# Tropical Stratospheric Circulation and Monsoon Rainfall

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ABSTRACT

Interannual variability of both SW monsoon (June–September) and NE monsoon (October–December) rainfall over subdivisions of Coastal Andhra Pradesh, Rayalaseema and Tamil Nadu have been examined in relation to monthly zonal wind anomaly for 10 hPa, 30 hPa and 50 hPa at Balboa (9°N, 80°W) for the 29 year period (1958–1986). Correlations of zonal wind anomalies to SW monsoon rainfall ($r = 0.57$, significant at 1% level) is highest with the longer lead time (August of the previous year) at 10 hPa level suggesting some predictive value for Coastal Andhra Pradesh. The probabilities estimated from the contingency table reveal non-occurrence of flood during easterly wind anomalies and near non-occurrence of drought during westerly anomalies for August of the previous year at 10 hPa which provides information for forecasting of performance of SW monsoon over Coastal Andhra Pradesh. However, NE monsoon has a weak relationship with zonal wind anomalies of 10 hPa, 30 hPa and 50 hPa for Coastal Andhra Pradesh, Rayalaseema and Tamil Nadu.

Tracks of the SW monsoon storms and depressions in association with the stratospheric wind were also examined to couple with the fluctuations in SW monsoon rainfall. It is noted that easterly / westerly wind at 10 hPa, in some manner, suppresses / enhances monsoon storms and depressions activity affecting their tracks.

**Key words:** QBO, Stratospheric wind and monsoon rainfall, Interannual variability of SW monsoon, Probability forecasts of droughts / floods

## I. INTRODUCTION

The circulation in the tropical stratosphere is characterized by an alternation of westerlies and easterlies on the time scale of about 24 to 30 months, and a downward propagation of change over from higher to lower layers with a speed of about 1 km / month. A link between Indian monsoon rainfall and stratospheric zonal wind was suggested by many researchers Raja Rao and Lakhole (1978), Thapliyal (1979), Mukherjee et al. (1985). In a recent study Bhalme et al. (1987) reported a strong and longer lead time correlation between Indian monsoon rainfall and 10 hPa zonal wind anomalies in January at Balboa (9°N, 80°W), suggesting some predictive value for summer monsoon rainfall of India as a whole. In this paper, the scope of Bhalme et al. (1987) was extended to include stratospheric winds at 10 hPa, 30 hPa and 50 hPa for Balboa and the subdivisional SW monsoon and NE monsoon rainfall over Coastal Andhra Pradesh, Rayalaseema and Tamil Nadu. Tracks of the SW monsoon storms and depressions in association with the stratospheric wind were also examined to couple with the fluctuations in SW monsoon rainfall.

## II. DATA

Monthly zonal wind anomalies at 10 hPa, 30 hPa and 50 hPa for the period (1958–1986) were obtained from the Climate Analysis Center of the U.S. National Meteorological Center. Monthly rainfall data for the three sub-divisions of India were made available to us by the

office of the Deputy Director General of Meteorology, India Meteorological Department, Pune. The tracks of storms and depressions were extracted from the Atlas of tracks of storms and depressions in the Bay of Bengal & the Arabian Sea 1877–1970, published by the India Meteorological Department (1979) and from the unpublished tracks of storms and depressions charts available at the Deputy Director General Meteorology (Forecasting), Pune for the years 1971–1987. All the values of rainfall data were expressed as percentage of the long term mean. The meteorological sub–divisions of Coastal Andhra Pradesh, Rayalaseema and Tamil Nadu considered for our study have been represented in Fig. 1. The SW monsoon rainfall accounts for about 52%, 58% and 34% of the annual rainfall respectively over Coastal Andhra Pradesh, Rayalaseema and Tamil Nadu, whereas NE monsoon accounts for 34%, 27% and 47% of the annual rainfall respectively over above mentioned three subdivisions.

## III. STRATOSPHERIC WIND ANOMALIES AND RAINFALL

Possible relationships between SW monsoon over Coastal Andhra Pradesh, Rayalaseema and Tamil Nadu and monthly zonal wind anomalies at 10 hPa, 30 hPa and 50 hPa for the 29–year period 1958–1986 were examined by correlation analysis. Fig. 2 shows the lag–correlation between the SW monsoon for Coastal Andhra Pradesh and the zonal wind anomalies for different levels. Y(0) denotes the reference monsoon year. It is noteworthy that the correlations of zonal wind anomalies to SW monsoon rainfall ($r=0.57$, significant at 1% level) is highest with longer lead time (August of the previous year) at 10 hPa level, suggesting some predictive value for SW monsoon rainfall over Coastal Andhra Pradesh. The highest correlation at 30 hPa and 50 hPa is respectively for the months of April ($r=0.52$) and August ($r=0.51$) of the reference year, which is consistent with the well known downward phase propagation of tropical stratospheric winds. The correlation for SW monsoon season over Rayalaseema and Tamil Nadu is relatively weak. The correlation coefficients are 0.44 for July, 0.46 for November of the previous years and 0.35 of February of the same year for 10 hPa, 30 hPa and 50 hPa respectively over Rayalaseema and 0.38 for April, 0.35 for September of the previous year and 0.33 of April of the same year over Tamil Nadu for the above three levels respectively.

