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Role of Red Sea trough on humidity source of east Mediterranean cyclones

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सार – भूमध्यसागरीय चक्रवात, विशेष रूप से समुद्र में आने वाले पूर्वी चक्रवात, ईरान में शीत ऋतु के समय होने वाली वर्षा की घटनाओं में अत्यंत महत्वपूर्ण भूमिका निभाते हैं। दूसरी और लाल सागर में बनने वाली सतही द्रोणी के कारण उष्णकटिबंधीय क्षेत्र से अति उष्णकटिबंधीय क्षेत्र में आर्द्रता का अपसरण होता है। ई. एम. चक्रवातों के आर्द्रता स्रोतों की आपूर्ति में लाग सागर की भूमिका का निर्धारण करने के लिए भू–विभव ऊँचाई के सतह आँकड़ों, उत्तरी अक्षांश के 5 से 65 डिग्री तक सीमित में और पूर्वी देशांतर के 0 से 80 डिग्री में पवन की विशिष्ट आर्द्रता और उर्ध्वाधर तथा क्षैतिज घटक का उपयोग किया गया है। इस अध्ययन के दौरान भूमध्य सागर के पूर्व में 56 चक्रवातों की पहचान की गई जो लाल सागर के द्रोणी घटनाओं के समकालिक थे। लाल सागर के प्रबल द्रोणी के समकालिक चक्रवातों के 10 मामलों में आर्द्र फलक्स के अभिसारी मानचित्र तैयार किए गए। चुनिंदा मामलों के आर्द्र फलक्स के अभिसारी मानचित्रों के सत्यापन से यह पता चला है कि ई. एम. चक्रवातों के लिए अपेक्षित कुछ आर्द्रता अरब सागर से आरंभ हुई और तत्पश्चात फारस की खाड़ी तथा अदन की खाड़ी में कुछ हद तक तो प्रबल रही और फिर लाल सागर से गुजरते हुए भूमध्य सागर के दक्षिण पूर्वी क्षेत्र में प्रवेश कर गई। वास्तव में लाल सागर इन चक्रवातों के आर्द्रता स्रोत में कोई महत्वपर्ण भूमिका नही निभाता है बल्कि उष्णकटिबंधीय क्षेत्र से बहि उष्णकटिबंधीय क्षेत्र की आर्द्रता के अपसरण के लिए उस मार्ग से मात्र गुजरने की भूमिका निभाता है तथा ई. एम. चक्रवातों में अपेक्षित आर्द्रता भर देता है। उच्च स्तरों पर जल के सक्शन की मात्रा और उन स्थानों का निर्धारण करने के लिए भू विक्षेपी अपसरण के संयुक्त मानचित्रों और ध्रुवीय फ्रंट के जेट प्रवाहों का उपयोग किया गया है।

ABSTRACT. Mediterranean cyclones, especially east cyclones of this sea, play a very important role in precipitation events of cold season in Iran. In the other hand formation of surface trough over the Red Sea makes possible the displacement of humidity from tropical area to extra-tropical area. To determine the role of Red Sea trough in supplying humidity sources of EM cyclones, surface data of geopotential height, specific humidity and Vertical and Horizontal component of wind in limited 5 through 65 degrees of north latitude and 0 through 80 degrees of east longitude were used. During the study 56 cyclones formed over the east of Mediterranean recognized which were simultaneous to the Red Sea troughs events. Convergence maps of moisture flux of 10 cases of simultaneous cyclones with Red sea trough which were strong, were drawn. Verification of convergence maps of moisture flux of selected cases show some required humidity for EM cyclones are initiated from Arabian Sea and then to some extent are reinforced over Persian Gulf and Gulf of Aden and then by passing over Red Sea enter to the south east of Mediterranean Sea. Actually Red Sea has not an important role in the humidity source of these cyclones and acts as a pass way for displacement of humidity of tropical area to extra-tropical area and injects the required humidity into the EM cyclones. To determine the regions and the amount of suction in the high levels, composite maps of ageostrophic divergence and jet streams of polar front were used.

Key words – East Mediterranean cyclone, Humidity source, Red Sea trough, Moisture flux convergence, Ageostrophic divergence, Polar front jet stream.

1. Introduction

The Red Sea Trough (RST) is a tongue of low-pressure extending northward from the southern Red Sea toward the Eastern Mediterranean (EM) and the Levant, at lower atmospheric levels (Ashbel, 1938 ; El-Fandy, 1948). The origin of the RST is the 'Sudan Monsoon Low', a part of a large-scale subtropical/equatorial low-pressure thermal system (Tsvieli & Zangvil, 2005).

