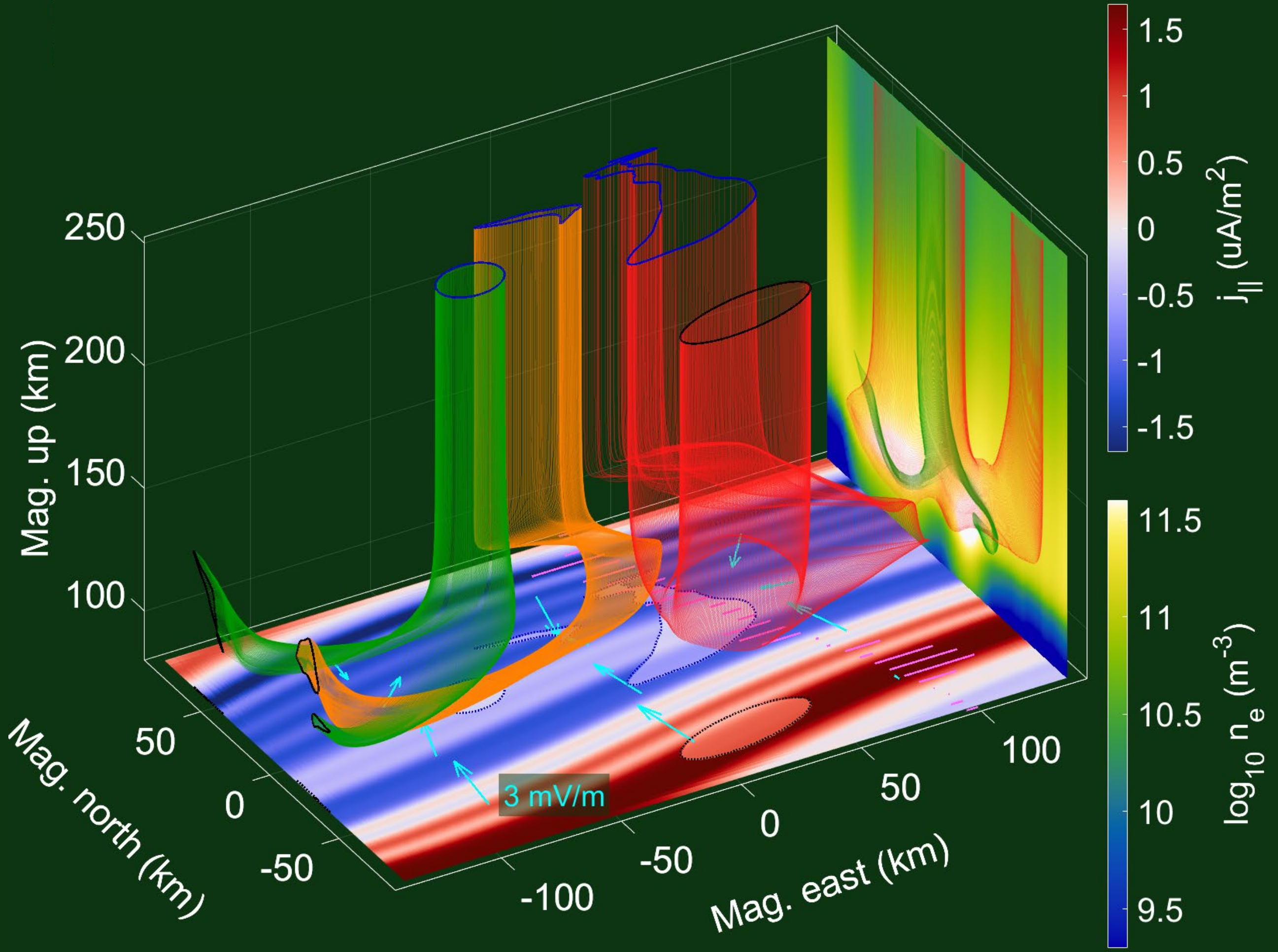
Current Continuity in Auroral System Science:
3D Data-Driven Auroral GEMINI Simulations



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I. Motivation & Methodology

Why the need for 3D in auroral simulations?

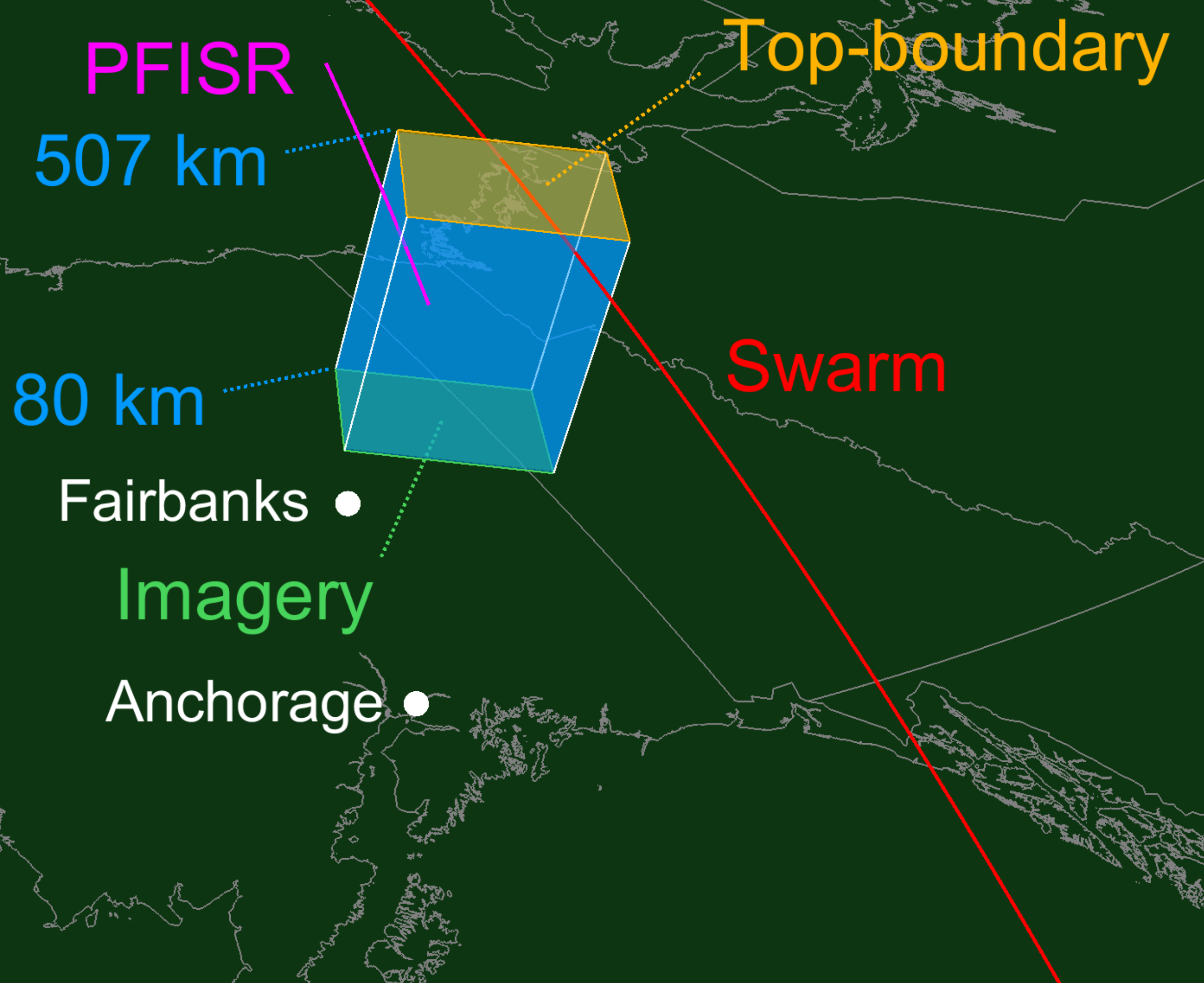
- Integrating over ionospheric altitudes can hide significant information about polar ionospheric systems (Yano and Ebihara, 2021, *JGR*).
- 3D simulations are sensitive to various parameters and methodologies when exploring current closure of auroral systems.
- Two examples of such sensitivities are:
  A. A choice of unaccelerated vs. accelerated electron precipitation spectra can significantly impact Hall-to-Pedersen conductance ratios.
  B. Enforcing a constant background electric field, $\mathbf{E}_{\mathrm{bg}}$, enhances the FAC impact by the imagery derived gradient terms and changes current closure morphology:

$$j_{\parallel}(x, y) = \Sigma_P \nabla \cdot \mathbf{E} + \mathbf{E} \cdot \nabla\Sigma_P + (\mathbf{E} \times \mathbf{b}) \cdot \nabla\Sigma_H$$

What’s needed to simulate auroral arcs in 3D?

A. 2D, top-boundary maps of
- Electron precipitation energetics
  - Determines 3D conductivity volume
  - Requires imagery, choice of energy spectra, and a transport model
- Field-aligned current + $\mathbf{E}_{bg}$
  - Forces the simulation
  - Requires 1D track data + replication

