Tropospheric Wind Shear Oscillations as a Characteristic of the Southwest Monsoon Atmosphere

C. R. V. RAMAN,[1] Y. P. RAO,[2] S. K. SUBRAMANIAN AND JOSE A. MALIEKAL

Meteorological Office, New Delhi-3, India

13 June 1979 and 15 December 1980

ABSTRACT

In earlier papers it was shown that tropospheric vertical wind shear in the layer 850–200 mb decreases appreciably prior to formation of depressions in the Indian summer monsoon area. Further analysis reveals that this decrease in shear stems almost entirely from the upper troposphere between 400 mb (7.4 km) and 250 mb (10.5 km).

During the southwest monsoon period (June–September) the tropospheric wind shear over the Indian subcontinent is found to wax and wane in periods of 5–10 days in the latitudinal belt 9–27°N with an amplitude of the order of 35 m s^{-1} (650 mb)$^{-1}$. These oscillations in wind shear thus appear to be a characteristic of the monsoon atmosphere. The phase of the shear oscillation south of about 16°N is opposite to that in the north.

1. Introduction

The north Bay of Bengal, where tropical depressions of the southwest monsoon form, is characterized by strong wind shear of ~20 m s^{-1} over a depth of 650 mb in the layer 200–850 mb in July/August. In two earlier papers, Raman *et al.* (1978, 1979) showed that this strong zonal vertical shear commences to decrease 2–3 days ahead of formation of monsoon depressions, recording values even <10 m s^{-1}. During 1974–79, no depression formed without such substantial decrease in tropospheric wind shear. The present investigation identifies the tropospheric layer in which the vertical wind shear decrease is predominant. A more important result that has emerged is that the monsoon atmosphere is characterized by marked fluctuations (waxing and waning) of the tropospheric vertical wind shear.

Rao (1976) presented a summary of the state of knowledge on monsoon depressions up to 1975. Krishnamurti *et al.* (1977) suggested from analysis of surface pressure data that a small fraction of monsoon lows and depressions are excited by typhoons in the Pacific as they come near the Asian coast at 20°N: During the week after the typhoon's arrival, pressure rises over Vietnam and Burma and during the following week, a monsoon disturbance forms in the north Bay of Bengal. Krishnamurti *et al.* regarded this sequence as downstream amplification phenomenon. However, the study (Krishnamurti *et al.*, 1977) did not deal with associated upper tropospheric features.

Shukla (1978) performed a combined CISK-barotropic-baroclinic analysis of the observed monsoon flow, using the quasi-equilibrium assumption for the parameterization of moist convection in the summer monsoon area. According to Shukla, the magnitudes of the growth rate and dominant energy transformations in monsoon depressions are determined by the CISK, the horizontal amplitude structure by the horizontal shears, and the vertical amplitude structure by the combined effects of vertical shear and condensational heating. He hypothesized that the primary role of the terrain is to produce the mean monsoon trough which is barotropically unstable at the lower levels and provides the triggering mechanism for monsoon depressions. Shukla's work did not uncover any critical relationship between vertical shear and monsoon depressions.

Bannon (1979) made a very interesting numerical modeling study of the dynamics of the East African jet. Although his work relates to lower tropospheric levels in a region close to the equator, far removed from the area of monsoon depression formation, it draws attention to the interaction between the passage of westerly troughs over South Africa and the East African jet.

2. Wind shear and monsoon depression

Gray (1968) adduced evidence that regions of formation of tropical storms have low tropospheric vertical wind shear. In the Bay of Bengal and the Arabian Sea, tropical cyclones from in and around the latitudes of low tropospheric wind shear during the months April, May, October and November. In April and May, cyclones form between 10 and 15°N where the shear is nearly zero between 200 and 850 mb. However, during the southwest monsoon period, depressions form around 19°N where the vertical wind shear exceeds 20 m s^{-1} in July and August and is 10–20 m s^{-1} in June and September.

[1] Nehru Fellow, Systems Research Institute, 17-A Gultekdi, Poona-411009, India.

[2] Retired Director General of Observatories, B3/33 Azad Apartments, New Delhi-3, India.

