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The omega blocking condition and extreme rainfall in Northwestern Iran during 25 - 28 October 2008

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Abstract

Heavy precipitation plays a significant role in arid and semi-arid regions of Iran. In order to understand the effect of blocking high system on rainfalls in northwest Iran during 25 - 28 October 2008, meteorological conditions including pressure, wind fields and temperature at multiple levels of the atmosphere were analyzed. Sea level pressure, the 1000-500 hPa thickness, perceptible water, relative humidity, temperature, u and v components of wind at 850 hPa, geopotential height at 500 hPa and relative vorticity of u and v were obtained from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) re-analysis dataset. Location and displacement of the atmospheric systems such as cyclones, anticyclones, fronts and wind fields were identified using synoptic charts. Daily rainfall data obtained over 50 weather stations. Results indicate that the existence of a blocking high over the northern portion of the Caspian Sea caused the activity of two accompanying low pressure systems in which the western low resulted in excessive and intensive rainfall over the study area for 4 days. The low pressure was built by suitable wind patterns in the underlying levels (850 hPa). Moreover, modeling the outputs of 24-hour rainfall by the Geographic Information Systems (GIS) indicates that during the examined period northeastern parts of the region received the maximum rainfall.

Keywords: Omega blocking system, Heavy precipitation, Synoptic pattern, Iran

1 Introduction

Atmospheric blocking leads to a stagnation of weather patterns and recognized as a form of high impact weather. Long-lasting blocking sometimes induces extreme events (e.g. extreme temperature and precipitation) and as Namias and Clapp (1944), Elliott and Smith (1944), and Rex (1950) have pointed out blocking retrogress or slows down the eastward movement of tongues, troughs, lows, etc. Atmospheric blocking is inherent to the atmospheric circulation variability in the Northern Hemisphere. It is defined as a long-lived and recurrent system embedded within the latitude belt of baroclinic westerlies (e.g., Tibaldi et al., 1997).

The frequent occurrence and prolonged duration of blocking exerts a strong impact on regional and global circulation systems. The definitions for the purpose of identifying such phenomenon are varied to meet the needs of the investigators writing on the subject and in accordance with the scope of their studies. Namias and Clapp (1944) concluded that blocking operates in the form of a progressively westward decline in the speed of the zonal circulation at 10,000 feet. Later, in

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discussing the index cycle, Namias (1950) suggested that as an exchange of air between the pole and the equator is an obvious necessity for the atmospheric heat balance, blocking waves that occur simultaneously with a great reservoir of cold polar air are materialized into an index cycle. As upstream blocking of an airflow can significantly influence the type and amount of orographic precipitation in the windward slopes of a steep terrain, a better understanding of its behavior and underlying mechanisms is required to mitigate forecast errors resulting from an under- (or over-) estimation of the amount of moist low-level air impinging on mountain ranges such as the Alps (Bousquet and Smull, 1999). Heavy rainfalls sometimes lead to floods across Iran with its complex climatic conditions, results in huge extensive damage in terms of human losses and environmental impacts. Due to complex geographic position of Iran, climate varies in different areas of the country. For instance, mountainous regions in western Iran (Zagros Mountains range) are influenced by the Mediterranean cyclones, whereas southeastern fringes of Iran are affected by the Monsoon weather phenomena. Under such circumferences, it is not surprising that critical climactic events often occur in Iran. In the case of blocking, the same pattern repeats for several days to weeks. This can lead to flooding, drought, above and below normal temperatures and other weather extremes. Therefore, it is important to recognize a blocking pattern in its initial development. Several studies have been conducted to understand the blocking system and atmosphere circulation patterns. For instance, Azizi (1996 and 1999) investigated the blocking system and its effect on precipitations of Iran. He found that the blocking highs that occur in the west of 40° E and south of 60° N, and if the foresaid phenomenon situated in the east of mentioned meridian, has positive results on precipitations of Iran. Blocking highs over the eastern North Atlantic Ocean and Western Europe was investigated by Sanders (1953). Maddox (1978) compared heavy floods in Big Thomson and Rapid City and found that these floods caused by low-level winds that transfer plenty of humidity into the regions, while other factors lift the humidity, thereby generating heavy precipitations. Taghizadeh (1984) investigated the rainfalls of August 1987 and attributed them to the monsoon phenomenon. Synoptic patterns of intensive precipitation over southwestern Iran investigated by Lashkari (1996). Khoshhal (1997) performed the synoptic – climatology models of precipitation above 100 millimeters over the southern border of the Caspian Sea. Woodhouse (1997) studied the relationship between winter climate and circulation patterns of Sonorant Dessert in the United Stated of America. Using principal components analysis, Corti et al. (1999) have analyzed the relationship between circulation patterns and precipitation and its effect on the climate change in Portages. Moradi (2007) also conducted synoptic analysis of the southern shores rainfalls of the Caspian Sea within a cold period of 6 months and found that the main factor for precipitation occurrence caused by a high-pressure vortex in the surface, with its center located over the Black Sea. Jahanbakhsh and Zolfaghari (2002) have studied the synoptic patterns of daily precipitations in western Iran. The genesis and development mechanism of the Sudan low pressure and its effect on precipitation over southern and southwestern Iran was investigated by Lashkari (2003). He found that sufficiently deep vortex of the North Africa during cold spells converts to a thermodynamic state and extends eastwards which creates heavy rainfalls. Precipitation over the Interior East Antarctic Ice Sheet related to the midlatitude blocking-high activity was studied by Robert *et al.* (2004). Mofidi (2005) studied the synoptic climatology of heavy rainfalls in the Red Sea. Synoptic analysis of the rainfall during 10 – 15 July 1999 over Iran was investigated by Arabi (2006). Tomozeiu et al. (2005) studied the variability of winter precipitations in Romania and its association with large-scale circulation patterns using the National Centers for the Environmental Prediction (NCEP) data. Occurrence of floods based on synoptic positions in south of the Caspian Sea predicted by Moradi (2006). He found that three types of air masses, low-pressure systems and migrant cyclones and anticyclones play a significant role in precipitation of the southern border of the Caspian Sea. Some studies (e.g. Krabill et al., 2004; Hanna et al., 2006) show that unusually high accumulation in southeastern of the Greenland in 2002/2003 winter was related to a persistent blocking high centered over Scandinavia.

The objective of the present study is to evaluate the rainfall amounts recorded as a result of an omega blocking high event over northwestern Iran. An attempt was made to perform a synoptic analysis of the phenomenon using weather charts during the examined period. This study is presented in the following manner: types of blockings will be illustrated in Sect. 2, while material and methods are given in Sect. 3, with a brief description of the hourly rainfall chart, the precipitation schemes and the case study. Results are discussed in Sect. 4, followed by rainfall analysis in Sect. 5. Modeling the 24 hour rainfall by the (GIS) is the subject of Sect. 6, while conclusions are presented in Sect. 7.

2 Types of blocking

Atmospheric blocking can be well seen on upper air analysis and forecast charts. Blocking over large areas is most common when a high-pressure system is dominated because it covers a large spatial area and tends to move slower than a low-pressure system. In some instances, low pressure can also cause an atmospheric block. Five types of blocks that are represented in this section are the Rex block, the Ring of fire, the Split flow, the cut-off low and the Omega block (Sanders, 1953).

- Rex Block

A Rex block resembles a "half figure 8" or "backwards S". A Rex block sets up with a strong high-pressure ridge adjacent to a strong low-pressure trough. A large ridge is north of a large trough.

- Ring of Fire / Cut-off High

This high-pressure cell can become fixed over the same general region for several days. The air is most stable at the center of the high pressure. The Ring of Fire is originally a geology term which describes the occurrence of earthquakes and volcanoes as being on the edge of plate boundaries. In meteorology, the thunderstorms are synonymous with fire.

- Split Flow

A Split flow occurs when the jet stream branches into two separate branches. Weather systems flow quickly through each branch of the jet, while the weather pattern becomes stagnant in the region between the two jets.

- Cut-Off Low

Cut-off lows commonly occur when the upper-level winds shift to a higher latitude and leave a low-pressure circulating behind. Several height contours encircle the low at upper levels. They can persist for several days, bringing several days of rainfall.

- Omega Block

It resembles the Greek letter Omega and is best analyzed at 500 hPa. The basic pattern of the Omega block is shown in Figure 1.

The region under the Omega block experiences dry weather and light winds for an extended period of time, while rain and clouds are common in association with the two troughs on the either side of the Omega block. The right side of the Omega block will have below normal temperatures, while the the left side will have above normal temperatures in this case. In the present work, an omega blocking affected the study area, resulted in an excessive and intensive 24 hour rainfall over the region.

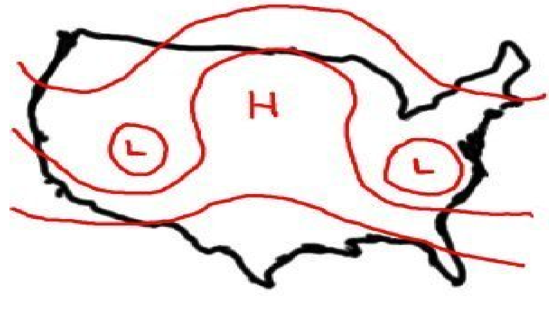

Figure 1. A schematic picture of the Omega blocking.

