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A study of winds upto 32 km over Hyderabad Deccan

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ABSTRACT. Rawin observations of eleven high altitude ascents at Hyderabad Deccan (India) during the months of February to March 1960 and April to May 1959 have been analysed. An abrupt change in direction of winds at an altitude of about 19 km during summer months, depth of westerlies and easterlies and the occurrence of two maxima and at least one minima of velocities and the relationship between their altitudes have been described. Also, vector average winds throughout the observed channel of atmosphere (0—32 km) and their relationship with the maxima have been determined and described. It was also found that the upper winds were quite steady. The steadiness factor has been calculated for each altitude for the month of March 1960.

1. Introduction

During the years 1959 and 1960, several high altitude wind observations were made at Hyderabad Deccan (Lat. 17°. 5 N, Long. 78°.5E) in connection with measurements on cosmic rays. An ultra-high frequency transmitter was attached with plastic balloons and was followed by means of radio theodolite ground equipment. Observations of these balloons were made by optical theodolites also. Azimuth and elevation angles were read every minute and altitudes with respect to time were determined by trigonometrical methods based on simultaneous observations from two stations. These balloons reached an altitude of about 30 km in about 90 minutes and then floated for a few hours at that level, when a cut off mechanism detached the load line which descended steadily with the help of a parachute. The average value of rate of ascent was about 17 km/hr upto 12 km altitude and about 27 km/hr in 12-32 kilometres region. All balloons were released between 0200 and 0300 GMT from Osmania University grounds (543 metres above m.s.l.).

Analysis of these high level soundings revealed the following interesting features of the winds at higher altitudes.

2. Change in direction from westerly to easterly at an altitude of about 19 km

Tropospheric westerlies above the surface trades became easterlies in the lower stratosphere during March, April and May. This reversal of direction was effected in a narrow zone of about 2-km thickness. The reversal was quite abrupt in most of the flights and took place through both north and south. In Fig. 1, wind arrows have been plotted, showing the speed and direction of winds at an interval of altitude of 1 km for all the eleven flights. Thick lines in Fig. 1 represent boundaries of a narrow region of very light and variable winds, where the change in direction takes place. Actual thickness of the region of transition and also the depth of westerlies and easterlies and the position of the altitude of maximum westerly and maximum easterly in their respective channels have been given in Table 1.

The thickness of the region of transition during the month of March is on an average, only 1·5 km; on rest of the days it is 2 km except on 17 April when it is abnormally high, 7 km.

Altitude of this reversal and so the depth of westerlies is very high in February, 27-28 km, as compared to the one in later months. In March and upto middle of April, the average of this altitude is 18 km while in later period it is about 15 km. Thus, a decreasing trend in the altitude of change over is evident as the summer advances and ground temperatures rise.

Wexler (1951) first noted such reversal of winds after observing spectacularly the spread of volcanic dust from the explosion of Krakatoa (6°S, 105°E) on 27 August 1883. He found the smoke moving from east to west at an altitude of about 19 km. These easterlies, since then, have acquired the name 'Krakatoa Winds'. It has been observed quite regularly by radio as well as optical theodolite methods that balloons reaching 100-mb level turn westward and increase in speed. Ockenden (1939) observed similar well marked discontinuity between the lower strong westerly current and an upper light easterly current between 70,000 and 80,000 ft in high altitude pilot balloon observations, which were made at Habbaniya (Iraq) during April-May 1939. Scrase (1949) and Brasefield (1950) described such reversal after a calm region between 15 and 20 km during summer months, 1 April to 1 September. Colon (1951) also observed similar reversal of direction during the year 1948 in several special high altitude wind observations over Puerto Rico. The pronounced

