Extending measured bottomside EDPs to the topside ionosphere and plasmasphere

Mohamed Osman[1], Bodo Reinisch[1,2], Ivan Galkin[1], Patrick Nsumei[1], Dieter Biltza[3]

[1] University of Massachusetts Lowell,

Lowell, MA 01854

USA

[2] Lowell Digisonde International (LDI),

Lowell, MA 01854

USA

[3]George Mason University

Fairfax, VA 22030

USA

Abstract

In the absence of operating topside ionospheric sounders, the task of providing measured topside electron density profiles (EDPs) in real-time is currently residing with the GNSS community deriving bottomside and topside EDPs from occultation measurements. EDPs measured with the ground-based global network of ionosondes are usually considered as "ground truth", and indeed they routinely measure the EDPs up to the peak of the F2 layer, but they cannot measure the topside profile. We have developed an extension of the measured bottomside profile to the topside by modeling the topside EDP as a Chapman function with a continually varying scale height, i.e., the Vary-Chap profile [Nsumei et al., 2012]. The normalized topside profile, Ne/NmF2, has been modeled using 80,000 measured ISIS-2 profiles. We have now started the verification & validation of these model profiles with profiles derived from GNSS occultation measurements in conjunction with COSMIC [Anthes et al., 2008] and GIRO Digisondes [Reinisch and Galkin, 2011]. For integration of the topside profile in the IRI electron density model [Bilitza et al., 2014], the topside profile model is expressed in terms of coefficients specifying the profile as a function of UT time, geographic longitude and latitude, and geomagnetic latitude, similar to the Jones-Gallet [1962] expansions for the foF2 mapping.

Currently the IRI-based Real Time Assimilating Model [Galkin et al., 2012] IRTAM provides real time specifications up to hmF2. Once validation of the Vary-Chap topside model is completed, IRTAM will specify the profile from the ground to the plasmasphere.

1. Introduction

Following the discovery of the ionosphere a century ago, scientists have developed remote sensing techniques to explore its structure [e.g., Evans, 1969; Rishbeth and Williams, 1985; Reinisch, 1986], and have attempted to develop models that represent the electron density distribution in the ionosphere. Unlike the bottomside ionosphere which has been well studied and modeled, topside ionosphere electron density profile measurements and models have remained a challenge. Empirical modeling of the topside ionosphere relies on the availability of good quality measured data that represent spatial and temporal variability with sufficient amount of data. The Alouette and ISIS satellite missions provided large amount of topside sounder data over more than an entire solar cycle, but large amount of these data were not processed into ionograms and were not processed into a digital form. An ongoing effort to convert Alouette and ISIS topside sounder data from the original analog telemetry tapes into digital ionograms is being in progress and increased amount of data is available now. This restoration project has provided data with a good coverage of relevant geophysical conditions (e.g., geographic location, diurnal, seasonal and solar activity).

2. Models and data

2.1. Vary-Chap model

The VaryChap profile used in the current paper to model the topside ionosphere is expressed by means of a shape function S(h):

$$\frac{N(h)}{N_m} = [S(h)]^{-1/2}\exp\left\{\frac{1}{2}[1 - Y - \exp(Y)]\right\};\ Y = \frac{1}{h_m}\int_{h_m}^{h}\frac{dh}{S(h)}. \qquad (1)$$

The shape function S(h) can be solved from (1) and expressed as

$$S(h) = \frac{X(1 - \ln X)}{\left[\frac{N(h)}{N_m}\right]^2} \qquad (2)$$

with

$$X(h) = 1 + \frac{1}{h_m}\int_{h_m}^{h}\left[\frac{N(h)}{N_m}\right]^2 dh. \qquad (3)$$

Equations (2) and (3) show that S(h) is uniquely specified by the measured profile N(h). Substituting $h = h_m$ in equations (2) and (3) gives $S(h_m) = 1$.

