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A study of Somali jet variability from Monsoon - 77 and MONEX data

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सार — सोमाली जैट की परिवर्तनशीलता के तीन पक्षों, (1) हिन्द महासागर उच्चिष्ठ क्षेत्र, उत्तर पूर्वी अफ्रीका के ऊपर जैट अक्ष के पास भूमध्य रेखा क्षेत्र तथा दक्षिण पश्चिम अरब सागर उच्चिष्ठ क्षेत्र के ऊपर आवर्तक कल्प उच्चावचन, (2) समुद्र तथा स्थल पर जैट की गति में दैनिक परिवर्तन तथा (3) अरब सागर के ऊपर जैट की गति एंव स्तर के उच्चावचन की जांच की गई है।

निम्नस्तरीय जैट क्षेत्र में हवाओं का शक्ति मानावली विश्लेषण 8 से 12 दिन की अवधि में प्रमुख तथा तीव्र मानावलीय शिखर निकालता है। 4–6 दिन तथा 18–25 दिन के परिसरों में दोलन भी देखे जाते हैं।

जैट की गति में दैनिक परिवर्तन स्थलीय क्षेत्र पर अधिक दिखाई देता है। यह समुद्री क्षेत्र पर परिमाण में कमी का एक अनुक्रम है तथा इसमें 850 और 800 मि. बार स्तरों पर एक विपरीत प्रावस्था है।

अधिकतम वायु स्तरों की मॉडल बारम्बारता अक्षांश के साथ परिवर्तनशीलता दर्शाता है जो अरबसागर के ऊपर दक्षिण से उत्तर की ओर निचली ऊंचाई पर तथा अधिकतम वायु प्रवणता के माध्य स्तर पर दक्षिण से उत्तर की दिशा में नीचे की ओर स्थानान्तरित हो जाता है।

ABSTRACT. Three aspects of the variability of Somali jet have been examined : (*i*) Quasi-periodic fluctuations over Indian Ocean maxima zone, equatorial zone near the jet axis over northeast Africa and southwest Arabian Sea maxima zone ; (*ii*) Diurnal variation in the jet speed over land and sea ; (*iii*) Fluctuations in the speed and level of jet over Arabian Sea.

The power spectrum analysis of the winds in the low level jet region brings out prominent and sharp spectral peaks in the period range of 8-12 days. Oscillations in the 4-6 days range and 18-25 days range are also seen.

Diurnal variation in jet speed is seen to be prominent over the land area. It is an order of magnitude less over the sea area and has an opposite phase at 850 and 800 mb levels.

Modal frequency of the level of maximum wind shows variation with latitude, shifting to a lower height from south to north over Arabian Sea and the mean level of maximum wind slopes downward from south to north.

1. Introduction

In recent years, investigations of the Indian summer monsoon by power spectrum analysis technique have revealed some predominent periodicities in the day to day fluctuations of rainfall, pressure and wind field. Ananthakrishnan and Keshavamurty (1970) applied the power spectrum analysis to the time series of wind, rainfall and surface pressure at selected stations all over India for the years 1965 and 1967. Bhalme and Parasni (1975) analysed the time series of meridional gradient of sea level pressure over India during the summer season from 1961 to 1967. They found peaks around 12-15 days and 4-6 days in their spectra. Murakami (1976) in a spectrum analysis of the zonal and meridional wind components over Calcutta — the region close to the cyclogenesis area in the north Bay of Bengal during the summer monsoon season noticed intense spectral peaks around 15-day period appearing in the variation of zonal wind throughout the upper and lower troposphere and another peak around 5-day period in both the zonal and meridional winds in the lower troposphere.

