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Lower ionospheric response during cyclone Taukate inferred using very low frequency signals

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Abstract

This study delves into the dynamics of the lower ionospheric region during instances of Taukate cyclone in 2021 over the Indian region. Very Low Frequency signals from VTX transmitter recorded over Dehradun are analyzed. Although the transmitter receiver's great circle path is away from the cyclone path vicinity significant anomalies were seen in the VLF signal. The wavelet analysis was used to examine the cause of VLF signal anomalies, which reveals the presence of atmospheric gravity waves of periods 100-128 minutes. These findings underscore the significance of atmospheric gravity waves in triggering alterations in D region parameters during cyclone events.

1. Introduction

The interaction of the atmosphere flow with topography, rapidly evolving imbalances of the large-scale flow, and disruptions to the atmosphere by moist convection are the three processes that typically generate gravity waves (AGWs) in the atmosphere [1]. The moist convection is the major source of AGWs during Cyclone events, thus perturbing various regions of the ionosphere and responsible for atmosphere-ionosphere coupling. NaitAmor et al. analysed cases of hurricanes and cyclones that formed in the Atlantic Ocean between August and November of 2016. The VLF amplitude anomalies during the day and night were clearly visible in the results. The anomalies revealed a strong decrease in the signal amplitude and presence of AGWs with period between two and three hours. They also conclude that travelling ionospheric disturbances caused by hurricanes may be the cause of the anomalies [2].

Das et al. investigated ionospheric disturbances using VLF signals generated over the Bay of Bengal during the Amphan super cyclonic storm. They observed change in the morning terminator during the cyclone's peak and change in the evening terminator time during the cyclone's landfall. They used the VLF data from transmitters JJI, VTX, and NWC, which was received at Cooch Behar-CHB & Kolkata-CUB, and estimated the cyclone's disrupted ionospheric zone during peak intensity to be 500-1000 km [3]. Further, while examined cyclone Fani, Das et al. observed, temperature changes on landfall day measured by NASA's TIMED satellite. Which showed cooling near the tropopause and warming in the stratopause and upper mesosphere, indicating widespread atmospheric disruption by cyclone affecting the troposphere to the ionosphere, with conductivity profile changes reflected in VLF waves [4]. Pal et al. examined the cyclone Fani of May 2019 and confirmed the presence of atmospheric gravity wave (AGWs) using wavelet analysis. They discovered that in the vicinity of cyclone landfalls, there is a notable enhancement of atmospheric gravity waves that lasts for between 10 minutes and two hours [5].

Wavelet analysis is becoming more and more popular for examining power variations that are localized within time series. By breaking down a time series into time-frequency space, this technique enables researchers to pinpoint dominating modes of variability and follow their temporal development [6]. In the present study, we utilize VLF and Morlet wavelet analysis to explore the D region of the ionosphere to investigate the impact of Cyclone Tauktae. We present the variation of the amplitude of the VLF signal and fluctuations in the ionosphere in the form of AGWs.

2. Data and method of analysis

Data on the formation and path of the cyclone were gathered from the Indian Meteorological Department (IMD) and used to illustrate the cyclone's path, as depicted in Figure 1.Additionally, it provided the wind speed and sea level pressure during the storm; in the current study, we have taken into account data values for 6 and 12 UT, which are shown in Figure 2(b).

Moreover, the Dst, Kp, and Ap index values are downloaded from https://www.ngdc.noaa.gov/geomag/data.shtml Figure 2(a) shows the geomagnetic activity during cyclone. Further, to observe the variation in VLF signal, we have used 1 minute mean VLF data in our analysis. The VLF data from five geomagnetically quiet days is used to estimate normal time variation. Afterwards, for geomagnetically quiet days, the standard deviation (σ) is determined. To observe the VLF signal anomalies caused by the cyclone, we also take into account the ±3σ criteria where σ is the standard deviation of five quiet days mean data. When compared to the amplitude of the VLF signal during the day, the night-time signal is more sensitive to atmospheric forcing from blow [7].

As per the report by the IMD, Tauktae, is an exceptionally powerful cyclone, developed over the southeast Arabian Sea and its surrounding areas from May 14 to 19, 2021. Cyclone Tauktae began its journey as a tropical depression on May 14 and changed into a cyclonic storm that evening. On May 15, the storm intensified into a severe cyclonic storm, and on May 16, the storm intensified into a very severe cyclonic storm. The storm intensified in regress the following day, May 17, and developed into a very strong cyclonic storm with winds of 100 km/h. Following the transition from an extremely severe to a severe landfall storm. This storm weakened further on May 18 and transformed into a cyclonic storm. It continued to move northeast, weakening further in the evening. On May 19, the storm dissipated.

