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Studying the Moisture Flux over West of Iran: A Case Study of January 1 to 7, 1996 Rain Storm

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Abstract: In order to define the moisture sources and flux over west of Iran, the January 1-7, 1996 rain storm was selected. During the study period six hourly data about the humidity and wind components at 9 different tropospheric levels were studied in the 10 to 80°E and 5 to 50°N window with 2.5 degrees resolution. The results showed that the main moisture source for the precipitation was the Arabian and Oman seas at the lower level. At the middle level the Red sea had more important role and the Mediterranean Sea are the source of the upper level moisture flux. Most of the moisture was transferred through the lower levels of troposphere. The wind flow originated from surface pressure systems was also important in conducting the moisture flux toward Iran.

Key words: Moisture flux, precipitation, rain storm over Iran, Middle East, West of Iran

INTRODUCTION

The transfer of moisture at any location is completely achieved by the atmospheric motions (Lindesay and Dabreton, 1993; Xiangde *et al.*, 2003; Renhe, 2001). Lindesay and Dabreton (1993) have studied the role of winds in transferring of moisture over South Africa. The rate of transfer changes not only according to the type of wind flow but also with the season of the year (Xiangde *et al.*, 2003). Renhe (2001) has shown this relation between the South Asian Monsoon flow and the moisture transfer from Indian Ocean. Also Jinhai *et al.* (2007) have studied seasonal transition features of moisture transport in the Asian-Australian Monson region.

In the Middle East, Dayan and Abramsky (1983) in their study about the moisture source of a single rain storm pointed out that the Subtropical Jet brings the moist air from southern areas such as Aden Sea and eastern Africa to Egypt and Jordan. Their study indicate a westerly trough has accompanied this jet in moisture transition. Alpert and Shay (1993) realized that despite the low rainfall of the northern Arabia and Southern Iraq, there is always moist air over the area. They stated that this moisture is not enough to produce rain and is being only transferred in the middle and upper clouds from the area.

The computation of moisture transfer has usually utilized the ECMWF data (Yatagai and Yasumari, 1998), but in recent years the use of satellite data has become very common (Roca *et al.*, 1997; Jedlovec and Lerner Jeffrey, 2000; Dayan *et al.*, 2001; Wood *et al.*, 2002; Bretherton *et al.*, 2004).

The moisture source of the precipitation in Iran has long been concerned by the researchers. Due to its dry situation and climate, there is no local moisture source and most of the moisture should be transferred from outside water bodies. Very few studies have concerned with the quantifying the moisture sources of the country's precipitation. Alijani (1995) has determined the moisture tracks of the country. He also reported the Mediterranean Sea as the main moisture source for all country. Smith *et al.* (2003) and Evans *et al.* (2003) have described the nearby water bodies of Caspian Sea and Persian Gulf as the moisture sources for the precipitation over the Alborz and Zagros mountains, respectively. Sudan low pressure systems have been concerned in recent years which emphasize the Persian Gulf as the main source for the rainfall of the southwestern Iran and during the development of these systems the high pressure over the Arabian Sea intensifies the moisture transfer of the Sudan Lows (Lashkari, 2002, 2003; Mofidi, 2005; Mofidi and Zarrin, 2005).

None of these studies have dealt with the moisture source of the precipitation in more detail. Therefore main object of this study is investigate more precisely the moisture sources of the precipitation over Iran.

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MATERIALS AND METHODS

The area of study is 10-80°E and 5-50°N (Fig. 1). In order to study the moisture source of the precipitation over the western parts of Iran, the rain storm of January 1-7, 1996 was selected. This storm had produced widespread rainfall over the western parts of the country. This rain storm caused about 45 mm rain fall in NW, 117 mm in W and 100 mm in SW of Iran.

The 2.5° by 2.5° latitude and longitude grid ECMWF reanalysis datasets is used for 1-7 January 1996. The zonal and meridional wind components (u and v), specific humidity (q), _data is obtained for four times daily (0000, 0060, 1200 and 1800 UTC) and for 9 levels (1000, 925, 850, 775, 700, 600, 500, 400 and 300 hPa).

The study area in this research classified into 3 categories including: (1) source (2) transit and (3) sink areas based on moisture transportation.

