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Some characteristics of tropopause over India

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ABSTRACT. Variations of the height and temperature of tropopause over India have been discussed in this paper. Seasonal and latitudinal variations over India have been compared with those over neighbouring stations. Smith (1963) suggested that increase in moisture contributes to the lowering of the tropopause; but a comparison of the mixing ratios with tropopause heights over India does not seem to bear this out.

1. Introduction

The earliest studies of the tropopause over India undertaken by Indian Meteorologists were based on data obtained from sounding balloons. Krishna Rao (1952) examined in detail the upper air temperatures and tropopause over India. Krishna Rao and Ganesan (1953) studied the seasonal variation of the height and temperature of the tropopause over Trivandrum based on radiosonde data for 1948-1951. Their study indicated that the tropical tropopause occurs at or slightly above the 100-mb level and is lower from June to October than during the rest of the year. In connection with the study of the jet stream, Koteswaram (1953) observed that the tropical tropopause occurs over India at a height of about 17 km and an extra-tropical tropopause at 12·5 km in winter months over north India. Bose (1962) studied a few cases of the variation in the heights of lower (extra-tropical) tropopause and the associated disturbed weather over north India. A study of stable layers and inversions over India by Ananthakrishnan and Rangarajan (1963) has indicated that the tropopause height in monsoon months of stations like Trivandrum and Madras is lower than that in the non-monsoon months.

Based on a pole to pole study of tropopause along the meridian of Cape Canaveral (28°28′N, 80°33′W), Smith (1963) observed that the tropopause is generally higher in winter than in summer *in all latitudes*, particularly in the northern hemisphere. He suggested that such variations are also possible for all regions over the globe and stated that the lowering of the tropopause in summer is possibly due to an increase of water vapour in the lower troposphere during these months.

Subsequent to the studies in India mentioned above, more tropopause data have become available. The present study concerns itself with the observational aspects of the height and temperature of the tropical tropopause over India and its relationship with moisture. Latitudinal and seasonal variations are presented through cross-sections and graphs. Monthly variation of the height and temperature of lower (extra-tropical) tropopause has also been briefly discussed. Tropopause data of Indian stations have been compared with those of the neighbouring countries.

2. Data

Mean tropopause data based on radiosonde observations (1200 GMT) for 5 years (1958-1962) have been utilised in this study. Mean monthly mixing ratios at 700 mb have been calculated for the stations around Long. 80°E.

3. Monthly mean cross-sections of tropical tropopause surface

Fig. 1 shows the cross-section of the height of tropopause (tropical) surface along longitude 80°E. This shows that the highest tropopause (17·4 km) occurs during June and July around 27°N. Another maximum is noticed around 15°N during February and March. The lowest (tropical) tropopause (15·6 km) is noticed around 10°N during the months August to October and a winter minimum towards the northernmost latitudes. It is interesting to note that the winter minimum of the tropopause height over the northernmost latitudes is of the same order as the summer minimum over the southernmost latitudes over India. While the mean position of the sub-tropical jet stream during winter is about 5 degrees to the south of the tropopause-height minimum over the northern latitudes, the mean location of the summer easterly jet stream lies about 5 degrees to the north of summer tropopause-height minimum over the southern latitudes. Another noticeable feature is a flat region of about 16·5 km height around the latitudes of Nagpur from January to July; here the height of tropopause does not also change significantly during the rest of the year, although the summer height is slightly more than the winter height.

Fig. 2 shows a cross-section of the temperature of the tropical tropopause surface along longitude 80° E. The tropopause is colder (198°A) during July near the latitude of Delhi; this is well

