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The research of the universal radar tropopause model

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Abstract

Based on the echo mechanism of the Wuhan MST radar, this paper builds a universal radar tropopause model which exports not only the height but also the echo intensity of the radar tropopause. Comparing with the meteorological tropopause from ten radiosondes, the variation of the radar tropopause is same with the meteorological tropopause. The average height of the meteorological tropopause is about 15.8 km, and the average temperature of the meteorological tropopause is about 201.9 K. While the average height of the radar tropopause is 13.9km; and the height of the meteorological tropopause is two kilometers higher than the radar tropopause.

Keywords: MST radar; radiosonde; Meteorological tropopause; Radar tropopause

1. Introduction

In 1996, the World Meteorological Organization (WMO) defined the height of the meteorological tropopause as follows: the decreasing rate of temperature decreases to -2K/km, and the minimum height of at least 2km is not higher than this decline rate, where is the climatology meteorological (WMO, 1996). While for the radar which could not directly provide the temperature parameters, Röttger et al. (2007) and Hall et al. (2009) redefined the heights of the radar tropopause: for a complex radar system, the heights of the tropopause should be the height corresponding to the maximum of the reflected power gradient in the in the upper troposphere and lower stratosphere (UTLS) region; for a simple radar system, the height of the tropopause is the height corresponding to the maximum of the echo power in the UTLS region. But for the MST radar which depends entirely on scattering of atmospheric turbulence and the reflection of the fixed layers to obtain the effective echoes, the quality of the echoes depends entirely on the intensity of disturbance in the volume of the radar beams. So, if that only depends on the gradient of echoes the determine the tropopause height will appear in large error. In this paper, based on the echo mechanism of MST radar, the tropopause judgment model of MST radar is constructed to effectively obtain the radar tropopause.

2. Radar tropopause model

From ST and MST radar, because of its good coverage region of troposphere and lower stratosphere, so people have been trying to do a better understanding the exchange of material and energy between the troposphere and lower stratosphere, and tropopause in this research field plays an important role. Currently, MST radar tropopause estimation models which are widely accepted by people are relatively limited. There are mainly two kinds of judgments models, one is gradient change based on temperature, and the other is radar echo mechanism. Because in the tropopause region, the minimum value of absolute value of gradient appears in the temperature profile of the troposphere, which can be shown in the obvious jump value of B-V frequency (Qing et al., 2014). In addition, the atmospheric refraction in the upper troposphere and lower stratosphere is mainly affected by the temperature, it can be based on the radar reflectivity and can use the approximate relationship between temperature to determine the tropopause. The echoes of MST radar in the troposphere are mainly turbulent scattering echo, and in the tropopause region and lower stratosphere will be superimposed corresponding stable stratification reflection echoes, However, for reflection echoes, it has obvious directional sensitivity. When the beam is perpendicular to the stable layer, the echo is very strong. Once the oblique incidence occurs, the reflected echo from radar will be greatly reduced. Based on this, we can also build a radar tropopause discriminant model.

The tropopause discriminant method with the MST radar, one is that Hermawan et al. (1998) obtained by statistical observation of the Japan MU radar with different angle beam comparison method and the other is that Das et al. (2008) compared with the method of distance weighted echo development reference model using atmospheric Gadanki radar in India. The two methods have their own advantages and disadvantages. The method of Hermawan et al. (1998) is based on radar echo mechanism, which has strong physical meaning and simple program implementation. It can be integrated into radar processing system well. But in the process of data processing, there is an implicit assumption that the stable layer of atmosphere does not have any inclination, that is, the vertical beam of radar must be perpendicular to the stable layer. Therefore, for the stable layer, the echo signals observed by the vertical beam of the radar must be stronger than the inclined beam, although this hypothesis is true in most cases, but there will be a stable layer of atmosphere node tilting the echo power of the vertical beam received not necessarily than strong beam tilt. The method of Das et al. (2008) first deduce the physical model between radar range weighted echo and temperature lapse rate theoretically, and judge the height of tropopause according to the intersection point of temperature lapse rate and radar echo profile. This method has two major drawbacks, the first is the theory ignores the influence of humidity, but the radar measured data must really exist the effects of humidity, second is the need for the local temperature and pressure reference value, making the model input more dependent on the prior value, and the operation is relatively complex.

The Wuhan MST radar mainly uses the five-beam detection mode, and the echo difference between the different direction of the inclined beam is very obvious to the stable layer of the atmosphere. Therefore, this paper is mainly based on the theoretical basis of Hermawan et al. (1998) to study a general tropopause discriminant model suitable for MST radar. For the existence of atmospheric stable stratification as shown in Figure 1, there are always five beams (**E**ast, **W**est, **S**outh, **N**orth, **V**ertical) using the MST radar. There is always a beam or two beams in the space, which is closer to the vertical. Their echo signals are relatively strong, and the echoes of the other one or two beams will be very weak. Therefore, for each height, the five-beam echo is defined as $\mathbf{M} = [P_E, P_W, P_S, P_N, P_V]$. Sorting the **M**, the two values of the maximum value are approximately the maximum value ($P_{\max}$)of the reflected echo, and the minimum value ($P_{\min}$) is the weakest value of the reflected echo far from the vertical direction. The ratio ($\mathbf{Q}(h_i)$) of the two represents the intensity of the space sensitivity.