3 Material and methods

Intensive rainfalls caused by a blocking high-pressure system over the northwest provinces of Iran. Hourly precipitation autograph of Rasht weather station indicates that the maximum rainfall over the study area occurred on 27 October, with the peak (96 mm) at 7 pm local time). This amount is only for 3-hours period as the rainfall intensity significantly decreased in the following day (Figure 2). Therefore, it seems essential to investigate the synoptic pattern of the blocking system. To analyze the precipitations during 25 – 28 October 2008 and the effect of the blocking high-pressure system over the region, the meteorological data including mean sea level pressure (MSLP), air temperature, u and v components of wind, mean relative humidity, the 1000-500 hPa thickness, geopotential height, and vorticity at the surface, 850 hPa and 500 hPa were obtained from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR). The atmospheric circulation patterns are more obvious at 500 hPa, the level which is recognized as the middle layer of the atmosphere (Alijani, 2002). In this paper, therefore, we used the geopotential height and vorticity at 500 hPa as a representative of the atmospheric middle level, the relative humidity and wind fields at 850 hPa to analyzes the moisture input for the rainy system and the 1000-500 hPa thickness and MSLP to study the location of the low-high systems and their displacements. Distribution of the weather stations recorded above 20 mm rainfall during 25 - 28 October 2008 over northwestern Iran is shown in Figure 3.

Table 1 shows the 24-hour total rainfall during 25 – 28 October for 50 weather stations in western and northwestern areas of Iran. According to the table, the rainfall began on October 25 from northwest and then the rainy system moved eastwards on 28 October. The maximum rainfall over northwest of the study region recorded on 25 October in Piranshahr station (56mm), over west of the region on 26 October in Gilangharb station (67mm), over northeast of the region on 27 October in Rasht station (96mm) and eventually on 28 October in Bandaranzali station (33mm).

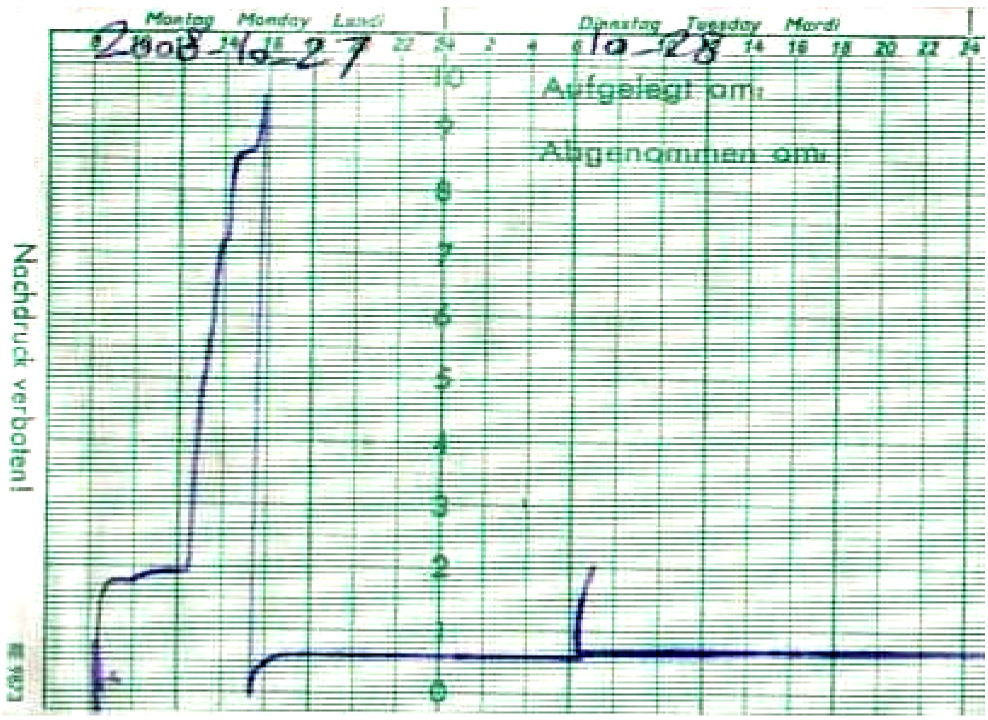

Figure 2. Hourly precipitation autograph during 27 - 28 October 2008 in Rasht station. X axes indicates a 2 hour interval time, while Y axes indicates precipitation values in millimeter multiplied by 10.

Table 1. The 24-hour total precipitation amounts for 50 selected stations during 25 - 28 October 2008.

24-hour total rainfall (Daily/mm)				Stations	List	24-hour total rainfall (Daily/mm)				Stations	List
28Oct.	27Oct.	26Oct.	25Oct.			28Oct.	27Oct.	26Oct.	25Oct.		
0	10	22	0	**Ilam**	**26**	2.5	20	2	0	**Arak**	**1**
0	23	32	0	**Ivan**	**27**	2.2	2	1	0	**Khomein**	**2**
0	50	10	0	**Darehshahr**	**28**	2.8	21	1	0	**Delijan**	**3**
2.9	8	21	0	**Malayer**	**29**	0	20	33	19	**Baneh**	**4**
6.5	9	22	0	**Nahavand**	**30**	3	4	21	10	**Saghez**	**5**
1	22	5	0	**Azna**	**31**	0	14	20	0	**Sanandaj**	**6**
1.2	12	26	0	**Aleshter**	**32**	0	21	17	0	**Qorveh**	**7**
3.1	20	3	0	**Aligodars**	**33**	0	12	23	8.5	**Marivan**	**8**
6.5	21	20	0	**Borojerd**	**34**	3.5	21	2	0	**Avaj**	**9**
0	21	11	0	**Pouldokhtar**	**35**	0	14	30	0	**Kermanshah**	**10**
5.5	22	12	0	**Doroud**	**36**	5	11	24	1.2	**Saravard**	**11**
5.5	31	11	0	**Silakhor**	**37**	0	20	45	0	**Sarpolzahab**	**12**
0	12	21	0	**Kohdasht**	**38**	0	10	25	0	**Songhor**	**13**
0	23	21	0	**Norabad**	**39**	0	21	33	0	**Qasre Shirin**	**14**
0	20	7	0	**Mahneshan**	**40**	0	51	67	0	**Gilangharb**	**15**
2	1	10	18	**Shahindej**	**41**	7	21	13	0	**Astara**	**16**
1	3	16	30	**Naghadeh**	**42**	5	29	2	3	**Roudsar**	**17**
1	6	12	45	**Mahabad**	**43**	6	96	8	0	**Rasht**	**18**
0	1	10	20	**Maragheh**	**44**	10	60	2	1	**Lahijan**	**19**
1	18	5	10	**Khoy**	**45**	33	70	22	1	**Bandaranzali**	**20**
0	1	12	21	**Tabriz**	**46**	1	20	5	0	**Ardabil**	**21**
1	2	18	27	**Boukan**	**47**	1	26	6	1	**Sarein**	**22**
0	1	11	27	**Miandoab**	**48**	1	22	7	31	**Ouromiyeh**	**23**
1	3	10	18	**Takab**	**49**	0	1	10	21	**Bonab**	**24**
1	**9**	**10**	**19**	**Bostanabad**	**50**	**5**	**15**	**16**	**56**	**Piranshahr**	**25**

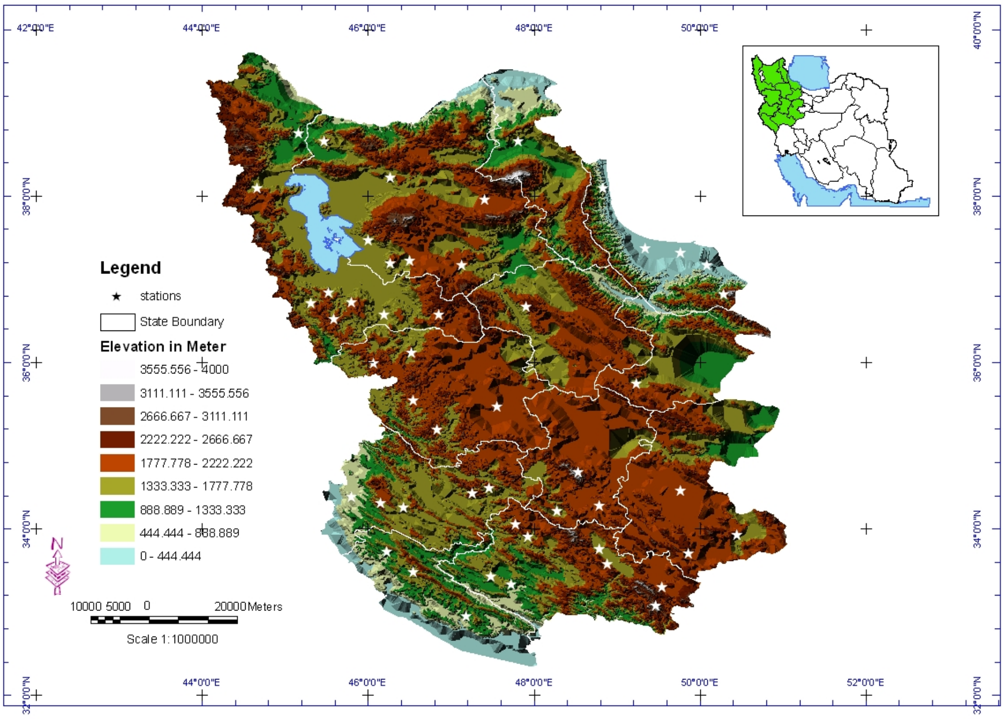

Figure 3. Geographical location and distribution of 50 meteorological stations used in the present study overlapped by the underlying topography.

