MAUSAM, 50, 3 (July 1999), 243-250

551.557.3 : 551.553.21 : 551.577 (203.31.5)

Zonal wind variations in the stratosphere and mesosphere over the equatorial region of Asia and possible association with Indian summer monsoon rainfall

U.S. DE, K. RATNAM and R.K. MUKHOPADHYAY

Meteorological Office, Pune-411005, India

(*Received 16 October 1998*)

सार — 1970 से 1993 तक की अवधि में थुम्बा (भारत) में 921 फ्लाइटों से लिए गए रॉकेट पवन आँकड़ों और 1970 से 1997 तक की अवधि के सिंगापुर (दक्षिण पूर्व एशिया) के निम्न समतापमंडल में लिए गए उपरितन पवन आँकड़ों का उपयोग करते हुए एशिया के भूमध्यरेखीय क्षेत्रों में समतापमंडलीय और मध्यमंडलीय आंचलिक पवनों के व्यवहार का अध्ययन किया गया है। इन आंचलिक पवनों के मासिक औसतों का अनुक्रम विश्लेषण किया जाता है। यह अनुमान लगाया गया है कि 22 से 30 महीने की लगभग द्विवार्षिक आवृति वाला दोलन (क्यू.बी.ओ.) और 11 से 12 महीने की आवृति वाला वार्षिक चक्र थुम्बा के निम्न समतापमंडल में प्रबल होता है जबकि ऊपरी समतापमंडल और मध्यमंडल में अर्द्धवार्षिक चक्र काफी प्रभावी है। सिंगापुर के निम्न समतापमंडल में 22 से 28 महीने की आवृति वाला लगभग द्विवार्षिक दोलन महत्वपूर्ण पाया गया है जबकि वार्षिक चक्र का कोई महत्व नहीं है।

थुम्बा में जनवरी से मई के पूर्ववर्ती महीनो में लगभग द्विवार्षिक दोलन के पूर्वी/पश्चिमी चरणों और प्रबल पूर्वी हवाओं से उत्तरवर्ती ग्रीष्मकालीन मानसून के दौरान होने वाली कम वर्षा एवं पश्चिमी हवाओं अथवा हल्की पूर्वी हवाओं से समूचे देश में होने वाली भारी वर्षा के बीच पूर्वानुमान संबंधी उपयोगिता है। भारत में मौसमी वर्षा और शीत ऋृतु के महीनों के दौरान 10 हैक्टापास्कल (30 कि.मी.) गति की आंचलिक पवनों तथा मानसून पूर्व महीनों के दौरान 30 हैक्टापास्कल (24 कि.मी.) की आंचलिक पवनों के बीच सहसंबंध गुणांक सांख्यिकीय रूप से महत्वपूर्ण हैं। तथापि यदि शीत ऋृतु के दौरान 10 हैक्टापास्कल गति की आंचलिक पवनों और मानसून पूर्व की 30 हैक्टापास्कल गतिकी पवनों के संयुक्त परिसंचरण को मान लें तो सहसंबंध में और वृद्धि होती है। सिंगापुर में मानसून महीनों के दौरान 50 हैक्टापास्कल (20 कि.मी.) और 30 हैक्टापास्कल (24 कि.मी.) गति की आंचलिक पवनों के समूचे भारत की महत्वपूर्ण संगामी सहसंबंध गुणांकों वाली मौसमी वर्षा में डायगनॉस्टिक मान के साथ लक्षण संबंधी उपयोगिता का पता चलता है किन्तु शीत ऋृतु में और मानसून ऋृतु से पहले चलने वाली पवनों के साथ भारतीय मानसून के महत्वपूर्ण सहसंबंध का पता नहीं चलता है। अतः इसका उपयोग दक्षिणी-पश्चिमी मानसून वर्षा की प्रगति के मानीटरन के लिए किया जा सकता है किन्तु पूर्वानुमान के लिए नहीं।

थुम्बा में ई. एन. एस. ओ. (ENSO) और विपरीत ई. एन. एस. ओ. (Anti-ENSO) वर्षों के दौरान 30 एं टी-हैक्टापास्कल गति से चलने वाली औसत आंचलिक पवनें उनके वार्षिक लक्षणों से उल्लेखनीय रूप से भिन्न पाई गई हैं।

ABSTRACT. Behaviour of stratospheric and mesospheric zonal winds in the equatorial region of Asia has been studied using rocket wind data from 921 flights for the period from 1970 to 1993 over Thumba (India) and upper wind data in the lower stratosphere over Singapore (S.E. Asia) from 1970 to 1997. Monthly means of these zonal winds are subjected to spectrum analysis. It is inferred that the quasi-biennial oscillation (QBO) with periodicity of 22 to 30 months and annual cycle with periodicity of 11 to 12 months dominate in the lower stratosphere over Thumba, while the semi-annual cycle is predominent in the upper stratosphere and mesosphere. QBO in the lower stratosphere over Singapore has been observed to be significant with periodicity of 22 to 28 months, whereas the annual cycle has no significance.

