NUMERICAL MODELING OF THE WEDDELL SEA ANOMALY

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Abstract. The numerous observations showed that in summer the F2 peak electron density over the Weddell Sea region of Antarctica were larger at night than during the daytime. We investigated this anomaly (WSA) using the global numerical Upper Atmosphere Model (UAM) and the empirical ionospheric model IRI-2001 for the quiet conditions of the December and June solstices under low solar activity. The WSA was reproduced by the IRI-2001 and UAM. The analogous longitudinal variation was obtained for the northern hemisphere under summer conditions. The numerical experiments have showed that both phenomena were caused by the non-coincidence of the geomagnetic and geodetic axes which produces the difference in vertical velocities of the ion momentum transfer by the thermospheric wind action at western and eastern longitudinal sectors.

Introduction
In the late 1950s ionosonde observations detected the phenomenon called the Weddell Sea Anomaly (WSA) [Bellchambers and Piggott, 1958; Penndorf, 1965]. The phenomenon is characterized by the summer nighttime F2-layer electron densities exceeding the daytime ones in the Antarctic region. No such anomaly occurred in this region in winter. First it was considered that the anomaly appeared over a larger area of the Weddell Sea. But the TEC observations have showed that larger part of the WSA is situated over the Bellinshausen Sea [Horvath and Essex, 2003]. The nighttime electron density enhancements are detected in the region from 40°S to 80°S in latitude and about 255°-315° in longitude in the southern summer hemisphere. The analogous phenomenon was found by the observations in the northern summer hemisphere from about 40°N to 80°N in latitude at the meridians of 75°-135° in longitude.

Whereas the WSA position is described in numerous papers basing on the ground-base and satellite observations, the main mechanism causing the phenomenon is not clearly understood yet. The effects of solar ionization, neutral winds, geomagnetic field geometry, energetic particles precipitations, electric fields and plasma convection are included in the possible WSA causes list [Dudeney and Piggott, 1978; Horvath, 2006; Karpachev et al., 2010; Horvath and Lovell, 2010].

Numerical modeling allows investigating relative contribution of different mechanisms to the whole effect pattern. The conclusion about the WSA physical source can be made after logical including and excluding physical processes by upper atmosphere parameters modeling.

Our paper presents results of investigating the Weddell Sea Anomaly and its forming mechanisms by the mathematical modeling using the Upper Atmosphere Model (UAM) [Namgaladze et. al., 1998] and the empirical model of the ionosphere IRI-2001 [Bilitza, 2001].

Model results
The Upper Atmosphere Model is the global, three-dimensional, time-dependent, numerical model simulating the thermosphere, ionosphere and plasmasphere of the Earth as a single system. The model includes the equations of the continuity, momentum and heat balance and the electric potential equation and calculates the concentrations, velocity vectors and temperatures of the basic neutral ($O_2$, $N_2$, $O$) and the charged ($NO^+$, $O_2^+$, $O^+$, $H^+$ and $e$) components of the atmosphere at the altitude range from 60 km to 100000 km. The UAM takes into account non-coincidence of the geodetic and geomagnetic axes and gives the opportunity to calculate upper atmosphere parameters variations with the coincided axes. Besides the fully self-consistent numerical calculations the model can be configured alternatively with using the empirical models, for example, the model of neutral composition and temperatures NRLMSISE-00 [Picone et al., 2002], as the corresponding model blocks.

We investigated the Weddell Sea Anomaly mechanisms using the following UAM configurations:
1) the version with thermospheric parameters and 3D circulation calculations by solving the momentum, continuity and heat balance equations (marked as UAM-TT);
2) the version with thermospheric parameters calculation using of the empirical thermospheric NRLMSISE-00 model (marked as UAM-MSIS).

The model calculations were performed using the UAM-TT, UAM-MSIS versions as well as the fully self-consistent version with taking into account the non-coincided geodetic and geomagnetic axes.

The numerical modeling results are compared with the IRI-2001 data.
Figures 1-2 present the results of all model calculations of the latitudinal-temporal $foF2$ variations for two geodetic meridians $\lambda_1=105^\circ$ and $\lambda_2=285^\circ$ (across the WSA region) under low solar activity for the following quiet conditions:
- the solstice of December 23, 1985 (summer in the southern hemisphere) (Fig.1);
- the solstice of June 23, 1986 (summer in the northern hemisphere) (Fig.2).

