Exploring the Development of GICs Related to Large dB/dt Variations in Space

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Abstract

Geomagnetically induced currents (GICs) can be driven in terrestrial electrical power grids as a result of the induced electric fields arising from magnetic field changes driven in the coupled magnetosphere-ionosphere-ground system. Substorms are often hypothesised to be associated with the largest GIC effects on the ground, especially at higher latitudes. However, recent studies have suggested that other dayside phenomena such as sudden impulses and even ULF wave trains might also drive significant GICs. To investigate the evolution of magnetospheric disturbances, ionospheric currents, and their associated GICs, we have searched for conjugate magnetometer measurements from the GOES East and West, Swarm, and e-POP satellites, and the CARISMA ground array. We have focused on large dB/dt events, since ground dB/dt can be used as a GIC proxy. Several such events in space have been found with dB/dt of the order of hundreds of nT in the span of only a few seconds. These are observed in both the nightside and dayside, and, as such, we seek to establish connections to drivers affecting both sides of the terminator; tail activations and substorms on the nightside, large amplitude ULF waves, solar wind sudden impulses, and rapid changes in MIC current systems on the dayside. The short duration of these events, coupled with the use of conjugate satellite measurements and ground magnetometer arrays when possible, allows us to investigate their localization and the latitudinal extent of their effects. Overall we further examine the potential role of non-substorm phenomena in generating the GICs which may have adverse impacts on electrical power grids.

Dayside GICs

As part of our study of large dB/dt events at geostationary orbit with GOES 13 and GOES 15, it emerged that several of them were in the daytime. Storm sudden commencements are known to be a significant cause of GICs in medium and low latitudes [1]; here we explore their effects on high latitudes. We have identified some events where GOES measurements are mirrored by those of conjugate stations on the ground. The most intense such event was found to be on December 19 2015, with fluctuations of B of the order of 100nT over a few seconds, as shown in Figure 1. Fort Simpson, a magnetometer of the CARISMA array, is the closest station to GOES 15's magnetic footprint, and shows large fluctuations of the horizontal components of B (the ones most clearly associated with GICs) at the same time.

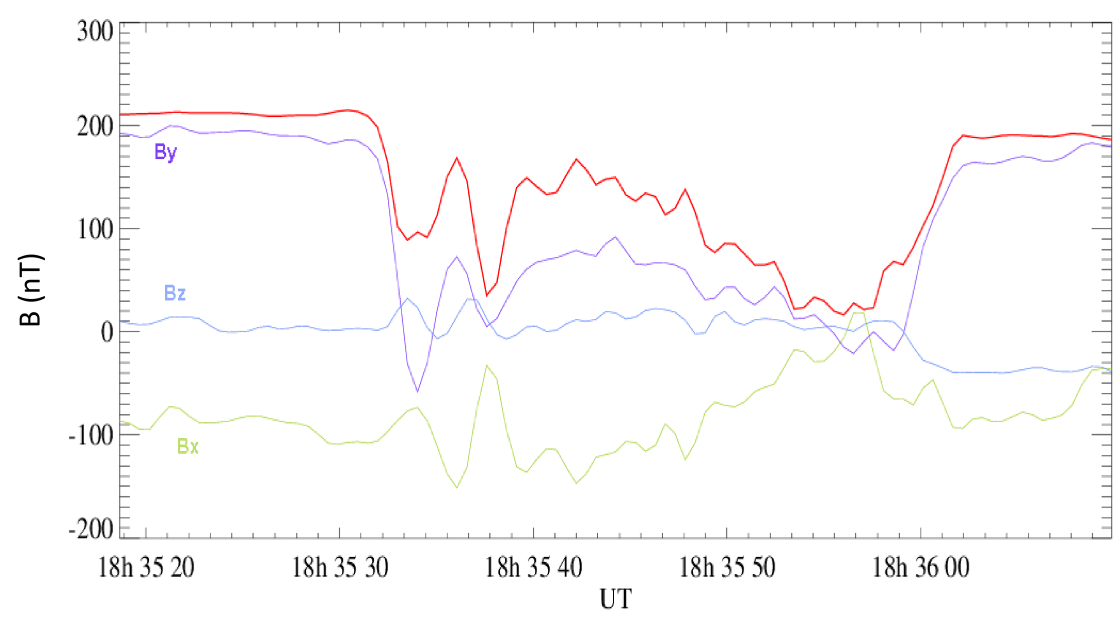

Figure 1: Magnetic field strength (red line) over time at GOES 15. The purple, blue, and green lines show the components of B.

