Analysis of Indian Monsoon and Associated Low–Level Circulation in 1980 and 1981

Tao Zuyu (陶祖钰)
Department of Geophysics, Peking University, Beijing

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ABSTRACT

In this paper, Indian monsoon of 1980 and 1981 is analysed based on the seasonal and half–month averaged data of 850 hPa of ECMWF analysis. The results show that Indian monsoon is related to Somali jet, the low–latitude easterlies and the mid–latitude westerlies over southern Indian Ocean, which are associated with the stationary wave of Southern Hemisphere. The forces affecting on the low–level flow are diagnosed, which display the relationship between Indian monsoon and the associated low–level flow.

I. INTRODUCTION

Since Findlater(1969) pointed out the relationship between Somali jet and Indain monsoon, great attentions have been paid on the associated low–level circulation of monsoon (Chen Longxun et al., 1979; Wang Zuoshu et al., 1979; Tao Shiyan et al., 1983). The observational results of SUMMER MONEX (1979) further display that the onset and fluctuation of monsoon are related to Somali jet and the low level current of Southern Hemisphere (Sikka. 1980). The onset of monsoon of 1979— 1982 was analysed by Pearce et al.(1984). Dynamical studies show that the diabatic heating and the associated pressure gradient force are the principal factors to the monsoon (Webster et al., 1972; Krishnamurti et al., 1979; Lin, 1983; Pant, 1983). However, the inertial force of mean flow is also important in the tropical region, especially in the entrance region of Somali jet (Stout et al., 1983). Synoptical study also shows that there is some kind of relationship between the intensity of Indian monsoon and the precipitation in Yangtze River valley (Shen Jianzhu et al., 1982). Thus, it is interesting to examine the factor affecting the intensity of Indian monsoon.

In the summer of 1980 and 1981, there are flood and drought in Yangtze River valley respectively, and the contrast of Indian monsoon for these two years is considerable. In this paper, the diagnosis and comparison of Indian monsoon and the associated low–level circulations for 1980 and 1981 are done to examine the factors affecting the intensity of monsoon. The data set used in this study are the seasonal mean (June, July, August) and half–month mean (from May to August) of 850 hPa data of 1980, 1981 and the 6–year averages (1979—1984), which were prepared by the Department of Meteorology at the University of Reading based upon ECMWF analysis (White, 1982).

In order to examine the contribution of transient eddies to the mean flow, we will analyse the divergence of E–vector $((\overline{v'^2}-\overline{u'^2})\vec{i}-\overline{u'v'}\vec{j})$, which was proposed by Hoskins et al.(1983) to determine the feedback of eddies onto the mean flow. Where E is divergent, the transient eddies are to increase the westerly mean flow.