The source areas including: Persian Gulf, Oman, Arabian, Red, Mediterranean, Black and Caspian Sea.

The transit area cover Arabian Peninsula, Iraq, Jordan, Syria and turkey.

The sink areas include Northwest, West and Southwest of Iran.

The moisture transfer and its path were determined as follows:

The wind vector is computed as:

$$V = ui_\lambda + vi_\phi \qquad (1)$$

Where, i_λ and i_ϕ are the unique vectors of east and west directions. λ is longitude, ϕ is latitude.

The moisture divergence was calculated as:

$$V q = -\left(\frac{\partial u}{\partial x}\cdot q + \frac{\partial v}{\partial y}\cdot q + \frac{\partial q}{\partial x}\cdot u + \frac{\partial q}{\partial y}\cdot v\right) \qquad (2)$$

Where, V q is the Horizontal Divergence of Water Vapor Flux (horizontal moisture flux) (the sign-is used to make the flux positive) and ∂x ∂Y are distances in east and north directions.

The positive flux values indicate the convergence and the negative values show the divergence.

The total vertically integrated of Horizontal Divergence of Water Vapor Flux (total moisture flux) at the

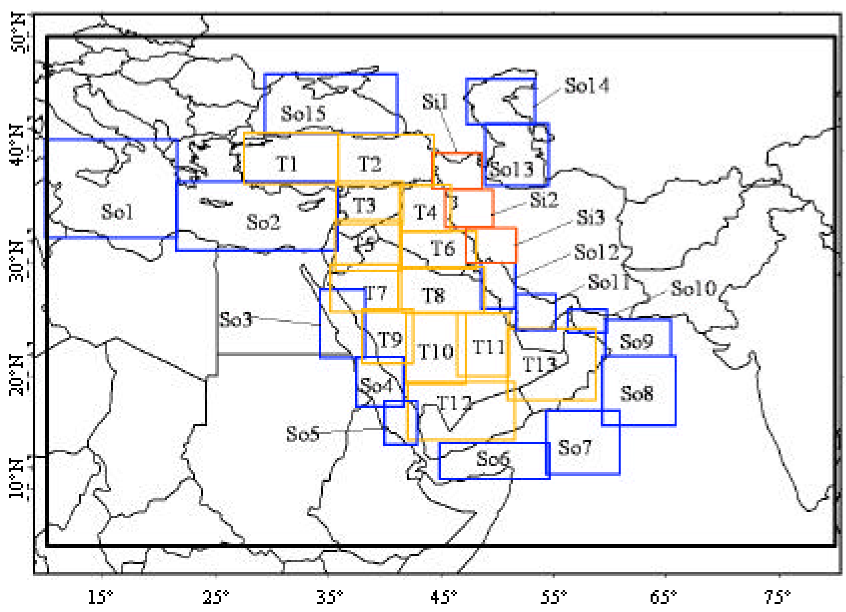

Fig. 1: Study area location. Defined separate regions for both sea and land, seas are source and lands are sinking or transit areas, (So1) Center of Mediterranean Sea, (So2) East of Mediterranean Sea, (So3) North of Red Sea, (So4) Center of Red Sea, (So5) South of Red Sea, (So6) South of Arabian Sea, (So7) Center of Arabian Sea, (So8) North of Arabian Sea, (So9) East of Oman Sea, (So10) West of Oman Sea, (So11) East of Persian Gulf, (So12) West of Persian Gulf, (So13) south of Caspian Sea, (So14) North of Caspian Sea, (So15) Black Sea. (T1) West of Turkey, (T2) East of Turkey, (T3) Syria, (T4) North of Iraq, (T5) Jordan, (T6) South of Iraq, (T7) Northwest of Arabian Peninsula, (T8) Northeast of Arabian Peninsula, (T9) West of Arabian Peninsula, (T10) Center of Arabian Peninsula, (T11) East of Arabian Peninsula, (T12) Southwest of Arabian Peninsula, (T13) Southeast of Arabian Peninsula. (Si1) Northwest of Iran, (Si2) West of Iran, (Si3) Southwest of Iran, So is (Source), T (Transit) and Si (sink)

lower, middle and upper levels and total atmosphere was computed according Eq. 3-6:

$$Q_{vi,1000-775} = 1/g.\int_{1000}^{775} Vq.dp \quad (3)$$

$$Q_{vi,775-500} = 1/g.\int_{775}^{500} Vq.dp \quad (4)$$

$$Q_{vi,500-300} = 1/g.\int_{500}^{300} Vq.dp \quad (5)$$

$$Q_{vi,1000-300} = 1/g.\int_{1000}^{300} Vq.dp \quad (6)$$

Where, Q_{vi} is total moisture flux.

