

Detection of Tropical Tropopause from MST Radar

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Abstract : A method to determine the height of the tropopause from backscattered echo power of the vertically looking MST radar beam has been developed using WMO criteria.

Introduction

Temperature is an important meteorological parameter which affects the radiation budget of the Earth. Due to varying vertical temperature structure, the atmosphere is divided in four different regions namely troposphere, stratosphere, mesosphere and thermosphere. The lowest region called troposphere is characterized by weak stability to vertical displacements, low ozone and high water vapour. In contrast, the stratosphere is having strong stability, high ozone and low water vapour. Also, the stratosphere is radiatively controlled while convective processes are dominant in the troposphere. The notional boundary between the two is termed as tropopause. The tropopause has several definitions : WMO tropopause, cold point tropopause, ozone tropopause, potential vorticity definition etc.

The tropopause separates the troposphere from the most stably stratified stratosphere and acts as a lid on tropospheric convection. It plays active role in the development of large weather and climate system. The chemical processes on either side of the tropopause differ widely and the tropopause acts as a permeable membrane, allowing stratosphere-troposphere exchange (STE). The mixing of tropospheric and stratospheric air due to adjustment of the height of the tropopause is one of the mechanism leading to STE.

The VHF radar observations show enhanced echo at vertical incidence. This enhancement of the radar echo is due to partial reflection from sharp gradient of the radio refractive index of the atmosphere or back scattering from clear air turbulence (CAT) from regions of strong hydrostatic stability. Many investigators have used this feature of the VHF radar to detect and monitor atmospheric stable layers. In particular, this ability of VHF radar has been used for detection and monitoring of tropopause.¹⁻³ A clear air VHF radar, such as Indian Mesosphere-Stratosphere-troposphere (MST) radar is a very powerful remote sensing tool to explore the dynamics of the lower and middle atmosphere. MST radar is recognized for its unique capability to measure all the three

components of velocity with significantly good accuracy on time scales of few tens of seconds.

The purpose of the present paper is to describe a new method for detecting the tropical tropopause height from Indian MST radar. The method is a two-step procedure : first we determine the vertical temperature profile of the atmosphere using the technique proposed by Das et al.⁴ This is followed by reconstruction of the height profile of the gradient of vertical temperature from which the height of the tropopause is detected using World Meteorological Organisation (WMO) criteria.

Radar System Description & Data Set

The Indian MST radar located at Gadanki (13.5° N, 79.2° S), is a pulse coded coherent VHF phased array radar operating at 53 MHz with an average power aperture product of $7 \times 10^8 \text{ Wm}^2$. The antenna system consists of 1024 crossed three element Yagi-antennas occupying an area of 130 m $\times$ 130 m generating a radiation pattern with a beam width of 3° and a gain of 36 dB. The peak-power that radar can transmit into the atmosphere is 2.5 MW. The description of radar system is given in detail by Rao et al.⁵

A campaign for simultaneous observations by MST radar and radiosonde flights was carried out at National MST Radar Facility (NMRF), Gadanki during the period July 19-August 14, 1999. The common-mode data set of the radar during this period is used in present analysis. The simultaneously launched radiosonde observations at Gandanki are used for validation of the result.

Theory

The theory of Fresnel scattering⁶ relates the magnitude of the power reflection coefficient $|\rho|^2$ from a stable region to the range resolution Δr of the radar and the mean gradient of generalized potential refractive index ($\bar{M}$) by

$$(1) \quad |\rho|^2 = (\Delta r)^2 \frac{F(\lambda)^2}{16} \bar{M}^2$$

where λ is the radar wavelength and $F(\lambda)$ must be determined empirically. For upper troposphere, $\bar{M}$ can be approximated by the dry term⁷ as

$$(2) \quad \bar{M} = -77.6 \times 10^{-6} \frac{P}{T^2} \left(\frac{\partial T}{\partial Z} + \Gamma_d \right)$$

