Sub-auroral longitudinal anomalies in ionosphere-protonosphere system according to GSM TIP model and IK-19 satellite and ground-based observation

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Summary

We studied the morphology of sub-auroral summer longitudinal anomalies, which includes Weddell Sea Anomaly (WSA) and Yakutsk Anomaly (YA). For this purpose, we used both IK-19 satellite and ground-based ionosonde data and GSM TIP model results. We also present WSA and YA manifestation in protonosphere.

1. Introduction

According to the observations of mid-latitude ionospheric stations Halley Bay and Argentine Island located in the Southern Hemisphere the anomalous foF2 diurnal variation was found in the December-February, when the nighttime *foF*2 values exceed daytime *foF*2 [1]. Such anomalous ionospheric feature was named as the Weddell Sea Anomaly (WSA). It has been shown that the anomalous diurnal variations in electron density are observed only in a certain longitudinal region [2-5].

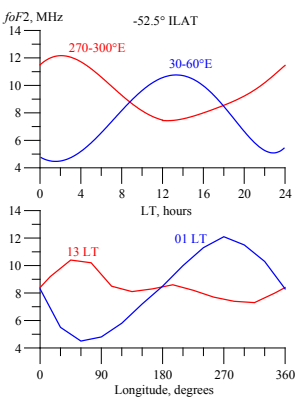

Figure 1. Diurnal variation in *foF*2 in different longitudinal sectors (top) and longitudinal variation in *foF*2 at 12:00 and 01:00 LT (bottom) at a latitude of 52.5°N according to IK-19 data.

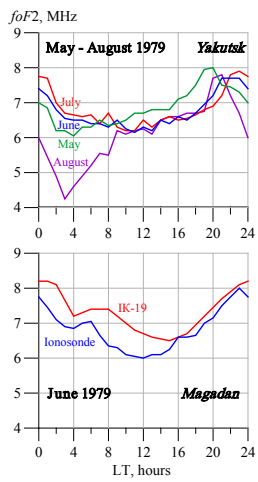

Figure 2. Diurnal variation in *foF*2 medians according to Yakutsk ionosonde data for the summer months in 1979 (top), Magadan and IK-19 ionosonde data on June 1979 (bottom).

Is there a similar anomaly in the Northern Hemisphere? In 1971, Mamrukov [6] firstly described the anomalous diurnal variations in *foF*2 at Yakutsk ionospheric station. This unusual effect in the Northern Hemisphere was named as Yakutsk Anomaly (YA). An attempt to highlight the area of Yakutsk anomaly has been made recently with used the data of radio occultation COSMIC experiment [3] and DMSP satellite data [4]. A better common nomenclature for the WSA and YA would be sub-auroral summer longitudinal anomalies that contradict to mid-latitude summer nighttime anomaly (MSNA) [7]. If Horvath and Lovell [4] made a rather unexpected conclusion that the YA is the usual phenomenon for the Northern Hemisphere, which has a different nature in comparison to the WSA, then Lin et al. [7] concluded that the MSNA, featured by a greater nighttime ionospheric electron density than during daytime, occurred in the mid-latitude regions in the Southern and Northern Hemispheres, is a general mid-latitude ionosphere phenomenon.

In order to verify the all the hypotheses on the sub-auroral summer longitudinal anomalies (YA and WSA) formation mechanisms it is necessary to perform the theoretical investigation with use of global self-consistent model of the thermosphere-ionosphere system. An attempt to such investigations has been made recently [8]. However, it should be noted that the model calculation results presented in this paper are not exactly reproduced the latitudinal range of MSNA. Objective of our studies is to describe the main morphological features of YA and WSA from the Intercosmos-19 satellite (IK-19) and ionosonde network data and reproduce these features using the Global Self-consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP) [9, 10]. These studies are the preliminary results that show the possibility of joint use of observation data and GSM TIP model for subsequent detailed study of MSNA.

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2. Observation data

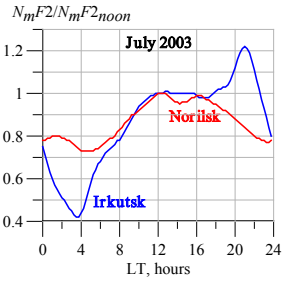

Figure 3. Normalized diurnal variations in 27-day median N_mF2 (i.e. N_mF2/N_mF2_{noon}) on July 22 for $F_{10.7}$ = 127 according to Irkutsk and Norilsk ionosonde data.

