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Atmospheric circulation patterns of heavy precipitation in warm season in Iran

SOHRAB GHAEDI

Assistant professor of climatology, Shahid Chamran University of Ahvaz, Iran

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e mail : sohrabghaedi@gmail.com

सार - वर्ष के गर्मी के मौसम में पश्चिमी पवनों के ऊँचे अक्षाशों की ओर बढ़ जाने से ईरान के अधिकांश भागों से पश्चिमी चक्रवात चला जाता है और वर्षा में काफी कमी आ जाती है कुछ निशिचत परिस्थितियों में भारतीय मानसून ग्रीष्म प्रणाली अरब सागर की ओर फैलती है और उस क्षेत्र में सकारात्मक भ्रमिलता को उत्पन्न करती है। कभी-कभी अरब सागर में बने चक्रवात ईरान की ओर मुड़ जाते है और उससे वर्षा होती है। विशेष रूप से दक्षिण पूर्व में वर्षा होती है। इस शोध पत्र में ईरान में गर्मी के मौसम (जून से अगस्त) में भारी वर्षा पैटर्नों का पता लगाया गया है। यदि एक दिन में कम से कम 10 मिली मीटर वर्षा भी हो जाती है तो इसे भारी वर्षा के रूप में परिभाषित किया जाता है। इस अवधि के दौरान धरातल और भूविभव ऊँचाई के मध्य स्तर में आँकड़ो के सामूहिक विशलेषण से धरातल स्तर पर पाँच पैटर्नों और मध्य स्तर में छह पैटर्नों का पता चलता है। धरातल स्तर के सभी पैटर्न बंगाल की खाड़ी से लेकर दक्षिण पश्चिमी ईरान में लो-लाँग दबाव बनाता है जो अरब सागर के चक्रवातीय प्रणाली को स्थानांतरित कर सकता है और ईरान में वर्षा उत्पन्न कर सकता है। मध्य स्तर पैटर्नों पर उप-उष्णकटिबंधीय उच्च दाब प्रबल होता है और यह पूर्व की ओर बढ़ता है और यूरेशियाई क्षेत्र में डाउनस्ट्रीम रॉस्बाए तरंग के स्रोत के रूप में कार्य करता हैं। धरातल स्तर पर प्रणाली में उष्णकटिबंध से नमी के आने को दर्शाता है। हालांकि ईरान में आर्द्रता संसाधन काफी जटिल है। 700 हैक्टापास्कल पूर्वाभिसुखी तरंग आर्द्रता से इस स्तर पर आर्द्रता के मॉनसून प्रणाली के पश्चिमी आर्द्रता स्रोत से स्थानातरित हो जाती है। पैटर्नों के निर्धारण से मानसून वर्षण के होने की प्रक्रिया को बेहतर ढंग से समझने, उसके पूर्वानुमान और उसके इस्तेमाल के लिए योजना बनाने में सहायता मिल सकती है।

ABSTRACT. In the warm season, with migration west winds to higher latitudes and thus exiting west cyclones from most parts of the Iran, precipitation decreased severely. In certain conditions expands Indian monsoon summer systems to Arabian Sea and create positive vorticity over the area. Sometimes cyclones formed in Arabian Sea curves to Iran and occurs precipitation, especially in the Southeast. In this paper were determined heavy precipitation patterns in the warm season (June to August) in Iran. If at least 10 mm of precipitation were observed at one day, the event was defined as heavy. A cluster analysis on the data in surface and middle level of geopotential height during the period showed five patterns in surface level and six patterns in the middle level. In all patterns of surface level established Low-long pressure from the Bay of Bengal to the southwest of Iran that can transfer Arabian sea cyclonic systems and produce precipitation over Iran. At the middle level patterns, the subtropical high pressure was stronger and expanded east ward and act as a source of downstream Rossby wave train over Eurasian region. Moisture flux convergence maps at the surface level show moisture enter from the tropics to the system, however humidity resources in Iran are very complicated. In 700 hPa east ward current humidity show in this level humidity transfer from west humidity source to monsoon systems. Identifying patterns can help better understand the process of formation of monsoon precipitation, forecasts and planning to use of it.

