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NUMERICAL MODELING OF THE THERMOSPHERE, IONOSPHERE AND PLASMASPHERE BEHAVIOR DURING THE APRIL 2002 MAGNETIC STORMS

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Abstract. Magnetic storm effects in the Earth's upper atmosphere, such as changes in the electric field, neutral composition and global thermospheric circulation, Joule heating, electron and ion temperature and density disturbances in the thermosphere, ionosphere and plasmasphere, have been investigated for specific conditions of April 17-20, 2002 magnetic storms. The consideration was performed in the framework of the global numerical Upper Atmosphere Model. The results of model calculations of electron and ion temperature and density have been compared with simultaneous observations of six incoherent scatter radars for this period. In general, a good agreement between the theoretical and experimental data is achieved. Analysis of the physical factors presumably responsible for some discrepancies between the model results and observations has been made.

1. Introduction

The April 2002 magnetic storms were predicted in advance and observed by many facilities including all incoherent scatter radars (ISR). This is a good opportunity to test modern global models of the Earth’s ionosphere and thermosphere such as e.g. UAM - the global numerical Upper Atmosphere Model - by comparing the calculation results obtained in their frameworks with observations. The data of observations as well as some model results can be found at http://www.haystack.mit.edu/~szhang/apr02.html and at http://www.haystack.mit.edu/~szhang/modelapr02.html .

The solar (F10.7) and magnetic (Kp and Dst) activity indices for the time period from April 13 to 24, 2002 are shown in Fig.1.

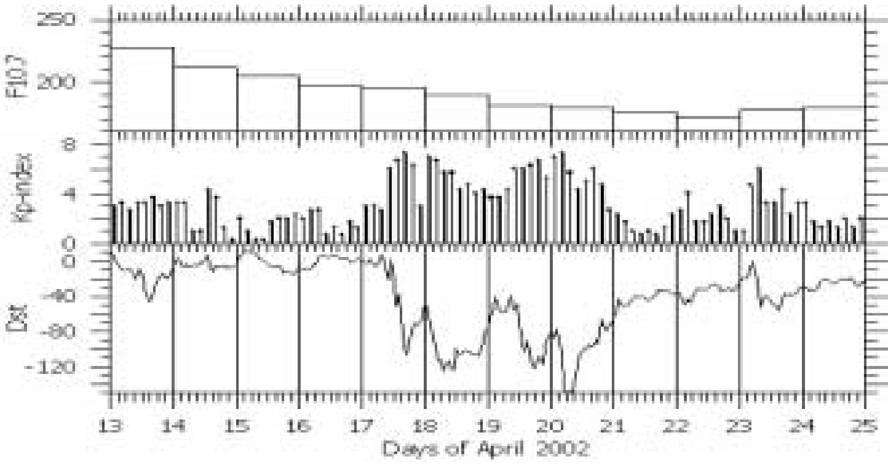


Fig.1. The solar (F10.7) and magnetic (Dst and Kp) activity indices for the time period from April 13 to 24, 2002.

2. Model calculations

The April 17-20, 2002 magnetic storm effects, such as changes in the electric field, neutral composition and global thermospheric circulation, Joule heating, electron and ion temperature and density disturbances in the thermosphere, ionosphere and inner magnetosphere of the Earth, have been investigated by the use of the global numerical Upper Atmosphere Model – UAM (*Namgaladze et al.*,1998a,b), which is a development of the model by *Namgaladze et al.* (1988).

The UAM reproduces time-dependent global distributions of densities and temperatures of the neutral and charged components at heights from 80 (sometimes 60) km up to geocentric distance of 15 R_E from the continuity and heat balance equations, electric fields from the electric potential equation, and thermospheric wind and ion drift velocities from the momentum equations.

The model takes into account the offset of the geographic and geomagnetic axes of the Earth. The computational grid has a variable latitudinal step (from 1° to 5° or 10°), a fixed step of 15° in longitude, and a variable height step (from 3 km at 80 km-altitude to 20 km at height of F2 layer maximum).

