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Quasi-biennial oscillation and summer southwest monsoon

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ABSTRACT. Stratospheric circulation in the height range of 16 to 60 km in the equatorial region has been studied using the rocket wind data of Thumba.

It is inferred that the quasi-biennial oscillation in the lower and middle stratosphere are out of phase by six months. The dominant feature in the lower stratosphere is the appearance of the monsoon easterlies during the period June to September. The westerlies or easterlies in the lower stratosphere over the equator extend to about 10°N in the period November to May. In the middle stratosphere, the quasi-biennial oscillation follows a regular alternation of easterlies and westerlies with a downward phase propogation of one km per month, while the quasi-biennial oscillation in the lower stratosphere interacts with the monsoon circulation.

The four possible wind phases W, W/E, E and E/W during March to May in the equatorial lower stratosphere are linked with the onset of southwest monsoon near the normal date and normal rains over India. Appearance of the easterlies in the lower stratosphere over Gan Island in May is an indication of the onset of monsoon over Kerala a month later.

The Berson westerlies are a poleward extension of the equatorial westerlies, rather than a descent from the upper stratosphere. The out of phase relationship between QBO in the lower and middle stratospheres suggests an interaction between the QBO and monsoon circulation. The phase of the QBO over the equator appears to give a prior indication of the onset of the southwest monsoon over Kerala and also the rainfall in the central parts of the country.

1. Introduction

The quasi-biennial oscillation in the zonal winds of equatorial stratosphere has been a subject of intense study in last two decades. Observational studies of Wallace and Kausky (1968) and theoretical model of Lindzen and Holton (1968) suggest that planetary scale vertically propagating internal gravity waves are the momentum source for the oscillation. Absorption of the westerly (easterly) momentum in the westerly (easterly) shear zones result in the general downward propagation of two shear zones, giving an alternation in zonally symmetric east and west wind regimes from one year to the next with a period varying between 20 to 30 months. The oscillation probably originates near 30 km level and propagates downward at the rate of 1 km/month without any change in amplitude in height range of 30 to 24 km, below which there is a rapid attenuation.

Knowledge of stratospheric circulation may be used in seasonal forecasting for macro processes in the atmosphere are better expressed in the stratosphere than in the troposphere, as a number of small perturbations disappear with increase in height and the seasonal nature of the stratospheric processes is well defined. In the 1960's, attention was given to the significance of higher layers of the atmosphere as predictors of tropospheric processes for long periods. In particular, Ebdon (1966) established a dependance of the general characteristic of weather on time of transition to easterly circulation at 50 mb surface. Labtize (1962) discovered a connection between the equatorial quasi-biennial cycle of the stratospheric circulation and the summer characteristics in Europe. The westerly flow of the cycle corresponds to a warm summer and the easterly flow to a cold wet summer.

In the present paper a study has been made of the quasi biennial oscillation (QBO) in the zonal

TABLE 1

Station	Latitude	Longitude	Period of data used
Trivandrum	08°29′N	76°56′E	1964-75
Gan Island	00°41′S	73°09′E	1964-75
Ascension Island	08°00′S	14°24′W	1964-72

wind over Trivandrum, Gan Island and Ascension Island. Interaction between the southwest monsoon and the QBO has been examined by study of contrasting features of the QBO over Trivandrum as against the same over Gan Island and Ascension Island. It is inferred that the QBO in the lower stratosphere over Trivandrum is not an alternation of east and west zonal winds from one year to the next, but a variation in the intensity of east zonal winds, as a result of the action of the annual wave. Relationship between lower stratospheric wind phases and the onset of southwest monsoon off the Kerala coast and rainfall in the central part of the country in association with monsoon have been inferred.

2. Data and analysis

The mean monthly zonal wind data for 100, 50 and 30 mb levels for the three equatorial stations have been used in the analysis. The locations of the stations and the length of the data series used are indicated in Table 1.

Missing data have been filled up by interpolation using trends of different wind regimes, persistency of winds, and vertical structure of winds in the stratosphere. Rocket wind data of Thumba (close of Trivandrum) for the period January 1971 to April 1974 and May 1975 to July 1976 have also been used. Fig. 1 plots the vertical time section of zonal winds over Thumba in the height range of 16 to 60 km. Vertical time sections of the zonal wind have been constructed for the three stations for lower stratosphere; and indicated in Figs. 2(a), 2(b) and 2(c).