II. PRIMARY SEASONAL FEATURES IN 1980 AND 1981

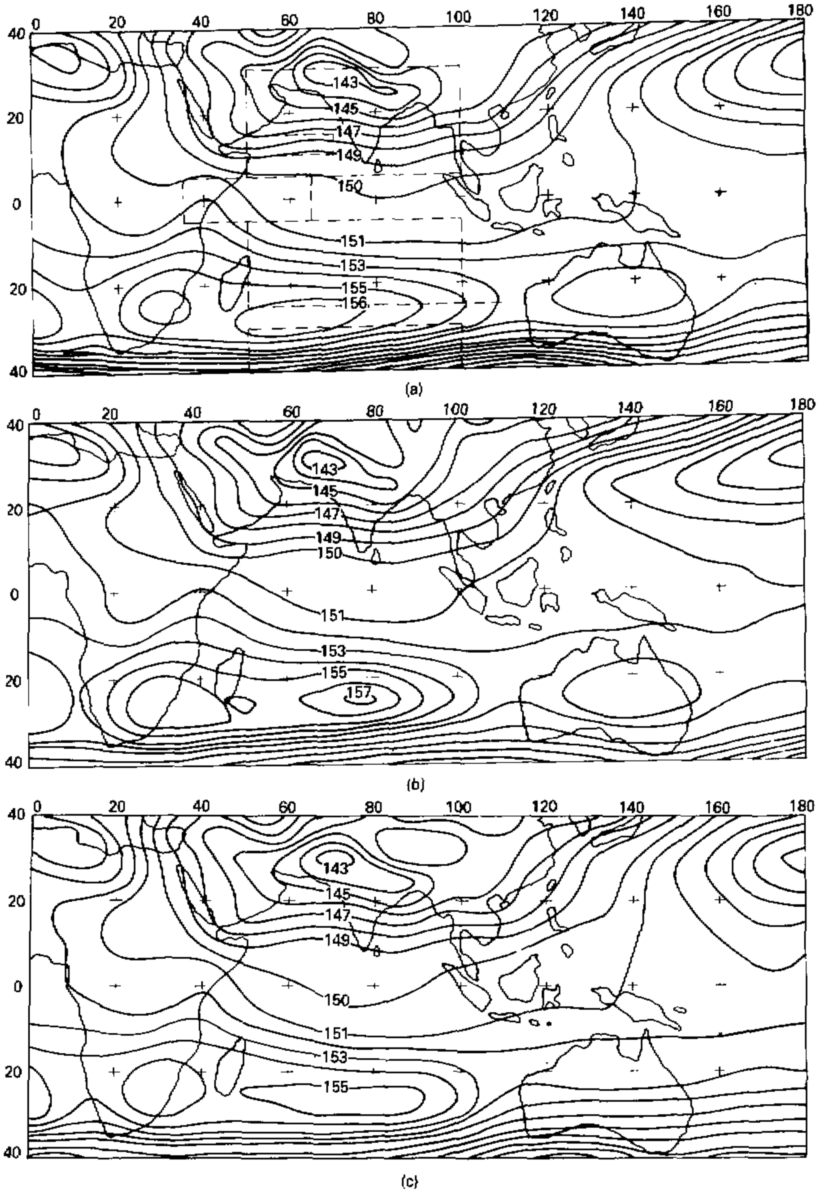


Fig.1. The summer (JJA) seasonal average of 850 hPa wind speed.(a)1980, (b)1981. (The contour interval is 2 m/s)

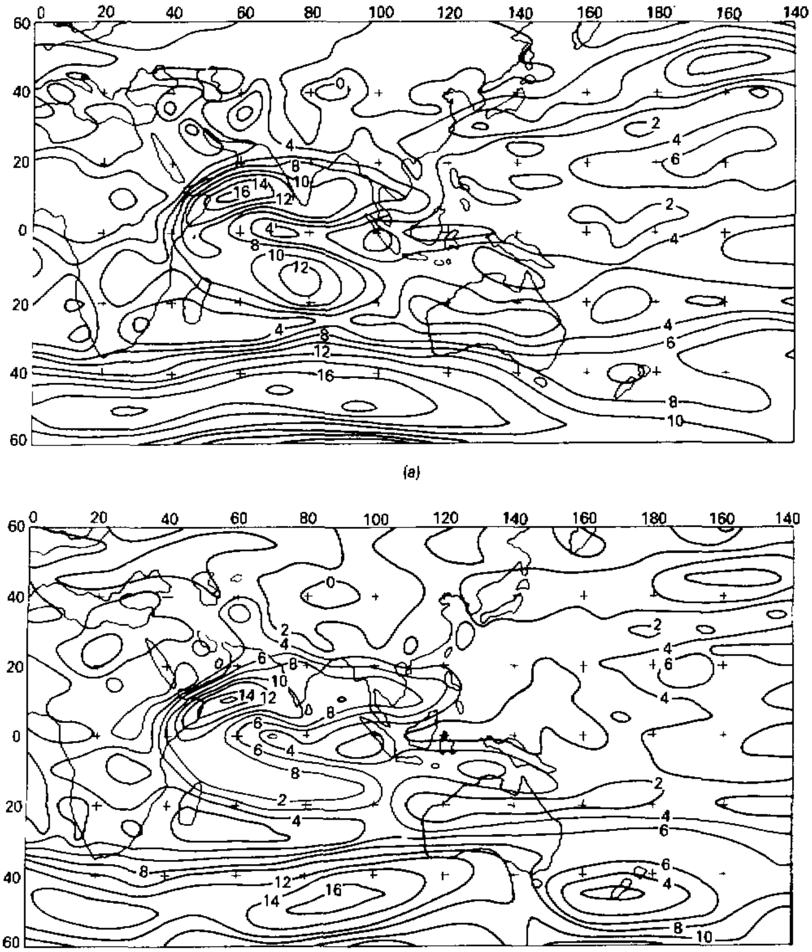
The contrast of Indian monsoon and the associated low–level circulation between 1980 and 1981 is considerable. It can be seen in the seasonal average of 850 hPa wind speed (Fig. 1) that in North Indian Ocean, the isotach of 10 m / s extended to 95 ° E in 1980, but just to 75 ° E in 1981. The isotaches in Fig. 1 display that Indian monsoon originates from Somali jet, and Somali jet links with the low–latitude easterlies of South Indian Ocean. It is stronger in 1980 than in 1981, too. For Somali jet, the strong wind speed area in 1980 enclosed by the isotach of 14 m / s is two times of the area of 1981. For the low–latitude easterlies of the South Indian Ocean, a stronger core (greater than 12 m / s) can be found in 1980. But, in 1981, the maximum speed of easterlies is less than 10 m / s. The midlatitude westerlies over South Indian Ocean are also different. There is a stronger core greater than 18 m / s at 70 ° E in 1980, but the maximum of westerlies is 16 m / s and located easterly at 90 ° E in 1981.