To quantify the moisture transport and understand its mechanism associated with moisture source and sink, we calculated areal (regional) average of Q_{vi} as defined in Fig. 1 by using the following equation.

$$A\bar{Q}_{vi} = \left(\int_{t1}^{t2}\left(1/g.\int_{p1}^{p2} Vq.dp\right)/dt\right)/A \quad (7)$$

Where:

AQ_{vi} = Average of Q_{vi} over time and area,

t = time and A is area, respectively.

The computations were carried out in three phases:

The first phase is defined as no rain period started at 00 GMT of January 1st and ended at 00 GMT January 3rd. The second phase, the rainy period, started from January 3rd and ended at 00 GMT January 7.

The whole study period from January 1st to January 7 was studied as the third phase.

RESULTS

The prepared maps of vertically integrated horizontal of water vapor flux showed for different studied periods of 1-3 January (Fig. 2), 3-7 January (Fig. 3) and 1-7 January (Fig. 4).

The mean moisture gains during the first two days of January over west coast of Arabian Peninsula and over Syria are indicated (Fig. 2a). The mean rate of moisture outflow observed over Arabian Sea, Oman and Red seas. In this duration there was no moisture influx to Iran at the lower troposphere but there seems an influx at the middle and upper troposphere over southwest and west Iran.

In 3-7 January period, the maximum outflow of moisture has occurred over Arabian sea, Oman and Red sea (Fig. 2b). Much of moisture has transferred at the lower troposphere. The main moisture gaining region are Arabian Peninsula and Syria in a southwest-northeast direction (Fig. 2b). During the rainy days of January 3- 7 the moisture flux has moved in a parabolic form to the west of Iran. The source regions were the Oman, Red and Arabian seas. The maximum outflow of moisture occurred from Arabian sea and Red and Oman seas, while the highest moisture sinks have moved to southwest and west of Iran and northwest of Iran. In this period the west and northwest of the Iran received about 2×10^{-4} kg m^{-1} sec^{-1} and moisture fluxes observed at the middle levels, while the southwest showed the moisture outflow. But the maximum moisture outflow was originated from southern part of the Red sea and the total

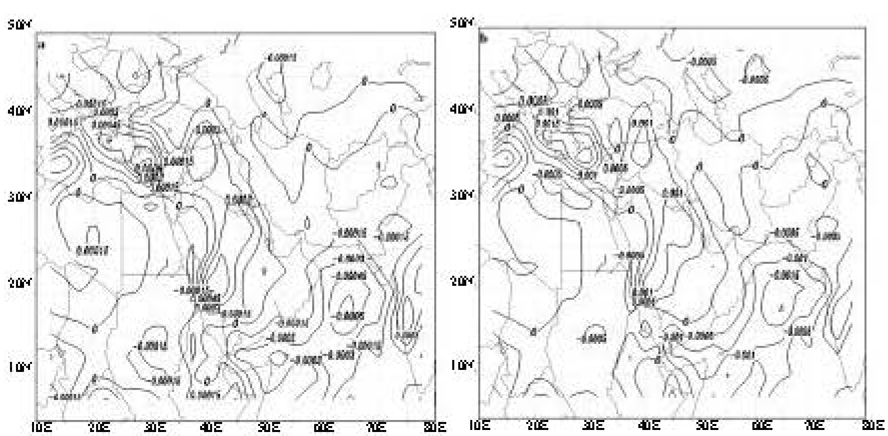

Fig. 2: Vertically integrated horizontal divergence of water vapor flux (kg m^{-1} sec^{-1}), positive value is convergence) a (lower levels) and b (tropospheric column), for 1 and 2 January

