Weddell Sea Anomaly: investigation using the global numerical model

Maria A. Knyazeva, Yulia V. Zubova, and Alexander A. Namgaladze

Murmansk State Technical University, 183010, Sportivnaya St., 13, Murmansk, Russia;
Namgaladze@yandex.ru; mariknyazeva@yandex.ru;
tel.: +7.8152.457.125; fax: +7.8152.232.492

Abstract

The Weddell Sea Anomaly morphology and the mechanism of its formation were investigated using the global numerical Upper Atmosphere Model (UAM) and the empirical model of the ionosphere IRI-2001. The numerical experiments have showed that the anomalous, inverted diurnal F2-layer electron density variations in the summer Weddell Sea area are caused by the non-coincidence of the geomagnetic and geodetic axes. This non-coincidence produces the difference in vertical velocities of the ion transportation by the thermospheric wind action at western and eastern longitudinal sectors.

1. Introduction

The Weddell Sea Anomaly (WSA) is characterized by the inverted diurnal F2-layer electron density variation. Particularly ionosonde and satellite observations have shown that the summer night-time electron density values exceed the day-time ones [1, 2]. The WSA is formed under the quiet geomagnetic conditions in the Antarctic region from 40°S to 80°S in geodetic latitude and about 255°-315° in geodetic longitude [3, 4]. The analogous phenomenon was found in the northern summer hemisphere from about 40°N to 80°N in latitude at the meridians of 75°-135° in longitude.

Numerous papers discussed different physical mechanisms of the Weddell Sea Anomaly formation. The most probable causes are electric fields both thermospheric [5] and magnetospheric [6] origin, plasma transportation along the geomagnetic field lines by the neutral wind [7], plasma fluxes from the plasmasphere [4].

All hypotheses are qualitative and require quantitative estimations of different mechanisms contributions to the ionospheric F2-layer formation. The presented paper is aimed at the Weddell Sea Anomaly investigation and the detection of the physical mechanism causing the anomaly.

2. Method

The investigation was performed using the global numerical Upper Atmosphere Model (UAM). The model was initially developed at the Kaliningrad observatory (now West Department) of IZMIRAN and then extended at the Polar Geophysical Institute of the Russian Academy of Sciences and at the Murmansk State Technical University [8]. 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 the non-coincidence of the geodetic and geomagnetic axes and gives the opportunity to calculate upper atmosphere parameters with the coincided axes. Besides the fully self-consistent version the model can be configured alternatively with using the empirical models, for example, the model of neutral composition and temperatures NRLMSISE-00 [9] as the corresponding model parts.

The three-dimensionality and self-consistence of the UAM permit to find out the role of different transport processes in the night-time mid-latitude F2-layer behavior correctly. Therefore the UAM was used for investigation of the Weddell Sea Anomaly mechanism.

3. Results

We have calculated global electron density patterns for two quiet days representing December (23.12.1985) and June (23.06.1986) solstices by using two UAM configurations: 1) fully self-consistent version with thermospheric

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parameters and 3D circulation calculations by solving the momentum, continuity and heat balance equations (marked as UAM-TT); 2) version with thermospheric parameters calculation using the empirical thermospheric NRLMSISE-00 model (marked as UAM-MSIS). The numerical modeling results are compared with those of the empirical IRI-2001 model [10].

Figure 1 shows the geodetic latitudinal-temporal NmF2 variations calculated by the UAM and IRI-2001 for the fixed geodetic meridians. The results for the December solstice (summer in the southern hemisphere) and λ=285° are presented in the left column, the results for the June solstice (summer in the northern hemisphere) and λ=105° - in the right column. The meridian λ=285° passes across the Weddell Sea Anomaly region. The geomagnetic equator is marked by the horizontal solid black line.

The WSA (marked by the solid black circles) is clear visible in the summer southern hemisphere for the December solstice at geodetic meridian λ=285° in all model calculation results. The anomaly covers geodetic latitudes from 45° to 55-60°. The model calculations produce night-time electron densities exceeding the day-time values up to 30 per cent. The UAM-MSISE version demonstrates more evident WSA effect in diurnal NmF2 variations than the fully self-consistent UAM-TT version.

For the June solstice in the northern hemisphere the IRI-2001 and both UAM versions show that the analogous anomalous phenomenon (marked by the solid black circles) is formed at the geodetic meridian λ=105°. As it was noticed in the previous case the UAM-TT underestimates this anomaly in comparison with the IRI-2001 data and the UAM-MSIS version.

4. Discussion

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. The WSA and the analogous phenomenon in the northern hemisphere occur under quiet geomagnetic conditions and at middle geomagnetic latitudes.

Under quiet geomagnetic conditions electric fields of magnetospheric and thermospheric origin are neglible low at middle latitudes [11], and energetic particle precipitations influence only on the high-latitude ionosphere [12]. Disturbances of the ionospheric F2-layer due to the thermospheric composition changes (particularly the $n(O)/n(N_2)$ ratio) are observed during geomagnetic storms [13].

So both phenomena are 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. The Fig.1 shows that the Weddell Sea Anomaly in the southern hemisphere and the analogous phenomenon in the northern hemisphere locate in the longitudinal sectors for which the $\cos I \cdot \sin I$ has the maximal values.