The backscattered echo power P_r of the radar and $|\rho|^2$ are related as

$$(3) \quad P_r = \frac{\alpha^2 P_t A_e^2}{4 r^2 \lambda^2} |\rho|^2$$

where P_t is transmitted power, A_e is effective antenna area, α is efficiency factor and r is the range of the target. The range corrected echo power $S_v (= P_r \times r^2)$ for vertical beam

of MST radar can be written as³

$$(4) \quad \ln(S_v) = \zeta + \ln \left[\left(\frac{\Gamma_d + \frac{\partial T}{\partial Z}}{T^2} \right)^2 + \frac{3(Z_0 - Z)}{H} \right]$$

where

$$\zeta = \ln(BP_0^2), \quad B = P_t \left[\frac{(-77.6 \times 10^{-6}) \alpha A_e F(\lambda) \Delta r}{8 \lambda} \right]^2$$

and P_0 is atmospheric pressure in mb at the reference altitude Z_0 . Thus, the constant ζ depends on meteorological conditions as well as on radar parameters.

Method for Detecting Tropical Tropopause

The constant ζ in Equation (2) can be evaluated by prescribing the values of T and $\frac{\partial T}{\partial Z}$ at a reference altitude Z_0 . Once ζ is known, the value of $\left(\frac{\partial T}{\partial Z} + \Gamma_d \right) / T^2$ can be obtained for each range-bin. The expression for $\left(\frac{\partial T}{\partial Z} + \Gamma_d \right) / T^2$ then becomes a first order nonlinear equation in T , which is solved numerically to estimate T . Thus, the vertical temperature profile of the atmosphere can be reconstructed from which we plot the height profile of the gradient of vertical temperature. Then, the tropopause height is determined as the lowest level above 500 mb pressure-level at which the temperature gradient reaches to -2°C/km and the average temperature gradient from this level to any level within the next higher 2 km does not falls below -2°C/km (WMO - criteria).

Results and Discussions

The Indian MST radar is routinely operated daily for about 45 minutes between 1630 and 1715 hrs IST close to the radiosonde launch time from Chennai (13.1°N , 80.2°E) in a standard mode called Common Mode Observations (CMO). Common mode observations are aimed at generating a long-term database for various scientific studies.⁸ Further, a campaign for simultaneous observations by MST radar and radiosonde flights was carried out at National MST Radar Facility (NMRF), Gadanki during the period July 19-August 14, 1999. The CMO data set of radar during this period has been used in present analysis. During the campaign period, balloons were launched from the radar site at 1630 LT. the radiosonde observations are used to validate the temperature profile obtained from MST radar data.

