Computation of the effects of solar phenomena on Global Ionospheric Weather using wave guide mode theory of VLF propagation

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Abstract

The sub-ionospheric VLF signal strength varies significantly with place and time. The solar eclipse and regular solar terminator motion effects on the Global Ionospheric Weather (GIW) and hence the VLF propagation. It has been simulated considering wave guide mode theory of VLF radio signal propagation along various transmitter to receiver great circular paths. Using Long Wave Propagation Capability code, the mode theoretical results are obtained. To estimate the ionospheric weather changes by VLF technique during a total solar eclipse, a three dimensional model of disk obscuration & its ionospheric consequences has been constructed.

1 Introduction

VLF signal propagates with very little attenuation through the earth-ionosphere wave guide [1-3]. A terrestrial subionospheric VLF signal gets modified accordingly while carrying signature of ionospheric perturbative changes. Thus VLF detection is an important tool to study the lower ionospheric layer structures. Starting from the analysis of the sunrise-sunset phenomena (day - night terminator), the detection solar flares of various classes [4], computation of solar eclipse effects [5] and predictions of earthquakes [6] can be done by studying these VLF wave propagation properties. Geomagnetic effect causes the East-West non-reciprocal propagation [7].

One can get the spatial and temporal distribution of the lower ionospheric properties in terms of ionospheric system parameters, which is the basic aim of Global Ionospheric Weather (GIW) study. In this work, the VLF signal (having frequency 18.2 kHz and coming from VTX transmitter), strengths spatial distribution profile with day-night terminator and solar eclipse effect on it are calculated. We used the well known Long Wave Propagation Capability (LWPC) [8] code. A three dimensional geometrical model is also being developed to represent disk obscuration factor during total solar eclipse and corresponding changes in the ionosphere. Recently, Indian Centre for Space Physics, Kolkata, organised VLF campaigns (2008-2009) throughout India to sample the signal strength from more than a dozen or so places [6] in both normal sun and eclipse time. The signal behaviour was found to be different in different places. Our final goal would be to theoretically understand this nature of GIW for a regular diurnal variation and for solar eclipse events, using these informative observational data.

2 Computational methods for wave guide mode theory

In the present work, the mode theoretical calculations has been done using LWPC code [8]. This computer program mainly calculates amplitude and phase variations of VLF & LF signal along any transmitter receiver great circular path (TRGCP) for any transmitter in the world. This code was built using exponential ionospheric profile [9], which has parameters like reference height (h') and sharpness factor (β). This default model depends on the signal frequency, conductivity profile etc. [10].

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2.1 Day - night terminator effect computation

The default ionosphere model runs through the 'bearing' part of LWPC code. Here the ionospheric daytime and nighttime standard parameter values in code are, $h' = 74$ km, $\beta = 0.30$ and $h' = 87$ km, $\beta = 0.38$ respectively. Field variation along TRGCP from VTX has been calculated for every geomagnetic bearing angle separately at a given time, hence the entire spatial variation is obtained. This process is repeated to have both the sunrise & the sunset variations over Indian subcontinent.

2.2 Solar eclipse effect computation

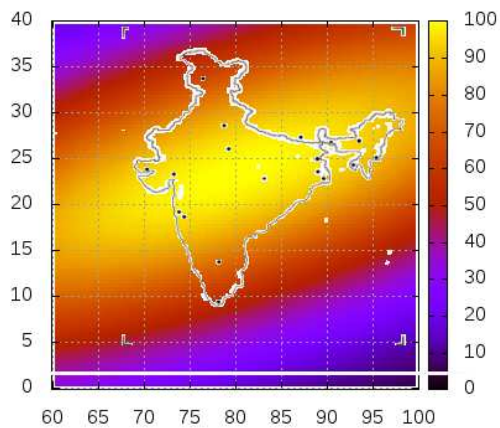

Figure 1: Variation of percentage (%) obscuration with latitude & longitude (shown by colour variations) for the total solar eclipse (22 July 2009). Time chosen is 6:30am IST (UT + 0530 hrs).

