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# Modeling the F2 topside and plasmasphere for IRI using IMAGE/RPI and ISIS data

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**Abstract**

Empirical models are an important tool for the study of the different geospace regions from Earth to Sun, providing the user with easy access to a synthesis of reliable measurements from ground and space for specific parameters and regions. This paper describes a new effort to develop a coherent model of the topside F2 layer and the plasmasphere with the goal to improve the representation of the topside electron density in the IRI model and to extend the IRI description into the plasmasphere. An α-Chapman function with a continuously varying scale height, dubbed a vary-Chap function, is used to describe the topside F2 vertical electron density profile $N(h)$ that seamlessly connects the ionosphere with the plasmasphere. The Chapman scale height $H(h)$ varies only slowly with height near hmF2 and increases rapidly at the $O^+$ to light–ion transition height. A hyperbolic tangent function suitably represents this variation. New plasmasphere density profile data from the IMAGE/RPI measurements and topside profiles from the ISIS topside sounders are used to construct a continuous profile from hmF2 to several $R_E$ altitude.


*Keywords:* Topside ionosphere; Plasmasphere; Profiles; Chapman function; IRI

## 1. Introduction

Comparisons with recently analyzed ionospheric topside sounder measurements from the ISIS satellites (Franklin and MacLean, 1969) and also with measured total electron content (TEC) data show shortcomings in the International Reference Ionosphere (IRI) representation of the topside electron density profile (Coisson et al., 2002; Triskova et al., 2002; Bilitza, 2004). Rawer et al. (1978) started the development of the IRI topside model based on the Bent et al. (1972) data compilation that divides the topside into three regions with different scale heights. Recent measurements from the radio plasma imager (RPI) on NASA's IMAGE satellite (Reinisch et al., 2000, 2001; Burch et al., 2001) offer the possibility of extending the topside profile into the plasmasphere. Based on the measured RPI profiles Huang et al. (2004) proposed an empirical plasmasphere model with plasma density profiles extending from several Earth radii ($R_E$) down to $h_0 = 3000$ km or lower. Given the well-tested IRI bottomside profile model (Bilitza, 2001), the task at hand is to construct a new topside profile model from hmF2 to $h_0$ that smoothly connects the topside profile to the plasmasphere model. This paper studies the feasibility of new techniques for the development of such a model.

### 1.1. Profile data and models

The Bent et al. (1972) topside model was based on some 40,000 topside profiles obtained from Alouette 1 ionograms. More topside profiles from the Alouette/ISIS ionograms became available in later years from worldwide manual scaling efforts. Recognizing the importance of the Alouette/ISIS ionograms NASA has, in the framework of its AISRP program, supported the digitization of a large volume of analog Alouette/ISIS ionograms and the subsequent inversion to electron density profiles using

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the newly developed TOPIST software (Huang et al., 2002; Bilitza et al., 2004). This new effort doubled the original number of topside profiles from 150,000 to about 300,000 profiles stimulating renewed efforts in studying and modeling the topside ionosphere (e.g., Marinov et al., 2004; Webb et al., 2006). The feasibility study reported in this paper uses a subset of the newly available ISIS 2 profiles to study the usefulness of describing the topside profile by a Chapman function with continuously varying scale height, called from here on a "vary-Chap" function.

The RPI instrument on IMAGE uses a radio sounding technique that is similar to the Alouette/ISIS topside sounders, but its frequency range is adjusted to the magnetospheric environment varying from 3 kHz to 3 MHz, corresponding to plasma densities from about $10^{-1}$ to $10^{5}$ cm$^{-3}$, and radar ranges up to several Earth radii. Similar to the classical ionograms, the RPI data are displayed as plasmagrams that show the echo amplitudes as function of frequency $f$ in kHz and virtual range $R'$ in Earth radii $R_E$ as illustrated in Fig. 1 ($R' = 1/2\ ct$, where $c$ is the free-space speed of light and $t$ the echo delay time). IMAGE has a highly elliptical orbit with a perigee of ~1000 km and an apogee altitude of 7.5 $R_E$. The insert in the upper left corner of Fig. 1 shows the location (square dot) of IMAGE at the time when RPI made the plasmagram measurement. The field lines of $L = 4$ are shown as black lines to serve as a reference indicating that in this example IMAGE was well inside the plasmasphere. The distinct echo traces for $f > 300$ kHz were used to calculate the electron density along the field line through the spacecraft. Reinisch et al. (2001) had shown that echoes propagating along the field line in the local and conjugate hemispheres to the points where the signal frequency is equal to the cutoff frequencies generate these discrete echo traces. Huang et al. (2004) have developed a profile inversion algorithm for the plasmagram traces that performs the integration along the curved propagation path, i.e., along the magnetic field where the gyrofrequency varies significantly along the path, unlike in the standard ionogram profile inversion (Huang

