Supersubstorm on 20 December 2015: Spatial Geomagnetic Effects

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Abstract

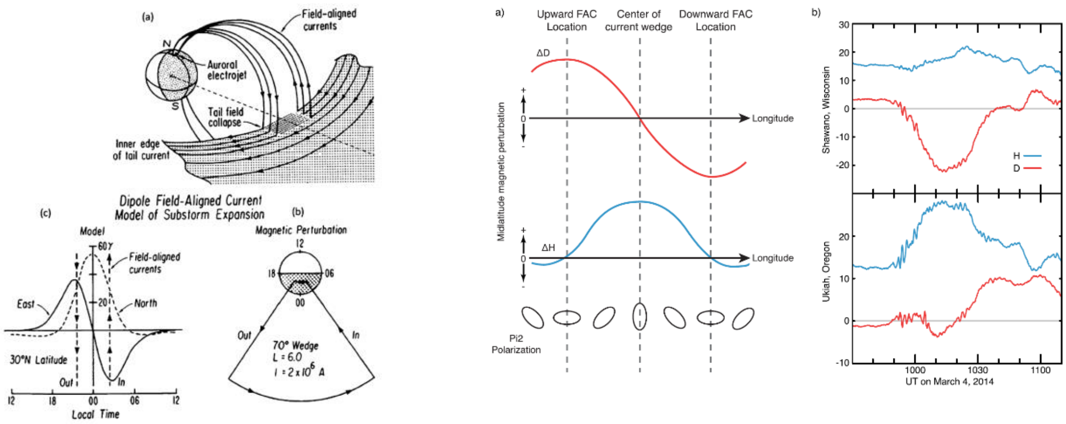
We analyzed the supersubstorm (SML- index ~2100 nT) observed on December 20, 2015 (onset at ~ 16:10 UT) during the intense magnetic storm caused by the magnetic cloud (MC), which included a stable southward Bz IMF direction. It is shown that the ionospheric currents, corresponding to this supersubstorm, developed on a global scale, from the evening to the late morning sectors. During its development, the very intense westward electrojet was observed with the maximum in the morning sector (~06 MLT). In the evening sector (~18 MLT), the strong eastward electrojet was observed. During the expansion phase of the substorm in the evening sector, variations in the magnetic field were observed, corresponding to the appearance of an additional current wedge in the opposite direction. The development of the substorm was accompanied by the appearance of a large positive variation in the X component of the magnetic field at geomagnetic latitudes from ~60° to ~50°, which could lead to the observed pulse of the MPB index (Midlatitude Positive Bay index). Thus, this supersubstorm demonstrated its global behavior accompanied an addition substorm current wedge development.

Keywords: solar wind**,** supersubstorm, substorm current wedge, MPB index

1. Introduction

Our work is devoted to the study of spatial geomagnetic effects of substorms as important elements of the space weather. It is known that the westward electrojet occurs in the night side during the expansion phase. This electrojet is a part of substorm current wedge (SCW), the classical picture of SCW presented in the Figure 1a. The large-scale current pattern was obtained by analysis of the magnetic disturbances at the mid-latitudes [McPheron et al. 1973; Horning et al. 1974]. This system is called the "substorm current wedge" because of its form in a polar projection (Fig.1a). In its simplest form, a model of the SCW consists of a single loop with line currents into and out of the ionosphere (on dipole field lines connected by a westward ionospheric line current and by an eastward magnetospheric line current). The SWC produces a distinctive pattern of changes in the ground-based magnetic field components, as shown in the Figure 1b [Kepko et al. 2015]. North component of the magnetic field (H) is positive and symmetric about the central meridian of the SCW, while the East component (D) is antisymmetric. In the northern hemisphere the D- component is positive premidnight and negative postmidnight. Note, that for estimation of the SCW intensity was introduced a new index – the mid-latitude positive bay index (MPB- index), which calculated by magnetic field variations at mid-latitudes [McPherron and Chu. 2016, 2018].

