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The axis of the tropical easterly jet stream over India and Ceylon

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ABSTRACT. Rawin observations of a number of stations for the months June to September for the five-year (1961-65) have been analysed to study the vertical structure of the tropical easterly jet stream over the Peninsular India and over the regions to the south of it upto the equator. Study of the daily rawin trajectories of Madras and Trivandrum at intervals of 0·5 km upto 17 km shows that the axis (core) of the easterly jet stream (altitude about 14·5 km) is nearer to Trivandrum in June and August and nearer Colombo in September. In July there is a broad band of high winds. It is found that in this region Trivandrum mean maximum wind is highest in all the months June to September, the maximum occurring generally at about 0·5 km higher at Madras than over Trivandrum and Colombo. Observations at Goa (Lat. 15° 29'N) have shown simultaneous existence of another speed maximum in the neighbourhood of Goa at about 16 km.

1. Introduction

1.1. The subject of Tropical Easterly Jet (TEJ) stream has attracted considerable attention during the past fifteen years and a number of studies on TEJ over India have appeared. In recent years with accumulating data, doubts have been expressed about the exact location of the axis of the TEJ over India. This is mainly due to the fact that earlier studies were based on limited data. With the accumulated rawin observations reaching greater heights frequently, it was considered opportune to examine and study the structure of the TEJ over India in greater detail.

1.2. The published data of upper winds are for standard levels only. As the level of maximum wind may occur in between standard levels, it is essential to have more detailed wind tabulations, particularly at the jet levels. The author therefore reanalysed the original trajectories of Madras and Trivandrum for the months June to September during the five years, 1961-65, to build up data of wind speed and direction at intervals of 0.5 km between 12 and 17 km. Along with these, rawin observations for the same period, June to September (1961-65) of two extra-Indian stations, Colombo (Lat. 06° 54′ N) and Gan (Lat. 00°41′ S), one to the south and the other to the southwest of Madras were utilised for the study. Recent radar/rawin data of Ahmadabad (Lat. 23°04′N), Nagpur (Lat. 21° 06′ N), Bombay (Lat. 19°07′N), Hyderabad (Lat. 17° 27′ N), Goa (Lat. 15° 29′ N), Madras (Lat. 13° 00′N), Trivandrum (Lat. 08° 29′ N) and Minicoy (Lat. 08° 18′ N) have also been taken into account.

2. Data used

2.1. The wind data (1961-65) now analysed are for the stations, levels and hours of observations as indicated below :

Station	*Levels (a.m.s.l.)*	*Hour*
Madras	9·0, 10·5, 11·2, 12·0 to 17·0 km at half km interval and 18 km	12 GMT
Trivandrum	Do.	Do.
Colombo	9·7, 12·4, 14·2, 16·5 and 18·6 km	Do.
Gan	9·0, 10·5, 12·0, 13·5, 15·9 and 18·3 km	18 GMT

2.2. The frequency of observations at 12 to 17 km at the stations are given below :

Station	*Hour (GMT)*	*Height(km)* 12	13	14	15	16	17
Madras	00 & 12	1018	913	852	737	647	479
Trivandrum	00 & 12	1083	1002	953	828	738	521
Colombo	12	581		557		449	
Gan	18	587		583		556	

2.3. Subsequent radar/rawin data of Minicoy (1963-70), Hyderabad (1967-70) and Goa (1970-72) for July (12 GMT) have been analysed for the standard levels in addition to those for the levels 11·2, 13·0, 15·0 and 17·0 km (a.m.s.l.) in the case of Goa. All these data refer to afternoon ascents.

2.4. Recent daily radar/rawin data for July and August 1971 (12 GMT) at levels 14·1, 15·0 and 16·2 km and maximum winds over Ahmadabad, Nagpur, Bombay, Hyderabad, Goa, Madras, Trivandrum and Minicoy have also been studied.

3. Statistical parameters and frequencies

3.1. The statistical parameters based on data from June to September (1961-65) have been computed and are given in Tables 1 to 4. The standard deviation of winds have not been worked out for levels 9·0 and 10·5 km in the case of Madras and Trivandrum. The sign convention for wind components followed in preparing the tables is that the wind components from east and north are positive while those from west and south are negative.

3·2. During the period, June to September (1961-65), 703 ascents (58 per cent of the total ascents) at Madras and 888 ascents (73 per cent of the total ascents) at Trivandrum had speeds of 60 kt or higher. The averages of maximum wind speeds and levels (heights) of their occurrence, determined from daily maximum wind data for June to September as well as for the entire season over Madras, Trivandrum, Colombo and Gan are given in Table 5(a). Table 5(b) gives the frequencies of maximum wind speeds for different heights over these stations for the four months and the season (June-September).

3.3. Average vertical wind shears are indicated in Table 6 for all the four stations for height ranges 9·7 to 16·5 km.

4. Results of analysis

In order to facilitate understanding the vertical structure of the winds, a number of diagrams for the months June to September based on the above data for Madras, Trivandrum, Colombo (12 GMT) and Gan (18 GMT) have been drawn (Figs. 1-5). Mean streamlines and isotachs over India and neighbourhood for levels 14·1 and 16·2 km for July are shown in Fig. 6.

It needs mention here that the profiles for Colombo and Gan are smoother than those for Trivandrum and Madras since the data for Colombo and Gan are available for only the standard levels and considerable smoothing has therefore resulted. Nevertheless, the trends of the curves are broadly comparable.

4.1. *Steadiness*

A very unique feature of TEJ is the remarkable steadiness of wind at and near the jet levels. The steadiness factor (mean vector wind/mean scalar wind) ranges from 95 to 100 per cent between 13·5 and 16·0 km. Even at 17 km steadiness is more than 90 per cent but over Gan it rapidly decreases. At 15·9 km steadiness varies between 74 to 93 per cent and at 18·3 km it is as low as 6 per cent in September. As the computations are based on about 100 ascents the steep decline with height in steadiness appears to be an important feature of wind structure over Gan. This may be due to the influence of quasi-biennial oscillations in the stratospheric winds.

4.2. *Levels of highest mean wind*

The height of the highest mean vector wind varies with latitude, being higher as we go towards Madras. The height at Gan is 13·5 km increasing to 14·2 km at Colombo, 14·5 km over Trivandrum and 15·0 km at Madras. Interestingly this feature has been noted with hardly slight variation for each of the months June to September and for the period as a whole. Further, in the case of Trivandrum and Madras the level of highest mean resultant wind is the same for both 00 and 12 GMT ascents.

4.3. *Mean levels of maximum winds*

If one averages the daily maximum wind and the level as reported, the results may slightly differ from (4·2) above. This has been done for Madras, Trivandrum, Colombo and Gan in Table 5(a) and percentage frequency of maximum wind speeds is given in Table 5(b). The averages are based on 703 ascents at Madras, 888 at Trivandrum, 159 at Colombo and 525 at Gan. The maximum occurs generally at about 0·5 km higher at Madras than over Trivandrum and Colombo. The level of maximum wind (LMW) is 15·06 km over Madras, 14·63 km at Trivandrum and 14·60 km over Colombo. The LMW over Gan is 14·50 km. Even the monthly variations are very small over these places. The mean values of the maximum wind and the levels of their occurrence show that they increase as one moves northwards from Gan to Trivandrum in all the months June to September.

The number of ascents with wind speed $\geqslant$ 100 kt in the case of Trivandrum is nearly twice that of Madras. Also, the total ascents with winds $\geqslant$60 kt in the case of Trivandrum are about 26 per cent more than that of Madras.

