2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Satellite model of *fo*F2 in the high-latitude winter ionosphere of the Northern and Southern hemispheres

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Abstract

The empirical *fo*F2 model in the high-latitude winter ionosphere of the Northern and Southern hemispheres was constructed. The data of the topside sounding onboard the Intercosmos-19 satellite, radio-occultation data and in-situ measurements onboard the CHAMP satellite were used. The new model covers the geographic latitudes interval of 40-85° and all hours of local time. It is valid for quiet conditions Kp = 2 and all levels of solar activity in the range *F*10.7 = 70-200. The model covers the period from November to February in the Northern hemisphere and from May to August in the Southern hemisphere. The new model reproduces for the first time the structure of the ionospheric trough, its position and shape. Therefore, it can be effectively used in the tasks of the radio waves propagation on high-latitude paths. The new model is much more accurate than IRI describes the longitudinal and latitudinal variations in *fo*F2 in the winter ionosphere. Its on-line version is available for use on the IZMIRAN website: http://www.izmiran.ru/ionosphere/sm-mit/.

1. Introduction

The most appropriate and therefore generally accepted model of the ionosphere until now is the IRI reference model [Bilitza et al., 2014]. However, it does not reproduce the structure of the ionospheric trough, which is the most important part of the ionosphere structure in the winter conditions [Karpachev et al., 2016]. The ionospheric trough determines the dynamics of the subauroral ionosphere and the conditions for the radio waves propagation on high-latitude paths. This paper describes the characteristics of the new empirical foF2 model in the winter ionosphere of both hemispheres, including the ionospheric trough.

2. Observation data

The model was constructed on the base of the Interkosmos-19 (IK-19) topside sounding data, CHAMP in-situ data and radio occultation data obtained in the COSMIC, GRACE and CHAMP experiments. The IK-19 operated from February 1979 to February 1982 for high solar activity *F*10.7~200. The CHAMP operated from July 2000 to September 2010. In this period, the index of solar activity *F*10.7 changed from 220 to 68. The CHAMP data are available on the site: http://isdc.gfz-potsdam.de/. The radio-occultation data were obtained from GPS receivers onboard CHAMP satellite, GRACE satellites (February 2007 – October 2010) and COSMIC constellation (January 2007 – December 2016) (http://cosmic-io.cosmic.ucar.edu/cdaac/index.html). The absolute *fo*F2 values were controlled by the IRI model, therefore the ground-based sounding data were in fact taken into account also. Fig.1 on the left shows examples of the observations of the night-time (22 LT) ionospheric trough according to the IK-19 data for high solar activity and daytime (12.6 LT) trough according to the CHAMP data for low solar activity.

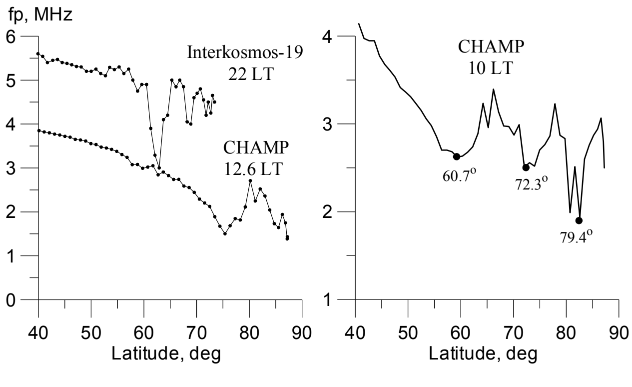

Figure 1. On the left: the ionospheric troughs, which were observed according to the IK-19 on February 28, 1980 at 13:15 UT, 22:00LT and the CHAMP on December 20, 2006 at 22:25 UT, 12:35 LT. On the right: there are three troughs identified according to the CHAMP on January 23, 2006 at ~ 19 UT in the morning (10 LT).

3. Ionospheric Trough Position Model

The model consists of two parts: the model of the ionospheric trough position and the model of the longitudinal and latitudinal variations in *fo*F2. The model of the ionospheric trough position was built according the IK-19 and CHAMP data for high solar activity (HSA) and low solar activity (LSA) in the Northern and Southern hemispheres. In the morning sector, several troughs are often observed as in Fig.1 on the right. This is the most difficult period for modeling.

