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Angular momentum transport and temperature gradient in the middle atmosphere over the tropical Indian region

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सार — यह शोधपत्र बालासोर और शार (SHAR) पर मध्य वायुमंडल के संवेग अभिगमन और तापमान प्रवणता तथा उसकी मौसमी परिवर्तन से सम्बन्धित है। बालासोर की 1979–1984 और शार की 1979–1982 की अवधि का कोणीय संवेग अभिगमन और तापमान प्रवणता का अनुमान लगाने के लिये साप्ताहिक आर. एच.–200 रॉकेट आंकड़ों का प्रयोग किया गया है। परिणामों से यह संकेत मिलता है कि शीतकाल होकर मानसूनोत्तर से मानसून-पूर्व के दौरान, भूमध्यरेखा की तरफ माध्य गति द्वारा पश्चिमी संवेग का अभिसरण, निम्न मध्यमंडलीय प्रदेश में ग्रीष्म में गोलार्द्धीय पूर्वी पवनों को शीत गोलार्द्ध में प्रवेश करने से रोकता है। मानसून के दौरान दक्षिणाभिमुख भंवर अभिगमन भूमध्यरेखा के अभिध्रुव स्थित मध्यमंडलीय पूर्वी पवन जेट क्रोड़ को बनाए रखता है। तापमान प्रवणता और पवन अपरूपण विश्लेषण उष्णकटिबन्धीय भारतीय प्रदेश पर पूरे वर्ष निम्न समतापमण्डल की दाबघनत्वी प्रवृत्ति को दर्शाता है।

ABSTRACT. The paper deals with the momentum transport and temperature gradient of the middle atmosphere over Balasore and SHAR and their seasonal variation. Weekly RH-200 rocket data for the period 1979-1984 over Balasore and 1979-1982 over SHAR were used to estimate the angular momentum transport and temperature gradient. The results indicated that the convergence of the westerly momentum by the mean motion towards the equator during post monsoon to pre-monsoon through winter restricted the penetration of the summer hemispheric easterlies into the winter hemisphere in the lower mesospheric region. During the monsoon, southward eddy transport maintained the mesospheric easterly jet core located poleward of the equator. The temperature gradient and the wind shear analysis showed the barotropic nature of the lower stratosphere throughout the year over tropical Indian region.

1. Introduction

Investigation of the middle atmosphere over India started with the advent of M-100 rocket launching from Thumba (8°32′ N, 76°51′ E). During Monex 1979, additional rocket launching began from Balasore (21° 31′ N, 86° 56′E) with RH-200 rocket, though it only provides the wind data.

Using global data many observational studies have been carried out on momentum transport and temperature structure of middle atmosphere. Notable among them are Newell (1963, 68) and Murgatroyd (1965,1969). Over the Indian region, these studies have not attracted much attention probably due to the non-availability of middle atmospheric data. Using M-200 rocket data of Thumba for the period December 1970 to December 1972, Raja Rao and Jayanthi (1975) calculated the eddy momentum in connection with the maintenance of stratospheric easterly jet at a height of 35 km over tropics. They showed that stratospheric easterly jet exists over the tropical Indian region throughout the year and is maintained by southward transport of the easterly eddy angular momentum,

Since no temperature data are available over Balasore temperature structure of the middle atmosphere over this part of the tropical region could not be much examined. Dash (1981), however, used Balasore data and calculated meridional temperature gradient as derived from thermal wind equation. His study concerned temperature gradient change associated with monsoon depression over northeast Bay. He found that the monsoon depression field north of Balasore is colder and south is warmer. However, Murgatroyd (1969) pointed out that in summer, the equatorial stratosphere is colder than the polar stratosphere.

In the present paper, an attempt has been made to estimate seasonal variations in the momentum transport and temperature gradient of the middle atmosphere over Balasore and SHAR (13°07′N, 80°20′E).

2. Data used and method of analysis

Weekly zonal and meridional wind data over Balasore for the period 1979-1984 and over SHAR for the period 1979-82 for the height 25 to 60 km are utilised for the study. The rocket data have been supplemented by the balloon data in the height range 20 to 24 km.