Keywords: Atmospheric circulation patterns, Heavy precipitation, Cluster analysis, Moisture flux convergence, Warm season, Iran.

1. Introduction

Precipitation is the result of atmospheric complex interactions. Temporal and spatial variability of rainfall is very high and it is more severe in arid regions. Iran, with 250 mm average precipitation per year, it also has extreme variability. In cold and warm seasons Humidity sources of Iran are different. In cold season humidity is often from Mediterranean and Red Sea and in warm season especially in the southeastern regions is more from monsoon systems. During the boreal summer season the southwest monsoon brings heavy rainfall to the Indian landmass. It is a regular annual phenomenon and one of the largest global phenomena of the general circulation (Yadav, 2016). The Asian monsoon is an enormous circulation system, which consists of two major monsoon subsystems: the Indian monsoon and the East Asian monsoon (Yihui and Chan, 2015). The advances in Asian monsoon studies have been comprehensively reviewed by leading scientist's publications (Goswami & Xavier, 2005; Mohapatra *et al.*, 2008). The monsoon is a manifestation of the annual cycle (Goswami & Xavier, 2005; Zeng and Li, 2002; Goswami *et al*., 2006; Wang and Ding, 2008). Solar radiation forcing is sinusoidal in nature, the seasonal cycle of the Asian monsoon system is more complex and includes both relatively smooth and abrupt changes (Tao and Chen, 1987; Ninomiya & Murakami, 1987; Matsumoto, 1992 & 1997; Ding, 1994 & 2004; Wang & Linho, 2002; Minoura *et al*., 2003; Ueda, 2005; Chang *et al*., 2005a&b).The summer monsoon rainfall over northeast India mostly depends on the synoptic systems over the region and neighborhood and the convection due to the interaction of orography with the synoptic and sub-synoptic scale systems. In the warm season with migration west winds to higher latitudes and thus exiting west cyclones from most parts of the Iran, the amount of rainfall in many areas is very low and even zero. In this season subtropical high pressure are displaced to high latitudes. One of the subtropical high is north Atlantic high. The Azores high (north Atlantic high) act as a source of downstream Rossby wave train over Eurasian region having barotropic structure consisting of a successive pressure trough and ridge (Yadav, 2009a).The subtropical high is above boundary level to the top the troposphere, at the surface it is low pressure area (Yadav, 2009b, 2017). The position of the highs varies between 40° N to 40° S. Subsidence is very common in subtropical high-pressure zones and therefore a lack of rainfall & a high evaporation causes the world's greatest dessert (Lamb, 1972). The low pressure area over Iran is the integral part of Indian summer monsoon. It is defined as thermal low because lack of moisture. Sometimes the Indian summer monsoon low pressure system travel to these regions, sometimes the Arabian Sea cyclonic circulation system recurve toward Iran and Oman and produce rains (Yadav, 2016). In this paper with environmental to circulation synoptic methods, were determined surface and mid-level circulation patterns to heavy precipitation of Iran. Identifying patterns can due to predict and reduce the floods damage in warm season.

2. Data and methodology

First, Barry and Perry (1973) defined synoptic climatology as the study of the relationship between the atmospheric circulation and local or regional climates. Later, Yarnal (1993) showed in his book that contemporary synoptic climatologists often utilize climatically related variables and refined the Barry and Perry definition stating that synoptic climatology relates the atmospheric circulation to the surface environment. Two fundamental approaches to classification are adopted: 'circulation to environment' or 'environment to circulation'. In the first approach, a correspondence to atmospheric circulation classification is performed and then related to an environmental phenomenon (Lana, 2007). In the second method, the circulation classification is carried along specific environment-based criteria set for a particular environmental phenomenon. In this paper was used from environmental to circulation method.