In our work we considered some peculiarities in the electojets development during one event of very intense substorm, so-called supersubstorm (SSS). First the term of "supersubstorms" was introduced by investigations of intense magnetic substorms by data of the SuperMag magnetometers network, the events with high negative values of SML index (< - 2500 nT) were called "supersubstorms" [Tsurutani et al. 2015]. The purpose of this work is the analysis of spatial geomagnetic effects and possible mid-latitudes magnetic effects during supersubstorm on 20 December 2015 (SML index ~ -2100 nT).



a) **b)**

Figure 1. *(a) dipole field-aligned current model of substorm expansion and ground-based magnetic perturbations (picture was taken from McPherron et al. 1973); (b) schematic pattern in the H- and D-components development as a result of SCW (picture was taken from Kepko et al. 2015)*

2. Data

The solar wind and IMF parameters are taken from OMNI database ftp://ftp.iki.rssi.ru/omni/ and the catalog of large-scale solar wind types ftp://ftp.iki.rssi.ru/pub/omni/catalog. Global magnetometer networks SuperMAG and IMAGE data were used for determination of the substorm development as at the midlatitudes well as at auroral latitudes. The IMAGE magnetometer data are taken from http://space.fmi.fi/image/. The global spatial distribution of electrojets was determined from the maps of magnetic field vectors obtained on the SuperMAG network. SML- index is taken from http://supermag.jhuapl.edu/. MPB index is taken from the Chu list (McPherron and Chu [2018]). To study the global distribution of ionospheric currents during SSS, we used magnetic registration data from 66 communication satellites of the AMPERE project (http://ampere.jhuapl.edu/products) as the maps of the distribution of geomagnetic disturbances summarized in 10 min with 2 min shift and the results of a spherical harmonic analysis of magnetic measurements.

3. Solar wind and IMF conditions

Figure 2 shown the variations of solar wind and interplanetary magnetic field (IMF) parameters and some geomagnetic indices on 20 December, 2015. It is seen that two consecutive structures in the solar wind were observed: SHEATH and magnetic cloud (MC). It is seen the passage of a magnetic cloud past the Earth, in front of MC there is a plasma compression region (SHEATH). Besides, solar wind was relatively slow, the speed does not exceed 500 km/s. In this event, a very high values of the solar wind density and dynamic pressure were registered. A stably negative Bz component of the magnetic field observed in the magnetic cloud (drops to -19 nT). As a result, the intense magnetic storm developed (SYM/H was -170 nT). Several substorms were observed during this magnetic storm. During one of them, at 16:13 UT, the SML index reach ~-2100 nT. At the Figure 2b the period on December 20, 2015 presented in more detail. It is seen, that before SSS the high values of the southern Bz component of the IMF (~-15 nT) were observed, By component of the IMF was positive, solar wind velocity was low (~400 km/s). Three peaks of MPB index were registered, first of them (~ 4000nT^2) correspond to SSS.