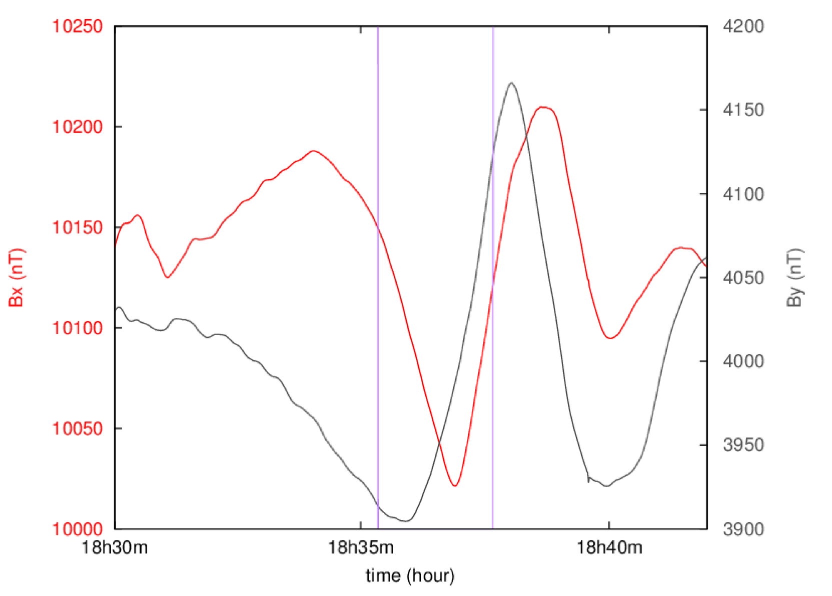

Figure 2: Magnetic field measurements at Fort Simpson, close to the magnetic footprint of GOES 15. The purple lines indicate the time span of Figure 1.

References

[1] Kappenman, J. G. (2003), Storm sudden commencement events and the associated geomagnetically induced current risks to ground-based systems at low-latitude and midlatitude locations, Space Weather, 1(3), 1016
[2] Viljanen, A., H. Nevanlinna, K. Pajunpää, and A. Pulkkinen (2001), Time derivative of the horizontal geomagnetic field as an activity indicator, *Ann. Geophys.*, 19, 1107–1118.
[3] Marshall, R. A., C. L. Waters, and M. D. Sciffer (2010), Spectral analysis of pipe-to-soil potentials with variations of the Earth's magnetic field in the Australian region, Space Weather, 8, S05002

The 7 January 2015 event

At around 8:50 UTC (just after local midnight over western Canada) a substorm (Dst = -50, Kp = 7-) caused an auroral onset, following very calm magnetic conditions. GOES 15 measured magnetic field fluctuations coincident with the onset and breakup of the aurora, with B_{min} = 8nT (Figure 3). Those fluctuations are seen mostly in the earthward component, hinting at a breathing mode wave. Among the THEMIS ground stations that were not hindered by cloudy weather, ATHA was the one closest to the epicenter, and recorded the onset and subsequent beading and breakup (Figure 4).

