VHF Radar echoes in the vicinity of Tropopause during the passage of Tropical Cyclone and Convection

Siddarth Shankar Das[1,2], A. K. Patra[2], D. Narayana Rao[2]*

* e-mail : dassiddhu@rediffmail.com **(Presenting author)**

[1]Centre for Wind Energy Technology, MNES, Govt. of India, Chennai, India
[2]National Atmospheric Research Laboratory, Dept. of Space, Govt. of India, Gadanki, India

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Centre for Wind Energy Technology
Ministry of Non-Conventional Energy Sources, Government of India
Velachery-Tambaram High Road, Pallikaranai
Chennai - 601 302 (TN) INDIA

Objective

To study the characteristics of Radar echoes in the vicinity of the Tropopause (VOT) during the passage of Tropical Cyclone and Convection.

Motivation

VHF radar echoes from the VOT are found to be highly aspect sensitive. It has been observed that signal strength decreases rapidly upto ~10^{o} zenith angle with an average rate of ~1.2 dB/degree and beyond 10^{o} zenith angle, it is ~0.6 dB/degree [e.g., *Jain et al., 1997*; *Tsuda et al.*, 1997]. These characteristics, however, are observed during clear-air conditions.

In the present study, an effort has been made to understand the characteristic of VHF radar echoes in the VOT during the passage of Tropical Cyclone and Convection, which contributes significantly in the Stratosphere-Troposphere exchange (STE) processes and vice-versa. This is the first Radar observation on the characteristics of VHF Radar echoes in the VOT during the passage of Tropical Cyclone.

Experimental Method

The observations presented here were made using the VHF radar located at Gadanki (13.5^{o}N, 79.2^{o}E), a tropical station in India [*Rao et al.*, 1995]. The radar was operated in three different modes

(1) mode-1: to estimate wind

(2) mode-2: to observe the spectral parameters as a function of zenith angle and height (referred to as "fan-sector" map)

(3) mode-3:vertical beam measurement of the spectral parameters as a function of height and time.

For the mode-2 experiments, the radar beam was scanned within ±20^{o} off-zenith angle with a step interval of 2^{o} in both the planes. The range resolution for all the above mentioned mode is 150 m.

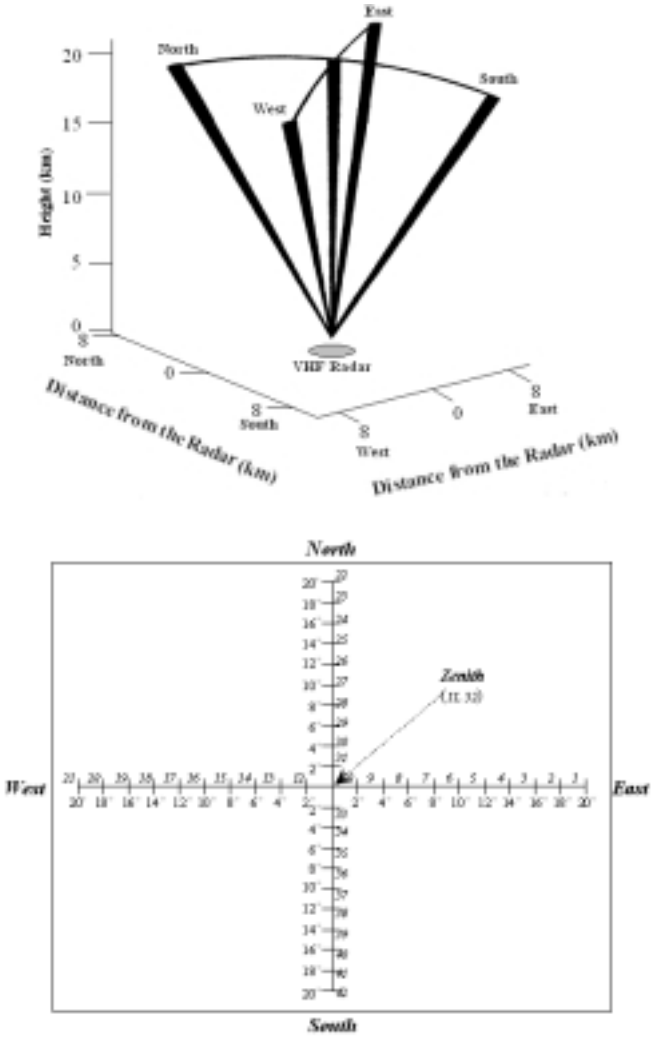

Figure 1 : ***Three-dimension view of beam switching pattern in EW & NS planes of the antenna array***

Results and Discussions

Clear-Air Condition

Figures 2a-d shows the observations corresponding to normal weather condition made at 11:00 IST (Indian Standard time) (IST=GMT+5:30 hrs) on April 28, 2005. Figures 2a and 2b represents "fan-sector" maps of signal-to-noise ratio (SNR) obtained from a single scan cycle in east-west (E-W) and north-south (N-S) planes, respectively. Figure 2c shows the average of 4 scan cycles (~16 minutes observations) made in both planes. Figure 2d represents the satellite picture on cloud activity. The circle in Figure 2d represents the location of the radar site (Gadanki).

