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Response of the mesosphere and lower ionosphere to the Extremely Severe Cyclone Fani of 2019 over the North Indian Ocean

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Key Points

- Significant modulations of the low latitude D-region ionosphere due to the extremely severe cyclone 'Fani' are analyzed using VLF radio signals and mesospheric temperature data

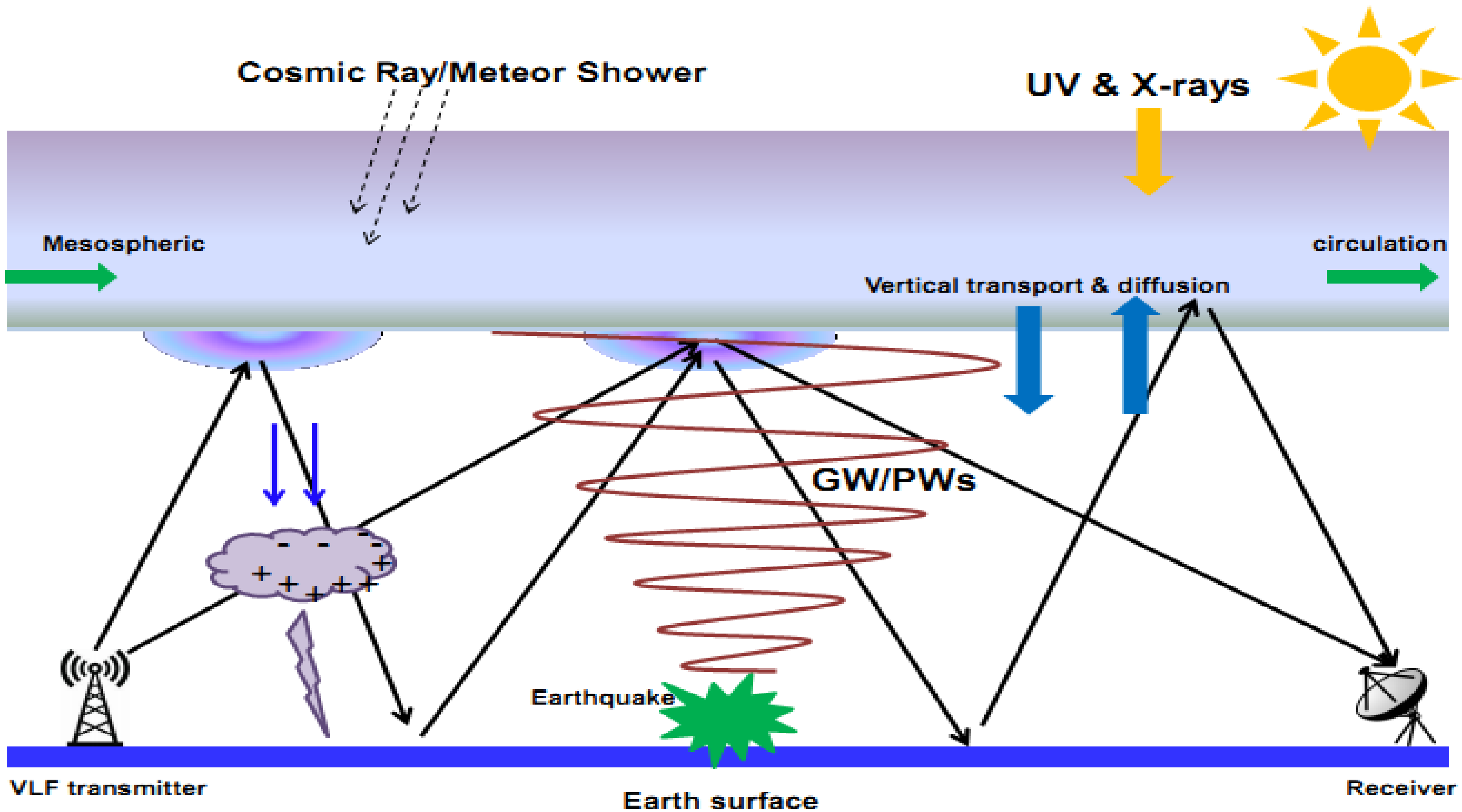
- VLF signal disturbance revealed maximum reduction of 7.9 km in the nighttime D-region VLF reflection height due to the extremely severe cyclone Fani

- Mesospheric temperature and Ozone concentration around VLF reflection heights showed significant enhancement during the cyclone

- Strong anti-correlation of atmospheric gravity waves and cyclone pressure indicates a possibility of monitoring cyclone intensity from VLF measurements

- Simulation of VLF radio signals estimated the size of the lower ionospheric disturbance as large as ~1650 km.