The Low-pressures of Red Sea region are formed in barotropic environment under the effects of regional circulation patterns or dynamic conditions (Mofidi, 2003). Sometimes the Red Sea trough is simultaneous with an extensive top trough from northward over the east of Mediterranean. This top trough helps the uplift movement and disturbance conditions (including extension of convergence storms) and sometimes is associated with heavy showers and thunderstorms especially in the east of

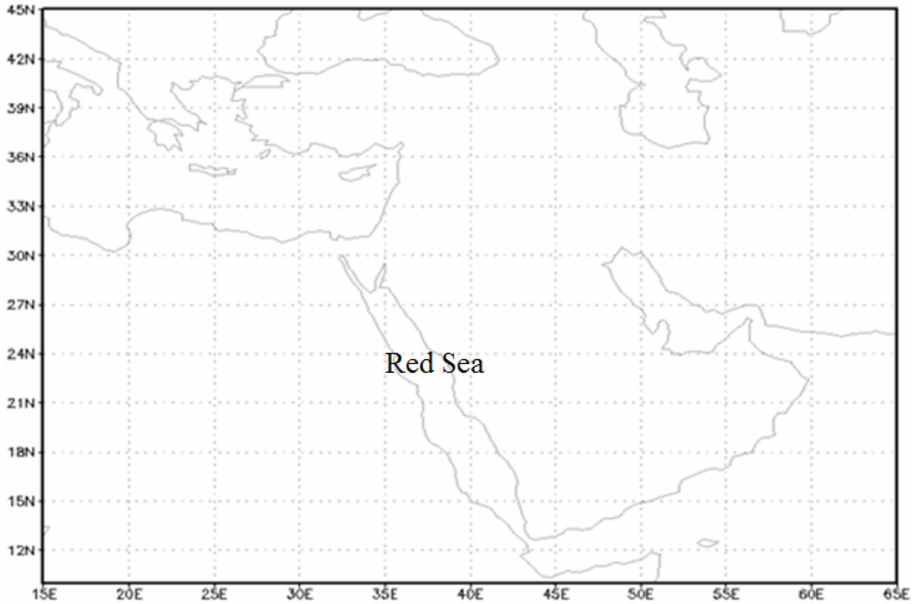

Fig. 1. The area of study

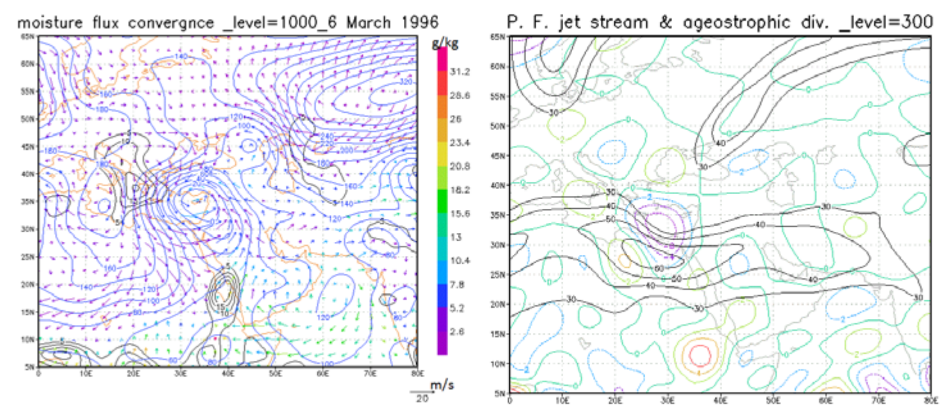

Fig. 2. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 6 March 1996

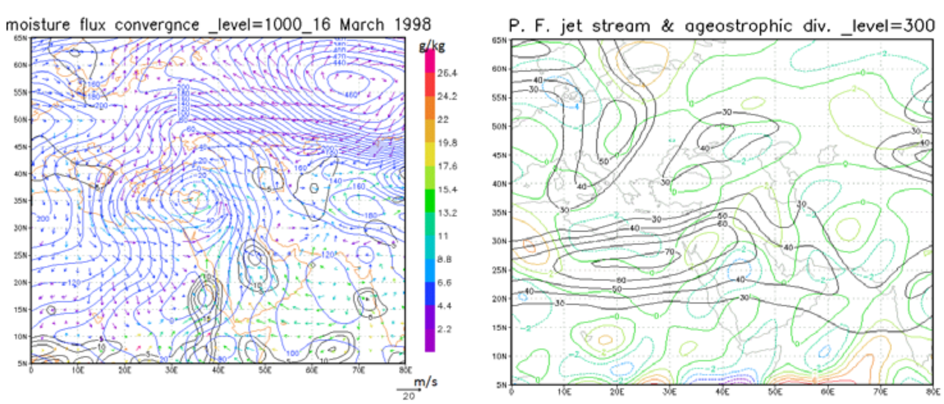

Fig. 3. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 16 March 1998

Mediterranean (Ziv 1994; Kahana *et al*., 2002; Goldreich 2003) Lashkari (2000) believes that in the southern half of Red Sea south-southwest currents and in the northern half north-northwest currents are formed and these opposite currents reach together and converge.

A cyclone is a region of low pressure and almost circular in form which may have diameter to hundreds kilometers. Cyclones in northern hemisphere rotates counter clockwise around each self and have uplifting motion. The EM is known as one of active cyclogenesis regions of Mediterranean (Petterssen 1956; Trigo 1999; Maheras *et al*., 2001).

Climatological and synoptic studies (Alpert *et al*., 1990; Dayan 1986; Dayan and Abramsky 1983; Reiter 1975) clearly have shown the seasonal characteristics of cyclones in this region. Most of the cyclones of this region especially in autumn and winter seasons can affect Middle East and Iran (Alijani 1994; Ahamdi Giv and Nasr Isfahani 2003; Shabrang *et al*., 2008; Jaafar Bigloo *et al*., 2009) because the most frequent path of cyclones over the Mediterranean Sea is toward east (Alpert *et al*., 1990; Karas and Zangvil 1999; Guijarro *et al*., 2006).

Mofidi (2003) has stated that Red Sea trough before activation for creating the flood needs a four day period for transmitting the humidity of far tropical regions. In the south of Mediterranean Sea, Sudan Monsoons Low gain main source of their humidity from tropical East Africa (Southeast of Sudan, south of Ethiopia) and then from southwest Arabian Sea and they reinforce on their path over the Red Sea and Persian Gulf (Mofidi and Zarrin 2005a).

