Relationship between Iran Surface Pressure and India Summer Monsoon

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ABSTRACT

The study examines the relationship between Indian summer monsoon rainfall and the Iran surface pressure. The analysis is based on trend analysis, correlations and regressions performed using ERA-Interim data and India Meteorological Department rainfall records based on station data from 1979 to 2015. The summer season shows decreasing trends in surface pressure and increasing trend in rainfall over Iran and NW India, respectively. The decrease in surface pressure over Iran is associated with the anomalous cyclonic circulation with northerlies and westerlies over Persian Gulf and north Arabian Sea, respectively. These intensify the climatological background cross equatorial flow over Arabian Sea and further converge towards NW India with abundant of moisture supply, favoring deep convection with active Indian summer monsoon.

***Keywords**: South-west monsoon, Blocking ridges, Westerly trough, Surface pressure, Very heavy rainfall event and Tibetan High.*

1. Introduction

The Indian summer monsoon (ISM) is one of the largest global phenomena of the general circulation that affects the weather and climate worldwide. The 80% of annual Indian rainfall occurs during this short span of four months from June to September (JJAS). It is also called southwest monsoon (SWM) and have significant temporal and spatial variations. The extreme departures from normal seasonal (JJAS) rainfall, such as large-scale droughts and floods, seriously affect agricultural output and thus the economy of the country. The rainfall distribution over different regions of India during the season JJAS is, however, inhomogeneous due to influence of several local and remote factors. For example, the central Indian plain is influenced by the north-south movement of the monsoon trough, the northwestern part is influenced by the extreme west northwest ward movement of the lows and depressions and mid-tropospheric cyclones (MTCs) over west India (Miller and Keshavamurty, 1968; Mak, 1975).While, the Himalayas are influenced by the interaction between mid-latitude troughs and monsoon circulations, and also the local and external factors play a dominant role in the rainfall variability.

The NW and Himalayan regions of India are considered as a separate macro-region within India (Parthasarathy et al., 1987).Being close to the mid-latitude jet stream location, the large-scale variability of mid-latitude plays an important role over here.The intrusion of an anomalous high-amplitude mid-latitude westerly trough into the NW India, with the interaction with the monsoonal flow, produces very heavy precipitation over NW India. The pioneering works by Ramaswamy (1956, 1962) on the dynamical aspects of monsoon-breaks highlighted the importance of anomalous southward intruding large-amplitude westerly troughs, from the mid-latitudes into the Indo-Pakistan region, in causing the break situations over India. Raman and Rao (1981) noted that prolonged monsoon-break situations are typically associated with upper tropospheric blocking ridges over West and East Asia. Dairaku and Emori (2006) suggested that a large-scale dynamic effect associated with the northward shift of monsoon circulation system during monsoon-breaks could enhance upward motion in the central-eastern parts of the Himalayan foothill area that could result in extreme rainfall events on a regional basis. In the recent years, the northwestern and the western Himalayas had experienced very heavy rainfall during SWM season (JJAS) which has caused very heavy casualties and loss of property in the region.

The main objective of this study is to bring out the teleconnection between summer time (JJAS) Iran surface pressure and NW India rainfall during the period 1979-2015.The surface low pressure over Iran is associated with the anomalous cyclonic circulation which favors deep convection over NW India. The analysis procedures and different datasets used in the present study are briefly described in Section 2. The results pertaining to the characteristic features of Iran surface temperature impact on NW India and the associated circulation patterns are discussed in Section 3 and 'conclusion' in Section 4.