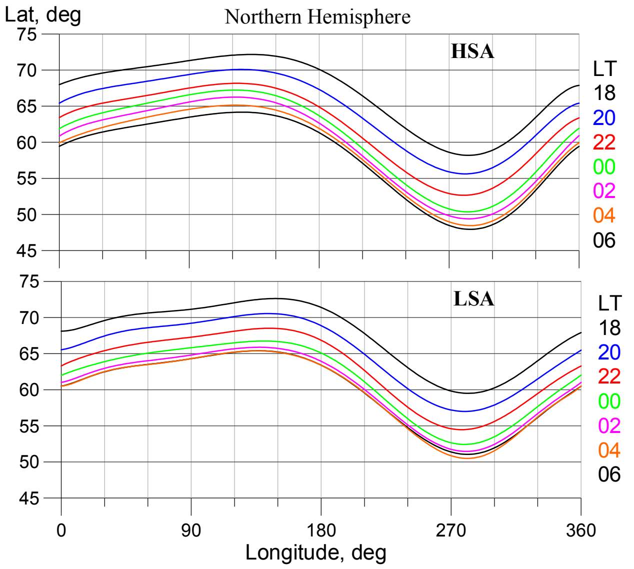

Figure 2. Longitudinal variations in the trough position in the Northern winter night-time ionosphere for HSA and LSA.

In Fig.2, for example, the longitudinal variations in the trough position in the Northern hemisphere for different LT hours are presented. They show the similar character for HSA and LSA, nevertheless one can see some difference. These variations in the day time hours have also the similar character but the trough is certainly located at higher latitudes. In Fig.3, for example, the longitudinal variations in the trough position in the Southern hemisphere for day time hours are shown. These variations differ for HSA and LSA stronger than in Fig.2. These variations for the night-time hours in the first approximation have similar character but the trough is certainly located at lower latitudes.

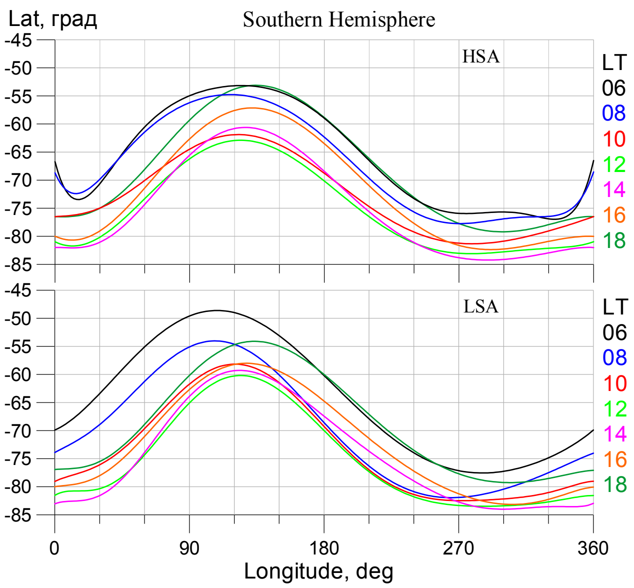

Figure 3. Longitudinal variation in the trough position in the Southern winter day time ionosphere for HSA and LSA.

4. Longitudinal Variations in *fo*F2

The longitudinal variations in *fo*F2 were determined according to the IK-19 for HSA and to the CHAMP for LSA. Absolute *fo*F2 values for LSA were controlled by the IRI model and by the radio-occultation data. In Fig.4, the longitudinal variations in *fo*F2 for LSA at latitude of 40° in the Northern hemisphere are presented for example. They have a similar character night and day, and in the transitional hours 08LT and 16LT they anticorrelate. The amplitude of the longitudinal effect is ~1 MHz, which is ~ 30% in night conditions.

