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First ever VLF monitoring of the lunar occultation of a solar flare during the 2010 annular solar eclipse and its effects on the D-region electron density profile

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ABSTRACT

A ground based Very Low Frequency (VLF) radio receiver of Indian Centre for Space Physics located at Khukurdaha (22°27′N, 87°45′E) monitored the VLF signal at 19.8 kHz from the NWC station during a partial solar eclipse (maximum obscuration 75%) which took place on January 15, 2010. The receiver and the transmitter were on two opposite sides of the annular eclipse belt. During the same period, a solar flare also occurred and it was partly blocked by the lunar disk. Thus the resultant signal was perturbed both by the eclipse and by the flare. The deviation of the signal from the normal value was obtained by subtracting from the average diurnal signal on days bracketing the eclipse. The deviation was analysed. We compare the data from GOES-14, HINODE and RHESSI satellites during the event. We got a clear depression in the data during the period of the partial eclipse. Most interestingly, there was also a flaring activity in the sun which reached its peak (C-type) just after the time when the eclipse was near maximum. By superposing the lunar disk on the image obtained by HINODE mission, we pin-point the time frame of blocking hard and soft X-rays. We extract the time variation of the electron density profile in the D-region of the ionosphere due to occulted solar flare from the combined effect of the eclipse and the flare. We also compare the results with a normal solar flare.

1. Introduction

Very Low Frequency (VLF) radio waves are used for long distance communication for their very low attenuation while propagating through the Earth-ionosphere wave guide. Indian Centre for Space Physics has been monitoring VLF radio wave transmitting stations from several of its monitoring stations. On January 15, 2010, there was an annular solar eclipse as seen from the southern regions of India. At Khukurdaha (22°27′N, 87°45′E) station, the eclipse was partial with a maximum obscuration of about 75%. From this station, we have been monitoring NWC transmitter operating at 19.8 kHz. We report the results of our observations *and interpretations* in this paper.

Periodic variation of the solar radiation on the upper atmosphere each day due to sunrise and sunset gives rise to a periodical variation in its charge density. After the sunrise, the extreme ultraviolet and the soft X-ray radiations create the D-region lowering the ionospheric height to $\sim 60-70$ km. Solar eclipse has always been a very important calculable event which changes the ionosphere in a predictable time frame. During a partial eclipse, the ionosphere experiences a reduction in intensity of the UV and soft X-ray photons from the solar disk. This gives us an opportunity to study the global variation of electron concentration in the ionosphere which could be useful to understand the ion chemistry. Long wavelength propagation models inside the Earth-ionosphere wave guide may be tested as well.

The effects of the solar eclipse on the amplitude and phase of VLF signals over the both short (<3000 km) and long (>3000 km) propagation paths have been reported by many authors (Bracewell, 1952; Sen Gupta et al., 1980; Lynn, 1981; Buckmaster and Hansen, 1986; Mendes da Costa et al., 1995). Clilverd et al. (2001) reported the results of monitoring the VLF signals from multiple transmitters and receivers paths during the total solar eclipse of August 11, 1999 in Europe. They calculated the variation of electron density at 77 km altitude throughout the period of solar eclipse, which showed a linear variation in electron production rate with solar ionizing radiation. Pal et al. (2012) reported the effects of total solar eclipse of 2009 in India for several propagation paths and also modelled the VLF amplitude deviations due to the eclipse using the Long Wave Propagation Capability (LWPC) (Ferguson, 1998) code. Chakrabarti et al.

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(2010, 2011a,b, 2012) presented results of observations during the Total Solar Eclipse (2009) from multiple receiving stations and found that for some stations, the amplitude of the signal is enhanced, while some other stations the amplitude is reduced from the normal values. Sudden ionospheric perturbations due to the solar flares are common (Mitra, 1974). The importance of our observation is that the flare and the eclipse both took place simultaneously and the effect of the flare is only partial due to the occultation by the moon.