4 Results and discussion

The study area was affected by a dynamic low as a consequence of an omega blocking high activity. This resulted in intensive rainfalls over west and northwest provinces of Iran including 50 weather stations. The meteorological conditions will be analyzed from the beginning to the end of the blocking high-pressure system activity using the obtained data including pressure, wind fields and temperature at multiple levels of the atmosphere. As mentioned earlier, mean sea level pressure, the 1000-500 hPa thickness, precipitable water (kg/m^2); relative humidity (%), temperature (^{0}C) and wind (m/s) at 850 hPa, as well as geopotential height at 500 hPa and relative vorticity were selected from NCEP/NCAR re-analysis dataset. We used geopotential height and vorticity at 500 hPa because this level represents the atmospheric middle level and, In addition, positive and negative vorticity at 500 hPa are associated with cyclones and anticyclones, respectively. Relative humidity, temperature and wind fields at 850 hPa were also considered order to analyze the moisture and temperature advections by the horizontal wind. Moreover, MSLP was used to indicate cyclones and anticyclones, while the 1000 - 500 hPa thickness denotes the mean temperature of air between the mentioned levels.

4-1 The beginning of rainfall (25 October)

The MSLP and the 1000-500 hPa thickness overlapped by precipitable water are shown in Figure 4. The bold black contours indicate MSLP in millibars. Low MSLP indicates cyclones near the surface of the Earth, while high MSLP indicates calm weather in general. The MSLP contours indicate a high-pressure system with the central pressure greater than 1032 hPa over north of the Black Sea, which is extended over northern border of Iran. This system also caused an extensive high belt at mid-latitudes. The tongue of the Sudanic low-pressure system prolonged over southeast of the Black Sea. The pressure pattern is northwest-southeast over Iran. The red dashed contours indicate vertical distance or thickness between 1000 hPa and 500 hPa levels. As air behaves nearly as an ideal gas, and vertical distance is proportional to volume over a specified surface area, the thickness between any two pressure levels is proportional to the mean temperature of the air between those levels. Thus, low values of thickness indicate relatively cold air. Precipitation above 60° N is generally in the form of snow. This is because 5540 m line is often used as a rule of thumb to indicate the division between rain and snow over low terrains. The blue shaded indicates total precipitable water in the atmosphere. Precipitable water is the total depth of the liquid water that and can be formed if all water vapor contained in a vertical column of air could be "wrung out", leaving the air completely dry. It indicates the total humidity of the air above a particular location, and is a good indicator of the amount of moisture potentially available to supply rainfall. The precipitable water amount is flexible between 15 – 30 mm over the study area. As rainfall started at this day (25 Oct.), precipitable water amounts are not considerable over northwestern Iran; however, it increased as time went by (Figure 4). Temperature at 850 hPa, humidity and wind fields are shown in Figure 5. The brown contours indicate air temperature at 850 hPa in degrees Celsius. The temperature value is flexible between 10 - 17.5 °C over northwestern Iran. As a result, precipitation occurred in the form of rainfall rather than snowfall as 0 °C contour is often used to distinguish between rain and snow. The blue shading also indicates relative humidity in percentage. High values indicate the availability of moisture. The percentage of relative humidity is flexible between 40 – 90 % over the study area. The moisture core is situated in northern Turkey. The wind streams are also shown in the figure. Southern winds flows over the Arabian Sea, the Indian Ocean and the Red Sea, continued to western areas of Iran – southwestern of the Persian Gulf and eastern half of Iraq – with a significant pressure gradient. In addition, 500 hPa mean geopotential heights and vorticity are presented in Figure 6. As low and high geopotential heights indicate the presence of a trough at and a ridge at mid-troposphere levels, respectively, a closed low with 6705 hPa central pressure located over Turkey (not shown) resulted in a deep trough, so that northwestern Iran is in front of a strong trough. Iran encircled by a tongue, except small divisions in northwest. Typically, positive and negative vorticity at 500 hPa is associated with cyclonic and anticyclonic circulation at the upper levels. The rainfall occurred in stations which located in northwestern parts of the study area.

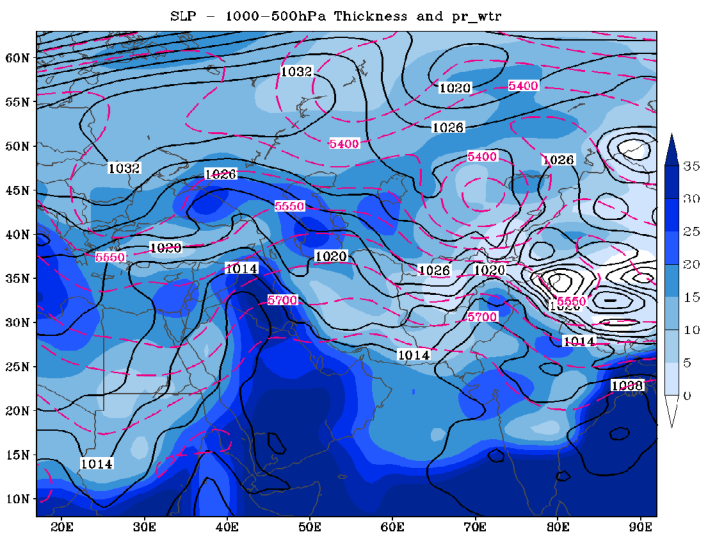

Figure 4. Solid black contours indicate mean sea level pressure (hPa), dashed red contours indicate the 1000-500 hPa thickness and colors are precipitable water (kg/m^2) on 25 Oct. 2008.

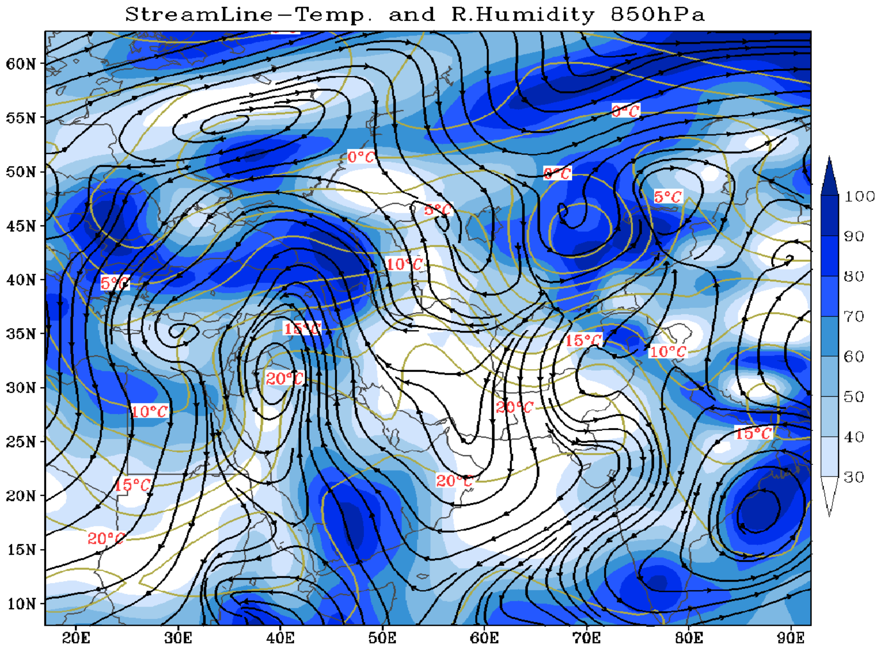

Figure 5. Mean relative humidity (%) at 850 hPa represented in chart's background in blue shaded, brown contour fields indicate mean temperature (°C), while wind components (m/s) are drawn in black streamline on 25 Oct. 2008.

