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ORIGINAL ARTICLE

The Impact of ENSO Phase Transition on the Atmospheric Circulation, Precipitation and Temperature in the Middle East Autumn

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Abstract

The impact of El Niño–Southern Oscillation (ENSO) phase transition on the atmospheric circulations, precipitation and temperature in the Middle East (ME) during the period of 1950–2018 autumn seasons were analyzed. ENSO events were selected based on the Oceanic Nino Index (ONI) and its phase transition from El Nino to La Nina (type 1) and from La Nina to El Nino (type 2) events during the study period. Monthly and climate means of data for precipitation, temperature, geopotential height, wind components (u and v) and Sea level pressure (SLP) obtained from National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis. Composites of the means and anomalies were derived from selected case studies of the ENSO phase transitions. Finally, the student's t test is used to determine the significance of the composite means in each grid point. The results show during transitions, the SLP structure over the Atlantic region changes, in a way that pressure differences between Iceland low and the Azores high during type 1 (type 2) is minimum (Maximum) and also statistically significant at 95% confidence level which, these conditions are accompanied by statistically significant enhancing (decreasing) rainfall over the most parts of the ME. In addition, the variability of upper level geopotential height and zonal wind were found over the region which lead to favorable or less favorable conditions for infiltration of planetary Rossby waves to the ME in type 2 and type 1, respectively. Also this study reveals that, moisture flux transport from the adjoining seas to the ME is extremely different in both types, so that during type 2 (type 1), the ME receives significant (insignificant) amounts of moisture. This study therefore identified that most parts of the ME experienced statistically significant positive (negative) anomalies of precipitation during type 2 and type 1 respectively.

Keywords ENSO phase transition · Atmospheric circulation · Middle East · Anomaly

1 Introduction

The Middle East Climate is mainly arid and semiarid because of its desert environment and rainfall deficiencies. Precipitation occurs primarily during winter and early spring due to the orographic capture of eastward propagating mid-latitude cyclones from the Atlantic Ocean and the Mediterranean Sea (Martyn 1992). The most robust influence of the North Atlantic Ocean on the region's overall precipitation is on December and January months (Cullen et al. 2002). Accumulated Rainfall vary considerably across the ME, the Caspian coastal areas of northern Iran receives up to 2000 mm annually (Nazemosadat and Ghasemi 2004), while most parts of the Saudi Arabia except it's southwestern region, has arid climate and is well known for containing the world's largest sand desert with less than 30 mm annually (Almazroui et al. 2012). Lack of enough precipitation in a large area of the ME with its less predictable nature has made undesirable consequences in different economic sectors including agriculture, environment, water sources and etc. So that some of the recent socioeconomic issues affecting the ME in part are related to prolonged droughts in recent decades (Gleick 2014; Kelley et al. 2015).

Different factors affecting the climate of this region are studied due to the importance of its climate variability. Influence of the Arctic Oscillation on winter temperatures in Iran is analyzed by Ghasemi and Khalili (2006), they suggested that the winter surface temperature is negatively correlated to the winter Arctic Oscillation index for most parts of

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Iran. Roshani et al. (2013) found that the high pressure circulation over the North East of Arabian Peninsula (AP) at surface to 700 hPa, coupled with trough over the East of the Mediterranean and west of the Red sea, transfer sufficient moisture in lower troposphere from west of Indian ocean (Oman and Arabian seas), Aden gulf and Red sea to the center and North of AP and south of Iran. El Kenawy et al. (2014) by investigating a multi-decadal classification of synoptic weather types over Saudi Arabia, demonstrated that airflows originating from the Indian Ocean are more frequent than those from the Mediterranean and Red seas. Attada et al. (2018a) by studying of the surface air temperature (SAT) variability over the AP and its links to circulation patterns, found that, the warm phase of ENSO is one possible reason behind the inter-annual increase in SAT over the southern AP. Also Attada et al. (2018b) by investigation of prominent mode of summer surface air temperature variability and associated circulation anomalies over the AP found that, the high Arabian Peninsula surface temperature variability is closely associated with strong middle to lower tropospheric descent anomalies, causing warm anomalies in the region. In another study, Attada et al. (2019) revealed that the role of Indian Summer Monsoon changes on the AP during strong monsoons, excess of moisture leads to atmospheric instability, which in turn triggers formation of clouds leading to more rainfall over the southwestern AP It is found that an important factor responsible for large-scale interannual changes in global weather patterns is the ENSO that is the dominant phenomenon for climate variability in a multi-year time scale (Ropelewski and Halpert 1987). This factor is a quasi-periodical climate image of the Pacific Ocean, which happens every 5 years. (2 to 7 years). Warm ocean level (El Nino) has high air pressure in western tropical Pacific Ocean and cold ocean level (La Nina) with low air pressure in the west of the Ocean. Both of them are associated with the anomaly of surface water temperature and also wind, and make different atmospheric and precipitation conditions on the earth.

Numerous studies have shown that the extreme phases of ENSO (El Nino and La Nina) are accompanied by extreme weather such as droughts and heavy rains in all over the world (Pozo Vazquez et al. 2001; Hendon 2003; Lim and Kim 2007; Feldl and Roe 2010; Ganguli and Reddy 2013; Davey et al. 2014; Shaman 2014; Yeh et al. 2014; Shimizu and Ambrizzi 2015; Xin Li et al. 2015; Yao and Huang 2016; Alizadeh 2017; Angel and Valcárcel 2018). While the responses of the climate to ENSO over the tropical and extratropical regions are well studied, the effect of ENSO on the southwest Asia and the ME is less certain. However, the impact of the extreme phases of ENSO on the precipitation and temperature in this region has been studied to some extent (Felis et al. 2000; Barlow et al. 2001; Pagano et al. 2003; Hasanean 2004; Mariotti 2007; Niranjan Kumar et al. 2015; Dasari et al. 2017; Singh et al. 2017). In all of these studies, the main attention has been drawn to the various atmospheric parameters in the occurrence of extreme phases of ENSO.

The changes in jet stream over the ME and Asia has also been linked to ENSO (Yadav 2009; Seong Kug et al. 2010; Chowdary et al. 2013). Yadav (2009) showed that the intensification of the Asian westerly jet stream over the ME during the positive phase of the AO/NAO and shift and intensification of Asian jet to the lower latitudes during the warm phase of ENSO is the physical mechanism responsible for increasing influence of ENSO and also decreasing influence of the AO/NAO over northwest India winter precipitation during the recent decades. Chowdary et al. (2013) suggested that strong subsidence, weaker low-level winds, less moisture availability and enhanced incoming downward shortwave radiation associated with El Nino in summer are responsible for surface warming over India. Sandeep and Ajayamohan (2014) found that the equatorward shift coupled with enhanced strength of the subtropical jet produce a stronger tropospheric convergence, leading to a subsidence and divergence at lower levels over the Arabian deserts.

As mentioned before, almost all previous studies examined the mean and anomaly of various atmospheric parameters such as temperature and precipitation or responsible dynamics processes for the region's climate in relation to extreme phases of ENSO which also have been well documented. Although a relatively comprehensive investigation has been made in these cases, the study of climate variation during phase transitions has received no attention so far. Hence, in this paper, we aim to fill this gap through the understanding of the climate variation and dynamic processes in relation to two types of ENSO phase transitions as described in Table 1. For this purpose, the present study is structured as follows: in section 2, we discuss the criteria for the selection of the different types of ENSO phase transitions. In this section, we also describe methods and the data used in the paper. In section 3, we make composites of autumn northern hemisphere sea level pressure, ME precipitation and temperatures, 850 hPa moisture flux as well as 200 hPa geopotential height and jet structure for the selected cases. Also, the statistical significance of observed patterns is discussed in this section. Finally, conclusions are stated in section 4.