The use of satellite observation data allowed us to investigate the latitudinal and longitudinal extent of sub-auroral summer longitudinal anomalies. We analyzed the topside sounding data onboard the Intercosmos-19 (IK-19) satellite in the Summer Hemisphere. Karpachev et al.5 with use of IK-19 data have shown that WSA occupy a wide range in latitude and longitude. In the current investigation, we consider only location and spatial extent of sub-auroral summer longitudinal anomalies according to IK-19 satellite data for summer solstice months 1979 and 1980. These data correspond to high solar activity ($F_{10.7}$ = 170–230) and quiet geomagnetic conditions ($K_p \leq 3$). In addition, we have used the ionosonde observations over different stations. During the considered period, all ionosondes operated in the standard cycle mode.

3. Brief description of the GSM TIP

Our study presents the WSA and YA occurrence as simulated by the modified Global Self-Consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP) [9, 10]. Thermospheric and ionospheric parameters are calculated in the altitude range from 80 km up to 15 Earth's radii with 1–2-min temporal resolution and spatial resolution of 5° in latitude and of 15° in longitude. The Earth's magnetic field is approximated by the central dipole. The calculations were carried out for quiet solstice conditions on 22.06.1979 and 22.12.1979 during solar activity maximum ($F_{10.7}$ = 200).

4. Results

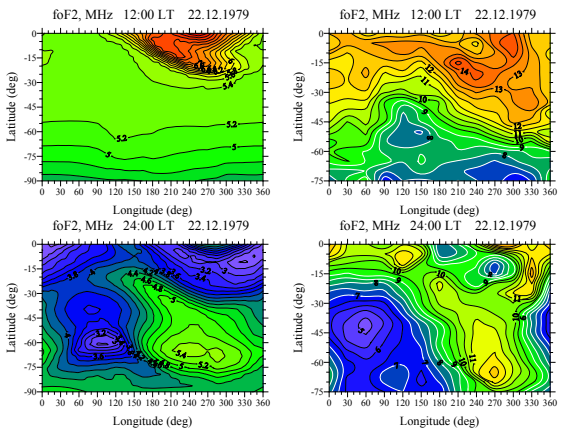

Figure 4. WSA: Global distribution of *foF*2 in the summer Southern Hemisphere according to the IK-19 data (right) and GSM TIP model results (left) for nighttime (00:00 LT) and daytime (12:00 LT).

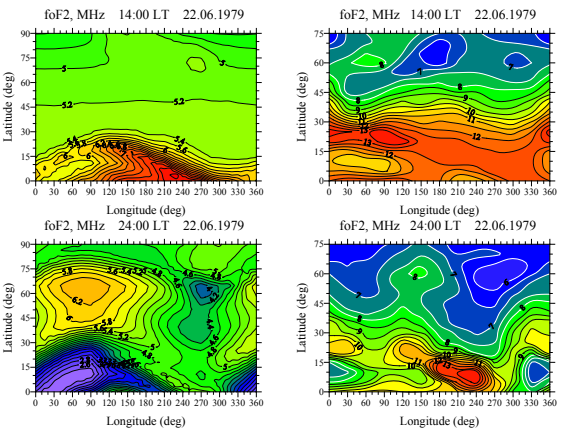

Figure 5. YA: Global distribution of *foF*2 in the summer Northern Hemisphere according to the IK-19 data (right) and GSM TIP model results (left) for nighttime (00:00 LT) and daytime (14:00 LT).

Figures 1–3 illustrates the existence of WSA and YA according to IK-19 and ground based ionosondes. Figures 4 and 5 present the nighttime and daytime *foF*2 global distribution in the summer Southern and Northern Hemisphere obtained from the IK-19 satellite data and GSM TIP model results. It is evident the occurrence of local maxima in nighttime *foF*2 at 65°S and 270°E (Fig. 4) and at 60°N and 90°E (model results) and 150°E (observation) (Fig. 5). At the same locations there are local minima in daytime *foF*2 distribution. At the certain region the nighttime *foF*2 values exceed the daytime ones, and this feature determines the WSA and YA occurrence. To distinguish the WSA and YA region, we calculated the difference between midnight and near-noon *foF*2 values. The regions of the positive difference are shown in Fig. 6 which demonstrates the WSA and YA occupations. The WSA and YA maxima are really seen near the Yakutsk and Weddell Sea locations. The IK-19 data show that the YA (1.5 MHz) is noticeably weaker then the WSA (4.5 MHz). From other hand we do not reveal essential distinctions between the WSA and YA from the GSM TIP simulations (the sub-auroral summer longitudinal anomalies maxima are about 0.5 MHz). This is explained by the fact that the Earth's magnetic field

in the GSM TIP model is approximated by a central dipole which does not enable to take into account the difference in distance between the geographic and geomagnetic pole for the Northern and Southern Hemispheres.

