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Stratospheric and Mesospheric Winds in July-August over an equatorial station

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ABSTRACT. Three successful rocket firings were made from Thumba Equatorial Rocket Launching Station during July-August 1964 and wind data obtained, for the first time over India, in the region 16 to 0·3 mb (~28-57 km). The winds are generally found to be eastnortheasterly with speed 60-90 kts upto 1 mb (~47 km). Further above, this regime appears to terminate giving place to a complex wind pattern with considerable wind shears.

RAWIN observations of Trivandrum and a few stations in the same latitude belt on the days of firing were also collected. The combined results are examined in relation to (*a*) the extra biennial oscillation in the lower stratosphere and (*b*) the summer anticyclonic circumpolar vortex which is marked in the higher stratosphere.

Apart from the actual wind data, considerable weight is attached to the character of reflection on the radarscope as observed by the Electronics Group. This gives an indication of pronounced turbulence in summer in the equatorial stratosphere in the region 0·3 to 0·15 mb (~57-63 km).

1. Introduction

The Indian Meteorological Rocket Launching Programme was initiated at Thumba on 14 July 1964. A schedule of dates of firings has been prepared taking into consideration the IIOE and IQSY programmes. So far, three JUDI-DART rockets have been fired successfully, one each on 14 and 16 July and 19 August 1964.

Thumba (08° 32′ N, 76° 52′ E) is an equatorial station. As is well known, there are hardly any observations available above 30 km altitude in the equatorial region, particularly over the extreme south of India. Thus data obtained from Thumba are indeed valuable.

For a proper study of the stratospheric circulation over the equator, a large number of observations would be necessary. However, it would be interesting to examine the results of the first three successful meteorological rocket firings in relation to the present state of knowledge of stratospheric winds. Batten (1961) has provided us with a pattern of the average zonal wind components in the stratosphere. Murgatroyd and Singleton (1961) have delineated the meridional winds. The synoptic analysis of rocket-sonde observations carried out by Finger, Teweles and Mason (1963) and similar research by various other workers in the field reveal a strong westerly zonal flow in winter and relatively weak easterly zonal flow in summer in the Northern Hemisphere at high altitudes. The analysis of observations during the last decade carried out by Veryard and Ebdon (1961a), Angell and Korshover (1962) and others indicate a periodic fluctuation in the 12-monthly running mean value of the zonal wind with a period of 24 to 28 months. It remains to be seen whether this biennial oscillation will continue throughout the present decade and if so, whether the amplitude of the fluctuations will be fully maintained. The data obtained from the rocket firings at Thumba may be viewed in the light of the results of previous investigations in the stratosphere.

2. Observations

The first JUDI-DART rocket with a dart weighing $9\frac{1}{2}$ lbs containing chaff cartridges was launched from Thumba at 1226 IST on 14 July 1964. The second successful firing was on 16 July when the launching was effected at 1440 IST. The next JUDI-DART rocket was launched at 1131 IST on 19 August 1964. The fuse that was employed during these firings was of the pyrotechnique delay type with a fixed time of operation of 135 sec, so that with an angle of firing of 78 degrees, chaff ejection could be expected at an altitude above 65 km. The chaff used was 0·005″ dia., S-Band copper chaff (length 2·1″ and rate of descent 1·5 to 2 km per min at 45 km). The descent of this chaff was tracked by the ground radar equipment—an MPS-19 system. This consists of a Radar Van operating on 2800 mcs for tracking, and a Computer Van in which the data are automatically plotted on various types of charts. The Computer provided the X–Y plot of the chaff target during its descent and also a subsidiary altitude-time strip chart. From these it was possible to carry out data reduction. Further, check could be made utilising the other subsidiary charts from the Computer Van which furnished the horizontal range-time curve and the azimuth-time curve. The general quality of the radar results was satisfactory, although because of the wandering of the radar beam and one or two short interruptions in the recording of data, a little smoothing and interpolation had to be resorted to.