2 Data and Methodology

2.1 ENSO Factor

There are some factors to describe ENSO teleconnection and its conditions, such as ONI developed by the climate prediction center (CPC[1]) from National Oceanic and Atmospheric Administration (NOAA), Southern Oscillation Index (SOI,

[1] Climate prediction center

Table 1 Types of ENSO events

ENSO phase transition type 1			
Strong El Nino to Strong La Nina	Strong El Nino to Weak La Nina	Weak El Nino to Strong La Nina	Weak El Nino to Weak La Nina
1973, 1988, 1998, 2010	1964, 1983, 2016	1954, 1970, 2007	1995, 2005
ENSO phase transition type 2			
Strong La Nina to Strong El Nino	Strong La Nina to Weak El Nino	Weak La Nina to Strong El Nino	Weak La Nina to Weak El Nino
1951, 1956, 1957, 1986, 2002	1976	1965, 1996, 1997, 2009	2006

Trenberth 1984), multivariate ENSO indices (MEI, Wolter and Timlin 2011; Wolter and Timlin 2012) and (TNI, Trenberth and Stepaniak 2001). In this research, ONI is used to describe the different conditions of ENSO (Fig. 1). An El Nino (La Nina) event is characterized by the ONI, the running three-month average sea surface temperature anomaly for the Nino 3.4 region, being above 0.5 °C (below −0.5 °C) in five consecutive instances. It should be mentioned that, using other indices such as SOI, MEI and etc. would not make any specific difference in the results of the review (Penalba and Rivera 2016).

Two types of ENSO phase transitions have been selected according to the following procedure: autumns during the ENSO phase transition from cold to warm or/and at the beginning of the warm phase and also during the ENSO phase transition from warm to cold or/and at the beginning of the cold phase selected as the ENSO phase transition type 1 and type 2, respectively. Also, it should be noted that, with regard to the ME climate, October, November and December are considered as the autumn season in this research. Finally, we found eight different types of ENSO phase transitions in characteristic shown in Table 1., four cases of ENSO phase transitions type 1 and four cases of ENSO phase transitions type 2. All eight cases were studied individually, but because of the high volume of content, just the average of four cases of two transition types detailed in the next section is stated. In Table 1, warm and cold phases of ENSO are considered as strong when ONI is greater than 1 or less than −1, and considered as weak if they are equal or less than 1 or equal or greater than −1, respectively.

2.2 Methodology

Monthly and climate mean precipitation, temperature, geopotential height, u and v component of wind and sea level pressure data from 1950 to 2018 obtained from NCEP/NCAR reanalysis. This data is available at https://www.esrl.noaa.gov/psd/data/gidded. With these data sets, composites of sea level pressure mean and anomalies, precipitation (land only), temperature as well as the geopotential height and wind vector in Middle East autumn were made based on the cases of two types of transitions. Changes from El Nino to La Nina events (type 1) and from La Nina to El Nino Events (type 2). Areas located at 20° to 80°east longitude and 10° to 50° north latitude considered as an area of study, with taking exception to SLP and jet stream patterns. A larger area was selected for SLP and subtropical jet stream, to study the effective pressure pattern anomalies and also jet structure in the region. The student's t test was used to compare the means of the composites at each grid. A signal was considered significant at the 75%, 85%, 95% and 99% confidence level for a two-tailed test of the null hypothesis of no difference between means. The test was applied to compare the composites of SLP, precipitation and temperature of the two types of transitions.

2.3 El Nino and La Nina Events during 1950–2018

A total of 21 El Nino and 17 La Nina events were identified from 1950 to 2018 (Table 2). All La Nina events tend to occur in the boreal late spring or summer with event peaks in boreal

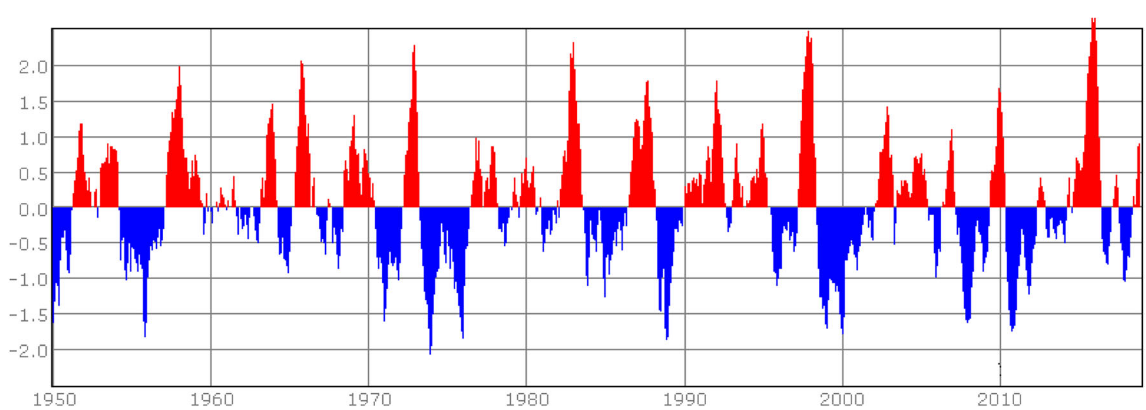

Fig. 1 ONI index 1950–2018 (http://www.cpc.ncep.noaa.gov)

Table 2 El Nino and La Nina event during (1951–2018)

ENSO phase	Start time	Peak time	End time
El Nino	MJJ 1951	SON 1951	DJF 1952
El Nino	JFM 1953	SON 1953	JFM 1954
La Nina	AMJ 1954	OND 1955	ASO 1956
El Nino	AMA 1957	DJF 1958	FMA 1959
El Nino	MJJ 1963	OND 1963	JFM 1964
La Nina	AMJ 1964	OND 1964	DJF 1965
El Nino	AMJ 1965	SON 1965	MAM 1966
El Nino	SON 1968	DJF 1969	DJF 1970
La Nina	JJA 1970	DJF 1971	DJF 1972
El Nino	AMJ 1972	NDJ 1972	FMA 1973
La Nina	AMJ 1973	NDJ 1973	JJA 1974
La Nina	SON 1974	NDJ 1975	MAM 1976
El Nino	ASO 1976	OND 1976	JFM 1977
El Nino	SON 1979	NDJ 1979	JFM 1980
El Nino	MAM 1982	NDJ 1982	MJJ 1983
La Nina	ASO 1983	OND 1983	DJF 1984
La Nina	SON 1984	NDJ 1984	JAS 1985
El Nino	ASO 1986	JAS 1987	JFM 1988
La Nina	AMJ 1988	NDJ 1988	AMJ 1989
El Nino	AMJ 1991	DJF 1992	MJJ 1992
El Nino	ASO 1994	NDJ 1994	FMA 1995
La Nina	JAS 1995	NDJ 1995	FMA 1996
El Nino	AMJ 1997	NDJ 1997	AMJ 1998
La Nina	JJA 1998	NDJ 1999	JFM 2001
El Nino	MJJ 2002	OND 2002	JFM 2003
El Nino	JJA 2004	OND 2004	JFM 2005
La Nina	OND 2005	DJF 2006	FMA 2006
El Nino	ASO 2006	NDJ 2006	DJF 2007
La Nina	JJA 2007	DJF 2008	MJJ 2008
La Nina	OND 2008	DJF 2009	FMA 2009
El Nino	JJA 2009	NDJ 2009	FMA 2010
La Nina	MMJ 2010	OND 2010	AMJ 2011
La Nina	JJA 2011	OND 2011	FMA 2012
El Nino	OND 2014	NDJ 2015	AMJ 2016
La Nina	JAS 2016	SON 2016	NDJ 2016
La Nina	SON 2017	NDJ 2017	FMA 2018

late autumn or early winter. With the exception of 1958, 1968, 1979 and 2014 El Nino, the others, in terms of the time of occurrence are similar to La Nina events. Although most El Nino events' peak, are in the boreal late autumn or early winter, there is one event (1987) that peak in summer. For our purpose, we found those autumn cases that El Nino (La Nina) occurs exactly after La Nina (El Nino) or during phase transitions, as described in Table 1.

