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Stratospheric and lower Mesospheric Wind Systems in the Equatorial Region

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ABSTRACT. Rocket wind data from 25 firings over Thumba (India) have been used in conjunction with similar data from other low latitude stations like Ascension Island, Colon (Panama), Natal (Brazil), Barking Sands (Hawaii) and Sonmiani (Pakistan). Behaviour of the stratospheric and mesospheric winds seasonally, in the equatorial region and outside it, has been studied. A strong easterly jet is detected over the equatorial stations in January, with core winds varying from 35 to 60 mps and height varying from 42 to 50 km. From a synoptic study of the rocket wind data pertaining to 17 March 1965 over Thumba, Ascension Island, U S. Navy ship *Croatan* at 13°S, 78°W, Barking Sands and Sonmiani, it is inferred that in the equinoctial month of March, the stratospheric wind speed increases with proximity to the equator, with the region of maximum wind speed to the south of the equator; but in the mesosphere the region of maximum wind is to the north of the equator. Jet stream in the troposphere (both easterly and westerly) in the Indian region, has been studied in relation to the stratospheric winds over Thumba and Sonmiani and found that there is no obvious relation between the trophspheric jets and the stratospheric wind system. Lack of correlation between the zonal (and also meridional) wind speeds in the stratosphere and the ozone content above the station, indicates that ozone mixing may be taking place mainly in the vertical. Vertical wind shears have been computed for rocket flights over Thumba and Sonmiani and their plots against height reveal that turbulence is larger over Thumba than over Sonmiani. In the equatorial region, there is considerable wind shear in the equinoctial months, which decrease in winter when there is a peak shear in the mesosphere near 52 km. Outside the equatorial region, there is very little seasonal variation in the wind shear, either in the stratosphere or in the mesosphere. The rocket wind data of Thumba do not indicate oppositely directed winds at each level from one year to the next, as is shown by the data of Kwajalein. It is, therefore, inferred that the amplitude of the quasi-biennial wave is greater over Kwajalein than over Thumba, contrary to expectation.

1. Introduction

Our understanding of the physical processes taking place in the stratosphere and mesosphere has taken a great stride in recent years, due to the advent of the sounding rockets. Although a general picture of the upper atmoshpere was known even earlier, our knowledge of the various meteorological elements like temperature, pressure, density, in the upper atmosphere is now more precise than before. In the equatorial region, Reed (1966) studied the rocket wind data over Ascension Island (Lat 8°S) and Barking Sands (Lat. 22°N) and found that the long term mean zonal wind was easterly near the equator, in the stratosphere and westerly in lower mesosphere. The semi-annual cycle is strongest near the equator and a core of maximum east winds exist in summer near Lat. 15° in the layer between 40 and 45 km. Miers (1967) analysed the rocket wind measurement over Colon, Panama (Lat. 9°N) and concluded that the same 6-month, 12-month, and quasi-biennial cycles were observed over Colon, as over other equatorial stations.

Rao (1967) presented the data obtained from rocket wind measurements over Thumba (Lat. 8°N) during the years 1964-66. He showed that in the stratosphere, the wind flow was predominently easterly, with westerly winds above 25-30 km in April and October-November. In the mesosphere westerlies became more frequent. The transition to this pattern from mid-latitude wind regime took place gradually in the subtropics. He also found that in certain periods a regime of pronounced shears and marked turbulence seemed to prevail in equatorial mesosphere.

In the present paper, the rocket wind data of Thumba (8°30′ N, 76°54′ E) have been studied with similar data over other equatorial stations—Ascension Island, Colon, Natal (Brazil) and over low latitude stations outside the equatorial region, like Sonmiani (Pakistan), and Barking Sands (Hawaii). The seasonal variation in the zonal winds over equatorial region has been compared with the seasonal variations outside the equatorial region. A study has been made of the rocket wind measurements on 17 March 1965, over a few low latitude stations and it is shown that the structure of the wind system in the equinoctial month of March, is the same on either side of the equator in a belt of 30° Lat. The wind system changes with increase of latitude. A study of the rocket wind data over Thumba and Sonmiani, in relation to the tropospheric jet stream activity reveals that there is no direct relationship between the upper tropospheric and stratospheric wind systems. It is shown that Thumba data do

