iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** IV **Month of publication:** April 2018

DOI: http://doi.org/10.22214/ijraset.2018.4711

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue IV, April 2018- Available at www.ijraset.com

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

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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 10Å. 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 represtative 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, N_2, O_2, 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.

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C. Ionizing fluxes

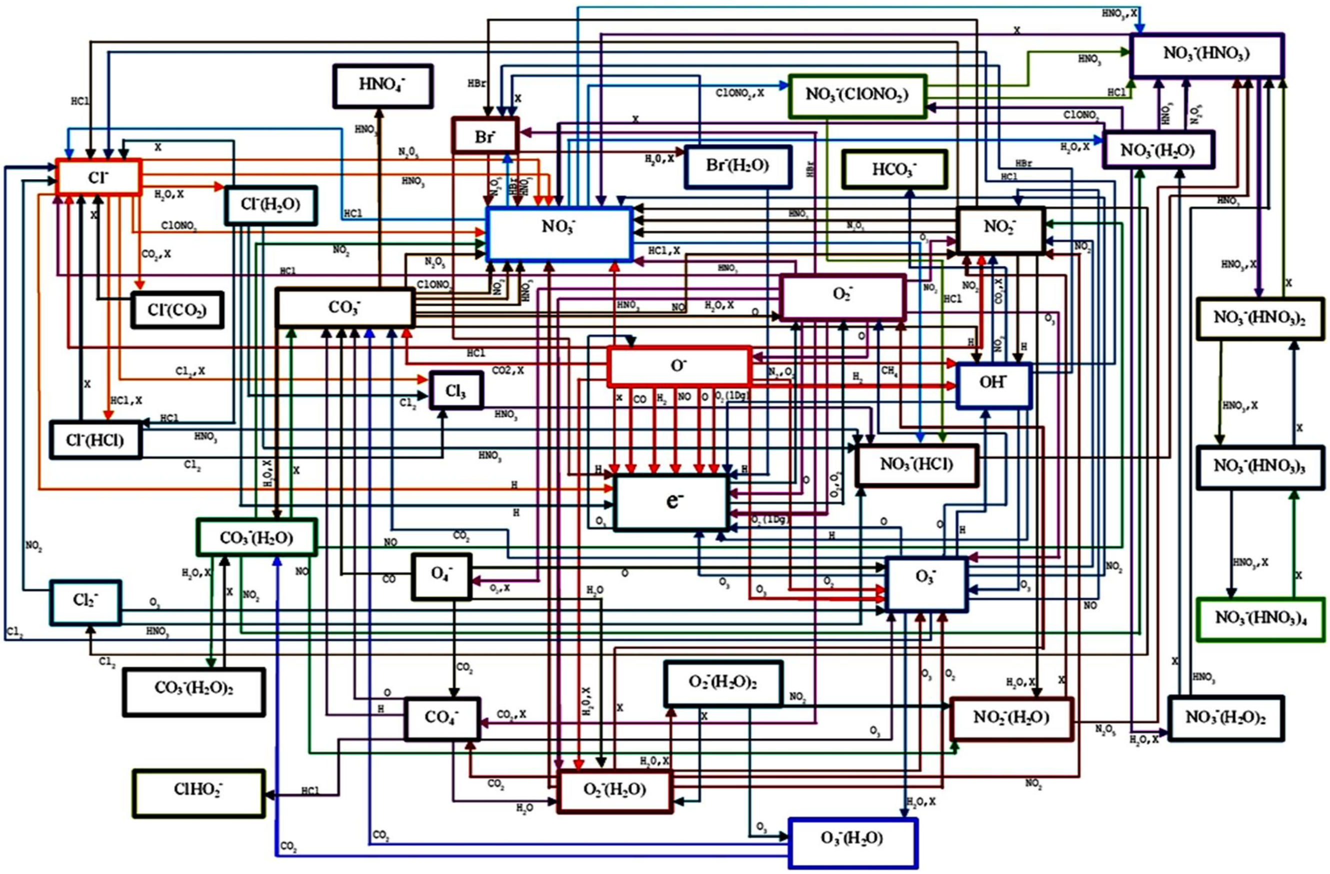


Fig.1 Negative ion flow chat for 37 ion scheme

The significant contributors to the lower ionospheric ionization are solar Lyman-alpha (1216Å), solar x-rays in the range 1-10Å and galactic cosmic rays below 65 km. During a flare event, the Lyman-alpha increases by relatively small amount compared to the huge normal solar Lyman-alpha emission. By contrast, observations of solar x-ray from GOES satellites show huge increase during flares. The solar flux above the atmosphere $I_\infty(\lambda)$ is estimated by the SOLAR 2000 model, which provides various daily 1 AU adjusted (or observed) solar irradiance products and historical data W.L.Tobiska et al.[6]. This spectral range of solar radiation is responsible for the main photo ionisation and photo dissociation processes in the upper stratosphere, mesosphere, and lower thermosphere Brasseur and Solomon [7]. A spectrum of the power law form-

