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Case study of a maximum heavy rain event over Western Iran: during March 2005

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Abstract. In this study presents an analysis of daily extreme precipitation events in Mrach 2005 in Western Iran. This event, with daily rainfall maximum of 122 mm in, was observed in the Marivan Station.
The aim of this work is to study simultaneously the thermodynamic and dynamic parameter in low level of troposphere which finally resulted in very severe precipitation rates, reaching up to middle level in a rainy day can assess. The relationship between extreme precipitation events and the mid and low tropospheric conditions is investigated by using NCEP/NCAR reanalysis data.
It is recognized that synoptic structures are different in heavy on 09-11 March 2005 in western Iran. The southerly wind (Low-Level-Jet) is very important for forming heavy rain so that changing of direction wind of southwesterly to southerly is accompanied increasing rain in western Iran of 09 to 10 March. Although heavy rain take places in western Iran, the convective precipitation isn't accompanied in forming heavy rain events. The humidity source needed in forming rain in western Iran is different including eastern Mediterranean sea ,Red sea and Aden gulf.

Keywords: heavy rain, southerly wind (LLJ), convergence, thickness advection, k-index

1. Introduction

The extreme precipitation events have a profound impact on society due to the growth of human vulnerability. The assessment of humidity sources origin and the evaluation of the different air mass trajectories allow a better understanding of hazard rainfall episodes and provide a powerful tool for forecasting and warning against potential damages. The responsible synoptic systems (mechanisms of forming rainfall) and the water vapor sources are substantially different for heavy rain in different times of the year. The heavy rain can be associated with convective rain.

Although the direct and immediate cause of heavy rain is usually convection, a front, the orographic ascent or a combination of some of these and other synoptic and small-scale mechanisms, a possible concurrent factor for heavy rain is the presence of a low-level cyclone center that contributes to flow organization and in particular to the establishment of a warm-wet destabilizing and feeding inflow current. Founding by [1], in most of the heavy rain events(around 90%) there is a cyclonic center in the vicinity, usually located so that its presence favors the creation or intensification of a feeding flow of Mediterranean air towards the area affected by heavy rain.

The convective instability in the lower part of the troposphere produces convective rain [2]. To sustain convective precipitation long enough to accumulate large quantities of rainfall, a feeding current of relatively warm and wet air is necessary to replace the water removed by precipitation. A relatively warm and wet low-level inflow favors vertical instability and can even lead to the instability if the environment is only just stable at the beginning. Therefore a large amount of precipitation is collected where the convergence is guaranteed [3].

The favorable threshold values and positions low-level jet (LLJ), precipitable water content, convergence and instability was used for heavy rain analysis by Mainville. The LLJ played a major role in not only providing the dynamic conditions but also the supply of water vapor for heavy rainfall in South China [2].

Thermodynamic instability indices, K-Index (KI) and Total Totals (TT), were analyzed in order to evaluate the degree of thermal atmospheric instability In Iberian [4]. Instability components showed large unstable conditions consistent with the synoptic situation and the observed precipitation rates. It is a fact that the thermodynamic factors, alone, weren't sufficient to lead to convective instability [5]. It appeared that the presence of the low-level forcing alone may not be sufficient for the development of heavy rainfall [6],[7]. The evolution of upper level dynamic structures (jet stream, cut-off low) affects the local low level circulation patterns [4].

The subtropical jet stream axis is aligned with the African coastline associated with upper level dynamics is connected with enhance large scale ascending motions, instability and leads to the development of severe precipitation events in eastern Mediterranean (Toreti et al., 2010) and Cyprus[5]. Convergence in the lower and divergence in the upper troposphere, resulted in intense ascending motion, enhance cloud formation and thundery activity. The warm air advection associated with ascending motion increase low to mid-tropospheric.

The western Iran provinces usually experience the heaviest rain in March. Maximum 24-Hours (total) rain was recorded rain gauge on 9 to 11 March 2005 (Table 1). So the weather system that makes such heavy rain was noticeable. The Figure.1.a displays occurred precipitation rate $10 \times 10^5 kgm^{-2}s^{-1}$ northwest of Iran in 12(UTC) 9 March 2005. After 24 hours, it is increased and shifted to south over Sanandaj Province (Fig.1.b). On 11 March, precipitation rate is enhanced to $30\times 10^5 kgm^{-2}s^{-1}$ and moved to Kermanshah and Ilam Province (Fig1.c). The convective precipitation rate didn't take place in Western Iran (not shown). In this study the synoptic charts will be examined to elicit the possible contribution factors for these heavy rain. The aim of this work is to study synoptic and low-level atmospheric condition including thermodynamic and dynamic which finally resulted in very severe precipitation rates and humidity resource.

