

On the relationship between Indian monsoon withdrawal and Iran's fall precipitation onset

Iman Babaeian¹ · Parviz Rezazadeh²

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Abstract Indian monsoon is the most prominent of the world's monsoon systems which primarily affects synoptic patterns of India and adjacent countries such as Iran in interaction with large-scale weather systems. In this article, the relationship between the withdrawal date of the Indian monsoon and the onset of fall precipitation in Iran has been studied. Data included annual time series of withdrawal dates of the Indian monsoon prepared by the Indian Institute for Tropical Meteorology, and time series of the first date of 25 mm accumulated precipitation over Iran's synoptic weather stations in a 10-day period which is the basis for the cultivation date. Both time series were considered in Julian calendar with the starting date on August 1. The studied period is 1960–2014 which covers 55 years of data from 36 meteorological stations in Iran. By classifying the withdrawal dates of the Indian monsoon in three stages of late, normal, and early withdrawals, its relation with the onset of fall precipitation in western, southwestern, southern, eastern, central, and northern regions of Iran was studied. Results demonstrated that in four out of the six mentioned regions, the late withdrawal of the Indian monsoon postpones the onset of fall precipitation over Iran. No significant relation was found between the onset of fall precipitation in central region of Iran and the monsoon's

withdrawal date. In the western, southwestern, southern, and eastern regions of Iran, the late monsoon delays the onset of fall's precipitation; while in the south Caspian Sea coastal area, it causes the early onset of autumnal precipitation. The lag in onset of fall precipitation in Iran which is coordinated with the late withdrawal of monsoon is accompanied with prolonged subtropical high settling over Iran's plateau that prevents the southward movement of polar jet frontal systems. Such conditions enhance northerly wind currents over the Caspian Sea which, in turn, increase the precipitation in Caspian coastal provinces, which has a different behavior from the overall response of Iran's climate to the late withdrawal of monsoon. In the phase of early monsoon withdrawal, the subtropical jet is located at the 200 hPa level in 32.5° north latitude; compared with the late withdrawal date, it shows a 2° southward movement. Additionally, the 500 hPa trough is also located in the Eastern Mediterranean, and the MSL pressure anomaly is between – 4 to – 7 hPa. The Mediterranean trough in the late withdrawal phase is located in its central zones. It seems that the lack of significant correlation between late withdrawal date of Indian monsoon and late fall's precipitation onset in the central region of Iran depends on three reasons:

1. Lack of adequate weather stations in central region of Iran.
2. Precipitation standard deviations over arid and warm regions are high.
3. Central flat region of Iran without any source of humidity is located to the lee side of Zagros mountain range. So intensification or development of frontal systems is almost prohibited over there.

✉ Iman Babaeian
I.babaeian@gmail.com

¹ Climate Change Division, Climatological Research Institute(CRI), I.R. of Iran Meteorological Organization, Mashhad, Iran

² Forecasting Center, I.R. of Iran Meteorological Organization (IRIMO), Tehran, Iran

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1 Introduction

In the warm periods of the year, when subtropical high pressure moves to upper latitudes, the maritime tropical air mass, known as monsoon air mass, affects Iran's climate from south-east. This air mass provides humidity for the summer precipitation in the southeast of Iran. Approximately all parts of Iran, except for north of 36° latitude, are dry. The main reason for such condition is the settlement of subtropical high system over Iran in summer which blocks air mass motion toward Iran. Since the settling of above mentioned high in the far north of Iran is not permanent, westerly winds bring Mediterranean humidity toward Iran, which accompanied with convective systems, causes the summer precipitation. Sometimes, as a result of strong monsoon regime, the center of subtropical high moves to the north and provides an opportunity for the monsoon humid air to penetrate into Iran's plateau causing summer precipitation onset (Alijani, 2001).

Satellite data have discovered that during most of the year, the central and southeastern parts of Tibet highland plateau remain without snow, therefore become warm rapidly in spring of the northern hemisphere. Such a heating which is close to the middle troposphere, generates upper level anticyclone accompanied by a divergence in upper and a convergence in lower levels of troposphere. This creates a suitable condition for development of Indian monsoon in late spring, then the high amount of released latent heat inside the system creates frontal summer monsoon system. Monsoon precipitations are formed in India as a result of convergent zone between south and southwestern monsoon currents and northwesterly currents over the Arabian Sea. One of the basic mechanisms in the development of monsoon is blocking of westerly flows by the Tibetan anticyclone (Ghaemi, 2012). From the beginning of spring onward, the strong surface tangible warmth in the Tibetan plateau continuously warms the air column over it by $2\text{--}4^\circ\text{C}/\text{day}$. The highly elevated air over the Tibetan plateau transfers its surrounding air to the center of plateau due to rising of hot surface air mass. This mechanism creates extreme convergent zone, causing surface air mass to elevate and create a positive vorticity near the Earth's surface and a negative one in the upper layer of atmosphere, and consequently, the upper troposphere anticyclone is formed over Tibet (Ghaemi 2012).

Summer of 2010 contained two high impact weather phenomenon, namely Russia's heat wave and Pakistan's torrential rainfall. During aforementioned phenomenon, a twin pressure pattern of a low pressure system with central pressure of 998 hPa over Pakistan and a high with 1017 central pressure over Russia formed, which was accompanied with blocking in upper levels of atmosphere (Azizi et al., 2013; Babaeian and Karimian, 2011). According to Ghaemi et al. (2010), subtropical high has gradually moved to higher latitudes since May onward, and it reached the highest geographical latitude in

August and moved back to southern latitudes in September–October. Based on the study done by Mofidi and Zarrin (2013) on the onset of monsoon circulation in the south and Southeast Asia, continuous westward zonal winds are formed in the upper troposphere as the main convergence region. The abovementioned conditions alter the largescale atmospheric circulation in the meridional and can transverse the Hadley circulation together with the onset of summer in western Asia. Monthly and annual summertime rainfall in southeast of Iran have a very close correlation with Indian summer monsoon intensity, especially with the extension of monsoon low pressures toward the Arabian Sea and Persian Gulf. During the strong monsoon of 1994, the number of monsoon lows has tangibly increased, the subtropical high has been stronger, and humid currents in the southwest of the Arabian Sea and the Bengal Gulf have also been remarkably more extreme (Alijani et al., 2008). Investigations have demonstrated that summer precipitation in the southeast of Iran—which occurs almost every year in the Sistan and Baluchestan province, located in Southeast of Iran—may have been affected by the Indian monsoon (Alijani et al., 2008).