$$I(\lambda) = A\,\lambda^B \qquad \text{...................(1)}$$

has been found to be adequate by many workers Rowe et al.[8]; P. A. J. Ratnasiri and C. F.Sechrist[9]; J. W. Parker and S. A. Bowhill[10] and in present work, the same form has been employed. Where I is the flux of wavelength in Wm^{-2} ,λ the wavelength in Å and A and B are constants depending on GOES x-ray detector chamber responses for 0.5-4Å and 1-8Å. typical spectrum is shown in figs 2-4

III. COMPUTATIONS

A. Production Rates

The ion production rates have been computed using the well known Chapman production function Rishbeth and Garriot, [11] using the fluxes described in the preceding sections and the ionization and absorption cross sections compiled from various sources. The photoionization of metastable O_2 ($^1\Delta g$) by ultra violet radiations in the range 1027- 1118Å is computed from the expression given by Paulsion et al. [12] and the cosmic rays ionization has been found by the expression given by Brasseur and soloman, 2005[7]

$$q(j,\lambda,h)= F(\lambda,\infty)\ I(j,\lambda)\ n(j,h)\ \exp[-\sum_{j} A(j,\lambda) \int_{h}^{\infty} n(j,z)dz] \ldots\ldots\ldots\ldots\ldots(2)$$

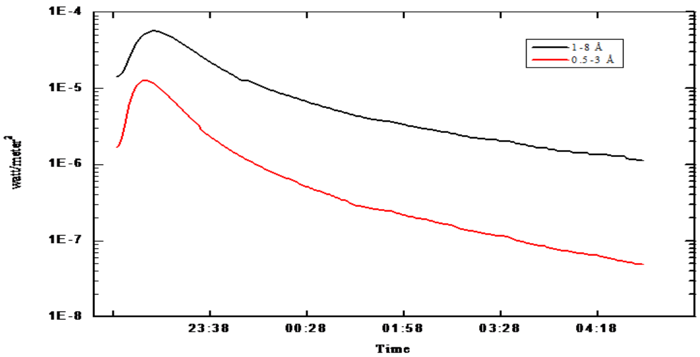


Fig. 2 - Typical X4.8 Class flare

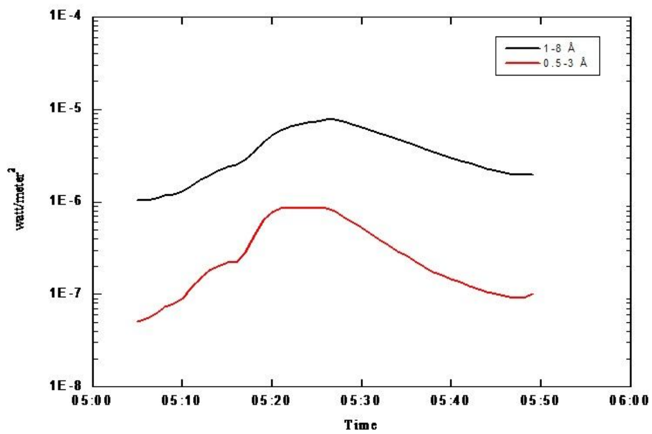
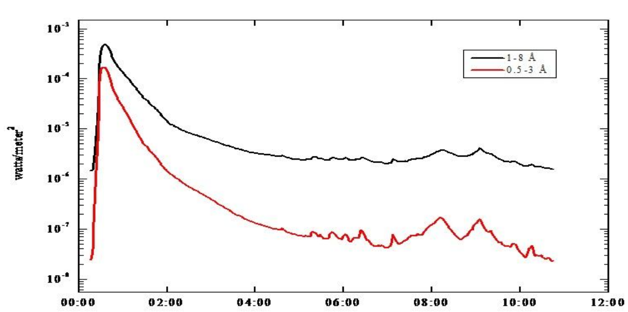