2. Data and Methodology

The global atmospheric reanalysis dataset *ERA-Interim* has been used in this study. ERA-Interim is the latest European Centre for Medium-Range Weather Forecasts (ECMWF) global atmospheric reanalysis of the period 1979 to present (Dee et al., 2011). The data assimilation system used to produce ERA-Interim is based on a 2006 release of the IFS (Cy31r2). The system includes a 4-dimensional variational analysis (4D-Var) with a 12-hour analysis window. The spatial resolution of the data set is approximately 80 km (T255 spectral) on 60 vertical levels from the surface up to 0.1 hPa. The monthly gridded rainfall data from the India Meteorological Department (IMD) have been used (Paiet al., 2014). The IMD data can be obtained by writing email to *ncc@imd.gov.in*. This gridded rainfall data are available since January 1901 at a spatial resolution of 0.25° latitude/longitude over the Indian land mass. This data set is derived from a daily record from about 7000 SRG stations well-spread across the country after incorporating the necessary quality control. After passing through standard quality control tests such as verification of the location information of the gauge station, missing data, coding errors and extreme value check, the station data are interpolated into a regular grid. Similar to the earlier existing SRG-based rainfall data derived by the IMD, this data set also uses the Shepard interpolation method to interpolate point observations into a regular grid.

Throughout the paper, the summer season is defined in the months from June through September. For understanding the dominant modes of variability, simultaneous correlation and regression analyses of rainfall, MSLP and 1000- to 200-hPa geopotential height (GPH) and wind fields (u and v) have been examined.

3. Results and Discussion

Variation and trends in Indian summer monsoon rainfall (ISMR) have significant social and political impacts. The trend analysis, for the period 1979-2015, for the seasonal (JJAS) rainfall over India shows

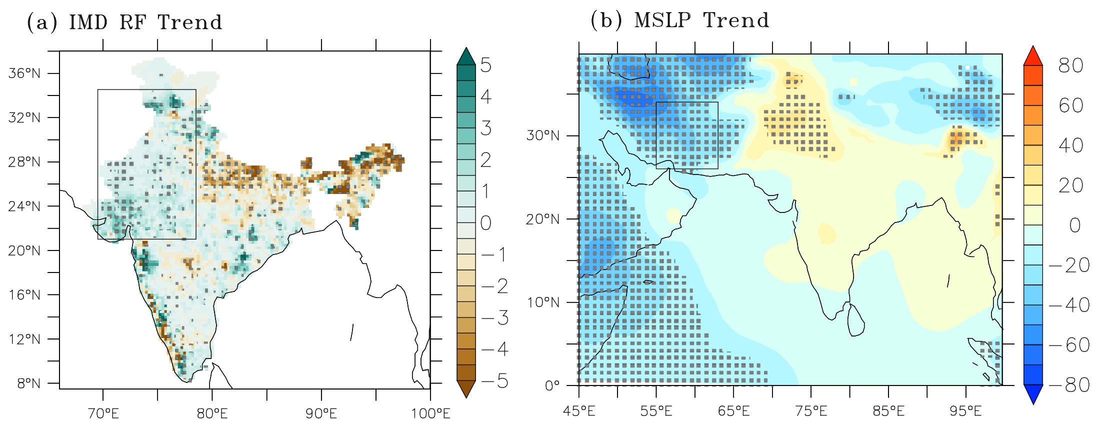

Figure 1: JJAS seasonal trend analysis for (a) Indian rainfall and (b) MSLP for the period 1979-2015. Areas of 95% significance level are shaded by tiny grey dots. The areas considered for NWISM and ISLP are represented by the boxes over NW India and Iran, respectively

significant increasing trend over some pockets of NW India, central India and Western Ghats and decreasing trend over north-east India suggesting strengthening of ISM (Fig. 1a).

Apart from this, as we know, the NW India had experienced some of the very heavy rainfall events in the recent years during the season, which had caused very heavy casualties and loss of property in the wide