Krishnamurthy and Bhalme (1976) examined the periodic behaviour of the Asian summer monsoon system as a whole, by applying the power spectrum analysis to the time series of nine components of the monsoon. The low level cross-equatorial jet was found by them to contain oscillations in the time scale of 15.3 days and 3-6 days. Their analysis was, however, based on a single station time series of averaged layer mean wind at Garissa (Kenya) for a 62 day period comprising of July and August 1962. In recent studies existence of oscillations in the longer period range (30 to 50 days) in the monsoon have also been detect-

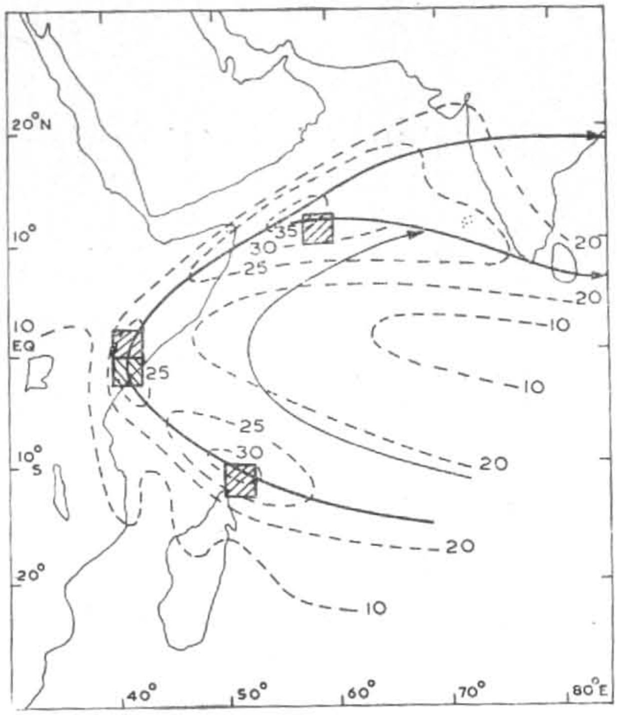

Fig. 1. Locations of the four grids (hatched areas) selected for power spectrum analysis

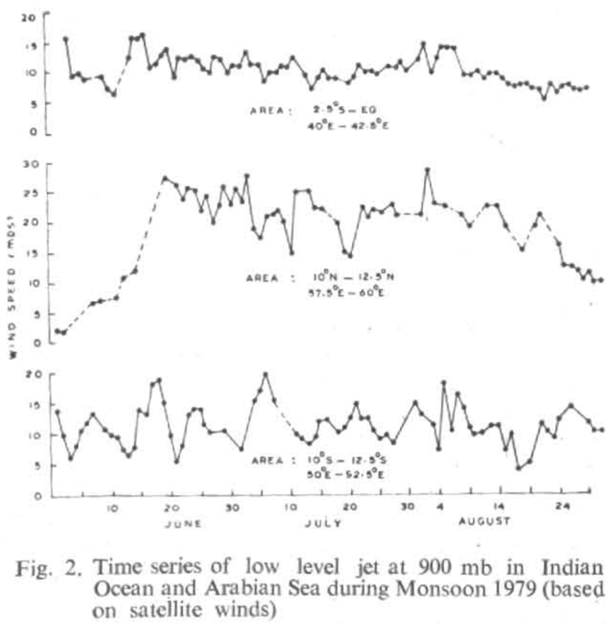

Fig. 2. Time series of low level jet at 900 mb in Indian Ocean and Arabian Sea during Monsoon 1979 (based on satellite winds)

ed by Yasunari (1981) and Krishnamurthy and Subrahmanyam (1982).

Apart from the oscillatory characteristic, Somali jet has been found by various workers to exhibit diurnal fluctuation in the speed and the variations in the level of the jet. Ardanuy (1979), Findlater (1981) and Hsu (1981) utilised upper wind observations from land stations of Kenya and Somalia to investigate the diurnal variation characteristic of the jet. From the upper air data collected over the Arabian Sea during Indo-Soviet Monsoon Experiment 1973 and the MONEX, Jambunathan *et al.* (1974) and Gupta *et al.* (1980) have shown spatial variations in the level of the maximum wind over the area.

In this study we have examined in detail the nature of oscillations in Somali jet, with more complete data and over a larger spatial extent, utilizing the satellite wind observations collected during MONEX. Besides, two other aspects of variability of the jet, namely the diurnal variation over land and sea, and variation in the speed and level of maximum wind have also been examined using Monsoon-77 data in addition to MONEX data.