A parameterized representation S*(h) of S(h) that describes the measured S(h) function by analytical function containing three parameters: α, β and h_T has been used in this study to model the topside ionosphere electron density profiles. Fihure 1 shows an example of using S*(h) to construct a topside profile from a measured profile. It is simple to analytically integrate1/S*(h) to efficiently calculate the profile N(h) in (1):

$$\frac{1}{S^*(h)} = \frac{1}{S_1(h)} + \frac{1}{S_2(h)} \qquad (4)$$

$$\frac{1}{S^*(h)} = \frac{1}{c_1}\left[\operatorname{sech}^2\left(\frac{z-1}{\beta/h_m}\right)\right] + \frac{1}{c_2}\frac{z}{(1+z^2)^\alpha} \quad ; \quad z = \frac{h}{h_m} \quad ; \quad \alpha > 1, \qquad (5)$$

The parametrized function is governed by the following boundary conditions:

$$1 = \frac{1}{c_1} + \frac{1}{c_2\,(2)^\alpha} \qquad (6) \qquad\qquad \frac{1}{c_1}\left[\operatorname{sech}^2\left(\frac{z_T-1}{\beta/h_m}\right)\right] = \frac{1}{c_2}\frac{z_T}{(1+z_T^2)^\alpha}; \quad z_T = \frac{h_T}{h_m}. \qquad (7)$$

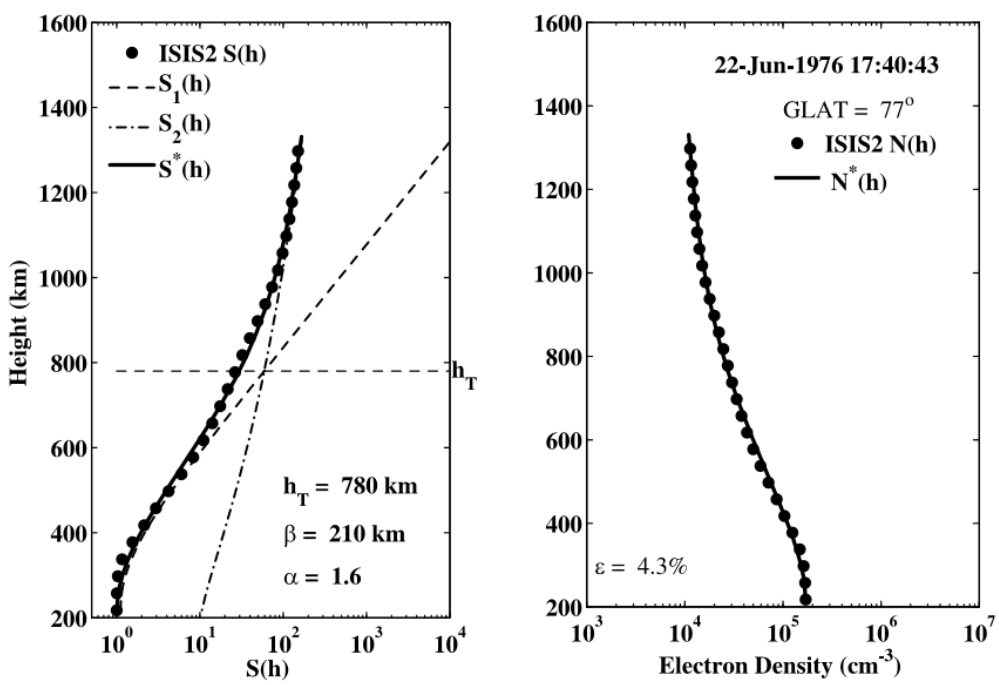

Figure 1. Vary-Chap construction for a high latitude profile (GLAT = 77°), 22 June 1976. (left) Parameterized shape function S_j*(h) (solid line) and its component functions S_{j1} and S_{j2} derived by fitting to S_j(h) (dots). (right) Parameterized Vary-Chap profile N_j*(h) (solid line) superposed on the measured profile N_j(h) (dots).

2.2. Topside Electron Density Profiles Data

The electron density profile data being processed in this study are obtained from NASA's online ftp archive at:

ftp://spdf.gsfc.nasa.gov/pub/data/alouette/topside_sounder/crc_ne_profile_ascii/
ftp://spdf.gsfc.nasa.gov/pub/data/isis/topside_sounder/crc_ne_profile_ascii/
ftp://spdf.gsfc.nasa.gov/pub/data/isis/topside_sounder/topist_ne_profile_ascii/

The data contain both manually scaled ISIS-2 ionograms using Jackson's profile inversion technique [Jackson, 1969; Jackson et al., 1980] and automatically scaled digitized ionograms [Huang et al., 2002; Bilitza et al., 2004; Benson, 2010].

