VHF radar Observations of gravity waves generated by convective storms

Gopa Dutta[1], P. Vinay Kumar[1] and M.C. Ajay Kumar[2]

[1]Anwarul-Uloom College, Osmania University, Hyderabad, India.
[2]Seethaiah Memorial College of Engg., Hyderabad, India.

Introduction

•High frequency gravity waves generated by deep tropical convection play a major role in shaping the general circulation of the middle atmosphere.

•Different mechanisms have been proposed to describe the possible sources of non-stationary gravity waves generated by convection, like obstacle effect [*Clark* et al., 1986], mechanical oscillator effect [Fovell et al., 1992], thermal forcing [Salby and Garcia, 1987]

•Observational studies to capture strong convective events and to characterize them are very difficult [Röttger et al., 2003; Dhaka et al., 2001, 2002; Kumar 2006, 2007; Vincent et al., 2004].

•Experiments were designed to observe gravity waves generated during thunderstorm activity over Gadanki (13.5^{o}N , 79.2^{o}E) using MST radar.

•Two deep convective events could be successfully captured on 16th May and 5th June 2006.

OBJECTIVE

- To study the characteristics of convectively generated gravity waves.

DATA DETAILS

MST Radar data:

- 16th May,2006 - Convective event
- 14th May,2006 - Control day
- 15th May,2006 - Control day

- 5th June,2006 - Convective event
- 6th June,2006 - Control day
- 7th June,2006 - Control day

OLR and TBB data :

- 13th -17th May 2006
- 4th –7th June 2006

[longitude/latitude grids of 0.05° between 11°N-15°N latitude and 77°E-81°E longitude covering the location of Gadanki].

GPS Sonde data:

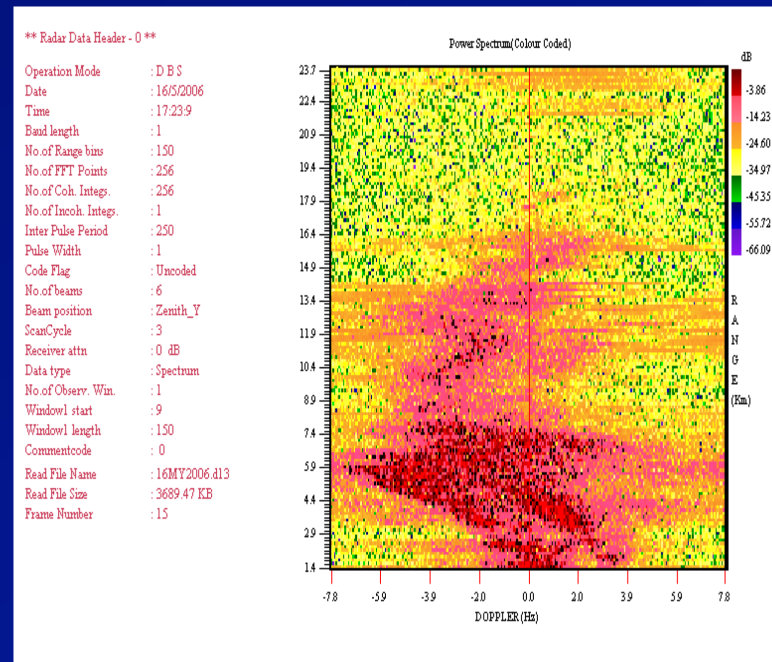
- 14th, 15th, 16th May 2006
- 5th, 6th , 7th June 2006

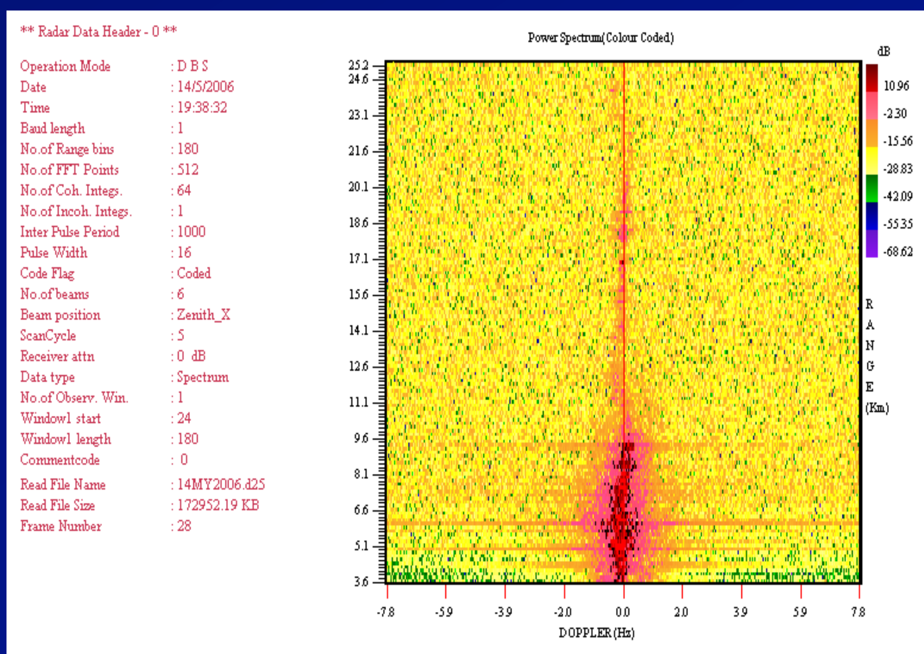
Spectrum data of Vertical Beam

Date: 16-05-2006

•Spectrum data at 17:23:9 when convection is strong.

•The spread shows convective event.