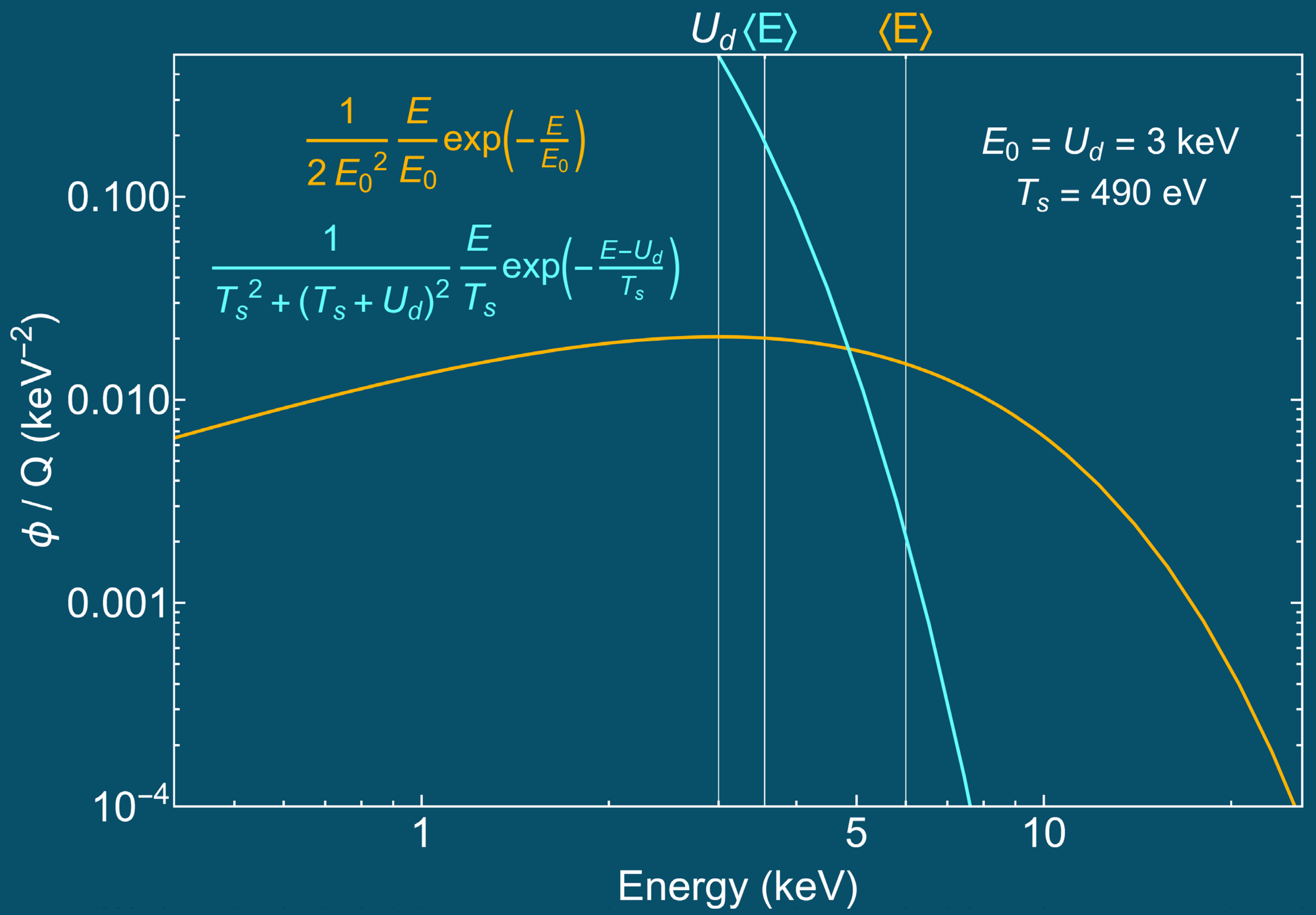
B. A 3D Model: GEMINI
- Provides state-of-the-art, 3D ionospheric, multi-fluid simulations
- Github.com/gemini3d

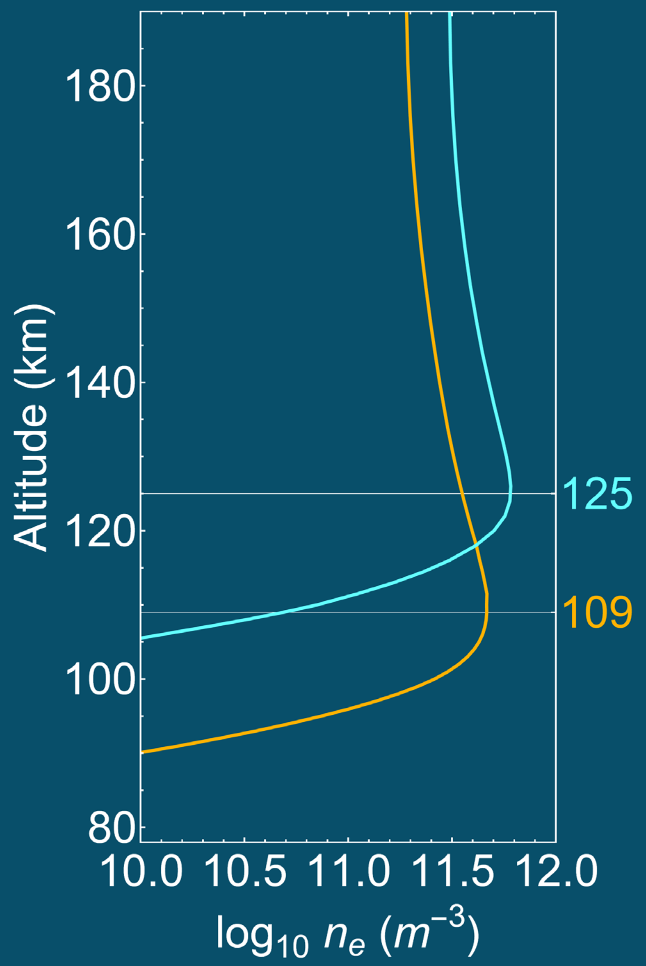


GEMINI model: Zetergren & Semeter, 2012, *JGR*; Zettergren & Snively, 2019, *GRL*
Swarm data: swarmhandbook.earth.esa.int – PFISR data: data.amisr.com

II. Top-Boundary Drivers

Choosing Electron Precipitation Energy Spectra

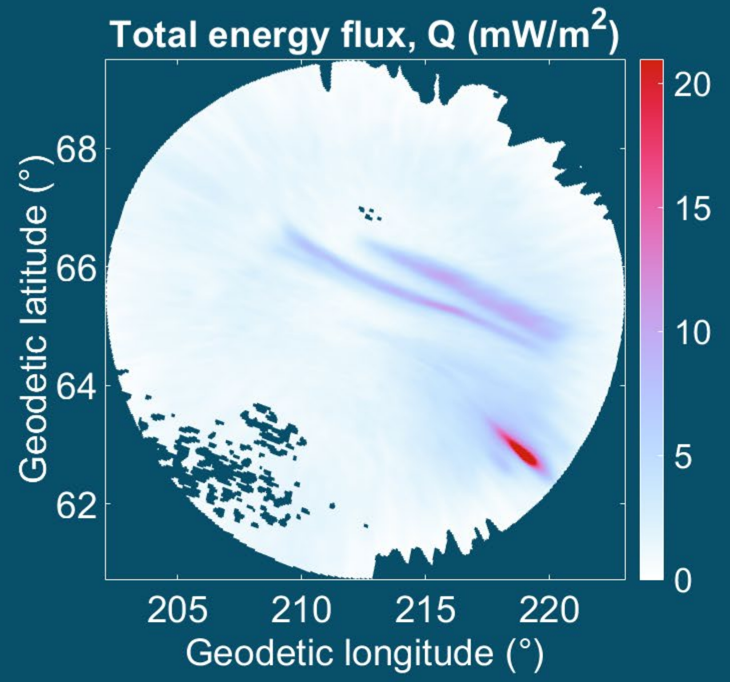


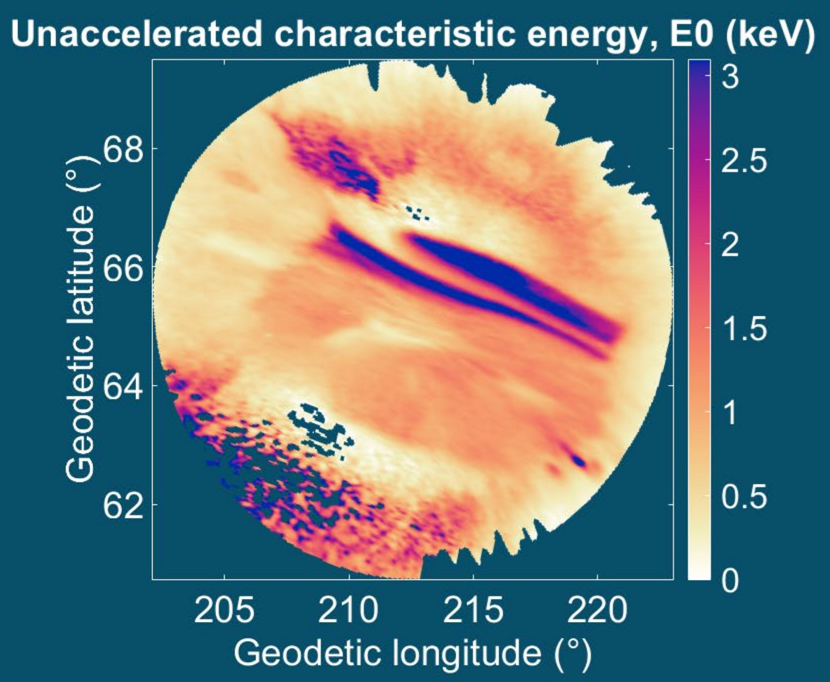


Transport model: Solomon et al., 1988, *JGR* (GLOW)
Ionization rate parameterization: Fang et al., 2010, *GRL*

Determining Source Region Characteristic Energy, T_s

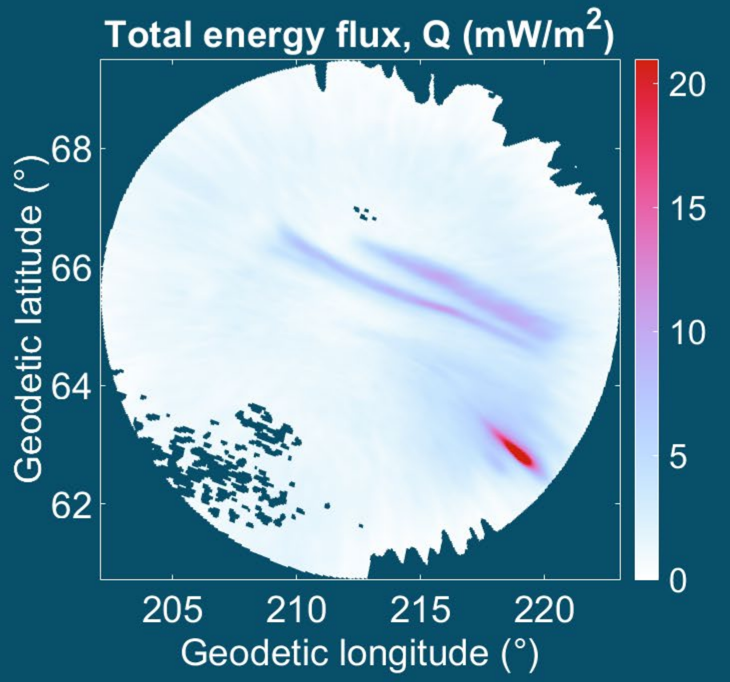
1) Invert multi-spectral imagery assuming unaccelerated Maxwellian spectra

