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Geomagnetically Induced Currents During Different Types of the Solar Wind

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Abstract

Relationship between geomagnetic activity and increasing of geomagnetically induced currents (GICs) during September 2017 have been studied. The September of 2017 was an extremely active space weather period. In this work were considered four time interval connected with various types of the solar wind (Magnetic Clouds, CIRs, Sheaths, High Speed Streams). The arrival of different types of solar wind to the Earth caused magnetic storms of different intensity (SYM/H~ -65- -150 nT). At the background these magnetic storms were registered several substorms from moderate to very intense (supersubstorms). The purpose of our work was to analyze which magnetic disturbances led to the enhancement of GICs. We analyzed the grow of westward electrojet using the latitudinal profiles of the IMAGE network and the equivalent currents of the MIRACLE system data. The increasing of GICs were controlled by EURISGIC data from Russian stations Vykhodnoy (VKH), Revda (RVD) and Kondopoga (KND) in the North-West of Russia (eurisgic.ru) and station Mäntsälä (MAN) in the South of Finland. The data from these stations are convenient for tracking the GIC increase from subauroral to high latitudes (~60° to ~69° geographical latitudes). Taking into account the fact that substorms are the main source of magnetic disturbances in the auroral zone, such an arrangement of GIC stations makes it possible to compare them with the motion of an electrojet to the pole during the expansion phase of a substorm. It was not possible to reveal the explicit dependence of the appearance of intense GIC on different solar wind streams. It is shown that, the main reasons for the growth of GICs during September 2017 were magnetic disturbances connected with an increasing and a moving of the westward electrojet during substorm expansion phase and sometimes with Pc5 pulsations observed at the recovery phase of substorms.

Keywords: different streams of the solar wind, substorms, magnetic pulsations, geomagnetically induced currents (GICs)

1. Introduction

It is known that sharp changes in magnetic field can produce Geomagnetically Induced Currents (GICs) in terrestrial technological networks [e.g. Pulkkinen et al., 2005; 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 reason for the GICs growth in the auroral zone [Vorobjev et al., 2018; Kozyreva et al., 2020; Tsurutani and Hajra, 2021; Despirak et al., 2022].

The aim of this work is the study of intense GICs occurrence observed during magnetic disturbances at the background of different types of the solar wind. For this, an extremely active space-weather period, September 2017, was chosen. 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), substorms and HILDCAAs [Haira et al., 2020].

2. Data

In the North-West of Russia, Polar Geophysical Institute together with Northern Energetic Research Centre built a system, called EURISGIC, to monitor such currents in the autotransformers neutral line in the existing Karelian-Kola power transmission line [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. Figure 1 shows the map of EURISGIC recording stations, as well as part of the PPN-NAL meridional chain of IMAGE magnetometers.

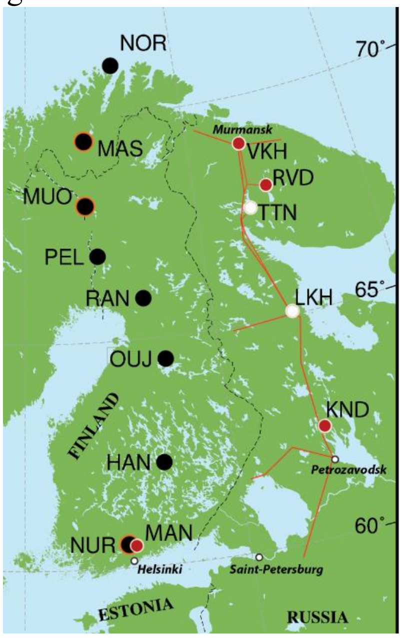

Figure 1*. The geographic map of EURISGIC and nearby IMAGE observatories. Black dots – IMAGE magnetometer stations, red dots with a white border – used in work GIC registration stations, black dots with an orange border – the magnetometer stations closest to GIC registration stations, white dots – GIC registration stations with no data at selected time.*

The spatial distribution of the substorm electrojets was determined using the magnetometers of the IMAGE (http://space.fmi.fi/image/) and SuperMAG (http://supermag.jhuapl.edu/) networks. To study the spatial distribution of magnetic disturbances on the IMAGE profile, instant maps of the distribution of ionospheric equivalent electric currents MIRACLE (https://space.fmi.fi/MIRACLE/) have been analyzed. The IL- and SML- indexes are also taken from IMAGE and SuperMAG networks, correspondingly. Note, that the IL index shows the variation of the magnetic field at the selected IMAGE stations, that is, it is similar to the AL index, which is associated with the auroral electrojet. We used also the Wp (wave and planetary) index which related to the power of the Pi2 pulsation wave at low latitudes and associated with onset of substorm. The solar wind and IMF parameters are taken from OMNI database https://cdaweb.gsfc.nasa.gov/ and the catalog of large-scale solar wind types ftp://ftp.iki.rssi.ru/pub/omni/catalog.

