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Characteristics of Large-scale Synoptic Types Associated with Precipitation over Southern Iran

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Abstract: Atmospheric circulation strongly modulates precipitation patterns throughout the south of Iran. A Characteristics of synoptic types was chosen to investigate their relation to the spatiotemporal distribution of precipitation within the south of Iran. In this study we examined the interannual variability of precipitation in the southern region of Iran and to establish links between the large-scale circulation patterns. In this region, the majority of precipitation occurs during the rainy season from October to May. The present study applied the empirical orthogonal function (EOF) analysis on the monthly precipitation anomaly data obtained from 302 meteorological stations for the 1981–2010 periods. In mostly month, the first mode explains more than 50 % of the total variance of precipitation. Spatiotemporal fluctuation in precipitation over the studied area can be attributed to moisture transport by dynamic factors. This study shows that the position and strength of high pressure over Arabian Peninsula play an important role during the wet and dry years. The results show that during wet years moisture flux in low and middle levels from west of the Indian Ocean, Gulf of Aden and Red sea transferred by the high pressure circulation to the central, North of Arabian peninsula and Southern Iran. This high pressure circulation coupled with the East Mediterranean trough over west of Arabian Peninsula at the level of 700hPa. The some parts of moisture flux transferred from Gulf of Aden and the Red sea in the middle and higher levels. In dry years, the anticyclonic circulation is strengthened in the west of the Arabian Peninsula, and blocks moisture advection into the region from the Indian Ocean.

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1. Introduction

Moisture is critically vital for every type of life living on Earth, and is very important for heat budget and hydrological cycle (Trenberth and Guillemot, 1998). Precipitation is one the widely used climate variable to gauge the climate change. Recent changes in Climate have resulted in rapidly increasing anomalies in the global hydrological cycle. Variations and changes in precipitation amounts, such as extreme precipitation and droughts, trigger relevant societal and environmental impacts (IPCC, 2007). Iran has low annual mean precipitation and commonly regarded as an arid or semiarid region. According to the Martonne and Pinna indices 88% and 96% area of Iran was categorized as arid and semiarid (Tabari et al., 2015). However, this is a simple climatic classification, because precipitation oscillates significantly at spatiotemporal scale (Domroes et al., 1998). Social, economic, environmental and agricultural vulnerability of a country or region is highly depends on the precipitation i.e., duration, intensity and frequency of precipitation or drought spells. Atmospheric circulation is strongly correlated with the precipitation variability and anomaly. Even the most advanced models are not able to eliminate large scale uncertainties to predict or forecast precipitation at regional scale (Ramanathan et al., 2001; Xie et al., 2013).

The atmospheric moisture transport and overall moisture budget plays vital role in the hydrology of Iran and surrounding countries. The major cause of aridity in southern Iran is subsidence scale due to high pressure circulation and a location far from oceanic moisture sources (Diaz and Bradley, 2004). However, the general and local circulations play an important role in transfer the moisture and other properties of atmospheric quantities from moisture source to the given area. Plenty of research work regarding this subject is available in the literature the geographical position of both the east Mediterranean trough in mid-troposphere and the anticyclonic circulation over Arabian Peninsula is mainly administered spatiotemporal variability of precipitation over Iran (Raziei et al., 2011). During 1970-74 more than 23 percent of the low pressure systems transported over southwest and southern part of Iran are originated from the southwest of the Red sea (Faraji, 1982). Alijani (1995) reported that the main source of moisture flux causing precipitation over Iran is the Mediterranean Sea. Persian Gulf and Caspian Sea are attributed as the main source of moisture loading for precipitation over Alborz and Zagros mountains (Smith et al., 2003; Evans et al., 2003). brings the warm and moist air are brought to the Middle East, in the middle and higher troposphere, from the South part of Saudi Arabia and Aden gulf by subtropical jet current (Dayan and Abramski, 1983).

The Mediterranean trough that deepen over the Red sea, is the Major elements that coupled with the high pressure circulation and transfer warm and moist air from moisture source to the southwest and south of Iran (Alpert, 2001). The formation of a low pressure system over the Red sea is associated with high potential acceptability of moisture. The high potential of warm air and moisture in this systems is main thermodynamical causes for occurs heavy rainfall over the study area. Extension of specific humidity from each moisture sources to the North part of Iran is derived as a value of moisture quantities as a specific humidity map (Rurerde, 2006).

In southern of Iran most of the annual precipitation (about 98 percent) occurs in October–May. Therefore, we selected these months for analysis in this study. The influence of prevalent synoptic situations on the distribution of precipitation amounts needs to be understood, as well as their frequency changes to appraise the impact of atmospheric circulation on fluctuations of precipitation amounts. Understanding the changing pattern of precipitation is very important for planning of a various mega projects of a country as construction of water storage reservoirs are based on moisture availability and climate behavior (Aziz and Burn, 2006). Main objective of this study was to elucidate the characteristics of precipitation in the south of Iran (Fig. 1), and determine the characteristics of moisture flux from adjacent moisture sources and their influence on the occurrence of rainfall during last three decades (1981 – 2010).

2. Materials and Methods

Iran is located in the south west of Asia with total area of more than 1.648 million km^2. At north and west Iran is surrounded by mountain ranges of Alborz and Zargos. Alborz mountain ranges act as barrier and avoid Mediterranean moisture containing circulation systems to move towards east. While the Zargos mountain range is entry point for the major portion of rain-producing winds from the northwestern and western areas, where high amount of precipitation occurs. Most of the areas of Iran are categorized as arid or semiarid, except some western parts and coastal areas at northern region (Raziei et al., 2005; Tabari et al., 2015).

This study was conducted with 30 years of data (1981–2010) using monthly precipitation data from 302 meteorological stations covering the whole Iran (Fig. 1) was obtained from the Islamic Republic of Iran Meteorological Organization (IRIMO) (www.weather.ir). The quality of data was checked and described earlier (Parak et al., 2015).

2.1 Empirical orthogonal function (EOF) analysis

Empirical orthogonal function (EOF) analysis can used to determine trends of spatiotemporal variability in the meteorological parameters. (North, 1984; von Storch, 1995). It is a statistical tool which transforms an original data set of variables to a considerably smaller sets of uncorrelated variables that characterize the most of the information of the original dataset of variables. EOF analysis is focused to reduce the dimensionality of the original data, producing. A small set of uncorrelated variables. Which is considerably easier to understand and manipulate for further analyses.

The EOF analysis has become a popular tool in meteorology and climatology (Sein et al., 2015; Wang et al., 2015, Wang et al., 2013, Dimri, 2012, Dae et al., 2011, Chen et al., 2009). The EOF uncorrelated over space and patterns obtained when an EOF is plotted as a map, represents a standing oscillation. The time evolution of an EOF shows pattern oscillates at temporal scales (Bjornsson and Venegas, 1997). Detailed mathematical treatment of EOF analysis is given in this paper based on the Bjornsson and Venegas (1997). We have used 30 years (1981-2010) dataset of monthly mean precipitation anomaly obtained from 302 stations across Iran and applied the EOF analysis to elucidate main pattern of spatiotemporal variability of precipitation in the study area. The monthly mean precipitation data is prepared in EXCEL software and the algorithm of EOF is written as a program in MATLAB software.