3 Results

3.1 Observed Patterns during Autumn

3.1.1 Sea Level Pressure

The composite of SLP mean and anomalies for ENSO phase transition type 1 (Fig. 2a) and type 2 (Fig. 2b) are shown. Regarding to Fig. 2a the Iceland low pressure center over Europe as well as the Azores and Siberian high pressures have been weaker than their normal values. Iceland low pressure has shifted slightly east and weakened about +8 hPa and Siberian anticyclone as weakened about −2 hPa spread much further west and south while Azores anticyclone spread east. Also over the most parts of the ME, the SLP anomaly pattern exhibited normal or less than normal values up to −6 hPa over Turkey and north of Mediterranean Sea. In general, in this case all effective pressure patterns on the ME climate (Iceland low, Azores and Siberian high) (Iqbal et al. 2012) have weakened compared with long term means. While, in type 2 these pressure patterns have shown a strongly different behavior as the Fig. 2a clearly shows. This figure, indicates deepening of Iceland low pressure up to −8 hPa as moving to east and strengthening of the Azores anticyclone. Azores as measured by 1020-hPa strengthened up to 4 hPa compared with long-term mean and its northeast-southwest ridge caused the intensifying and also movement of Iceland low trough eastward and southeastward. The intensification of this low, caused to extend its trough into the Europe and Mediterranean Sea and reinforcing the Mediterranean trough. Also Siberian high pressure over the north east of the ME was weakened about −4 hPa and displaced to the west of its permanent position. It is expected that the Enhancement and also north and eastward movement of anticyclonic circulation on Saudi Arabia and the existence of cyclonic strong and eastward of Mediterranean currents may provide favorable conditions for moisture penetration into the region (Lashkari and Mohammadi 2015), that will be discussed in section 3–2.

In the ME, the SLP anomaly pattern shows a negative anomaly up to −8 hPa in the northwest of Iran and also Azerbaijan and Armenia. Generally, in this section, we found a weak (strong) low pressure over north and a weak (strong) high pressure over south Atlantic in type 1 (type 2) which these conditions are known as a response to the occurrence of El Niño and La Nina, respectively (Zhang et al. 2019) that brings wet (dry) conditions to the ME (Pagano et al. 2003). while, in this research, we found that in the condition of ENSO phase transition, the SLP structure over the Atlantic region changes, in a way that pressure difference between Iceland low and the Azores high during type 1 is the minimum value that brings drought to the region and conversely maximum differences found during type 2 which is accompanied by an increase in rainfall in the ME (which is detailed in the following).

Figure 2c–f show the differences of SLP at 2 types of transitions with a student's t test of significance at the 75%, 85%, 95% and 99% confidence level. Statistically significant areas were found by comparing patterns in Fig. 2a, b. For this purpose, 2-tailed t-test at the difference levels were computed, and the areas of significant or nonsignificant values were detected. As Fig. 2c shows, an area of statistical significance over the North Atlantic Ocean at 99% confidence level, and

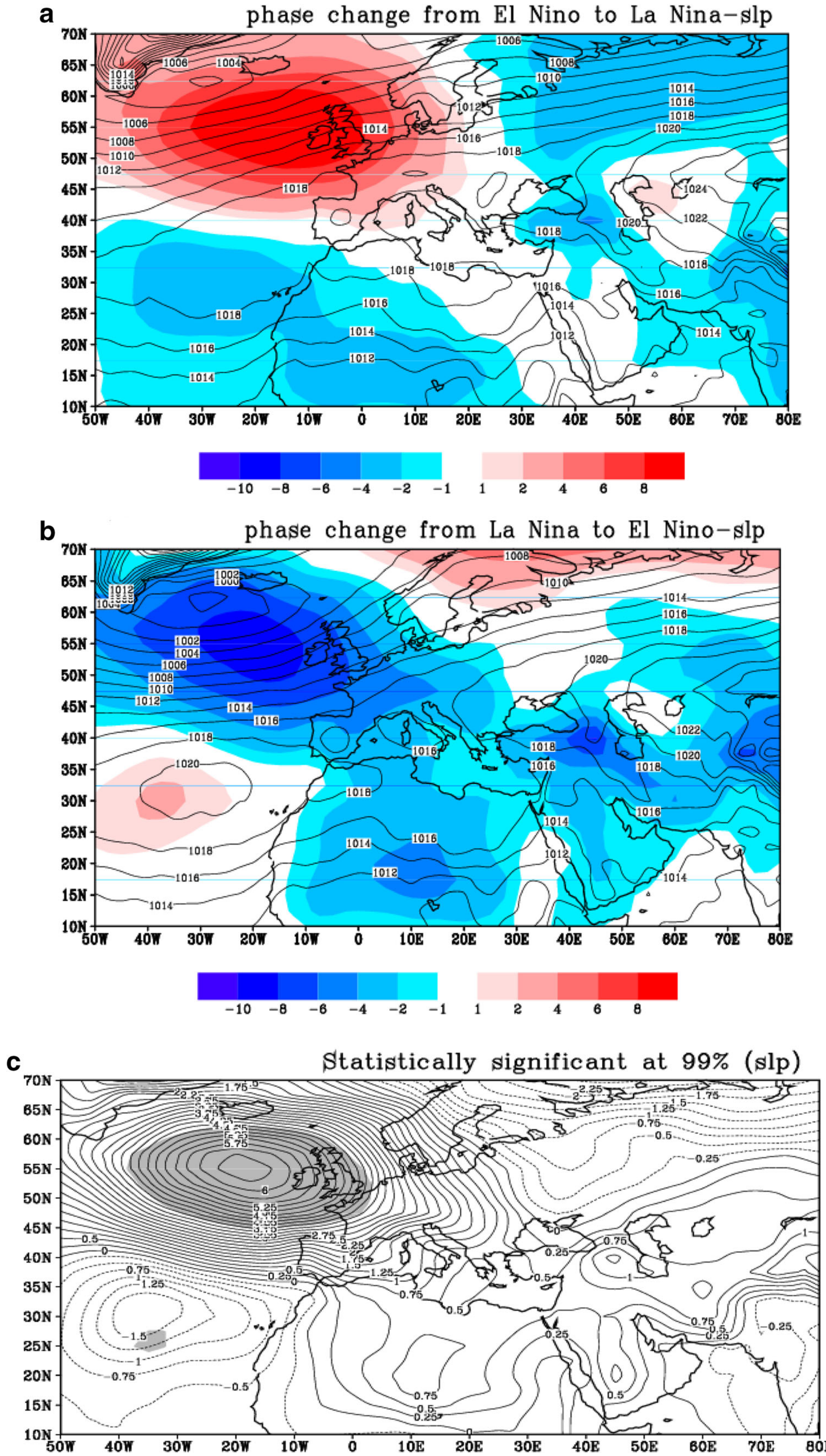

Fig. 2 Composite of autumn (OND) observed SLP anomalies (**a**) during ENSO phase transition type 1 and (**b**) type 2. (c-f) statistical significant of SLP differences at different confidence levels

an area of statistical significance of 95% confidence level over the South Atlantic Ocean were found, (Fig. 2d). Nonsignificant areas were found over the Middle East at 95 and 99% confidence level, but north and east of Iran, some parts of Tajikistan, eastern Mediterranean Sea and also Arabian Sea were statistically significant at 75% confidence level (Fig. 2f). These finding imply that during transition phases the SLP variability in the Icelandic low and the Azores high pressure (Fig. 2a, b) as effective pressure patterns in the ME, are statistically significant.

