Topside Ionospheric Model Based On the Electron Density Profile Data of Cosmic Mission

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Abstract: The ionosphere is a name for the layer of the earth's atmosphere that is ionized by solar radiation. Since the ionosphere affects people's life in many aspects, studying and modelling of it is important in both sense of science and daily life. With the growth of data amount by different techniques, the models of ionosphere are becoming better, but the topside ionosphere model is less reliable due to little amount of data in that region. Since 1960s, the method of radio occultation has been adopted for studying planetary atmosphere, and later on, radio occultation between GPS satellites and LEO satellites is widely used for studying terrestrial atmosphere, including troposphere and ionosphere. COSMIC is one such project recently carried out. Besides great amount of tropospheric data, it also has provided ionosphere data that has great resolution in both space and time. Our work is using the second level global electron density profile data from the COSMIC project to study the characteristic of topside ionosphere. By analyzing the data statistically in both space and time dimensions, we made some modulation on the existing topside ionosphere theory model based on Chapman-type profile, and got some satisfying preliminary results.

Keywords: topside ionosphere, COSMIC, statistical analysis

1. Introduction

Developing an adequate model for the topside ionosphere has always been one of the central topics in ionospheric research. But with the limitation of the available electron density profile achieved from previous experiments, all the existing models are not well-established enough to describe the structure of the topside ionosphere. The COSMIC project, launched on April 14th, 2006, consists of six LEO satellites. During its working phase, atmospheric and ionospheric measurements are obtained with radio occultation method. After entering its final configuration, the COSMIC constellation have been providing more than 2000 electron density profiles every day with approximately global coverage. With its good distribution, the electron density profile data from COSMIC has provided a great opportunity to improve the topside ionospheric model. The objective of our work is to improve the topside ionospheric model with statistical methods using electron density profile data from COSMIC project. Daily and seasonal variations are taken into account in our analysis. A comparison between our new topside model and the International Reference Ionosphere 2007 (IRI2007) model shows there are several advantages in the new one.

2. Method

Since the electron density profile data from COSMIC project has the advantages of good coverage and huge quantity, we decided to include mainly statistical analysis in the treatment.

First, every profile is fitted into a Chapman type model:

$$N(h) = N_m\mathrm{F}_2 \exp[c(1 - Z - e^{-Z})]$$

$$Z = \frac{h - h_m\mathrm{F}_2}{h_0}$$

where $N(h)$ is the electron density varying with height h. $N_m\mathrm{F}_2$ and $h_m\mathrm{F}_2$ are the electron density and height of the F_2 maximum. c is a parameter which is usually assigned the value of 0.5 or 1. h_0 is the F_2 layer scale height .

Second, we used spherical harmonic analysis to obtain the mapping of parameter c and scale height h_0 with reference to local time and geological latitude:

$$c(\theta, LT) = \sum_{l=0}^{20}\sum_{m=-l}^{l} c_l^m Y_l^m(\theta, LT)$$

$$h_0(\theta, LT) = \sum_{l=0}^{20}\sum_{m=-l}^{l} h_{0l}^m Y_l^m(\theta, LT)$$

LT is the local time, and θ is the geological latitude. The spherical harmonic functions are defined as

$$Y_l^m(\theta, LT) = \sqrt{\frac{(2l+1)}{4\pi}\frac{(l-m)!}{(l+m)!}} P_l^m(\cos\theta)e^{imLT}$$

where $P_l^m(\cos\theta)$ are the associated Legendre functions.

Third, a comparison between our new model and the IRI2007 model was carried out. The topside Total Electron Content (TEC) derived from both models were compared with the real measurements from COSMIC project.

3. Database

The working orbits for COSMIC satellites are circular ones at the altitude of 700 to 800 kilometers with the inclination angle of 72 degrees. There are mainly three payloads onboard every tiny satellite: GPS Occultation Receiver (GOX), Tiny Ionospheric Photometer (TIP), and Tri-Band Beacon (TBB). Radio occultation technique is adopted in the experiment in which the L1 and L2 GPS phase measurements collected by the GPS antenna onboard the COSMIC satellites are inversed to get the total electron content (TEC) along the line between the COSMIC satellite and the GPS satellite. Further on, the TEC measurements are turned into electron density profile data under the assumption of spherical symmetry and straight-line propagation (Schreiner et al., 1999).

In order of taking into account seasonal variations, we used the electron density profile data from the 36th day in year 2007 to the 35th day in year 2008. The database was divided into four seasons of 91-days each, centering on the corresponding solstice/equinox day (Stankov et al., 2006).

