

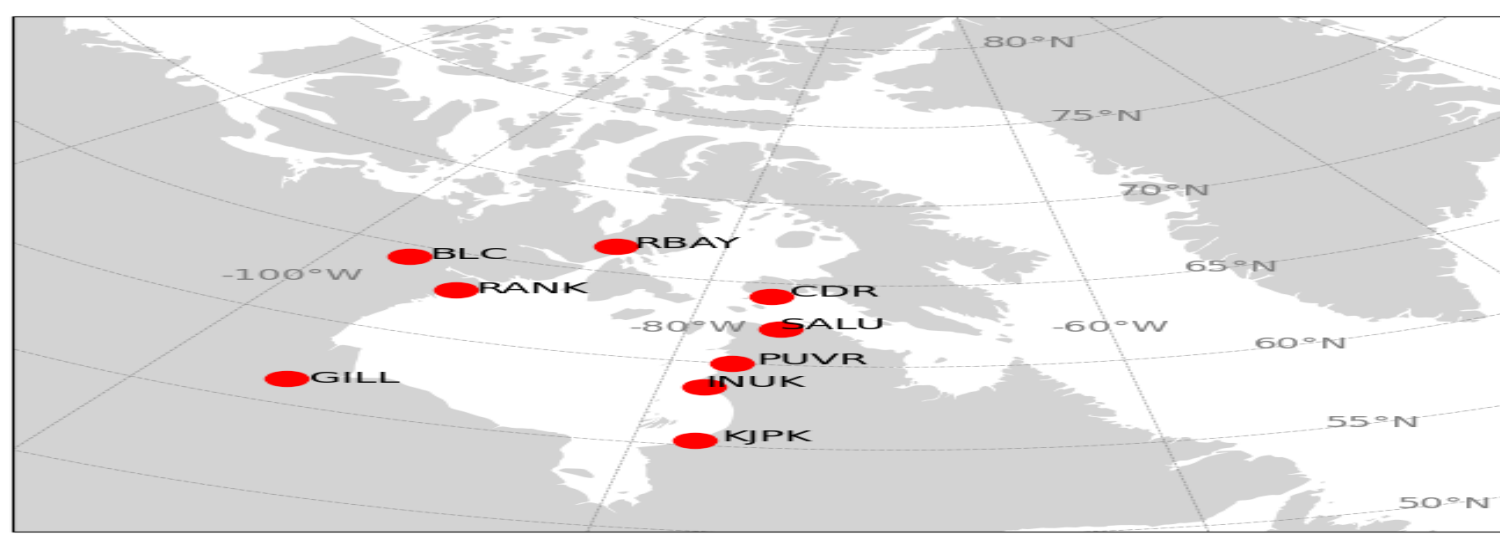
Introduction

- This study investigates the impact of powerful space weather events, known as substorms, on Earth's magnetic field, which can disrupt power grids and satellites.
- The research analyzed two significant substorms in December 2015 using data from spacecraft (THEMIS) and ground-based magnetometers across Canada.
- Magnetic disturbances were observed to initiate at lower latitudes (approximately 64–70° MLAT) and shift toward higher latitudes (up to 75° MLAT) over a period of 20–30 minutes.
- These disturbances were driven by changes in the magnetosphere, where energy bursts and fast-moving particles from the magnetotail caused sudden drops in the SML magnetic index.
- The SML drops, occurring about 7 minutes after magnetotail processes, resulted in intensified currents in Earth's upper atmosphere, particularly in the auroral region over the Canadian Arctic.
- The study's maps reveal vertical current density variations ranging from approximately -10 to 10 $\mu\text{A}/\text{m}^2$, with upward and downward flows associated with vibrant auroras.
- The findings enhance our understanding of the connection between space weather and ground-level effects, aiding in improved predictions to safeguard technology.