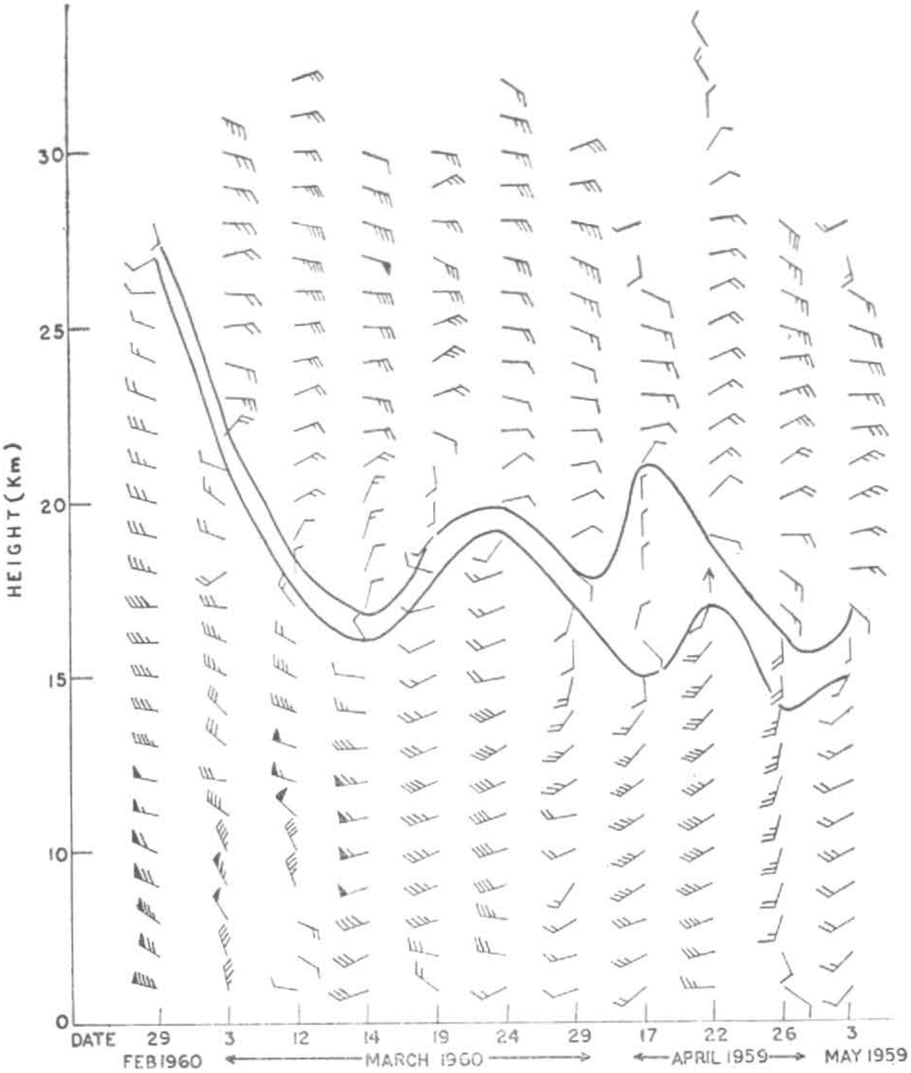

Fig. 1. Wind speed and direction from 29 February to 29 March 1960 and 17 April to 3 May 1959

easterly flow, according to Brasefield (1950) commenced about three weeks after the vernal equinox and ceased about three weeks before the autumnal equinox. Whipple (1935), describing monsoon wind theory from the anomalous propagation of sound explosions, deduced such reversal of winds at high levels at the end of March. In the present observations, marked reversal has taken place at the beginning of March, although on 29 February, the westerlies prevailed right up to 27 km.

This reversal of direction, a characteristic phenomenon of the stratosphere winds, may, probably, be due to the fact that the lower layers of stratosphere are colder over the equator and warmer over poles (unlike surface of the earth where equatorial region is the hottest and the polar region coldest). Due to this reversal of hot and cold regions (Sheppard 1949), the planetary winds system in the stratosphere may be reverse to that at the surface of the earth. According to this view, we may again get upper westerlies at some higher altitudes over the tropical regions. Flights of 17 and 22 April and 3 May 1959 indicate the beginning of upper westerlies over the top of stratospheric easterlies at an altitude of 28, 32 and 27 km respectively, the depth of this region of transition being 1 km in all these three ascents. Also, such reversal of winds is consistent with the existence of an anti-cyclonic stratospheric circumpolar vortex — Brasefield (1950).