3. September 2017 - solar wind and IMF conditions

September 2017 was divided in four time intervals connected with various types of the solar wind. 7-8 September connected with magnetic storms caused by Sheath and magnetic cloud (MC). 12-13 September connected with magnetic storms caused by Sheath. 14-17 September connected with non-storm interval during High Speed Stream (HSS), when HILDCAA events were registered. And 27-28 September connected with magnetic storm caused by CIR, the region of compressed plasma before HSS. Solar wind and interplanetary magnetic field (IMF) parameters for four periods of September 2017 are shown in Figure 2.

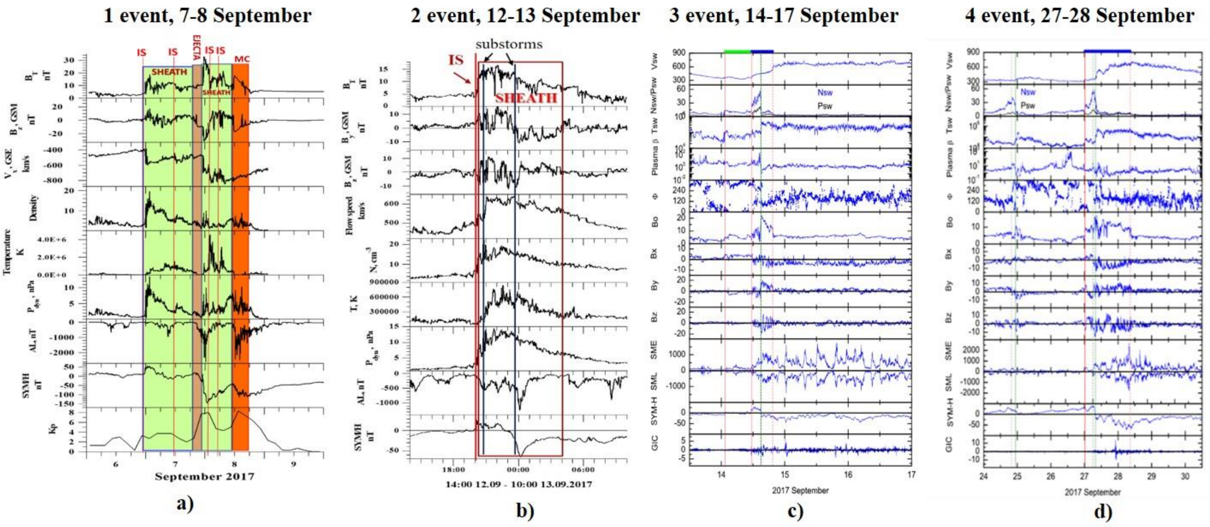

Figure 2. *Solar wind and interplanetary magnetic field (IMF) parameters for 4 periods of September 2017: a) and b) -the magnitude (B_T) of the IMF; the Y- and Z-component of the IMF; the flow speed (V), the density (N), temperature (T), and dynamic pressure (P) of solar wind, and the geomagnetic indices AL and SYM/H; c) and d)- pictures taken from paper Haira et al., 2020.*

4. Magnetic disturbances and GIC observations

- **7-8 September 2017**

The increasing of GICs were considered during two periods corresponding to the development of supersubstorms: from 23 UT on September 7 to 04 UT on September 8 and from 12 UT to 20 UT on September 8 [see more Despirak et al., 2023]. These two periods are marked with ovals and arrows in the Figure 3. At the left panel shown the common picture of the geomagnetic variations and GIC: SML index; X- component of the magnetic field at IMAGE network; IL and Wp indices and GICs. At the right panel the first period presented in more detail: MIRACLE equivalent currents; the map of magnetic field vectors by the SuperMAG for 23:30 UT; IL and Wp geomagnetic indices and GICs at stations Mäntsälä, Kondopoga, Vykhodnoy and at stations TOR, HWB (GIC pictures for TOR and HWB are taken from [Clilverd et al., 2021]).

It was found that the increasing of the GICs was related to the poleward motion of the substorm westward electrojet and followed the development of its spatiotemporal structure (the occurrence and poleward propagation of each intensification of substorm). The highest GICs were observed when the recording station was in the night sector. The sudden commencement (SC) of the substorm was reflected in the GIC data regardless of the location of the recording station.