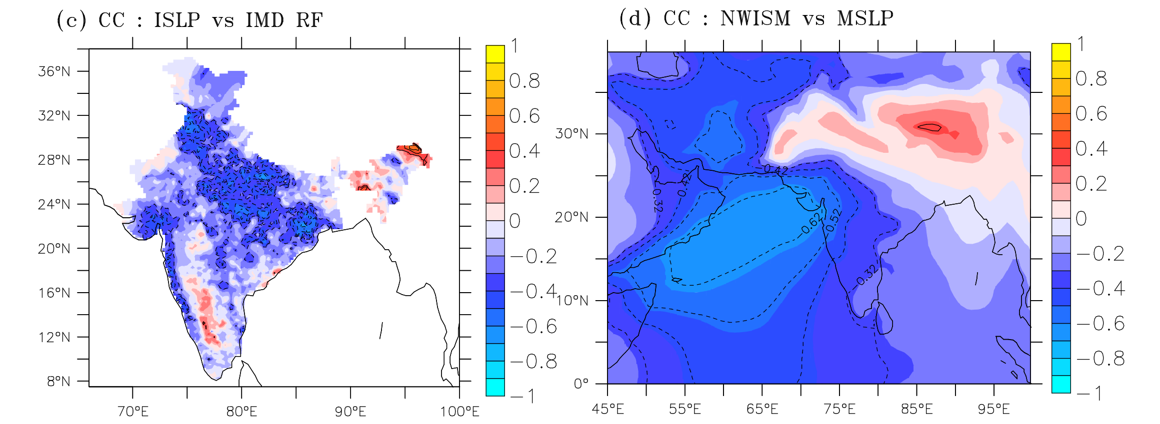

Figure 1(c): The simultaneous CC between ISLP and gridded rainfall over India and (d) CC between NWISM and gridded MSLP for the period 1979-2015.The areas considered for NWISM and ISLP are represented by the boxes over NW India and Iran, respectively

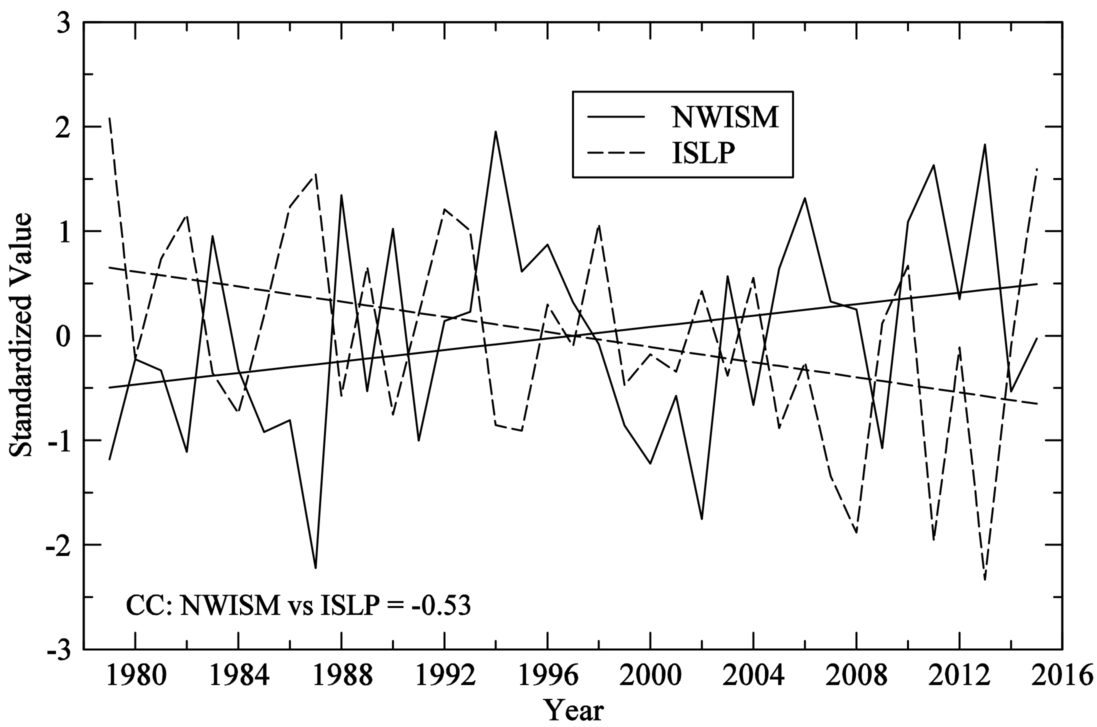

Figure 2: Year-to-year variation of NWISR (continuous line) and ISLP (dash line) indexes expressed as the standardized values. The straight continuous and dash lines are linear trend lines for NWISM and ISLP, respectively

spread region of NW India. Similarly, the trend analysis for the seasonal (JJAS) MSLP have been carried out for the period 1979-2015 shows (Fig. 1b) significant decreasing trend over Iran.