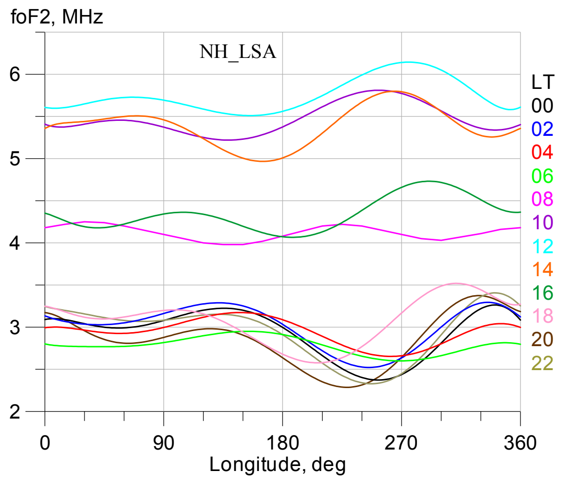

Figure 4. Longitudinal variations in *fo*F2 for LSA at latitude of 40° in the Northern hemisphere for different LT.

In Fig.5, for example, the longitudinal variations in *fo*F2 at latitude of -40° of the Southern hemisphere for HSA are shown. The longitudinal effect under these conditions varies greatly in shape during the day, and its amplitude reaches ~3 MHz, which is ~ 70% in night conditions. The reasons for the strong longitudinal variations in *fo*F2 are considered in [Klimenko et al., 2016].

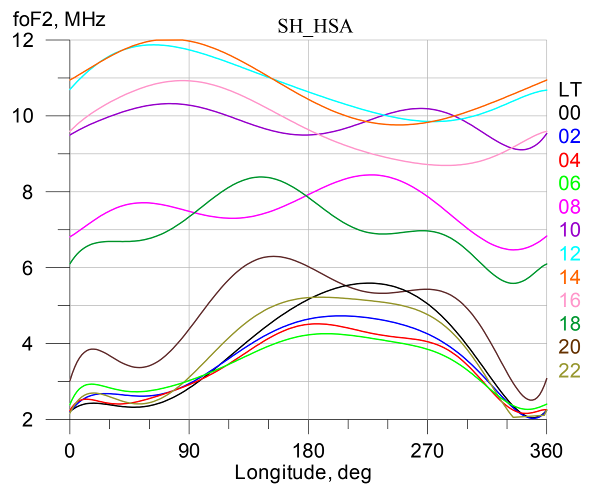

Figure 5. Longitudinal variations in *fo*F2 for LSA at latitude of 40° in the Northern hemisphere.

5. Latitudinal Variations in *fo*F2

The latitudinal variations in *fo*F2 at the minimum of the trough and on its polar wall were determined by a rather complicated technique according to IK-19, CHAMP, and radio-occultation data. The exact position of the trough minimum was determined from the model presented above. Compare the latitudinal variations in *fo*F2 obtained in the new model with the initial CHAMP and radio-occultation data, and also with the IRI model. Fig.6 shows, for example, the latitudinal variations in *fo*F2 for 00 LT, LSA at longitudes of 0° and 300° in the Northern hemisphere. The CHAMP data and radio-occultation data actually determined the structure of the trough in its minimum and on the polar wall. The IRI model does not reproduce the structure of the trough for these conditions in general, even at longitudes of Europe, where there are many ground stations. Note that the radio-occultation data generally agree with absolute *fo*F2 values obtained from other data sets at mid-latitudes, but can strongly diverge at high latitudes.

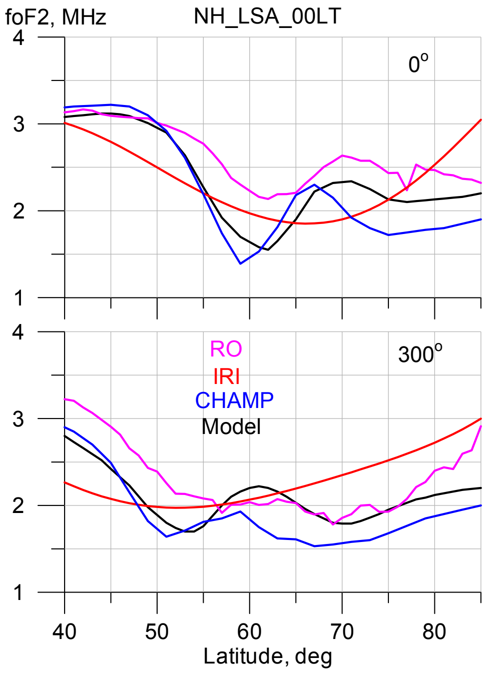

Figure 6. Latitudinal variations in *fo*F2 for 00 LT, LSA at longitudes of 0° и 300° in the Northern hemisphere according to model (black), CHAMP data (blue), radio-occultation data (madgenta) and IRI-2016 model (red).