Strong and long-lasting monsoons are generally accompanied by an upper troposphere blocking in west and East Asia. Extreme droughts in India's plateau are accompanied by a "break" in the monsoon of the southwest of Asia. The behavior of precipitation in extreme droughts shows that "break" happens due to the development of tropospheric blocking in West Asia which seems to cause other blockings in East Asia. In recent years, western and northwestern Himalaya has experienced such heavy precipitation in monsoon seasons (June to September) that caused huge economic damages to the region. Examples are the flood at the end of July 2010 in Pakistan, and the heavy precipitation in northern parts of India in the middle of June 2013. In both cases, a westerly upper level trough existed in middle latitudes. The process seen in monsoon precipitation and above normal sea surface temperature of tropical oceans is well related to the meridian variations of monsoonal winds. In simulations of 22 GCMs of CMIP3 series, a relation was found between Indian Ocean's warm up and weakening of monsoon circulation. Interactions between the southward trough in the middle latitudes and the south Asian monsoon circulation in its weak phase intensify precipitation anomalies in eastern foothills of central Himalaya. Such interaction eases the enhancement of vorticity in the middle troposphere and causes an extreme rise in temperature, convection, and concentration of precipitation over central eastern foothill zones in Himalaya. At the time of monsoon's break, the sudden stop of monsoon precipitation in the central north of India's plateau is accompanied by high anomalies which allow the monsoon trough to move toward foothill zones of Himalaya. Numerical modeling has shown that in the presence of monsoon's basic currents, Rossby waves which are created because of north-south gradual

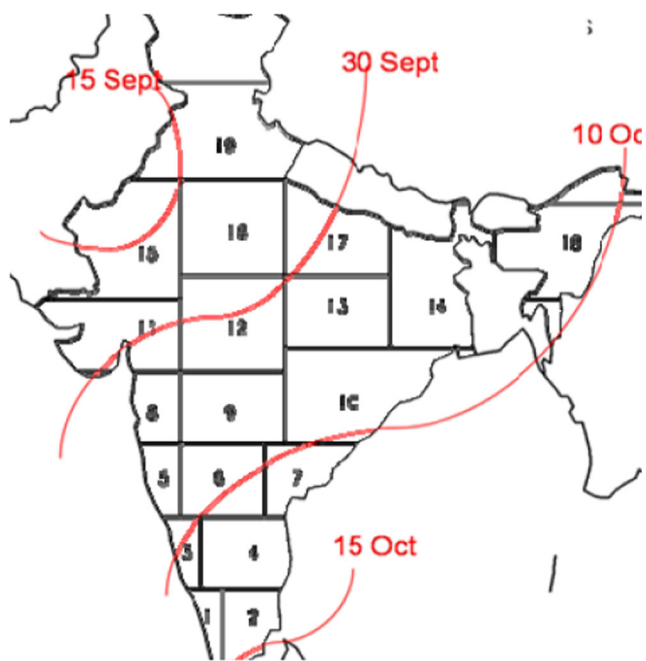


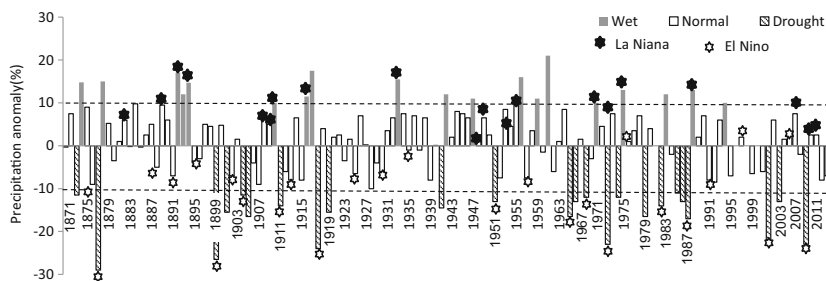
Fig. 1 Normal withdrawal date of Indian monsoon according to historical data (from: IITM)

warming, are the primary physical mechanisms controlling monsoon break. In an active monsoon, a monsoonal trough is usually accompanied by a deep cyclonic vortex from the Earth’s surface up to the 350 mb level along the Indo-Gathas (Choudhury and Krishnan, 2011).

High resolution general circulation models have demonstrated relationships between monsoon troughs and precipitation, convection systems, and zonal circulations. Satellite data and ground-based observations verify that monsoon is a display of seasonal movement in the Inter Tropical Convergence Zone (ITCZ) (Gadgil 2003).

Southwestern monsoon currents have significantly weakened in the last 50 years. The Indian monsoon’s response to global warming has received attention from many researchers. For example, one of the monsoon simulations using dynamic downscaling of the CMIP3 models with a 20 × 20 resolution have confirmed that the weakening of quasi-Hadley cell of summer monsoon in response to global warming can potentially weaken monsoon currents and decrease convection precipitation in the Western Ghats Mountains.