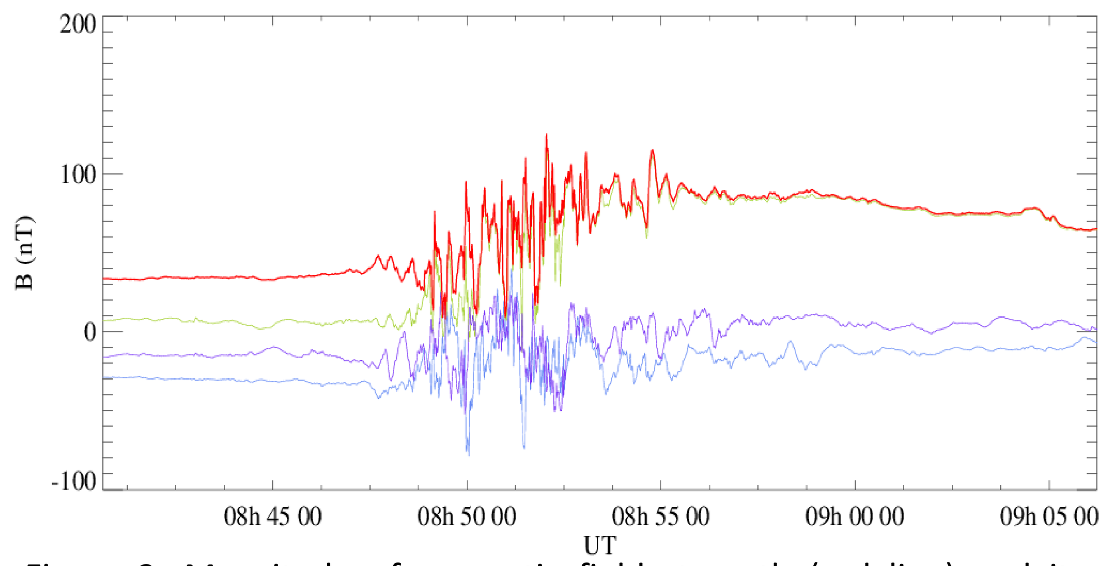

Figure 3: Magnitude of magnetic field strength (red line) and its vector components, Hn (eastward, blue line), Hp (northward, green line), and He (earthward. Purple line), measured by GOES 15.

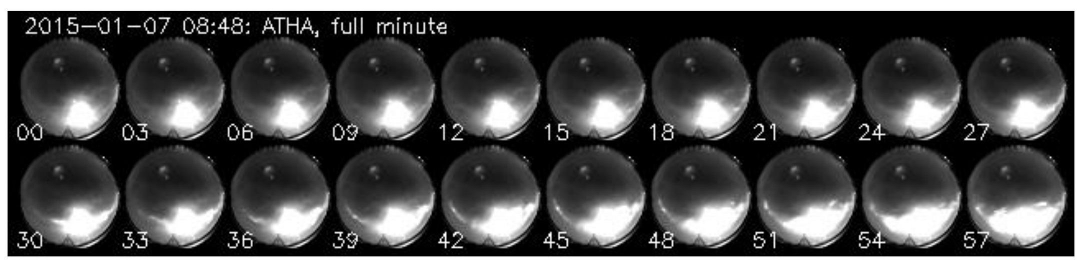

Figure 4: Ground THEMIS observation of auroral onset between 8:48 and 8:49, from ATHA. The moon partially covers the southern parts of the images.

Ground magnetometers registered the event strongly, with Bx at DAWS dropping by around 1500nT a few minutes after the onset, while stations closer to the epicenter had smaller bays but temporally closer to the onset. MSTK, directly south of the THEMIS station at ATHA, observed fluctuations in Bx with about a half minute lag from the GOES 15 measurement (Figure 5). At around 8:53, Swarm A and Swarm C flew over the breakup area, and their Bx measurements are plotted in Figure 6.

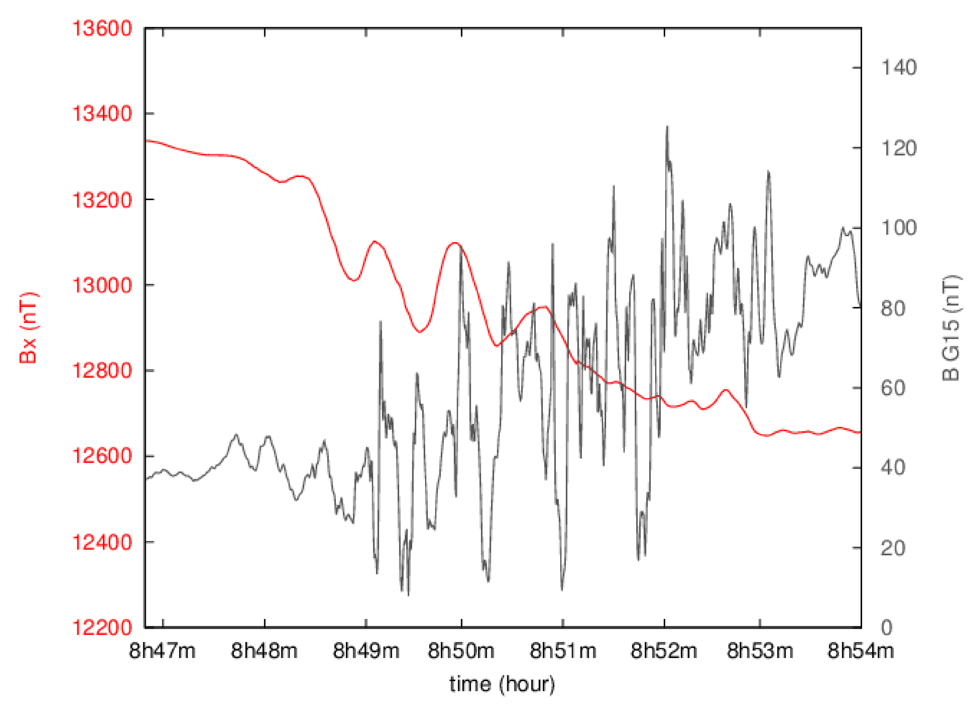

Figure 5: Bx (eastward) measurements at the Ministik Lake (MSTK) ground station (red line) overplotted on the GOES 15 B measurements (black line).