For each profile the three parameters α, β and h_T were calculated. The following table illustrates the data collected from ISIS2 satellite between 1971 and 1983. It contains the data ordered by month, universal time (12 pins), latitude (46 pins), longitude (47 pins). For each profile the three parameters are calculated to represent the measured profile.

Table 1: ISIS2 profiles represented by three parameters: α, β and h_T

id_auto	number_of_observations	Year	Day	Month	Day_of_Month	Universal_Time	Local_Time	Geographic_Lat	Geographic_Long	Alpha	Beta	Transition_height
1	1	1975	25	1	25	0	13	0	25	1.1	340	1072
2	1	1975	25	1	25	0	9	1	17	1.1	230	909
3	1	1975	17	1	17	0	9	5	16	1.1	250	942
4	1	1975	7	1	7	0	10	5	18	1.1	240	793
5	1	1975	28	1	28	0	8	8	15	1.1	200	674
6	1	1982	10	1	10	0	18	9	32	3.1	110	757
7	1	1975	17	1	17	0	9	10	15	1.1	350	1113
8	1	1975	25	1	25	0	8	11	16	2.5	160	801
9	1	1975	17	1	17	0	9	12	15	2.1	320	1288
10	1	1975	25	1	25	0	8	13	16	2.1	170	686
11	2	1975	17	1	17	0	9	14	15	1.9	240	968
12	2	1975	17	1	17	0	9	14	15	1.1	210	921
13	1	1975	7	1	7	0	9	14	18	2.3	90	524
14	1	1975	17	1	17	0	9	15	15	1.7	260	987
15	3	1975	17	1	17	0	9	16	16	1.5	190	870
16	3	1975	17	1	17	0	9	16	16	1.1	220	965
17	3	1975	17	1	17	0	9	16	16	1.9	120	557
18	2	1975	17	1	17	0	9	17	16	1.1	350	1005
19	2	1975	17	1	17	0	9	17	16	1.1	270	1125

For each geographic location, month and universal time the median values for α, β and h_T were calculated.

3. First results

We implemented the Vary-Chap function with the parametrized shape function S*(h) using the median values for α, β and h_T calculated for each geographic location, month and universal time for ISIS2 measured data. Figure 2 illustrate the difference between the vary-chap representation and the IRI model. Both topside profiles use the measured bottomside profile from Millstone Hill Digisonde station.

