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Effects of tropical cyclones on the VLF atmospherics observed from low latitude receiving stations

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Abstract

The response of electric field intensity of VLF radio atmospherics during two tropical cyclones Fani (May 2019) and Amphan (May 2020) has been summarized in this paper. The amplitudes of VLF radio atmospherics (or VLF sferics) received at Cooch Behar (CHB) and Kolkata (CUB) at three discrete frequencies (4 kHz, 7 kHz, and 9 kHz) showed distinct variations with respect to the reference level during the two cyclonic storms,which is explained using the electrical structure and distribution of cloud-to-ground lightning associated with the cyclones.

1 Introduction

Lightning emits the strongest natural electromagnetic radiation in the Earth's atmosphere within the frequency range from a few Hz to 10 GHz [1,2]. Radio atmospherics or lightning sferics are the broadband electromagnetic emissions that are generated during a lightning discharge. These emissions are mostly concentrated in the Very Low Frequency (VLF) band having frequency 3-30 kHz and called VLF sferics. The sferics can propagate through the Earth-Ionosphere Wave Guide (EIWG) up to thousands of kilometers with attenuation coefficients of 2-3 dB/Mm [3,4]. Since the acceleration of charged particles within the lightning return stroke produces the VLF sferics, they are important to contain information about the lightning generation process [5]. VLF sferics can be received directly or indirectly by a suitable receiving system from the ground. On average, at any moment 50 lightning occur per second globally. The total field intensity of the VLF sferics, is the result of those individual lightning flashes. The arrival of lightning sferics may occur directly or by reflection from the D-region of the ionosphere [6]. The amplitude of VLF sferics shows diurnal variation depending on the location of the receivers [7,8] (De and Sarkar 1996; Sen et al. 1982). The diurnal nature of VLF electric field atmospherics may not always show 'Carnegie curve' in some areas of the globe depending on the atmospheric weather at the receiving location [9, 10]. The diurnal variations can also be modified by natural phenomena like solar events, lightning thunderstorms, or even by earthquakes [11]. The study of VLF sferics during severe meteorological conditions such as tropical cyclones attracts special attention in the tropical region [12]. VLF radio atmospherics, during a tropical cyclone associated with intense lightning activity, show sharp variation in their field intensity. For example, the radio atmospherics in the ELF (Extremely Low Frequency) and VLF band show a fluctuation during Tropical Cyclone 'Roanu' in May, 2016 [13]. De et al. (2011) observed VLF sferics during the cyclone 'Aila' and reported sudden enhancement in the field intensity of VLF sferics at 3 kHz and 9 kHz which were much higher than normal thunderstorms [14].

Here we present an analysis of electric field intensity of VLF sferics in the frequency band (4-10 kHz) as received by two ingeniously developed VLF receivers associated with the two tropical cyclones 'Fani' of 2019 and 'Amphan' of 2020 over the North Indian Ocean region. The 'Fani' was in the category of Extremely Severe Cyclonic Storm (ESCS), and the 'Amphan' was in the category of Super Cyclonic Storm (SuCS).

2 Experimental Arrangement and data

We monitor electric field amplitude of VLF signals of several navigational transmitters e.g. VTX of India (18.2 kHz), NWC of Australia (19.8 kHz), JJI of Japan (22.2 kHz) along with the electric field intensity sferics signals at 4 kHz, 7 kHz and 9 kHz from two low latitude stations Cooch Behar (CHB) and Kolkata (CUB). The stations CHB (26.35° N, 89.45° E) and CUB (22.57^0N, 88.26^0E) are approximately 450 km apart from each other. VLF reception is done by an E-field antenna. We use Spectrum lab V2.0 software (https://www.qsl.net) for data reording. Location of the receiving stations and transmitter-receiver Great Circle Paths (GCPs) along with the cyclone tracks are shown in Fig. 1.

Our focus is on the cyclone associated lightning events and their impacts on the VLF radio atmospherics received at the two places. To check the lightning events associated with the cyclones, the total lightning data are taken from the Earth Networks Total Lightning Network (ENTLN). ENTLN detects of in-cloud (IC) and cloud-to-ground (CG) flashes using sensors that operate in a frequency band spanning the VLF, LF, MF, and HF ranges [15]. We have considered only the CG flashes since these are the strongest source of VLF sferics. Relevant data related to the cyclones are obtained from the website of the India Meteorological Department (IMD).