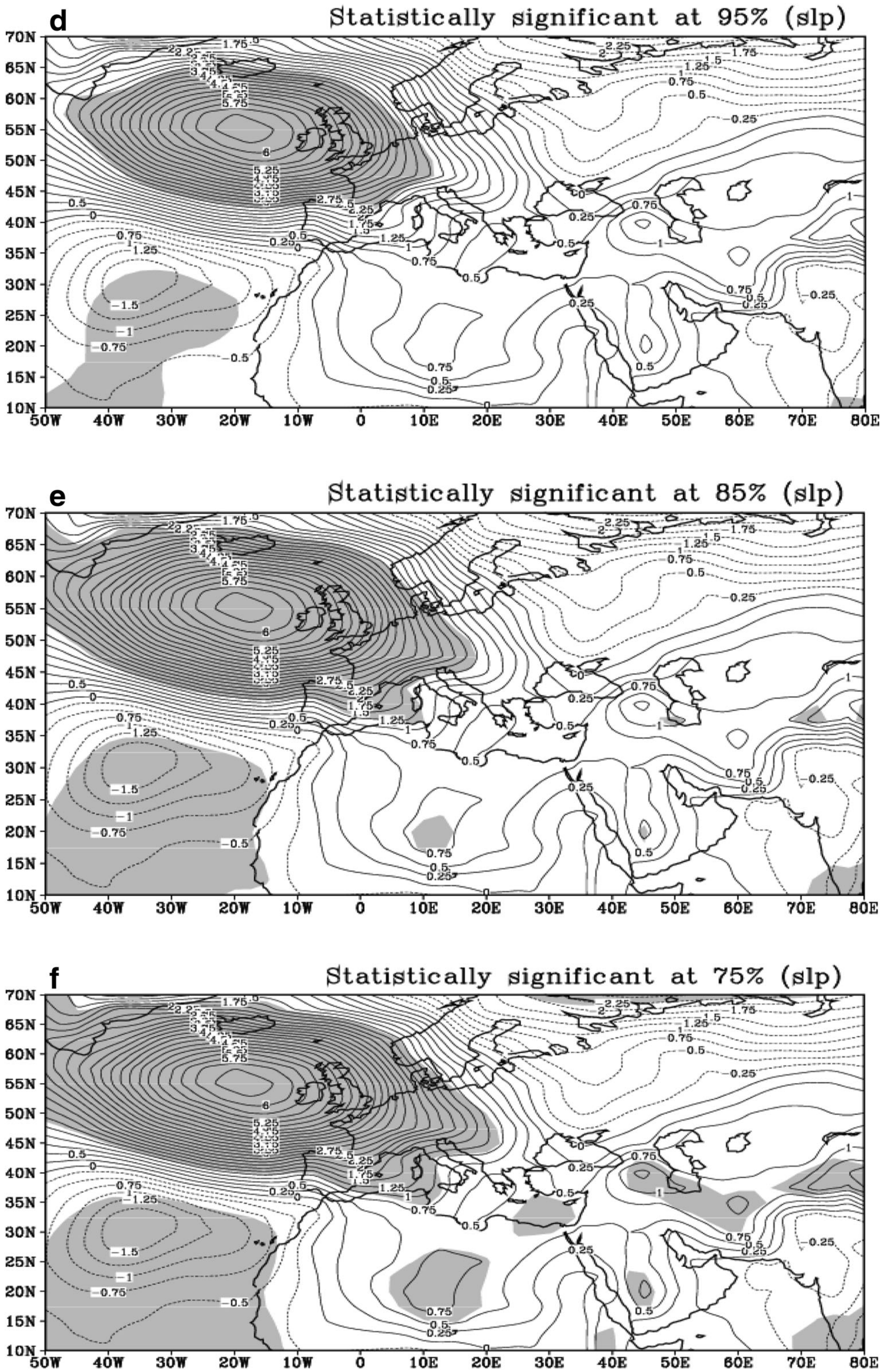

Fig. 2 (continued)

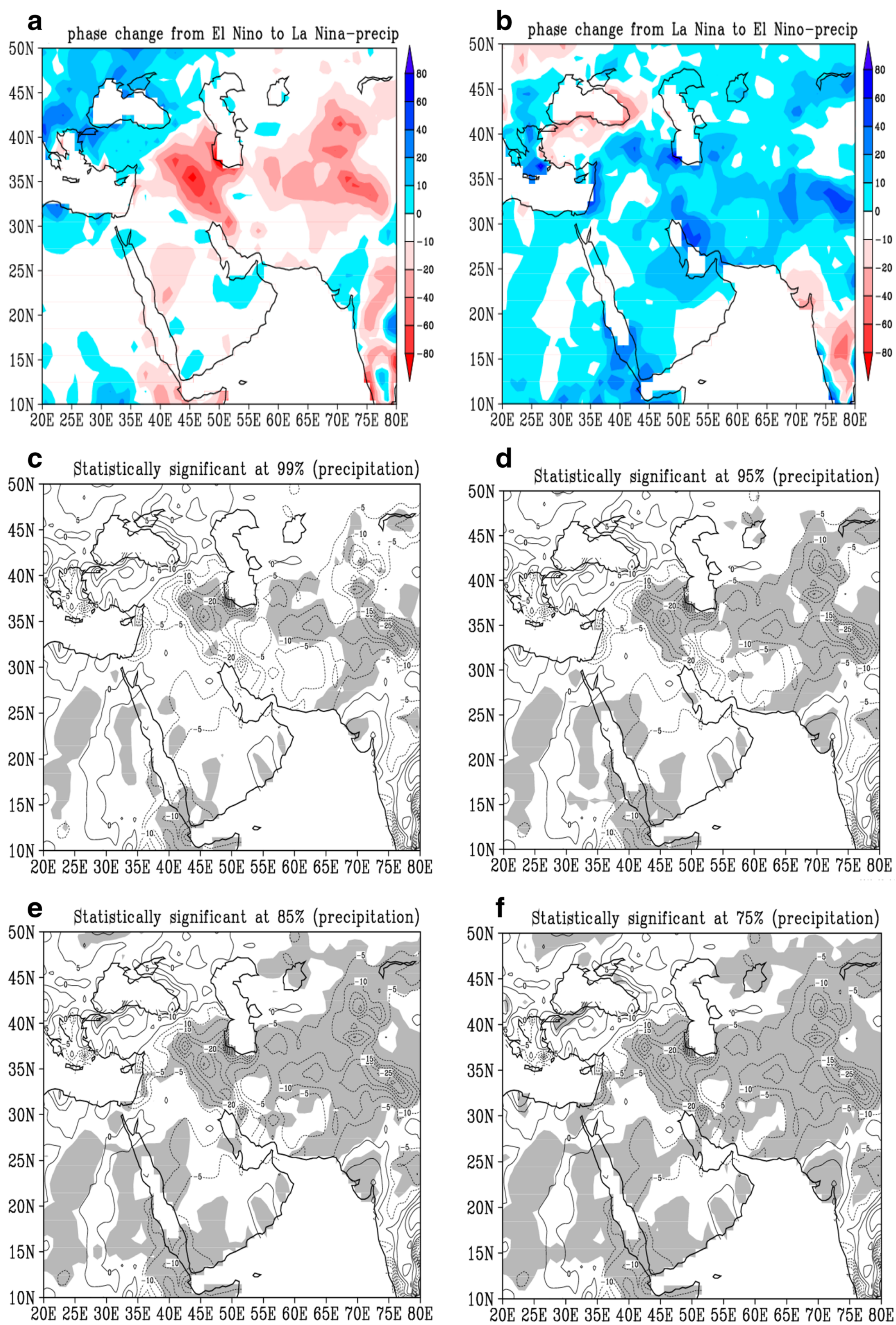

Fig. 3 Composite of autumn (OND) observed precipitation anomalies, **a** during ENSO phase transition type 1 and (**b**) type 2. **c-f** statistical significant of precipitation differences at different confidence levels