3. Reduction of Data

The method adopted for reduction of data was somewhat different from the nomogram method commonly used in the United States. A simple adaptation of the India Meteorological Department method for Pilot Balloon computations (with modifications as required) was worked out and utilised. The first step was to interpret the subsidiary altitude-strip chart. On this chart the computer recorder traces out a height-time curve, with spikes giving fine reading every ten seconds on an expanded scale, magnified in the ratio 1 : 10. Some care had to be exercised due to the wandering of the base line (coarse reading), but after a little careful puzzling out, the accurate fine height values at the end of the spikes could be determined at various instants of time. These height values were plotted against time on graph paper and an altitude-time curve was drawn. Next, the X–Y plot was considered. The direction of wind at various times was read out and tabulated. Also, by measuring the distance between two points at short intervals of time and multiplying by an appropriate factor depending upon the scale of the chart, the speeds at various instants of time were evaluated and tabulated. The plotting of the wind directions and speeds was carried out on the same graph sheet as the altitude-time curve. But, time was eliminated by reading out the altitude at any particular time from the first curve and plotting the direction as well as speed directly against altitude. Thus, from the points plotted, a direction *vs* altitude curve and a speed *vs* altitude curve could be obtained. Whenever possible the data thus plotted were checked with the figure that could be deduced from the horizontal range and azimuth strip charts, by simple triangulation. Proceeding further, the wind directions and speeds were first determined at mandatory levels at intervals of 5 km as prescribed by the International ROCOB Code approved by W.M.O. Then, following the criteria specified in the ROCOB code, the various significant levels were systematically determined and the wind speed and direction at these levels evaluated. Arranging the results in order of ascending height, the ROCOB messages were prepared and transmitted in less than 6 hours after the time of firing to a number of addresses including the Director General of Observatories, New Delhi, International Meteorological Centre, Bombay and INCOSPAR, Ahmedabad.

4. Results of the three firings

From the first firing, data were obtained from 56 to 36 km. The second successful flight (16 July) yielded results from 54 to $28\frac{1}{2}$ km and the subsequent firing (19 August) from 57 to 37 km. On 14 July, it is seen (Fig. 1a) that the winds were generally ENE, speed about 80 knots below 46 km. Above 46 km, the wind pattern is