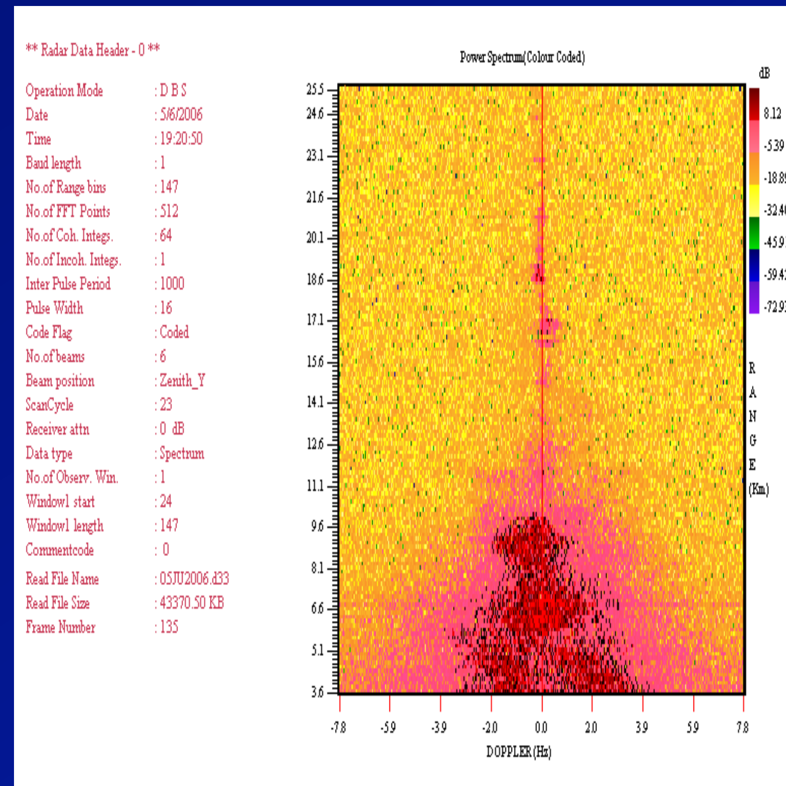




Date: 14-05-2006

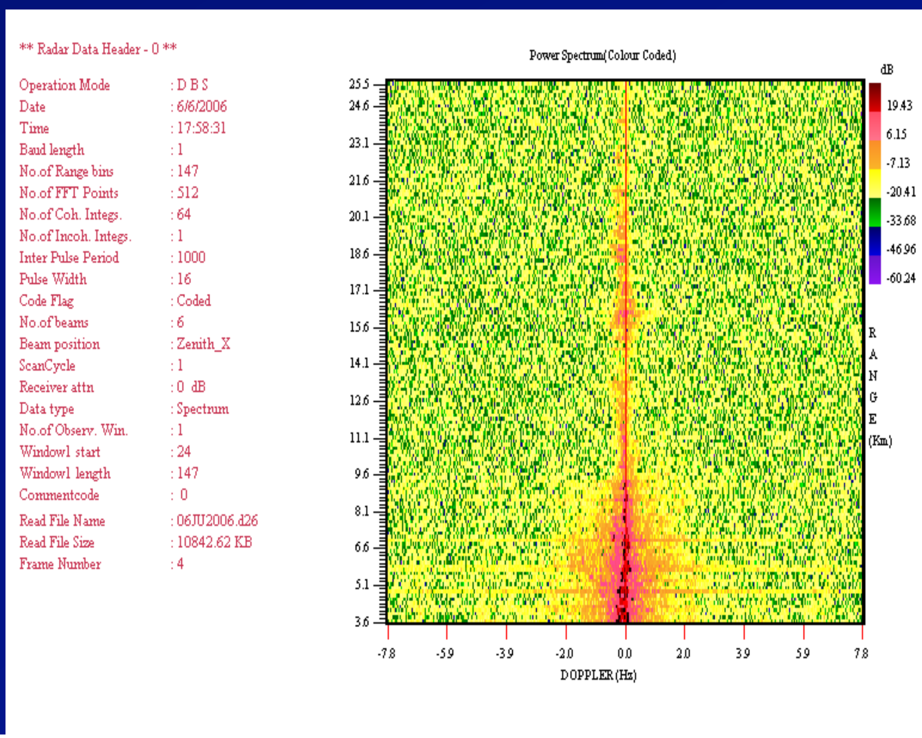
•Spectrum data at 19:38:32

Spectrum data of Vertical Beam



Date: 05-06-2006

- Spectrum data during strong convection.
- **The spread shows convective event**



Date: 06-06-2006

- Spectrum data at 17:58:31 for a control day.

