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Study the variation in Sub ionospheric Very Low Frequency (VLF) Signal during geomagnetic storm

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Abstract:

The propagation characteristics of sub-ionospheric VLF signal depends in variation in geomagnetic field of earth. For a long propagation path variation in solar zenith angle influence on the VLF signal propagation characterises. To study the effect of variation in geomagnetic field on VLF signal propagation, we study the propagation characteristics of four VLF signals transmitted form VLF transmitter (i.e. ICV, NAA, NRK and TBB) during geomagnetic storm occur on year 2018. We conclude that VLF signals show shift in morning and evening terminator time and spiky nature during all geomagnetic storm under consideration.

1. Introduction

VLF signals are propagated within the spherical waveguide formed between the Earth and the ionosphere known as Earth Ionosphere Waveguide (EIWG). Such signal is said to be propagating ‘‘subionospherically’’. At VLF range all the antennas are electrically short and therefore have low radiation efficiency. However, operationally this is compensated by using very high input powers which make these transmitters expensive to run. As a result the creation and operation of manmade VLF transmitters is generally due to military requirements. Nevertheless, the scientific use of the transmissions from these stations has a long and successful history. Using a technique developed by Hollingworth [1] of making VLF recordings as a function of range, VLF transmitter signals were shown to exhibit an interference pattern which could be compared with theoretical estimates [2]. The upper and the lower edge of EIWG are strongly affecting the propagation conditions for the VLF signal. As the conducting ground (land, sea, or ice) is essentially unchanging with time it is the upper boundary that drives most of the temporal variability in the amplitude and phase of manmade transmitters observed from a distant location. The upper boundary of the waveguide is the ionized D-region at 70-85 km and shows variations caused by local changes in ionization rates at altitudes below the D-region caused by space weather events. During undisturbed conditions the amplitude and phase of fixed frequency VLF transmissions varies in a consistent way and thus space weather events can be detected as deviations from the ‘‘quiet day curve.’’

Early investigation of VLF emissions by Storey [3] and Allcock [4] disclosed an association between magnetic disturbances and VLF emissions. Many researchers reported the strong absorption in amplitude of 16 kHz VLF signals transmitted from GRB VLF transmitter from Rugby to Cambridge [5 - 7]. Belrose and Thomas [8] reported that the VLF amplitude showed rapid fluctuations during geomagnetic storms and also anomalous diurnal variations during the days following the recovery of the geomagnetic field. Crary and Diede [9] noted the decrease in VLF signal strength in relation to the precipitation of energetic protons. Mendes et al [10] reported the phase and amplitude changes of the VLF signal with reference to south Atlantic geomagnetic anomaly. Abdu et al. [11] reported a good correlation between VLF phase fluctuations and the variation in the horizontal component of the Earth’s magnetic field during the main phase of the storms. Cummer et al. [12] compared night time observations of the amplitude of the NLK transmitter signal as recorded in Gander, Newfoundland with UARS satellite measurements of auroral precipitation during November 1993 and January 1994. Almost 94% of the particle precipitation onsets recorded by the satellite during those 2 months could be readily identified in the VLF amplitude data. Foster et al. [13] examined the November, 3-4, 1993 geomagnetic storm using amplitude perturbations of VLF signals to localize the energetic electron precipitation between 56 and 58.5 degrees latitude and resolved the precipitation onset to the pre-midnight sector.

The main theme of this paper is to study the variation in VLF signal amplitude during various geomagnetic storms observed from the SID monitoring stations. Ground based studies have shown that the occurrence of VLF signal amplitudes during geomagnetic storms is partly controlled by ionospheric propagation conditions, particularly absorption and reflection at the base of the ionosphere.

