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Ionospheric Irregularities over Norilsk during the 27–28 May 2017 Geomagnetic Storm

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Abstract

We present the multi-instrumental study of ionospheric irregularities with different scales, which were observed over the Norilsk area, Russia, during a moderate-to-strong geomagnetic storm at May 27-28, 2017. Ionospheric electron density variations were observed by GNSS receivers, at the Swarm and DMSP satellites. From UHF radar data, we observed an intense auroral backscatter right after the initial phase of the geomagnetic storm. Concurrently, we have registered high rate of TEC fluctuations as deduced from the Norilsk GPS-receiver. Ionosonde data also exhibited a presence of the E-layer irregularities.

1. Introduction

The geomagnetic storm is associated with the chain of events and phenomena in space environment, beginning at the Sun and transmitted through the magnetosphere into the thermosphere-ionosphere system. In this paper we studied the high-latitude ionospheric irregularities over the Norilsk region during the 27–28 May 2017 geomagnetic storm by using GNSS, UHF radar, low Earth orbit Swarm, and DMSP satellites, vertical sounding station (ionosonde) and ground based magnetometer at Norilsk. Using such a multi-instrumental and multi-point database provides an excellent opportunity to allocate an occurrence of ionospheric irregularities with various scales and at different altitudes (E-region, F2-layer and topside ionosphere).

2. Observations

A moderate geomagnetic storm occurred on the 27th May 2017. The main phase developed at the 28th May and was characterized by a minimal excursion of the Dst index to -125 nT. The maximum AE index was ~2000 nT. The recovery phase began on 28 May 2017 and lasted until the 30th May 2017. Figure 1 shows the interplanetary and geomagnetic conditions during 26 – 29 May 2017.

The magnetic storm discussed at the first its stage was initiated from a quite background by quick changes in the solar wind velocity and dynamic pressure. The new growth of the magnetic perturbation appeared later after IMF Bz changed its sign to a negative. The Kp-index well follows after IMF Bz.

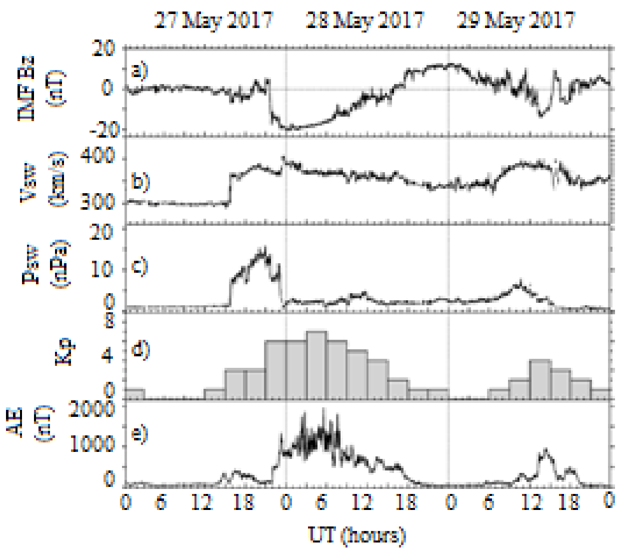

Figure 1. The IMF Bz (a), solar wind velocity (b) and pressure (c) taken from the OMNI database and the geomagnetic indices Kp (d) and AE (e) for the period 26 – 29th May, 2017 are presented.

2.1 GNSS data

We have analyzed data from two GNSS stations: NRIL (Norilsk, 69.3°N, 88.3°E) and NOVM (Novosibirsk, 55.0°N, 82.9°E) to reveal signatures of ionospheric irregularities occurrence in the vicinity of these stations. These GNSS receivers provide observations with 30 seconds recording interval and allow to detect irregularities with a scale size of about tens of kilometers.

For this purpose, the rate of TEC (ROT) was calculated from observational data (RINEX files) using the method proposed by Pi et al. [1]. ROT was calculated in units of TECU/min for each visible satellite over GNSS station. ROT was calculated for all GPS satellites with elevation angle above 20 degrees.