4.4. *Strength of mean winds*

An examination of Fig. 1 clearly brings out that Trivandrum is stronger than Madras in June and August while in July, Trivandrum and Madras have practically the same maximum of

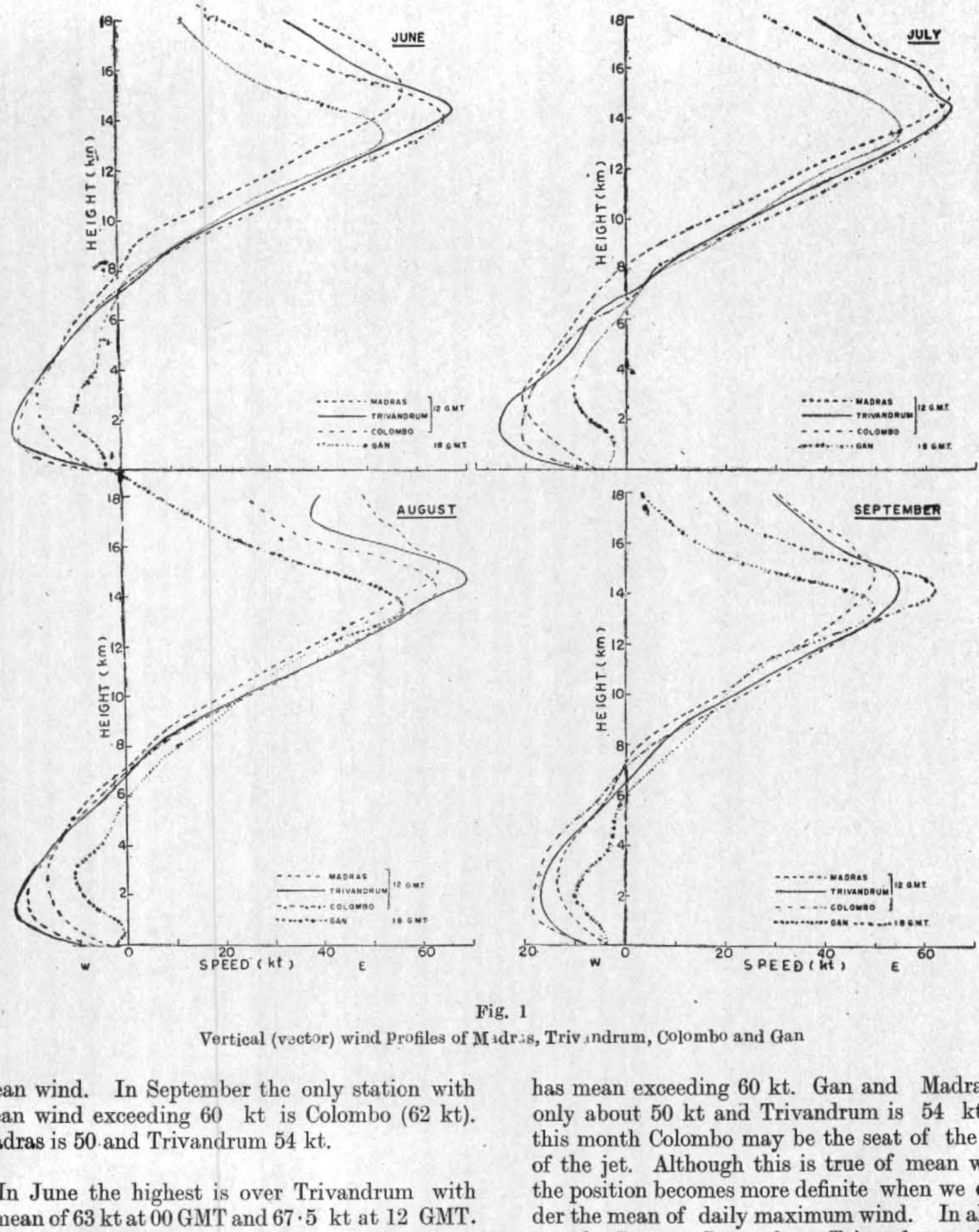

Fig. 1

Vertical (vector) wind Profiles of Madras, Trivandrum, Colombo and Gan

mean wind. In September the only station with mean wind exceeding 60 kt is Colombo (62 kt). Madras is 50 and Trivandrum 54 kt.

In June the highest is over Trivandrum with a mean of 63 kt at 00 GMT and 67·5 kt at 12 GMT. Madras at 12 GMT is only 58 kt. Colombo mean is 66 kt. The strongest region in this month is perhaps between Trivandrum and Colombo and away from Madras. Gan highest is only 54 kt. When we come to July, we are faced with practically same values from Colombo (64 kt) to Madras (65 kt). In August, Trivandrum (69 kt) regains its maximum position with 63 kt at Madras and Colombo. The position of the jet axis is well marked near Trivandrum in this month. September has an interesting feature in that only Colombo (62 kt) has mean exceeding 60 kt. Gan and Madras are only about 50 kt and Trivandrum is 54 kt. In this month Colombo may be the seat of the axis of the jet. Although this is true of mean winds; the position becomes more definite when we consider the mean of daily maximum wind. In all the months June to September, Trivandrum wind is stronger than Madras, Colombo and Gan. The trend for the axis seems to being closer to Trivandrum though with such close values the mean position of the Jet Core may be difficult to fix. One would have to examine the daily charts. However, considering the general distribution of horizontal shears on the cyclonic and anticyclonic sides of the jet stream, it may be concluded that the axis of the jet stream is likely to be closer to Trivandrum than to Madras.

