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The seasonal variability of stratopause height, temperature, density, zonal wind field and their oscillations over equatorial India

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सार — प्रस्तुत अध्ययन में भूमध्य रेखीय भारत के ऊपर समतापक्षोभ तल पर ऊंचाई, ताप, घनत्व और क्षेत्रीय पवन के ऋतुनिष्ठ परिवर्तनों का विस्तार से विचार किया गया है। यह दिखाया गया है कि ऊंचाई, ताप और घनत्व दोहरे उच्चिष्ठ प्रदर्शित करते हैं और क्षेत्रीय पवन पूर्वी और पश्चिमी के प्रत्यावर्ती ढर्रे दर्शाते हैं जो छह महीनों की अवधि में दोहराये जाते हैं। यह भी देखा गया है कि क्षेत्रीय पवन और ताप की अधिकतम परिवर्तनशीलता शीतकाल और ग्रीष्मऋतु में होती हैं। समतापक्षोभ ताप, घनत्व और क्षेत्रीय पवन के दोलन के अधिक अध्ययन से यह निष्कर्ष निकलता है कि दोनों, 'ताप और क्षेत्रीय पवन' वार्षिक दोलन के ऊपर अर्द्धवार्षिक की सर्वाधिकता प्रदर्शित करते हैं।

ABSTRACT. Present study deals in detail the seasonal variation of height, temperature, density and zonal wind at stratopause level over equatorial India. It has been shown that height, temperature and density exhibit double maxima and zonal wind shows alternating pattern of easterly and westerly which repeat with a period of six months. It was also observed that maximum variability of zonal wind and temperature occur during winter and summer. From a further study of oscillation of stratopause temperature, density and zonal wind, it is concluded that both temperature and zonal wind exhibit predominance of semi-annual over annual oscillation.

1. Introduction

The term stratopause is applied to the boundary between the stratosphere and mesosphere, ideally characterised by an abrupt change of lapse rate. The stratopause separates the layer of markedly different vertical temperature gradients; the distinct features of these layers being increase in temperature with height in the stratosphere and decrease in temperature with height in mesosphere.

The probing of Indian middle atmosphere has started from 1971 with the launching of weekly M-100 rocket from Thumba and as such study on the stratopause is very much limited. As a result our knowledge on different aspects of stratopause over equatorial India is not yet fully developed.

In the earlier study based on M-100 rocketsonde data from Thumba for the period December 1970 to 1977 by Appu *et al.* (1980) indicated that the mean stratopause height and temperature over Thumba was 45.6 km and —8°C respectively and summer and winter months were colder than equinoctial periods. They also observed that stratopause temperature showed well marked semi-annual oscillation.

The present study based on about 14 years data has been taken up with an aim to present climatological information of average height of stratopause and its temperature, density and wind over Thumba. Seasonal variation as well as the oscillation of these parameters are also discussed.

2. Data analysis procedure

Weekly M-100 rocketsonde data from Thumba (8° 32′ N, 76° 51′ E) for the period 1971-84 (with break in operation from June 1974 to April 1975) are utilised for this study. Altogether about 525 flights data are considered. Stratopause height is determined by following one of the criteria given below :

(*a*) the lowest level (above 40 km) at which temperature maximum occurs and above which there is decreasing trend of temperature,

(*b*) the lowest level (above 40 km) from which increase in temperature with height is restricted to 2°C/km or less within the next 5 km and thereafter, there is steady decrease of temperature with height.

After fixing the stratopause height, temperature,)nal wind and density at that height were collected om the individual flight. Then the following cal- llations and analyses were performed :

(*i*) Yearwise monthly means of height, temperature,)nal wind and density.

(*ii*) Normals of above parameters from the monthly eans (*i.e.,* mean monthly values for the station record igth). Any month having less than two flights was t included in the calculations.

(*iii*) Variance of the monthly mean of height, zonal id and temperature about their normal values.