Fig. 2 Time series of Indian monsoon anomaly data during 1871–2014. El Niño, La Niña, heavy rainfall, drought, and normal year have been shown in the figure



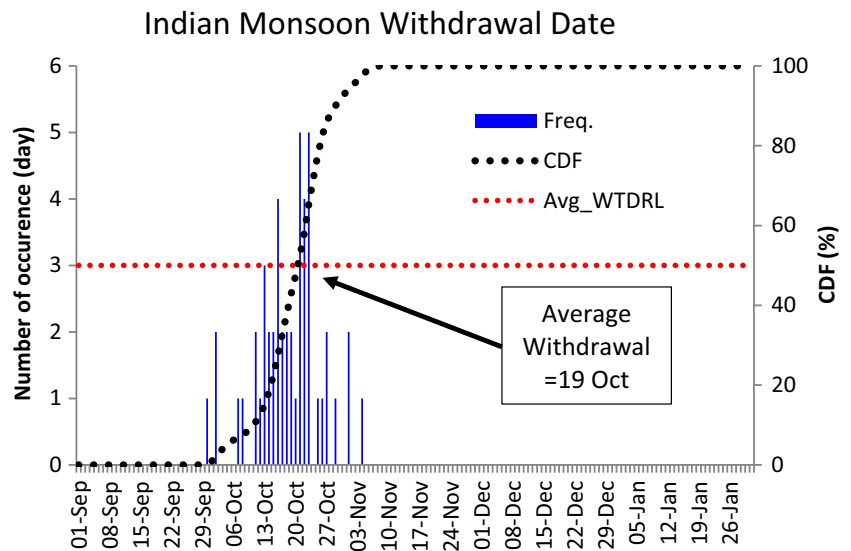
The main objective of this study is to find the relationship between the withdrawal of the Indian monsoon and the onset of Iran’s fall precipitation. A sample of above-normal fall precipitation of Iran can be seen in 2015 which caused rare heavy precipitation in western and southwestern regions of Iran. Despite to above mentioned unusual heavy fall precipitation in most regions of Iran, southern parts of the Caspian Sea experienced lower than normal precipitation. This condition was accompanied by the 2015 weak and early Indian monsoon withdrawal.

2 Indian monsoon

Highlands in Tibet, Himalaya, Karakoram, and Hindu Kush located in the central part of eastern hemisphere, consisting of continuous lands in north and west and ocean in east and south, act as high heat sources in summer of the northern hemisphere. In response to deep tropospheric warming, a strong pressure gradient is formed toward this region in lower layers, and a pressure gradient is formed outward in the upper layers of troposphere inside and around this region easing convergence in lower layers and divergence in upper layers causing ocean-atmosphere and tropical-extratropical interactions. The Equatorial low or the Inter-Tropical Convergence Zone (ITCZ) has its most northward movement in tropical zones between the land of Africa and Asia in the west and water divisions of the Indian and Pacific oceans in the east.

The physical mechanism responsible for the Asian Summer Monsoon onset is usually attributed to seasonal changes in the ocean-landmass thermal contrast. The seasonal transition of the atmospheric circulation over the mid and low latitudes of Asia in late spring or early summer is generally regarded as a result of the rapid warming of the Asian landmass (Murakami and Ding 1982; Yanai et al. 1992). As an elevated heat source in spring and summer, the role of the Tibetan Plateau in this transition has also attracted significant and continuous attention of meteorologists since the 1950s (Luo and Yanai 1984). He et al. (1987) identified two successive stages of upper tropospheric warming over the eastern Tibetan Plateau in May and over the Iran Plateau in June, each of which is accompanied by a distinct seasonal transition of the atmospheric circulation. Yanai et al. (1992)

Fig. 3 Cumulative probability distribution and number of events of monsoon’s withdrawal



indicated that diabatic heating over the eastern Tibetan Plateau accounts for the tropospheric warming there in the first transition, which leads to the reversal of the meridional temperature gradient and the establishment of low-level south westerlies over the Bay of Bengal. Li and Yanai (1996) suggested that such heating mainly results from sensible heating over the plateau in May and June. Yanai et al. (1992) further point out that adiabatic warming produced by strong subsidence in the upper troposphere is the dominant cause of the warming over the Iran Plateau, which was also illustrated clearly by Hsu et al. (1999).

The Southeast trade winds blow from south, southwest, west, and even east toward different zones after passing the Equator in an area between Somalia coastland and Indonesia–Malaysia land, which are known as monsoon currents. They receive humidity by large scale sea breeze from oceans. During this time, known as monsoon season, warm and humid monsoon currents create significant precipitations over India. Normally, monsoon starts at the beginning of June from the southern parts of the Indian subcontinent and reaches its northwestern parts around July 15. Monsoon withdrawal starts at the beginning of September from the northwest, and in October 15, it ends in Kerala, the

southern part of India (Singh and Ranade 2010). In Fig. 1, the normal dates of monsoon withdrawal in different zones of India are shown.

In Fig. 2, the states of monsoon precipitation in India in different phases are presented. Researchers found that monsoon phases in India and ENSO generally act contrastingly, so that monsoons with more than normal precipitation are accompanied by La Niña, while those with less than normal precipitation are accompanied by El Niño; however, based on most studies carried out in Iran (such as Nazemossadat and Ghasemi, 2004; Yarahmadi and Azizi, 2008) strong La Niña is mainly accompanied by less than normal, and strong El Niño by more than normal precipitation over Iran.

In Fig. 3, the cumulative probability distribution and the number of occurrences of the Indian monsoon withdrawal have been demonstrated on the horizontal axis. The mean monsoon withdrawal date is October 19, based on data from India Meteorological Department (IMD).

