551·524 : 537.554 : 513.2 (548.1)

A study of vertical wind profile of the tropical easterly jet stream over Madras

R. Y. MOKASHI

Meteorological Office, Poona

(*Received 27 September 1969*)

ABSTRACT. Rawin observations for the months June to September during five consecutive year (1961-65) have been analysed to study the vertical wind profile of the tropical easterly jet stream over Madras, Visakhapatnam and Trivandrum. The main finding is that the stronger the tropical easterly jet stream, the higher is the altitude of maximum wind. This is just the opposite of the author's earlier finding in the case of sub-tropical westerly jet stream where the stronger the jet maximum the lower is its level of occurrence. It is also seen that the tropical easterly jet strengthens as one moves towards south from Visakhapatnam to Trivandrum while the level of its occurrence lowers.

1. Introduction

The occurrence of an easterly jet in the northern summer over Arabia along 15°N near the tropical tropopause was pointed out by Sutcliffe and Bannon (1954). Koteswaram (1958) found that the easterly jet extends over nearly half the globe from the east coast of China to the west coast of Africa with its core roughly along 15°N at about 15 km and that the level of maximum wind slopes upwards towards the north over the Indian subcontinent (Koteswaram 1969).

The strength of the easterly jet in relation to the height of its core is examined in the present note.

2- Method of analysis and presentation of data

2.1. During the period under consideration (1961-65), 429 ascents of Visakhapatnam, 703 of Madras and 888 of Trivandrum with winds ⩾60 knots were available. These were grouped into the following three categories depending upon the value of the maximum wind reported in the observation, for facility of handling the data.

Category 1 : Ascents with max. wind speed ⩾100 knots.

Category 2 : Ascents with max. wind speed ⩾80 knots and <100 knots.

Category 3 : Ascents with max. wind speed <80 knots.

It is seen (Table 1) that ascents of Category 3 are more common over Visakhapatnam and Madras during the period June to September than ascents of Categories 1 and 2, while in the case of Trivandrum the ascents of Category 2 are more common. A comparison between the three stations shows that the number of ascents of Category 1 in the case of Trivandrum is nearly twice that of Madras and more than five times that of Visakhapatnam. The number of ascents of Category 2 of Trivandrum is nearly one and half times that of Madras and three times that of Visakhapatnam. The number of ascents of Category 3 of Trivandrum is nearly the same as that of Madras and roughly one and half times that of Visakhapatnam. The total ascents of the three categories together, in the case of Trivandrum are more than one and quarter times that of Madras and more than twice that or Visakhapatnam. In other words, winds ⩾60 knots over Madras are more frequent as compared with Visakhapatnam and less frequent as compared with Tirvandrum.

The relative percentage frequencies of the three categories are given in brackets in Table 1 for each station.

2.2. In Table 1 are also given the mean and median scalar values of the maximum winds and their heights for the three categories separately and for the 3 categories together.

The mean/median values of the maximum winds over Madras during June to September exceed well over 75 knots. Taking the percentage fre-

TABLE I

Category	Station	No. of rawin ascents (1961-65)	Wind speed (kt) of the max. wind		Ht. (km) of the level of maximum wind	
			Mean	Median	Mean	Median
1	Visakhapatnam	21 (4·9)	106·6	106·0	16·06	15·92
	Madras	55 (7·8)	107·4	106·0	15·93	15·85
	Trivandrum	109 (12·3)	109·9	107·0	15·16	14·91
2	Visakhapatnam	135 (31·5)	87·7	87·0	16·01	15·70
	Madras	265 (37·7)	87·7	87·0	15·26	15·20
	Trivandrum	404 (45·5)	88·2	87·0	14·80	14·66
3	Visakhapatnam	273 (63·6)	69·0	69·0	15·26	15·33
	Madras	383 (54·5)	69·7	70·0	14·79	14·56
	Trivandrum	375 (42·2)	70·2	70·0	14·13	13·96
Three categories together	Visakhapatnam	429	76·7	74·0	15·54	15·50
	Madras	703	79·4	78·0	15·06	14·98
	Trivandrum	888	83·3	78·0	14·58	14·46

