Auroral oval boundary observations by Meteor 3M satellite

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Abstract: The results of the observations of auroral oval boundaries by satellite METEOR 3M are presented. The satellite was lunched December 10, 2002 to the polar heliosynchronous orbit with the altitude of 1018 km and the inclination of 99.63°. The satellite mission includes the observations of the Earths resources, the control of the conditions in the near the Earth environment, meteorological and heliogeophysical parameters. The main goals of the mission are the forecast of the solar flare activity, control and prediction of the Earths radiation and the state of the Earths magnetic field, prediction of the conditions for the radio wave propagation, diagnostic and the control of the conditions in the magnetosphere and ionosphere. The electrostatic analyser MSGI-5EI is used for the analysis of the variations of the fluxes of auroral protons and electrons. It measures the electron and proton fluxes within the energy range from 0.1 to 10 keV in 50 energetic channels and the integral flux of electrons with energies > 40 keV. Determined by MSGI-5EI positions of the auroral oval boundaries are compared with the predictions of OVATION model. It is shown that due to auroral substorm activity the difference between observed and predicted by OVATION positions can exceed 5 degrees in latitude.

Key words: auroral oval, auroral satellite, OVATION model.

1. Introduction

Study of the main features of auroral substorm development requires constant monitoring of radiation and plasma near the Earth, determination of the position of the auroral oval and variations of fluxes of auroral particles, what is one of the main goals of the Meteor-3M No 1 satellite mission. Auroral oval boundaries move to the equator during substorm growth phase. Polar boundary move to the pole after substorm expansion phase onset forming the auroral bulge. OVATION model based on DMSP, POLAR and radar observations gives the position of auroral oval for concrete time intervals.

In this paper we describe the main features of satellite operation, present examples of particle measurements and results of the comparison of the predictions of OVATION model with the Meteor-3M No 1 measurements.

2. The features of the operation of the satellite METEOR 3M No 1

The satellite Meteor-3M No 1 mission includes study of the natural resources, the control of the environment conditions, the hydrometeorological and heliosphysical testing. The satellite was lunched December 10, 2002 to the heliosynchronous orbit with the altitude 1018 km and the inclination 99.63° by the rocket “Zenit” from the Baikonur cosmodrom. Table 1 summarizes the main technical characteristics of the satellite.

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Satellite Meteor-3M No 1 is designed by the Electromechanical Institute in Istra town having as a prototype the satellite Meteor-3M. However, significant changes have been introduced including the modification of attitude system, installation of new radio transmission system and modification of the information devices and measurement instruments. According to the main goals of the mission, the complete set of instruments includes three main subsets:

1. Visual informative nature-resources complex (BIK-M1);
2. Complex of scientific measuring instruments (BKNA);
3. Complex of meteorological instruments (MP-700M).

Heliophysical instruments realize measurements of solar flare particles and radiation in the inner magnetosphere that allows forecasting of radiation conditions and conditions of radio wave propagation. One of the applied aspects of the mission is to guarantee more reliable and effective work of satellites due to developing of more confident forecast of near-Earth radiation environment, and also due to imrovement of the satelite design.

3. Spectrometer MSGI-5EI

Measurements of auroral particle fluxes are made using the MSGI-5EI spectrometer [1]. The instrument includes the following sub-systems: high sensitive spectrometric module for low energy ion and proton measurements; high sensitive spectrometric module of low energy electron measurements; low sensitive spectrometric module for low energy electron measurements, and module for the measurements of integral flux of charged particles with the energies > 40 keV.

The detection of low energy particles, energy-charge separation is realized by two kinds of spectrometric modules representing the cylindrical electrostatic analyzers, secondary electron multiplies of the type VEU-6 (low sensitive module) or VEU-7 (high sensitive module), charge-sensitive amplifier and

Orbital parameters, technical characteristics	Value
Local solar time of rising knot	9 h 15 min $\pm$ 15 min
Altitude	1018.63 ± 10.71 km
Inclination	99.63°
Orbital period	105.33 ± 0.06 min
Eccentricity	0.000806
The angle distance between turns	-26.334°
Daily change of the longitude of rising knot	-8.670°
Period of izorote	3 days (41 turn)
Total mass	2600 kg
Mass of the paying load	800 – 1000 kg
Time of operation, year	greater than 3
Parameters of three axial orientation: accuracy accuracy of the stabilization	 $10'$ $0.005^\circ/\mathrm{s}$