In order to study the linkage between the different wind phases in equatorial stratospheric QBO and southwest monsoon, mean area weighted, rainfall departures have been worked out for central India consisting of five sub-divisions of India—Vidarbha, east Madhya Pradesh, west Madhya Pradesh, Marathawada and Telangana, for a period 1964 to 1975. Fig. 3 plots these.

The QBO over the three stations at the levels 100, 50 and 30 mb has been isolated using a simple filter, *viz.*, the 12-month running mean. Figs. 4(a), 4(b) and 4(c) plot the filtered values which represent the QBO and the unfiltered values which represent the combination of the QB, annual and semi-annual waves.

3. The quasi-biennial oscillation in the Indian region

3.1. *Circulation of the stratosphere over Thumba (Trivandrum) during pre-monsoon and monsoon months (June to September)*

From the pattern of the zonal winds in the stratosphere in the height range of 16 to 60 km the stratosphere has been divided into three regions as given below.

(*a*) 16 to 24 km (lower stratosphere) where 20 to 30-month periodicity predominates.

(*b*) 24 to 34 km (middle stratosphere) where also 20 to 30-month periodicity exists and is modified by the annual wave, *viz.*, the monsoon circulation.

(*c*) 34 to 50 km upper stratosphere and lower mesosphere where semi-annual wave dominates. 20-30 month periodicity generally prevails over Thumba (Trivandrum) in both lower and middle stratosphere but winds in the lower one appear to be more influenced by the equatorial lower stratospheric winds (Gan Island) while middle stratosphere is influenced by downward propagation from upper stratosphere. Fig. 1 clearly suggests that the lower, middle and upper stratosphere are under different circulation regimes.

The striking features of the middle stratosphere is the presence of the stratospheric easterly jet which is very intense during the monsoon and its influence extends on either side into the lower and upper stratosphere. From the analysis of 100 rocket wind measurements over Thumba the existence of a easterly jet in the height range of 32-42 km throughout the year, is inferred. The SEJ is a world wide phenomenon, confined to the equatorial region only. There are seasonal variations in its height and intensity. Strong wind shears exist in the vicinity of the SEJ varying between 8 mps/km to 22 mps/km. Intensities of

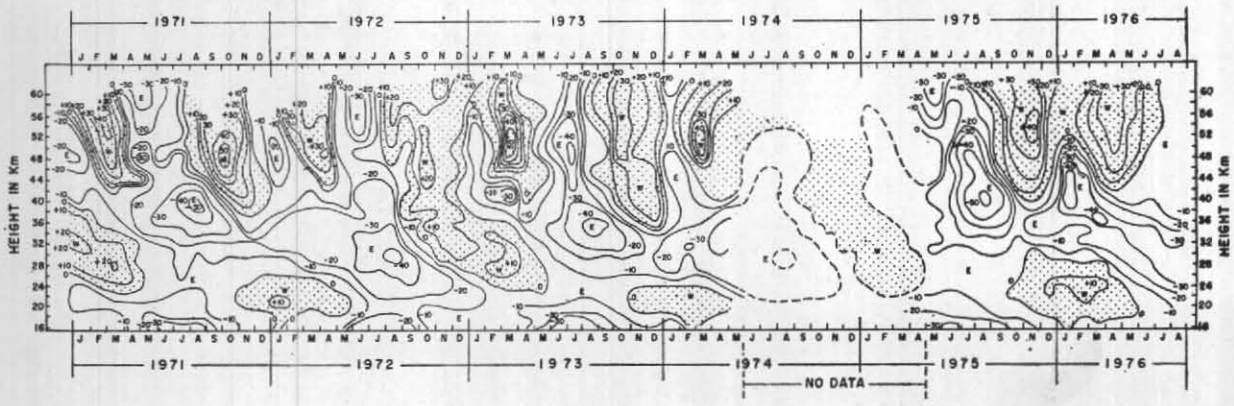

Fig. 1. Monthly mean zonal rocket winds (ms^{-1}) in the height range of 16 to 60 km over Thumba