Some of the researchers believe that because of weakening of siberian high presure, EM type cyclones (Cyprus) from the beginning of 1980s have remarkable decrease which is associated with reinforcement of Hadley cell, high pressure and sub-tropical jet streams and also substantial increase in the activity of Sudan Monsoon Low in the southeastern Mediterranean (Alpert *et al*., 2004).

This fact can cause decrease in the activity of Mediterranean cyclones over the Middle East and also highlighted role of Sudan Monsoon Low in the future (Mofidi and Zarrin 2005b). Khoshhal *et al*., (2009) have stated the source of humidity of very heavy precipitations of Bushehr is tropical regions of east Africa, Indian Ocean, Arabian Sea, Red Sea, Oman Sea and Persian Gulf. Farajzadeh *et al*. (2009) also believe Oman Sea and Arabian Sea are main humidity sources of precipitations over western Iran.

Closeness of Red Sea and Mediterranean Sea and location of Red Sea between tropical and extra tropical regions on the other hand, makes this question whether Red Sea has any roles in providing the humidity in EM cyclones? This study aims to determine the role of Red Sea in providing the EM cyclones.

2. Data and methodology (1st Jan 1995 to 19th Mar 2004)

Mediterranean cyclones play a very important role in Iran precipitations event. In this research to identify the humidity sources of EM cyclones by means of subjective method at a 10 years period (1 January, 1995 to 19 March, 2004), EM cyclones in the box of 20 to 40 degrees of east longitude and 30 to 40 degrees of north latitude at 1200 UTC, were identified.

Totally 384 cyclones were recognized. From these cyclones during days with simultaneous occurrence of EM cyclone and Red Sea trough those with simultaneous occurrence with Red Sea trough, were selected. Selected cases were sorted according to mid regional of geopotential height gradient. Moisture flux convergence maps and the composite maps of polar front jet stream and ageostrophic divergence for 10 cases were plotted.

In this research environment to patterns method has been used which is one of the fundamental methods of synoptic climatology. In environment to patterns method, circulation patterns and synoptic analysis is based on environmental variables (Yarnal 1993; Alijani 2002; Masoudian and Kaviani, 2008).