VLF/LF remote sensing



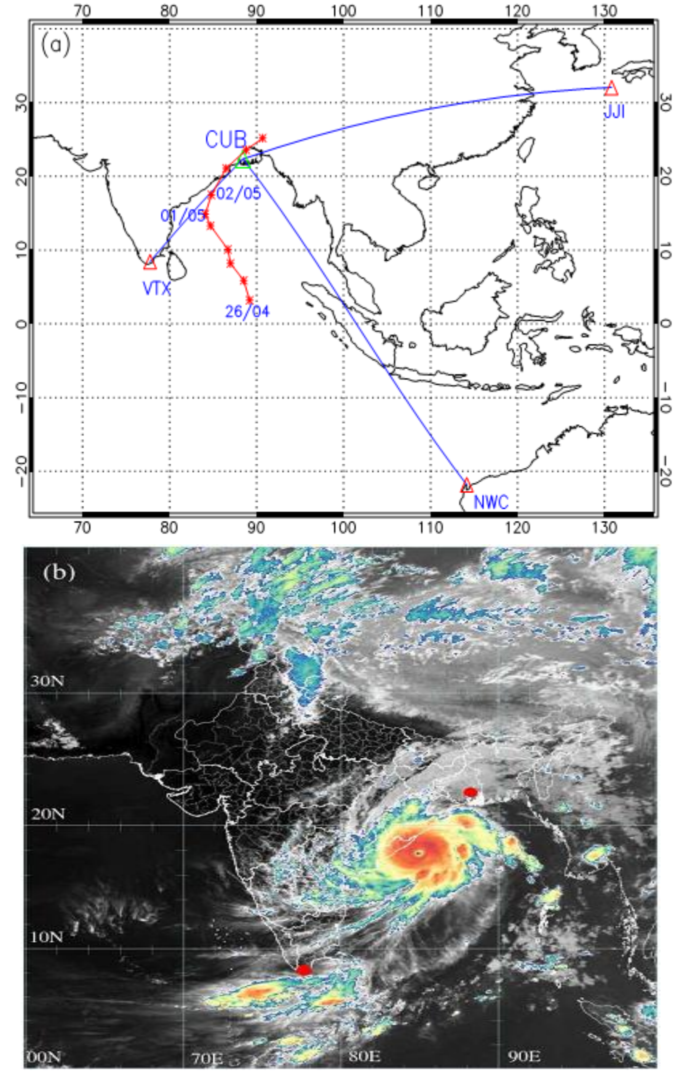
➢Monitoring of signals from navigational transmitters around the world gives us the opportunity to examine the lower ionospheric conditions

Introduction

➢Tropical cyclones or simply cyclones are significant sources of non-stationary atmospheric gravity waves (AGWs) that propagate upward and outward from deep moist convection of the storm center.

➢AGWs transport energy and momentum flux from the source region to upper atmosphere and thus play a significant role in coupling the different layers of the atmosphere.

➢The lower ionosphere (60-100 km) is also expected to show influence by the cyclonic storms. We investigate the lower ionosphere response to the cyclone Fani and analyze how the ionospheric response can be utilized to remotely monitor the cyclone intensity.



❖ Great circle paths (GCPs) between the three transmitters (VTX, NWC and JJI) and the receiver (CUB) are shown by the blue lines. The MSG satellite image shows the colorized infrared clouds of the Extremely Severe Cyclone Fani over the Bay of Bengal on 02 May, 2019 at 1400 UT before landfall.

Data & Methodology

- The sub-ionospheric radio signals from three transmitters VTX (18.2 kHz), NWC (19.8 kHz) and JJI (22.2 kHz) received at Kolkata (CUB) have been used for the study. The receiver is a part of the observational network set up by the **Near-Earth Space and Atmospheric Observatory (NESAO), Kolkata**.

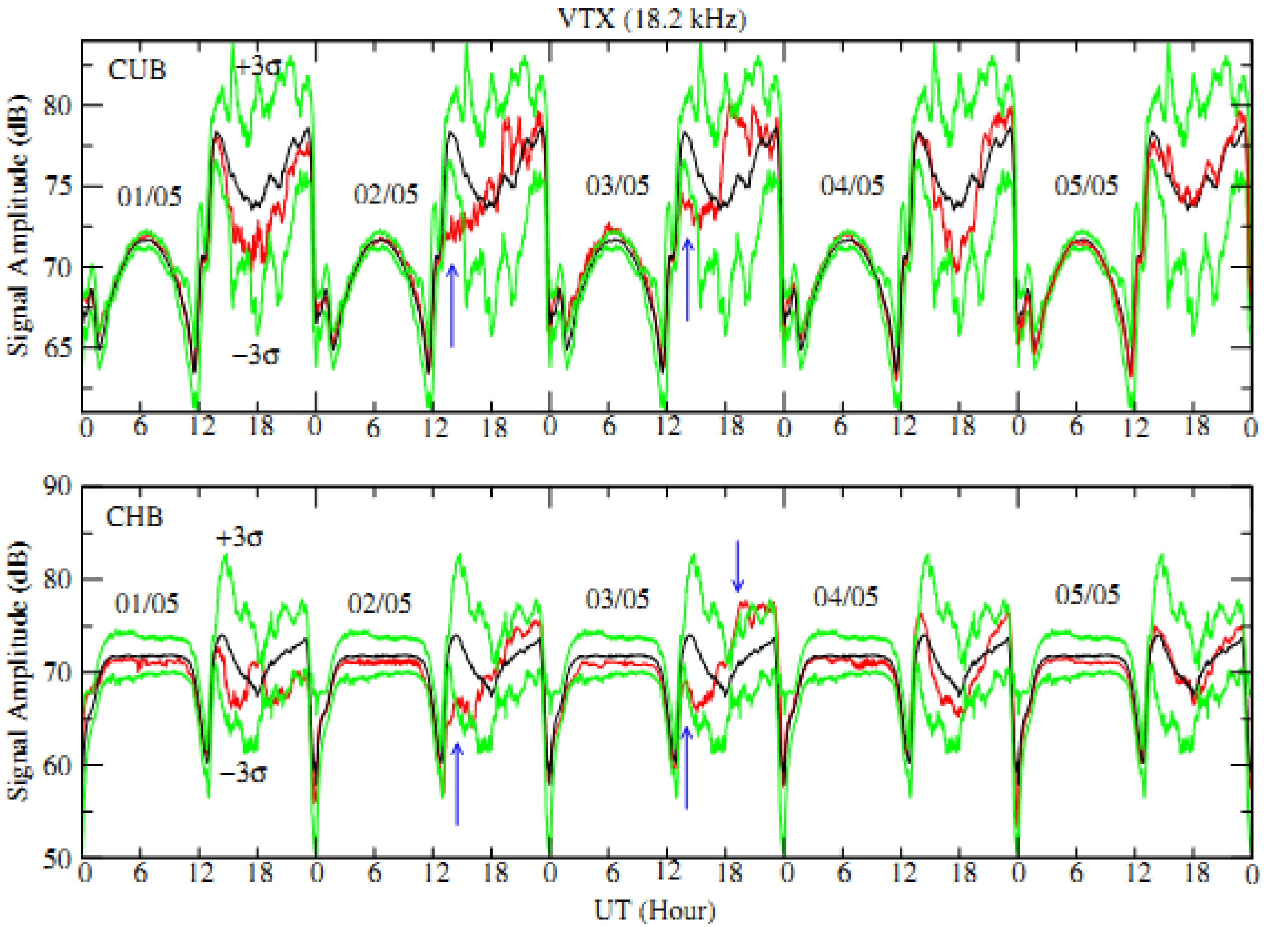
- Temperature and Ozone data are taken from the Atmosphere using Broadband Emission Radiometry **(SABER)** instrument on the NASAs TIMED satellite during cyclone period over the Bay of Bengal region within 12 ×12 grid.

