter AO was in its extremes.

Median sequential correlation coefficient between the winter NCP and the winter AO indices was 0.59 (significant at the 1% level) for 25-year periods. Figure 3b shows the sequential correlation coefficients with 25- and 15-year periods between the winter NCP and the winter AO. For 25-year periods, these correlations were calculated for periods of 1958–82, 1959–83, . . . , and 1976–2000 and for 15-year periods for the periods of 1958–72, 1959–73, . . . , and 1986–2000. The starting year of each period is shown by the horizontal axis. As Fig. 3b shows, all of the correlation coefficients with the 25-year periods were significant (at the 5% level). The highest correlation was found to be about 0.71 for the period of 1970–94. However, for later years the correlations were rather poor. Closer inspection (correlation coefficients with the 15-year periods) shows that the link between the winter NCP index and the winter AO index is poor and insignificant for the periods of 1984–98, 1985–99, and 1986–2000. The above results suggest that, in the investigation of the effects of either AO or NCP on climate variability, especially in the Northern Hemisphere, both phenomena should be considered.

3.4 Partial correlation

As noted in Sect. 3.3, the NCP index is strongly correlated with the AO index in winter. Therefore, the correlation between the NCP and winter SAT in Iran may not imply a direct relationship, and it is possible that both of them may be influenced by AO. A partial correlation analysis was performed to check this. In this case the effect of the AO on the NCP and the winter SAT was removed. In other words, we investigated to see if the NCP could be viewed as an independent index for explaining winter SAT variability, or it only reflects the effect of the AO pattern on the winter SAT.

The squared value of the partial correlation coefficient (Eq. 1) indicates the proportion of the residual variance (i.e. the variance not associated with AO) of the winter NCP which is associated with the residual variance of the winter SAT. If the fluctuations of the NCP index in Iran directly force the winter SAT anomalies, then the correlation pattern should still exist in the partial correlation results. Otherwise, it is concluded that the observed correlations between the NCP and the winter SAT reflect the effects of the AO on both.

Figure 2a, b and c show the sequential correlation coefficients between the minimum, the maximum and the mean winter SATs and the NCP index when the effect of the AO is removed. Removal of the effects of the AO weakened all of the correlations between the NCP and SAT, but remained significant (at the 5% level) for most stations. These results would suggest that, both NCP and winter SAT are influenced by AO.

Furthermore, when the effect of the NCP was removed from the relationships, the correlation coefficients between the winter AO index and the winter mean SAT became very weak and for most stations insignificant (not shown). Comparison between these results suggests that, the winter temperature variability over a large portion of Iran is more influenced by the fluctuation of the NCP index than by the AO phenomenon.

For six stations including Bam (6), Birjand (8), Kerman (14), Yazd (29), Zahedan (30) and Mashhad (18) (located over the eastern part of Iran) which have significant correlation with NCP, the correlation coefficients became insignificant when the effects of AO was removed. Apart from Mashhad and Yazd, the correlation coefficients remained significant when the effect of the NCP was removed from the relationships (not shown). This suggested that, winter mean SAT of the eastern part of Iran is consistently more influenced by the AO than by the NCP. For minimum and maximum SAT also all of the coefficients became weak when the effect of the AO was removed (Fig. 2b and c). This suggested that, the AO index has a significant impact on both the NCP and the winter minimum and the maximum SAT in all stations studied.

The correlation coefficients between the mean winter temperature and the NCP index in Anzali (3), Babolsar (5), Gorgan (12), Ramsar (20), Rasht (21) (over the southern costal of the Caspian Sea) and Mashhad (18) did not change significantly as a result of removing the effects of the AO (Fig. 2a). In other words, fluctuations of the NCP index directly force the winter SAT over this portion of Iran, and the AO does not have a major impact on the SAT variability in this region. Ghasemi and Khalili (2006) also showed that, the relationship between the winter AO and the winter SAT over this region are very weak and insignificant. The high mountain ranges (the Alborz) located over the northern Iran have separated this region from other parts. These mountain ranges block the northerly winds, producing a unique climate in this region. This area is the wettest region in Iran with an annual precipitation of about 1000 mm, while the annual precipitation in Iran is about 250 mm.