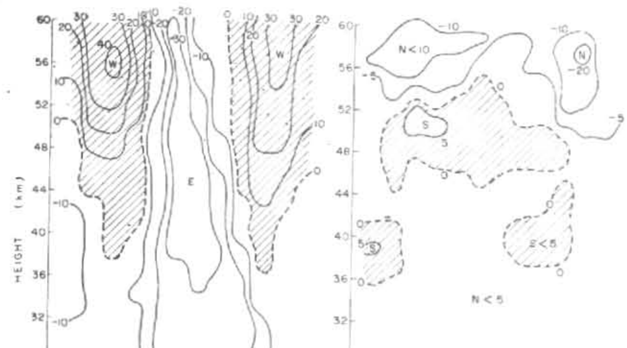

Fig. 1. Vertical time-section of mean wind (mps)

The rocketsonde wind data are obtained from radar tracking of copper chaff released from RH-200 rockets. Experimental checks showed that the accuracy of winds obtained by this process is reasonably good. Devarajan *et al.* (1984) estimated the root mean square (r.m.s.) errors of the data and they found that r.m.s. error is 2-4 mps over the 20-60 km range for the rocket wind data from SHAR and Balasore, the lower values being applicable in the lower part of the range.

First mean monthly values of wind at 1 km height interval (Fig. 1) for the entire period were calculated. From the mean monthly values the angular momentum, transport and temperature gradient were computed at different heights in the height range 20 to 60 km. These values were then combined to arrive at the seasonal values.

In principle, an observed wind can be analysed into mean motion (steady component), standing eddy (spatial irregularities) and transient eddy (temporal irregularities). But owing to the lack of data, only transient eddies are calculated. Observed wind (u) can be written as :

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

and

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

where, $\bar{u}$, $\bar{v}$ are the mean zonal and meridional velocities respectively and u' and v' their corresponding irregularities. Transport of angular momentum is calculated from the following relationship :

$$\frac{1}{n}\sum uv = \frac{1}{n}\sum (\bar{u}+u')(\bar{v}+v') \simeq \bar{u}\bar{v} + \overline{u'v'}$$

as $\Sigma u'$ $\Sigma v'$ are considered negligible over a long period; here n is the number of observations and bar signifies mean values and $\bar{u}\bar{v}$ and $\overline{u'v'}$ are the average angular momentum transport by mean motion and eddies respectively.

Meridional temperature gradient, dT/dy at a height z is calculated by the following thermal wind equations (Chapman 1954) :

$$\left(\frac{dT}{dy}\right)_z = \frac{f}{R}\,\frac{u(z_1) - u(z_0)}{\ln(z_1/z_0)}$$

where, $z_1 > z > z_0$. R is the gas constant and f is the coriolis parameter. Positive temperature gradient, (dT/dy) implies north of Balasore/SHAR is colder.

3. Results and discussion

3.1. *Angular momentum transport by mean motion*— Fig. 2 depicts the angular momentum transport by mean motion over Balasore and SHAR. It can be seen that practically no significant transport occurs on the whole stratosphere throughout the year except during monsoon. In monsoon, the average transport in the stratosphere is northward over Balasore while over SHAR the northward transport is restricted up to 40 km and southward flux is seen between 40 & 52 km. In the lower mesosphere particularly above 53 km the transport is northward over both these stations. The highest value of this northward transport hardly exceeds 80 m^2/sec^2 in the monsoon season. In other seasons in the lower mesosphere, the transport is found to be southwards over both the stations. The maximum southward transport in the lower mesosphere of more than 350 m^2/sec^2 occurs in the post monsoon season over Balasore at a height around 58 km. Further more, it can be seen that except monsoon, during the remaining seasons, the highest values of the southward transport of the angular momentum by mean motion occurs over Balasore. This indicates that there is a convergence of westerly momentum towards the equator in the lower mesosphere from post monsoon to pre-monsoon through winter, though in all these seasons the lower mesospheric westerly jet is located at higher latitudes, mean zonal wind analysis over Thumba and Balasore (Mukhopadhyaya and Sarkar 1986) indicates the presence of easterlies in the whole stratosphere up to about 50 km during the winter season. This is due to the penetration of summer hemispheric easterlies into winter hemisphere (Hopkins 1975). It is believed that convergence of the westerly momentum towards the equator restricts the penetration of the summer hemispheric easterlies into the winter hemisphere in the lower mesospheric region.