Table 1 Early and late Indian monsoon withdrawal years (from: IITM and IMD)

Monsoon phase	Years
Early withdrawal	1965, 1968, 1969, 1979, 1980, 1982, 1984, 1985, 1988, 1989, 1997, 2000, 2002, 2006
Late withdrawal	1960, 1961, 1964, 1975, 1976, 1977, 1978, 1990, 1991, 1993, 2001, 2004, 2008, 2009, 2013

Table 2 Geographical regions and names of stations under study

No.	Geographical region	Name of station
1	West	Tabriz, Orumia, Khoy, Saghez, Sanandaj, Hamedan, Kermanshah
2	South west	Khorramabad, Shahrekord, Shiraz, Ahwaz, Abadan, Dezful, Bushehr
3	South-southeast	Bandarabbas, Zahedan, Iranshahr, Kerman, Bam
4	East	Mashhad, Birjand, Torbatehdyariyeh, Sabzevar, Shahrud
5	Center	Isfahan, Yazd, Arak, Tehran, Zanjan, Ghazvin
6	Caspian basin	Bandaranzali, Rasht, Ramsar, Babolsar, Gorgan

Table 3 Correlation between Indian monsoon withdrawal and fall's precipitation onset in different regions of Iran

Region	West	Southwest	South	Center	East	Caspian
Correl.	0.3	0.43	0.22	0.08	0.3	-0.25
Sig.	✓	✓	✓	×	✓	✓
Sig. lev.	0.01	0.01	0.05	×	0.01	0.05
Direction	Positive	Positive	Positive	×	Positive	Negative

3 Materials and methods

In this study, the relation between the onsets of effective fall's precipitation in different regions of Iran and withdrawal of the summer Indian monsoon will be analyzed. A 10-

day accumulated precipitation of more than 25 mm has been considered as effective precipitation based on agrometeorological studies (Azimzadeh and Taliei, 2010). Time series of Iran's fall precipitation onset and Indian monsoon withdrawal are computed based on Julian days starting from the first of August. Monsoon withdrawal dates have been taken from the website of the Indian Institute of Tropical Meteorology (www.tropmet.res.in) in its most recent update. The period of study covers 55 years (1960–2014). Early and late monsoons withdrawals and 50% of dry monsoons are categorized in Table 1.

In order to determine the onset of fall precipitation in Iran, the daily precipitation data of 35 meteorological stations starting from 1960 were used. Information regarding the stations are presented in Table 2.

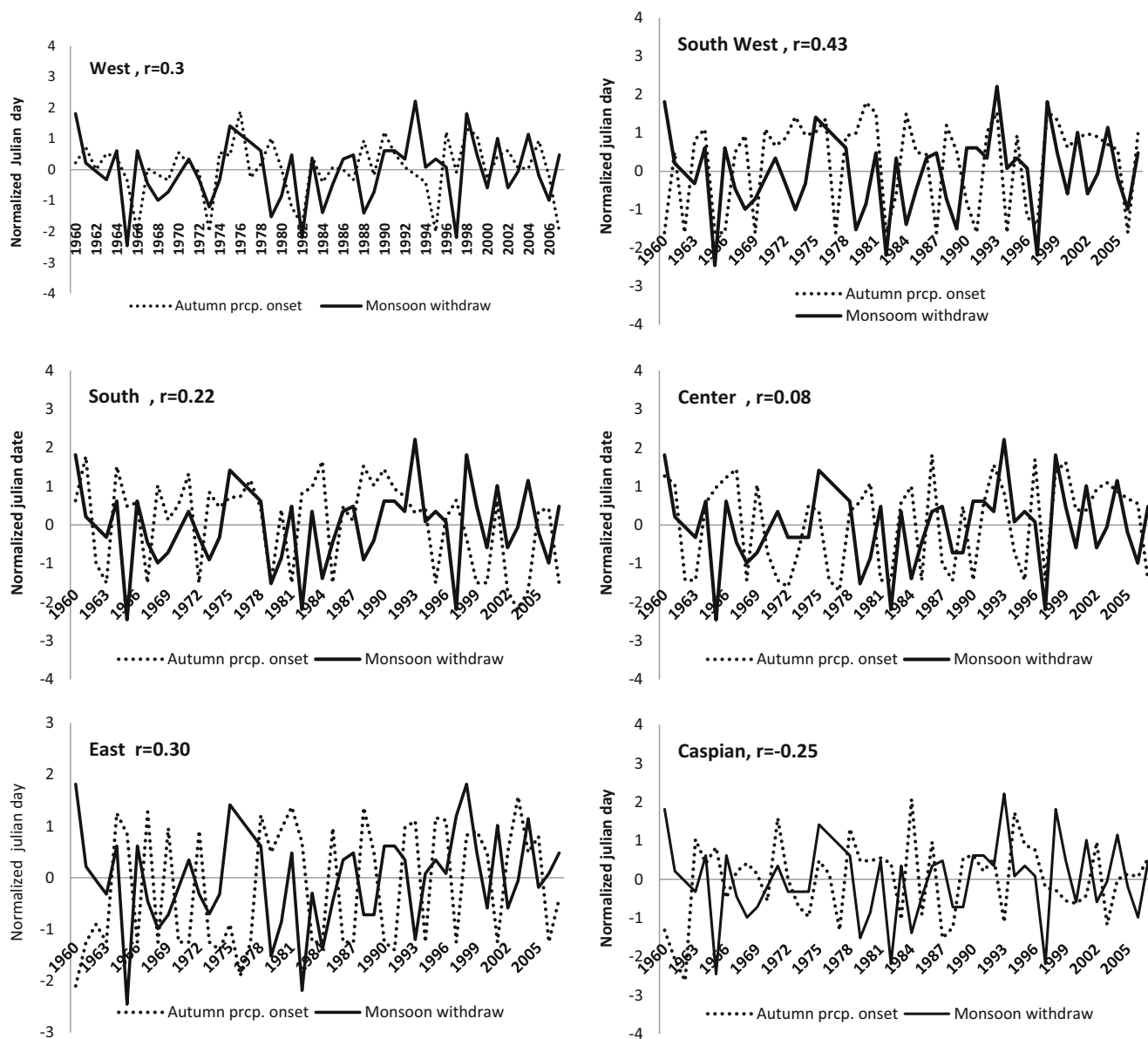


Fig. 4 Correlation between Indian monsoon withdrawal and fall precipitation onset in different regions of Iran