The core of maximum MSLP decreasing trend, in the proximity of NW India, is observed over Iran and has been considered for further examination to find its association with ISMR over NW India. Two indexes have been prepared by averaging the boxes69.5°E-

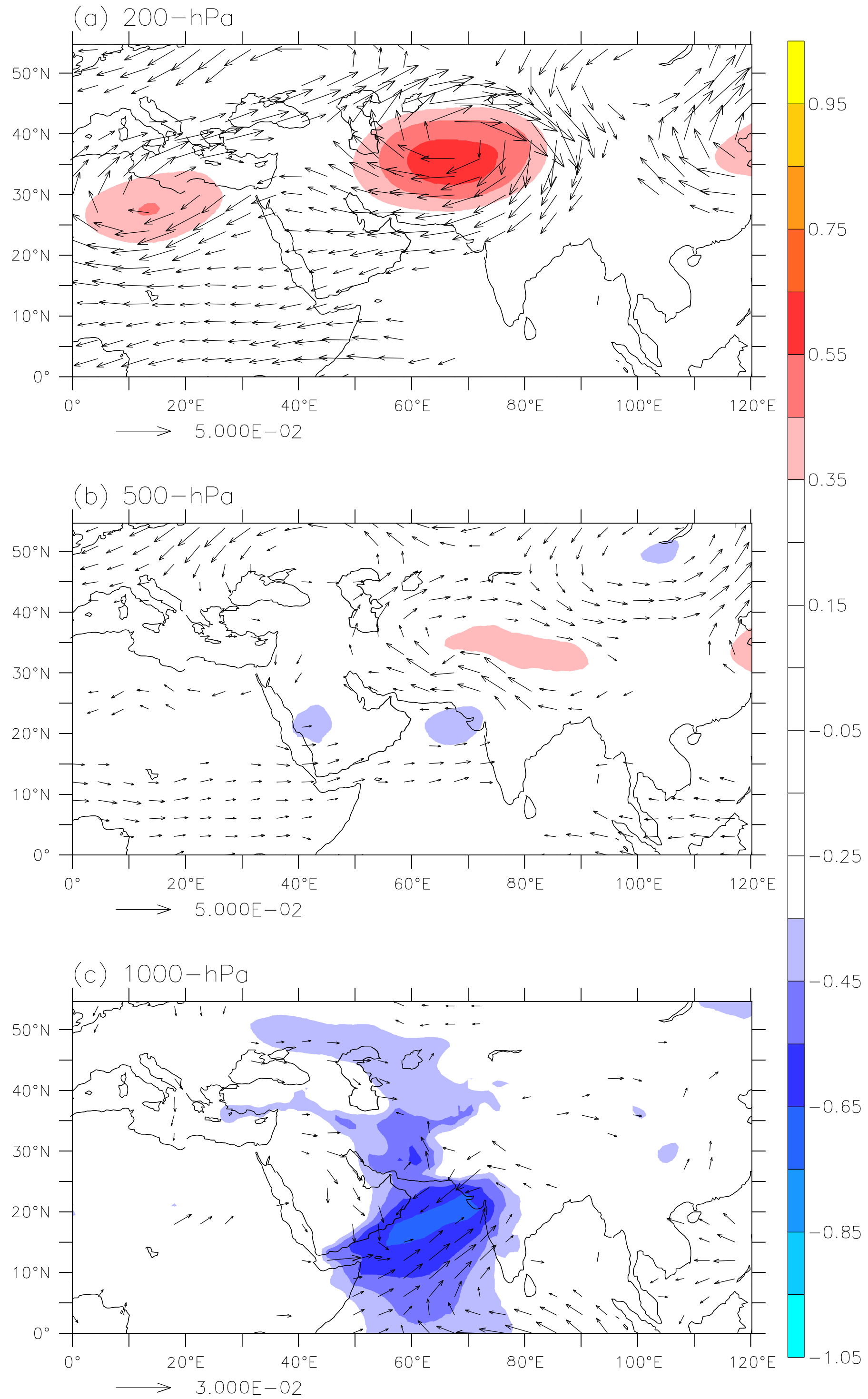

Figure 3: JJAS simultaneous CC between NWISM and gridded GPH and regression of winds with I2MT at (a) 200-, (b) 500- and (c) 1000-hPa levels for the period 1979-2015. GPH (m) are shown as shaded and winds as arrows (m/s)

78.5°E; 21°N-34.5°N and55°E-63°E; 26°N-34°N of seasonal (JJAS) rainfall and MSLP, named hereafter as NWISM and ISLP, respectively. Since several of the data series shows significant trends over the data period, all the data series have been de-trended before carrying out the correlation coefficient (CC) and regression analysis. The regression of the ISLP index onto gridded rainfall data (Fig. 1c) shows significant negative CC over north, NW and Western Ghats and negative CC over north-east and southern peninsular India. The CC between NWISM and gridded MSLP data shows (Fig. 1d) shows significant negative anomaly over Iran and Arabian Sea.

Figure 2 shows the year-to-year variation of NWISM and ISLP indexes for the period 1979-2015. The NWISM shows increasing trend of 0.0276 mm/day of rainfall, the trend is not significant at 95% level. While, the ISLP shows decreasing trend of -0.0364 hPa/year of pressure, the trend is significant at 95% level. The CC between both the de-trended indexes is -0.53, significant at 99.9% level. This suggests the robust relationship between NW India summer rainfall and Iran summer surface pressure.

Figure 3 shows the CC pattern between gridded GPH and NWISM and regression of zonal and meridional winds onto NWISM for different tropospheric levels at 1000, 500 and 200 hPa. The GPH anomalies are shown as color shade and wind anomalies as black vectors. The upper troposphere (200 level) GPH and wind anomalies (Fig. 3a) shows significant positive GPH anomalies associated with anti-cyclonic circulation anomalies over NW of India, Sahara Desert and East Asia.