Analysis of the ROT variations (see Figure 2) has revealed: (1) the occurrence of ionospheric irregularities over Norilsk (NRIL) almost at the same time as at E region irregularities appear (see part 2.2 below); (2) the absence of ionospheric irregularities over the Novosibirsk station (NOVM).

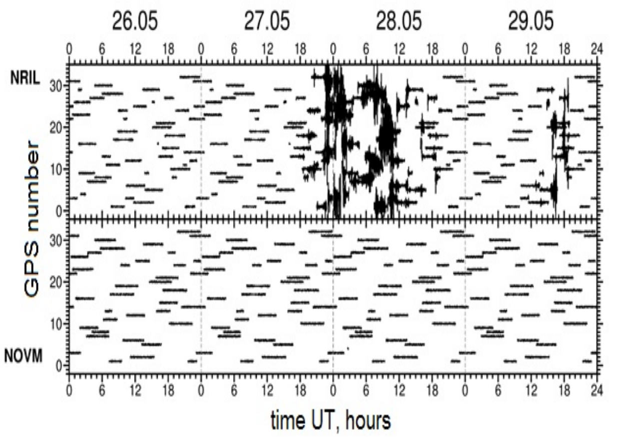

Figure 2. GPS ROT fluctuations as a function of UT over NRIL and NOVM stations during the 26-29th May 2017.

2.2 Radar data

We have analyzed echoes from the UHF High-Power Large-Aperture radar (440 MHz) located in the Krasnoyarsk area (56°N, 93°E) with a poleward orientation field of view. This radar covers distances up to 2000 km in azimuth sector of about 100 degrees at an elevation angle of about 3 degrees. The minimum off-orthogonal angle for this radar was about 3 degrees. Since the radar operating frequency is about 440 MHz then E-layer irregularities observed have a size of 0,7 m.

We will analyze a height band of 70 – 150 km through all radar measurements. The echoes at heights of approximately 90 – 130 km correspond to auroral radar backscatter [2]. Each echo at these heights corresponds to field aligned ionospheric irregularity with a size of about 35 cm.

Through all data we will discuss three cases. Figure 3 represents the first case relative to (a) quite geomagnetic conditions in the auroral zone and (b) initial phase of the geomagnetic storm which leads to intense auroral backscatter. One can see in Figure 3 a sharp increase of echoes at 100 - 130 km. Echoes in the first part of this case (22:10 – 22:33 UT) correspond to weak auroral backscatter and meteor echoes (specular, non-specular and head echo) [3]. Intense auroral backscatter lasted for about 13 hours until May 28, 10:55 UT.

Generally, the considered time interval on Fig. 3 covers complex and prolonged geomagnetic storm consisting of several substorm-like activisations.

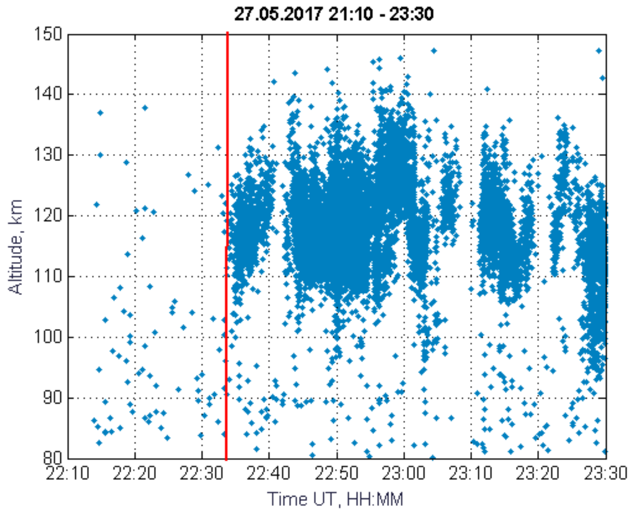

Figure 3. The time-altitude dependence of radar echoes (the blue dots) including meteor echoes, weak and intense auroral radar backscatter. The red vertical line is a start of magnetic storm in small-scale irregularities

Figure 4 presents a second case: a time interval when the auroral radar backscatter disappeared for ~1.5 hours. We don’t have direct measurement but this phenomenon most likely related to decreasing ionospheric electric field. Also, the absence of auroral backscatter could be explained as the ionospheric convection changing direction.