The depth of easterlies channel could be determined only in three flights of 17 and 22 April and 3 May when the easterlies have disappeared at an average altitude of 28 km followed by another calm region of 1-km thickness containing variable winds. This second calm zone was topped by

TABLE 1

Altitudes (km) and depths (km) of westerlies and easterlies

	29 Feb 1960	3 Mar 1960	12 Mar 1960	14 Mar 1960	19 Mar 1960	24 Mar 1960	29 Mar 1960	17 Apr 1959	22 Apr 1959	26 Apr 1959	3 May 1959	Average
1. Altitude where westerly appears	2	2	2	2	2	2	2	2	2	2	2	2
2. Altitude where westerly becomes maximum	6	9	12	12	12	9	12	10	11	12	10	11
3. Altitude where westerly disappears	27	21	17	16	19	18	15	14	17	14	15	18
4. Altitude where easterly appears	28	22	19	17	21	19	18	21	19	16	17	20
5. Altitude where easterly becomes maximum	—	31	27	27	26	28	27	24	25	24	22	26
6. Altitude where easterly disappears	—	—	—	—	—	—	—	27	31	—	27	28
7. Altitude where second westerly appears	—	—	—	—	—	—	—	28	32	—	28	29
8. Depth of westerly up to westerly maximum (2—1)	4	7	10	10	10	7	10	8	9	10	8	8
9. Total Depth of westerly (3—1)	25	19	15	14	17	16	13	12	15	12	13	16
10. Depth of first region of transition (4—3)	1	1	2	1	2	1	3	7	2	2	2	2
11. Depth of easterly up to easterly maximum (5—4)	—	9	8	10	5	9	9	3	6	8	5	7
12. Total depth of easterly (6—4)	—	—	—	—	—	—	—	6	12	—	10	—
13. Depth of second region of transition (7—6)	—	—	—	—	—	—	—	1	1	—	1	1

light westerlies (Fig. 2). On the other flight days, easterlies did not disappear completely till the balloon could reach the highest altitude. From Table 1, it is apparent that the westerly maximum and the easterly maximum lie in the middle of their respective channels. Average depth of westerly channel upto westerlies maximum is about 8 km (total average depth being 16 km), while depth of easterly channel upto easterly maximum is about 7 km. Total average depth of easterlies could not be determined due to lack of data. But as evident from flights of 17 and 22 April and 3 May, the total depth of easterlies double the depth up to easterly maximum. The average easterly depth can thus be assumed to be 14 km (double the average depth up to easterly maximum). The total depth of westerly and easterly channels seems, therefore, to be nearly the same. Depth of easterlies given by Colon (1951) was about 7 km only. But Johnson (1946) and Scrase (1949) showed easterly components to be present upto 30 km during summer months. Brasefield's (1950) strong easterlies prevailed up to as high as 36 km. However, apart from the few observations, the upper limit of Krakatoa currents have not yet been definitely delineated.

3. Maxima and Minima of winds

In all the flights (Fig. 2) there were found two maxima and at least one minimum of wind velocities. The first maximum velocity occurred at an altitude of about 11 km in the westerlies of the upper troposphere. Then at an altitude of about 18-19 km, velocity became minimum and the direction variable. After this the easterly direction was well established (except on 29 February 1960) and the winds approached a maximum value at about 26 km (Table 1), after which their velocity began to decrease. This second maxima at 26 km was quite conspicuous and, on 29 March 1960, exceeded even the first maxima of lower altitudes. The first maximum