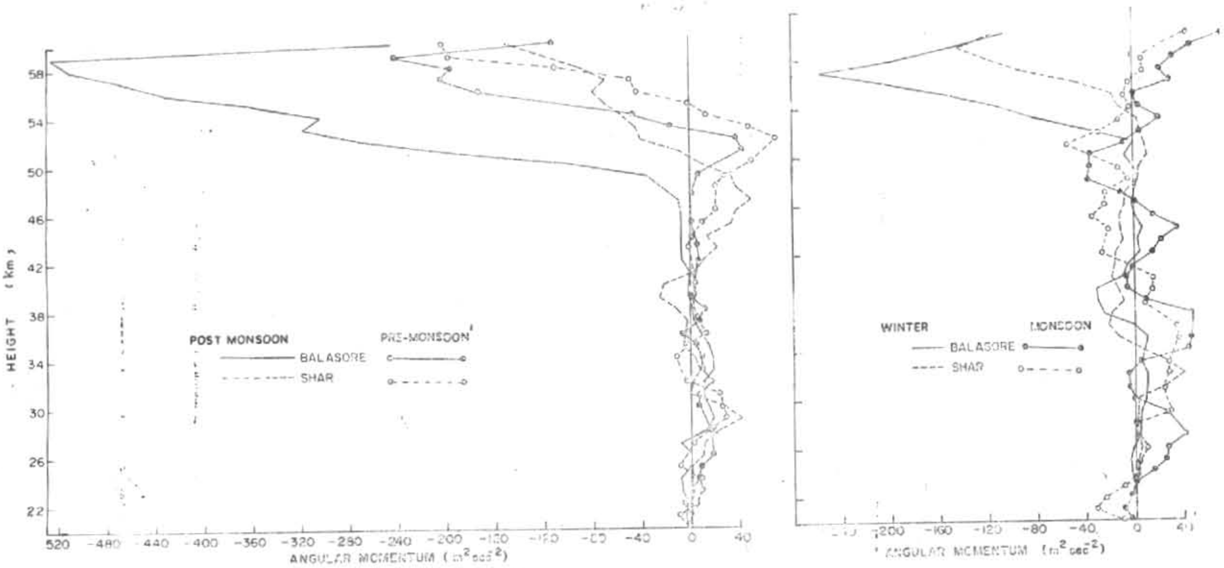

Fig. 2. Angular momentum transport ($\bar{u}\,\bar{v}$) by mean motion in different seasons over SHAR and Balasore