Fig. 3 Typical C7.7 Class Flare

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).



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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 (N_2^++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.

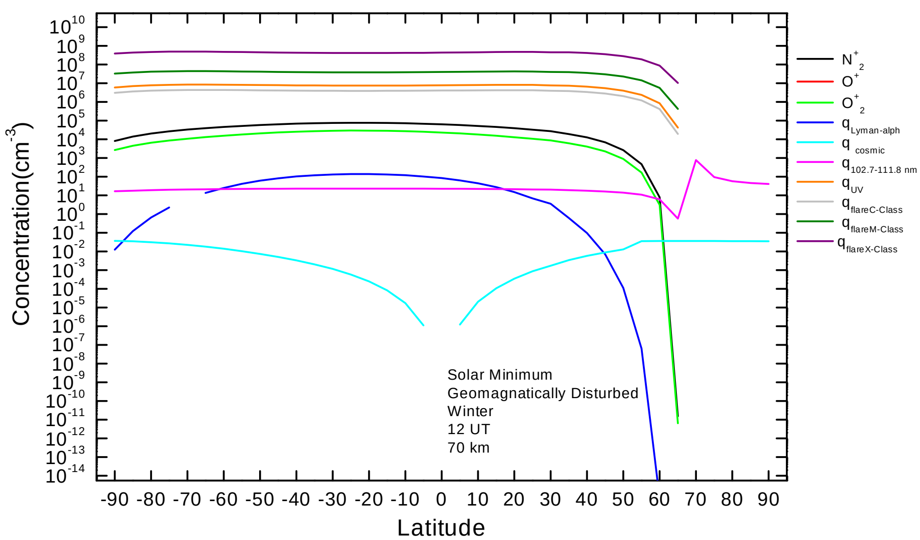

Fig. 5- Computed ion production Rates for winter

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 magn0etoionic 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.

V. ACKNOWLEDGEMENTS

The authors are thankful to Dr. Raj Kumar Tyagi for help in plotting graphs And Dr. N K Batra for completing this work.