The locations of the polar cap and auroral oval boundaries, and precipitating electron fluxes have been taken as dependent on Kp or AE or AL-index or directly on UT, as well as electric potential drop across the polar cap. These dependencies have been chosen to be consistent with the DMSP data when such data were available. The results presented below were obtained with using the Kp dependences of the auroral oval boundaries and precipitating electron mean energy and flux intensities from *Hardy et al.* (1985). For more details see *Zubova et al*. (2003).

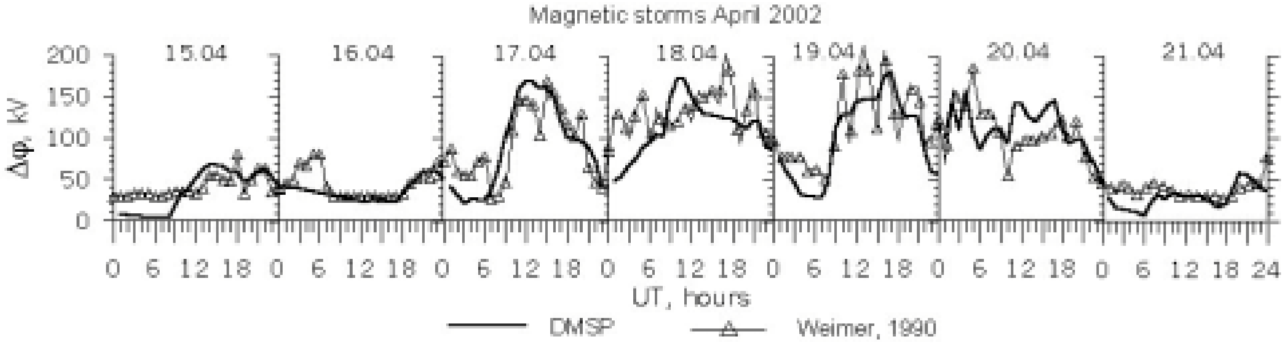


Fig.2. The electric potential drop across the polar cap in April 2002 according to the DMSP data and to the AE-dependence by Weimer, 1990, which has been used in the model calculations presented in this paper.

The model calculations have been made using both empirical MSIS2000 (NRLMSISE-00) and theoretical thermosphere models, which is allowed within UAM framework.

3. Thermospheric effects of the magnetic storm

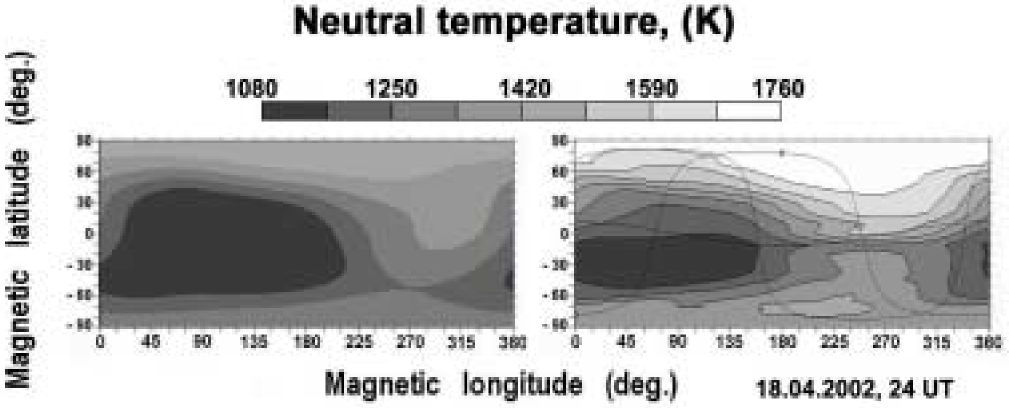


Fig.3. Neutral temperature at height of 300 km calculated with MSIS (left plot) and with the theoretical thermospheric model (right plot) for the time of maximum thermospheric disturbance.