The comparison between the partial correlations once the AO effect is removed and once the NCP effect is removed suggest that, apart from eastern parts of Iran, the influence of the winter NCP pattern on the Iranian winter SAT is stronger than the winter AO. The winter NCP pattern alone has a major impact on the Iranian winter SAT and explains (for the significant values) about 14–34% of the mean winter SAT, 14–39% of the maximum temperature and 11–38% of the minimum temperature, respectively.

Table 3. Sequential multiple correlation coefficients with 25-year periods between the minimum, maximum and mean winter temperature, NCP and AO. Significance level for 1% level is −0.46

Station	min	max	mean	Station	min	max	mean
Abadan	0.67	0.66	0.73	Khoy	0.78	0.66	0.73
Ahvaz	0.72	0.63	0.71	Mashhad	0.34	0.38	0.37
Anzali	0.56	0.40	0.50	Oromieh	0.68	0.65	0.67
Arak	0.62	0.59	0.61	Ramsar	0.63	0.47	0.55
Babolsar	0.60	0.47	0.52	Rasht	0.49	0.40	0.47
Bam	0.53	0.60	0.59	Sabzevar	0.47	0.47	0.48
Bandar abbas	0.65	0.69	0.66	Sanandaj	0.66	0.66	0.67
Birjand	0.38	0.54	0.53	Shahre kord	0.51	0.54	0.55
Bushehr	0.71	0.64	0.71	Shahroud	0.59	0.57	0.60
Esfahan	0.63	0.58	0.64	Shiraz	0.57	0.61	0.71
Ghazvin	0.61	0.55	0.58	Tabriz	0.72	0.65	0.70
Gorgan	0.57	0.43	0.50	Tehran	0.70	0.60	0.65
Hamadan	0.61	0.61	0.63	Yazd	0.60	0.54	0.61
Kerman	0.43	0.49	0.53	Zahedan	0.53	0.43	0.49
Kermanshah	0.73	0.61	0.70	Zanjan	0.68	0.64	0.67
Khoram abad	0.58	0.70	0.69				

3.5 Multiple correlation between the winter temperatures, NCP and AO

The fact that partial correlations become weaker once either the AO or the NCP effects are removed would suggest that, the role of the NCP and AO on the winter temperature regime is very clear, indicating that both AO and NCP influence the winter SAT of Iran and also each other. So in this section we investigated the simultaneous effects of both the NCP and the AO on the Iranian winter SAT, using sequential multiple correlation method. The Multiple Correlation approach can be used to simultaneously analyze the combined relationship of one variable with two or more variables.

Simultaneous sequential multiple correlation coefficient (with 25-year periods) between the winter SAT and the winter NCP and AO indices are shown in Table 3. The multiple correlation coefficients for the minimum, the maximum and the mean winter SAT are significant at 1% level in most stations. Combined AO and NCP explain 12–61% of the winter minimum SAT variations. These values are 14–49% for the maximum and 14–54% for the mean winter SAT.

Comparison of the multiple correlation and the simple correlation between the NCP and the winter SAT showed that the values of the multiple correlation coefficients for most of the stations were greater than (for a few stations are equal to) the values of the simple correlation coefficients, changing from 0.01 to 0.37. This suggested that, although the simultaneous effect of the NCP and AO on the winter SAT is different for different stations, for most parts of Iran the combined effect of the NCP and the AO would improve correlation values.

Overall, the results indicated that, on the average, the winter NCP explains about 33% of the mean winter temperature variance in Iran. This value for the partial correlation (correlation of the winter NCP and SAT when the effect of the AO is removed) is 21% and for the multiple correlation is 37%. These values for the minimum winter temperature are 30, 18, and 37% and for the maximum temperature are 29, 20, and 33%, respectively. According to the results, when the effect of the AO is removed from the relationships, the values become weaker and when the effect of the AO and the NCP is combined the values become stronger.