4. Results

The fitting of the topside profile is carried out using least square method after N_mF_2 and h_mF_2 are decided. Figure 1 shows an example of an electron density profile,

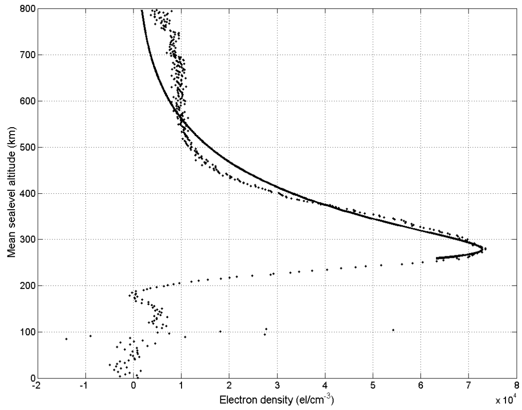

Figure 1. Example of an electron density profile before and after fitting

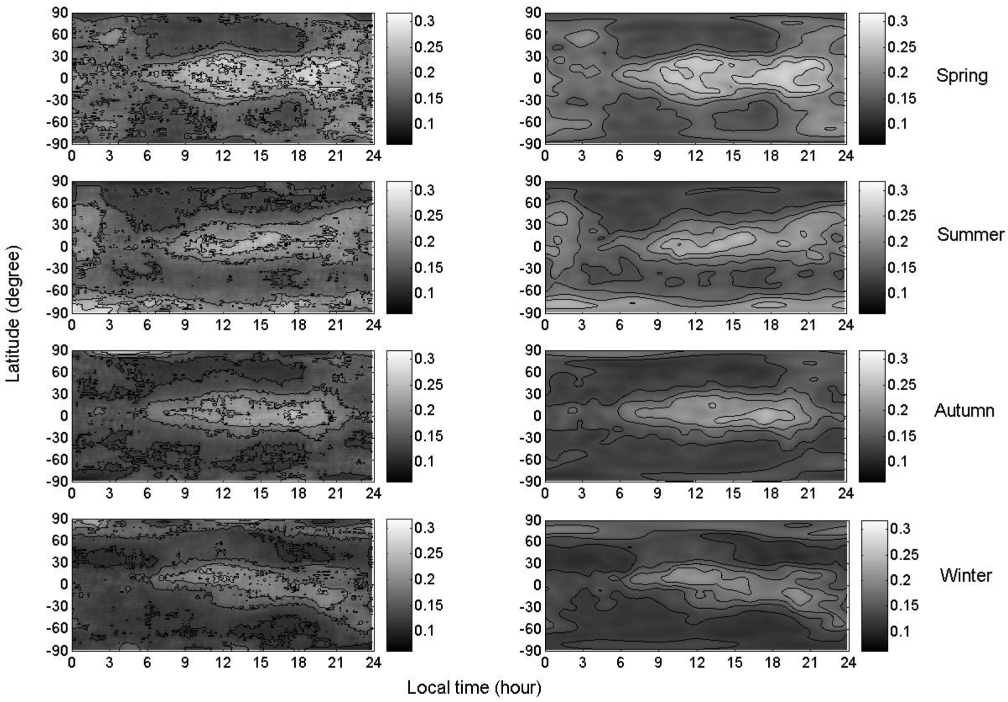

Figure 2. The global mapping of parameter c before and after spherical harmonic analysis

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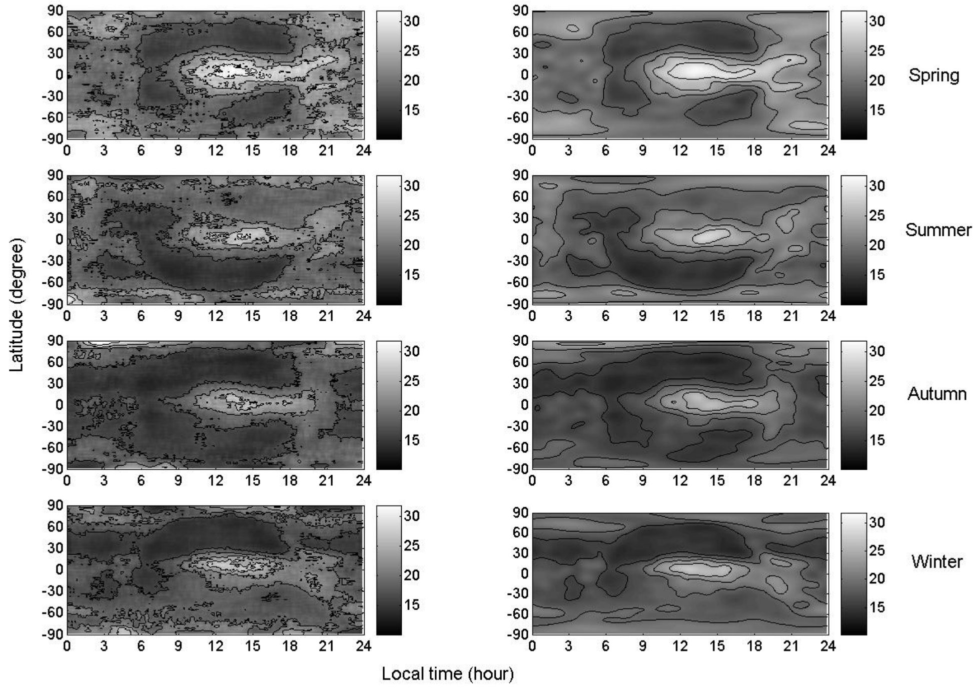

