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GEOINDUCED CURRENTS DURING GEOMAGNETIC STORM ON 27-28 SEPTEMBER 2017

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Abstract. The complex space weather events of September 2017 included interplanetary coronal mass ejections (ICMEs), magnetic clouds (MCs), Sheaths, Corotating Interaction Regions (CIRs), solar wind high-speed streams (HSSs), fast forward shocks. This month can be divided into four events with different space weather conditions: first period on 7-8 September, second period on 12-13 September, third period on 14-17 September and fourth period on 27-28 September. In this report we considered the increasing of geoinduced currents (GICs) during moderate magnetic storm (SYM/H ~ −74 nT) occurring on September 27-28 caused by CIR connected with the high-speed streams (HSS). This storm was characterized by a gradual, multi-step main phase development with maximum at ~06 UT on 28 September. At the background of the storm another geomagnetic activities were also registered – substorms and geomagnetic pulsations – which caused intense GICs on the Vykhodnoy (VKH), Revda (RVD) and Kondopoga (KND) stations in the North-West of Russia and on the Mantsala (MAN) in the South of Finland. The increasing of GICs were controlled by data from registration system on Karelian-Kola powerline in the auroral zone (eurisgic.ru) and in Finland obtained from gas pipeline near Mantsala in the subauroral zone. The fine spatiotemporal structure of electrojet development during substorms were analyzed using the maps of the equivalent currents of the MIRACLE system and IMAGE magnetometers data. It was shown that intense GICs observed in the subauroral and auroral zones were associated with two sources - the movement and intensification of the substorm westward electrojet during the expansion phase of the substorm (in the premidnight sector) and Pc5 pulsations during the recovery phase of the substorm (in the morning sector).

Introduction

It is known that by rapid changes of the geomagnetic fields occurrence the intense, quasi-direct currents flowing in the conductor systems of terrestrial technological networks, these currents were called as Geomagnetically Induced Currents (GICs) [e.g., *Viljanen et al.*, 2006]. Rapid changes in the geomagnetic field are usually associated with the arrival of solar wind shock waves, coronal mass ejections (CMEs) and high-speed streams from coronal holes to the Earth, which lead to the development of magnetic storms and substorms, as well as the appearance of magnetic pulsations [e.g., *Lakhina et al.*, 2020]. Recently it has been confirmed that strong disturbances of the westward electrojet during expansion phase of substorm is one of the reasons for the GICs growth in the auroral zone [*Vorobjev et al.*, 2018; *Tsurutani and Hajra*, 2021; *Despirak et al.*, 2022]. The excitation of GICs in power transmission lines on the Kola Peninsula is controlled by system of continuous observations at three to five nodes of the operating power transmission line from 2011 to the present [*Sakharov et al.*, 2007, 2016]. A number of transformer substations of the Karelia–Kola power transmission line, which runs from south to north across Karelia and the Kola Peninsula, have a continuous metering system for GICs [*Sakharov et al.*, 2019].

In this work we study the case on 27-28 September 2017 when intense GICs on Karelian-Kola power line (Vykhodnoy, Revda and Kondopoga stations) and Finland pipeline near Mantsala are registered. Note, that September 2017 was an extremely active space-weather period with multiple events leading to varying impacts on the Earth's magnetosphere. A large number of space-weather events took place during a period of only one month and resulted in several geomagnetic effects such as magnetic storms (of varying intensity), which caused by CME and CIR, and also high-intensity long-duration event of geomagnetic activity (HILDCAA). The September 2017 was divided into four events with different space weather conditions: first period on 7-8 September, second period on 12-13 September, third period on 14-19 September and the fourth period on 27-28 September [*Haira et al.*, 2020]. Appearance of intense GICs during the first space-weather event on September 7-8, 2017, associated with the development of two strong substorms (supersubstorms), which were observed against the background of two magnetic storms caused by two successive CMEs, was discussed in our previous work [*Despirak et al.*, 2023]. Recently we considered also the appearance of intense GICs during second event on 12-13 September and it has been shown that the increase in GIC amplitudes at different latitudes was associated with the poleward movement of the westward electrojet during the expansion phase of the substorm. Besides, it has been found that the source of the GICs at the recovery phase of the second substorm appeared to be a short pulse of Pc5 pulsations and the amplitudes of GICs during pulsations were comparable with substorms one [*Setsko et al.*, 2023].