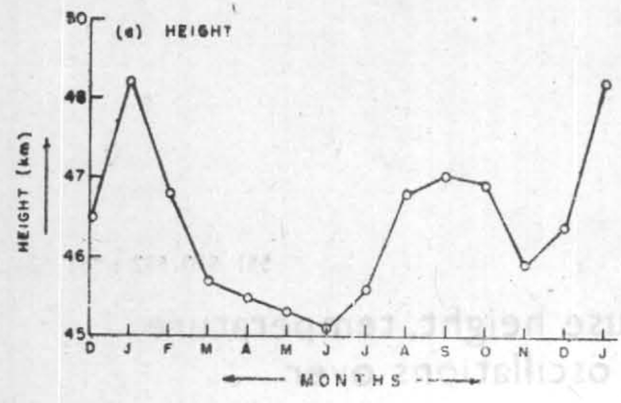

Fig. 1. Seasonal variation (a) of stratopauseheight, (b) temperature

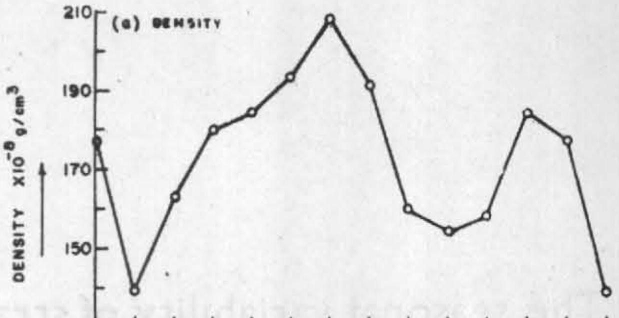

Fig. 2. Seasonal variation of (a) density at stratopause height and (b) zonal wind at stratopause height

(*iv*) Harmonic analysis of normals of zonal wind, temperature and density.

3. Results and discussion

3.1. *Seasonal variation of stratopause height*

Seasonal variation of stratopause height is shown in Fig. 1(a). Stratopause height is found to have double maxima in January and September/October and double minima in June and November. The highest and lowest values are 48.2 km and 45.1 km, occurring in January and June respectively. The annual mean is 46.3 km. Generally stratopause remains fairly at a lower height from March to July than the other month. Further, it is observed that stratopause height decreases from its highest value in January and attain minimum in June or, in other words, in general stratopause height show a decreasing trend from January till the onset period of monsoon and increasing trend till the end of monson. It may be mentioned that analysis of Appu *et al.* (1980) indicated April as the month of lowest stratopause height.

3.2. *Seasonal variation of temperature*

Seasonal variation of temperature is shown in the Fig. 1(b). Coldest stratopause is found to occur in the month of December with temperature of —9°C and warmest temperature in the month of April (—3°C). Like height, stratopause temperature also shows double maxima and minima. Secondary maximum and minimum occur in the month of September/October (—6°C) and June (—8.2°C) respectively.

It may be noted that rise and fall in temperature from January to February and April to May respectively, are very steep compared to other months and also equinoctial period are warmer than winter and summer (monsoon) months. In fact, temperatures in the months of February to April are appreciably higher than the remaining months and magnitude of temperature maximum (—3°C) is twice as large in April than that in September/October (—6°C).

The behaviour of stratopause temperature during January to May may be partly due to frequent occurrence of sudden stratospheric warming in the lower stratospheres of higher latitude during mid-winter periods. While studying high level warming over Thumba, Mukherjee & Ramanamurty (1972) pointed out that the mid-winter stratospheric warmings observed in lower levels at high latitude may be associated in some manner with the warmings at higher levels in the lower latitude of winter hemisphere. Also it is known that major stratospheric warmings generally do not occur before February. These facts may explain, at least to some extent, the steep rise of temperature from January to February, appreciably high temperature during February to April and steep fall of temperature from April to May.

Harmonic analysis of normal temperature (Table 1) shows the predominance of semi-annual cycle at stratopause level where S.A.O. (amplitudes 2.3°C) alone accounts for 66% of the total variability in comparison to 25% accounted by annual oscillation (amplitude 1.4°C); phase (time of maximum) of temperature oscillation (S.A.) is in early March. Further, not only at stratopause, S.A.O. in temperature are found to be predominant between 45 and 50 km with slight decrease in amplitude with height.