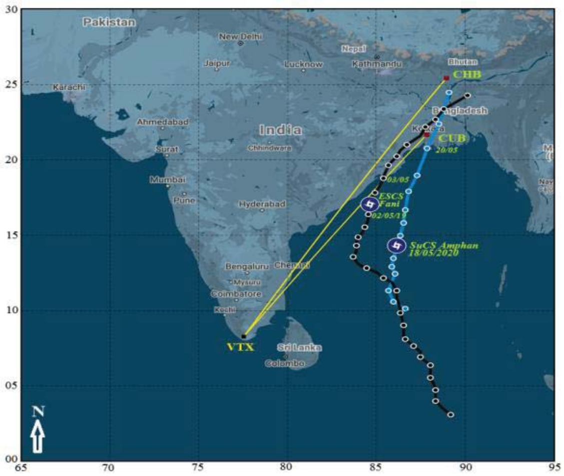

Fig. 1: Locations of VLF transmitter VTX (Black Square), receivers CHB (Maroon Square) and CUB (Maroon Square) including VTX-CHB and VTX-CUB Great Circle Paths (yellow line). Black curve (with black dots) showing track of ESCS Fani and Blue curve (with blue dots) presents the track of SuCS Amphan. Violet circulating symbols showing respectively the positions the maximum intensity of the cyclones.

3 Results and Discussion

3.1 Effects of ESCS Fani on VLF atmospherics

Fig. 2 shows the time series of the electric field amplitudes at 4 kHz (upper panel), 7 kHz (middle panel), and 9 kHz (lower panel) signals from 26 April to 8 May 2019 for the CHB station. The red dotted curve in each panel shows the average electric field variation obtained from the mean of 7 days signal before the depression formed. The two red solid horizontal lines in each panel show the ±3σ range, and the blue solid curves are the actual field amplitude of the sferics. In general, minimum in diurnal variation was observed around 4 UT (9:30 LT) and maximum was observed around 15-16 UT (20:30-21:30 LT) for any normal day at CUB. The cyclonic storm Fani converted to ESCS on 30 April with maximum intensity on 02 May. Accordingly, we can see in Fig. 2, signal amplitudes deviated by more than -3σ from 01 May onward and had maximum deviations on 02 May 2019 at all the sferics amplitudes. The signal strength increased from the minimum value from the same day (02 May) onward. The cyclone crossed the coastal region of Puri, India on 03 May and moved toward North. Fig. 3 shows the variation of sferics amplitudes at the same frequencies for the Kolkata (CUB) station. In general, minimum in diurnal variation was observed around ~4-5 UT (9:30-10:30 LT) and maximum was observed around 12-14 UT (17:30-19:30 LT) for any normal day at CUB. Here the amplitudes increased from 30 April 2019 and stayed above +3σ level for the entire day-night times up to 03 May 2019. From 04 May onward the signal amplitudes came back to their normal variation.

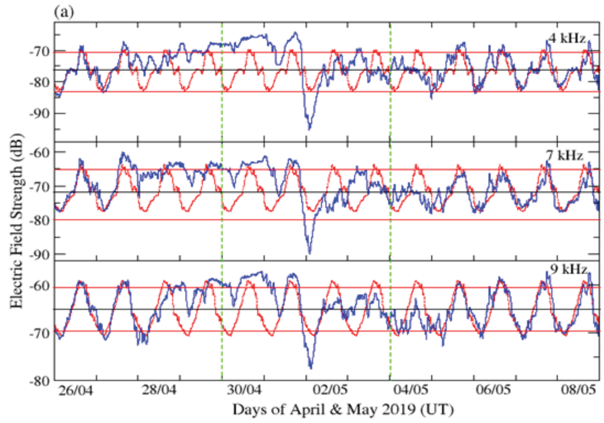

Fig. 2: Each panel represents the VLF sferics amplitude (dB) from 26/04/2019 to 10/05/2019 received at CHB (solid blue curve), compared with the mean amplitude (red dotted curve). Two red solid horizontal lines represent ±3σ range. Upper panel represents the sferics amplitude at 4 kHz, middle and lower panel are the VLF sferics of 7 kHz and 9 kHz respectively. Two green dashed vertical lines indicate the period of ESCS Fani.