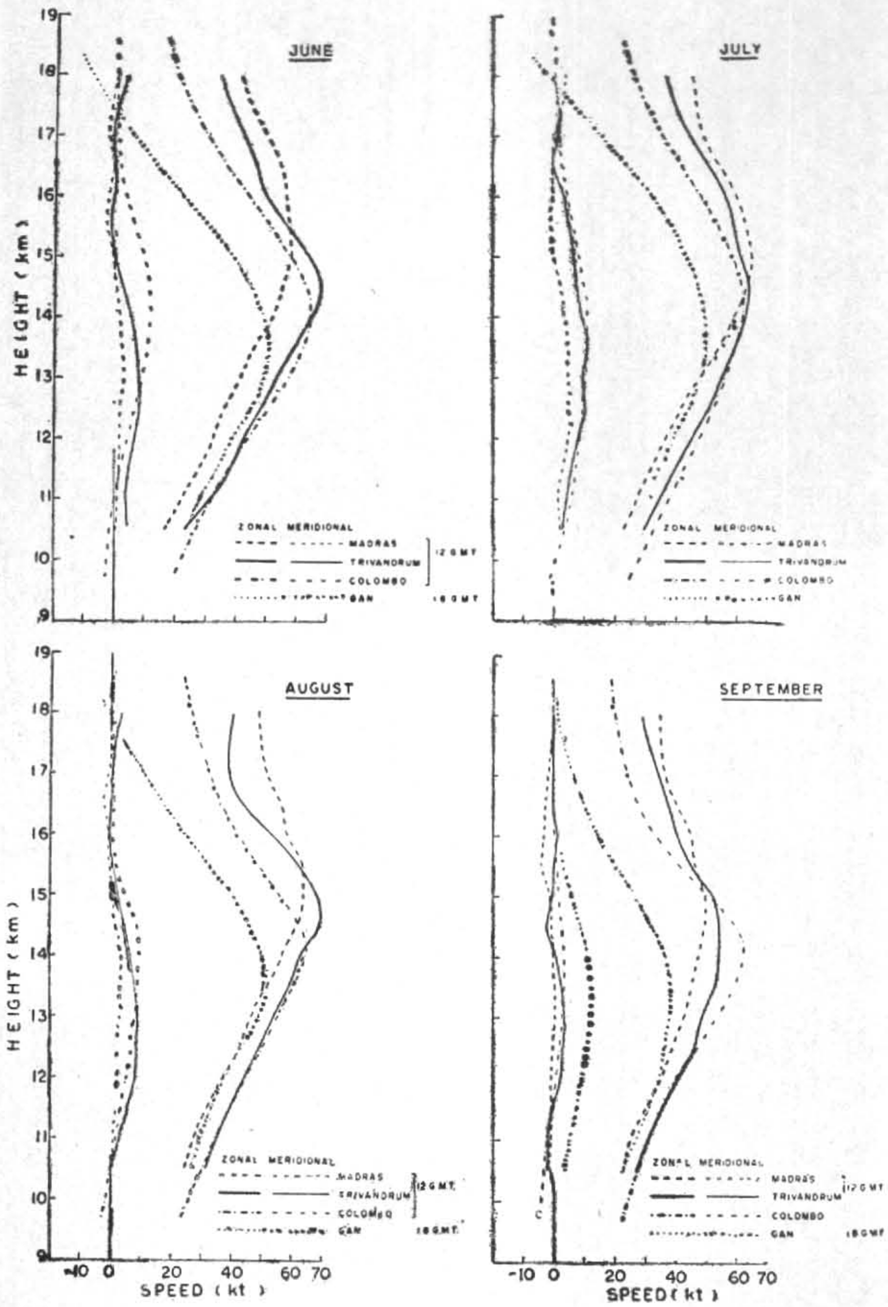

Fig. 2
Vertical (zonal and meridional) wind profiles

To see the mean picture for the season June to September we have the following :

	Gan	*Colombo*	*Trivandrum*	*Madras*
Mean vector wind (kt)	49.5	62.0	64.1	59.4
Mean max. wind (kt)	78.7	81.3	83.2	79.4

Colombo-Trivandrum is therefore obviously the region of the core of TEJ.

4.5. *Meridional winds*

The meridional components are lowest at Madras being generally 1 to 2 kt. At Trivandrum it is much higher, July having four times the value of Madras (2 kt). Colombo also has high values of 9 kt for the season. The highest is at Gan with values ranging from 12·5 to 17·7 kt. These data seem to suggest low values of meridional winds with increasing latitude but would need confirmation by examining winds at higher latitudes.

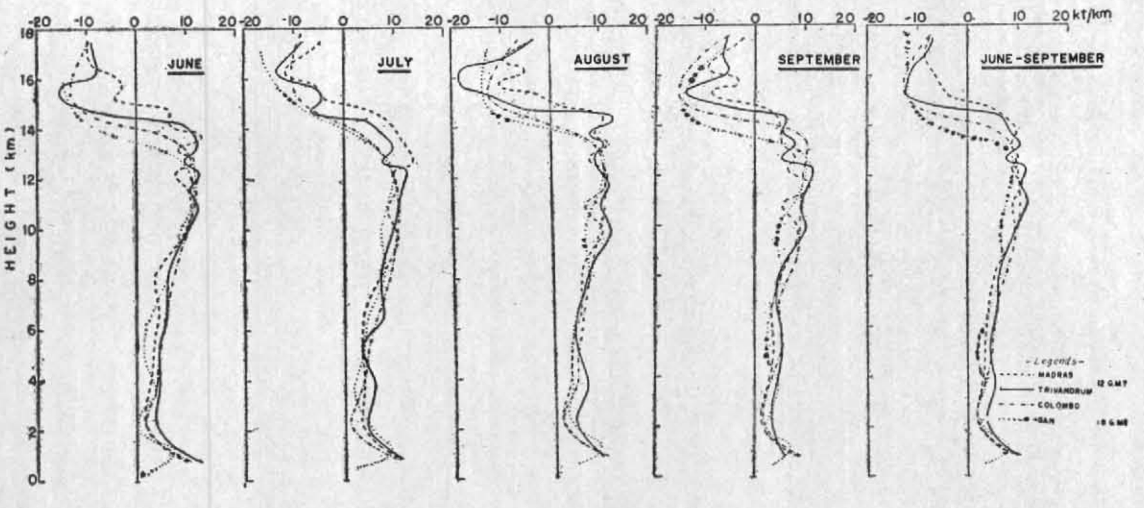

Fig. 3
Shear vector changes

4·6. *Zonal winds*

Both from Fig. 2 and discussion in 4·5 above, it is readily seen that the flow at these upper levels is mainly zonal. The features of maximum mean wind are the same as for vector wind. Trivandrum and Colombo areas form the core of the jet except in July, when because of little or no difference, Colombo to Madras is mostly a diffuse region.

4.7. *Coefficient of variation*

It is seen that the lowest variability is generally over the Colombo area. Gan shows the highest variability with Trivandrum and Madras coming in between Colombo and Gan in order of steadiness.

The standard vector deviation is high at all the stations and in all the months. The values range about 20 kt with a maximum of 24-25 kt over Trivandrum. The coefficient of variation defined as the standard vector deviation expressed as percentage of vector mean wind, varies at level of maximum wind as follows :

	Madras (15 km)	*Trivandrum* (14·5 km)	*Colombo* (14·2 km)	*Gan* (13·5 km)
Jun	34	36	23	41
Jul	31	30	28	37
Aug	33	35	34	35
Sep	42	43	31	41
Jun-Sep	36	37	30	41

Gan shows the highest variation with the least at Colombo. Madras and Trivandrum are practically the same.

4.8. *Variability*

The question of high variability could be explained by the frequency distribution of wind speeds.

The frequency distribution ranges widely from less than a few knots to over 100 kt. At Trivandrum at the levels of 14 to 15 km, winds have varied from less than 10 to over 120 kt. This is the general feature at the other stations also. The percentage frequency of winds $\geqslant 60$ kt is as follows:

	Level (km)	*Jun*	*Jul*	*Aug*	*Sep*
Madras	14·0	45	62	61	26
	15·0	48	66	60	33
Trivandrum	14·0	63	60	62	42
	15·0	62	68	69	46
Colombo	14·2	65	63	66	64
Gan	13·5	42	60	61	53

The highest frequency is over Trivandrum-Colombo areas. In July and August the frequencies are nearly of the same order (between 60-70 per cent). Madras and Gan have less frequency in the other months.

4.9. *Standard deviation*

Zonal Component (S_x) — The standard deviation of the zonal component (S_x) is about 15 to 20 kt. But as the means are also high, 50 to 60 kt at and near jet levels, the coefficient of variation is 30 to 40 per cent only. Even though this is very much less than the coefficient of variation of meridional component, yet this is large. As already remaked while discussing the variability of vector mean wind, the speeds of the zonal wind also vary widely.

Meridional Component (S_y) — The standard deviation of meridional component (S_y) is generally more than 10 kt at and near jet levels though the mean components are very small and sometimes the sign is negative too. The coefficient of variation is often several hundred per cent indicative of the extremely variable eharacter of this component.

Ratio, S_x/S_y — (S_x/S_y) varies between 1 and 2 and is suggestive of the extreme variability of the meridional component. The lowest values of this ratio are noticed at the levels of highest mean wind or immediately below the same.

Mokashi (1969) has found that the ratio (S_x/S_y) in the case of the sub-tropical westerly jet stream over Delhi is of the order of 0·6. This would imply that in the westerlies of winter season, troughs and ridges are predominant features, while they are not so predominant in the summer easterlies over the Indian Peninsula and its neighbourhood. Perturbations (waves) are much less pronounced in the easterlies than in the westerlies; this is probably the reason for little correlation between zonal and meridional components and smaller values of S_x/S_y.

