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VLF radio signal perturbations during two recent solar eclipses observed from a VLF receiving station, Cooch Behar, India

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Abstract

Effects of two recent solar eclipses of December 2019 and June 2020 on the Very Low Frequency (VLF) radio signal amplitudes, observed from a single receiving station at Cooch Behar (CHB), India, have been presented in this paper. Signal amplitudes of VLF transmitters such as VTX (18.2 kHz), NWC (19.8 kHz), JJI (22.2 kHz), and DHO (23.4 kHz) experienced both enhancement and reduction during the eclipse period. Depending on the eclipse obscuration over the propagation path, propagation distance, and frequency of the signal, increase and decrease of signal amplitudes were observed. The amplitude perturbation on the VLF signals was also opposite for the two eclipses on each propagation path. The possible reason behind the amplitude perturbations is the changes induced in the earth ionosphere waveguide during the solar eclipses and corresponding constructive or destructive interference that occurred between the waveguide modes of the received signal at each frequency.

1 Introduction

During the solar eclipse, the radiation from the Sun to Earth gets reduced due to moon's occultation of the Sun and corresponding modification happens in the earth's atmosphere as well as in the ionosphere [1-3]. The D-region ionosphere is mostly left to probe by satellite, balloon and high frequency radio technique [4]. Very low frequency (VLF) navigational transmitter's signals (10-30 kHz) propagate through the earth ionosphere wave guide (EIWG) and respond to the solar radiation. This fact is being used to monitor the lower ionosphere (60-90 km) as the VLF signals are reflected from this region [5]. Natural phenomena taking place in the tropospheric layer, like tropical cyclones, lightning-thunderstorm etc. can modify lower part of EIWG in both day and night time [6-7]. Day time upper layer of EIWG formed by lower ionosphere can be modified from far outer space, if there is any extra ionization process occurred due to solar or space weather activity like solar flares, or geomagnetic storms. Reducing of solar radiation can take place during solar eclipses which is also responsible for ionospheric D-region variation [8-10]. Variation in the ionospheric composition comes as a decrease in the electron-ion temperature. Due to the modifications in the electron-ion distribution, very clear changes are observed in the amplitude and phase of VLF signals [11]. At the earliest, Bracewell 1952 showed VLF/LF signal modification during solar eclipse [12]. Since then there were many studies of VLF signals perturbations during solar eclipses [13-18]. A recent study showed no amplitude variation of VLF/LF signals at three frequencies (21.4 kHz, 25.2 kHz, and 40.75 kHz) with propagation path lengths 2200-6400 km but only phase disturbances were observed [11]. Presence of Atmospheric gravity waves (AGWs) was also investigated in several studies [19-20]. The movement (in supersonic speed) of the cooling spot developed by solar eclipse in the Ozone layer breaks the thermal equilibrium of atmosphere which is the possible major source of AGWs during any solar eclipse [21].

Table 1: Details of two eclipses

Eclipse Date	Obscuration at CHB (26.3452° N, 89.4482° E)	1st Contact (UT)	Maximum (UT)	2nd Contact (UT)
Dec, 2019	35.03%	03:04	04:25	05:59
June, 2020	80.16%	05:19	07:08	08:49

In this paper, we present the effects of two solar eclipses of 2019 and 2020 on VLF signal propagation paths at four frequencies (VTX-18.2 kHz, NWC-19.8 kHz, JJI-22.2 kHz and DHO-23.4 kHz) as observed from Cooch Behar (CHB) in the North-Eastern part of India. Eclipse zone of the two consecutive solar eclipses on 26th December, 2019 and on 20th June, 2020 was almost in opposite side of the receiving station. In Figure 1 we have presented the path of the eclipse zone with the greatest eclipse (GE) and duration (GD) location. Duration of both eclipses was almost 3 hours from CHB. Obscuration of the Dec, 2019 eclipse was ~35% and for June, 2020 eclipse obscuration was ~80% from the VLF receiving station. Details of two eclipses are presented in Table 1. In the next section we describe the experimental arrangement to record the amplitudes of navigational transmitters of four discrete frequencies. Later we discuss the results and finally we make conclusion of this study.