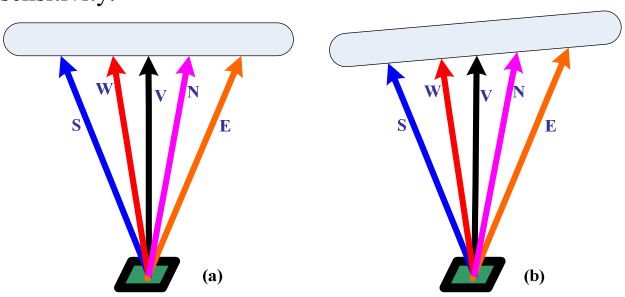

Figure 1. Beam direction of atmospheric stable layer, (a) no tilt situation and (b) tilt situation

If the turbulence is isotropic scattered, the difference between the strongest echo and the weakest echo will not be too large in a certain angle range. However, when the stable stratification is present, the difference between the strongest echo and the weakest echo will increase with the increase of relative oblique angle. Therefore, the radar tropopause height (H_T) can be defined by the relative maximum of the ratios ($\mathbf{Q}(h_i)$) in the tropopause region. Based on this, the radar tropopause model in this paper is summarized as follows: for the set of $\mathbf{Q}(h_i)$ at all heights of troposphere region, the definition of tropopause is as follows.

$$H_T = \max(\mathbf{Q}) \tag{1}$$

$$s.t. \begin{cases} \mathbf{Q}(i) = P_{max}(h_i)/P_{min}(h_i) \\ P_{max}(h_i) = \max[0.5\mathbf{M}(n) + 0.5\mathbf{M}(m)], \quad n \neq m \\ P_{min}(h_i) = \min(\mathbf{M}) \\ h_i \in \mathbf{R} \end{cases}$$

3. Observation and Analyze

To verify the accuracy and reliability of the radar tropopause model presented in this paper. We use ten sets of temperatures of the radiosondes from September 10 to 12,2017 to compare with the result computation of the radar tropopause model in this paper. For better comparison studies, first the temperature datas of the radiosonde are fitting with cubic spline interpolation, and the result is interpolated to a distance of 100 meters. Base on the integrated temperature section of the radiosondes that we fitting, according to the definition of the meteorological tropopause, the different observations of the meteorological tropopause are showed in Figure 2. The points of intersection in the figures are the point of intersection of the decreasing rate is a line of -2K/km (red line) and temperature data (blue line), that is the height of the meteorological tropopause.