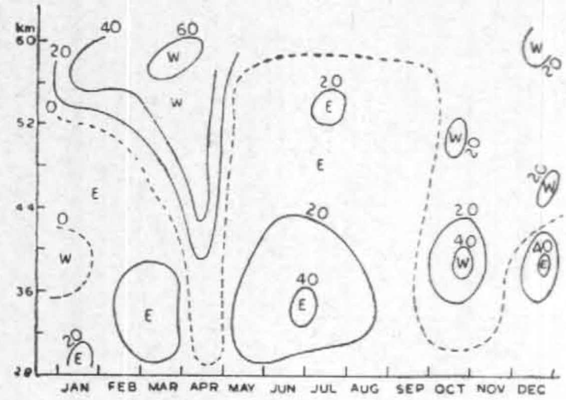

Fig. 1(a). Thumba, India

Fig. 1(b). Ascension Island
(*after* Reed 1966)

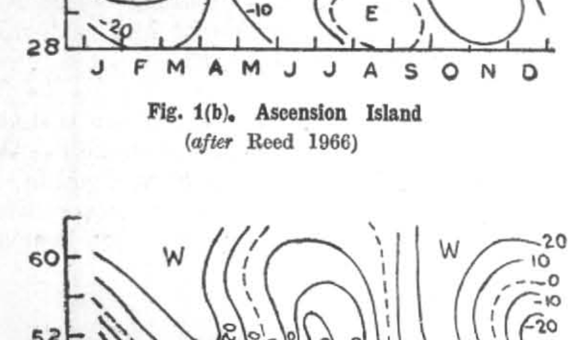

Fig. 1(c). Colon, Panama
(*after* Miers 1967)

Fig. 1(a)-1(c). Variation of zonal wind (m/sec) with month and altitude

not support the view that in the stratosphere the quasi-biennial oscillation is so strong as to cause wind reversals in every 12 months. Thus, an attempt is made to present a synthetic picture of the stratospheric and lower mesospheric wind systems in the equatorial region.

2. Analysis of data

In the following study, the rocket wind measurements over the following stations have been used.

	Latitude	Longitude
Thumba (India)	8° 30′ N	76° 54′ E
Ascension Island	7° 59′ S	14° 28′ W
Colon (Panama)	9° 20′ N	75° 59′ W
Natal (Brazil)	5° 45′ S	35° 10′ W
Sonmiani (Pakistan)	25° 12′ N	66° 45′ E
Barking Sands (Hawaii)	21° 54′ N	159° 35′ W

For Thumba, the data have been extracted from the original working sheets. For the other stations they have been taken from the papers by Reed (1966), Miers (1967) and Quiroz and Miller (1967).

In the study of the seasonal variation of the stratospheric and mesospheric winds, we have departed from the conventional practice of division into monsoon, post monsoon, winter and premonsoon seasons. We have followed the practice of dividing the year by the change in the declination of the sun, as it is done in most geophysical studies. Thus J-season (summer in the Northern Hemisphere) comprises May, June, July and August; D-season (Northern winter) consists of November, December, January and February and E (equinoctial season) is made of March, April, September and October.

3. Zonal winds over equatorial stations

Figs. 1(a), 1(b) and 1(c) represent the average zonal winds month by month from 28 to 64 km for Thumba (1964-66), Ascension Island (1964-65), and Colon, Panama (1964-65). Figs. 1(b) and 1(c) have been reproduced from Reed and Miers. It is seen from these figures that the winter easterlies (J-season) over Ascension Island extend upto about 60 km with a core near 48 km. The rocket wind measurements over Natal (Brazil, 5°45′S, 35° 10′W) also show similar wind pattern (Quiroz and Miller 1967). But over Colon (Lat. 8°N) the winter easterlies (D-season) extend upto 56 km in December, January and February and only upto 32 km in November.

But over Ascension Island in summer (D-season) easterly winds prevail over the entire stratosphere and mesosphere (extending at least upto 64 km) with a maximum near 48 km. The same situation prevails in J-season over Colon and Thumba. These observations suggest that the southern hemispheric wind systems in the stratosphere and mesosphere extend into the northern hemisphere, at least upto about 10° N Lat.

In the northern hemisphere (over Thumba and also Antigua, Lat. 17°N) we have weaker summer easterly maximum located at lower latitude than in winter. The altitude of the core of the summer easterly maximum is different at different stations—Thumba 34 km, Colon 52 km, and Antigua 45 km. But, in the southern hemisphere (over Ascension Island), we have stronger summer easterly maximum at lower altitude, than in winter. There appears to be a latitudinal symmetry in the easterly maxima. However, all the equatorial stations clearly show a marked semi-annual variation in the wind system—easterly in the solstices and westerly in the equinoxes.