3.3. *Seasonal variation of density*

Seasonal variation of densities at stratopause height is shown in Fig. 2(a). This also shows double maxima pattern like stratopause height and temperature. Two

TABLE 1

Parameters	Height (km)	Annual oscillation: Amplitude	Annual oscillation: Variability accounted by (%)	Annual oscillation: Phase in months	Semi-annual oscillation: Amplitude	Semi-annual oscillation: Variability accounted by (%)	Semi-annual oscillation: Phase in months	Standard deviation
Wind	Stratopause	6 m/s	12	0.30	18 m/s	84	4.1	13 m/s
	45	3.8 m/s	4	9.1	16.9 m/s	82	4.2	13.2 m/s
	50	8.5 m/s	14	0.6	19.4 m/s	77	3.7	15.6 m/s
	55	11.7 m/s	26	1.3	18.7 m/s	66	3.5	16.3 m/s
Density	Stratopause	0.1652 g/m³	35	2.1	0.1533 g/m³	30	5.2	0.198 g/m³
	44	0.0726 g/m³	33	6.0	0.086 g/m³	47	5.8	0.089 g/m³
	45	0.1397 g/m³	25	3.5	0.1642 g/m³	35	5.5	0.197 g/m³
	50	0.0363 g/m³	45	6.5	0.0273 g/m³	25	5.2	0.038 g/m³
Temperature	Stratopause	1.4°C	22	3.5	2.2°C	60	3.1	1.9°C
	45	1.4°C	23	5.6	2.1°C	51	3.4	2.1°C
	60	1.6°C	35	1.4	1.9°C	52	3.2	1.9°C

maxima occur in June (2.08 gm/m³) and November (1.85 gm/m³) and two minima in January (1.39 gm/m³) and September (1.54 gm/m³). As understandable, density variation closely follows the variation of height, *i.e.*, month of highest stratopause height corresponds to month of lowest density and *vice versa.* But the seasonal variation of density at a fixed height of 46 km (which is close to average stratopause height) is somewhat different. Two maxima occur in May (1.86 gm/m³) and October (1.83 gm/m³) and two minima in January (1.72 gm/m³) and August (1.77 gm/m³).

Harmonic analysis of density at stratopause level and also at 44, 45 and 50 km height indicate (Table 1) that at stratopause level both annual and semi-annual oscillation have almost equal contribution to the total variance; semi-annual oscillation plays a dominant role at 44 and 45 km, whereas at 50 km annual oscillation is predominant. Phase (time of occurrence of maximum amplitude) of semi-annual oscillation at these levels occur in May/June. Hence, density and temperature oscillation are found to be out of phase by about 2 months. This is contrary to the findings of Subbaraya and Lal (1980) who observed that semi-annual features in densities and temperatures go in phase below about 50 km.

3.4. *Seasonal variation of zonal wind*

Seasonal variation of zonal wind at stratopause height is shown in Fig. 2(b). This shows the alternating pattern of westerly and easterly wind which repeat with a period of 6 months and is a clear indication of presence of strong semi-annual oscillation. On an average very weak zonal wind is observed in the months of May, September and December and strong westerly and easterlies are seen in the months of March-October and January-July respectively. Westerlies in October are about 64% stronger than that in March whereas easterlies in July are 75% stronger than that in January. By comparing Figs. 1(b) and 2(b), it may be stated that in general colder stratopause is associated with easterly wind field and warmer stratopause with westerly wind field.

It may be mentioned here that in stratosphere and mesosphere net radiative heating distribution together with coriolis torque generate mean zonal easterlies in the summer hemisphere and westerlies in the winter hemisphere which are in approximate thermal wind equilibrium with zonal temperature field and equinoctial conditions must feature relatively weak mean zonal winds in both hemispheres (Holton 1975). The wind field at stratopause height over Thumba nearly corroborates the above facts with exception of appearance of easterlies in winter months. These winter easterlies is merely a consequence of incursion of summer mesospheric easterlies into winter hemisphere. Usually incursion of these summer easterlies is maximum at stratopause level (Hopkins 1975).

By comparing the amplitude of annual and semi-annual oscillation of zonal wind it is seen that S.A.O. is most significant and pronounced at stratopause height (Table 1). S.A.O. alone accounts for 84% of the total variation in the zonal wind field. Its maximum amplitude is 18 mps and time of maximum westerly wind field is in early April. So, phase of temperature precedes that of zonal wind by about a month.

3.5. *Variance of monthly means of height, zonal wind and temperature*

3.5.1. *Variance of monthly mean height* — Variance of monthly mean height (Fig. 3a) indicates two height variance maxima in the months of April and September and two minima in February and October. Noting the magnitudes of variance in different months, which varies from 10% to 20% of the mean height, it may be inferred that stratopause remains fairly steady at an average height of 46.3 km throughout the year.