3.6 The physical mechanisms behind the NCP effect on the Iranian winter SAT

In this section first, the cold and the warm years are defined as the years that standardized SATs are below −0.5 and above +0.5, respectively. According to this classification 8 out of 12 positive NCP years, including 1959, 64, 72, 76, 82, 89, 92, and 93 are cold (hereafter selected positive years) and 8 out of 12 negative NCP years, including 1958, 62, 66, 70, 78, 79, 95, and 99 are warm (hereafter selected negative years) in most of the studied stations. The composite maps used in this study are extracted separately for both warm and cold years. Composite maps allow studying of the full circulation and also the difference between the warm and cold NCP years. Ziv et al. (2006), for example, analyzed ten of the

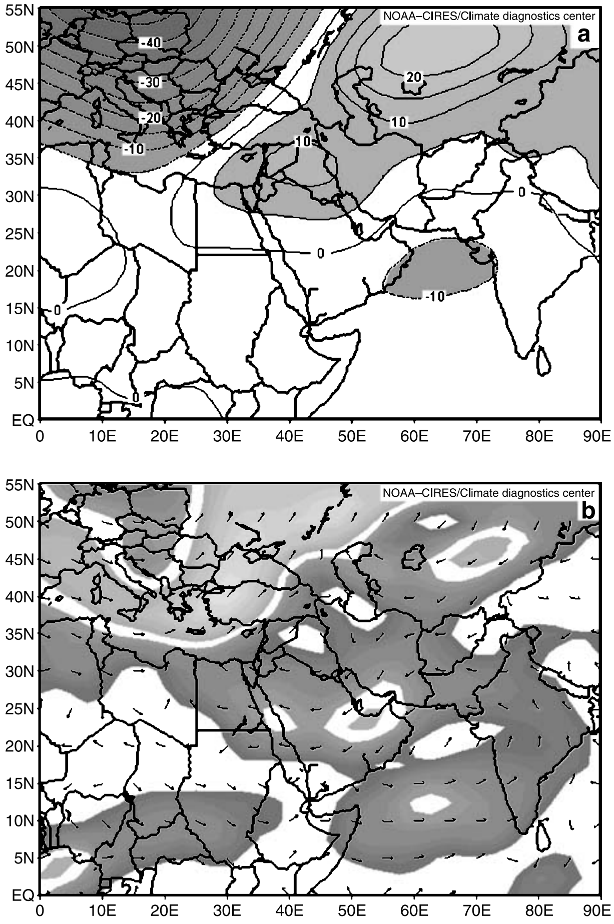

Fig. 4. Composite anomalies of geopotential height (**a**) and vector wind (**b**) at 700 hPa level for the negative NCP years

driest and ten of the wettest winter years in Israel. Their results showed that the variability of the large-scale atmospheric circulation strongly influenced the variability of the winter precipitation in that region.

A negative NCP phase implies an increased clockwise anomaly circulation around the eastern pole of the NCP, in the north of the Caspian Sea (Kutiel and Benaroch, 2002). During the selected negative years a small cyclone (an increased counterclockwise anomaly circulation) is formed over the Arabian Sea, between about 55–75° W and 15–25° N (Fig. 4a). Similar conditions are observed at higher levels, but this small cyclone shifts towards the northern parts of the Indian peninsula (not shown). This small cyclone is removed during the selected positive years. The anomalies associated with these circulation patterns imply an increased westerly anomaly circulation towards the Indian peninsula (Fig. 4b). These westerlies originate from the warm tropical regions over Africa and the Indian Ocean. This mechanism results in an increased easterly anomaly circulation towards Iran and Saudi Arabian Peninsula (Fig. 4b). As is the case of GPH, similar conditions are also observed at higher levels.

