A CAMPAIGN OF SIMULTANEOUS OBSERVATIONS OF VERTICAL TRANSPORT USING THE INDIAN MST RADAR AND BALLOON-BORNE OZONESONDE

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Abstract
To examine the transport of ozone from the stratosphere to the troposphere at the time of tropopause "weakening" at tropical latitudes, simultaneous observations were carried out using the Indian MST radar located at Gadanki (13.5°N, 79.2°E) now fully operational in the MST mode. and ozonesonde flights from Trivandrum (8.9°N, 76.6E) during January 3-8, November 9-16, December 5-10, 1994 and May-July, 1995. Range-time-intensity (RTI) maps for January 7-8, 1994, show the occurrence of the tropopause "weakening." Simultaneous observations of ozone profiles show evidence of a decrease in stratospheric ozone and a corresponding increase in tropospheric ozone, the total ozone remaining reasonably constant on these days.

1. Introduction
The multiple layered structure near the tropopause and its "weakening" was observed by the ST mode operation of the Indian MST radar [Jaya Rao et al., 1994]. Mass exchange may take place from the stratosphere to the troposphere during this event [Danielsen et al., 1968] only if the magnitude of vertical velocity is low or the direction is downward. The special ozone transport campaign was designed to examine it using the Indian MST radar at Gadanki near Tirupati (13.5°N, 79.2°E), synchronized with balloon-borne ozonesonde ascents at neighboring station Trivandrum (8.9°N, 76.6°E). The ozonesonde ascent site is around 500 km southward of the radar site. Though the two sites are not collocated, any small scale phenomena within a range of 1000 km can affect both sites simultaneously and to the same degree. In this paper, the main thrust is on the quantitative analysis of transport of ozone from the stratosphere to the troposphere from the ozone vertical profiles following the weakening of the tropopause.

2. Experimental Description
The Indian MST radar is a highly sensitive VHF phased array radar with an operating frequency of 53 MHz and an average power aperture product of 7×10^8 Wm^2 [Rao et al., 1995]. As described by Jain et al. [1994], the online data processing carries out FFT and incoherent integration of the Doppler spectra. The inclination of off-zenith beam of radar was taken at an angle of 20°. The experimental details are given in Table 1. For the quantitative estimation of ozone transport during and after the tropopause weakening (break), the Brewer type balloon-borne ozonesonde ascents were taken on the radar observation days as given in Table 1.

3. Data Analysis
The Doppler spectra obtained as output was subjected to the calculation of three low order spectral moments which provide total signal power, radial wind velocity and its spread for each range bin. The procedure for obtaining these moments is similar to the one for the Poker Flat radar and is briefly described by Woodman et al. [1974]. The Doppler beam swing (DBS) method as described by Sato [1989] is used here in transferring the radial wind vector into three dimensional wind velocity components, U, V, W, respectively, and the method requires a

minimum of three non-coplanar beam positions. Vertical velocity (W component) calculated this way is contaminated by the horizontal wind velocity which is much greater in magnitude than the vertical wind velocity at each height. It was also obtained independently by using Doppler data from the zenith beam alone.

4. Results and Discussion

The data collected during the campaign of January 3-8, 1994, are presented here in the context of stratosphere-troposphere exchange process related to tropopause "weakening." To verify it only the main findings will be highlighted here. On January 7-8, the multilayered tropopause at 15-17 km (Figure 1) became more diffuse at 05:00 LT and remained so up to 08:00 LT and after that it recovered its old pattern. In Figure 2 the ozone profile taken at 08:40 LT on January 7 shows that the maximum peak is available at around 35 km. It behaves as the reference ozone profile in the tropics. On January 8, the ozone profile (Figure 2) taken after the tropopause weakening, shows that the normal peak has come down from 35 km to around 28 km with the one-fold increment in partial pressure of tropospheric ozone. During the abnormal tropopause period the horizontal wind vector (Figure 3) above the tropopause shows a turbulent nature and the vertical velocities on the observation days were low and downward below the tropopause (Figure 4). Mass exchange is evident from the increment of the tropospheric ozone and simultaneous decrease of stratospheric ozone in the ozone profile taken after the weakening of the tropopause (Figure 2). But the tropospheric ozone may be increased due to its vertical as well as horizontal transport. The diffuse and multilayered tropopause with turbulent wind vector above the tropopause with quite low and downward vertical velocity facilitates the vertical transport. Since the direction of the horizontal wind vector in the lower height remained unchanged during the whole observation, any change in the ozone concentration due to horizontal transport seems not possible.

5. Conclusion

Summing up the above discussion, the transport process of stratospheric ozone into the troposphere across the tropopause can be postulated as follows:

(i) A large scale instability in the wind field observed above the tropopause destroying the stability at the tropopause results first in the weakening and then disappearance (break) of the tropopause.

(ii) Stratospheric air mass descends to the upper tropospheric region through the "weak tropopause" if the magnitude of vertical velocity is low or the direction is downward during the "weakening period ."

(iii) Ozone is either carried along with this descending air mass or in addition to it also diffuses downward, driven by its own vertical gradient. These two mechanisms can also take place simultaneously.

(iv) However it cannot be ascertained at this stage which of the two mechanisms predominates. Though in both cases it results in a decrease of ozone concentration from the normal in the stratosphere and an increase in the troposphere.

