VHF-RADAR OBSERVATIONS OF TEMPERATURE SHEETS IN THE STRATOSPHERIC-TROPOSPHERIC REGION

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1. Introduction:

In past two decades VHF radar observations have contributed much in understanding the various small-scale atmospheric processes. However, knowledge of the VHF radar backscattering plays a vital role in understanding and interpreting these observed atmospheric phenomena. In this regard, several experiments were carried out across the globe to understand the VHF radar backscattering mechanisms. Many of these experiments have reported the multiple layered structures at and around the tropopause regions, especially in the lower stratosphere [e.g. *Jaya Rao et al.,* 1994, *Jain et al*., 1994 and 2001]. It is now well established that these layered structures are due to the presence of strong negative and positive temperature gradients [e.g. *Dalaudier et al*., 1994, *Luce et al*., 2001], commonly known as 'temperature sheets'. VHF radar observations of these temperature sheets in the lower stratosphere are extensively reported by several researchers [*Dalaudier et al.,* 1994], [*Luce et al.,* 2001, *Jayarao, et al*., 1994]. Though, earlier studies have suggested few causative mechanisms for the formation of temperature sheets, they are restricted by means of uncertainty in their proposed mechanism and also due to limited radar resolutions (interms of spatial and temporal). The suggested mechanisms include Kelvin-Helmholtz Instability, (KHI) [*Muschinski* and *Wode*, 1998], viscous or thermal conductive waves [*Hockings et al.* 1991] and gravity waves [*Luce et al.,* 2001]. It has been further showed that the propagation and dissipation of gravity waves, which in turn affected by the KHI [*Frittis* and *Rastog*i, 1985], is responsible for the observed temperature sheets in the lower stratosphere.

In the present study, simultaneous VHF radar located at Gadanki (13.47^o N, 79.18^o E, a tropical site, India) and balloon measurements have been employed to divulge the occurrence of temperature sheets. An attempt has also been made to understand the causative mechanism for the presence of multiple layers structure in terms of gravity waves.

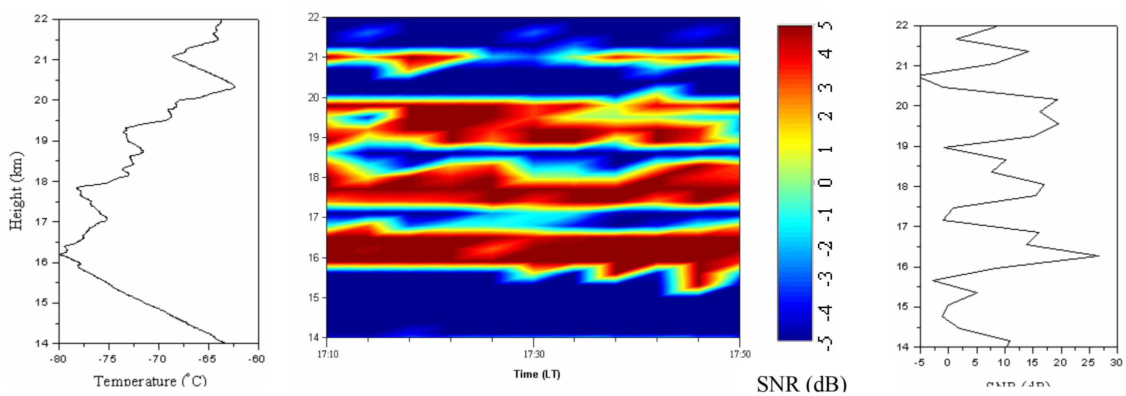
2. Results and Discussions:

The results from concurrent VHF Radar observations at Gadanki and GPS sonde measurements at Tirupati (nearby the radar site) during September 2000 are presented here. GPS sondes provides high-resolutions measurements of temperature, pressure, humidity, wind speed and direction. A temperature profile obtained from GPS sonde, on September 4, 2000, is shown in figure 1(a). This figure displays clearly the existence of inversion layers, by strong positive and negative temperature gradients in the stratospheric-tropospheric height regions. The recorded radar observations interms of range-time signal to noise ratio (SNR) section is shown in figure 1(b). This figure reveals the existence of multiple layered structures in the lower stratosphere and upper troposphere height regions. It further illustrates that the high intensity in SNR is due to the prevailing temperature gradient at the same height region (refer figure 1(a)). Radar measurements at vertical and off-vertical directions provide the measure of aspect sensitivity of the backscatters. The difference in SNR profiles of vertical and off-vertical directions, which gives the first order aspect sensitivity measurements, is shown in figure 1(c). From this figure high aspect sensitivity can be noticed around the temperature sheets, which in turn confirms the layered structure of the backscatters.

In order to know the vertical wave length of temperature and SNR perturbations, wave analysis have been carried out and is shown in figure 2. As there was no continuous radar observations, the wave anlysis is done in height domain only to find out the vertical wavelenth of the observed perturbations. Both SNR and temperature show a peak in amplitude at the vertical wavelength of 1.6 km. This suggests that the modulation of temperature is due to the propagation of atmospheric waves, which in turn reflects in the SNR observations. As mentioned earlier,due to the lack of continuous observations (both temperature and radar intensity), wave periodicities are not estimated.