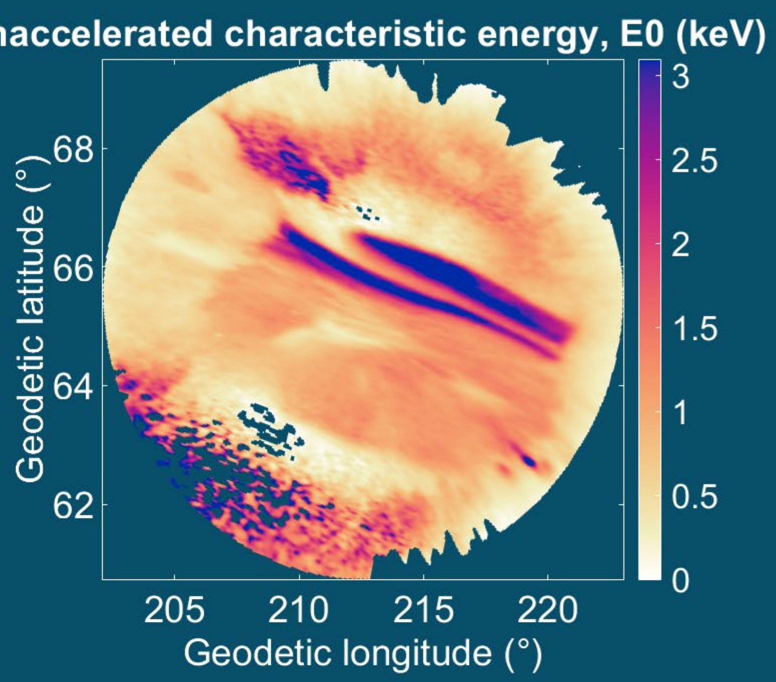


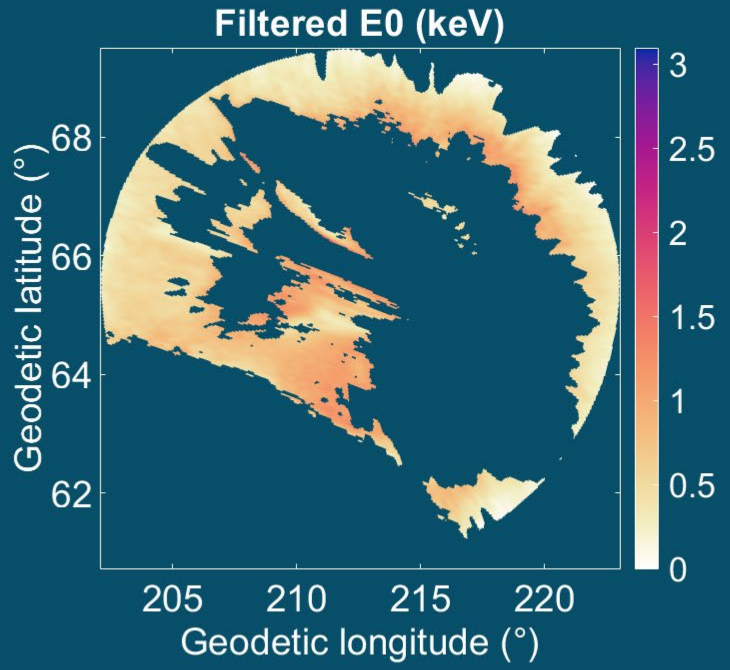


Determining Source Region Characteristic Energy, T_s

1) Invert multi-spectral imagery assuming unaccelerated Maxwellian spectra
2) Filter for low energy fluxes (where we assume $U_d \approx 0$) and low 630 nm light

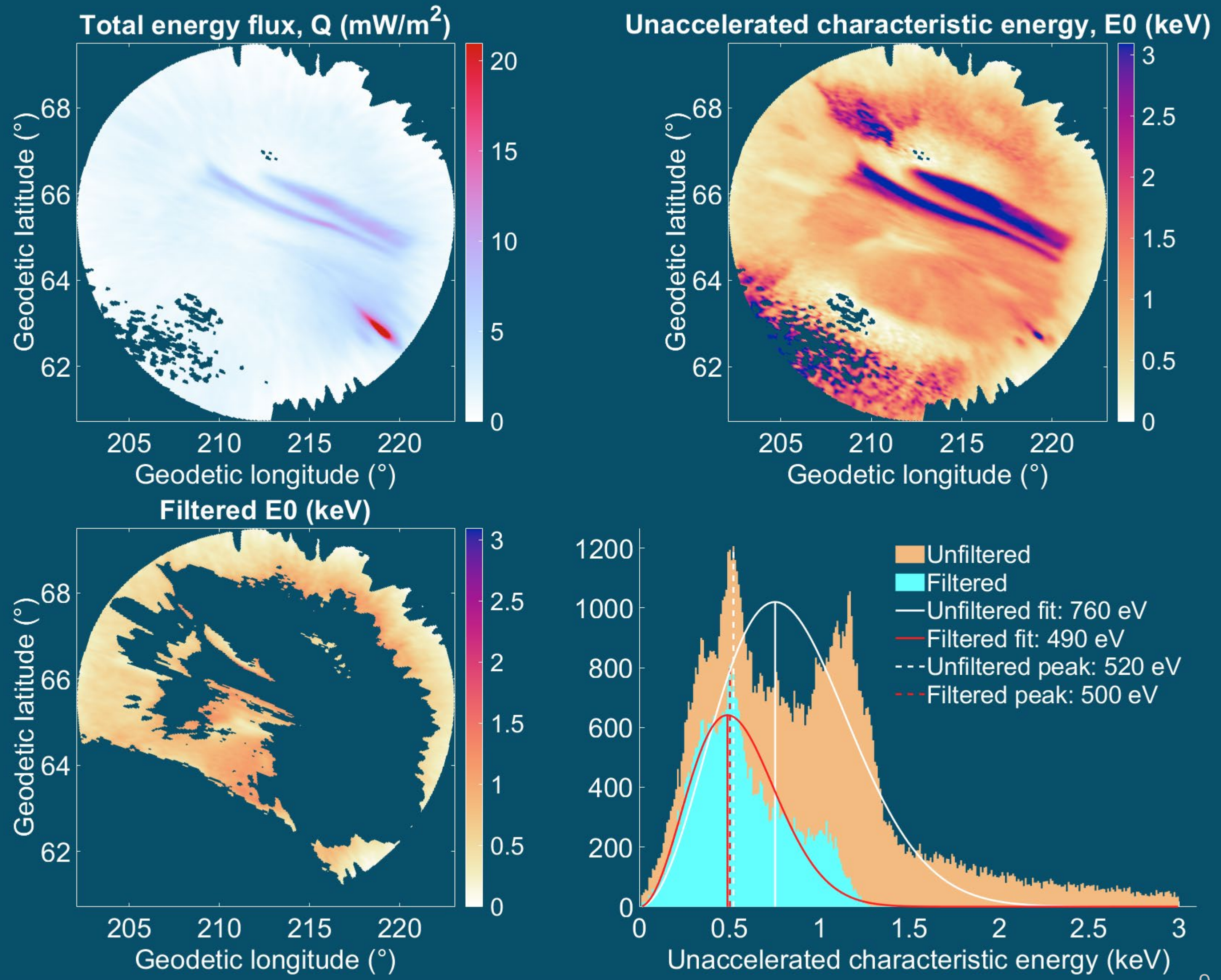






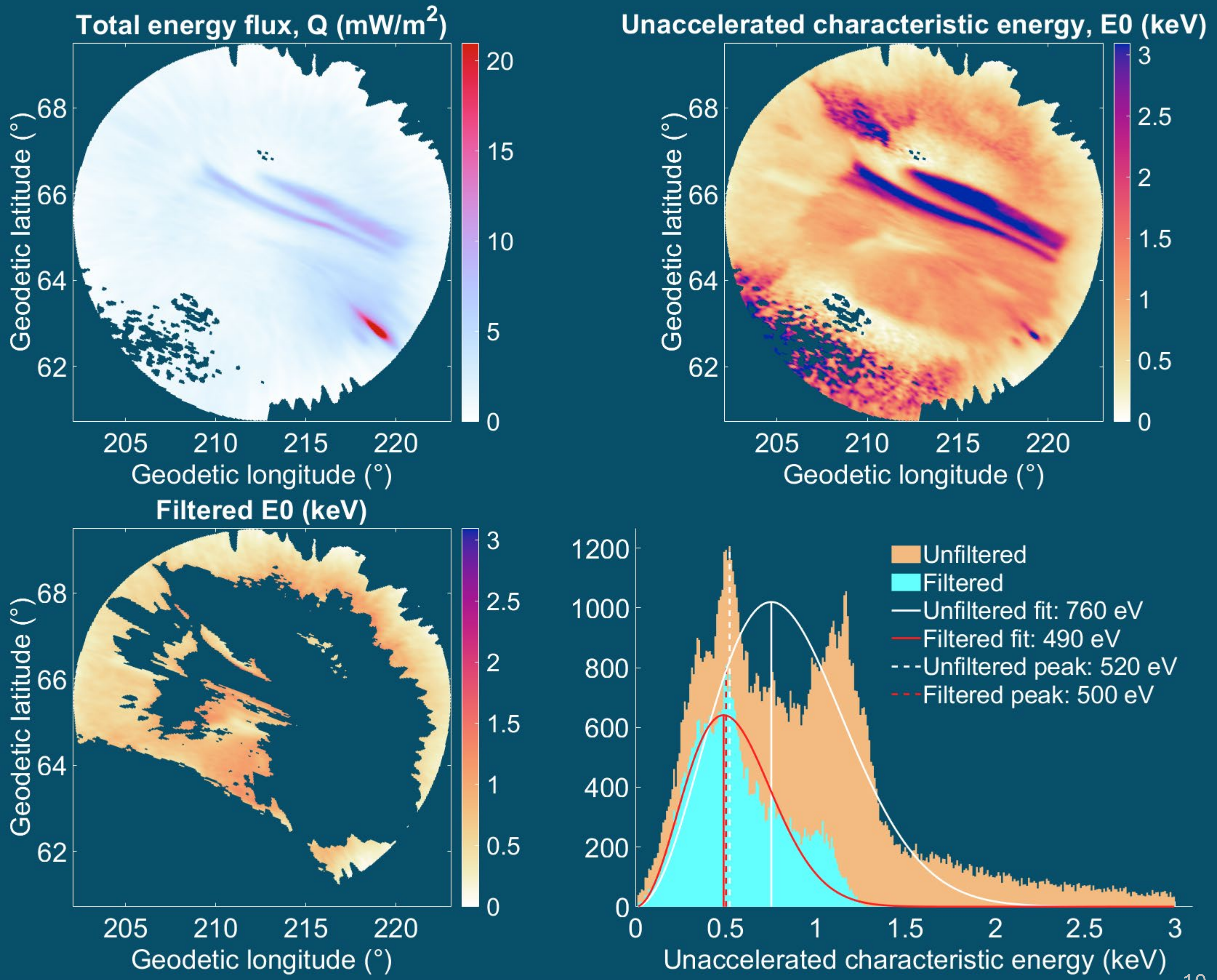
Determining Source Region Characteristic Energy, T_s