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Table-1. Campaign Details (January 3-8, 1994) :

MST Radar operation	Balloon-Borne Ozonesonde Ascents	
Time in IST (Date)	Time in IST (Date)	Maximum height reached
10.00(3rd)---18.00(3rd)	14.00(3rd)	35 km (3rd)
10.00(4th)---10.00(5th)	10.00(4th) & 14.00(5th)	26 km(4th) & 36 km(5th)
10.00(6th)---10.00(7th)	No Ascent(6th) & 08.40(7th)	35 km(7th)
18.00(7th)---18.00(8th)	--------------- 09.00(8th)	34 km(8th)

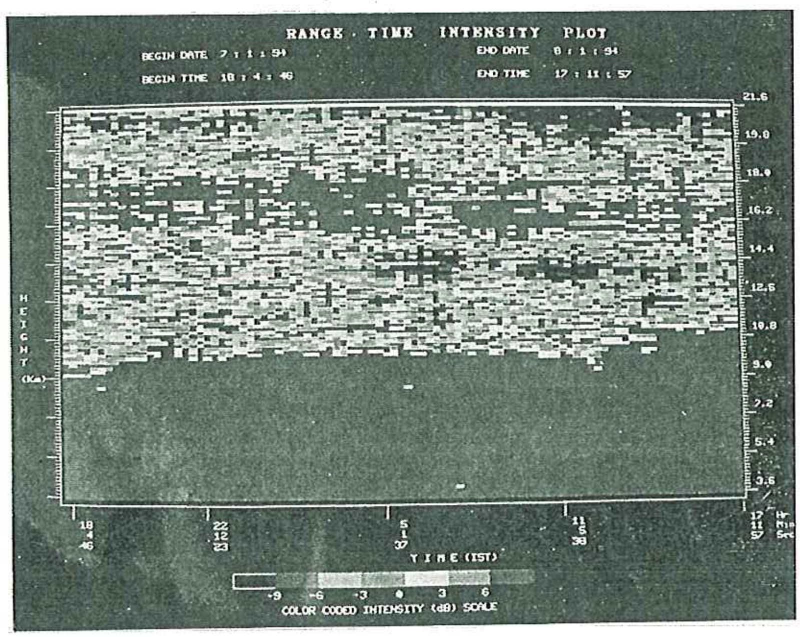

Figure 1. It presents the range time intensity plot measured with the Indian MST radar (13°N) on January 7-8, 1994. The intensity interval is 3 dB. The high intensity at 15-17 km shows the radar tropopause as reported by radiosonde observation at Madras, 100 km away from the radar site.

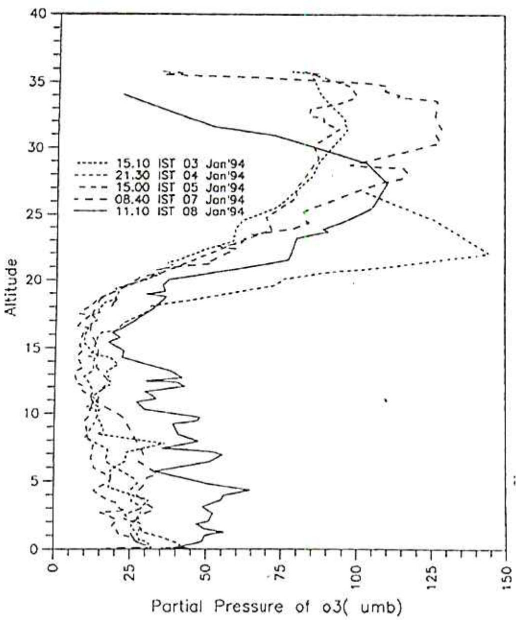

Figure 2. The partial pressure of ozone in micromillibar plotted as a function of height on radar observation period January 3-8, 1994. The times given in the figure refer to the ozonesonde ascent time.

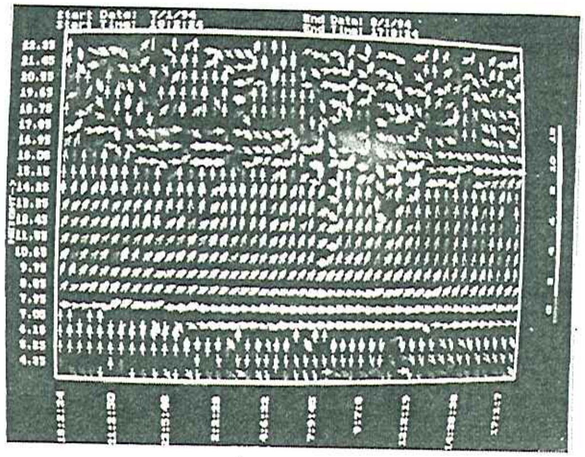

Figure 3. The angle between zonal and meridional velocity is taken as a direction of horizontal wind vector. The change in direction is plotted as a function of height and time on January 7-8. The horizontal velocity interval is taken here 2 m/s.

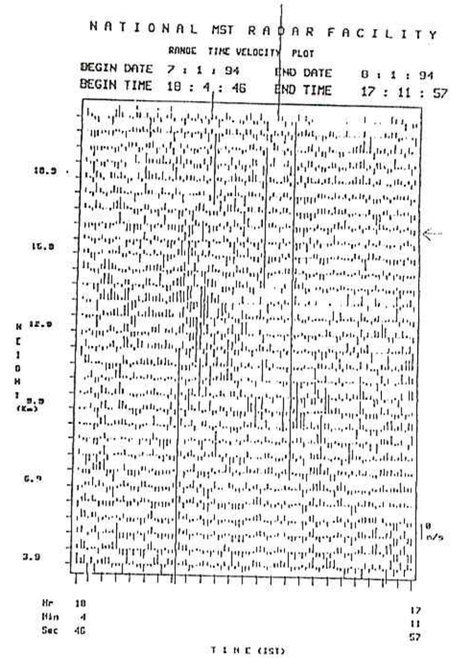

Figure 4. It represents the vertical velocity taken from vertical beam observation of radar is plotted here as a function of height and time on January 7-8, 1994.