

Intense dB/dt variations driven by near-Earth bursty bulk flows (BBFs): A case study

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Abstract

During geomagnetically disturbed times, geomagnetically induced currents (GICs) flow in power systems potentially causing damage to these systems. GICs are often produced when the surface geomagnetic field abruptly changes (in particular, the induced rate of change of the horizontal ground magnetic field component, dH/dt is a suitable proxy). It is well established that intense dB/dt variations in space and on the ground take place in the main phase of a geomagnetic storm, and can be particularly driven by magnetic substorms occurring during the active storm period. There are currently few studies that report intense dB/dt variations which are directly driven by bursty bulk flows (BBFs) at low-Earth orbit. In this study, we investigate the characteristics and response in the magnetosphere-ionosphere system during the recovery phase of a geomagnetic storm that occurred on 7 January 2015 by using a multi-point approach combining space-borne Cluster and Swarm measurements, and a group of ground-based magnetometer observations. The magnetic footprints of Cluster and Swarm map to the same conjugate region as a group of magnetometer ground stations at the time of the BBF. The measurements show that corresponding signals in all measurements occur simultaneously in this region (or with suitable lag times). Our results suggest that the most intense dB/dt (and dH/dt) variations are associated with large-scale FACs that are driven by BBFs at geosynchronous orbit around substorm onset.

Introduction

Geomagnetically Induced Currents (GICs)

GICs represent a significant challenge for society, given our strong dependence on stable electricity supply. GICs are specified by the geoelectric field conditions, which in turn are proportional to the **time derivatives of the ground magnetic field variation (dB/dt)**. GICs are well known to occur during severe geomagnetic storms, particularly those caused by coronal mass ejections from the Sun.

Bursty Bulk Flows (BBFs)

The BBFs in the **inner plasma sheet** of the magnetosphere are important phenomena that are closely related to magnetospheric activities and transport of energy and magnetic flux. BBFs are **enhanced bulk velocity events** of order of 20 min in duration, containing many **short-lived high-velocity** (400 km/s or more) flow bursts. BBFs and its braking may be an important physics process that can link most substorm phenomena such as **reconnection**, **current disruption**, and **aurora**.

Motivation

- During geomagnetic disturbances, rapid fluctuation of the surface geomagnetic field (dB/dt) is produced and drives GIC in man-made electrically conducting technological infrastructure.
- There are currently few studies that report on GIC effects driven by BBFs.

Solar Wind Conditions and Geomagnetic Indices

Figure 1 shows the **solar wind** and **interplanetary magnetic field (IMF)** conditions, **SYM-H index**, and **AE index** from OMNI data between 08:00 UT and 14:00 UT for the 07 January 2015 geomagnetic storm. After 08:50 UT, a substorm began.