From the intensity maps, aspect-sensitive property of the echoes in the height range of 14-18 km is clearly seen. Signal-to-noise ratio is found to decrease as a function of zenith angle and the rate is found to be ~1.2 dB/degree between 0^o to 10^o zenith angle and ~0.6 dB/degree between 10^o to 20^o zenith angle.

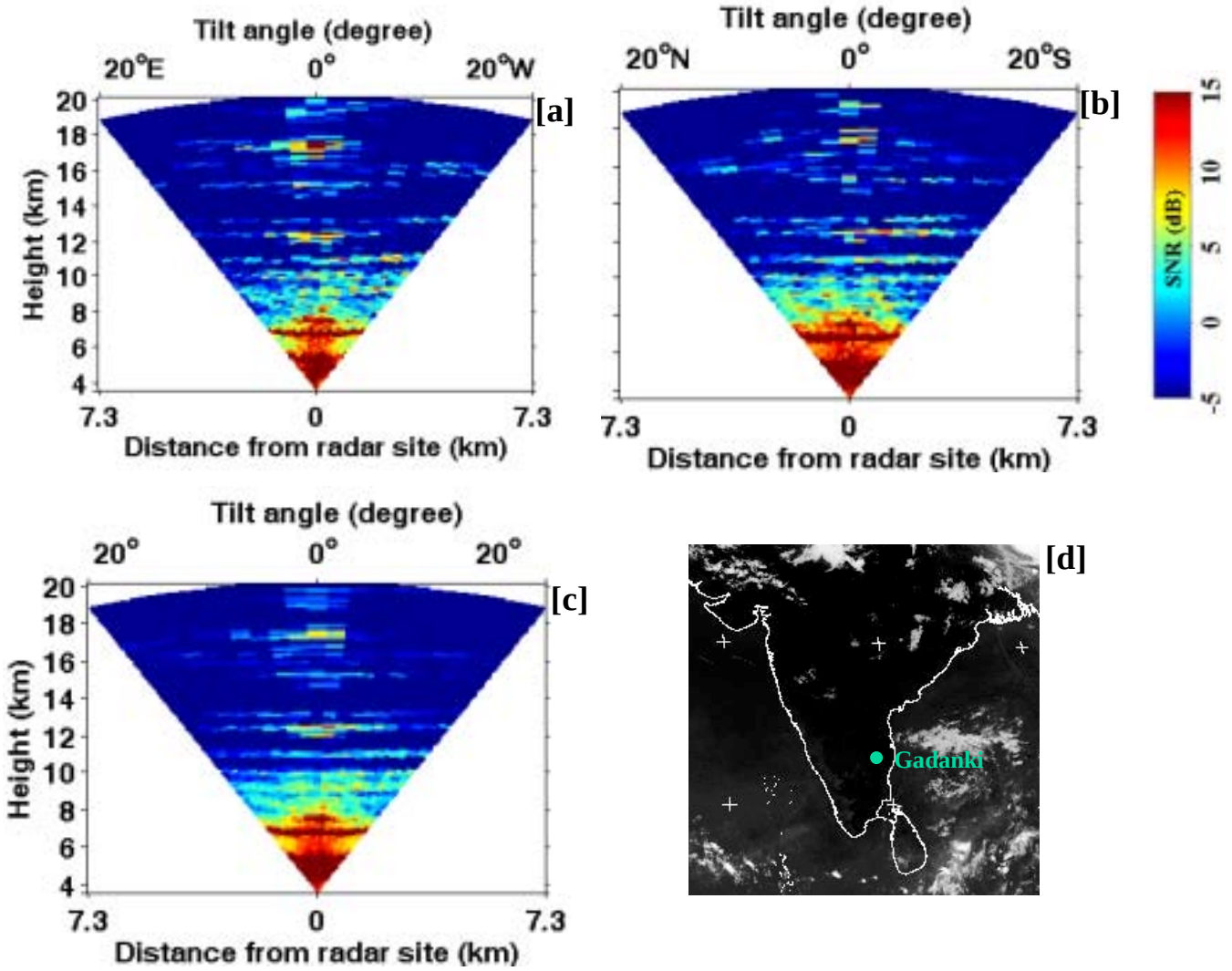

Figure 2 : ***The "fan-sector" map of SNR in (a) E-W, (b) N-S plane and (c) average of E-W and N-S plane during clear-air conditions observed at 11:00 IST on April 28, 2005.***

Cyclonic Condition

Figure 3a-d show the observations made during 18:50-19:06 IST on December 12 in a similar way as that of Figure 2. It may be noticed that the cyclone was well developed at this time but the cyclone center is located at a radial distance of ~ 1000 km from the radar site. The un-averaged fan-sector maps (Figure 3a and 3b) show that the radar echoes from altitude of about 16 km observed by north and east beams are somewhat stronger than that from the south and west beams. The average picture (Figure 3c), however, show no remarkable difference when compared with that during normal condition (Figure 2c).

Figure 4a-d show the observations made at ~ 23:30 IST on December 14, 2003 when the cyclone center is close to the radar site. It may be noticed that while the center of the cyclone was ~200 km away from the radar site, there were well-developed bands just over the radar site. The fan-sector maps clearly show that strong echoes were observed at all zenith angles from altitudes close to ~16 km unlike that observed in normal condition. When the cyclone dissipated, this feature vanished as shown in Figure 5a-d and observations identical to normal conditions were observed.

