Variations of O+/H+ Transition Height over East Siberia from Joint Analysis of Irkutsk Incoherent Scatter Data and GPS Total Electron Content

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Abstract— In the paper we analyze the dynamics of O+/H+ transition height estimated on the base of Irkutsk ISR date and GPS TEC for different ionosphere conditions and compare these data with other models developed by using satellites topside sounder data.

1. INTRODUCTION

The topside ionosphere is the ionosphere area which placed above F2 ionization maximum. There is a significant scientific and practical interest for investigation of the topside ionosphere area both for practical cosmonautic and radio communication. There are, however, large difficulties of direct diagnostic of this area by using ground base and satellite instruments. Thus one has not enough knowledge about topside ionosphere. O+/H+ transition height (TH) is one of key parameters for all ionosphere models. TH is height where heavy ions O+ are changed by light ions H+ and He+. By theoretic predictions TH is 500–2500 km altitude according to geomagnetic latitude, day of year, time of day and geomagnetic and solar conditions. Therefore determination of real TH value is the actual problem nowadays and last ten years there are many papers about TH investigation.

The direct satellite measurements is the most accurate measurements of ion composition [5], but these measurements are restricted by satellites orbits and detail investigation of TH by direct methods is not possible. There are many techniques of calculating TH from topside sounder data (ISIS and Alouette program) which obtained for 60th and 80th years. However, there are serious differences of calculated TH values between different techniques, for example between Webb method [14] and Marinov method [4].

Another power instruments for sounding topside ionosphere are the incoherent scatter radars (ISR). Unfortunately the world network of ISR is restricted by about ten radars and not all of them are able to do measurements at heights above 1000 km. Actually only Arecibo ISR has possibility to carry out these measurements [2].

In most cases direct TH measurements are impossible on Irkutsk Incoherent Scatter Radar (IISR). Therefore we developed technique for indirect TH measurements by using IISR data and Global Positioning System (GPS) total electron content (TEC) data [7, 8]. IISR-GPS method is the name of this technique. We used TEC data from Global Ionospheric Map (GIM). IISR-GPS method based on the calculating difference between TEC GPS and ionosphere electron content obtained from Irkutsk ISR data. In addition to TH measurement indirect measurement of the plasmasphere electron content can be done by IISR-GPS method.

For determination of the topside ion composition we developed the topside ionosphere model. This model based on the determination of the electron density profile by the modified Chapmen layer. Using the Chapmen layer for approximation electron density profiles is widely accepted technique [9]. Our model takes into account that topside ionosphere plasma consist of three kinds of ions: O+, H+ and He+. Exponential distribution of each ion component is describes by the scale height. Difference between O+ scale height and H+ scale height is determined by mass-factor coefficient, which is $M = 16$ for pure H+ ions and decreases if He+ ions present.

In most cases the He+ concentration is negligible. However, sometimes there are moments when He+ concentration is rather high, for example, during high solar activity. The maximum of the He+ concentration is often observed at TH [2, 3]. Thus for considering of He+ concentration in our model we describe He+ profile by the Gaussian layer which maximum at the TH. Figure 1 presents ion densities profiles according to our topside ionosphere model.

As additional TEC data we used the data from Center of Determination Orbit in Europe (CODE). These data are one of the reliable TEC data for today [6]. For verification of represent ability CODE map data in IISR site we compared them with Irkutsk's GPS receiver and found good agreement [15].

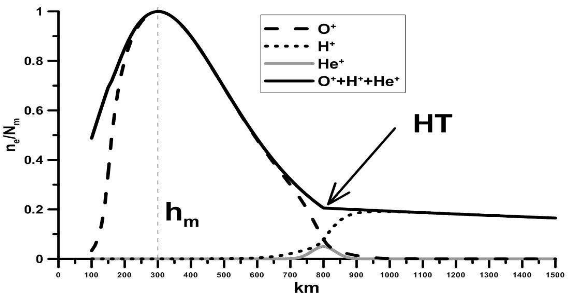

Figure 1: Ion composition profiles according to our topside ionosphere model.

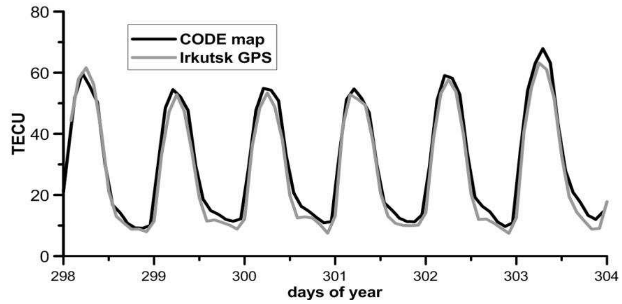

Figure 2: Comparison between TEC from Irkutsk GPS and CODE.