There exists a prognostic value between easterly /westerly phases of QBO over Thumba during the antecedent months of January to May and the performance of succeeding summer monsoon rainfall over India with strong easterlies favouring decreased rainfall and westerlies or light easterlies favouring increased rainfall over the country as a whole. Correlation coefficients are statistically significant between the seasonal rainfall over India and zonal winds at 10 hPa (30 km) during winter months and also zonal winds at 30 hPa (24 km) during premonsoon months. However, there is an improvement in correlation if combined circulation of zonal winds at 10 hPa during winter and at 30 hPa during premonsoon is considered. Zonal winds at 50 hPa (20 km) and 30 hPa (24 km) over Singapore during monsoon months show diagnostic value with seasonal rainfall over India having significant concurrent correlation coefficients, however winds during winter and premonsoon do not show significant correlation with Indian monsoon. Thus, this could be used to monitor the progress of south-west monsoon performance but not in predicting it.

Over Thumba, the mean zonal winds at 30 hPa during ENSO and anti- ENSO years differ significantly in the annual feature.

Key words -- Stratosphere, Mesosphere, Zonal winds, Indi lan summer monsoon rainfall, ENSO.

1. Introduction

Knowledge of stratospheric and mesospheric circulation features is useful in seasonal forecasting because macro processes in the atmosphere are better expressed in the stratosphere and mesosphere than in the troposphere. Also, a number of small perturbations disappear with increase in height and the seasonal nature of the stratospheric and mesospheric processes is well defined. A large number of studies have shown that the Quasi- Biennial Oscillations (QBO) play an important role in linking the different layers of the atmosphere. The QBO slowly descends from the middle stratospheric levels and after a few months it affects several tropospheric and surface phenomena. Labitze (1962) has shown a connection between the equatorial quasi-biennial cycle of the stratospheric circulation and the summer characteristics in Europe, suggesting the westerly flow of the cycle corresponds to a warm summer and the easterly flow to a cold wet summer. Raja Rao (1977) and Raja Rao and Lakhole (1978) have come up with a relation between QBO and southwest monsoon where as Thapliyal (1984) has tried to predict Indian droughts with stratospheric winds at 50 hPa. Mukhopadhyay and Sarkar (1990) have come up with a tentative conclusion of the descent of lower mesospheric westerlies over Balasore in March to have some association with the subsequent good monsoon over India.

Earlier studies on the circulation pattern in the equatorial stratosphere and lower mesosphere are based only on a limited data of few years or some individual years. But in the present study an attempt has been made using data of fairly long period to relate the variations of zonal wind in the equatorial region of Asia during antecedent months with the behaviour of rainfall of the subsequent Indian summer monsoon. Singapore (lat. 1° 17′N, long. 103° 51′E) is choosen to represent equatorial south east Asia and Thumba (lat. 8° 32′N, long. 76° 52′E) in India is choosen to represent equatorial south Asia.

2. Data and analysis

From weekly launchings of rocket sonde, data of zonal wind over Thumba (using M-100 rocket) for the period from December 1970 to September 1993 with total number of flights of 921 have been utilised to calculate, for each year, the monthly mean of zonal wind from the level 16 km to 80 km at an interval of 2 km. The monthly means in turn have been averaged for the entire period to get mean monthly zonal wind for each of the level. In general, the rocket flights reached upto the height of 66 km and data beyond this level are based on a few rocket flights only. Monthly mean values of zonal winds over Singapore for the levels 50 hPa (20 km) and 30 hPa (24 km) for the period from 1970 to 1997 are also considered for the study. These monthly means of zonal winds of both Thumba and Singapore in the lower stratosphere are also subjected to spectrum analysis. Westerly and easterly zonal wind speeds are represented by positive and negative values respectively. The performance of the monsoon of individual years have been categorised using the area weighted June to September rainfall of the country and obtained from the India Meteorological Department, Pune.

3. General characteristic features of wind circulation in the stratosphere and mesosphere over Thumba

From the pattern of mean zonal winds in the stratosphere and mesosphere over Thumba, the existence of pronounced seasonal and non-seasonal variations in the speed is observed. The region of well defined quasi-biennial oscillations in the lower stratosphere is flanked by semi-annual cyclic oscillations above, in the upper stratosphere and mesosphere and annual cycle below, in the troposphere.

Figs. 1(a & b) depict the annual course of mean monthly zonal winds based on data of 23 years and monthly mean zonal winds for the individual consecutive years of contrasting monsoons of 1987 and 1988. The most striking feature of the equatorial Indian region (Thumba) is that the winds are invariably easterlies throughout the stratosphere and mesosphere during the monsoon months of June, July and August. Strong westerlies at the time around equinoxes are maintained in major part of the mesosphere, weaken in strength with decrease in height and become easterlies at 32 km in the stratosphere. As a result, winds are easterlies throughout the year at 32 km and below. Thus, in the mean picture between 64 km to 40 km it may be seen that the winds are westerlies at the time around equinoxes and easterlies or nearly easterlies around the time of solstices, displaying semi-annual cyclic oscillations in the zonal winds. Similar