Table 1: 24-hours rain in Western Iran (mm)

	Rain 24-hours(mm)															
Station	Piranshahr	Takab	Sardashat	Sagez	Zarine	Bijar	Marivan	Sanandaj	Ravansar	Sarpol	Kermanshah	Eslamabad	Kangavar	Elam	Dehloran	Total
9 March	8	5	7	3	12	3	44	21	30	29	18	26	8	9	0.7	
10 March	8	30	17	*43*	*46*	*22*	*122*	25	24	26	14	33	11	46	4.5	
11 March	14	17	43	13	21	20	33	*49*	*67*	*48*	*46*	*72*	*37*	*79*	*31*	
Total	30	45	67	59	79	45	199	95	121	103	78	101	56	134	36.2	

2. Data and Methodology

Hourly rainfall data were taken from the rain gauge sites in 16 meteorological Station showing in Figures by triangles to analyze the heavy rain events over Western Iran on 9 to 11 march 2005.

In order to study the characteristics of the weather system, synoptic and several dynamical, thermodynamic parameters were calculated for selected isobaric layers. The data used for the required mathematical calculation were deduced from the NCEP/NCAR global reanalysis with a grid dimension $2.5^0 \times 2.5^0$ which are geopotential height, meridonal and zonal wind, temperature and vertical motion in 17 major levels.

The synoptic structure was reviewed by geopotential height in 500 hPa level and mean sea level. The dynamical parameters are vertical motions at 500 hPa, wind convergence at 850 hPa, mixing ratio advection and convergence mixing ratio flux. The precipitation and convective precipitation rate were extracted from NCEP/NCAR and plotted with Grads software. For the needs of the thermodynamic analysis, several thermodynamic indices including K-index, mixing ration in 850 hPa, precipitable water content, were examined. The definition and interpretation of the various thermodynamic parameters can be found online (http://www.crh.noaa.gov/lmk/soo/docu/indices.php). The selected domain is bounded 20 to 45 N^0 and 20 to 55 E^0.The figures are plotted by Surfer software.

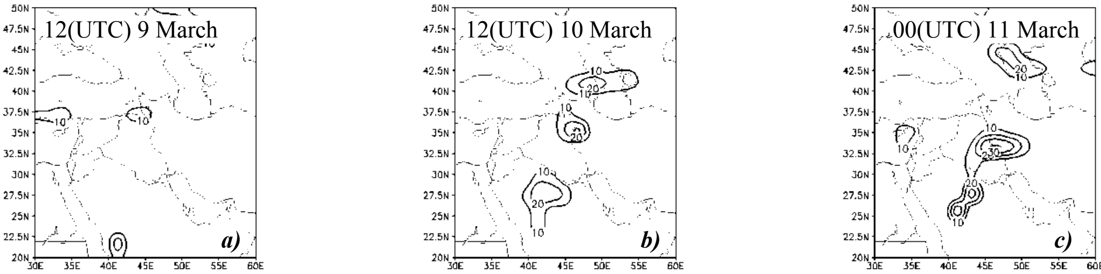

Fig.1 : precipitation rate$10^5 kgm^{-2}s^{-1}$: a)12 (UTC) 09, b)12(UTC) 10 and c) 00(UTC) 11; March 2005.

3. Results

3.1. Synoptic scale analysis

The pressure trough is located in North of the Caspian sea with extended minor trough to east of Turkey that is associated with height trough 500 hPa in 12(UTC) 9 March 2005 (Fig.2.a) that weak rain is took place in northwest of Iran. Plus Red Sea pressure trough 1010 hPa contour that is spread to center of Saudi Arabia coincided with height ridge at 500 hPa level, while upward vertical motion covers Saudi Arabia to eastern Turkey between two pressure trough (Fig.2.a). To 24-hours after, northern trough changes to low pressure with 1010 hPa central contour (Fig.2.b). Moving to east height trough at 500 hPa, Red sea pressure trough extend to northern latitude while upward motion is increased near and above northern Saudi Arabia in 12 (UTC)10 March (Fig.2.b) that precipitation rate increase to $30 \times 10^5 kgm^{-2}s^{-1}$(Fig.1.b). In 00(UTC) 11 March, gradient pressure intensifies in west and southwest of Iran due to pass of 1012.5 pressure contour of Red sea in north Saudi Arabia and shift weak low pressure to northeast of Iran(Fig.2.c). So upward motion moves to south of Iraq and southwest of Iran while increased maximum precipitation rate is shifting to Ilam Province (Fig1.c).