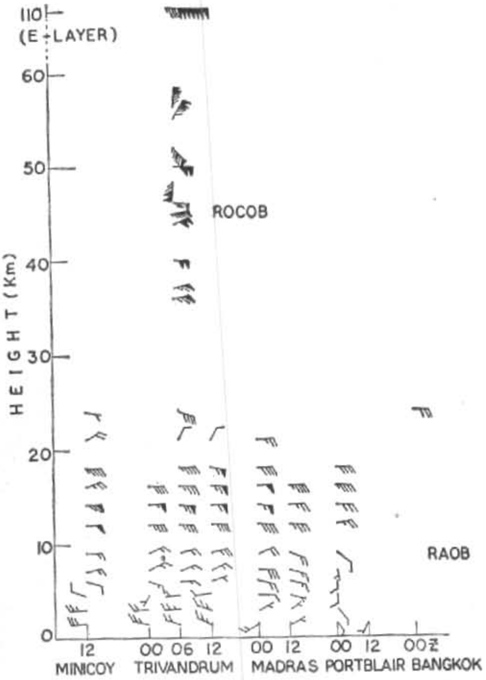


Fig. 1(a). Space-time cross-section from Minicoy to Bangkok on 14 July 1964

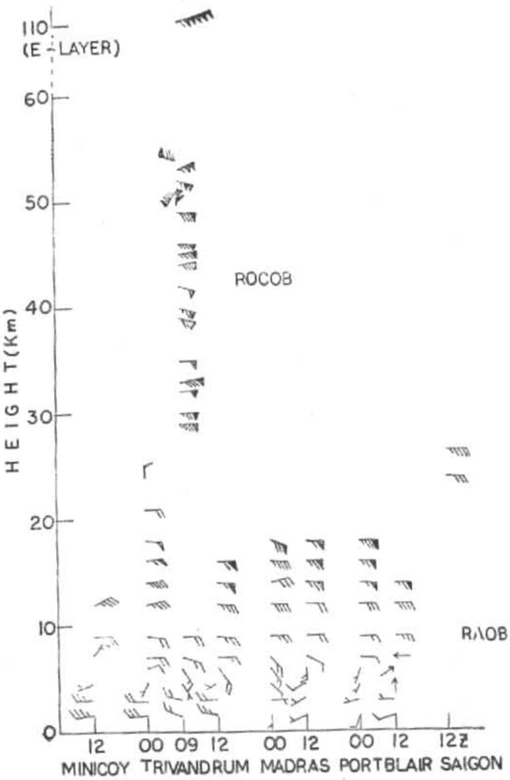


Fig. 1(b). Space-time cross-section from Minicoy to Saigon on 16 July 1964

confused. The data obtained from the subsequent rocket firings confirm fairly well the results of the first firing. The winds on 16 July (Fig. 1 b) are again ENE/E in direction with a speed of about 70 kts upto 48 km. Above 48 km, the pattern is once again complex. On 19 August (Fig. 1 c), a similar distribution of winds is noticed — ENE winds of speed about 80 kts in the region below 46 km with an overlying region of strong and variable winds. On all the three days, the shear values (*see* Figs. 3a to 3 c) show a sharp increase above the meso-peak* region. More will be said about this region later, when examining the radarscope observations.

5. RAWIN and other observations in the same latitude belt

Special Rawin ascents were arranged on 14 July, 16 July and 19 August at Trivandrum (Lat. 08° 18′N, Long. 76° 57′E) at times as close to the rocket launching time as was feasible. Also, special attempts were made at Port Blair (Lat. 11° 41′N, Long. 92° 46′ E), Madras (Lat. 13° 06′ N, Long. 80°18′E) and Minicoy (Lat. 08° 17′N, Long. 73° 03′ E) to attain highest possible levels during Rawin ascents. The available ionospheric wind data from the Ionospheric Station at Thumba for the observation closest to the firing time were also obtained. Almost all these observations have been presented diagrammatically in Figs. 1(a) to 1(c). In addition, the obtainable 30-mb and 20-mb wind data of Bangkok (Lat. 13° 42′N, Long. 100° 36′E) and Saigon (Lat. 10° 48′N, Long. 106° 42′E) are also shown in the figures.

The station nearest to the equator available from the MRN Rocket Network Data Report, Vol. II, published by the