In this paper we present comparison between TH obtained from IISR-GPS method for Eastern Siberia region and TH obtained from theoretic empirical ionosphere model and TH direct satellite measurement.

2. EXPERIMENT

Comparison between CODE TEC and Irkutsk GPS receiver is presented on Figure 2. We can see that difference does not exceed 3 TECU. Errors 3 TECU corresponds to ∼80 km errors in TH calculating by IISR-GPS method. Maximal errors of CODE maps and Irkutsk GPS receiver are also about 3 TECU.

We calculate TH value by using IISR-GPS method for Eastern Siberia region for years 1998–2005. This is main part of 23rd solar cycle. Typical values TH for this period are 500–900 km for night time and 900–1200 km for day time. For verification of our results we compare these values with values obtained from ionosphere models and data of direct satellite measurements.

Nowadays there are many theoretical and empirical ionosphere models. Empirical models based on the topside sounder data: Danilov and Yaichnikov model (DY-85), Triscova Truhlik Smilauer model (TTS-03) [1, 12]. Sheffield University Ionosphere Plasmasphere Model (SUPIM), Field Line Intehemispheric Plasma model [11] (FLIP) and Tashilin model [10] are theoretical models which take into consideration movement ionosphere plasma along geomagnetic line. It should be noted that DY-85 and TTS-03 models are included as options into IRI-2012 model.

Values of TH from these models have essential divergences from each other. It is caused by different nature of models and it is suggested to be determined by influence of solar activity. The main harmonic of TH dynamics depends on solar radiation flux and duration of day. Seasonal variations are also governed by these factors. According to TTS-03 model difference between TH at high solar activity and during low solar activity can be as much as 200%. Therefore during low solar activity TH from DY-85 and TTS-03 has good agreement but it has bad agreement during high solar activity. On Figure 3 we present comparison of TH from IISR-GPS method, DY-85 and TTS-03 models. Top panel shows results for 1–3 October, 2002 and bottom panel shows results for 17–21 September, 2004.

Solar conditions for top panel and bottom panel on Figure 3 are different. For 1–3 October, 2002 index F10.7 is equal to 140, Ap index is equal to 150. For 17–21 September 2004 index F10.7 is equal to 100, Ap index is equal to 30. We can see from comparison of these data that TH calculated by IISR-GPS method for this period agrees with TH from DY-85 model. Daytime TH values from TTS-03 model greatly exceed IISR-GPS method values. Maximum of TH values from IISR-GPS method is shifted to evening from noon during 1–3 October 2002 (top panel Figure 3) and maximum is located in night hours (bottom panel Figure 3).

Daytime TH values from FLIP and Tashilin's models are about 2000–2500 km. We should note that comparing to model derived from theoretical estimations the transition heights calculated from the topside sounder data and data of radio occultation experiment (Formosat-3/COSMIC) always has lower values [13].

It is obvious that for estimation of actual TH values and for verifying of IISR-GPS method we need the direct satellite measurements of TH. Unfortunately, due to deficiency of this data only DMSP and CINDI/C/NOFS data can be used. But these data are fragmentary and verification of IISR-GPS method by this data is very problematic because orbital characteristics of these missions provide only morning and evening measurement. Irkutsk ISR can carry out direct measurements

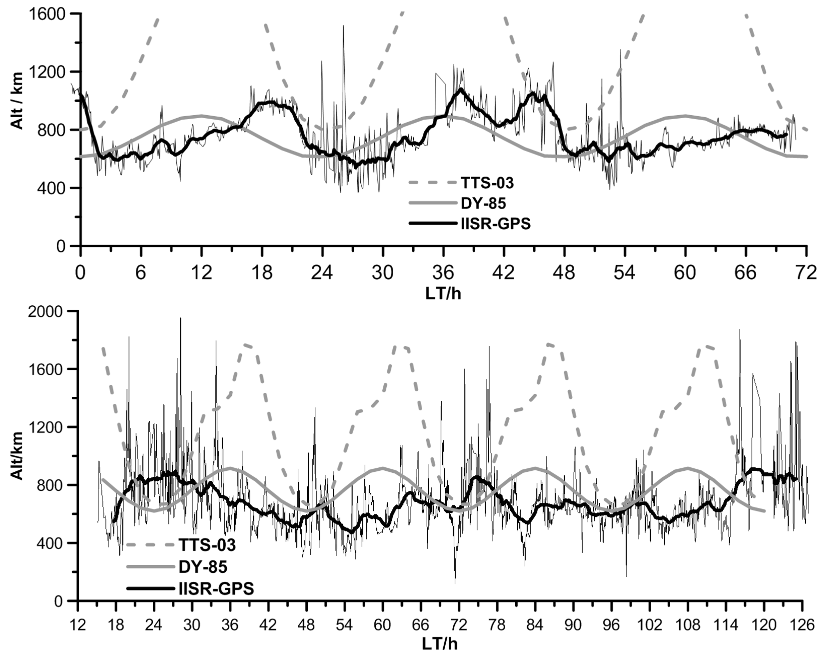

Figure 3: Comparison of transition height (TH) from IISR-GPS method, TTS-30 model and DY-85 model for 1–3 October 2002 (top panel) and 17–21 September 2004 (bottom panel).