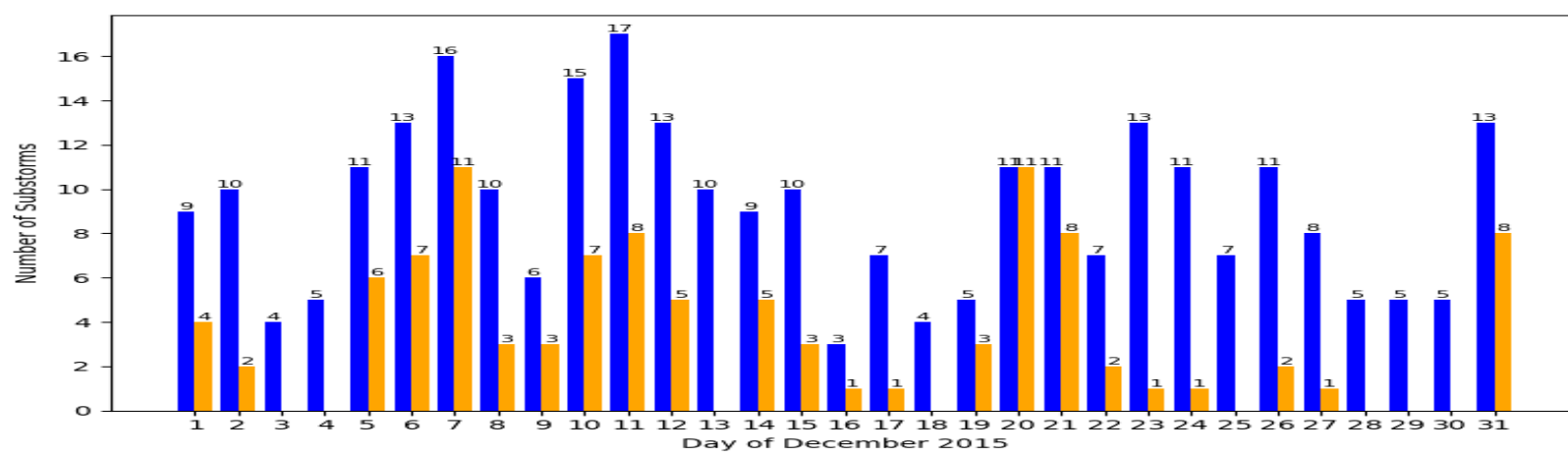
Data

- The main analysis utilizes magnetic field and ion moment data from THEMIS A, D, and E satellites (Angelopoulos, 2008), alongside ground-based data.
- Vector magnetometer measurements are sourced from nine stations across Eastern Arctic Canada, drawn from the MACCS (Engebretson et al., 1995), AUTUMNX (Connors et al., 2016), CARISMA (Mann et al., 2008), and CANMOS (Nikitina et al., 2016) arrays.
- SECS data, offering total field-aligned current (FAC, J) in Amperes, is retrieved from <https://vmo.igpp.ucla.edu/data1/SECS/>, with vertical current density (J, in $\mu\text{A}/\text{m}^2$) calculated by dividing total current by the estimated grid cell area.
- Substorm onsets are identified using a list by Forsyth et al. (2015) from the SuperMAG database (<https://supermag.jhuapl.edu/>, Gjerloev, 2012), which also provides the SML index for enhanced westward electrojets.