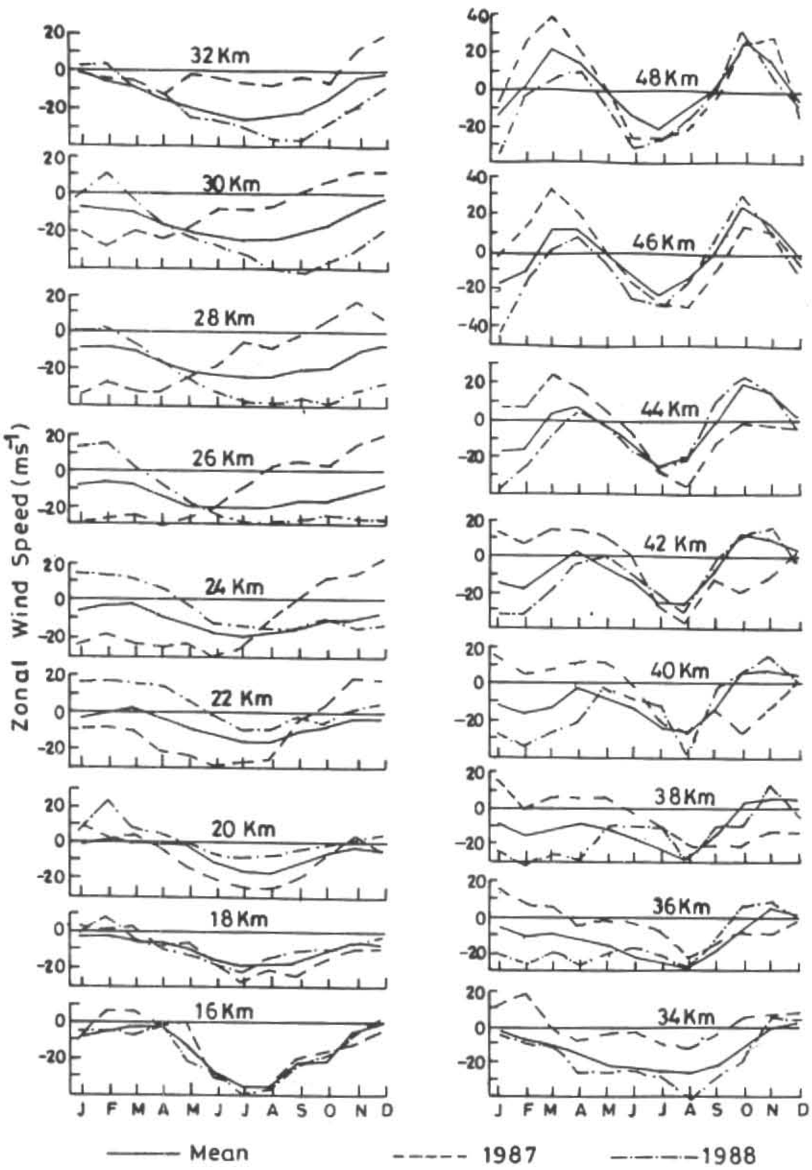


Fig.1 (a). Variation of zonal wind in the vertical with time (—— M ean, - - - - 1987,—.— 1988) Thumba

semi-annual cyclic oscillations are also seen during the individual years of which monthly means of zonal winds of severe drought years 1987 and good monsoon year 1988 are plotted in Figs. 1(a & b). Such semi-annual oscillations of the zonal winds in equatorial stratosphere and mesosphere have been discovered by Reed (1966). George and Narayanan (1975) have also described such semi-annual cyclic oscillations over equatorial stratosphere. The change over from westerlies to easterlies from higher to lower levels is rapid at the time of Vernal equinox and is slow at the time of Autumnal equinox. Above the level of 60 km the easterlies during monsoon season become weak and from 74 km to 80 km westerlies around equinoxes change over to easterlies.

4. Quasi-biennial oscillations

It will also be seen that in the lower stratosphere, westerlies and easterlies change bi-annually. While the easterly-westerly oscillations in this region have a bi-annual period, at no level over Thumba, the westerly regime is pronounced when compared to the easterly regime. Also, the predominantly easterly regime has very long duration having bi-annual characteristics. This can be seen in Figs. 2 (a & b) where 11 - month running means of zonal wind speed over Thumba and Singapore are depicted. Over Singapore also easterly regime is strong when compared to westerly regime of QBO. While easterly zonal wind speeds over Singapore are comparable with that over Thumba, westerly