In this work we considered the fourth event of space weather registered in September 2017, the event on 27-28 September, when a moderate magnetic storm (SYM-H ~ −74 nT) developed. Solar wind and interplanetary magnetic field (IMF) parameters on 26-29 September 2017 are shown in Figure 1. This time period was characterized the arrival of a high-speed stream (HSS) to Earth, the CIR was registered from ~23 UT on 26 September to ~09 UT on 28 September, then HSS was observed with high speed ~650-700 km/s. Accordingly Haira et al., 2020, the storm was caused by several southward IMF periods (~ −15.4 nT, ~ −11.3 nT, ~ −10.5 nT, ~ −9.5 nT) inside the CIR, this storm was characterized by a gradual, multi-step main phase development with maximum at ~06 UT on 28 September. At the background of the storm three substorms at the IMAGE magnetometers were registered, moments of the substorm onsets are shown by the vertical red lines. We analyzed the fine spatio-temporal structure of the westward electrojet development during these substorms and magnetic pulsations registered at the substorm recovery phase.

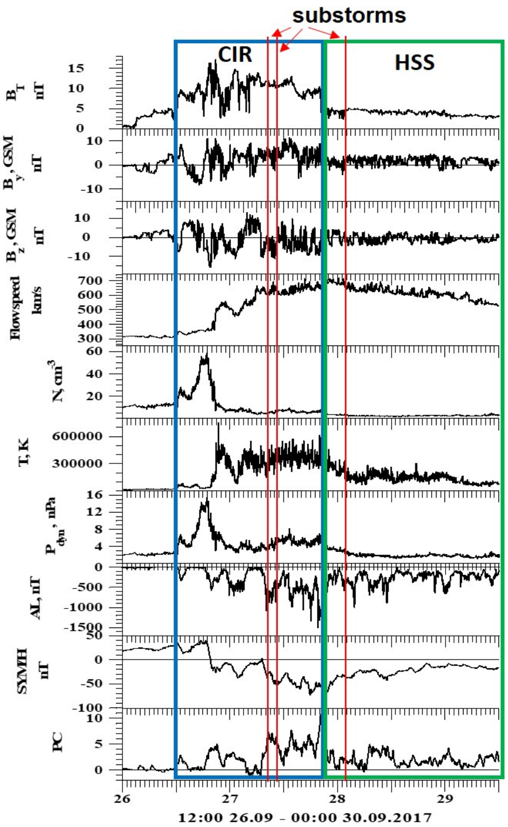


Figure 1. Variations of the solar wind and IMF parameters (B_T, B_Y, B_Z, V, N, T, P_{dyn}) and some geomagnetic indexes (AL, SYM/H, PC) from 12 UT on 26 September to 24 UT on 29 September 2017. The boundaries of the solar wind types are marked by the blue and green rectangles and inscription: CIR and HSS. Moments of the substorm onsets at the IMAGE meridian are shown by the vertical red lines.

