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DAYTIME MAGNETOSPHERE-IONOSPHERE DISTURBANCES IN RESPONSE TO SHARP INCREASES IN THE SOLAR WIND DYNAMIC PRESSURE: EVENT 21-22 JUNE 2015

L.A. Dremukhina[1,2], L.I. Gromova[1], S.V. Gromov[1], V.G. Petrov[1]

[1]Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation RAS, Moscow, Russia
[2]Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia
e-mail: dremukh@izmiran.ru

Abstract. In this work we analyze high-latitude ionosphere-magnetosphere disturbances, appearing as a response to the sharp fronts of the solar wind dynamic pressure in the preliminary phase of the storm on 21-23 June 2015, one of the greatest storms in the 24th solar cycle (Dst_{min} = -204 nT). The analyzed storm is characterized by unusually long initial phase, which was preceded by a long interval (about two days) of extremely quiet solar wind with *Bz* and *By* IMF closed to zero. During the storm initial phase, it was observed near the Earth three shock fronts with the dynamic pressure *Psw* increased to ~ 12, 10 and 60 nPa. The first two fronts were caused by an increase of the solar wind density at low speed, and the most powerful third front was caused also an increase of the solar wind velocity. The storm main phase followed after only the third jump of *Psw*, when the IMF *Bz* turned south and reached values ~ -37 nT. It is shown that the perturbation scenario in the daytime polar region is determined by the prehistory of conditions in the solar wind, the direction of the IMF and the ratio between values of its component *Bz* and *By*. Analysis of spectral characteristics of energetic electrons and ions from the DMSP indicated an increase flux of electrons with energies of 0.1-3 keV and protons with energies of 1.0-10 keV after each dynamic impact of the solar wind. Magnetograms of SWARM satellites, obtained after treatment, showed that field-aligned currents (FAC) with a density of ~ 1.5 μA/m^2 develop in the daytime sector at geomagnetic latitudes ~ (75-85) º after each *Psw* sharp increase. We believe that the emergence and intensification of these current systems leads to the development of specific polar-latitude negative bay-like magnetic disturbances recorded by ground magnetometers.

Introduction

The work is a continuation of a comprehensive study of one of the most intensive magnetic storms of the 24th solar activity cycle (*Sym*H ~ -220 nT), registered on June 22-23, 2015. Earlier [1] the authors considered geomagnetic high-latitude effects at different phases of this storm caused by atypical conditions in near-Earth space. In this work we analyze daytime high-latitude ionosphere-magnetosphere disturbances in the preliminary phase of the storm, connected to the sharp fronts of the solar wind dynamic pressure (*Psw*). Most of the earlier works focuses on the effects, associated with sharp fronts of *Psw*, at medium and low latitudes. However, it is known that such jumps of *Psw* can cause both rapid reorganization of the convection system [2] and the appearance of a new systems of field-aligned currents (FAC) in the daytime sector of high-latitude ionoshpere [3]. For our study we used 1-min data on solar wind parameters and simultaneous ground measurements of Scandinavian profile *IMAGE* and antipodal on LT North-American network of observatories, as well as data on energetic ions and protons fluxes from DMSP satellites over the auroral oval, and measurements of the magnetosphere magnetic field by low-orbit satellites of the SWARM mission, the trajectory of which lies near midday-midnight meridian.

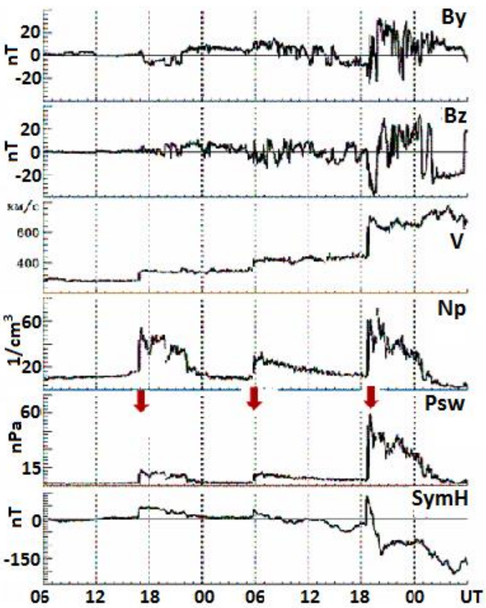

Figure 1. 1-min variations in the solar wind and IMF parameters and the *Sym*H index for June 21-22, 2015.