Another cyclonic event observed at 11:40 IST on October 10, 2005 is shown in Figure 6a-d in a similar way as that of December 14, 2003. On this day the cyclonic condition was less pronounced but strong cyclonic cloud was just overhead of the radar site (as can be seen from the satellite picture). Nevertheless, the fan sector maps show features similar to that of December 14, 2003. In this case also, the echoes were observed in all zenith angle from altitudes close to 16 km.

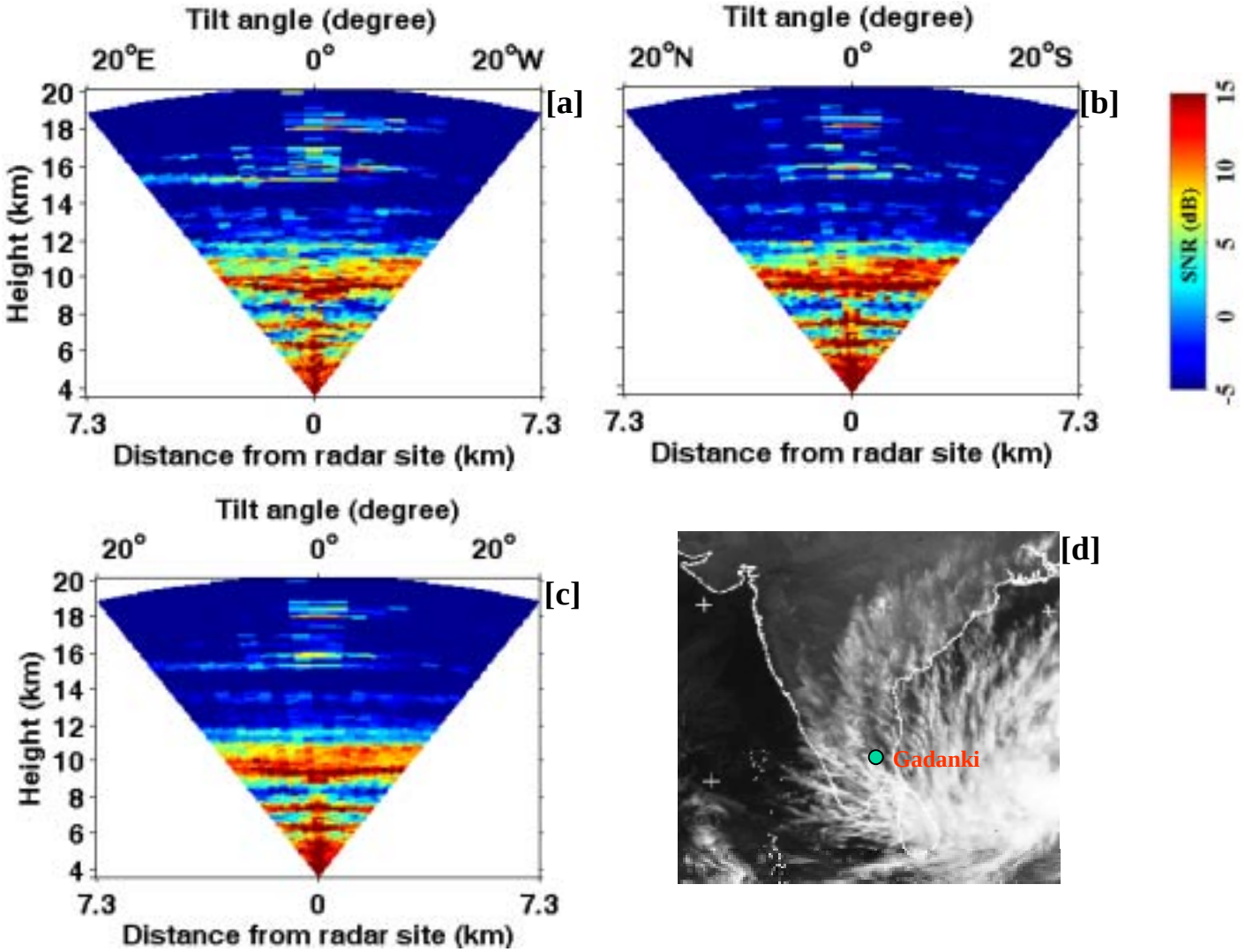

Figure 3 : ***Same as Fig-2, but during the developing stage of Tropical Cyclone on December 12, 2003.***