Table 1. Orbital parameters and the main technical characteristics of the Meteor-3M No 1 satellite

the device for the formation of normalized pulses. The spectrometric modules measure differential energy spectra of low energy ions (protons) and electrons in the energy range from 0.1 to 20 keV. Dynamical range of the measurements of the ion channel is 10^3–10^8 particles$/(\mathrm{cm}^2 \cdot \mathrm{s} \cdot \mathrm{ster} \cdot \mathrm{keV})$. Dynamical range of the measurements of low energy electrons for the spectrometer MSGI-5EI is 10^3–$2 \cdot 10^9$ particles$/(\mathrm{cm}^2 \cdot \mathrm{s} \cdot \mathrm{ster} \cdot \mathrm{keV})$. Measurements of energy spectra of electrons and ions (protons) have two modes, controlled by external commands. The fast one is used for the study of space-time variations during the periods of geomagnetic disturbances. The time of measurements of energy spectra is 2 s, the number of energy channels is equal 10. The second mode (the slow one) has the time of measurements of energy spectra of 10 s, but the number of energy channels is substantially higher and equal to 50. Batten gas discharge detectors realize measurements of charged particles of medium energy. Dynamical range of the integral channel constitute 1–10^3 pulses per second. Measurements are realized in monitor regime independent on the regime of the work of spectrometer. Figure 1 demonstrates the example of auroral oval crossing.

The data base of the satellite Meteor-3M No 1 contains the values of particle fluxes with energy 0.1–10 keV and particle spectra. Every flight gives four auroral oval boundary crossing for each hemisphere to determine the auroral oval position. The determination of inner auroral oval boundary becomes difficult in cases of overlapping of auroral oval and external electron radiation belt.

4. Comparison of results of Meteor-3M No 1 observations with OVATION model

OVATION model [http://sd-www.jhuapl.edu/Aurora/] (see [3, 4]) uses multiple data sets cross-calibrated to a single standard. The model gives and predicts the position of auroral oval in real time. Data from the DMSP satellites, from NASA's Polar UVI imager, from the University of Alaska, Fairbanks Meridian Scanning Photometer and SuperDARN are used for model fitting. The DMSP particle precipitation data provides the "core" of OVATION. But DMSP temporal resolution is poor (about 50 minutes per updated position). The time resolution of Polar UVI (in the LBH-L filter used for this work) is typically one image every 1 min 30 s, but auroral images are available only for the northern hemisphere. Large data gaps occur daily, whenever Polar is not in position to observe the northern hemisphere polar regions. The Super Dual Auroral Radar Network consists of a collection of HF radars located in the Northern and Southern hemispheres, but its data are used not in all cases. University of Alaska, Fairbanks MSP (Meridian Scanning Photometer) data is high time resolution, but only works (1) in darkness, (2) under fair skies, (3) when the auroral oval is within a few degrees of Fairbanks. The verification of OVATION model requires using of data of auroral satellite which was not used in OVATION model.

In this study we compare the predictions of OVATION model with the results of Meteor-3M No 1 observations. This includes the determination of the geomagnetic coordinates and time of the oval boundary crossings by Meteor-3M No 1 satellite and simultaneously the position of auroral boundaries according to the OVATION model. After that we determine a difference in degrees between both geomagnetic latitudes. Fig. 1 shows precipitating electron fluxes observed by the METEOR-3M satellite January 1, 2003. Fig. 2 shows the auroral oval position provided by the OVATION model for the event January 9, 2003. The Meteor-3M crossings of auroral oval boundaries are shown by black squares, and the closest in time DSMP satellite trajectories are shown by white squares. "R" are the results of radar measurements used in the OVATION model. As it can be seen from Fig. 2, the auroral oval position provided by the OVATION model coincides very well with the Meteor-3M No 1 measurements for the event January 9, 2003. Nevertheless this coincidence is not observed for all events analyzed. Fig. 3 shows precipitating electron fluxes observed by the METEOR-3M satellite January 8, 2003 and Fig. 4 shows the auroral oval position provided by the OVATION model for this event. The discrepancy larger than 4° is observed.