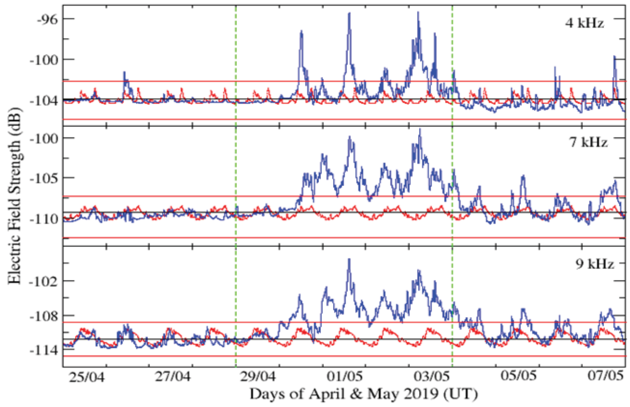

Fig. 3: Same as Fig. 2 but for the CUB receiver.

To check the response of the VLF sferics with its lightning sources, we differentiate the lightning events as 'local lightning' that occurred within 100-200 km of the receiver and 'distant lightning' that occurred generally far (~1000-2000 km) from the receiver. Fig. 4 shows the distribution of 'local lightning' for each of the receiver. We have observed that when there was 'local lightning' around the CHB, the sferics signal amplitudes increased from the mean due to the more direct waves received by the receiver. But increase in 'distant lightning' such as during the cyclone did not increase the sferics amplitudes always. On the other hand, at CUB amplitudes of sferics signals at each frequencies always increased from the mean at all times which does not depend on the distance of the lightning sources.

Thus the ionospheric propagation of sferics originating from distant lightning in CUB resulted in a constructive interference among various waveguide modes causing an increase in field intensity of sferics. Constructive or destructive interference of the sub-ionospheric signals depends on the propagating distance. We have observed positive effects in CUB and negative effects in CHB due to ionospheric propagation effects. Nevertheless, the observations at two sites suggest that monitoring of signal amplitudes from sferics can give important information about the cloud-to-ground lightning associated with tropical cyclones and can be used to assess the electrical structures of the tropical cyclones as well.

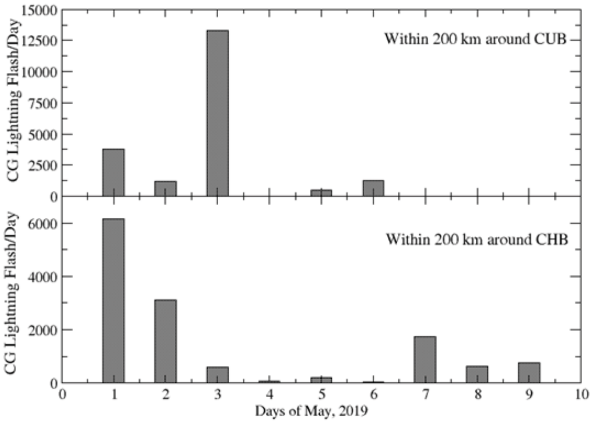

Fig. 4: Cloud-to-ground (including +CG and -CG)) lightning flash count per day from 01 May to 10 May 2019 within 200 km of the receiver CUB and CHB. The lightning on 01-03 May 2019 was associated with the ESCS Fani at CUB and was most on 03 May in the region.

3.2 Effect of 'Amphan' on VLF atmospherics

Amphan was originated from a low-pressure area in a near-equatorial region that converted into a Cyclonic storm (CS) in the evening of 16th May and intensified further into a SuCS on 18th May 2020 with a peak wind speed of 260 km/h (1-minute sustained) around 12:00 UT. Thereafter, it continued to be over the Bay of Bengal and made landfall over the West Bengal coast around 10:00 to 12:00 UT on 20 May with 1-minute sustained winds of 155 km/h. On 21 May at around 1800 UT it weakened into a low-pressure area over Bangladesh. The two VLF receivers at CUB and CHB were also monitoring the cyclone, but unfortunately, the system at CUB did not save the text file. Fig. 5 presents the diurnal variation of the field intensity of VLF sferics at three frequencies 4 kHz (upper panel), 7 kHz (middle panel), and 9 kHz (lower panel) respectively from 11 May to 27 May 2020 for CHB station. Tthe entire diurnal variations at each frequency were much lower than the mean signal from 17 May to 23 May 2020. In this case, the maximum deviation can be seen on the landfall day 21 May and the 7 kHz signal responded most during the period. We plot the 'local lightning' near the receiver at CUB and CHB in Fig. 6 which shows the absence of a significant amount of 'local lightning' during the cyclone period 17-22 May 2020. The day when significant 'local lightning' occurred near the receiver, field intensity of sferics at each frequency enhanced from their mean level (as can be seen for 13-16 May). The number of lightning associated with the Amphan increased significantly from 17 May which can be considered as 'distant lightning' as the sferics signals traveled ~1000-3000 km to reach CHB. When the sferics originated from 'distant lightning' associated with the Amphan reached the receiver at CHB via earth-ionosphere waveguide destructive interference reduced the sferics amplitudes at all frequencies. This was also seen in the case of ESCS Fani of 2019 at CHB. Thus at CHB, it is the ionospheric radio propagation characteristics that caused the reduction in signal amplitudes for sferics signal.

