A NEW EMPIRICAL MODEL OF ION COMPOSITION IN THE OUTER IONOSPHERE
AND ITS COMPARISON WITH AVAILABLE SATELLITE DATA

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ABSTRACT

A new global empirical model of relative ion composition for the O\(^+\), H\(^+\), He\(^+\), and N\(^+\) ions in the altitude range of 500 to 2500 km was proposed using the ACTIVE mission data for solar maximum and the Atmospheric Explorers data for solar minimum. Relative ion density obeying first order influences has been approximated at fixed altitude ranges by a system of associated Legendre polynomials. To obtain vertical profiles, interpolation based on Booker formalism is employed. This model is compared with available mass spectrometers data measured onboard the mentioned and several other satellites.

INTRODUCTION

The current options of the IRI model of the topside ion composition, IRI standard and Danilov-Yaichnikov models, rely on small sets of satellite data from periods of minimum and medium solar activity (e.g. [1] and references therein). The period of high solar activity (maximum of the solar cycle 22) is covered by data measured by a mass spectrometer onboard Intercosmos 24 (IK24), the main satellite of the ACTIVE mission with perigee 500 km, apogee 2500 km, and inclination 83°. A new outer ionosphere ion composition model has been developed, further on quoted as TTS (Truhlík, Třísková, Šmilauer) model. This model consists of submodels for three altitude levels under low solar activity and for four altitude levels under high solar activity with the possibility of interpolation for a given altitude, day of year, and solar activity level. It deals with relative densities of four main plasma components (O\(^+\), H\(^+\), N\(^+\), and He\(^+\)) and represents a continuation and improvement of the two component model for solar maximum proposed in [2]. In the present study we also test this new model comparing its results both with the initial data that the model was calculated from and with other available satellite data.

PROPOSED MODEL

The whole model consists of submodels for individual altitude ranges and seasons. All available data was grouped for seasons (80 day periods centered on equinoxes and solstices to ensure coverage at all local times by orbital precession) and for altitude ranges:

IK24: 550 ± 80 km, 900 ± 100 km, 1500 ± 150 km, and 2250 ± 250 km
AE: 400 ± 50 km, 650 ± 80 km, and 1000 ± 150 km

Different model altitude ranges for solar maximum and minimum were chosen with respect to different thermal plasma distribution (characterized by scale height, upper transition height etc.) in dependence on solar activity conditions. Summer and winter data from corresponding hemispheres was coupled for solstices, and for equinoxes data from both hemispheres were put together and latitude symmetry was assumed.

Coordinate system

Magnetic local time (MLT) and modified latitude were chosen as the main coordinates. Longitudinal variation can be reduced to a second order effect if the latitudinal coordinate takes into account the real configuration of the geomagnetic field. A new coordinate (inv dip), introduced in [3], is used. Inv dip is close to the dip latitude (diplat) near the equator and gets closer to the invariant latitude (invl) at higher latitudes.
Analytical model

A system of associated Legendre polynomials up to the 6th order is employed to represent the data:

\[
\log_{10} \frac{N_i}{N_T} = \sum_{l=0}^{6} \left\{ a_l^0 P_l^0(\cos \theta) + \sum_{m=1}^{l} \left[ a_l^m \cos m\varphi + b_l^m \sin m\varphi \right] P_l^m(\cos \theta) \right\},
\]

where
- \( P_l^m \) = associated Legendre function
- \( \theta \) = invdip colatitude (0..\( \pi \)), \( \varphi \) = magnetic local time (0..2\( \pi \))
- \( N_i \) = O\(^+\), H\(^+\), He\(^+\) or N\(^+\) density,
- \( N_T \) = total ion density (\( \sum N_i \)).

Associated Legendre polynomials \( P_l^m \) were used without normalization factors. The coefficients \( a_l^m \) and \( b_l^m \) in (1) were calculated by a standard least squares fitting procedure. Before applying this fitting procedure, data (10\(^4\) - 10\(^5\) points for each data group) were binned on a MLT vs. invdip grid.

To calculate the relative ion density for a given day of year and a given solar activity level a linear (in this version) interpolation between submodels is used. To obtain vertical profiles, interpolation using Booker formalism [4] is employed. The model uses a simple procedure which guarantees normalization for 100%:

\[
n_i = \frac{n_i^*}{\sum_{i=1}^{4} n_i^*},
\]

where \( n_i^* \) = non normalized relative density of the i-th ion, \( n_i \) = normalized relative density of the ith ion.

MODEL RESULTS

Vertical profiles

Examples of the vertical profiles of relative ion density of the main outer ionosphere plasma components are presented in Figures 1 and 2. These profiles are obtained by interpolation between values taken from submodels for the basic altitude levels. Examples of profiles for equinox day and night at the equator and at lower mid-latitudes in periods of the solar maximum and minimum are shown. During the solar minimum the amount of He\(^+\) is systematically lower than that of H\(^+\) and the ratio of the He\(^+\) and H\(^+\) densities 1:9 as supposed in the current IRI model can be considered as very roughly valid. Figure 1 shows that at mid-latitudes below 1000 km during the day in the solar maximum there are systematically more He\(^+\).

Fig. 1. Examples of equinox daytime vertical profiles of the relative ion density distribution following from the model.
ions than H$^+$ ions. This fact has not been respected in the existing empirical models so far. While the H$^+$ and He$^+$ relative densities exhibit changes of several orders over the altitude range studied, the N$^+$ relative density remains of the order of units percent without regard to the season, daytime, or solar activity.

DATA COMPARISON

Figures 3 presents an example of measured and corresponding TTS model data. They show to what extent the TTS model reflects the initial experimental data.

![Figure 3](image)

Fig. 3. Equinox daytime density profiles of H$^+$, He$^+$, O$^+$, and N$^+$ as measured by ACTIVE (*high solar activity*) at 0°, 30°, and 45° invariant latitude in comparison with the model (**** experimental data, and --- model values). Bins: ±7.5° invariant latitude, ±2h magnetic local time, ±30 days. When measured and model data are identical, only model values are visible.
Figure 4 plots all available experimental data at a fixed altitude of 1400 km, their averaged values and error bars. Model values are presented only by averages in individual bins. Results for the TTS model, and for both options of the IRI95 model are shown.

Fig. 4. Equinox daytime (13h±2h) and nighttime (0h±2h) latitude density profiles of O+, H+, He+ and their comparison with the TTS model and IRI95 (----- ISIS 2 data, • averaged values with error bars; ——— TTS; ——— IRIS; ——— D-Y).

CONCLUSIONS

A new outer ionosphere ion composition model is presented. It deals with the relative densities of four main plasma components. A comparison with initial and other available satellite data is given. Corresponding results of current options in IRI 95 are also shown. As to the low and middle latitudes, the proposed TTS model correctly follows the initial data and agrees with other measured ion densities better than the models used so far.

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