VLF study of Ionospheric properties during solar flares of varied intensity for a fixed propagation path

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Abstract

Deviations of subionospheric VLF signal amplitude due to solar flares of several energy classes have been computed for the VLF signal propagating along the VTX-Kolkata baseline. Using Long Wave Propagation Capability Code (LWPC), the variation of the effective height h' and steepness β parameters have been computed for X, M and C classes of solar flares. We compute the temporal variation of the electron number density.

1 Introduction

It is well known that the solar flares perturb ionosphere and thus the VLF amplitude and change the phase of the wave [1]. In spite of being the main source of ionisation, it has been reported that there is no significant change in Lyman-α flux during solar flare. However a solar flare contains both the soft and the hard X-ray components. Soft X-rays reach the D-region where they produce extra ionisation. The enhancement in ionisation in the ionosphere due to flares modify the electrical property of the ionosphere, which in turn perturb the VLF amplitude and phase [2]. In this paper, the VLF (18.2 kHz) amplitude perturbations due to the X2.2 (occurred on 15th Feb, 2011), M2.0 (occurred on 12th June, 2010) and C4.8 (occurred on 15th Feb, 2011) classes of flares are being discussed. The 18.2 kHz VLF signal is being received at Kolkata station (22^0 $34'$ N, 88^0 $24'$ E).

2 Comparison of GOES satellite & VLF data during solar flares

In Fig. 1, we present the GOES satellite data of the X-ray flare on three days and the corresponding deviation of the VTX signal amplitude due to the X2.2, M2.0, C4.8 classes of flares as received from Kolkata in these dates. The VTX signal amplitude deviation in (dB) was obtained by subtracting the data of the previous day from the data of the flare-day. The VLF signal is behind the GOES signal by about 2.0, 2.5, & 4.0 minutes for X, M & C flares respectively.

3 LWPC technique for flare effect computation

To deduce the changes in the ionospheric parameters due to the solar flare, we have used the LWPC code developed by NWSC [3]. The LWPC code is a collection of separate programs.The default propagation model in LWPC is Long-Wave Propagation Model (LWPM) which treats the ionosphere as having exponential increase in conductivity with height. A log-linear slope (β in km^{-1}) and a reference height (h') define this exponential model. To calculate the quiet day value of β and h', the default model has been used. The range-exponential model has been used to calculate the β and h' parameters during the perturbed conditions. In this case, the user provides a set of trial β and h' parameters at each time. The LWPC program is run to obtain the signal amplitude for that set and this amplitude is compared with the observed amplitude at the same time [4]. This process is repeated till LWPC gives the signal amplitude which roughly agrees with

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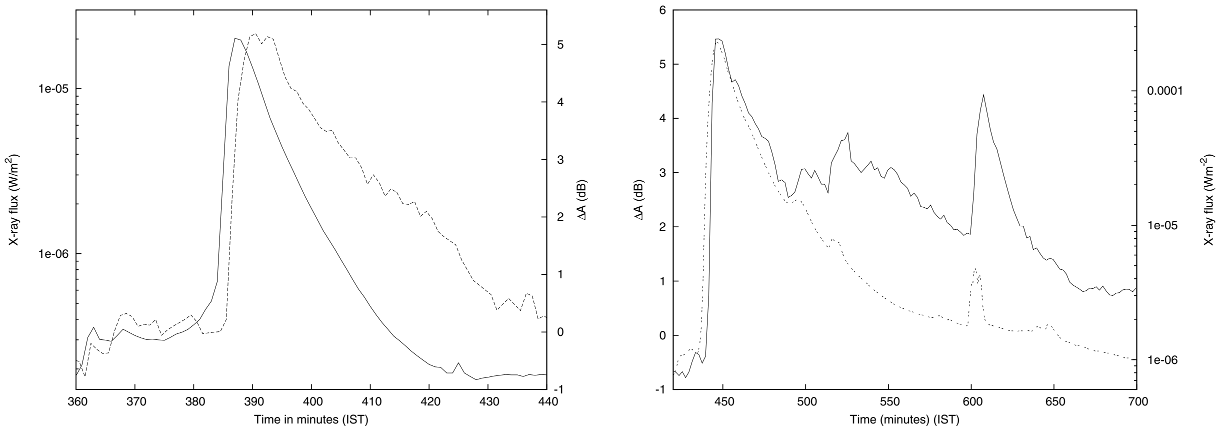