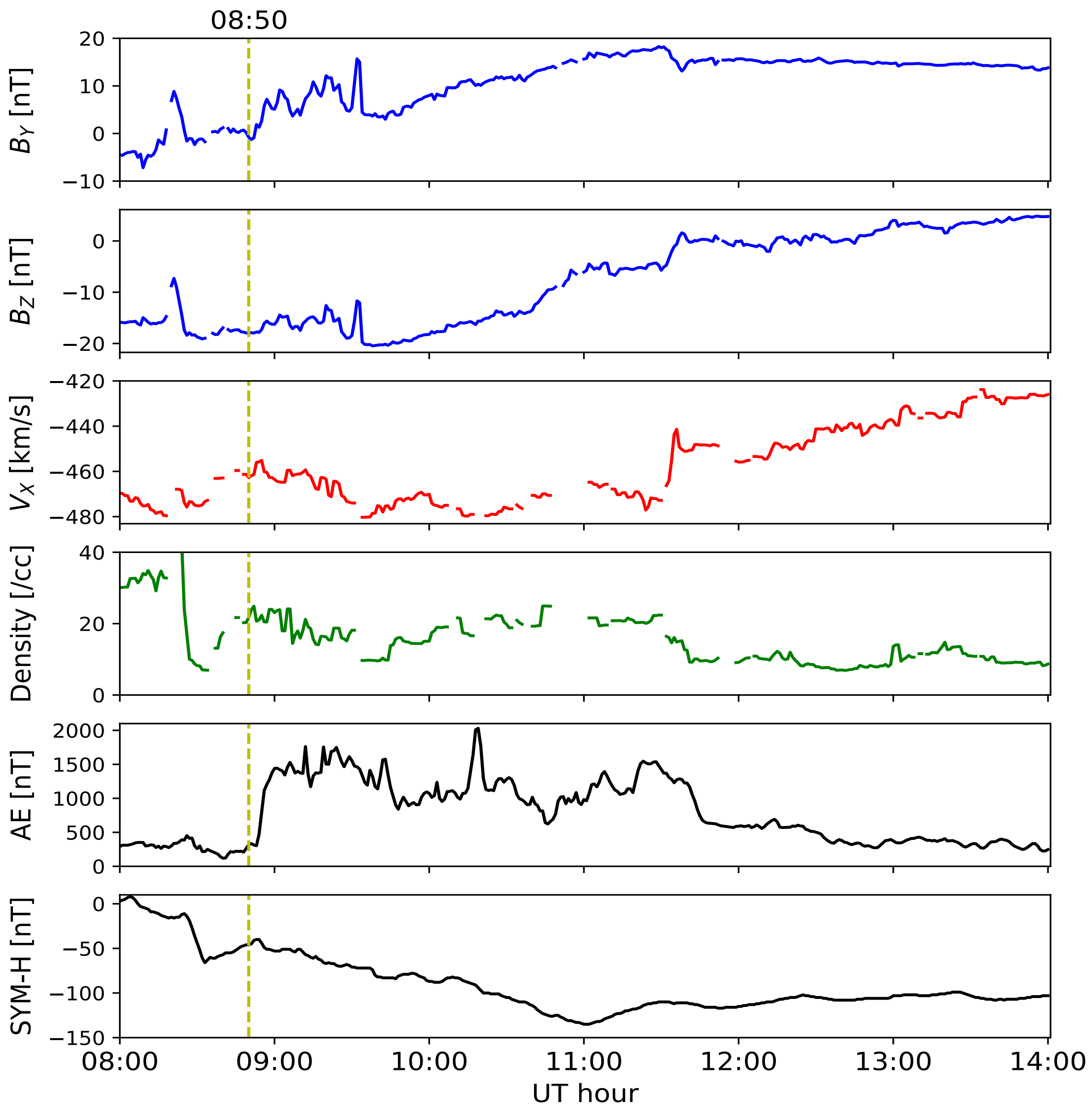


Figure 1: Solar wind and interplanetary magnetic field (IMF) conditions, SYM-H index, and AE index

Methodology

This study analyzed the features of **magnetosphere**, **ionosphere** and **ground** through **multi-point measurements**. Instruments onboard **Cluster C1 C2 C4**: CIS, FGM, PEACE, RAPID and **Swarm A/C**: ASM Geomagnetic Fields Data (1 min) from **SuperMAG**

Case Overview

Cluster satellites Magnetospheric Observations

From 08:50:10 UT, a BBF was detected by Cluster-4 (yellow shade) at L=6.22, V_x was up to **1000 km/s**, and B_z enhanced significantly.