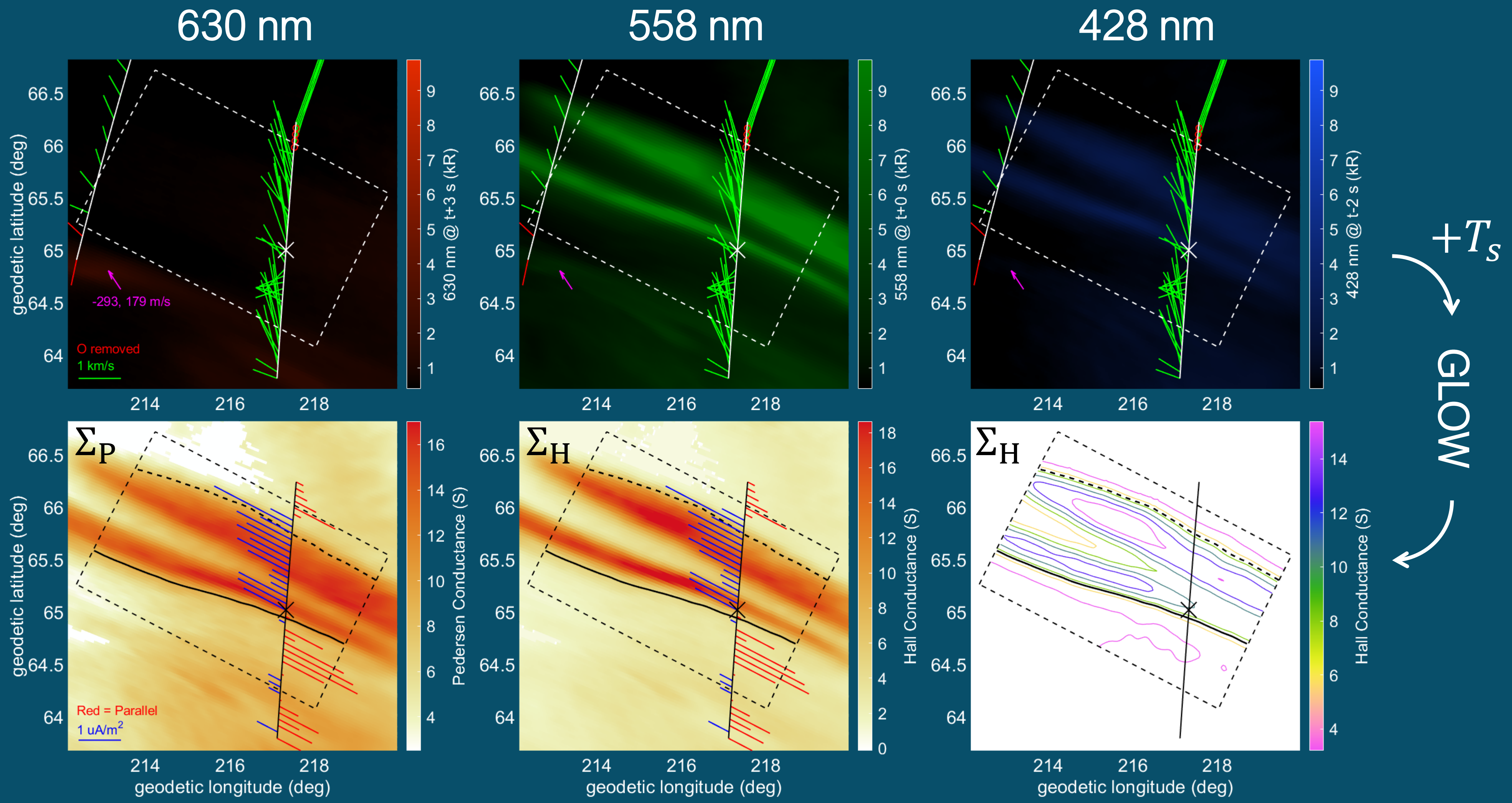
1) Invert multi-spectral imagery assuming unaccelerated Maxwellian spectra
2) Filter for low energy fluxes (where we assume $U_d \approx 0$) and low 630 nm light
3) Find T_s, the peak energy of filtered E_0



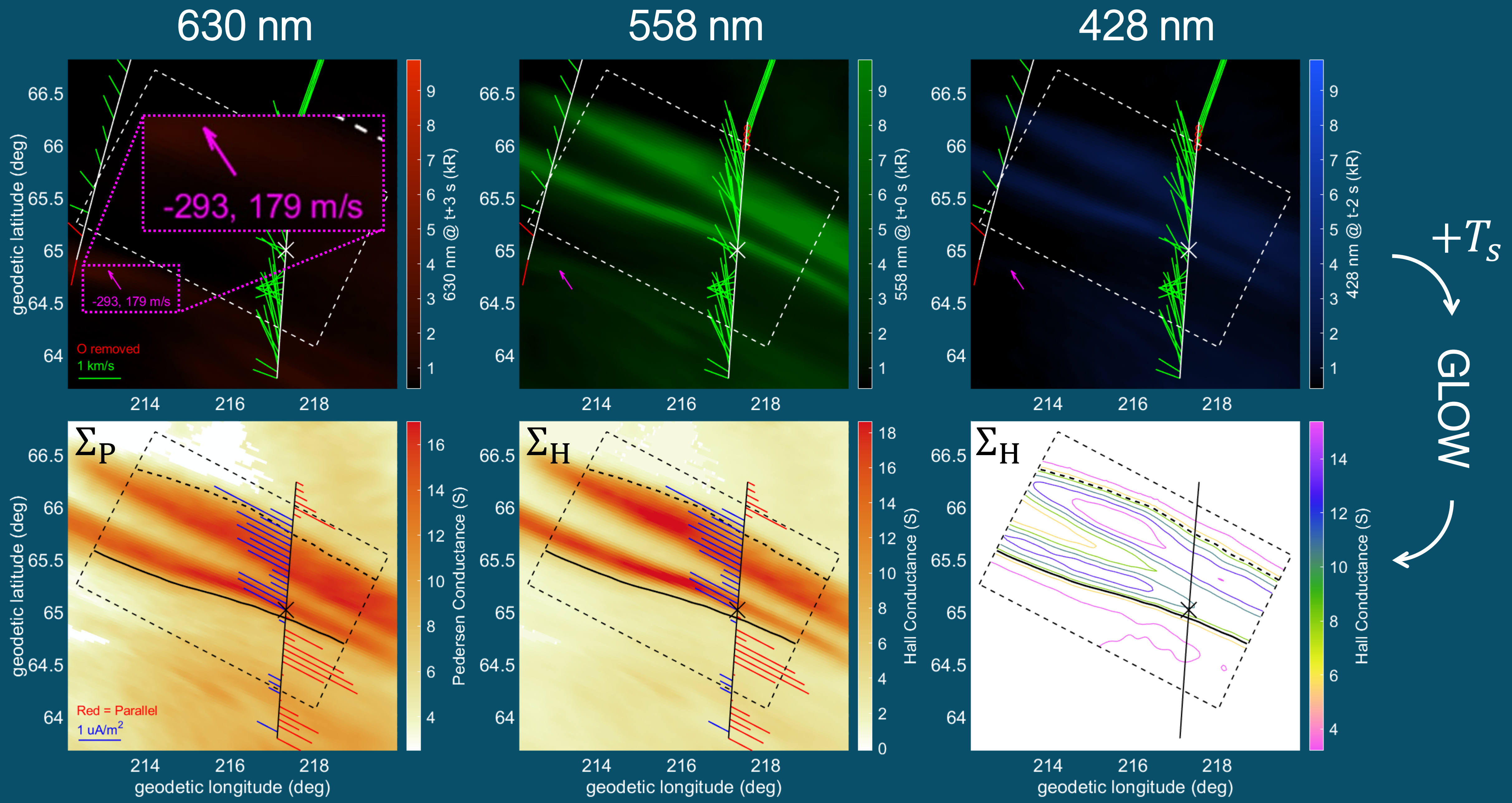
Determining Source Region Characteristic Energy, T_s

1) Invert multi-spectral imagery assuming unaccelerated Maxwellian spectra
2) Filter for low energy fluxes (where we assume $U_d \approx 0$) and low 630 nm light
3) Find T_s, the peak energy of filtered E_0
4) Invert imagery using accelerated spectra





Imagery data: optics.gi.alaska.edu/optics/archive



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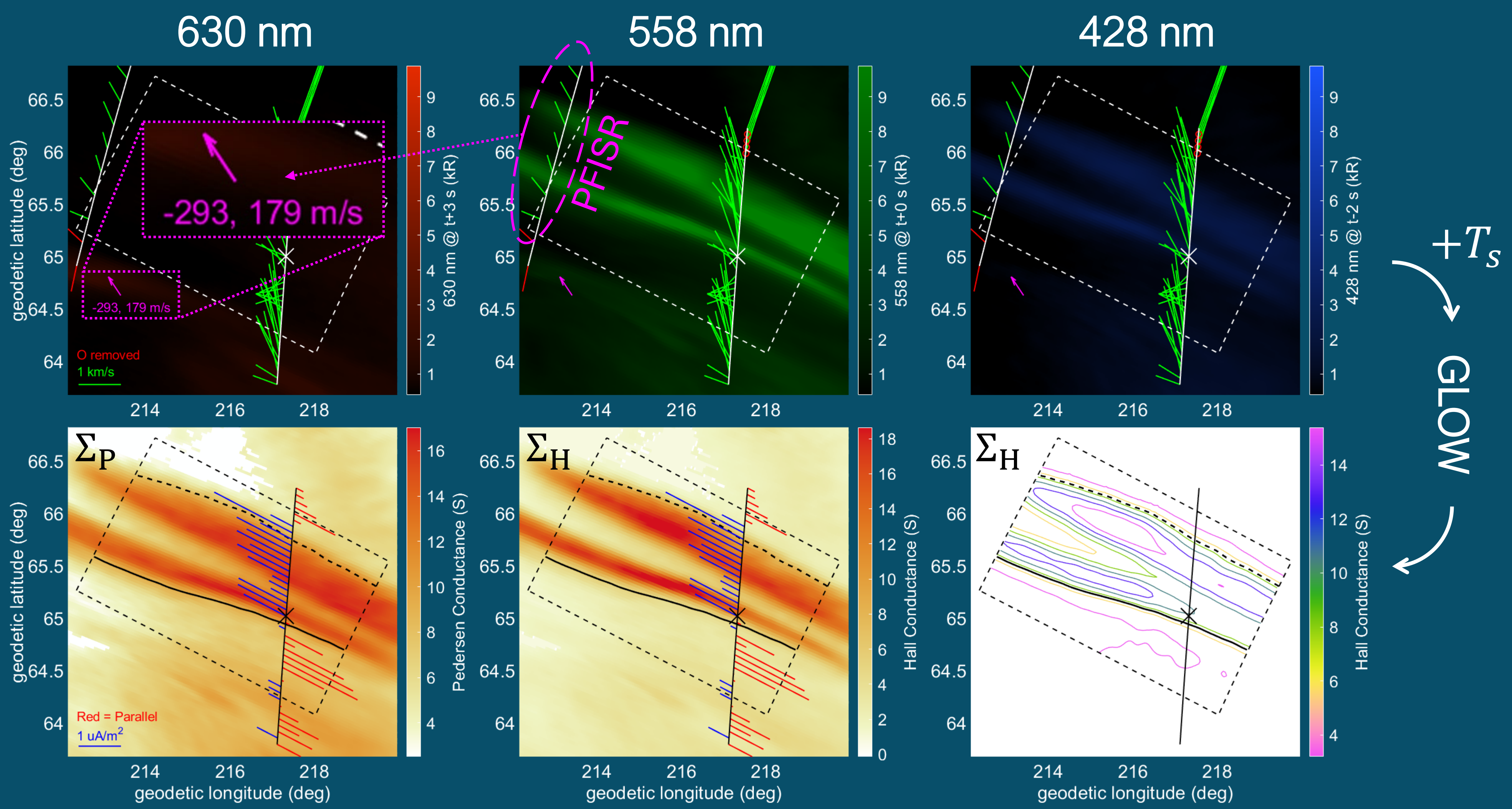
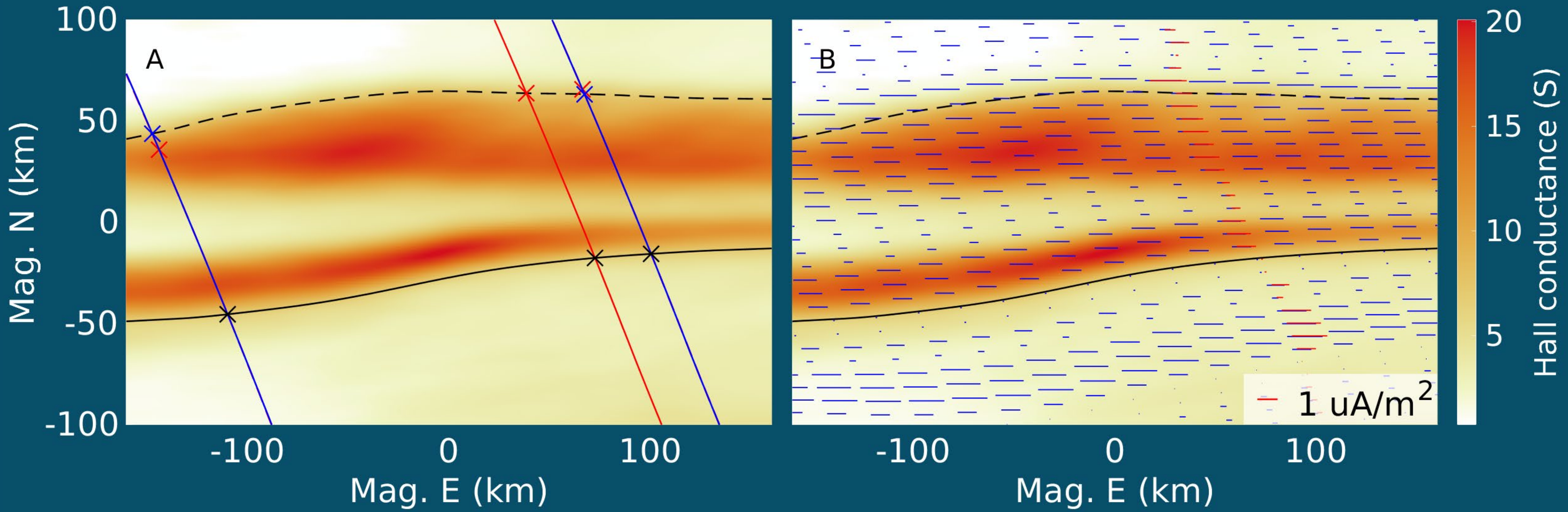