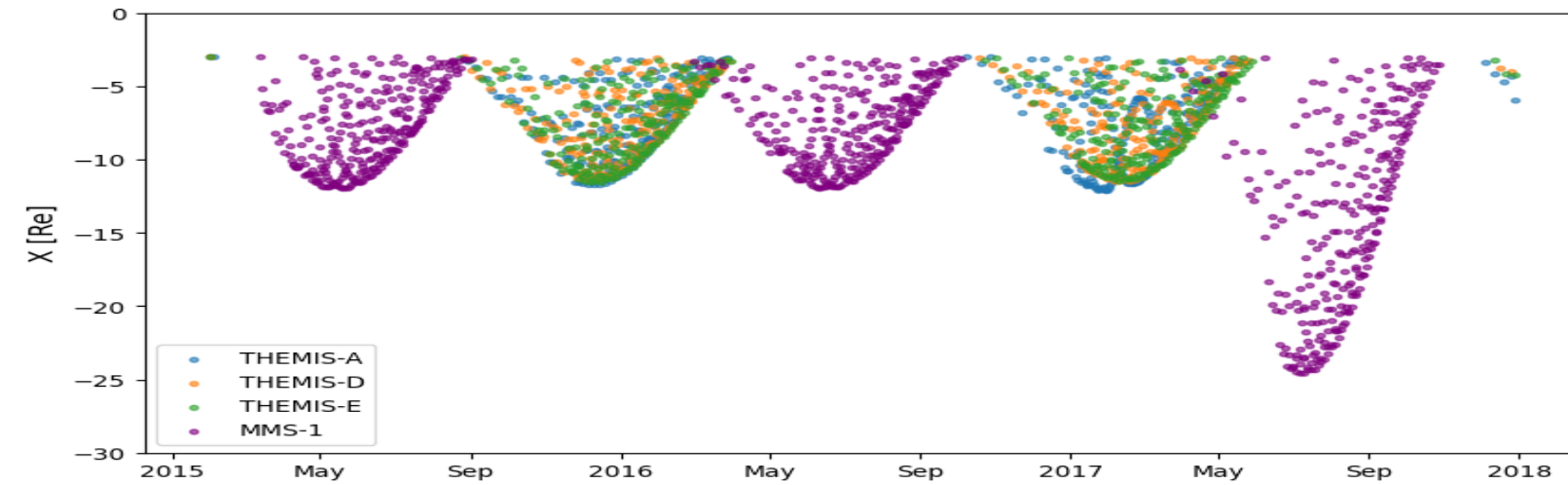
Results



Map of the Hudson Bay region in sub-Arctic and Arctic Canada displaying Ground magnetometer stations used in this study (marked with red dots).



Number of substorms (strong substorms SML < -500 nT) for each day of December in 2015 are represented in blue (orange) (Forsyth et al., 2015).