2. Observation and Data

It is important to select a transmitter that is sufficient to limit ground wave field strength. The DCF77web site mentions a major ground wave up to 500 km (300 mi) and asimilar ground and sky wave field strength from 600 to 1100 km(400 to 700 mi). As a result, one must choose a transmitter at least 500 km (300mi), and preferably over 1100km (700mi). The upper limit of having a single hop is about1900 km (1200 mi) during the day and night (a D-layer at an altitude of 7 km) and at an altitude of 2100 km (1300 mi)(at an altitude of 90 km).Transmitters at greater distances will be received via two or more hops and will display more than one sunrise and sunset pattern. In the present analysis we have used the data of subionospheric VLF signal during three geomagnetic storm occurs on April, 20 2018 (Dst=-66), May05,2018 (Dst=-56), August 18,2018(Dst=-18) during these geomagnetic storm Dst index have the value below -50. In this work we have used VLF signal transmitted form ICV (20270), NAA (24000), NRK (37500) and TBB (26700) VLF transmitter located at different part of the globe. The short description of VLF signal transmitter used in this work is given in table – 1.

List.1 List of VLF transmitter

SN.	Call sign	Frequency (in Hz)	Location	Latitude	Longitude
1	ICV	20270	Isola di Tavolara, Italy	N 40° 55' 23.26"	E 009° 43' 51.64"
2	NAA	24000	Cutler, ME	N 44° 38' 41.77"	W 067° 16' 53.90"
3	TBB	26700	Bafa, Turkey	N 37° 24' 45.81"	E 027° 19' 24.03"
4	NRK	37500	Grindavik, Iceland	N 63° 51' 1.31"	W 022° 28' 0.38"

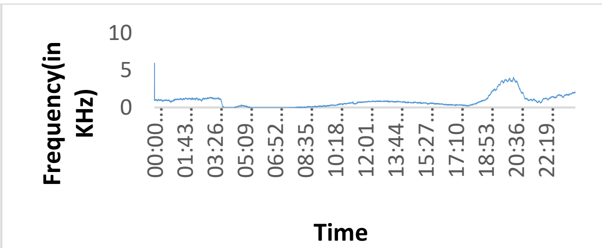

Fig. 1 (a) Quite day graph of VLF signal transmitted form ICV VLF transmitter

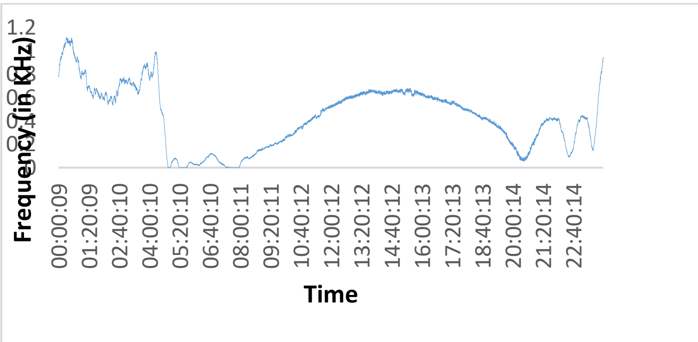

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Fig. 2 (b) Quite day graph of VLF signal transmitted form NAA VLF transmitter