Imagery data: optics.gi.alaska.edu/optics/archive

Top-Boundary Driver: Field-Aligned Current

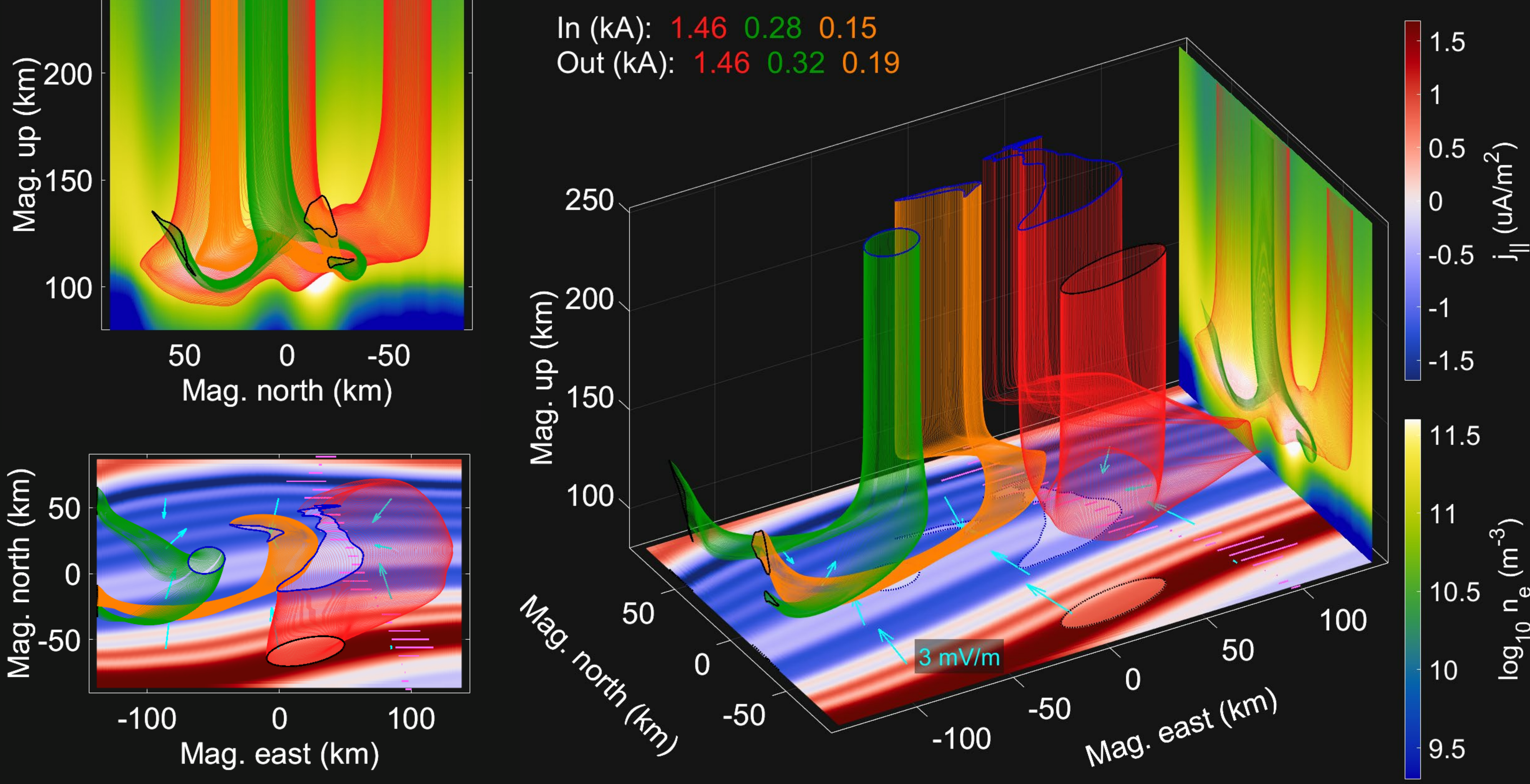
- We convert 1D FAC data tracks into continuous 2D top-boundary drivers
- Arc-like assumption: minimal gradients along the arc
- Github.com/317Lab/aurora_gemini (van Irsel et al., 2024, *JGR*)



III. Simulation Results

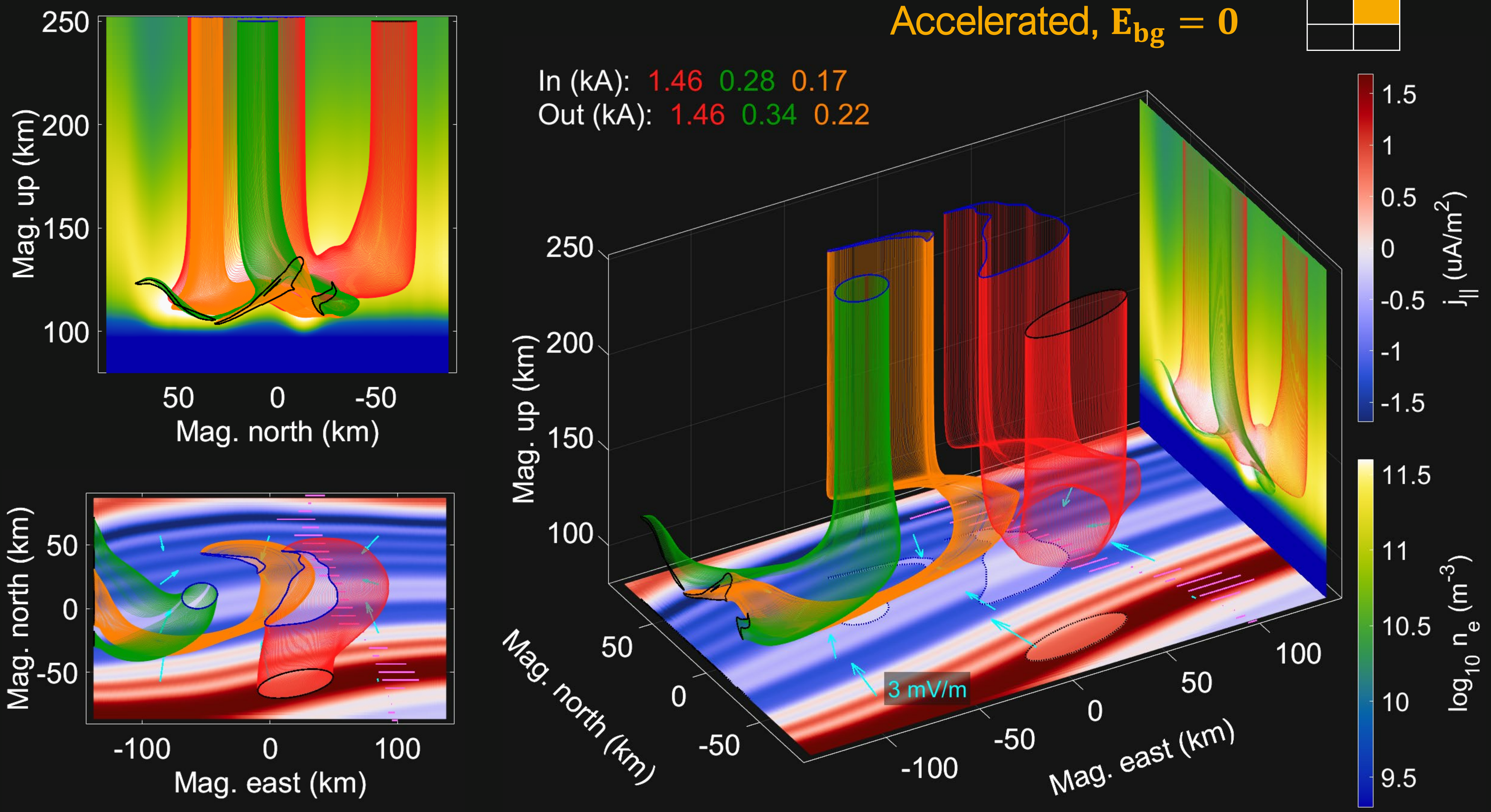
$\mathbf{E}_{\mathrm{bg}} = 0$ Unaccelerated	$\mathbf{E}_{\mathrm{bg}} = 0$ Accelerated
$\mathbf{E}_{\mathrm{bg}} \neq 0$ Unaccelerated	$\mathbf{E}_{\mathrm{bg}} \neq 0$ Accelerated