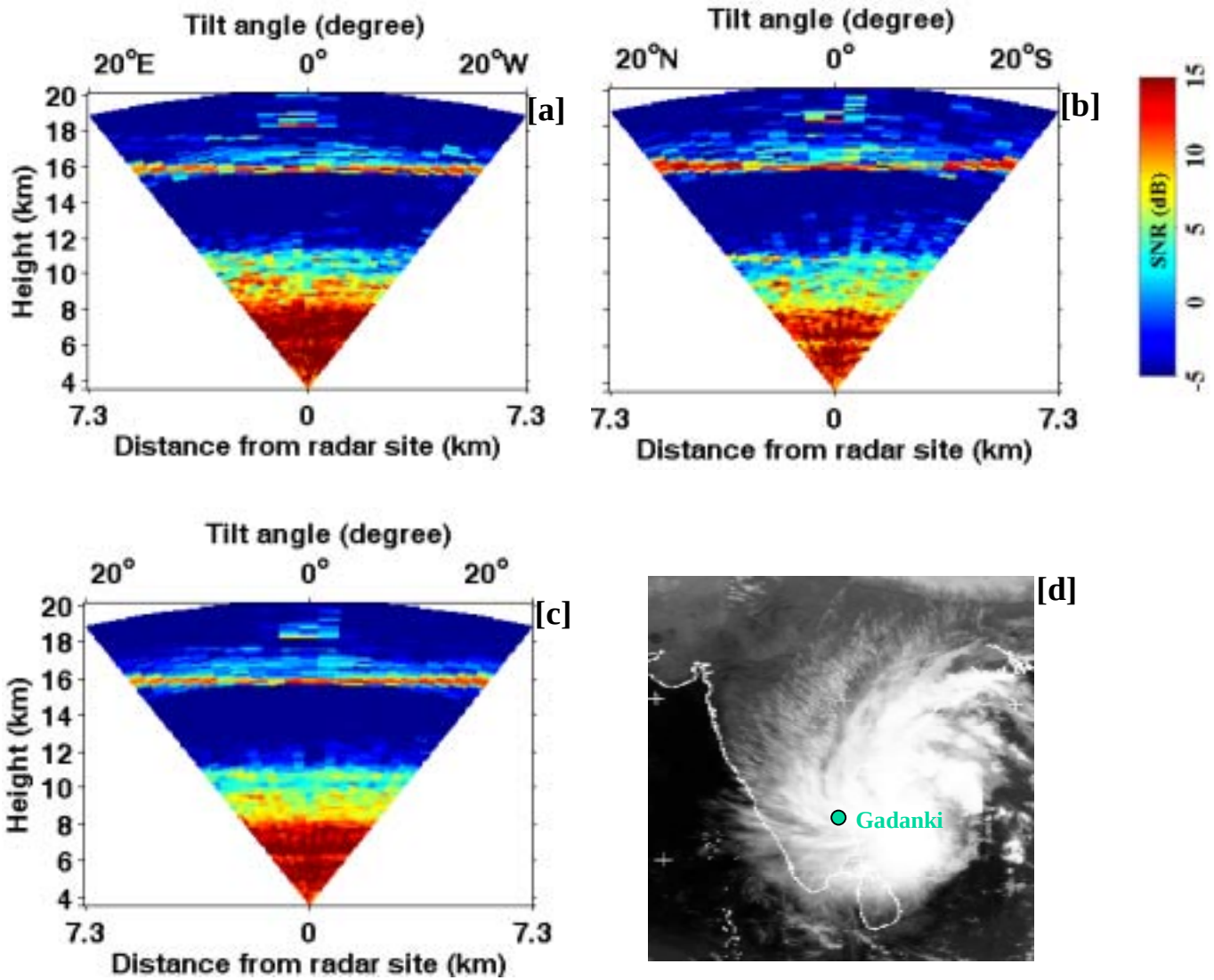

Figure 4 : ***Same as Fig-2, but during the passage of Tropical Cyclone on December 14, 2003.***

