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# Equatorial stratospheric jet and its coupling with the tropospheric jet

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ABSTRACT. Analysis of 100 rocket wind measurements over Thumba (India) indicates the existence of an equatorial stratospheric jet stream in 32-42 km range throughout the year. Similar data from other equatorial meteorological rocket stations show that the ESJ is a worldwide phenomenon, confined to the equatorial region only. There are seasonal variations in the intensities and heights of the ESJ. Strong wind shears exist in the vicinity of the ESJ varying between 8 mps/km in the post mosnsoon season to 22 mps/km in the winter. Covariance of $u'$ and $v'$ which is a measure of the angular momentum transport, is computed from surface up to 55km. The height profile of the covariance shows a southward transport of angular momentum maintains the ESJ.

Intensities of the ESJ and the tropical easterly jet (TEJ) are highly correlated. The heights of the tropopause and the stratopause which influence the tropospheric and stratospheric jets respectively, are negatively correlated. The instabilities near the ESJ is highly correlated with the instability near the TEJ seven days later, suggesting that the disturbance near the ESJ travels down to the levels of the TEJ in seven days. From these correlations it is inferred that the tropospheric and stratospheric jets are strongly coupled, just as the polar front jet and the Arctic stratospheric jet are coupled.

## 1. Introduction

In recent years there has been in progress speculation concerning the circulation in the stratosphere. The advent of meteorological rocket launchings has significantly contributed to our knowledge of the stratospheric circulation. Existence of jet stream in the stratosphere over the Arctic region, near 70°N latitude (Reiter 1963) has been known. But in the equatorial region winds of jet intensity were observed only in the winter season.

It was thought till recently, that the stratosphere and troposphere were distinctly separate regions, with different sources of heating. Since the atmosphere is a continuous fluid, stratosphere and troposphere cannot act independently of each other, for changes in one part of the fluid will affect its other parts. Hines (1960) suggested that a coupling between the regions is possible by means of atmospheric internal gravity waves. Newell (1963 a) showed that energy and momentum transport may take place from the troposphere into the stratosphere through the break in the tropopause. Much of the mass exchange between the troposphere and stratosphere takes place in the regions of the jet stream and of tropopause discontinuity. Yanai and Hayashi (1969) studied the three dimensional structure of the large scale equatorial disturbances with special reference to their penetration from the upper troposphere into the lower stratosphere.

In the present paper the stratospheric winds over Thumba (Lat. 08°30'N, Long. 76°54'E) spread over a period of more than two years have been examined alongside with the winds over other equatorial rocket stations. The analysis indicates the existence of stratospheric jet stream, throughout the year.

A study has been made of the possible coupling between the troposphere and stratosphere in the equatorial region, using meteorological rocket observations over Thumba. Instabilities in the tropospheric and stratospheric jet streams and the instabilities near the tropopause and the stratopause seem to be inter-related suggesting a possible coupling between them.

## 2. Data used

The observational support for this study has been mainly from the meteorological rocket launching over Thumba, India. Over 100 flights during the period December 1970 to December 1972, once every week, have been analysed. Observations have also been used from the following stations to support the results obtained from the Thumba data.

| *Stations* | *Latitude* | *Longitude* | *Period* |
|---|---|---|---|
| Ascension Island | 07°59'S | 14°28'W | 1966 – 1971 |
| Kwajalein | 08°44'N | 167°44'E | 1968 – 1971 |
| Fort Sherman | 09°20'N | 79°59'W | 1967 – 1971 |
| Natal | 05°45'S | 35°10'W | 1971 |