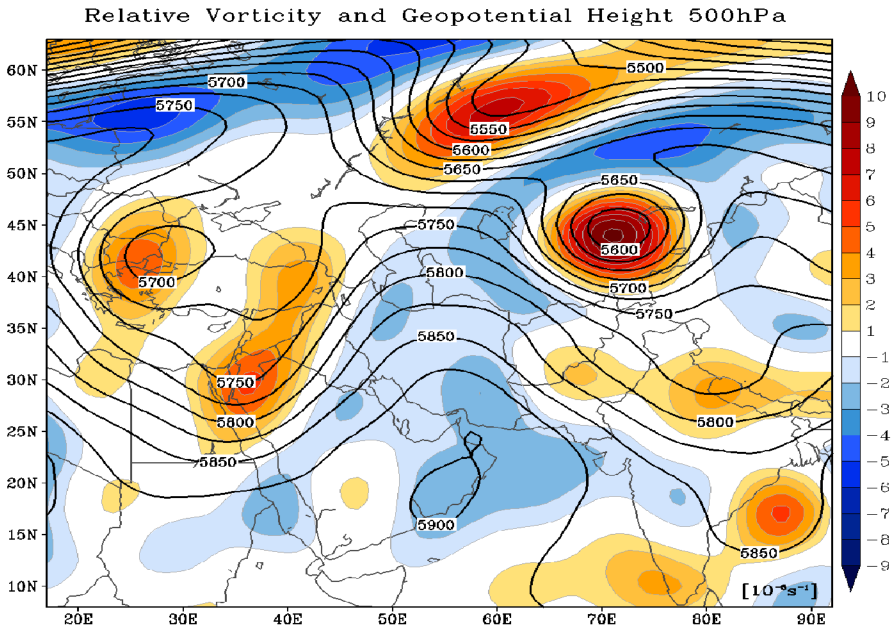

Figure 6. Bold black contours indicate mean geopotential height at 500 hPa and colors shading indicate relative vorticity (1e-5/sec): red for positive vorticity and blue for negative on 25 Oct. 2008.

4-2 The maximum rainfall over the west of the region (26 October)

Mean sea level pressure and the 1000-500 hPa thickness accompanied by precipitable water are shown in Figure 7. The high-pressure system moved eastwards and now centered over northwest of the Caspian Sea and extending a tongue over the Zagros Mountains range. A tongue of Sudanic low moved slightly eastwards and the western areas of Iran affected by the southern flows. The isobaric contour value is 1020 hPa over the study area. A 580 hPa contour closed over east of the Saudi Arabia in thickness contours, resulted formation of a ridge over eastern Iran. The thickness contours are between 555 and 565 hPa over the study area. The blue shaded indicates total precipitable water in the atmosphere, with the value is flexible between 15 – 40 mm over northwestern Iran. The maximum precipitable water and rainfall in this day, observed in the west of the region (see Table 2). The 850 hPa mean temperature, relative humidity and wind fields are shown in Figure 8. The temperature value decreased slightly as compared to the previous day and lies between 7.5 - 15ºC. The 0 ºC line is above 45º N and most likely many regions experienced rainfall rather than snowfall, except high altitudes where snowfall in some stations was reported. Wind field indicates an eastwards displacement of the low-pressure system located at Mesopotamia. Convergence of wind flows over the Oman Sea caused by the high-pressure system, so that the warm-humid advections air from Kuwait, the western sectors of the Persian Gulf and southeastern Iraq provided suitable moisture supply, causing intensive rainfall over the study region (precipitable water amount is considerable between 20-30 kg/m over the study area). Consequently, the most rainfall occurred over the west of the region. The low-pressure system over western Turkey lies between the northern and southern height belts, while high-pressure system vortex over the south of Saudi Arabia located over the center of Iran, not only became relatively weak, but also displaced slightly eastwards and the trough over the Red Sea passed across the western areas, although the region is still influenced by the low-pressure system surges over Turkey. The positive vorticity coincided well with the trough in the geopotential height field over the Turkey, so that western parts of Iran were affected by the positive vorticity (Figure 9).

4-3 The maximum rainfall over northeast of the region (27October)

Mean sea level pressure and the 1000-500 hPa thickness along with precipitable water are shown in Figure 10. The isobaric contours indicate the blocking high system displaced southeastwards of the Caspian Sea, providing a very good pressure gradient over the north half of Iran. The pressure value is flexible between 1017 and 1020 hPa over the study area. Furthermore, the eastern streams over the Caspian Sea are transferring abundant moisture into the southwestern divisions of the Sea. The low-pressure system enfeebled slightly locating over northeastern parts of the Mediterranean Sea. Based on thickness, precipitations were rain over the region, except mountainous areas where some snowfall was reported. Moreover, the highest amount of precipitable water (30 – 40 mm) observed in northeastern parts of the study area such as Gilan. In addition, Figure 11 illustrates 850 hPa temperature, humidity and winds on 27 October 2008. Wind flow pattern indicates the southern warm-humid streams kept going from the southwest side to the country, although there is not a suitable contour curves at the middle levels of the atmosphere over southwestern and western areas of Iran. The most important note is that, northeastern streams over the Caspian Sea towards Gilan province resulted in an appropriate condition for intensive rainfall due to a suitable divergence of middle levels streams. In addition, the tongue of the blocking high-pressure system extended northwestward parts of the region, causing a significant decrease in temperature and moisture for western divisions of the region. The temperature value varies between 7.5 - 15ºC over the study area. The 500 hPa mean geopotential heights, height change and vorticity are also shown in Figure 12. The blocking high-pressure system vortex weakened over Iran, in particular over the central parts of the Caspian Sea, so that a high axis generated between two low systems over east of the Aral Lake and Turkey. Blocking high-pressure system in northern of the Caspian Sea led to a suitable activity of two troughs. Moreover, divergence of southwestern streams at the middle level of the atmosphere over northwestern and southeastern areas of the Caspian Sea caused a good condition to make intensive and extensive rainfall over western shores of Caspian Sea. The positive vorticity value is 2 - 6 ($1e^{-5}$/sec) over the region.

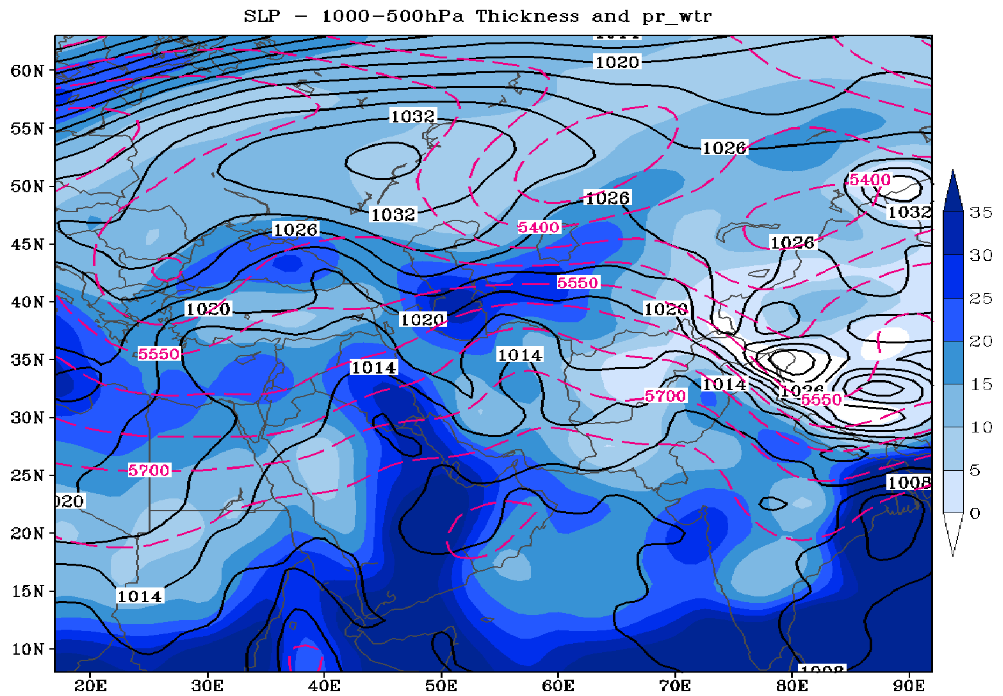

Figure 7. Solid black contours indicate mean sea level pressure (hPa)-, dashed red contours indicate the 1000-500 hPa thickness and colors are precipitable water (kg/m^2) on 26 Oct. 2008.