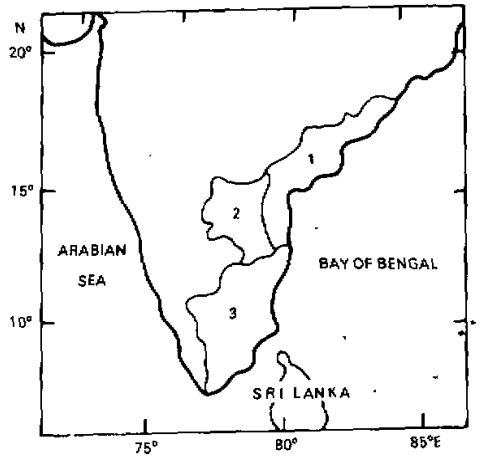


Fig. 1. Meteorological sub–divisions of India considered for the study. Index to Subdivision numbering (1) Coastal Andhra Pradesh (2) Rayalaseema (3) Tamil Nadu.

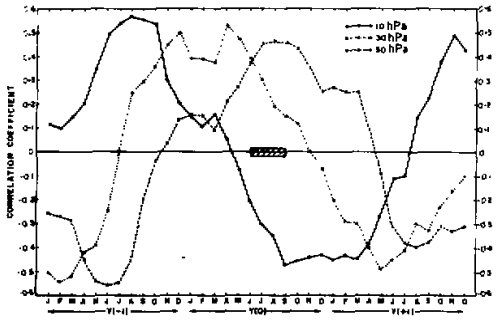

Fig. 2. Correlation coefficients between SW monsoon rainfall for Coastal Andhra Pradesh and the monthly zonal wind anomalies for 10 hPa, 30 hPa and 50 hPa at Balboa for the reference year Y(0), preceding Y(−1) and following Y(+1) years for the period of 1958–1986. The period of SW monsoon reference year is marked by hatching.

The correlation coefficients for NE monsoon season over all the three subdivisions are relatively much smaller ($r = |0.15$ to $0.20|$) suggesting a weak relationship.

It may be noted that the SW monsoon rainfall over the Coastal Andhra Pradesh is significantly related with 10 hPa wind anomaly at Balboa.

## IV. SYNOPTIC LINK

In the foregoing sections we provided an evidence for significant relationships between the stratospheric zonal wind and Indian SW monsoon rainfall. The important question centres on what rain–producing weather systems act to couple stratospheric wind with fluctuations in SW monsoon rainfall.

We present link between occurrences of SW monsoon storms / depressions with the phases of stratospheric wind to produce observed relationships.

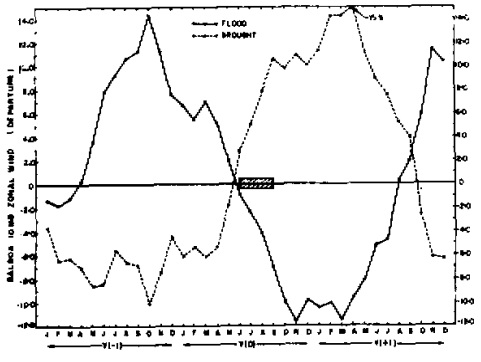

Fig. 3. The composites of Balboa 10 hPa monthly zonal wind anomalies (mps) averaged separately for all the drought years and for all the flood years over Coastal Andhra Pradesh for reference year Y(0), preceding Y(−1) and following Y(+1) years for the period of 1958–1986. The period of SW monsoon reference year is marked by hatching.

It is well known that fluctuations in the intensity of rainfall during the monsoon season are to a large extent associated with frequency, intensity and tracks of monsoon storms / depressions. The tracks of storms / depressions that occurred over the Indian region during westerly or easterly wind regimes of wind at 10 hPa at Balboa are shown in Fig. 4 & Fig. 5. It is seen that frequency of occurrence of storms / depressions is much smaller during easterly wind regimes than that during westerly wind regimes. Furthermore, the westward extent of the tracks is shorter and moves in north or northeastward during easterly than during westerly wind regimes. This contrast is most conspicuous for the years of easterly wind regimes during the month of June and September.