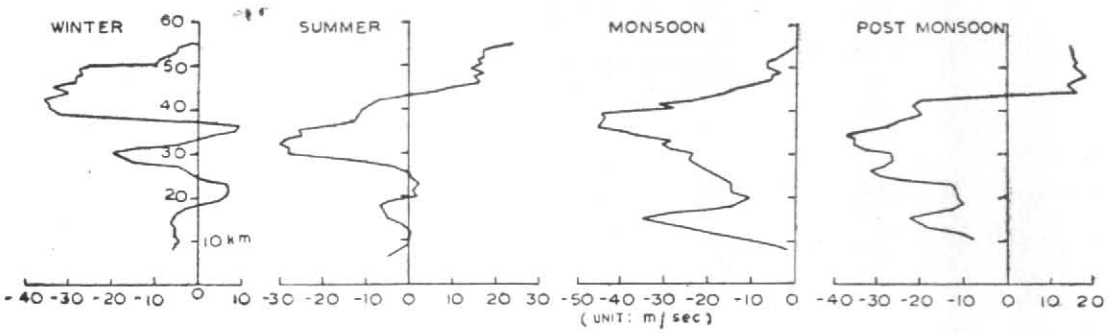


Fig. 1. Average upper wind profile over Thumba

**TABLE 1**

**Seasonal variations in the heights and intensities of the equatorial stratospheric and tropical easterly jets**

| Season | Stratospheric jet | | Tropospheric jet | |
|---|---|---|---|---|
| | Height (km) | Intensity (mps) | Height (km) | Intensity (mps) |
| Winter | 42 | 35 | — | — |
| Pre-monsoon (Summer) | 32 | 30 | 17 | 7 |
| Monsoon | 36 | 50 | 15 | 36 |
| Post monsoon | 34 | 40 | 15 | 23 |

### 3. Stratospheric Easterly Jet

Stratospheric winds over Thumba in the height range 25 to 40 km are easterly during the major part of the year. This is brought out clearly in Fig. 1, which depicts the wind profile during the four seasons—winter (December to February); summer (March to May); monsoon (June to August) and post monsoon (September to November). In the lower mesosphere, generally, strong westerlies prevail with speed reaching even 150 knots, though in December and January the flow is predominantly easterly.

Raja Rao and Joseph (1969) in their study of the stratospheric winds, found a strong easterly jet at a height of about 35 km in the winter months. They did not have enough data for other seasons. With the available data they inferred that the jet was present only in the winter months. In the present study regular weekly rocket launching for a period of over two years have provided adequate material to study the morphology of the stratospheric jet in the equatorial region.

From Fig. 1, it is inferred that the stratospheric easterly jet is present throughout the year, being most intense, 50 mps, in the monsoon season, and least intense in the pre-monsoon season. The height of the jet also varies seasonally, being highest in monsoon and lowest in the post monsoon season.

Seasonal changes in the intensities and heights of the equatorial stratospheric and tropospheric jets are given in Table 1.

These figures suggest a close relation between the stratospheric and tropospheric jets. The seasonal variations in their intensities are similar.

The wind structures in the stratosphere over Ascension Island, Kwajalein, Fort Sherman and Natal also indicate the presence of the easterly jet between 32 and 42 km as shown in Table 2.

The easterlies decrease in intensity with increase of latitude. Over Barkings Sands, Hawaii (Lat. 22°N), no strong winds of jet intensity are observed. It is, therefore, inferred that the easterly jet in the stratosphere is a worldwide phenomenon existing throughout the year but confined to the equatorial region only. The intensity and height of the stratospheric easterly jet vary with season.