TABLE 2

Height (km)	Speed (kt)							
	60—69	70—79	80—89	90—99	100—109	110—119	120—129	130—139
25	1							
24		1						
23	2							
22								
21	1	1	1					
20		1	1	1				
19	1	2	1		1			1
18	7	4	5	3	2			
17	19	13	10	13	11	3		
16	20	24	45	22	**13**	**4**	**1**	
15	41	**71**	**61**	**37**	9	3		
14	**45**	57	30	14	6			
13	22	29	18	2		1		
12	12	4	1					
11	2	2						
10	1							

quency of ascents of Category 3 also into consideration, it is reasonable to expect maximum wind speeds of about 70-80 knots over Madras on more than half the number of days during the four months June to September. In the same manner taking the percentage frequency of ascents of Categories 3 and 2 into consideration, it is reasonable to expect maximum wind speeds of about 76 to 77 knots over Visakhapatnam on nearly two-thirds the number of days and 83 to 84 knots over Trivandrum on nearly half the number of days during the 4 months (June to September). The highest maximum winds reported at Madras was 132 knots at 18·9 km, over Visakhapatnam the highest maximum winds reported were 122 knots at 16·4 km and over Trivandrum 148 kt at 19·2 km respectively. Since all ascents did not record the maxima during this period, it is possible that some higher values were missed at these stations. No conclusions can , therefore, be drawn about the latitudinal variation of the highest wind speeds in the easterly jet streams.

2.3. It is seen from the mean/median values of the maximum wind speed and the levels of their occurrence, separately for the three categories as well as for the three categories together, that they increase as one moves southwards from Visakhapatnam to Trivandrum while the height of the level of maximum wind decrease (Table 1). Thus, the tropical easterly jet stream strengthens as one move towards south froms Visakhapatnam to Trivandrum, while the level of its occurrence lowers.

2·4. The mean and median values of the maximum wind speeds and heights of their levels, in the case of Visakhapatnam, Madras and Trivandrum for the different categories of ascents, as well as for all the ascents taken together (Table I), are seen to be very close to each other suggesting a symmetric distribution of the individual values about the mean.

2.5. The mean heights of the level of maximum wind relating to the three categories of flights over Madras (Table 1) suggesting a significant relationship between the maximum wind speeds and the heights of the levels of their occurrence, for Category 1 with maximum wind speeds exceeding 100 knots, the mean heights of the level of maximum wind is 15·9 km, while for Categories 2 and 3 with lower wind speeds, the mean levels are 15·3 and 14·8 km, respectively. The same relationship between the three categories in the case of Visakhapatnam and Trivandrum can be seen. It thus appears that the stronger the tropical easterly jet stream the higher is the altitude of the maximum

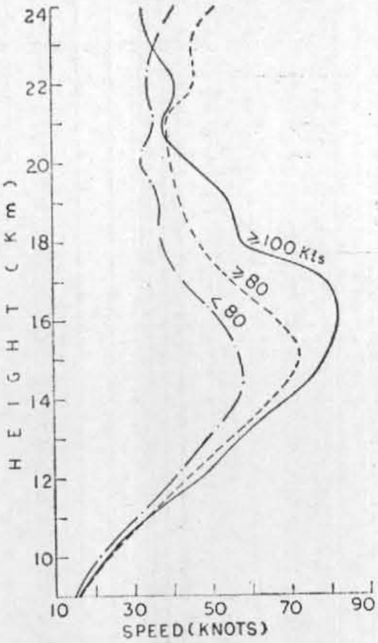

Fig. 1. Mean vertical wind profiles of the three categories of ascents over Madras

wind. This is just the opposite of the author's (Mokashi 1969) earlier finding in the case of sub-tropical westerly jet stream that the stronger the sub-tropical westerly jet stream the lower is the altitude of the maximum wind.

2·6. Table 2 gives the frequency occurrence of maximum wind speeds over Madras in ranges of 10 knots from 60 to 139 kt.

The level of maximum wind in the speed ranges 60-69, 70-99, and 100-129 knots has frequency maxima near 14, 15 and 16 km, respectively, leading to the inference that the stronger the tropical easterly jet stream, the higher is its altitude.