2. Quasiperiodic fluctuations of the Somali jet

2.1. *Data series for spectrum analysis*

During MONEX upper wind observations were obtained over the Arabian Sea, Indian Ocean and adjoining land areas from the geostationary satellite GOES-1 which was located at 58 deg. E. The cloud imageries from GOES-1 were processed at the Space Science and Engineering Centre (SSEC) at Wisconsin, USA to derive wind sets. The rapid scan of 10-15 minutes were made for meso-scale wind sets four times a day over the tropical region between 30 deg. N to 20 deg. S (The Global Weather Experiment Final Report of U.S. Operations, 1981). Though the wind sets over an area varied from day-to-day, low-level winds at closely spaced points were generally available over southwest Arabian Sea and Indian Ocean on most of the days of the MONEX period, *i.e.*, May-August 1979.

The previous studies of wind observations over the Arabian Sea and Indian Ocean by Findlater (1971), Jambunathan *et al.* (1974), Pant (1978), Gupta *et al.* (1980) and Rao *et al.* (1981, 1982) suggest that the level of maximum wind of the Somali jet over Indian Ocean and Arabian Sea lies close to 1.0 km altitude. The wind vectors at 900$\pm$25 mb in the area from 15°N to 15°S and 40°E to 60°E were, therefore, extracted from GOES-Indian Ocean wind sets to examine the fluctuations in Somali jet. The area was divided into 2.5 degree square grids and wind vectors for all observations during the day falling within each grid were split into u and v components to obtain average wind vectors for each grid.

As the sufficient data was not available for all the grids in the area for meaningful time series for the spectrum analysis, four grids relevant to the position of Somali jet axis and its maxima were chosen, where data

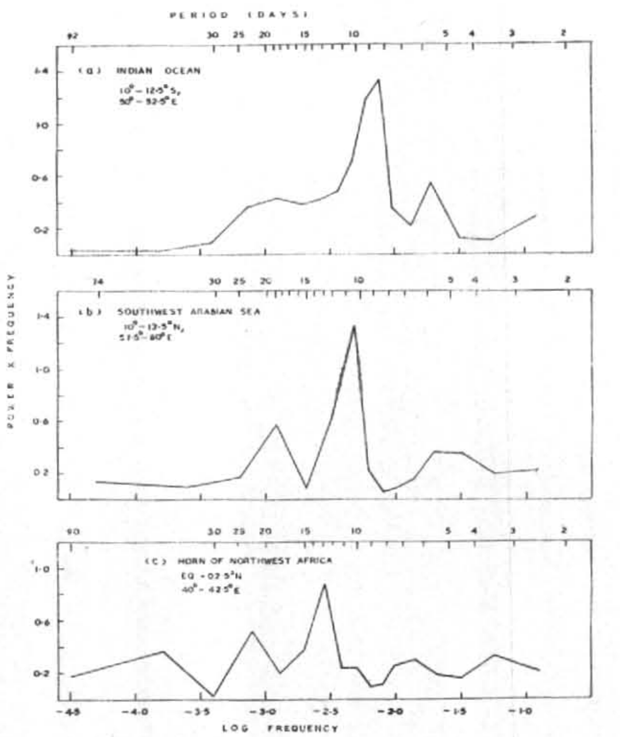

Fig. 3 (a-c). Power spectra of low level jet in : (a) Indian Ocean (b) southwest Arabian Sea and (c) Horn of northwest Africa during summer monsoon 1979

availability was also adequate. These four grids were as follows :

(10-12.5°N; 57.5-60°E)	the zone of maxima in southwest Arabian Sea,
(10-12.5°S; 50-52.5°E)	the zone of maxima in Indian Ocean,
(EQ-2.5°N; 40-42.5°E) (EQ-2.5°S; 40-42.5°E)	the eqatorial zones where the jet axis passes across the horn of northeast Africa.

These grids are shown in Fig. 1.

The time series contained 92 data points from 1 June to 31 August in the Indian Ocean grid, 88-90 points in the equatorial zones and 74 points in the Arabian Sea grid from 19 June to 31 August (continuous data in this grid were available only from 19 June after the low level jet was established in the Arabian Sea). There were a few missing values in the time series, which were linearly interpolated.