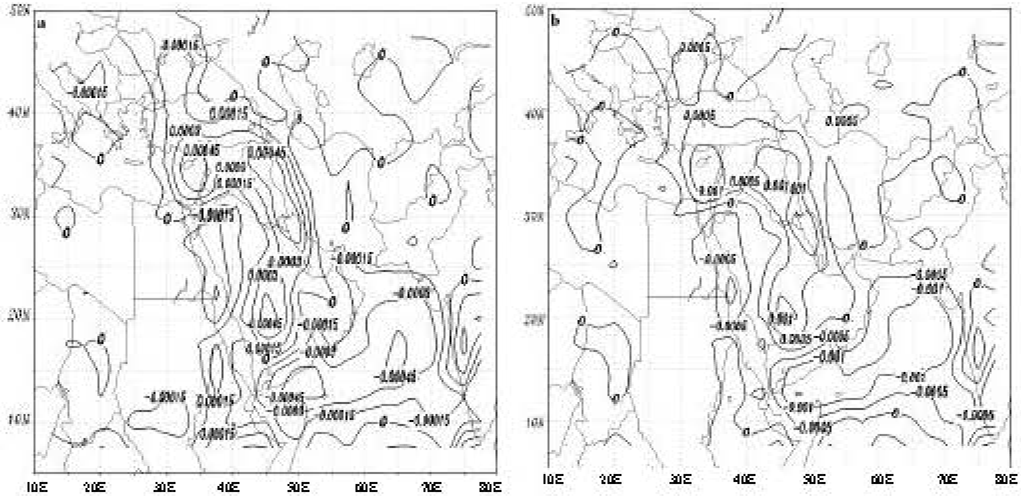

Fig. 3: Vertically integrated horizontal divergence of water vapor flux (kg m^{-1} sec^{-1}), positive value is convergence) a (lower levels) and b (tropospheric column), for 3-7 January

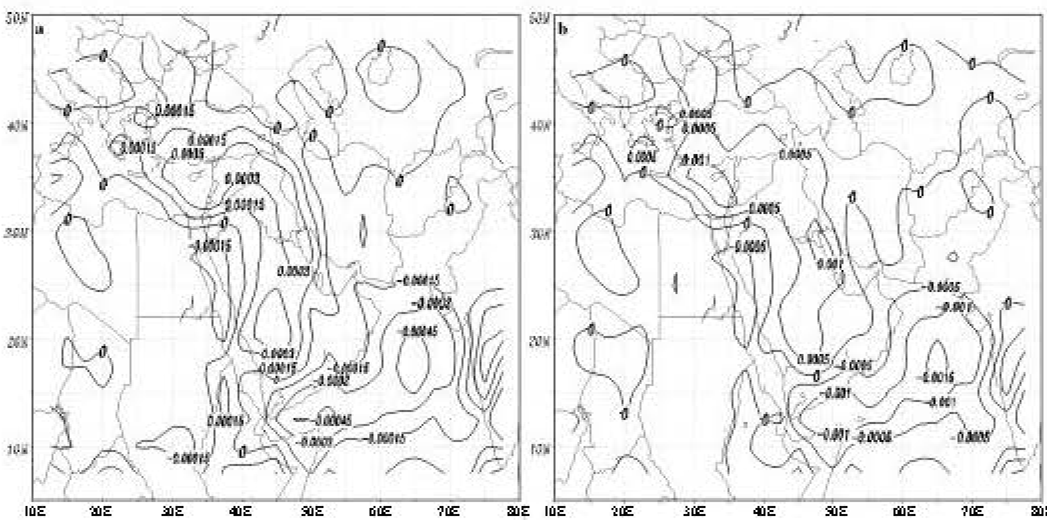

Fig. 4: Vertically integrated horizontal divergence of water vapor flux (kg m^{-1} sec^{-1}), positive value is convergence) a (lower levels) and b (tropospheric column), for 1-7 January

tropospheric moisture influx occurred during the rainy days with more than 1.5×10^{-4} kg m^{-1} sec^{-1} over the west of Iran (Fig. 3b).