Table 1 represents frequency of occurrences of storms / depressions June through September and monsson season total. Note that monsoon storms / depressions frequency is in general, more frequent when 10 hPa stratospheric winds are westerly and less frequent when they are easterly, except for the month of July. Monsoon season storms / depressions frequency of occurrence during westerly and easterly wind regimes differs significantly at level of 10% of significance according to a $t$–test.

The present evidence suggests that easterly / westerly wind at 10 hPa in some manner suppresses / enhances SW monsoon seasona' storms and depression activity affecting their tracks and thus influencing monsoon rainfall.

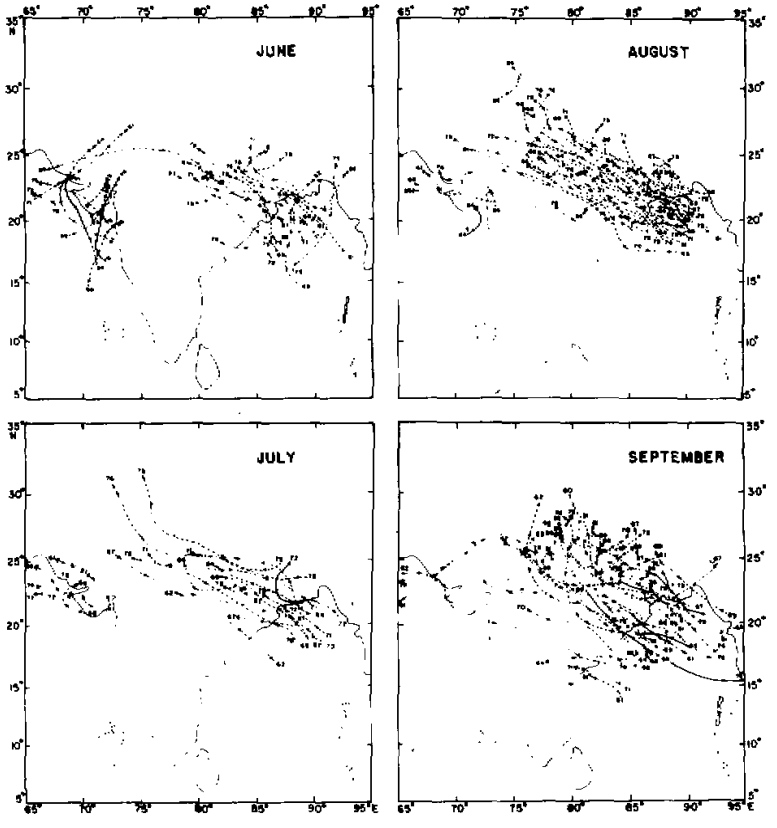


Fig. 4. Tracks of storms and depressions for different SW months when 10 hPa wind at Balboa were Westerly during the period of 1958–1986.

**Table 1.** The Frequency of Occurrence of Storms and Depressions during Easterly and Westerly 10 hPa Stratospheric Winds at Balboa for the Period of 1958–1986

| Phase / Month | June | July | August | September | Seasonal |
|---|---|---|---|---|---|
| Easterly | 18 | 23 | 24 | 21 | 86 |
| Westerly | 26 | 21 | 39 | 39 | 125 |
| Total | 44 | 44 | 63 | 60 | 211 |

Note: Season $t = 2.20$, significant at 10% level

## V. COMPOSITES OF STRATOSPHERIC WIND ANOMALY FOR DROUGHT AND FLOOD YEARS

The composites of the wind anomalies for 10 hPa prepared separately for all the flood (excessive rainfall) years and drought (deficient rainfall) years are shown in Fig. 3. The extreme events (droughts / floods) over Coastal Andhra Pradesh appear related to distinct inverse variations. The striking feature is occurrence of large positive (negative) zonal wind anomalies for flood (drought) SW monsoon year during previous October suggesting its usefulness in predicting drought / flood over Coastal Andhra Pradesh from zonal wind anomalies at 10 hPa.