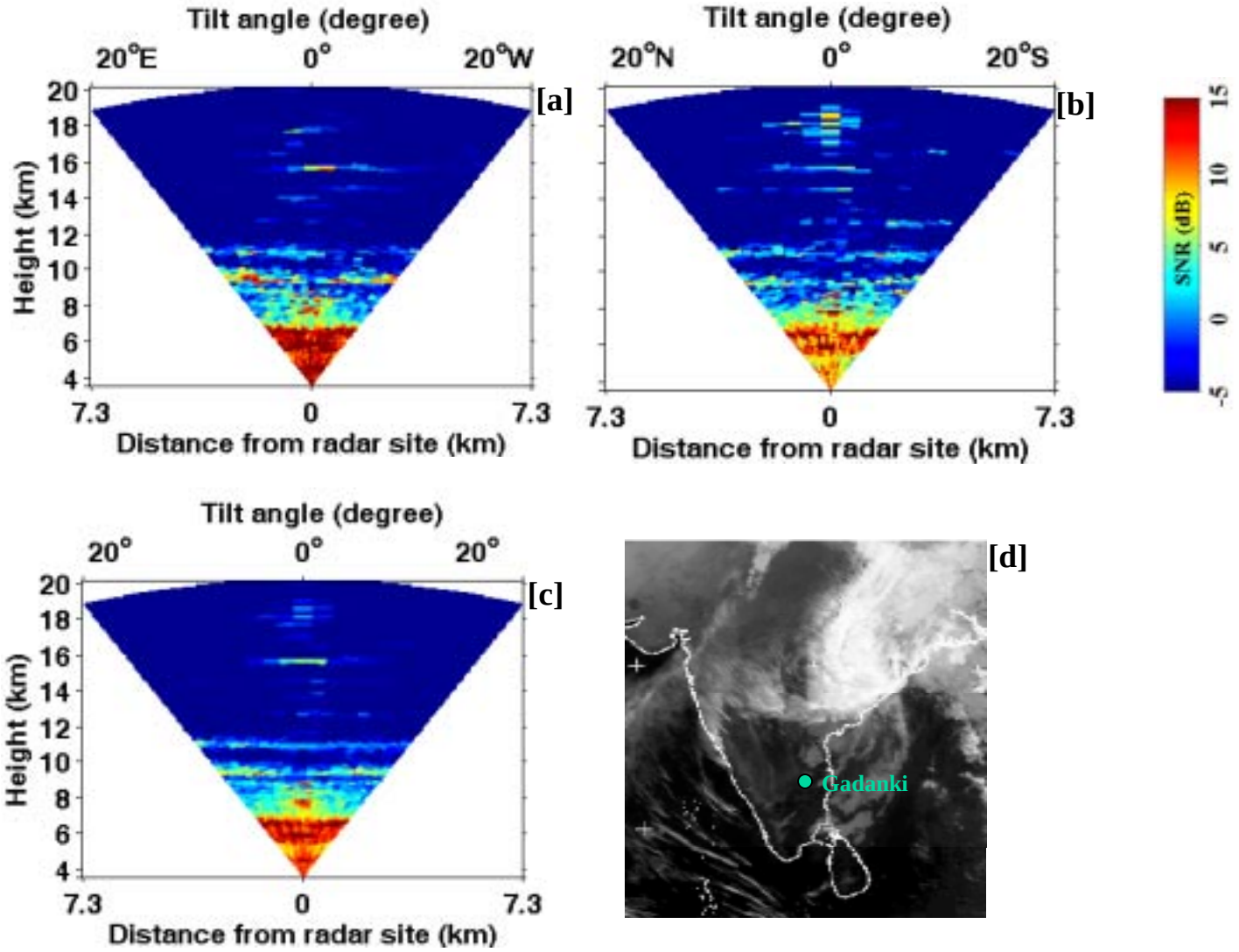

Figure 5 : ***Same as Fig-2, but during the dissipation stage of Tropical Cyclone on December 16, 2003.***

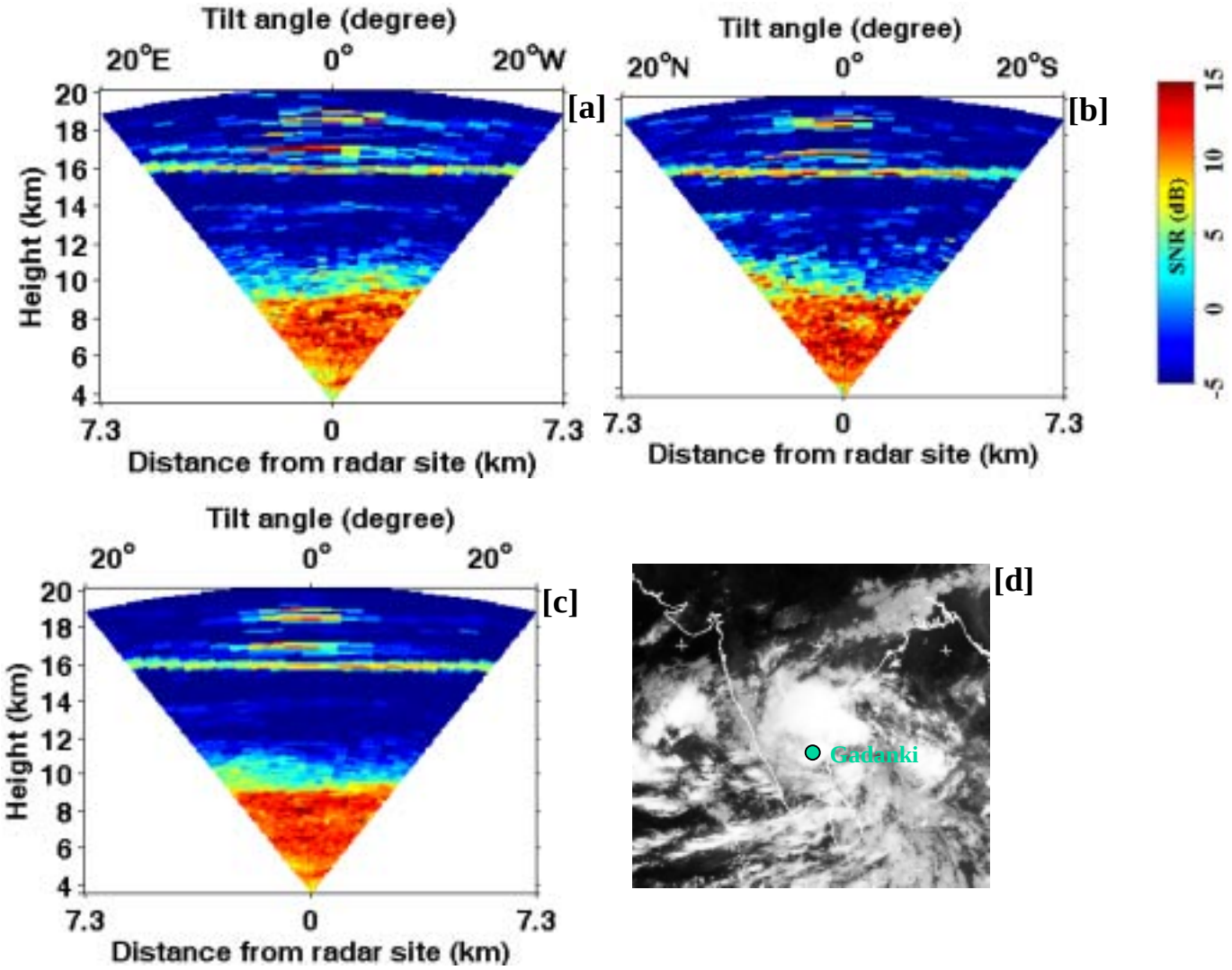

Figure 6 : ***Same as Fig-2, but during the passage of Tropical Cyclone on October 13, 2005.***