Over the study period from January 1 to 7, the total influx was computed about 3×10^{-4} kg m^{-1} sec^{-1} at the lower troposphere (Fig. 4a). At the middle levels there due to the changing wind direction and speed, the moisture influx was located over northwest and west of the Iran and the southwest showed moisture outflow. During the study period the Arabian sea was the moisture source at the lower levels (Fig. 4a) but being replaced at middle and upper levels by Red and Mediterranean seas. Most of the moisture flux has occurred at the lower level being over the southwest and over the west and northwest (Fig. 4b). The moisture source of the precipitation was the Arabian Sea at the beginning but changed to the Aden Gulf during the rain days. In general the Arabian Sea was the main moisture source for the storm and the Red sea was the second.

Areal average vertically integrated horizontal divergence of water vapor flux for there duration (Fig. 5) indicated that maximum areal average is over Arabian Sea (north, center and south). But in the first period, the moisture flux is more than the two periods. Generally moisture transported from Arabian Sea to Arabian Peninsula several days before start rain over Iran. The next area is east of Oman, north of red and west of Oman Sea that temporal pattern's is different, the maximum moisture divergence in the Oman sea is in the first period but the maximum of red Sea is in the rainy period. The center of red sea in the first period is convergence area due to convergence moisture southern and northern. The east of Mediterranean Sea is a convergence area of moisture in the each three duration.

West of Persian gulf at the three periods is a sink area in the all of levels and only east part of it in the lower and upper levels have a little divergence of moisture. The transition areas in the each three duration are a sink moisture area (convergence area) except west and northwest of Arabian Peninsula due to divergence of south and northwest of Red Sea (Table 1).

The northeast and center of Arabian Peninsula and Iraq are greatest area of convergence moisture. Temporal

Table 1: Areal average vertically integrated horizontal divergence of water vapor flux for there duration (1-3 January, 3-7 January, 1-7 January)

	All CT			Upper			Middle			Lower		
Area	1-7	3-7	1-3	1-7	3-7	1-3	1-7	3-7	1-3	1-7	3-7	1-3
Transit area												
T1	4.20	3.80	4.10	-0.01	-0.07	0.08	0.45	0.09	1.10	1.30	1.46	0.80
T2	4.70	4.82	5.30	-0.03	-0.09	0.09	0.26	-0.16	1.20	1.56	1.90	1.10
T3	8.10	8.67	9.24	-0.12	-0.18	-0.05	-0.73	-0.91	-0.36	3.27	3.37	3.40
T4	8.13	10.70	4.70	-0.08	-0.16	0.11	-0.04	-0.39	0.47	3.20	4.37	1.36
T5	3.40	1.62	5.80	-0.03	-0.08	0.01	-0.01	-0.12	0.10	1.16	0.73	1.70
T6	6.90	7.16	7.10	-0.07	-0.16	0.13	-0.31	-0.78	0.55	2.60	3.00	2.00
T7	-3.70	-5.70	-1.00	-0.02	-0.07	0.02	-0.60	-1.00	-0.10	-0.96	-1.40	-0.50
T8	6.20	4.10	11.00	-0.10	-0.16	0.44	0.11	-0.50	1.50	2.50	2.10	3.20
T9	-1.30	-4.80	3.70	-0.05	-0.06	-0.06	-1.40	-1.70	-1.30	0.41	-0.65	2.10
T10	6.47	5.64	8.60	-0.12	-0.17	-0.1	-0.66	-1.30	0.81	3.17	3.20	3.35
T11	4.60	5.20	4.50	-0.09	-0.15	0.06	0.80	0.38	2.00	1.30	1.80	0.53
T12	-1.80	-2.60	0.03	-0.04	-0.07	-0.08*	-0.89	1.10	-0.31	-0.22	-0.38	0.07
T13	-0.80	-0.30	-0.80	-0.04*	0.04	0.04	0.58	0.95	0.08	-0.70	-0.70	-0.70
Sink												
Si1	3.7	5.00	0.68	0.02	-0.03	0.12	0.80	1.00	0.25	0.69	1.10	-0.30
Si2	6.8	9.30	1.60	-0.09	-0.20	0.14	0.64	0.58	0.80	2.30	3.40	-1.80
Si3	4.9	7.20	0.72	-0.10	-0.20	0.16	-0.40	-1.00	0.86	2.20	3.60	-0.30