The main thermospheric effects of the magnetic storm are high-latitude neutral temperature and wind increase due to Joule heating with corresponding decrease of O/N2 ratio (i.e. the ratio of neutral O and N2 concentrations). At height of 300 km maximum neutral temperature grows from ~1350K to ~1600K in calculations with MSIS and to 1760K within completely theoretical framework. The corresponding wind velocities reach values of about 800 m/s in both cases. The O/N2 ratio decreases by factor ~3 in the former case and by factor ~10 in the latter. It means that neutral temperature and composition disturbances are much stronger in completely theoretical framework than in the version with MSIS.

It should be noted that thermospheric temperature and gas composition calculated with MSIS are independent of the UAM input parameters, such as locations of the polar cap and auroral oval boundaries, precipitating electron fluxes and electric field potential drop across the polar cap. On the other hand, in completely theoretical framework both temperature of neutrals and gas composition depend directly on these input parameters.

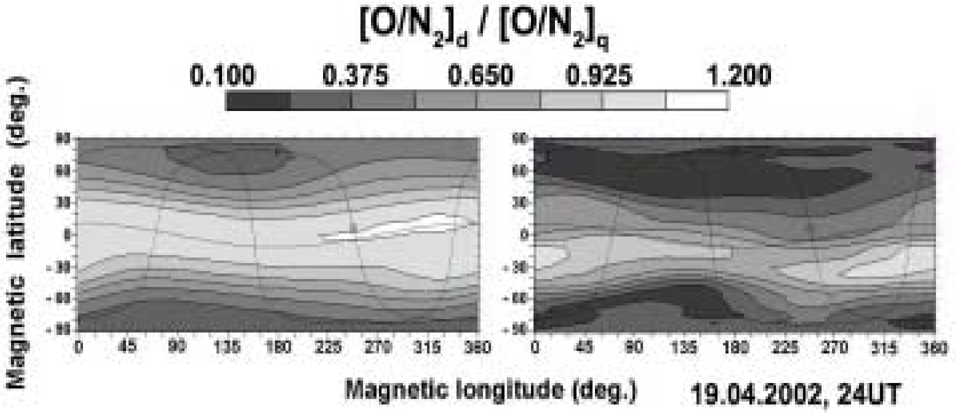


Fig.4. The ratio of disturbed O/N2 to quiet O/N2 at height of 300 km calculated with MSIS (left plot) and with theoretical thermospheric model (right plot) for the time of maximum thermospheric disturbance.

4. Comparison with the ISR data

The results of the model calculations of electron and ion temperature and density have been compared with the data of simultaneous observations of six incoherent scatter radars for this period. Some of these comparisons are shown in Figs.5-7.