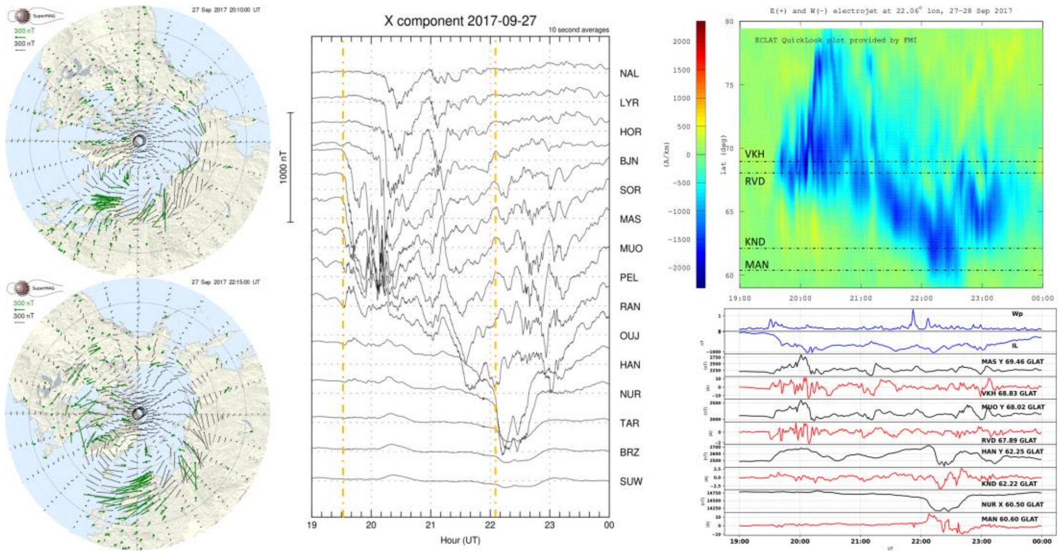
Data

To analyze the GIC appearance, data from two recording systems were used: 1) EURISGIC (http://eurisgic.ru/), located in the North-West of Russia in auroral zone; the points of registration of the GIC and the location of magnetometers can be found in previous works [*Sakharov et al.*, 2007, 2016, 2019]. This power line is located at geographical (geomagnetic) latitudes from ~60° to ~69° (56.6º to 65.5º) directed from south to north. Note that this location corresponds to auroral latitudes where substorm disturbances are usually observed. 2) GIC registration system in Finland obtained from gas pipeline near Mantsala is the subauroral zone (https://space.fmi.fi/gic/index.php) The geographic coordinates of substations, whose data are used in the work: Vykhodnoy (VKH) (68.8°N, 33.1°E), Revda (RVD) (67.9°N, 34.1°E), Kondopoga (KND) (62.2°N, 34.3°E), Mantsala (MAN) (60.6°N, 25.2°E). The development of the substorm was determined by the magnetometers of the IMAGE (http://space.fmi.fi/image/) network, the IL-index is also taken from IMAGE network. Maps of the distribution of ionospheric equivalent currents was taken from MIRACLE (https://space.fmi.fi/MIRACLE/). We used the Wp index is related to the power of the Pi2 pulsation wave at low latitudes. 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.

Results

GICs during substorm activity on 27 September 2017

We divided the time period on 27-28 September on two intervals: the pre-midnight period from 19 to 24 UT on 27 September, when substorms were registered at IMAGE network, and the after-midnight period from 00 to 08 UT on 28 September, when geomagnetic pulsations were observed. Development of substorms and GIC during first period are shown in Figure 2. The first substorm began at ~19:30 UT on September 27 at station PEL and then reached the station SOR. The onset was marked by red vertical line on the IMAGE magnetograms (Figure 2b). The MIRACLE map shows that initially this substorm developed at latitudes from 66° to 72º geographical latitude. At this time, GIC were recorded only at the RVD (~2 A) and VHD (~8 A) stations, located at high auroral latitudes; at the lower latitude stations KND and MAN, GIC were not registered. The second intensification of this substorm began at ∼20:08 UT on PEL station, then the westward electrojet reached the station NAL at ~20:15 UT. Note that the second intensification was more intense (IL ~ 1000 nT), and stronger GIC were observed at the RVD and VHD (~13 A) stations. The second substorm began at ~22:05 UT at NUR station, then the westward electrojet moved to the pole and at ~ 23 UT reached the station SOR. At this moment the intense GIC were registered at VHD (~11 A) and RVD station. While at the beginning of the second substorm, GIC were registered at the MAN (~14 A) and KND stations. Thus, the appearance of intense GIC at different stations occurred in accordance with the leap of the westward electrojet to the pole (movement along latitude) during the expansion phase of the second substorm.



a) **b)** **c)**

Figure 2. September 27, 2017 from 19 to 24 UT: two maps of magnetic vectors from SuperMAG network (a); X-components of geomagnetic field from IMAGE magnetometers (chain SUW-NAL) (b); latitudinal profile of the westward electrojet develpment by MIRACLE system, Wp and IL indexes, Y-components of geomagnetic field from MAS, MUO, HAN and X-component from NUR (black lines), GIC registration on Mäntsälä, Kondopoga, Revda, Vykhodnoy stations (red lines) (c).