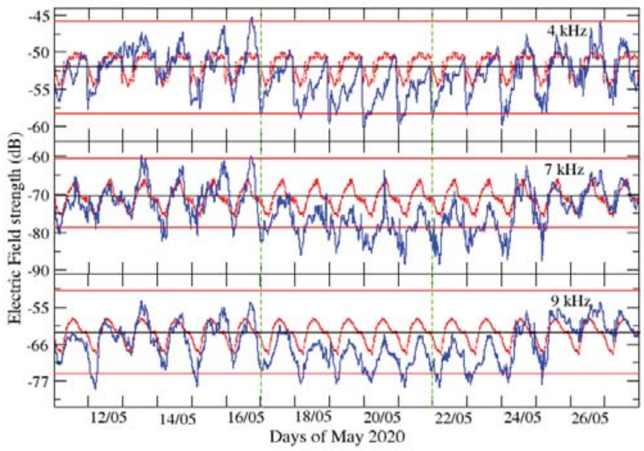

Fig. 5: VLF sferics amplitude (dB) from 11/05/2020 to 27/05/2020 received at CHB (solid blue curve) and compared with the variable mean amplitude (red dotted curve) and Amm (black solid horizontal line). Two red solid horizontal lines represent ±3σ range. Two green dashed vertical lines indicate the period of SuCS Amphan.

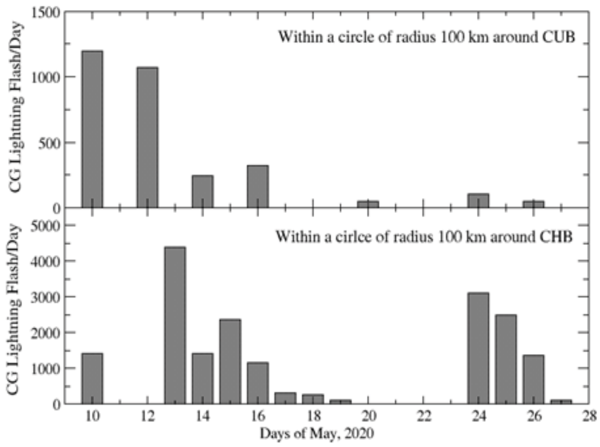

Fig. 6: Cloud-to-ground (both positive CG and negative CG) lightning flash per day within the 100 km radius of the receivers at CUB (upper panel) and CHB (lower panel).

3 Conclusion

In this paper, we explore the possibility of monitoring the electrical characteristics of tropical cyclones using VLF sferics recorded at two places. This is the first work of its kind over the North Indian Ocean associated with ESCS and SuCS. Both enhancement and reduction in amplitudes of the VLF sferics are observed during cyclone days. Amplitudes of VLF sferics at three frequencies (4 kHz, 7 kHz and, 9 kHz) have deviated significantly from mean reference level during cyclone days. A large increase in amplitudes observed at CUB both during 'local lightning' and 'distant lightning' events. On the other hand, reduction in amplitudes is found at CHB during 'distant lightning' events and enhancement in amplitudes is observed during 'local lightning' events. The response of sferics amplitudes is greater at CUB than at CHB. Further, sferics amplitude at 7 kHz seems to respond strongly with lightning at both places. The diurnal amplitude variation of sferics at each frequency was affected for 6-7 days during Amphan. But, the diurnal variation was affected for 4 days at CUB and 2 days at CHB during Fani. This is because of more lightning associated with the SuCS Amphan compared to ESCS Fani. This type of investigation is important to know the sub-ionospheric propagation characteristics of VLF sferics with respect to electrical structure and distribution of lightning associated with cyclonic storms.

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