2.2. *Results of spectrum analysis*

The time series of average wind speed data in the Indian Ocean, Arabian Sea and one equatorial zone are shown in Fig. 2. Oscillations of a quasiperiodic nature are apparent in all the series. However, it is interesting to see that the oscillations in the equatorial zone are much damped.

The time series were subjected to power spectrum analysis. Spectral estimates were obtained by computing the Fourier transform of the series by the usual

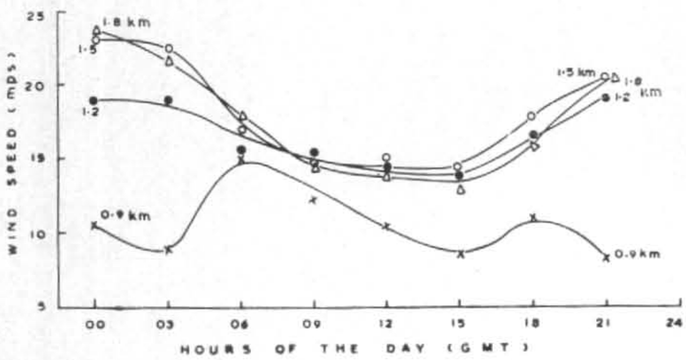

Fig. 4. Diurnal variation of the low level jet at Gardo (9.52° N, 49.08°E) based on mean wind speed from 9 June to 27 June 1979

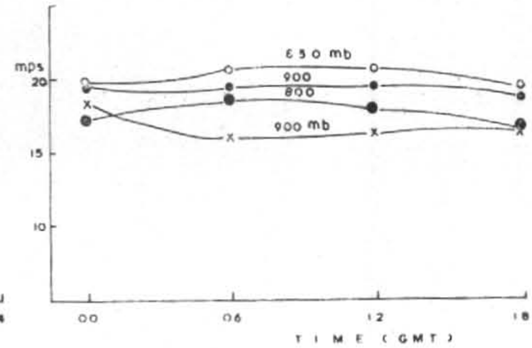

Fig. 5. Diurnal variation of the low level jet in the Arabian Sea at 12.5° N, 64° E

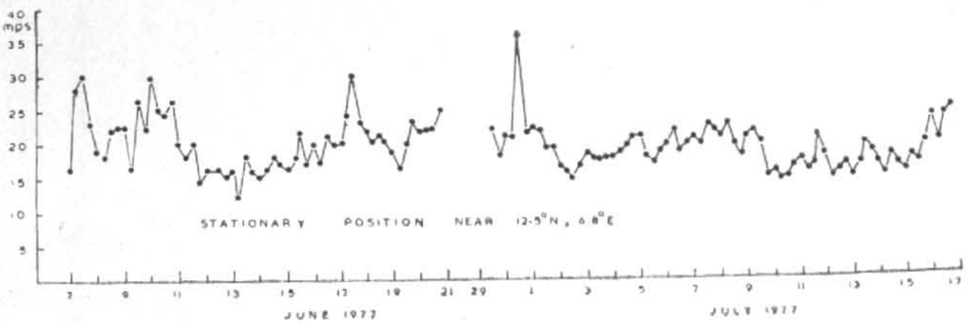

Fig. 6. Time series of low level maximum wind in Arabian Sea from upper wind observations taken on board USSR ship *Shirshov* during Monsoon 1977

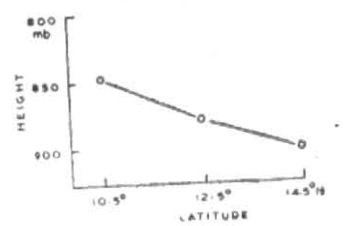

Fig.7. Variation of the mean level of maximum wind with latitude over south central Arabian Sea based on Monsoon - 77 USSR ship upper air data

procedure. Spectral information was graphically represented by plotting the products of power spectral density and frequency against natural log of frequency, following the method proposed by Zangvil, quoted by Krishnamurthy and Bhalme (1976). The procedure has the advantage that when the variation with a certain time scale is localised in the time series, it can represent a proper spectral peak instead of the red noise spectra, which would otherwise appear when the conventional representation is used. Frequency averaging was done to smoothen the spectra by taking averages of spectral estimates falling within one day ranges.