Positive GPH anomaly NW of India displays upper tropospheric outflow of the strong convection over India, having tilted baroclinic structure. The positive GPH anomaly over East Asia is due to westerly wave train excited by excess activities of ISMR over India, extending to East Asia. At 500 hPa (Fig. 3b) significant negative GPH anomaly over north-east head of Arabian Sea associated with the anomalous cyclonic circulation over west India are observed.

The negative GPH anomaly over west India suggest the intensification of MTCs which are one of the main synoptic scale system causing heavy rainfall over west and NW India. At 1000-hPa (Fig. 3c), the significant negative GPH anomalies over north Arabian Sea and Iran are observed.

The positive GPH anomaly at the upper troposphere has converted into negative GPH anomaly at the lower troposphere over Iran as the troposphere is having baroclinic structure over there. The winds anomalies display northerlies and westerlies over Arabian landmass and Arabian Sea, respectively. The westerly anomaly over Arabian Sea intensifies the climatological background cross-equatorial flow over Arabian Sea. Arabian Sea acts as the source of moisture supply. These winds are converging over NW India and supplying with abundant of moisture for the deep convection, which intensifies ISMR. This suggest that the excess NWISM is associated with the intensification of Tibetan High westward, intensification of MTCs over west India and intensification of shallow low pressure anomalies over north Arabian Sea and Iran. The north Arabian Sea acts as moisture supply. Hence it is clear that there is a close relationship between Iran surface pressure and intense India summer monsoon rainfall.

Similarly, Figure 4 shows the CC pattern between gridded GPH and -ISLP and regression of zonal and meridional winds onto -ISLP for different tropospheric levels at 1000, 500, and 200 hPa.

The -ISLP series is the multiplication of ISLP with -1 to show the results consistent with NWISM, as they are anti-correlated. The GPH anomalies are shown as color shade and wind anomalies as black vectors. At 200 (Fig. 4a) level, the GPH anomalies show significant positive anomaly over south of east Mediterranean, Iran and east Asia, with maximum anomaly over Iran.