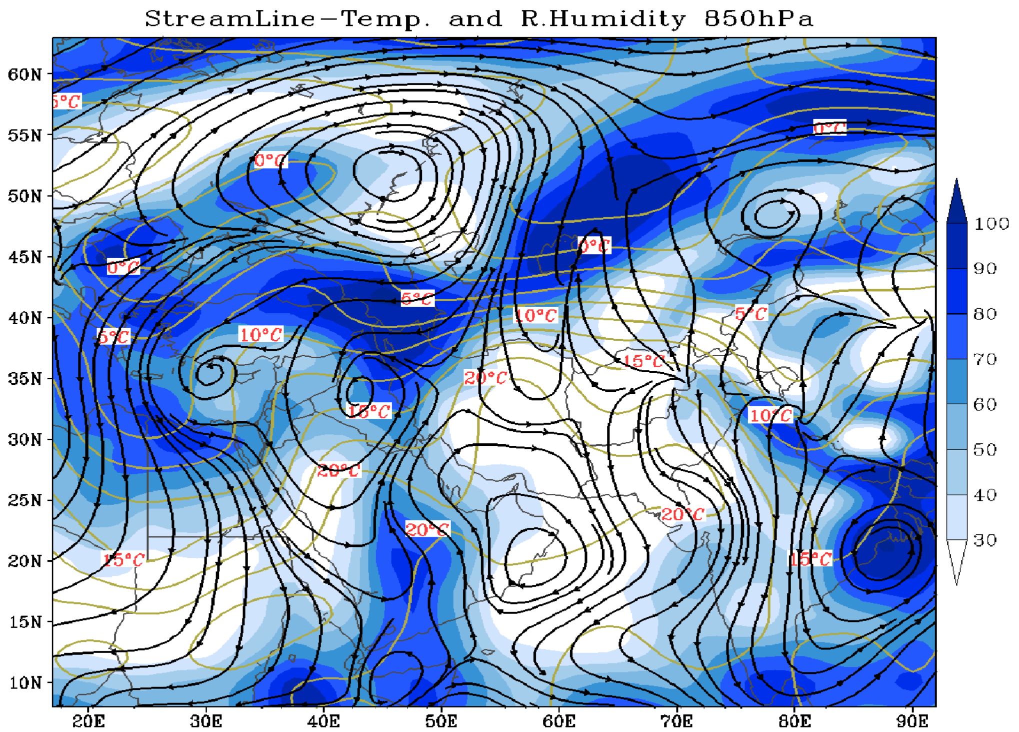

Figure 8. Mean relative humidity (%) at 850 hPa (colors), brown contour fields indicate mean temperature (^oC) and wind fields (m/s) are drawn in black streamline on 26 Oct. 2008.

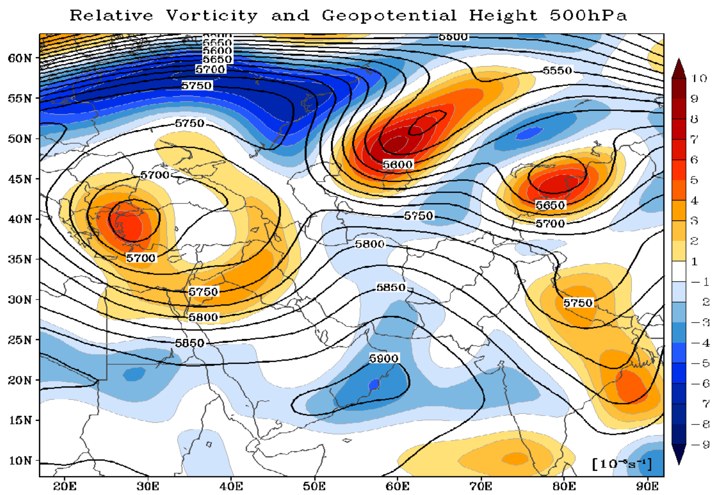

Figure 9. Bold black contours indicate mean geopotential height at 500 hPa and colors indicate relative vorticity ($1e^{-5}$/sec) of horizontal windon 26 Oct. 2008.

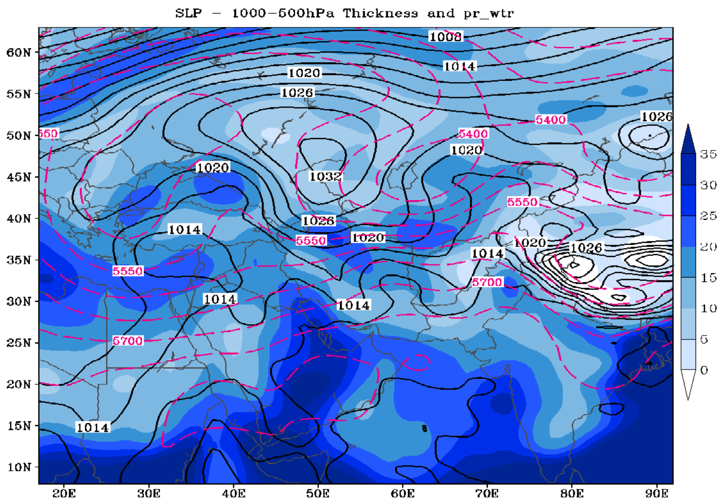

Figure 10. Solid black contours indicate mean sea level pressure (hPa), dashed red contours indicate the 1000-500 hPa thickness and colors represent precipitable water (kg/m^2) on 27 Oct. 2008.

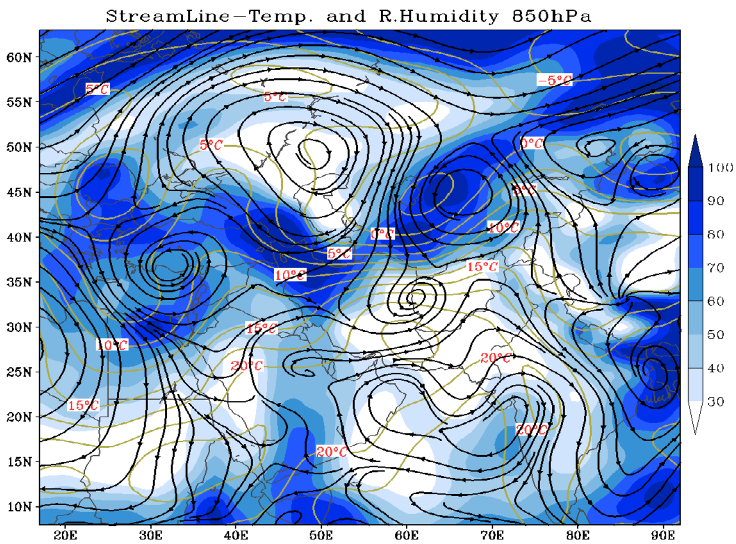

Figure 11. Mean relative humidity (%) at 850 hPa represented by colors, brown contour fields indicate mean temperature (^{o}C), and wind fields are drawn in black streamline on 27 Oct. 2008.

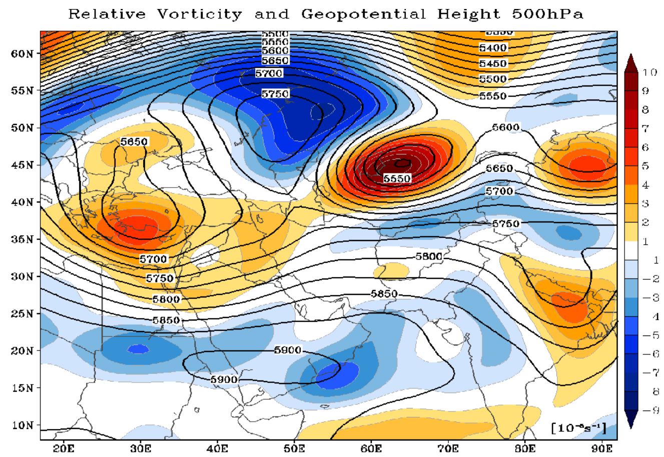

Figure 12. Bold black contours indicate mean geopotential height at 500 hPa and colors represent relative vorticity (1e^{-5}/sec) of horizontal wind on 27 Oct. 2008.

4-4 The last day of rainfall (28 October)

Mean sea level pressure and the 1000-500 hPa thickness accompanied by precipitable water are shown in Figure 13. The isobaric contours indicate a ridge of high over most parts of Iran and the streams blow mostly eastward over the eastern half of Iran. The trend of temperature dramatically declined in all stations and some stations experienced drop in temperature when the low system left the region and the blocking high system moved toward the lower latitudes. The amount of precipitable water decreased to a large extent in western Iran, in particular over the study area as a result of cold advections. At 850 hPa, wind fields indicate the streams weakened slightly over the region. Rainfall decreased in most parts of the study area because the low system moved eastwards, although some rainfall recorded in the eastern region (Figure 14). Mean geopotential heights at 500 hPa, height change and vorticity are also shown in Figure 15. At 500 hPa the blocking system persisted over the area and did not show any displacement. The southwestern and western streams have also become more zonal. The high vortex over central parts of Iran became weaker than previous days and the low-pressure center that was located over Turkey is now. In general, the blocking high-pressure system was persevered itself as an omega blocking and was active for a while. Therefore, this phenomenon caused an intense rainfall in northwestern Iran.