Figure 3. The global mapping of scale height h_0 before and after spherical harmonic analysis

where the dotted line is the original data while the solid line shows the fitting result. The position of the occultation point is defined as the mean value of the corresponding positions for every point in the profile.

Interpolation and extrapolation were done to acquire a global distribution of c and h_0 with the resolution of one degree for spherical harmonic analysis. Figure 2 and figure 3 show the global mapping of these two parameters before and after spherical harmonic analysis. Illustrations on the left side are before spherical harmonic analysis while on the fight side after.

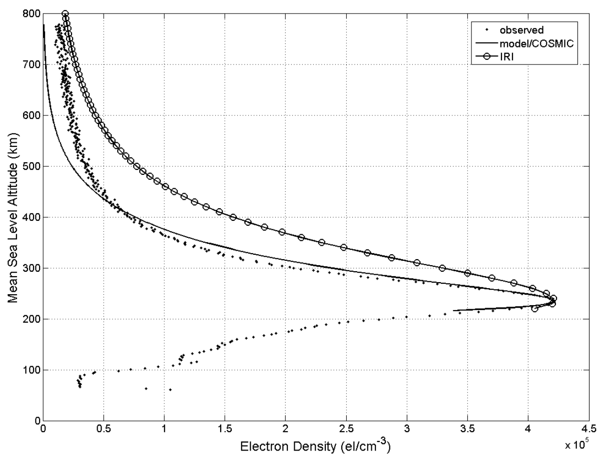

Figure 4. One example of comparison between our new model and IRI2007 model

Finally, comparison is done between our new model and the IRI2007 model. The same $N_m F_2$ and $h_m F_2$ are provided to two models for every profile. Figure 4 shows an example of comparison between two models.

Topside TEC was calculated both using IRI2007 model and our new topside model to compare with the measured value from COSMIC. Figure 5 shows the result for four seasons in year 2007. Illustrations on the left and right columns represent respectively for TEC data calculated by:

$(TEC_{\text{new model}} - TEC_{\text{COSMIC}}) / TEC_{\text{COSMIC}} \times 100\%$ and $(TEC_{\text{IRI2007}} - TEC_{\text{COSMIC}}) / TEC_{\text{COSMIC}} \times 100\%$

Note that the scales for left and right columns are different.

Another comparison is done to test the prediction ability of our new model. The parameters' mappings derived from the spring of year 2007 were used to predict the electron profiles in the spring of year 2008. Figure 6 shows the result. The upper illustration is the comparison between our new model and the COSMIC measurements in percentage while the lower one is between IRI2007 and the COSMIC measurements.

It could be seen that the difference between the new model and the COSMIC measurements is much smaller and has a smoother distribution than the IRI2007 model which is probably the benefit of statistical analysis.