Geopotential height data (in meter) vertical and horizontal wind (in meter per second) specific humidity in (gram per kilograms) were acquired from NCEP-NCAR website (www.cdc.noaa.gov). The box of 5 to 65 degrees north and 0 to 89 degrees east were selected which includes Mediterranean Sea and its eastern part. Considering 2.5*2.5 regular cells of these data, totally this range includes 891 cells (33*27).

Formation of cyclones were identified in limited 20 through 40 degrees of east longitude and 30 to 40 degrees of north latitude in the time interval 1 January, 1995 to 19 March, 2004 at 1200 UTC. Then by subjective method, geopotential height maps during days of EM cyclones were analysed. The maps of the days when simultaneous occurrences of EM cyclones with important Red Sea trough were observed, was separated. Table 1 shows the list of the days when simultaneous happening of these two events had occurred.

TABLE 1

Simultaneous EM cyclones with Red Sea trough

Day	Month	Year	Row	Longitude	Latitude	Geopotential height of cyclone center	Mid Regional of Geopotential gradient
1	3	1996	-31	35	32.5	6	106.376
2	3	1998	-70	35	35	16	80.3369
3	12	1996	47	35	30	4	77.8954
4	2	2003	63	35	32.5	13	55.372
5	1	2000	54	35	35	4	55.2393
6	1	2002	68	35	35	6	54.8662
7	1	2001	69	30	40	2	54.4108
8	1	2002	109	30	35	27	53.8133
9	1	1996	87	37.5	22.5	27	52.9351
10	11	2000	110	35	32.5	30	50.4906