- Cyclone data are taken from the Indian Meteorological Department (IMD).

- The Northeastern part of the Indian Ocean named as the Bay of Bengal is the source of many strongest tropical cyclones. The cyclone ‘Fani’ formed from a depression on 26th April, 2019 over the Bay of Bengal and turned into an extremely severe cyclone (Category 4)) on 2nd May, 2019 which made landfall on 3rd May, 2019 with maximum sustained wind speed (3-min average) of 175-185 km/h gusting to 205 km/h.

Results: VLF signal perturbations during the cyclone

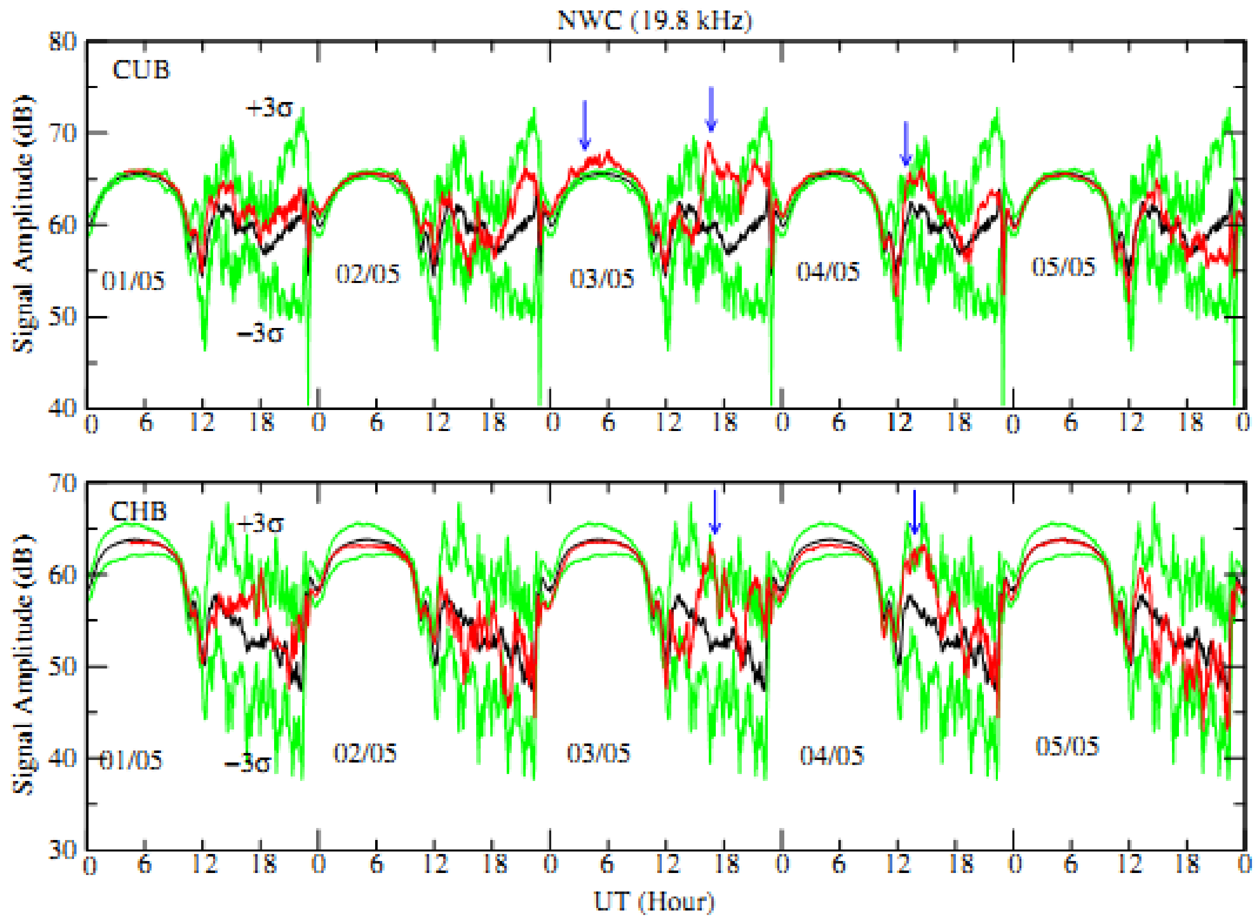
- Perturbations are clearly visible on 02-03 May, 2020



❖ Diurnal variations of the VTX (18.2 kHz) signal amplitude received at two places CUB (upper panel) and CHB (lower panel) are shown in red from 1st May, 2019 to 5th May, 2019. Black curve is the variation of reference signal at each place and the two green colors curved denote the ±3σ level. Blue arrows indicate the time period when the signal shows disturbances beyond ±3σ level.