0027-0644/81/040910-06$05.50

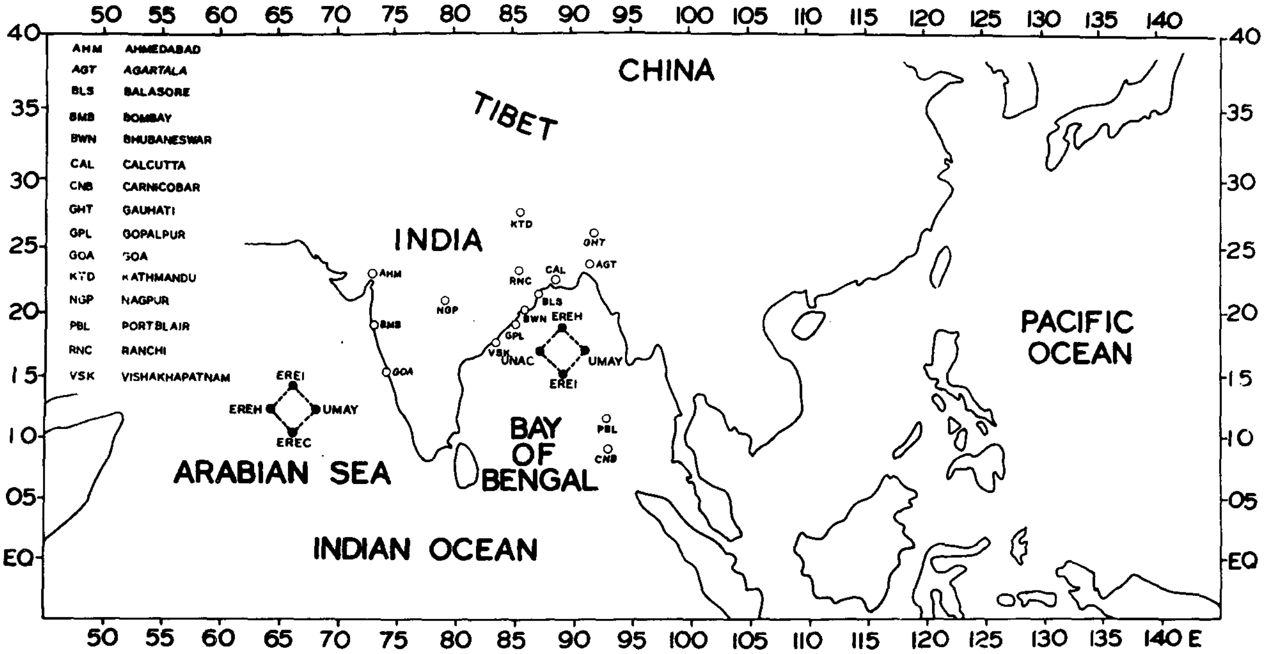

FIG. 1. Chart showing locations of upper air stations (station identification, upper left) during Monsoon-77.

During Monsoon-77, a close network of upper wind observations was organized by India along the east coast while U.S.S.R. stationed four research ships in a polygon in the north Bay of Bengal (Fig. 1). Analysis of these upper wind data (Raman *et al.*, 1978) showed substantial decrease of wind shear 2–3 days prior to development of a monsoon depression on the morning of 19 August 1977. On the morning of 16 August 1977 at Gopalpur, 600 km west of the location of formation of the monsoon depression three days later, vertical wind shear began to register a sharp decrease. By 17 August 1977, still two days before the birth of the monsoon depression, two Soviet ships also began recording a spectacular decrease of vertical wind shear. This suggested that vertical wind shear decreases even a few days before monsoon depression formation over an area much larger than the circulation system of a depression. Such an instance was not confined to the Bay of Bengal alone. The June 1977 depression in the east Arabian Sea was preceded by decrease in vertical wind shear along the west coast of the Indian peninsula and the U.S.S.R. research vessel nearby (Raman *et al.*, 1979). A further study of all synoptic systems during July–August of 1974–77 shows that the eleven depressions that formed in the north Bay of Bengal were preceded by decrease in wind shear along the coast (mid-monsoon months of July and August were considered to exclude transitional characteristics in June and September). In five cases, while vertical wind shear was increasing, preexisting incipient lows in the north Bay of Bengal did not develop into depressions. However, there also were four cases of incipient lows not developing into depressions in spite of decrease of vertical wind shear.