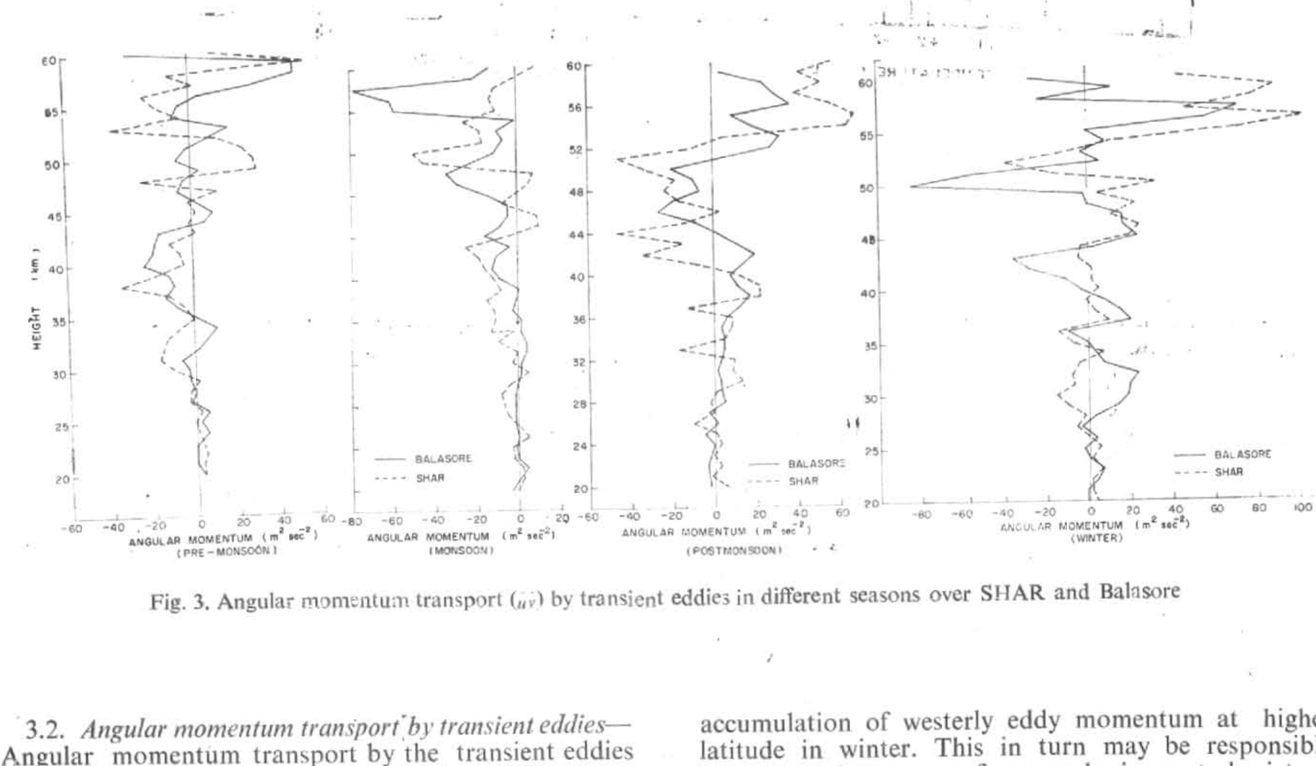

Fig. 3. Angular momentum transport ($\overline{u'v'}$) by transient eddies in different seasons over SHAR and Balasore

3.2. *Angular momentum transport by transient eddies*— Angular momentum transport by the transient eddies during the various seasons are shown in Fig. 3. Significant eddy momentum transport can be observed in the upper stratosphere as well as in the lower mesosphere throughout the year. From post monsoon to pre-monsoon the eddy transport is mainly in the lower mesosphere. The maximum northward transport occurs during winter, with a value 100 m^2/sec^2 over SHAR and 70 m^2/sec^2 over Balasore. This indicates that there is an accumulation of westerly eddy momentum at higher latitude in winter. This in turn may be responsible for the maintenance of mesospheric westerly jet at middle latitude (~40°N) in winter.

Though during post monsoon and pre-monsoon seasons the transport is northward in the lower mesosphere, its value is almost half of the winter value over both the stations.