This significant positive GPH anomaly over Iran intensifies and shifts the Tibetan High westward. The zonally elongated Tibetan High then dynamically weakens in the middle and is typically associated with upper tropospheric blocking ridges over West and East Asia (*Raman and Rao*, 1981). These blocking

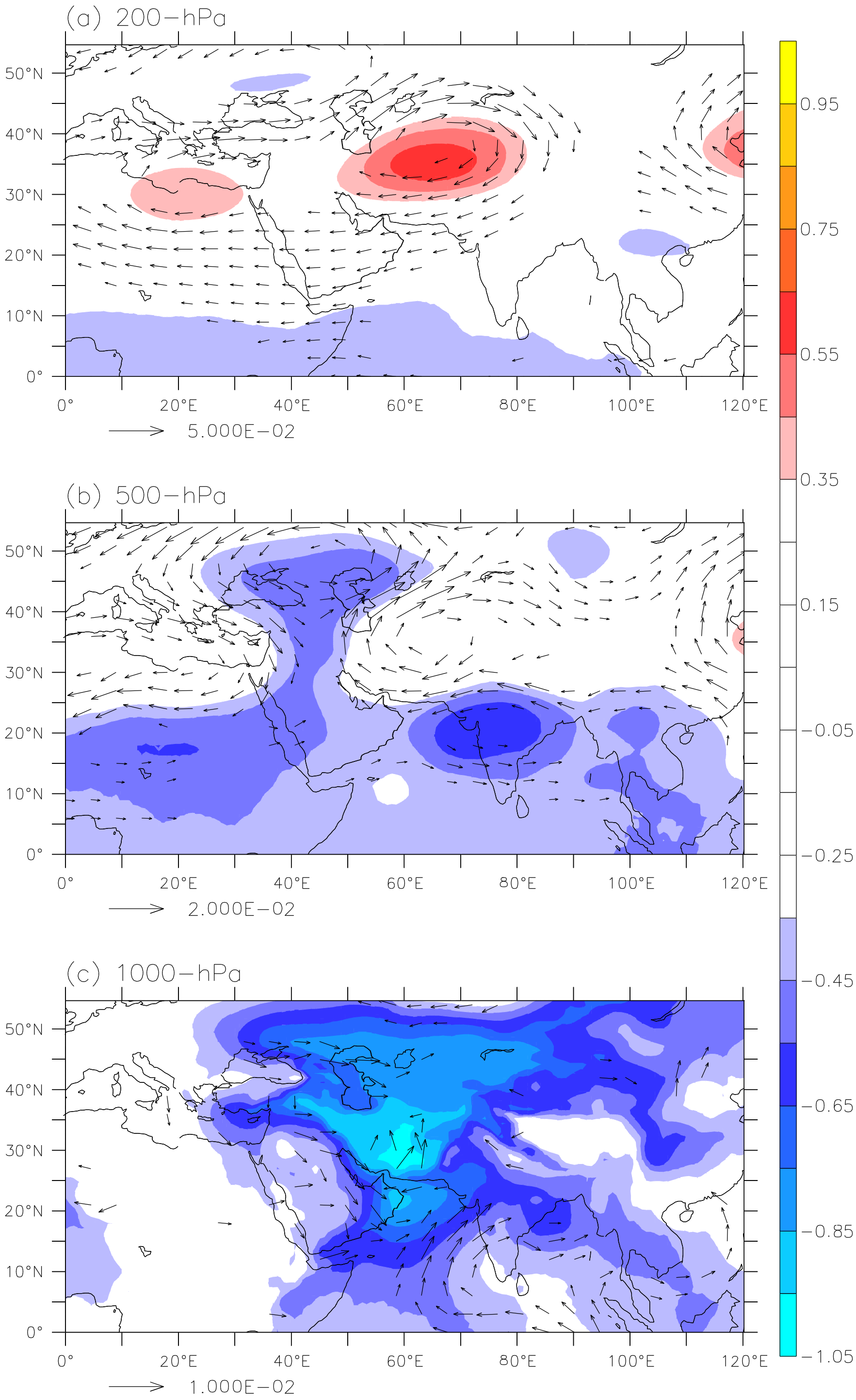

Figure 4: Same as Figure 3 but for -ISLP

ridges dynamically allow the anomalous southward intruding large amplitude westerly troughs, from the mid-latitudes into the north Indian subcontinent region (Ramaswamy, 1956, 1962).