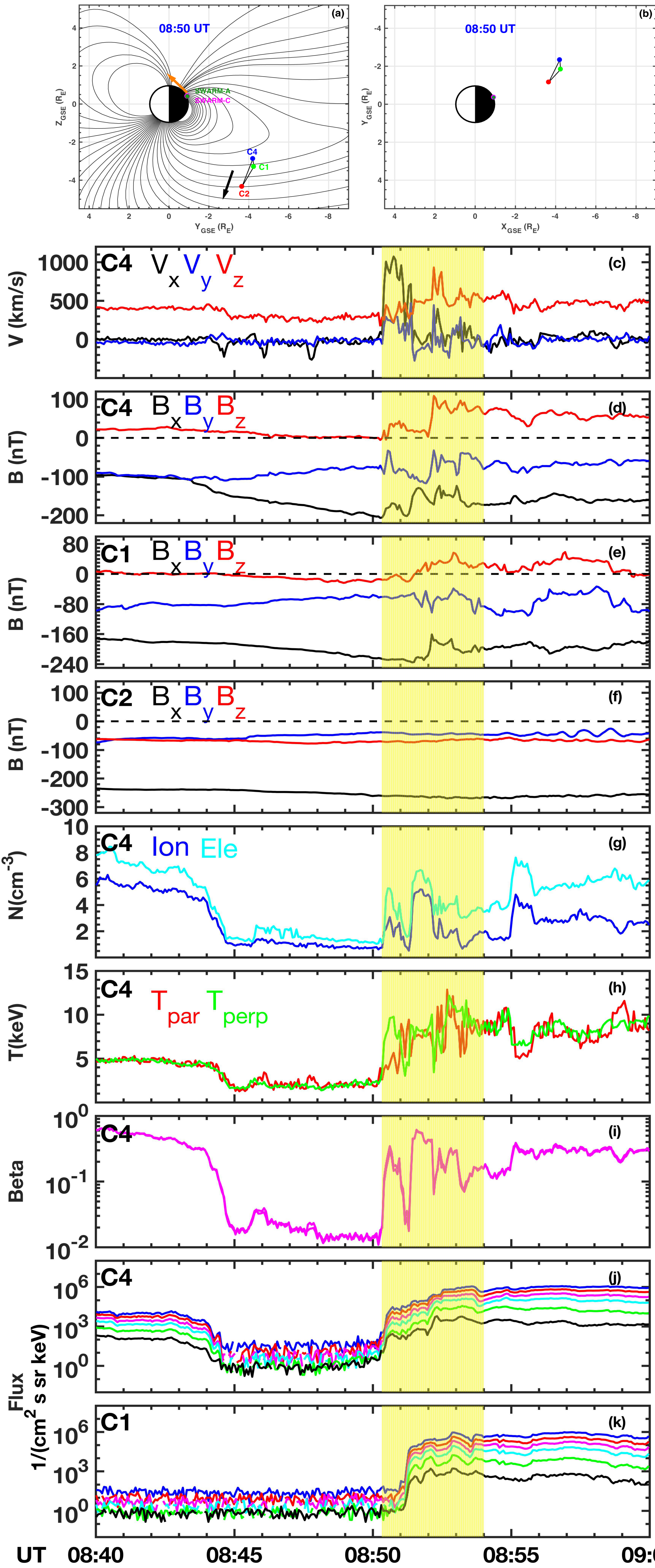


Figure 2: The positions of Cluster and SWARM relative to the Earth in GSE coordinates at 08:50 UT on the 7 January 2015, projected into (a) Y-Z plane and (b) X-Y plane. The Earth is shown as a circle with model geomagnetic field lines. The Cluster colors are: C1-green, C2-red, and C4-blue, while the SWARM colors are: A-forestgreen, and C-magenta. (c)-(k) Overview of magnetospheric parameters recorded by C1, C2 and C4 from 08:40 UT to 09:00 UT, 7 January 2015. Cluster satellites observations of (c) C4 ion bulk flow velocity, (d) C4 magnetic field, (e) C1 magnetic field, (f) C2 magnetic field in GSE coordinates, (g) Ion (blue) and electron (cyan) number density, (h) C4 ion parallel (red) and perpendicular (green) temperature, (i) Plasma Beta, (j) C4 differential electron particle flux, and (k) C1 differential electron particle flux with six energy channel (39 keV, 51 keV, 68 keV, 95 keV, 128 keV, 244 keV).

Footprints of Cluster-Swarm A/C on the ground and Locations of 7 geomagnetic stations

During 08:49 UT to 08:56 UT, five stations (GIM, RAL, SMI, FMC, T42, ISL, C04, C12), Swarm-A/C and Cluster C1/C4 are located at the **same conjugate region** on the ground.