To make a statistical analysis of discrepancies observed we separated all events analyzed in 6 sets according to the absolute value of the difference: from 0 to 1 degrees, from 1 to degrees, from 2 to 3 degrees, from 3 to 4 degrees, from 4 to 5 degrees and larger than 5 degrees. Fig. 5 shows the results of produced analysis. Values on the ordinate axes show the number of analyzed events (in %). Upper part of the figure corresponds to the equatorial boundary of the oval; lower part corresponds to the polar boundary. It is possible to see that the model gives quite good predictions of auroral oval location in half of cases. Events with large discrepancy correspond to substorm periods or to cases when the angular difference of DMSP and Meteor-3M trajectories is larger than 20° (in longitudes). Medium value of the discrepancy is $1.8^\circ \pm 1.3^\circ$ for the equatorial boundary and $2.8^\circ \pm 2.5^\circ$ for the polar boundary.

The average positions of polar and equatorial auroral boundaries are also determined. Equatorial boundary is located at $68^\circ \pm 4^\circ$ near noon and $62^\circ \pm 6^\circ$ near midnight. Polar boundary is located $77^\circ \pm 3^\circ$ near noon and $70^\circ \pm 10^\circ$ near midnight. These values are in agreement with existing models of auroral oval position [2, 5–9].

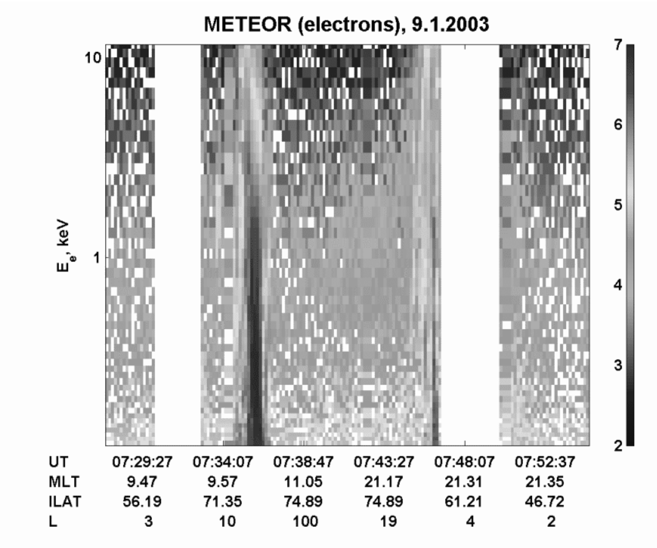

Fig. 1. Precipitating electron fluxes observed by the METEOR-3M satellite January 9, 2003

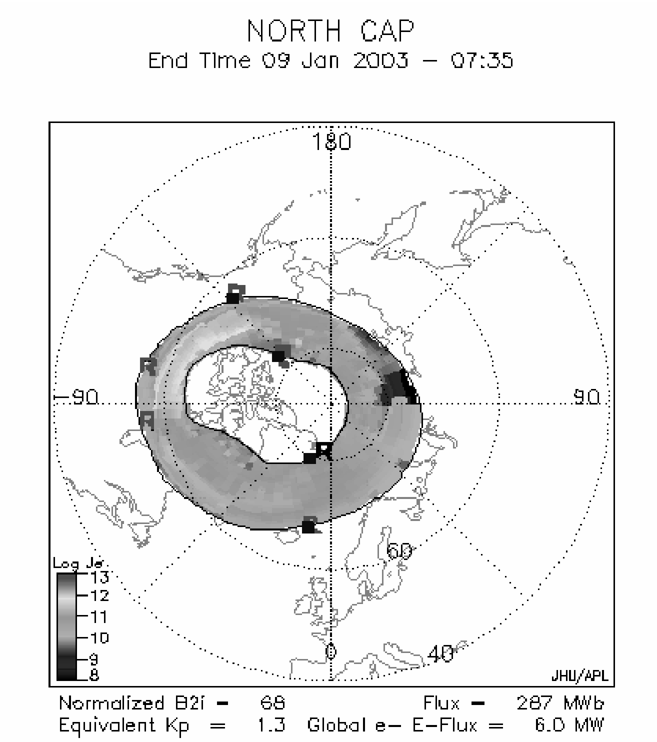

Fig. 2. Visualization of the results of the comparison of the OVATION model with Meteor-3M No 1 data for the January 9, 2003 event. Crossings of the Meteor-3M No 1 trajectories of the auroral oval are shown by black squares, white squares show nearly simultaneous crossings by one of the DMSP satellites, R are the results of radar measurements used in OVATION model

