Mausam, (1985), **36**, 2, 221-228

551.557.5

A study of TEJ current characteristics from MONEX data

M. G. GUPTA, S. C. GUPTA and I. C. GOEL
Meteorological Office, New Delhi

(*Received 5 August 1983*)

सार — मोनेक्स के दौरान एकत्रित आँकड़ों की सहायता से तेज धारा की विशेषताओं का उनकी निर्माण अवस्था में तथा स्थापित अवधि में अध्ययन किया गया है । मोनेक्स तथा एफ० जी० जी० ई० जहाजों से प्राप्त अरब सागर, बंगाल की खाड़ी तथा हिन्द महासागर के ऊपर की ऊपरी वायु आंकड़ों का उपयोग किया गया है । यह पाया गया है कि तेज धाराएं सर्वप्रथम 40° से 100° पूर्व देशान्तर के बीच भूमध्य रेखा क्षेत्र में स्थापित होती है तथा बाद में उत्तर दिशा की ओर बढ़ जाती है ।भारत के पश्चिमी तट पर क्रोड़ो सहित धाराओं के दो अक्ष, उत्तर की ओर इनका बढ़ना तथा अधिकतम वायु विशेषताओं के स्तर आदि अन्य लक्षणों की विस्तार से जांच की गई है ।

ABSTRACT. The characteristics of TEJ current during the formative stage and established periods have been studied with the help of data collected during MONEX. The upper air data over the Arabian Sea, Bay of Bengal and Indian Ocean from MONEX and FGGE ships have been also utilised. It is found that the TEJ current first establishes over the equatorial region between 40-100 E and the later advances northwards. Other features like two axes of the current with cores over the west coast of India, northward extent and level of maximum wind characteristics have been examined in detail.

1. Introduction

During the southwest monsoon advent of the strong easterly winds is one of the main synoptic features of the upper troposphere over south Asia. These were first noted over southern India during periods of weak monsoon when pilot balloons could be followed to great heights (Venkiteshawaram 1950; Krishna Rao 1952 & Krishna Rao & Ganeshan 1953). The existence of easterlies over Aden during summer with an average maximum of 70 kt between 150 and 100 mb was pointed out by Frost (1952). Winds of similar strength over Nairobi during December-February and July-September were attributed by Davies and Sansom (1952) to the easterly jet stream near the equator. Clarkson (1956) observed that winds over Singapore occasionally reach to 100 kt in August and September. Koteswaram (1958) analysed the upper tropospheric circulation during the summer of 1955 over southern Asia and adjacent north Africa and discovered the Tropical Easterly Jet (TEJ) stream. He found that the easterly jet stream overlies southern Asia in the high troposphere (150-100 mb) with core near 75 E. Flohn (1964) located the TEJ in the layer 200-100 mb level from 5 N to 20 N with a core of maximum wind at 150 mb level near the southern tip of the Indian Peninsula. Koteswaram (1969) analysed all available upper air data in July over the tropics upto 1966 and found that the mean TEJ consists of two wind maxima over the Indian area 40 mps over 15 N at 100 mb and 32 mps over the equator at 150 mb. Van de Boogaard (1977) in his streamline/isotach maps for the tropics in July identified two maxima 25 mps over 5 N and 35 mps over 15 N. Mokashi (1974) made detailed analysis of the upper wind observations of Madras, Trivandrum, Colombo and Gan Island for the month of June-September for the five year period of 1961-65. He also utilised the available radar/rawin observations during the same period from other stations in Peninsular India. His analysis indicated the existence of two axis of TEJ. The one being over the southern tip of India near 150 mb and the other distinct core in the neighbourhood of Goa near 100 mb. Tanaka (1980) studied the role of the circulation at 150 mb level during monsoons. He observed that during summer monsoon wind speed at 150 mb reaches its peak near 75 E at the southern end of the Indian sub-continent. He also found that strength of TEJ varies from year to year. Fukang *et al.* (1981) made a preliminary study of observations for the period May-July 1979 and found that during the established phase of the monsoon, the easterly jet with core of 50 mps was located over north Bay of Bengal during 21-25 July 1979. An analysis of eight years (1968-1975) upper air data over Gan Island was made by Maruyama (1982) using monthly mean vectors. He found that during June-September easterlies greater than 25 mps prevailed over the station.