OLR Contour and TBB

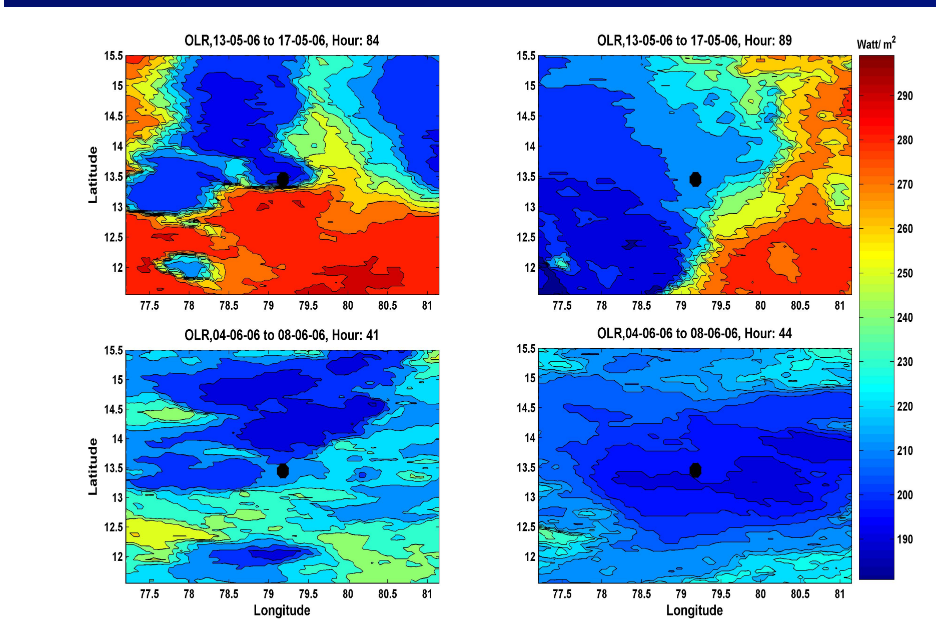


Figure: Latitude-longitude distribution of the satellite Brightness Temperature (TBB) observed on 16th May 2006 at 1730 hrs LT and 2230 hrs LT and on 5th June 2006 at 2230hrs LT and 0130 hrs on 6th June 2006. The black dot in each slot shows the location of Gadanki.

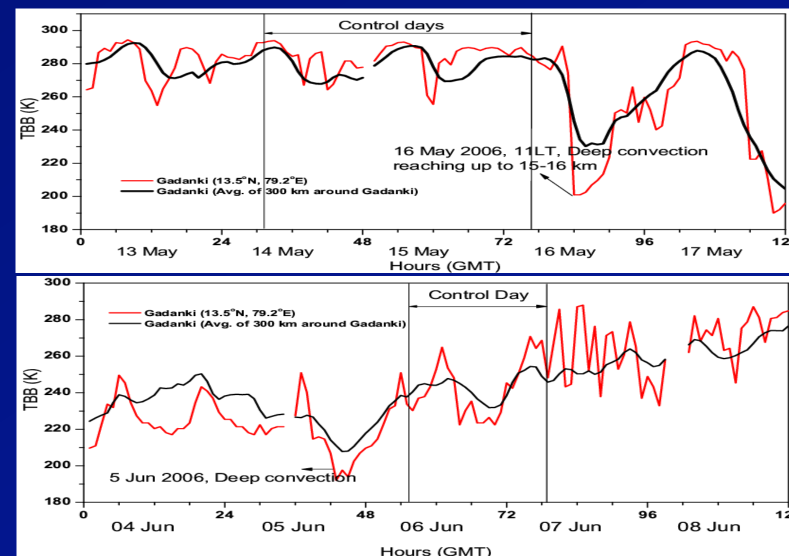


Figure: The hourly TBB data exactly over Gadanki (13.5°N, 79.2°E) (thin line) along with average of ±2° latitude-longitude grid around Gadanki (thick line) observed during 13-17 May 2006 and 4-8 June 2006.

- Lower values of TBB indicate deep convection in the tropical region.
- Deep convective cells coming from north of Gadanki and passing over the radar site confirm the strong individual convective events.
- The cloud top temperature observed using OLR data over Gadanki and its height estimated using corresponding radiosonde observations show that deep clouds reached 14 - 15 km, during the passage of convection.