Results: VLF signal perturbations during the cyclone

- ➢ Strong perturbation from 03 May, 2020
- ➢ The intensity or the perturbation magnitude of the NWC signal was less at CHB compared to CUB due to the greater distance of the receiver from the cyclone

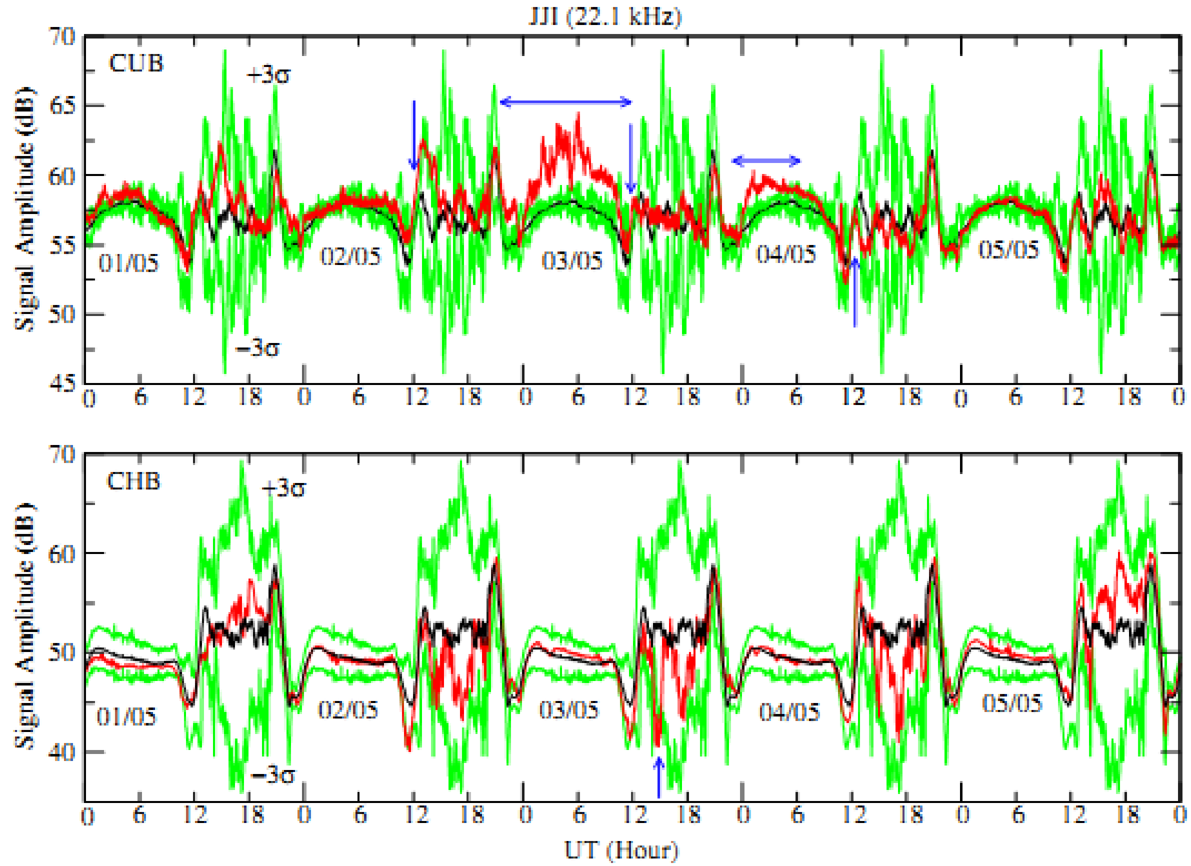


❖ Diurnal variations (red) of the NWC (19.8 kHz) signal amplitude received at two places CUB (upper panel) and CHB (lower panel) are shown in red from 1st May, 2019 to 5th May, 2019.