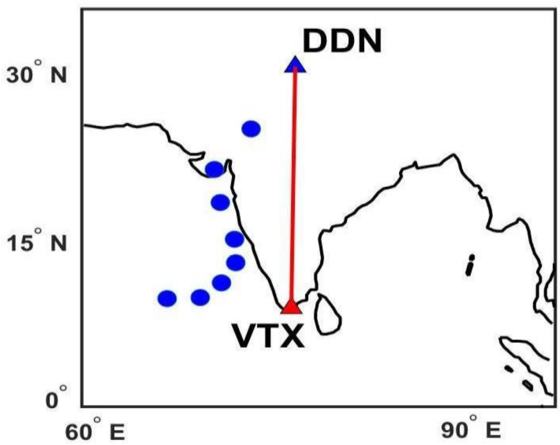

Figure 1. The blue circle shows the paths of Cyclone Tauktae, from14-19 May 2021. VTX (red triangle) is the transmitter and DDN station (blue triangle) is the receiver.

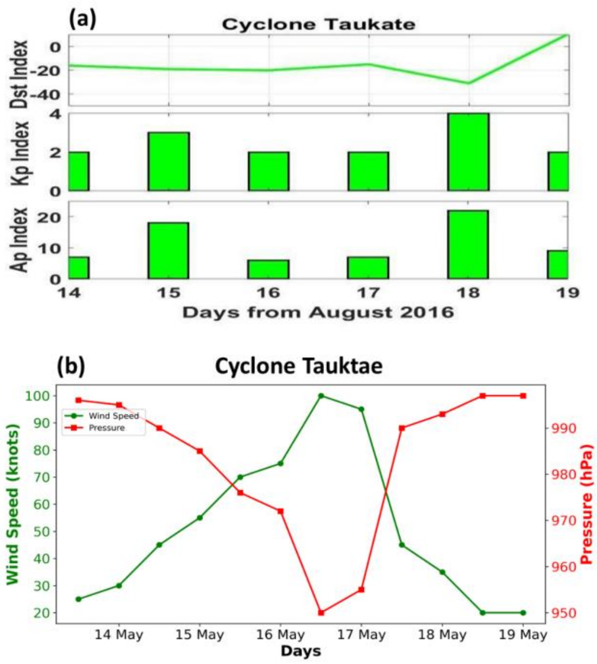

Figure 2: (a) Geomagnetic activity (b) sea level pressure (in red) and wind speed (in green) during Cyclone Taukate.

We have examined the 18.2 kHz VLF signal that the DDN (30.269°N, 78.043°E) station received from the VTX (8.387ºN, 77.752ºE) transmitter. Figure 1 shows the route taken by the VLF signal between the transmitter and the receiver using a red line, the path of the cyclone represented with blue dots. There was no geomagnetic activity during the cyclone display in Figure 2(a), as indicated by the values of the Dst, Kp, and Ap indices in the geomagnetic activity plot. The pressure and wind speed during the Taukate are obtained at 6 UT and 12 UT from the IMD report and displayed in Figure 2(b). On 17 May, the central pressure was at its lowest value at around 950 hPa and the maximum wind speed was 100 km per hour.

3. Results

The daily fluctuations in the VLF signal from May 14 to May 19, 2021, are displayed in Figure 3. These plots show changes in the VLF signal, as indicated by the red colour line. The x-axis shows the time in UT, and the y-axis represents the amplitude of the VTX signal. The green line shows the reference VLF signal of quiet days, and the two black lines show the ±3σ deviation. The blue circles in Figure 3 indicate that the amplitude signal touches the ±3σ level. Anomalies in the amplitude of the VLF signal were noted during different stages of cyclone Tauktae. The +3σ criteria crossed by the VLF signal on May 15, 16, 17, and 18. However a VLF signal indicates a -3σ level cross on May 14, 2021. There are no late-night VLF data available for May 14 and 19.

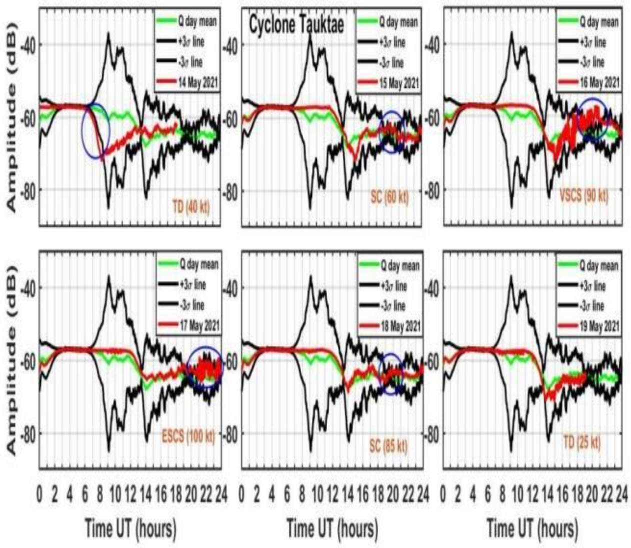

Figure 3: Amplitude variation of VLF signal (red) during hurricane event. The green line shows the mean of quiet days, and the black line represents the ±3σ criteria. Wind speed and hurricane different phase are display on the panels. The blue circle shows the crossing of the 3σ criteria during hurricane days.