The above evidence leads to infer that decreasing vertical wind shear is an important and necessary pre-condition for the formation of monsoon depressions over the north Bay of Bengal and the Arabian Sea. Increase in vertical shear seems to inhibit monsoon cyclogenesis. In all cases of decreasing wind shear which led to depression formation, shear decrease occurred at least two days before, at stations not less than 200 km west of the site of cyclogenesis. This evidence seems to preclude the possibility of the decrease of tropospheric shear being an effect or consequence of the process of formation of monsoon depressions. Data are presented here to show that variations of vertical shear are a regular feature of the monsoon atmosphere.

3. Layer of shear decrease

In the earlier investigations, shear has been considered between 850 and 200 mb covering almost the entire troposphere. However, the vorticity patterns over the north Bay of Bengal, derived from the upper wind data of Soviet ships in polygon formation during August 1977, showed marked differences between the upper and lower tropospheres. Hence, an examination was made of the variation of shears in different layers of the troposphere before the formation of monsoon depression.

Fig. 2 shows the variation of normal vertical wind shear per 50 mb at different levels in July at Calcutta, Bhuvaneshwar and Visakhapatnam which are

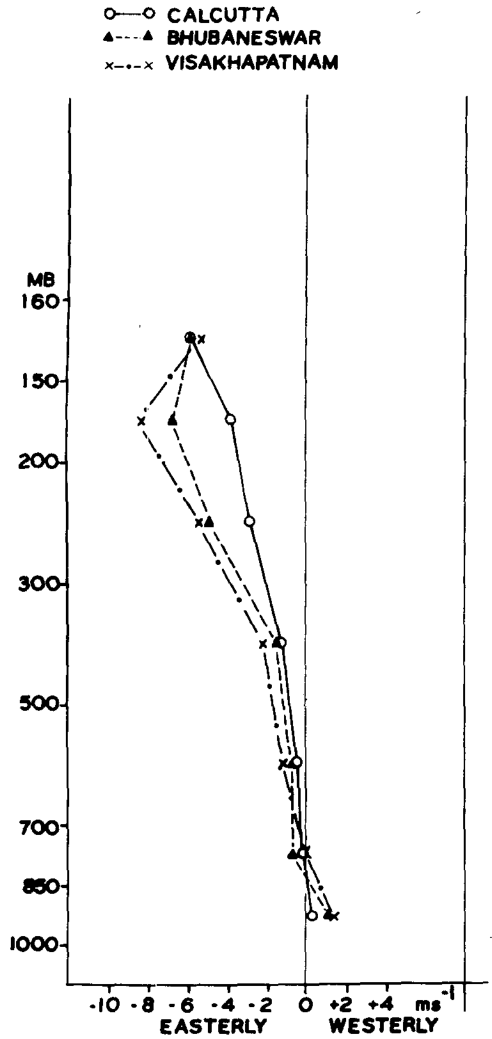

FIG. 2. Vertical variation of mean wind shear [m s^{-1} (50 mb)$^{-1}$] for July at selected stations in east coast of India. Values plotted corresponding to the midpoint of the layer. Note the small value of the layer shear below 400 mb.

closest to the cyclogenetic area of the north Bay of Bengal. Shears are within 2 m s^{-1} (50 mb)$^{-1}$ from the surface to 400 mb, westerly changing to easterly at ~800 mb. The easterly shear increases sharply aloft and reaches a maximum of ~8 m s^{-1} (50 mb)$^{-1}$ near 175 mb at Bhuvaneshwar and Visakhapatnam.

Profiles for 16 and 18 August 1977 for Gopalpur are given in Fig. 3. As climatological data are not available for Gopalpur, the normal profile for August for Bhuvaneshwar, a nearby station, is indicated. Likewise, the variation of vertical wind shear is also presented for the ship at 17.5°N 91°E (UMAY) for 17 and 18 August 1977 in Fig. 4 along with the normal pattern for near about that position in the Bay for August. These curves clearly indicated that there was no significant change in the wind shear from surface to about 400 mb. At the coastal station, the actual layer shear above 400 mb on 16 August 1977 was even larger than the normal value. The layer shear above 400 mb on 18 August 1977 at the ship location was appreciably smaller than the normal. The only notable change was between the 400 and 200 mb levels. At both the locations, an easterly shear of ~8 m s^{-1} (50 mb)$^{-1}$ changed to a westerly shear of 2 m s^{-1} (50 mb)$^{-1}$ in the vicinity of 300 mb/250 mb levels. (On 15 August 1977, the easterly shear at Gopalpur was even greater than on 16 August 1977.) The decreased vertical shear in the upper tropospheric layer 400–200 mb was smaller than the normal, both along the coast and the ship location. It thus clearly follows that the layer of decrease in shear is only between 400 and 250 mb leaving the lower troposphere almost unaffected.