Realizing the importance of these studies a comprehensive campaign is carried out to further understand the existence of temperature sheets. During this campaign, we found a similar kind of structure as discussed above on September 25, 2002. On this day, continuous radar observations were taken for a period of 12 hours with time and height resolutions of 7min and 150 m respectively. The radar observations are also supported by the simultaneous GPS measurements at the radar site. Figure 3(a) shows the height profile of temperature, which is revealing the prominent temperature structures in the lower stratosphere.

September 4, 2000



(a) (b) (c)

Figure 1. (a) Height profile of temperature derived from GPS-Sonde measurements, (b) Height-Time-SNR section obtained from Gadanki VHF radar and (c) height profile of SNR difference between vertical and off-vertical (10°) beam directions on September 4, 2000.

September 4, 2000

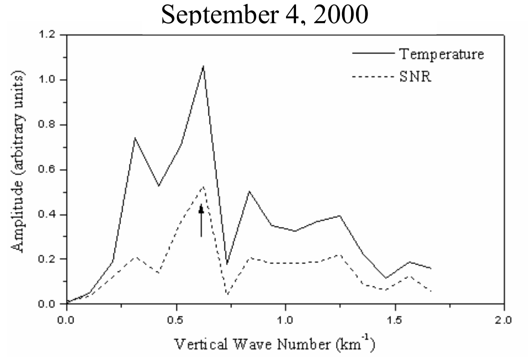
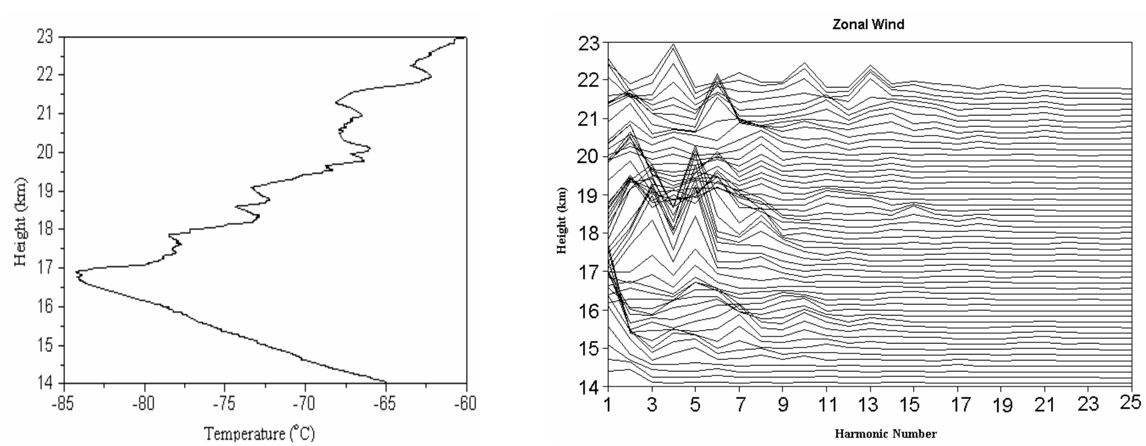


Figure 2. Vertical wave number spectra of temperature and SNR obtained on September 4 2000 (arrow indicates the dominant wave number)

Continuous radar observations have been used to obtain the zonal, meridional and vertical velocities [*Anandan et al*., 1997]. The time series data of zonal, meridional and vertical velocity perturbations are further subjected to Fourier analysis to get the power spectra of the velocity perturbations. Figure 3 (b) shows the power spectra of zonal wind perturbations on September 25, 2002. From this figure it can be noticed that the oscillation with a time period of ~82.4 min is dominant at most of the heights, especially in the lower stratosphere. Moreover, it shows peak amplitudes in the lower stratosphere. But, it has been observed that the wave amplitudes are relatively weaker in the meridional and vertical velocities (figures are not shown). The direction of horizontal propagation of gravity waves in the troposphere are uniform in all directions whereas it will be eastward in the lower stratosphere. This may be the reason for observed enhancement in the zonal wind perturbations in the lower stratosphere [*Tsuda et al*., 1994].

Generally, the gravity waves transport energy and momentum from lower atmosphere to middle atmosphere. Often, these waves break wherever it encounters the dynamic and convective instabilities. When these waves break they deposit the momentum and energy in that region, which are very crucial for understanding the wave interaction with the large-scale environment. In the present study the temperature and wind field observations clearly shows the modulation of respective fields by the gravity waves. A thorough study is underway to reveal the gravity wave breaking and their consequences in the lower stratosphere.



(a) (b)

Figure 3. (a) Height profile of temperature derived from GPS-sonde measurement and (b) the spectra at different height levels for zonal wind perturbations on September 25, 2002 which shows the dominant time period of 82.4 min (period =412/5) corresponding to 5th harmonic number. The total period of observations corresponds to ~412 min.

3. Concluding remarks:

The existence of layered structures in the stratospheric-tropospheric height region using VHF radar observations are presented in this paper. The enhanced radar reflectivity layers associated with high aspect sensitivity are observed in the same height region, which are attributed to the presence of temperature gradients. The spectral analysis revealed the vertical wavelength of ~1.6 km indicating the perturbation of temperature by the propagating gravity waves. For the same kind of structure, on the other day, the periodicity of the propagating waves is found to be 82.4 min. These wave oscillations are more prominently seen in the zonal winds, which have shown the peak amplitudes in the lower stratosphere.

The present observations thus emphasize the gravity waves as an important source for the observed temperature sheets in the lower stratosphere. However, further observations and evidences are required to shed more light on to this aspect.

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