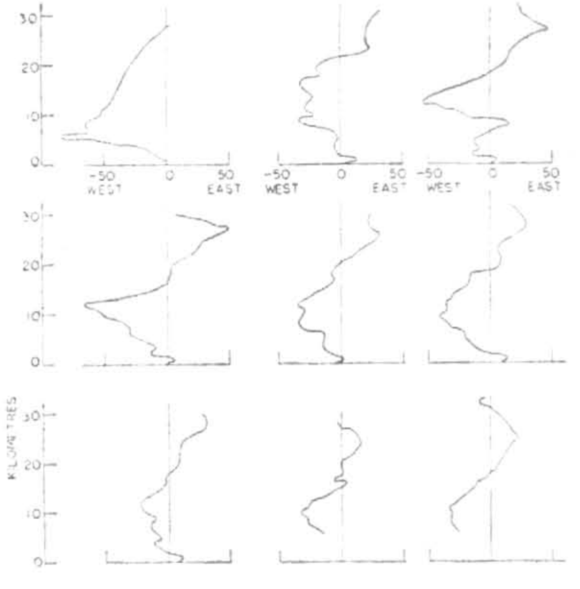

Fig. 2. Easterly — Westerly components (in kt) *vs* altitude in km

is a well studied phenomenon in meteorology, and is referred to as 'Jet stream'. The mean level of this maximum is very much near to the mean position of the jet stream over all latitudes (Davis 1951). Krishna Rao (1952) found these jets to be easterly between 5°N and 18°N at 16-18 km in summer. Davies (1952) also found easterly winds (greater than 45 knots) between 12 and 15 km on many occasions during January 1948 and November 1951 at Nairobi (East Africa). But the present study for Hyderabad (which lies at 17°·5N) shows these jets to be westerly in all the eleven observations extending from 29 February to 29 March 1960 and from 17 April to 3 May 1959.

The other maximum at higher altitude has not been observed or described to any great extent due to lack of such high altitude observations. There have been no observations, particularly, over and near about the meteorological equator in India. In the present study, easterly winds appear at about 19 km, increase in strength, reach a maximum value at about 26 km (Table 1) and then, begin to slow down and come to almost a calm value in some of the ascents. Thereafter, the direction again changes from easterly to westerly. Tables given by Ockenden (1939) also indicated such maxima at the same altitude as shown by the present study. Winds, in his case, after reaching 20-25 miles per hour at an average altitude of 26 km began decreasing and approaching a calm region. While ratio of first maximum velocity to second maximum velocity lies between 1 and 2 (Table 2), Ockenden's ratio was too high (between 2 and 6). Gutenberg (1946) showed the wind velocity to be continuously increasing up to 60 km (from 20 km onward). His data had been estimated by using observations of noctilucent clouds, smoke from meteors in day time and sparks from meteors at night. The present data differed from Gutenberg's height velocity curve in as much as the wind velocity did not rise continuously but reached a maximum and, then, began decreasing in most of the ascents.

In Table 2, ratios of maximum westerly component to the mean westerly component in the tropospheric westerlies and a similar ratio for stratospheric easterlies have been found out. In an earlier communication by Kulshrestha and Gupta (1961), relationship between maximum wind velocity and the scalar mean was described. The ratio between the two for westerlies channel varied from 1·6 to 2·9, the average ratio being 2·3, while for easterlies it varied between 1·5 to 2·5, average being 1·9. Here, only east and west components have been considered, as these are the only prominent and steady components throughout the channel of observations. In this case, the ratio comes out to be the same (1·9) in westerlies, as well as easterlies; while for total scalar speed it was greater (2·3) for westerlies than for easterlies (1·9). This proves that easterlies have very little of northerly and southerly components, while westerlies do have northerly and southerly components.

Table 3 gives, datawise, the average scalar winds and average east and north components throughout the observed channel (0-32 km) of atmosphere. Column 2 shows the average scalar winds value ranging from 16 to 37 knots. Average for the month of March comes out to be 23 and for April 18. In columns 3 and 4 of this table, average east and north components have been shown. Except on 29 February when the easterlies did not establish till the highest altitude reached, average easterly/westerly and northerly/southerly components are very small for each day; average resultant wind for March is 7 knots and for April-May 8 knots only. The ratio between scalar mean and vector mean comes out to be of the order of 3 as shown in col 6 of Table 3. It may also be seen from cols 3 and 4 that upto middle of March northerly component is prominent in the atmosphere and after that period southerly

TABLE 2

Relationship between maximum and mean velocities

	Westerlies			Easterlies		
	Maxima (knots)	Mean (knots)	Ratio west. max./west. mean (col. 2)/(col. 3)	Maxima (knots)	Mean (knots)	Ratio east. max./east mean (col. 5)/(col. 6)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
29-2-60	85	35·2	2·4	—	—	—
3-3-60	33	17·3	1·9	32	20·8	1·5
12-3-60	54	27·1	2·0	47	20·2	2·3
14-3-60	66	29·9	2·2	50	19·5	2·5
19-3-60	34	17·8	2·0	31	16·1	1·9
24-3-60	39	22·9	1·8	29	14·2	2·0
29-3-60	21	9·9	2·1	31	14·7	2·1
17-4-59	33	20·4	1·7	15	8·5	1·7
22-4-59	33	20·7	1·6	21	10·8	1·9
26-4-59	12	7·5	1·6	27	15·2	1·8
3-5-59	21	10·8	1·9	29	17·0	1·7
Average			1·9			1·9