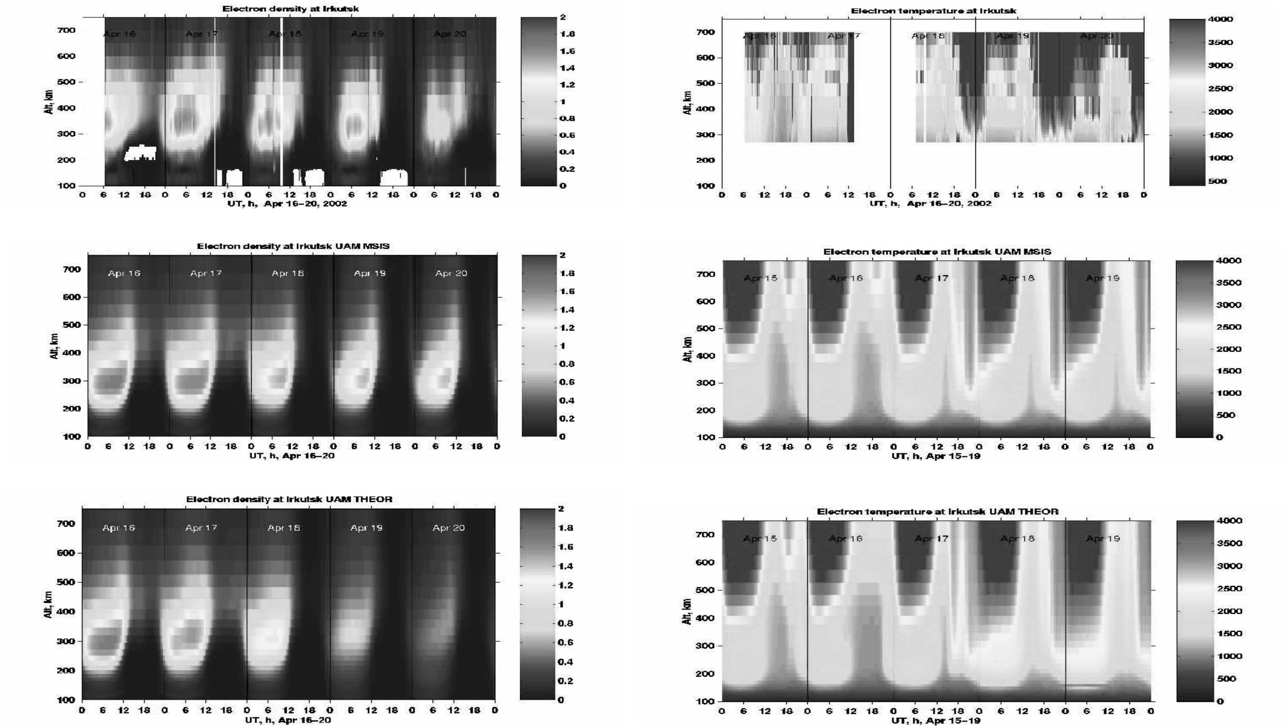


Fig.5. Electron density (left) and temperature (right) over Irkutsk (magnetic latitude 41.7^0) as observed by ISR (top panels), and calculated by UAM using MSIS (middle panels) and theoretical thermosphere model (bottom panels)