*Meso-peak, also called stratopause, occurs somewhere around 48 km

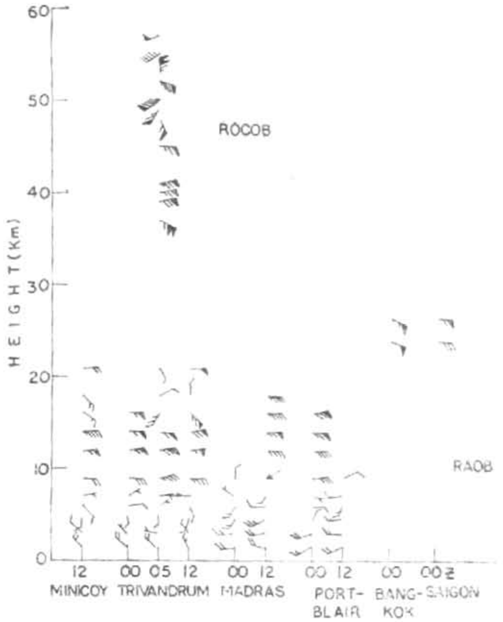


Fig. 1(c). Space-time cross-section from Minicoy to Saigon on 19 August 1964

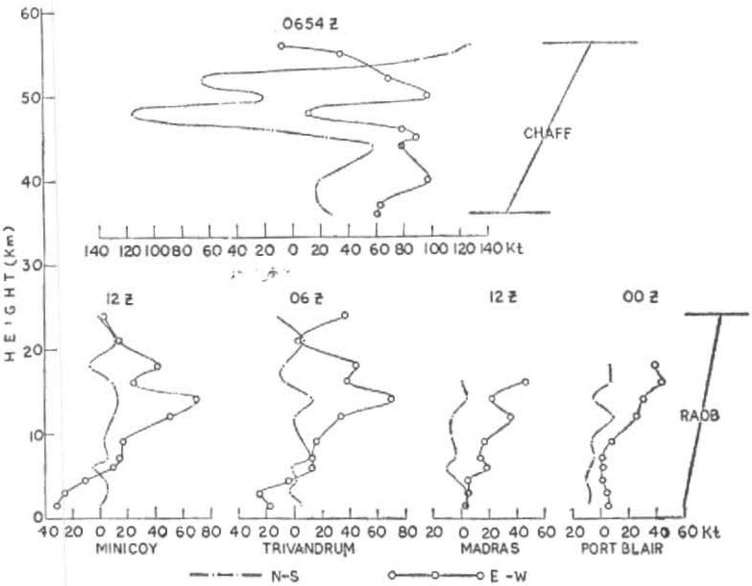
Meteorological Working Group—IRIG, is Kauai, Hawaii (Lat. 21° 54′N, Long. 159° 35′W). The results of July 1962 firings at Kauai and the present firings at Thumba may be examined together. Figs. 2 (a) to 2 (c) show the N-S and E-W components of the winds over Thumba on 14 and 16 July and 19 August respectively and Fig. 2(d) gives similar components of a few representative summer firings at Kauai. It will be seen that in both places the winds below the meso-peak (*i.e.*, 47–49 km) are predominantly easterly.

6. Examination of Results

From stratospheric zonal wind pattern presented by Batten it is seen that, in summer at a latitude of about 8½°, the zonal wind may be expected to be easterly with a speed of about 60 kts at 30 km, increasing gradually to a maximum of about 95 kts at a height of about 47-48 km (meso-peak region). The agreement between this and Thumba data is surprisingly good. Above 47-48 km, the data from the three firings at Thumba deviate from Batten's picture. Instead of gradually diminishing easterlies we find from the Thumba firings strong winds variable in direction.

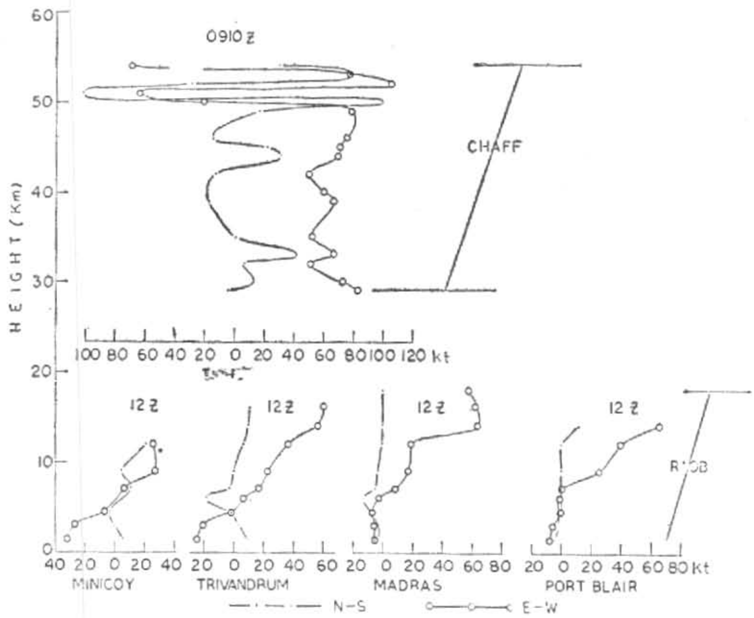
The recently discovered extra-biennial oscillation has a maximum amplitude in the equatorial region. Indeed, according to Veryard and Ebdon (1961a, 1961b) the fluctuations are pronounced some distance (a few degrees of latitude) away from the equator. From all available literature on the subject, it would also appear that the fluctuations are maximum in the 25-30 mb region. The curves representing the biennial oscillation up to 1960 are available in the paper of Veryard and Ebdon (1961 a) and in that of Angell and Korshover (1962). Extrapolating from these curves up to the present time, it is seen that in July-August 1964, it is reasonable to expect that we are about two months past the easterly maximum. Besides, the value of the maximum easterly wind, as can be estimated from these curves, is somewhere between 50 to 60 kts. Interpolating between the highest Rawin data (ascent closest to the time of rocket firing) and the lowest rocket data at Thumba, we find that the zonal component of wind between 25 and 30 mb is positive (easterly) about 45 kts on 14 July, positive about 60 kts on 16 July and positive about 55 kts on 19 August.