2.2 Moisture flux divergence/convergence

The NCEP-NCAR reanalysis monthly datasets from October to May employed to data to study the moisture flux and moisture source. Similar dataset have been widely used by various researchers study various aspects of Climatic trends (Alijani, 1995; Kalnay, 1996; Milind, 2006; Farajzadeh et al., 2007).

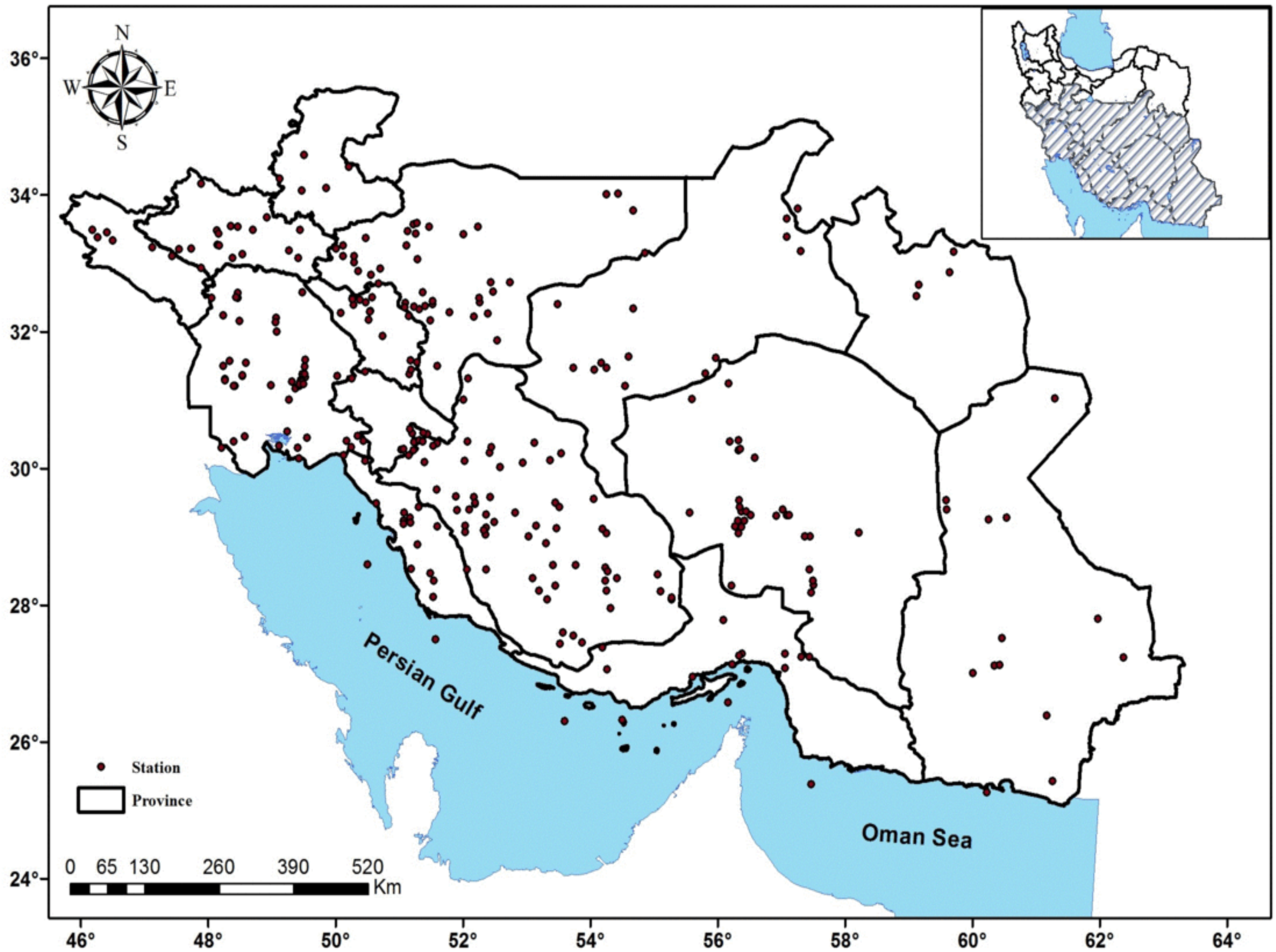

Fig. 1. Geographical chart of the study region; the dots indicates the spatial distribution of the meteorological stations. (The maps in the figure were created by F.P. using "ARCGIS 10.x").

The present study focuses on the 1981–2010 periods, and using monthly precipitation data from 302 meteorological stations, while other atmospheric parameters such as specific humidity, meridional and zonal wind speed components were used from the NCEP-NCAR reanalysis data. Since this research is focused on various aspects of moisture transport, we used all levels of specific humidity and wind components from the above reanalysis in this work. We computed moisture flux divergence to study moisture flux over target area using formulas expressed in equation 1:

$$HFD = -\left(\left(u\frac{\partial q}{\partial x} + v\frac{\partial q}{\partial y}\right) + \left(q\frac{\partial u}{\partial x} + q\frac{\partial v}{\partial y}\right)\right) \qquad [1]$$

where q is the specific humidity, u is zonal wind speed and v is meridional wind speed. Variations in specific humidity and wind are expressed as $(\frac{\partial}{\partial x})$ and $(\frac{\partial}{\partial y})$. Horizontal divergence of moisture flux is represented by horizontal flux divergence (HFD), where negative sign of HFD means convergence and positive indicates divergence. The vertically-integrated moisture flux can be expressed as:

$$Q_{wi} = 1/g.\int_{pB}^{pt} Vq.dp \qquad [2]$$

Where Q_{wi}, is the total of moisture flux along the meridional (kg/m^{2}s^{-1}), g is acceleration due to gravity, V is the meridional wind speed, q is specific humidity, dp is the differential of pressure (Deng et al., 2014).