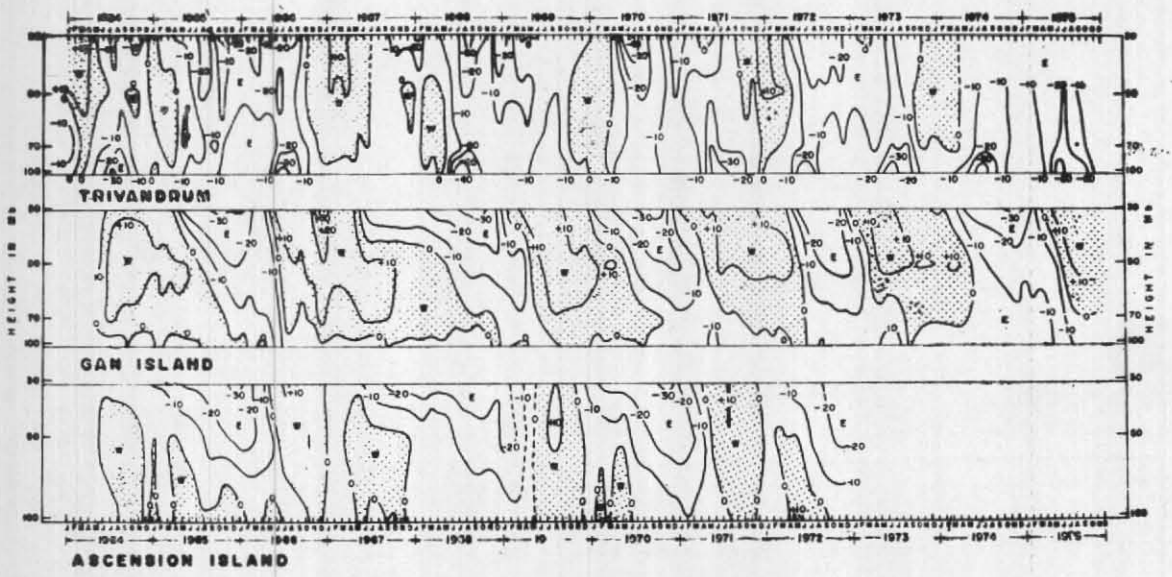

Fig. 2. Monthly mean zonal winds (ms^{-1})

the SEJ and the tropical easterly jet in the troposphere are highly correlated. The SEJ is also most intense in the monsoon season. We see that easterlies extend upto 60 km during May to July, indicating that monsoon circulation is not limited to the troposphere but extends to the base of mesosphere. In August between 44 and 50 km these easterlies start disappearing indicating a weakening of the monsoon circulation. These westerly winds descend downward till May to a level of about 24 km and situation as discussed earlier makes the appearance, *i.e.*, a monsoon circulation builds up with SEJ. The years 1971 to 1975 illustrate this situation. As the rocket observations are not taken for period May 1974 to April 1975, existence of westerly wind regime could not be seen, but rawin data of Trivandrum corroborate this inference.

The QBO in the height range of 16 to 24 km is not in phase with the QBO in the height range of 24 to 34 km. This phase difference is in our view a result of the monsoon circulation.

3.2. *Equatorial stratospheric wind phases and stratospheric circulation near 8° N.*

During the pre-monsoon season there are four possible manifestations of wind regime in the lower stratosphere over equator. They are W, W/E, E, E/W as depicted in diagram for Gan Island (Fig. 2). Here E/W means westerlies at lower level with easterlies aloft.

