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A Model Study of Lower Ionospheric Composition during Solar Flares: I- Negative Ions and Electron Concentration

Yogendra Kumar Verma¹, Sanjeev Srivastava²

¹Department of Physics, Guru Hari Kishan Degree College Gola-Kheri,

²Principal, Govt. Degree college, Hempur, Bisalpur(Pilibhit)

Abstract: An ion chemical model study of seasonal and latitudinal variation of the composition of lower terrestrial ionosphere under M, C and X class x-ray flares is made under varying solar and geomagnetic activity. Computed concentrations are seen to vary from 10^2 to 10^4 for dominant ions for class C to class X flare for all latitudes. The seasonal variation of flare time concentrations is however not very well defined. Effectiveness of a flare is seen to depend on its time of occurrence.

Keywords: Lower Terrestrial Ionosphere, Solar Flares, Geomagnetic Activity, Negative Ions, Electron Concentration

I. INTRODUCTION

The lower part of the ionosphere, which comprises of the D-region and lower E-region covering the altitude range from nearly 60 km to 110 km has practical importance because, it influences radio propagation to distant places on the Earth K. Rawer [1]. Solar flares affect this region due to excess ionization caused by the enhanced solar x-rays flux, below $10\text{\AA}$. This increase in x-ray radiation could be of several orders of magnitude for very strong flares. The excess ionization is responsible for enhanced radio wave absorption.

The solar x-ray flares which occurred on 19.01.2005, 04.11.2004 and 23.07.2002 and belonging to Class C7.7, M5.4 and X4.8 respectively have been adopted as representative flares for C, M and X classes, are used to study seasonal and latitudinal variation of negative ions and electron concentrations under Solar Maximum ($F_{10.7} > 250$) and Solar Minimum ($F_{10.7} < 70$) conditions for geomagnetically quiet ($A_p < 20$) and disturbed days ($A_p > 50$).

In order to do that, for taking the inputs from various models, we have chosen the dates 24.2.2008, 18.8.2008 and 25.10.2007 as representative of winter, summer and equinox respectively under solar minimum and geomagnetically quiet conditions; 15.12.2006, 15.5.2005 and 11.9.2005 as representative of winter, summer and equinox respectively under solar minimum and geomagnetically disturbed conditions; 26.12.2001, 19.7.2000 and 24.9.2001 as representative of winter, summer and equinox respectively under solar maximum and geomagnetically quiet conditions; 06.11.2001, 15.7.2000 and 31.3.2001 as representative of winter, summer and equinox respectively under solar maximum and geomagnetically disturbed conditions as these days were found to have the appropriate levels of solar and geomagnetic activity.

II. ION CHEMICAL MODEL

A. Reaction schemes

In order to obtain the densities of major negative ions and electrons, in this work we have employed detailed ion-chemical model is shown in fig 1, which present the negative ion flow chart. This scheme takes into 36 negative and electron is essentially similar to the reaction scheme given by J. Kazil [2]. Details of the reactions and their kinetic rates are given elsewhere Y.K.Verma [3].

B. Neutral atmosphere

Neutral atmospheric parameters namely the number densities of He, O, N₂, O₂, Ar, H, and N, total mass density; neutral temperature and exospheric temperature, are adopted from the MSISE model A.E. Hedin[4],[5], which describes the neutral temperature and densities in the Earth's atmosphere from ground to thermospheric heights.

$$q(j,\lambda,h)=F(\lambda,\infty) I(j,\lambda) n(j,h) \exp[-\sum_j A(j,\lambda) \int_h^\infty n(j,z)dz] \dots\dots\dots(2)$$

Fig. 2 - Typical X4.8 Class flare

Fig. 3 Typical C7.7 Class Flare

Fig. 4 - Typical M5.4 Class flare

B. Ion Composition

The reaction schemes are used to construct the rate equations for computing the densities of various ions. The some typical computed height profiles of negative ions under C, M and X class flare and under Solar Maximum ($F_{10.7} > 250$) and Solar Minimum ($F_{10.7} < 70$) conditions for geomagnetically quiet ($A_p < 20$) and disturbed days ($A_p > 50$).

IV. RESULTS AND DISCUSSION

A. Production Rates

computed results are obtained for the effect on the ion production rate for latitude 0°N to 90°N and 0°S to 90°S for solar minimum and solar maximum conditions for geomagnetically quiet and disturbed days. Fig 6-11 show typical plots of ion production rate at 70 Km. Under varying solar and geomagnetic activity levels, for all latitudes, the galactic cosmic ray contribution is less compared to the ionization due to Lyman alpha which in turn is less than the contribution of metastable oxygen. The total non flare value of ion production is found to be very close to the total ion production rate for C-class flare typically of the order of 10^6 cm^{-3} . However, this value is surpassed for M-class flare (10^7 cm^{-3}) and X-class flare (10^8 cm^{-3}), with hard X-rays under flare conditions contributing significantly to the ion production. Yet another feature quite discernible from our model computations is that $(\text{N}_2^+ + \text{O}_2^+)$ usually much below the NO^+ , quickly overtakes the production rate of NO^+ under flare conditions. These results are in conformity with earlier studies carried out for specific flares based on experimental observations A.P. Mitra[13], Srivastava et al.[14]; Verronen et al.[15]. The flare induced ionization is found to vary with solar zenith angle, i.e. a solar flare of same class occurring at different times of the day induces varying degree of ionization at different latitudes. During flare, the ion production rates are found to reach a maximum between 85 km and 100 Km and show a decrease thereafter, a feature which can be very well understood in the light of the effectiveness of hard x-rays in producing ionization at lower altitudes.

Fig. 5- Computed ion production Rates for winter

B. Negative Ion and Electron Concentrations

The model results obtained for all latitudes under varying level of solar and geomagnetic activity show the concentrations to vary from 10^2 to 10^4 for the dominant negative ions for C class flare to X class flare. Similar effects have been obtained by other workers. The seasonal variation for flare time concentrations is however again seen to be not very well defined. Effectiveness of a flare is seen to depend on the time of occurrence of the flare. The hydrated cluster ions are seen to be present only up to a height of about 70 Km and their concentrations fall off very rapidly above this height. This trend is observed for all flare types. The radio wave absorption has also been computed for a radio wave of 2.2 MHz using Sen-Wyller magnetoionic theory in conjunction with appropriate collision frequency profiles and electron density obtained from our model. Typical values of 42 dB for the C-class flare, 63dB for M- class flare and 96 dB for X-class flare are obtained.

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Fig. 6 -Computed Negative ions and Electrons height profiles for winter in Solar Minimum and Geomagnetically disturbed

Fig. 7 -Computed Negative ions and Electrons height profiles for winter in Solar Maximum and Geomagnetically disturbed

Fig. 8 -Computed Negative ions and Electrons height profiles for Equinox in Solar Minimum and Geomagnetically disturbed

Fig. 9 -Computed Negative ions and Electrons height profiles for Equinox in Solar Minimum and Geomagnetically disturbed

Fig. 10-Computed Negative ions and Electrons height profiles for winter in Solar Maximum and Geomagnetically disturbed

Fig. 11 -Computed Negative ions and Electrons height profiles for winter in Solar Maximum and Geomagnetically disturbed

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