At 500- (Fig. 4b) level, the negative GPH anomaly is observed over west India associated with the cyclonic circulation anomaly, which is consistent with Figure 3b. This suggests intensification of mid-tropospheric cyclone (MTC) over west India is related to low pressure over ISLP.

The 1000 hPa level (Fig. 4c) shows significant low pressure anomaly over Iran and central India.

The lower-level (1000 hPa) winds show cyclonic circulation anomaly with northerlies over east Saudi Arabia, south westerlies over north Arabian Sea and southerlies over Afghanistan and Pakistan. These wind anomalies are the source of moisture supply over NW India, as they are coming from warm desert land, they can hold more moisture after blowing over north Arabian Sea. Previous study by Yadav (2009, 2016) has shown this relationship between ISMR and Iran surface pressure. The southerlies observed over Afghanistan and Pakistan hinders the intrusion of mid-latitude cold and dry air towards Indian subcontinent favoring excess monsoon over India.

Studies by Ramaswamy (1956, 1962) and Raman and Rao (1981) had explained that the prolonged monsoon-break situations are typically associated with upper tropospheric blocking ridges over West and East Asia. During these conditions the monsoon trough shifts towards the foot hills of Himalaya. The sub-divisions near to foot hills of Himalaya only gets copious of rainfall and rest of country remains dry. A recent study by Yadav 2016 has stated that, in the recent decades, the ridges of the mid-latitude wave train over Iran had deepened the surface pressure over Iran. This decreasing trend in surface pressure had intensified the anomalous cyclonic circulation with intense northerlies and westerlies over Persian Gulf and north Arabian Sea, respectively. These winds converge towards NW India with abundant of moisture supply, favoring deep convection. This relationship was not significant prior to 1976 major climate shift observed in the Indo-Pacific Ocean (Nitta and Yamada, 1989; Graham, 1994; Trenberth and Hurrell, 1994).

4. Conclusions

In this study, it has been found that the decreasing trends of Iran surface pressure and India summer monsoon rainfall during JJAS season are closely related. The deepening of surface pressure over Iran has shifted the ISM westward with more floods over NW India and droughts over NE India in the recent decades. NW India had experienced very heavy rainfall events during the summer season in the recent years which had led to devastating floods, affecting millions of people by destruction of property, livelihood and infrastructure. These events were associated with the anomalous southward intrusion of large amplitude westerly troughs, from mid-latitudes into the NW Indian subcontinent and had produced copious rainfall over some part of NW India subcontinent and wide spread floods over the region.

The decrease of surface pressure over Iran intensifies the northerlies and westerlies are intensified over eastern Saudi Arabia and north Arabian Sea, respectively. These winds converge towards NW India with abundant of moisture supply, favoring deep convection. It also increases the frequency and intensity of MTCs over west India. These MTCs are one of the main systems for producing heavy rainfall over NW India. The increased GPH anomaly at upper troposphere intensifies the Tibetan High westward, accordingly shifting the monsoon rainfall westward. It also dynamically develops into blocking ridges over East and West Asia and an anomalous high-amplitude mid-latitude trough intrusion into NW India favoring very heavy rainfall events over NW India.The results from this investigation may help in improving the understanding and prediction of the NW India summer monsoon rainfall on inter-annual time scales.

Acknowledgments

IMD gridded data have been obtained by writing email to ncc@imd.gov.in and other data have been taken from Web sites. All data sources are duly acknowledged. Computational and graphical analyses required for this study has been completed with the free software NCL, Ferret and xmgrace.

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