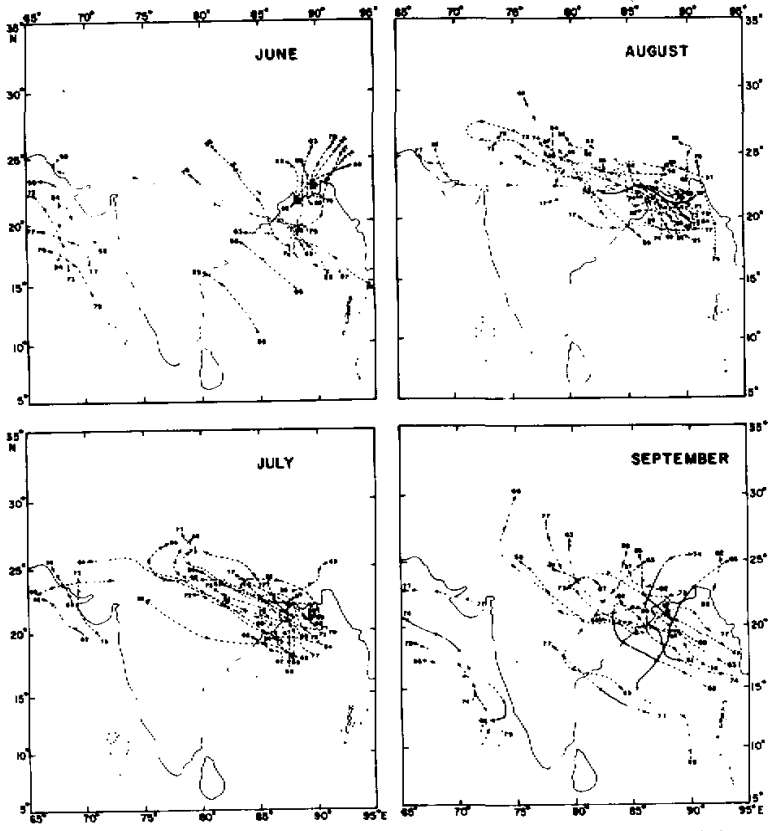


Fig. 5. Tracks of storms and depressions for different SW months when 10 hPa wind at Balboa were Easterly during the period of 1958–1986.

## VI. FORECASTING IMPLICATIONS

The detailed analysis for implications of forecasting extreme years such as drought or flood years over Coastal Andhra Pradesh is presented in this section.

The contingency table for the frequency of occurrence of droughts / floods during the SW monsoon season over Coastal Andhra Pradesh in relation to westerly and easterly wind anomalies for August of previous year of SW monsoon is provided in contingency Table 2.

**Table 2.** Contingency Table of Frequency of Occurrence of Drought (D), Flood (F) and Normal Rainfall (N) over Coastal Andhra Pradesh during Monsoon (June–September) Season Vs. Westerly ($\Delta U+$) Easterly ($\Delta U-$) Zonal Wind Anomaly in Previous August for 10 hPa at Balboa

| | F | N | D | Total |
|---|---|---|---|---|
| $\Delta U+$ | 7 | 9 | 1 | 17 |
| $\Delta U-$ | 0 | 9 | 3 | 12 |
| | 7 | 18 | 4 | 29 |

Note: $X_2 = 7.354$ significant at 5% percent level

Probabilities estimated from contingency results: (1) Neglecting Stratospheric wind $P_r(D) = 0.137$; $P_r(F) = 0.241$; (2) In westerly ($\Delta U+$) anomaly years $P_r(D) = 0.059$; $P_r(F) = 0.412$; (3) In easterly ($\Delta U-$) anomaly years $P_r(D) = 0.250$; $P_r(F) = 0$.

The relation is significant at 5% level. The probabilities estimated from the contingency table reveal non–occurrence of flood during easterly wind anomalies and near non–occurrence of drought during westerly wind anomalies for August of the previous year at 10 hPa which is a useful information for forecasting of performance of SW monsoon over Coastal Andhra Pradesh.

## VII. RESULTS AND CONCLUSIONS

1) The highest ($r = 0.57$) statistically significant correlation with 1% level between Coastal Andhra Pradesh SW monsoon rainfall and zonal wind anomaly for 10 hPa at Balboa is found for August of the previous year, suggesting some predictive value for the SW monsoon rainfall with longer lead time.

2) High correlation suggests that stratospheric wind variations play an important role in interannual variability of SW monsoon rainfall over Coastal Andhra Pradesh.

3) The probabilities estimated reveal near non–occurrence of drought during westerly wind anomalies at 10 hPa for August of the previous year which is a useful information for forecasting of performance of SW monsoon over Coastal Andhra Pradesh.

4) However, NE monsoon rainfall over all the three subdivisions is weakly related with the stratospheric wind anomalies.

5) Examination of tracks of the SW monsoon storms and depressions in association with the stratospheric wind at 10 hPa revealed that easterly / westerly wind at 10 hPa suppresses / enhances, in some manner, storms and depressions activity affecting their tracks.

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