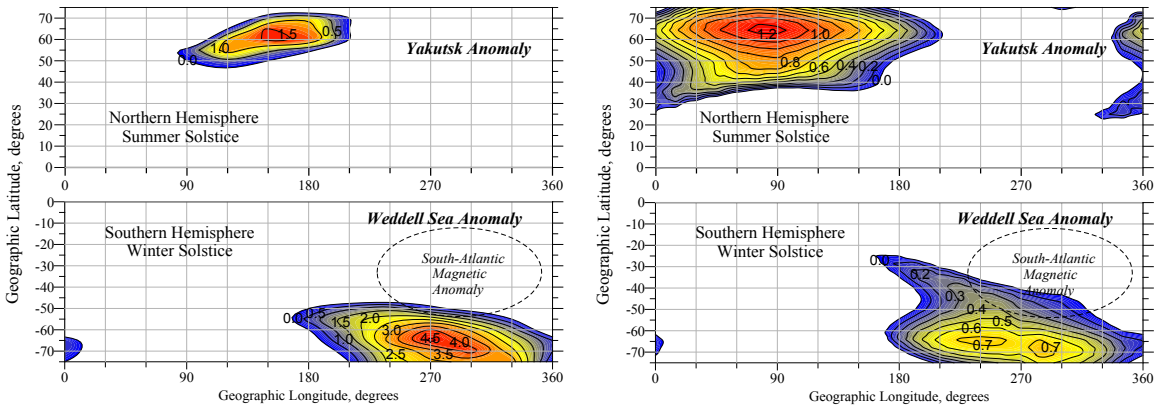

Figure 6. Distribution of positive difference between midnight and near-noon foF2 values showing WSA and YA regions. Left – IK-19 data, right – GSM TIP model results.

Finally, now the experimental plasmaspheric (protonospheric) electron content (PEC) can be estimated by comparison of GPS total electron content (TEC) observations and FORMOSAT-3/COSMIC radio occultation ionospheric electron content (IEC) measurements. Using GSM TIP model results we tried: (1) to predict the observed PEC longitudinal variations for 2009 winter and summer solstice; (2) to illustrate the WSA and YA manifestations in plasmaspheric (protonospheric) electron content. Figure 7 and 8 present the daytime (12:00 LT) and nighttime (24:00 LT) global maps of IEC, TEC and PEC for 22 December, 2009 and 22 June, 2009. It is evident the WSA and YA manifestation in all considered parameters: (1) the daytime minima of electron contents are formed at WSA and YA longitudes in local summer conditions; (2) the nighttime maxima of electron contents are formed at WSA and YA longitude in local summer conditions.