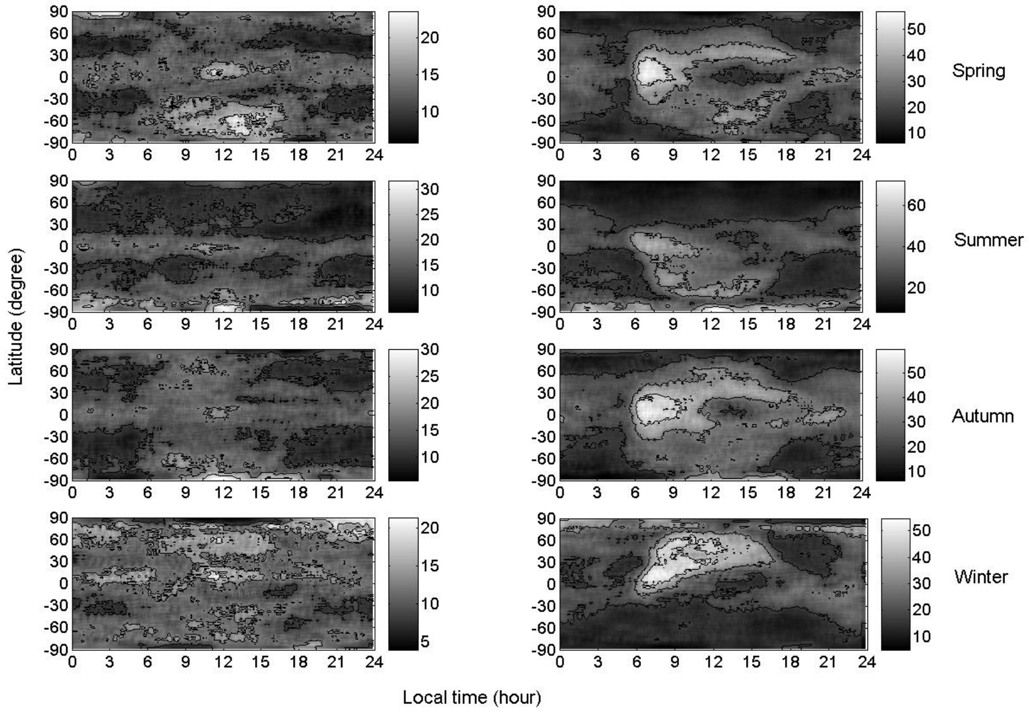

Figure 5. Comparison of topside TEC in year 2007 between our new model and IRI2007 model

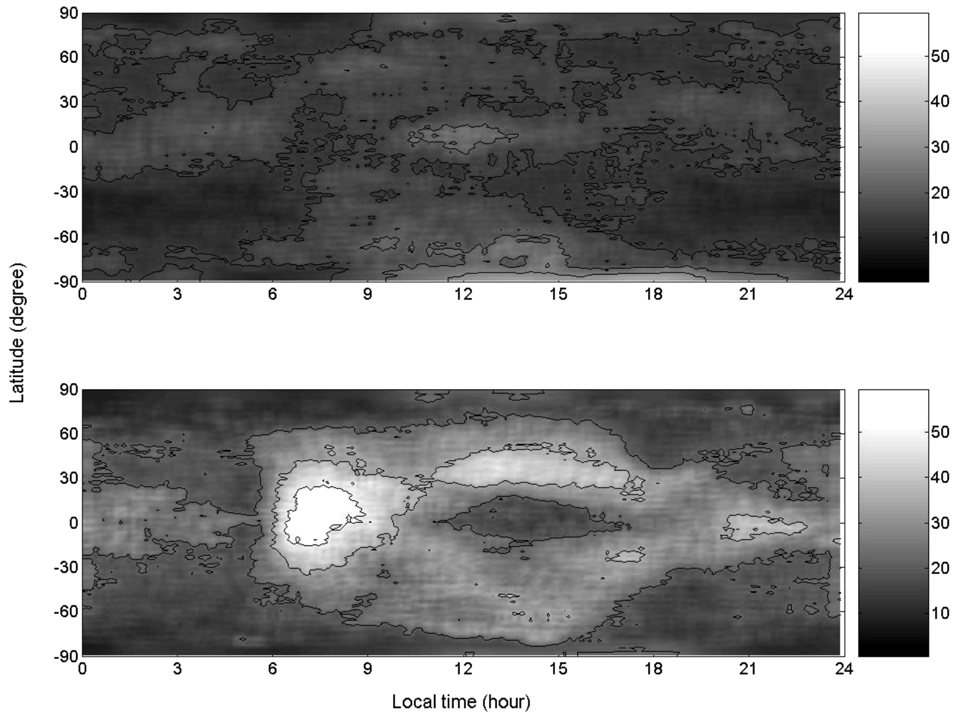

Figure 6. Comparison of topside TEC in year 2008 between our new model and IRI2007 model

5. Discussions

COSMIC project has been providing good ionospheric data both in quality and quantity. Considering of its fine global coverage, which is the most different from those data sets before COSMIC, we chose statistical analysis to improve the topside electron density profile model. The preliminary result has shown a quite satisfying perspective. For present and future, our work will include more detailed divisions in the data set for different conditions, and will verify the results using different data sources.

References

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