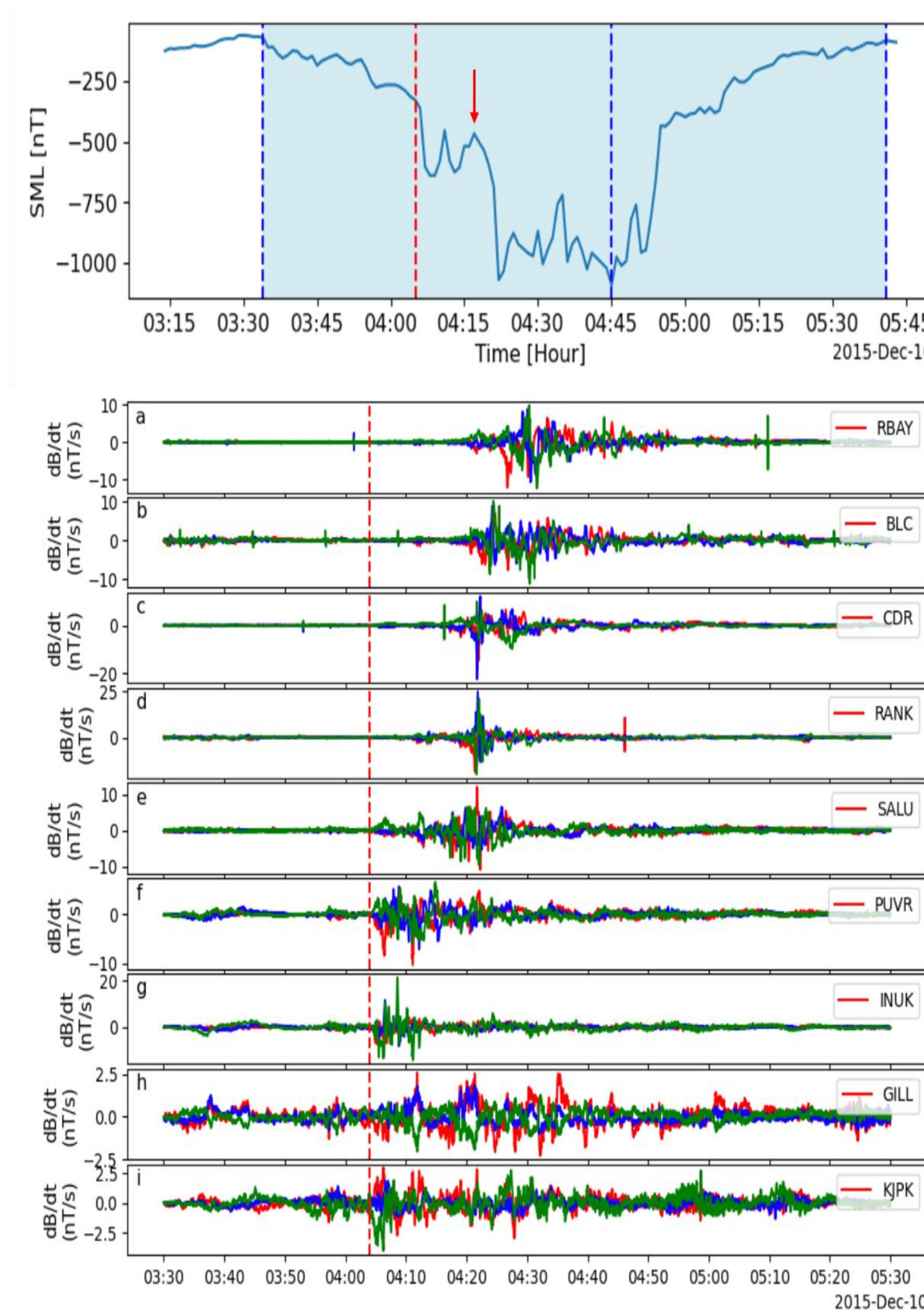


The locations of the THEMIS A, D, E, and MMS spacecraft in the central magnetotail (within $-5 < Y < 8\text{RE}$ and $X < -3\text{RE}$) during 2015–2017.

Summary

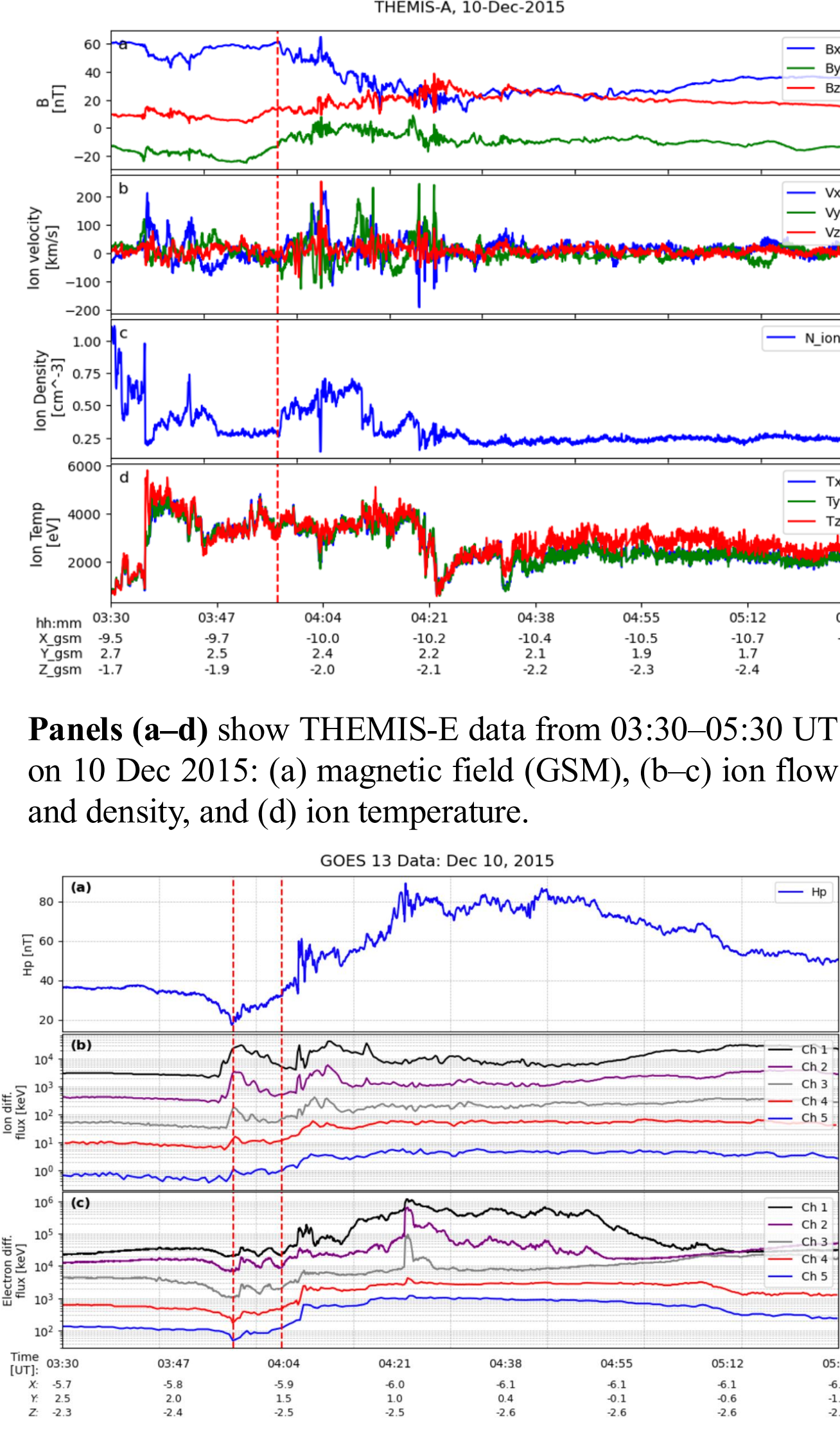
Studied two intense substorm events on December 10 and 20, 2015, using THEMIS and SuperMAG data, revealing GMD development and propagation. Disturbances progressed poleward from 64°–70° to 70°–75° magnetic latitudes over 20–30 minutes, linked to substorm current wedge and westward electrojet intensification. THEMIS data showed magnetotail dynamics (dipolarization, 200–400 km/s flows) preceded SML drops by ~7 minutes, tying magnetospheric changes to ionospheric currents. SECS analysis found vertical current density peaking at ~8–10 $\mu\text{A}/\text{m}^2$ over the Canadian Arctic, matching ground perturbations (e.g., ± 20 nT/s at INUK). GOES-13 data showed magnetic field reconfiguration and particle energization during the substorm expansion phase. Results trace substorm effects from magnetotail to ground disturbances, highlighting localized currents' role in GMD variability.