Background atmospheric conditions

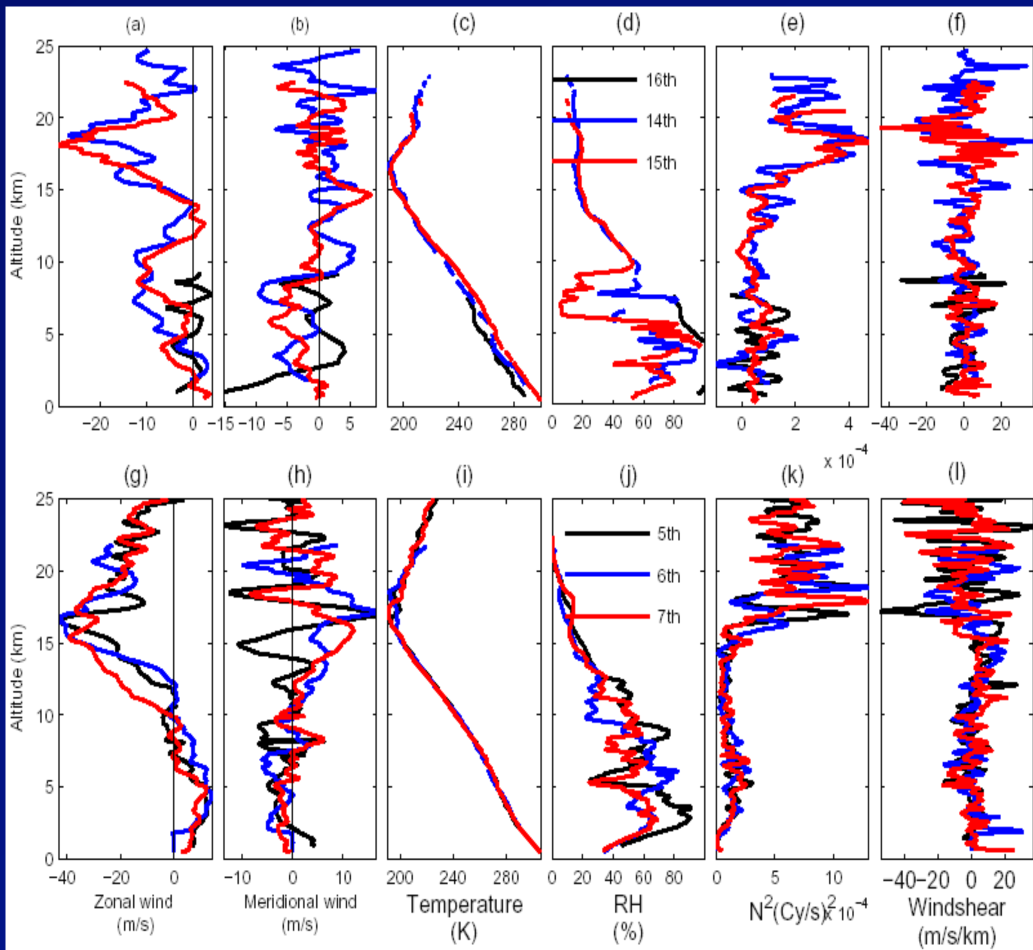


Figure : Profiles of zonal wind (m/s), meridional wind (m/s), temperature (K), relative humidity (RH), Brunt-Väisälä (BV) frequency squared (cy/s)^2 and vertical shear of horizontal wind (m/s/km) observed during 14-16 May 2006 (top panel) and 5-7 June 2006(bottom panel).

- **GPS sonde data on 16th May was available only up to 9 km since the balloon flew away to ~ 450 km after reaching that height .**
- **Large humidity can be observed on the days of convective events.**
- **Zonal velocities are found to be strong particularly in the month of June (jet stream) where as meridional wind is quite weak.**
- **A double tropopause can be seen on 5th June 2006 (similar observations for DAWEX campaign, Hamilton et al. 2004).**
- **Profiles of *N*^{2} on 6th and 7th June are not very different from 5th June in the upper troposphere and lower stratosphere**

Vertical Velocity Contours

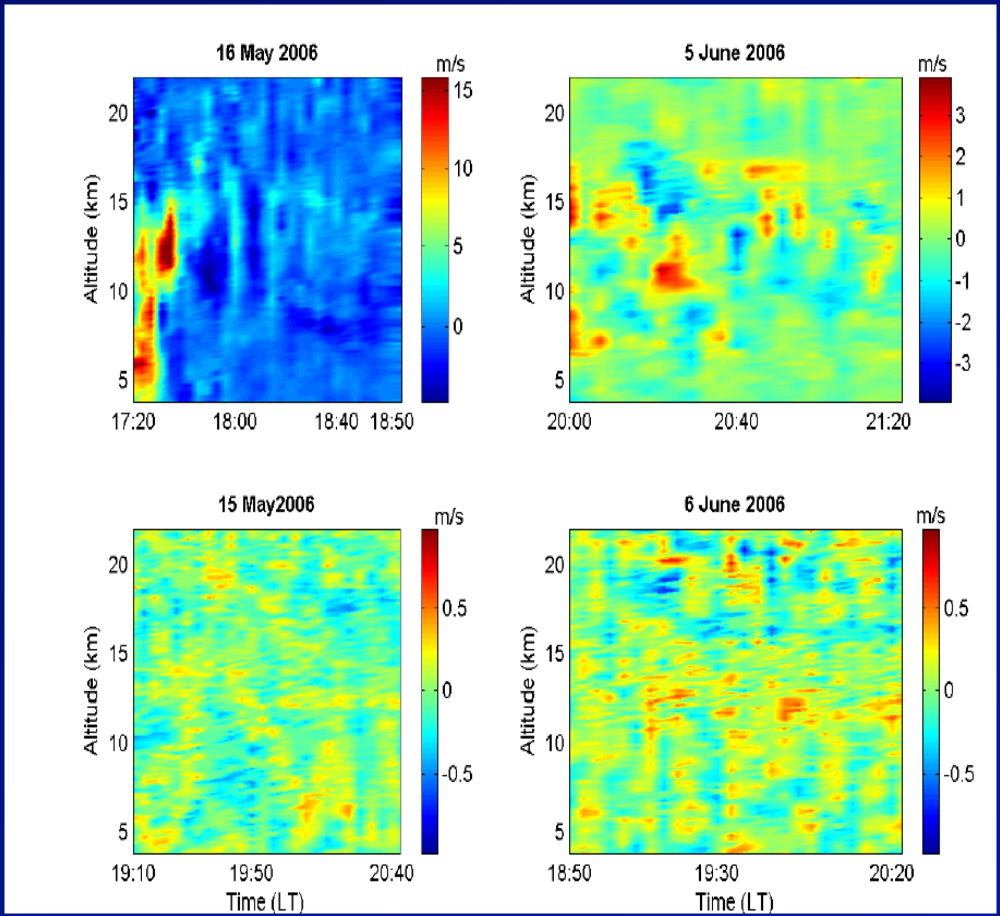


Figure : Contours of vertical velocities observed during the events of 16th May 2006 and 5th June 2006 (top panel) and on two control days (bottom panel).