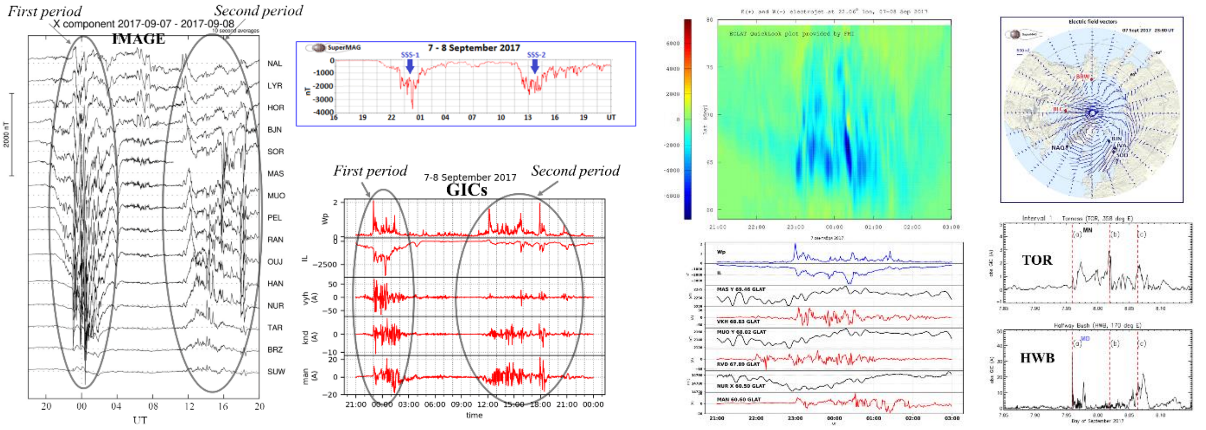

***Figure 3** The common (left) and detail (right) pictures of geomagnetic disturbances and GIC at 7-8 September 2017*

- **12-13 September 2017**

Geomagnetic activity and increasing of GICs during a moderate magnetic storm (SYM/H ~ −65 nT) on September, 12-13 2017 is shown on Figure 4. Note, that two intense substorms (AL ~600 nT and ~ 1200 nT) were observed within this period. Three periods of different magnetic disturbances and large values of GIC from 20 to 23 UT, from 23 to 01 UT and from 01 to 02:30 UT are marked by bars on the plots pf IMAGE magnetometers (PPN-NAL chain) and GICs data. The first two blue bars show the periods of two substorms. The orange bar shows the period of Pc5 pulsations, observed at the recovery phase of second substorm. SuperMAG polar maps correspond to maximum of magnetic disturbances for these three events in time. The map of latitudinal profile of the westward and eastward electrojet calculated by MIRACLE, and GICs (red lines) with corresponding magnetic component of nearest IMAGE station (black lines) and geomagnetic indexes Wp and IL (blue lines) are shown at the right side.