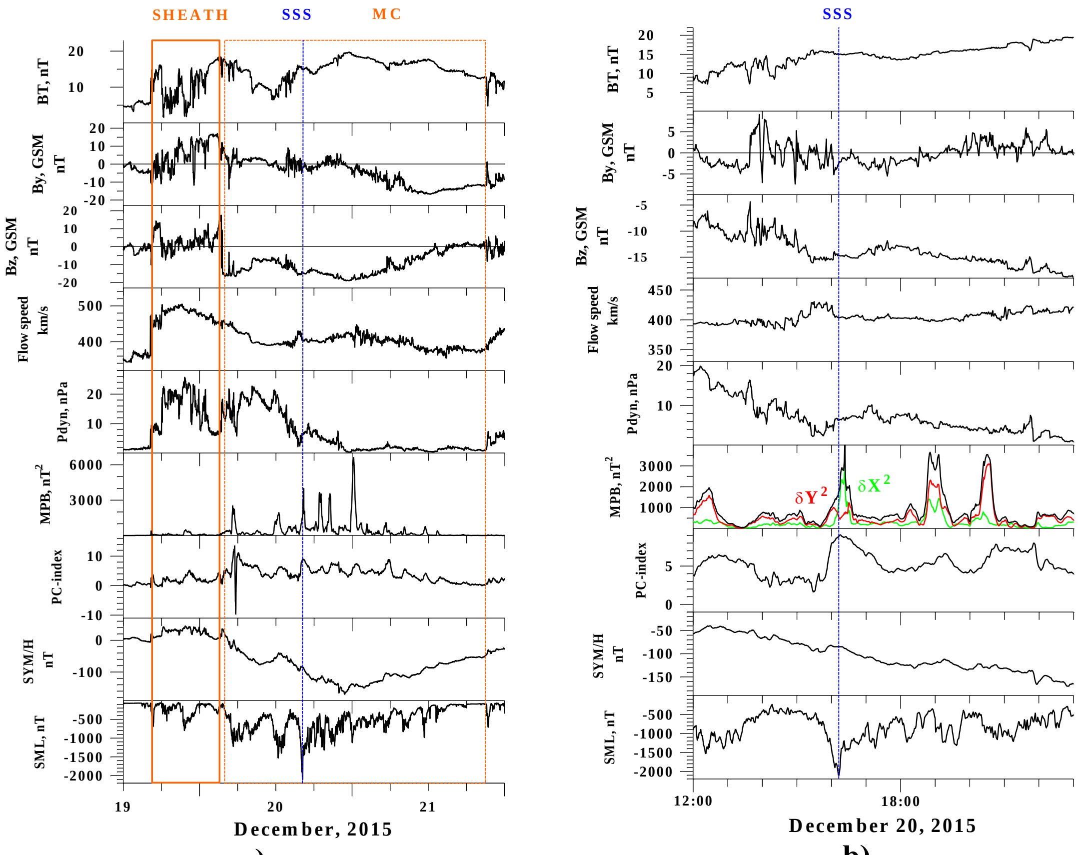
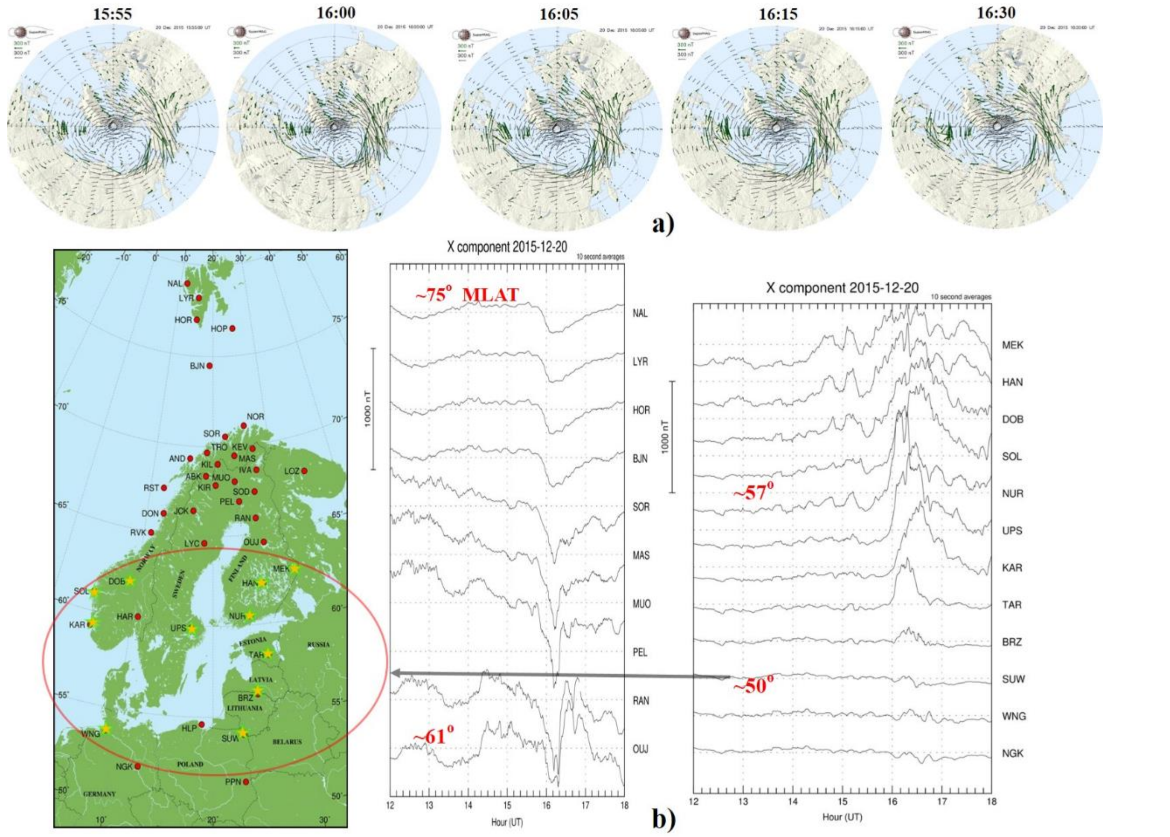