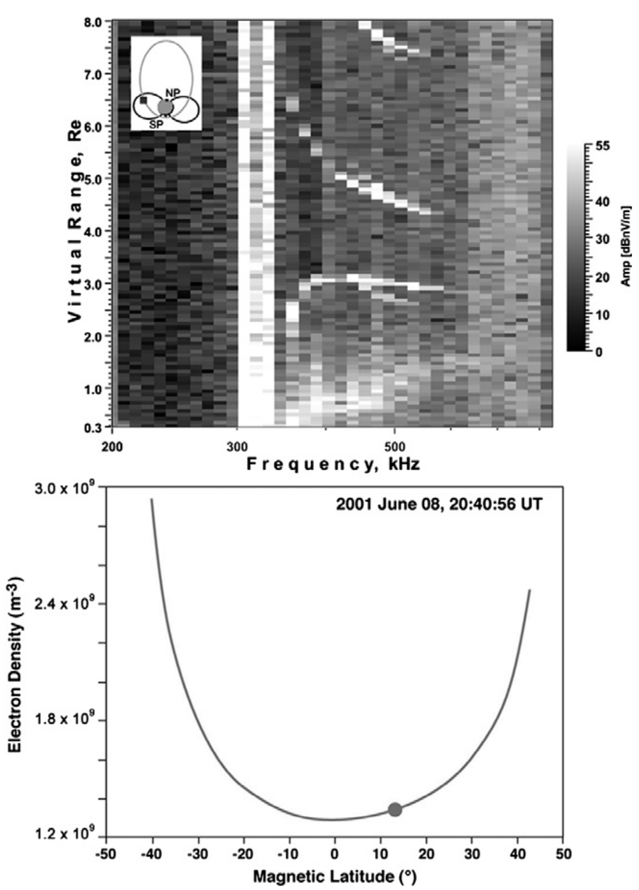


Fig. 1. RPI plasmagram (top) shows the echo amplitudes as a function of frequency (horizontal axis) and virtual range (vertical axis). The insert in the upper left shows the IMAGE orbit with the small square indicating the current IMAGE location. The density profile (bottom) along the field line through the spacecraft, derived from the discrete echo traces, is plotted against magnetic latitude. The dot indicates the latitude of IMAGE when the profile was measured.

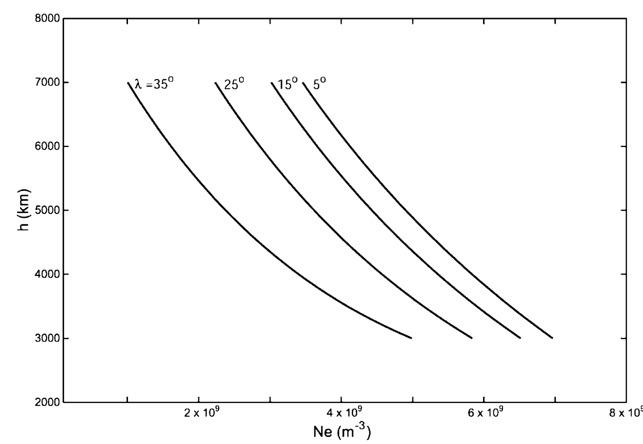


Fig. 2. $N(h)$ profiles for different magnetic latitudes derived from the RPI plasmasphere model ($A = 4.83 \times 10^9$ m$^{-3}$, $B = 3.64$, $C = 0.20$, $D = 0.03$, $\gamma = -0.14$, and $\alpha = 1.25$).

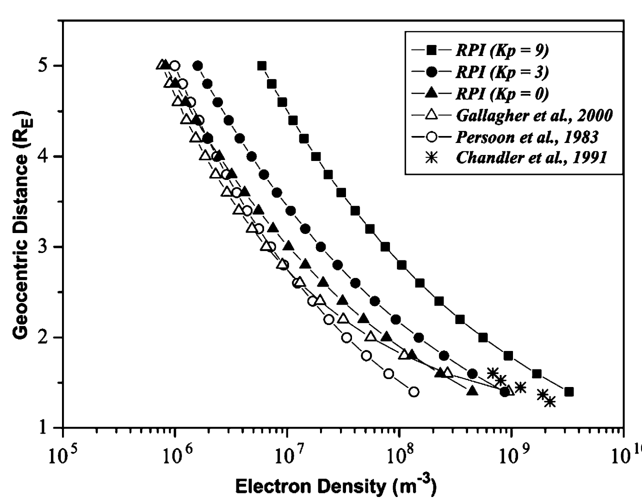


Fig. 3. Polar cap electron density models, $N_{RPI}(\mathrm{m}^{-3}) = 3.433.10^9\ (R/R_E)^{-5.09}\ e^{0.23\ \mathrm{kp}}$ (Nsumei et al., 2003) The RPI results show clear evidence of the dependence on magnetic activity. See above-mentioned references for further information.