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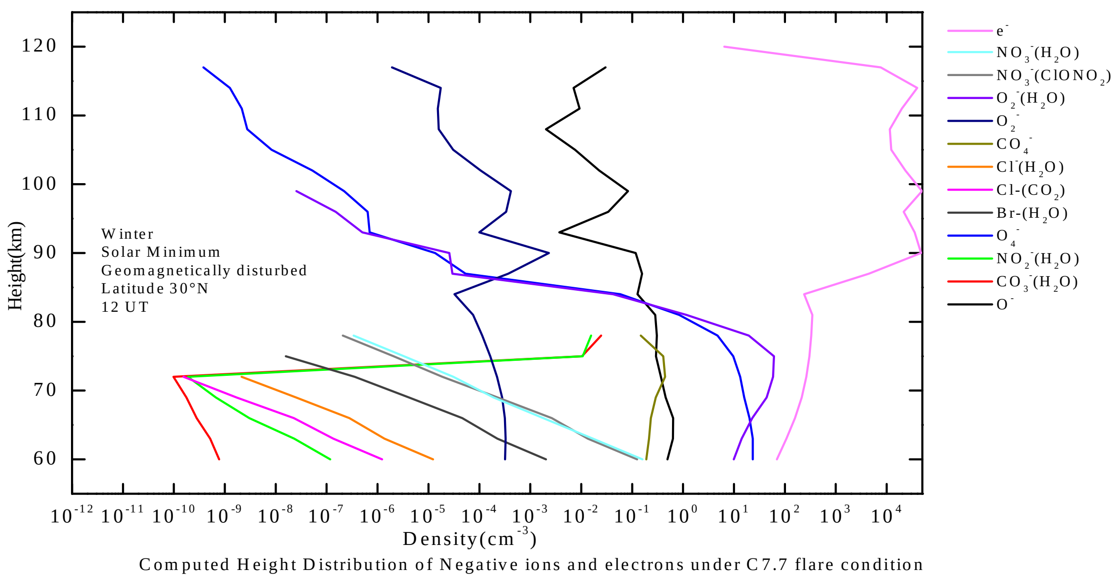
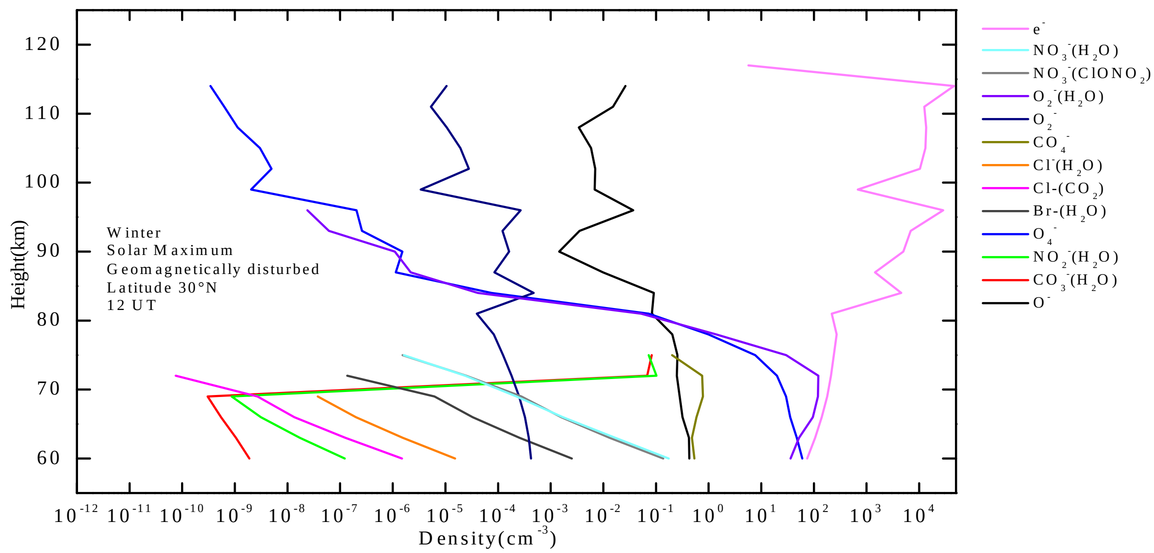
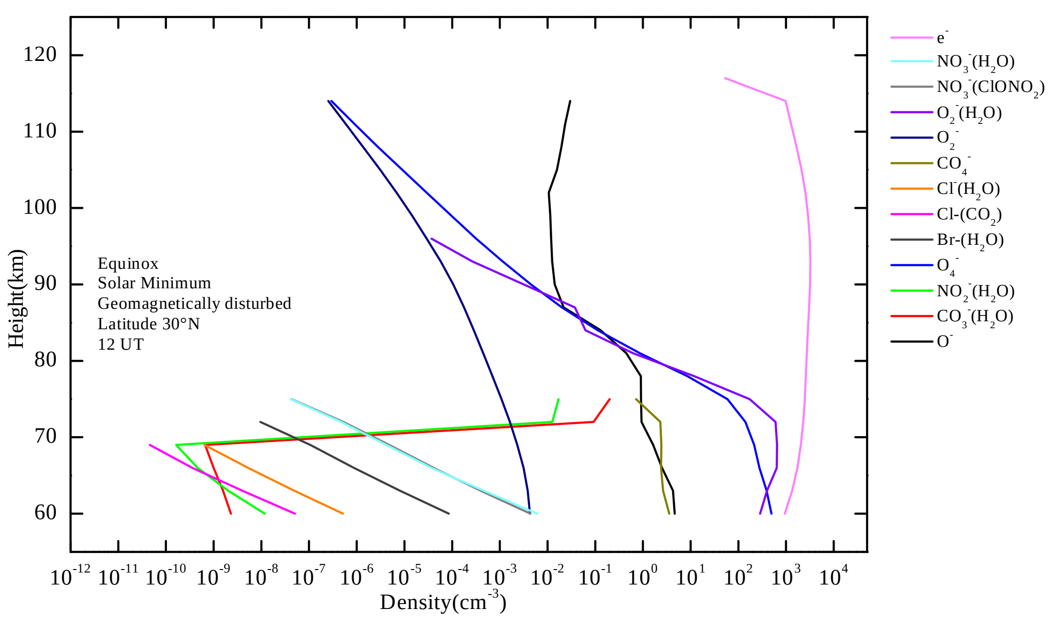