Area definition in Fig. 1, Values is (×10[illegible] (kg m^{-1} sec^{-1})) and *: (× 10^{-7} (kg m^{-1} sec^{-1})), All C.T (all tropospheric column)

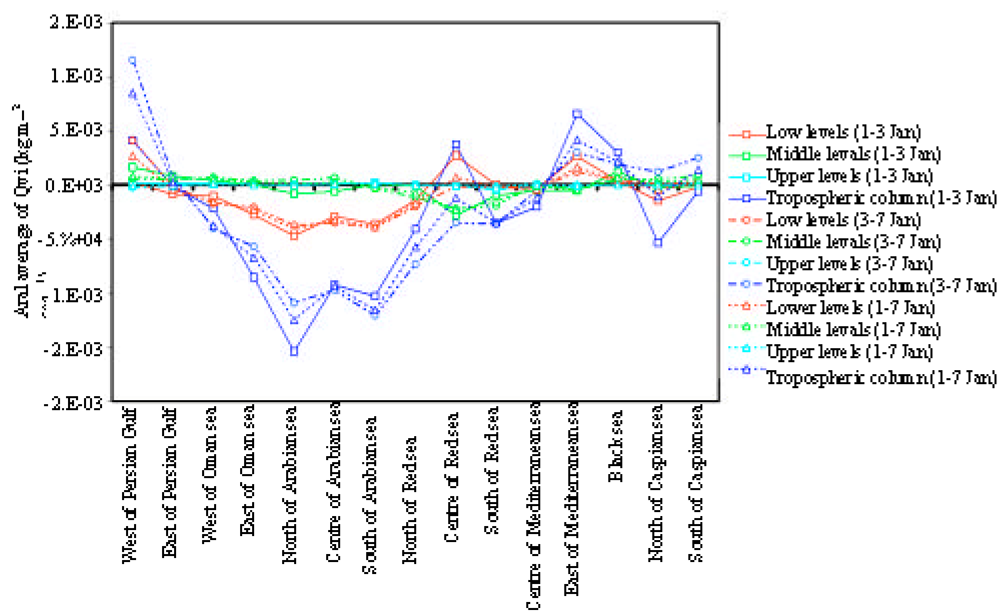

Fig. 5: Areal average vertically integrated horizontal divergence of water vapor flux for there duration and area definition in Fig. 1, source of moisture area (seas)