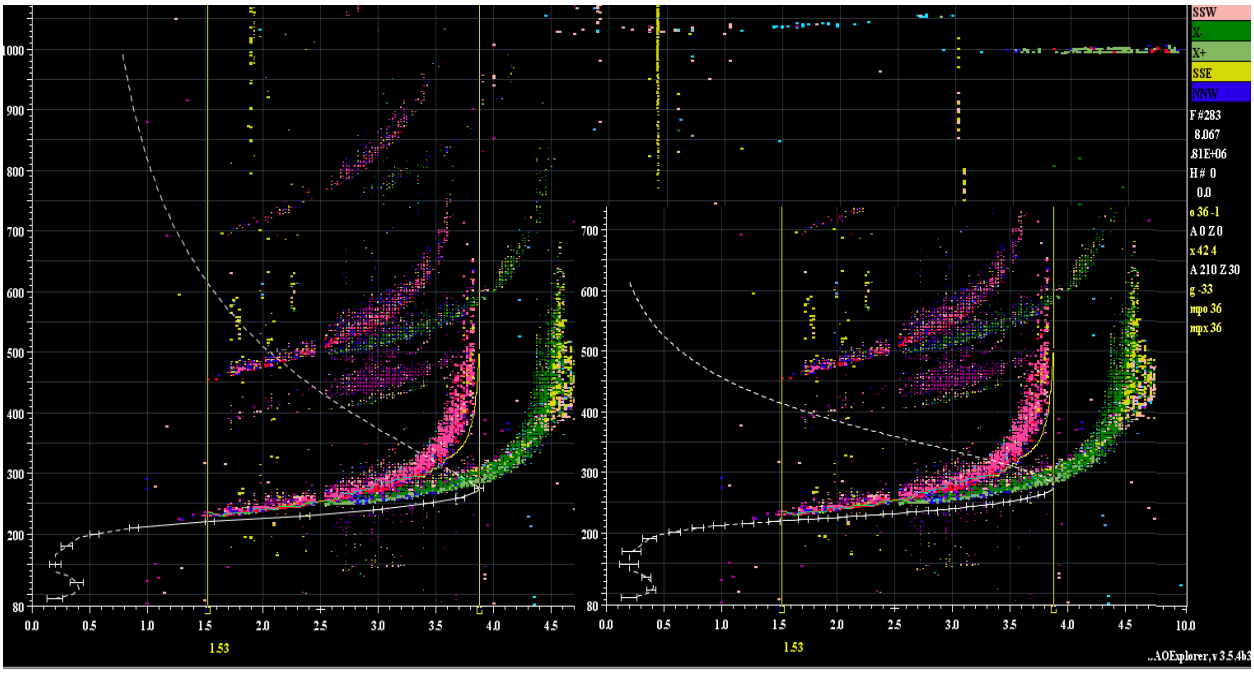

Figure 2. Vary-Chap profile representation for the topside profile (left) compared to Modeled IRI topside profile (right). The Vary-Chap representation shows significant increase in TEC comparing to IRI model. Millstone Hill on 10 February 2017.

Figure 3 illustrates ongoing effort to cover the world grid with smoothed representation for the three parameters α, β and h_T that represent the Vary-Chap function with the parametrized shape function S*(h). The figure illustrate the median values for h_T for January at 2:00UT using the median values obtained from ISIS2 measurements.