The previous studies have thus shown that TEJ is one of the main synoptic features associated with Summer Monsoon circulation. During established phase of monsoon it is seen as broad current over Asia and Africa extending from equator to about 20 N latitude. It has been found to have upward slope from south to north with more than one core of maximum wind. These and other characterstics like temporal and spatial fluctuations of TEJ are examined in this paper with the help of large amount of upper air data collected over land, sea and ocean areas of monsoon regime during Summer Monsoon Experiment (SMONEX) 1979.

2. Data

During Summer Monsoon Experiment (May-August 1979) upper air observations were taken over the Arabian Sea and Bay of Bengal by USSR and Indian MONEX ships. The upper air data over the Indian Ocean and west Pacific Ocean were also available for the Special Observing Period-II (May-June 1979) from the cruises of eight ships devoted to FGGE Programme. A number of temporary land station were also operated by the India Meteorological Department. Data from ships and land stations for the period May to August 1979 are available in the Summer MONEX Level II-b data set which have been utilised for the study. Mean upper winds for the Indian stations were, however, obtained from the publication Aerological Data of India Part I & II. Upper winds observations and the vertical profiles for observations from ships available in MONEX data set volumes were also used.

3. Formation of TEJ

The upper tropospheric easterlies over south Asia attain jet strength with the onset of the southwest monsoon. TEJ is first seen over southeast Asia which slowly progresses westward to Arabia. As the monsoon advances northward, TEJ covers a broad belt from equator to 20 N occasionally reaching to 25 N.

Sometimes during the month of May, easterlies of jet strength set up temporarily over parts of south Asia. This occurs in the wake of the deep trough in westerlies passing across west Asia and northern parts of the Indian sub-continent. Ahead of the trough the sub-tropical anticyclone moves northward resulting in the strengthening of easterlies on its southern periphery. A similar case of temporary formation of TEJ over Indo-China Peninsula and south Bay of Bengal occurred between 14 & 23 May 1979. On 00 GMT of 14 May 1979 a deep trough in westerlies was located roughly along 65 E which extended from 40 N to 17 N at 200 mb (Fig. 1). East of the trough, the sub-tropical anticyclone was located with its axis near 22 N over the Indo-China Peninsula. With the northward displacement of the anticyclone ahead of the trough, all available upper winds to the south of the anticyclone showed increase in wind speed and attained jet strength between 150 & 100 mb layer. The westward progress of the TEJ to the Indian Peninsula

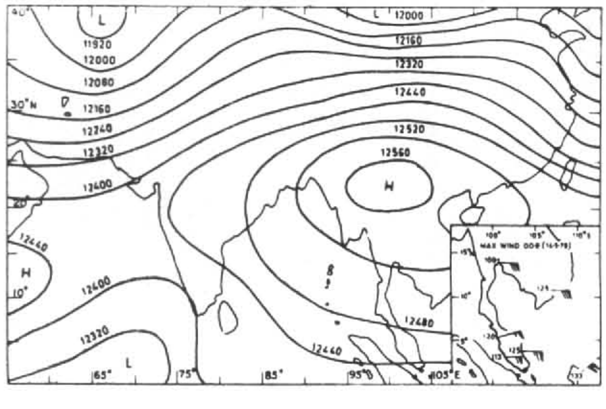


Fig. 1. Contour analysis at 200 mb for 00 GMT on 14 May 1979. Heights are given in gpm; Maximum wind reported over the Indo-China Peninsula area are shown in the insert chart

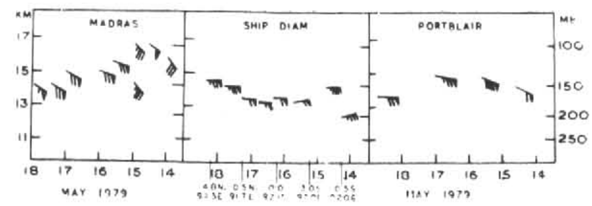


Fig. 2. Maximum winds during 14-18 May 1979, reported in the observations of Port Blair, FGGE ship *Diamond* and Madras