The plots of power frequency against log frequency for the Indian Ocean, Arabian Sea and equatorial zone are shown in Fig. 3 (a-c). The spectra show prominent and sharp spectral peaks around 8 days and 10 days respectively in the southern and northern maxima zones, and 12-13 days in the equatorial zone. Some power is contained in the 4-6 days range and about 18 days also in both the maxima zones. Similar peaks at slightly longer periods 6-7 days and 20-25 days are also noticed in the equatorial zone.

The above results are generally in agreement with the findings of earlier authors. In a case study of fluctuations in the Somali jet during the Indian summer monsoon based on satellite derived winds of Meteosat, Cadet and Desbois (1981) have recorded an instance where the low level jet exhibited a complete cycle of oscillation with a period of about 10-12 days between 11-23 July 1978. They attributed this oscillation to the interaction between an extratropical perturbation moving eastward at middle latitudes of the southern hemisphere and southeast trade winds of the monsoon circulation over the southern equatorial Indian Ocean.

Cadet (1981) in a subsequent spectrum analysis obtained results which are in good agreement with our findings. Working with the 850 mb gridded wind fields for May, June and July 1979, he noted maximum power in the 6-7 days period in the Mozambique channel and near the Mascerene islands in the south Indian Ocean. According to him this is the time scale of the systems at the middle latitudes of the southern hemisphere. He also noted, that when progressing northward along the jet axis this influence disappears around the equator and the maximum power shifts at higher periods typically greater than 10 days. This feature is seen in our study also with a different type of data series.

Young (1981) has also shown with the help of sample sequences of five day mean low level circulation maps prepared from Indian Ocean geostationary satellites cloud wind tracers, the existence of variability of periods of the order of 10 days or longer.

TABLE 1

Frequency of the level of maximum wind in Somali jet (Based on Monsoon-77 ship data over Arabian Sea for the period 7 June-16 July 1977)

Level of maximum wind ±12.5 mb	Frequency (%)		
	10.5°N	12.5°N	14.5°N
1000	0	0.4	5.3
975	0	2.1	8.0
950	4.8	6.1	12.0
925	2.4	4.1	2.7
900	12.8	34.9	37.3
875	7.2	12.1	8.0
850	31.2	25.1	25.3
825	12.8	6.2	1.3
800	28.8	7.3	0
775	0	1.3	0
750	0	0.5	0

3. Diurnal variation

The low level jet has been shown to exhibit diurnal variation by various workers, using upper wind data of some stations in northeast Africa. Ardanuy (1979) investigated diurnal variation in the Somali jet with the help of pilot balloon data of Burao and Obbia collected during Monsoon-77 experiment. Findlater (1981) reported diurnal variation from the analysis of averaged wind data of four hours of the day recorded at Garissa (Kenya). According to him the low level jet attains its maximum speed by the early morning. Hsu (1981) also reported such a diurnal variation with the data of two special ascents taken at Mogadishu and Gardo in Somalia. Hsu offered an explanation for this phenomenon in terms of land-sea breeze system augmented by the mountain and valley winds associated with regional topography.

In this study the diurnal variation has been examined over land and sea with the following data : (a) Somali Experiment data from 9-27 June 1979 — Radio-sonde and Pilot Balloon ascents taken at Gardo (9.52 deg. N, 49.08 deg. E) in Somalia, and (b) upper wind observations taken on board USSR ships in their stationary positions over Arabian Sea during Monsoon-77.

The low level wind speed data at Gardo available for the period 9-27 June 1979 were averaged for 0.9, 1.2, 1.5 and 1.8 km at each 3-hour interval. These were plotted against hour of day for all the levels and the profiles are shown in Fig. 4. A marked diurnal variation can be seen at all the levels. The diurnal wave shows maxima from 21 to 00 GMT (local time late night/early morning) and minima in a afternoon except at 0.9 km where the pattern is different from other levels. The variation from minima to maxima is of the order of 10 mps at 1.2, 1.5 and 1.8 km levels.