- **High vertical velocities of the order of ~16 m/s and ~4 m/s are seen on 16th May and 5th June 2006 respectively.**
- **The control day measurements show the values between ±0.5 m/s.**

Back ground winds

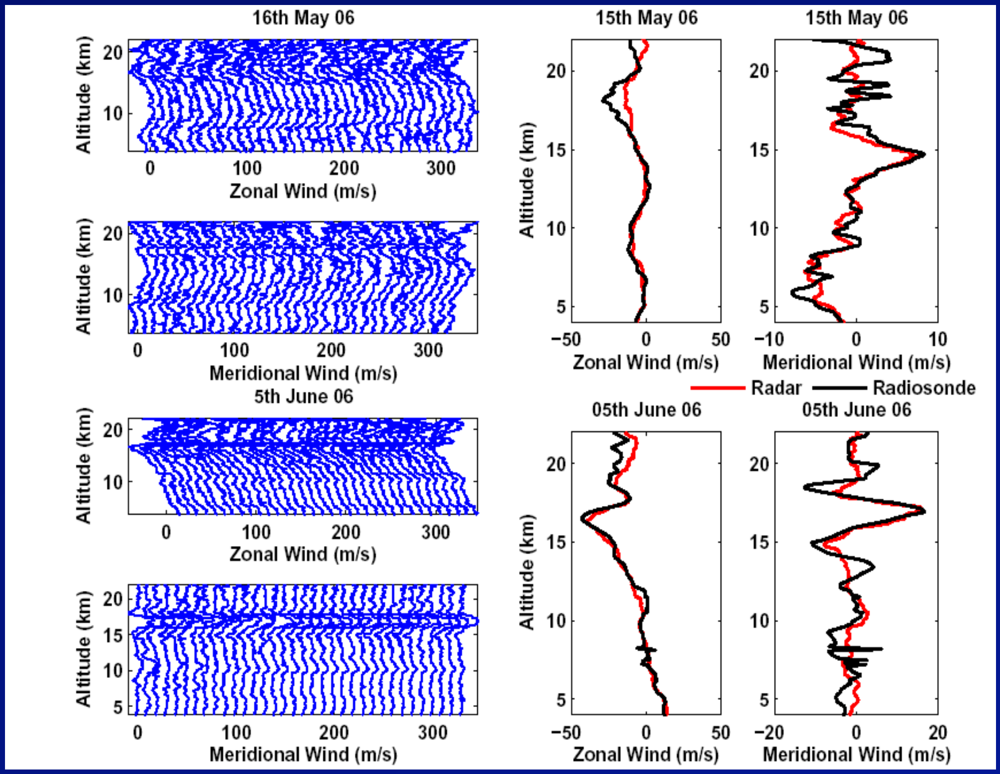


Figure: Profiles of zonal and meridional winds shifted by 2 m/s observed on 16th May 2006 (top left panel) and 5th June 2006 (bottom left panel). The right panel shows comparison between 1 hour averaged MST radar observed zonal and meridional winds and GPS radiosonde observations

Left panel:

- Zonal and meridional wind components have been derived after the storm subsided on 16th May and 5th June 2006.
- The shifted profiles show short period gravity wave oscillations in the UTLS region.

Right panel:

Radar and GPS sonde wind measurements show very good agreement suggesting that winds measured by radar after convection is accurate enough to study the waves generated by the convection.

Wavelet analysis

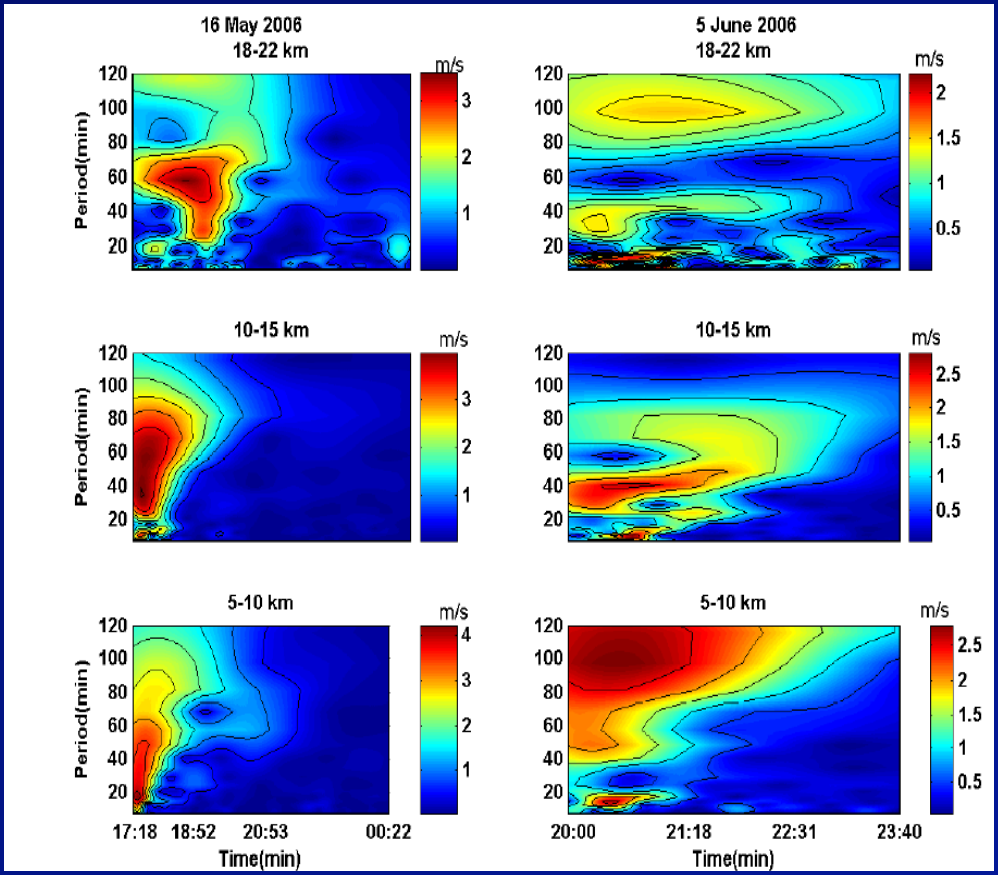


Figure: Wavelet spectra of vertical winds for tropospheric and stratospheric segments of 16th May 2006 (left panel) and 5th June 2006 (right panel)

16th May 2006:

Gravity waves of ~15 min, 40-60min and 60-80 min periods are found to be prominent in the troposphere.