December 10, 2015 Substorm



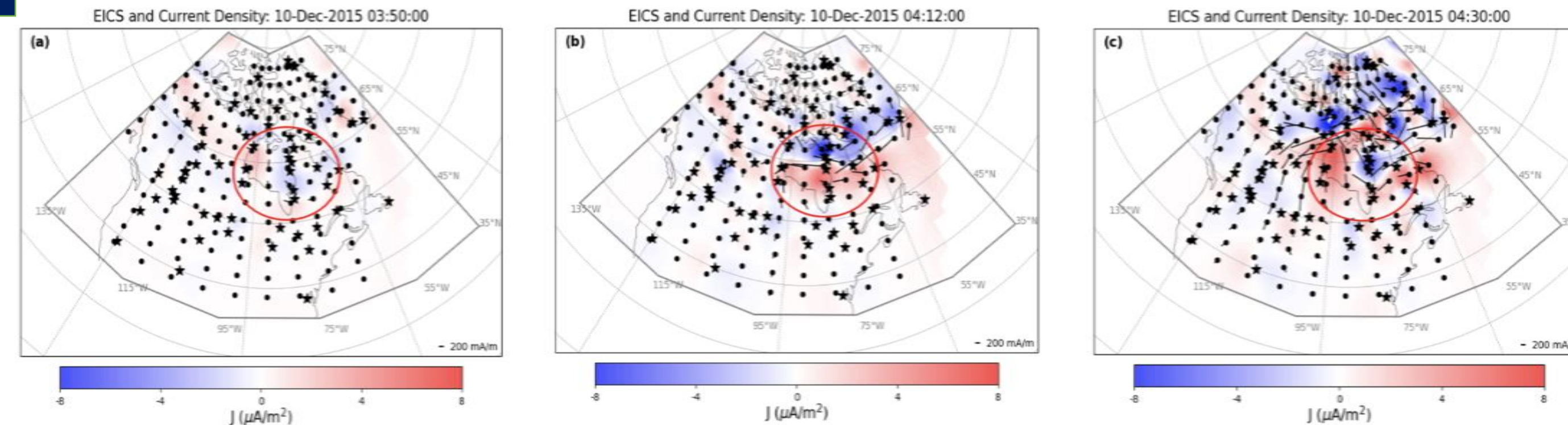
Top panel: Strong substorm on December 10, 2015. The shaded region marks the substorm interval, blue dashed lines indicate onset, peak, and end time, and red dashed line and arrow show GMD initiation times.