For the determination of heavy precipitation patterns in warm season, first was obtained precipitation data from meteorology organization of Iran. The studied period was 55 years from synoptic, climatology and precipitation stations during the study period 21 March, 1961 to 31 December, 2014. Precipitation more than 10 mm from the beginning of June until the end of August was chosen. To identification the circulation patterns, geo-potential data in surface and middle level from the National Center for Atmospheric Research of United States (NCAR/NCEP) for the period from 21 March, 1961 through 31 December, 2014 in the covering grid point 0 to 50 northern degrees (Lat.) and 0 to 100 eastern degrees (Lon.) has been used (Kalnay *et al*., 1996). Daily data has been available from 1948 to the present and at 0000, 0600, 1200 and 1800 UTC, in this station. With a spatial resolution 2.5 * 2.5 degree, this territory involves 861 cells. A cluster analysis on the data in surface and middle level was done. For cluster analysis, first determined distance by Euclidean method.

The immediate consequence of this is that the squared length of a vector $x = [x_1.\ x_2]$ is the sum of the squares of its coordinates and the squared distance between two vectors $x = [x_1.\ x_2]$ and $y = [y_1.\ y_2]$ is the sum of squared differences in their coordinates. To denote the distance between vectors x and y we can use the notation $d_{x,y}$ so that this last result can be written as (Greenacre & Primicerio, 2013):

$$d_{xy}^2 = (x_1 - y_1)^2 + (x_2 - y_2)^2 \tag{1}$$

For calculate the link between distance was used from Ward's method. A and B, is how much the sum of squares will increase when we merge them:

$$\Delta(A,B) = \sum_{i\in A\cup B} ||\overrightarrow{x_i} - \overrightarrow{m_{A\cup B}}\,||^2 - \sum_{i\in A} ||\overrightarrow{x_i} - \overrightarrow{m_A}\,||^2 - \sum_{i\in B} ||\overrightarrow{x_i} - \overrightarrow{m_B}\,||^2 \tag{2}$$

$$\Delta(A,B) = \frac{n_A n_B}{n_A + n_B} ||\overrightarrow{m_A} - \overrightarrow{m_B}||^2 \tag{3}$$

where, $\overrightarrow{m_j}$ is the center of cluster j and n_j is the number of points in it, Δ is called the merging cost of combining the clusters A and B.

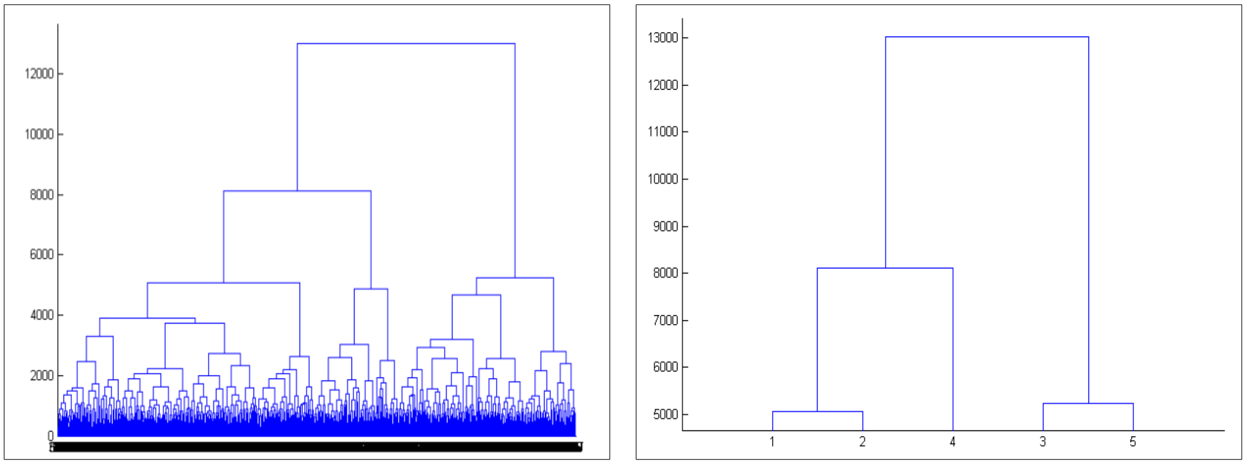

Fig. 1. Tree diagram of geopotential height in surface level

TABLE 1

The occurrence percentage of patterns in surface level

	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5
percentage of occurrence	11	38.4	24.3	16.4	9.9