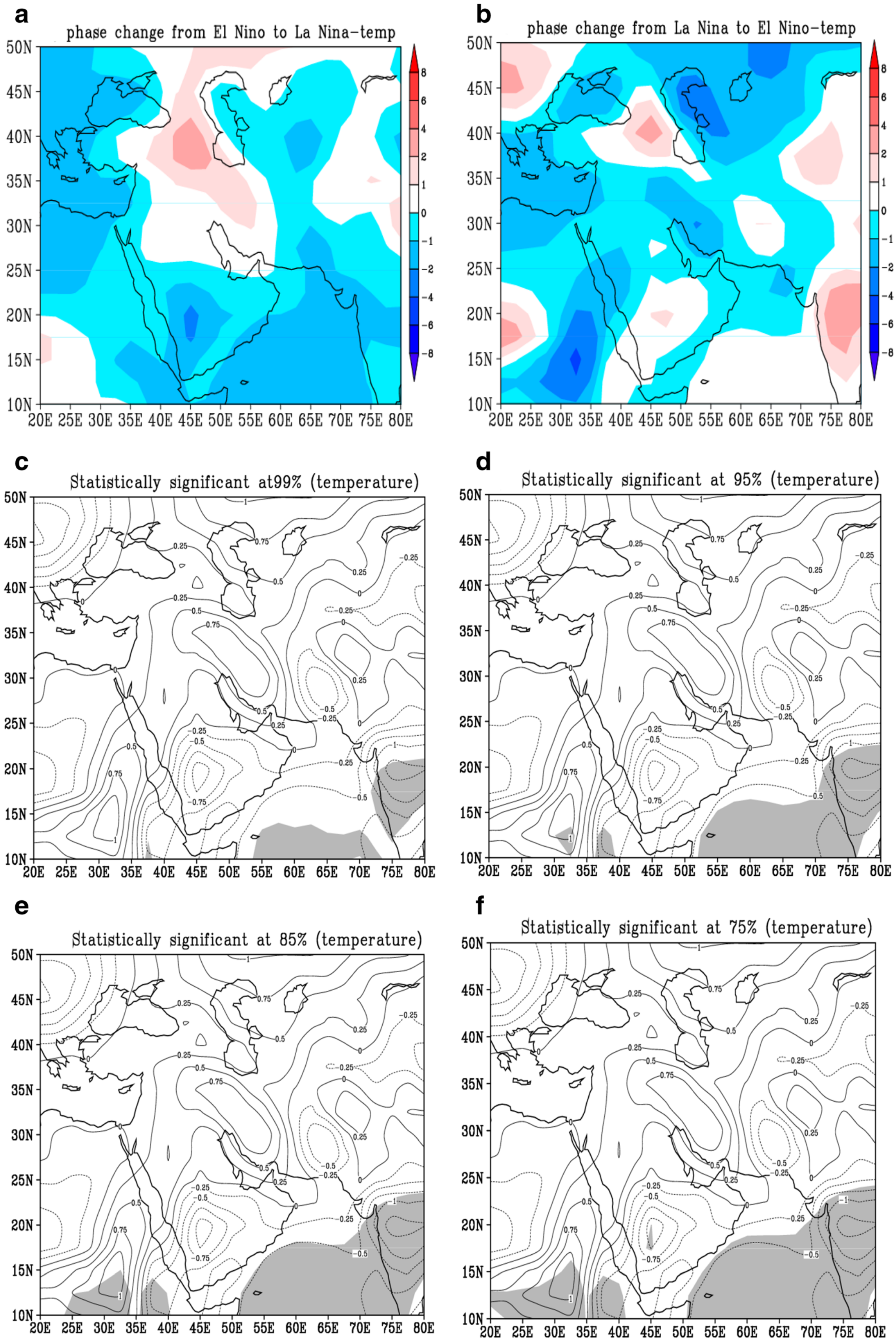

Fig. 4 Composite of autumn (OND) observed temperature anomalies (**a**) during ENSO phase transition type 1 and (**b**) type 2. **c**-**f** statistical significant of temperature differences at different confidence levels

3.1.2 Precipitation

As in the case of sea level pressure, composites of precipitation values and anomalies were made based on the selected ENSO events. (Figure 3a, b) respectively show the precipitation values and anomalies for the selected cases of both types of transitions according to Table 1. During type 1, statistically nonsignificant positive anomalies of the value 30 mm/month were found over west of turkey. Areas located in the northwest of the ME experienced statistical significant positive precipitation anomaly up to 30 mm/month during type 1, and in the rest of the studied area negative to normal values were found. Most negative precipitation anomaly in this periods was found over the west and Northwest Iran up to −40 mm/month. With the exception of western Turkey and south India, nearly other regions have had positive precipitation anomaly in the case of ENSO phase transition type 2 (Fig. 3b). In this period north of India, southwest and northwest of Iran, east of Turkey and Mediterranean Sea have received more rainfall than normal up to 50 mm per month.