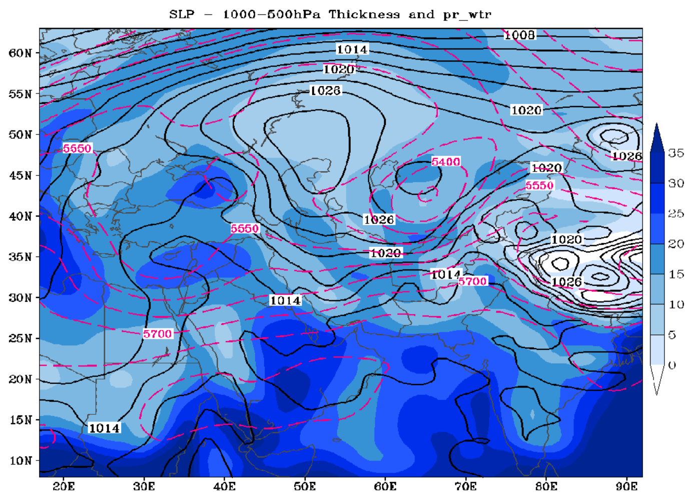

Figure 13. Solid dark contours indicate mean sea level pressure (hPa)-, dashed red contours indicate the 1000-500 hPa thickness and colors are precipitable water (kg/m^2) on 28 Oct. 2008.

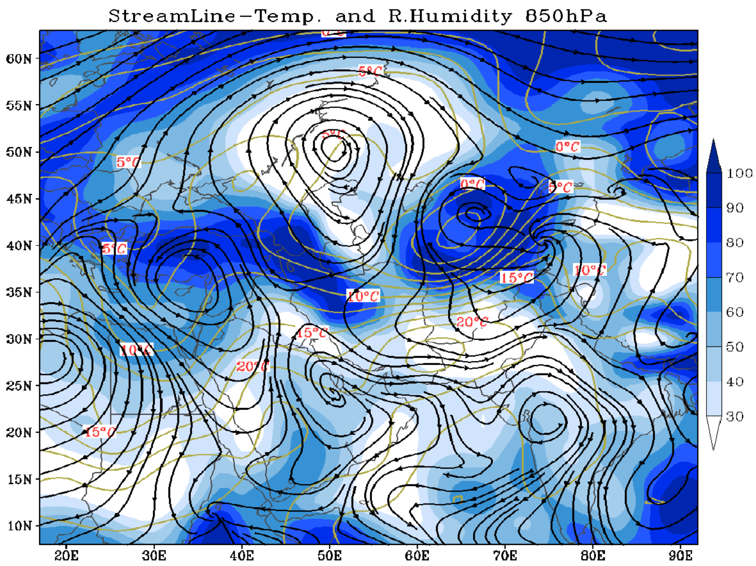

Figure 14. Mean relative humidity (%) at 850 hPa represented in by colors, brown contour fields indicate mean temperature (°C) –and wind fields (m/s) are drawn in black streamline on 28 Oct. 2008.

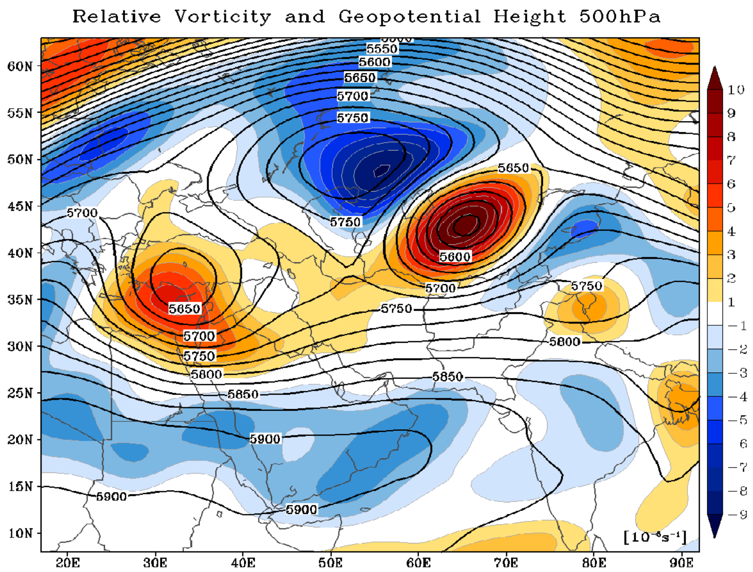

Figure 15. Bold black contours indicate mean geopotential height at 500 hPa and relative vorticity (1e^{-5}/sec) is represented by colors on 28 Oct. 2008.

5 The rainfall analysis

As mentioned earlier, an omega blocking system was centered over north of the Caspian Sea, resulted in the activity of two dynamic low-pressure systems. The low-pressure system on the right side of the omega blocking caused a substantial amount of rainfall during 25 - 28 October 2008. Rain over the region started on 25 October, resulted in a considerable amount of rainfall over the northwestern parts of the study area as reported in some stations such as Piranshahr, Mahabad and Ouromiyeh. Precipitation rate values (Kg/m^2/s) on 25 October is shown in Figure 16. The rainfall core-cell situated out of Iran, although the western border of the region affected by the rainy system. In the following day, the activity of the system extended to the southwards of the region, producing heavy rainfall over southwestern stations such as Gilan Gharb, Kermanshah, Ghasreshirin and etc (Figure 17).

On this day the rainy system consists of two rainfall core-cells: the north core located outside of Iran, with no rainfall reported over the area, whereas the south rainfall core influenced southwestern stations, with the maximum rainfall recorded in Gilan Gharb station. On 27 October, the rainy system moved eastwards and slightly to the south over the northeast of the region, resulted in occurrence of large amounts of rainfall in stations such as Rasht, Bandar Anzali and Lahijan. The maximum rainfall was recorded in Rasht station (more than 90 mmm) due to the accessibility of the rainfall core over the region during this day. The second rainfall core located over southwestern parts and Gilan Gharb station recorded the highest amount of rainfall after Rasht station (Figure 18). The rainy system, however, moved northeastwards; consequently rainfall ceased in most southern and western stations, except in northeastern parts in Bandar Anzali and Lahijan stations (Figure 19).

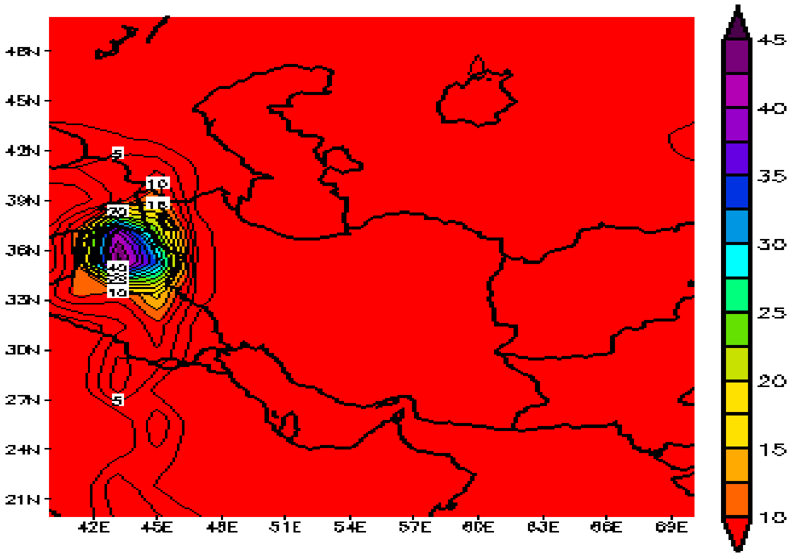

Figure 16. Distribution of precipitation rate (Kg/m^2/s) over the study area on 25 October 2008.

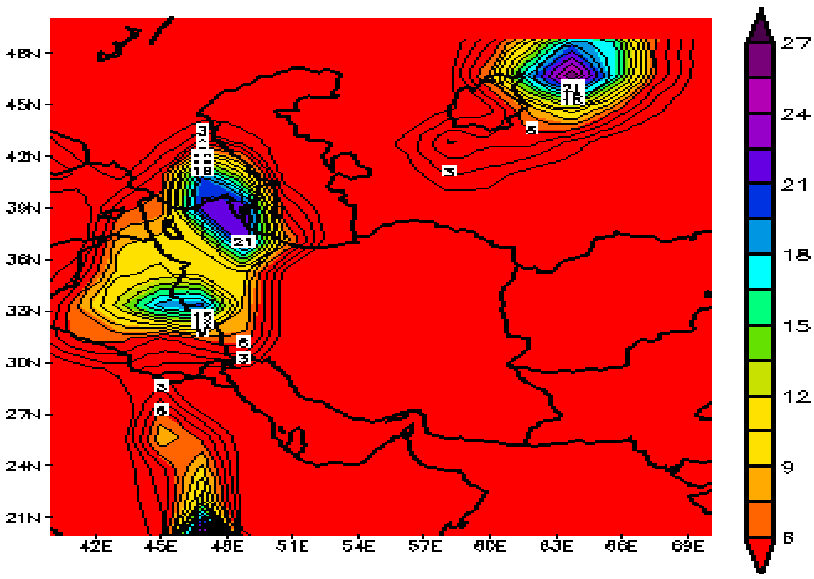

Figure 17. Distribution of precipitation rate (Kg/m^2/s) over the study area on 26 October 2008.