Results: VLF signal perturbations during the cyclone

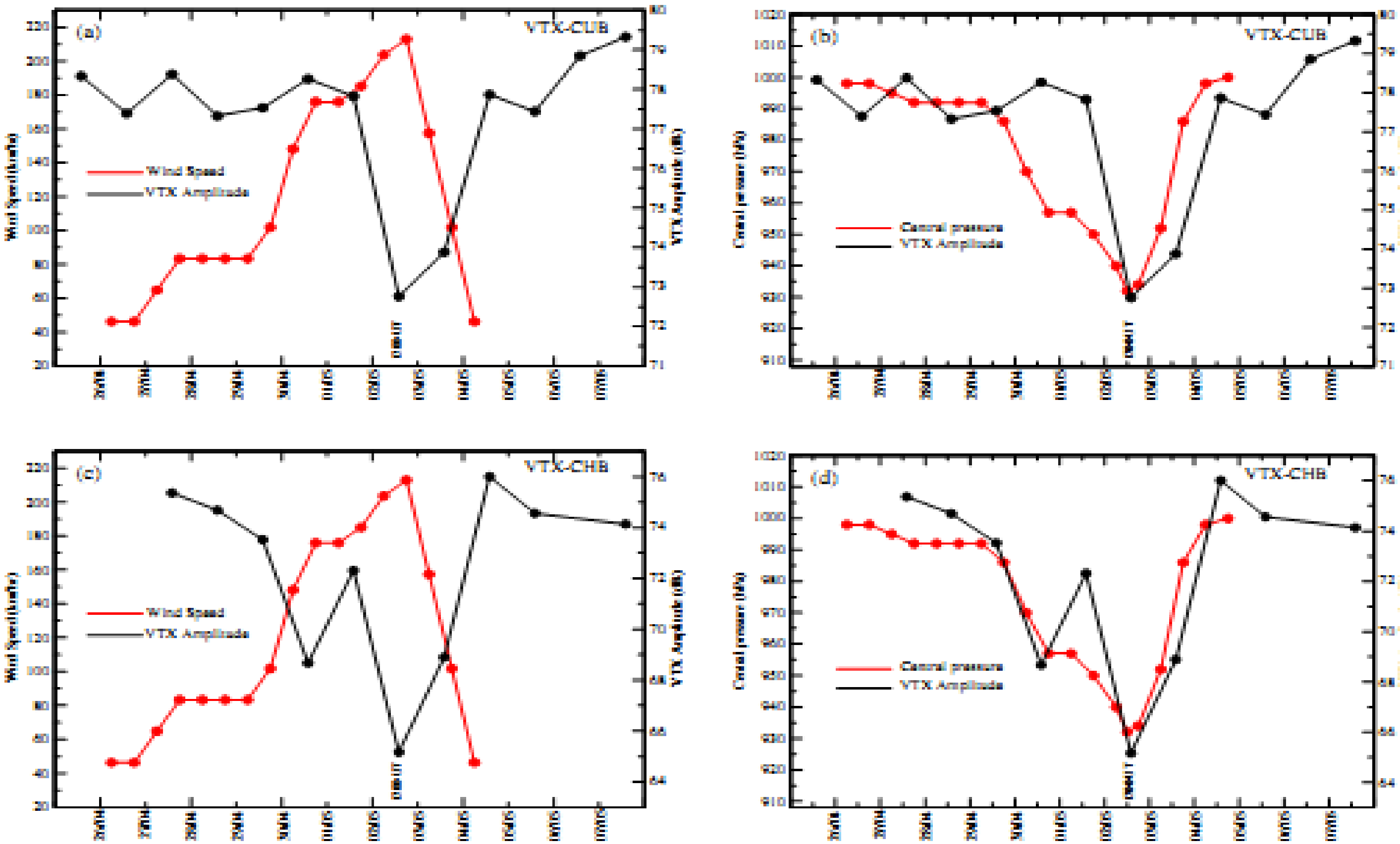
➢Maximum perturbations were observed on 03 May, 2019 in CUB

➢But the JJI signal at CHB showed very little disturbances on 03 May, 2020 due to the greater distance of the receiver from the cyclone centre



❖ Diurnal variations (red) of the JJI (22.1 kHz) signal amplitude received at two places CUB (upper panel) and CHB (lower panel) are shown in red from 1st May, 2019 to 5th May, 2019.

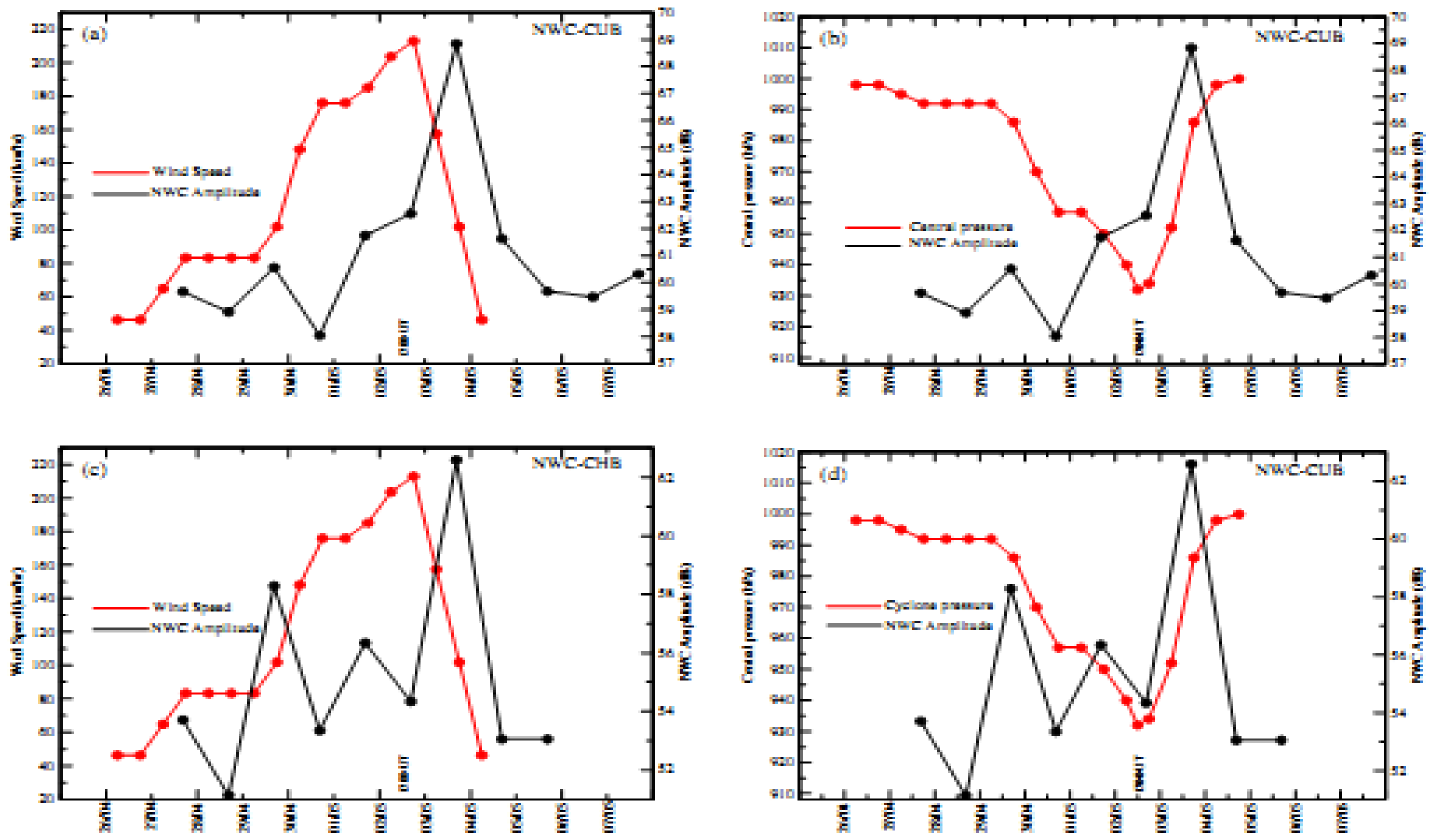
Results: Correlation between cyclone intensity and VLF perturbation