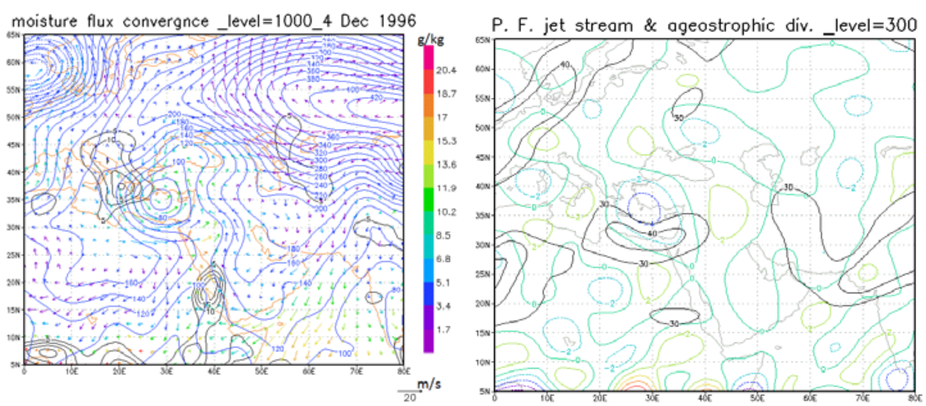

Fig. 4. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 4 December 1996

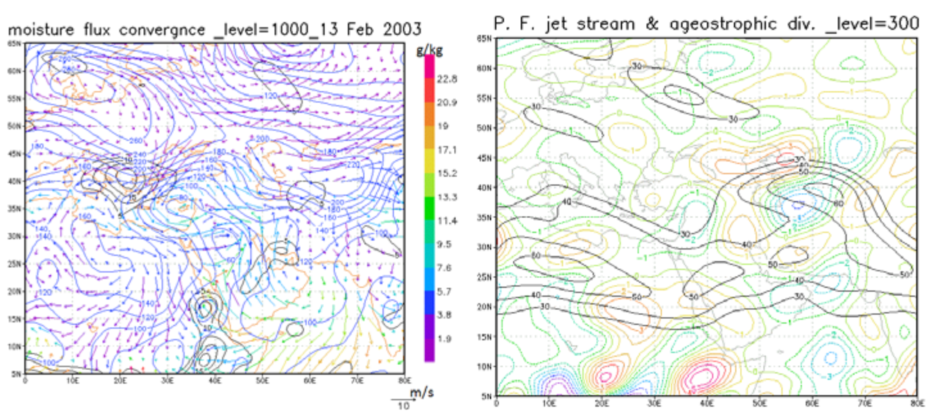

Fig. 5. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 13 February 2003

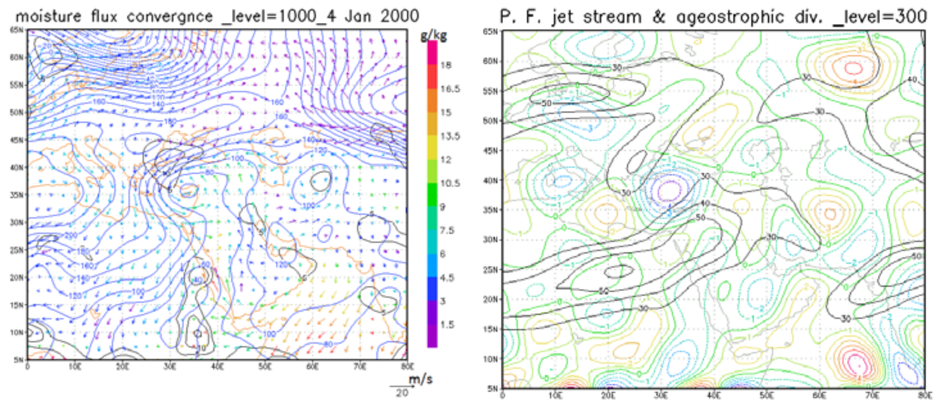

Fig. 6. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 4 January, 2000

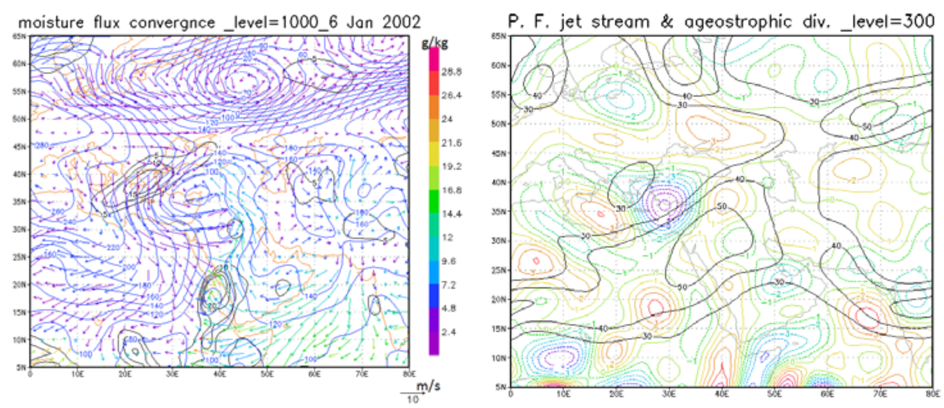

Fig. 7. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 6 January, 2002

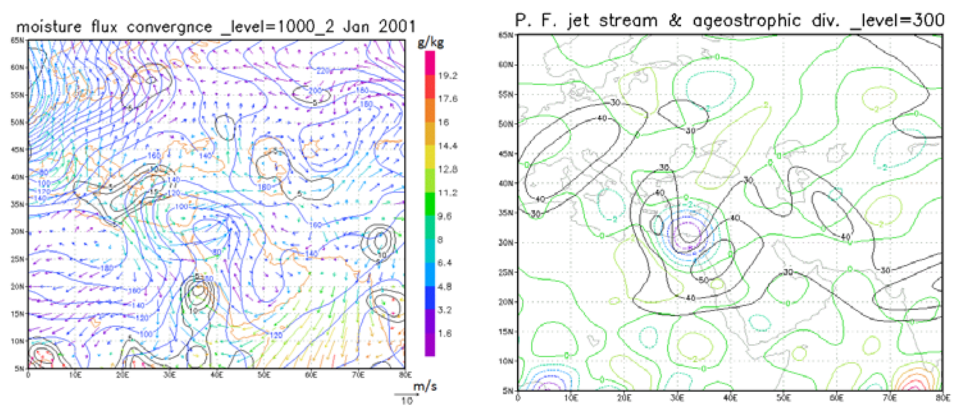

Fig. 8. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 2 January, 2001

These maps were sorted on the basis of mid-regional geopotential height gradient factor.

To locate the center of surface level cyclone, two conditions were used:

1. Geopotential height of verified cell with respect to its eight neighbors must be minimum.

2. The mean of geopotential height gradient over verified cell and its eight neighbors must be equal or less than one hundred meters over one thousand kilometers. This condition causes the exclusion of weak cyclones and bypasses thermal weak and transient cyclones.