In order to see whether the diurnal variation is present over the sea area also, a similar exercise was done with the ship data collected during Monsoon-77, when the four USSR ships were located in a stationary polygon over the Arabian sea. The ships were positioned at :

(*i*) 10.5°N, 66°E

(*ii*) 14.5°N, 66°E

(*iii*) 12.5°N, 64°E

(*iv*) 12.5°N, 68°E

The ships took four ascents a day at 00, 06, 12 and 18 GMT. The 6-hourly observations were available from 7 June to 16 July 1977 with a break from 21 June to 28 June.

The average wind speed data were plotted against hour of the day for four levels 950, 900, 850 and 800 mb levels. The graphs of one ship *Priboy* located at 12.5 deg. N, 64 deg. E are shown in Fig. 5. It may be seen that though some diurnal variation in the low level jet over the sea area does exist, it is comparatively insignificant, being an order of magnitude less than that observed over the land stations. The variation from minima to maxima is only of the order of 1-2 mps. It is further seen that the diurnal wave shows maxima during the day time at 850 and 800 mb, opposite to the one seen over land. At 950 mb the minimum occurs during day at 06 GMT and maximum at 00 GMT. 900 mb shows practically no variation.

It appears that the diurnal variation in the low level jet speed is a phenomenon peculiar to land areas caused by local effects.

4. Variations in the speed and level of the jet

The ship data of Monsoon-77 over Arabian Sea were also analysed to investigate the variability of the speed and level of maximum wind in the low level jet.

The time series of daily maximum wind speed recorded by one of the four ships located at 12.5 deg. N, 68 deg. E is shown in Fig. 6. The speeds are seen to fluctuate widely from day to day. The plotted series also suggest existence of fluctuations of quasiperiodic nature. The series was not treated for spectrum analysis due to very short period of record.

The data of the level of maximum wind were summarised in a frequency classification table, taking a class interval of 25 mb, for the four ships separately. The frequency classification is presented in Table 1. The levels are seen to fluctuate from 1000 to 750 mb. The levels corresponding to maximum frequency occur at 900 and 850 mb at 12.5 deg. N and 14.5 deg. N and 850 & 800 mb at 10.5 deg. N. In about 70% cases the levels of maximum wind lie between 850 to 800 mb at 10.5 deg. N and 900 to 850 mb at 12.5 deg. N and 14.5 deg. N. This suggests that the level of maximum wind has a variation with latitude, lowering from south to north. The mean levels of maximum wind were worked out at the four locations for the entire period, which are plotted in Fig. 7. The level of maximum wind lowers from about 850 mb at 10.5 deg. N to about 900 mb at 14.5 deg N. No variation in the mean level of maximum wind from west to east was found.

The above finding is in conformity with the results of Pant *et al.* (1980), who also found, with data collected in an aerial exploration of the low level jet over Arabian Sea during MONEX, that the jet core slopes downward from south to north over the Arabian Sea.

5. Conclusion

The power spectrum analysis of low level jet has shown the existence of quasiperiodic fluctuations which are most prominent in the 8-12 day period range in both the maxima zones of the jet in the northern and southern hemisphere and in the equatorial zone near the jet axis. Oscillations in the 4-6 day and 18-25 day ranges also exist.

Analysis of 3-hourly upper wind data collected during MONEX has confirmed the existence of diurnal variation in the jet found by earlier workers, over the land areas of northeast Africa. The diurnal wave has a maxima in the late night/early morning and minima in the afternoon. Similar analysis of 6-hourly data collected by four USSR ships over Arabian Sea during Monsoon-77 has revealed that diurnal variation over the sea area is an order of magnitude less than over the land area and has phase opposite to one observed over land at 850 and 800 mb.

Analysis of data of the speed and level of the jet shows that the level of maximum wind has a variation with latitude sloping downward from south to north from an average height of about 850 mb at 10.5 deg. N to 900 mb at 14.5 deg. N.

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References

Ananthakrishnan, R. and Keshavamurty, R. N., 1970, On some aspects of the fluctuations in the pressure and wind field over India during the summer and winter monsoon seasons, Proc. Symp. Trop. Met., Honolulu, Hawaii.