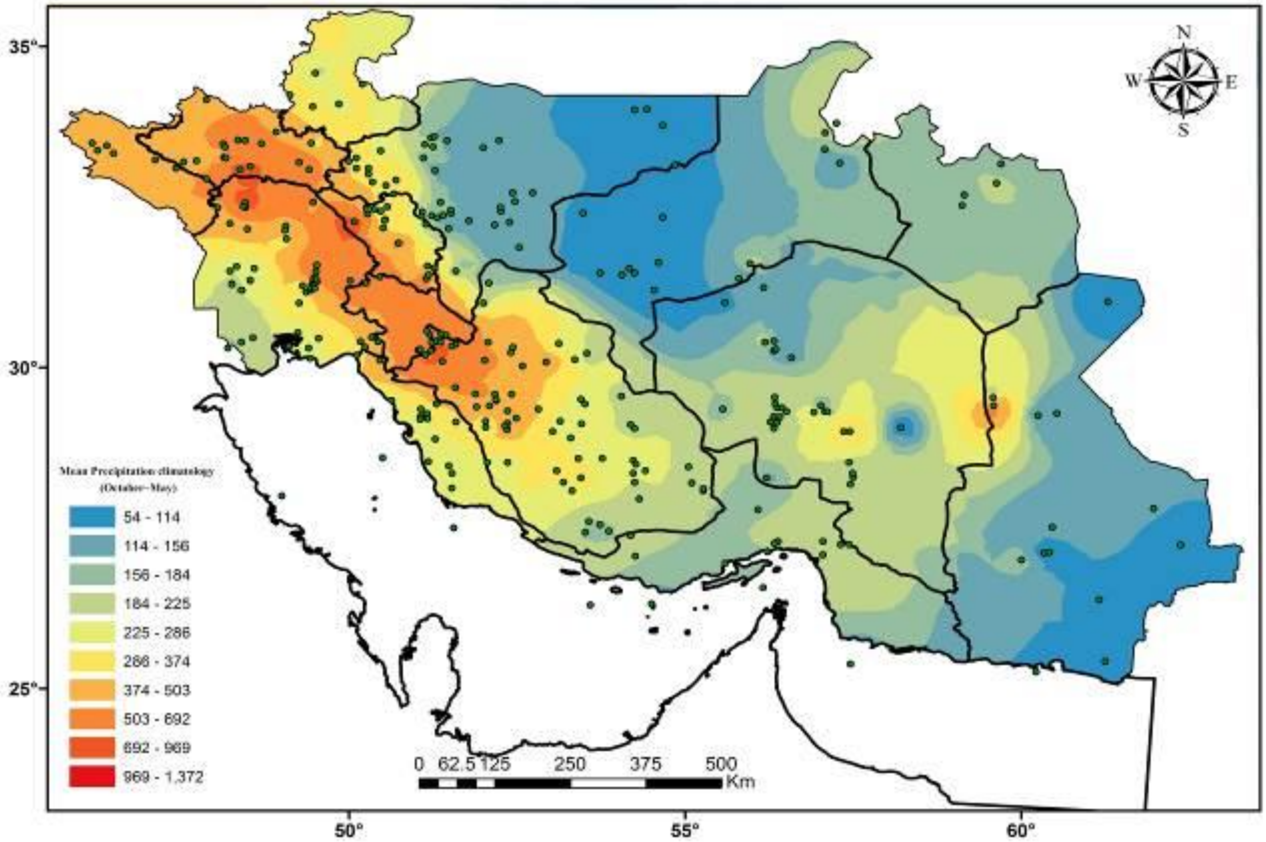

Fig. 2. Climatology of mean precipitation in the south of Iran (October-May). (The maps in the figure were created by F.P. using "ARCGIS 10.x").

Variation of local circulation and moisture content in each level of troposphere and for whole region is better to compute the moisture flux in three individual pressure levels i.e., 1000-700 hPa [equation 3], 700-500 hPa [equation 4] and 500-300 hPa [equation 5], as well as all troposphere levels *i.e.*, 1000-300hPa [equation 6]:

$$Q_{vi_{low}} = 1/g.\int_{1000}^{700} Vq.dp \quad [3]$$

$$Q_{vi_{mid}} = 1/g.\int_{700}^{500} Vq.dp \quad [4]$$

$$Q_{vi_{top}} = 1/g.\int_{500}^{300} Vq.dp \quad [5]$$

$$Q_{vi_{lclu}} = 1/g.\int_{1000}^{300} Vq.dp \quad [6]$$

Equation [7] was used for total vertical, horizontal divergence of moisture flux.

$$Q_{vi} = \int_{PB}^{Pt}\left(1/g.\int_{PB}^{Pt} Vq.dp\right).dt \quad [7]$$

3. Results and discussion

3.1 Interannual variation

Owing to the complex topography of southwestern Iran with the Zagros Mountains and dry deserts in the east of the study area, precipitation is highly variable in southern Iran. The most part of precipitation in this area occurs in 8 months (October–May) (Fig. 2). The seasonal climatology of precipitation during October–May reveals a strong decreasing gradient from western part to the central and southeastern part of country.

Analysis was performed on monthly precipitation anomaly fields from 302 stations of Iran during 1981-2010 to explore spatiotemporal and interannual precipitation variability.