Table 4 Kolmogorov-Smirnov test to explore the significant different between Iran's fall precipitation onset in early and late monsoon withdrawal cases

Region	West	Southwest	South	Center	East	Caspian
K-S test (D)	0.49	0.37	0.51	0.20	0.65	-0.46
Sig.	✓	✓	✓	×	✓	✓
Sig. lev.	0.05	0.10	0.05	×	0.01	0.05

To reveal the significant relation between the Indian monsoon withdrawal and Iran's fall precipitation onset, Pearson's r and the Kolmogorov-Smirnov tests were used in two phases of early and late withdrawal of the Indian monsoon. Since their distributions are unknown and there was no assurance about their normality, in order to check the significance or rejecting the differences between two different phases of early and late withdrawal of monsoon and their effects on the fall precipitation onset, the non-parametric Kolmogorov-Smirnov tests which puts no constraints on population distribution were used (Jabbari, 2014) (Table 3). Moreover, synoptic patterns of different phases of monsoon were analyzed based on NCEP reanalysis data.

4 Results and discussion

The effects of the withdrawal date of monsoon in the south-eastern parts of India on Iran's fall precipitation onset (the first occurrence date of 25 mm 10 days accumulated precipitation) in different regions of Iran were investigated from two statistical and synoptic viewpoints. In what follows, the results will be analyzed and discussed by both methods.

4.1 Statistical analysis

In Fig. 4, in addition to drawing a time series of withdrawal dates of monsoon and the onset of effective fall precipitation in the west, southwest, south, east, central part, and the southern basin of the Caspian Sea, Pearson's r correlations have

also been computed and written on the diagrams. Correlations in the western, southwestern, south, east, and the south coast of the Caspian Sea are significant at the 0.01 confidence level. The highest correlations have been observed between those stations located in the southwest of Iran, but the correlation in the central part of Iran is not significant.

An important and remarkable point in the areas with significant correlations is existence of positive correlation between the Indian monsoon withdrawal and fall effective precipitation onset in the southwest, south, and east of Iran; while for the provinces located in south Caspian Sea basin, correlation is negatively significant. This means that the later the Indian monsoon withdrawal, the later Iran's fall precipitation onset. Caspian Sea is an exception where the delay in the withdrawal of the Indian monsoon can even significantly lead to an early occurrence of effective fall precipitation. One reason can be the effect of surface high pressure which leads to northerly winds over Caspian Sea and causes an early occurrence of fall precipitation in this basin.

The non-parametric test of Kolmogorov-Smirnov was used to investigate the possibility of significant difference between the cumulative probability distributions of the fall precipitation onset time series in different regions of Iran in two phases of monsoon including early and late withdrawal dates. To this end, dates of the fall precipitation onset in different regions of Iran during the years with early and late withdrawals of monsoon in the period of 1960–2014 (Table 1) were extracted. In Table 4, the results of Kolmogorov-Smirnov tests have been presented to show the significant difference between cumulative probability distributions of early and late onset of effective fall precipitation in different regions of Iran comparing to two phases of early and late withdrawal of Indian monsoon. Based on the table, a significant difference is observed between cumulative distribution in the onset of fall precipitation in the western, southwestern, southern regions, and the Caspian basin in early and late monsoon withdrawals; but no such significant difference was seen in the central part of Iran.

Metadata analysis shows that spatial distribution of weather stations is not homogeneous over Iran (Table 5). The area of central arid and hot region is almost one third of Iran. Lack of

Table 5 Large scale synoptic patterns and related meteorological parameters in vertical cross-section over Iran

	Early monsoon withdrawal (EMW)	Late monsoon withdrawal (LMW)
Upper level atmosphere (200 mb)	-Jet stream core located in 32.5° N -Zonal currents	-Jet stream core located in 34.5° N -Tendency to ridge
Middle atmosphere (500 mb)	-Tendency to zonal currents -Trough in the east of Mediterranean sea -Geopotential height in the south of Caspian is 5775 gpm	-Ridge pattern with closed high over Saudi Arabia -Trough in the center of Mediterranean sea -Geopotential height in the south of Caspian is 5805 gpm
Mean sea level (MSL)	-Contour of 1018 mb in the east of Mediterranean sea -Contour of 1019 mb over Persian Gulf	-Contour of 1014 mb in the east of Mediterranean sea -Contour of 1012 mb over Persian Gulf

adequate weather stations in central region of Iran made it hard to find significant correlation between Indian monsoon withdrawal and fall's precipitation onset.

Furthermore, intensity of hydrological cycle over dry and warm region is high when compared to other regions (Donat et al. 2016). Modarres (2007) found that mean annual rainfall over central region of Iran is very low, ranging from 62.1 mm at Yazd to 344.8 mm at the Shiraz station. In general, the standard deviation is high, ranging from 27.1 to 130.3 mm. In this regard, due to the high precipitation standard deviations and lack of adequate weather stations, it is

difficult to find significant correlation in the arid to semi-arid central areas of Iran.