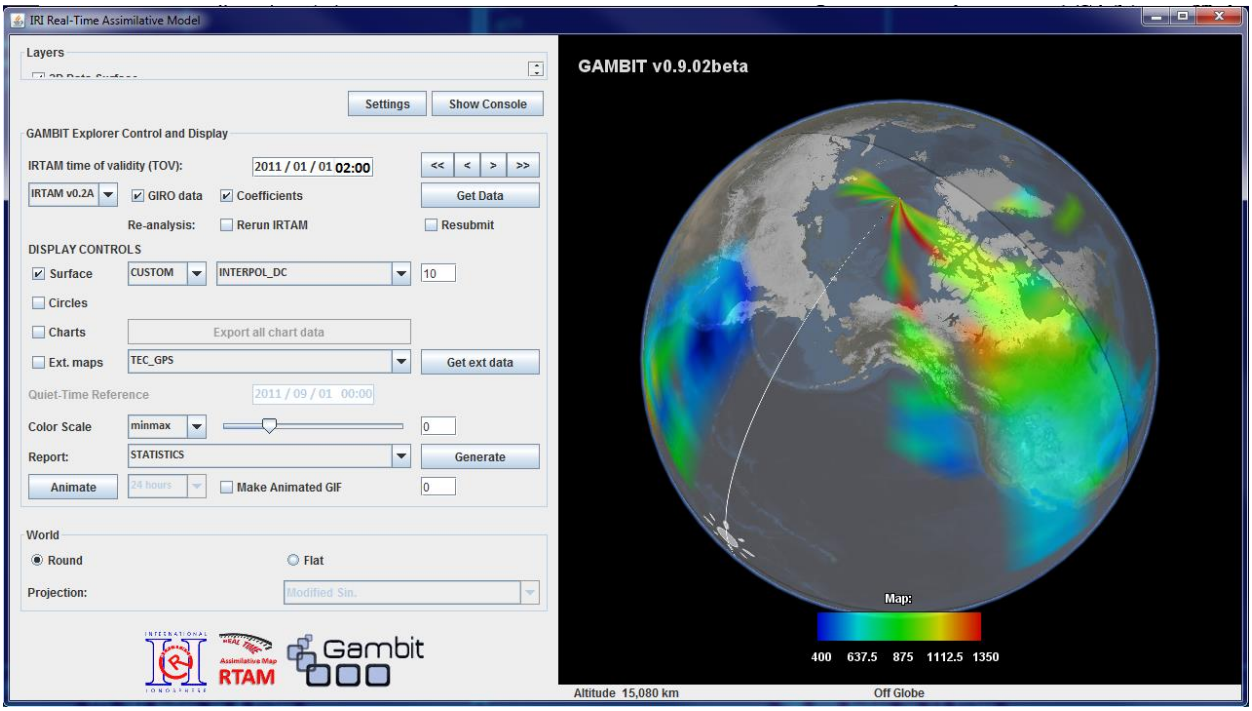

Figure 3: ongoing effort to fill the worldwide grid with smoothed median values for the Vary-Chap function Transition Height parameter. The map shows little coverage since the work of retrieving the profiles from ISIS2 repositories is currently in progress.

4. Conclusions

A Vary-Chap function representing the electron density profile for the topside ionosphere using a parametrized shape function S*(h) is implemented in this study. A global coverage for median values for three parameters α, β and h_T that describe the shape function S*(h) and topside profile N*(h) is being obtained for each geographic location, month and universal time based on Alouette and ISIS measured data. The Vary-Chap representation with the parameterized shape function S*(h) resulted in significant increase in the Total Electron Content (TEC) for the topside ionosphere compared to IRI model.

5. Acknowledgements

We thank NASA's SPDF for providing Alouette-1, Alouette-2, ISIS-1 and ISIS-2 topside sounder data.

6. References

R. A. Anthes, P. A. Bernhardt, Y. Chen, L. Cucurull, K. F. Dymond, et al. (2008), The COSMIC/ FORMOSAT-3 mission: Early results," in Bull. Amer. Meteorol. Soc. (BAMS), vol. 89, pp. 313–333. , doi: 10.1175/BAMS-89-3-313.

Benson, R. F. (2010), Four decades of space-borne radio sounding, Radio Sci. Bull., 333, 24

Bilitza, D., X. Huang, B. W. Reinisch, R. F. Benson, H. K. Hills, and W. B. Schar (2004), Topside ionogram scaler with true height algorithm

Bilitza D., D. Altadill, Y. Zhang, C. Mertens, V. Truhlik, P. Richards, L.-A. McKinnell, and B. Reinisch: The International Reference Ionosphere 2012 – a model of international collaboration. J. Space Weather Space Climate, 4, A07, 1-12, doi:10.1051/swsc/2014004, 2014.

Huang, X., B. W. Reinisch, D. Bilitza, and R. F. Benson (2002), Electron density profiles of the topside ionosphere, Ann. Geofis., 45, 125–130.

Evans, J. V. (1969), Theory and practice of ionosphere study by Thompson scatter radar, Proc. IEEE, 57, 496–530, doi:10.1109/PROC.1969.7005.

Jackson, J. E. (1969), The reduction of topside ionograms to electron density profiles, Proc. IEEE, 57, 960–976, doi:10.1109/PROC.1969.7140.

Jones, W. and R. Gallet (1962), Representation of Diurnal and Geographic Variations of Ionospheric Data by Numerical Methods, *J. Res., NBS 66D*, No. 4, 419-438.

Galkin, I. A., B. W. Reinisch, X. Huang, and D. Bilitza (2012), Assimilation of GIRO Data into a Real-Time IRI, *Radio Sci., 47,* RS0L07, doi:10.1029/2011RS004952.

Nsumei, P., B. W. Reinisch, X. Huang, and D. Bilitza (2012), New Vary-Chap profile of the topside ionosphere electron density distribution for use with the IRI model and the GIRO real time data, Radio Sci., 47, RS0L16, doi:10.1029/2012RS004989.

Reinisch, B. W. (1986), New techniques in ground-based ionospheric sounding and studies, Radio Sci., 21, 331–341, doi:10.1029/ RS021i003p00331.

Reinisch, B. W. and I. A. Galkin (2011), Global Ionospheric Radio Observatory (GIRO), *Earth Planets Space*, vol. 63 no. 4 pp. 377-381, doi:10.5047/eps.2011.03.001.

Rishbeth, H., and P. J. S. Williams (1985), The EISCAT ionospheric radar: The system and its early results, Q. J. R. Astron. Soc., 26, 478–512.