Fig.7 shows, for example, the latitudinal variations in *fo*F2 for 12LT, HSA at longitudes of 0° and 270° in the Northern hemisphere. In the daytime over Europe the IRI model as a rule coincides with the new model, but a shallow trough certainly does not reproduce. The most strongly IRI differs from the new model at longitudes of the Pacific and for some reason over America, where there are many stations. The CHAMP and radio-occultation data help to restore the *fo*F2 latitudinal profile in the minimum of the trough.

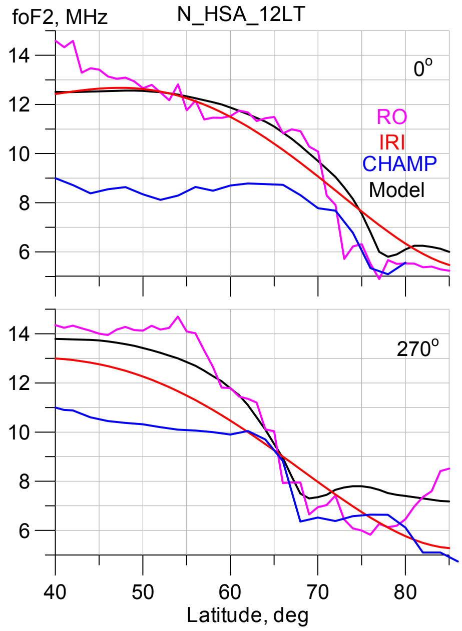

Figure 7. The same as in Fig.6 but for 12LT, HSA at longitudes of 0° and 270°.

Fig.8 shows, for example, the latitudinal variations in *fo*F2 for 00LT, LSA in the longitudinal sectors of 60° and 300° in the Southern hemisphere. At longitude of 300°, the radio-occultation data reproduce well the structure of the trough. At longitude of 60°, the structure of high latitudes is generally reproduced, but values of the radio-occultation data are higher. The IRI model again does not reproduce the structure of high latitudes. The difference between new model and IRI especially large at night and over the oceans.

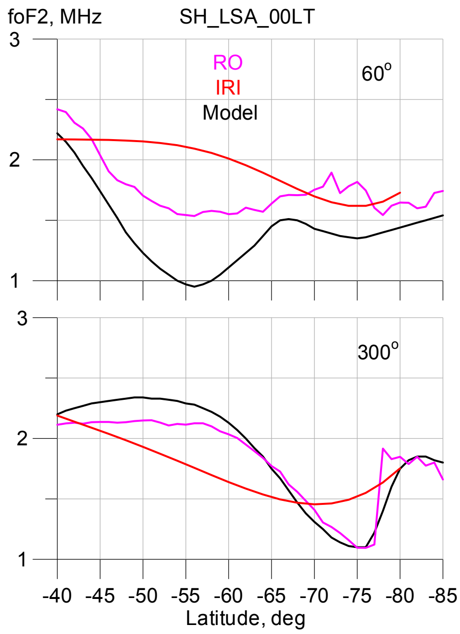

Figure 8. The same as in Fig.6 but for 00LT, HSA at longitudes of 60° and 300°.

6. Global *fo*F2 distribution

Fig.9 shows, for example, the *fo*F2 distribution in the Northern hemisphere for midnight winter conditions at high solar activity and for noon conditions at low activity. The comparison both maps shows that the ionospheric trough is much more pronounced at night, even at high solar activity.