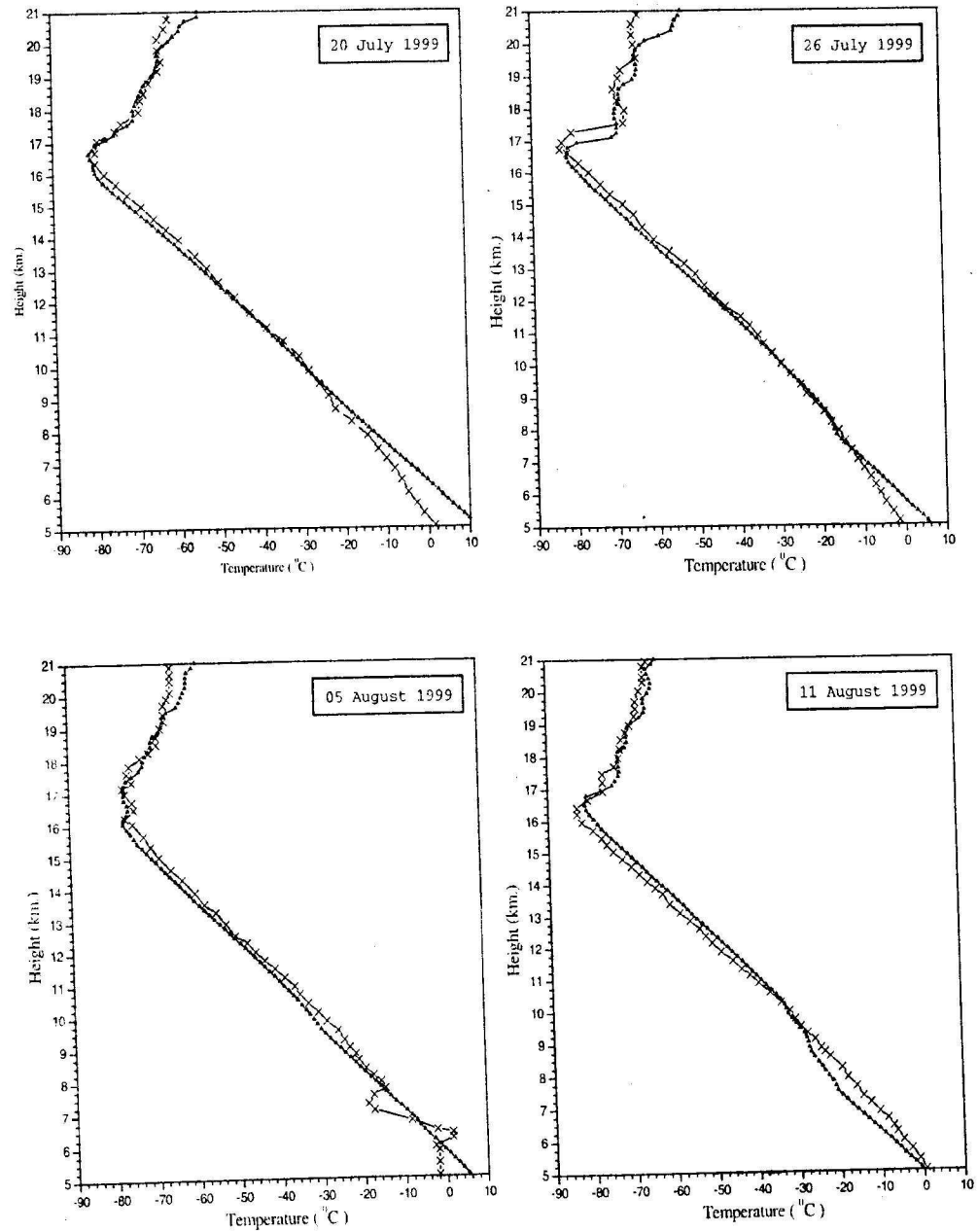


Figure 1. Comparisons of temperature profiles obtained using MST radar (—) and simultaneous radiosonde observation (---x---).