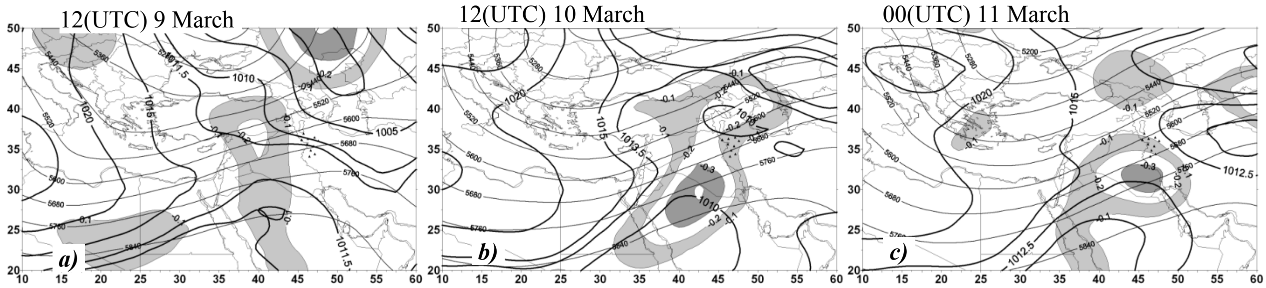

Fig.2 : mean sea pressure(thick line- hPa), geopotential height(thin line-m) in 500 hPa, upward motion(hatch area-ps^{-1})in 700 hPa;a) 12 (UTC) 09, b) 12(UTC) 10 and c) 00(UTC) 11, March 2005.

3.2.Thermodynamic analysis

In this section thermodynamic structure is examined. In 12(UTC) 09 March, 24 to 29 mm values of precipitable water content is over Western Iran(Fig.3.a). Flowing westerly and southwesterly wind of eastern Mediterranean and Iraq, it can transport humidity toward Western Iran so maximum mixing ration advection with -3$\times 10^{-6} grkg^{-1}s^{-1}$ is formed in northern Iran. It is elicited by Fig.3.b humid flux convergence is not strong in east of Turkey in 12(UTC) 09 March. On the other hand, upward motion can move up wet air to mid-level of troposphere but it can be found that process is weak in comparison Figure3.a and 2.a. Precipitable water content 24 to 29 mm covers western Iran. In western Iran Ki-index has values between 23 to 26 C^0, which means that thunderstorms with heavy rain or severe weather is possible. So, in 12 (UTC) 9 March, weak precipitation occurred in western Iran without convective rain. It is found that source water vapor content areas in 00(UTC) 09 are eastern Mediterranean and north of Red sea.

This patterns will change during 24-hours later so mixing ration advection will increase over northern Iran and over Saudi Arabia with forming southerly wind(LLJ) over Saudi Arabia causing northward wet air to southern Iraq and southwestern Iran as precipitable water content increases to 25 to 35 mm that represents low-level troposphere water content improvement (see Fig.3.c) in 00(UTC) 10 March. Although Ki-index is enhanced to $32C^0$ that means increases probability of thunderstorms with heavy rain, convective rain hasn't produced in Western Iran. Resulted of Fig.3.d and 2.b, humid flux convergence is intensified by increased upward motion that confirms intensification rain as it shown by Fig.1.b. This process transfers humidity from lower to middle troposphere. It is recognized, in 12(UTC) 10 March, Red sea and Aden gulf are source of wet and warm air for heavy rain in Iran.