3.5.2. *Variance of the monthly mean temperature* — Variance of monthly mean temperature is shown in Fig. 3(b). This shows that variance of temperature has two maxima which occur in December/January and June/July with variance in winter months (December-February) is about 40% less than that in summer months

(June-August), while minima occur in transitional months. The presence of two maxima of variability in the beginning and middle of the year may be accounted for by the response of the lower latitudes strato-mesosphere to higher temperature variation during winter periods in the northern and southern hemispheres (Koshelkov *et al.* 1983).

3.5.3. *Variance of monthly mean zonal wind* — The plot of zonal wind variance *vs.* time shown in Fig. 3(c) clearly illustrates the seasonal dependence of zonal wind with two maxima occurring in February and July and coinciding with the period of easterly flow. The zonal wind variance maximum is about 70% higher during winter than that during the summer, which is just opposite to that found in case of temperature variance maxima.

4. Conclusion

From this study the following features may be stated :

(*i*) Height of stratopause, temperature and density at this level show double maxima.

(*ii*) Highest and lowest stratopause occur in January and June respectively and annual average of stratopause height is 46.3 km, which remains fairly steady throughout the year.

(*iii*) Warmest (—3°C) and coldest (—9°C) stratopause are found in the months of April and December respectively. Generally, winter and summer months are colder and associated with easterly wind and equinoctial months are warmer and associated with westerly wind.

(*iv*) Maximum and minimum density at stratopause occur in June and January respectively. As expected, monthly variation of density follows closely that of height, though the maximum density at about average stratopause height (46 km) occurs one month earlier than at the stratopause height during that month.

(*v*) Zonal wind at stratopause height exhibits strong semi-annual oscillation which is vastly more important than the annual oscillation. Variance of monthly mean zonal wind shows two maxima, one in January and another one in July. Magnitude of winter (January) variance maximum is about 70% higher than that of summer (July) variance maximum. These findings are consistent with that of Hopkins (1975).

(*vi*) Temperature at stratopause shows strong semi-annual oscillation with maximum occurring in March.

(*vii*) Annual and semi-annual oscillation contribute equally to total variation of the density at stratopause height. Phase of semi-annual oscillation occurs in May/June, *i.e.*, temperature and density oscillation are out of phase by about 2 months.

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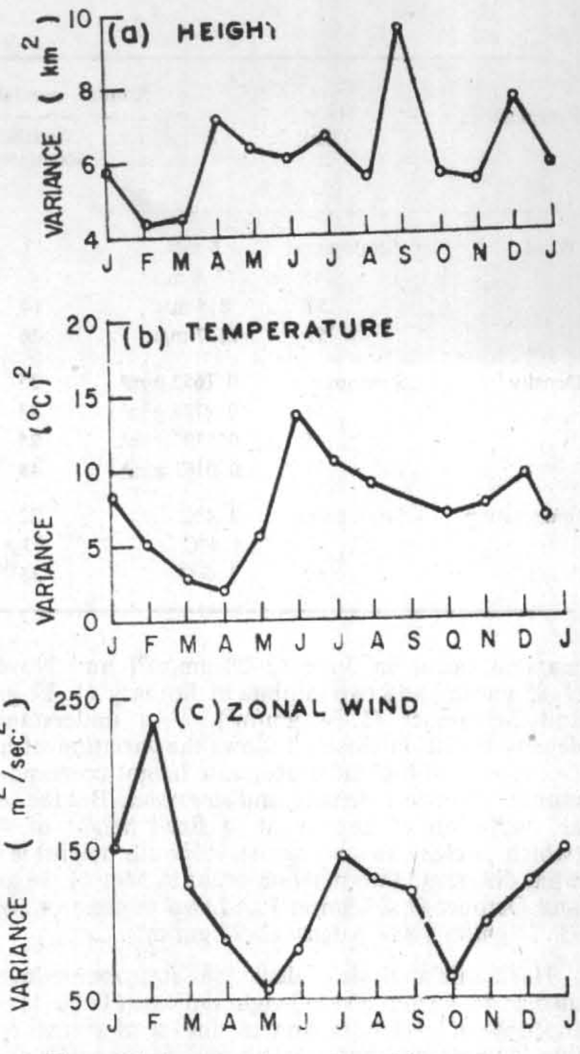

Fig. 3. Time variation of variance of monthly mean (a) stratopause height, (b) temperature and (c) zonal wind

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