The solar wind parameters and ground-based observations

Fig. 1 shows 1-min variations of the *By*, *Bz* components of IMF, the density *Np* and the velocity *V* of the solar wind, and the geomagnetic activity index *Sym*H for June 21 - 22, 2015 (*http://omniweb.gsfc.nasa.gov*). It can be seen in Fig. 1 that during the initial phase of the storm, three sharp *Psw* jumps were recorded, mainly due to sharp increases in density (up to 50-60 cm-3) at a low solar wind speed (350-400 km/s). Only in the third event the growth of the solar wind speed was recorded from ~400 to ~700 km/s. The nature of variations in the solar wind parameters (long structures with an increased density) indicates that all three *Psw* jumps were initiated by coronal mass injections (CME). A similar event became possible as a result of a series of flares of the X-ray class "M" on the Sun on June 21, 2015, which threw the CME toward the Earth. The approach to the magnetopause of the first two dynamic impacts, as can be seen from Fig. 1, did not lead to the development of a magnetic storm, but caused the development of high-latitude bays. The main phase of the storm begins only after the approach of the third blow with the rotation of the *Bz* component of IMF to the south.

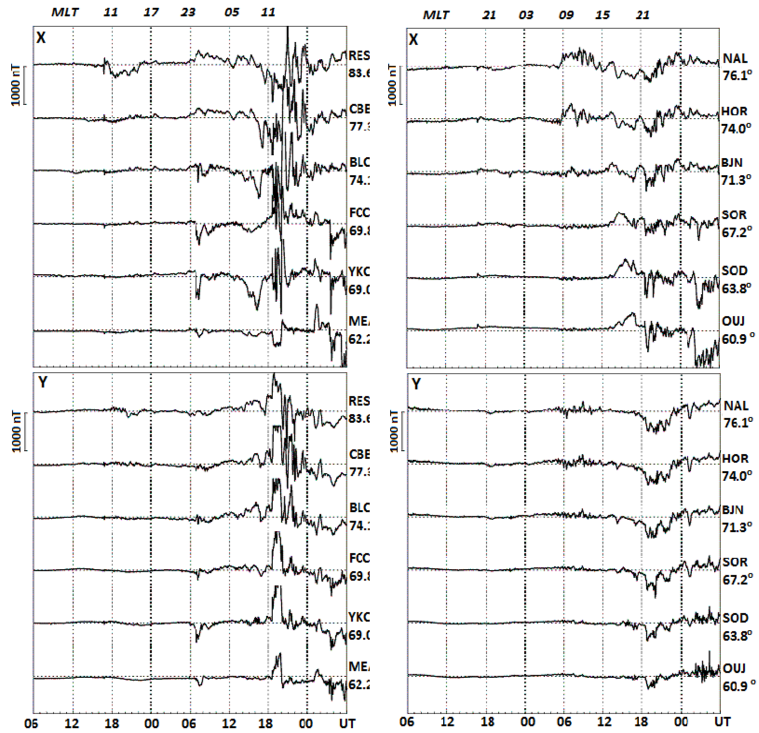

Figure. 2. Magnetograms of the polar observatories on the IMAGE profile and the antipodal on LT North-American sector for June 21 - 22, 2015.