Kutiel and Benaroch (2002) showed that, during the positive NCP we should expect an increased clockwise anomaly circulation around the western pole of the NCP and an increased counterclockwise anomaly circulation around the eastern pole of the NCP. This circulation suggests an increased northwesterly circulation towards Eastern Europe, and an increased northeasterly circulation towards the Black Sea. This results in an increased northeasterly anomaly circulation towards the Balkans. Our analysis of the vector wind during this phase over Iran does not shows a clear result, suggesting decreasing of the winter SAT during this phase does not have any relationships with wind circulation so, it may be related to other factors.

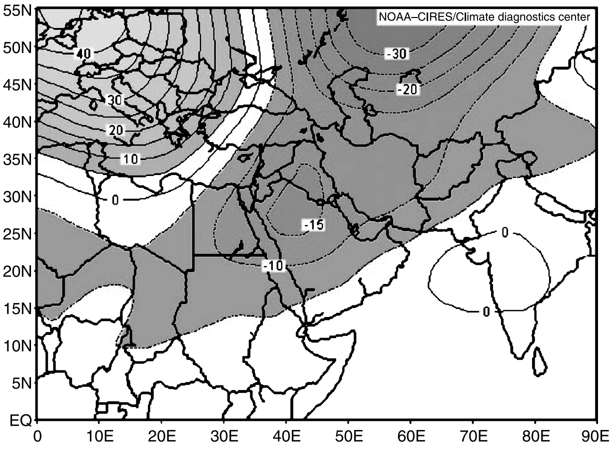

Fig. 5. Composite anomaly of geopotential height at 700 hPa level for the positive NCP years

The selected positive years are associated with enhanced cyclone activity over Iran, (Fig. 5) causing a trough over Iran that is associated with enhanced precipitation and cloudiness conditions. During these years the precipitation anomalies are about or above normal in all parts of Iran (not shown). Also the correlation between the winter NCP index and winter precipitation in most parts of Iran is significantly positive (not shown).

The values of outgoing long-wave radiation (OLR) are known to respond strongly to variations in cloudiness. The analysis of OLR shows this factor decreases over most parts of Iran during the selected positive NCP years (Fig. 6a), indicating a cloudy sky. In other words, the sun radiation decreases during these years and the

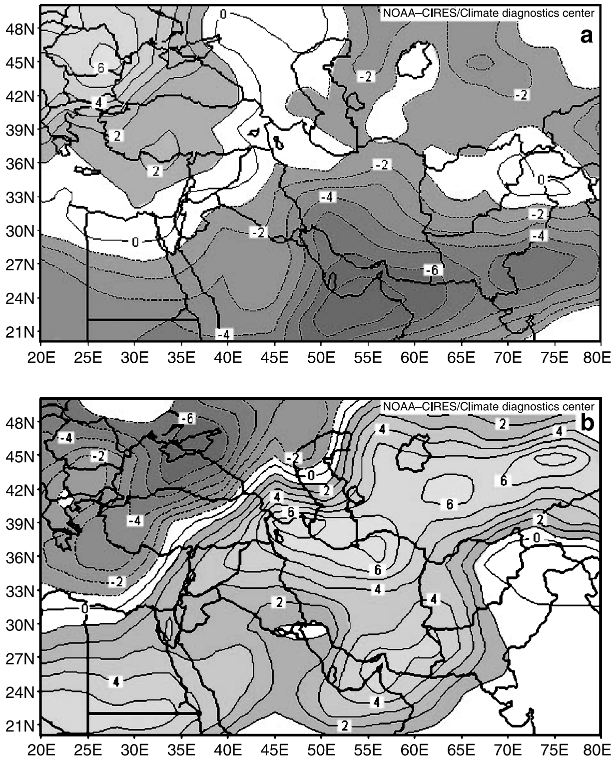

Fig. 6. Composite anomalies of Outgoing Long-wave Radiation (OLR) for the positive (**a**) and negative (**b**) NCP years

winter SAT also decreases, consequently. During selected negative NCP years, the anomaly of the OLR is positive (Fig. 6b) and the anomaly of the precipitation rate is negative (not shown), which suggests low cloudy conditions over Iran during these years. The OLR difference values between the two groups of winters (selected positive years minus selected negative years) range from about -8 to $-12\,\mathrm{w/m^2}$ over Iran (not shown).