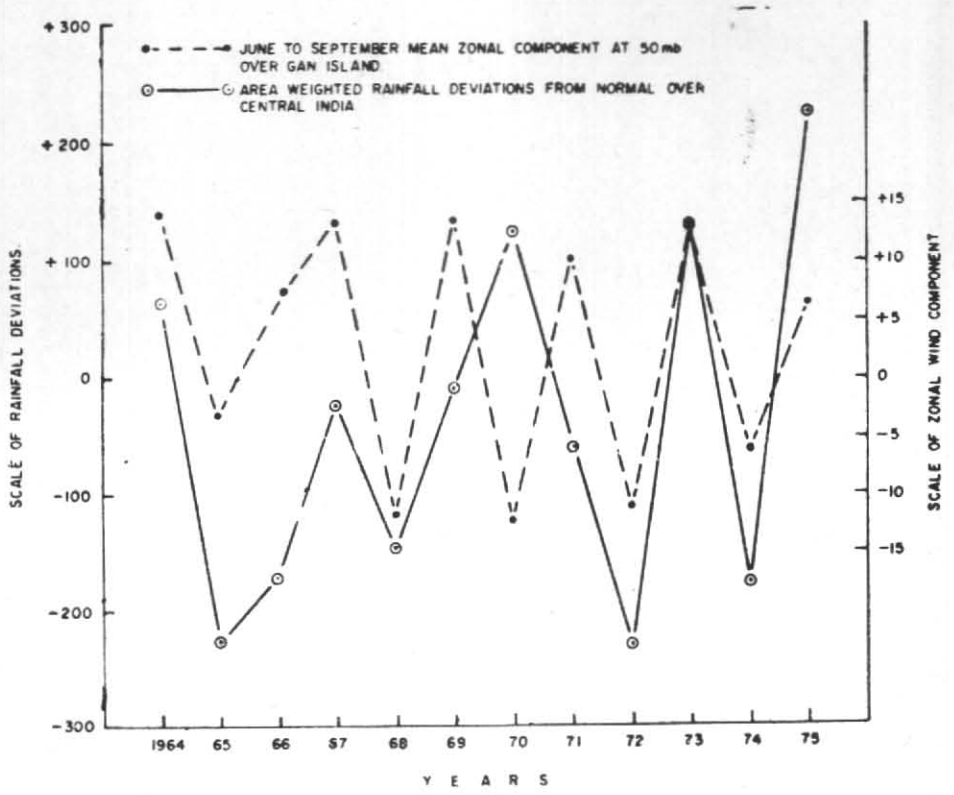

Fig. 3. 50 mb mean zonal wind over Gan Island and the rainfall deviations over central India during June-September

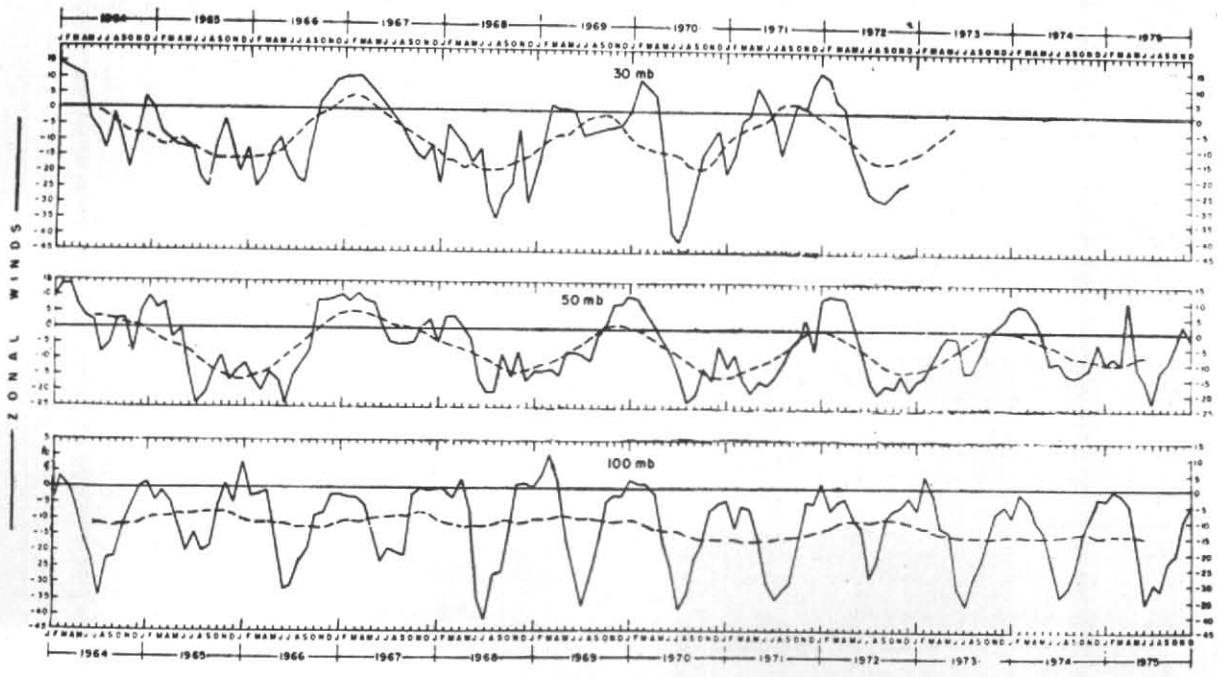

Fig. 4 (a). Monthly mean zonal winds (ms^{-1}) and 12-monthly running means over Trivandrum