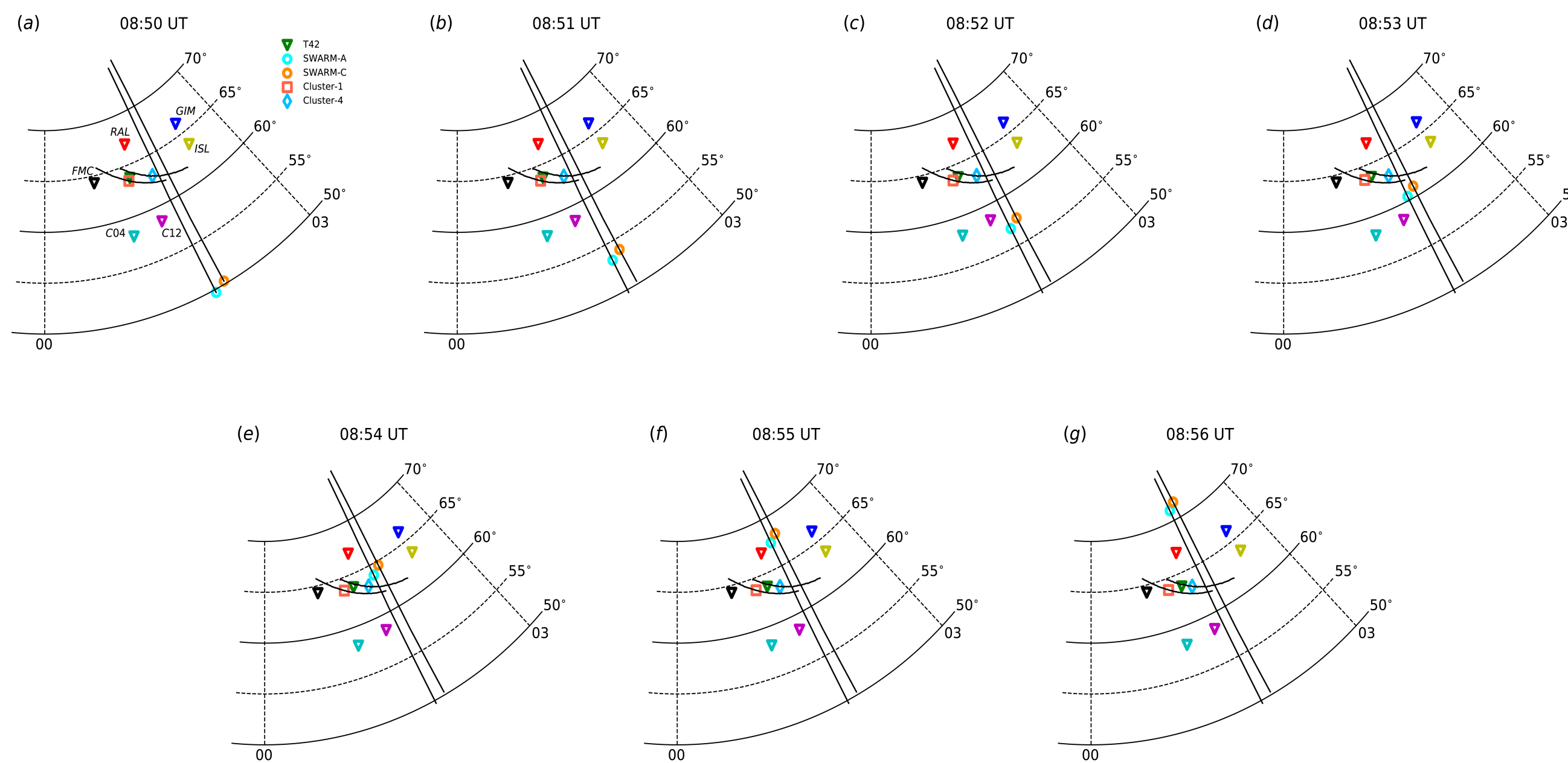


Figure 3: (a)-(g) The locations of the seven ground magnetometers in the North America sector, SWARM A/C tracks in the ionosphere and ionospheric footprints of Cluster C1/C4 from 08:49 UT to 08:56 UT (the lines mark the trajectories of Swarm A/C and Cluster C1/C4).