Convective Condition

Figures 7a and 7b show the "fan-sector" maps of SNR in E-W and N-S plane, respectively, during the passage of Tropical Mesoscale Convective System (TMSC) at 13:15 IST on May 31, 2004. Figure 7c shows the average picture in EW and NS planes. It may be noted that the echo extended upto the altitude close to ~16 km. Furthermore, the echo strength is not symmetric as a function of zenith angle. These maps seem to indicate that the stronger echoes are associated with the convective regions visible by the radar. It may be inferred that the convective region was located southwest of radar site. It may also be noticed that during this event the radar echo in the vicinity of tropopause (~16.1 km) is not visible as in case of normal weather conditions, which are characterized as due to the stability of the tropopause. This means that the tropopause is disturbed during the convective period. The radar echoes are also show distribution difference than that during the passage of cyclone. The vertical velocity as observed from the radar observations is found to be 1-2 m s^{-1}.

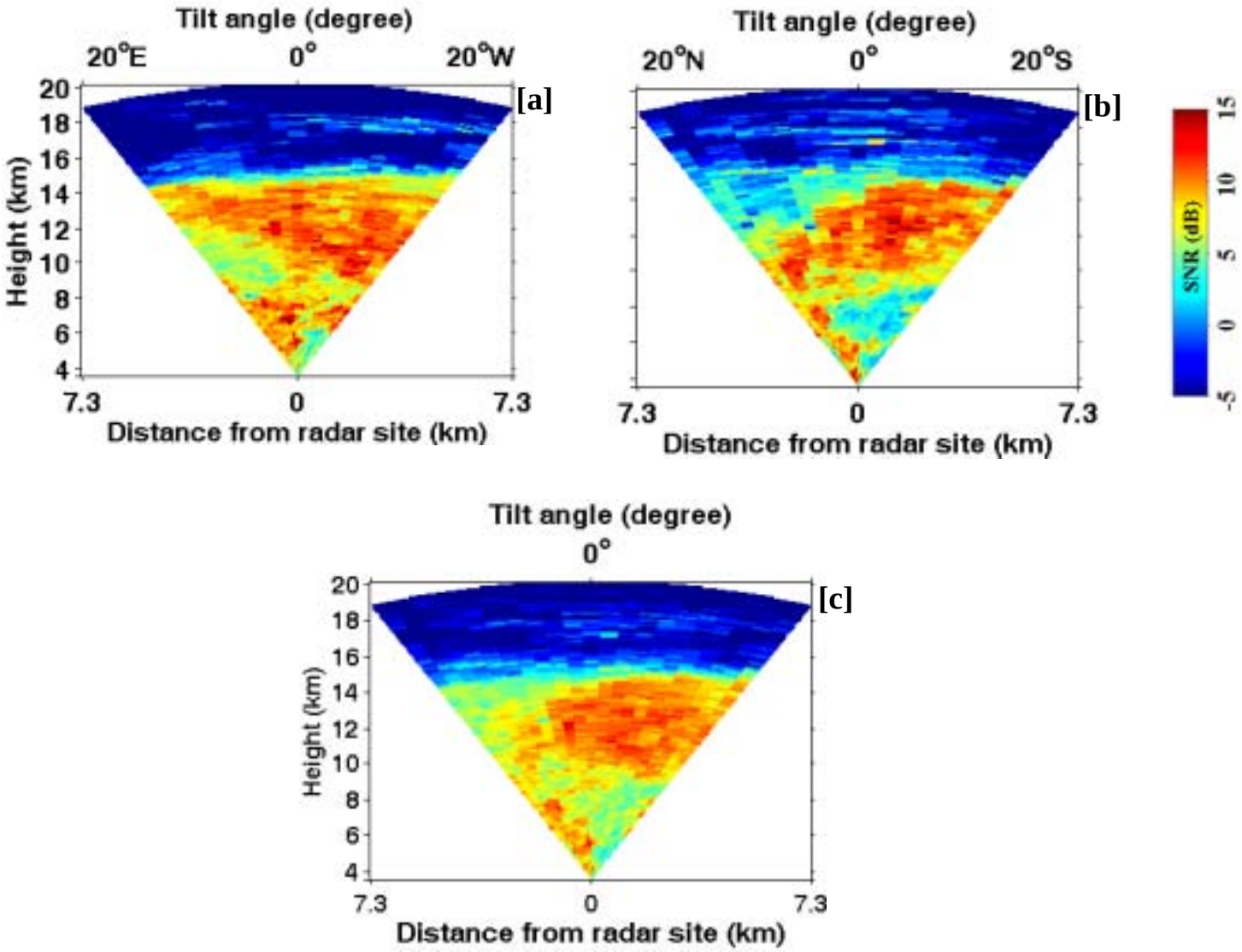

Figure 7 : ***Same as Fig-2, but during the passage of Tropical Mesoscale Convective system (TMCS) on May 31, 2004.***

Analysis

Figures 8a, 8b and 8c show the of SNR corresponding to altitude ~16 km as a function of zenith angle observed during the clear-air, cyclonic and convective weather conditions with standard deviation, respectively.

