VLF amplitude anomaly during the total solar eclipse of 22 July, 2009

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Abstract. During the total solar eclipse in India on July 22, 2009, we measured the amplitude of the fixed frequency VLF transmitter signals (\(f = 19.8\) kHz, NWC, Australia) at Agra (Geographic Lat. 27.2° N, Long. 78° E), using a SoftPAL (Software based phase and amplitude logger) receiver. It was the longest total solar eclipse in the 21st century seen in India ever since 18 August, 1968. We analysed the VLF data for a period of fifteen days (±7 days from the date of the event) and found that the amplitude of the signal decreased on 22 July in the time sector of 2 hrs between 0530 and 0730 hours LT with the maximum depletion during the period of total solar eclipse. The result is interpreted in terms of depletion of electron density in the D region of the ionosphere caused by the solar eclipse.

Key words: VLF, amplitude, solar eclipse

1. Introduction

The total solar eclipse provides a unique opportunity to study the response of the ionosphere to the changes of the solar illumination. Many workers have reported the results of study of ionosphere during a solar eclipse with various methods, such as the Faraday rotation measurement, ionosonde network, incoherent scatter radar, Global Positioning System (GPS), and satellite measurements (Bauer, 1910; Evans, 1965; Klobuchar and Whitney, 1965; Rishbeth, 1968; Bowhill, 1970; Hunter et al., 1974; Oliver and Bowhill, 1974; Cohen, 1984; Salah et al., 1986; Cheng et al.1992; Chandra et al., 1997; Tsai and Liu, 1999; Huang et al., 1999; Farges et al., 2001; Farges et al., 2003; Tomas et al., 2007; Gerasopoulos et al., 2007; Adeniyi et al., 2007; Le et al., 2008). The results drawn from these studies have shown that there is almost a constant behaviour at low altitudes where electron density drops by a large percentage during a solar eclipse, whereas the \(F_2\) region behaviour is quite complicated during different eclipse events, showing either an increase or a decrease in electron density. De and Sarkar (1997) reported the effect of total solar eclipse of October 24, 1995 on long distance VLF radio wave propagation of 22.3 kHz from North West Cape, Australia to Calcutta. It was shown that, after the commencement of the total eclipse, the signal exhibited a small attenuation followed by a recovery and a sudden enhancement to a value comparable to seasonal maximum. Clilverd et al. (2001) studied the total solar eclipse observed in Europe on August 11, 1999. Measurements were made of the amplitude and phase of four VLF transmitters in the frequency range 16-24 kHz at five receiver sites and significant variations in phase and amplitude were reported for 17 paths. Typically, positive amplitude change( increase over daily averages) were observed throughout the whole...
eclipse period on path lengths <2000 km, while negative amplitude changes (decrease from daily averages) were observed on paths >10,000 km. Negative phase changes were observed on most paths, independent of path length. Although there was significant variation from path to path, the typical changes observed were ~3 dB in amplitude and ~50° in phase.

In this paper, we present the results of VLF amplitude data corresponding to the total solar eclipse, which occurred on 22 July, 2009 and was seen in India during 0626h-0630h LT (LT=UT+5.5 h). We studied the data for a period of fifteen days from 15 to 29 July, 2009, ±7 days before and after the occurrence day of the event. We observed significant depletion in VLF amplitude on the day of solar eclipse, a result consistent with those of earlier workers.


The total solar eclipse lasted for nearly four minutes, from 0626h to 0630h, and was seen in Surat (Gujarat), Bhopal (Madhya Pradesh), Patna (Bihar), Varanasi (Uttar Pradesh), Darjeeling (West Bengal), and in North eastern states. Fig.1 shows a track of the total solar eclipse in India.

Fig.1: Path of solar eclipse from India and surrounding countries.

This solar eclipse was seen in India for a longest period ever since that of 18 August, 1968 and may not be seen in future until after 123 years. The total solar eclipse and the Moon's umbral shadow on Sun began in India and crossed through Nepal, Bangladesh, Bhutan, Myanmar, China and ended in the Pacific Ocean.

3. Experimental setup and method of data analysis

We have employed SoftPAL (Software based phase and amplitude logger) obtained from LF*EM Research Ltd, Dunedin, New Zealand. SoftPAL is an advanced version of AbsPAL (Absolute Phase and Amplitude Logger) (Clivard et al., 2001). We monitored the phase and amplitude of the frequency 19.8 kHz (NWC, Australia). The
great circle path (GCP 6672 km) of this signal is shown in Fig.2. The equipment includes a service unit, preamplifier, GM-44 GPS head, a creative audiigy sound card, a dongle and necessary connecting cables. The SoftPAL records data through Lab' Chart. The sampling rate is 1 sample/sec. The observations have been carried out at Bichpuri, a rural area about 12 km west of Agra city where local electric and electromagnetic disturbances are low.