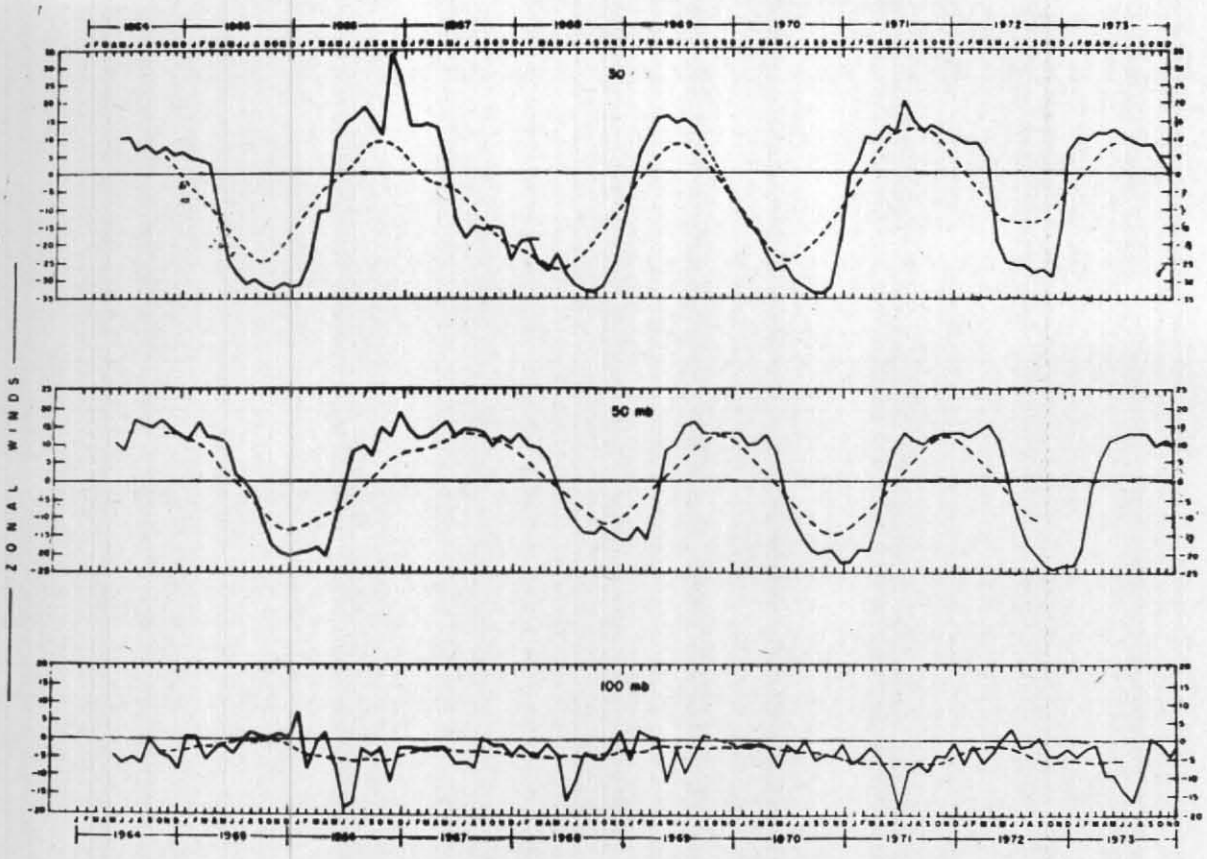

Fig. 4 (b). Monthly mean zonal winds (ms^{-1}) and 12-monthly running means over Gan Island