Fig. 6 -Computed Negative ions and Electrons height profiles for winter in Solar Minimum and Geomagnetically disturbed



Computed Height Distribution of Negative ions and electrons under C 7.7 flare condition

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



Computed Height Distribution of Negative ions and electrons under M5.4 flare condition

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

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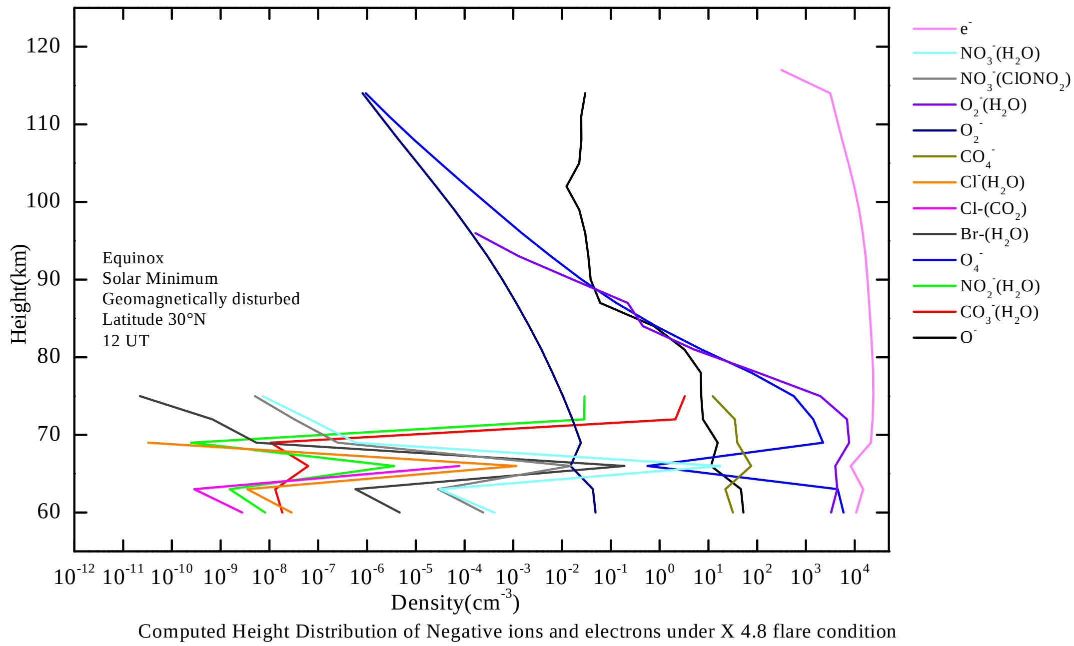


Fig. 9 -Computed Negative ions and Electrons height profiles for Eqinox in Solar Minimum and Geomagnetically disturbed