The peaks in the stratosphere do not show exactly the same periods as in the troposphere

5th June 2006:

Shows a similar structure with wave periods ~15 min, 35-50 min and 60-80 min in the troposphere.

The stratospheric spectrum shows similar periods as in the troposphere.

Wavelet analysis

•The periods of spectra displayed in the stratosphere on 16th May are neither harmonics of the tropospheric oscillations nor they are generated due to non linear resonance as reported by Kumar (2007). Hence mechanical oscillator effect does not appear to be the source of gravity waves on this day.

•Beres et al.(2002) examined the interaction of vertical shear of horizontal wind with thermal forcing and found that the stratospheric gravity wave spectrum is decided by the depth of tropospheric heating which gets modified by the tropospheric wind.

•Deep heating forced by latent heat release within the convective storm may be the main forcing in this case.

•The periods of spectra displayed in the stratosphere on 5th June are exactly the periods of gravity waves observed in the troposphere which possibly supports mechanical oscillator mechanism.

Hodograph Analysis

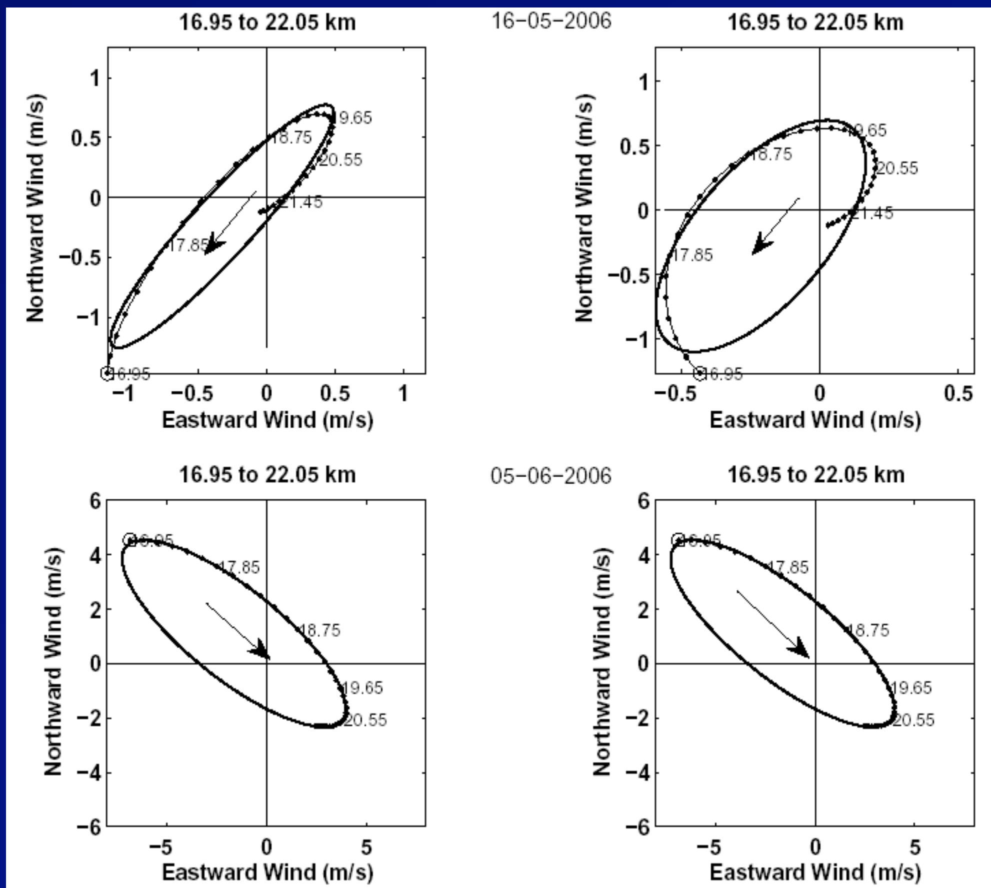


Figure: Hodographs of 16th May 2006 (upper panel) and 5th June 2006 (lower panel) after about 2 hours of cessation of convection with the propagation directions.

- **Fluctuation profiles of zonal (u), meridional (v) winds have been obtained by removing quadratic back ground from each profile.**
- **Hodograph in the stratospheric region show more clockwise rotation i.e., upward energy propagation and those in the troposphere show anti-clockwise rotation.**
- **The directions of gravity waves inferred from the hodograph analyses are not very conclusive.**
- **The observed intrinsic periods mostly lie between ~ ½ an hour and 6 hours.**
- **The horizontal wavelength is ~367 km.**