Fig 2. shows variations of X- and Y-component of ground magnetic field, registered by the stations of Scandinavian profile *IMAGE* and antipodal on LT North-American network of observatories for June 21 - 22, 2015. On magnetograms of high-latitude observatories, the first shock front (at 16:45 UT) was observed in the dusk sector as a sharp impulse in the X-component (negative at higher latitudes and positive at lower latitudes). In the near-noon and post-noon sectors a negative magnetic bay started too. The pulse sign reversal at Φ ~ (67-71)° allows to assume that the boundary of open and closed field lines in the dusk sector was located there. In the daytime sector, at latitudes > 80 °, insignificant bays developed. The second front (at 05:44 UT on June, 22) was weaker, but occurred with negative *Bz* IMF, and led to the development of positive polar bay ~ 400 nT in the daytime and night sectors, which change to negative at the auroral stations of the North-American sector. The third, most powerful, jump of *Psw* (at 18:38 UT on June, 22) occurred at the beginning of the main phase of the storm. It caused very intensive negative X-bays (up to ~ 1500 nT) in both the night and day sector. The top panel of Fig.1 shows the local time on the chains of stations, and to the right of each chart the station abbreviated designation and their geographical latitudes are signed.

Observations on spacecrafts

To trace the dynamics of magnetic disturbances in the ionosphere, we used SWARM A and C satellites data and the auroral oval OVATION model. The SWARM has a circular orbit at an altitude ~ 400 km in the midday-midnight meridional plane with a period of about 1.5 h. To determine the perturbations, the main field IGRF-2015 was subtracted from the measured magnetic field. SWARM A and C satellites orbits are near. Fig. 3 shows examples of the distribution of magnetic perturbation vectors recorded during three flights of SWARM A over the northern polar region on June 21, 2015: before the shock arrival, immediately after it and by two hours after. To the right and left of the vector diagrams, MLT of flight and departure of the satellite is shown. As can be seen from Fig. 3, significant magnetic perturbations appeared in the daytime region of the polar cap (Φ > 75°) immediately after the arrival of the shock. In this case, when the *By* IMF changes from a weak positive to a negative at ~17:30 UT, magnetic vectors observed in the near-noon sector of polar latitudes, change sign to the opposite. This indicates a reorganization of FAC systems, associated with them. On the bottom panel of Fig. 3 auroral oval locations at UT=16:00 and UT=16:50 (that is, before and after the first pressure front) from the OVATION model are shown too. Black circles show the positions of observatories of the IMAGE and the North-American chain. The time UT=16:50 corresponds to the time between the first and second spans of the SWARM A on the top panel of Fig. 3. The auroral oval shows a noticeable expansion both towards the high and low latitudes at all MLT sectors.