❖ Amplitude variation of the VTX signal at 1400 UT (black) is compared with the cyclone wind speed (a) and cyclone pressure (b) for CUB. The same VTX amplitude variation at 1400 UT is compared with the cyclone wind speed (c) and cyclone pressure (d) for CHB.

❖ Correlation of cyclone pressure and wind speed with VLF response, suggests that monitoring of radio signal perturbation can possibly be used to remotely monitor the cyclone intensity.

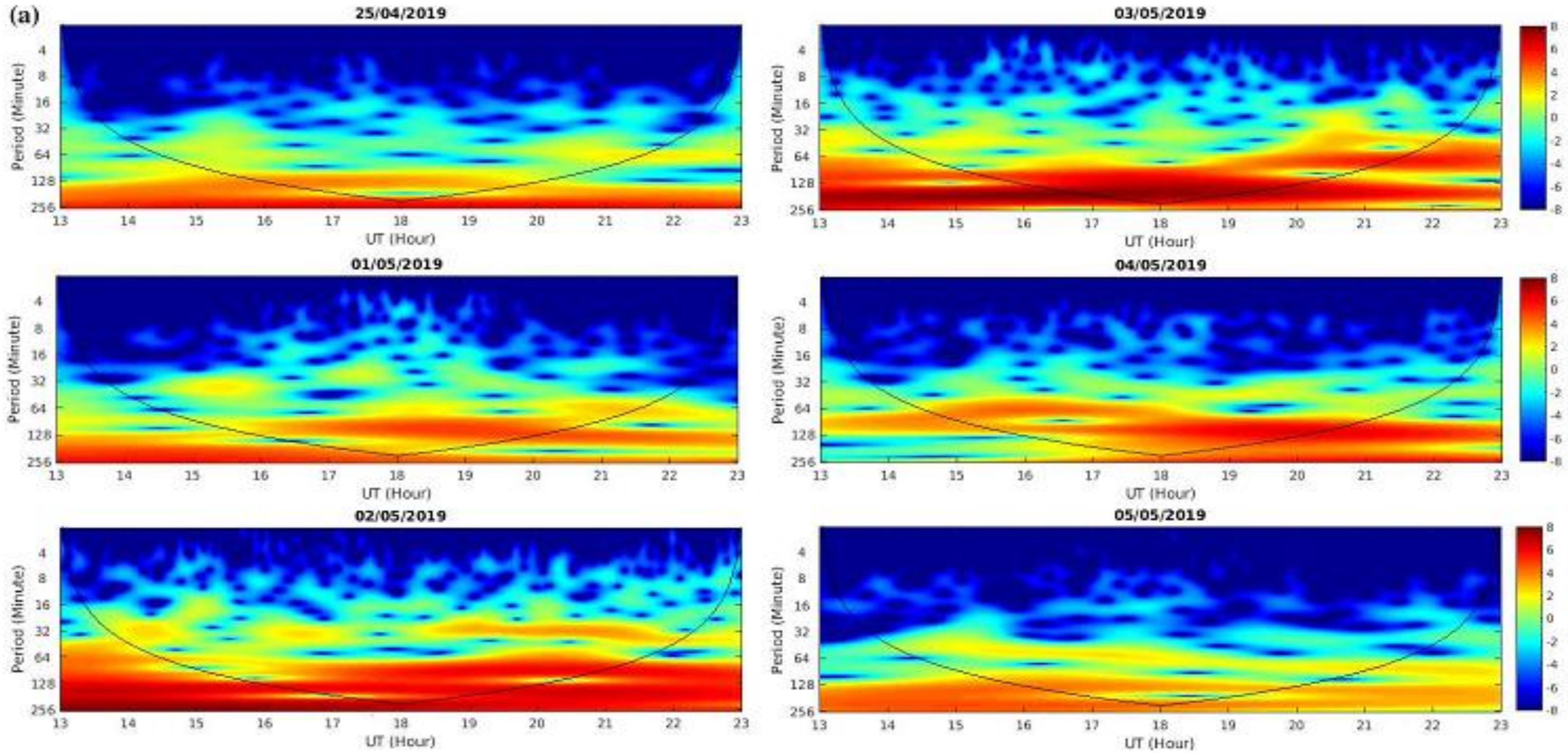
Results: Correlation between cyclone intensity and VLF perturbation



❖ Amplitude variation of the NWC signal at 1630 UT (black) is compared with the cyclone wind speed (a) and cyclone pressure (b) for CUB. The same NWC amplitude variation at 1630 UT is compared with the cyclone wind speed (c) and cyclone pressure (d) for CHB.