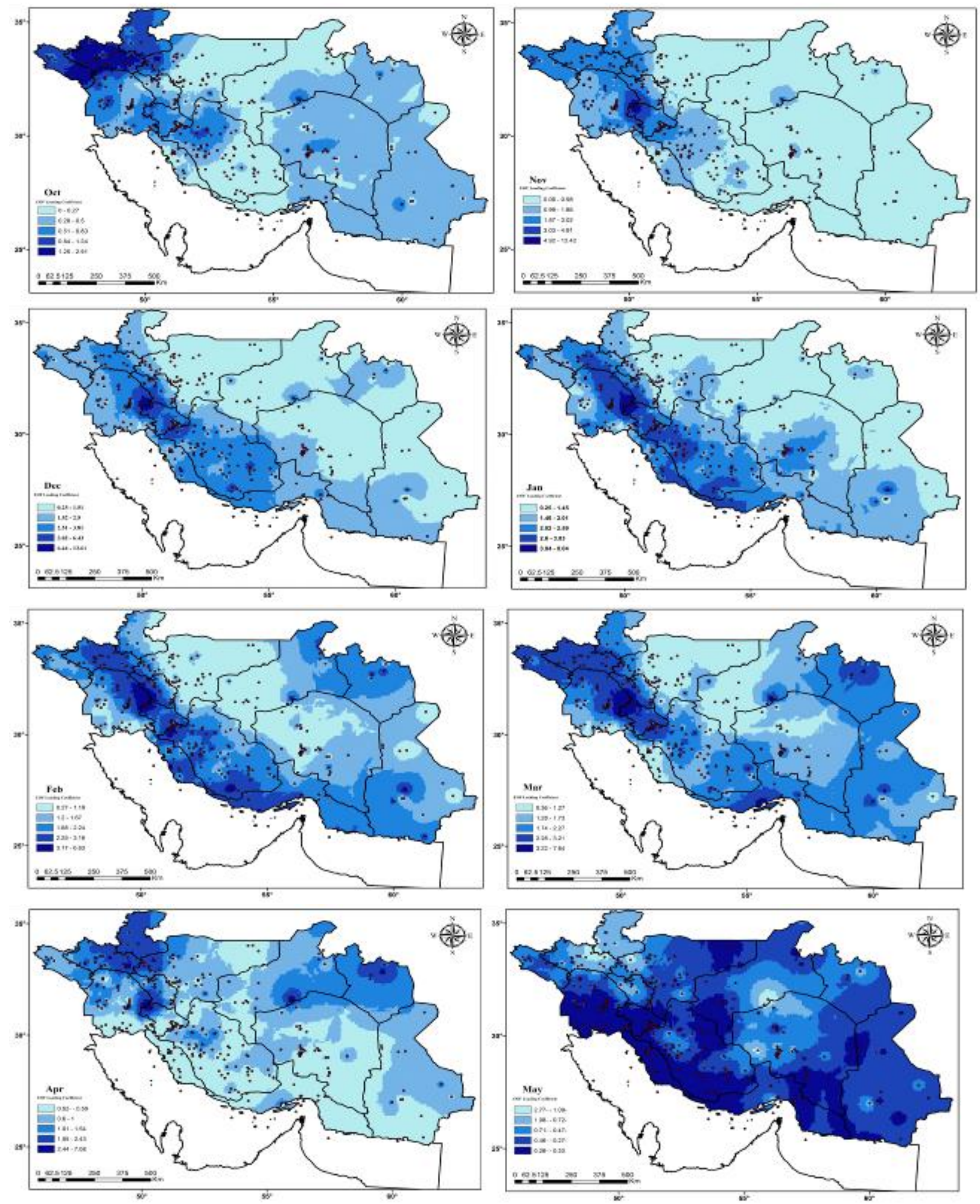

Fig. 3. Distribution of Precipitation loading coefficients of EOF1 of study area from October-May during 1981-2010. (The maps in the figure were created by F.P. using "ARCGIS 10.x").

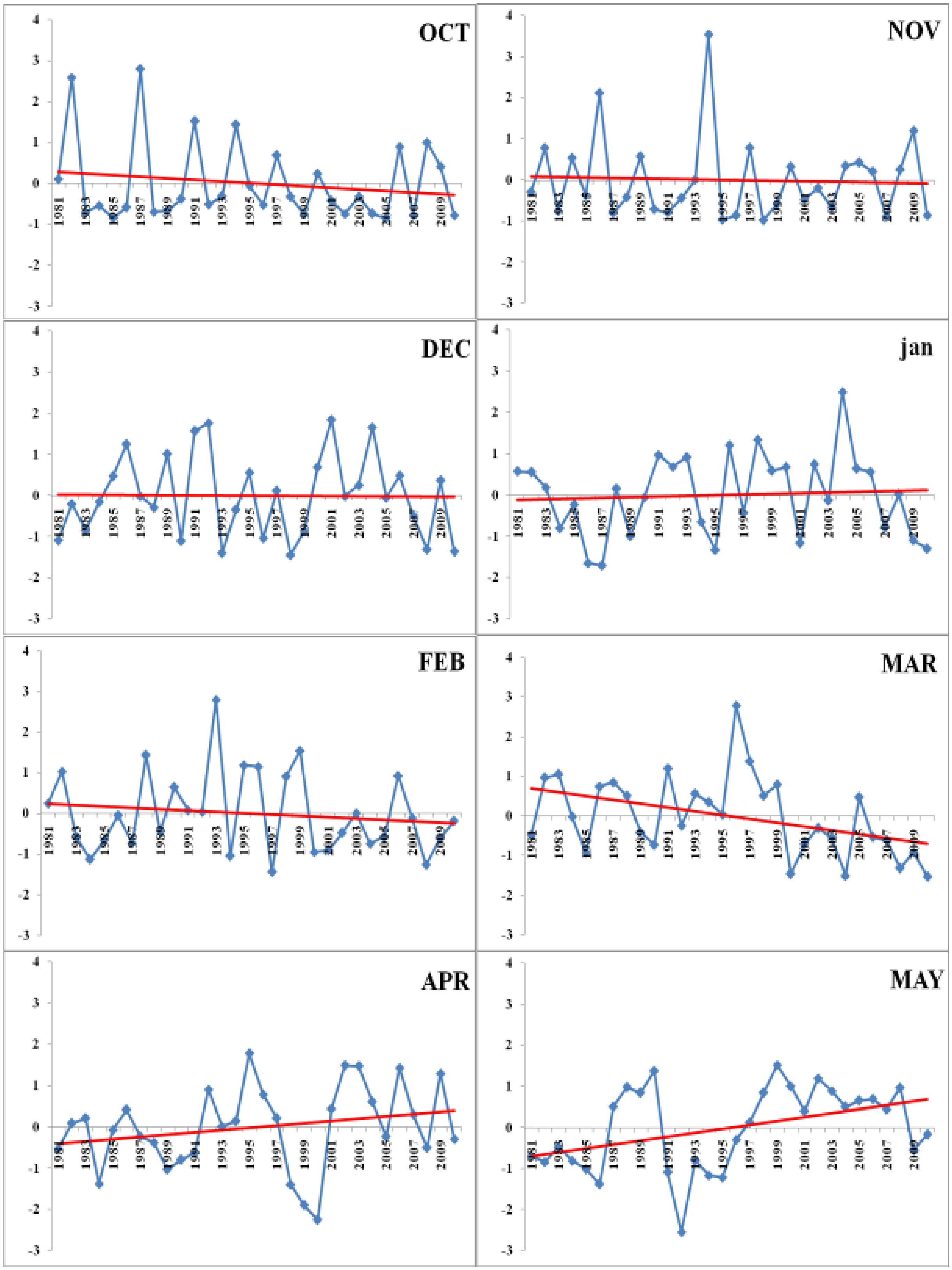

Fig. 4. Normalized (standard deviation) and trend (Red lines) of PC coefficients of EOF1 (Oct-May)

Table. 1 The variance contributions (%) of EOFs for each month from October to May.

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
EOF 1	52.8	68.98	58.06	54.04	58.85	51.45	43	31.81
EOF 2	13.26	8.21	18.45	8.95	9.68	8.79	13.67	17.92
EOF 3	7.23	5.33	4.53	6.26	7.22	6.66	6.78	11.14

Variance of three EOF modes, from October to May, are presented in Table 1. The first EOF mode approved to be a good indicator for spatiotemporal variation of precipitation because for the most of the months it explained more than 50% of total precipitation anomaly. Therefore, we limited our further analyses on first EOF mode. Spatial patterns of the first EOF mode (Fig. 3) and time series (Fig. 4) of the corresponding principal components presented. EOF1 essentially represents the characteristic of precipitation variability on the south of Iran. This pattern covers most of stand oscillations in the study area, that the highest loading with the same sign can be seen on the southwestern of Iran. The strong loading of this mode revealed over the Zagros Mountain. On the other hand, higher amount precipitation were observed in the middle of the rainy season i.e., December to March. Analysis of precipitation over Asia and global scale using EOF and based on correlation between principal components and Nino index also found that first mode have more influence on ENSO (Trenbert et al., 1998; Smith et al., 2003; Deng et al., 2014).