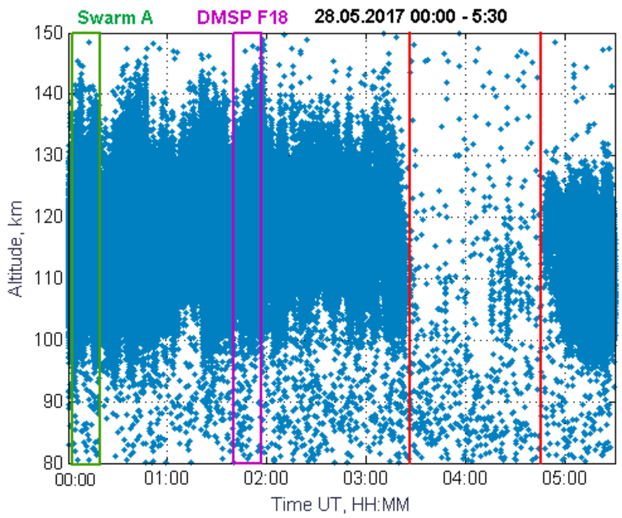

Figure 4. The time-altitude dependence of echoes (the blue dots) illustrates the intense auroral radar backscatter (before and after the solid red lines) during the main phase of the geomagnetic storm. The pink and green lines correspond to time intervals when satellites DMSP F18 and Swarm A, respectively, were passing through the Norilsk region (see Figure 6).

Figure 5 represents the third case: a time interval with auroral radar backscatter evolution, from intense to weak, during the recovery phase of the geomagnetic storm.

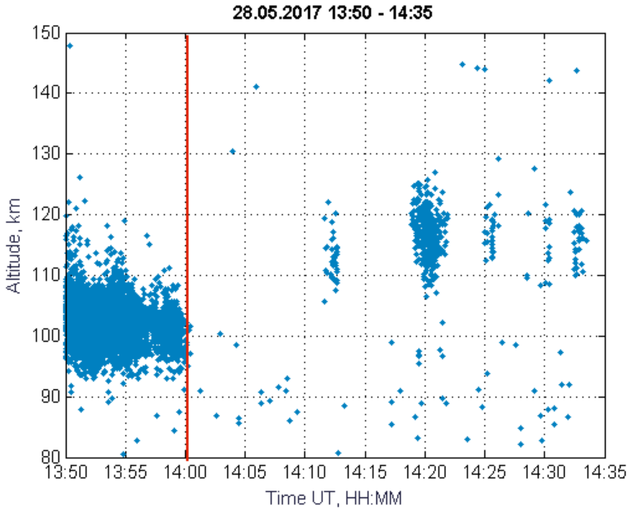

Figure 5. The time-altitude dependence of echoes (the blue dots) during the recovery phase of geomagnetic storm and end of the intense auroral radar backscatter (after the solid red line).

2.3. Satellite data

The Swarm and DMSP satellites provide in-situ measurements of electron/ion density along their polar orbit. The projections of Swarm A and DMSP F18 orbits onto the surface of the Earth at two different UT epochs, on 28 May, 2017, are presented in Figure 6. Figure 7 illustrates an example of a comparison of two plasma density profiles by Swarm A and DMSP F18 for the quiet day of 26 May 2017 and the storm day of 28 May 2017. One can see an occurrence of intense plasma density irregularities during the main phase of the storm was registered as southward as 60°N at both altitudinal regions of 465 km and 835 km, whereas at quiet conditions ionospheric irregularities were observed mainly poleward of 75-80°N.