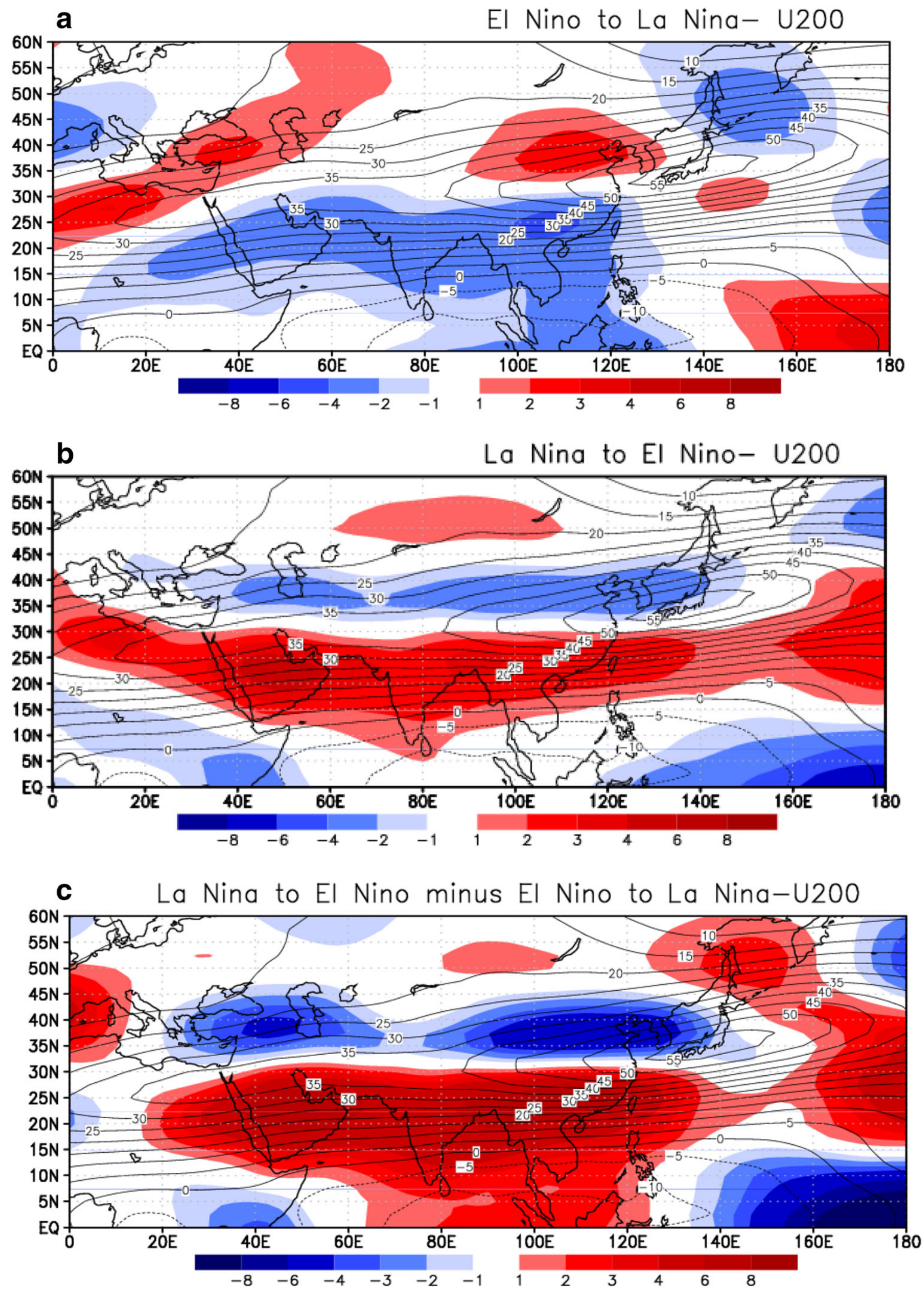

Fig. 5 Differences in 200 hPa zonal wind autumns (a) anomaly of ENSO phase transition type1

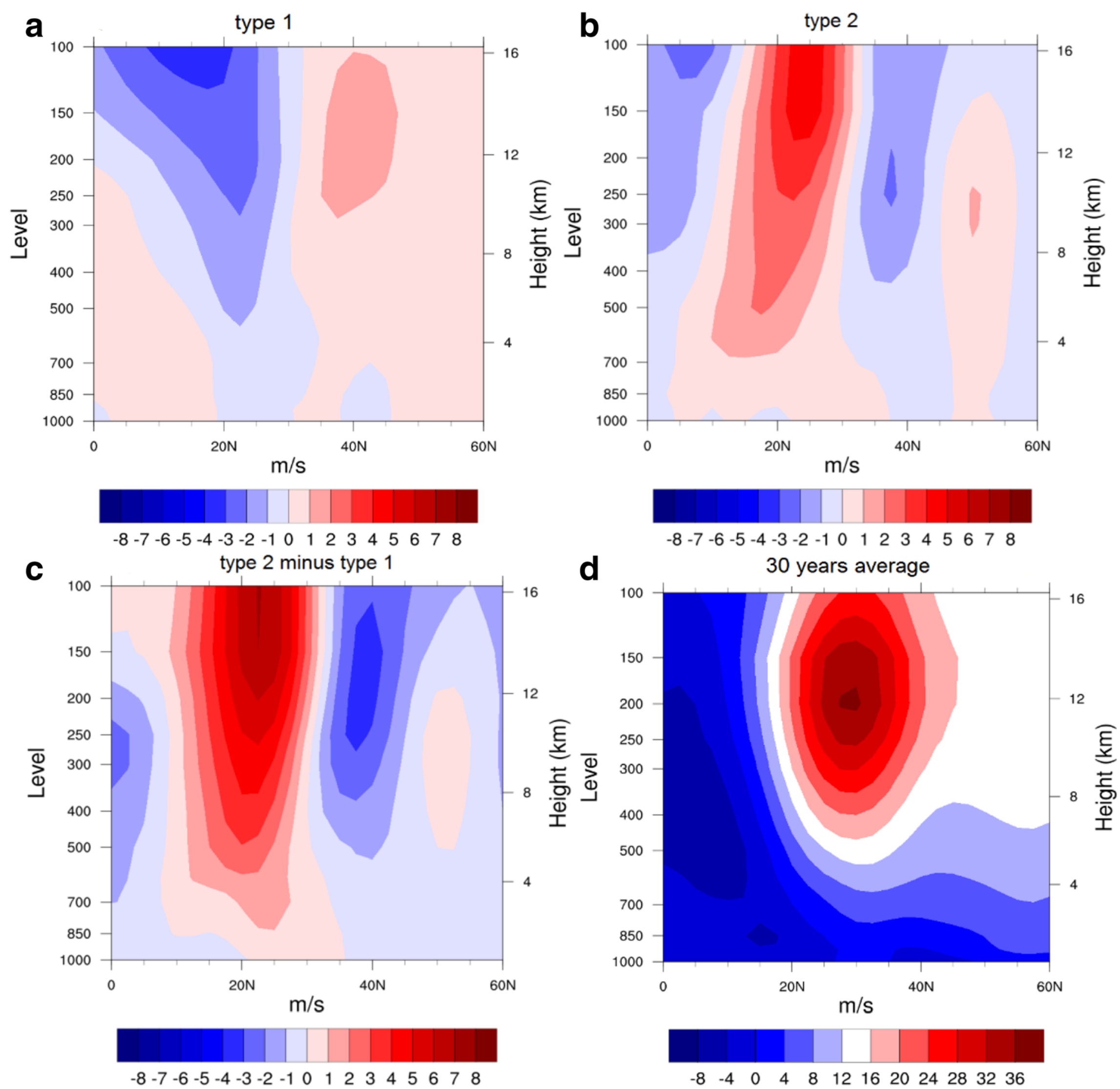

Fig. 6 Seasonal mean composites of latitude-height cross section (25–65° E) of 200 hPa zonal wind anomalies for (**a**) ENSO phase transition type 1, **b** type 2, **c** differences and (**d**) 30-year climate

(Figure 3c–f) show the statistical significance of differences between Fig. 3a, b at the different confidence levels. As the Fig. 3c shows, at 99% confidence level, statistical significance of precipitation was found over northwest and northeast of Iran, also Pakistan, Tajikistan, and Afghanistan, some part of Saudi Arabia, Sudan and Egypt. At 95% confidence level, south of Turkmenistan and Kyrgyzstan have been statistically significant and also negative (Fig. 3d). At the 85% confidence level east of Iraq, some other regions of India, north, west and east of Iran have been significant (Fig. 3e). Finally, Fig. 3f shows the statistical significance of differences between two ENSO phase transition types at 75% confidence level. These figures generally suggest that, northeast, most areas in the center and some regions in the southwest of ME have been significant at 75% confidence level or higher. Generally, the most statistically significant were found over north east, south west and center of the ME at the different confidence levels.

So, these findings imply that, the phase transition due to the SLP pattern structure change, as described in the previous section as well as some other reasons that will be discussed in the following sections may affect the precipitation pattern, so that causes more or less than normal rainfall in different parts of the region.