The observations show that the echo power intensity variations as a function of zenith angle in clear-air, cyclonic and convective weather conditions are quite different from each other.

Radar echoes are opposite to each other in clear-air and cyclonic conditions. However, during convection, radar echoes are tilted in SW direction. This reveals that the convective cell is SW of radar site.

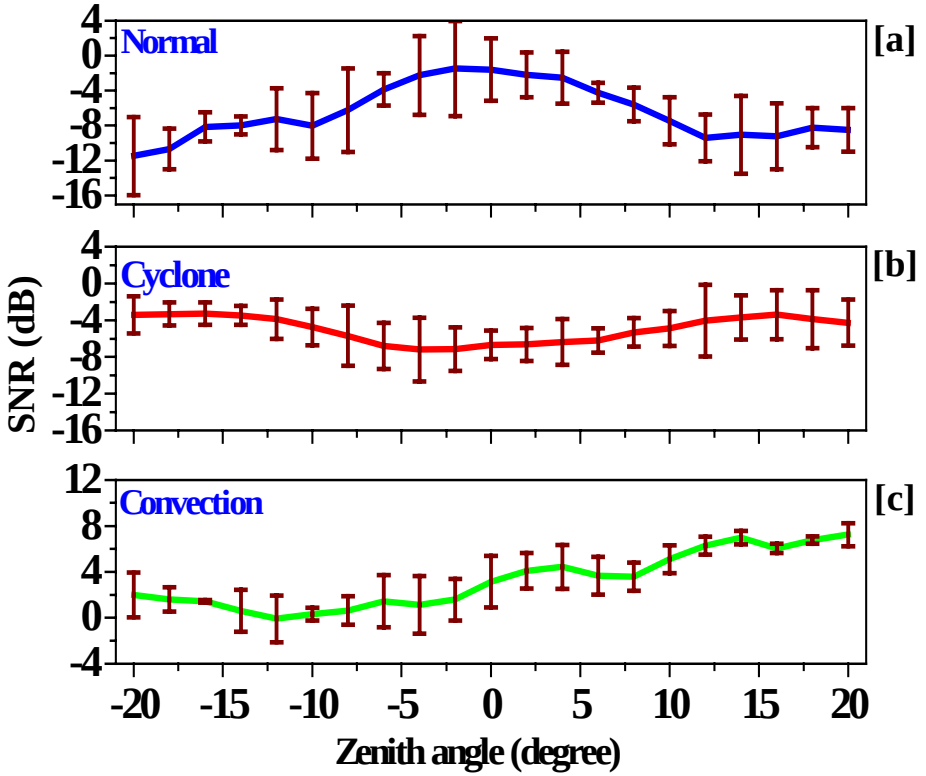

Figure 8 : ***SNR as a function of zenith angle with standard deviation averaged over 10 snap-shots in EW & NS planes for (a) Normal Case, (b) 2 cases of Tropical cyclone and (c) convection.***

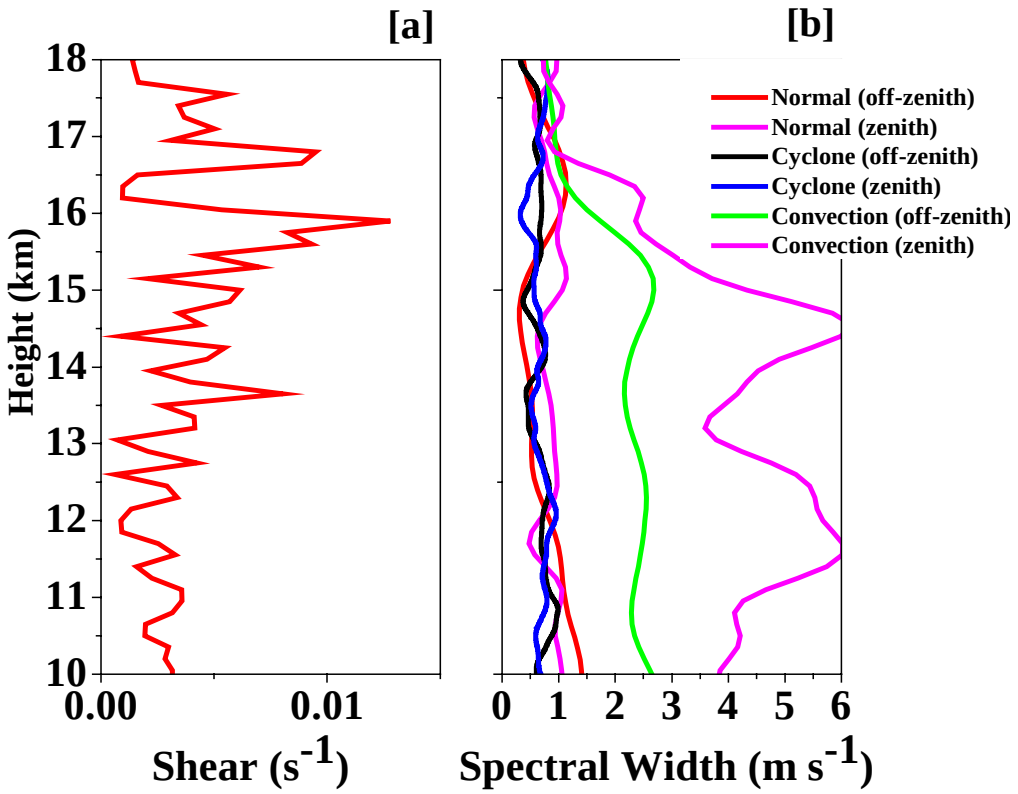

Figure 9 : ***Height profiles of (a) vertical shear of horizontal wind during cyclone, and (b) spectral width during cyclone and normal conditions.***