GICs during geomagnetic pulsations on 28 September 2017

During after-midnight period, from 00 to 08 UT, were registered also intense GIC connected with substorm at ∼00:40 UT and geomagnetic pulsations observed during recovery phase of substorm in the morning sector. Development of substorms, geomagnetic pulsations and GIC during second period are shown in Figure 3. Format Fig.3 is the same as Fig.2, but without the map of magnetic vectors from SuperMag network. It is seen that small negative bays in the X-component began at ~00:40 UT from NUR to OUJ stations. This moment corresponded the GIC occurrence at MAN (~2 A) and KND. Then the substorm began at ~ 01:30 UT from NUR to SOR stations (red vertical line at the IMAGE magnetograms). The substorm reached its maximum development at ~ 02 UT, at that moment small GICs were registered at VHD (~5 A) and RVD. On the recovery phase of this substorm there were magnetic pulsation Pc5 from ~02:40 to 07 UT. It is a short burst of Pc5 at a frequency of ~ 3MHz with an amplitude maximum at auroral latitudes. It can be seen that the strongest pulsations were observed from 02:40 to 03:20 UT and from 06:20 to 07:00 UT, at the same time points strong GICs were recorded at the VHD (~22 A) and RVD (~3 A), more small intense GIC were observed at KND and MAN (~3 A). So, the magnetic pulsations Pc5 are also seen in the GICs data at all stations, but with a difference in amplitude depending on latitude.

Conclusions

It was shown that GIC occurrence during moderate storm on 27-28 September 2017 were connected with the westward electrojet increasing and expansion during substorms and with bursts of Pc5 pulsations. The intense GICs (> 10 A) in the premidnight sector were recorded in the expansion phase of the substorm, besides GIC amplification at different latitudes occurred simultaneously with the jump to pole of the westward electrojet. The source of the GIC burst (> 20 A) in the morning sector were a pulses of Pc5 pulsations at the recovery phase of substorm. Note that in this case (unlike the case of September 12-13, 2017), more intense GICs were observed during Pc5 pulsations than during substorm.

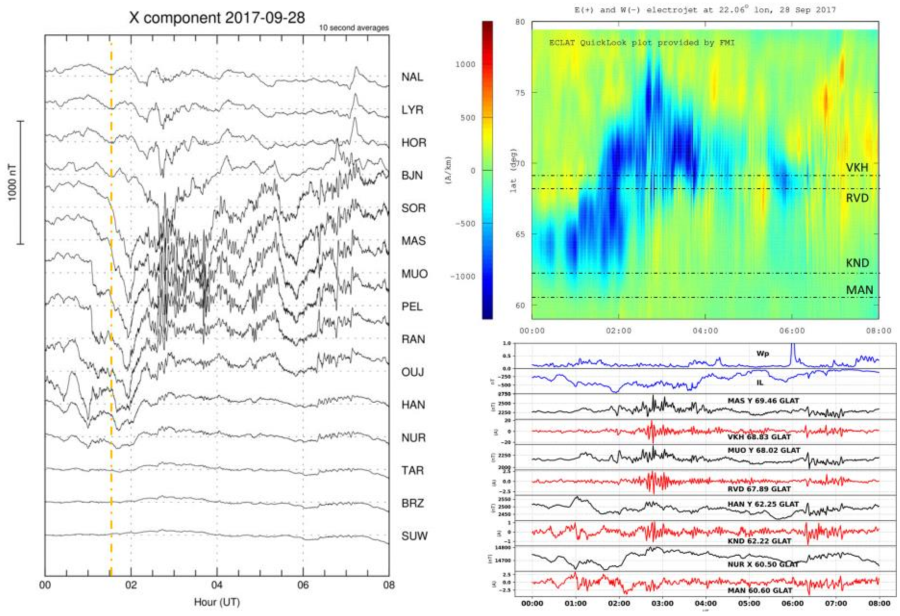


Figure 3. Second period in more details, from 00 to 08 UT 28 September 2017. Format Fig.3 is the same as Fig.2.

Asknowlegments

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