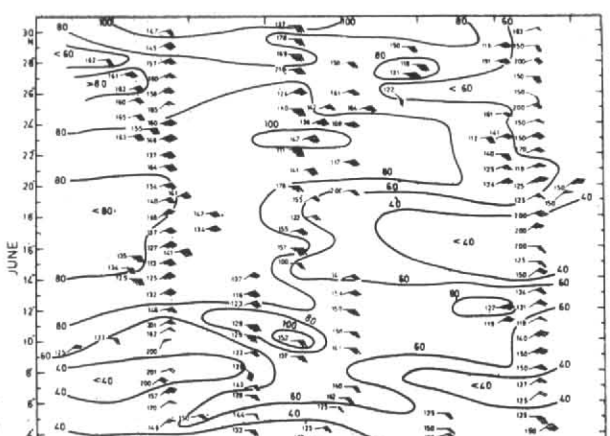


Fig. 3. Maximum winds over the equatorial region (between 5S & 5N latitude) from 40 to 110 E longitude during the month of June 1979 (Wind speed in knot & level of maximum wind in mb)

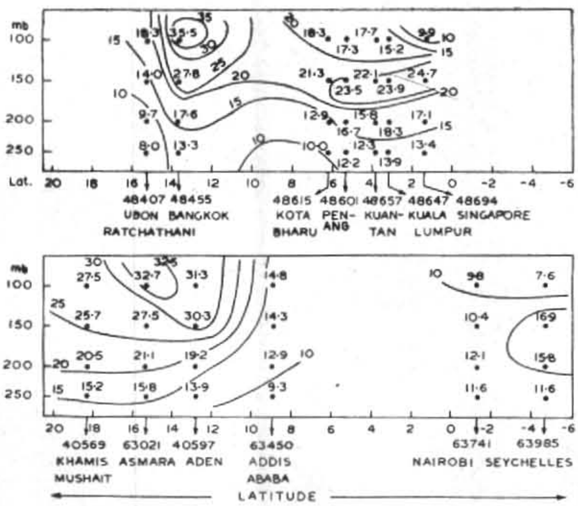


Fig. 4. Vertical cross-section for the average wind speeds in mps for the month of July 1979. Upper and lower cross-sections are along 100 E and 40 E meridions respectively

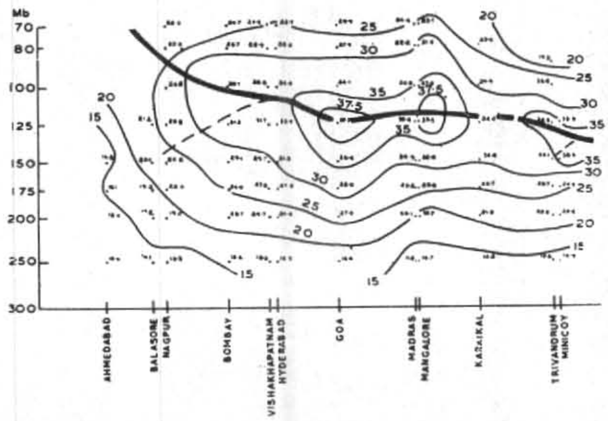


Fig. 5. Vertical cross-section for the average wind speeds in mps for the month of July 1979, along 90 E meridion. Thick line represents the level of maximum wind. The broken lines from the axis depict the splitting characteristic of the TEJ current, is shown by the lines emarating from the core of maximum wind

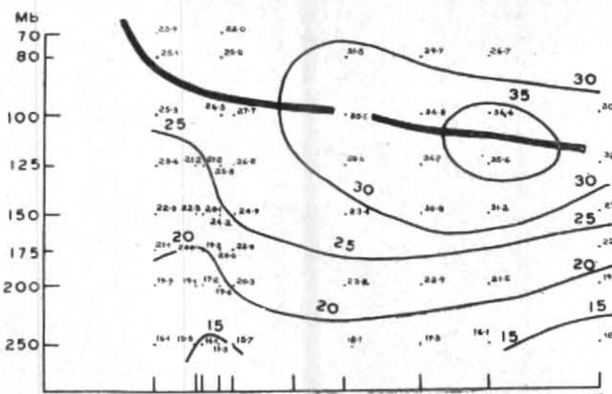


Fig. 6. Vertical cross-section for the average wind speed in mps for the month of July 1979, along 77.5 E mreridion