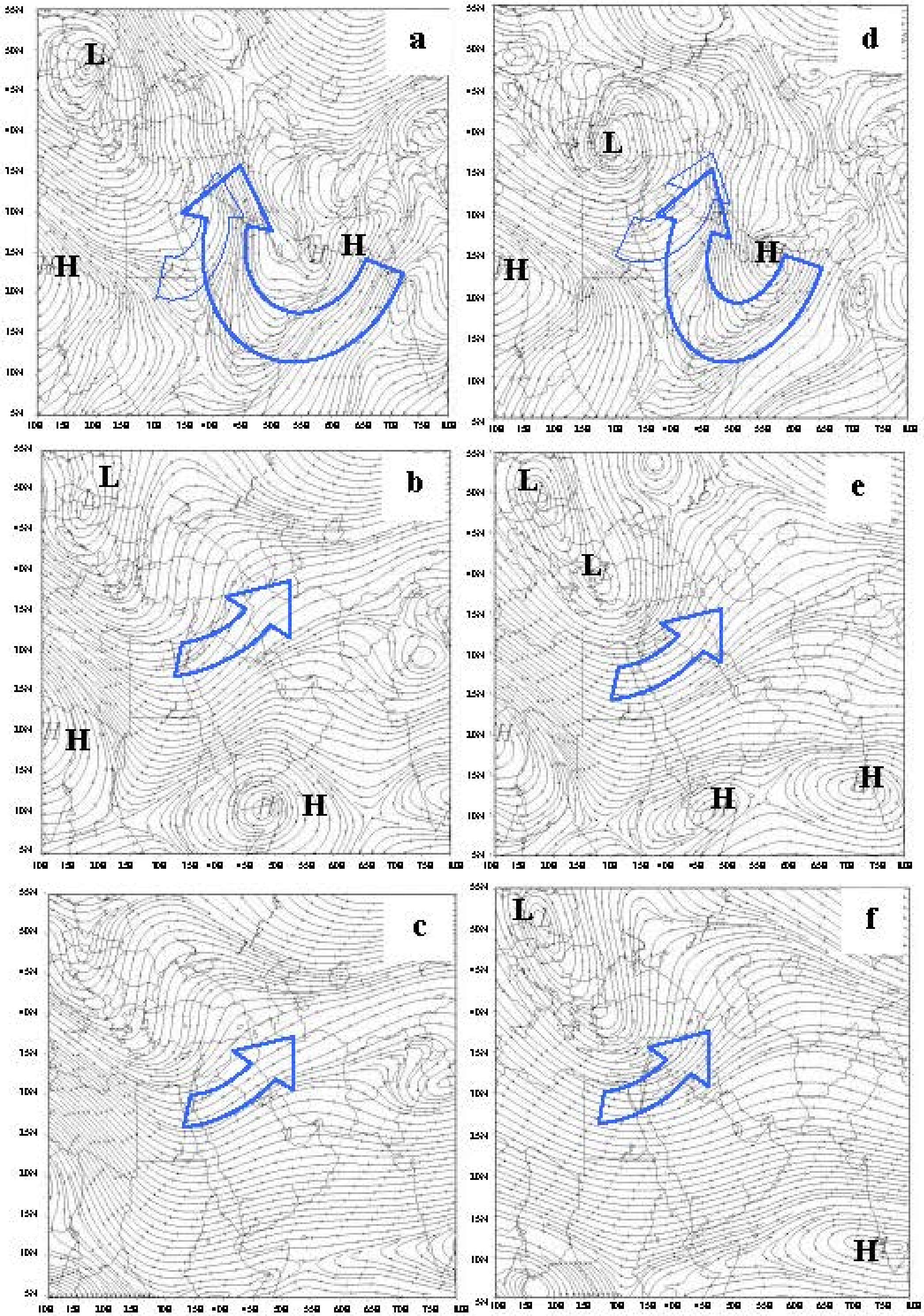

Fig. 6: Average of streamline at the lower levels (1000-775 hPa) (a and d), middle levels (775-500 hPa) (b and e) and upper levels of troposphere (500-300 hPa) (c and f), 00Z1jan96 to 00Z3jan96 (a-c), 00Z3jan96 to 00Z7jan96 (d-f), the arrows shows dominate direction moisture transport

Trend of moisture convergence shows spatial pattern is center of Arabian Peninsula, next northeast of it, after Iraq and the final entered to Iran. Arabian Sea is major moisture source for Middle East and Specific west of Iran (Fig. 5).

In the west of Iran middle levels corporate in the moisture transport, but in the northwest relation between lower and middle levels is equal (Table 1).

According to these maps a high pressure center was located over east of Arabian Peninsula. This system has important role in conducting moist air to Iran. This system has produced northeasterly flow to its east and southwesterly flow to its west conducting the moist air from Arabian sea toward Iran. At the middle and upper levels the deep trough located over Red sea has conducted the moist air to Iran (Fig. 6).

CONCLUSIONS

The results of this study showed that the moisture flux over the lower levels of the troposphere is different from the upper levels. At the lower level the surface high pressure systems located over the Arabian Peninsula advect the moisture of the Arabian and Red seas to the north and then east over Iran. While at the middle and upper levels the moisture flux is from west to east. The numerical computation of moisture flux showed that the Arabian and Oman seas are the main moisture source at the lower levels of troposphere. The Red sea is the moisture source at the middle level. But the Mediterranean Sea contributed to the precipitation of Iran only at the upper level. Its contribution is very little compared with the other sources. The findings of this study confirmed the results of previous investigations (Lashkari, 2002, 2003; Mofidi and Zarrin, 2005; Milind, 2006) and highlighted the role of surface flow and pressure systems. It also completed the results of the works of Alijani (1995) and showed that using wind directions will be very accurate if accompanied with numerical computations of moisture sources and sinks.

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