Quasi-Biennial Oscillation in Stratospheric Zonal Wind and Indian Summer Monsoon

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ABSTRACT

In an earlier study a relationship was pointed out between phases of the quasi-biennial oscillation (QBO) in the lower stratospheric (30 mb) zonal wind and percentage departures of summer monsoon rainfall of India. That study was based on analysis of wind data for Thumba (8°32'N, 76°52'E) and the rainfall data for India for a short-period (1971–76). Wind data for Balboa (9°N, 80°W), which is also an equatorial station, and rainfall activity over India are now examined for a longer period (1951–82). About 15% of the variability in rainfall over India during the summer monsoon is associated with the pattern of the QBO.

1. Introduction

Veryard and Ebdon (1961), Reed *et al.* (1961) and Reed (1965) discovered a major oscillation in the equatorial stratospheric wind with a period of about 26 months. This oscillation later came to be known as QBO. A dominant QBO-spectral peak in the Indian monsoon rainfall was also reported (Jagannathan and Bhalme, 1973). Mukherjee *et al.* (1979), using short-period data for Thumba (8°32'N, 76°52'E), showed a significant relationship between the phases of the QBO in the zonal wind in the lower stratosphere (30 mb) and the percentage departures of the summer monsoon rainfall of India considered as a whole. They showed that the strong easterly phase of the QBO was associated with the weak monsoon and the weak easterly/westerly phase with the active monsoon. As this result was based on analysis of short-period data only, a study has now been undertaken using the long-series (1951–82) of the wind data for the lower stratosphere (30 mb) for Balboa (9°N, 80°W), which is also an equatorial station. It is known that the distribution of rainfall over the Indian subcontinent varies from one region to another during the monsoon season (June–September). Keeping this in mind, an attempt has also been made in the present study to examine the relationship for different regions of the Indian subcontinent.

2. Methodology

The mean zonal wind (June–August) at 30 mb for Balboa for the available 32-year period (1951–82) is considered. The mean percentage departures of the rainfall for India from its 32-year normal are calculated for each monsoon season (June–September). Since winds show variability in the stratosphere during September (transition month), data during June–August are considered to represent the characteristics of the winds in the lower stratosphere during the monsoon. Rainfall in the country is recorded for subdivisions by the India Meteorological Department (IMD). The number of the meteorological subdivisions varied from 27 to 29 during 1951–60, from 30 to 32 during 1961–66, 33 during 1967–71 and 35 during 1972 and onwards. A plot of 35 meteorological subdivisions is given in Fig. 1. The variation in number of meteorological subdivisions noted during different periods is due to reorganization of the Indian states. The number of stations recording rainfall in each subdivision has varied from one subdivision to another commensurate with the area of each subdivision.

Rainfall in the country varies from one region to another due to fluctuations of the axis of the monsoon trough from south to north and back from its normal position during the period. The axis of the monsoon trough normally passes through northwest India in the west and the Gangetic valley in the east up to the head of the Bay of Bengal. In view of the large variability in distribution of rainfall over the country, analysis has also been made for different regions of the country in order to examine the relationship of rainfall of those regions with QBO. The regions considered are (i) north of 20°N, i.e., rainfall of all the Indian stations lying northward of 20°N, (ii) south of 20°N, i.e., rainfall of all the Indian stations lying southward of 20°N, (iii) south of 15°N, i.e., rainfall of all the Indian stations lying southward of 15°N, and (iv) Himalayan foothills (north of 25°N).

The values of correlation coefficients between the rainfall departures of India (June–September) and the mean zonal wind at 30 mb for Balboa (June–August) for 1951–82 were calculated and are shown in Table 1. The correlation coefficients, considering the winds

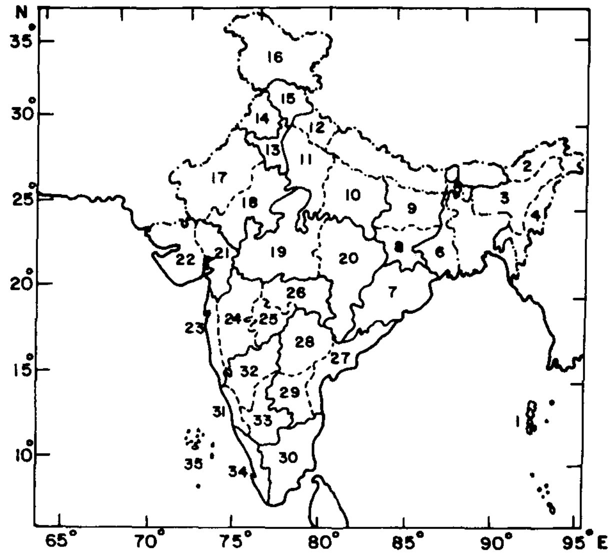

FIG. 1. The 35 meteorological subdivisions of India.

also for June–September, are shown in brackets in the Table.