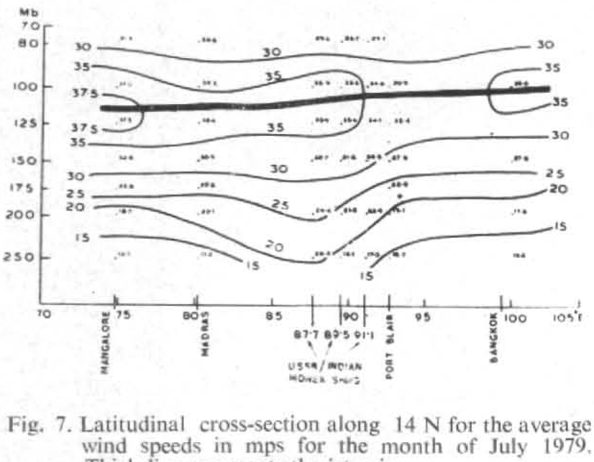


Fig. 7. Latitudinal cross-section along 14 N for the average wind speeds in mps for the month of July 1979. Thick line represents the jet axis

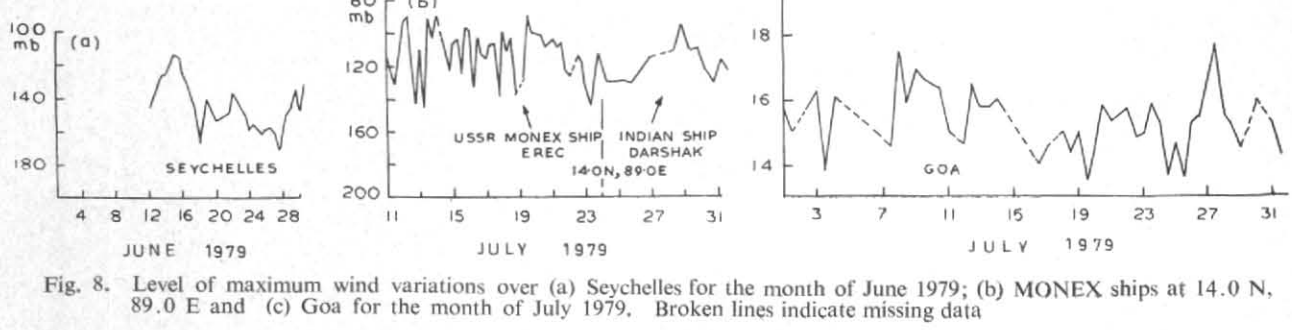
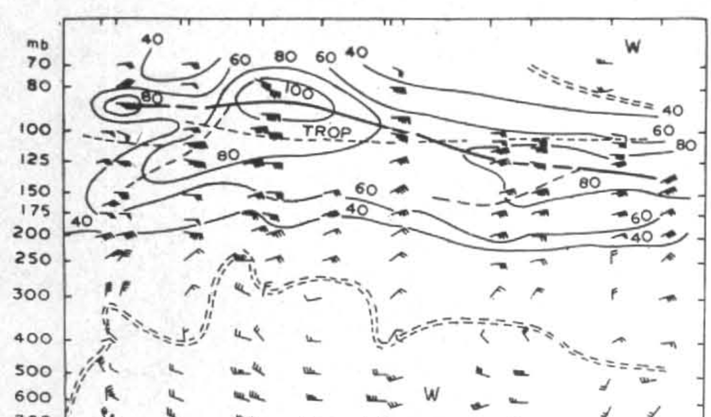


Fig. 8. Level of maximum wind variations over (a) Seychelles for the month of June 1979; (b) MONEX ships at 14.0 N, 89.0 E and (c) Goa for the month of July 1979. Broken lines indicate missing data