3.2 Mean monthly moisture flux divergence/ convergence (October to May) during 1981-2010

Based on climate simulation models and data from satellite it is highlighted that during past 20 years total amount of moisture in the atmosphere has increased with the increase temperature at rate of 7% per kelvin rise in temperature (Wentz et al., 2007). Changes in mean global temperature can significantly modify median intensity of extreme precipitation with a range of 5.9% to 7.7% per kelvin (Westra et al., 2013). More precipitation will be an outcome of warmer climate due to increased moisture holding capacity of air (Deng et al., 2014). Analysis of long term meteorological data (1961-2010) over Iran showed increasing trends in temperature indices especially after 1970s (Parak et al., 2015). Thermodynamic component linked with rising atmospheric moisture usually results in positive change in precipitation (Held and Soden, 2006). However, other factors also contributed the net outcome including variations in atmospheric circulation, which ultimately determines increase or decrease in precipitation (Fooland et al., 2001; Emori and Brown, 2005; Lu et al., 2007; Huang et al., 2013). The main sources of moisture (during October to May) are the eastern Mediterranean and the Arabian Sea, including the Persian Gulf (Fig. 7). The weather systems are strengthened by accumulated moisture from these sources. Some parts of the domain, such as the Adan Gulf, Red Sea and Indian Ocean showed higher values of negative moisture flux divergence. Higher values of moisture flux convergence toward the south of Iran during the cold season are associated with greater moisture advection from the Indian Ocean and Red Sea. Our result shows that some moisture is intercepted as condensation over the Zagros Mountains in the north of the Persian Gulf and produces the moisture flux convergence maximum region on the windward side of the mountains (Fig. 7). A trough over the central domain plays an important role in the moisture divergence from the source and convergence into the region (Fig. 5 and 6). The variability of temperature show the strength of each elements of local circulation (Fig. 5 and 6). While, moisture advection from west toward the region have been controlled by the persistence of anticyclonic circulation over the west of the Indian Ocean and the resulting low pressure trough over the Arabian Peninsula (Fig. 5 and 6). Areas of positive or negative moisture flux divergence or convergence change depending on whether the year is wet or dry.

3.3. Anomaly of moisture flux divergence/ convergence in wet period

The characteristics of moisture flux and amount of precipitable water for different troposphere layers and whole troposphere are presented (Fig. 8). The divergent reflects the moisture (-source)/(+sink) region; the rotational describes the atmospheric water vapor transport. These components are described in the data and methodology.

In wet years, anticyclonic circulations over the west of the domain become weaker and the trough over the central domain is strengthened, deepens and extends to the extreme east, allowing for an increase in moisture advection into the study area and showed positive moisture flux convergence anomalies. The ultimate result of these anomalies is an enhancement of the moisture flux convergence during the wet years and increased precipitation.

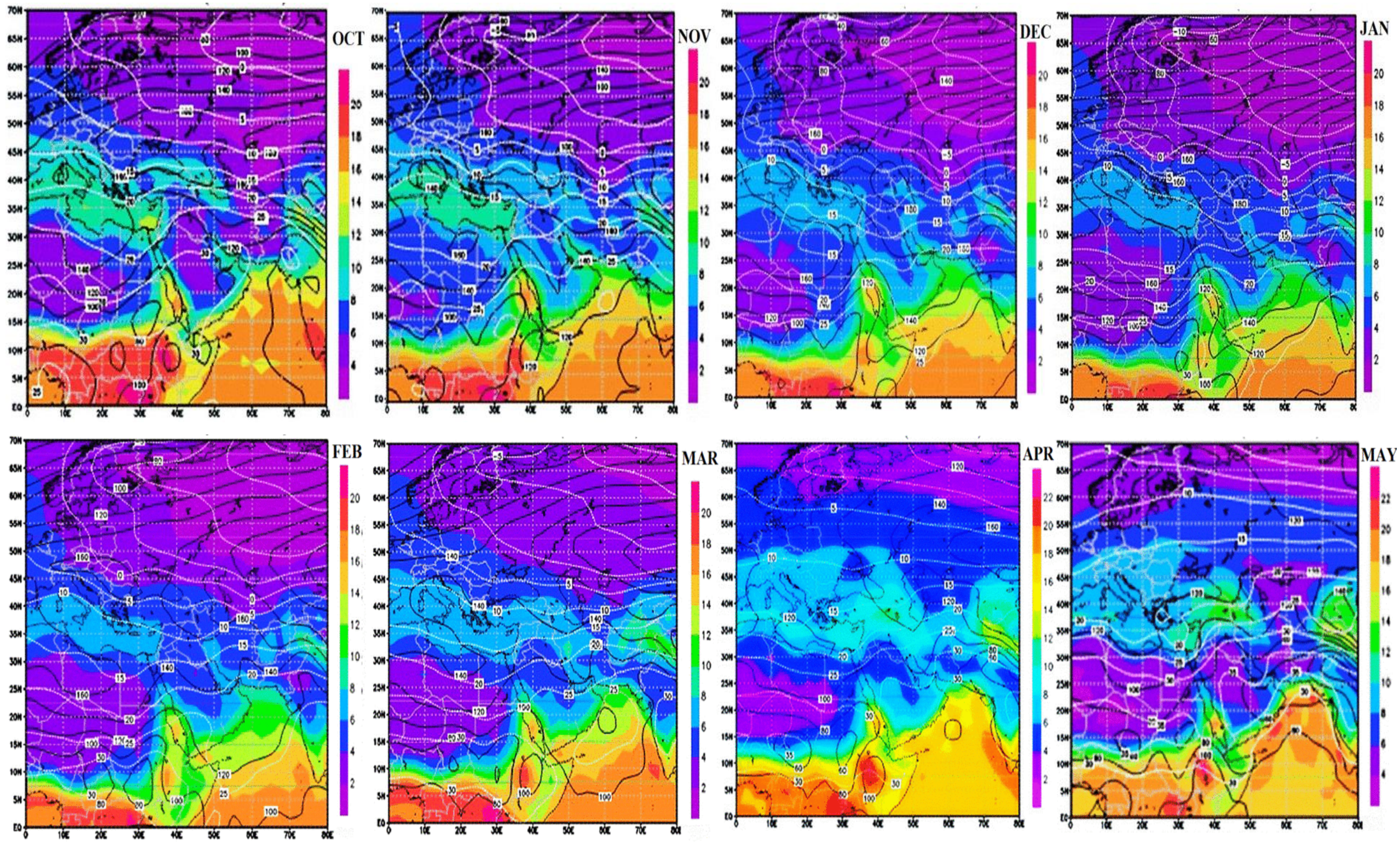

Fig. 5. Mean monthly pressure (black contours), temperature (white contours) and specific humidity (shaded) of 1000hPa level over studied area (Oct.-May) during 1981-2010. (The maps in the figure were created by F.P. using "GRADS").