Thus, for each detection (year, month, day and hour of detection) the center of cyclone (longitude and

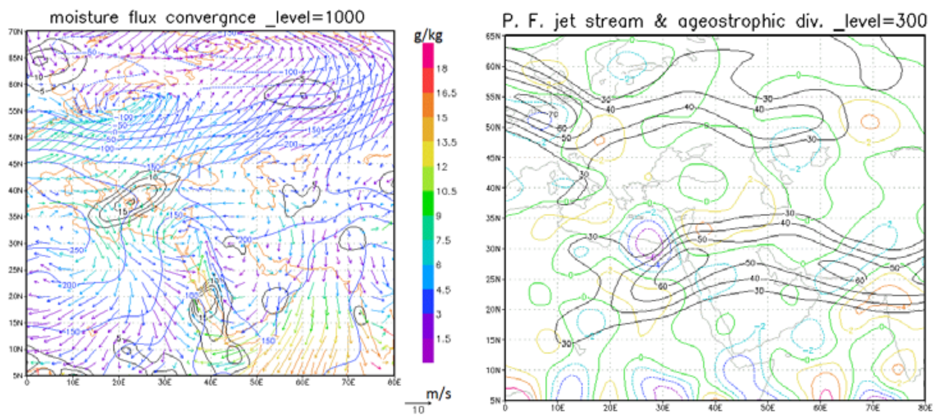

Fig. 9. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 27 January, 2002

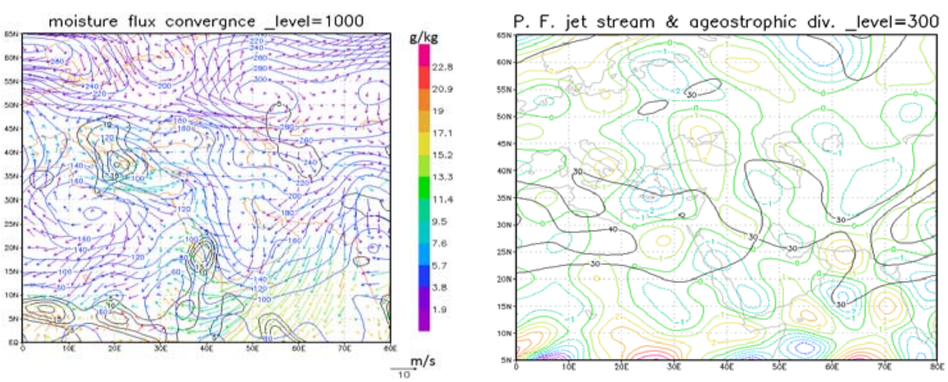

Fig. 10. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 27 January, 1996

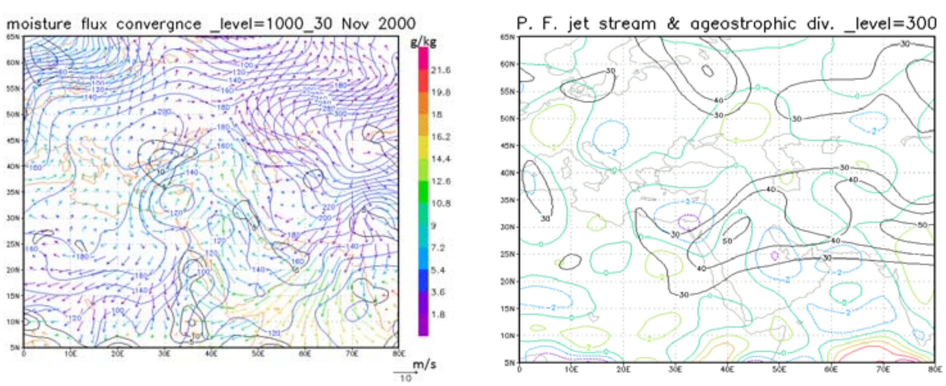

Fig. 11. Moisture flux convergence g/kg per day (left) and composite map of polar front jet stream and ageostrophic divergence (right) 30 November, 2000

latitude), geopotential height and mid regional of geopotential height gradient of cyclonic centres were obtained and its data base was constructed.