Figure 2. *Variations of the solar wind and IMF parameters (BT, By, Bz, V, Pdyn) and some geomagnetic indexes (MPB, PC, SYM/H, SML) from 12 UT on 19 December to 12 UT on 21 December 2015 (a) and from 12 to 23 UT on 20 December 2015 (b). The boundaries of the solar wind types are marked by red rectangles and inscriptions: SHEATH and MC. The moment of the SSS onset is shown by the vertical blue line.*

4. Magnetic field variations by ground-based magnetometers

Ground-based magnetic disturbances during SSS are shown in Figure 3. At the top panel shown the global maps of magnetic field vectors by SuperMag data for 5 time moments, from onset to maximal study of SSS development (Fig.3a). Magnetic vectors rotated to 90° clockwise and shown the direction of ionospheric currents. SuperMag maps also shown the locations of magnetic stations: IMAGE network was located in the evening sector, the station of Greenland and Canada - in the day sector, Siberia and Alaska stations- in the night and morning sector, respectively. It is seen that very strong disturbances were observed at the auroral zone in the postmidnight and morning sectors on the Alaska stations (Barrow, College and Yellowknife). The westward electrojet developed in a global scale in the longitude - from dawn to the dusk one.

Figure 3b presents the variations of X- component of magnetic field observed at the IMAGE magnetometers, at the left panel shown the map of IMAGE stations. An analysis of the IMAGE data showed that at the stations from Ny-Ålesund to Oulujärvi negative bays were observed in the X-component of the magnetic field (~ -850 nT). At this time, to the South, from Mekrijärvi to Birzai, positive bays were observed, these stations are marked by yellow stars on the map.



F**igure 3**. *(a) - Global maps of spatial distribution of magnetic field vectors from the SuperMAG network at 15:55, 16:00, 16:05, 16:15 and 16:30 UT (a);the map and magnetograms of some stations on IMAGE network from 12 to 18 UT on 20 December 2015 (b). Yellow stars are marked the stations, were observed the positive magnetic bays.*

Figure 4 shows some magnetograms by the SuperMAG data at different longitudes from 12 to 20 UT on 20 December 2015. It is seen that negative bays were observed from the North of Norway (AND) through Siberia to the North-West of the Canada (C07). The maximal disturbances were registered in the morning sector (BRW). At the right panel, you can see positive bays, which observed at station located at ~56 - 60° magnetic degrees from the North of Scotland (LER) through the South of Scandinavia to the South of the Arkhangelsk region (KLI). The positive bays were also registered at latitudes of ~52°, in Moscow, Kazan and near Yekaterinburg (~100 nT).

5. Ionospheric currents from AMPERE observations

Figure 5 presents some maps of magnetic field vectors, obtained by SuperMAG, spherical harmonic analysis of magnetic registrations and equivalent downward (upward) currents obtained by AMPERE project. Three panels corresponded to growth (a), expansion (b) and maximal (c) phases of SSS. It is seen that during expansion phase the magnitude of the westward electrojet strongly increases, and the electrojet observed at the global scale – from midnight to day sector. The eastward electrojet also intensifies. Then, in the evening sector, rotation of the magnetic vectors around the eastward electrojet begins to be observed. Better the vortex of magnetic vectors observed at middle maps of the Figure 5. During maximal development of SSS, the very strong vortex observed in the evening sector, corresponded the increased upward currents. At the left panel the turn of vectors is carried out clockwise (counterclockwise), blue ovals indicated their longitudinal dimensions.