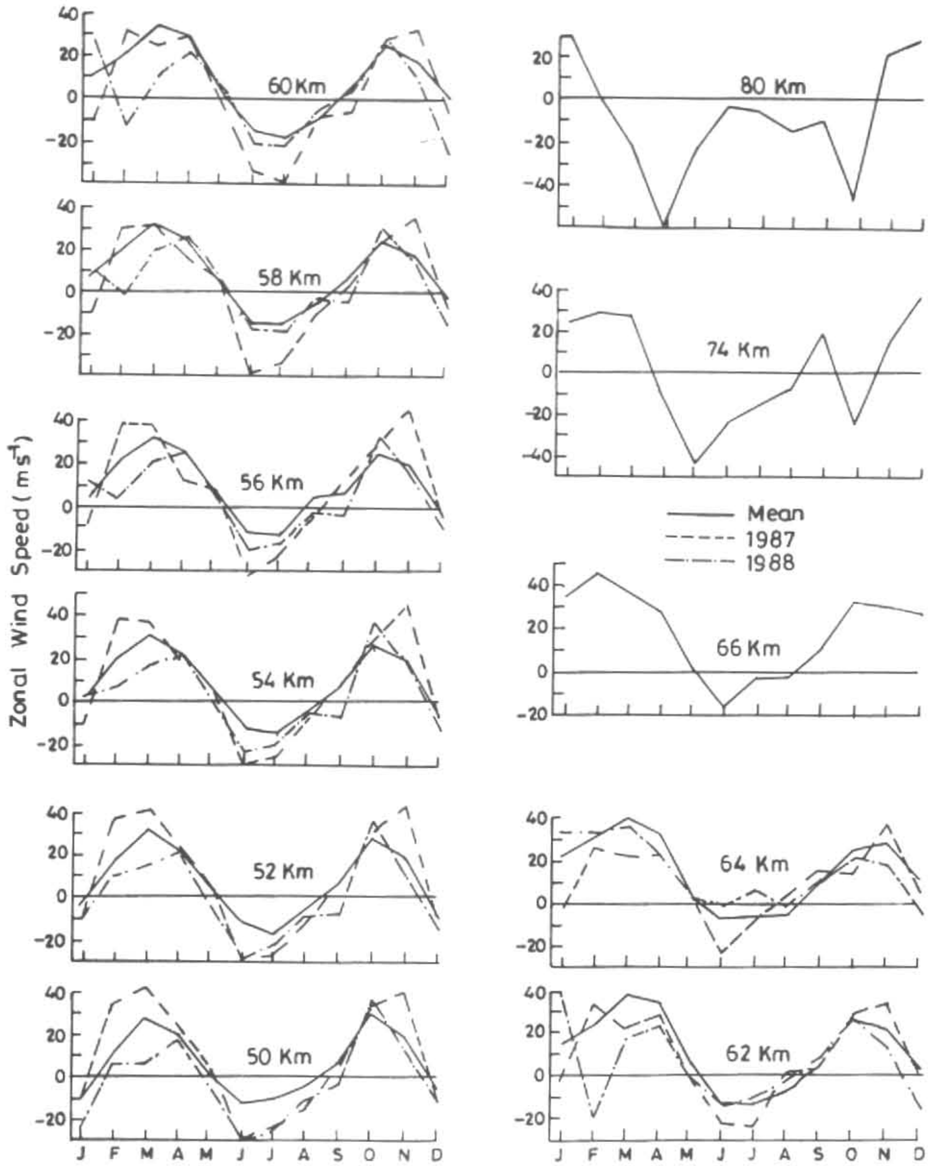


Fig.1(b). Variation of zonal wind in the vertical with time (—— Mean, - - - - 1987, —.—1988) Thumba

zonal winds are stronger than those over Thumba indicating larger amplitudes in QBO.

From the spectrum analysis of monthly mean zonal winds, it can be seen that at 25 km over Thumba, both QBO and annual cycle are found to be significant at 95% level of confidence. From Figs. 3 (a&b) it can be observed that QBO has periodicity of 22 to 30 months while the annual cycle has a periodicity of 11 to 12 months. At 30 km also the same periodicity holds good. Over Singapore, at 30 hPa, QBO with periodicity of 22 to 28 months is observed to be significant whereas the annual cycle is not found to be significant at 95% confidence limit. At 50 hPa also the same picture is observed.

5. Monsoon performance in relation to stratospheric and mesospheric winds

Thapliyal (1979) has shown that the mean January circulation features at 50 hPa level are able to indicate the difficient monsoon rainfall in westerly QBO years. Pisharoty (1981) has suggested that the monsoon is a delayed response to the inadequacy of the poleward transport of heat during the preceding winter. Patwardhan, *et al.* (1994) have arrived at a conclusion of highest statistically significant correlation between Indian summer monsoon rainfall and zonal wind anomalies at 10 hPa of Ascension for the month of January. In this paper it is attempted to relate the combined circulation features during the antece-