Vertical wave number spectra

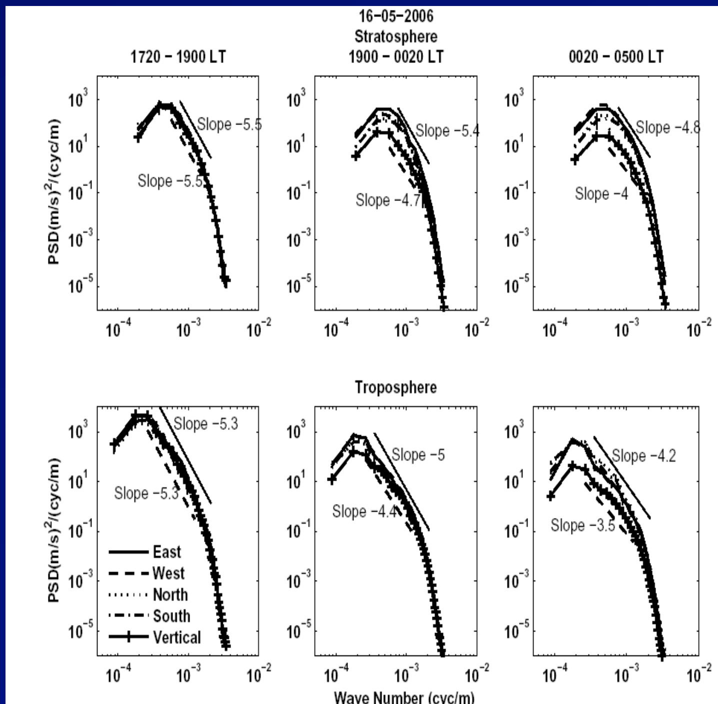


Figure: Vertical wave number spectra of radial and vertical velocity fluctuations of 16th May 2006.

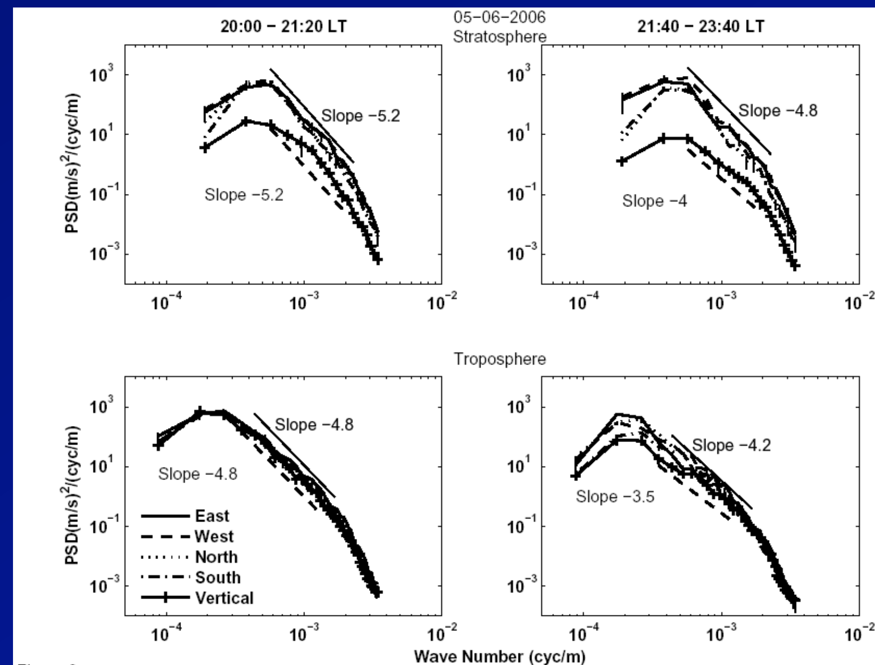


Figure: Vertical wave number spectra of radial and vertical velocity fluctuations of 5th June 2006

- The PSD spectra of all radial and vertical velocities during convection are found to merge with each other in both stratosphere and troposphere.
- Amplitudes ~ 10^3 - 10^4 ((m/s)^2/cycle/m) : slopes ~ -5.5 (strat) & -5.3 (tropo) for 16th May 2006.
- The spectral slopes of 5th June are less steeper since the event was not as strong as 16th May 2006.
- Average slopes of control days are –4.8 (strato) & -4.2 (tropo) for oblique beams and –4 & -3.5 for vertical beams.
- Theoretical estimates of squall line simulation by *Alexander et al. (*1995) shows the power to fall of steeply following a power law proportional to 10^{-4} or 10^{-5}.