In 00(UTC) 11 March, rain event still continues in western Iran, southerly wind is shifted to north(toward southern Iran) associated with mixing ration advection though its value is decreased in comparison the past 12 hours(Fig.3.e). By Fig3.e it can be found precipitable water content is 20 to 30 mm in western Iran that is weaker than its past 12 hours(Fig.3.c). In addition, Ki-index is decreased 19 to 26 in western Iran. Reducing maximum convergence humid flux to -5 $\times 10^{-6} grkg^{-1}s^{-1}$, that progresses toward south of Iraq and southwest of Iran according to heavy rain continuity(Fig.2.c).

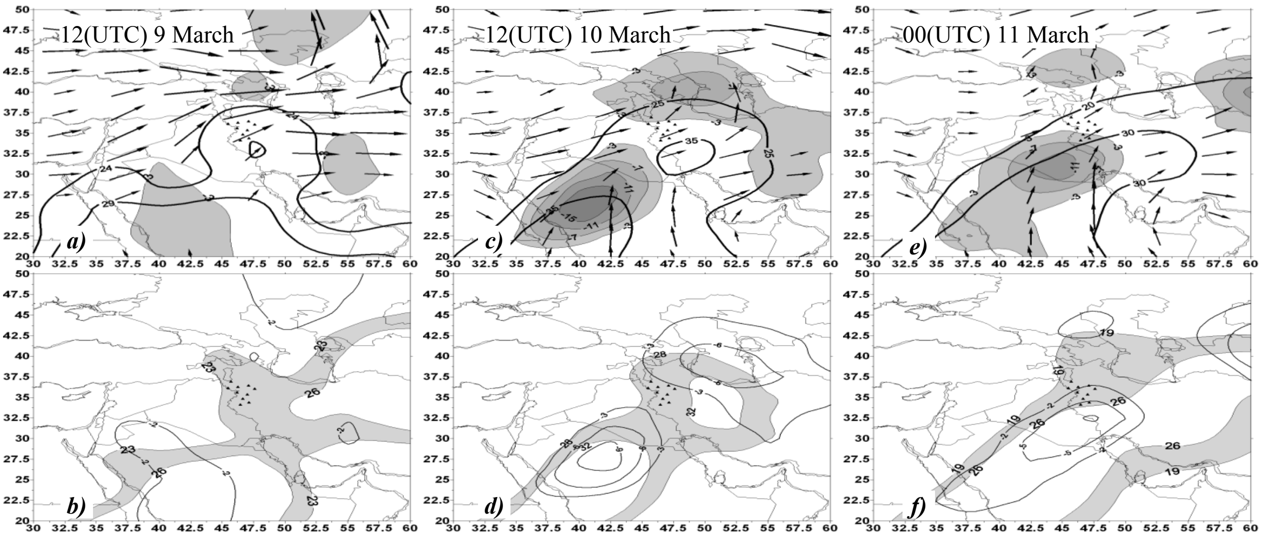

Fig.3: a) mixing ration advection(hatched- $10^{-6} grkg^{-1}s^{-1}$) in, wind direction in 850 hPa , precipitable water content (thick line-mm); b)K-index(hatched-C^0), convergence mixing ratio flux(thin line- $10^{-6} grkg^{-1}s^{-1}$) in 12(UTC) 09; c) same as a) and d) same as b) but for 12(UTC) 10; e) same as a) and f) same as b but for 00(UTC)11; March 2005.

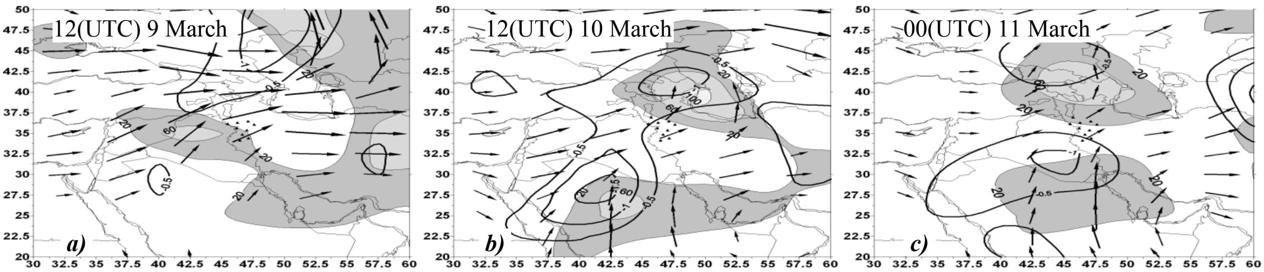

Fig.4: a) thickness advection (hatched-$10^{-5}ms^{-1}$), wind direction in 850 hPa, convergence (thick line-$10^{-5}s^{-1}$) in 12 (UTC) 09 in 850 hPa; b) same as a) but 12(UTC) 10 and c) same as a) 00(UTC)11; March 2005.