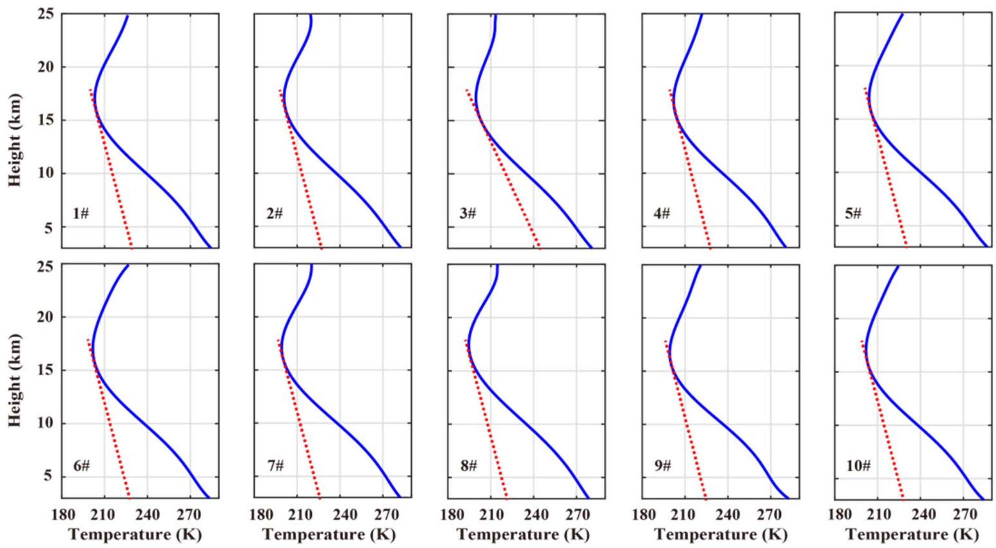

Figure 2. The meteorological tropopause

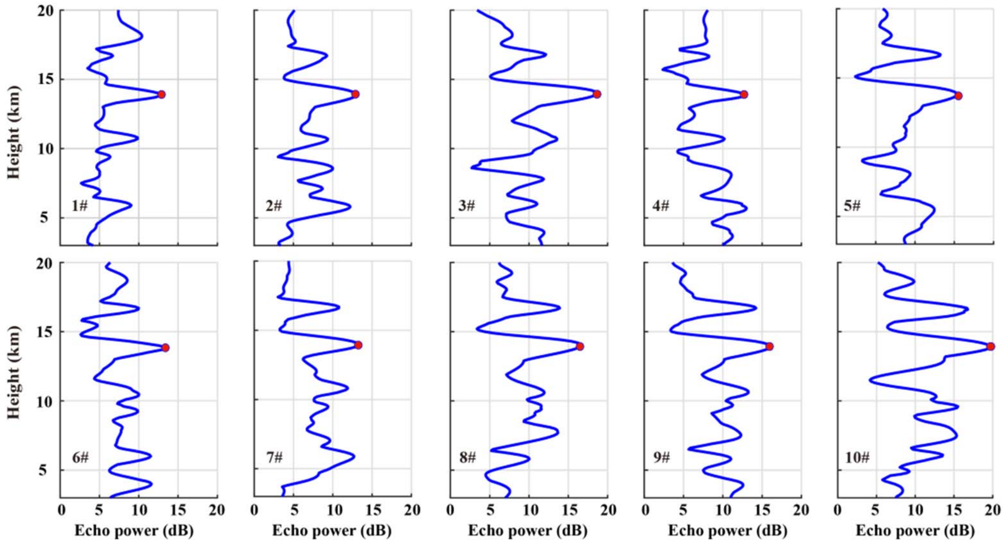

Figure 3. The radar tropopause

Using the pattern detection data in Wuhan MST radar, we first need to make the tilted beams and vertical beam to the same level. For the converted radar echoes, we use the data from 3 km to 20 km with the three-spline interpolation to make the distance resolution of 100 meters. Then the radar tropopause could be calculated by using the model in this paper. Because during the radiosondes rise, the radar mode detection results are more than one group, this paper in order to facilitate the calculation first put every radiosonde in all corresponding mode detection results were statistical average, get the average profile of the final, as shown in Figure 3. The red point on the profile is the height of the radar tropopause, which is automatically identified by the model. According to the statistics, the variation range of the tropopause of Wuhan is about 10~20km. It is evident from Figure 3 that, although the whole troposphere (including troposphere) they have strong direction sensitivity, which shows the constant change of the difference of echo energy, there exists a maximum value in the tropopause region, which indicates that the tropopause as a relatively stable atmospheric stable layer has been at some level.

Table 1 shows the meteorological tropopause from ten set of radiosondes and the radar tropopause from the Wuhan MST radar in the corresponding time period. It can be seen from table 1 that 1) the fluctuation of the tropopause is not very large during the day; 2) the meteorological tropopause height average value is about 15.8km and the average temperature is about 201.9K; 3) the average height of radar tropopause is 13.9km, and the average difference of echo power is 15.2dB. The height of the meteorologic tropopause is slightly higher than the height of the radar troposphere about 2km, this rule is basically the same as that of Alexander et al. (2013) using the tropopause contrast observed by the Antarctic Davis MST radar and the radiosondes. In contrast, the tropopause height observed by the Wuhan MST radar is relatively constant, which may be related to the range resolution of the mode in the radar, because the actual range resolution of the radar is 600 meters at this time, the response to the height of the troposphere over a hundred meters is not too sensitive. If we study the variation of tropopause height in small time scale, we need a higher distance resolution mode

Table 1. tropopause parameters

Equipment	Radiosonde		Wuhan MST radar	
	Height (km)	Temperature (K)	Height (km)	Echo power (dB)
1#	15.76	204.4	13.9	12.81
2#	15.93	202.1	13.9	13
3#	15.72	201.1	14	18.69
4#	15.37	203.7	13.9	12.81
5#	15.68	205.4	13.8	15.36
6#	15.9	202.7	13.8	13.44
7#	16.15	200	14	13.27
8#	16.31	195.8	14	16.66
9#	15.55	200.4	13.8	15.86
10#	15.62	203.5	13.9	19.72

4. Summary

Thinking of the tilt condition of the atmosphere, based on radar echo mechanism, a universal radar tropopause model is built in this paper. It can not only give the height of the radar tropopause, but also can give the echo intensity of the radar tropopause. The results show that the height of the tropopause is little changed in the daytime by comparing with the meteorologic tropopause from the radiosonde. The average height of the meteorological tropopause is about 15.8km, and the average temperature of the meteorological tropopause is about 201.9 K. While the average height of the radar tropopause is 13.9km; and the height of the meteorological tropopause is two kilometers higher than the radar tropopause.

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