Lack of correlation between fall's precipitation onsets in the central arid to semi-arid regions of Iran with Indian monsoon withdrawal can be discussed from synoptic aspect. Central flat regions of Iran without any inland sources of humidity are located to the lee-side of Zagros mountain range, so intensification or development of frontal systems is almost prohibited over there. Mountain barriers have significant role in the development of frontal systems. In this regard, Zagros Mountains which is located in the west of Iran can intensify

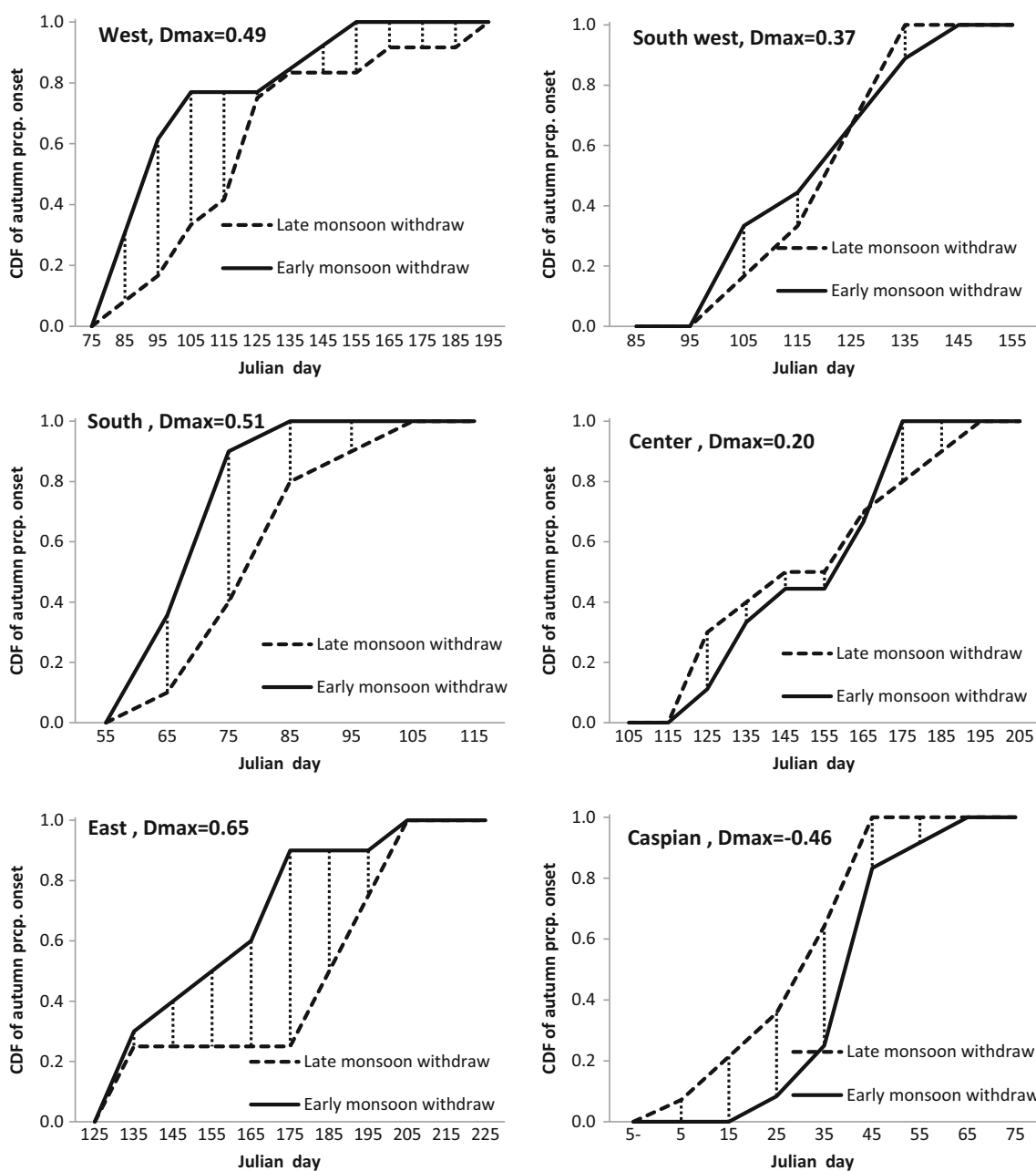


Fig. 5 Probabilistic cumulative distribution of fall precipitation onset in different regions of Iran in two phases of late and early monsoon withdrawal

cyclogenesis in the windward west side of Iran. This can be understood by comparing the mean annual precipitation of two central cities of Shiraz and Arak. Although the latitude of Arak is higher and more elevated than Shiraz, it is located in the lee-side flatland and receives less precipitation than Shiraz which is located in Zagros mountainous area. Significance of the difference between the two series of data in the Caspian basin is in the opposite direction of monsoon's withdrawal. In other words, the response of Caspian basin to monsoon's withdrawal is opposite to the response of other regions in Iran.

In Fig. 5 the cumulative probability distribution of the fall precipitation onset has been shown in two phases of late and early Indian monsoon withdrawal.

4.2 Synoptic analysis

An upper level ridge at 200 hPa is seen over Iran during late monsoon withdrawal; whereas in the early withdrawal phase, the upper level currents are zonally distributed. In the early monsoon withdrawal phase, a contour of 12,050 gpm passes the northernmost parts of Iran in 200 hPa level, showing 100 gpm less than late withdrawal phase, which leads to the formation and passage of frontal systems over Iran compared to normal and late monsoon withdrawal conditions. A 2.2 (4.2)° southward displacement of subtropical jet stream can be seen in 200 hPa layer over Iran in early monsoon withdrawal phase, which lets the frontal systems to extend over the region under study (Fig. 6).