TABLE 3

Scalar and vector winds throughout 0-32 km channel

	Mean scalar wind (knots)	Mean easterly (+) or westerly (—) (knots)	Mean northerly (+) or southerly (—) (knots)	Resultant		Ratio Mean scalar/Mean resultant (col. 2)/(col. 6)
				Direction (Degrees) from true north	Velocity (knots)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
29-2-60	37	—34	+12	290	36	1·0
3-3-60	27	—04	+10	340	11	2·5
12-3-60	25	+02	+08	10	08	3·1
14-3-60	27	—05	—02	255	05	5·4
19 3-60	21	—05	—05	225	07	3·0
24-3-60	22	—05	—03	235	06	3·7
29-3-60	17	+03	—05	150	05	3·4
Average for March 1960	23	—02	+0·5	—	07	3·5
17-4-59	16	—06	—07	215	09	1·8
22-4-59	19	—04	—03	215	05	3·8
26-4-59	21	+09	—10	140	13	1·6
3-5-59	18	+03	—05	155	06	3·0
Average for April, May 1959	18	+0·5	—06	—	08	2·5

component comes into the picture. There is no such case with easterly and westerly components, although the westerly components outnumber the easterly components.

Another interesting feature about these maxima and minima is revealed from the three curves indicating heights of first maximum, minimum and second maximum respectively with respect to different days of observations (Fig. 3). The slope of the first (westerly) maxima seemed to be opposite to the slope of the minima, while slope of the second (easterly) maxima tended to be similar to that of minima. This meant that when the first maxima was at the lowest altitude, the minima and the second maxima were at the highest and *vice versa*. Table 1 gives the altitudes of the first maxima, minima and

TABLE 4

Steadiness of winds in 0—32 km atmospheric channel for March 1960

Altitude	Mean resultant vector winds				Mean scalar wind speed (knots)	Steadiness $\frac{\text{Vector wind}}{\text{Scalar wind}}$ $\left(\frac{\text{col. 5}}{\text{col. 6}} \times 100\right)$
	East (+) West (—) (knots)	North (+) South (—) (knots)	Resultant direction (degrees)	Resultant velocity (knots)		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0	+2	—16	170	16	16	100
1	+9	—03	110	10	12	83
2	—7	+03	290	07	12	58
3	—9	+07	310	11	15	73
4	—12	+06	295	13	16	81
5	—12	+07	300	14	18	78
6	—13	+04	290	14	20	70
7	—18	+04	285	19	25	76
8	—21	+01	275	22	31	71
9	—29	+06	280	30	41	73
10	—30	+06	280	30	37	81
11	—34	+03	275	35	39	90
12	—40	—08	260	42	42	100
13	—32	—05	260	32	36	89
14	—25	—03	265	25	29	86
15	—18	+01	275	18	21	86
16	—13	+01	275	13	16	81
17	—10	+02	280	10	13	77
18	—05	—01	260	05	11	45
19	—08	+03	350	03	12	25
20	+03	+05	40	06	12	50
21	—06	+02	70	06	11	55
22	+13	+03	80	13	14	93
23	+17	+01	85	17	17	100
24	+19	+01	85	19	19	100
25	+24	0	90	24	24	100
26	+29	—03	95	29	29	100
27	+33	+07	75	34	35	97
28	+30	—04	100	30	31	97
29	+29	0	90	29	29	100
30	+23	—01	90	24	24	100
31	+27	—01	90	27	28	96
32	+20	+09	65	22	22	100