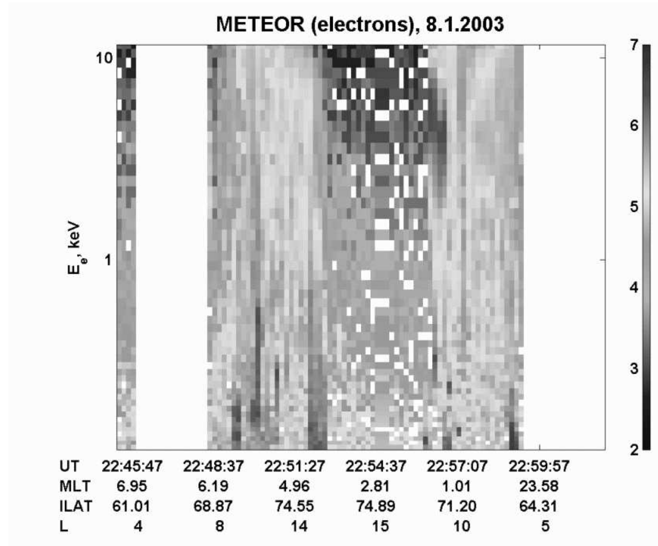

Fig. 3. Precipitating electron fluxes observed by the METEOR-3M satellite January 8, 2003

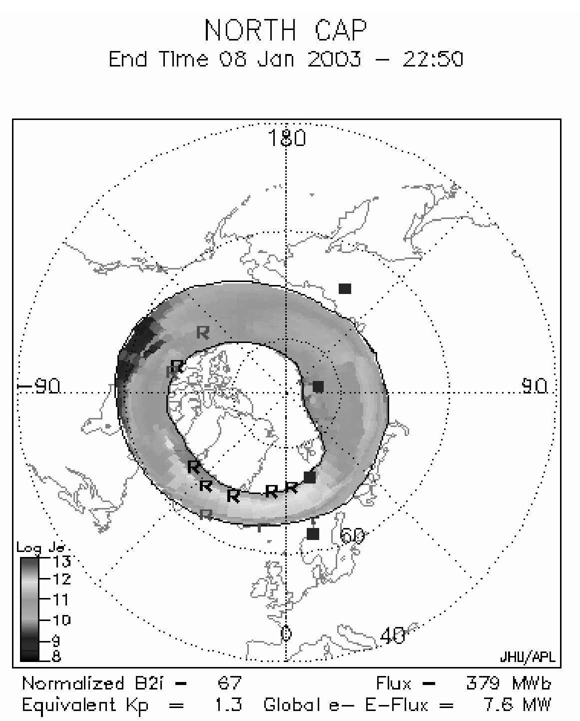

Fig. 4. Visualization of the results of the comparison of the OVATION model with Meteor-3M No 1 data for the January, 8, 2003 event