A strong easterly jet core is present in the equatorial region in January. Its height over different stations and the strength of the maximum wind speed are given below—

	Height of jet core (km)	Maximum wind speed (mps)
Thumba	42	35
Colon	48	40
Ascension Island	44	60
Natal	50	50

The easterly jet appears to be stronger in the southern hemisphere than in the northern, the core being at a height between 42 and 50 km. The jet is not present over Antigua (17°N) and therefore it may be inferred that it is purely an equatorial phenomena. (In this discussion, by 'Jet' we mean only a wind maximum; we have no observations of temperature gradient).

In the E-season (March, April, September and October) over the equatorial region, the easterlies are confined to the lower stratosphere and westerlies exist in the upper stratosphere and mesosphere. The maximum of the westerlies is to be found in the mesosphere between 56 and 60 km. The maximum westerly above Thumba is far stronger than over other stations. There is no perfect symmetry about the equator in regard to the maximum wind speed or the vertical extent of the easterly regime.

4. Zonal winds in the low latitudes beyond the equatorial region

Reed (1966) studied the stratospheric and mesospheric winds over Barking Sands, Hawaii (Lat. 22°N). His Fig. 2 (page 4225) is reproduced as Fig. 2 in the present paper. The seasonal variation over Barking Sands is altogether different from the variation in the equatorial region. The winds in the stratosphere and mesosphere, between

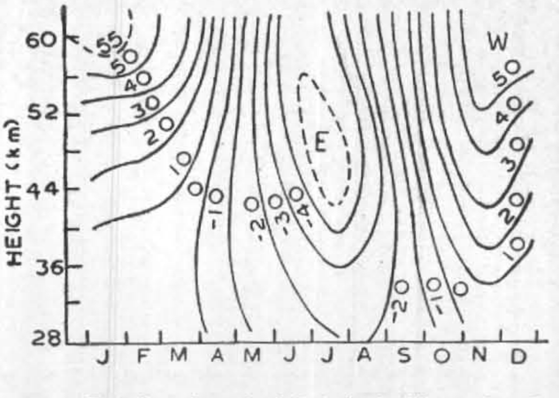

Fig. 2. Variation of zonal wind (m/sec) with month and altitude at Barking Sands, Hawaii

(*After* Read 1966)

28 and 64 km are easterly in the J-season, and westerly in the D-season. The maximum westerlies appear near 60 km in the mesosphere and maximum easterlies near 48 km in upper stratosphere. The stratospheric easterly jet in January is not present. It looks, therefore, that the jet is confined only to the equatorial region. In the E-season winds are very light; transition takes place from westerly to easterly in March-April and from easterly to westerly in September-October.

Winds are much stronger in the low latitudes outside the equatorial region than inside. Also wind speed increases with increase of height, in summer and winter months. In general wind system in the equatorial region is more complex than it is outside.

5. Seasonal variation in the zonal winds over equatorial and non equatorial stations

The zonal winds over Thumba (equatorial station) are compared with those over Sonmiani (non-equatorial station), both situated in comparable longitudes. Figs. 3(a) and 3(b) graph the zonal wind speeds at 35, 45 and 55 km observed over Thumba and Sonmiani, month by month during the period 1964-66. These levels have been chosen to represent the mid-stratosphere, upper stratosphere and lower mesosphere respectively. Fig. 3(a) shows that in the winter month of January, February in the stratosphere (35 and 45 km) winds are easterly, but in the mesosphere (55 km) they are westerly and very strong. This phenomenon extends to the equinoctial month of March. But in the summer months, May to August, at all the levels winds are easterly, decreasing in speed with increase of height. In September and October the change from easterly to westerly takes place