4.10. *Vertical wind shears*

The levels of maximum wind as determined from the values of vertical wind shears (Table 6 and Fig. 3) are tabulated below :

	Madras	*Trivandrum*	*Colombo*	*Gan*
Jun	15·0	14·4	14·1	13.5
Jul	15·0	14·4	14·2	13·8
Aug	15·0	14·6	14·1	13·6
Sep	14·9	14·5	14·1	13·4
Jun-Sep	14·9	14·5	14·1	13·5

These levels agree with the levels of maximum mean wind as given in 4·2.

The highest value of vertical wind shear (19 kt/km) is observed over Trivandrum at 16 km in August. Next highest (17 kt/km) is over Trivandrum at 15·4 km in June and over Colombo at 15·2 km in September,

4.11. *Wind variation above and below the level of maximum wind*

Fig. 4 reveals an interesting feature that the level of maximum wind for each station remains the same throughout the four months June to September and for the season (June to September). It is also seen that the level of maximum wind is higher for the stations at higher latitudes indicating a downward slope of the level of maximum wind from north to south.

At Madras the decrease below the jet level is greater than above. Trivandrum shows greater symmetric features.

4·12. *Vertical cross-section of average wind speed (July and August)*

The isolines for various wind speeds (Fig. 5) show two wind maxima — one in the neighbourhood of Goa and another over Trivandrum-Minicoy area. There appears to be, by comparison, lower wind speeds in the in-between region around the latitude of Madras. It is readily seen that in the month of July the wind maxima of 75 kt lies over the latitude of Goa at 16 km. The maximum wind surface slopes down southwards and over Trivandrum latitude a wind maxima of 65 kt lies at about 14·2 km. In the month of August the wind maxima over Goa decreases in strength to 70 kt and lowers to about 15 km. An interesting feature in August is the increase in the strength of wind maxima over Trivandrum reaching to 70 kt and rise in the surface of maximum wind to about 14·7 km. These also confirm the author's (Mokashi 1970) finding that the stronger the tropical easterly jet, the higher is the altitude of maximum wind. The area of maximum winds examined over latitude and altitude seems to suggest a diffuse character quite unlike the sub-tropical westerly jet.

4.13. *Mean streamlines and isotachs*

The average winds based on all available wind data of Indian and extra-Indian stations upto 1965 have been plotted for the month of July for the levels 14·1 km and 16·2 km (Fig. 6). Data for intervening levels between 14·1 km and 16·2 km have not been computed except for the four stations (Madras, Trivandrum, Colombo and Gan) already mentioned in the paper. The charts for these levels could not, therefore, be presented. However, some idea of the jet profile and extent can be had from the charts for 14·1 and 16·2 km. In the chart for 14·1 km, the 60 kt isotach encloses

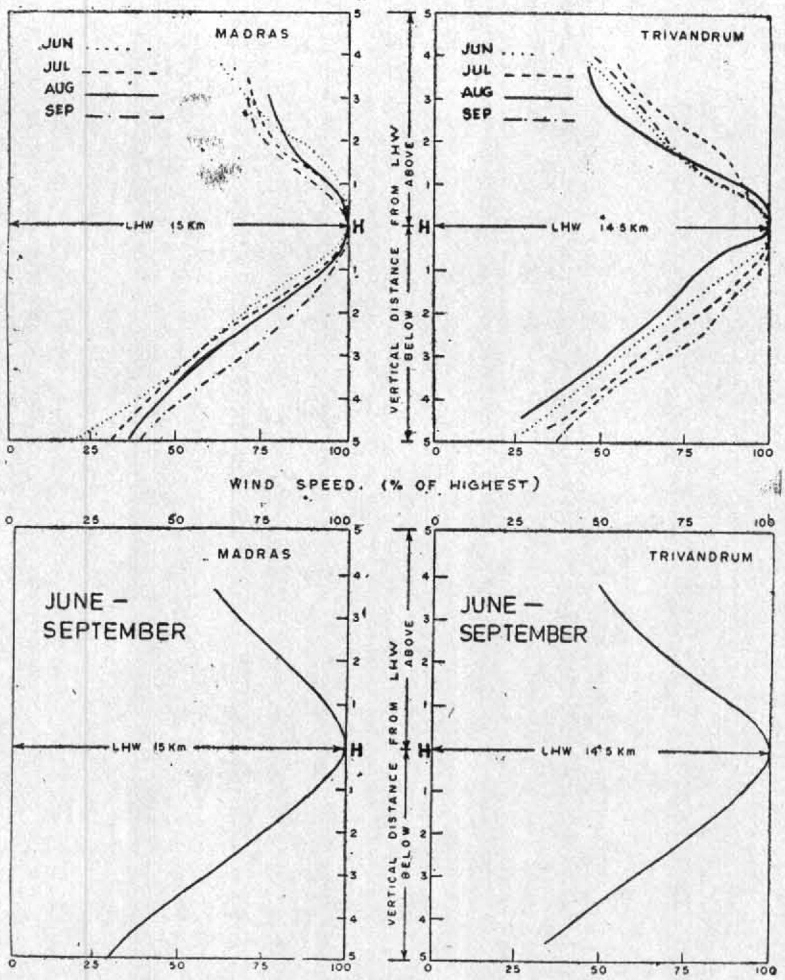

Fig.-4

Average percentage decrease of wind speed above and below the level of highest mean (vector) wind (LHW)

the region between latitudes 4° and 14° N approximately across and adjoining the south Indian Peninsula. In the 16·2 km chart the 60 kt isotach encloses the area between latitudes 12°N and 19°N across the Peninsula. From these charts and the vertical cross-section for July shown in Fig. 5, it is apparent that in the 16·0 km level there is a maximum in the neighbourhood of Goa while in the 14·2 km level there is a maximum over the Trivandrum-Minicoy area. This is an interesting indication of the possibility of two cores of maxima, one at a higher level and at a higher latitude and the other at a lower level and at a lower latitude. This also brings out the existence of a downward slope in the jet profile from north to south (Koteswaram 1969). It is obvious that this conclusion is a climatological feature, based on average data. Day to day synoptic developments may alter this picture and introduce marked variations.

4.14. *Simultaneous existence of cores of max. wind*

With a view to find out whether two cores of maximum wind in the zone of the TEJ exist simultaneously the day to day (12 GMT) winds at levels 14·1, 15·0 and 16·2 km and 'maximum winds' (at any level in the upper troposphere) over Ahmadabad, Nagpur, Bombay, Hyderabad, Goa, Madras, Trivandrum and Minicoy for July and August 1971 were plotted. The highest value of wind speed amongst these stations on each day has been noted. The number of occasions when the highest wind speeds were recorded at each of the stations and their grouping according to