3. Results

a. Entire India

Figure 2 shows the plot of percentage departures of rainfall (June–September) for India as a whole, and mean zonal wind (June–August) at 30 mb for Balboa for the period 1951–82. The rainfall is noticed to vary with the strength of the easterlies in 23 of 32 cases (1951–82). This relationship, however, tends to break down during the years 1952, 1957, 1958, 1967, 1970, 1971, 1977, 1981 and 1982. The correlation coefficient between rainfall departures and strength of the zonal wind is +0.39, significant at less than 3% level (Table 1).

b. *Regions north of 20°N and south of 20°N*

The plots are shown in Fig. 3. The correlation coefficient between rainfall departures and wind is +0.30 (significant at less than 10% level) for north of 20°N and +0.36 (significant at less than 5% level) for south of 20°N (Table 1). The correlation coefficient between the rainfall values of the two regions considered is +0.45 (significant at less than 1% level).

c. *Himalayan foothills north of 25°N and south of 15°N*

Figure 4 shows the plots of these two regions. For the region of the Himalayan foothills, the data for all of the meteorological subdivisions north of 25°N, except East Rajasthan, Bihar plains and West Rajasthan, have been considered. The correlation coefficient between rainfall and wind is +0.25 (not significant) for the Himalayan foothills and +0.42 (significant at less than 2% level) for south of 15°N (Table 1). The correlation coefficient between the rainfall values of the two regions considered is +0.21, which is not significant.

4. Discussion

The quasi-biennial oscillation in the zonal wind is a major global phenomenon in the lower stratosphere over low latitudes. Studies by Lindzen and Holton (1968), Holton and Lindzen (1972) and Holton (1975) have pointed out that the QBO is excited primarily by vertically propagating equatorial wave modes, and that these modes excite a quasi-biennial mean zonal wind response through the mechanism of radiative damping which causes the waves to decay in amplitude with height and thus to transfer momentum to the mean zonal flow. This feature leads to the hypothesis that there could be a linkage between the tropospheric disturbances and the QBO in the zonal winds of the lower stratosphere over lower latitudes. The weak, but significant, relationship noted between rainfall activity (a tropospheric phenomenon) and the QBO which has been highlighted in the present study helps to corroborate this hypothesis.

The rainfall of the Himalayan foothills has shown weakest correlation with that of the region south of 15°N (Table 1). It is known that during the breaks in the monsoon activity over the central part of the Indian subcontinent, rainfall activity increases over both the foothills of the Himalayas and the extreme south of India. During this period, the axis of the monsoon trough (a line of discontinuity between easterly/southeasterly flow to the north and westerly/southwesterly flow to the south) shifts northward towards the foothills from its normal position and the low-pressure waves travel westward across the land mass of the southern peninsular India. This situation would suggest a strong relationship between the rainfall of the Himalayan foothills and south of 15°N, but the present analysis has not shown this feature. It is, therefore, considered that a strong

TABLE 1. Correlation coefficient between rainfall departures of India (June–September) and zonal wind at 30 mb (June–August) for 1951–82. Values in brackets indicate correlation coefficients of rainfall with wind considered for June–September.

Regions	Correlation coefficient	Level of significance (%)
Entire India	+0.39 (+0.37)	<3 (<3)
North of 20°N	+0.30 (+0.29)	<10 (10)
South of 20°N	+0.36 (+0.33)	<5 (<7)
Himalayan foothills	+0.25 (+0.24)	Not significant
South of 15°N	+0.42 (+0.38)	<2 (<3)

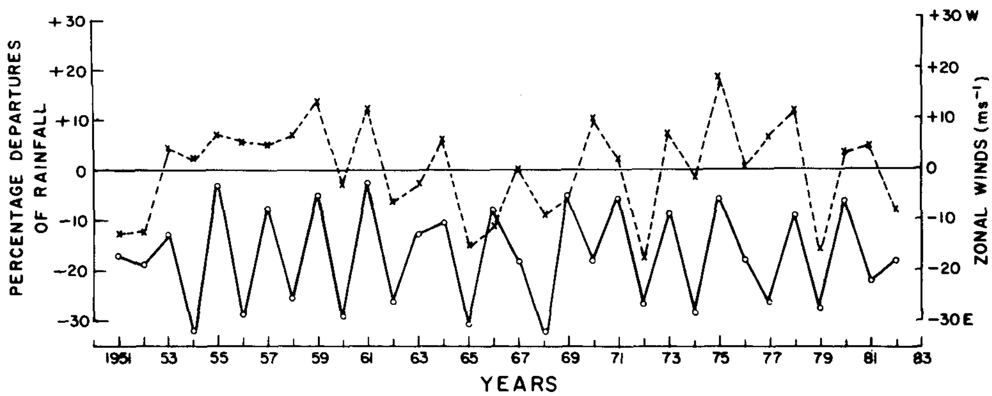

FIG. 2. Mean zonal wind (June–August) at 30 mb for Balboa during 1951–82 (solid) m s^{-1} and percentage departures of rainfall for the same period (dashed) for entire India.