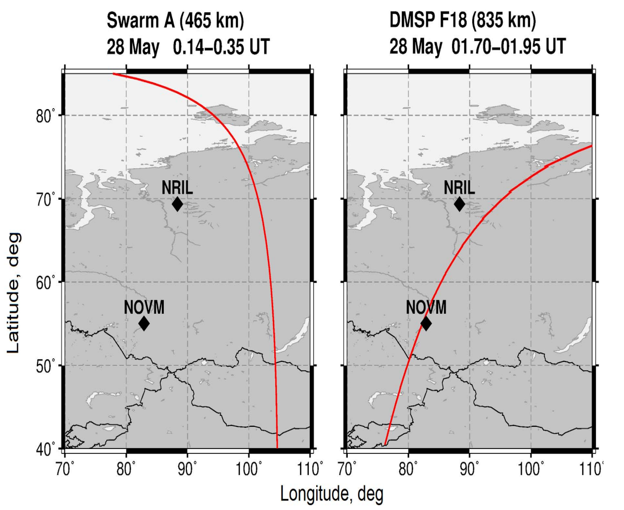

Figure 6. Swarm A and DMSP F18 passes on the 28th May.

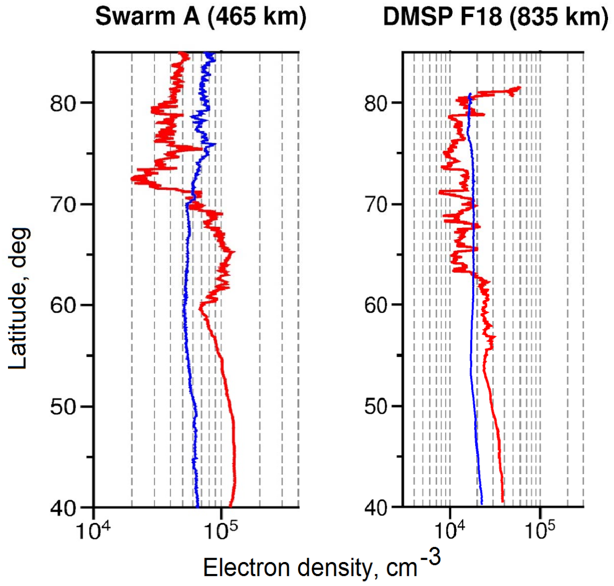

Figure 7. Latitudinal profiles of in situ plasma density measurements by Swarm A (left) and DMSP F18 (right). The red line corresponds to the 28th May 2017 (storm day), the blue line – 26th May 2017 (quiet day).

2.4 Ionosonde data

In addition, we used the Norilsk DPS-4 ionosonde. Figure 8 illustrates an example of the ionogram, recorded by the Norilsk station at 20:45 UT on 27 May, 2017. An intense sporadic E-layer was observed at the ionogram as a function of the virtual altitude. We conclude that the E region ionospheric irregularities most probably can be associated with high-energy particle precipitation in the expanded auroral oval.

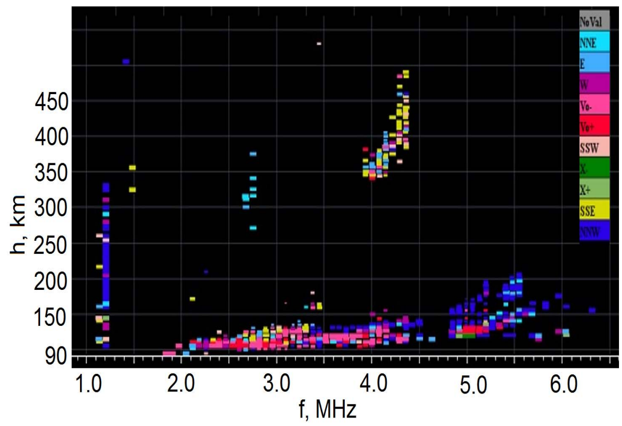

Figure 8. Norilsk vertical sounding ionogram for 20:45 UT on the 27th May 2017.