Bottom panels (a–i): Time derivatives of magnetic field components at nine stations in geomagnetic coordinates (03:30–05:30 UT). The red dashed line marks the GMD onset at each station.



Panels (a–d) show THEMIS-E data from 03:30–05:30 UT on 10 Dec 2015: (a) magnetic field (GSM), (b–c) ion flow and density, and (d) ion temperature.

GOES-13 data on 10 Dec 2015: Panel (a) shows Hp magnetic field, (b) ion flux, and (c) electron flux. Red dashed lines mark key times: 03:37 UT (dipolarization onset from THEMIS-A) and 04:04 UT (sharp SML drop). The figure highlights magnetic reconfiguration and particle energization during the substorm expansion phase.

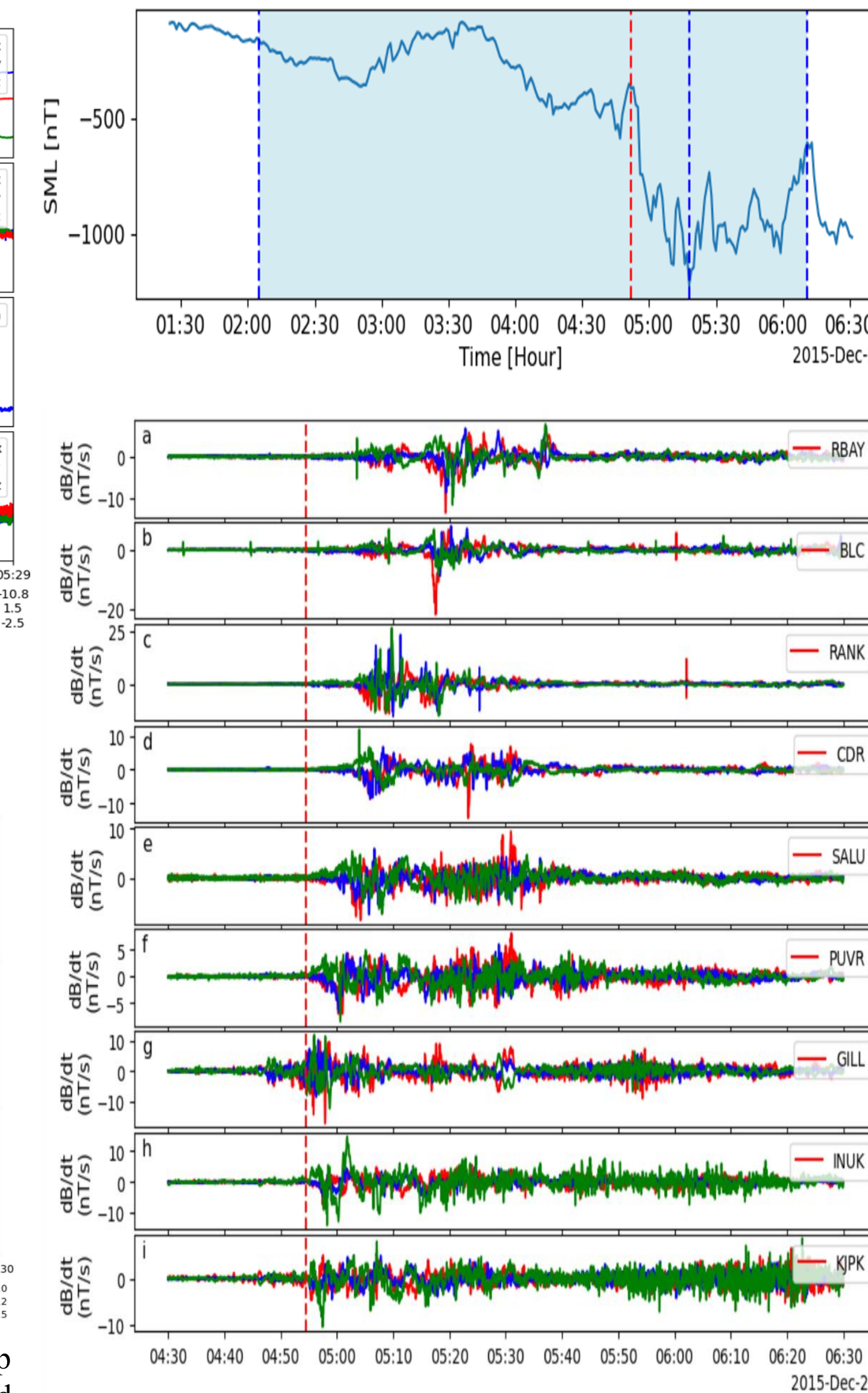


Equivalent ionospheric currents (EICs) from 03:50–04:30 UTC on 10 Dec 2015, derived via the SECS technique. Black arrows show horizontal currents; colored contours represent vertical current density ($\mu\text{A}/\text{m}^2$), with red for upward and blue for downward FACs. A red circle highlights an area of interest.

References

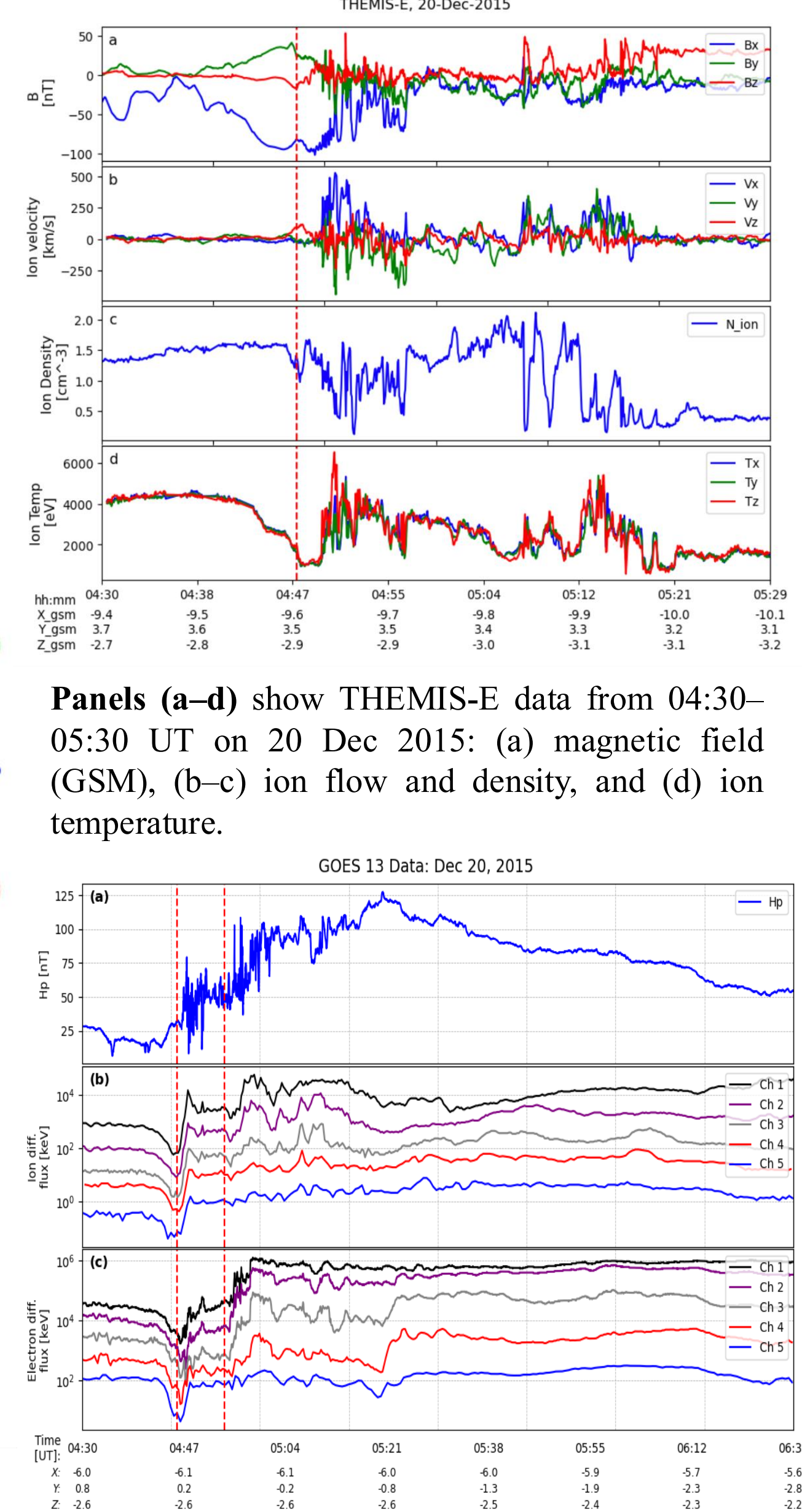
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December 20, 2015 Substorm