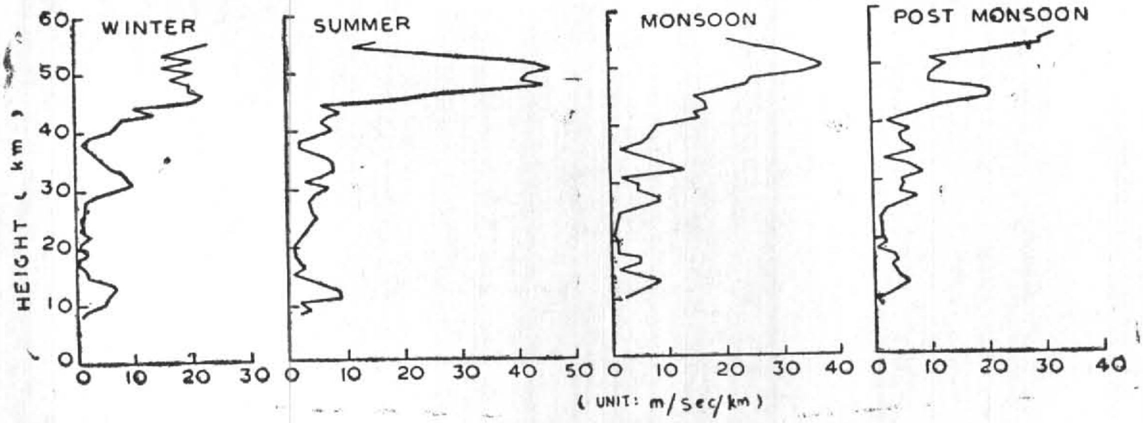


Fig. 2. Variation of wind shear with height

**TABLE 2**

**Heights and intensity of the equatorial stratospheric jet over different stations**

| Station | Winter | | Summer | | Monsoon | | Post monsoon | |
|---|---|---|---|---|---|---|---|---|
| | Height of jet core (km) | Max. wind speed (mps) | Height of jet core (km) | Max. wind speed (mps) | Height of jet core (km) | Max. wind speed (mps) | Height of jet core (km) | Max. wind speed (mps) |
| Thumba | 42 | 35 | 32 | 30 | 36 | 50 | 34 | 40 |
| Ascension Island | 47 | 45 | 33 | 33 | 30 | 40 | 30 | 35 |
| Fort Sherman | 44 | 35 | 34 | 30 | 32 | 40 | 31 | 35 |
| Kwajalein | 45 | 35 | 33 | 30 | 31 | 50 | 30 | 30 |
| Natal | 47 | 45 | 32 | 30 | 34 | 50 | 32 | 35 |

Presence of the equatorial stratospheric easterly jet at about 35 km all through the year is apparently inconsistent with the quasi-biennial oscillation which is characteristic of the stratosphere. We suggest the amplitude of the QBO which is large at about 25 km, decreases with increase of vertical distance from the 25 km level. Therefore, at 35 km level the amplitude of the QBO is small and is, therefore, masked by the intensity of the easterly regime. Hence the existence of the stratospheric easterly jet throughout the year, but varying in intensity.

3.1. *Wind shear in the region of stratospheric jet*

Fig. 2 which depicts the vertical profiles of wind shear during the four seasons, indicates large wind shear in the region of the core of stratospheric jet. This is in conformity with the criteria associated with the tropospheric jet which is characterised by strong wind shear in its vicinity. The wind shear in the stratospheric jet varies between 8 m/sec/km in post monsoon season to 22m/sec/km in the winter, although the intensity of the jet is greatest in the monsoon season. The half width of the jet is largest in the monsoon, being 6.5 km. Therefore, criteria for a narrow core of strong winds with large wind shear also hold good for the stratospheric jet. The thermal aspect of the stratospheric jet forms part of another paper, and has not been considered here.

3.2. *Angular momentum transport*

To study the maintenance of the jet streams by transport of angular momentum northward or southward, the angular momentum transport is computed, for the four seasons, using the seasonal mean values of $u$ and $v$, the zonal and meridional components of wind. In terms of the mean

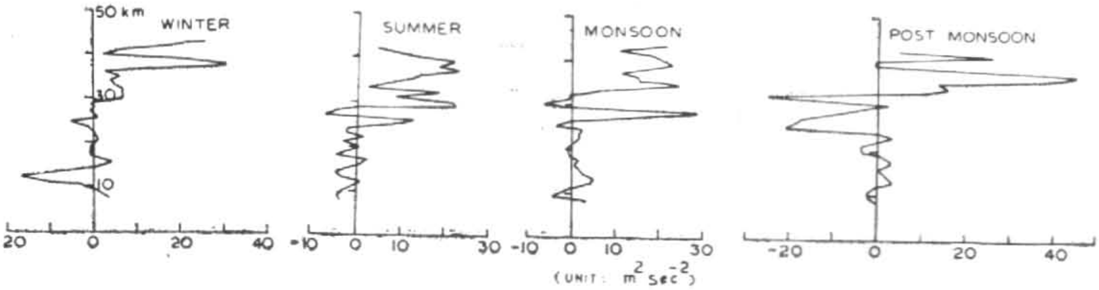


Fig. 3. Covariance of horizontal wind components

velocities $\bar{u}$ and $\bar{v}$ and the corresponding perturbations, $u'$ and $v'$ we write :

$$u = \bar{u} + u'$$
$$v = \bar{v} + v'$$

Angular momentum

$$\frac{1}{n}\,\Sigma\, uv = \frac{1}{n}\left(\bar{u}\,\bar{v} + \bar{u}\,\Sigma\, v' + \bar{v}\,\Sigma\, u' + \Sigma\, u'v'\right)$$