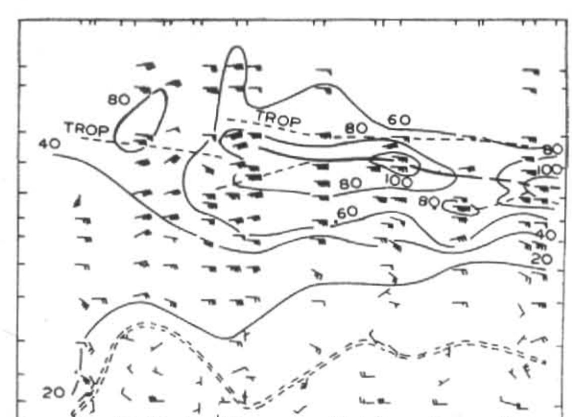


Fig. 2. Vertical cross-section for 24, June 1979. Winds are plotted in knot. Thick line represents level of maximum wind. Splitting characteristic of TEJ current is shown by the broken lines emarating from the core of the maximum wind

Fig. 10. Vertical cross-section for 12 July 1979. Winds are plotted in knot. Thick line represents level of maximum wind. Splitting characteristic of TEJ current is shown by the broken lines emarating from the core of the maximum wind

was noticeable from the upper air observations from Port Blair in the Bay of Bengal and Madras on the east coast of India. The ship *Diamond* in the Bay of Bengal cruising northsouth from south of equator to about 5 N between 92 & 94 E during 14-18 May 1979 also showed strengthening of easterlies in the upper troposphere north of the equator. The upper winds reported by Port Blair, Madras and ship *Diamond* during 14-18 May are shown in Fig. 2.

As the westerly trough moved east the sub-tropical high over Indo-China retreated southward. The upper tropospheric easterlies over the area decreased in speed and became 20-40 kt between 5-15 N and 50-60 kt approximately between equator and 5 N. The upper easterlies of jet strength over Indo-China Peninsula during 14-23 May 1979 were thus short lived and could be called as temporary.

An east-west time section for the maximum wind in the upper troposphere over the equator (between 5 S & 5 N latitude) covering the area from 40 to 100 degree east longitude was prepared for the month of June to examine the progress and fluctuations of TEJ in the equatorial region during its formative stage. The same is presented in Fig. 3. In the time-section all the wind reports from land stations, FGGE and MONEX ships in the area have been utilised for plotting the maximum reported wind in the upper troposphere. The followings can be summarised from the analysis of the winds in the figure :

(*i*) Upper tropospheric easterlies attained jet strength of about 60 kt between 60 & 90 E on 5-6 June 1983. They however, weakened during the next 3-4 days.

(*ii*) TEJ established over the equatorial region from 9 June as thereafter easterlies of jet strength prevailed over the area except over eastern parts where maximum winds of less than 40 kts were observed during the periods of weak winds.

(*iii*) Fluctuation in the TEJ during the month of June were maximum over the eastern part of equatorial region where the wind varied from 25-30 kt to 75 kt. Similar observations were made by Koteswaram (1958) from the time section charts of Singapore for the month of August 1955. Winds of jet strength occasionally reaching to about 100 kt occurred west of 90 E. They, however, slightly decreased west of 55 E.

(*iv*) The weakening or strengthening of winds generally occurred simultaneously over the region. There was no east-west movement of the maxima or minima (Weak period 15-20 June; Strengthening period 20-24 June).

Northward progress of TEJ from equator to southern parts of Indian Peninsula occurred simultaneously with establishment of TEJ over the equatorial region. Colombo reported maximum wind of 60 kt on the afternoon of 9 June, Karaikal, Mangalore and Hyderabad reported winds of jet strength on the morning of 10 June 1979. During the strengthening of TEJ from 20 June over the equatorial region it progressed northward also and extended upto about 20 N over the Indian sub-continent.

4. Structure of the TEJ current

To examine the structure of TEJ current, vertical cross-sections of average wind speeds in the upper troposphere for the month of July 1979 were prepared along the meridions of 40, 77, 90 and 100 E. These are presented in Figs. 4-6. Cross-sections for the eastern and western sectors extend from 5 S to 20 N (Fig. 4). Due to data limitations, the cross-sections for 90 and 77 E meridion extend in the south upto 12 to 8 N respectively (Figs. 5 & 6). Average values of winds for July in respect of Indian ships and land stations, were obtained from the *Aerological Data of India, Part I & II*, published by the India Meteorological Department. For other stations, the average wind speeds for standard isobaric levels were computed from the wind reports in SMONEX Level II-b data set.