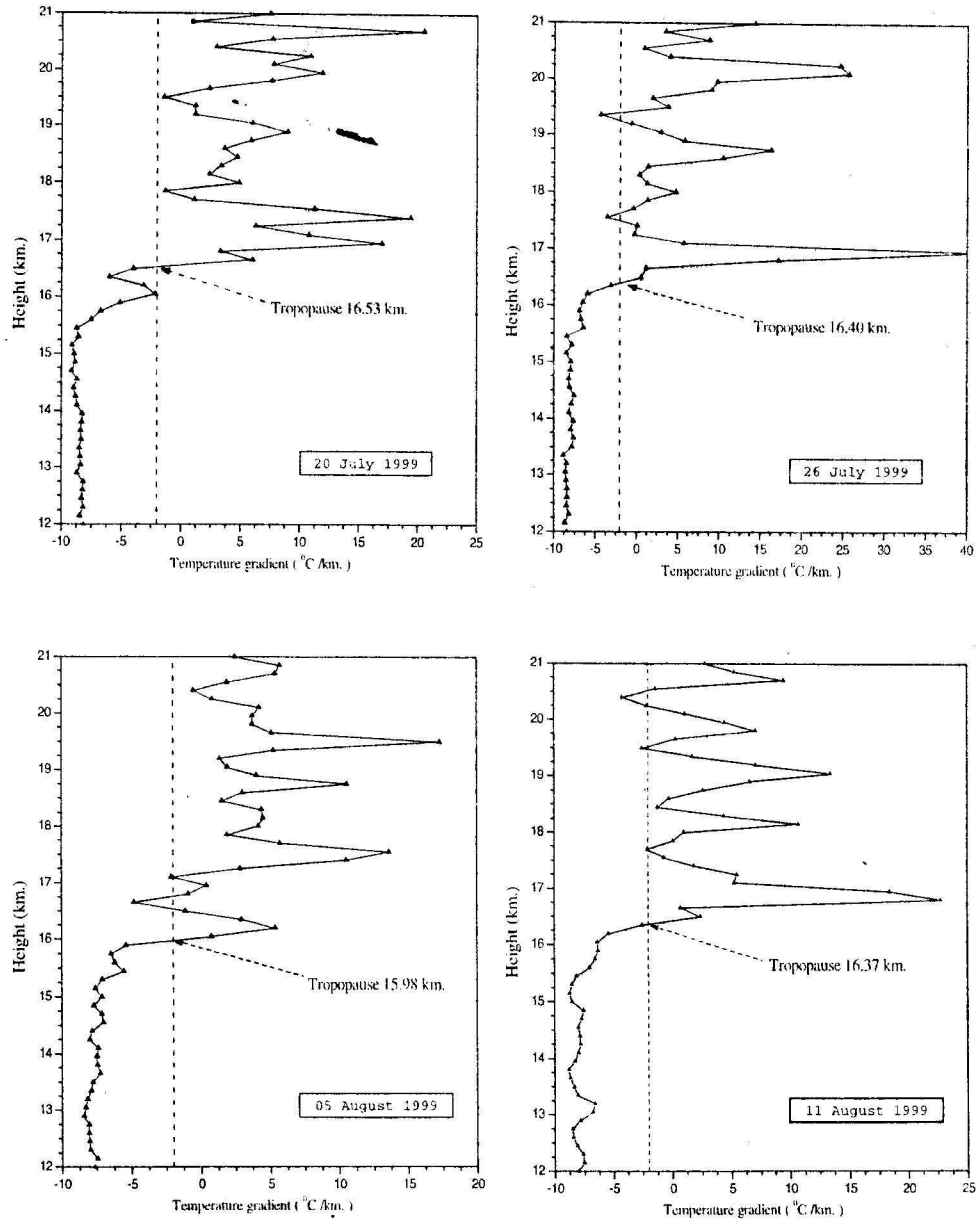


Figure 2. Estimation of tropopause height based on WMO - criteria.

(— dT/dZ estimated from Radar and - - - $dT/dZ = -2$ °C/km.)

The temperature was estimated from Eqn. (4) using the technique outlined by Das et al.⁴ Four such temperature profiles for different dates during the campaign period are shown in Fig. 1. We have also plotted the corresponding temperatures deduced from the simultaneously launched radiosonde flights at the radar site for the purpose of comparison. It is observed that the two temperature profiles are in good agreement with each other validating our approach. The method has been followed for several months of the year when there are no radiosonde flights at the radar site and the results are compared with the radiosonde observations of Chennai (13.1°N, 80°2 E). Chennai is the nearest India Meteorological Department radiosonde observing station located 120 km southeast of the radar site. Again, we found a very good correlation between the radar derived temperature profile and the temperatures inferred from radiosonde flights. This gives us confidence about the correctness of the estimated temperature. Finally, we obtain the height profile of the gradient of vertical temperature from which tropopause height is calculated using WMO criteria. The results are shown in Fig. 2. The height of the tropopause so derived compares well with the radiosonde observed tropopause height.

Conclusions

We have successfully demonstrated that clear air VHF radar such as Indian MST radar located at a tropical location of Gadanki can be used to estimate temperature of the lower atmosphere by modeling the radar SNR. The tropopause can be detected and height of tropopause can be estimated using the widely used definition of tropopause as prescribed by WMO.

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