Analysis of the ionogram sequence on 27-28 May allows us to conclude that: (1) clear traces from the E and F2 layers (and also during the daytime from the F1-layer) are visible on May 27 up to 16:00 UT; (2) from 16:00 to 17:15 UT the E layer develops; (3) from 17:45 to 20:00 UT the ionograms over Norilsk are very variable – total absorption is replaced by strong F-spread; (4) from 20:15 to 21:00 UT the ionograms indicate the development of an irregular auroral E-layer over Norilsk; (5) from 21:00 UT on May 27 to 12:00 UT on May 28, the useful information on ionograms is practically absent (at this time on ionograms, one can see only a part of the trace from the E-layer and then only at certain points in time). The lack of information on the ionograms at the end of May 27, and in the middle of May 28, may be due to the complete absorption of the signal at heights of the lower ionosphere, and a significant decrease in the electron density in the F region over Norilsk. Both can be due to the fact that Norilsk was, at that time, in the region of precipitations of auroral electrons and more severe energetic particles.

2.5 Magnetic measurements

We analyzed variations of the vertical component of geomagnetic field $dZ = Z_{storm} - Z_{quiet}$, where Z_{storm} corresponds to the storm time (the 27th May) and Z_{quiet} – to the quiet day (the 26th May). Norilsk station (59.9°N, 166.7°E - geomagnetic coordinates) detected negative dZ from ~16:00 UT on the 27th May (Fig. 9) that corresponded to a global compression of the magnetosphere. The compression resulted in increase of the Z component, which was directed downward in the Northern Hemisphere, i.e. Z is negative. Hence the increase of negative Z led to an increase of negative dZ. From 22:00 to 24:00 UT, positive peak of dZ was observed. This peak was produced by the high-latitude westward electrojet. From 22:13 to 23:12 UT, the magnetometer observed very strong positive dZ variation of several hundred nT magnitude. From 23:13 to 24:00 UT on the 27th May the variations of strong negative dZ up to 300 nT were observed.

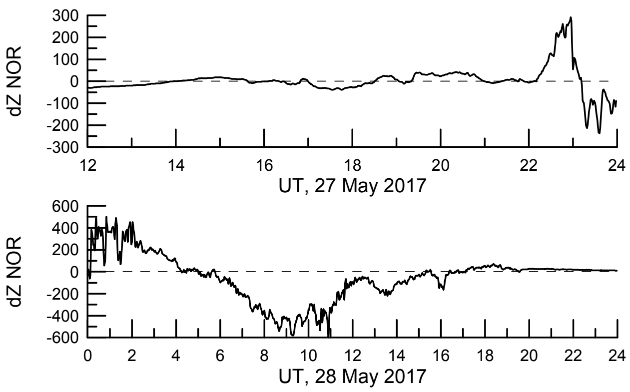

Figure 9. Storm-time variations of the vertical magnetic component (dZ) observed by ground based station Norilsk on (a) 27 and (b) 28 May 2017.

The variations were produced by the equatorward shifting of the westward electrojet. From 00:00 to ~02:30 UT on 28th May, the variations of strong positive dZ with ~500 nT magnitude were observed. Those variations were related to a strong auroral electrojet and intense auroral activity above Norilsk. Another time interval of strong variations of negative dZ with amplitude up to 600 nT was observed from ~08:30 to ~10:00 UT on the 28th May. This interval was corresponded to the equatorward shifting of the westward electrojet and very intense auroral activity above and southward from Norilsk.

3. Conclusion

This paper represents the multi-instrumental overview of the main features of multi-scale high-latitude ionospheric irregularities observed over the Norilsk region during geomagnetic storm at the 27-28th May, 2017. Large-scale irregularities and associated TEC fluctuations were registered by the Norilsk GPS station. Small scale irregularities in the E region were detected by UHF radar and ionosonde.

We have revealed a coincidence between the initial phase of geomagnetic storm, and the appearance of intense auroral radar backscatter with growth of the GPS ROT fluctuation intensity. In our presentation we will show more detailed results of this event analysis by involving the AMPERE satellite constellation data [4], and ground-based magnetometers, as well as UV-spectrographic measurements in order to compare the spatial structure of a visible aurora and an auroral radar backscatter.

4. Acknowledgements

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5. References

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