TABLE 2

The occurrence percentage of patterns in middle level

	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5	Pattern 6
percentage of occurrence	15.3	24.5	25.4	15.4	8	11.3

Determine the number of patterns is done on observation and experience.

To determine humidity source to heavy precipitation in study period, use from moisture flux convergence concept (Ghaedi & movahedi, 2013). Moisture flux convergence show humidity transmission in grams per kilograms in day:

Advection humidity

$$HA = -\vec{v}\,.\nabla q \qquad (4)$$

Humidity gradient

$$\nabla q = \frac{\partial q}{\partial x}\hat{\imath} + \frac{\partial q}{\partial y}\hat{\jmath} \qquad (5)$$

Moisture convergence

$$MC = -q\left[\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right] \qquad (6)$$

Moisture flux convergence function:

$$-\nabla\,.(q\vec{v}_h) = -\vec{v}_h.\nabla q - \nabla q.\vec{v}_h.1000.24.3600 \qquad (7)$$

Where, q is special moisture in gram per kilogram, $\vec{v}$ horizontal wind vector, $\nabla = \frac{\partial}{\partial x}\hat{\imath} + \frac{\partial}{\partial y}\hat{\jmath}$,$\vec{v}_h = (u, v)$, u zonal and v meridional wind component ($m.s^{-1}$).

3. Discussions

Statistical analysis of heavy precipitation occurrence (more than 10 mm) in study period showed the frequency of occurrence of precipitation in June is more than other months (July and August). Of the total 2114 occurrence of heavy precipitation, 735 precipitation in June, 667 in July and 714 in August has occurred. To determine the patterns in surface level, a cluster analysis on surface geopotential height data was performed. Fig. 1 shows cluster analysis in surface level. Tree diagram in left present all clusters and in right selected clusters. It seems than can be