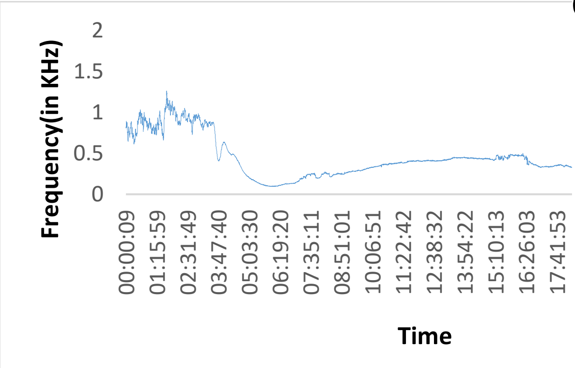

Fig. 1 (c) Quite day graph of VLF signal transmitted form NRK VLF transmitter

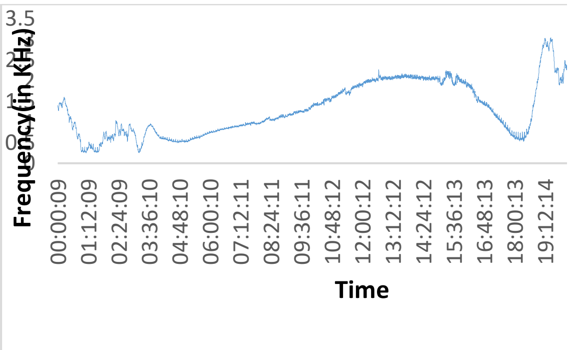

Fig. 1 (d) Quite day graph of VLF signal transmitted form TBB VLF transmitter

Figure 1 (a) to 1 (d) shows the graph of VLF signal of all the VLF transmitter on March 20, 2018 which is geomagnetically quite day as value geomagnetic Dst index was significantly high and no other geomagnetic disturb conditions are observed on this day. It was noticed form figure that VLF signals are smooth on this day and comparable less spikes are observed in all signals.

3. Comparison of Storm time VLF signal with Quiet signal

To study the effect og geomagnetic storm on subionospheric VLF signal. We have done comparative study of VLF signal transmitted from four VLF transmitter located at four different locations.

3.1Variation in VLF Signal Analysis during the Geomagnetic Storm 20-04-2018 (Dst=-66)