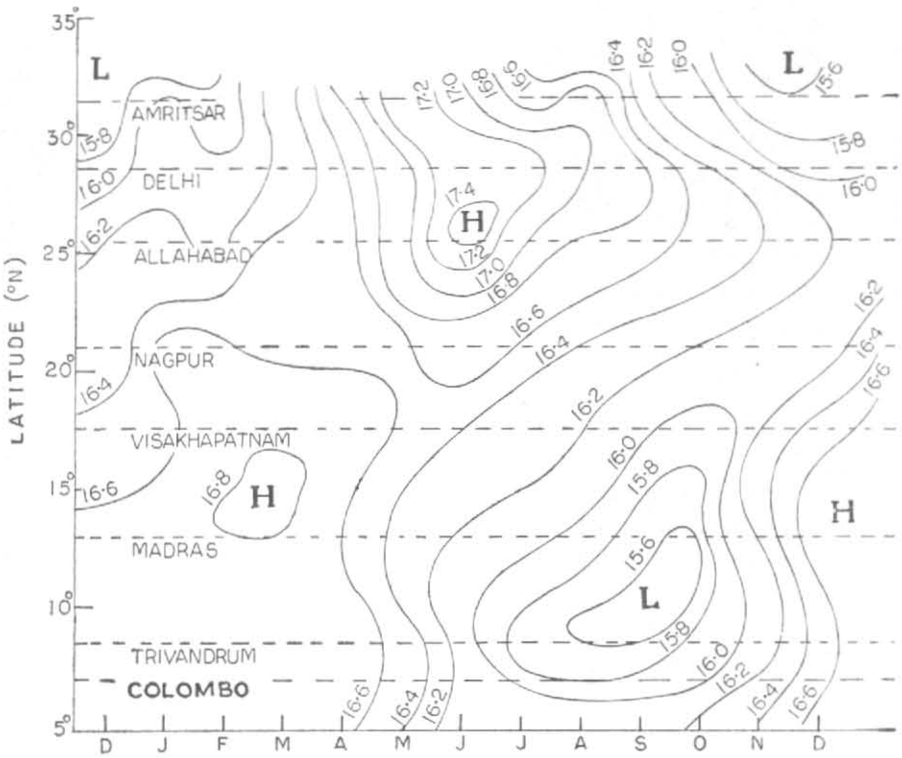

Fig. 1. Seasonal variation of Tropopause height with latitude

correlated with the maxima of the tropopause height (*see* Fig. 1). The winter tropical tropopause over the northernmost latitudes over India is warmest (213°A) as is to be expected with the minima of the tropopause height over the area during these months (*see* Fig. 1). The isotherms over the tropopause surface show a large gradient north of Allahabad which agrees with the mean winter positions of the sub-tropical jet stream. Such large temperature gradients are, however, not noticed during summer in the southern latitudes. Figs. 3 (a) and (b) show the meridional cross-sections around 80°E on two individual days, one representing a summer situation and the other one representing a typical winter day. An examination of these cross-sections illustrates the features discussed above.

Fig. 4 shows the variation of tropopause (tropical) height at some neighbouring stations outside India. It is seen that (1) Over Aden (Lat. 13°N) the tropopause is highest in January and is lowest in October, (2) Over Bangkok (Lat. 14°N) the tropopause is generally higher from January to April than in July to October, (3) Over Colombo (Lat. 7°N) the tropopause is higher in January than during July to October, (4) Singapore (Lat. 1°24′N) tropopause height is high from December to May and decreases rapidly from May to July and starts increasing again from October. The variation is similar to that of Aden, Bangkok and Colombo, in that the summer tropopause is lower than the winter tropopause, (5) However, over Bahrein (Lat. 26°N) the tropopause is higher in July than from October to January.