where $n$ is the number of observations. In general the mean of the meridional component and its perturbation are negligible over a long period. Hence, $(1/n)\,\Sigma u'v'$ the covariance of $u'$ and $v'$ can be taken to be a measure of the angular momentum transport. Thus the covariance of $u'$, $v'$ which is a measure of the angular momenum transport has been computed for the four seasons at each kilometre level from the surface upto 55 km over Thumba, as shown in Fig. 3. Fig. 3 shows that in the troposphere there is a positive maximum between 12 km and 15 km, only during monsoon season, indicating the maintenance of the tropical easterly jet by the southward transport of angular momentum. The quasi-horizontal eddy process maintains tropical easterly jet in the same way as the sub-tropical westerly jet in the mid-latitudes. In the latter case there is a large northward drift.

In the stratosphere there is a positive maximum in the covariance of $u'$ $v'$, in all the four seasons, varying in height and intensity seasonally, indicating the southward transport of angular momentum. There exists the quasi-horizontal eddy process in the equatorial stratosphere necessary to maintain the easterly jet in the stratosphere. This is another evidence in favour of the existence of the stratospheric easterly jet in the equatorial region, throughout the year. In the climatological study of the International Geophysical Year Stratospheric data, Starr, and his colleague (*see*, for example, Newell 1963 b) have also found equatorward motion in 100-30 mb region over a wide zone in mid-latitudes. Therefore. the equatorial stratospheric jet is a reality and is present throughout the year.

## 4. Tropospheric-Stratospheric Coupling

Newell (1963 a) suggested that much of the mass exchange between the troposphere and stratosphere occurs in the region of the jet stream and tropopause discontinuity. A large part of tropospheric-stratospheric exchange occurs by what are essentially quasi-horizontal exchange processes in the vicinity of jet streams and tropopause gaps. In the higher latitudes such a coupling exists between the Arctic stratospheric jet and the tropospheric polar front jet (*see*, for example Reiter 1961, p. 254; Palmer 1959). In order to study how far in the equatorial region the tropospheric jet activity and the stratospheric jet activity are coupled, the intensities of the two jet streams during the monsoon season have been correlated. The correlation is highly significant, being 0.893 for about 30 observations. We, therefore, infer that there is a strong coupling between stratospheric jet stream and the tropical easterly jet.

### 4.1. *Instability near the stratospheric and tropospheric jets*

Using the well known formula :

$$R_i = \left(T + \frac{\partial T}{\partial z}\right) g \bigg/ T\left(\frac{\partial v}{\partial z}\right)^2$$

the Richardson number has been computed for different levels from the surface upto the mesopause, for the 100 flights. Large values of $R_i$ (of the order $10^3$) suggest that stratosphere generally is a stable region. Only above 40-42 km instability sets in as indicated by the value of $R_i$ less than 1. Near the stratospheric jet (around 35 km) the $R_i$ is low.

The instabilities near the stratopause and the tropopause on any day have no obvious correlation; when lag correlations between these factors are worked out, it is seen that the instability near the stratopause has a very high correlation with the instability near the tropopause 7 days later; the correlation coefficient being +0.954 for winter and +0.839 for monsoon season. We interpret this result in the following way. In the equatorial region an instability caused by a disturbance near the stratopause travels into the troposphere in seven days. In the study of the coupling between the Arctic stratospheric jet and the polar front jet it has been observed that a change in circulation in the Arctic area seems to become evident first in the stratosphere and only several days later in the troposphere (Reiter 1961, p. 254). Therefore, present study indicates that the tropospheric-stratospheric coupling exists in the equatorial region also, just as it does in the higher latitudes.

### 5. Conclusions

Study of the rocket wind data from 100 meteorological rocket launchings over Thumba spread over two years, indicates the existence of the equatorial stratospheric jet stream throughout the year, in the height range of 32-35 km. The jet stream is a global phenomenon, but confined to the equatorial region only. Strong wind shears also exist near core of the ESJ. There is large southward transport of angular momentum near the ESJ, necessary for the maintenance of the easterly jet.

The significant correlation between the intensities of the ESJ and TEJ suggests strong coupling between them. An instability near the stratospheric jet travels down to the level of the tropospheric jet in seven days.

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