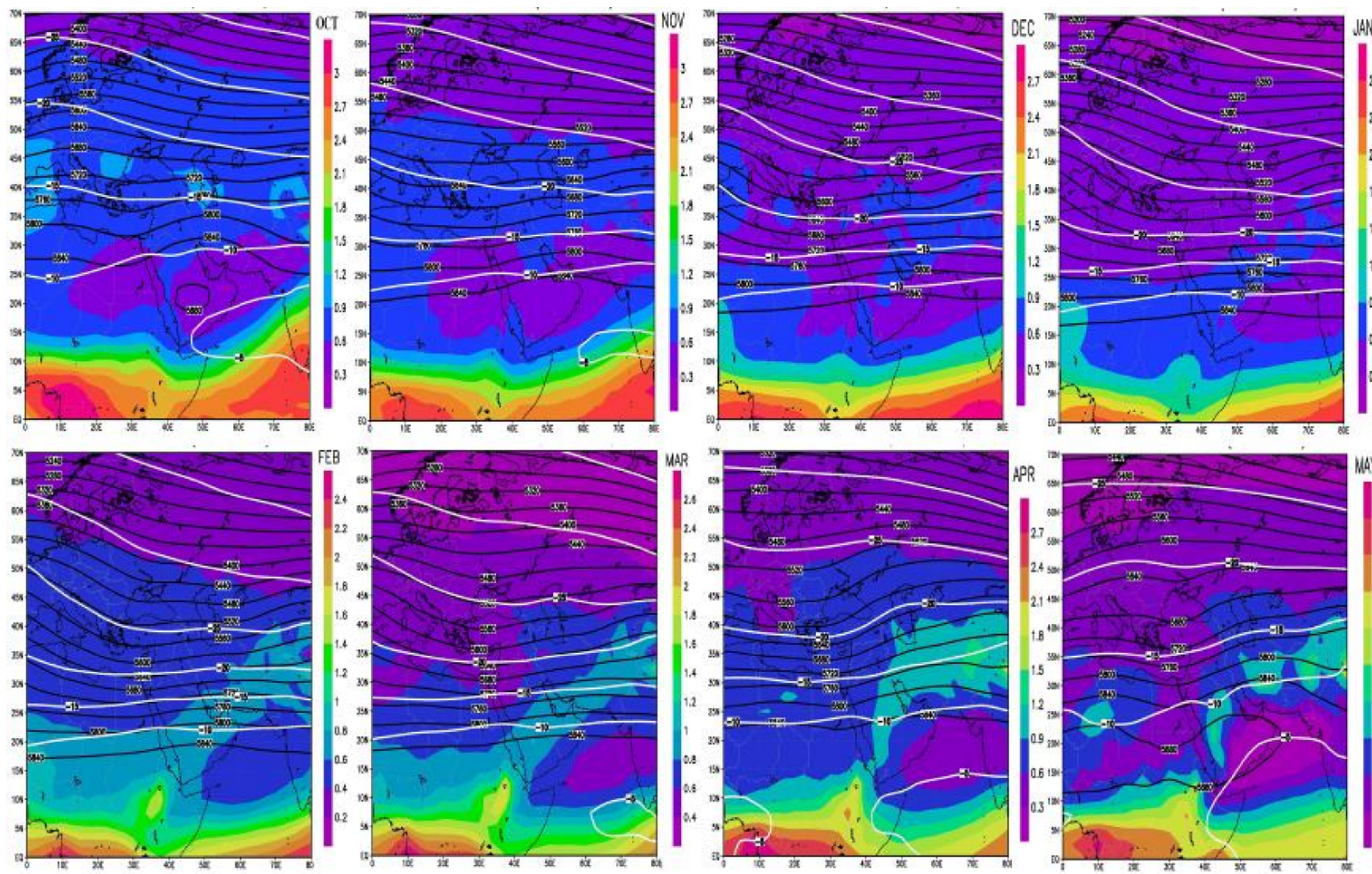

Fig. 6. Mean monthly pressure (black contours), temperature (white contours) and specific humidity (shaded) of 500hPa level over studied area (Oct.-May) during 1981-2010. (The maps in the figure were created by F.P. using "GRADS").

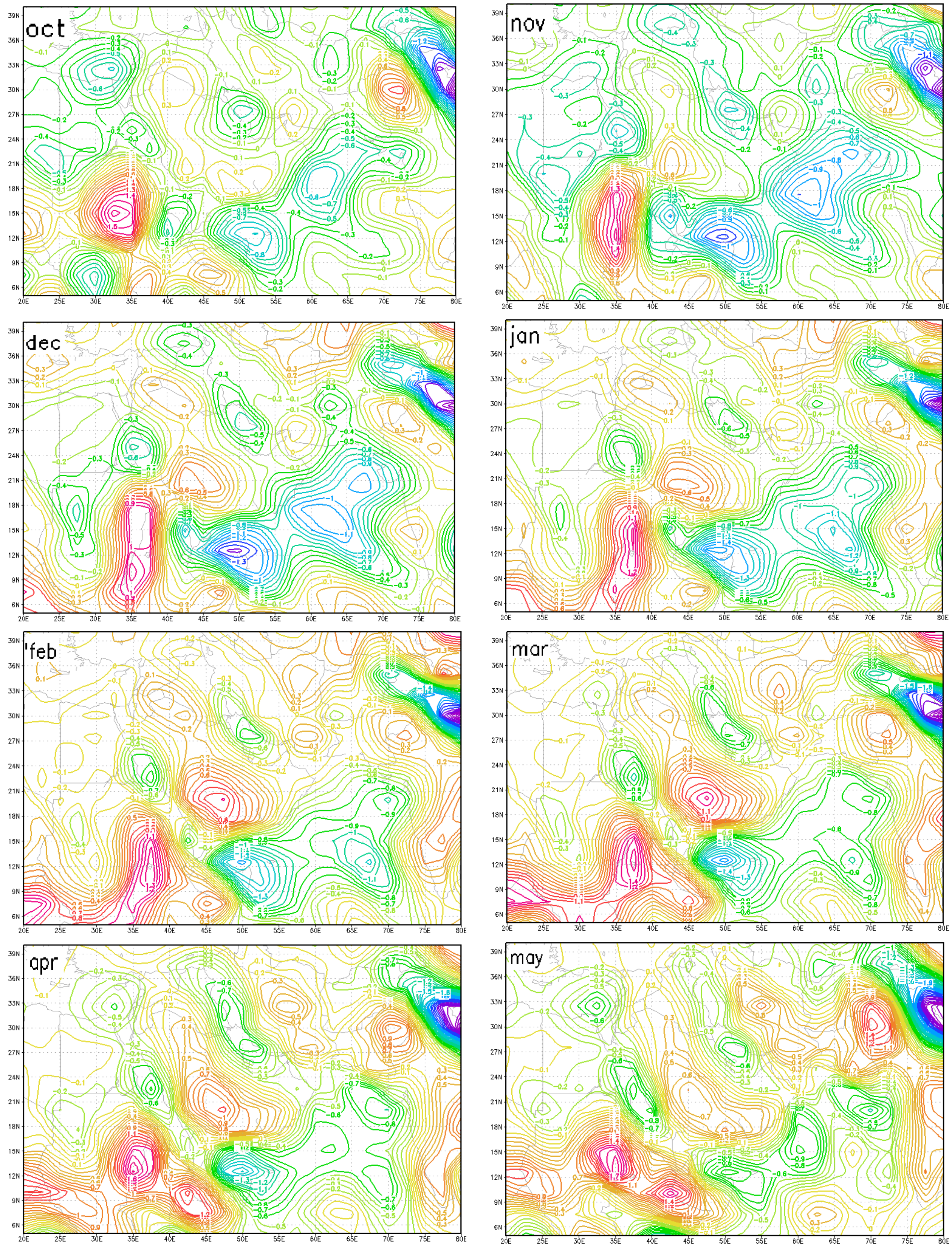

Fig.7. Mean monthly moisture flux divergence/convergence (October to May) over studied area during 1981-2010. (The maps in the figure were created by F.P. using "GRADS").