Unaccelerated, $\mathbf{E_{bg}} = 0$

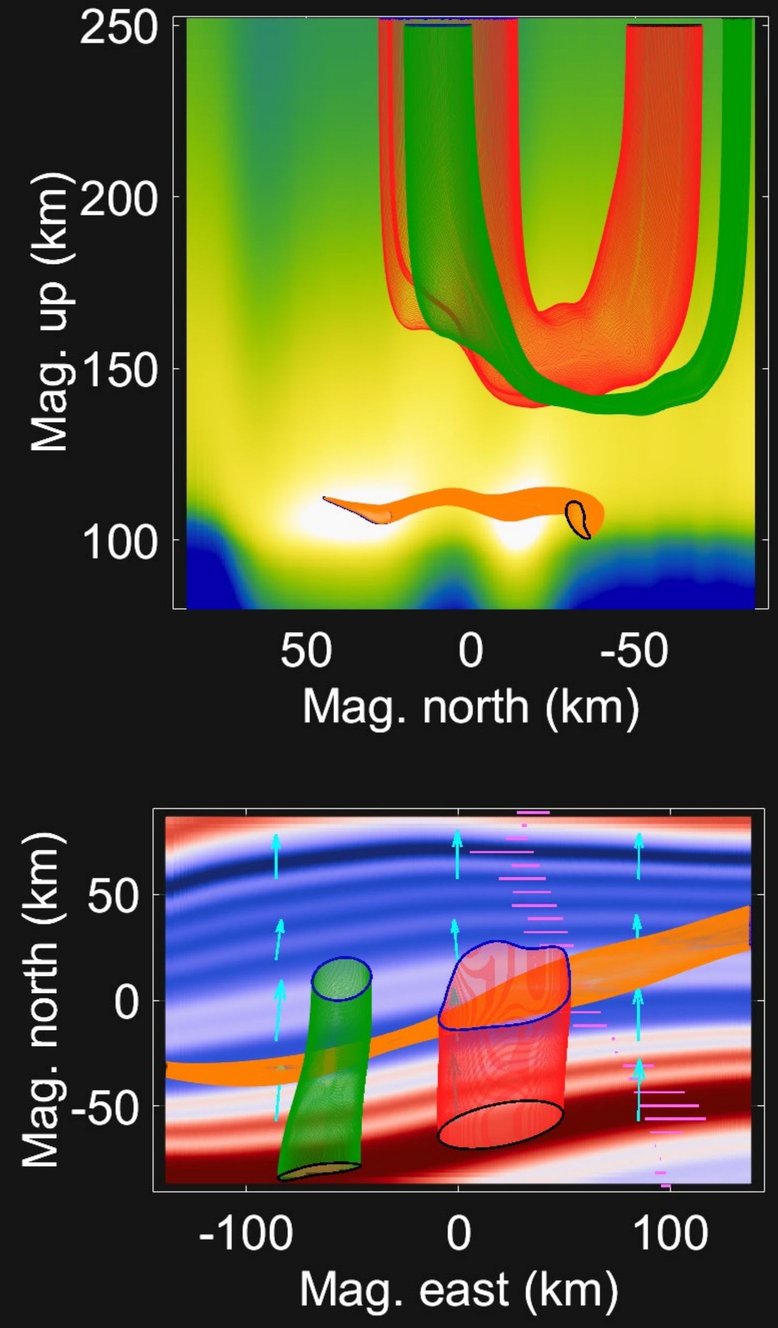


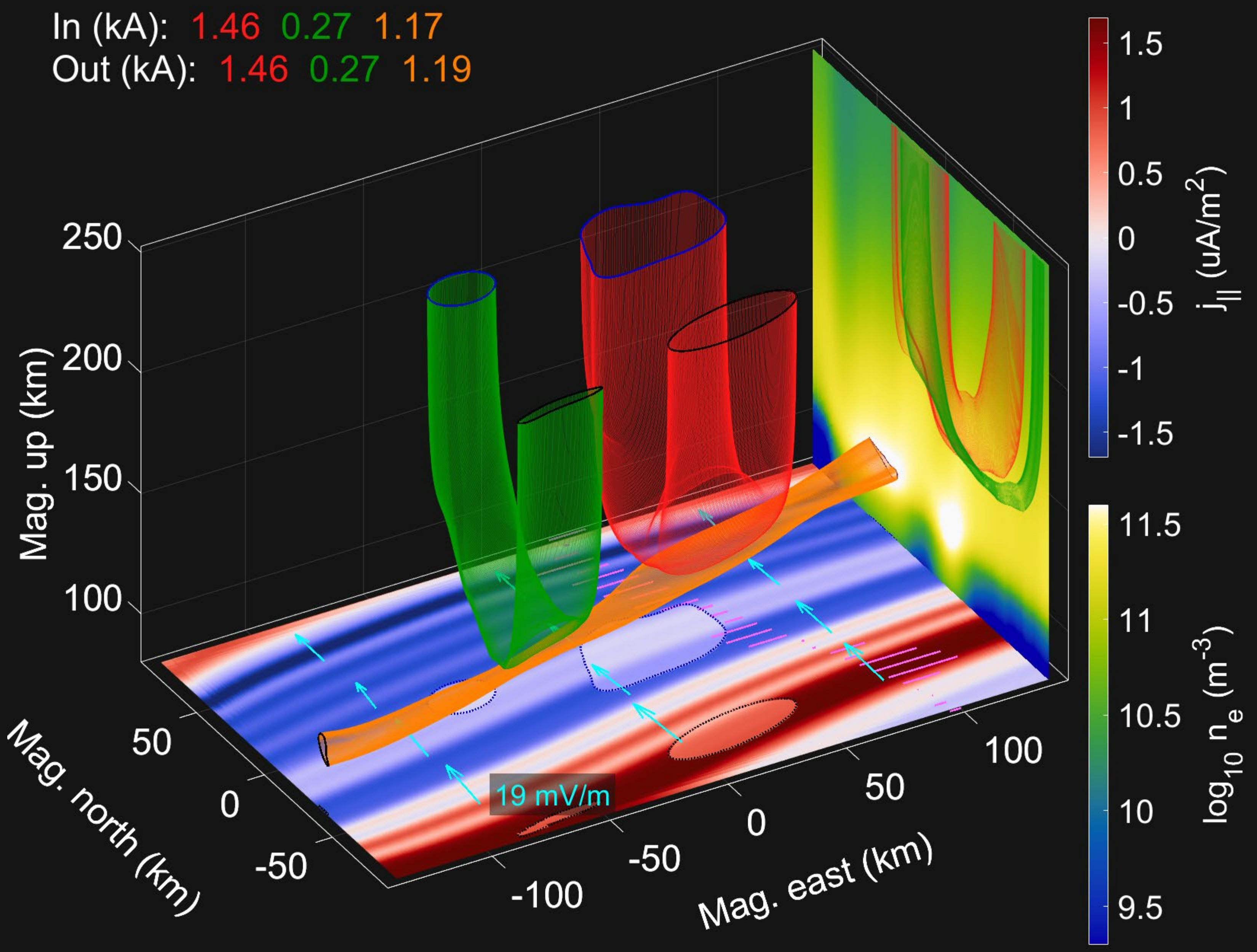
Accelerated, $\mathbf{E_{bg}} = \mathbf{0}$