To calculate the regional gradient of geopotential height gradient, based on the value of gradient at center of geopotential heights minimum and its eight neighbours, the following equation was used:

$$\nabla Z = \frac{\partial z}{\partial x}\hat{i} + \frac{\partial z}{\partial y}\hat{j}$$

∇Z is regional gradient of geopotential height gradient, ∂z geopotential height difference (in meter), ∂x longitudal distance (in meter) and ∂y latitudal distance (in meter).

$$|\nabla Z| = \sqrt{\left(\frac{\partial Z}{\partial x}\right)^2 + \left(\frac{\partial Z}{\partial y}\right)^2}$$

ΔZ The magnitude of gradient was calculated and weighted mean of these nine gradients was considered as regional gradient.

To determine required humidity sources of cyclones in selected days and the direction of their movement, moisture flux convergence was used. Moisture flux convergence maps which show humidity transmission in gram per kilograms in day was calculated by following method:

Advection humidity : $HA = -\vec{v}.\nabla q$

Humidity gradient : $\nabla q = \frac{\partial q}{\partial x}\hat{i} + \frac{\partial q}{\partial y}\hat{j}$

Moisture convergence : $MC = -q\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)$

Moisture flux convergence function (g/kg per day) :

$$MFC = -\nabla \cdot (q\vec{V}_h) = (-\vec{V}_h \cdot \nabla q - q\nabla \cdot \vec{V}_h) \times 1000 \times 24 \times 3600$$

Here q is special moisture in gram per kilograms, $\vec{v}$ horizontal wind vector, $\nabla = \frac{\partial}{\partial x}\hat{i} + \frac{\partial}{\partial y}\hat{j}$, $\vec{V}_h = (u, v)$, u zonal and v meridional wind components (m/s^{-1}), MFC is moisture flux convergence function in gram per kilograms in day and MC is moisture convergence function.

For selected days composite map of polar front jet stream and a geostrophic divergence (300 hPa) was plotted to identify the regions in these special days in which required force to suction surface weather and subsequently to ascend the air masses, are generated.

In meteorology, because of the predominance of horizontal motions, the divergence usually refers to the two-dimensional horizontal divergence of the velocity field:

$$\text{Divergence} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$$

Ageostrophic divergence = Actual divergence – Geostrophic divergence

3. Results and discussion

Figs. 2 to 11 are related to moisture flux convergence maps and the composite map of polar front jet stream and ageostrophic divergence of 10 cases of simultaneous occurrence of EM cyclones and Red Sea trough. Moisture flux convergence maps, show sources and the displacement path of humidity. Because of severe variability of humidity, taking average has been avoided. These maps have been prepared for 1200 UTC and most of the researchers have selected this time to identify Red Sea trough. Verification of moisture flux convergence maps show that some humidity source of EM cyclones is Arabian Sea which reinforces over Gulf of Aden and Persian Gulf and by passing over the Red Sea enters EM cyclones. However, Red Sea also plays a role in providing the humidity source but the principle role of this Sea is a dynamic role and acts as humidity uplifting agent to higher levels.

Polar front jet streams form over polar front. Jet streaks inside these cyclones are displaced toward the east. So as the polar front is effective in formation of cyclones, polar front jet stream and its jet streaks has a role in guiding and determining displacement path of cyclones. In other words, the location and intensity of mid-latitude cyclones depend on the form and the position of the waves created in polar front jet stream. Cyclones are formed in eastern part of jet streams troughs and beneath the jet stream move towards east (Masoudian and Kaviani 2008).

The composite map of polar front jet stream and ageostrophic divergence in 300 hPa were verified to identify the suction of high levels in uplifting direction of humid weather. As it can be observed the jet streak of most of cyclones is between Red Sea and Mediterranean Sea. Ageostrophic divergence maximum also is located at these speed cores. This fact confirms the earlier statement that described the part of Red Sea a dynamic role which assists uplifting air masses (Figs. 2 to 11).

In these Figures, the closed curves show moisture flux convergence; and the arrows show moisture flux.

4. Conclusions

Verification of moisture flux convergence maps for these conditions during days with simulataneous occurrence of EM cyclone and Red Sea trough show that main humidity sources are originated from Arabian Sea and are reinforced by passing over Persian Gulf and gulf of Aden. Red Sea has a transition role and imports the humidity sources into the EM cyclones. Regarding the moisture flux convergence maps and the composite maps of polar front jet stream and ageostrophic divergence, it seems that Red Sea has no important role in the feeding of moisture into cyclones and it acts more as a surface convergence region and top divergence and causes uplifting of the air masses. In fact, it can be said that Red Sea trough is a thermodynamic system which displaces the humidity from tropical regions to extra tropical regions and plays a critical role in the formation of EM cyclones.

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