Changes in vertical electric field and phase variation of VLF wave due to the perturbed ionospheric situation, is computed by 'range exponential model' part of LWPC code. Apart from default conditions any model values of h' and β can be supplied here to represent the perturbed lower ionospheric state. In this case, a two- dimensional Gaussian function profile has been given to h' and β parameters. The peak value and FWHMs of that Gaussian function have been adjusted by keeping consistency with solar disk obscuration factor (see, Fig. 1) of total solar eclipse (TSE) of 22nd July 2009. At eclipse time on the eclipse totality zone, a partly local ionospheric nighttime situation is assumed to be created. Finally, the amplitude deviation (ΔA) due to eclipse has been obtained after subtracting the quite day values from this perturbed values (here the previously mentioned bearing angle variation technique is used).

3 Results using wave guide mode theoretical results

In this section, the spatial amplitude distribution has been calculated and plotted using the LWPC code (mode theory approach).

3.1 Sunrise & sunset effects

we present the spatial distribution of the amplitude (in dB units) of VLF signal throughout Indian subcontinent in an winter morning (6:00am IST) and evening (6:30pm IST) respectively. Colours represent amplitudes. The circular patches of amplitude maxima and minima could be clearly seen. In the sunrise picture (Fig. 2), the left side of the terminator shade is showing the nighttime amplitude variation and right

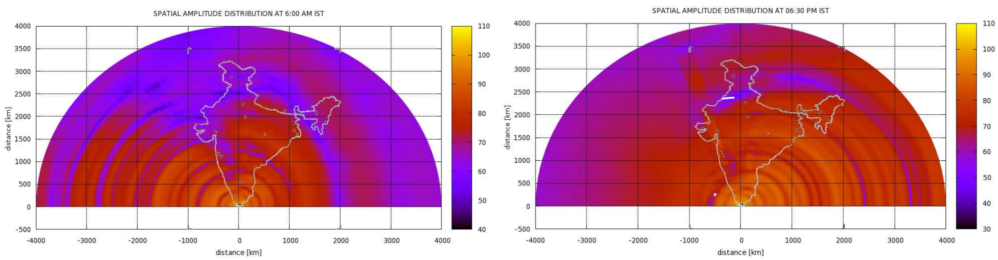

Figure 2: Spatial amplitude distribution profiles of 18.2 kHz VLF signal (coming from VTX transmitter) over Indian subcontinent at sunrise (6:00am IST) (above) and sunset (6:30pm IST) (below) on a winter day [11]. LWPC code (Ferguson, 1998) was used. The great circular paths (GCP) are plotted along X & Y axis in km. The black dots within map of India denote the VLF campaign places.

side is showing the daytime amplitude variation. The sunset picture is showing exactly the opposite. In the sunrise picture, some regions, especially in the western India, we see evidence of weaker signals clearly due to propagation effects in the west [12]. We also notice the movement of the terminator (low amplitude patch) from the east to the west. It is evident from these Figures that presence of solar flux in the ionosphere is changing the whole scenario of subionospheric VLF propagation profile.

3.2 Total solar eclipse (TSE - 2009) effects

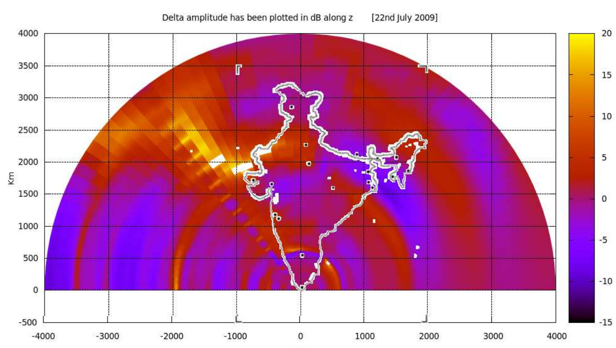

Figure 3: Spatial amplitude deviation profile of 18.2 kHz VLF signal (coming from VTX transmitter) over Indian subcontinent, due to TSE 22nd July 2009. This has been done for time 6:30am IST. LWPC code (Ferguson, 1998) was used. The great circular paths (GCP) are plotted along X & Y axis in km. The black dots within the map of India denote the solar eclipse campaign receiving sites.

The circular patches of different colours show both the positive and the negative deviations of amplitude due to solar eclipse. This is verified from observational results. The propagation of comparatively weaker signal in the west is seen in this eclipse results also.

4 Conclusion

By simulating the ionospheric condition at different celestial phenomenon, we can monitor global ionospheric weather (GIW) condition through a mapping between VLF signal amplitude variation profile and GIW over Indian subcontinent as modulated by the sunrise and the sunset, solar flares, solar eclipse etc. We computed the distribution from the wave guide mode theory (LWPC code).

5 Acknowledgments

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