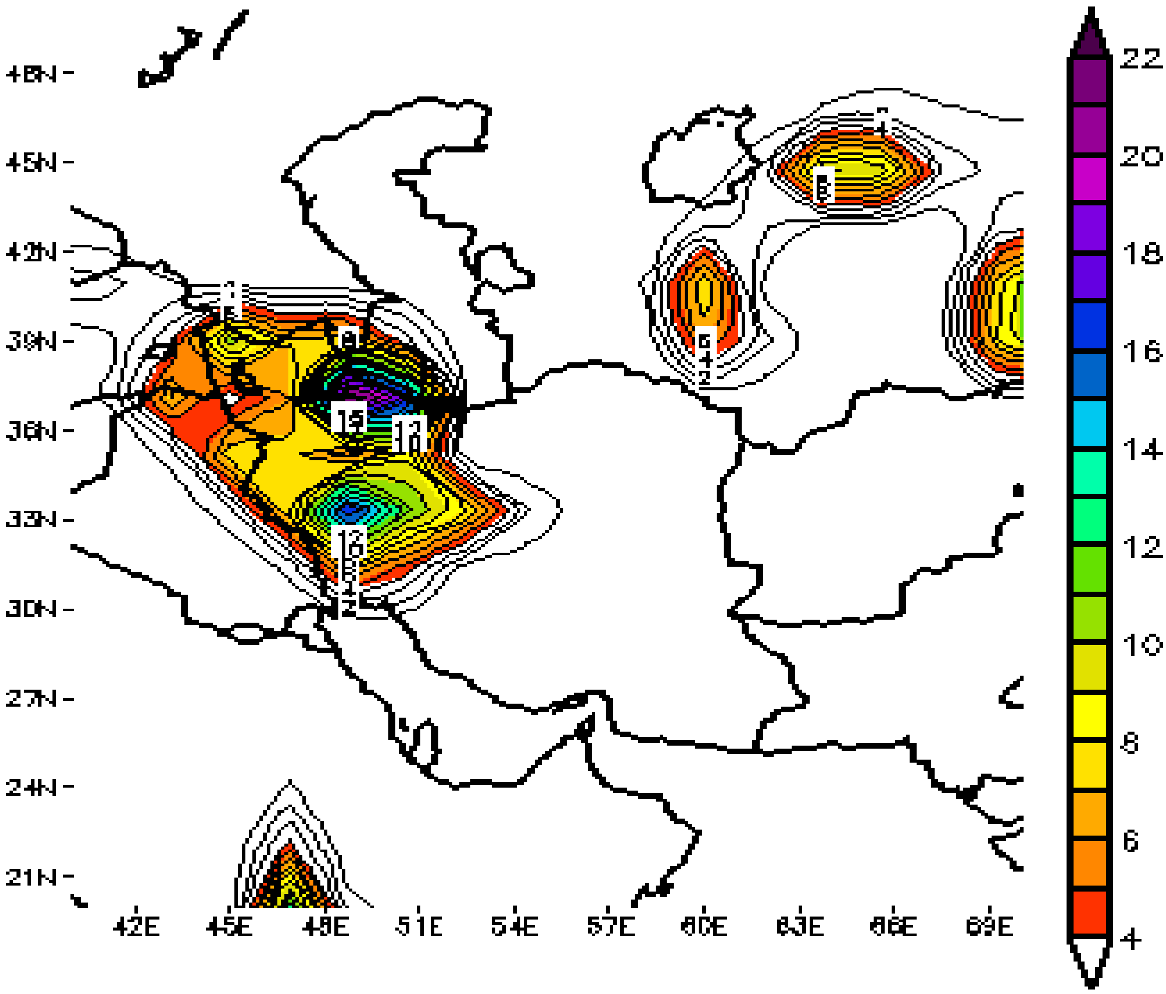

Figure 18. Distribution of precipitation rate (Kg/m^2/s) over the study area on 27 October 2008.

6 Modeling 24 hour rainfall by the geographic information system (GIS)

Displacement of the rainy system during 25 - 28 October from west to east in 12 provinces over northwest Iran will be modeled to track the rainy system. We used the Inverse Distance Weighted (IDW) method to interpolate the values. The 24 hour total rainfall amounts of the stations evaluated and the isohyetal maps of northwestern provinces of Iran generated by the GIS and analyzed in brief. The modeling results showed that rainfall on 25 October mostly occurred in northwestern parts of the study area (Piranshahr and Mahabad stations), while no rainfall was recorded in other parts (Figure 20). By displacement of the system to lower latitudes on 26 October, the maximum rainfall occurred over southwestern sections of the region (Kermanshah province, especially in Gilan Gharb weather station more than 60 mm precipitation was reported) (Figure 21). On 27 October the northeastern provinces of the study region received the highest 24 hour rainfall value because the low-pressure system moved eastwards. As a result, the extreme rainfall reported in Gilan province (with more than 90 mm in Rasht station). Some rain was also recorded over southwestern parts of the region, particularly over Gilan Gharb station which recorded the second highest rainfall with the value of 30mm (Figure 22). The last day of rainy activity was over northeastern parts of the region on 28 October, so that the 24 hour maximum rainfall was reported in Bandar Anzali station. Rainfall was approximately zero over other parts of the region (Figure 23).

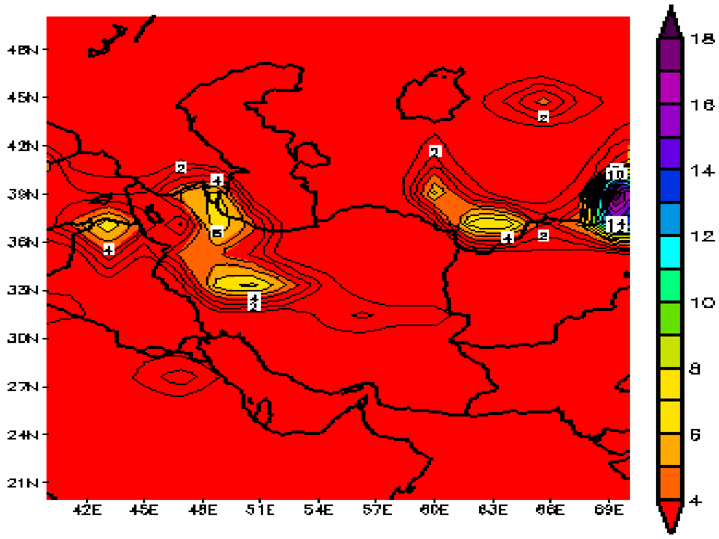

Figure 19. Distribution of precipitation rate (Kg/m^2/s) over the study area on 28 October 2008.

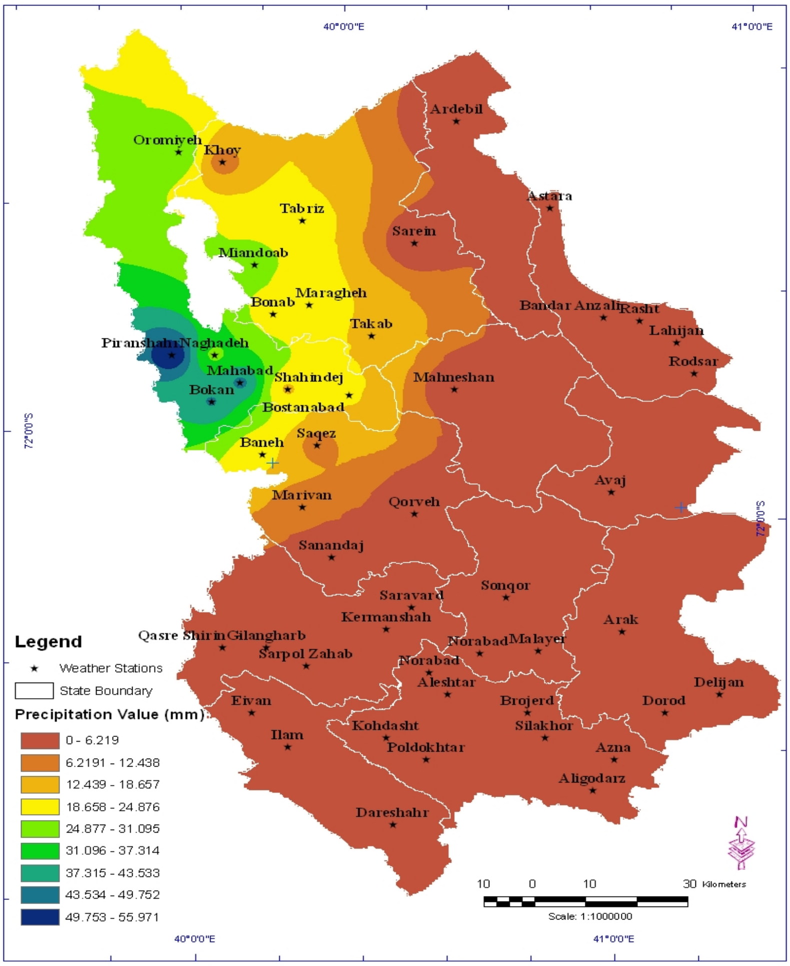

Figure 20. Interpolation of the 24hour precipitation amounts on 25 October 2008.