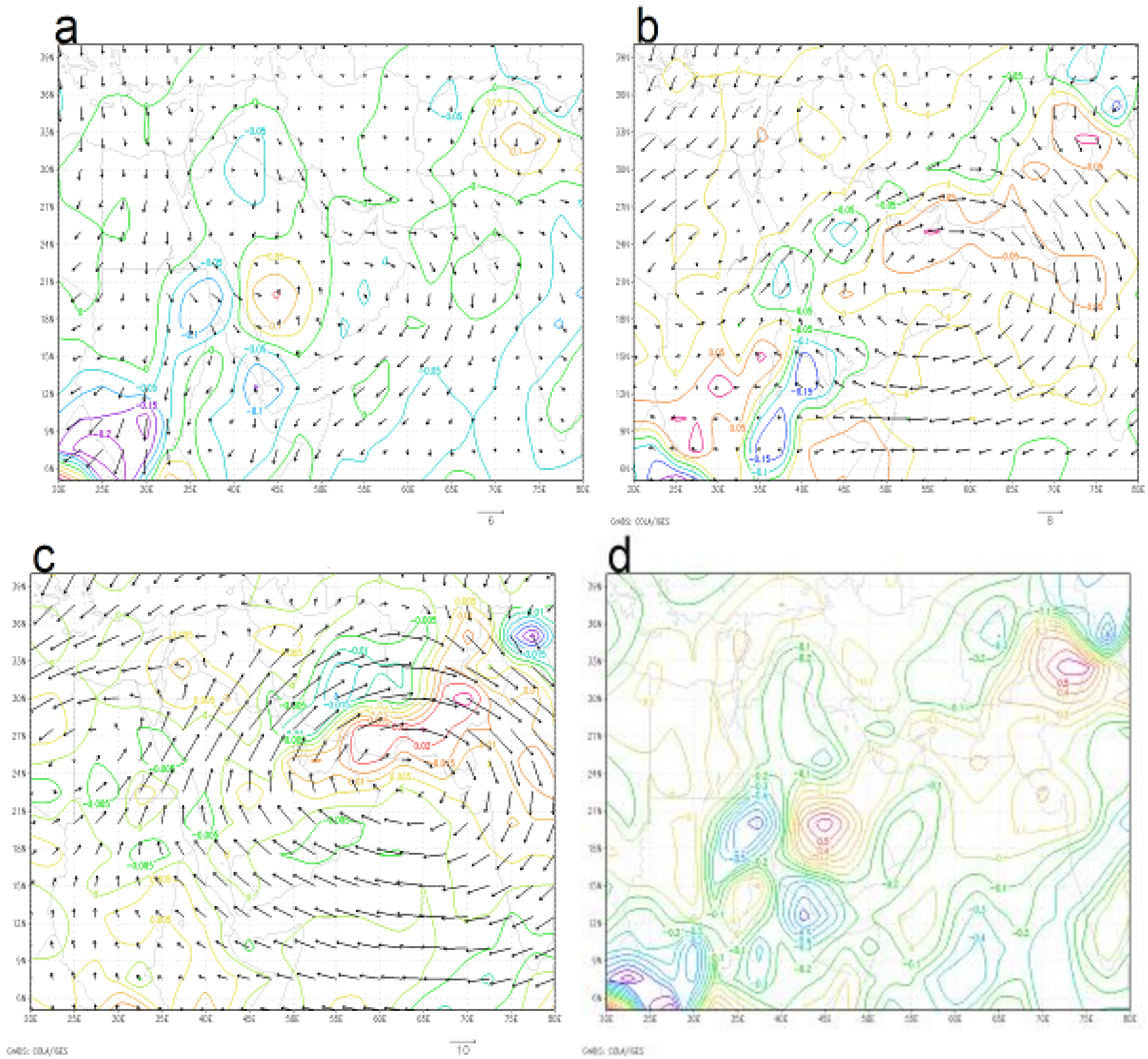

Fig. 8. Composites of moisture flux anomaly divergence/convergence in wet years: a) lower layer; b) middle layer; c) top layer; d) all layers. (The maps in the figure were created by F.P. using "GRADS").

In the lower troposphere, more precipitable water transferred to the eastern Saudi Arabia than other part of the area (Fig. 8a). Aden Gulf and Red sea are two moisture source regions, which supply moisture to study the region. During wet years the study area receives mainly moisture flux from the moisture sources such as west of the Indian Ocean, Red sea and the some extent from the Mediterranean. Divergent moisture flux in the middle troposphere, is a very important characteristics of local circulation and rainfall over the southern Iran (Fig. 8b). During wet years the centers of divergent moisture flux was observed over the northern part of the Indian Ocean, Aden gulf, central of the Red sea. While, convergence centers was located over South and central of Arabian Peninsula, and also southwest and south of Iran.

During this study, the mechanism of convergence of moisture flux in the lower troposphere and divergence of this flux in the middle troposphere are indicative of the upward motion of moist air. This upward motion continue until the latent heat that may be the source of low-level latent heat instability, release due to condensation. The centers of divergence moisture flux was located over the same region in this period. In the middle troposphere the large amount of precipitable water was transferred by local circulation from the Red sea and Mediterranean to the western Saudi Arabia.