Figure 1: (a) M2.0 class solar flare event (solid line) with a peak x-ray irradiance at 06:27 (IST) on 12 June, 2010 and the corresponding disturbance of VLF signal amplitude of VTX (18.2 kHz) transmitter (dashed line). The VLF signal amplitude peak occurred at 06:29.5 (IST). (b) X2.2 & C4.8 classes of two solar flare events (dashed lines) with peaks of x-ray irradiance at 07:26 & 10:02 (IST) respectively on 15th Feb 2011 and the corresponding VLF signal disturbances of VTX (18.2kHz) (solid line). The VLF amplitude peak occurred at 7:28 & 10:06 (IST) respectively.

the observed data. The set of β and h' which agrees best is chosen for that time. The process is repeated for each time during the flare.

4 Determination of β, h' and N_e under a flare condition

We determine the observed amplitude perturbations ΔA by subtracting the quiet day data,

$$\Delta A = A_{perturb} - A_{quiet}$$

These perturbations ΔA are then added to the simulated unperturbed value which is obtained from the LWPC default program at the receiver site to obtain,

$$A'_{perturb} = A_{lwpc} + \Delta A.$$

These $A'_{perturb}$ are then used for obtaining the β and h' parameters under flare conditions. The unperturbed values obtained from LWPC program for VTX-Kolkata propagation path is 71.56 dB (above 1μV/m). It corresponds to β=0.3 km^{-1} and $h' = 74.0$ km.

To calculate the electron density profile for the lower ionosphere the following well-known Wait's formula was used [5-6],

$$N_e(h, h', \beta) = 1.43 \times 10^{13} exp(-0.15h') exp[(\beta - 0.15)(h - h')],$$

where N_e is in m^{-3}.

Table 1: An example of how the ionospheric parameters vary due to a solar flare.

Date of flare	Class of solar flare (IST)	FPT (IST)	OPT	Time	$\Delta A(dB)$	β (km^{-1}	h' (km)	N_e at 74 km (m^{-3})
15.02.2011	X2.2	07:26	07:28	07:21	1.4797	0.327	72.2	0.38930E+09
				07:28	5.4792	0.482	65.4	0.1364E+11
				07:48	3.90	0.351	69.0	0.1249E+10
				08:09	2.5046	0.355	71.0	0.6268E+09
12.06.2010	M2.0	06:27	06:29	06:20	0.176	0.329	73.2	0.28117E+09
				06:29	5.135	0.48	68.0	0.38498E+10
				06:40	3.713	0.395	69.6	0.12288E+10
				07:20	0.208	0.32	73.36	0.26522E+09
15.02.2011	C4.8	10:02	10:06	09:58	1.8044	0.321	72.0	0.41066E+09
				10:06	4.4484	0.401	68.6	0.1884E+10
				10:15	3.3982	0.350	70.0	0.8760E+09
				10:43	1.4066	0.325	72.3	0.3755E+09
				11:26	0.7542	0.307	73.2	0.2762E+09

5 Results

Table 1 shows the deduced β and h' parameters and electron densities at different times during the flare. In the second column we give the flare peak time (FPT) according to GOES data. In the third column, we present the observed peak time (OPT). Other columns are self-explanatory.

In Fig. 2, we present the variation of the electron number density with height (in km) at various times during the flare using the VTX data. At the peak times of the flares, the variation became steeper. At higher altitudes, say, at 90 km, the number density increased by a factor of a few hundred roughly, while at lower height, say at about 60 km, the number density went up by the factor of a few. As time passes by and the flare decays, the electron number density distribution eventually goes back to it 'normal' (quiet) value.