The geomagnetic equator is marked by the horizontal solid black line, the positions of the WSA and the analogous phenomenon in the northern hemisphere are marked by the dash black lines.

Figure 1. Diurnal $foF2$ variations at different latitudes for two geodetic meridians $\lambda_1=105^\circ$ (right panel) and $\lambda_2=285^\circ$ (left panel) calculated by the IRI-2001 and different UAM configurations for December 23, 1985.

Figure 1. Diurnal $foF2$ variations at different latitudes for two geodetic meridians $\lambda_1=105^\circ$ (right panel) and $\lambda_2=285^\circ$ (left panel) calculated by the IRI-2001 and different UAM configurations for December 23, 1985.
Figure 2. Diurnal $f_{o}F_{2}$ variations at different latitudes for two geodetic meridians $\lambda_1 = 105^\circ$ (right panel) and $\lambda_2 = 285^\circ$ (left panel) calculated by the IRI-2001 and different UAM configurations for June 23, 1986.

The Figures show that the UAM versions with non-coincided axes and the IRI-2001 model reproduce the Weddell Sea Anomaly in the summer southern hemisphere and the analogous phenomenon in the summer northern hemisphere. The model calculations give night-time electron densities exceeding the day-time values up to 30 per cent. The UAM-MSISE version demonstrates move evident effect in diurnal $f_{o}F_{2}$ variations at different latitudes than the fully self-consistent version.

Discussion: what is the mechanism of the Weddell Sea Anomaly?

The diurnal F2-layer electron density variations are controlled mainly by the following mechanisms: corresponding variations of neutral composition, thermospheric wind, electric fields and energetic particles precipitations. Under quiet geomagnetic conditions electric fields of magnetospheric and thermospheric origin are negligible low at the middle latitudes [Lyatsky and Maltsev, 1983], and energetic particle
precipitations influence only on the high-latitude ionosphere [Vorobjev and Yagodkina, 2005]. Disturbances of the ionospheric F2-layer due to the thermospheric composition changes (particularly the n(O)/n(N2) ratio) are observed during geomagnetic storms [Prölss, 1980].

The WSA occurs at the middle geomagnetic latitudes and under quiet geomagnetic conditions. So this phenomenon is formed by the neutral wind action, particularly by the ion momentum transfer along the geomagnetic field lines induced by the thermospheric wind. In the night sector the equatorward neutral wind drives the F2-layer plasma to higher altitudes where the ion loss rate is lower. It results in the increase of the ionospheric F2 region plasma density.

The vertical ion velocity induced by the wind is proportionally to the $\cos I \cdot \sin I$ value, where $I$ is the inclination of the geomagnetic field. When the geomagnetic and geodetic axes are not coincided, the $\cos I \cdot \sin I$ magnitude at the fixed geodetic latitude depends on the geodetic longitude value (see Figure 3). The Figure shows that the Weddell Sea Anomaly locates in the longitudinal sector (255°-315°) for which the $\cos I \cdot \sin I$ has the maximal values.

Thus we conclude that the main cause of the WSA and analogous phenomenon in the northern hemisphere is the non-coincidence of the geodetic and geomagnetic axes. Due to this non-coincidence the ion momentum transfer along the geomagnetic field lines by the thermospheric wind forms the anomalous longitudinal electron density variation in the southern and northern hemispheres under summer condition.

In order to check this we calculated the electron density variations in the same longitudes without taking into account non-coincidence of the geodetic and geomagnetic axes. The results of UAM calculations are presented in the Figures 1-2 (bottom panels). The Figures show that in this case the WSA and analogous phenomenon in the northern hemisphere are practically disappeared. We suggest that the whole disappearance of the phenomenon can be reached by the exception of the initial conditions influence on model results.

Conclusion
The Weddell Sea Anomaly is reproduced by the IRI-2001 empirical model and all UAM configurations. The analogous longitudinal variation is presented in the model results for the northern hemisphere under summer conditions. The numerical experiments have showed that both phenomena are caused by the non-coincidence of the geomagnetic and geodetic axes which produces the difference in vertical velocities of the ion transfer by the thermospheric wind action at western and eastern longitudinal sectors.

References