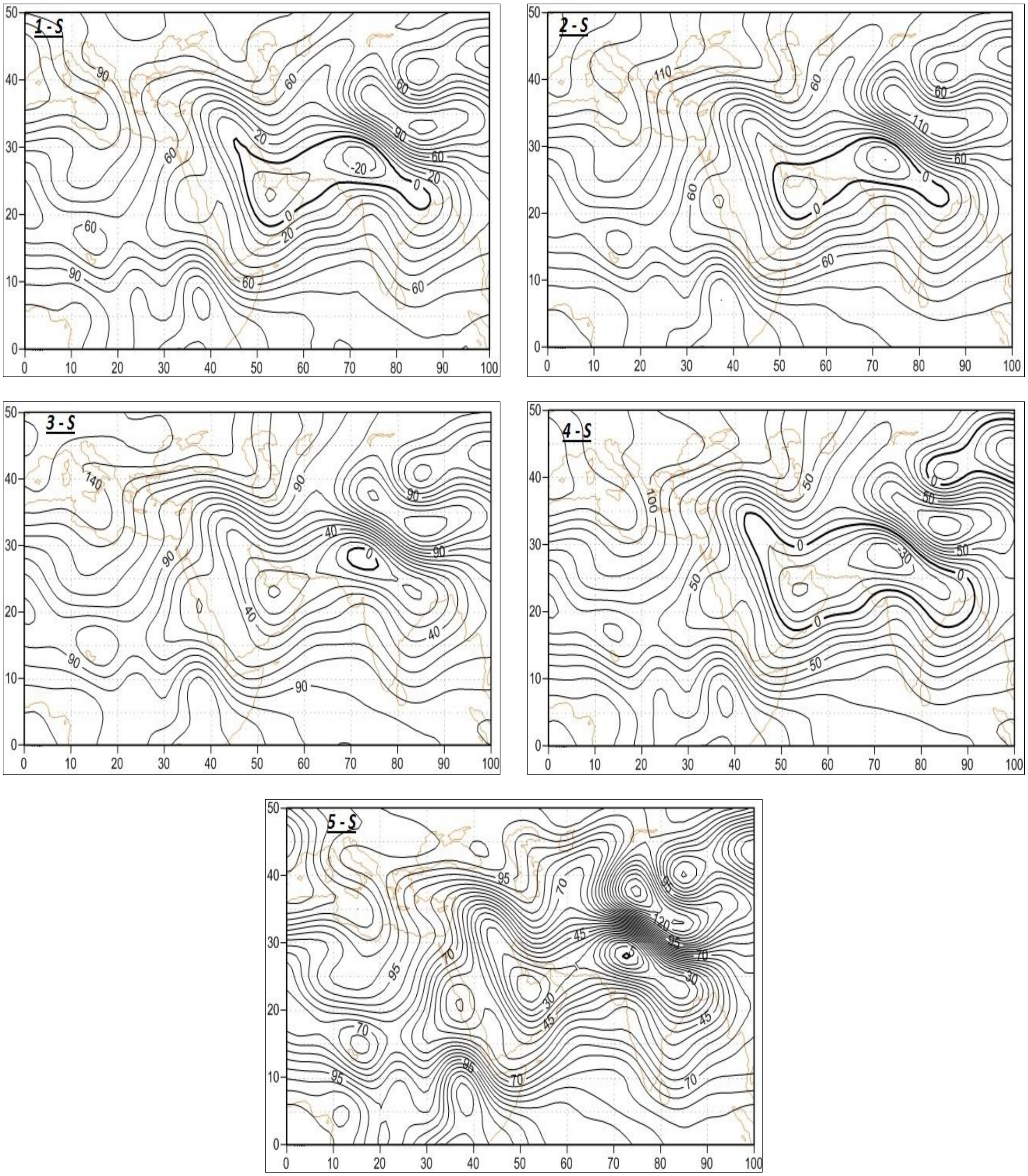

Fig. 2. Atmospheric circulation patterns in surface level. Indian Monsoon summer has influenced west ward in all patterns and has expanded in southern Iran. Its influence transfer Arabian Sea humidity toward Iran. A high pressure formed in the north of Himalayas (High pressure Tibet). Between the two systems, counters are very compact. In fact, Himalayas cause the separation between these two Opposition systems.

detected 5 patterns for this level. Table 1 presented the occurrence percentage of each pattern in surface level. Most events related to the second pattern with 38% and fifth pattern with about 10% is least.