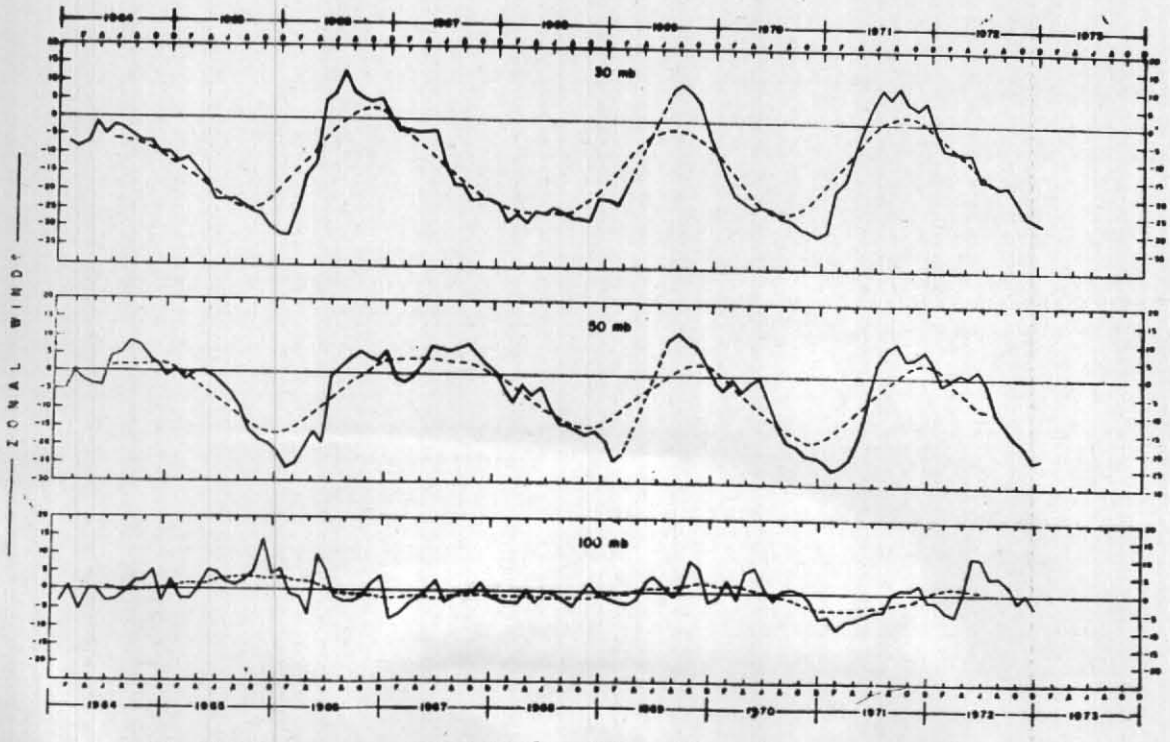

Fig. 4 (c). Monthly means zonal winds (ms^{-1}) and 12-monthly running means over Ascension Island

Let us consider easterly wind phase over Gan Island and look for its effect on the stratospheric circulation existing near 8°N during October to June. Figs. 2(a) and 2(b) indicate that whenever easterly wind phase is present over the equator during October to May, easterlies prevalied over 8°N. The months from October to May of 1965-66, 1968-69, 1970-71, 1972-73 and 1974-75 illustrate situations explained as above. From this it is inferred that equatorial easterlies merge into the cirulation at latitudes away from the equator upto 10°N.

There is a definite mechanism by which these four wind phases play a vital role in modifying the monsoon circulation. As equatorial easterlies merge in the circulation during October to May, *i.e.*, prior to monsoon season, they modify the circulation to resemble a typical monsoon type so that the stratospheric winds get organised. Once such a circulation is established advance of SW monsoon current starts. Since equatorial quasi-biennial oscillation is a feature of the stratospheric circulation they first react on stratosphere of equatorial region and then interact with tropospheric winds. As a result of this, easterlies occur in pre-monsoon months with easterly phase of quasi-biennial oscillation at equator, which during monsoon gets accentuated and in turn accentuates tropospheric easterly jet as coupling between these two jets have been established. It is, therefore inferred that easterly phase of quasi-biennial oscillation over the equator has a prognostic value for forecasting the onset of the southwest monsoon off the Kerala coast. Table 2 indicates the dates of onset of the monsoon off the Kerala with easterly phases of quasi-biennial oscillation.

With westerly phase at the equator during October to May, westerly winds are observed in the lower stratosphere near 8°N. This is the situation during years 1964-65, 1966-67, 1969-70, 1971-72, 1973-74 and 1975-76.

3.3. *Berson westerlies*

A thin stream of westerlies appearing in the lower stratosphere every alternate year, with its base at 16-18 km and thickness 6-12 km, is known as Berson westerlies. Its activity is limited to Lat. 10° on either side of the equator. It touches southern parts of the Indian Peninsula during October to May every alternate year. It has been noticed that the appearance of this stream is more regular since 1968 (observed during 1968, 1970, 1972, 1974 and 1976). It is our view that this stream is a result of northward extension of equatorial stratospheric westerly wind regime rather than influence of downward propagation of westerlies from higher regions. For, there exists a layer of strong easterlies (about 10 km thick) between the westerlies descending from the stratopause upto 30 km, and the Berson westerlies. Corresponding to every Berson westerly stream over Trivandrum there exist westerly winds over Gan Island. From Fig. 2 it can be inferred that—