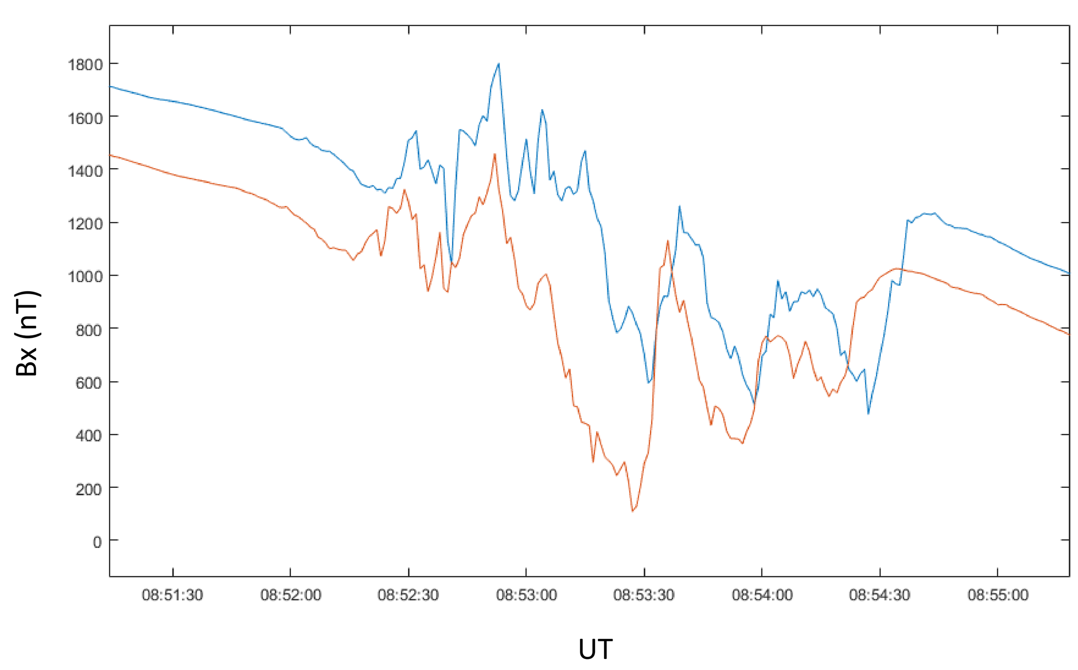

Figure 6: Bx (east) measurements from the VFM instruments on Swarm A (blue line) and Swarm C (orange line) at the time of the auroral crossing.

The fortuitous passage of Swarm A and C should help us to piece together the nature of the geomagnetic disturbances at that time, more specifically the nature of Alfvén wave exchange during the breakup of the aurora, in this ongoing investigation.

Nightside GICs with CARISMA

In order to assess the potential for GICs, we use the horizontal component of d**B**/dt (d**H**/dt) on the ground as a proxy. Values of d**H**/dt > 1nT/s are considered large [2], although their total effect is cumulative with time (see [3] for discussion on a GIC index). Having identified several large dB/dt events from GOES, we visualized the temporal and spatial distribution of d**H**/dt on the ground with maps such as that presented in Figure 7 for the 7 January 2015 event. For MSTK, d**H**/dt reached as high as 16 nT/s in the seconds after the auroral onset. In Figure 8 we have plotted the distribution of angles between vectors over distance, between 8:48 and 9:00, for the 13 stations nearest the auroral onset. The median is around 40°, with indications of divergence beyond 1500km. In Figure 9 we have plotted the distribution of relative magnitudes of H, where we see a weak convergence for small distances, its resolution limited by the minimum distance between stations. For a better view of its behaviour at smaller distances, we examined the June 26 1998 measurements of the BEAR magnetometer array, which we plot in Figure 10. From there, it appears that magnetometers can map the spatial extent of GIC with a fair degree of accuracy at distances of about 200km.