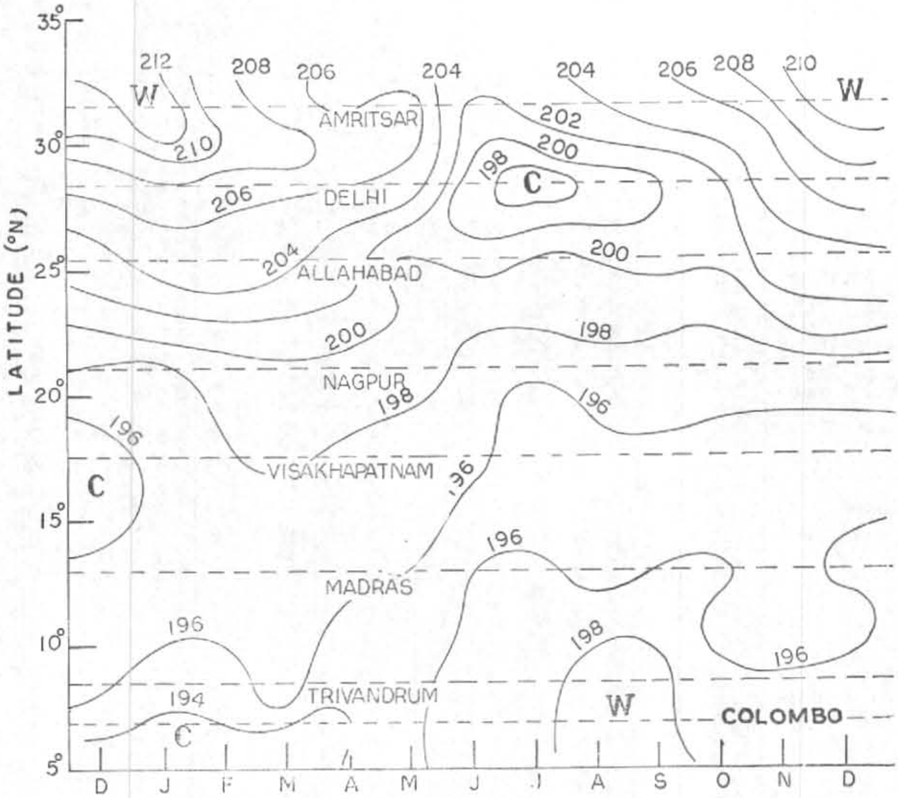

Fig. 2. Seasonal variation of Tropopause temperature (°A) with latitude

Here, Bahrein shows a variation similar to that of the stations north of 20°N over India, whereas, Aden, Colombo, Singapore and Bangkok agree well with the Indian stations south of 20°N. In his study for the region along 80°W, from equator to about 40°N, Hess (1948) observed that the tropical tropopause was about 2 km lower in summer than in winter. Smith (1963) has concluded from his data that the summer tropopause is lower than the winter tropopause in all latitudes. It is clear that the stations north of 20°N over India show that summer tropopause is higher than the winter tropopause whereas it is *vice versa* in respect of stations south of 20° North. This is also true of the extra-Indian stations such as Bahrein, Bangkok, Aden and Singapore.

4. Tropopause height *vs* moisture

Smith (1963) while discussing the possible causes for the lower summer tropical tropopause discarded the convection hypothesis on the ground that, if convection controlled the lapse rate, the tropopause should be higher in summer when the convection is most active. At a majority of stations investigated by him, the tropopause was lowest in summer months when rainfall was greatest although the release of latent heat should cause the tropopause to rise. He infers that the only other factor which can cause a similar change as the tropopause height-change, is water vapour. He plotted the 1 gm/kg mixing ratio for different months against altitudes for Cape Canaveral and found that the mixing ratio line showed a variation similar to that of the tropopause heigh

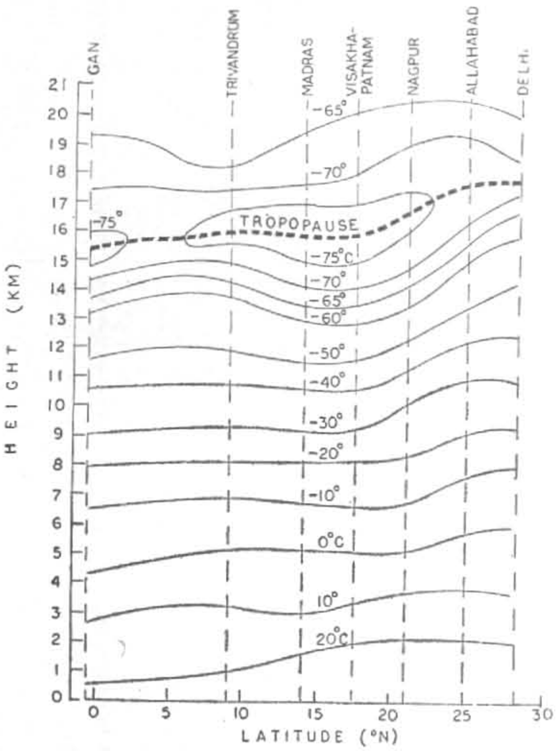

Fig. 3(a). Temperature cross-section, 12 July 1964 (12Z)