❖ Enhancements or reduction of the VLF signal amplitude at both places during the cyclone are attributed to the change in propagation effects due to the modification of lower ionospheric conductivity profiles.

Results: Wavelet Analysis



➢ We present the wavelet power spectrum (color map) of the perturbed amplitude data of VTX signal from 1300 to 2300 UT for quiet and disturbed days.

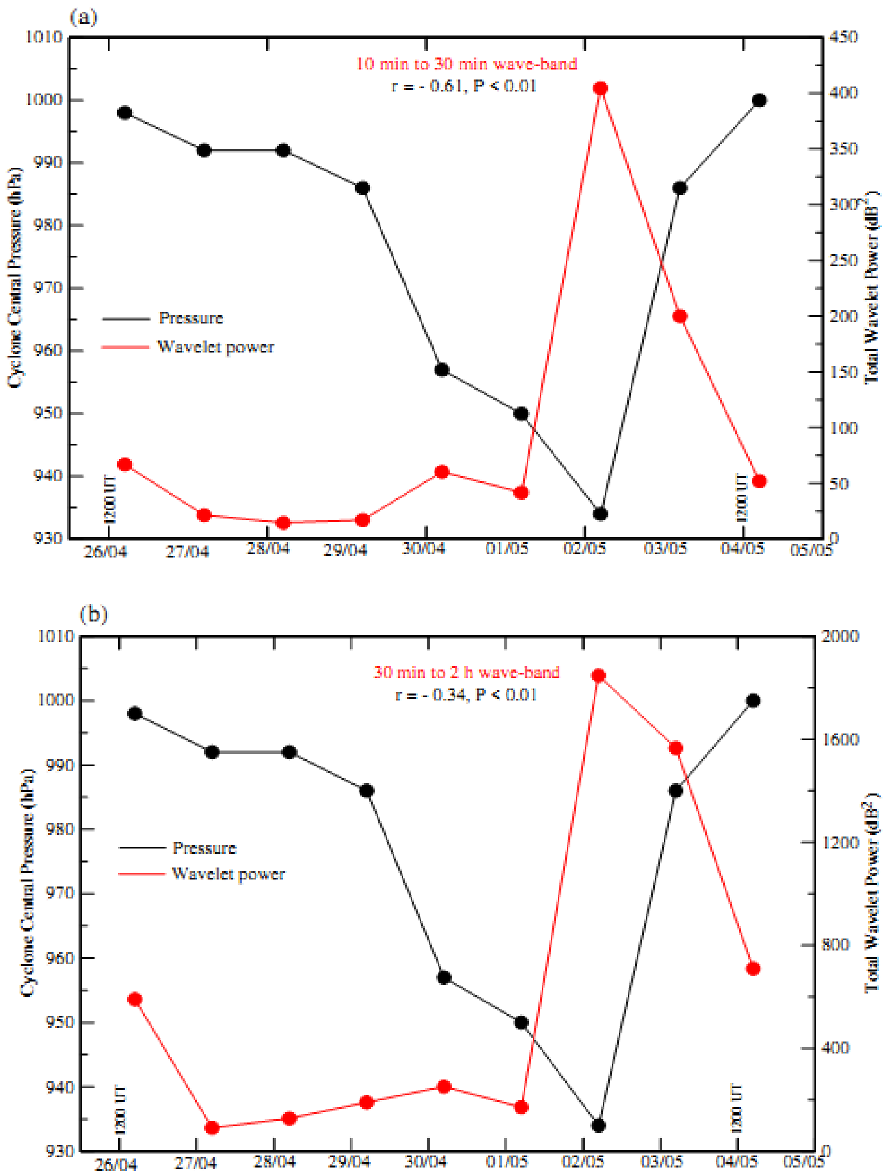
➢ Increased wave-like activities in the band with periods 10 min to ~ 2 hr, which fall within the AGWs periods, can be noted on 2 May and 3 May when the cyclone intensity was maximum and cyclone center was closer to the receiver.

Results: Wavelet Analysis

➢ Here, We compare the cyclone central pressure with the total wavelet power in two bands with the periods of 10–30 min and 30 min to 2 hr respectively in (a) and (b).

➢ Strong correlation (-61%) exists between total wavelet power and cyclone pressure in the 10–30 min wave band, while the correlation coefficient for 30 min to 2 hr band is only −34.0 %.

➢ This observation also suggests a possibility of monitoring cyclone intensity from observations lower ionospheric AGWs using VLF sub-ionospheric signals.