Responses of Ground Geomagnetic Fields

- After 08:50 UT, the |dH/dt| began to increase and minimum around 08:52 UT. This intense |dH/dt| may result in GIC on the ground.
- The surface dH/dt response time at these stations coincides with the presence of abrupt variation of electron flux energy of C4 and C1 from 39 keV to 244 keV (Figure 2j and 2k).
- The rates of surface geomagnetic fields of these stations are nearly dominated by the variations of northward components (third column in Figure 4), except ISL, while the eastward components of geomagnetic fields change only slightly (fourth column in Figure 4).

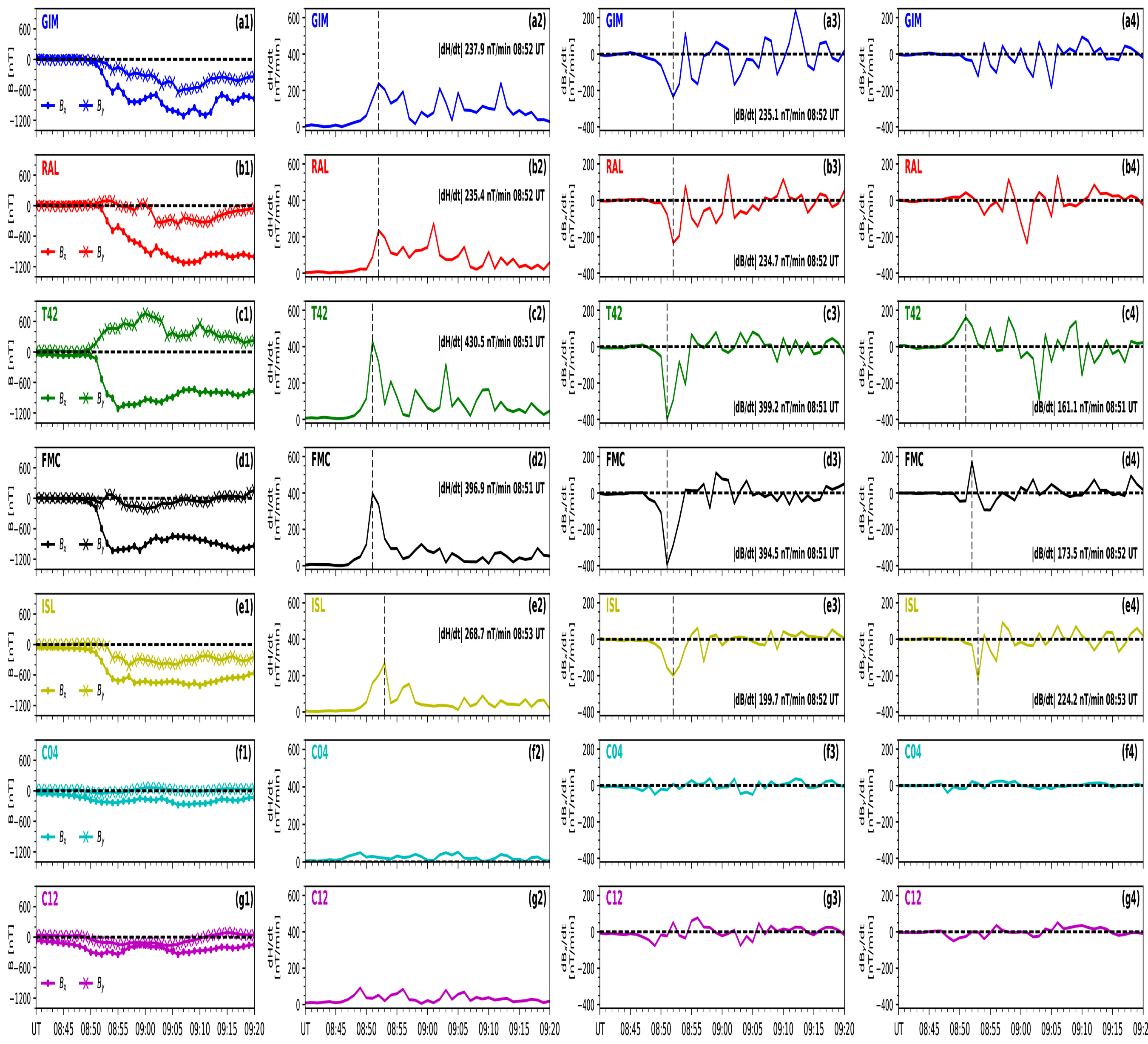


Figure 4: Plot of the geomagnetic field B_x, B_y, and the rate of change dB/dt from 08:40 UT to 09:20 UT at ground sites in the North America sector during the 7 January 2015. (a1)-(g1) The components of B_x (northward) and B_y (eastward) geomagnetic fields, (a2)-(g2) The rate of horizontal geomagnetic field variations |dH/dt|, (a3)-(g3) The rate of northward geomagnetic field variations (dB_x/dt), and (a4)-(g4) The rate of eastward geomagnetic field variations (dB_y/dt).

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Field-aligned Currents (FACs) in the Magnetosphere/Ionosphere

- For Cluster, in the magnetosphere, an upward-downward-upward FACs structure appeared between 08:50:10 UT and 08:52:10 UT, where the second upward current is dominant (see Figure 5a, the positive value represented the field aligned direction and the main signal appears between the two dashed black lines).
- Figure 5b and 5c are the FAC density of Swarm A/C from 07:18 to 07:22 UT, we can find the FAC is weak, because this time is the geomagnetic quiet period. After 94 min (one orbit period of Swarm A/C), at the similar locations, it is indicated from Figure 4c-4d that the FAC density intensified greatly after the BBF is detected from magnetosphere at 08:50:10 UT.
- During this 94 min, although the maximum AE is 452 nT (08:26 UT), and the minimum SYM-H is up to -66 nT (08:33 UT), the variations dB/dt of chosen 7 stations are very weak before 08:50 UT (Figure 4). Therefore, this BBF is very likely to result in the variation of FAC.