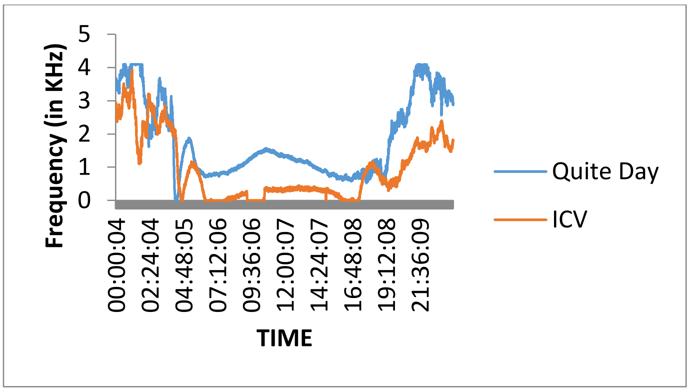

Fig .2 (a) ICV Disturb day graph signal with Quiet signal on 20-04-2018

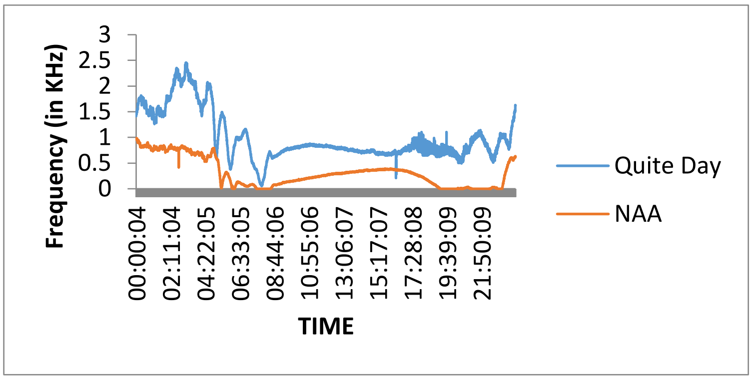

Fig . 2 (b) NAA Disturb day graph signal with Quiet signal on 20-04-2018

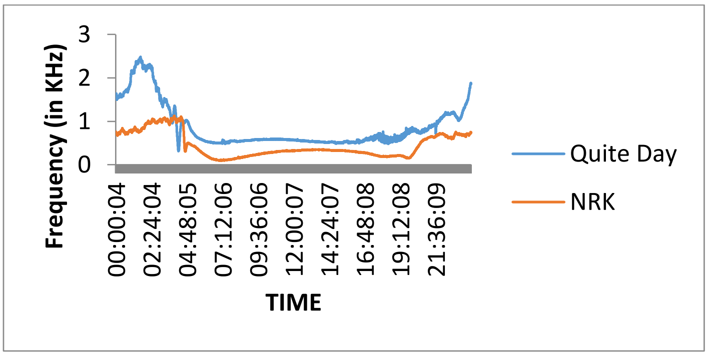

Fig . 2 (c) NRK Disturb day graph signal with Quiet signal on 20-04-2018

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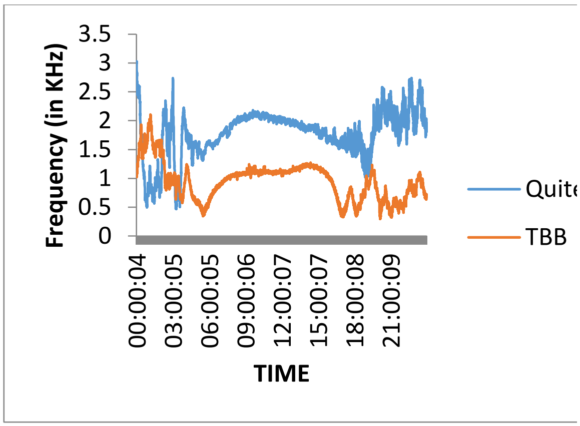

Fig .2 (d) TBB Disturb day graph signal with Quiet signal on 20-04-2018

To determine the effect of geomagnetic storm occurred on April 20, 2018 on the propagation of VLF signal, we have used signals of four VLF signal transmitter (i.e. NAA, NRK, TBB, ICV). In figure (a-d) blue graph shows the transmitter signal during quiet day, when no geomagnetic storm or other geomagnetic was recorded. Also the red colour graph shows the VLF transmitter signal during geomagnetic storm. As seen in figure there is a significant decrease in amplitude of VLF signal during the storm day for all transmitter signals, which is more pronounced near the evening and morning terminator time. It is possible to take this point as reference to study the effect of geomagnetic storm on VLF signal propagation. Further it also seems that amplitude of VLF signal decrease significantly at morning for the NAA, NRK and TBB transmitter signal, which may be possibly associated with geomagnetic storm. It was noticed that in more spikes are observed in VLF transmitter signal on the day of geomagnetic storm as compared to quiet day signal.