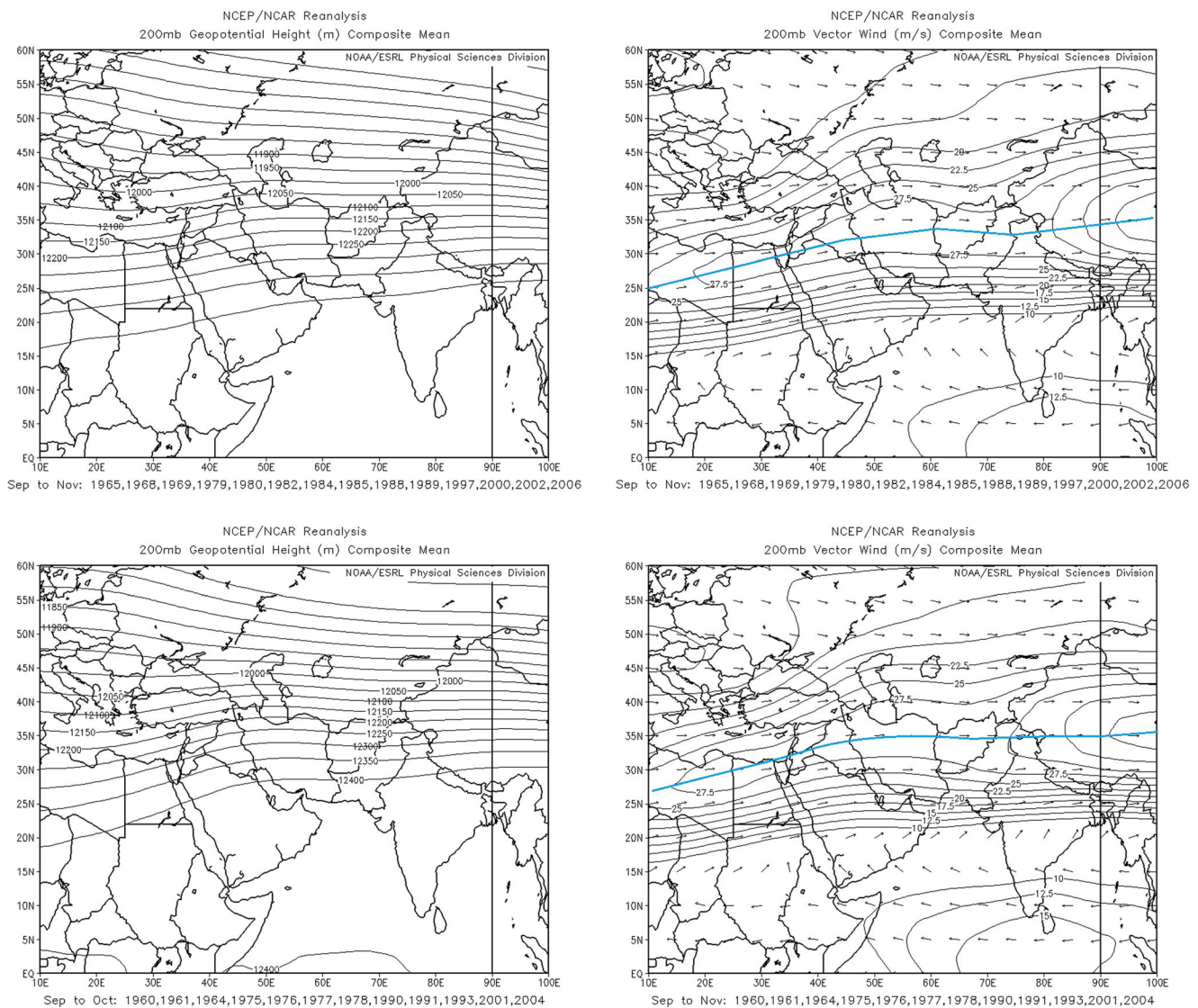


Fig. 6 Average (left) and anomaly (right) of 200 hPa synoptic patterns in early (up) and late (bottom) monsoon withdrawal during September–November

Similar pattern with more clarity are also seen in the middle troposphere layer of 500 hPa. In the late monsoon withdrawal phase, extension of the contour 5850 gpm is seen over Iran (Fig. 7)—even the eastern current in the south of the Arabian Peninsula is clearly observed. A closed contour of high is also settled in south of the Middle East, but in the early withdrawal phase, the easterly waves are gone, and the inclined ridge pattern is moved toward the southern part of Iran and has facilitated penetration of frontal systems. In the late withdrawal phase, the 5735 gpm contour has passed the northern-most part of Iran, whereas in the early withdrawal phase, the passing contour is 5775 gpm which shows a 40 m decrease. Moreover, in the early withdrawal phase, the 500 hPa trough on the Mediterranean Sea has become deeper than it was in the late withdrawal phase of monsoon, and has also moved further

to the south, which helps the formation of early frontal systems in the fall and converts Sudan surface low pressure from thermal to dynamic.

The mean sea level pressure is 1014 hPa in the East Mediterranean during early withdrawal phase, whereas it is 1019 hPa in late withdrawal phase, which makes higher potential for instability in the early withdrawal phase. The mean sea level pressures in the coastline of the Caspian Sea during early and late monsoon withdrawal are 1016 and 1023 hPa, respectively. Such high pressure in the southern coasts of the Caspian Sea can strengthen the northerly humid flow progressing toward north of Alborz mountain range, producing heavy precipitation along Caspian basin. Such condition helps early onset of precipitation in the Caspian basin.