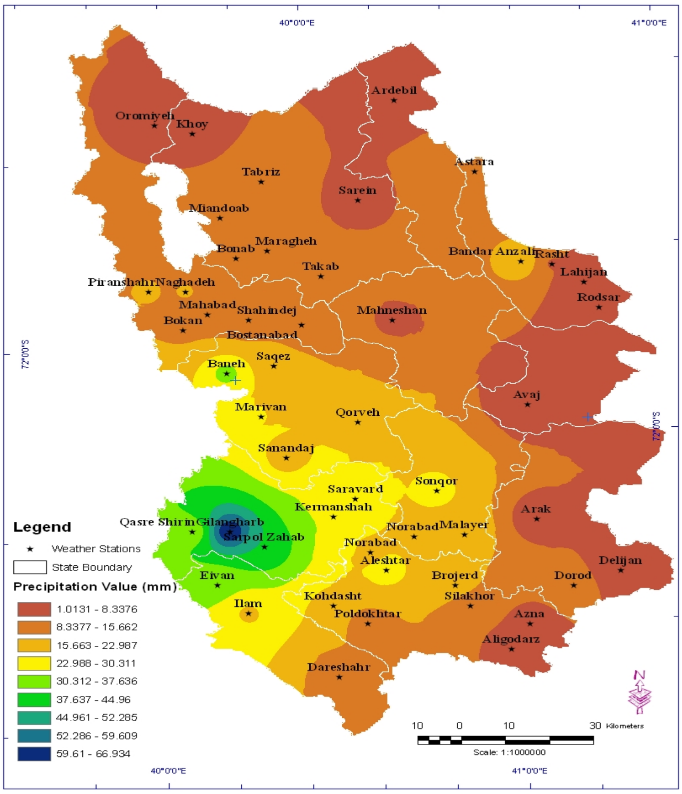

Figure 21. Interpolation of the 24-hour precipitation amounts on 26 October 2008.

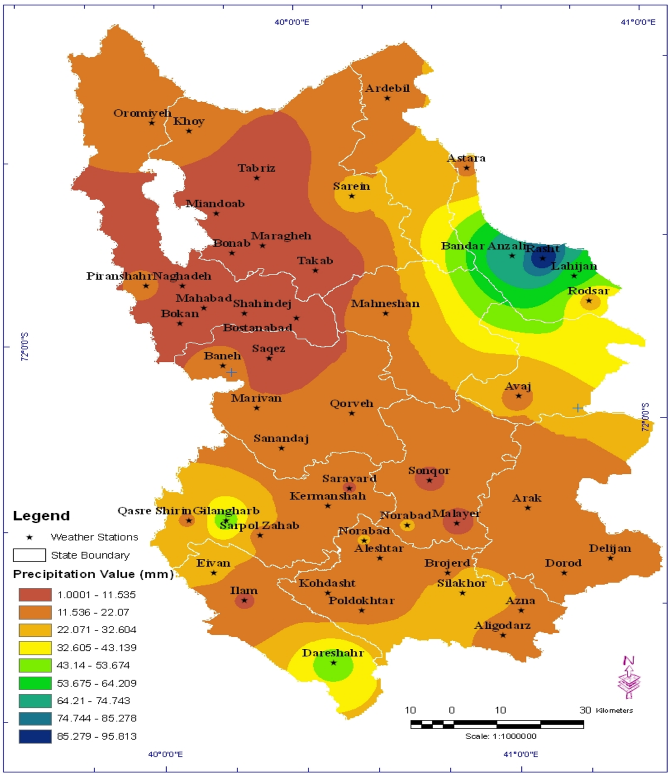

Figure 22. Interpolation of the 24-hour precipitation amounts on 27 October 2008.

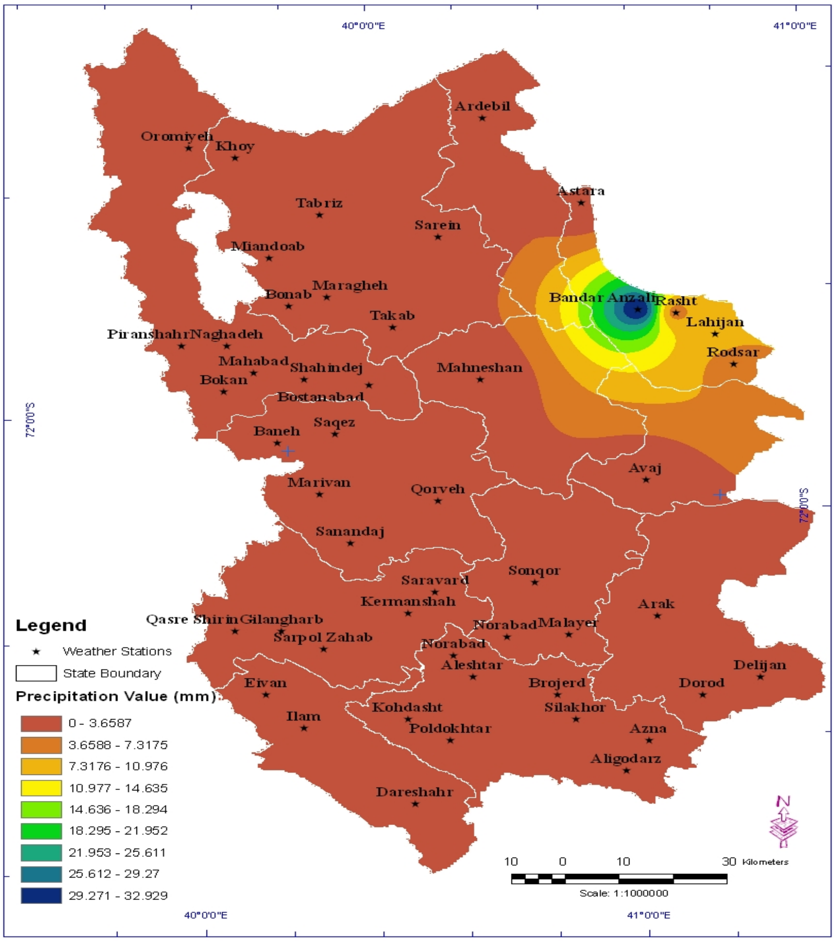

Figure 23. Interpolation of the 24-hour precipitation amounts on 28 October 2008.

7 Conclusion

An omega blocking high system was active in northwestern Iran during 25 - 28 October 2008, resulted in an intensive rainfall over the 12 provinces in northwestern of Iran. Synoptic pattern of weather charts on 25 October indicate that the Sudanic low system supplied substantial amounts of humidity from the Arabian Sea, the Indian Ocean and the Red Sea. A tongue of the Sudanic low system also developed southeastwards of the Black Sea, causing a closed center to be developed over southern Iraq. On the basis of 500 hPa, a blocking high system was active for 4days over Iran, while a closed low-pressure system lied across the Black Sea and Turkey. Furthermore, a trough located over the Red Sea with a substantial pressure gradient Atmospheric currents flow southern side after passing the Arabian Sea, the Indian Ocean and the Red Sea, moving towards the western areas of Iran afterwards. The positive vorticity was coincided well with troughs in geopotential height fields. On 26 October a ridge of the blocking high extended over the Zagros Mountains range and the belt of the Sudan low displaced towards Iran. On 27 October, the blocking high moved slightly southeastwards and caused a suitable pressure gradient over the northern half of the country. Easterly streams over the Caspian Sea also provided a considerable amount of humidity into the coastal areas; while the blocking system in northern parts of the Caspian Sea provided a suitable condition for the activity of two low-pressure systems. The low-pressure systems moved eastwards, whereas the wind direction shows a high-pressure system on the north of the Caspian Sea, which its ridge moved towards southwest, and became unstable by passing over the Caspian Sea. As a result, it intensified the rainfall over the northeast of study area on 28 October, the high belt weakened and a tongue of the blocking high situated over the Caspian Sea and Iran. The blocking high-pressure system extended to lower latitudes, causing a reduction in temperature. The vortex over central Iran is weaker compared to the previous days. The modeling results of the 24 hour rainfall values by the GIS indicated the onset and the time of leaving of the rainy system over the study area during 25 - 28 October 2008. The 24 hour maximum rainfall occurred over the northwestern of the region on 25 October, while due to displacement of the system to lower latitudes on 26 October, Gilan Gharb station received the maximum with more than the value of 60 mm. As the low-pressure system displaced eastwards, northeastern sections of the study region on 27 October experienced the maximum rainfall (more than 96 mm in Rasht station). The last day of rainfall occurred over the northeastern sectors and no rainfall was recorded in other parts on 28 October. All in all, the blocking high system was persevered itself as an omega blocking. On the other hand, the blocking high did not lost its nature and disposition after leaving northwest Iran; instead the blocking high system accompanied by two low-troughs continued its activity outside of Iran for several days. Therefore, this phenomenon deep-seated over the region on 25 to 28 October 2008, causing an intense rainfall in northwestern Iran.

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