(*a*) Berson westerlies make appearance after monsoon season, *i.e.*, in November and last for 5-6 months;

(*b*) There is a layer in the middle stratosphere where strong easterly winds prevail separating westerly winds of upper stratosphere observed near 28 km and Berson westerlies below 24 km;

(*c*) The observations from 1964 to 1975 indicate that Berson westerlies have made appearance over Trivandrum only when there is a westerly wind regime prevailing over equatorial stratosphere;

(*d*) The stream does not appear over Trivandrum during June to September as monsoon circulation resists the northward movement and appears in November when monsoon circulation in the stratosphere over 8°N becomes weak. Fig. 1 illustrates this situation in the years 1972, 1974 and 1976 respectively.

This stream remains in the height range of 16 to 24 km till May. When the monsoon circultion starts building up May onwards, Berson westerlies offer resistance at initial stage and get replaced by easterlies but influence of the stream remains as long as westerly phase exist at equator.

As a result of the stream a considerable uncertainty is introduced during the initial phase of onset of the southwest monsoon over India. The appearance of Berson westerlies have been very regular during 1972, 1974, 1976. Table 2 indicates the progress of southwest monsoon with east and west wind phases during March to May.

Hence it is clear that presence of Berson westerlies is not favourable for arrival of southwest monsoon off the Kerala coast on time, because they make their appearance every alternate years and a

TABLE 2

Year	Temporary advance	Withdrawal	Revival
1971	27 May	10 June	23 June
1972	Mid May	23 May	18 June
1973	4 June	—	—
1974	26-27 May	15 June	17 July
1975	31 May	—	—
1976	31 May	10 June	5 July

spell of break monsoon conditions follow after their disappearance and therefore loose forecasting value. Therefore, the view expressed by Narayanan and George (1974), *i.e.*, "disappearance of Berson westerlies is a signal of coming of monsoon" is not tenable. The basic feature, in our view, is the appearance of "easterlies in pre-monsoon months, more favourable rather than appearance or disappearance of Berson westerlies" as easterlies are cause of their disappearance.

3.4. *E/W and W/E phases during period March to May*

We have so far discussed the effect of pure east or west winds over equator in the period November to March; we shall now consider a combination of the two regimes existing in the lower stratosphere in the period March to May. These shear zones present a complex situation in the study of their interaction with the winds away from the equator, but are generally observed in pre-monsoon. It has already been referred that easterly phase is favourable for normal onset of southwest monsoon. Fig. 3 suggests that westerlies during June to September are favourable for normal monsoon rains over India. Therefore, W/E combination of shear zone in vertical plane of the equatorial stratosphere may suggest both normal onset and normal monsoon rains. Table 3 gives the wind regimes in the lower stratosphere during the period March to May in each of the years 1964 to 1975 and the monsoon rainfall in central parts of India.

It is inferred that W/E regime is conducive to good rainfall in the central parts of the country in the following months June to September. It has already been suggested that E/W phase of equatorial QBO during pre-monsoon season is neither conducive to a normal monsoon rains over India nor smooth onset. The Fig. 3 shows that except

TABLE 3

Years	Wind phases	Date of onset	Rainfall deviations from normal over central India	Rainfall activity over India in general
1964	W	6 Jun	+ 64·3	normal
1965	E/W	26 May	—227·5	< normal
1966	W/E	1 Jun	—171·4	< normal
1967	W	9 Jun	— 20·4	≈ normal
1968	E/W	8 Jun	—148·8	< normal
1969	W/E	25 May	— 1·1	≈ normal
1970	E/W	26 May	+126·4	normal
1971	W/E	27 May	— 58·9	≈ normal
1972	E/W	18 Jun	—231·5	< normal
1973	W/E	4 Jun	+132·7	normal
1974	E/W	26 May	—179·1	< normal
1975	W/E	31 May	+222·7	normal

during 1970 remaining years of the easterly phases during monsoon season resulted in below normal rains.