Because the low–level circulations relate to the geopotential height field, the 850 hPa charts (Fig.2) are examined. It is found that the Mascarene high, the Australian high and the southern Africa high are stronger in 1980 and weaker in 1981. In the east of Mascarene high, the zonal pressure gradient along 25 ° S between 80–110 ° E is also stronger in 1980 than in 1981. It implies that the meridional air flow (southerly) of South Indian Ocean between mid–latitude and low–latitude is stronger in 1980 than in 1981. The contrast of stationary wave of Southern Hemisphere is also reflected in the distributions of seasonal average of 850 hPa v–component and ω (Figures are not given).

In sum, the seasonal features suggest that the anomaly of Indian monsoon is accompanied by the anomalies of Somali jet; by the anomalies of low–latitude easterlies, mid–latitude westerlies and the stationary wave over South Indian Ocean.

III. DIAGNOSIS OF SEASONAL ANOMALIES

In order to examine the reason of the anomaly of Indian monsoon, the area–averages of the effective force on unit air mass for the monsoon region are calculated, which are the meridional pressure gradient force $[-g\partial\bar{z}/\partial y]$, Coriolis force $[-f\bar{u}]$, the zonal inertial force of transient eddies $\frac{1}{A}\oint_{c} E_n\, dl$, where A denotes the area, C, the boundary of the monsoon region and E_n, the perpendicular component of $\vec{E}$ to the boundary of A (positive denotes out of the integral region). The horizontal advective inertial force of mean flow $[-(\overline{\mathbf{V}}\cdot\nabla)\overline{\mathbf{V}}]$ is calculated over the contact area between monsoon and Somali jet in order to show the effect of Somali jet on monsoon. Because the pressure field of monsoon region depends on the thermal situation as pointed out in Section I, the area–averaged temperature over the monsoon region is also calculated. The area average of kinetic energy of monsoon is calculated to show the intensity of monsoon. The domains for area–averaged calculating are given in Fig. 2a. The unit of the force affecting on per unit of air mass is m/s^2 (i.e. N / kg). The results are shown in Table 1. The values of climatology are the averages for 6 years (1979—1984). The following remarks can be drawn from Table 1:



(a)

(b)

Fig.2. The summer seasonal average of 850 hPa geopotential height. (a)1979–1984,(b)1980, (c)1981. The contour interval is 10 meters. The domains for the area average in diagnosis are shown in (a).

1. The most considerable forces affecting on monsoon are the pressure gradient force and the Coriolis force. Thus, the intensity of monsoon mainly depends on the pressure gradient force. The correlation between the anomalies of monsoon and the temperature, as pointed out by Pant (1983) is also seen in Table 1. Namely the monsoon is stronger when the temperature is higher. It is necessary to be pointed out here that the Coriolis force is greater than pressure gradient force either for climate or individual year. The supergeostrophic feature of Indian monsoon implies that there are also other factors affecting on the intensity of monsoon besides the pressure gradient force.

2. The inertial force of transient eddies is very small, and points westward. Hence, the

transient eddies in the monsoon region act as a bar to monsoon.

3. The zonal inertial force of Somali jet affecting on monsoon is the smallest one. But, the meridional inertial force is larger than the inertial force of the transient eddies and its signs of the anomalies are the same as the signs of the anomalies of the kinetic energy of monsoon, although the value of anomaly is rather small.