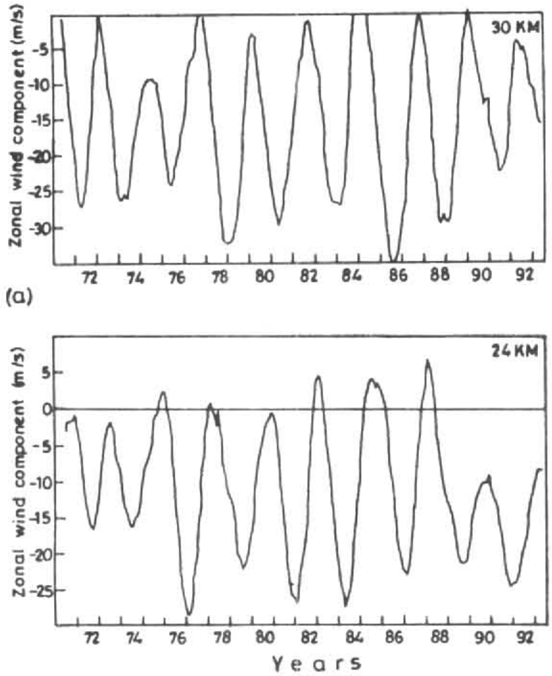


Fig.2(a). 11 - month running means of zonal wind Thumba

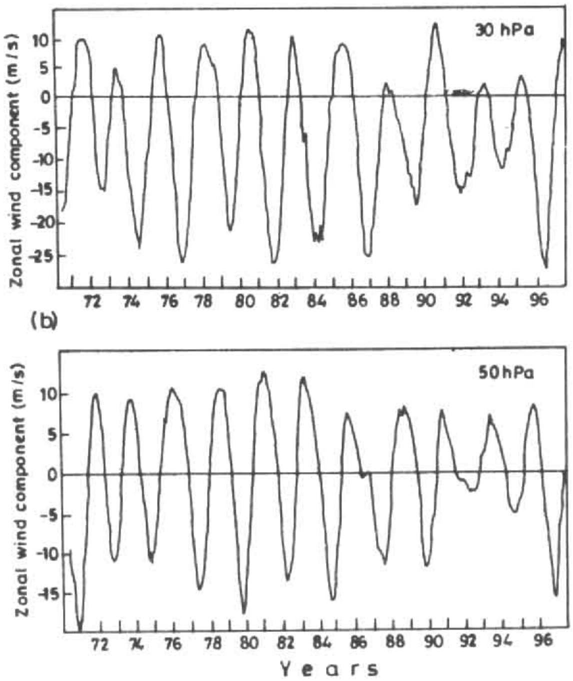


Fig.2(b). 11 - month running means of zonal wind Singapore

dent months of January to May and the performance of summer monsoon rainfall. From the year-to-year variation of monsoon rainfall from 1971 to 1993, it is seen that the inter-annual variation in seasonal rainfall is well marked in the four pairs of years 1972, 1973; 1979, 1980; 1982, 1983; and 1987, 1988. These years are also happened to be simultaneously bad and good monsoon years. Bad monsoon year is categorised where the seasonal rainfall deficiency is 15% of the normal or more and also where more than 70% of the areal extent of the country has been affected by deficient rainfall. A detailed study of the monthly mean middle atmospheric circulation pattern during these four pairs of consecutive years of bad and good monsoon may therefore provide some useful reasoning of such monsoon performance.

For examining the relationship between the mean monthly wind circulation patterns in the stratosphere and mesosphere during winter months and the performance of subsequent monsoon, seasonal mean winds have been worked out at the interval of 2 km and the variation of winds in the stratosphere and mesosphere over Thumba in the vertical during winter season has been depicted in Fig.4, for the above said four pairs of years. From the figure it may be seen that the bad monsoon years of 1972, 1979, 1982 and 1987 are characterised by invariably strong easterly zonal winds in the lower stratosphere (24 km to 30 km) while the good monsoon years of 1973, 1980, 1983 and 1988 are characterised by westerly zonal winds in this height region. A similar circulation feature is observed (Fig. not shown) in premonsoon seasonal pattern during bad and good monsoon years. A change over takes plays from winter and premonsoon circulation to monsoon seasonal circulation where the winds are easterly throughout the stratosphere and mesosphere. During the monsoon season also easterlies are stronger in bad monsoon years in the lower stratospheric region between 24 km to 30 km. Above this height range no consistent difference is noticed in the circulation features of bad and good monsoon years either in winter, premonsoon or monsoon seasons.

Thus in the height range of 24 km to 30 km in the lower stratosphere, the seasonal circulation features during winter premonsoon and monsoon are very much differentiated from bad monsoon years to good monsoon years.

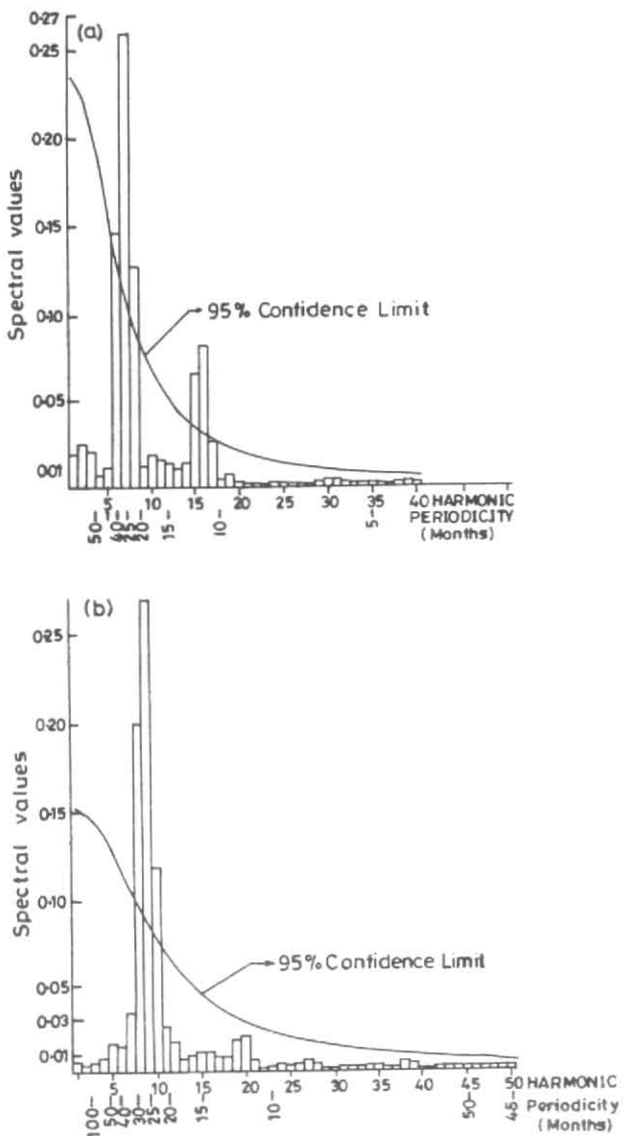
6. Indian summer monsoon rainfall in westerly and easterly phases of QBO