Figure 7a shows the correlations between OLR and the winter SAT in Iran, suggesting positive significant correlations overall parts of Iran. So a negative/positive OLR is associated with a negative/positive winter SAT. Correlations between the winter NCP index and the winter OLR are also negative in Iran (Fig. 7b), implying the positive NCP index is associated with the negative OLR and vice versa. This is consistent with the above findings.

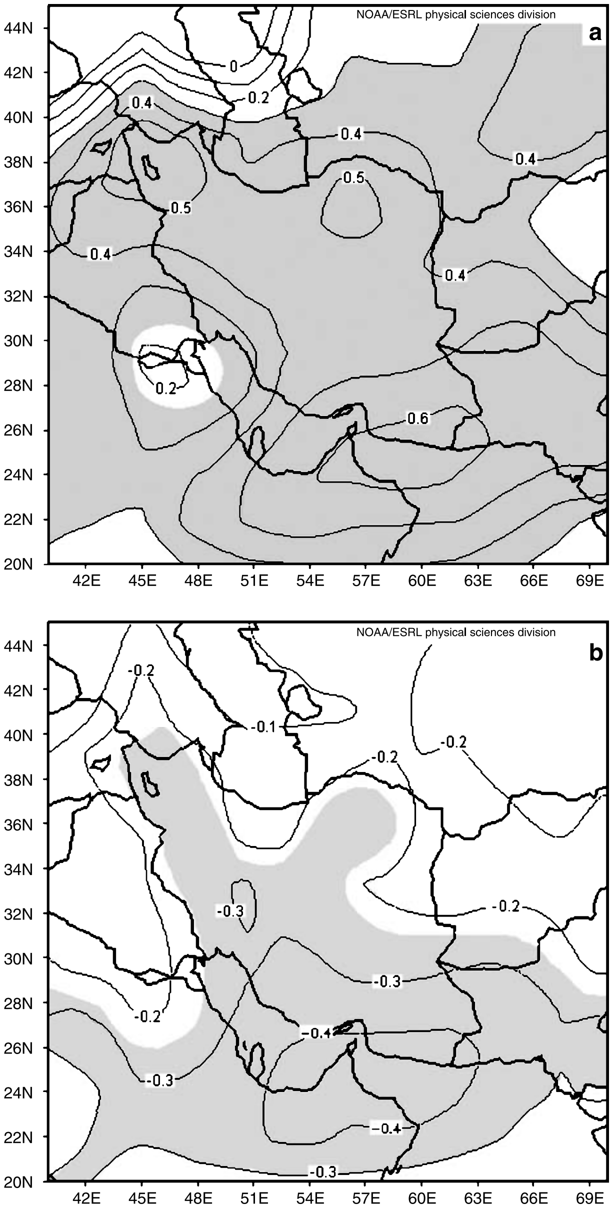

Fig. 7. Correlation coefficients between Outgoing Longwave Radiation (OLR) and mean winter temperature (**a**) and NCP (**b**) for the period 1958–2000. Significance regions at the 5% level are shaded

3.7 Regional teleconnections

Figure 8a and b show the composite mean SLP fields for the selected positive and negative NCP