3.1.3 Temperature

The composites of temperature values and anomalies for ENSO phase transition type 1 (Fig. 4a) and type 2 (Fig. 4b) were computed. As the figures show anomalies up to +4 °C were found over the northwest Iran and east Turkey. Most areas of the ME have experienced the negative temperature anomaly up to −4 °C with the highest value in the south of Saudi Arabia. Also the temperature in some parts of Iran, north of AP, Iraq, east of Afghanistan and Pakistan have had

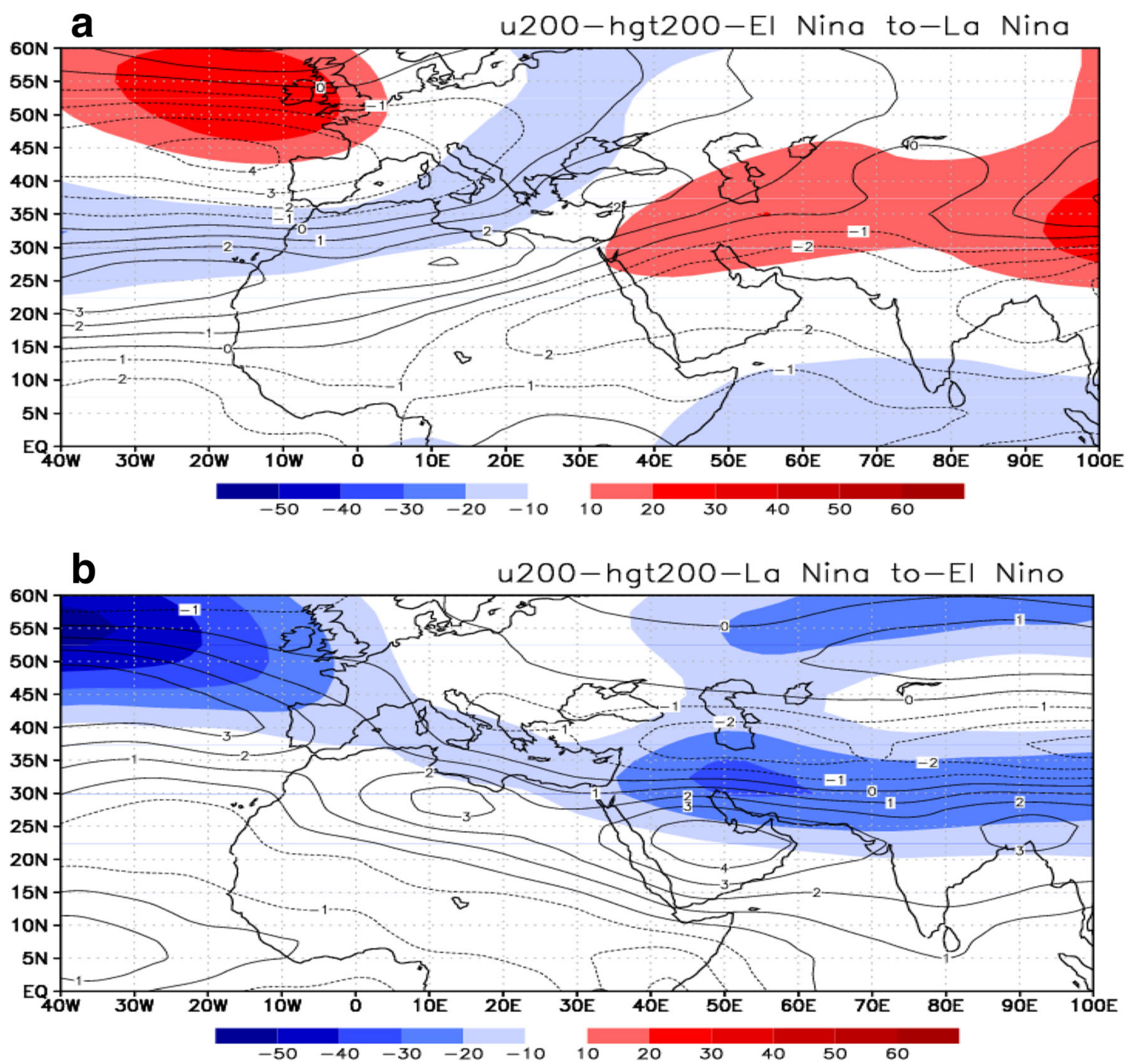

Fig. 7 Anomaly of 200 hPa geopotential height and zonal wind type 1(**a**) and type 2 (**b**)

no changes compared with normal values. Temperature anomaly pattern during type 2 in Fig. 4b. indicates negative values up to −4 °C, over the east of the Caspian Sea as well as Sudan and in contrast positive values up to +4 °C in center and south India, the border of Afghanistan, Pakistan and Tajikistan and also border of Iran, Turkey, Azerbaijan, Armenia and Georgia. As the Fig. 4a, b show, most areas of the ME have had normal to negative temperature values compared with long term mean in both cases. So, we found some changes in temperature over different areas of the ME in Fig. 4a, b for two types of transitions, but computing of statistical significance of differences between these two figures at different confidence levels showed that only the regions located at the south of India and Oman Sea were significant. These regions have been significant at the 99% confidence level. At 95% confidence level more areas of India and Oman Sea and at the 85% and 75% confidence levels beside these, areas at 25 to 40E and 10 to 15 N, have been significant. Differences of temperature anomalies in other regions of the ME were nonsignificant at any confidence levels (Fig. 4c–f).

3.2 Dynamics of Middle East Precipitation

The teleconnection between ENSO and global weather patterns is well known (e.g., Bjerknes 1969; Horel and Wallace 1981; Trenberth 1998). Climate variability such as ENSO is often linked to recurring jet stream, ocean temperature, and tropical rainfall patterns (Bell 2013). The normal condition of the subtropical jet stream over the region is the one in which the jet axis at 200 hPa (40,000 ft.) is geographically to the south of the jet axis at 300 hPa (30,000 ft) and has a cyclonic curvature (Dayan and Abramski 1983). The subtropical jet strengthens on the equatorward side in both hemispheres during El Niño events (Gill 1980). Jet strengthening during El Nino impacts the propagation of transient eddies in the upper troposphere (Seager et al. 2004). The position of subtropical

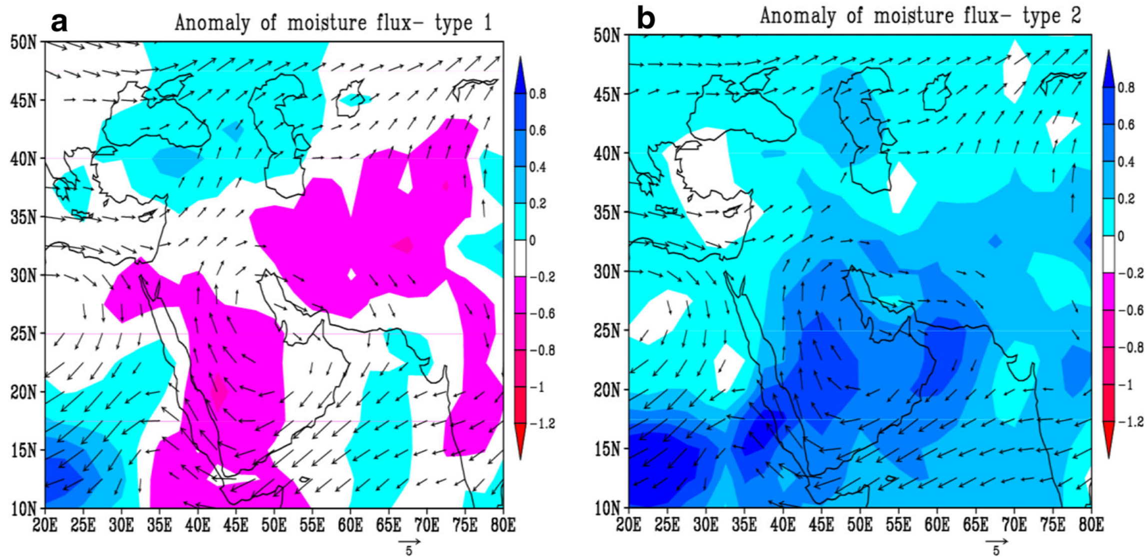

Fig. 8 Anomaly of moisture flux for type 1 (**a**) and type 2 (**b**)

jet stream during two types of ENSO phase transition is shown in Fig. 5. in type 1, jet has weakened up to -4 m/s toward the equator over the southern part of ME and conversely much stronger values as much as +8 m/s toward the equator were found during type 2 (Fig. 5a, b). Shift in jet is clearly seen in Fig. 6 for both types of transitions. In these figures, seasonal mean composites of latitude-height cross section of 200 hPa zonal wind over 25–65°E show a stronger jet during type 2 over the ME region (Fig. 6b, c) and a poleward shift in jet has been detected during type 1 (Fig. 6a, c). Normally the subtropical jet stream is located close to latitude 30° (Fig. 6d), but as previously mentioned, natural phenomena such as El Nino southern oscillation may alter the path and intensity of the jet stream. Hence, in type 2 mean zonal wind anomalies reveal more equatorward strengthening than normal values in jet and poleward shift in type 1 over the region (Fig. 6a, b).