As seen from section 4, QBOs are well established in the equatorial region of Asia with easterly phases dominating over westerly phases. Mukherjee (1990) has worked out phase relationship between mean zonal wind (June-August) at 30 hPa for Balboa and percentage departure of rainfall during 1951-1982. To examine similar such relationship between zonal winds over Thumba and Singapore (equatorial Asia) Correlation coefficients (CCs) at specific levels in lower stratosphere between monthly mean zonal winds, over Thumba and Singapore and seasonal rainfall over India have been calculated and tabulated in Table 1(a). In respect of zonal winds over Thumba, CCs are positive and significant at 1% level at 30 km in winter months of January and February and at 24 km in premonsoon months of March, April and May showing prognostic value. But, in respect of zonal winds over Singapore at 50 hPa the CCs are positive

TABLE 1 (a)

Correlation coefficient values between monthly mean zonal winds and southwest monsoon rainfall over India

Station	Level	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Thumba	24 km	0.38	0.39	0.44	0.47	0.60	0.47	0.42	0.29	0.24
	30 km	0.55	0.58	0.46	0.0	0.25	0.25	0.10	-0.06	-0.32
Singapore	50 hPa	-0.27	-0.28	-0.18	0.11	0.21	0.36	0.52	0.54	0.34
	30 hPa	-0.01	0.02	0.02	0.03	0.04	0.05	0.04	0.03	0.03



Figs.3(a&b). Power spectrum of monthly mean zonal winds over (a) Thumba at 24 km (1970-1993), and (b) Singapore at 30 hPa (1970-1997). 95% confidence limit added

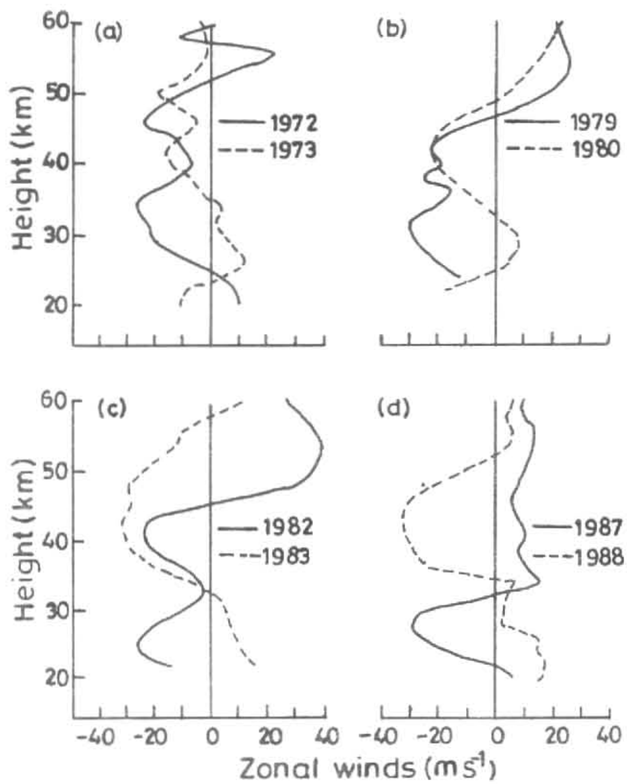
and significant at 1% level during monsoon months of June to September indicating diagnostic value. Negative CCs are obtained during winter months. At 30 hPa CCs are not significant.

CCs between seasonally averaged zonal winds and monsoon seasonal rainfall over India have also been worked out and tabulated in Table 1 (b).

TABLE 1(b)

Correlation coefficients between seasonally averaged zonal winds and southwest monsoon rainfall over India

Station	Level	Winter	Pre-monsoon	Monsoon
Thumba	24 km	0.29	0.52	0.51
	30 km	0.52	0.39	0.15
Singapore	50 hPa	-0.24	0.05	0.59
	30 hPa	0.09	0.34	0.46



Figs.4(a-d). Vertical profile of zonal winds over Thumba (winter)

As can be seen from Table 1(b), positive and significant CCs are obtained over Thumba at 24 km during premonsoon and at 30 km during winter season indicating prognostic value. But positive and significant CCs are observed at 50 hPa and 30 hPa over Singapore during monsoon season indicating diagnostic value. Over Thumba highest value of CC(0.63) is obtained when the mean of seasonally averaged zonal winds at 30 km during winter and at 24 km during premonsoon season is considered. As also can be seen from Fig.5 that there is one-to-one correspondence between increase or decrease of rainfall over India and increase in westerly or easterly phases of QBO. Thus, from the mean of