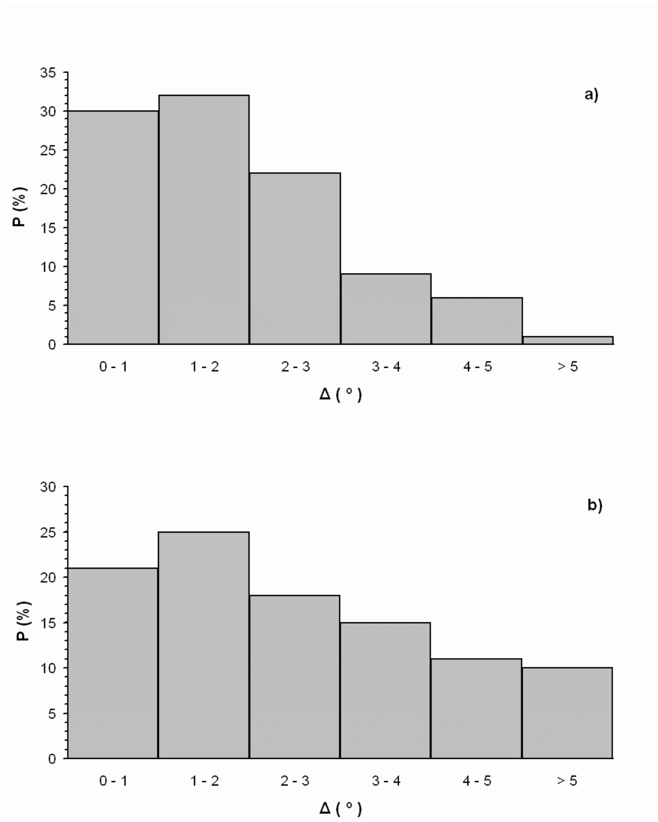

Fig. 5. Results of statistical analysis of coincidence of OVATION model predictions with Meteor-3M No 1 observations: a) for the equatorial boundary, b) for the polar boundary

5. Discussion and conclusions

The preliminary results presented here show the capability of the Meteor-3M No 1 satellite to verify and precise the auroral oval positions given by the OVATION model. We have found that the positions of the auroral oval boundaries, observed using the Meteor-3M precipitating particle flux measurements, generally coincide with these provided by the OVATION model. Nevertheless, for some events observed and modeled boundaries differ in a few degrees in geomagnetic latitude. It was found that this discrepancy increases with the angular distance between Meteor-3M No 1 and DMSP satellite used by the OVATION model as an input. We consider that the main reason of observed noncoincidence when the angular distance of DMSP and Meteor-3M No 1 satellite is small is the auroral boundary motions during magnetospheric substorms.

Acknowledgments

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References

1. Marjin B. V., M. V. Teltsov, M. O. Riazantseva, E. E. Antonova, V. V. Khoteenkov, M. A. Saveliev, V. M. Feigin. Meteor-3M No 1 particle observations: Initial results, *Proceedings of the 5th International Conference Problems of Geocosmos St. Petersburg, Petrodvorets, May 24–28*, 92–95, 2004.
2. McDiarmid I. B., Burrows J. R., Budzinski E. E. Average characteristics of magnetospheric electrons /150 eV to 200 keV/ at 1400 km, *J. Geophys. Res.*, 80, 73–79, 1975.
3. Newell P. T., Sotfrelfs T., Ruohonfemf J. M., *Ovation: Oval variation, assessment, tracking intensity, and online nowcasting*, *Annales Geophysicae*, 20, 1039–1047, 2002
4. Sotirelis T., Newell P. T., Boundary-oriented electron precipitation model, *J. Geophys. Res.*, 105, 18655, 2000.
5. Spiro D. J., Reiff P. Y., Maher L. J. Precipitating electron energy flux and auroral one conductances an empirical model, *J. Geophys. Res.*, 87, 8215, 1982.
6. Hardy D. A., Gussenhoven M. S., Holeman E. A statistical model of auroral electron precipitation, *J. Geophys. Res.*, 90, 4229, 1985.
7. Vorobjev V. G., O. I. Yagodkina, G. V. Starkov, Ya. I. Feldstein, A substorm in midnight auroral precipitation, *Annales Geophysicae*, 21(12), 2271–2280, 2003.
8. Vorobjev V. G., Yagodkina O. I. Midnight electron precipitation pattern for substorm development. *Proceedings of the conference in memory of Yuri Galperin "Auroral Phenomena and Solar-Terrestrial Relations"*, eds: L. M. Zelenyi, M. A. Geller, J. H. Allen, *CAWSES Handbook-001*, 341–349, 2004.
9. Yagodkina O. I. Vorobjev V. G., Daytime auroral precipitation during substorm development. *Proceedings of the 26th Annual Seminar Physics of auroral phenomena.* Apatity, 2003. 49–52, 2003