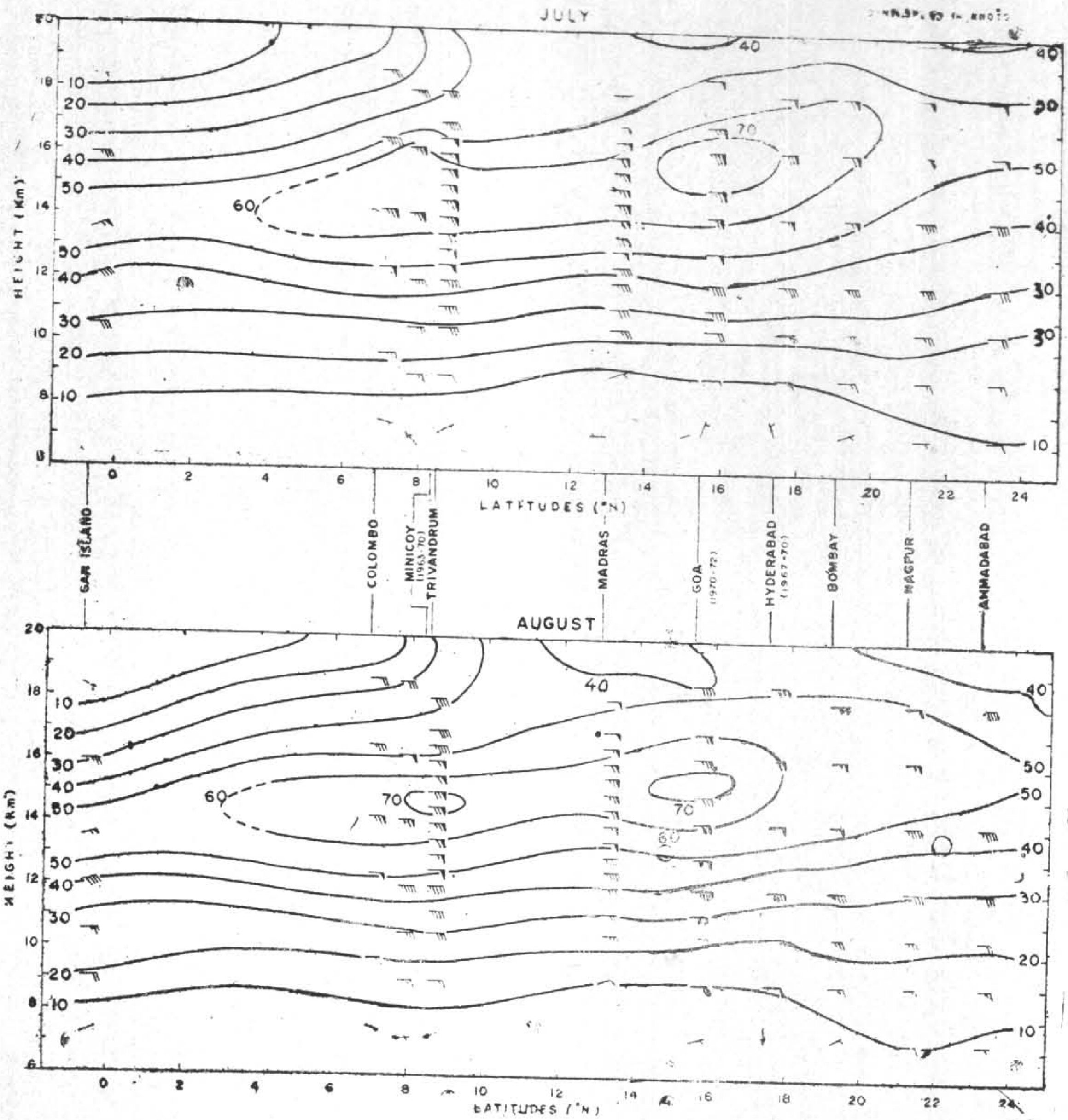

Fig. 5

Vertical cross-section of average wind speed in a longitudinal belt of about 7°

The averages are based on 12 GMT data (1961-65) except Minicoy (1963-70), Hyderabad (1967-70) and Goa (1970-72)

latitudinal belts are tabulated below :

	14·1 km	*15·0 km*	*16·2 km*	*Max. wind*
Ahmadabad	3	1	4	4
Nagpur	2	1	4	0
Bombay	3	3	10	6
Hyderabad	4 } 12	4 } 8	7 } 32	3 } 11
Goa	5	1	15	2
Madras	7	9	7	5
Trivandrum	11 } 41	9 } 41	13 } 18	5 } 45
Minicoy	30	32	5	40

It may be seen that in the levels 14·1 and 15·0 km, the highest values of wind speed lie concentrated over the Trivandrum-Minicoy region while at 16·2 km, the highest values are shifted towards the north and lie over the Bombay-Goa region. The fact that there is a region of maximum wind at a higher altitude in the latitude around Goa-Hyderabad-Bombay and another simultaneous region of maximum wind at a lower altitude in the latitude around Trivandrum-Minicoy seems to indicate that the idea of two cores of maximum wind existing simultaneously in the rather diffuse zone of the TEJ is not unreasonable. However, this has to be confirmed by more frequent simultaneous wind soundings of comparable and sufficient accuracy from closer network of stations across the zone of the TEJ.

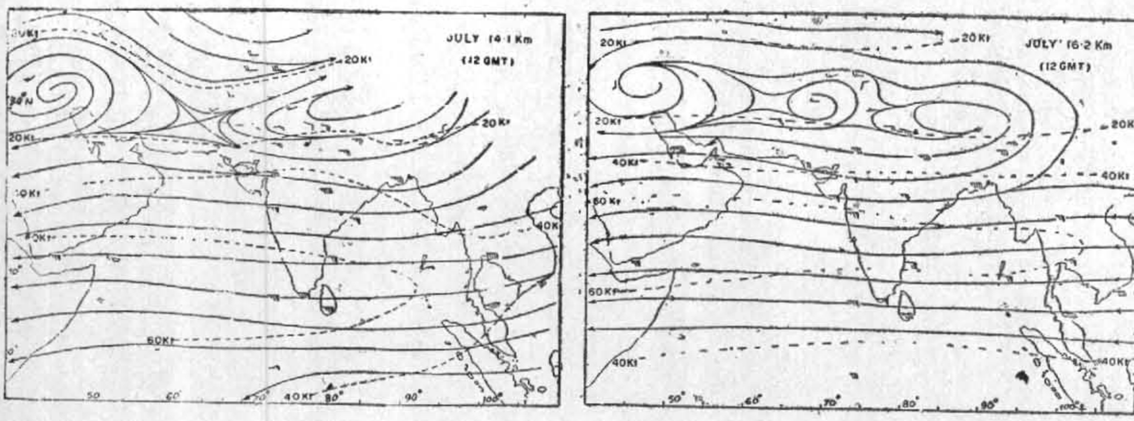

Fig. 6

Mean streamline and isotachs over India and neighbourhood
(Based on all available wind data at 12 GMT upto 1965)

5. Concluding remarks

The above analysis has brought out that the position of the axis of the TEJ varies with the month. TEJ occurs on about two third of the days during these months, being mostly confined to Trivandrum-Colombo region (*i.e.*, Lat. 7° to 9°) at about 14·5 km except in July when the area of strong winds becomes diffuse. Trivandrum mean maximum wind is highest in the region in all the months June to September; the maximum occurs generally at about 0·5 km higher at Madras than over Trivandrum and Colombo. The simultaneous existence of another distinct core of wind maxima in the neighbourhood of Goa at about 16 km is brought out by the recent radar wind observations over Hyderabad and Goa. It is interesting to note that in the case of the tropical easterly jet, the zone of maximum winds extends over a wider area suggesting a diffuse character quite unlike the sub-tropical westerly jet. The present study is based on the mean monthly winds. For a fuller understanding of the structure of TEJ and its relation to areas of precipitation in India, more detailed daily examination would be necessary.