Ardanuy, P., 1979 On the observed diurnal oscilltaion of the Somali jet, *Mon. Weath., Rev.*, **107**, 1694-1700.

Bhalme, H. N. and Parasnis, S.S., 1975, 5-6 day oscillations in the pressure gradients over India during southwest monsoon, *Indian J. Met. Hydrol. Geophys.*, **26**, 77-80.

Cadet, D. and Desbois, M., 1981, Interaction between southern Hemisphere and the monsoon circulation, Int.Conf. on Early Results of FGGE and Large Scale aspects of its Monsoon Experiments, Tallahassee, USA, session 5, 17-14.

Cadet, D. and Deshois, M., 1979, low level air flow over the western Indian Ocean as seen from METEOSAT, *Nature*, **278**, 538-539.

Cadet, D. and Desbois, M., 1981, A case study of a fluctuation of the Somali Jet during the Indian Summer Monsoon, *Mon. Weath. Rev.*, **109**, 182-187.

Findlater, J., 1971, Mean monthly air flow at low levels over the western Indian Ocean, *Geophys.* Mem., (HMSO, London), **16**, 115, 1-53.

Findlater, J., 1981, An experiment in monitoring cross-equatorial air flow at low level over Kenya and rainfall of western India during the northern summer, *Monsoon Dynamics*, Ed. Sir James Lighthill and R.P. Pearce, Camb. Univ. Press, 309-319.

Gupta, M.G., Pant, M.C., Rawat, M.S. and Goel, I.C., 1980, Low-level jet stream over Arabian Sea during onset phase of Monsoon 1979, Results of Summer MONEX Field Phase Research (Part B), FGGE Operations Report No. 9, 275-290.

Hsu, S.A., 1981, Diurnal variation of the low-level jet in Somalia, Intl Conf. on Early Results of FGGE and large scale aspects of its Monsoon Experiments, Tallahassee, USA, Session 12, 63-67.

Jambunathan, R. and Ramamurthy, K., 1974, Wind field in the lower and middle troposphere over the Arabian Sea during the southwest Monsoon 1973, *Indian J. Met. Geophys.*, **25**, 403-410.

Krishnamurti, T. N. and Subrahmanyam, D., 1982, The 30-50 day mode at 850 mb during MONEX, *J. atmos. Sci.*, **39**, 2088-2095.

Krishnamurti, T. N. and Bhalme, H. N., 1976, Oscillations of a monsoon system, Pt. I -Observational aspects, *J. atmos. Sci*; **33**, 1937-1954.

Murakami, M., 1978, Spectrum analysis relevant to Indian Monsoon, *Pageoph*, **115**, 1145-1166.

Pant, M. C., 1978, Vertical structure of the Planetary boundary layer in the west Indian Ocean during the Indian Summer Monsoon as revealed by ISMEX data, *Indian J. Met. Hydrol. Geophys.*, **29**, 88-98.

Pant, M.C., Mohanty, U.C., and Sharma, M.C., 1980 Aerial explorations of west Arabian Sea low level jet stream during Summer MONEX 1979, Results of Summer MONEX Field Phase Research (Part B) FGGE Operations Report No. 9, Geneva, 269-271.

Rao, G.V. and Van de Boogard, H.M.E., 1981, Structure of the Somali Jet deduced from aerial observations taken during June-July 1977, *Monsoon Dynamics*, Ed. Sir James Lighthill and R. P. Pearce, Camb. Univ. Press, 321-551.

Rao, G.V. and Haney, J. L., 1982, Kinematic and thermal structures of two surges of flow in the northern Mozambique channel area, *Quart. J. R. Met. Soc.*, **108**, 957-974.

Yasunari, T., 1981, Structure of an Indian Summer Monsoon System with around 40-day period, *J. Met. Soc.*, Japan, **59**, 336-354.

Young, J.A., 1981, Low-level summer monsoon circulations, Int. Conf. on Early Results of FGGE and Large scale aspects of its Monsoon Experiments, Tallahassee, USA, session 5, 4-11.