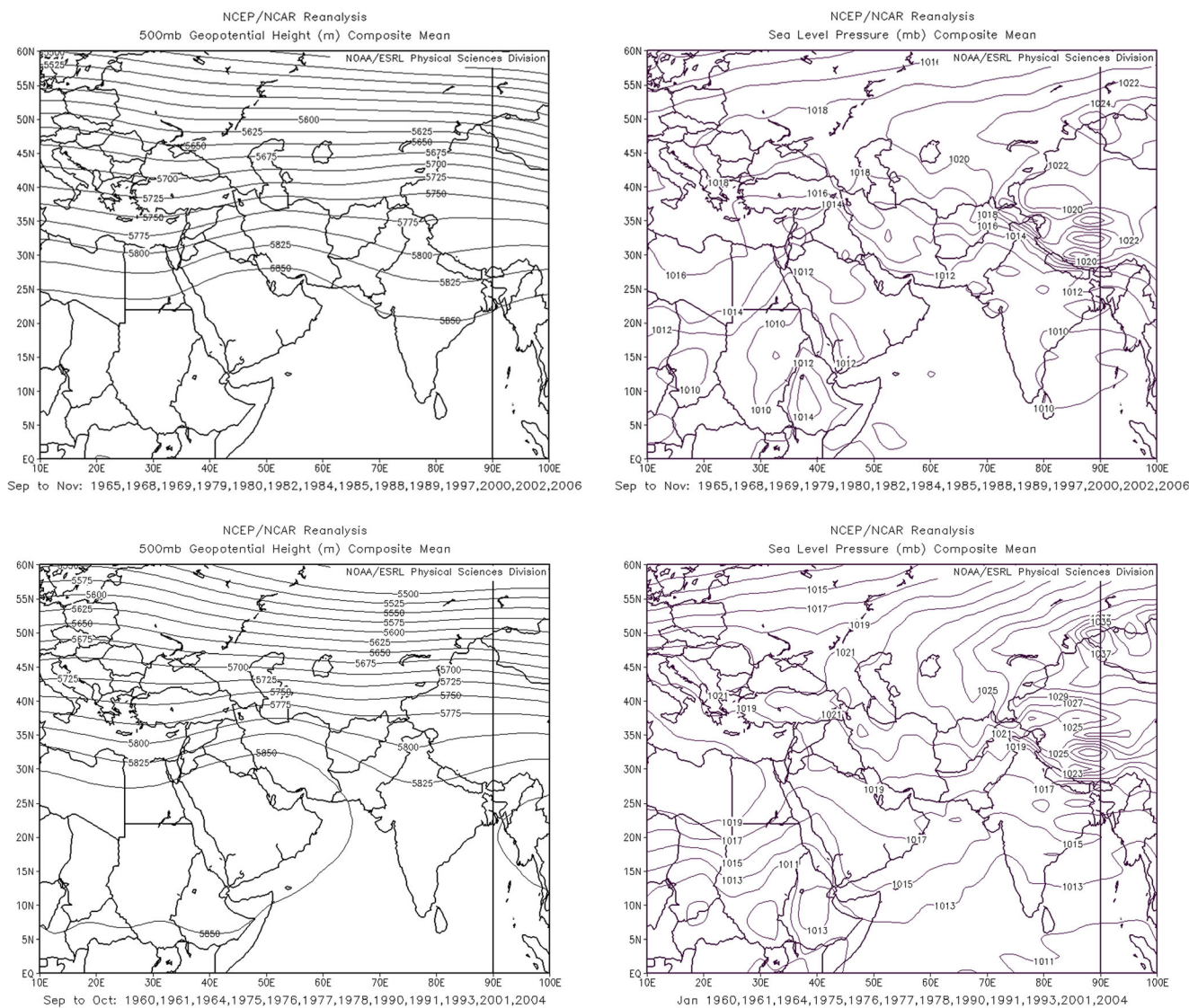


Fig. 7 Average of 500 hPa (left) and mean sea level pressure (right) in early (up) and late (bottom) monsoon withdrawal during September–November

5 Conclusion

The relationship between the Indian monsoon withdrawal date and Iran's fall effective precipitation onset is investigated in this research. A 10-day accumulated precipitation of more than 25 mm has been considered as effective precipitation. Iran's fall precipitation onset data for western, southwestern, southern, eastern, central zones, and the southern basin of the Caspian Sea were separately classified in two groups according to the Indian monsoon's early or late withdrawal dates. Kolmogorov-Smirnov and Pearson's r tests were used to find the probable significant relationship between Indian monsoon withdrawal dates and Iran's fall effective precipitation onset. The significant difference between cumulative distribution of early and late fall precipitation onsets was also studied. Results confirmed that in four out of the six regions of Iran, late/early withdrawal of the Indian monsoon causes a delay/precedence in the fall effective precipitation onset, while no significant relationship was found between fall precipitation onset in central parts of Iran and the Indian monsoon withdrawal. Response of the Caspian Sea basin to the Indian monsoon withdrawal is different comparing to other regions of Iran. Persistence and late withdrawal of Indian monsoon increases the fall precipitation over Caspian Sea basin.

The major reason for the late onset of Iran's fall precipitation in the late Indian monsoon withdrawal conditions may be the persistence of the subtropical high over Iran plateau which prevents the penetration of westerly frontal systems. It strengthens the shallow high pressure over Caspian Sea basin which can increase precipitation over the Caspian region, which is in contrast to the overall response of Iran's climate to the late Indian monsoon withdrawal. Weather stations are not homogeneously distributed in Iran. The area of central arid to semi-arid regions is almost one third of Iran's total area. Lack of adequate weather stations and high amount of precipitation standard deviation made it hard to find out significant correlation between Indian monsoon withdrawal and fall's precipitation onset in the central part of Iran. Furthermore, in the early monsoon withdrawal, the location of 200 hPa jet core which is usually located in the 32.5° north, has moved about 2° toward the south. In the early withdrawal phase of monsoon, the trough is located in the eastern Mediterranean region in 500 hPa level, whereas in the late withdrawal phase, it is settled in the central region of Mediterranean Sea. Moreover, mean sea level pressure patterns in the early withdrawal phase are 4 to 7 hPa less than in the late withdrawal phase.

Such a behavior may challenge the future climate change projected by GCMs regarding the fall precipitation reduction in the southern basin of the Caspian Sea. The reason is that while most of the GCMs predict the reduction of fall precipitation in the southern basin of the Caspian Sea under IPCC emission scenarios, studies done by researchers from the

Indian subcontinent predict the existence of a significant positive trend in monsoon's late withdrawal (Gautman and Regmi, 2013) leading to an increase in precipitation in Caspian region. The proposed mechanism of fall precipitation onset in Iran is being further evaluated using a comprehensive set of historical and reanalysis data based on a state-of-art numerical models.

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