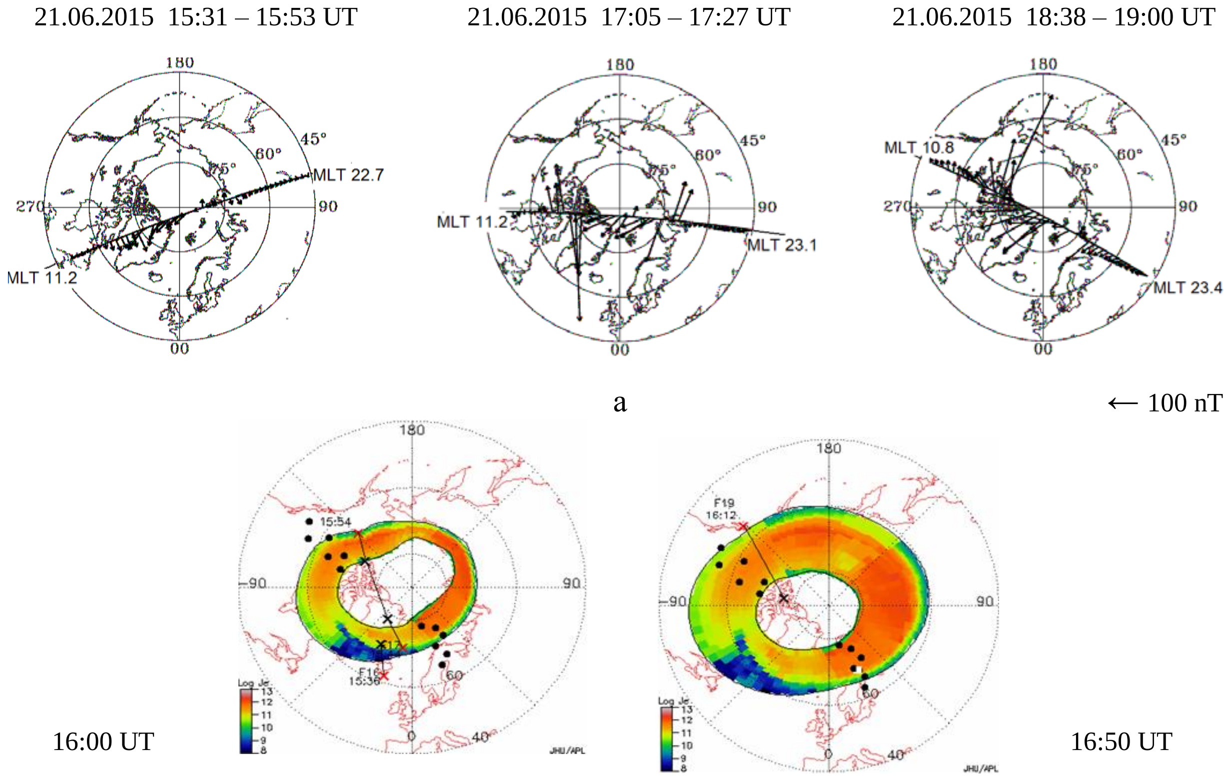

Figure 3. Magnetic field vectors from the SWARM A data (top panel) and positions of the auroral oval from the OVATION model *[http://sd-www.jhuapl.edu/Aurora/ovation]* on June 21, 2015.

The size of publication does not allow placing the all available data from satellites spans. Therefore, here we give magnetograms of SWARM A, demonstrating the response to the arrival of the most powerful, the first and third, shock fronts to the Earth. Fig. 4 shows trajectories of SWARM A, C satellites (blue and red lines) on June 21-22, 2015 (top panel); variations of the east-west component dB_y of the geomagnetic field before and after arrivals of shock fronts at 16:45 UT on June 21 and at 18:38 UT on June 22 (middle panel); spectrograms of the DMSP satellites in close time spans (bottom panel). Green line shows trajectories of the DMSP satellites. Since the trajectories of the satellites are presented in geographic coordinates, MLT of an entry and departure of the SWARM is shown on the top panel of Fig. 3. From the measured variations of the magnetic field one can estimate the FAC intensity (in 1D approximation). Estimates give the following values, respectively: $J_{\|} \sim 0.3$ μA/m^2, $J_{\|} \sim 1.5$ μA/m^2 and $J_{\|} \sim 2.1$ μA/m^2. The shown magnetic disturbances are recorded in the near-noon sector of polar latitudes $\Phi > 75°$, corresponding to the location of the NBZ (or zone 3) of field-aligned currents. Their dynamics shows that an intensity of associated FAC increases after an arrival of each impacts. Spectrograms DMSP also show an increase in the flux of electrons with energies of 0.1-3 keV and ions with energies of 1.0-10 keV in the daytime sector of polar latitudes after each shock. Thus, it can be assumed that the intensification of FAC in the near-noon sector leads to the development of specific polar-latitude negative bay-like magnetic disturbances observed on the ground.

Conclusions

It is shown that the development of perturbations in the high-latitude ionosphere in response to the arrival of the shock front of the solar wind dynamic pressure *Psw* depends on the prehistory in the solar wind conditions. After few days of quiet solar wind, the intensive front did not lead to the development of significant disturbances. However, the like shock front, following after the two previous ones, led to the development of daytime and night substorms as well as to the beginning of the intensive storm.

Magnetic disturbances, obtained after treatment of SWARM satellites data, showed that each of the three *Psw* jumps led to the development of field-aligned currents with a density of ~ 1.5 μA/m^2 in the near-noon sector at geomagnetic latitudes ~ (75-85)º. We believe that the emergence and intensification of these current systems lead to the occurring of specific polar-latitude bay-like magnetic disturbances recorded in the daytime sector by ground magnetometers.