In general, composite analyzes reveal that in type 1 (type 2) the jet on the equatorward is much weaker (stronger) than the strengthening (weakening) on the poleward side, it suggested that a poleward (equatorward) shift and weakening (strengthening) of the jet stream during type 1 (type2). Differences of both types in Fig. 8c clearly illustrate the equatorward shift in jet in type 2 with an increase of more than 8 m/s compared with type 1. This equatorward weakening during type 1 and also equatorward strengthening of the jet during type 2 are consistent with negative (positive) precipitation anomalies in Fig. 3a, b respectively.

Figure 7 reveals the anomaly of geopotential height and zonal wind at 200 hPa level. Figure 7a clearly shows the subtropical jet stream over the region weakened about -2 m/s compared with long mean values. This negative anomaly are associated with positive anomaly in 200 hPa geopotential height. Positive anomalies of geopotential height over the north west of Atlantic and northern parts of the ME along with the negative anomaly of geopotential and positive values of zonal wind between 20 to 25-degree latitude are favorable conditions to cross the waves toward the north east. While in type 2 because of the significant decrease of geopotential height over the northwest of Atlantic as well as the Mediterranean and most parts of the ME, which are associated with positive anomaly of the jet stream values in these regions, the condition is more favorable than type 1 to pass the waves down to the ME. Since, the upper level jet may act as wave-guide (Branstator 2002; Martius et al. 2008; Newman and Sardeshmukh 1998) the changes in its intensity and location affects the formation and direction of transient eddies.

The large-scale moisture flux transport may be described in terms of the specific humidity and the wind vector components (Peixoto and Oort 1983). Both of these climatic variables are interactive and play a crucial role in determining other climatic variables (Peixoto and Oort 1992). Figure 8 displays the seasonal moisture flux anomalies for 850 hPa level over the study area, in the case of ENSO phase transition type 1(a) and type 2(b). West and northwest wind circulation from the Indian Ocean has transferred considerable moisture to the Oman, Red and Arabian Sea and Gulf of Aden in type 2 (Fig. 8b). Transfer of the moisture flux from these seas to the south, center and also northern parts of the ME is more pronounced while the Mediterranean Sea has an insignificant role in moisture transmission under these circumstance, so that, the moisture flux transport from the Oman, Arab and Red Sea has increased up to 0.6 g/kg while, from the Mediterranean Sea is just 0.2 g/kg more than long mean value. The moisture flux in type 1 decreased strongly so that, moisture transport from the seas are less than long mean. Figure 8a shows the moisture transport originated from the Indian Ocean and Red Sea have decreased up to −0.6 g/kg and those from the Mediterranean Sea have decreased about −.2 g/kg as well.

4 Conclusion

The impact of ENSO on the atmospheric circulation, precipitation and temperature in the Middle East autumn has been analyzed during the period of 1950–2018. This study is carried out with the constraint that the ENSO events change from warm to cold phase (type 1), and cold to warm phase (type 2) during the autumns of study. Composites of autumn's SLP, air temperature, precipitation, moisture flux, geopotential height and also u and v components of wind data were obtained for each case of two transition types. The composite analysis of SLP show the weakening of the Iceland low pressure by slightly eastward shift and also Azores high pressure compared with long term mean. While in type 2, both pressure centers are strengthened and statistically significant at 99% and 95% confidence level, respectively. Also pressure anomaly values over the Middle East region is normal or less than normal in event type 1 and less than normal in type 2 and the differences are statistically significant at 75% confidence level. Generally, in this research, we found that in the condition of ENSO phase transition the pressure structure over the Atlantic region have been changed, in a way that pressure differences between Iceland low and the Azores high during type 1 is the minimum value that brings drought and conversely maximum value during type 2 which is accompanied by a statistically significant increase in rainfall.

For long time it was known that the extreme phases of ENSO El Nino (La Nina) events led to wet (dry) conditions over the Middle East region (see Niranjan Kumar et al. 2016), but in this research we found high (low) frequency of rainfall over the ME could be due to the transition of ENSO phases which the result are as follow:

composites of precipitation values and anomalies showed that, during type 1, Areas located in the northwest of the ME have had statistically significant positive precipitation anomaly up to 30 mm/month during ENSO phase transition type 1, and the rest of the studied area have had statistically significant of negative to normal precipitation anomaly compared with long-term mean. Most negative precipitation anomaly in these periods is found over the west and Northwest Iran up to −40 mm/month. And during type 2, with the exception of western Turkey and south India, nearly all other regions have experienced statistically significant values of positive precipitation anomaly. in general, during type 2 nearly all parts of ME have been experienced lower than normal precipitation values, while during type 1, higher than normal values were recorded over the most areas of the ME.

By studying of the 850 hPa moisture flux parameter, we found that The Indian Ocean, along with the Red Sea and the Arabian Sea, are the major sources of moisture for the region. So the Red and Arabian sea, transfer considerable moisture to the ME in type 2 due to the east and northeast wind circulation from the Indian Ocean while the Mediterranean Sea has an insignificant role in moisture transmission for this region under these circumstance. So that one major reason of high frequency of rainfall during type 2 over the ME is because of the east and northeast wind circulation from the Indian Ocean which has transferred considerable moisture through the Red and Arabian Sea to the region. Our result is also consistent with the result of the review by Roshani et al. (2013).

Finally, for the temperature we found statistically nonsignificant values over the most parts of the region. Although some changes in temperature over different areas of the ME were found in Fig. 4a, b, but computing of statistically significant of differences between these two figures at different confidence levels showed that only the regions located at the south of India and Oman Sea have been significant at the 99% confidence level. And beside these at the 75% confidence, areas at 25 to 40E and 10 to 15 N, have been significant and in the rest of the region significant variability of temperature anomalies were not found.

Also this research suggests that, the transition of ENSO phases have the ability to change the jet stream structure as well as pressure patterns in terms of intensity and location which causes the climate variability in all over the region. Therefore, we found the equatorward weakening and conversely equatorward strengthening of the jet stream during type 1 and type 2 respectively which are consistent with the negative and positive precipitation anomalies in these cases.

Generally, in this paper we found that in the periods of phase transition due to the maximum (minimum) differences between the Iceland low and Azores high over the Atlantic with negative (positive) anomaly of geopotential height, positive (negative) anomaly of jet stream and also positive (negative) anomaly of moisture transport from the adjoining seas, the precipitation considerably increases (decreases) and also statistically significant during the ENSO phase transition type 2 (type 1). Hence, this research suggests that the transition phases could be more important than extreme phases of ENSO for the ME and also could be considered as a seasonal precipitation forecast for the region. Of course more researches are required for this consideration.

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