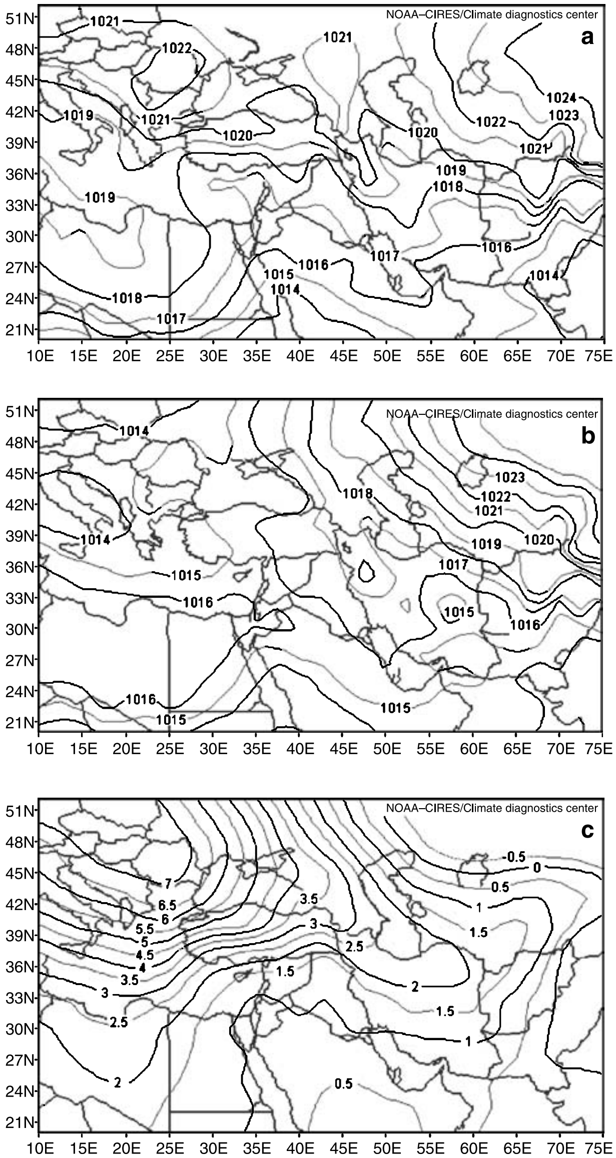

Fig. 8. Composite mean SLP fields for the selected positive (**a**) and negative (**b**) NCP years and the difference between the associated positive and negative values (**c**)

years, respectively. The selected positive NCP composite exhibits two closed anticyclones, one over the western Caspian Sea and the other over the Eastern Europe. Although the Eastern Europe anticyclone is more pronounced than the one over the western Caspian Sea, but it could be that western Caspian Sea center may have more impact on the winter temperature variability of Iran.

However, the selected negative NCP composite map indicates that the Eastern Europe center is removed and the western Caspian Sea center is weakened (Fig. 8b). A closer examination revels another difference between the two composites, the ridge that extends from the western Caspian Sea towards Iran is far more pronounced in the selected positive NCP years than in the negative NCP years. As illustrated by Fig. 8a and b there is a tendency for anticyclone to be formed over western Caspian Sea in the selected positive NCP rather than the selected negative NCP years.