3. Vertical wind profiles

3·1. The mean vertical wind profiles of the three categories of ascents over Madras are depicted in Fig.1. The mean profiles are drawn by picking out values of wind speeds at one km interval from 9·0 to 24·0 km above m.s.l. for each of the ascents and evaluating their means which were then plotted for the three categories. The peak values shown by the mean profiles fall short of the mean values given in Table 1, due to the variance in the levels of maximum wind from flight to flight. The mean profiles for the categories 1 and 2 are identical till about 11·2 km and at this level the mean profiles for the three categories branch out till they come closer at about 21·0 km. The heights of the peak values for Categories 1, 2 and 3 show the relation between the jet maximum and its level of occurrence as discussed above.

TABLE 3

Various parameters for maximum winds (winds ≥ 60 knots) over Madras

Level (km)	No. of observations	Mean zonal comp.	Mean meridional comp.	Mean scalar wind	Mean vector wind	Direction of mean vector wind (°)	Standard deviation of the comp. (Sx)	Standard deviation of the meridional comp. (Sy)	Standard vector deviation	Sx/Sy	Steadiness factor (%)
					Category 1 : ≥ 100 kts						
12·0	51	44·1	4·7	45·8	44·5	089	13·2	10·7	17·1	1·23	97
12·5	50	48·0	5·4	49·3	48·4	084	14·0	8·9	16·7	1·57	98
13·0	50	52·8	6·6	54·4	53·4	083	14·0	9·7	17·1	1·44	98
13·5	50	60·0	7·2	61·2	60·6	083	14·4	9·9	17·5	1·45	99
14·0	52	67·0	5·1	68·4	67·2	085	16·1	12·6	20·4	1·28	98
14·5	52	72·5	3·7	73·8	72·7	087	14·6	13·8	20·0	1·06	99
15·0	51	78·1	4·5	79·1	78·3	087	15·3	12·4	19·6	1·23	99
15·5	50	80·2	2·1	81·6	80·4	088	16·1	14·6	21·8	1·10	99
16·0	47	*81·4*	0·8	*82·6*	*81·6*	089	17·7	14·2	22·5	1·25	99
16·5	44	77·3	2·0	78·5	77·5	089	22·0	13·2	25·6	1·67	99
17·0	38	76·5	1·2	77·9	76·7	090	25·6	14·4	29·5	1·78	98
					Category 2 : ≥80 and <100 kt						
12·0	252	42·5	1·4	43·9	42·7	089	14·0	10·1	17·1	1·39	97
12·5	252	47·4	1·9	48·9	48·2	088	14·4	10·9	18·1	1·32	99
13·0	252	53·6	3·5	54·8	54·0	087	14·6	10·5	17·9	1·39	99
13·5	250	58·1	3·9	59·3	59·0	086	14·4	10·9	18·1	1·32	99
14·0	248	63·7	3·9	65·1	64·5	086	12·8	11·5	17·3	1·11	99
14·5	238	68·4	3·1	69·5	69·0	087	12·6	12·2	17·5	1·03	99
15·0	236	*70·9*	1·0	*72·3*	*71·5*	088	13·4	13·2	18·6	1·02	99
15·5	224	67·8	—0·6	69·0	68·0	091	14·2	12·6	18·8	1·13	99
16·0	216	64·9	—0·8	66·2	65·5	090	16·9	12·8	21·2	1·32	99
16·5	202	59·6	—1·4	60·6	60·0	092	17·9	11·5	21·2	1·56	99
17·0	164	53·8	—1·7	54·8	54·0	092	18·6	10·1	21·4	1·84	99
					Category 3 : < 80 kt						
12·0	350	38·3	2·9	39·8	38.5	086	13·0	9·9	16·3	1·31	97
12·5	345	43·5	3·3	45·1	44·0	087	13·8	10·1	17·1	1·37	98
13·0	337	47·2	3·9	48·6	48·0	086	13·6	10·5	17·1	1·30	99
13·5	326	51·1	3·9	52·6	52·0	085	13·0	11·5	17·3	1·13	99
14·0	321	55·0	2·9	56·3	55·8	084	12·8	11·7	17·5	1·09	99
14·5	286	*56·7*	1·4	*57·9*	*57·0*	088	10·9	11·7	15·9	0·93	98
15.0	269	*56·9*	0·4	*58·5*	*57·0*	089	10·7	11·3	15·5	0·95	97
15·5	243	54·6	—1·0	55·7	55·0	091	12·2	10·7	16·3	1·14	99
16·0	231	50·9	—2·5	51·9	51·2	092	13·6	10·5	17·1	1.30	99
16·5	202	46·2	—2·1	47·0	46·5	093	15·2	8·9	17·5	1·71	99
17·0	171	41·4	—0·4	42·2	41·5	091	15·7	8·4	17·9	1·87	98
					Three categories together						
12·0	653	40·4	2·5	42·0	41·0	088	13·6	10·1	16·9	1·35	98
12·5	647	45·5	2·9	46·8	46·0	087	14·2	10·3	17·5	1·38	98
13·0	639	50·1	3·9	51·7	51·0	087	14·4	10·5	17·7	1·37	99
13·5	626	54·6	4·1	55·9	55·5	086	14·2	11·1	18·1	1·28	99
14·0	621	59·6	3·5	60·8	60·2	087	14·0	11·7	18.3	1·20	99
14·5	576	62·9	2·3	64·1	63·5	088	13·6	12·0	18·1	1·13	99
15·0	556	*64·9*	1·0	*66·2*	*65·0*	089	14·6	12·2	19·0	1·20	98
15·5	517	62·7	—0·6	63·9	63·0	091	15·9	12·0	19·8	1·33	99
16.0	494	59·8	—1·4	51·2	60·0	092	18·3	11·8	21·8	1.55	98
16·5	448	55·4	—1·4	56·3	55·8	092	19·6	10·7	22·3	1·83	99
17·0	373	50.5	—0·8	51·5	50·8	091	21·2	9·9	23·3	2·14	99