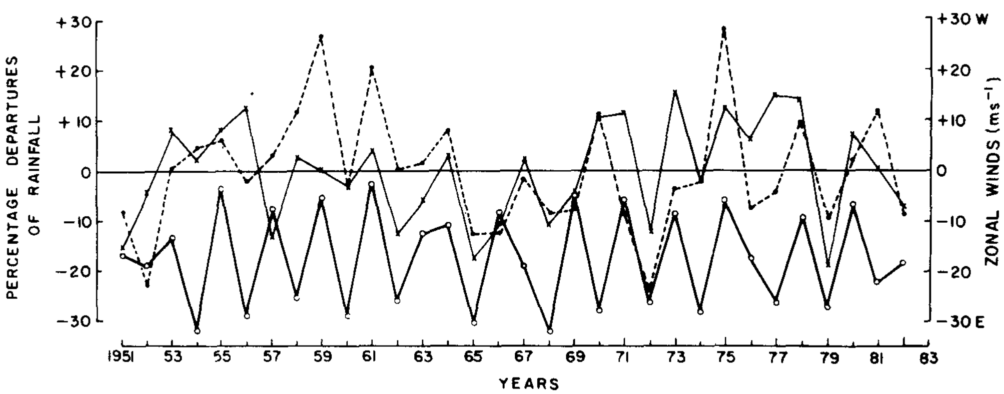

FIG. 3. Mean zonal wind (June–August) at 30 mb for Balboa during 1951–82 and percentage departures of rainfall for the regions north of 20°N and south of 20°N for the same period: (heavy line with open circles) mean zonal wind; (light line with crosses) rainfall departures north of 20°N; (dashed line with dots) rainfall departures south of 20°N.

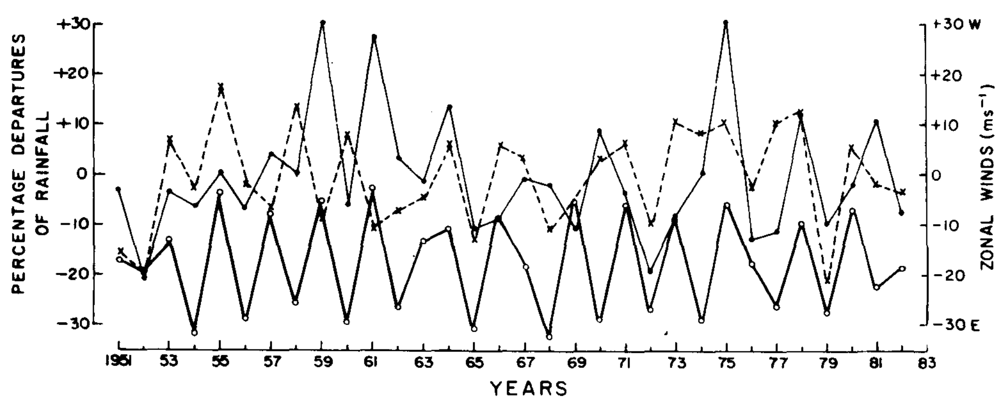

FIG. 4. Mean zonal wind (June–August) at 30 mb for Balboa during 1951–82 and percentage departures of rainfall for the regions Himalayan foothills (north of 25°N) and south of 15°N: (heavy line with open circles) mean zonal wind; (dashed line with crosses) rainfall departures north of 25°N; (light line with dots) rainfall departures south of 15°N.

relationship could probably be attained during the spells of occurrence of the above meteorological phenomena only. The relationship may be masked when rainfall for the entire monsoon is considered, as in the present analysis. This feature requires further study.

During the nine years (1952, 1957, 1958, 1967, 1970, 1971, 1977, 1981, 1982) when the relationship between the rainfall departures and the phases of the QBO broke, the years in question included the five El Niño years—1957, 1958, 1970, 1977, 1982. Rasmusson and Carpenter (1983) have suggested a link between the El Niño–Southern Oscillation events and the Indian monsoon rainfall. Also the relationship between the QBO and the El Niño–Southern Oscillation events has been discussed (Quiroz, 1983). It is considered, therefore, that a more comprehensive study, which would take into account the preceding features as well as consider the regional and the altitudinal relationships (among conditions in the Indian troposphere and the Balboa stratosphere) along with the possible leads and lags, is necessary.

5. Conclusion

The study of rainfall variations of the Indian subcontinent and the quasi-biennial oscillation in the zonal winds of the lower equatorial stratosphere at Balboa has pointed out that a percentage ($\sim$15%) of rainfall variability over India during the summer monsoon is associated with the pattern of the quasi-biennial oscillation of the zonal wind in the lower stratosphere. If the natural cyclical pattern of the QBO could be anticipated, the present finding may have some value in the general context of long-range forecasting of the Indian summer monsoon rainfall.

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