The following features are worth noting :

(a) There are two distinct cores of wind maxima over the eastern sector of TEJ (Fig. 4). One of these extend from equator to about 6 N with average speed of 23-25 mps at 150 mb. The average of the speed in the area is apparently affected by the fluctuations in the wind speed as pointed out in previous section. The other maxima over Bangkok (13.8 N) have the wind speed of 35.5 mps at 100 mb. The winds north of Bangkok fall rapidly.

(b) Over the Bay of Bengal, TEJ appears as a broad current extending from Port Blair to Calcutta with the core of 35 mps between 100 & 125 mb over 14 N latitude (Fig. 5). There is no data to examine the strength and location of the wind maxima near the equatorial region.

(c) Cross-section along 77.5 E (Fig. 6) suggests the existence of a broad current of upper tropospheric esterlies of jet strength over the Indian Peninsula. It extends to about 20 N and has two cores of wind maximum in the average for the month of July. Both the cores lie over the west coast of India. One of them is over the southern tip of the Peninsula (Trivandrum-Minicoy) with average speed of 35 mps at 150-125 mb. The second core of 37.5 mps is nearly 200 km wide between Mangalore and Goa at 125 mb. A noteworthy feature is that, north of the core there is tendency for the jet to appear as splitting in two parts. This is reflected in the vertical wind profiles either as broad layer of wind maxima or two levels of wind maxima. This is further elaborated in the vertical cross-sections of 24 June and 12 July presented in section 7.

(d) In the western sector the TEJ current does not appear to exist south of 11 N (Fig. 4). This is also supported by the fact that the average wind speed over Seychelles and Nairobi decrease in intensity from the previous month. The available data suggests that the TEJ current over the area extends from north of 11 N to 20 N with the core of 32.7 mps over Asmara (15.3 N) at 100 mb.

Meridional cross-sections thus indicate the existence of two axis of wind maxima in the broad

TABLE 1

Percentage frequency of the occurrence of wind speed (kt)

Lat. (°N)	July: Total no. of cases of max. wind reports	July wind (kt) 60-80	81-100	>100	August: Total no. of cases of max. wind reports	August wind (kt) 60-80	81-100	>100
18	Visakhapatnam, Hyderabad and Bombay							
	145	43	52	5	96	77	23	0
13	Madras, Bangalore and Mangalore							
	153	24	63	13	131	44	52	4
8	Trivandrum and Minicoy*							
	109	35	51	14	49	20	53	27

*Minicoy observations available for four days only for the month August 1979.

TABLE 2

Level of maximum wind with respect to tropopause

	Total no. of obsns.	No. of cases of wind maxima (km): Above tropopause >1	0.6-1	0-0.5	Below tropopause 0-0.5	0.6-1	>1
TRV	100	1	1	2	9	12	75
MNG	35	—	3	8	4	7	13
HYD	48	9	8	7	3	6	15
BMB	40	2	2	9	11	4	12

current of TEJ. The strongest of the two runs roughly along 13-15 N latitudinal belt and extends from Indo-China to east Africa. Latitudinal cross-section along this axis is shown in Fig. 7. The core of maximum wind in the axis is of 37.5 mps over west coast of India where its width is of about 200 km (Mangalore to Goa). Its altitude is lowest at the core. The second axis of the TEJ is restricted to eastern and central sectors. It is seen to extend from Malaysian Peninsula to the southern tip of Indian Peninsula nearly at 150 mb. It is weak compared to the axis in the north. Its core of 35 mps is also found over the west coast of India.

5. Variations during July-August

Frequencies of the occurrence of wind speed in the ranges of 60-80, 81-100 and > 100 kt along different latitudes over the Indian Peninsula are given in the Table 1.

It may be seen from the table that along 18 N from July to August total number of cases of maximum wind reports decreased from 145 to 96 and frequency of higher wind speed (>81 kt) decreased from 57% to 23%. The decrease is, however, less marked along 13 N. Over 8 N the frequency of wind speeds>81 kt, however, increased in August. Frequency table thus suggests that the TEJ current is in its northern most position during July and it commences retrograding southward during August.