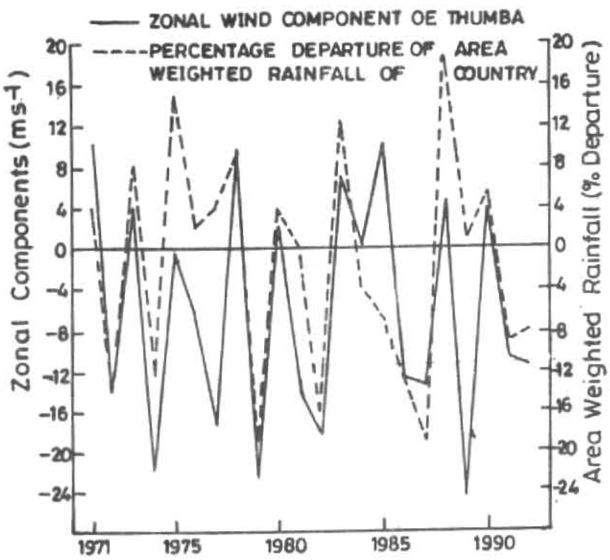


Fig.5. Variation of zonal wind (mean of winter at 30 km and pre-monsoon at 24 km) over Thumba and area weighted seasonal rainfall

seasonally averaged zonal winds at 30 km in winter and at 24 km in premonsoon season, westerly or light easterly phases of QBO favour increased rainfall activity over the country leading to good monsoon and strong easterly phases of QBO in zonal winds favour decrease in rainfall activity.

A measure of discrepancey existing between observed and expected frequencies of these two events, *viz*., mean of seasonally averaged zonal winds at 30 km in winter and at 24 km in premonsoon over Thumba and area weighted rainfall over the country is worked out by the statistic chi-square (χ^2) given by

$$\chi^2 = \sum_{i=1}^{m} \frac{(O_i - e_i)^2}{e_i}$$

where, Oi is observed frequency and e_i is expected or the oretical frequency and m is the number of categories. There spective frequencies are tabulated in Tables 2 (a & b).

By definition, "normal monsoon" indicates seasonal rainfall within ±10% of the Long Period Average (LPA) rainfall which is 881 mm based on (1901 - 1970 rainfall data) for India as a whole. The excess and deficient monsoon indicate rainfall >110% and < 90% of the LPA rainfall respectively. For two category classification, normal monsoon and the excess monsoon are included in good monsoon over the country.

The value of χ^2 thus obtained is 6.75 which is greater than the theoretical value or critical value of 3.84 at 5% probability level and for degree of freedom 1. Thus χ^2 is significant.

TABLE 2 (a)

(Observed frequencies)

Rainfall	Zonal wind(mps)		Total
	> - 6.0	< -6.0	
E/N	10	6	16
D	0	6	6
Total	10	12	22

E-excess, N-normal 'D-deficient

TABLE 2 (b)

(Expected frequencies)

Rainfall	Zonal wind(mps)		Total
	> - 6.0	< -6.0	
E/N	7.3	8.7	16
D	2.7	3.3	6
Total	10	12	22

E- excess, N-normal, D-deficient

7. ENSO and stratospheric circulation

Studies have shown that certain phenomena occuring over places for away from India such as El Nino, observed to occur over the equatorial east Pacific ocean influence the overall performance of Indian summer monsoon. The conditions typical of El Nino, such as local warming in the eastern Pacific, a shifting of precipitation from the western to the eastern Pacific, weakening of the trade winds and sea level changes are still with us for the area of study. A relationship between the El Nino events over the eastern equatorial Pacific ocean and monsoon failure over India has been suggested by Sikka (1980). From a detailed examination of data from 1971 to 1978, Mooley and Parthasarathy, (1983) have indicated that the Indian rainfall was generally below normal over the most parts of the country for each El Nino year. From the circulation pattern of equatorial Asia, it can be mentioned that there is considerable evidence of a teleconnection between stratospheric circulation over equatorial Asia and the warm and cold events of El Nino Southern Oscillation (ENSO). During the period of availability of rocket wind data over Thumba, the years 1972, 1976, 1977, 1982 and 1987 have been categorised as ENSO years and the years 1973, 1975, 1983 and 1988 have been categorised as anti-ENSO years. This categorisation is based on the criteria used by De and Mukhopadhyay (1998). The criteria has been fixed on the basis of Southern Oscillation Index (SOI). When SOI progressively falls (rises) for at least three consecutive seasons and the total fall (rise) should be less than (greater than) one standard deviation which is 1.5 hPa. On the basis of this criteria, ENSO and anti - ENSO years have been identified.

Zonal winds during ENSO and anti-ENSO years have been analysed in the lower stratospheric levels at 24 km and 30 km over Thumba. The difference in the zonal winds between the events of ENSO and anti-ENSO years has been obtained using the statistic "Students" t - distribution given by

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S} \sqrt{\frac{n_1 n_2}{n_1 + n_2}}$$

where, $\bar{x}_1$, is the mean of zonal wind speed at a particular level during ENSO years with n_1 denoting number of years and $\bar{x}_2$ is the mean of zonal wind speed at the same level during anti-ENSO years with n_2 denoting such number of years. The combined standard deviation S, given by

$$S = \sqrt{\frac{\Sigma (x_1 - \bar{x}_1)^2 + \Sigma (x_2 - \bar{x}_2)^2}{n_1 + n_2 - 2}}$$

At 24 km the mean zonal wind over Thumba during ENSO and anti- ENSO years differs significantly in the annual feature. The "t" value on the annual is 7.234 while the table value is 2.080 at 0.05 probability and with degree of freedom, 21. If the combination of zonal wind at 30 km in winter and at 24 km in premonsoon season is considered during ENSO and anti- ENSO years, the "t" value works out to be also significant with 6.30. Over Singapore also, the mean zonal wind at 30 hPa during ENSO and anti-ENSO years differ significantly, the "t" value being 5.25.