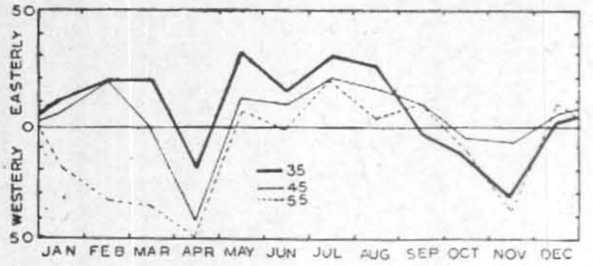

Fig. 3(a). Thumba, India

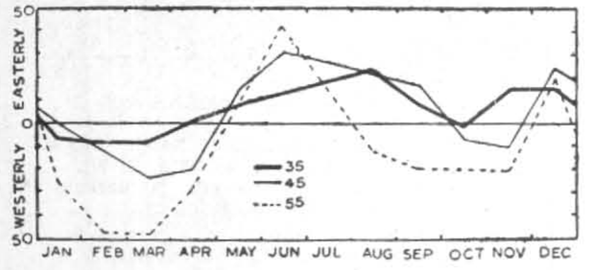

Fig. 3(b). Sonmiani, Pakistan

Figs. 3(a) and (3(b). Variation of zonal wind (m/sec) with month at 35, 45 and 55 km altitudes

beginning at the lowerl evel (35 km). In November winds appear to be more in tune with the equinoctial season than with the winter; we have strong westerly winds at 35 and 55 km, with weak winds at the intermediate level. Some aspects of the seasonal variation of the wind speed over Thumba, has already been discussed earlier.

Over a higher latitude (Sonmiani, 25°N), the wind system is different, as seen in Fig. 3(b). It is not in complete conformity with the time section over Barking Sands, as depicted by Reed (1966). Therefore, it can be inferred that Sonmiani wind system is in a state of transition from the equatorial to the mid-latitude pattern, although Sonmiani is at a slightly higher latitude than Barking Sands. This also indicates that the separation between the equatorial and mid-latitude wind systems, does not take place along the same parallel, at all longitudes.

Over Sonmiani we have summer easterlies and winter westerlies. But in the equinoctial months of March and April Sonmiani has weak westerlies throughout, and in September and October weak easterlies at 35 and 45 km and westerlies at 55 km. As at Thumba, November appears to agree better with the equinoctial months of September and October than with the winter month of December. However, in December we have easterly winds contrary to expectations.

As at Barking Sands, at Sonmiani, winds increase with height, unlike the Thumba winds. Summer easterlies are stronger over Sonmiani than over Thumba. But in the equinoctial months, Sonmiani winds are similar to those of Thumba. These facts lend support to the view that Sonmiani is situated in the zone of transition between the equatorial and mid-latitude wind systems, in the stratosphere and lower mesosphere.

6. Synoptic study of rocket wind measurements

The availability of rocket wind measurements on 17 March 1965, over Thumba, Ascension Island, Sonmiani, Barking Sands, and also by the U.S. Navy vessel *Croatan* at Lat. 13°S, Long. 78°W made possible a synoptic study of the stratospheric and mesospheric wind systems.

Fig. 4 which plots the winds over these five stations, reveals that the location of the ship, Ascension Island and Thumba have similar winds, easterly in the stratosphere, upto 44 km and westerly thereafter. In the equatorial stratosphere, the wind speed increases with the proximity to the equator. As Ascension Island and Thumba are nearly equidistant from the equator, if symmetry considerations apply, the winds would be of the same speed at both the places. However, we find that the Ascension Island winds are stronger than the Thumba winds, indicating that the line of separation between the northern and southern hemispheric winds in the stratosphere, may be to the south of the equator.

In the mesosphere at all these locations, winds are westerly, increasing with height, and at each level increasing again, with proximity to the equator. Here, unlike in the stratosphere, the Thumba winds are stronger than the Ascension Island one, indicating that the region of strongest winds may be to the north of the equator.

Beyond the equatorial region (Sonmiani and Barking Sands), winds are westerly throughout, increasing from 10 mps at 30-km level upwards. Winds over Barking Sands are stronger than those over Sonmiani, in the mesosphere. But in the stratosphere, winds are stronger over Barking Sands than over Sonmiani.

The region separating the easterlies and the westerlies, is near 44 km in the equatorial region, while it is near 26 km outside it.

7. Stratospheric wind and the tropospheric jet stream

It is well established (Koteswaram 1953, 1958) that in the Indian region we have two jet streams in the upper troposphere—a westerly jet in the winter months north of latitude 25°N, at an altitude of 12 km with an average speed of 50 mps; an easterly jet in the summer months, south of latitude 15°N, at an altitude of 14–16 km with wind speed of 50 mps. The easterly jet some times comes down as far south as Trivandrum. With a view to find out whether any relation exists between these upper tropospheric jets and the winds in the stratosphere and lower mesosphere, the rocket winds over Sonmiani and over Thumba, have been examined with respect to the westerly and easterly jets respectively, on the days of rocket firing. The data relating to the jet stream were supplied by the Northern Hemispheric Analysis Centre of the India Meteorological Department, New Delhi.