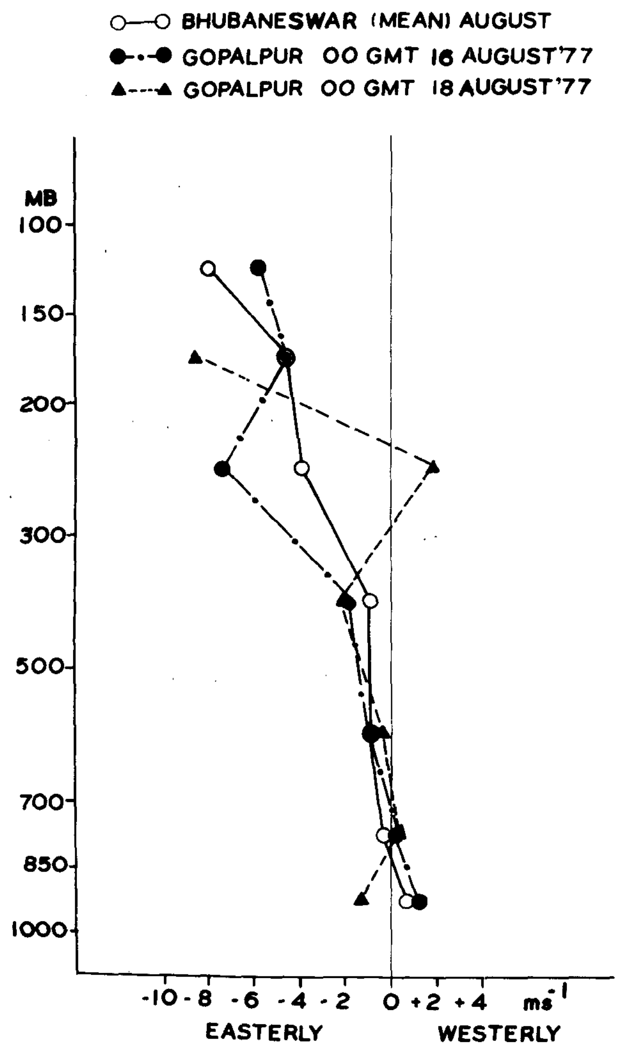

FIG. 3. Profile of wind shear in the vertical [m s^{-1} (50 mb)$^{-1}$] for Gopalpur prior to depression formation in the Bay of Bengal derived from ascents of 0000 GMT 16 August 1977 and 0000 GMT 18 August 1977. The mean profile for Bhubaneshwar for August also shown. Values plotted correspond to midpoint of the layer.

4. Pulsations of vertical wind shear

The questions arise: Is the decrease in wind shear a singularity in only a certain area, which occurs now and then to facilitate monsoon cyclogenesis? Or is it a characteristic of the general circulation of the southwest monsoon? It may be recalled that on a few occasions, a decrease of vertical wind shear (hereinafter called wind shear) occurred at Calcutta/Bhuvaneshwar but cyclogenesis did not result, in spite of incipient lows also being present. This would suggest that decreases and increases in wind shear take place with some rhythm in the tropospheric layers over and around the north Bay, the decreases no doubt facilitating formation of monsoon depression. Fig. 5 shows the variation in the tropospheric wind shear (between 200 and 850 mb) at a number of stations at different latitudes from Gauhati (GHT) at 27°N to Car Nicobar (CNB) at 9°N. Many of these stations lie along the east coast of India bordering the Bay of Bengal. Port Blair and Car Nicobar are islands. Data of U.S.S.R. ships have also been incorporated; stations north of 23°N are land stations. The Hovemoller diagram may be regarded as representing variation of tropospheric vertical shear with latitude between the longitudes 83 and 93°E for July–August 1977. Three-day running averages of wind shear have been presented in this diagram in order to filter out noise due to daily variation. Though wind shear from 200 to 850 mb has been plotted, from the evidence in the previous section, it will be natural to regard the fluctuations as taking place mostly in the upper troposphere.