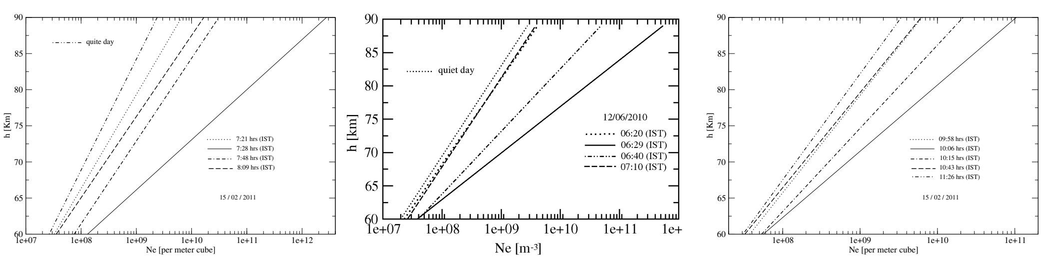

Figure 2: *Changes in the electron density profile in the lower ionosphere from 60 km-90 km during the X2.2, M2.0 & C4.8 (Figures from left to right) class solar flares as deduced from the VTX (*18.2 *kHz) data.*

Depending on the recombination time scale at different heights, the number density of electrons would vary with time. In Fig. 3, we show in the same plot the variations of both the X-ray flux and electron density with time at a height of 74km. The shape roughly follows the VLF signal amplitude, but not the X-ray flux, owing to the time delay due to recombination.

It is to be noted that the parameters one obtains from the LWPC are average properties along the propagation path. They are not the absolute values at the receiver point or the mid-point of the path (i.e., the place of first reflection). This can be easily verified by comparing the deduced values for two VLF signals which record the same flare. The X & C flares took place on the same day successively and it is observed that the effect of C class flare on VLF data is more in this case as the ionospheric D layer was already ionised enough due to X class flare and C flare occurred well before degree of ionisation dropped to the quite state.

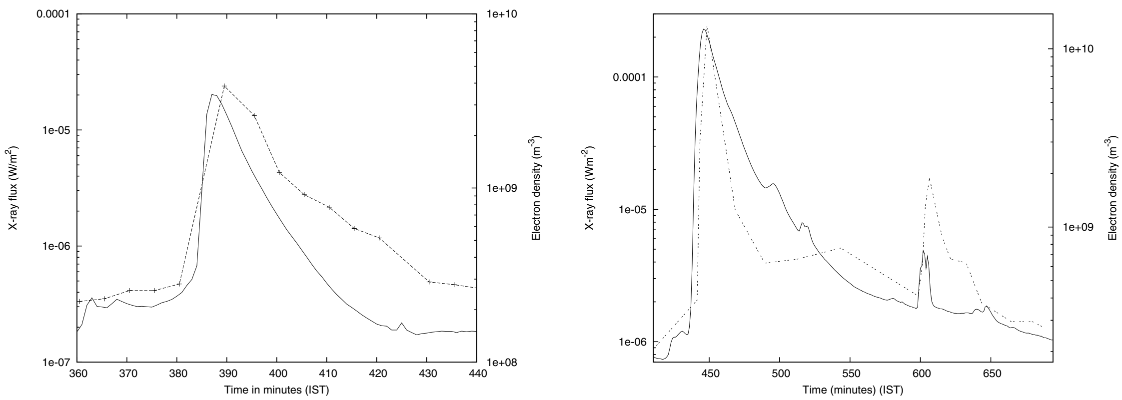

Figure 3: *Comparison of temporal variations of electron density at 74km height and X-ray flux measured by GOES satellite during solar flare. The Figure in the left is showing M2.0 class flare data and figure of right is showing the X2.2 & C4.8 class flares. The VLF (18.2 kHz) data transmitted from VTX transmitter.*

6 Conclusion

Subionospheric VLF signal and its analysis using wave guide theory are good tools for studying the effects of the solar flares on the ionosphere. Variation in the degree of ionisations hence the perturbations in VLF signal data due to different energetic flares help to understand ionospheric chemistry as well. From the information of the electron density change of lower ionosphere during flare, the recombination time scales and ionospheric chemical component ratios can be understood.

7 Acknowledgements

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8 References

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