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TABLE 1

Statistical parameters of upper winds (1961-65) for Madras at 1200 GMT

Level (km)	No. of obs.	M.Z.W.	M.M.W.	M.S.W.	M.V.W.		S.D.		S.V.D.	S_x/S_y	S.F.
					Mag.	Dir.	(S_x)	(S_y)			
					JUNE						
9·0	137	2·9	1·5	8·5	3·3	064					39
10·5	124	17·1	0·0	20·8	16·5	090					79
11·2	119	24·1	0·4	25·8	24·1	089	14·2	8·0	16·3	1·77	93
12·0	112	32·1	1·2	33·6	32·2	087	16·1	8·4	18·1	1·92	96
12·5	110	35·9	1·4	37·3	35·9	088	16·5	8·2	18·5	2·01	96
13·0	105	41·4	2·7	43·1	41·6	086	17·9	9·9	20·4	1·81	96
13·5	102	45·5	2·1	46·6	45·6	088	16·9	9·1	19·2	1·86	98
14·0	100	51·9	1·7	52·8	51·9	088	16·7	9·5	19·2	1·76	98
14·5	93	54·8	0·1	55·7	54·8	090	17·1	9·7	19·6	1·76	98
15·0	84	57·9	—0·8	59·2	57·9	091	15·7	11·8	19·6	1·33	98
15·5	78	57·3	—2·9	58·7	57·5	093	19·0	11·1	22·7	1·71	98
16·0	78	55·9	—2·3	57·3	55·9	092	18·1	12·0	21·6	1·51	98
16·5	66	54·2	—0·2	55·4	54·2	090	19·6	11·1	22·5	1·71	98
17·0	54	49·9	—2·3	51·1	49·9	092	20·4	10·5	23·1	1·94	98
					JULY						
9·0	146	7·0	0·4	12·0	7·0	060					58
10·5	141	21·6	1·5	23·5	22·7	085					97
11·2	136	28·6	1·7	30·1	28·6	087	12·4	8·7	15·1	1·43	95
12·0	129	36·3	4·9	38·7	36·7	082	14·8	10·7	18·3	1·38	95
12·5	124	41·2	5·1	43·5	41·6	083	15·3	11·1	18·8	1·38	96
13·0	117	48·0	4·7	49·5	48·4	085	16·1	9·9	18·8	1·63	98
13·5	107	54·2	4·9	55·4	54·4	085	16·1	9·9	19·0	1·63	98
14·0	103	59·6	3·9	60·8	59·8	086	16·5	11·7	20·2	1·41	98
14·5	99	63·5	2·1	64·7	63·7	088	16·9	11·1	20·2	1·52	99
15·0	98	65·1	0·0	65·8	65·1	090	16·9	10·9	20·0	1·55	99
15·5	91	63·3	—1·0	64·1	63·3	091	15·5	9·7	19·2	1·60	99
16·0	89	60·6	—0·2	61·8	60·6	090	17·3	11·1	20·6	1·56	98
16·5	85	54·8	—0·6	55·6	54·8	090	19·6	9·9	21·9	1·98	99
17·0	70	49·9	0·8	51·3	49·9	089	22·1	11·7	25·1	1·89	97
					AUGUST						
9·0	146	9·3	0·4	14·4	10·1	065					70
10·5	140	23·3	—0·8	25·3	24·5	091					97
11·2	137	29·1	1·0	30·7	29·3	088	14·0	8·7	16·5	1·61	95
12·0	133	37·5	2·5	39·2	37·7	087	15·0	10·1	17·9	1·49	96
12·5	128	42·7	2·3	44·1	42·9	087	14·2	9·9	17·3	1·43	97
13·0	121	46·4	3·1	47·6	46·6	086	15·3	10·3	18·5	1·49	98
13·5	113	51·9	3·7	53·0	52·1	086	16·3	10·5	19·2	1·55	98
14·0	111	56·3	3·7	57·3	56·5	086	15·9	9·7	18·7	1·64	99
14·5	104	61·2	1·9	62·4	61·4	088	16·3	11·5	20·0	1·42	98
15·0	100	63·3	0·8	64·7	63·3	089	16·7	12·2	20·8	1·37	98
15·5	95	63·1	—0·6	64·1	63·1	090	16·9	10·9	20·2	1·55	98
16·0	93	57·9	—1·0	58·7	57·9	091	20·4	9·9	22·7	2·06	99
16·5	83	55·9	—2·5	56·9	56·1	093	21·2	9·5	23·3	2·23	99
17·0	75	51·3	—0·8	51·9	51·3	091	20·8	7·2	21·9	2·89	99
					SEPTEMBER						
9·0	137	9·7	—0·8	13·4	9·9	094					74
10·5	133	21·2	—0·8	23·1	22·7	092					98
11·2	134	26·4	—1·4	28·0	26·4	093	11·1	8·5	14·0	1·31	94
12·0	125	35·0	—1·0	36·1	35·0	092	11·1	9·1	14·4	1·22	97
12·5	116	38·3	—0·6	39·4	38·3	091	13·0	9·7	16·3	1·34	97
13·0	105	42·2	0·2	43·3	42·2	090	13·8	10·7	17·3	1·29	97
13·5	101	44·9	0·0	46·2	44·9	090	13·4	10·3	16·9	1·30	97
14·0	100	47·4	—0·6	48·6	47·4	091	14·4	10·7	17·9	1·35	98
14·5	97	49·5	—1·0	50·9	49·5	091	15·7	11·3	19·4	1·39	97
15·0	93	49·9	—1·4	51·5	49·9	092	17·5	11·7	21·0	1·50	97
15·5	84	46·6	—4·3	48·2	46·8	095	16·7	11·5	20·2	1·45	97
16·0	81	45·1	—3·5	46·4	45·3	094	17·5	10·1	20·2	1·73	98
16·5	73	40·4	—2·9	41·2	40·6	095	16·7	8·0	18·5	2·09	99
17·0	59	36·7	—1·9	37·7	36·9	093	15·5	8·4	17·7	1·85	98

M.Z.W. — Mean zonal component
M.M.W. — Mean meridional component
M.S.W. — Mean scalar wind
NOTE — Wind speed in knots.

M.V.W. — Mean vector wind
S.D. — Standard deviation
S.V.D. — Standard vector deviation
S.F. — Steadiness factor