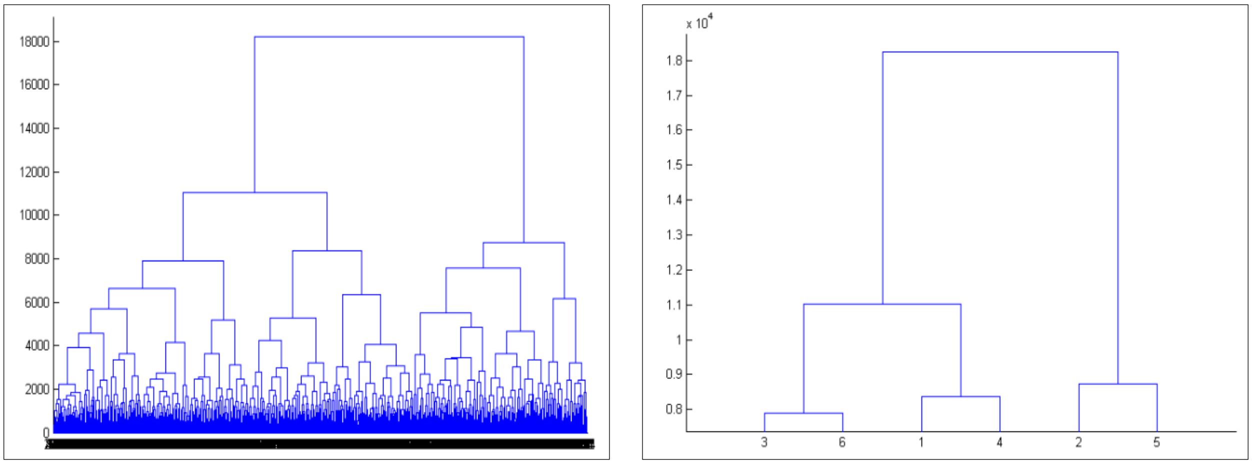

Fig. 3. Tree diagram of geopotential height in mid-level

Fig. 2 shows atmospheric circulation patterns of surface level. The numbers on contours presents geopotential height value (m). Whatever numbers in center low pressure be smaller that is stronger, thus forth and first patterns is stronger other patterns. In all patterns Indian monsoon summer expand from Bay Bengal to southwest of Iran. This low pressure transfer Arabian Sea humidity to the east. Its orientation is in accordance with the direction of the Persian Gulf and its moisture reinforced the system. A high pressures observed in the north of the Himalayas (high pressure Tibet) and one over Mediterranean Sea. Himalaya's mountain Separating role plays between high pressure in the north and low pressure in the south and the most compact contours are located there. The establishment of east - west Himalayas is provided conditions for the formation of the monsoon system in this area.

To determine mid level patterns, a cluster analysis was done on geopotential height data in 500 hpa level. Many of the synoptic atmospheric phenomena occurrence related to the circulation patterns in the middle level. In fact, the middle level be known as synoptic phenomenon controller. It seems that six patterns can be determined for this level. Tree's diagram is presented in Fig. 3. Table 2 shows the occurrence percentage of each pattern in middle level. Third and second pattern had most events respectively and fifth pattern had the least.

The subsidence at the upper and middle troposphere causes high pressure at the upper and middle troposphere. Increasing surface temperature due to formation low pressure in lower troposphere. Western winds displaced pole ward and leave most of the Iran. In certain conditions with transfer humidity air from Arabian Sea by Indian monsoon summer provide rainfall for Iran, especially in south-east regions. When subtropical high be stronger displaced eastern ward and expanded Iran and India at middle and higher levels. This high is a bridge between Eurasian waves and Indian monsoon summer. With establishment of easterlies current in warm season in region, Gang low pressure with transfer humidity from Arabian Sea to region, provide precipitation. Fig. 4 shows the patterns in midlevel. In these patterns contour with a height 5775 meters, was known as the subtropical high pressure. In all patterns, the subtropical high pressure have been stronger and expanded east ward over Iran at the higher levels. Trough and ridge Successive in Rossby Waves be seen in middle latitudes.

Moisture flux convergence component determines transmission, divergence and convergence humidity. Fig. 5 shows it in surface and 700 hPa level. Transfer of moisture in the surface level is very more severe and its direction is from southwest to northeast. In surface level strong current transfer humidity from warm tropical water to the south of Iran. Moisture transfer of warm tropical waters to higher latitudes and formed southwest monsoon season (Yadav, 2009b). A moisture convergence center formed in south and north of Himalayas. Other source humidity is upper latitude spatially Caspian Sea. Moisture divergence center over Caspian Sea transfer humidity to lower latitude. At 700 hPa level moisture current is east ward over Arabian Sea and Indian Ocean and the amount of moisture decreased. Humidity currents converge in southern Iran and have a counterclockwise rotation. East ward current humidity show in this level humidity transfer from Mediterranean Sea, Red Sea, Arabian Sea and Persian Gulf to Iran and east India.