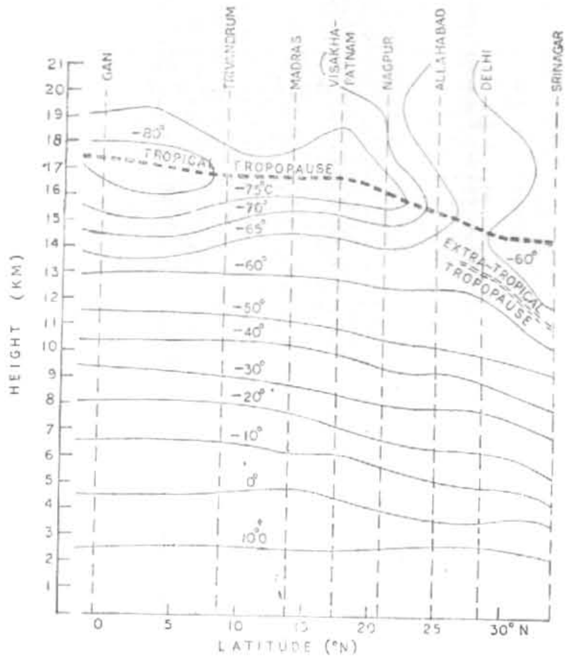

Fig. 3(b). Temperature cross-section, 18 January 1964 (12Z)

Sverdrup (1945) has shown that as temperature and humidity increase, the net emission of radiant energy from the surface of the earth back to space decreases. Smith proposes this as a possible cause for the low summer tropopause.

In the present investigation, the mixing ratio has been computed for all the months at different stations over India. Fig. 5 shows the 700-mb level mixing ratio variations with latitude for January (winter) and July (summer). As is to be expected, the mixing ratios are less in winter than in summer. If Smith's conclusion on the effect of moisture on the summer tropopause is to be considered for conditions over Indian latitudes, the higher mixing ratios in July correlated well with the lower tropopause in summer at stations south of 20°N. But this feature is not borne out for latitudes north of 20°N as evident from the charts presented here.