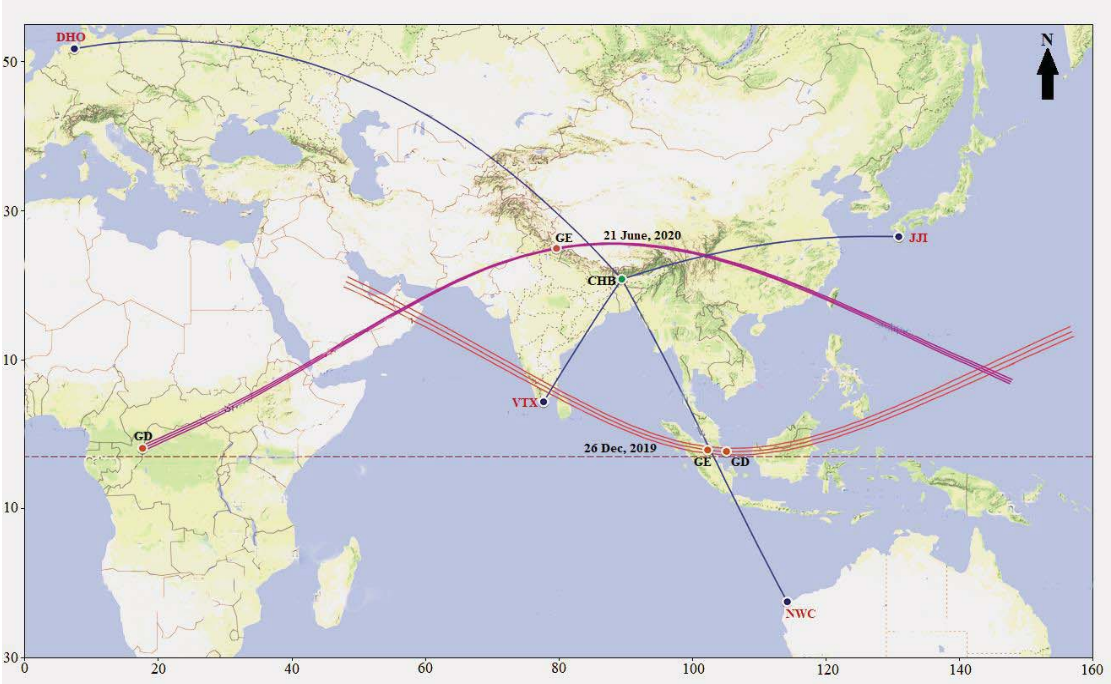

Figure 1. Path of 26 Dec 2019 (Red) and 21 June 2020 (Violet) eclipses on the world geographical map. Navigational transmitters VTX, NWC, JJI, and DHO are indicated by blue dot symbols. Green dot indicates the receiving station (CHB). Great Circle Paths are also indicated by blue lines.

2 Experimental Arrangement and data set

We monitor electric field amplitude of VLF signals of several navigational transmitters e.g. VTX [8.39N, 77.75E] of India (18.2 kHz), NWC [21.82S, 114.17E] of Australia (19.8 kHz), JJI [32.08N, 130.83E] of Japan (22.2 kHz), DHO [53.08N, 7.62E] of Germany (23.4 kHz) and other lower band of radio signals at Cooch Behar (CHB) in the north eastern part of India. Geographically CHB (26.35° N, 89.45° E) is located at a sub-tropical low latitude region. At CHB, the amplitudes of VTX and JJI signals are independent of solar zenith angle and are almost flat during day time and other two transmitter signals show smooth variation with solar position. During the solar eclipse of December 2019, the DHO transmitter was off the air as per our observation. Reception of these radio frequencies is done by a ingeniously developed stable receiving system which includes an active E-field antenna fed to a two stage band pass pre-amplifier with a gain factor 21. Signal is carried to the indoor recording unit by a RG-54 coaxial cable. For continuous logging of the E-field amplitudes with a sampling rate 4 Hz we use Spectrum lab V2.0 software (https://www.qsl.net). Internal computer clock have been synchronized with fixed internet time server. Geographic location of the receiving stations and transmitter-receiver Great Circle Paths (GCPs) are shown in Figure 1. For eclipse path data we took help of NASA's eclipse web-service (https://eclipse.gsfc.nasa.gov/eclipse.html) and for calculation of eclipse parameters we use Local Circumstances Calculator (v1.0.6) (https://xjubier.free.fr/en/site_pages).

3 Results and Discussion

The variation of three VLF frequencies namely VTX, NWC, and JJI during the December 2019 solar eclipse is presented in Figure 2. Black curves are the variations for 25 December used here as the reference signal to compare with the eclipse day variations (blue). The VTX signal during the solar eclipse was off the air for few moments which caused data gaps shown in the Figure.

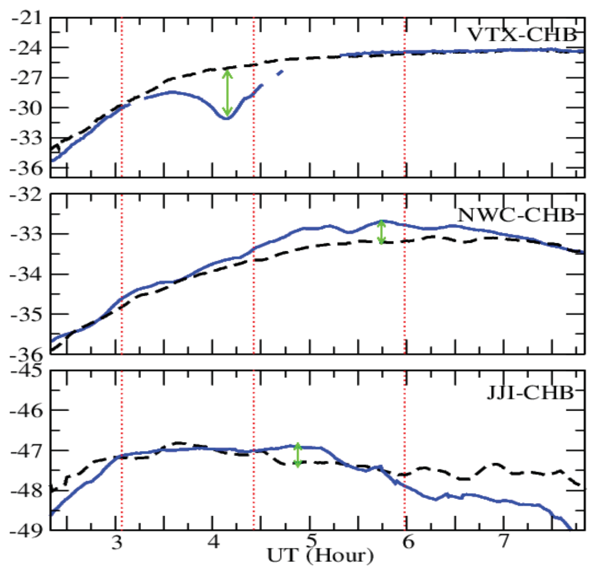

Figure 2: Signal amplitudes of VTX, NWC and JJI signals for 26th December, 2019 (Blue) compared with the Reference signals (Black dashed). Green arrows indicate peak amplitude deviations. Red vertical lines indicate respectively the times of 1st contact, maximum and 2nd contact during the eclipse.