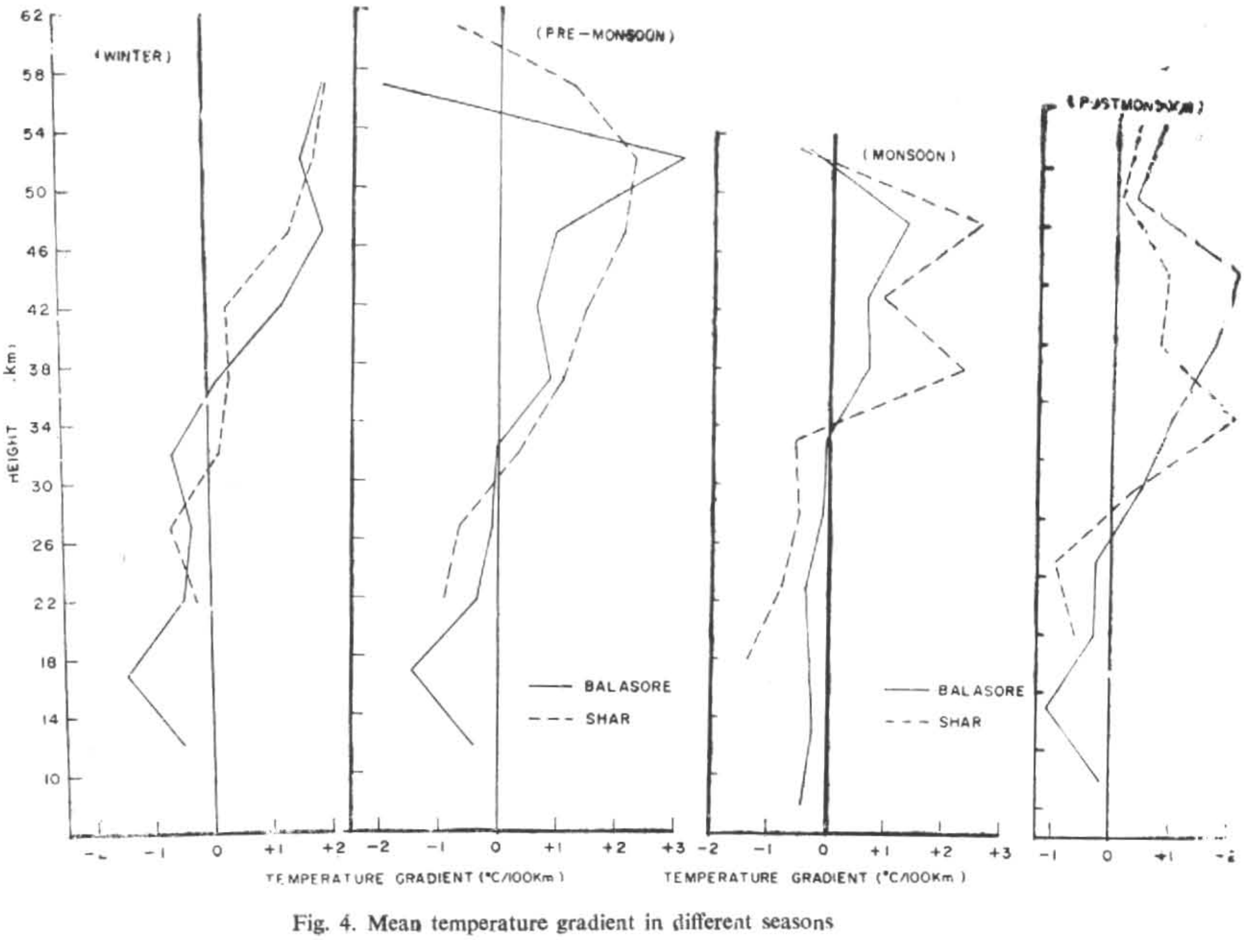

Fig. 4. Mean temperature gradient in different seasons

During the monsoon season, in the upper stratosphere and lower mesosphere, the eddy transport is mainly southward. The maximum southward transport occurs over Balasore with a value 80 m^2/sec^2 at 58 km. The southward transport is generally less over SHAR than over Balasore. Moreover at Balasore, the southward transport is almost the same as that of the winter northward transport. But over SHAR the southward transport is half of the winter northwards transport. The southward transport of eddy momentum during the monsoon season over Balasore and SHAR in the upper stratosphere and lower mesosphere, confirm the prediction of Hunt's (1981) model atmosphere. In his model, Hunt predicted a region of large southwards eddy flux in the summer mesosphere around 60 km in the tropics. But he could not substantiate this due to lack of observation support. Newell (1963, 1972) with global data, also found that in the summer mesosphere, the eddy momentum is directed southward only at 60 km over subtropics and mid-latitudes. Apparently, these southward flux deposit westerly momentum towards the equator. This not only restricts the easterlies to the summer hemisphere but also maintains the mesospheric easterly jet core located poleward of the equator.

It is further observed that in the monsoon practically no eddy transport occurs in the lower and middle stratosphere (upto 40 km) both over Balasore and SHAR. This is in sharp contrast to the findings of the Raja Rao and Jayanthi (1975), who showed that the stratospheric easterly jet at 35 km over the tropics is maintained by southward transport of eddy momentum.

It would be worth mentioning here that except in the monsoon the transport of the angular momentum by mean motion is much higher than that by eddies. In monsoon the transport by both processes are comparable.

3.3. *Temperature gradient* — The temperature gradient, though has been calculated at each kilometre from 20 to 60 km height, the 5 km average has been presented in the Fig. 4. The 5 km average has been taken in order to eliminate level to level fluctuations. In the lower stratosphere, *i.e.*, 20-30 km it can be seen both over Balasore and SHAR that the temperature gradient is almost negligible. A significant gradient can only be observed from middle stratosphere to lower mesosphere.