In (kA): 1.46 0.28 0.17
Out (kA): 1.46 0.34 0.22

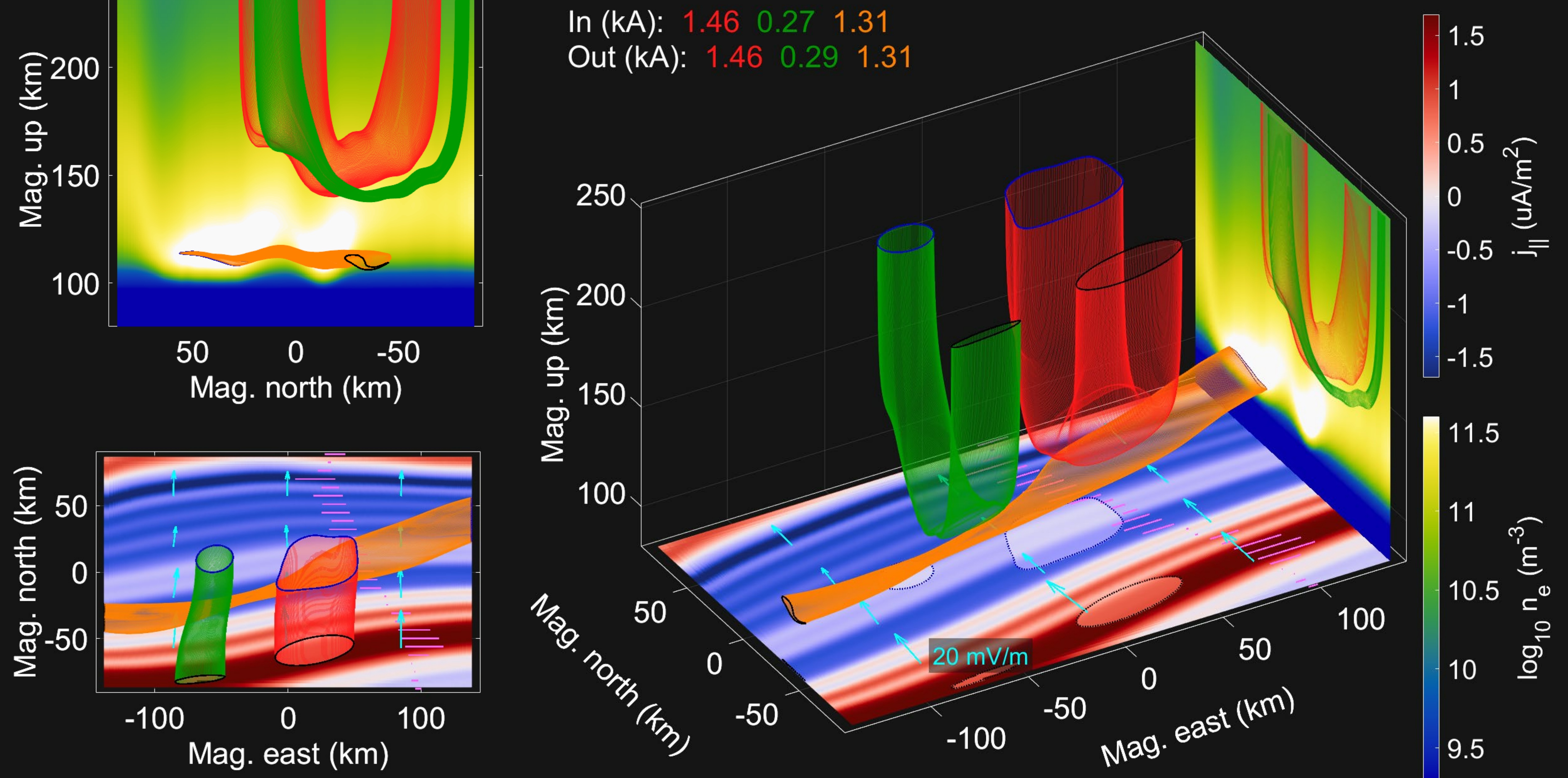


Unaccelerated, $\mathbf{E_{bg}} \neq 0$

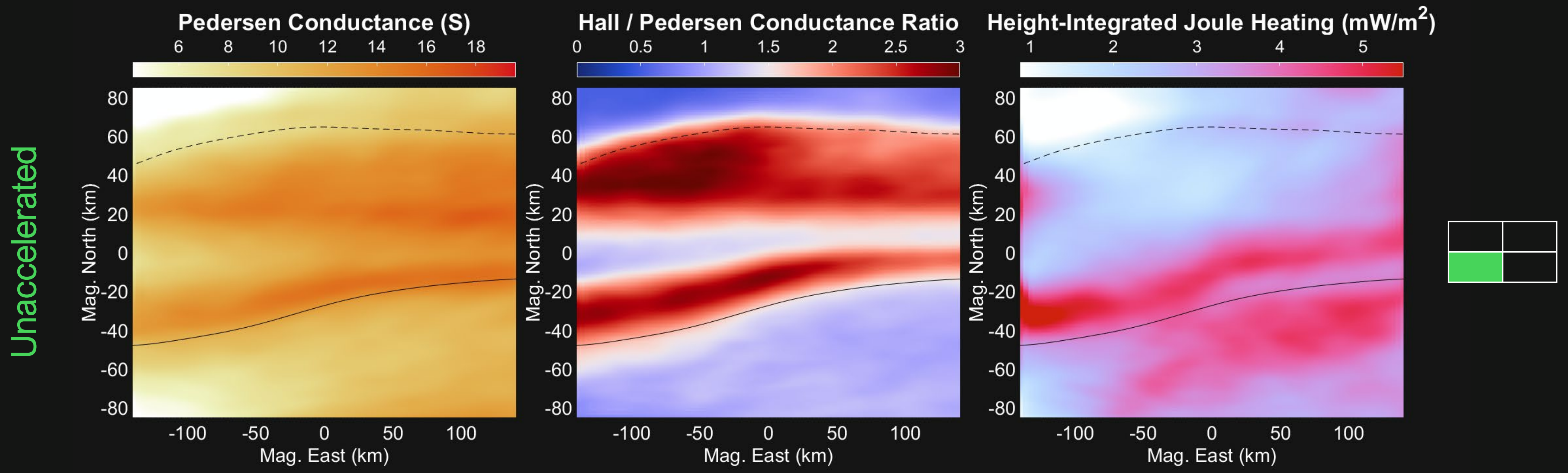




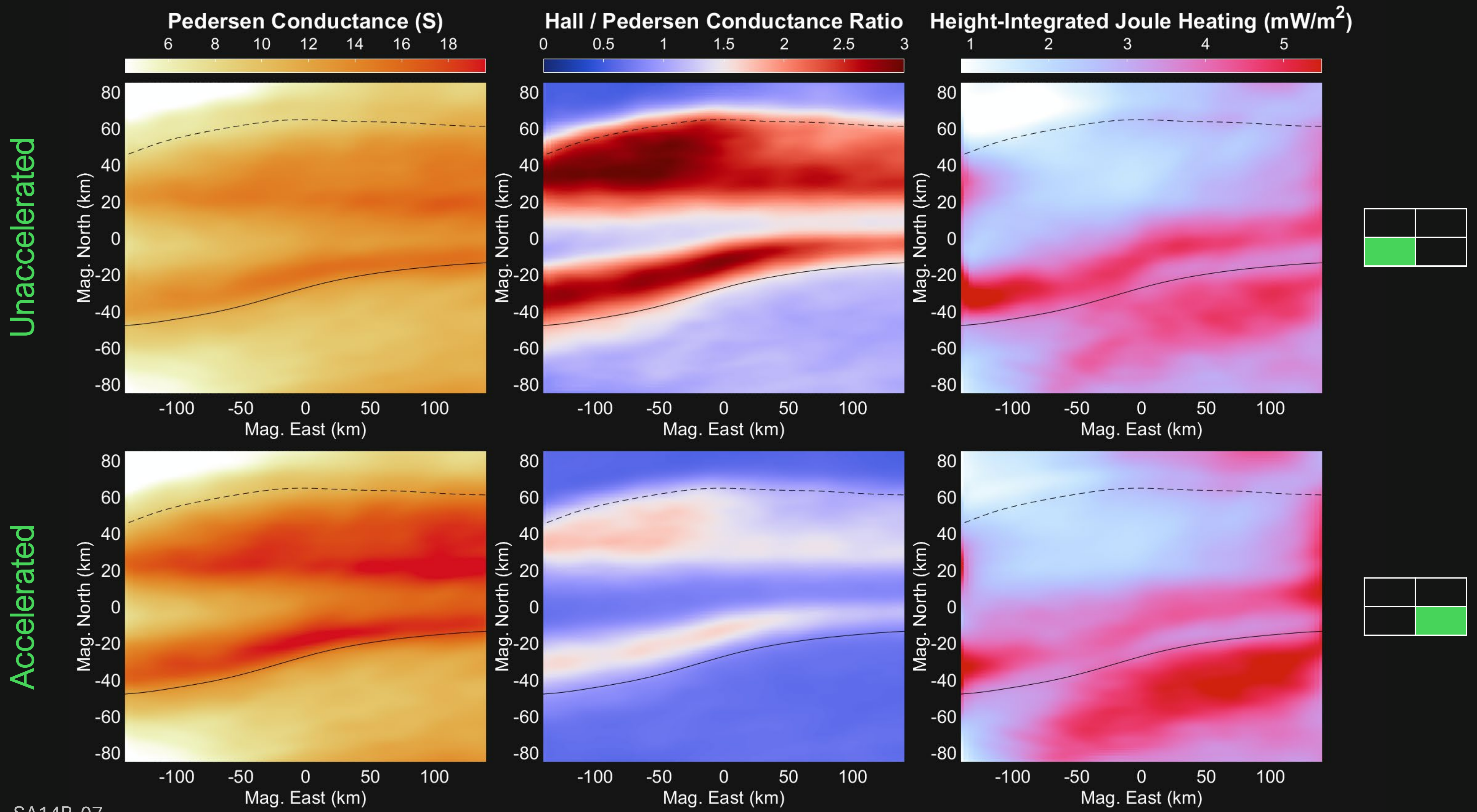
Accelerated, $\mathbf{E}_{\mathbf{bg}} \neq 0$