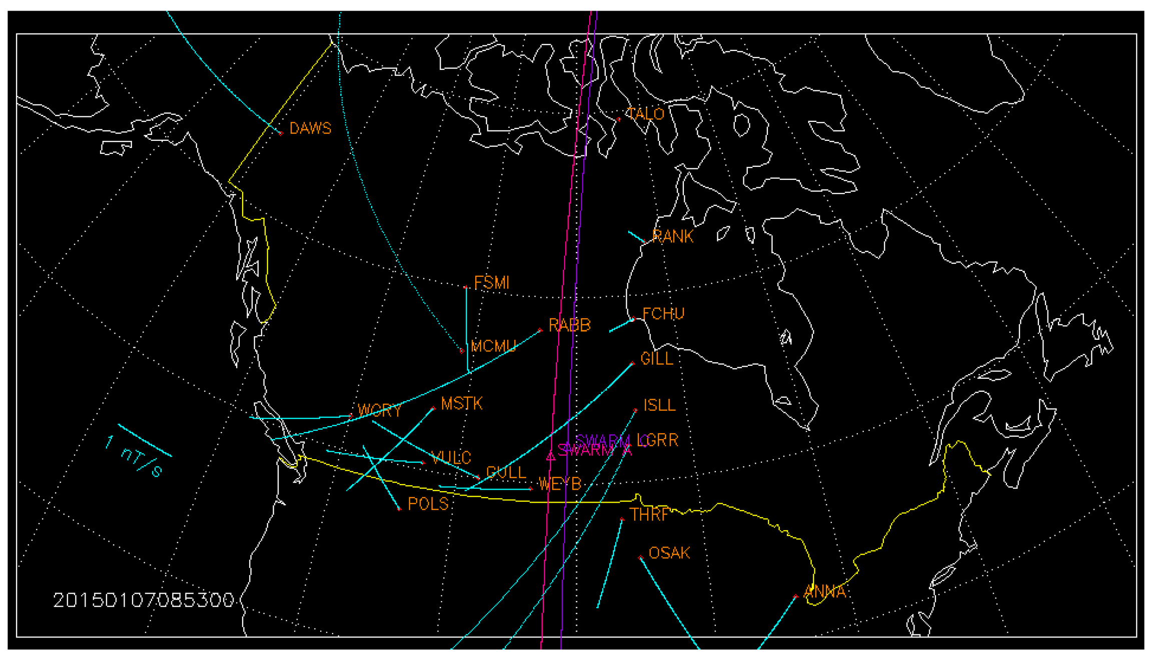

Figure 7: A 1s snapshot of d**H**/dt measurements at CARISMA during breakup, when Swarm A and C are passing overhead. Purple lines plot the Swarm orbits, while purple triangles show their magnetic footpoints at the time this snapshot was taken.

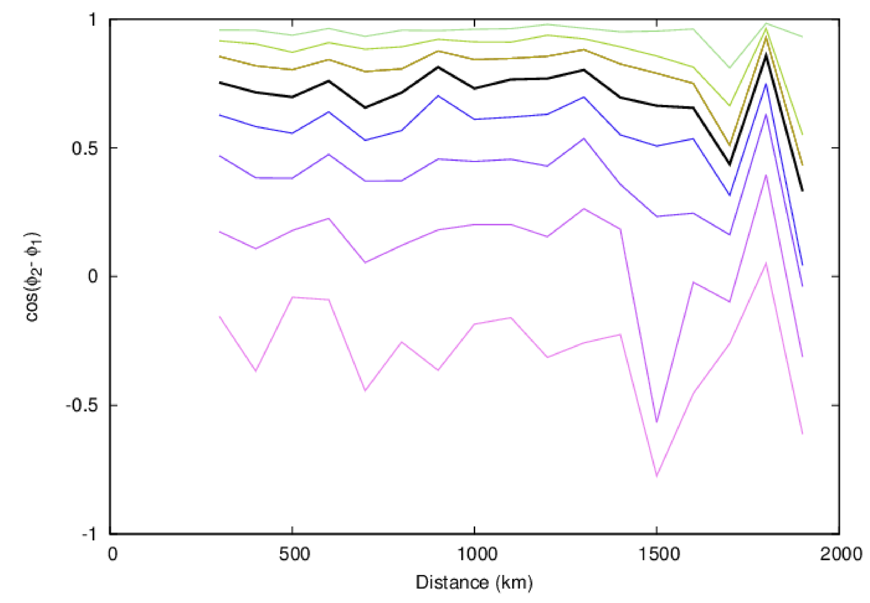

Figure 8: Distribution of differences in direction between d**H**/dt vectors over 1nT/s and those of other stations. The median angle (black line) appears to be about 40° for the first 1500km. All the lines correspond to borders of deciles of data. Distances are binned by 100km.