6. Fluctuations in the level of the maximum wind

Though the TEJ current is quasi-stationary in nature, yet there are day to day variations in the wind speed and its levels. Frequencies of wind speeds are briefly discussed in the previous section. Level of maximum wind fluctuations at three different positions of the current, *viz.*, equatorial region, Indian Peninsula and the Bay of Bengal are shown in Fig. 8. It is seen that the level of maximum wind at all the places shows variations which depict phases of increasing and decreasing altitudes. Generally the level of the maximum wind is more than 1 km below the tropopause. It, however, approaches the tropopause level during its phase of increasing altitude and occasionally rises above the tropopause level also. The altitudes of the level of maximum wind with respect to tropopause was examined for four stations of the Indian sub-continent for the month of July. This is given in the Table 2. It will be seen that at lower latitudes (Trivandrum) where the level of maximum wind is near 125-150 mb in the average for the month, there are only 4% occasions when the maximum wind was found above the tropopause level. It was more then 1 km below the tropopause on 75% occasions. The frequency of the occurrence of maximum wind above tropopause increases northward. It is, however, almost on 50% occasions Hyderabad reported maximum wind above tropopause. An examination of the day-to-day vertical wind profiles of the stations indicated that it has the characteristic of either broad layer of wind maxima or two levels of wind maxima.

7. Cases of intense TEJ current

It has been shown in section 3 that the weakening and strengthening of the wind in TEJ current occurs rather simultaneously. No movement of the core in the current from east to west is noticed. In this section we present two cases when TEJ current was fairly strong. These are of 24 June and 12 July 1979. A monsoon depression in the north Bay of Bengal crossed coast near 20 N/85 E on 24 June. The synoptic situation on 12 July was of active monsoon trough at its normal position. In the former case TEJ extended from equatorial region to about 18 N and in the later, the current extended beyond 20 N. Vertical cross-section charts for 00 GMT observations of these days are shown in Figs. 9 & 10. In both the cases two cores of wind maxima are clearly seen. On 24 June which represents the formative stage of TEJ, one maxima lies over the equatorial region with the core of 90-95 kts. The second core of 110 kt is seen over 13 N and is more than 1 km above the tropopause level.

During the established phase the southern core is near the tip of the Indian Peninsula. The second core, in this case, is also found over 13 N. The northern limit of TEJ current, however, extends to the north up to about Nagpur. Maximum winds in both the cases are of 100-110 kt and are found below the tropopause. A noteworthy feature in both the cases is the splitting tendency of the jet north of the axis. The splitting characteristic in the wind profiles of the four stations, out of which Karaikal lies north of the southern core and the remaining three stations are north of the other core (Figure not shown). Similar characterstic is also seen in the profiles of the stations north of the two jet area of 24 June 1979. A feeble break in the tropopause is noticed in both the cases far north of the cores.

8. Conclusions

Detailed analyses of the upper air observations collected during MONEX have revealed interesting characteratics of the TEJ current. It has been found that the current first establishes over the equatorial regions. With the onset of the SW monsoon it advances northward. Earlier studies have, however, suggested that TEJ advances westwards from east. These conclusions were apparently arrived in absence of data from the equatorial region. Temporary strengthening of upper tropospheric easterlies to jet strength may occur in association with the passage of deep trough in westerlies when sub-tropical high ahead of the trough shifts northward. In such a case, the easterlies of jet strength are first seen over Indo-China Peninsula and thereafter advance westwards to Indian Peninsula. A similar case of temporary formation of TEJ occurred between 14-23 May 1979.

TEJ is a broad current and is seen as a quasi-stationary feature of the monsoon circulation system. There are, however, day-to-day fluctuations in its intensity, level of the maximum wind and the northern limit. It is seen that during the intense phases the level of maximum wind rises which confirms the observations of Mokashi (1974). It is also seen that during the intense phases the current spreads northward. The level of maximum wind north of the jet core is occasionally found above the tropopause level.