In this paper, we describe our results in detail and compare the VLF signals with the light curve of hard and soft X-rays obtained by the GOES-14 and RHESSI satellites. We also present the magnetogram around the flare obtained by the GONG project and the image of the flare from the HINODE X-Ray Telescope (XRT) data. From the relative positions of the Sun, the Moon and the receiving station, we derive the time variation of the lunar occultation of the flare. From these, we obtain the time variation of the electron number density in the lower ionosphere over the entire event. In the next Section, we describe the events of which the results are reported. In Section 3, we present the experimental set-up, the process of data acquisition and the observational results, including those from various satellites. In Section 4, we separate the eclipse component and the flare component from the combined VLF signal. In Section 5, we simulate VLF signal received by us and derived ionospheric parameters, such as the electron number density and the reflection height. Finally in Section 6, we make concluding remarks.

2. The solar eclipse and the solar flare

The Indian Centre for Space Physics (ICSP) made Gyrator-III VLF receiver (1–22 kHz) with a loop antenna was monitoring NWC station from Khukurdaha. The annular solar eclipse of January 15, 2010 started at 12:05 IST (=UT+5:30) and continued up to 15:28 IST. The eclipse was partial (maximum coverage 75%) as seen from Khukurdaha. The maximum obscuration at the receiver occurred at 13:56:26 IST. The distance between transmitter and receiver is about 5700 km (Fig. 1). Thus the transmitter was far away from the annular solar eclipse belt. During propagation of signal from NWC to Khukurdaha, there was no eclipse in 24.5% of the total path while 75.4% of the total path experienced some eclipse. The whole propagation path experienced an average value of solar obscuration at the most 40% calculated using a numerical integration over the whole path. Fig. 2 shows the degree of solar obscuration during eclipse at receiver and over the whole path at 70 km above the ground.

While the eclipse is in process, a C1.3 solar flare started at 07:22 UT (12:52 IST) and continued till 10:22 UT (15:52 IST) with an extended maximum in Soft X-ray from 08:41 UT (14:11 IST) to 08:44 UT (14:14 IST) The hard X-ray peaked at 08:36 UT (14:06 IST). Thus the hard and the soft X-ray peak within the eclipse period. The soft X-ray peak is about 15 min after the maximum obscuration of the solar disk. The peak energy flux in 1.5–12.5 keV was 1.3×10^{-6} ergs/cm^2 which is well above the detectability limit of our VLF antenna (typically, C1.0 flare).

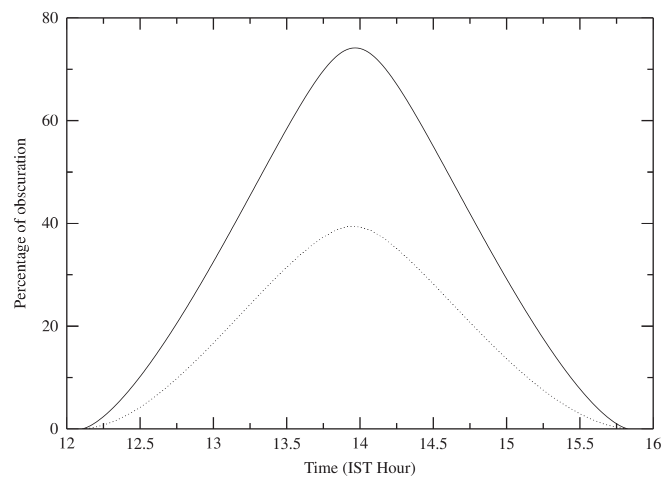

Fig. 2. Variation of percentage of solar obscuration (S) as a function of time. Solid curve represents the solar obscuration at the receiver and the dotted curve represents the average value of solar obscuration over the whole path.

Fig. 1. Great circle path between the NWC transmitter and receiver. The shaded area is the path of total annularity of January 15, 2010.