Marked fluctuations in wind shear with time are quite apparent. The magnitude of the wind shear variation in the Bay of Bengal during July–August 1977 is 25–35 m s^{-1} (650 mb)$^{-1}$ [850–200 mb] at all these stations. Without implying any further analogy, this seems somewhat similar to the variations of the strength of westerlies in middle latitudes between low and high circulation indices. Two zones of separate wind shear oscillations can be identified from Fig. 5, the northern one being centered around 20°N and the southern one around 10°N in the south Bay of Bengal. The region of transition between these two distinct zones of pulsation of wind shear appears to be around 16°N, where the amplitude of variation seems to be less. The northern Bay oscillation manifests itself north of 16°N and the southern Bay oscillation to the south. During individual epochs, one or the other oscillation may extend further south or north of 16°N.

Table 1 shows correlation between different stations of the three-day running averages of wind shear. The generally high correlation of Calcutta with Agartala, Ranchi and Bhuvaneshwar shows that the same type of fluctuations prevail over a 10° square extending up to 27°N from 17°N. In contrast, Port

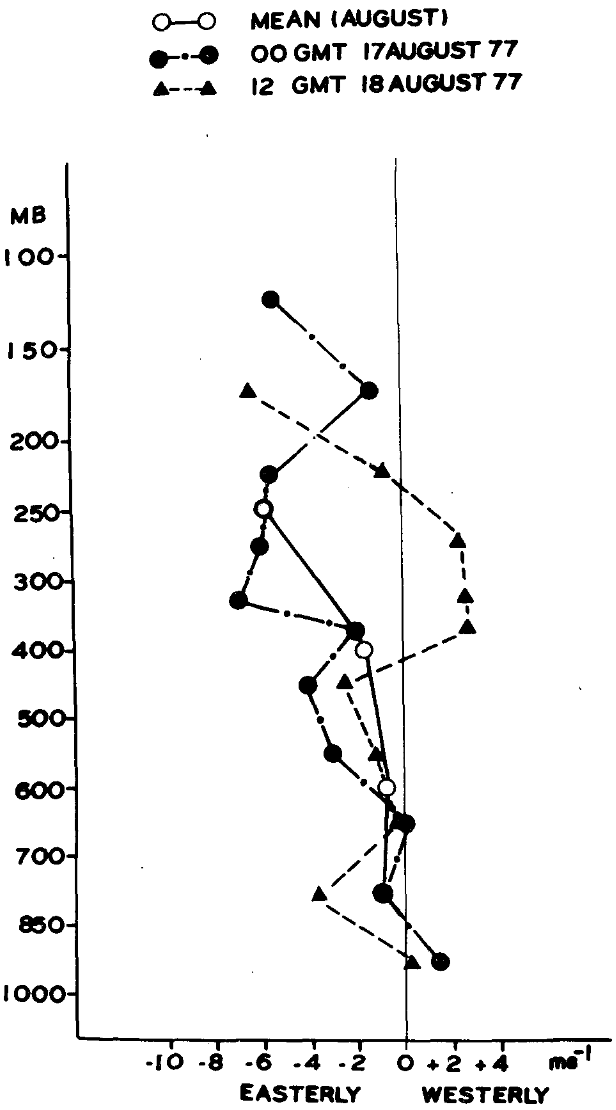

FIG. 4. Profile of wind shear in the vertical in [m s^{-1} (50 mb)$^{-1}$] for Soviet ship *Umay* (17.5°N, 91.0°E) prior to depression formation in the Bay of Bengal on 19 August 1977. Derived from ascents of 0000 GMT 17 August 1977 and 1200 GMT 18 August 1977. Mean profile for the location 17.5°N 90.0°E for August also shown. Values plotted corresponding to midpoint of the layer.

Blair is negatively correlated with Calcutta, while Car Nicobar is very much like Port Blair. It is but right to identify the growth and decrease of shear ~ 10°N latitude as distinct from that of 20°N. Again, the low correlation coefficients of Calcutta with Visakhapatnam indicate that the dividing line is near about that latitude. A striking feature is the maximum negative correlation of the wind shear of Calcutta with Port Blair in 1974 and 1979, two years of poor southwest monsoon rains.

Correlations between these pairs of stations during individual epochs of decreasing and increasing vertical wind shear are also similar.