The duration of this eclipse was almost for three hours with maximum at 04:25 UT. Compared to past investigations we see a large amplitude reduction (5.2 dB) for VTX signal during the eclipse period. The maximum reduction of amplitude was at 04:09 UT, before the eclipse peak at CHB. In this case, the orientation of the solar eclipse belt with respect to the propagation path and the propagation distance favored the destructive interference among the propagating modes resulting negative amplitude perturbation for the VTX signal.

For the long path NWC signal, we see amplitude enhancement which started prominently after the mid-eclipse phase at the receiver and stayed above the reference signal for almost 1.5 hours. This prolonged disturbance could be due to the reason that the receiver and the middle portion of the NWC-CHB propagation path experienced solar eclipse maximum at different times. The JJI-CHB propagation path experienced less amount of solar obscuration during the December solar eclipse and correspondingly no significant deviation was observed during the maximum eclipse phase.

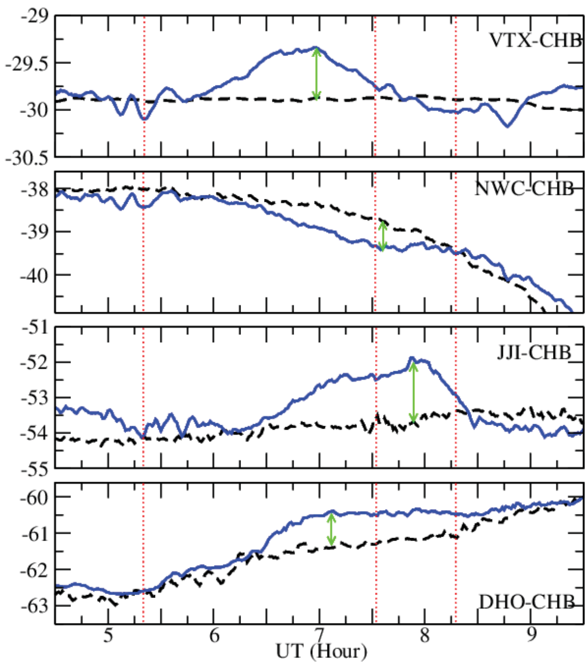

Figure 3: Same as Figure 2. Signal amplitudes of VTX, NWC, JJI and DHO signals for the June 2020 solar eclipse (blue) are compared with the reference signals (black).

Signal amplitude variations for the four propagation paths, namely VTX-CHB, NWC-CHB, JJI-CHB and DHO-CHB are shown in Figure 3 associated with the 21t June 2020 solar eclipse. Duration of the eclipse is depicted in Table 1. From Figure 1 it can be seen that the total eclipse belt was opposite and much closer to the receiver compared to the December 2019. Consequently, CHB experienced maximum obscuration of 80%. In this case, we see amplitude enhancement of the VTX signal amplitude unlike the previous case. The peak amplitude enhancement (0.54 dB) of VTX signal was observed at 06:57 UT after the greatest eclipse at 06:40 UT. Opposite amplitude deviation (0.33dB) was also observed for NWC signal at 07:33 UT after the maximum eclipse at CHB as described in Table 1. In case of JJI signal, we observe 0.60 dB amplitude increment (07:54 UT) and for DHO-CHB signal amplitude increased by 0.332 dB at 07:03 UT during the eclipse period.

4 Conclusion

We have summarized the observation of amplitude perturbations of VLF radio signals received in a single station for two recent solar eclipses of 2019 and 2020. The perturbation of the VTX signal (reduction in amplitude) during the solar eclipse of December 2019 was greater than the perturbation (enhancement in amplitude) associated with the solar eclipse of June 2020 although the receiver experienced greater eclipse obscuration during the later event. This is because of the fact that the total VTX-CHB propagation path experienced greater percentage of eclipse obscuration during the December 2019 event resulting destructive interference among the propagating modes. The NWC signal also exhibited opposite behavior during the two eclipses, though the magnitude of perturbation (enhancement or reduction due to the eclipses) remained almost same. On the other hand, the JJI signal responded strongly (positive deviation) to the solar eclipse of June 2020 as the whole of the propagation path experienced solar eclipse obscuration and the eclipse totality belt crossed the path. We are working on the detail analysis of the two solar eclipses and the effects on the D-region ionosphere in terms of its conductivity and electron density profiles will also be presented for the two solar eclipses from a network observation using ~10 receivers.

Acknowledgements

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