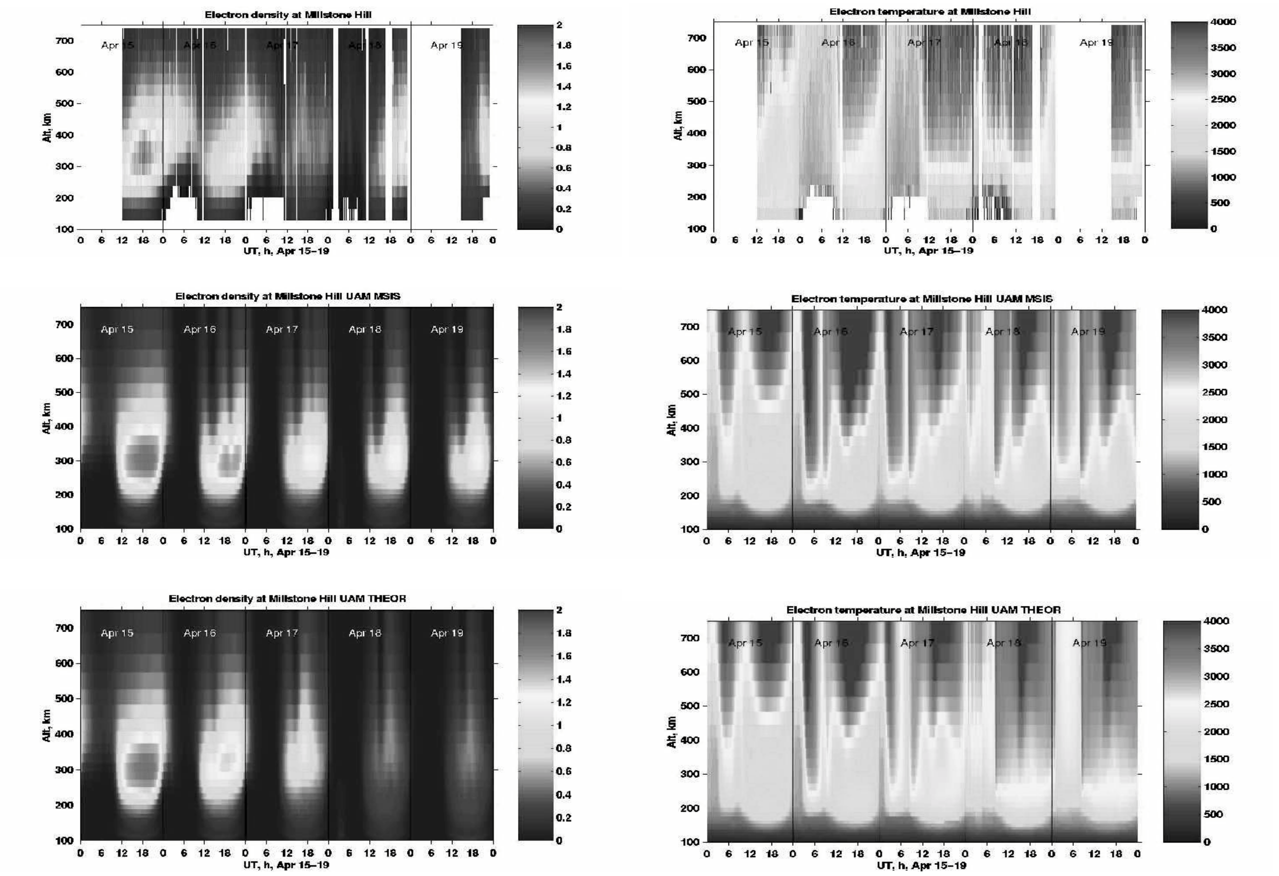


Fig.6. The same as in Fig.5 but for Millstone Hill (magnetic latitude 54.4).

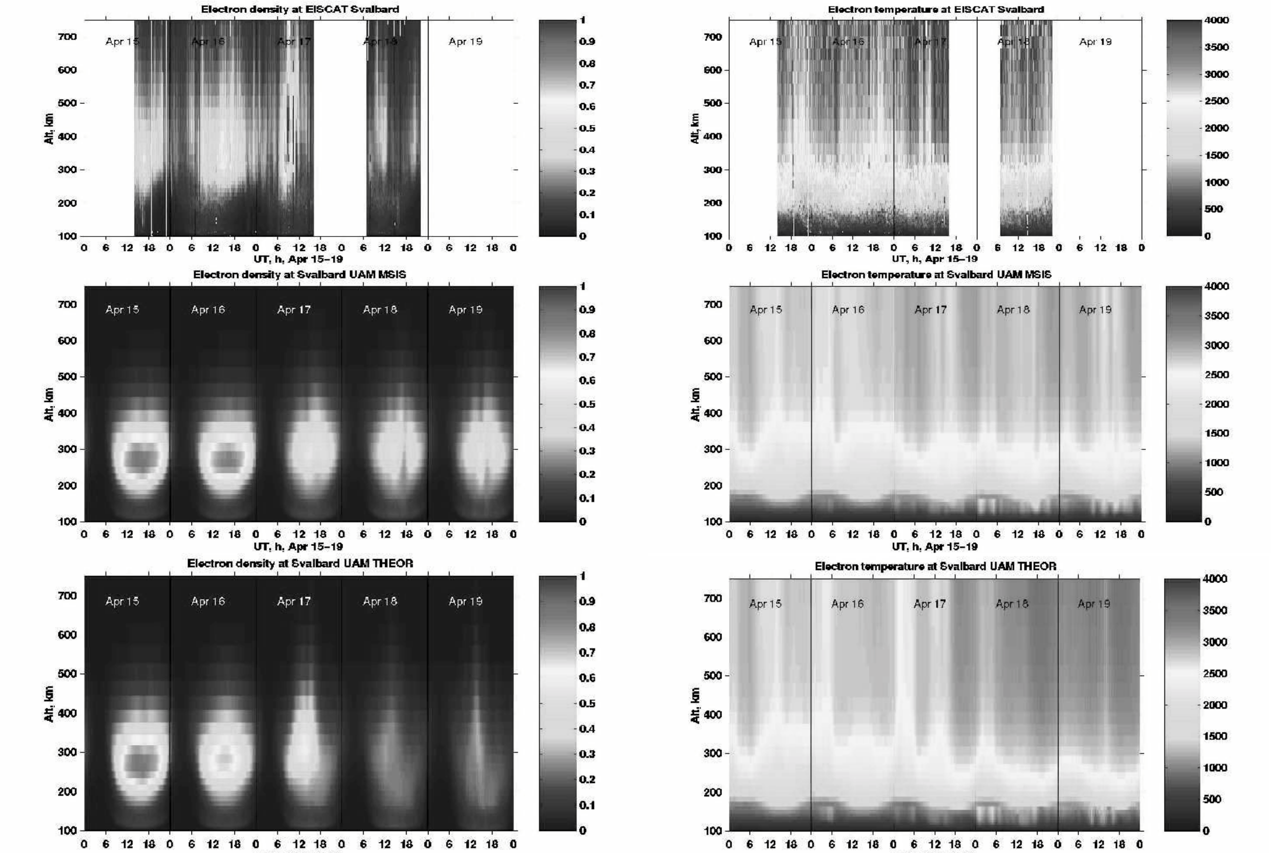
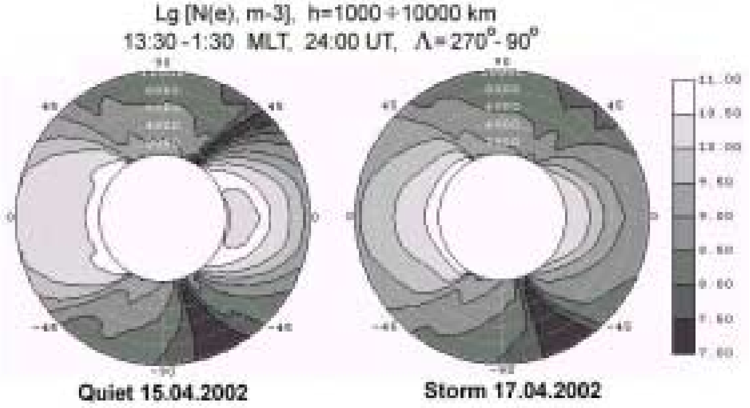