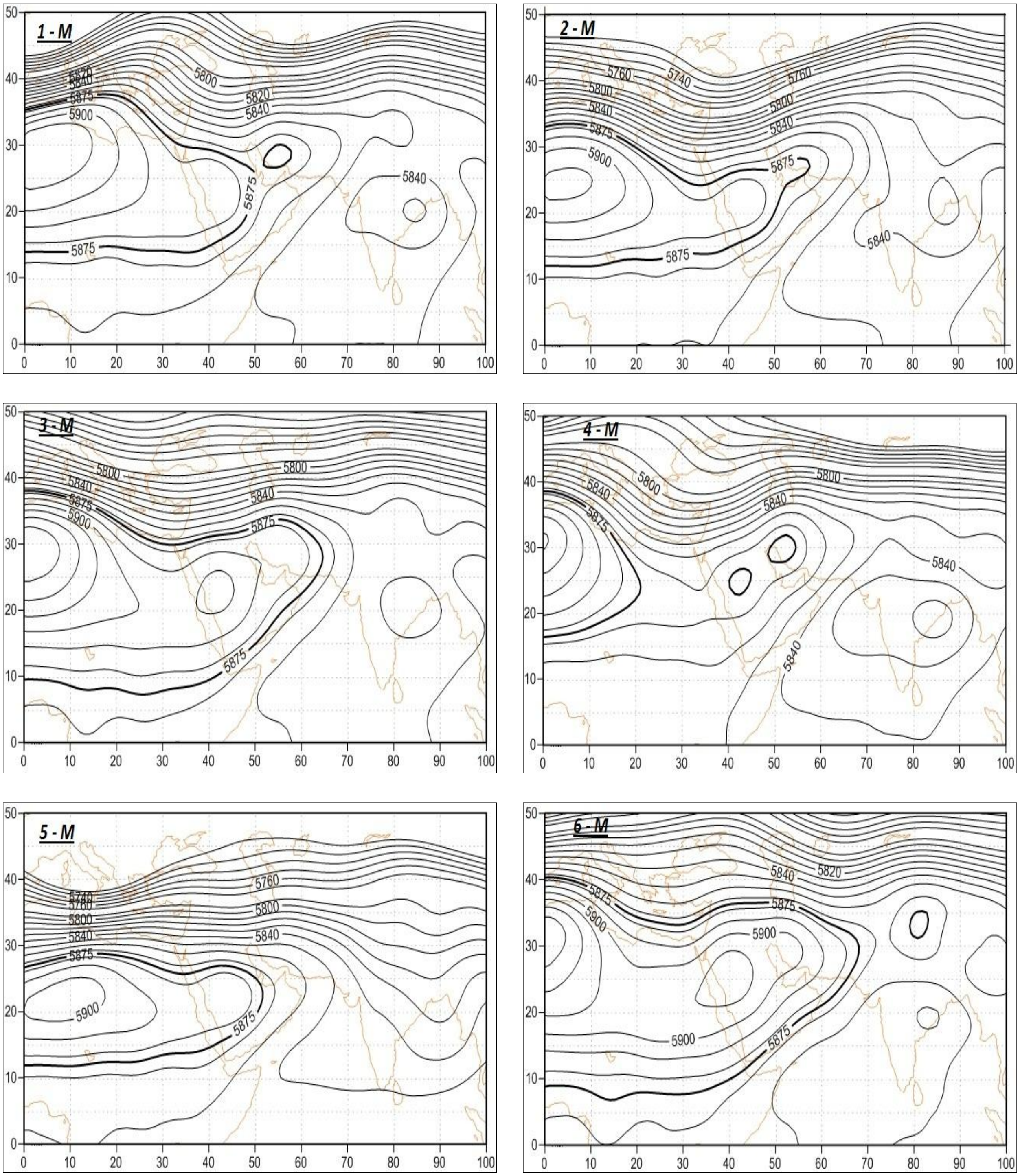

Fig. 4. Atmospheric circulation patterns in middle level. The contour with the value of 5775 m as the subtropical high pressure index marked on all patterns. In most patterns, the subtropical high pressure was stronger and expanded east ward over Iran and transfer downstream Rossby wave train over Eurasian region

Also, the successive troughs and ridges of the Rossby waves through east ward expanding subtropical high, transfer humidity to Indian Monsoon summer systems. Centers of moisture convergence and divergence were formed over north and south Himalayas respectively, while on the surface level over the Himalayas formed a convergence center.