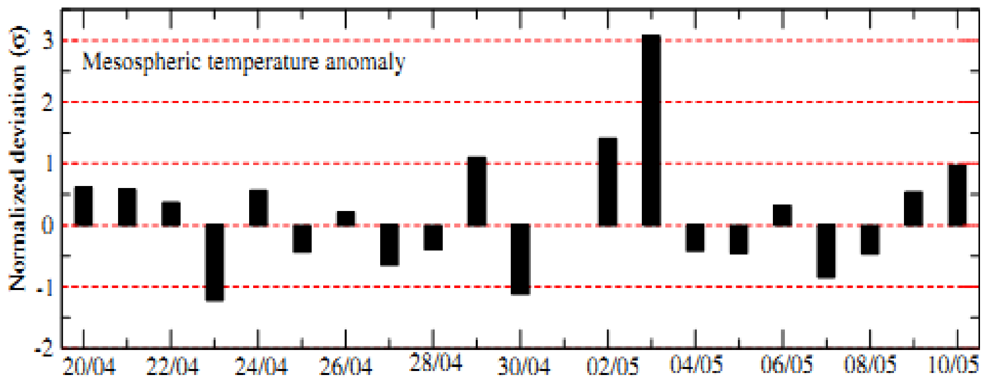


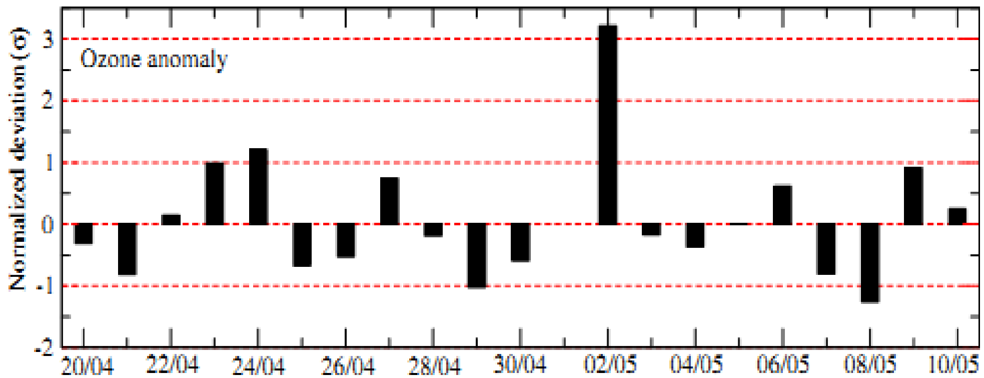
Results: Mesospheric temperature and Ozone anomaly

➢ Mesospheric temperature (upper panel) and ozone (lower panel) anomalies (obtained from the SABER/TIMED measurement) for the altitude range of 75–85 km before, during, and after the cyclone period are shown here.

➢ Maximum temperature anomaly greater than 3σ has been observed on 3 May, while the maximum ozone anomaly greater than 3σ has been observed on 2 May.

➢ Stratospheric ozone, changes in CH4, mesospheric NOx, and water vapor concentration may lead to changes in ozone level, in the mesosphere and lower thermosphere, connected through various chemical channels .





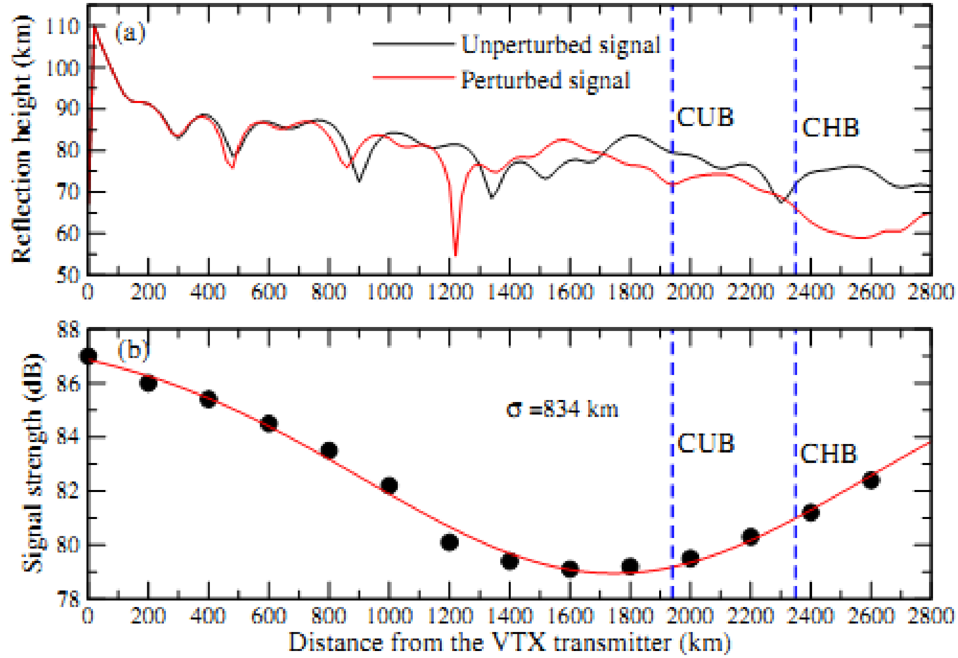
❖ Maximum anomaly in mesospheric ozone concentration and VLF amplitude are observed on same day when the cyclone intensity was maximum, but the maximum temperature anomaly occurred with 1 day time lag during landfall.

Results: Simulation of VLF radio signals

- We calculate the maximum deviation of the VLF amplitudes at two places during the cyclone using the well-known radio wave propagation model, the Long Wave Propagation Capability (LWPC) v2.1 code (Ferguson, 1998).

- The reflection height profile is best fitted by a Gaussian curve (red) with σ = 834 km.

- Since this profile reproduced observed VLF deviation in both the propagation paths, we can say that the spatial dimension of the disturbance in the lower ionosphere due to the cyclone was approximately as large as 2σ ~ 1650 km



(a) Variation of the VTX signal amplitude for unperturbed midnight (black) and maximum perturbed (red) (at 1400 UT) conditions. The dashed vertical lines indicate the positions of the two receivers along the propagation path. (b) Variation of the effective VLF reflection height along the propagation path estimated from the LWPC calculation (black dots) and best possible Gaussian fit (red) of it with σ = 834 km.

References

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THANK YOU

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