Fig.7. The same as in Figs. 5, 6 but for the EISCAT Svalbard (magnetic latitude 74.1^0).

We can see from these Figures that UAM with using MSIS underestimates the ionospheric effects of the April 2002 magnetic storms (the electron density depletions), whereas UAM with theoretical thermospheric model overestimates them, perhaps because of uncertainties in the input parameters.

5. Plasmaspheric effects of the magnetic storm

The main plasmaspheric effects of the magnetic storm are clearly seen in Fig. 8, where electron density at heights from 1000 to 10000 km along the 13:30-01:30 MLT magnetic meridian is shown for quiet and disturbed conditions. The overall depletion of plasmaspheric electron density takes place, the plasmasphere contracts and non-monotonous electron density height dependence disappears. The latter is clearly seen in the right (nightside) part of the left plot in Fig.8 as plasma tubes of increased plasma density along the geomagnetic field lines intersecting the Earth's surface at middle geomagnetic latitudes. We consider the equatorward thermospheric winds to be the main cause of these plasma tubes. The positive wind effect in ionospheric and plasmaspheric electron density is largest at midlatitudes due to geomagnetic field geometry. During and after the magnetic storm this effect diminishes because of overall electron density depletion, resulting from the change in neutral composition (O/N2 decrease).



Quiet 15.04.2002

Storm 17.04.2002

Fig.8. Plasmaspheric electron density at heights from 1000 to 10000 km along the 13:30-01:30 MLT magnetic meridian for the quiet (left plot) and disturbed (right plot) conditions

6. Conclusions

The results presented above clearly show that a general picture of the April 2002 magnetic storm effects in the Earth's upper atmosphere, such as thermospheric temperature and wind increase, O/N2 decrease and overall elecron density depletion (the negative ionospheric storm) is reproduced quite well by the UAM. Calculated electron and ion temperature and density, on the whole, are quite consistent with the data of simultaneous observations of six incoherent scatter radars for the period of interest.

To get the best agreement between the UAM results and observations one should use the real time DMSP data as input parameters for the UAM calculations in accordance with (*Zubova et al.*, 2003).

UAM predicts a non-monotonous Ne(h) dependence inside the plasmasphere, which is associated with thermospheric wind effect.

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