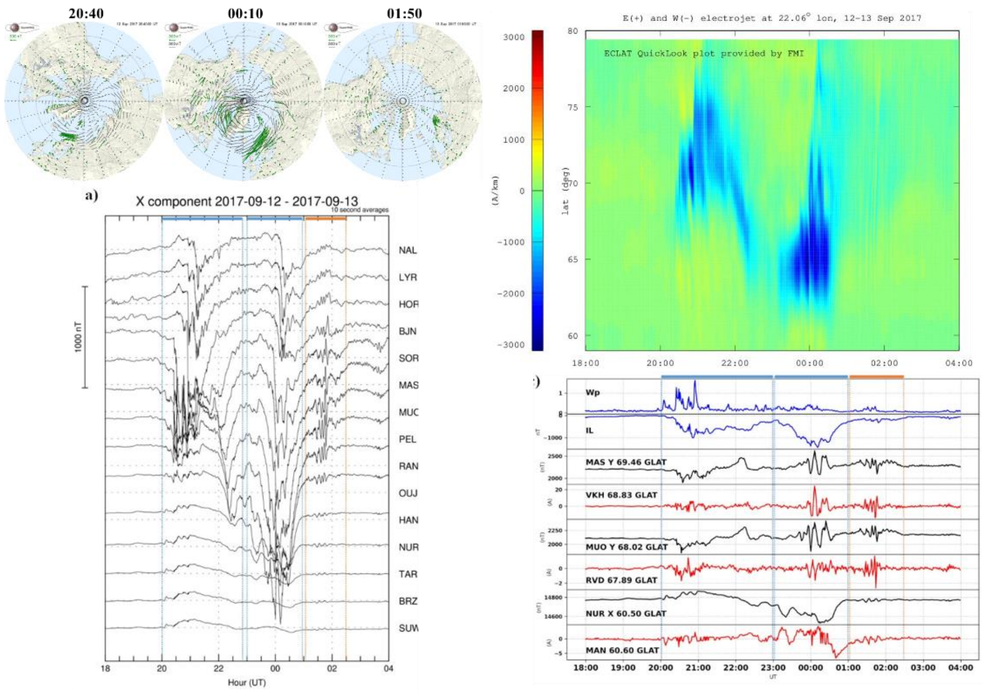

***Figure 4** The detail pictures of geomagnetic disturbances and GIC at 12-13 September 2017*

So, three events of GICs enhancement were connected with an increase and an expansion of the westward electrojet during two substorms and with short bursts of Pc5 pulsations. It was possible to track GICs enhancement along the meridian according to fine spatial temporal structure of the substorm development for the given events. GICs increase at different latitudes corresponds to the poleward movement on the westward electrojet. The source of the GICs during the third period was short pulses of Pc5 pulsations at the recovery phase of an intense second substorm [see more Setsko et al., 2023].

- **14-17 and 27-28 September 2017**

Geomagnetic activity and increasing of GICs during HILDCAA period, on 14-17 September (left side) and during the moderate magnetic storm (SYM/H ~ −74 nT) with multistage development on September, 27-28 (right side) are shown on Figure 5.

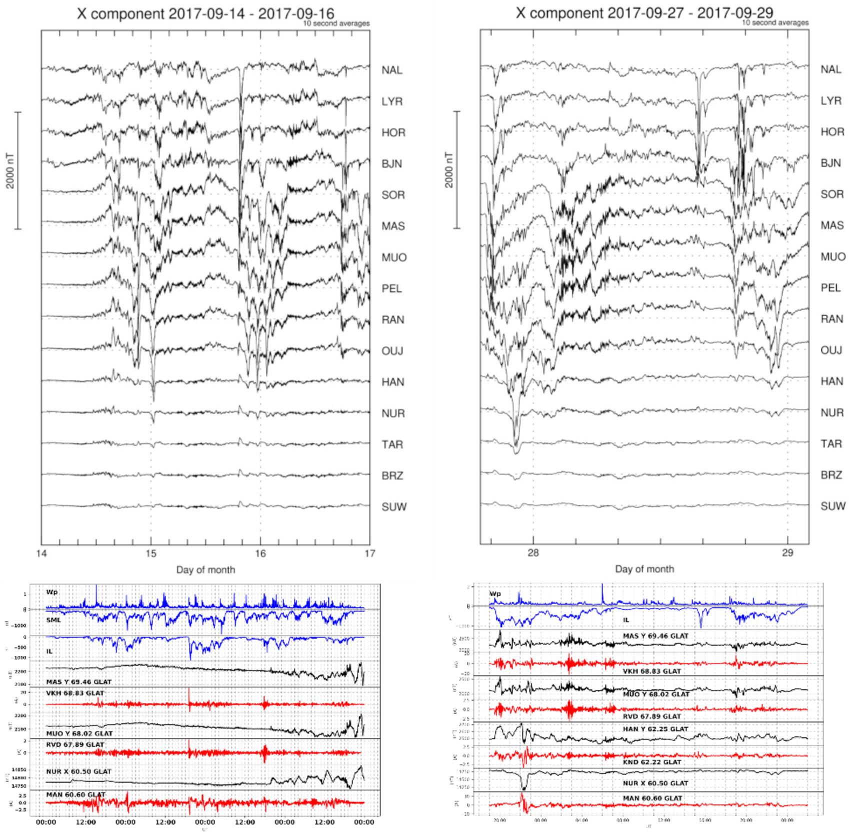

Figure 5. Geomagnetic disturbances and GIC at 14-17 (left) and 27-28 (right) September 2017

It is shown that despite on the HILDCAA event, GICs were associated only with the development of a substorms, when IMAGE network located close to the night sector. It was shown also that GICs corresponded to the fine spatiotemporal structure of the development of a substorm. For the period of September 27–28, GICs were associated with the increasing and expansion of the westward electrojet during three substorms and bursts of Pc5 pulsations during the recovery phase of the substorm.

5. Summary

Using the latitudinal profiles of the EURISGIC, IMAGE and MIRACLE data made it possible to trace the GIC amplification in accordance with the development of the fine structure of the substorm:

1) GIC amplification at different latitudes occurred simultaneously with the jump to pole of the westward electrojet during the substorm expansion phase

2) On September 12–13, the largest GICs were observed during the expansion phase of the second substorm. But on September 27-28, on the contrary, the largest GICs were

observed during Pc5 pulsations at the recovery phase of the substorm. Both of these events occurred during the main phase of the corresponding magnetic storm near the maximum.

3) On September 7–8 and 14–17, the largest GICs were also observed during intense substorms (or supersubstorms).

Thus, in September 2017, intense GICs observed by the EURISGIC system were associated with two sources - the movement and intensification of the substorm electrojet during the expansion phase of the substorm and Pc5 pulsations during the recovery phase of the substorm

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