We may now proceed to higher altitudes. As the result of the rocket-sonde observations over the last few years, it is now known that in summer there is an anticyclonic and in winter a cyclonic circumpolar vortex. The synoptic analysis charts for 10, 2 and 0·4 mb, constructed by Finger, Teweles and Mason (1963) provide a great deal of information about the circumpolar vortices. Unfortunately in these charts there are no wind observations south of 20°N. This is because of lack of rocket-sonde stations in the equatorial region. The wind observations at Thumba made at 08° 32′N



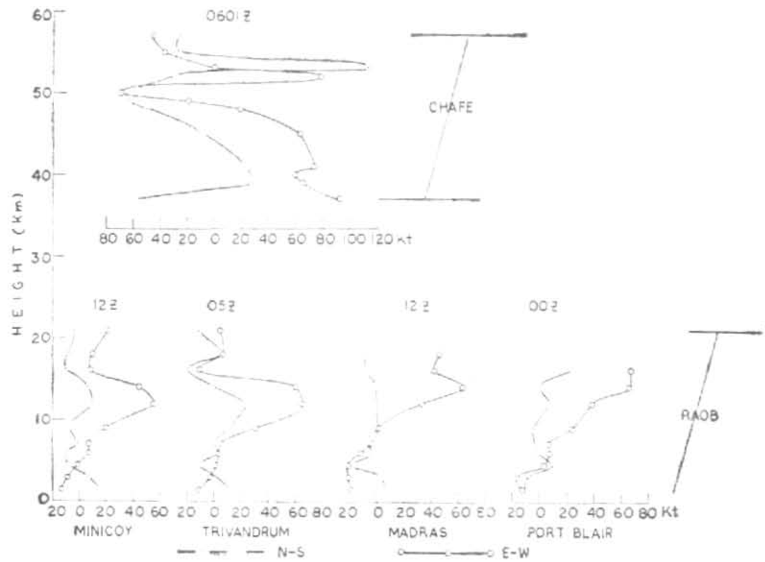
Station — Thumba

Fig. 2(a). N-S and E-W component winds on 14 July 1964



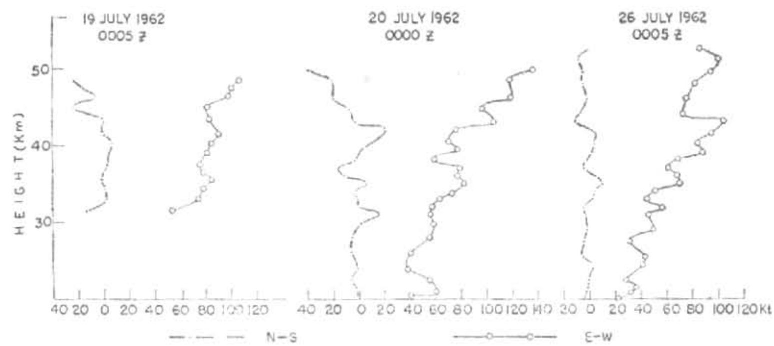
Station — Thumba

Fig. 2(b). N-S and E-W component winds on 16 July 1964



Station — Thumba

Fig. 2(e). N–S and E–W component winds on 19 August 1964



Station—Kauai (Hawaii)