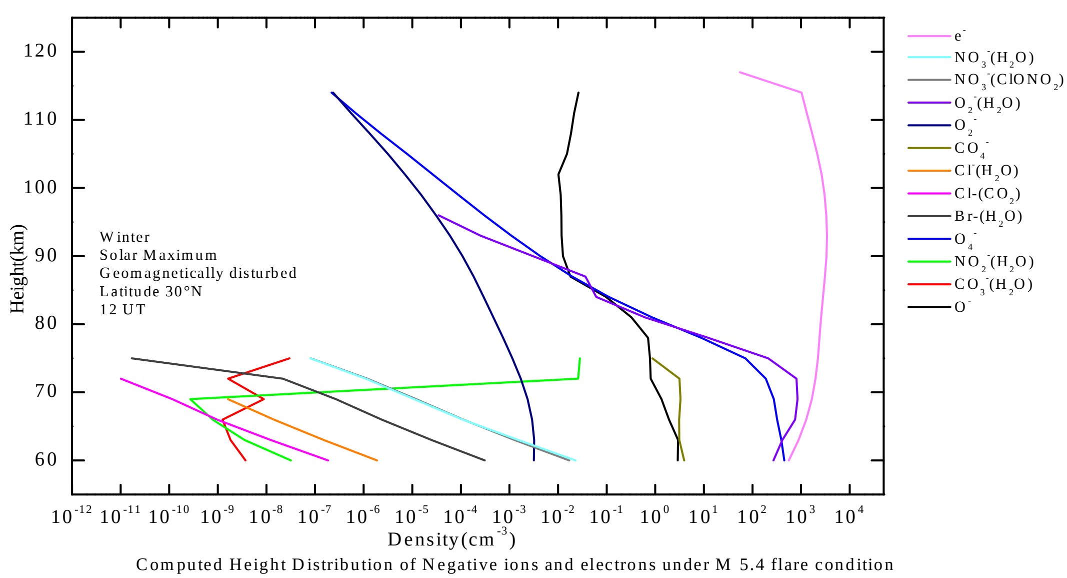
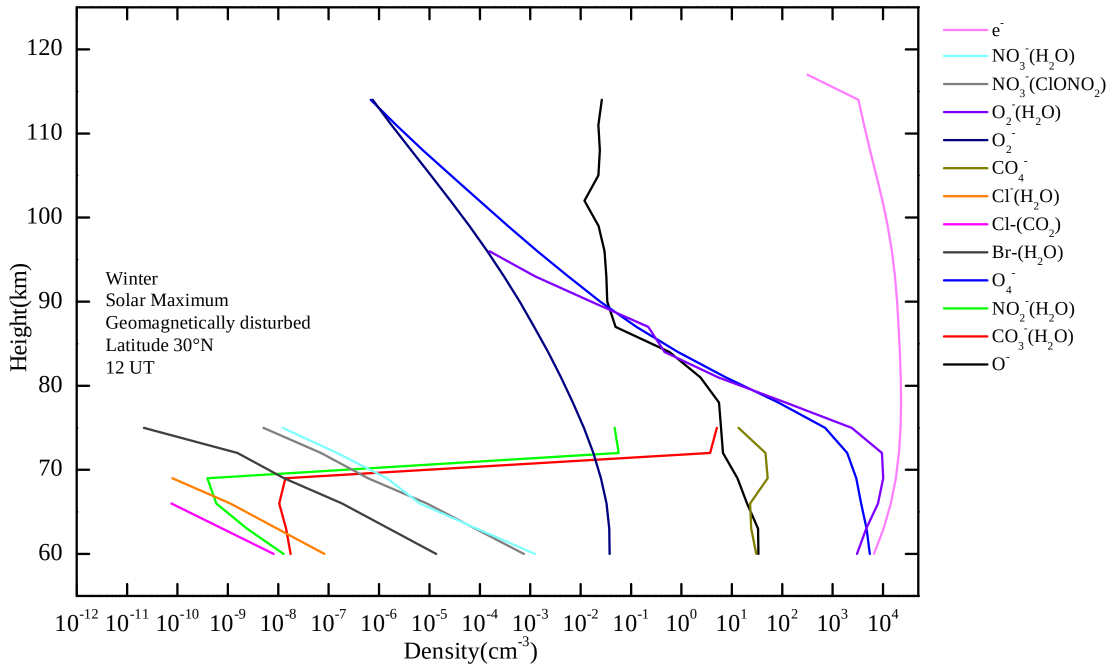


Fig. 10-Computed Negative ions and Electrons height profiles for winter in Solar Maximum and Geomagnetically disturbed



Computed Height Distribution of Negative ions and electrons under X 4.8 flare condition

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