Table 1. The Area-Averaged Intensities of the Indian Monsoon and the Force Affecting on Per Unit Air Mass of 850 hPa for JJA of 6-year Climate. 1980 and 1981(See text for detail)

Term	Domain	Unit	Climate 1979—1984	Anomaly	
				1980	1981
Kinetic Energy $[\frac{1}{2}(u^2 + \bar{v}^2)]$	5°—30° N 50°—100° E	m^2/s^2	70.9	+4.0	−6.3
Pressure Gradient Force $[-g\partial\bar{z}/\partial y]$	5°—30° N 50°—100° E	10^{-5} m/s^2	19.5	+2.1	−2.6
Coriolis Force $[-f\bar{v}]$	5°—30° N 50°—100° E	10^{-5} m/s^2	−27.2	−0.4	−1.8
Inertial Force of Transient Eddy $[\frac{1}{A}\oint E_y dl]$	5°—30° N 50°—100° E	10^{-5} m/s^2	−1.9	−3.5	−0.7
Temperature $[T]$	5°—30° N 50°—100° E	K	295.0	+0.7	−1.2
Meridional Inertial Force of Mean Flow $[-\bar{\mathbf{V}}\cdot\nabla\bar{v}]$	10°—15° N 50°—70° E	10^{-5} m/s^2	5.7	−0.3	−0.4
Zonal Inertial Force of Mean Flow $[-\mathbf{V}\cdot\nabla\bar{u}]$	10°—15° N 50°—70° E	10^{-5} m/s^2	−0.5	+0.4	+0.4

In order to examine the factor affecting on the intensity of Somali jet, the cross–equatorial pressure gradient force is calculated. The zonal Coriolis force is calculated along the northern boundary of Somali jet (5° N, 35° —65° E) to show the force which causes Somali jet turning eastward and becoming Indian monsoon. The kinetic energy of Somali jet is also calculated to denote its intensity. The results in Table 2 suggest that:

1. The kinetic energy of Somali jet almost equals to the kinetic energy of monsoon. The considerable positive anomaly of kinetic energy in 1980 suggests that the intensity of monsoon relates to Somali jet.

2. The meridional pressure gradient force is significant in Somali jet region. The anomalies of meridional pressure gradient force are positive in 1980 and negative in 1981, which im-

plies that the intensity of Somali jet is associated with the meridional acceleration due to the pressure gradient force. It coincides with the facts that the generation of kinetic energy of mean flow is very strong in the region of Somali jet (Chen Shujun et al.) and the kinetic energy of Somali jet (69.5 m^2/s^2) is stronger than the associated low–latitude easterlies (55.4 m^2/s^2) in South Indian Ocean.

3. The anomaly of zonal Coriolis force along the 5°N is greater in 1980 than in 1981, which displays the association between Indian monsoon and Somali jet.

Table 2. The Area–Averaged Intensity of Somali Jet and the Effective Forces Associated with It on 850 hPa

Term	Domain	Unit	Climate 1979—1984	Anomaly	
				1980	1981
Kinetic Energy $[\frac{1}{2}(\bar{u}^2+\bar{v}^2)]$	5°S—5°N 35°—65°E	m^2/s^2	69.5	+10.2	+4.2
Meridional Pressure Gradient Force $[-g\partial\bar{z}/\partial y]$	5°S—5°N 35°—65°E	10^{-5} m/s^2	8.4	+0.7	−0.4
Zonal Coriolis Force of Northern Boundary $[-f\bar{v}]$	5°N 35°—65°E	10^{-5} m/s^2	8.0	−0.8	+0.5

Similar diagnosis has been done for the low–latitude easterlies, mid–latitude westerlies and subtropical meridional flow over South Indian Ocean. The results suggest that the kinetic energy of low–latitude easterlies and mid–latitude westerlies is stronger in 1980 than in 1981. Especially, the kinetic energy of low–latitude easterlies is greater than normal over 20% in 1980, but, on the contrary in 1981. The westward Coriolis force of subtropical meridional flow along 25°S in eastern Indian Ocean (80°—110°E) is by 60% greater than normal, which displays that the intensity of low–latitude easterlies relates to mid–latitude westerlies.

Similar diagnosis also has been done for the onset and intraseasonal fluctuation of Indian monsoon based on the half–month–averaged data. The results are not discussed in this paper. It is worthy to point out that the seasonal changes of temperature of monsoon region and Somali jet are prior to the onset of monsoon and relate to the anomaly of monsoon, which may be helpful for the predicting of monsoon.

IV. SUMMARY

1. The seasonal anomalies of Indian monsoon in 1980 and 1981 are accompanied by the anomalies of Somali jet, the low–latitude easterlies, the mid–latitude westerlies and the subtropical stationary wave over South Indian Ocean.

2. The intensity of Indian monsoon relates to Somali jet, and the intensity of Somali jet mainly depends on the meridional pressure gradient force around the equator.

3. The Coriolis force of subtropical meridional flow over South Indian Ocean displays the relationship between the low–latitude easterlies and the mid–latitude westerlies.

4. The anomalies of monsoon are related to the thermal situation in the monsoon region.

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