The model results were obtained by using the UAM taking into account the non-coincided geodetic and geomagnetic Earth's axes. The bottom panels of Fig.1 present the results of UAM calculations performed with the coincided geomagnetic and geodetic poles. In this case both anomalies are practically disappeared. We suggest that the whole disappearance of these phenomena can be reached by the exception of the initial conditions influence on the model results.

4. Conclusion

The Weddell Sea Anomaly in the summer southern hemisphere and the analogous longitudinal variation in the northern hemisphere under summer conditions are caused by the non-coincidence of the geomagnetic and geodetic axes which produces the difference in vertical velocities of the ion transportation by the thermospheric wind action at

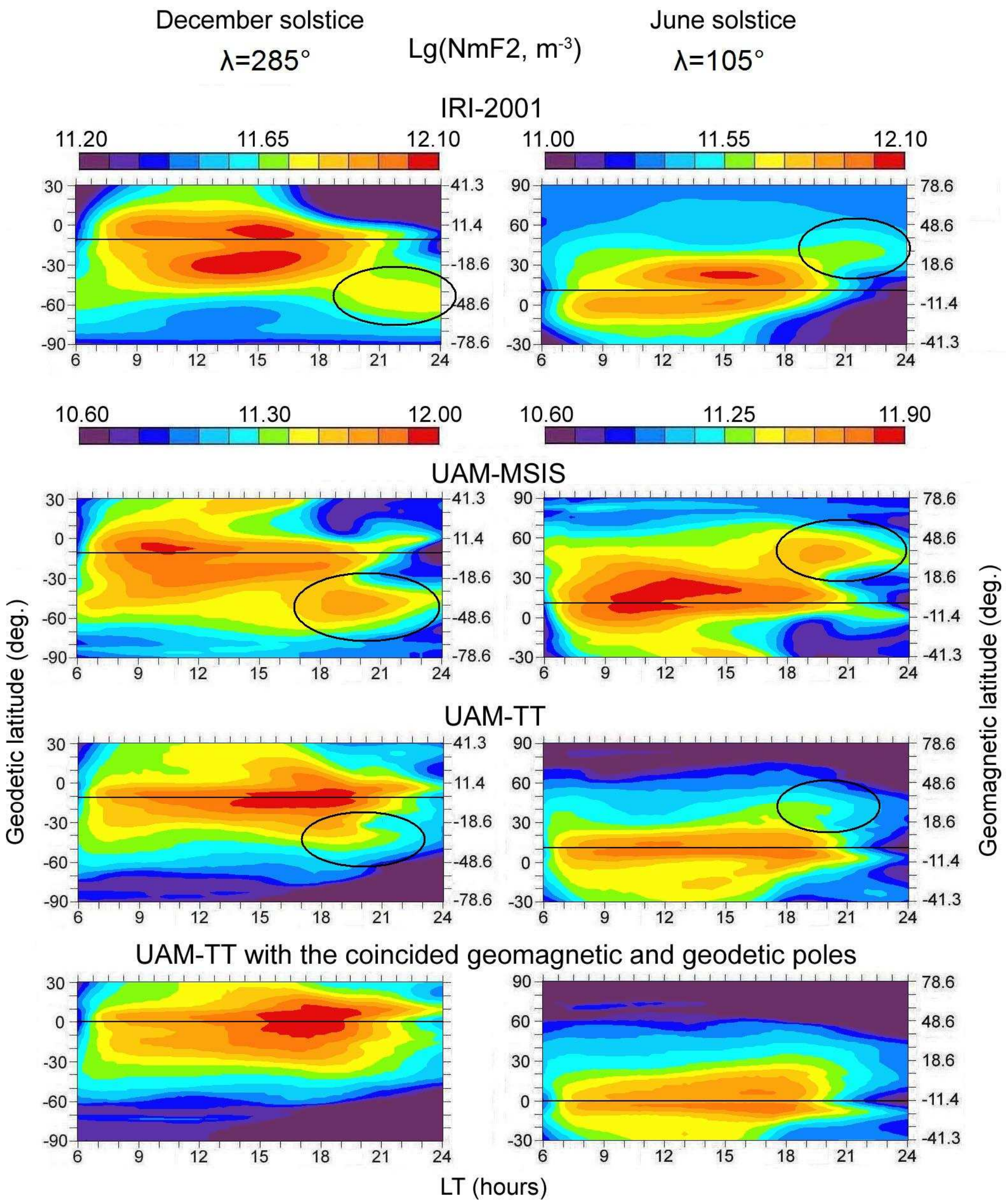

Fig.1. Latitudinal-temporal NmF2 variations in the summer southern hemisphere calculated for the December solstice (23.12.1985) for geodetic meridian λ=285° (left column) and in the summer northern hemisphere for the June solstice (23.06.1986) for meridian λ=105° (right column). At the first upper row the IRI-2001 results are presented; at the second one – the results of the UAM-MSIS version; at the third one – of the UAM-TT. The bottom row shows the results of the UAM-TT version with the coincided geomagnetic and geodetic axes. The geomagnetic equator is marked by the horizontal solid black line.

different longitudinal sectors.

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