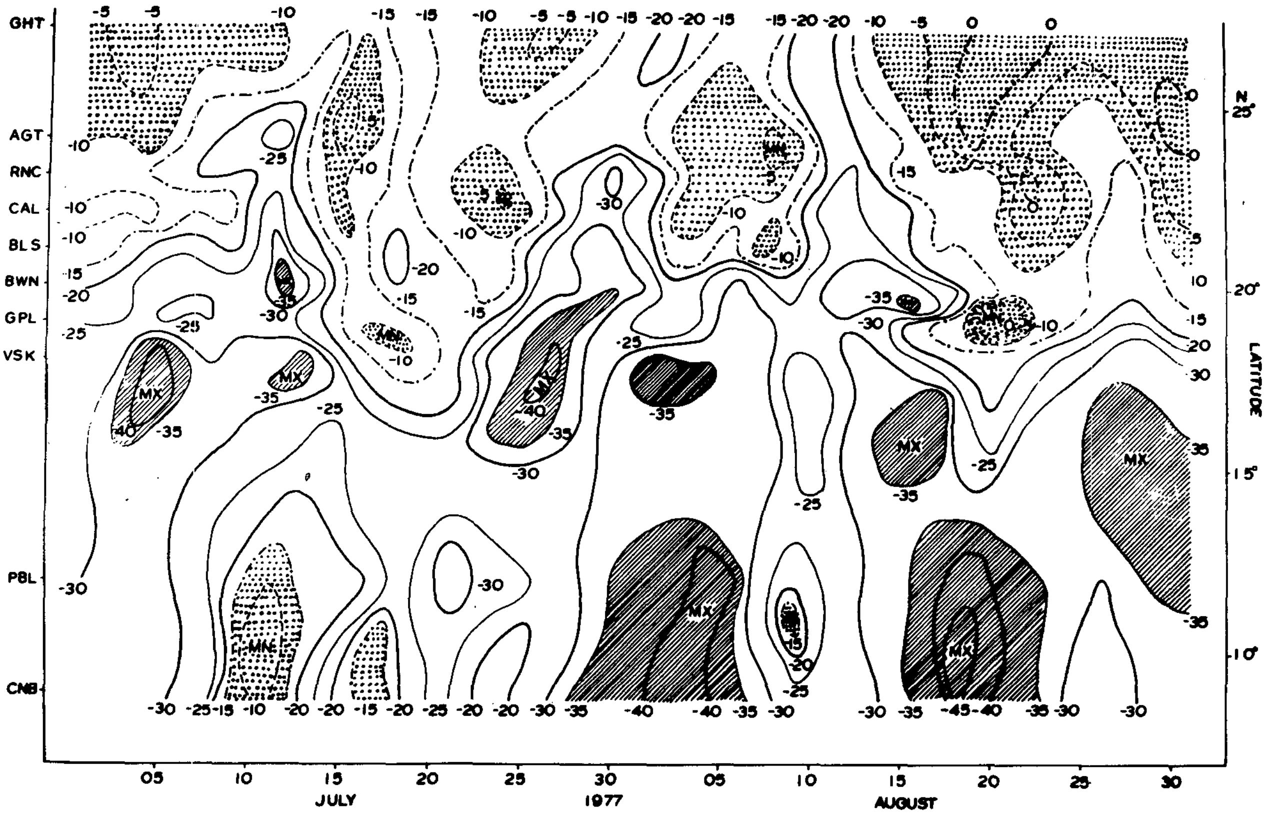

FIG. 5. Cross section of three-day running-average of tropospheric shear [U (200 mb) minus U (850 mb)] in m s^{-1} (650 mb)$^{-1}$ along meridian 89°E for July–August 1977. Incorporates data of Soviet ships as available. Dotted areas denote low values and cross shaded areas high values of vertical shear. Note alternation of growth and decrease of vertical shear. Shear decrease seems to progress equatorward from north to south; shear increase seems to spread from south to north.

The correlation between Calcutta (23°N) and Nagpur (21°N)/Bombay (19°N) is rather low compared with the correlations with stations to the north of Calcutta, though fluctuations in wind shear are noticed at Nagpur and Bombay as well. Bombay lies ~20° of longitude to the west of Calcutta. Correlation between Calcutta and Bombay, taking Bombay values 1–3 days behind did not show any improved relationships.