Figure 4 shows the induced perturbations in the D region of the ionosphere caused by the AGWs produced by cyclone Tauktae from the lower atmosphere. We use wavelet spectra to represent the disturbance's duration in minutes on the y-axis, and we plot all of the days of the event from May 14 to May 19, 2021, on the x-axis. AGWs with periods of 100–128 minutes that were seen on May 15, 16, and 17 of 2021 are shown in Figure 4. The AGW perturbations shown in Figure 3 on these days are notably consistent with the VLF signal crossing the ±3σ level.

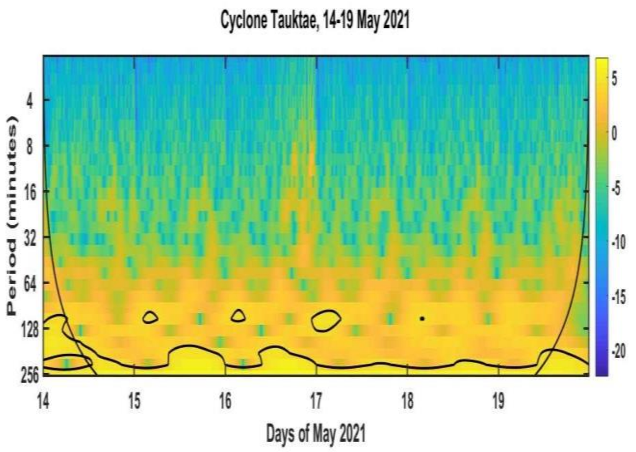

Figure 4: Wavelet spectra based on the Morlet wavelet analysis on NPM signal during hurricane Jimena event.

There was no geomagnetic activity during cyclone Taukate, but a VLF signal crossed 3σ criteria and wavelet spectra, with periods ranging from 100 to 128 minutes. Thus, cyclone Taukate is the reason for these changes in the wavelet spectra and VLF signal.

4. Discussion

IMD consider Tauktae as an extremely severe cyclonic storm over the Arabian Sea. Figure 1 and Figure 2 show the path of the cyclone, wind speed & sea level pressure and geomagnetic activity during the cyclone respectively. The Dst index is -38 nT, while the geomagnetic index Kp ranges from 0 to 4. The Ap index is likewise 0–20. Figure 2 illustrates the extremely low geomagnetic activity during cyclone Taukate. We utilize the ±3σ criteria and cover the days of the Tuaktae cyclone to visualize the variation in the VTX VLF signal amplitude. On May 15, as the storm intensifies into a severe cyclone, the VLF signal crosses +3σ. Similarly, VLF signal perturbation increased with storm severity on May 16 and 17. On May 18, as the storm began to weaken, there was less variation in the VLF. On the following days, at night, a VLF signal crossed the 3σ criteria: the cyclone on May 15, 16, 17, and 18, 2021, as indicated by the blue circle in Figure 3

Omkar et al. investigated the lighting activity that affected AGWs in the ionosphere's D region during Cyclone Fani. Using 2σ criteria, they observed the variation in the NWC VLF amplitude received at PRG. They concluded that since the VLF signal's great circle path (GCP) crosses a cyclone's path, cyclone Fani's AGW disturbance is caused by it [8]. Das et al. examined the effects of the extremely severe cyclone Fani, which originated in the Indian Ocean, on the D region of the ionosphere using data from two VLF transmitters (VTX and NWC) received at CHB. Their findings indicate that the Fani cyclone perturbed the atmosphere from the troposphere to the ionosphere. Using 3σ criteria on the VLF waves, they observed the variation in night-time VLF signal during peak intensity of cyclone [4]. The current study's cyclone path away from the GCP of the VLF signal, and because of the geomagnetically quiet days that occur during a cyclone, we were able to conclude that the ionosphere is disturbed by the AGWs that the cyclone generates and that VLF signal perturbations are observed.

The disturbance in the amplitude data of VLF signals during cyclone days was observed in Figure 4 through the use of wavelet spectra. The cyclone's peak was observed on May 15, 16, and 17, and there was an increase in wave-like activity in the band with a period of 100 min to 128 min, which is connected to the disruptions in the VLF signal on cyclone days. Pal et al. used the VLF signal received at CUB from various transmitters to investigate the Fani cyclone. They also observed anomalies in the amplitude of the VLF signal using the 3σ criteria during the night. Moreover, they observed the wavelet analysis of the VLF signal from VTX. They reported wavelike activity in the band with periods ranging from 2 minutes to 4 hours during the peak of cyclone activity [5]. In the present study we observed the correlation between, VLF amplitude variation during cyclone and AGWs confirm by Morlet wavelet analysis.

5. Conclusion

This study presents our analysis of VLF signal data aimed at understanding the lower ionospheric region during hurricanes and a cyclone. Our investigation focused on the cyclone Tauktae (2021) in the Indian region. We employed various VLF receiver and transmitter pairs to assess their impact on the ionosphere, VTX data received at DDN to analyse the lower ionosphere.

Despite the presence of observed geomagnetic conditions during Cyclone Tauktae, we found that VLF amplitude variation still correlated with wavelet analysis. This indicates that observable effects on the ionosphere persisted despite the small geomagnetic disturbances. The alterations in D region parameters during these geophysical events, particularly heightened convection during cyclones, trigger AGWs, in the D-region.

6. Acknowledgements

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