Note : Sign convention for wind components—Wind components from East and North are designated as positive while wind components from West and South are designated as negative. The unit for wind speed is knot.

3·2. Percentage frequencies along the vertical of the levels of maximum wind for the 703 ascents taken up for study are shown in Fig. 2. The highest percentage frequencies of the levels of maximum wind for the Categories 1, 2 and 3 occur at about 16·3, 15·2 and 14·6 km respectively.

3.3. The vertical wind shears calculated for the different levels between 9·0 km and 24·0 km, separately for the three categories are depicted in Fig. 3. The wind shear is lowest at about 16·2, 15·2 and 14·6-km level in the case of the Categories 1, 2 and 3 respectively. This shows that the stronger the jet maximum, the higher its level of occurrence. It may be seen from Fig. 3 that the highest values of wind shear are in Category 1 and the lowest in Category 3.

4. Statistical Parameters

4.1. Statistical parameters of upper winds for the levels 12·0 to 17·0 km. above m.s.1. have been computed at intervals of ½ km It is not possible to get a correct picture of the mean maximum wind and its corresponding height from the wind data for standard levels. The original rawin trajectories were therefore re-analysed and wind data tabulated at closer height intervals of ½ km to get over this difficulty. Table 3 gives the various parameters for the three categories of ascents separately and for the three categories together, in respect of Madras for June to September (1961-65).

4.2. The highest values of mean zonal component, mean scalar wind and mean vector wind are at 16·0, 15·0 and between 14·5 and 15·0 km in the case of the Categories 1, 2 and 3 respectively (Table 3). The figures confirm that the stronger the tropical easterly jet stream, the higher is the altitude of maximum wind.

The highest values of mean zonal component, mean scalar wind and mean vector wind for the three categories together (Table 3) are 65-66 knots at 15·0 km. In other words the average core of easterly jet over Madras, during the period June-September 1961-65 is at 15·0 km and its speed 65-66 knots.