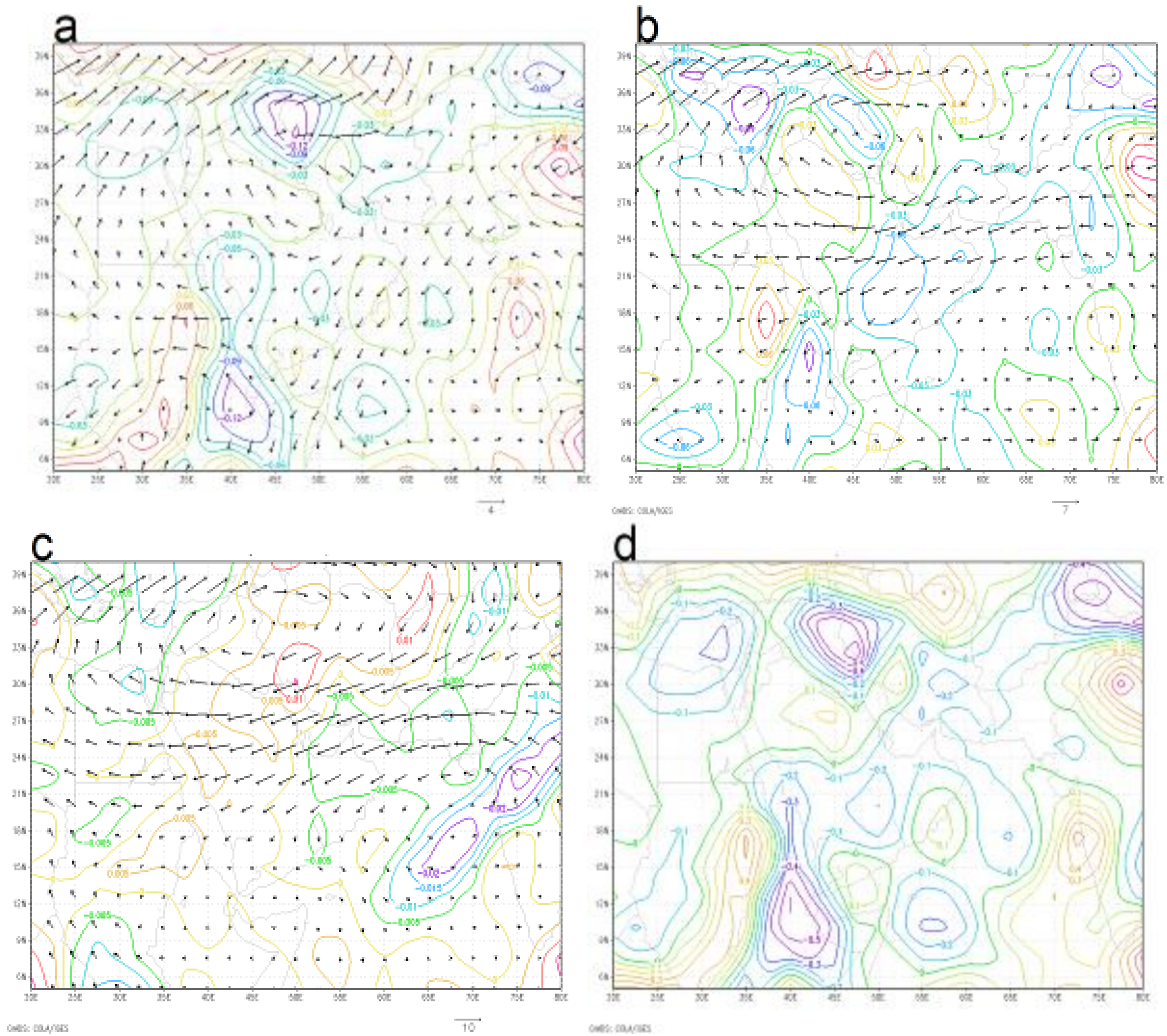

Fig. 9. Composites of moisture flux anomaly divergence/convergence in dry years: a) lower layer; b) middle layer; c) top layer; d) all layers. (The maps in the figure were created by F.P. using "GRADS").

The southwest part of the Iran, leeward of the Zagros Mountains, showed moisture divergence, possibly associated with divergent cross barrier subsiding flow. Thus, the precipitable water content in the upper troposphere distribution is lower than the middle and lower troposphere. Thus, moisture content of upper-level troposphere may not have much influence on total precipitation anomaly in the study area (Fig. 8c).

3.4. Anomaly of moisture flux divergence/ convergence in dry period

In drier years, East Mediterranean, the Red Sea, the western half of the Arabian Peninsula and southwest of Iran has a positive anomaly in the surface pressure and geopotential height in the upper layers of the troposphere. In this pattern, the minimum and maximum temperature center, are consistent with the low and high altitude centers.

In dry years, the anticyclonic circulation is strengthened in the west of the Arabian Peninsula, and its extension over this area blocks moisture advection into the region from the Indian Ocean (Fig. 9). Positive anomalies are evidence of deepening high pressure ridges and are indicative of the variation in the position of these anomalies seen in dry years. The ridge is stronger in dry years, further restricting moisture advection from the west. It was observed that in dry years, cyclonic flow from the higher latitudes of 30 ° north, crossed and the trough becomes shallower, resulting in less moisture advection. The maps in dry years (Fig. 9a) generally show reduced moisture flux convergence and areas of stronger moisture flux divergence, although there are increasing over the southwest of Iran. This suggests that during dry years, less moisture is transported to the study area.

4. Conclusion

This work is a diagnostic analysis of moisture transport and its potential influence on precipitation over Iran. Since the most of precipitation in the south of Iran receives during October to May, We studied interannual variations of precipitation in this area using rainfall data of 302 stations during 1981 to 2010. The results show that in most months, more than 50 % of the total variance explained by the first mode of empirical orthogonal function (EOF) in the precipitation anomaly. This indicates that the maximum rainfall anomaly occurs in the first mode and the maximum anomaly can be seen in the southwest and west regions. The results show that the dominant synoptic patterns of the first mode have an important role in creating wet and drought conditions. Therefore, knowledge of the synoptic patterns has a most important role in the prognosis of precipitation in the region. The synoptic investigation shows that the position and strength of high pressure over Arabian Peninsula play an important role during the wet and dry years. The analysis suggested that the Moisture flux convergence is strongly associated with precipitation in the region and variation in the moisture flux convergence was associated with the position and the extinction of the high pressure over the Arabian Peninsula. Therefore, two synoptic patterns can be assigned in the wet and drought years. In wet years, due to East Mediterranean trough that deepen over the West of Red Sea, the cold air transfer from northern to the southern latitudes resulting development of cyclones. Due to the development of cyclones the moisture flux transfer over Arabian Peninsula, and then to the Southwest of Iran. The release of sensible heat from the Arabian Desert and latent heat, which transfer from the adjacent seas results to the transfer of this cyclones to the south of Iran. Low-level latent instability in these systems, which contain significant value of precipitable water affect the study area. It is seen that Arabian Sea plays an important role in the low-layer of troposphere and the moisture flux in the middle and upper layers comes from the Red and Mediterranean seas. In dry years, the high-pressure shifted to the west of the Arabian Peninsula, it disturbed and blocking the moisture advection from the Indian Ocean and Adan Gulf. So, the magnitude of moisture advection into the south of Iran during dry years was reduced. Therefore, the Indian Ocean is important to pay more attention in predicting the precipitation over this area. On the other hand the interannual variability of precipitation more affected by variability of moisture flux from other source such as the Mediterranean and Red Seas. So, the induced large-scale atmospheric circulation anomaly controls the moisture supply of troposphere over the study area.

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Competing Interests

Authors declare that they have no competing interests.

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