Fig. 2(d). N–S and E–W component winds on 19, 20 and 26 July 1962

are, therefore, of immense value. The 10-mb (~30 km) chart of Finger, Teweles and Mason for 9 August 1960 shows an easterly wind of about 30 metres/sec at the lowest latitude belt (round about 28° N) for which data are plotted on their chart. The 30-km wind at Thumba on 14 July is about 090°/28 metres per sec (interpolated value), on 16 July is 090°/38 metres per sec (actual rocket-sonde value) and on 19 August is 090°/40 metres per sec (interpolated value). Proceeding to the 2 mb (~43 km) chart, the winds plotted in the latitude belt around 28°N are again easterly 30 metres per sec. The 43 km wind at Thumba on 14 July is about 075°/51 metres per sec, on 16 July 090°/33 metres per sec and on 19 August 090°/35 metres per sec. Proceeding still higher to the 0·4 mb (~55 km) chart, we find the winds in the 28° N latitude belt to be

080°/30 metres per sec. At this level, over Thumba, only data of 14 July and 19 August are available and the winds appear to be strong but highly variable. Thus the winds at $8\frac{1}{2}$°N compared with the lowest latitude (28°N) winds on the American August charts are in the same direction but perhaps stronger, especially in the higher levels.

It is impossible with only three rocket observations to draw any inferences about the meridional circulation. However, it may be of interest to note that on each of the three occasions the average wind below 48 km has a small northerly component showing a cross latitude flow towards the equator. This may be compared with the meridional circulation models of Goldie (1950), Kellogg and Schilling (1951) and Hubert (1962), which show equatorward flow in summer in the northern hemisphere at similar altitudes.

7. Data at and above the Meso-peak

The reduced data above 48 km and up to about 54-56 km show a confused wind pattern. The Electronics Group who were responsible for tracking the chaff and getting the plots, observed unusually quick dispersion of chaff on all three occasions, during the initial period of chaff descent. It may be mentioned here that the same Electronics Group operated the very same MPS-19 Radar and Computer Vans at Wallops Station, Virginia, U.S.A. in 1963. As such, their remarks on the comparative character of radar reflection are of great significance. According to them at Thumba, on all the three occasions, by the time chaff was acquired, the reflection on the A-scope of the radar showed that the chaff had dispersed widely. The times of chaff acquisition were as follows—First firing 3 min 20 sec, second firing 4 min and third firing 2 min 30 sec after launch time. During all the firings the fuse setting was 135 sec. Taking into consideration the rocket trajectory, as well as the result of upward extrapolation of the chaff descent curve (from the time of acquisition up to 135 sec), it may be inferred that the height at which chaff was ejected was round about 63 km. On 14 July, the Radar Group reported a width of the chaff-cloud of about 2000 yds soon after acquisition. On 16 July, the width of the chaff-cloud at acquisition time reported by them was about 1700 yds. On 19 August the width of cloud was 750 yds at 2 min 30 sec growing rapidly to 2000 yds by 6 min 15 sec. They also add that this much horizontal spread was observed normally at Wallops Station only after about 15-20 mins of chaff descent. Although equally definite data about the dispersion in the vertical (elevation) could not be obtained, the Radar Group feel that the vertical dispersion was also somewhat higher than their normal experience in U.S.A.