On 16 July 1964, the easterly jet stream was active over Thumba, with maximum wind speed of 45 mps, at the 100-mb level. In the stratosphere and lower mesosphere, winds were easterly, speed varying from 25 to 40 mps. But on 21 July 1965 there was no jet activity in the Indian region, still stratospheric winds over Thumba were easterly with speed of 30 mps at 35 km.

Again on 15 September 1965 easterly jet was present along Lat. 14°N with maximum wind speed of 25 mps at 100 mb. But the stratospheric winds over Thumba were westerly (light) from 34 km, changing to light easterlies at 54 km. On 16 June 1965 there was no jet activity but the stratospheric winds over Thumba were easterly (strong) up to 41 km, weakening thereafter.

On 19 August 1964 the easterly jet existed over Ahmedabad. Over Thumba there were strong winds in the stratosphere and mesosphere—23 to 56 mps. On 18 August 1965, there was easterly jet activity over south Peninsula, with a maximum wind speed of 25 mps at 200 mb, the upper stratospheric and mesospheric winds were weak. Therefore, the easterly jet activity in the troposphere shows no correlation with the winds in the stratosphere and lower mesosphere over Thumba.

A similar examination was made for possible relationship between the westerly jet activity and the stratospheric and lower mesospheric winds over Sonmiani (Lat. 25°N, Long. 67°E).

On 21 October 1964, 12 January 1966, 16 February 1966, 16 March 1966 and 12 October 1966, the westerly jet was active close to Sonmiani. But the stratospheric and mesospheric winds were not particularly strong on 21 October 1964. But on 16 February 1966, stratospheric winds were weak westerly increasing from 5 mps at 25 km to 13 mps at 48 km. On 17 November 1965, the westerly jet was far away from Sonmiani (running along 37°N from 66°E to 76°E). But the winds in the stratosphere and lower mesosphere were similar to those of 16 February and 16 March, *viz.*, weak westerlies in the stratosphere and strong westerlies in the lower mesosphere. On 20 May and 18 June 1964 there were strong winds exceeding 25 mps in the upper stratosphere and mesosphere but there was no jet activity near Sonmiani.

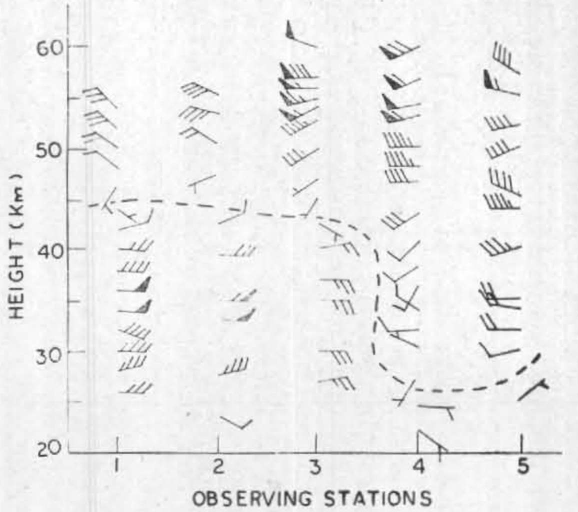

Fig. 4. Rocket winds (m/sec) on 17 March 1965 at (1) U.S. Navy Vessel Croatan (13°S, 78°W), (2) Ascension Island, (3) Thumba, (4) Barking Sands and (5) Sonmiani

Full barb—10 mps; flag—50 mps

These observations indicate that there is no direct correlation between the upper tropospheric wind system and the wind systems in the stratosphere or mesosphere.

8. Correlation between Ozone content and the Stratospheric winds

In order to find out whether there is any relation between the ozone value and the stratospheric winds, correlation coefficients have been worked out between the ozone value over Kodaikanal and the zonal as well as the meridional wind speeds over Thumba at 25 and also at 30 km; similarly correlation coefficients have been worked out between the ozone content over Ahmedabad and the zonal as well as the meridional wind speeds at 25 and 30 km over Sonmiani. As Kodaikanal and Ahmedabad are situated close to Trivandrum and Sonmiani respectively, it is thought that ozone content over Kodaikanal and