3.3.dynamical analysis

Figure.4. displays dynamical structure. In 00(UTC) 09 March, Positive thickness advection with values 60$\times 10^{-5}ms^{-1}$that represents temperature advection is located in northern Iraq because of southwest wind direction existence at 850 hPa(Fig.4.a). The convergence center with 0.5$\times 10^{-5}s^{-1}$ is formed over northern Saudi Arabia(Fig.4.a) and second center weaker over northern Iran and eastern Turkey. Because of maximum upward motion center, due to positive thickness advection, is coincided with convergence center and convergence mixing ratio in north of Iran and east of Turkey; wet air can transport to middle level troposphere. Therefore in 00(UTC) 09 March rain is low in northwestern Iran.

Founded of structure changes, positive thickness advection is moved to north of Iran with increasing values to $100 \times 10^{-5}ms^{-1}$ and the second center with $60 \times 10^{-5}ms^{-1}$ is formed over Saudi Arabia where southerly wind (LLJ) direction is formed that carries warm air to northern latitude (Fig.4.b) as is shown in thermodynamic structure(Fig.3.c and d). Comparing Figure 3.c and 4.b it is recognized that intensification convergence is associated with convergence humid flux plus convergence at 850 hPa has increased during the past 24 hours to -1.5 $\times 10^{-5} s^{-1}$ over Saudi Arabia coinciding with positive thickness advection and increasing upward motion (Fig.4.b and 2.b). Northward mixing ratio transportation is due to the formation in southerly wind (LLJ) resulted by 4.b, 4.c and d ,12(UTC) 10 March, increasing heavy rain events in Western Iran. Over the next 12 hours, although positive thickness advection will decrease in Saudi Arabia the same as north of Iran, southerly wind are shifted to southern Iran (Fig.4.c). In addition, convergence at 850 hPa is weak(Fig.4.c). In 00(UTC) 11 March, all thermodynamic and dynamic conditions are weak but they shift to south and west of Iran so that the heavy rain will continue in Western Iran.

4. Conclusions

We revisit the 9-11 March 2005 weather systems that produced maximum rain in western Iran border at synoptic and thermodynamic using NCEP/NCAR reanalysis data. Environment conditions of the 9-11 March 2005 were analyzed in order to assess the evolution of the dynamic and thermodynamic structures which led to the intense rainfall episode.

It is recognized that synoptic structures are different in heavy rain days in Iran. The rain in northwestern Iran in 09 March is weak and associated with north Iran pressure trough, in 12(UTC) 10 March is associated with weak low located in north Iran and Red sea pressure trough with increasing rain to heavy. But heavy rain in 00(UTC) 11 March is due to northward Red sea pressure trough. Although the thermodynamic and dynamic parameters in 12(UTC) 10 are stronger than 00(UTC) 11,these structure shift to northward and rain will be continue in Western Iran and produce increasing rain values.

The southerly wind (LLJ) is very important for forming heavy rain so that changes direction wind of southwesterly to southerly, according to [2], is accompanied increasing rain in western Iran of 09 to 10 March. Southerly wind(LLJ) affects several way. When wind direction shift to southerly, it can feed wet and warm air of Saudi Arabia, Red Sea and Aden gulf to south and southwestern Iran that is according to Mainvilee founding that environment contains high humidity, as pointed out by high magnitudes of precipitable water content, and when humidity is advected by the southerly wind (low-level jet) towards the surface convergence area as noted by[3].

Besides wind direction in low-level increase surface convergence which is turn transport improve upward motion and humid flux convergence causing upward humid air to middle level. In the third way, intensification positive thickness advection that increasing upward motion and convergence near the surface is resulted by warm air advection causing southerly wind.

Although ki-index values is exceeded 30 C^0 in some days, means that the probability of convective precipitation increase it isn't occurred (resulted by[5],[6],[7])in Western Iran. The humidity source needed in forming rain is different so that it is supplied by eastern Mediterranean sea on 09 March and Red sea and Aden gulf on 10-11 March 2005.

5. References

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