Frequency spectra

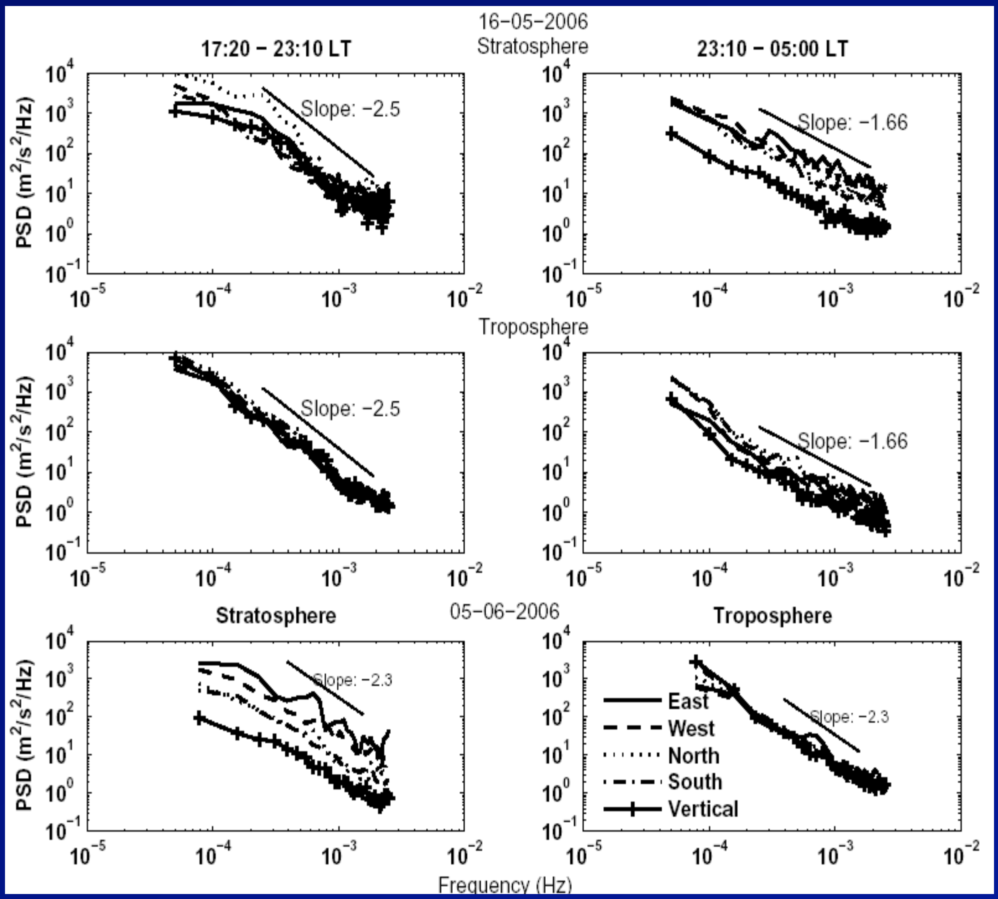


Figure: Upper and middle panels show the frequency spectra of radial and vertical velocity perturbations of 16th May 2006 (two sets). The bottom panel depicts the spectra of 5th June 2006.

16th May 2006:

•Spectral index is observed to increase to –2.5 in both stratosphere and troposphere during convection.

•Spectral slopes of second half are found to be reduced to –1.66 which is same as the control observation.

5th June 2006:

• Spectral Index is found to be –2.3 which is less steeper than that of 16th May 2006

➢It is to be noted that the frequency spectra may be effected by Doppler shift.

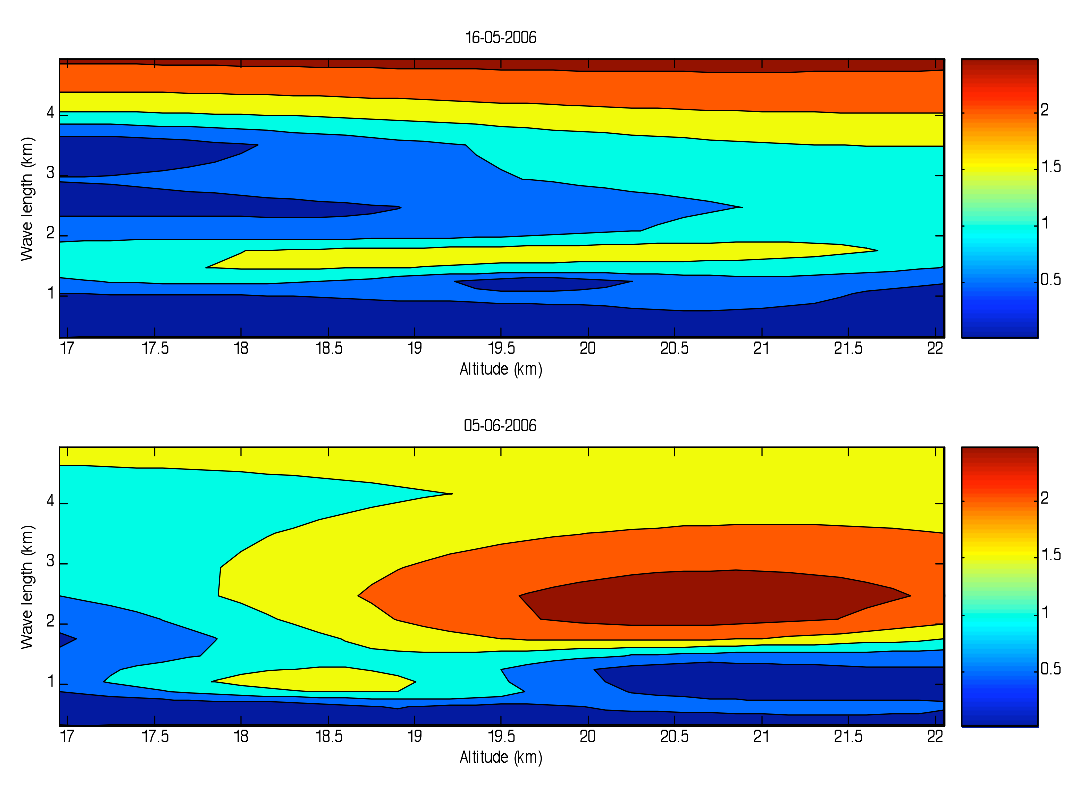
Wavelet Spectra of vertical wind profiles

- The vertical wind profiles after the cessation of convection on 16th May and 5th June have been averaged between 17 and 22 km and are subjected to wavelet analysis

- Prominent vertical wavelengths on 16th May are found to be 4-5 km and ~1.5 km

- The dominant vertical wavelengths on 5th June are found to be 2- 3 km

- The generation mechanism of gravity waves may be different on the two convective days



CONCLUSIONS

- Wavelet spectra of vertical wind revealed prominent oscillations in the period bands of 15-20 min, 40-60 min and 60-80 min in the troposphere.

•Frequencies which reached the stratosphere did not confirm generation of gravity waves by mechanical oscillator effect on 16th May whereas the 5th June case study shows similar frequencies in both troposphere and stratosphere which possibly supports mechanical oscillator mechanism.

•Hodograph analysis does not show clear propagation direction. The approximate intrinsic periods range between ½ an hour to 6 hours.

•The dominant vertical wave lengths are observed to be 4-5 km on 16th May and 2-3 km on 5th June.

•The spectral indices got enhanced with larger values of power spectral densities during convection which slowly comes back to normal values after the cessation of the event.

Contact:

Dr. Gopa Dutta

Email: gopadutta@yahoo.com