TABLE 2

Statistical parameters of upper winds (1961-1965) of Trivandrum at 1200 GMT

Level (km)	No. of Obs.	M.Z.W.	M.M.W.	M.S.W.	M.V.W. Mag.	M.V.W. Dir.	S.D. (S_x)	S.D. (S_y)	S.V.D.	S_x/S_y	S.F.
					JUNE						
9·0	143	11·9	1·7	15·9	12·0	081					75
10·5	140	26·3	1·0	29·1	26·4	084					91
11·2	135	34·4	3·5	36·3	34·8	085	15·2	9·9	18·1	1·54	96
12·0	133	42·3	6·2	44·5	42·9	081	17·1	10·3	19·8	1·66	96
12·5	131	48·2	7·8	50·1	48·9	080	16·9	10·1	19·6	1·67	98
13·0	131	53·0	7·8	54·8	53·8	082	16·7	10·9	20·0	1·53	98
13·5	130	58·9	6·8	60·4	59·4	083	17·9	11·1	21·0	1·61	98
14·0	123	64·5	5·4	66·0	64·9	085	17·3	13·0	21·8	1·33	98
14·5	112	67·4	2·5	68·8	67·6	088	20·6	13·4	24·5	1·54	98
15·0	109	64·1	—0·2	65·5	64·1	090	23·3	12·2	26·4	1·91	98
15·5	105	56·7	—1·7	58·3	56·9	092	23·7	12·4	26·8	1·91	98
16·0	104	49·5	—0·6	51·3	49·5	090	22·5	13·0	26·0	1·73	97
16·5	96	46·0	—1·0	47·8	46·2	091	21·6	12·0	24·7	1·80	97
17·0	79	41·9	—1·3	43·7	42·1	091	20·0	12·2	23·5	1·64	96
					JULY						
9·0	144	15·0	1·4	19·2	14·9	085					78
10·5	130	29·3	2·7	31·7	29·3	085					92
11·2	129	36·3	4·7	38·5	36·9	083	13·0	10·3	16·7	1·26	96
12·0	126	44·9	8·2	46·8	45·6	080	12·8	10·3	16·5	1·24	97
12·5	123	50·9	10·3	53·2	52·1	078	12·6	10·9	16·7	1·16	98
13·0	117	54·8	9·9	56·9	55·9	080	13·0	11·5	17·3	1·13	98
13·5	113	59·4	11·5	62·0	60·8	079	13·6	12·8	18·7	1·06	98
14·0	111	62·7	9·3	64·9	63·7	082	15·0	13·6	20·2	1·10	98
14·5	101	64·3	8·0	65·9	65·1	083	15·0	12·2	19·4	1·22	99
15·0	98	61·4	6·8	63·1	62·0	084	18·1	14·0	22·9	1·29	98
15·5	92	59·8	5·2	61·8	60·2	086	20·4	14·2	24·9	1·44	97
16·0	89	57·1	3·5	58·9	57·5	086	22·1	15·0	26·8	1·47	98
16·5	80	51·3	—0·2	52·8	51·3	090	22·5	11·3	25·3	1·99	97
17·0	68	45·6	1·5	47·6	45·8	089	19·4	12·6	23·1	1·54	96
					AUGUST						
9·0	151	13·8	—0·6	17·5	13·8	092					79
10·5	150	28·9	1·5	31·9	28·9	088					91
11·2	151	36·7	4·1	39·6	37·1	084	15·3	12·2	19·6	1·25	94
12·0	151	44·9	8·0	47·0	45·6	080	14·0	11·5	18·1	1·22	97
12·5	147	49·5	8·5	51·5	50·5	080	14·2	11·1	17·9	1·28	98
13·0	145	53·8	8·5	55·6	54·6	080	15·0	10·9	18·5	1·38	98
13·5	142	59·1	8·0	60·8	59·8	082	15·0	12·4	19·6	1·21	98
14·0	141	62·5	6·0	64·1	63·1	085	16·1	12·8	20·6	1·26	98
14·5	129	68·6	4·7	70·0	69·0	086	20·2	13·2	24·3	1·53	98
15·0	126	67·8	2·1	69·3	68·0	088	22·0	14·2	26·0	1·55	98
15·5	115	61·6	0·4	62·7	61·6	090	23·7	11·8	26·4	2·01	98
16·0	110	52·6	—0·6	53·8	52·6	090	22·9	10·7	25·3	2·14	98
16·5	99	43·5	0·0	44·9	43·5	090	21·6	10·5	23·9	2·06	97
17·0	78	38·3	0·2	40·4	38·3	090	16·9	12·6	21·0	1·34	95
					SEPTEMBER						
9·0	149	12·2	1·0	17·7	12·4	095					70
10·5	147	25·9	—3·5	27·6	26·0	097					94
11·2	143	32·6	0·2	34·2	32·6	090	14·2	8·9	16·9	1·60	95
12·0	143	40·2	1·9	41·6	40·4	087	14·8	9·1	17·3	1·63	97
12·5	137	45·8	2·5	47·0	46·0	087	14·4	9·1	17·1	1·58	98
13·0	128	48·4	3·1	49·5	48·6	086	15·0	9·9	17·9	1·52	98
13·5	121	52·3	2·3	53·4	52·4	088	14·6	10·5	18·1	1·39	98
14·0	115	54·3	0·4	55·9	54·3	090	15·7	13·0	20·6	1·21	97
14·5	103	54·2	—2·7	55·8	54·4	093	19·8	12·4	23·3	1·60	97
15·0	99	52·4	—1·0	54·0	52·6	091	20·6	13·0	24·3	1·58	97
15·5	96	45·5	—0·2	46·8	45·5	090	20·8	11·3	23·7	1·84	97
16·0	91	40·6	0·8	42·3	40·8	089	19·4	12·6	23·1	1·54	97
16·5	82	37·9	0·4	39·4	37·9	090	18·8	10·5	21·6	1·79	96
17·0	63	34·8	—0·5	37·3	34·8	090	19·6	11·1	22·5	1·77	93

TABLE 3

Statistical parameters of upper winds (1961-65) for Colombo at 1200 GMT

Level (km)	No. of Obs.	M.Z.W.	M.M.W.	M.S.W.	M.V.W. Mag.	M.V.W. Dir.	S.D. (S_x)	S.D. (S_y)	S.V.D.	S_x/S_y	S.F.
						JUNE					
9·7	146	19·4	—3·3	22·1	19·7	100	12·2	8·6	15·0	1·42	89
12·4	143	49·1	6·0	50·3	50·0	083	14·3	9·0	16·9	1·59	99
14·2	136	64·6	11·8	66·2	66·0	080	13·3	7·7	15·4	1·73	100
16·5	110	36·5	1·2	38·1	36·6	088	18·3	9·5	20·7	1·93	96
18·6	78	16·4	—0·8	20·4	16·5	092	15·2	7·6	17·0	2·00	81
						JULY					
9·7	148	24·3	—1·4	26·2	24·4	093	11·7	8·3	14·3	1·41	93
12·4	145	51·3	9·5	53·0	52·0	080	12·6	9·4	15·7	1·34	98
14·2	139	62·4	10·9	64·3	64·0	070	13·7	11·1	17·7	1·23	99
16·5	111	42·3	2·6	44·2	43·0	087	18·1	10·2	20·8	1·77	97
18·6	80	23·6	0·4	24·7	23·6	090	13·0	6·3	14·4	2·06	95
						AUGUST					
9·7	149	20·8	—3·0	23·1	21·1	098	11·6	7·8	14·0	1·49	91
12·4	149	47·6	6·4	49·0	48·5	083	14·2	9·6	17·1	1·48	99
14·2	146	62·3	9·8	64·4	63·2	081	16·4	13·4	21·2	1·22	98
16·5	119	34·7	0·9	36·1	34·8	088	17·0	8·7	19·1	1·95	96
18·6	83	22·1	0·1	23·9	22·1	090	15·4	7·3	17·0	2·11	93
						SEPTEMBER					
9·7	142	20·1	—4·8	22·1	20·7	104	11·0	6·5	12·8	1·69	94
12·4	144	43·9	1·3	45·0	44·2	088	14·6	9·1	17·2	1·60	98
14·2	136	61·1	2·9	62·3	62·0	087	15·1	11·6	19·0	1·30	99
16·5	109	25·6	—0·2	27·8	25·7	094	17·1	8·5	19·1	2·01	92
18·6	82	14·8	—0·2	19·2	14·8	090	17·3	7·5	18·9	2·31	77