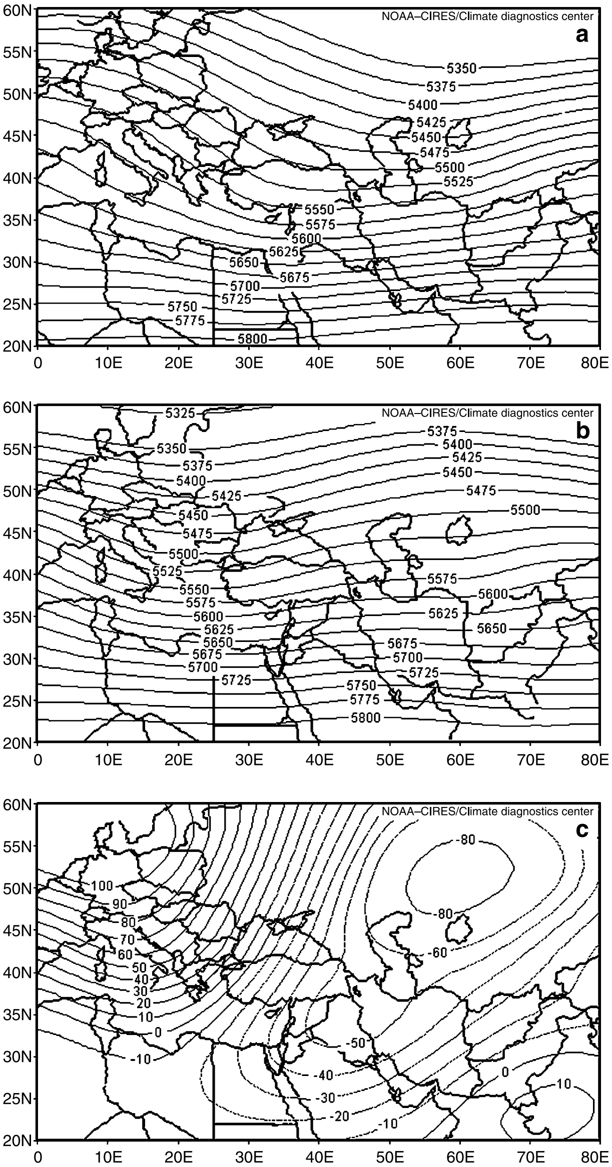

Fig. 9. Composite mean of geopotential height at 500 hPa for the positive (**a**) and negative (**b**) NCP years and the difference between the associated positive and negative values (**c**)

The contrast between the two groups of winters is further elucidated by the map showing the SLP difference between them (selected positive years minus selected negative years), Fig. 8c. This map exhibits a continuous increase in pressure difference from a low of +0.5 hPa over the Saudi Arabia to a high of +7 hPa over Eastern Europe.

The 500-hPa composites mean for the selected positive and negative NCP years (Fig. 9a and b) indicate that in each group a trough is found. In the selected negative NCP years a weak trough is found along about 30° E and for the selected positive NCP years a more pronounced trough is located over northern Iran and eastern Mediterranean. The 500-hPa difference map between the two groups (Fig. 9c) indicates a major decrease (10 to about 55 m) over Iran. These values increase at higher levels up to 250-hPa, especially in the northern regions of Iran.

The above findings are further examined through correlation maps that emphasize the anomalous circulation features related to Iranian winter SAT. The SLP correlation map (Fig. 10a) reveals a widespread negative correlation pattern over Europe and the Middle East with a maximum correlation of $R > -0.7$ over the Eastern Europe. This is consistent with the large difference found between the two groups of NCP years over the Eastern Europe compared to the small pressure difference found over Saudi Arabia (Fig. 8c). The strong signal in the SLP over Eastern Caspian Sea is also consistent with the change in the eastern Caspian Sea high pressure center in both groups of the NCP years.

In the 500-hPa correlation map (Fig. 10b) there is a very strong positive center over Iran and a strong negative center over north Europe. Similar values were obtained also at higher levels up to 200-hPa. The strong correlation centers found for the 500-hPa over the northern Europe and Iran demonstrate that pressure systems over