3.2 Variation in VLF Signal Analysis during the Geomagnetic Storm 06-05-2018 (Dst=-56)

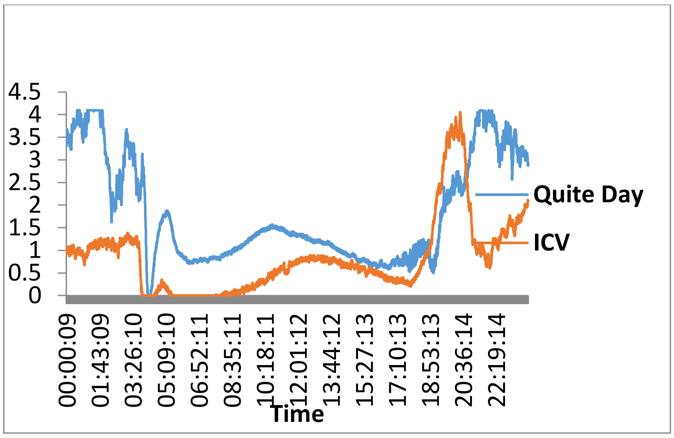

Fig . 3 (a) ICV Disturb day graph signal with Quiet signal on 06-05-2018

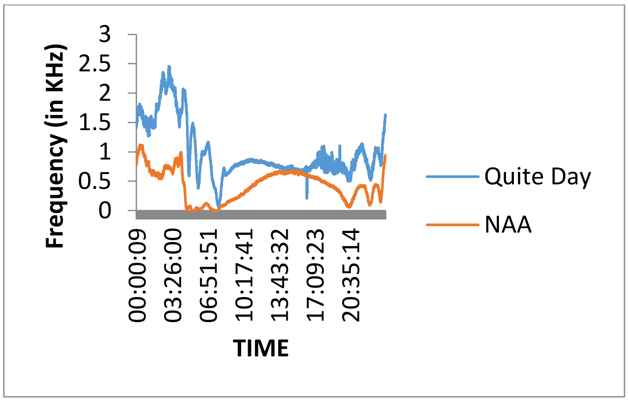

Fig . 3 (b) NAA Disturb day graph signal with Quiet signal on 06-05-2018

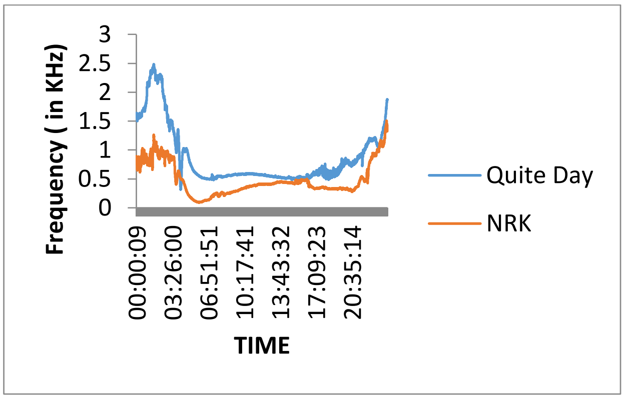

Fig . 3 (c) NRK Disturb day graph signal with Quiet signal on 06-05-2018

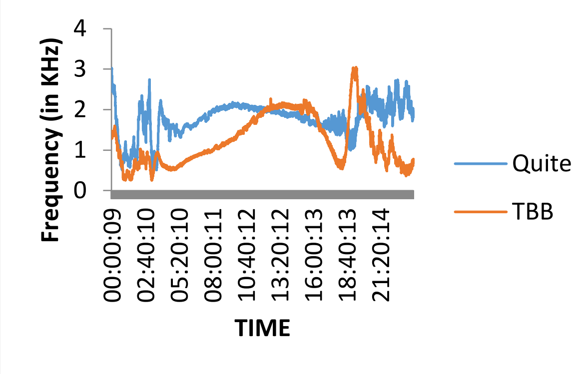

Fig . 3 (d) TBB Disturb day graph signal with Quiet signal on 06-05-2018

We have analyze the VLF transmitter signal during geomagnetic storm occurred on Mat 05, 2018 with Dst index approx -56. In figure 3 (a) to 3 (d) shows the comparison between VLF signals transmitted from four different transmitters with the signal recorded on the day of geomagnetic storm. In all figures red graph shows the transmitter signal during quiet day, when no geomagnetic storm or other geomagnetic was recorded. Also the blue colour graph shows the VLF transmitter signal during geomagnetic storm. It was noticed form figure that there is significant decrease in VLF signal in VLF signal, which is more pronounced near the evening and morning terminator time, which may be probably associated with geomagnetic storm. All signal shows spiky behavior as compared to quit day signal, which affect the quality of VLF signal received at the receiver.