It might also be mentioned that a balloon carrying radar reflecting foil was launched at Thumba on 14 July, 16 July and also on 19 August, a short while before rocket launching. This was tracked by the same MPS-19 system. The points obtained on the X-Y plot during balloon tracking are relatively well defined, but when chaff was tracked, a little while later in each case, the points were spread out and could not be distinguished properly. This is probably due to the radar beam shifting between centres of concentration in the spread-out chaff-cloud, instead of remaining steady on a relatively pin-point target. From what has been said above, it would be reasonable to infer that between 55-63 km atmospheric turbulence should be marked. The coefficient of relative diffusion should be high. These inferences are also compatible with the wind data in the region 48-57 km, obtained after reduction from the three actual rocket soundings. Putting both together, it might be said that the region above 1 mb (~47 km) upto at least 0·15 mb (~63 km) over Thumba in July-August is a region generally of turbulence, marked diffusivity and shear.

8. Wind shears

The wind shears have been calculated for various slabs, according to convenience,

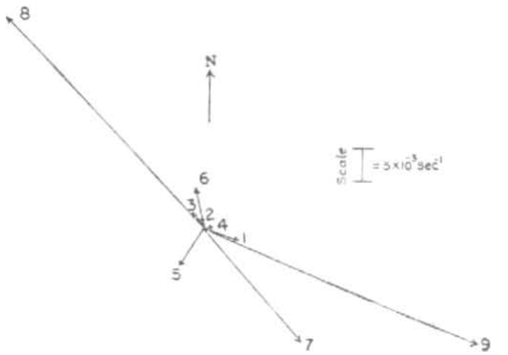


Fig. 3(b). Distribution of vertical wind shear over Thumba on 16 July 1964

Code	1	29—32 km
	2	32—35
	3	35—38
	4	38—42
	5	42—45
	6	45—47
	7	47—50
	8	50—52
	9	52—54