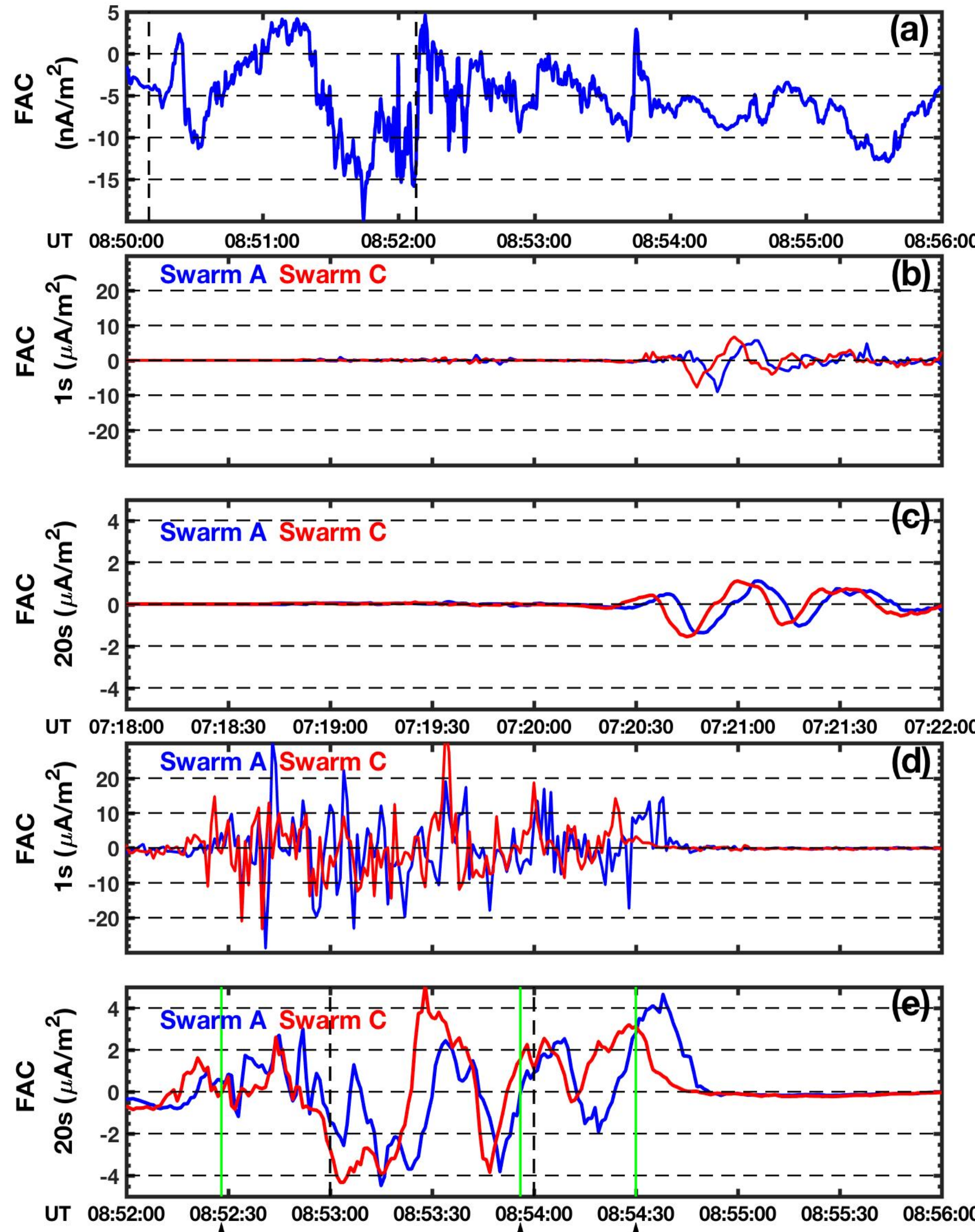


Figure 5: (a) The Cluster FACs estimated from one face formed by C1, C2, and C4 from 08:50:00 UT to 08:56:00 UT, (b) The single SWARM FACs estimate from magnetic fields data, and (c) the filtered single SWARM FACs estimate (20s window) during 07:18:00 UT to 07:22:00 UT, (d)-(e) The same format as (b)-(c) but during 08:52:00 UT to 08:56:00 UT (the black vertical dashed lines mark the two time intervals of the same FACs structure appeared, and the green vertical lines represent the estimated locations of ground stations along the Swarm A/C orbits).

- It is found that the FAC structure seen at Cluster in the magnetosphere (see Figure 5a, the FAC data between the two dashed black lines) is very similar to the structure observed by Swarm A/C in the ionosphere (see Figure 5e, from 08:53 UT to 08:54 UT, showing similar upward-downward-upward FAC structure between the two dashed black lines). This ionospheric signature might be caused by the large-scale FACs driven by BBF in the magnetosphere.
- Around 08:54:00 UT, two stations (T42 and FMC) show positive Eastward perturbation (Figure 4c4-4d4) with the downward current of Swarm A/C in Figure 5e, while ISL (Figure 4e4) shows negative Eastward perturbation, indicating that a downward current sheet is flowing between these stations. The T42/FMC and ISL therefore sit on either side of the current sheet, although T42/FMC are located at a higher latitude relative to the current sheet, and the ISL is at a lower latitude. We can also find that the Eastward perturbations of GIM and RAL (Figure 4a4-4b4) occur in the same way.

Summary

- Clear near-Earth BBFs structures are observed at geosynchronous orbit in the magnetosphere.
- Intense dB/dt variations are associated with R1-type FACs that are driven by BBFs.
- The orientations of FACs sheets from Swarm data are used to identify the geomagnetic perturbation.