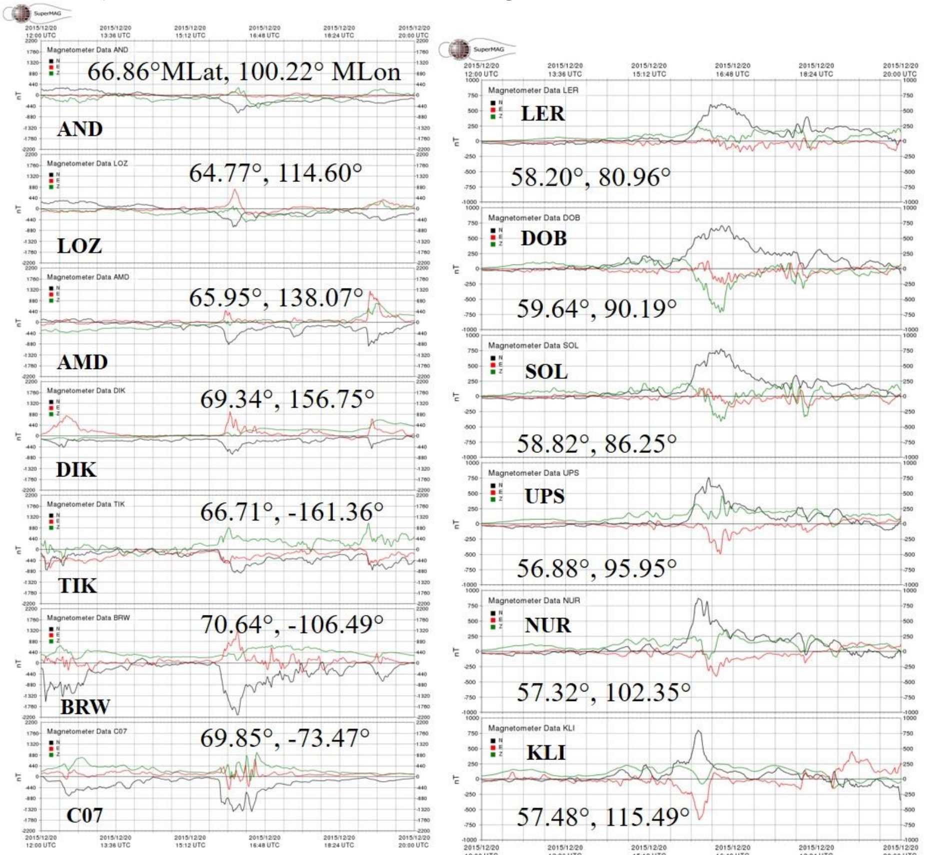


Figure 4. *Magnetograms of some stations by SuperMAG, where negative (a) and positive bays (b) were registered.*

6. Summary and discussion

Spatial geomagnetic effects of the supersubstorm on 20 December 2015 were analyzed using data from the global magnetometer networks SuperMAG, IMAGE and AMPERE project data. It is shown, that supersubstorm developed on a global scale: very intense westward electrojet was observed from the late morning to the evening sector, with the maximum in the morning sector (~06 MLT).

Moreover, the intense eastward electrojet was observed in the evening sector (~18 MLT). During the expansion phase of the substorm, a current structure was observed in the evening sector, which corresponded to the appearance of an additional current wedge of the opposite direction. This idea was proposed in earlier works, when authors considered another supersubstorm events [Zong et al, 2021; Despirak et al., 2022]. Note, that the enhancement of partial ring current simultaneously with formation of SCW indicated in the earliest works [Horning et al., 1974].

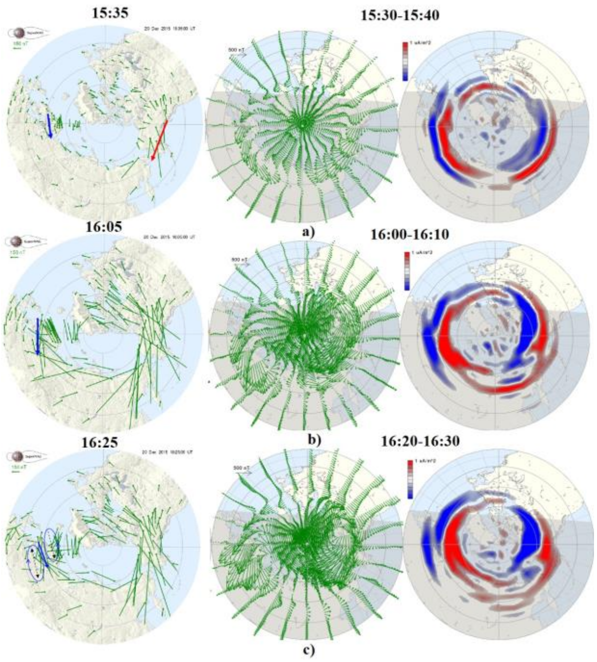


Figure 5. *Global maps of spatial distribution of magnetic field vectors from the SuperMAG network (left maps), spherical harmonic analysis of magnetic field vectors (middle maps) and field-aligned current distribution for three moments: at ~ 08:30 UT and ~ 08:55 UT on December 20, 2015 according to AMPERE data. The upward currents mark by red, the downward ones – by blue. Three panels corresponded to growth (a), expansion (b) and maximal (c) phases of SSS.*

Acknowledgments

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