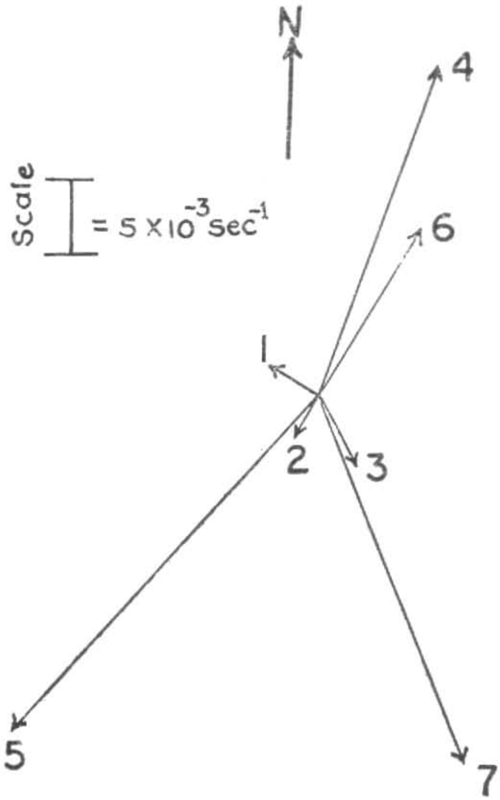


Fig. 3(a). Distribution of vertical wind shear over Thumba on 14 July 1964

Code	1	36—38 km
	2	38—42
	3	42—44
	4	44—48
	5	48—50
	6	50—52
	7	52—56

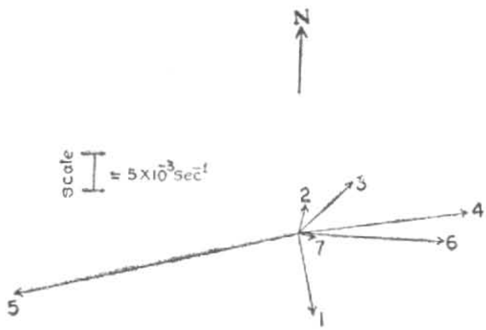


Fig. 3(c). Distribution of vertical wind shear over Thumba on 19 August 1964

Code	1	37—41 km
	2	41—45
	3	45—48
	4	48—50
	5	50—52
	6	52—55
	7	55—57

from the rocket-sonde wind data. The results for 14 and 16 July and 19 August are presented in Figs. 3 (a), 3 (b) and 3 (c) respectively. It will be seen that, below 48 km, the shear values are in the region 9 m/sec/km on 14 July, 4 m/sec/km on 16 July and 9 m/sec/km on 19 August. These shear values agree at least in order of magnitude with the results of many other rocket-sondes in temperate latitudes. Above 48 km, the shear values suddenly jump upto an average of 24 m/sec/km on 14 July, 40 m/sec/km on 16 July and 21 m/sec/km on 19 August.

9. Stability considerations

The order of magnitude of the Richardson's number may be evaluated with the help of the wind gradient ascertained from the rocket firings. As no temperature measurements were made at the same time, we have no alternative but to use climatological values of temperature — although this is unsatisfactory, this might give us the order of magnitude, which may be of some use. A further assumption is made that the meso-peak is in the vicinity of 47-48 km over Thumba in July-August in order to explain the sharp change from a steady easterly flow regime below to a highly turbulent regime above. On this basis the Richardson's number

$$Ri = \left\{ g \, \frac{1}{T} \left(\frac{\partial T}{\partial z} + \Gamma \right) \right\} \Big/ \left(\frac{\partial u}{\partial z} \right)^2$$

assumes the following values—

(*a*) Below the meso-peak

$$\partial T/\partial z \simeq 2°\text{C/km (climatological value)}$$

$$\beta \text{ (Static stability)} = \frac{1}{T} \left(\frac{\partial T}{\partial z} + \Gamma \right)$$

$$\simeq \frac{11 \cdot 8}{280} \text{ km}^{-1}$$

$$\simeq 4 \cdot 2 \times 10^{-2} \text{ km}^{-1}$$

$\partial u/\partial z$ from the three rocket ascents below 48 km is 7·3 metres/sec/km (average value).

$$\therefore Ri = g \, \beta \, / \, (\partial u/\partial z)^2$$

g may be taken as 9·64 metres/sec ^{2} at 48 km.

$$\therefore Ri \simeq (9 \cdot 64 \times 4 \cdot 2 \times 10^{-2}) \, / \, (7 \cdot 3/1000)^2$$

$$\simeq 7 \cdot 6$$

(*b*) Above the meso-peak

$$\partial T/\partial z \simeq -3°\text{C/km (climatological value)}$$

$$\beta \text{ (Static stability)} = \frac{1}{T} \left(\frac{\partial T}{\partial z} + \Gamma \right)$$

$$\simeq \frac{6 \cdot 8}{280} \text{ km}^{-1}$$

$$\simeq 2 \cdot 4 \times 10^{-2} \text{ km}^{-1}$$

$\partial u/\partial z$ from the same rocket ascents above 48 km is 28·3 metres/sec/km (average value).

$$\therefore Ri = g \, \beta \, / \, (\partial u/\partial z)^2$$

g=9·64 metres/sec^2 as in (*a*) above.

$$\therefore Ri \simeq (9 \cdot 64 \times 2 \cdot 4 \times 10^{-2}) \, / \, (28 \cdot 3 \, / \, 1000)^2$$

$$\simeq 0 \cdot 29$$

Thus the Richardson's number changes by a factor of more than 25 from the conditions in (*b*) to the conditions in (*a*). The large value of the Richardson's number (~7·6) in (*a*) fits in with the stable conditions and steady easterly flow. On the other hand the very small value of the Richardson's number (~0·29) in (*b*) should lead to considerable instability and this fits in with the observed turbulent regime.

10. GEOALERTS

There was only one message reporting the existence of MAGCALM on 16 July. Except for this, no STRATWARM or other Geoalert messages were received on 14 July, 16 July and 19 August. Sudden stratospheric warming is, of course, not to be expected in July or August in the northern hemisphere even at high latitudes.

11. Acknowledgements

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