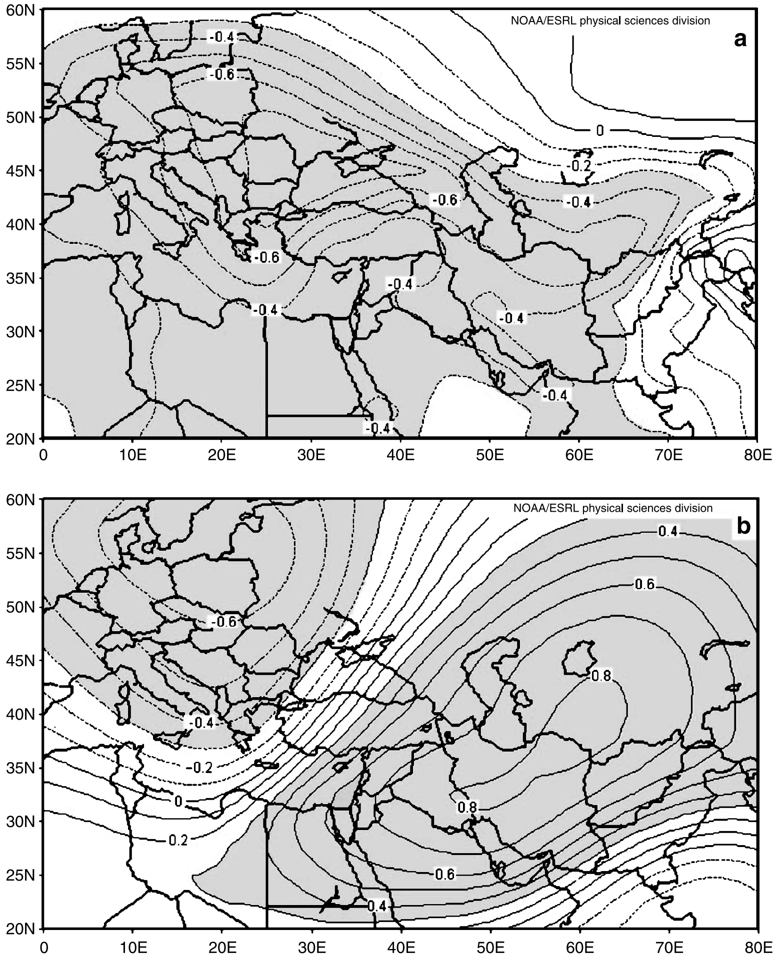

Fig. 10. Correlation coefficients between mean winter temperature in Iran and SLP (**a**) and geopotential height at 500 hPa (**b**) for the period 1958–2000. Significance regions at the 5% level are shaded

these regions are the major synoptic-scale factors for winter temperature variability in Iran.

4. Conclusion

This study has examined the simultaneous correlations between the NCP index and the mean, maximum and minimum temperatures in Iran. The main conclusions are summarized as follows:

- This study has demonstrated that, the NCP index exerts strong significant influence on temperature variance in Iran which explains 12–52% of the variance of the mean winter temperature. These values are in the range of 16–56% for the maximum and 12–49% for the minimum temperature, respectively.
- The shifts in the mean, maximum and minimum winter temperatures in the positive and the negative NCP phases are considerable and significant in most stations. Apart from a few exceptions, temperature differences between the two phases of the NCP are significant at the 1% level. The highest difference is found for the mountainous regions in the western and the northwestern parts of Iran. Also most of the hottest and the coldest winter temperatures occur in the negative and positive NCP phases, respectively.
- The winter NCP index is highly correlated with the winter AO index. The median sequential correlation coefficient with 25-year periods between these two indices is 0.59 (significant at the 1% level). Closer inspection shows that the link between these two indices is poor and insignificant for recent years.
- Using of partial correlation showed that, both NCP and AO have significant effects on the winter temperature regime in Iran. Except from eastern part of Iran, the winter temperature variability over Iran is more influenced by the fluctuation of the NCP index than by the AO.

- For most parts of Iran the combined effect of the NCP and the AO would improve correlation values. Combined AO and NCP explain 14–54% of the mean winter temperature. These values are 12–61% for the minimum and 14–49% for the maximum winter temperature.
- Negative NCP episodes tend to bring an increased easterly anomaly towards Iran. These easterlies originate from the warm tropical Africa and the Indian Ocean, causing above normal temperature over Iran. This episode is associated with blow normal precipitation and positive anomaly OLR.
- The positive NCP years are associated with enhanced cyclone activity over Iran, causing enhanced cloudiness conditions (negative anomaly OLR), precipitation and above normal temperature over Iran.
- The correlation between the winter NCP index and the winter precipitation in most parts of Iran is significantly positive and between the winter NCP and the winter OLR is significantly negative.
- The GPH over both Iran and northern Europe has shown strong correlation with winter temperature over Iran. The northern Europe region is the western pole of the NCP, suggest that there is a good linkage between this pole and Iranian winter temperature.

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