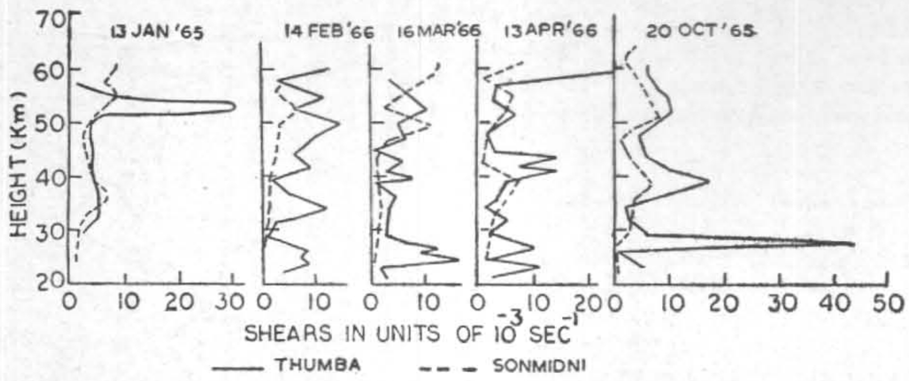

Fig. 5. Vertical wind shear (10^{-3}/sec) over Thumba (—) and Sonmiani — — —)

Ahmedabad would be representative of the conditions over Trivandrum and Sonmiani respectively. The ozone content on the day of the rocket firing, in excess of the monthly mean value is correlated with the wind speed. The correlation coefficients are given below—

	Height in (km)	Correlation Coefficient	
		Zonal wind	Meridional wind
Sonmiani	25	—0·2	0·04
	30	—0·3	0·3
Thumba	30	—0·1	0·5
	35	0·1	—0·4

From these figures it is clear that there is no correlation between the ozone content and the stratospheric winds, zonal or meridional, indicating that there is very little transport of ozone by way of zonal or meridional circulation in the stratosphere.

9. Vertical wind shear

Rao (1967) computed the wind shears over Thumba. He found the mean shear to be slightly higher in the mesosphere than in the stratosphere and suggested that there might be a small peak in the vicinity of 34 km in the stratosphere and another peak in the mesosphere near 53 km.

In the present paper vertical shears have been computed for winds over Thumba and Sonmiani, a few typical cases have been plotted in Fig. 5. These plots show that in general the magnitude of shear is greater over Thumba than over Sonmiani. It indicates greater turbulence near the equator than at a higher latitude.

In the equatorial region, in January, the maximum turbulence is in the mesosphere around 52 km, the stratosphere being more or less steady. But, from February onwards the stratospheric winds exhibit large shears and the peak shear in the mesosphere disappears. It is possible that this reappears in the summer months, May to August. In the equinoctial months (March, April and October) the stratospheric winds show considerable shear (October winds having a peak near 27·5 km). Judging from January winds, one can assume that the winter stratosphere is stable.

Outside the equatorial region, the variation in the stratospheric or mesospheric wind shear, month to month is not significant. The peak shear in the mesosphere near 52 km, is also not present. One can, therefore, infer from these figures, that the mesospheric and stratospheric winds are more stable outside the equatorial region, than inside it.

10. Quasi-biennial oscillation

Reed (1965) has shown that the quasi-biennial oscillation in the zonal wind persists in the middle and upper stratosphere. He and other workers (Veryard and Ebdon 1963, Newell 1964) have shown that the amplitude of the quasi-biennial oscillation is greater near the equator and decreases with increasing latitude. Also it is greater near the stratonull and diminishes with increase or decrease in height. Belmont and Dartt (1966) made an extensive study of the non-periodic variation of the wind in the equatorial stratosphere at 50-mb level. Their figures 1(a), 1(b), 1(c) and 1(d) indicate large changes from year to year. They inferred from these figures that the quasi-biennial wave is much stronger than the annual wave in the region 10°N to 10°S. The rocket wind data of Thumba (and also of other equatorial stations studied in this paper) do not indicate such large changes from year to year, at 30 km and higher. It may, therefore, be inferred that the amplitude of the quasi-biennial wave is large near 50-mb (20-km) level and becomes smaller with increase of height.