4·3. The easterly jet stream is very steady (steadiness factor nearly>97%). The standard vector deviation is nearly 30 per cent of the resultant wind vector and the ratio of the standard deviation of the zonal component to that of the meridional component is of the order of 1. The author (1969) has found that this ratio (Sx/Sy) in the case of the sub-tropical westerly jet stream (over Delhi) is

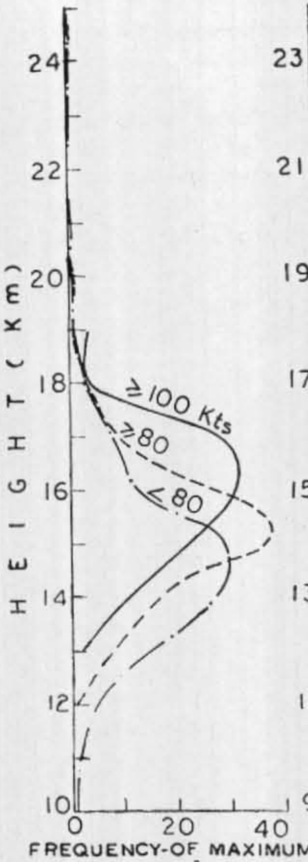

Fig. 2

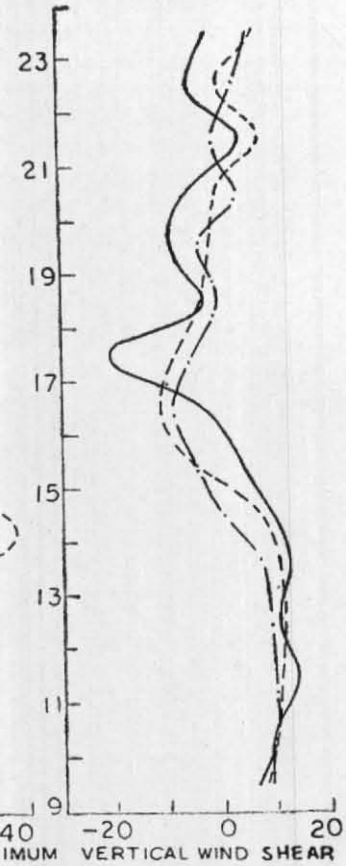

Fig. 3

of the order of 0·6. This would imply that in the westerlies of winter season, troughs and ridges are a predominant feature, while they are not so predominant in the summer easterlies over the Indian Peninsula.

5. Discussion

It is interesting to examine the reason for stronger westerly jets of winter occurring at lower altitudes, as well as for the stronger easterly jets of summer occurring at higher altitude. The jet maximum is due to thermal wind building up with height until the horizontal temperature gradient evens out or reverses. Its strengthening is , therefore, associated with increase of meridional temperature gradients. In the case of the sub-tropical westerly jet over northern India in winter, the temperature gradient decrease is towards north and is strong in the lower layers over the north India. With the arrival of cold air from the north, polar out-breaks associated with lower tropopauses (about 12 km), the gradient in the lower layers increases further, building up a stronger jet at a lower level, In summer the temperature gradient is directed towards south building up an easterly wind, but the gradient is weak and the tropopause occurs at a greater height (about 16 km). Increase in the temperature gradient should be associated with warm air outbreaks from the north and the associated higher tropopauses. The above explanation is offered as a tentative one pending a close examination of individual cases. Therefore easterly jets reach their highest speed at greater heights.

6. Acknowledgements

I wish to express my sincere thanks to Dr. P. Koteswaram, Director General of Observatories, for his guidance in the study of this problem. Thanks are also due to members of staff of the Upper Air Section who helped in the computations involved in the study and in the preparation of the diagrams.

REFERENCES

Koteswaram, P. 1958 *Tellus*, **10**, 1, pp. 43–58.

1969 *WMO Tech. Note*, **95**, pp. 218-228.

Mokashi, R. Y. 1969 *Indian J. Met. Geophys*, **20**, 4, pp. 361-368.

Sutcliffe, R. C. and Bannon, J. K. 1954 Seasonal changes in the upper air condition in the Mediterranean-Middle East area, Sci. Proc. Int. Ass. Met. IUGG, Rome, pp. 322-334.