Koteswaram (1958) found that TEJ currents forms off the east coast of China and extends to Arabia with jet axis along 15 N and core near 75 E. Flohn (1964) and Tanaka (1980) located the core at 150 mb near the southern tip of the Indian Peninsula. Mokashi (1974) indicated two cores. This study confirms the existence of two jet axes. The southern axis generally has weaker core and is located near the southern tip of the Indian Peninsula in the month of July between 150-125 mb. The axis is found to extend from Malaysian Peninsula to southeast Arabian sea. Wind speed fluctuations are marked in the eastern sector of this axis. The other axis at 13-15 N is seen to extend from Indo-China Peninsula to Arabia and lies between 100-125 mb. The cores along both the areas are found in the average for July as well as on daily charts over west coast of India. The spatial limit of the current is from equatorial region to about 15 N and 20 N in the eastern and central sectors respectively. In the western sectors, it initially appears over the equatorial region and later placed from about 11 N to 20 N. The current is therefore broadest over the sub-continent and strongest over the west coast of India. Koteswaram (1958) indicated that the TEJ occupies a northerly position during break monsoon conditions. According to Ramamurthy (1969) it not only shifts north with axis along 15 N but also intensifies. Ramaswamy (1978), however, pointed out that during the break periods upper easterlies decrease in strength over the south India. Tanaka (1980) has shown that fluctuations in the strength of TEJ at the 150 mb are closely related to the monsoon fluctuations. He found that TEJ is strong when active monsoon results in the increase of the release of the latent heat. Rainfall study of southern Asia conducted by Kobayashi (1974) has also suggested general increase in precipitation at India and Burma when the TEJ over India is strong. The cases presented in this study also support this view.

Another significant feature observed in the broad layer of maximum wind or the two levels of maximum winds north of the jet axes. This characterstic is similar to westerly jet where stations south of the axis have similar vertical wind profiles.

Acknowledgements

Authors are grateful to the staff members of MONEX Data Centre at the office of the Director General of Meteorology for the valuable assistance in the computations, preparation of the diagrams and typing the manuscript of the paper.

References

Clarkson, L. S. 1956, Analysis of winds at 40,000 ft and 50,000 ft. over Singapore, *Meteor. Mag.*, **85**, 1.

Davies, D. A. and Sansom, H .W., 1952, Easterly jets over east Africa, *Weather*, **1**, 343.

Flohn, H., 1964, Investigations on the tropical easterly jet, *Benner. Meteor. Abhandl.*, **4**, 83.

Frost, R. 1952, Great Britain Meteor. Office, Prof. Notes No. 107.

Fukang, Zhu., Lu Longhual and Chen Xianji, 1981, Some observational facts of the tropical easterly jet in May-July 1972, Int. Conf. on Early Results of FGGE and Large scale Aspects of its monsoon experiments, Tallahassee, USA.

Kobayashi, H., 1974, Interannual variations of tropical easterly jet stream and rainfall in south Asia, *Geophys. Mag.*, **37**, 123,

Koteswaram, P., 1958, The easterly Jet stream in the tropics, *Tellus*, **10**, 43.

Koteswaram, P., 1969, Forecasting of upper winds and temperatures with special reference to jet streams, WMO Tech. Note No. 95.

Krishna Rao, P. R., 1952, Probable regions of 'JET' stream in the upper air over India, *Cur. Sci.*, **21**, 63.

Krishna Rao, P. R. and Ganeshan, V., 1953, The mean jet stream over India and Burma in winter, *Indian J. Met. Geophys.*, **4**, 193.

Maruyama, Taketo, 1982, Fluctuations with a period of 30-50 days over the equatorial Indian ocean report of Sci. result on MONEX in Japan, 49.

Mokashi, R. Y., 1974, The axis of the tropical easterly Jet stream over India and Ceylon, *Indian J. Met. Geophys.*, **25**, 55.

Ramaswamy, C., 1978, The southwest monsoon over India and its teleconnection with the middle and upper tropospheric flow patterns over the southern Hemisphere, *Tellus*, **30**, 126.

Ramamurthy, K., 1969, Monsoons of India : Some aspects of the 'break' in the Indian southwest monsoon during July and August, Forecasting Manual Pt. III, No. 18.3.

Tanaka, Minoru, 1980, Role of the circulation at 150 mb level in the winter and summer monsoon in Asian and Australian regions Climatological Notes 2, Occasional paper No 2, Institute of Geoscience, Univ. of Tsukuba, pp. 134.

Van de Boogaard, H., 1977, The mean circulation of the tropical and sub-tropical atmosphere July, NCAR Tech Note TN 118+STR, pp. 48.

Venkiteshawaram, S. P., 1950, Mem. India Met Dep, **28**, 55.