![Fig.2: Great circle path of the NWC signal (f = 19.8 kHz).](image)

For the present study we consider the amplitude data only. Time period of data analysis was chosen to be between 0530h and 0730h LT for 15 days between 15 July and 29 July, 2009.

4. Results and discussion

The measurement of phase and amplitude of VLF transmitter signals (f=19.8 kHz, NWC, Australia) has been started at our Bichpuri, Agra station since 14 July, 2009 using the SoftPAL receiver details of which are described earlier. The great circle path of such signals (GCP = 6672 km) is shown in Fig.2. In order to study the effect of solar eclipse of

![Fig.3: Raw amplitude data of two hours (0530 – 0730 hrs LT) of NWC (19.8 kHz) signal on 22 July, 2009 (eclipse day). The downward vertical arrow shows the time of total solar eclipse.](image)
22 July, 2009, we analyse the amplitude data for a period of 15 days from 15 July to 29 July (±7 days from the date of the event). In Fig.3, we show the variation of amplitude for a period of two hours between 0530h and 0730h LT on the day of the eclipse.

Here, a downward arrow indicates the time of total solar eclipse. It may be seen clearly that the amplitude of the signal is depleted during the total solar eclipse and then recovers its normal condition as soon as the Sun reappears from moon’s shadow. This result is consistent with that of Clilverd et al. (2001) for long paths. An amplitude minima just after 0600h is due to sunrise terminator when the D-layer starts appearing and due to collisions between electron and neutral particles, the amplitude of the signal is attenuated. In Fig.4, we show the variation of raw data for the duration of total solar eclipse (4 minutes between 0624 and 0628h LT) on five days between 19 July and 23 July, 2009.

![NWC (19.8 KHz)](image)

Fig.4: Raw Amplitude data (0624-0628h LT) for five days from 19-23 July, 2009.

As expected the amplitude level is lowest on 22 July, but surprisingly a large enhancement in the amplitude level may be seen on 21 July, a day before the solar eclipse. These results are more clear in Fig.5 in which we show by histograms four minutes averaged data for amplitude of the signal. The data gaps in the figure are due to no
observation. The results stated before are reflected very well in this figure. We have attempted to find the possible reason for the large enhancement of the amplitude on 21 July, especially in the light of the fact that the whole period of 15 days was magnetically quiet ($\sum Kp<25$ on each day). Then we examined the lightning activity data from the website www.wunderground.com. We found that there occurred intense lightning activity between Delhi and Jaipur (between 200 and 250 km from Agra station). It is well known that the lightning and thunderstorm activities heat the lower ionosphere and create additional ionization and the amplitude of the signal is enhanced while passing through such a localized enhancement of ionization (Mika, 2007).

![Histogram of VLF amplitude anomaly](image)

**Fig. 5:** Histograms showing the average amplitude between 0624 – 0628 hrs LT. The enhanced amplitude on 21 July is due to local lightning.

The depletion of the amplitude of the signal during the period of total solar eclipse is interpreted very well in terms of the ionosphere approaching a nighttime condition when the effective height of the waveguide channel increases and multimode propagation occurs. Due to interference between the different modes, the effective amplitude of the signal decreases. In other words, the increase of the effective height leads to a decrease in the phase velocity of VLF waves. The phase front deforms in such a way as to make possible the focusing of VLF waveguide modes at a definite distance from the lunar shadow spot. The VLF focusing effect has been verified using a hydroacoustic model (Bilokh and Shubova, 1979). The gradual increase in phase and reflection height after the initial contact and then a total change in the reflection height of about 5 km was also reported earlier by Jain and Subrahmanyan (1979) who measured amplitude and phase of VLF signals ($f=22.3$ kHz) during a solar eclipse.

It may be noted that D-layer of the ionosphere is most sensitive to the loss of the Sun light, because it is the lowermost of the layers and is quickly overwhelmed by the neutral air around it, once the active source ionizing radiation from the Sun is removed.
The study of D region during eclipse conditions, is common with the study of normal D region, has suffered from the difficulty of measuring very small electron densities (<10^4 cm^-3) which occur below 90 km. However, measurement of amplitude and phase of VLF radio signal during an eclipse shows a change in the phase height of reflection and amplitude depletion as stated before, making the study of the effect of solar eclipse possible conveniently.

5. Conclusion
We studied the VLF amplitude data of the fixed frequency VLF transmitter signal (f=19.8 kHz, NWC, Australia) for a period of fifteen days from 15 July to 29 July, 2009 (±7 days from the date of total solar eclipse occurred on 22 July, 2009). The VLF data is obtained through SoftPAL (Phase and Amplitude Logger) receiver. The amplitude variation of the VLF transmitter signal shows a depression during the time of the total solar eclipse. The results are interpreted in terms of depletion in electron density due to disappearance of the solar radiation under lunar shadow.

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