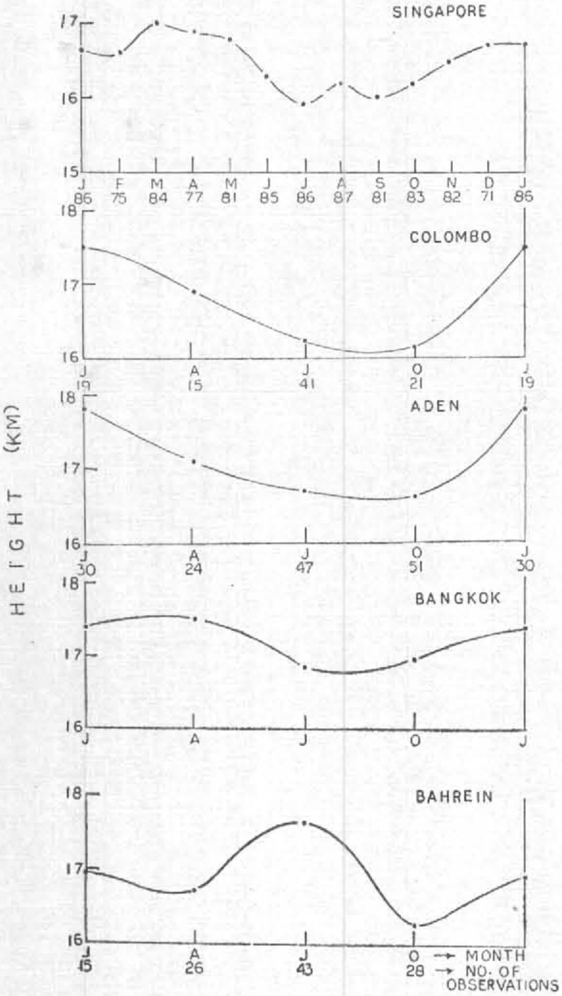

Fig. 4

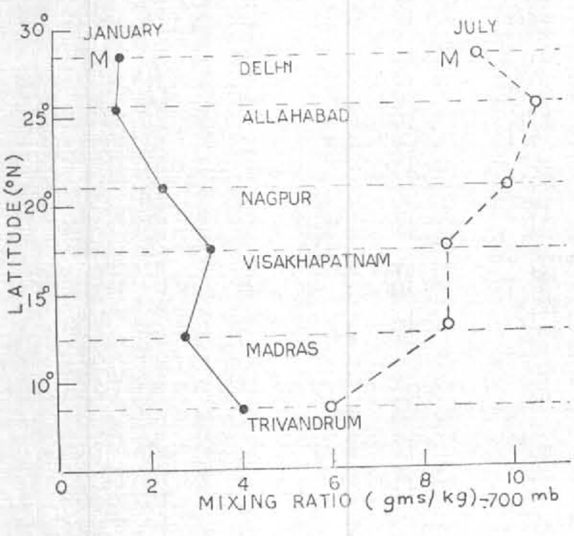

Fig. 5

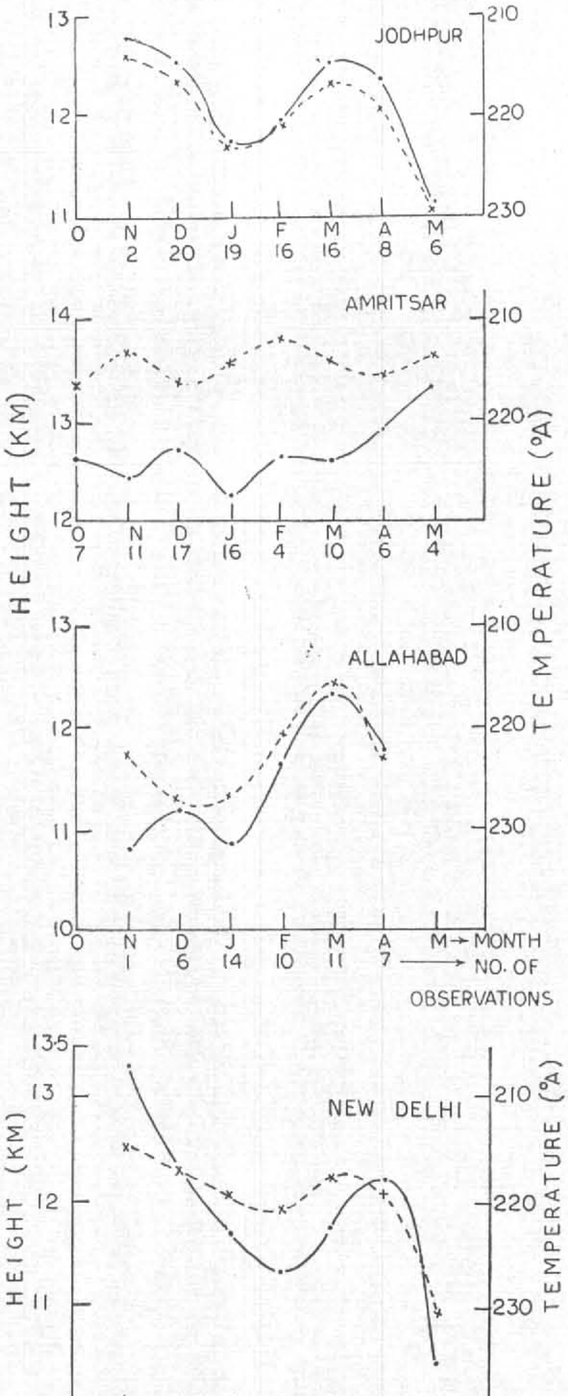

Fig. 6

TABLE 1

Height difference between tropical and extra-tropical tropopause (in metres)

Stations	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Amritsar	3420	3090	3010	3890	3190	3330	3890	3890
Allahabad	—	5600	5040	5390	4550	4330	4800	—
New Delhi	—	2480	3610	4450	4670	4480	4560	—
Jodhpur	—	3410	3540	4510	4470	3480	4270	—
Gauhati	—	—	4020	4570	5250	3730	3360	—

5. The extra-tropical type of tropopause over India

The extra-tropical type of tropopause occurs over northern latitudes of India from October through May, maximum frequency being in December and January (Fig. 6). It is absent in the months from June to September, *i.e.*, during the southwest monsoon season. This absence is due to the northward shift of westerlies with the poleward movement of the sub-tropical ridge aloft during these months.

Fig. 6 shows marked lowering in the extra-tropical tropopause height and a consequent increase in tropopause temperature during January and February at the four stations presented here.

The mean height differences between the tropical and extra-tropical tropopause over some stations are given in Table 1.

6. Conclusion

The tropopause is higher in winter than in summer at stations south of 20°N, over India, and similar features are also noticed at other stations in the corresponding latitudes, *e.g.*, at Aden, Bangkok, Singapore and Colombo.

Smith's suggestion of summer increase of moisture as a probable cause for summer tropopause drop is not found to be true for Indian stations north of latitude 20°N.

The extra-tropical tropopause occurs over north India in winter months between 10·5 and 11·5 km. Its height is lowest in January-February.

7. Acknowledgement

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