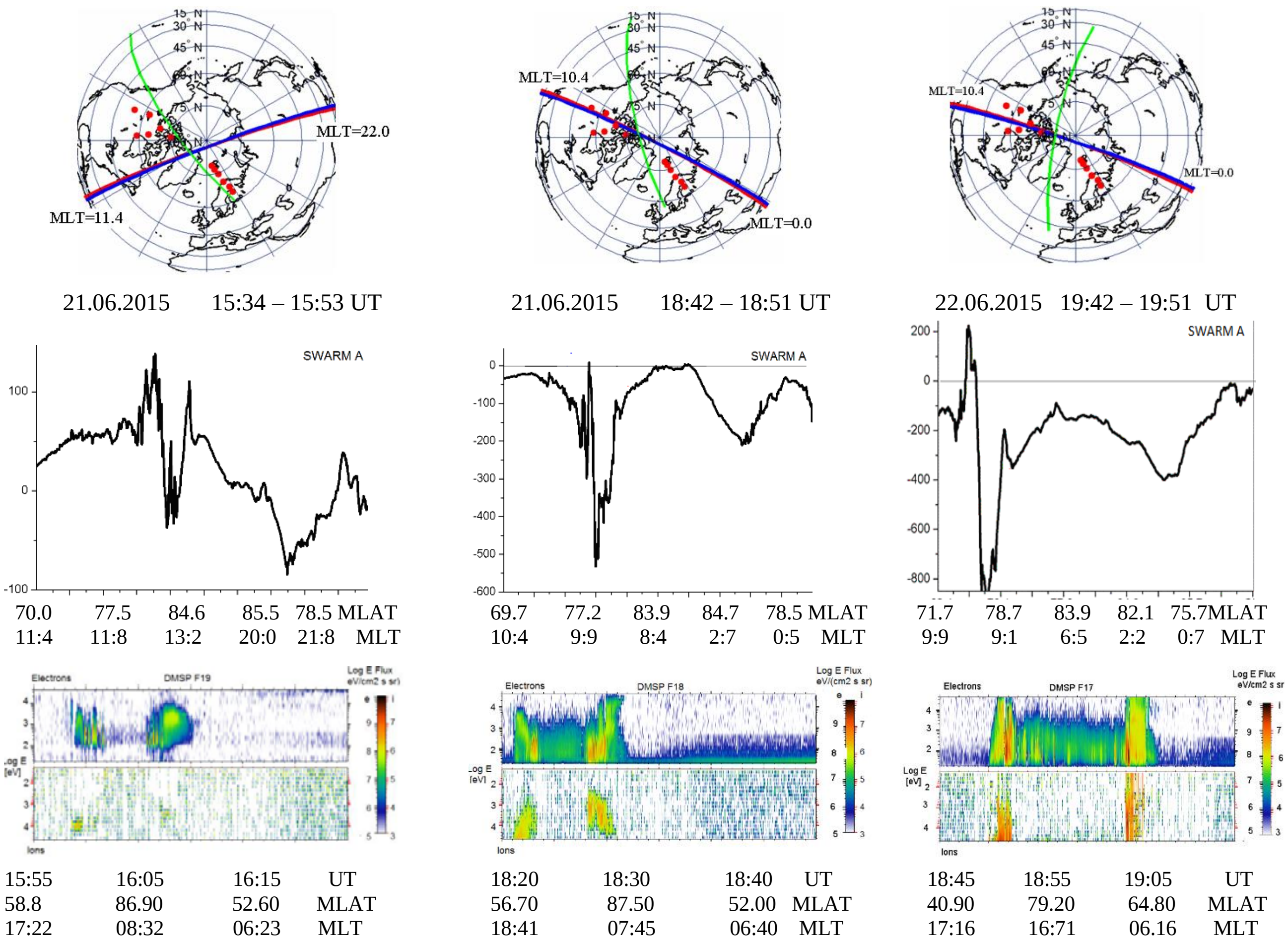

Figure 4. Trajectories of SWARM A, C satellites (blue and red lines) on 21.06.2015 before and after the arrival of the shock fronts (*top panel*) (green line shows the simultaneous spans of DMSP satellites); variations of the east-west component of the magnetic field, measured by the SWARM A (middle panel); spectrograms of the DMSP satellites (*bottom panel*).

References

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