The westerly zonal winds of W/E shear zone possess the property of propagating downward to the tropopause at the rate of 1·0 km/month and encompass the entire lower stratosphere during monsoon season. Easterlies of E/W shears zone are also noticed to behave in a similar way. Therefore once such shear zones are noticed in lower stratosphere during March to May it is possible to predict their appearance in the subsequent monsoon months. The westerlies or easterlies in turn play their role in modifying the upper tropospheric circulation away from the equator. This speculation provides some explanation to the energetics of the QBO and modification of tropospheric circulation. Firstly, for the maintenance of easterly or westerly phase in the lower stratosphere a continuous upward transport of easterly or westerly momentum is necessary. This is provided by the vertically propagating wave modes, *i.e.*, mixed Rossby gravity waves or the Kelvin waves. In view of this the situation becomes clear that during westerly phase in the lower stratosphere, there is maximum upward transport of westerly zonal momentum at the equator, so that easterly momentum which is required to maintain tropospheric easterly jet is observed in the troposphere away from the equator. This absorption of easterly momentum to the north accentuates the upper tropospheric tropical easterly jet over Indian

Peninsula and leads to a good rainfall activity over India. On the other hand with easterly phase of QBO at equator, there is more upward transport of easterly momentum which results in the distribution of easterly momentum transport throughout the equatorial region and the tropical easterly jet over Indian Peninsula gets proportionally strengthened or weakened and results in less rainfall activity over India.

3.5. *Stratospheric circulation over 8° south*

Correlation coefficients between mean monthly zonal wind series over Gan Island at 50 mb and 30 mb, with those of Ascension Island 50 mb and 30 mb are 0·85 and 0·83 respectively, as against 0·53 and 0·48 between Gan Island and Trivandrum. The very high correlation coefficient indicates that lower stratosphere over the south of equator behaves in a way similar to the equatorial stratosphere. The time sections show approximately one to one correspondence in the appearance of east and west shear zones together with Berson westerlies. In the height range of 16 to 24 km over Ascension Island westerly winds appear with two different characteristics. One appearing with downward propagation from upper stratosphere and subsequently vanishing during southern hemispheric monsoon (January to March), and other with a poleward extension of westerly phase of the QBO over the equator. This extension of westerlies in the southern hemisphere is so close that even if it is confined to a very thin layer at equator, it makes appearance approximately in the same layer near 8° south.

4. QBO in the lower stratosphere over the equatorial region

With a view to filter the annual wave from the raw data, twelve-month running means have been worked out for the time series of three levels (100, 50 and 30 mb) over the three places under consideration (Fig. 4 a,b,c). The plot of filtered data indicate that QBO exists at all levels with variation in intensities of easterly wind over Trivandrum, a regular east to west sinusoidal pattern over Gan Island, and with large amplitude of easterly phase (17 mps) and westerly amplitude about 4 mps over Ascension Island. It also indicates that east and west alternations exist with same phases at these places. To the north removing annual wave, the remaining data show a QBO in the intensity of easterly zonal winds. Over equator there is regular alternation like a sinusoidal pattern. To the south at Ascension, a SEJ has been noticed at lower levels in the stratosphere than over Trivandum, amplitude of easterlies are more than that of westerlies, but there is a regular appearance of westerlies. It therefore, proves that annual wave is less marked over Ascension Island.

5. Conclusions

Following are conclusions drawn from the above study :

(1) Berson westerlies appearing in the lower stratosphere within 10° north and south of the equator are the result of northward and and southward extension of westerly zonal winds of equatorial QBO. This stream makes it appearance only when westerly phase prevails over the equatorial lower stratosphere.

(2) Existence of easterlies in the lower stratosphere on either side of the equator during November to May is a result of merging of equatorial quasi-biennial easterlies.

(3) Appearance of westerlies over Gan Island during southwest monsoon season as a result of existence of W/E shear zones in pre-monsoon months can be used to forecast rainfall over central parts of India.

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DISCUSSION

(Presented by K.S. Raja Rao)

M. RAHAMATULLAH : Will you please indicate the number of rockets fired up on which your results are based and how representative these would be of the stratospheric circulation in the SW monsoon ?

AUTHOR : Stratospheric jet concept is based on more than 100 rocket firings. The QBO study is based on once weekly launching from 1971 to 1976 (with a small gap in 1975).

B.M. MISRA : What is the time lag between establishing of the easterlies and the onset of the monsoon?

AUTHOR : If the easterlies establish in the lower stratosphere over Gan Island by May, there is a normal onset of monsoon over Kerala (*i.e.*, 31 May).

COMMENT

K.R. SAHA : If the behaviour in regard to QBO is found to be different in Gan and Ascension Islands from that of Trivandrum and if this difference is attributed to the influence of SW monsoon, I would like to suggest that another station in the northern hemisphere in a non-monsoon region be studied to find out if the difference disappears or still persists.