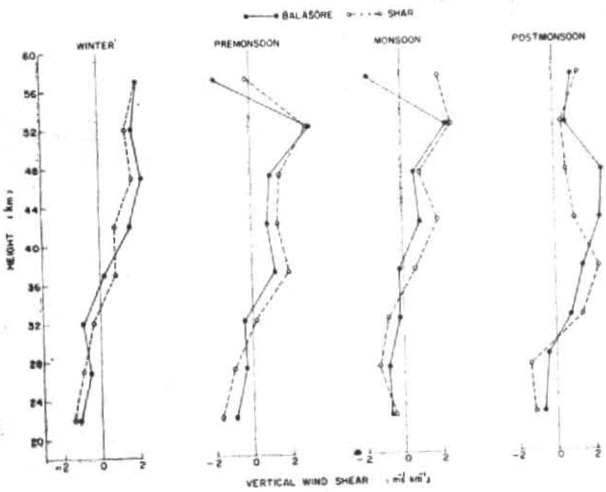

Fig. 5. Seasonal variation of vertical wind shear

In winter, the gradient is negative fron 20 to 37 km and positive above till 60 km over Balasore. A similar pattern is observed over SHAR. The maximum temperature gradient is 2°C/100 km occurs at 50 km over Balasore.

In pre-monsoon, both over Balasore and SHAR, a negative temperature gradient is present below 30 km and above 55 km; while the gradient is positive between 40 & 54 km. This positive gradient is more over SHAR than over Balasore in the middle and upper stratosphere. At the stratopause level or at about 50 km the positive temperature gradient is more than 3°C/100 km over Balasore but is 2°C/100 km over SHAR.

In the monsoon season, a positive temperature gradient can be observed between 40 and 54 km over both the stations. The reversal of temperature gradient occurs below 40 km and above 55 km. The maximum gradient are 1.5°C/100 km at 53 km over Balasore and 2.6°C/100 km over SHAR. The temperature gradient is more over SHAR than that over Balasore both in the stratosphere and mesosphere in this season.

In the post monsoon, the positive temperature gradient builds up from above 30 km. Maximum value of 2°C/100 km occurs at 47 km over Balasore and at 37 km over SHAR.

It may be worth mentioning here that during all the four seasons, the order of the maximum temperature gradient per 100 km both over Balasore and SHAR, well agrees with that obtained by Webb (1966) and Holton (1975).

From the above mentioned facts it can be seen that throughout the year, north of Balasore is colder than the equatorial regions in the upper stratosphere and lower mesosphere. This indicates that the temperature decreases from equator to northern latitudes. The global analysis of temperature data indicates that there is a uniform temperature increase from winter pole to summer pole between 30 & 60 km height (Holton 1975). While winter temperature structure of middle stratosphere and lower mesosphere over tropical Indian region agrees well with the mean global picture, the same for monsoon months appears to be opposite to that of global pattern. This discrepancy may be due to the analysis of regional data.

In the lower stratosphere, an increase in temperature to north of Balasore in all seasons is understandable because of gradual lowering of tropopause with increasing latitudes.

As temperature gradient is calculated from vertical wind shear following thermal wind equation, it is quite obvious that vertical wind shear follows the same pattern as that of temperature gradient. Easterly thermal wind prevails in the middle stratosphere while the westerly thermal wind prevails in the upper stratosphere and lower mesosphere (*vide* Fig. 5). In the lower stratosphere, the wind shear as well as the temperature gradient are very negligible in all the seasons. Hence, it may be inferred that the lower stratosphere over the tropical Indian regions is more or less barotropic in nature throughout the year.

4. Conculusion

The study is based on data for two stations utilising limited period. It is, therefore, unlikely to provide a general picture of momentum transport and temperature gradient over tropical areas. The following conclusions can, however, be drawn :

(*i*) The angular momentum transport by the mean motion is significant in the lower mesosphere and is directed southward except in monsoon. This southward transport appears to restrict the penetration of summer hemispheric easterlies into the lower mesosphere of the winter hemisphere.

(*ii*) Significant eddy transport can be seen both in upper stratosphere and lower mesosphere throughout the year.

(*iii*) Northward eddy transport during post monsoon to pre-monsoon through winter may be responsible for the maintenance of mesospheric westerly jet at the middle latitude in the winter.

(*iv*) Southward eddy transport in the monsoon season not only restricts the easterlies to the summer hemisphere but also maintaining the mesospheric easterly jet core located poleward of the equator.

(*v*) North of Balasore is colder throughout the year, where the maximum temperature gradient is 3°C/100 km, occurs in summer at 50 km.

(*vi*) The vertical wind shear and the temperature gradient analyses in the lower stratosphere indicate its barotropic nature.

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