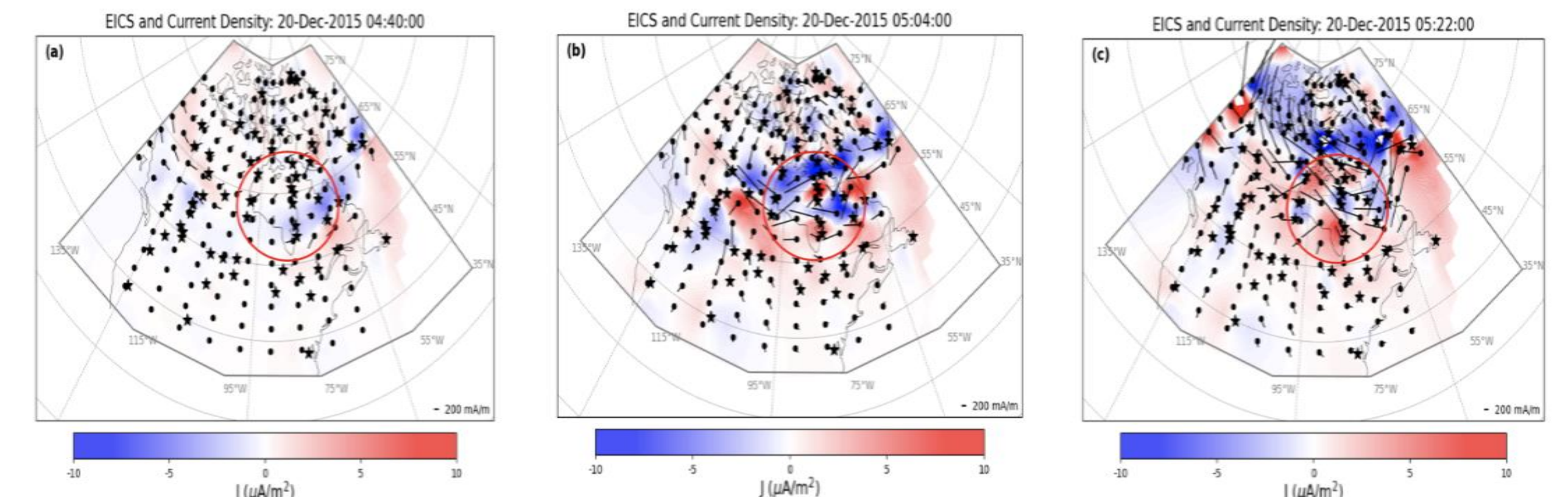
Top panel: Strong substorm on December 20, 2015. The shaded region marks the substorm interval, blue dashed lines indicate onset, peak, and end time, and red dashed line and arrow show GMD initiation times.

Bottom panels (a–i): Time derivatives of magnetic field components at nine stations in geomagnetic coordinates (04:30–06:30 UT). The red dashed line marks the GMD onset at each station.



Panels (a–d) show THEMIS-E data from 04:30–05:30 UT on 20 Dec 2015: (a) magnetic field (GSM), (b–c) ion flow and density, and (d) ion temperature.

GOES-13 data on 20 Dec 2015: Panel (a) shows Hp magnetic field, (b) ion flux, and (c) electron flux. Red dashed lines mark key times: 04:47 UT (dipolarization onset from THEMIS-A) and 04:54 UT (sharp SML drop). The figure highlights magnetic reconfiguration and particle energization during the substorm expansion phase.



Equivalent ionospheric currents (EICs) from 04:40–05:22 UTC on 20 Dec 2015, derived via the SECS technique. Black arrows show horizontal currents; colored contours represent vertical current density ($\mu\text{A}/\text{m}^2$), with red for upward and blue for downward FACs. A red circle highlights an area of interest.

Acknowledgments

- This work was partially supported by NASA Grant 80GSFC23CA042 and 80NSSC20K1779.73312].