As already mentioned, the fluctuations of wind shear with a maximum at 20°N covers at least a 10° square extending from 27–17°N. Waxing and waning of tropospheric vertical wind shear over such a large area on a synoptic scale is in itself a strong reason to conclude that the variation in wind shear is not caused by the process of depression formation. Evidence so far advanced seems to indicate that the growth and decrease of the wind shear, in effect in

TABLE 1. Correlation between wind shear (three-day running average) of Calcutta and stations along and near its meridian and to its west.

Pairs of stations		Latitude Longitude	1974	1975	1976	1977	1979
Calcutta (CAL)	Gauhati (GHT)	26°N					0.55
(22.5°N 89°E)	Agartala (AGT)	24°N	0.71	0.78	0.53	0.63	
	Ranchi (RNC)	23.5°N	0.82	0.85	0.75	0.81	0.72
	Bhuvaneshwar (BWN)	20°N	0.55	0.39	0.30	0.72	0.57
	Visakhapatnam (VSK)	18°N	0.27	+0.15	−0.09	0.05	0.16
Calcutta	Port Blair (PBL)	12°N	−0.77	−0.32	−0.13	−0.3	−0.61
Port Blair	Car Nicobar (CNB)	9°N					0.89
Calcutta	Nagpur (NGP)	79°E				0.49	
	Bombay (BMB)	73°E				0.31	

the upper troposphere, takes place, perhaps, over the entire Indian monsoon region in periods of 5–10 days. Earlier it had been noted that during the southwest monsoon period, the upper tropospheric east wind maxima underwent a phase of generation and degeneration in an interval of 5–9 days.

5. Mechanism of shear variation

The occurrence of easterlies in the upper troposphere during the southwest monsoon months is consistent with the strong thermal gradient directed northward between the atmosphere over the Tibetan Plateau and that near the equator. Assuming sufficient geostrophic balance, one would expect decrease in temperature gradient (easterly thermal wind) for the easterlies to decrease in the upper troposphere. Evidence for actual temperature changes in the upper troposphere in the area under study was carefully sought on occasions of decrease of wind shear. However, no significant variations in temperature were observed.

Initial examination suggests that there may be some association between positions of westerly wave troughs to the north of India and shear variations over India during the southwest monsoon season. This aspect requires further detailed investigation.

6. Conclusions

The following inferences are drawn from the study presented:

1) During the southwest monsoon season (June–September) the decrease in tropospheric vertical wind shear [U (200 mb) minus U (850 mb)] observed well before the formation of a depression in the north Bay of Bengal stems almost entirely from the upper troposphere between 400 mb (7.4 km) and 250 mb (10.5 km). Though the wind speeds in the tropospheric layer below 500 mb do vary, changes in wind shear in this layer are negligible. The shear decrease appears to be independent of the process of formation of monsoon depressions.

2) In the whole of the Indian monsoon area, the tropospheric wind shear waxes and wanes in periods of 5–10 days.

3) There are two latitudes of maximum variation in wind shear over the Bay of Bengal, one near about 20°N and another near 10°N, the two being negatively correlated.

4) These oscillations in wind shear are features of the general circulation of the monsoon atmosphere.

REFERENCES

Bannon, P. R., 1979: On the dynamics of the East African Jet I: Simulation of mean conditions for July. *J. Atmos. Sci.*, **36**, 2139–2152.

Gray, W. M., 1968: Global view of the origin of tropical disturbances and storms. *Mon. Wea. Rev.*, **96**, 669–700.

Krishnamurti, T. N., J. Molinari, H. Pan and V. Wong, 1977: Downstream amplification and formation of monsoon disturbances. *Mon. Wea. Rev.*, **105**, 1281–1297.

Raman, C. R. V., Y. P. Rao and S. K. Subramanian, 1979: Wind shear in monsoon depressions. *Weather*, **34**, 252–257.

——, ——, —— and Z. E. Sheikh, 1978: Wind shear in a monsoon depression. *Nature*, **276**, 51–53.

Rao, Y. P., 1976: Southwest monsoon. *Meteor. Monogr. Synoptic Meteor.*, Indian Meteor. Dept., 107–185.

Shukla, J., 1978: CISK-barotropic-baroclinic instability and the growth of monsoon depressions. *J. Atmos. Sci.*, **35**, 495–508.