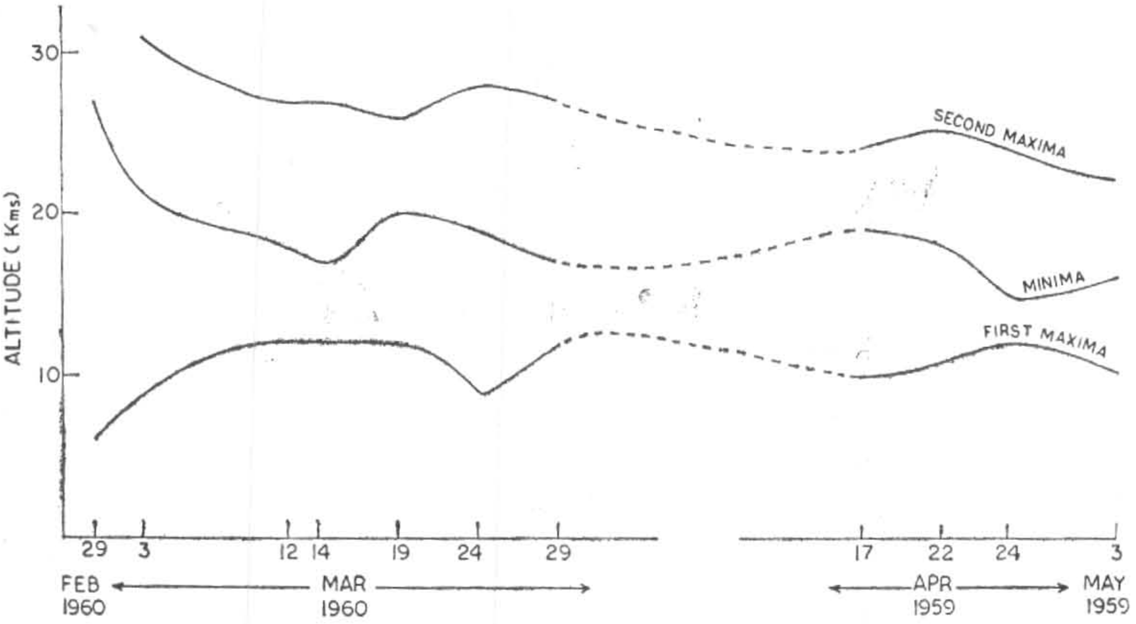

Fig. 3. Relationship between altitudes of first maxima, minima and second maxima

second maxima for different days. Although the present data are too meagre to confirm this effect, it is, perhaps, more than a mere coincidence that such a relationship exists between tropospheric maximum and stratospheric maximum. It looks that the later does affect the former to some extent besides an effect of equatorial and polar regions anticipated by Rossby and Willett (1948).

4. Steadiness of upper winds

North and east components for each altitude were determined and their values for a particular altitude were algebraically added for all the days of observations for the month of March and thus, the resultant wind for each altitude, at an interval of 1 km up to 32 km, was found for the month of March 1960 (steadiness has not been calculated for February 1960 and April and May 1959 as the number of days in these months, for which data are available, was too inadequate to extract any useful information regarding percentage steadiness). Mean scalar wind was also found for the same altitudes for the same month. The mean resultant winds and the average scalar winds for different altitudes are plotted and shown in Fig. 4. It is found that the two curves run very close to each other and maintain parallelism at high altitudes. If the percentage steadiness of winds is denoted by $\frac{\text{Vector wind}}{\text{Scalar wind}} \times 100$, it is concluded that the winds in the upper atmosphere are very steady. Table 4 shows that the steadiness approaches 100 per cent at higher altitudes. Steadiness varies from 58 to 100 per cent in the westerlies, while in the upper easterlies it is maintained nearly at 100 per cent throughout the observed depth of easterlies. In the calm region, at about 19 km steadiness is comparatively poor, being only 25 per cent. The quantitative analysis of the steadiness of high altitude winds, as presented above, is not of much statistical significance and requires confirmation by further data. But it definitely indicates qualitatively that the upper winds are quite steady and the easterlies are comparatively more steady than the westerlies.

5. Results

1. There are two well established opposing horizontal currents in the atmosphere up to 32 km (Fig. 1), westerly current in the troposphere and easterly in the stratosphere in the months of March, April and May.

2. Change over from westerly to easterly current takes place in a narrow zone of very light and variable winds just above the tropopause.

