

The quantification and possible sources of spatially structured and large amplitude geomagnetic depressions during strong geomagnetic storms measured by IMAGE

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Introduction

Geomagnetically Induced Currents (GICs) are a space weather hazard that can negatively impact large ground-based infrastructures such as power lines, pipelines, and railways. They are driven by the dynamic spatiotemporal behaviour of currents flowing in the ionosphere, which drive rapid geomagnetic disturbances on the ground. In some cases, geomagnetic disturbances are highly localised and spatially structured due to the dynamical behaviour of geospace currents and magnetosphere-ionosphere (M-I) coupling dynamics, which are complex and often unclear.

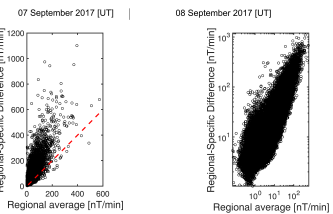
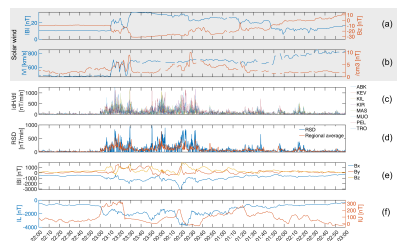
In this work, we investigate and quantify the spatial structure of large geomagnetic depressions exceeding several hundred nT according to the 15 strongest events measured over Fennoscandia by IMAGE. Using ground magnetometer measurements, we connect these spatially structured geomagnetic disturbances to possible M-I coupling processes. To complement the observations, we also utilise high-resolution runs (>7 million cells) of the Space Weather Modeling Framework (SWMF) to determine to what extent global MHD models can capture this behaviour.

Background/motivation

The figures below show (top) the dB/dt for closely located IMAGE stations for the September 2017 event. Panel (c) shows that stations separated by only hundreds of km can exhibit markedly different amplitudes of dB/dt.

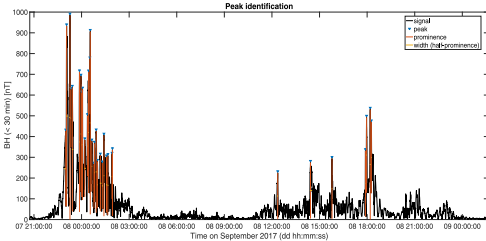
The bottom plot shows the regional variability of dB/dt (RSD parameter) as a function of the spatial average. The regional variability often exceeds the regional average by a factor of 3.

We noticed that for most strong storms, the horizontal magnetic field exhibits complex short-scale (<30 min) peaks. We expand on this work by analysing these peaks for large storms over Fennoscandia. Here we present preliminary results.



Small-scale magnetic peaks

Geomagnetic disturbances often exhibit complex features in the form of short-scale (<30 minutes) peaks, which can be localised in time and space. By identifying these features in the ground magnetic field data, we can study their characteristics and spatial variability. Here we show preliminary results. The image below shows the horizontal magnetic field (Oulujärvi) for the September 2017 event, which was high-pass filtered above 30 minutes. Peaks are visible. The criteria are that a peak is a point where either side are smaller, the point exceeds 100 nT, and the prominence is at least 200 nT.



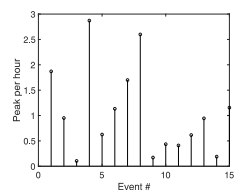
We analyse 15 intervals/events, which are selected based on the largest westward electrojet currents determined from IMAGE. These are:

- 01 - 2003 10 28
- 02 - 2004 11 07
- 03 - 2012 03 14
- 04 - 2001 11 24
- 05 - 2013 03 17
- 06 - 2001 11 05
- 07 - 2017 09 07
- 08 - 2000 07 15
- 09 - 2003 10 13
- 10 - 2002 09 31
- 11 - 2005 01 21
- 12 - 2002 09 07
- 13 - 2003 11 20
- 14 - 2000 04 05
- 15 - 2001 04 11



To assess the spatial structure of these events, we use IMAGE data from the region where the networks are particularly dense as indicated by the black box in the map on the left.

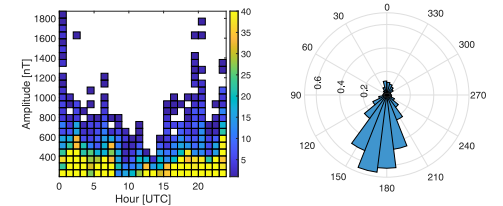
The plot on the right shows the peaks per hour based on the time between the first and last peak and the average number of peaks across all stations indicated above.



There is a large disparity across these events. This suggests that some events exhibit fundamentally 'smoother' magnetic profiles than others.

Thus, for some large storms, the rate of these peaks is quite small, but comparatively large for others.

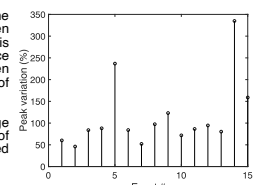
The image below (left) shows a 3D PDF for the time of each peak and corresponding amplitude. The plot on the right corresponds to the angle of each peak on the horizontal plane (180 corresponds to disturbance pointing southward).



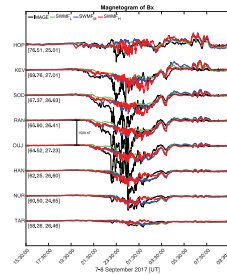
- Small-scale peaks are more likely to occur around midnight, as well as having the largest amplitudes.

- Although the majority of disturbances are associated with westward auroral currents, these events are also associated with eastward currents.

On the right, we show the variation of the number of small-scale peaks between stations for each event. The y-axis shows the relative percentage difference between the range of peaks (between the stations) and the average number of peaks over these stations.



A large percentage indicates a large degree of variability in the number of small-scale peaks across closely-placed magnetometers.



These short disturbances may cause large dB/dt and explain the significant regional variability reported in other studies. It is also possible that these types of short-lived disturbances are not captured well by models.

The plot on the left shows a magnetogram for the September 2017 event using IMAGE data (black) and virtual magnetometers from SWMF (green, blue, red). The different colours correspond to low, medium, and high spatial resolutions. The key point here is that short-term spike features are not captured well in terms of amplitude and timing at high latitudes regardless of the resolution.

Next Steps

This work is preliminary and there are many future steps:

- Refine criteria for peak identification, determine the corresponding dB/dt and also investigate the link to external driving.
- Perform simulations for more events and perform the analysis on SWMF runs for a quantitative comparison.
- Map disturbances to the magnetosphere to identify a possible origin.