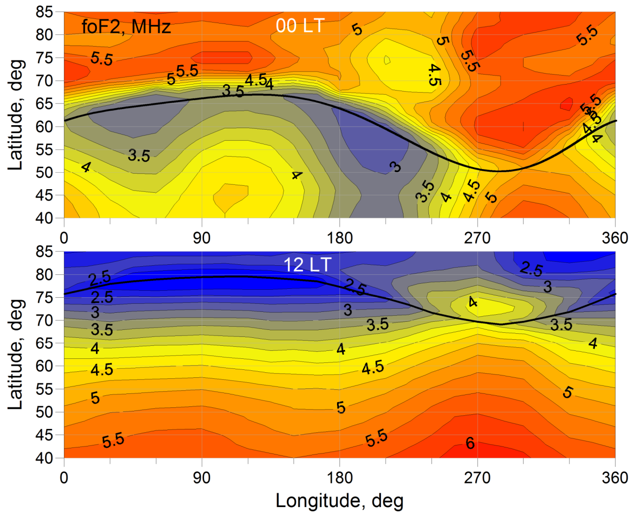

Figure 9. Distribution of *fo*F2 in the Northern hemisphere for HSA, 00LT (top) and for LSA, 12LT (bottom). Black thick line shows the through minimum position.

Fig.10 shows the *fo*F2 distribution for the same conditions as in Fig. 9 but in the Southern hemisphere. The trough is more pronounced than in the Northern hemisphere and occupies a much larger interval of latitudes. Therefore the trough dynamics will determine the high-latitude ionosphere variations. In both hemispheres at high solar activity, the polar wall of the night trough is more pronounced than the equatorial wall.

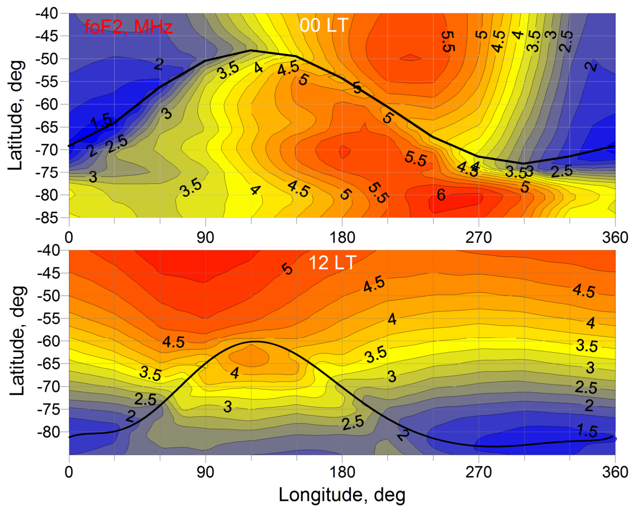

Figure 10. Distribution of *fo*F2 in the Southern hemisphere for HSA, 00LT (top) and for LSA, 12LT (bottom).

7. Conclusion

A new empirical *fo*F2 model has been created in the winter ionosphere of the Northern and Southern hemispheres. For its construction, all available ionospheric data were in fact used. Consequently, there are, generally speaking, no independent data to test it. Moreover, the data of the ground-based sounding are highly inaccurate at high-latitudes due to strong spread F. The radio-occultation data generally agree with absolute *fo*F2 values obtained from other data sets at mid-latitudes, but can also strongly diverge at high latitudes. The new model describes for the first time the structure of the ionospheric trough. Therefore, the model can be effectively used in the radio propagation problems. The new model reproduces the structure of the high-latitude ionosphere more accurately than the IRI model, especially in the night conditions, when the inaccuracy of ground-based sounding data, which underlies IRI, greatly increases. The model is available on the IZMIRAN website: http://www.izmiran.ru/ionosphere/sm-mit/.

8. Acknowledgements

The authors are grateful to sponsors and operators of the FORMOSAT-3/COSMIC mission; Taiwan's National Science Council and National Space Organization (NSPO), the US National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA) and the University Corporation for Atmospheric Research (UCAR). The authors would like to give thanks to sponsors and operators of the CHAMP and GRACE missions; Deutsches GeoForschungs Zentrum (GFZ) Potsdam, German Aerospace Center (DLR), and the US National Aeronautics and Space Administration (NASA).

9. References

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