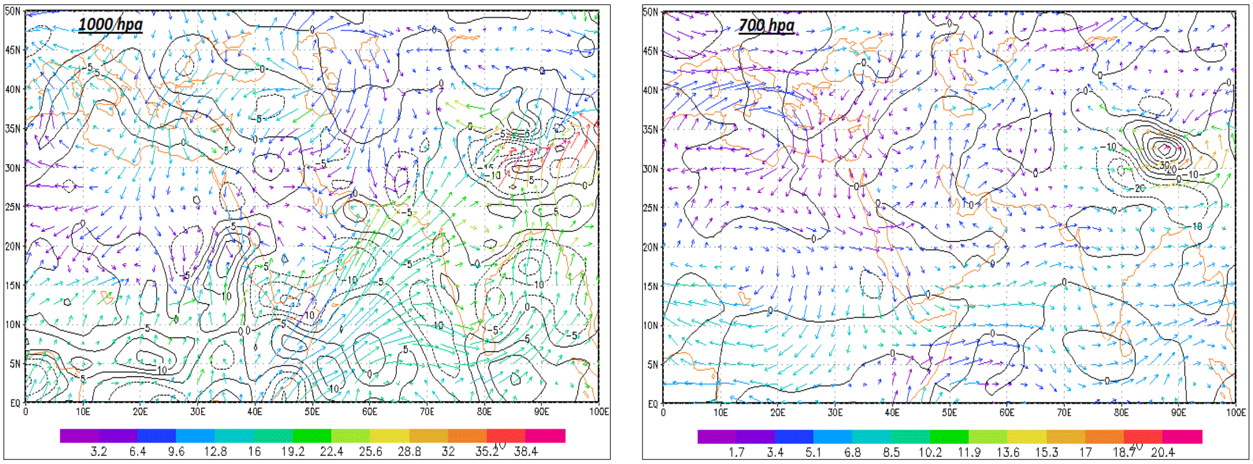

Fig. 5. Moisture flux convergence at surface level (left) and 700 hPa (right). Positive numbers show centers of moisture convergence and negative numbers show centers of moisture divergence. Whatever arrows color close to red, the humidity increases. In surface level the direction of humidity is southwest to northeast and in 700 hPa level be west to east

4. Conclusions

Synoptic climatology surveys relation between surface environmental and atmospheric circulation patterns. In this paper investigated atmospheric circulation patterns when occur heavy precipitation in warm seasons in Iran. Precipitation with at least 10 mm was selected as heavy precipitation. A cluster analysis on surface geopotential data showed that can recognized five patterns in surface level. In all pattern a long low pressure expanded from Bay Bengal to west south of Iran. This low pressure covered Persian Gulf and joins to low pressure Persian. Whatever the amount of geopotential height of a pattern less, that pattern is stronger, therefore, forth pattern is strongest and fifth pattern is weakest. Passing low pressure over Oman Sea and Persian Gulf strengthens the system and increases humidity. Himalayas Mountain divided high pressure center north from low pressure in the south. Cluster analysis in middle level shows than six patterns in this level can be determined. In middle level, contour at an altitude of 5875 meter known as subtropical high pressure. When subtropical high be stronger displaced eastern ward and expanded Iran and India at middle and higher levels and can transfer downstream Rossby wave train over Eurasian region. In all patterns subtropical high pressure expanded east ward over the Arabian Peninsula and North Africa and prevailed on south of Iran. Maps of moisture flux convergence at surface level showed transfer strong current humidity from warm tropical water to the south of Iran. At 700 hPa level moisture current is east ward on Arabian Sea and Indian Ocean and the amount of moisture decreased.

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