TABLE 4

Statistical parameters of upper winds (1961-65) for Gan at 1800 GMT

Level (km)	No. of obs.	M.Z.W.	M.M.W.	M.S.W.	M.V.W. Mag.	M.V.W. Dir.	S.D. (S_x)	S.D. (S_y)	S.V.D.	S_x / $_y$	.F.
						JUNE					
9·0	136	11·0	1·5	15·9	11·3	084	12·7	6·9	14·5	1·84	71
10·5	136	23·5	4·1	26·0	23·9	080	13·3	8·7	15·9	1·53	92
12·0	136	39·3	10·6	42·5	40·8	073	14·5	12·1	18·9	1·20	96
13·5	136	51·1	16·5	55·5	54·0	072	18·3	12·4	22·1	1·48	97
15·9	133	22·3	2·6	29·9	22·6	085	20·9	10·3	23·2	2·03	76
18·3	104	—11·8	1·9	18·0	12·0	098	14·4	7·7	16·4	1·87	67
						JULY					
9·0	154	17·2	1·0	20·2	17·3	086	12·0	7·9	14·4	1·52	86
10·5	154	27·4	5·0	30·5	28·0	080	14·2	9·8	17·3	1·45	92
12·0	154	39·0	11·8	42·9	40·8	075	14·5	12·9	19·4	1·12	95
13·5	153	50·5	17·7	55·5	55·0	070	14·1	14·9	20·5	0·95	99
15·9	146	33·0	5·4	36·1	33·5	080	20·7	11·5	23·7	1·80	93
18·3	104	—6·8	0·7	18·7	6·9	095	18·9	6·8	20·1	2·78	37
						AUGUST					
9·0	153	17·7	—0·4	20·2	17·8	091	12·4	7·0	14·2	1·77	88
10·5	153	26·6	2·7	28·5	26·8	085	11·8	8·8	14·7	1·34	94
12·0	153	37·7	11·1	41·2	39·3	073	15·4	10·3	18·5	1·50	95
13·5	152	52·0	17·5	56·0	56·0	070	15·3	12·8	19·9	1·20	100
15·9	143	26·3	3·2	30·8	26·6	084	22·1	9·5	24·1	2·30	86
18·3	102	—4·3	1·1	18·4	4·5	105	18·9	7·1	20·2	2·66	25
						SEPTEMBER					
9·0	145	15·7	0·8	19·1	15·8	088	12·6	7·2	14·5	1·75	83
10·5	144	22·0	3·3	24·4	22·4	081	12·0	8·9	14·9	1·35	92
12·0	144	34·0	9·7	37·2	35·4	072	13·7	11·0	17·5	1·25	95
13·5	142	48·6	12·5	51·6	49·5	076	16·3	12·1	20·3	1·35	96
15·9	134	15·0	2·0	20·6	15·2	082	18·5	7·1	19·8	2·61	74
18·3	104	0·7	1·1	22·1	1·4	030	25·6	7·0	26·7	3·66	06

TABLE 5(a)

Average of maximum wind speeds and levels (heights) of their occurrence

	Madras (1961-65) (00 and 12 GMT)			Trivandrum (1961-65) (00 and 12 GMT)			Colombo* (1964-70) (12 GMT)			Gan (1964-70) (12 GMT)		
	No. of obs.	Max. wind (kt)	Level of max. wind (km)	No. of obs.	Max. wind (kt)	Level of max. wind (km)	No. of obs.	Max. wind (kt)	Level of max. wind (km)	No. of obs.	Max. wind (kt)	Level of max. wind (km)
Jun	164	80·0	15·04	231	84·6	14·71	37	84·1	14·69	124	78·7	14·55
Jul	203	81·7	15·05	223	84·7	14·61	37	84·4	14·54	159	80·4	14·40
Aug	206	81·3	15·01	255	85·0	14·63	46	18·4	14·61	155	79·0	14·56
Sep	130	72·9	15·16	179	77·0	14·58	39	75·4	14·55	87	74·8	14·49
Jun-Sep	703	79·4	15·06	888	83·2	14·63	159	81·3	14·60	525	78·7	14·50

*Data extracted from daily weather charts

TABLE 5(b)

Percentage frequency of maximum wind speeds over Madras, Trivandrum, Colombo and Gan

	Speed (kt)									
	60-69	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149	Total
				Madras (1961-65, 00 and 12 GMT)						
Jun	22·6	34·1	24·4	9·2	6·7	1·8	0·6	0·6	—	164
Jul	19·2	29·6	24·6	16·3	6·9	3·4	—	—	—	203
Aug	20·4	24·8	29·6	17·4	6·8	1·0	—	—	—	206
Sep	43·1	32·3	16·9	6·2	1·5	—	—	—	—	130
Jun-Sep	24·7	29·8	24·6	13·2	5·8	1·7	0·1	0·1	—	703
				Trivandrum (1961-65, 00 and 12 GMT)						
Jun	20·8	17·7	26·8	19·9	9·6	2·2	1·7	0·9	0·4	231
Jul	14·3	22·9	30·0	20·2	7·7	2·7	1·8	—	0·4	223
Aug	15·3	21·2	30·6	15·6	11·0	4·7	1·6	—	—	255
Sep	20·1	41·3	30·8	6·1	1·1	0·6	—	—	—	179
Jun-Sep	17·5	24·8	29·4	16·0	7·8	2·7	1·4	0·2	0·2	888
				*Colombo** (1964-70, 12 GMT)						
Jun	5·4	27·0	37·9	10·8	16·2	—	2·7	—	—	37
Jul	21·6	10·8	21·6	27·0	16·2	2·7	—	—	—	37
Aug	15·2	30·4	30·4	13·0	8·8	—	—	—	2·2	46
Sep	30·8	25·6	28·2	10·3	5·1	—	—	—	—	39
Jun-Sep	18·2	23·9	29·6	15·1	11·4	0·6	0·6	—	0·6	159
				Gan (1964-70, 12 GMT)						
Jun	25·8	32·3	20·2	16·1	5·6	—	—	—	—	124
Jul	20·8	27·7	30·8	13·8	5·7	0·6	0·6	—	—	159
Aug	26·5	29·0	22·5	15·5	6·5	—	—	—	—	155
Sep	39·1	31·0	18·4	9·2	2·3	—	—	—	—	87
Jun-Sep	26·7	29·7	23·8	14·1	5·3	0·1	0·1	—	—	525

*Data extracted from daily weather charts

TABLE 6

Average vertical wind shears (kt/km)

(1961-65)

	Layer (km)						Layer (km)			Layer (km)		
	13·0 to 13·5	13·5 to 14·0	14·0 to 14·5	14·5 to 15·0	15·0 to 15·5	15·5 to 16·0	9·7 to 12·4	12·4 to 14·2	14·2 to 16·5	10·5 to 12·0	12·0 to 13·5	13·5 to 15·9
	Madras (12 GMT)						*Colombo (12 GMT)*			*Gan (18 GMT)*		
Jun	8·4	13·0	6·8	6·6	—4·4	—3·0	11·6	9·3	—12·0	11·5	8·9	—12·4
Jul	12·4	11·0	8·8	5·4	—4·4	—5·6	10·9	6·2	—9·0	8·7	8·7	—9·0
Aug	11·2	8·8	10·6	4·8	—3·0	—10·4	10·6	8·4	—12·6	9·3	10·4	—12·3
Sep	5·4	5·2	4·4	1·2	—8·8	—3·4	9·1	5·7	—15·5	9·1	9·9	—14·7
Jun-Sep	8·8	9·6	7·4	4·4	—4·4	—5·6	10·4	8·3	—12·6	9·5	9·5	—12·0
	Trivandrum (12 GMT)											
Jun	12·0	11·6	8·4	—8·6	—15·0	—14·6						
Jul	9·8	8·2	4·2	—6·6	—4·6	—6·4						
Aug	10·6	7·8	12·4	—5·4	—12·8	—18·2						
Sep	8·0	5·6	6·2	—5·0	—14·0	—10·0						
Jun-Sep	10·2	8·6	7·0	—4·6	—12·2	—12·0						