Figures 9a and 9b show wind shear and spectral width, respectively, observed during the cyclone. In Figure 8 (b), spectral width observed during clear-air, cyclone and convection. It may be noticed that the spectral width in the VOT during the cyclone and convection are significantly more than that observed in normal conditions. During convection it is expected due to high turbulence activities. Wind shear corresponding to the same height region during cyclone is estimated to be as high as 0.012 s^{-1}.

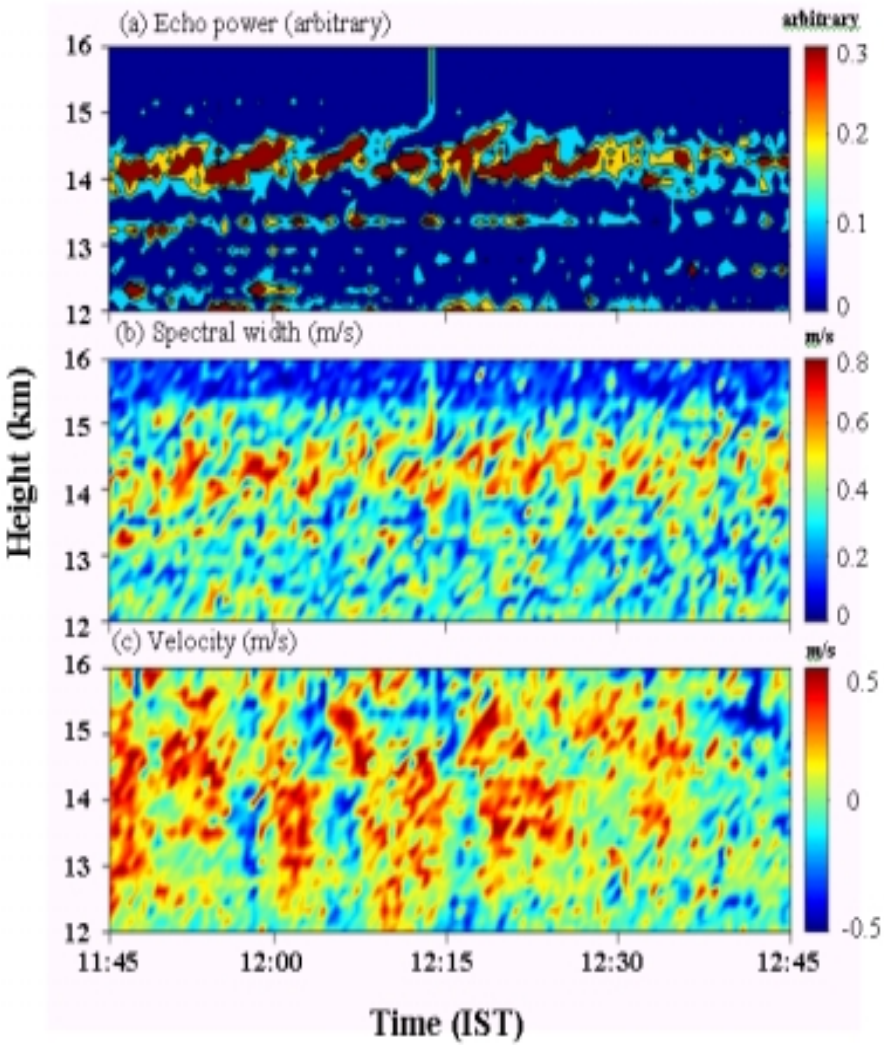

Figure 10 : ***Height-time variation of (a) echo power, (b) spectral width, and (c) velocity observed in the vertical beam on November 24, 2002.***

During similar cyclonic condition, experiments were also conducted on November 24, 2002, but in mode-1 and mode-3. Figures 10 (a), (b) and (c) show zenith beam echo power, spectral width and velocity, respectively, as a function of height and time. Signal intensity variations at 14.2 km altitude clearly show structures resembling to Kelvin-Helmholtz (KH) billows. The vertical velocity map shows periodic updraft and downdraft (updraft being dominant) and enhanced spectral widths, which are the typical characteristics of KH instability (KHI).

Summary & Concluding Remarks

- **Remarkable change in the characteristics of Tropopause during the passage of Tropical Cyclone and Convection.**
- **Aspect-sensitive characteristics of Radar echoes changes, i.e., echo power goes on increasing with zenith angle during cyclone instead of decreasing as in clear-air.**
- **Radar echoes are tilted one side during the passage of tropical convection.**
- **Enhanced Spectral width in the VOT during the cyclone and convection is noticed, which reveals the Turbulence nature.**
- **Enhancement in the wind shear is also observed in the VOT during cyclone**
- **One of the possible mechanism for changing the characteristics of Tropopause during cyclone is due to the occurrence of Kelvin-Helmholtz instability (KHI) associated with Tropical Cyclone.**
- **Echoes similar to cyclone is not observed during convection though the atmosphere highly turbulent.**

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