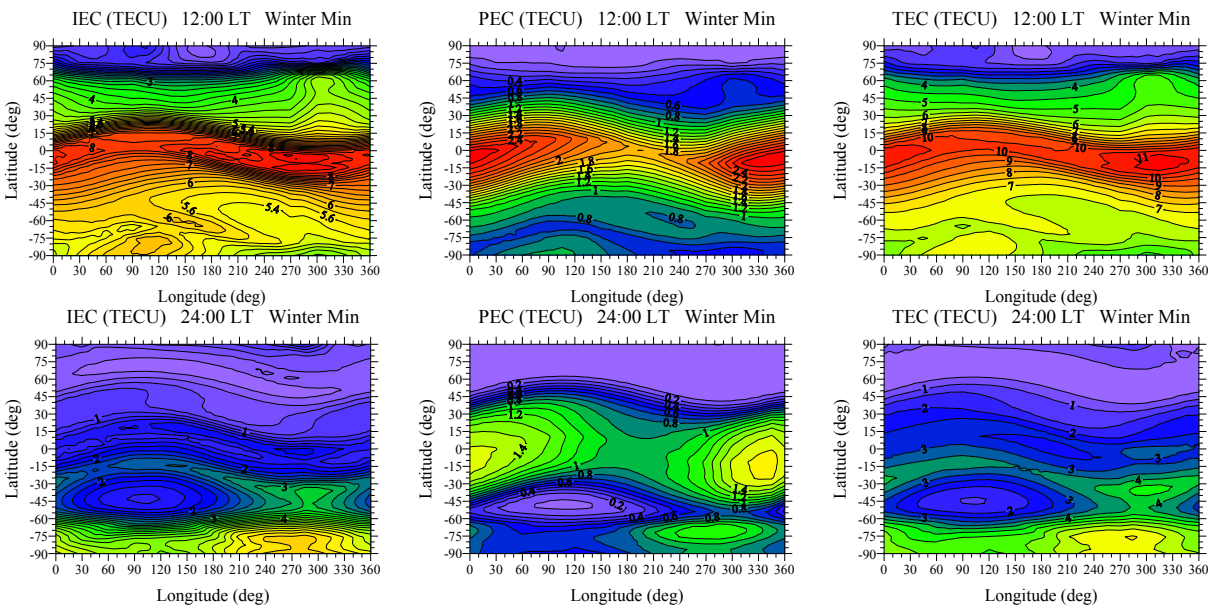

Figure 7. From left to right: ionospheric, plasmaspheric (protonospheric) and total electron content calculated in GSM TIP model for December 22, 2009 at 12:00 LT (top) and 24:00 LT (bottom).

5. Conclusion

We investigated the morphological features of the Weddell Sea and Yakutsk anomalies using the IK-19 satellite observations and ground-based ionosonde database. GSM TIP simulations qualitatively reproduced the IK-19 satellite observations. We can already note that the main morphological characteristics of the WSA and YA are similar that indicating the common nature of their occurrence.

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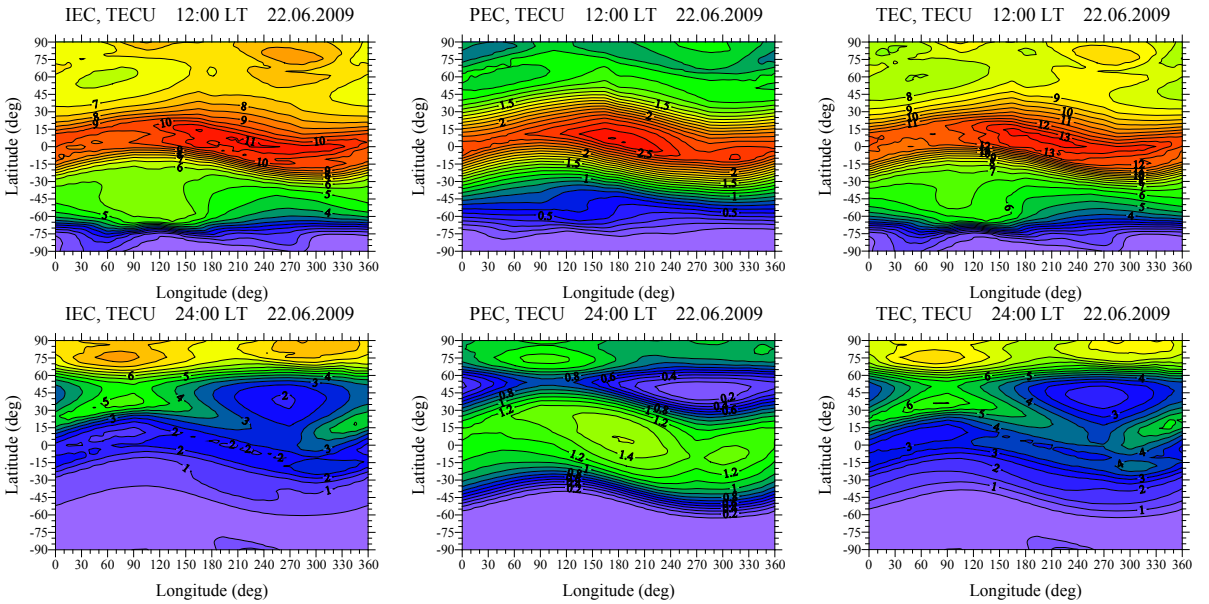

Figure 8. The same as Fig. 7 for June 22, 2009.

6. References

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