3.3 Variation in VLF Signal Analysis during the Geomagnetic Storm 18-08-2018 (Dst=-18)

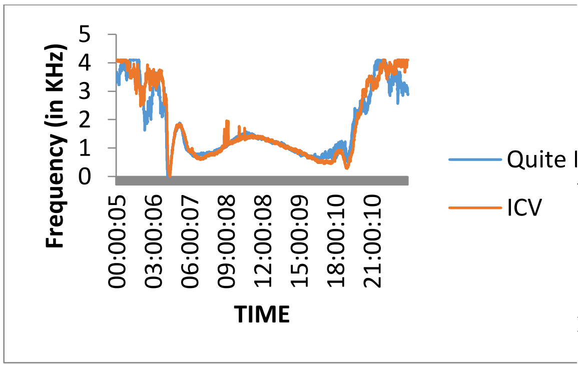

Fig . 4 (a) ICV Disturb day graph signal with Quiet signal on 18-08-2018

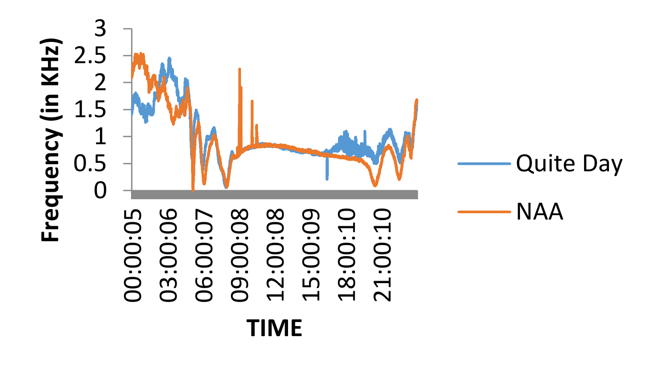

Fig . 4 (b) NAA Disturb day graph signal with Quiet signal on 18-08-2018

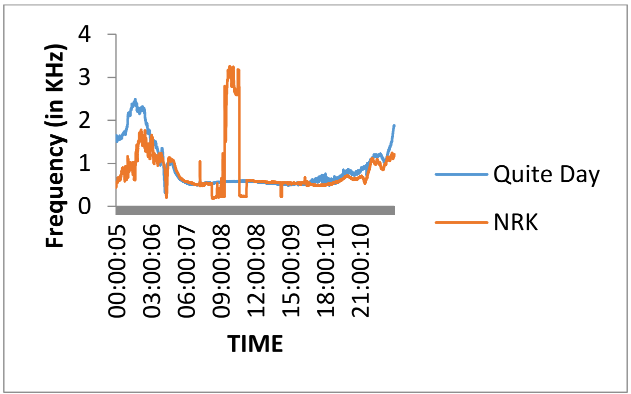

Fig . 4 (c) NRK Disturb day graph signal with Quiet signal on 18-08-2018

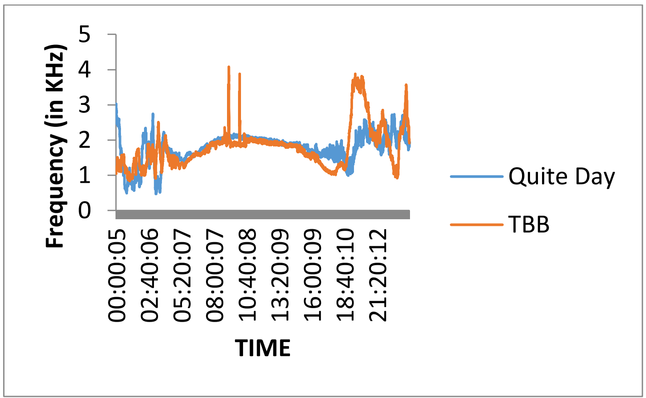

Fig . 4 (d) TBB Disturb day graph signal with Quiet signal on 18-08-2018

Intense geomagnetic storm was occurred August 18, 2018 with Dst index – 56. Figure 4 (a) to 4 (d) shows the comparison between VLF signals recorded on the day of geomagnetic storm and geomagnetically quit day. In figures red graph shows the transmitter signal during quiet day and the blue colour graph shows the VLF transmitter signal during geomagnetic storm. From all figure it was clear that there is significant decrease in amplitude of VLF signal. Since geomagnetic storms effect the VLF signal propagation and its amplitude, which affect the quality of VLF signal received at the receiver. Sometimes these variations are considered as a noise in VLF signal which appear as anomalies near morning and evening terminator time, which is very difficult to estimate during the modelling process.

4. DISCUSSION AND CONCLUSION

We have analyzed the effects of the three geomagnetic storm occurred on year 2018 on sub-ionospheric VLF signal transmitted by four VLF transmitter located at four different places. In cases, we found significant decrease in amplitude of VLF signal, which is more pronounced at the morning and evening terminator time. It was also noticed that these signals shows spiky behavior during geomagnetic storms. This variation in morning and evening terminator time in VLF signal can be considered as anomalies in VLF signal, which can be used to estimate the D region changes along the propagation paths during the main and recovery phases of storms. In all the cases we studied here, it was clearly observed that amplitude of VLF signal decreased during the geomagnetic storms. This result was in agreement with the work done by Araki et al. [14] who analyzed the VLF signal transmitted by NWC VLF signal transmitter and recorded at Japan and the anomalous variation in its phase of to geomagnetic storm, which he recognized an increase in the D region reference height. Many researchers study the variation in reference height of D region during sever geomagnetic storms [15 – 16].

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