of ion composition only below 700 km. In quiet solar conditions we can sometimes make direct TH measurements on IISR. This often can be realized in winter night. However, in many other cases we can measure the O+ distribution when it does not reach the transition height but decreases up to 60–70%. In these cases the ion distribution of topside ionosphere below 700 km can be used as additional data for estimation of transition height. Further we will plan to upgrade IISR-GPS method via coupling of this method with direct measurements of ion composition.

3. CONCLUSION

IISR-GPS method is perspective indirect method for estimate TH when direct measurements TH are not possible. Calculating of TH in the Eastern Siberia has been carried out for the first time. The problem of IISR-GPS method accuracy is under discussion.

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REFERENCES

1. Danilov, A. D. and A. P. Yaichnikov, "A new model of the ion composition at 75 to 1000 km for IRI," *Adv. Space Res.*, Vol. 5, No. 7, 75–79, 1985.
2. Gonzalez, S. A., M. P. Sulzer, and M. J. Nicolls, "Solar cycle variability of nighttime topside helium ion concentrations over Arecibo," *J. Geophys. Res.*, Vol. 109, A07302, 2004, doi:10.1029/2003JA010100.
3. Hysell, D. L., J. L. Chau, and J. D. Huba, "Topside measurementsa at Jicamarca during solar minimum," *Annals of Geophysics*, Vol. 27, 427–439, 2009.
4. Marinov, P., I. Kutiev, and S. Watanabe, "Empirical model of O^+-H^+ transition height based on topside sounder data," *Adv. Space Res.*, Vol. 34, 2021–2025, 2004.
5. Rich, F., "Technical description for the topside ionospheric plasma monitor (SSIES, SSIES-2 and SSIES-3) on space-craft of the defense meteorological satellite program (DMSP)," Technical Report PL-TR-9J-213, 69, Air Force Phillips Lab, Bedford, Massachusetts, 1994.
6. Schaer, S., "Mapping and predicting the Earth's ionosphere using the global positioning system," *Geod. Geophys. Arb. Schweiz. Inst. für Geod. und Photogramm*, Vol. 59, Zurich, Switzerland, 1999.

7. Shpynev, B. G., "Incoherent scatter Faraday rotation measurements on a radar with single linear polarization," *Radio Sci.*, Vol. 3, RS3001, 2004.
8. Shpynev, B. G. and D. S. Khabituev, "Estimation of the plasmasphere electron density and O^+/H^+ transition height from Irkutsk incoherent scatter data and GPS total electron content," *2014 JASTP*, 2014, Doi: 10.1016/j.jastp.2014.01.007.
9. Strangeways, H. J., I. Kutiev, L. R. Cander, S. Kouris, V. Gherm, D. Marin, B. De La Morena, S. E. Pryse, L. Perrone, M. Pietrella, S. Stankov, L. Tomasik, E. Tulunay, Y. Tulunay, N. Zernov, and B. Zolesi, "Near-earth space plasma modeling and forecasting," *Annals of Geophysics*, Vol. 52. Nos. 3–4, 2009.
10. Tashchilin, A. V. and E. B. Romanova, "Numerical modeling the high-latitude ionosphere," *Proceeding of COSPAR Colloquia Series*, Vol. 14, 315–325, 2002,
11. Torr, M. R., D. G. Torr, P. G. Richards, and S. P. Yung, "Mid- and low-latitude model of thermospheric emissions 1 O+(2P) 7320 A and N2(2P) 3371 A," *J. Geophys. Res.*, Vol. 95, 21147–21168, 1990.
12. Triscova, L., V. Truhlik, and J. Smilauer, "An empirical model of ion composition in the outer ionosphere," *Adv. Space Res.*, Vol. 31, No. 3, 653–663, 2003.
13. Truhlik, V., D. Bilitza, and L. Triscova, "Towards better description of solar activity variation in the international reference ionosphere topside ion composition model," *Adv. Space Res.*, 2014, Doi: 10.1016/j.asr.2014.07.033.
14. Webb, P. A. and E. A. Essex, "A dynamic diffusive equilibrium model of the ion densities along plasmaspheric magnetic flux tubes," *JASTP*, Vol. 63, 1249–1260, 2001.
15. Yasyukevich, Y. V., A. A. Mylnikova, and A. S. Polyakova, "Estimating the total electron content absolute value from the GPS/GLONASS data," *Results in Physics*, Vol. 5, 32–33, 2015.