Masterman *et al.* (1966) studied the rocket winds over Kwajalein (Lat. 8° 44'N, Long. 167° 44'E) by comparing the zonal wind profiles for June 1964 with those of June 1963. In their Fig. 7 reproduced here as Fig. 6(a) they have obtained oppositely directed winds at almost each level. They attributed this reversal in wind direction to the large quasi-biennial wave. Fig. 6(b) plots the stratospheric zonal winds over Thumba for January 1965 and 1966 and July 1965 and 1966. These plots do not reveal any such wind reversal noticed by Masterman and coworkers (1966), although the latitude of Thumba is comparable to that of Kwajalein. This discrepancy in the two observations may be interpreted as a longitudinal variation in the amplitude of the quasi-biennial wave which is large near the longitude of Kwajalein and may be small in the longitude of Thumba.

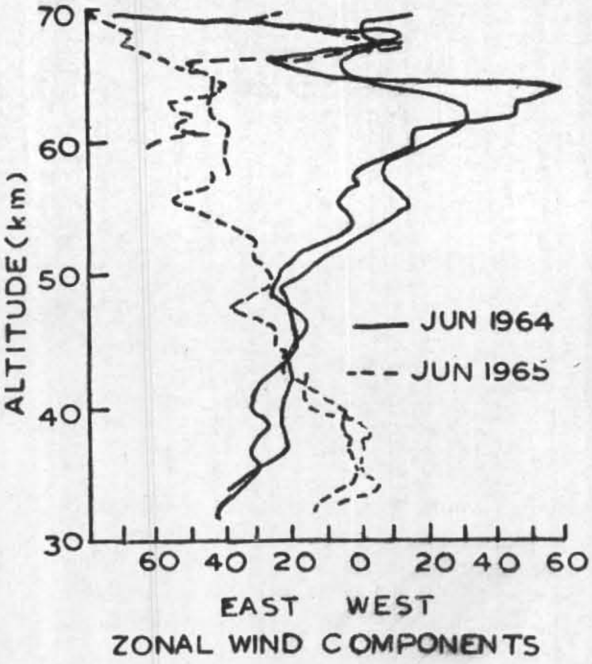

Fig. 6(a). Comparison of four zonal wind profile· f or June 1963 and 1964 at Kwajalein which supports the 26-month cycle theory

(*after* Masterson *et at.* 1966)

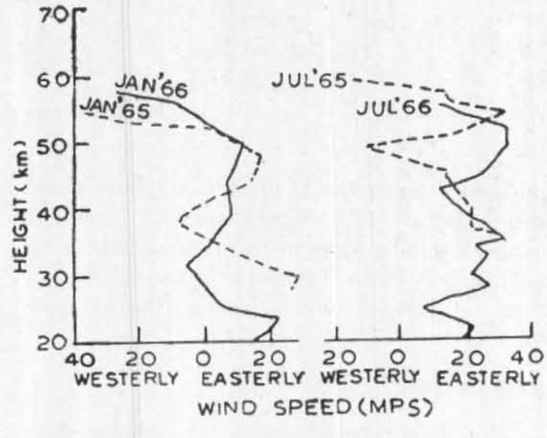

Fig. 6(b), Comparison of four zonal wind profiles for January 1965, 1966 and July 1965, 1966 at Thumba which does not support the 26-month cycle theory

11. Conclusions

In summary, we infer that the wind system in the equatorial zone clearly shows a seasonal variation with easterly winds in the solstices and westerly in the equinoxes. There is an easterly jet in January, between 42 and 52 km, which is stronger in the southern hemisphere than in the northern. It is confined to a narrow region of about 10° on either side of the equator. There is a weaker summer easterly maximum located at lower altitude, than in winter, in the northern hemisphere. But in the southern hemisphere the winter maximum is stronger than the summer one. The seasonal variation in the stratospheric and mesospheric winds, is very much different beyond the equatorial region, being easterly in J-season and westerly in D-season with maxima above 60 km; in the transition months winds are very light. In the equinoctial months, the winds are easterly in the stratosphere up to 44 km and westerly above it, while outside it is all westerly from 28 km upwards. The easterly wind speed increases with promixmity to the equator; but the region of maximum winds is to the south of the equator for the easterly and to the north of it for the westerly.

There is no correlation between the wind system in the stratosphere (and mesosphere) and the wind system in the upper troposphere. Also the stratospheric winds, zonal or meridional are not related to the ozone content near a station. The vertical wind shear in the stratosphere and lower mesosphere is larger near the equator than in the mid-latitudes. There is a seasonal variation in the wind shear near the equator, while it is not present in the mid-latitudes. There appears to be a longitudinal variation in the amplitude of the quasi-biennial oscillation in the winds in stratosphere.

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