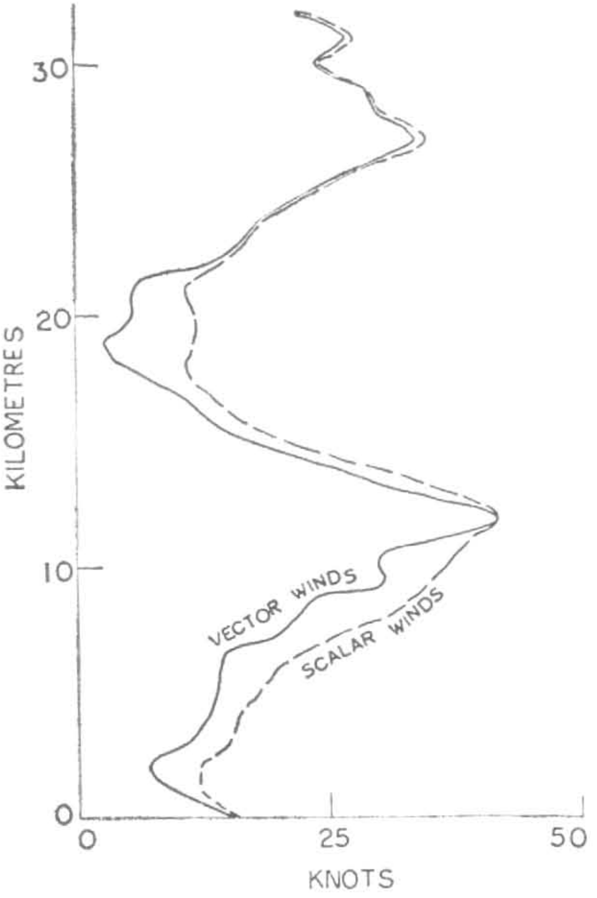

Fig. 4. Steadiness of upper winds

3. There is an indication of another region of westerlies at the top of stratospheric easterlies.

4. Depth of westerlies decreases as the summer advances whereas the depth of easterlies seems to vary irregularly.

5. Each current has a maximum of its own.

6. The ratio of westerly maximum to the mean westerly current is of the order of 2.

7. While westerlies do have northerly and southerly components, easterlies are more zonal. The ratio between the scalar mean and the vector mean of winds in the region 0—32 km is of the order of 3.

8. The winds in the region above 20 km are very steady, percentage steadiness approaching 100 per cent (Fig. 2).

Although the data on which the present study is based are meagre, the features shown by these are in broad agreement with the findings of Kochanski (1955) and Murgatroyd (1957).

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REFERENCES

Brasefield, C. J.	1950	*J. Met.*, 7, pp. 66-69.
Colon, J. A.	1951	*Bull. Amer. met. Soc.*, 32, p. 52.
Davies, D. A. and Sansom, H. W.	1952	*Weather*, 7, 11, pp. 343-344.
Davis, N. E.	1951	Met. Res. Comm., M, R.P., p. 615.
Gutenberg, B.	1946	*J. Met.*, **3**, 2, pp. 27-30.
Johnson, N. K.	1946	*Nature*, **157**, p. 24.
Kochanski, Adam	1955	*J. Met.*, 12, p. 95.
Krishna Rao, P. R.	1952	*Curr. Sci.*, **21**, 3, pp. 63-64.
Kulshrestha, S. M. and Gupta, R. G.	1961	*Indian J. Met. Geophys.*, **12**, 4, pp. 678-681.
Murgatroyd, R. J.	1957	*Quart. J.R. met. Soc.*, **83**, pp. 426 and 448.
Ockenden, C. V.	1939	*Ibid.*, **65**, 282, pp. 551-553.
Rossby, C. G. and Willett, H. C.	1948	*Science*, 108, pp. 643-652.
Scrase, F. J.	1949	*Nature*, **164**, p. 572.
Sheppard, P. A.	1949	*Sci. Prog.*, **37**, pp. 488-503.
Wexler, H.	1951	*Bull. Amer. met. Soc.*, 32, p. 48.
Whipple, F. J. W.	1935	*Quart. J. R. met. Soc.*, **61**, p. 285.