8. Summary and concluding remarks

(*i*) At 24 km and 30 km, over Thumba the QBO and annual cycle are significant with periodicity of 22 to 30 months and 11 to 12 months respectively at 95% confidence limit (C.L). Over Singapore, at 50 hPa and 30 hPa QBO is significant with periodicity of 22 to 28 months at 95% C.L. But the annual cycle is not significant at 95% C.L.

(*ii*) Over Thumba, the mean of seasonally averaged zonal winds in westerly phases of QBO at 30 km in winter and of 24 km in premonsoon favour increased seasonal rainfall activity with increasing speed leading to good monsoon performance over India and increase in speed in easterly phase of QBO favour decrease in rainfall activity over the country with correlation coefficient of 0.63 which has a prognostic value. Even seasonally averaged zonal winds over Thumba at 24 km in premonsoon or 30 km in winter give the same picture with correlation coefficient of 0.52.

(*iii*) Zonal winds over Singapore at 50 hPa during monsoon season and mean of seasonally averaged zonal winds at 50 hPa and 30 hPa during monsoon season have diagnostic value to Indian rainfall during monsoon season with significant correlation coefficient of 0.59.

(*iv*) Over Thumba, the mean zonal winds at 24 km during ENSO and anti-ENSO years differ significantly in the annual feature. The "t" value on annual feature is 7.234. The mean of zonal winds at 30 km in winter and of 24 km in premonsoon also differ significantly during ENSO and anti-ENSO years with equally significant "t" value of 6.30. Over Singapore also, the mean zonal winds at 30 hPa during ENSO and anti-ENSO years differ significantly in the annual feature with "t" value of 5.25.

Acknowledgements

The authors are thankful to all the staff members of stratosphere and mesosphere unit for their co-operation in writing the paper and Shri D.D. Raskar for typing the manuscript and the DTP unit for typesetting the same.

References

De, U.S. and Mukhopadhyay, R.K., 1998, "The effect of ENSO/anti ENSO on NE monsoon rainfall", (To be published in *Mausam*, **50** , 4).

George, P.A. and Narayanan, V., 1975, "Circulation pattern in the equatorial stratosphere and its relation with the circulations in the mesosphere and upper troposphere. Part I", *Indian Journal of Met. Hydrol. Geophysics*, **26**, 4, 443-454.

Labitze, K., 1962, "Beitr Synoptik Hochstratosphare Met. Abh, 36, H3".

Meteorological Monograph, 1991, "Climatology of the middle atmosphere over the equatorial region of India (Thumba) 1970-1983 Part I".

Meteorological monograph. "Climatology of the middle atmosphere over the equatorial region of India (Thumba) 1970-1993", (under publication)

Mooley, D.A. and Parthasarathy, B., 1983, "Variability of the Indian summer monsoon and tropical circulation features", *Mon. Weather Rev*., III, 967-978.

Mukherjee, B.K., 1990, "Middle atmosphere dynamics and monsoon variability", *Mausam*, **41**, 2, 203-208.

Mukhopadhyay, R.K. and Sarkar, T.K., 1990, "Middle atmospheric oscillation over India and its possible association with Indian summer monsoon", *Mausam*, **41**, 1, 75-80.

Patwardhan, S.K. Sikder, A.B. and Bhalme, H.N., 1994, "Stratospheric wind at Ascension for long-range forecasting of Indian monsoon rainfall", Proc. National symposium on climate variability, Tropmet, 8-11, Feb., 1994.

Pisharoty, P.R., 1981, "The Asiatic monsoon a new theory, International conference on early results of the FGGE and large scale aspects of its monsoon experiments", 12-17 January 1981, Tallahasi, Florida, U.S.A.

Raja Rao, K.S., 1977, "Waves in equatorial stratosphere and their linkage with southwest monsoon", *J. Sci. Indu. Res*., **36/11**, 624- 633.

Raja Rao, K.S. and Lakhole, N.J., 1978, "Quasi-biennial oscillation and summer southwest monsoon", *Indian Journal Met. Hydrol. Geophysics*, **29**, 1 & 2, 403-411.

Reed, R.J., 1966, "Zonal wind behaviour in the equatorial stratosphere and lower mesosphere", *J.Geophys. Res*., **71**, 4223- 4233.

Sikka, D.R., 1980, "Some aspects of large scale fluctuations of summer monsoon rainfall over India in relation to fluctuations in the planetary and regional scale circulation parameters", *Pro. Indian Acad. Science (Earth Planetary Science)*, **89**, 179-195.

Thapliyal, V. , 1979, "Stratospheric circulation in relation to summer monsoon over India", Proc. International symposium on Hydrological aspects of droughts, 3-7, Dec., 1979. Vol.I, Indian Institute of Technology, New Delhi, India.

Thapliyal, V., 1984, "Prediction of Indian droughts with lower stratospheric winds", *Mausam*, **35**, 3, 367-374.