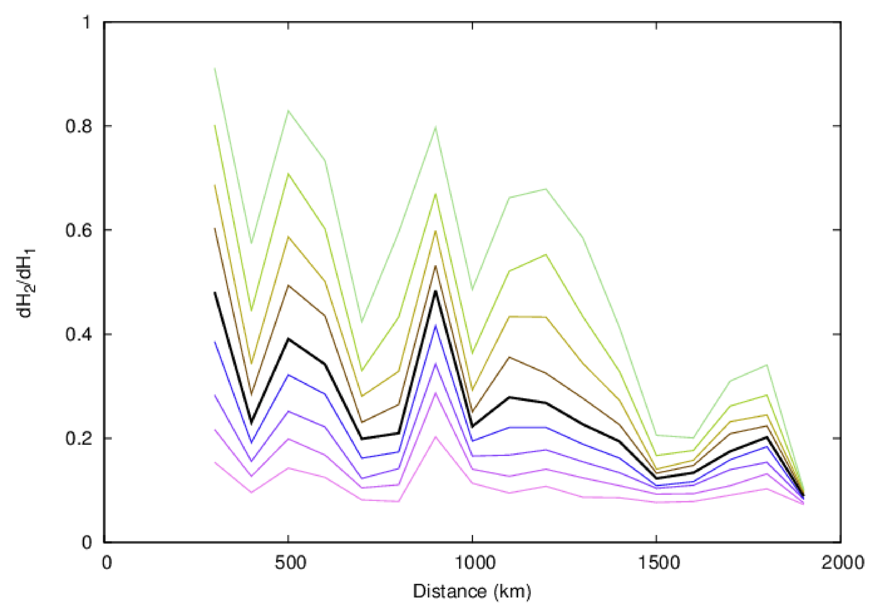

Figure 9: Distribution of magnitude ratios between d**H**/dt vectors over 1nT and those of other stations. The median ratio (black line) is consistently closer to 0 than to 1, but there is indication of convergence for small distances.

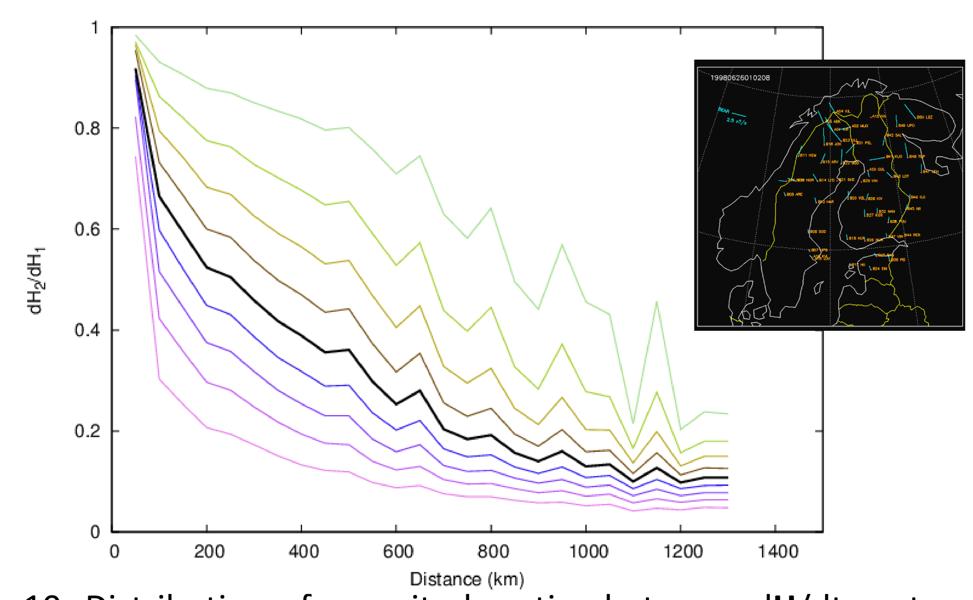

Figure 10: Distribution of magnitude ratios between d**H**/dt vectors over 1nT and those of other stations for the BEAR array in 1998 (insert). The mean ratio (black line) is close to 1 for short distances, but diverges from that value at longer ones.

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