Height-Integrated View, $\mathbf{E_{bg}} \neq \mathbf{0}$



Height-Integrated View, $\mathbf{E_{bg}} \neq \mathbf{0}$



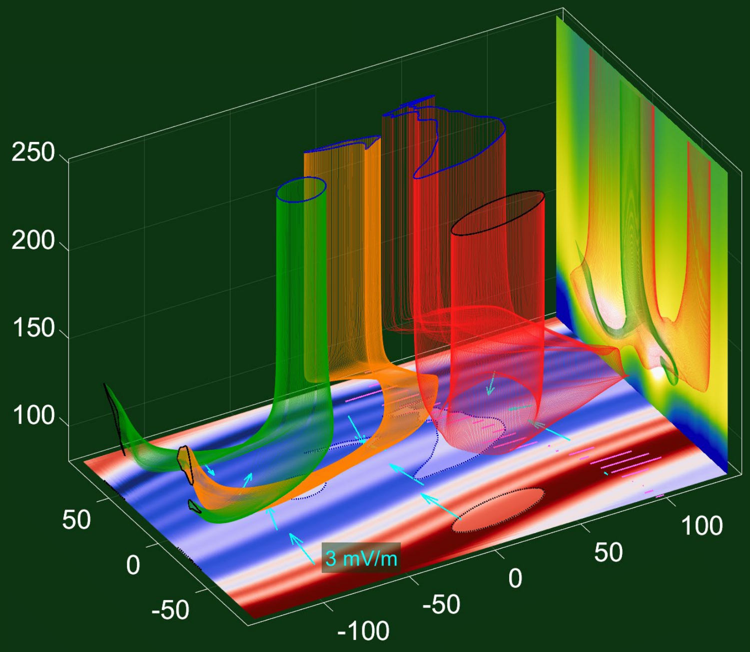
IV. Comments & Conclusions

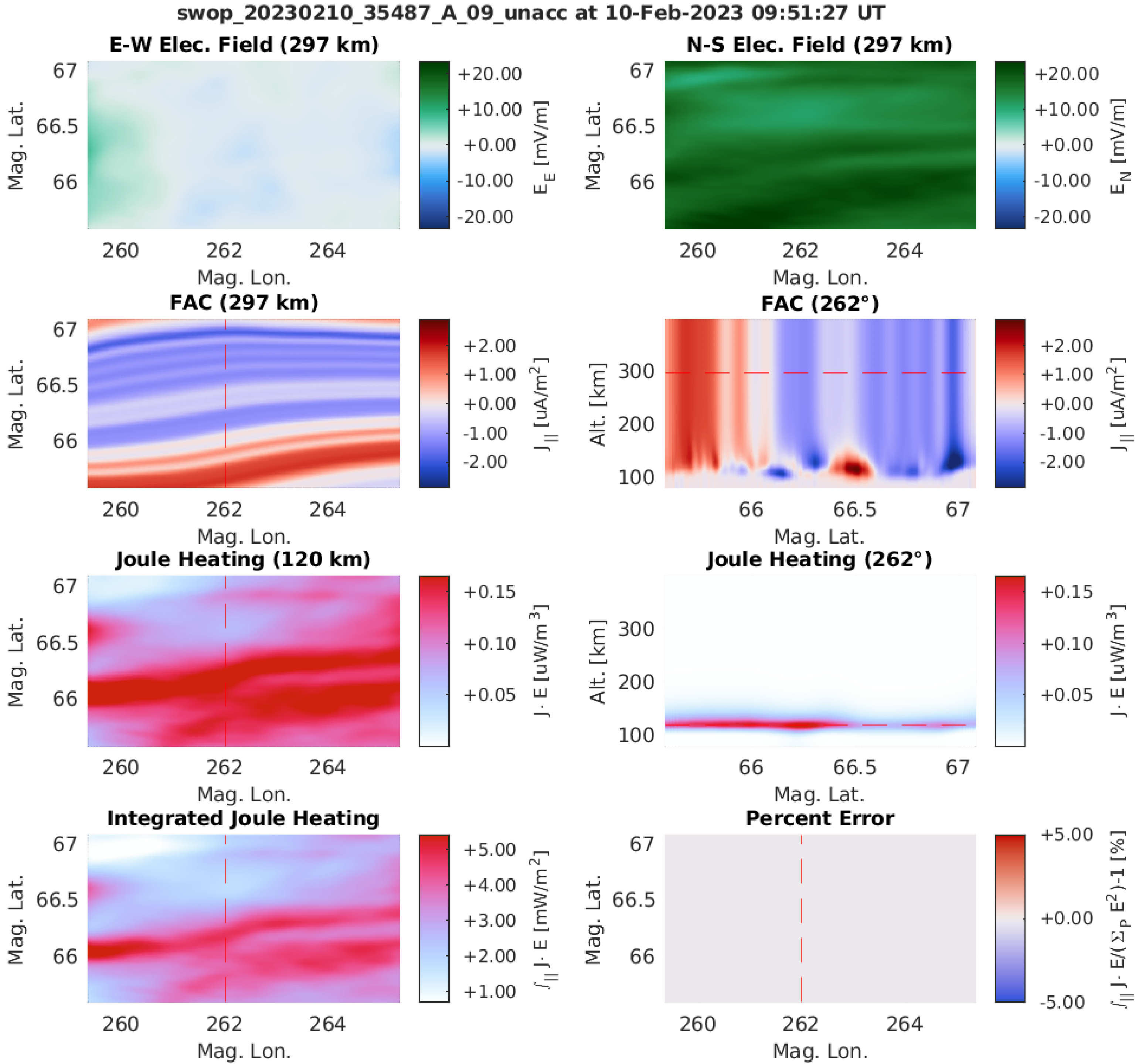
Comments & Conclusions

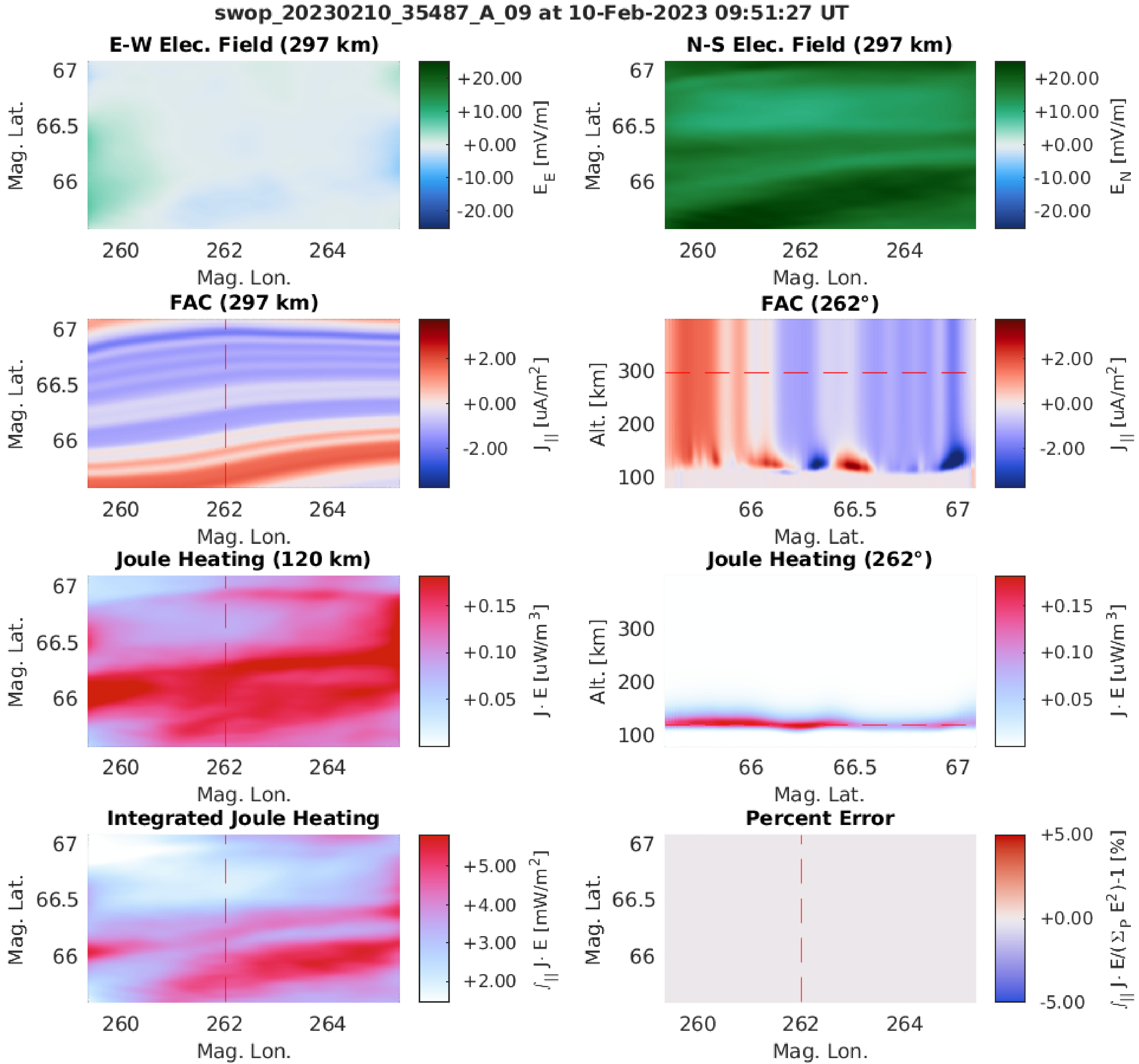
- The height-integrated view of the auroral ionosphere, albeit very useful, can hide the 3D nature of current continuity.
- Simulating auroral arc systems in 3D is a sensitive undertaking:
  A. The choice of unaccelerated precipitation spectra can:
    - Overestimate the thermal spread, hence overestimate lower E-region densities.
    - Affect Hall closure and Hall-to-Pedersen conductance ratios.

  B. The electric potential solution is not unique:
    - An inappropriate background electric field can provide erroneous current closure morphology.
    - PFISR can provide an $\mathbf{E}_{\mathrm{bg}}$ which better compares simulation results against Swarm's TII Ion flow data (see future work).
- For details on imagery inversion, see poster SA33B-2521 by Alex Mule.
- jules.van.irsel.gr@dartmouth.edu

Scan for videos of current flux tubes and more!




swop_20230210_35487_A_09_unacc at 10-Feb-2023 09:51:27 UT
E-W Elec. Field (297 km)
N-S Elec. Field (297 km)
E_E [mV/m]
E_N [mV/m]
FAC (297 km)
FAC (262°)
$J_{||}$ [uA/m^2]
Joule Heating (120 km)
Joule Heating (262°)
J · E [uW/m^3]
Integrated Joule Heating
Percent Error
$\int_{||}$ J · E [mW/m^2]
$\int_{||}$ J · E/(Σ_P E^2)-1 [%]
Mag. Lat.
Mag. Lon.
Alt. [km]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Percent Error
Mag. Lat.
Mag. Lon.
Alt. [km]
E_E [mV/m]
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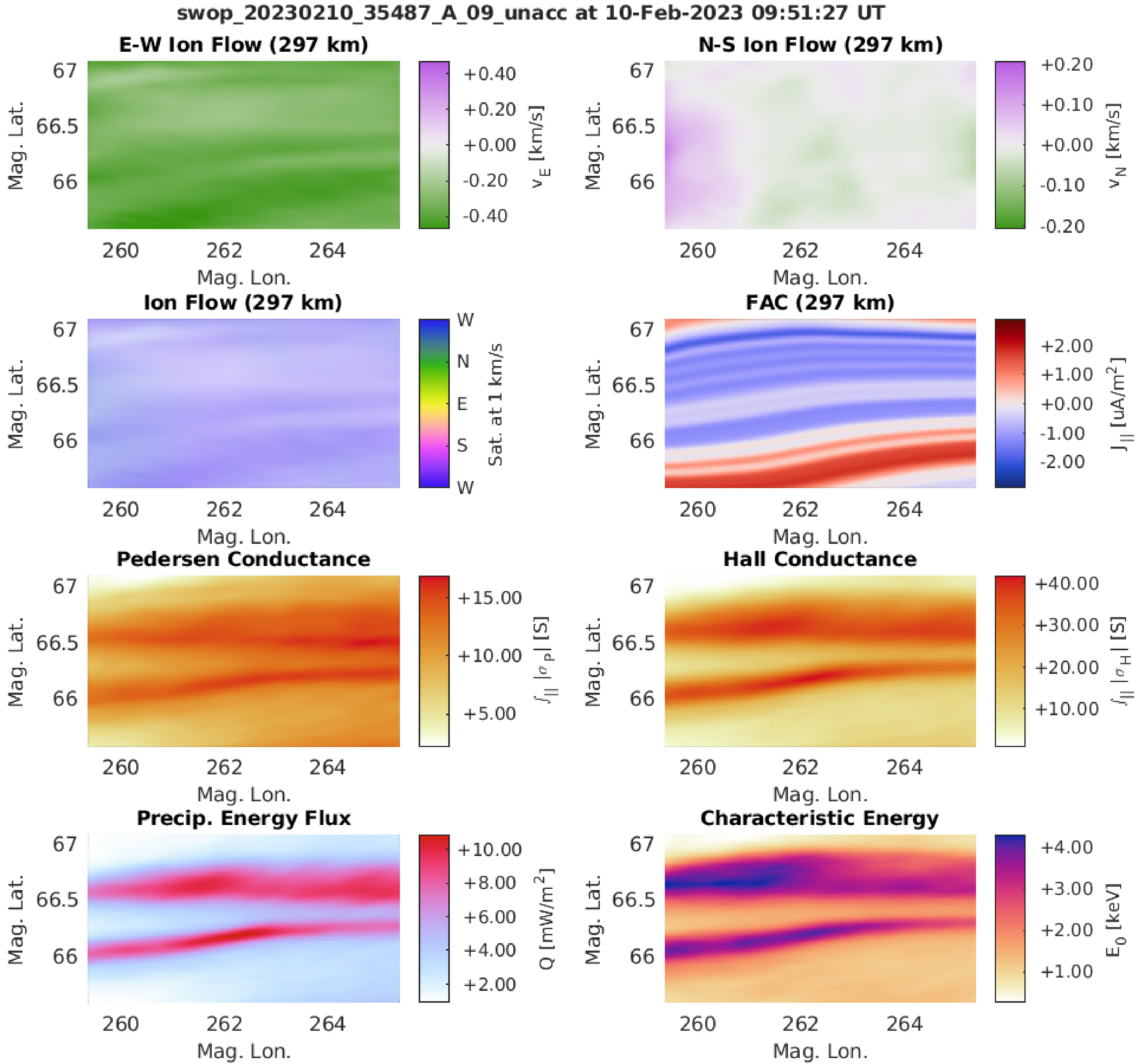
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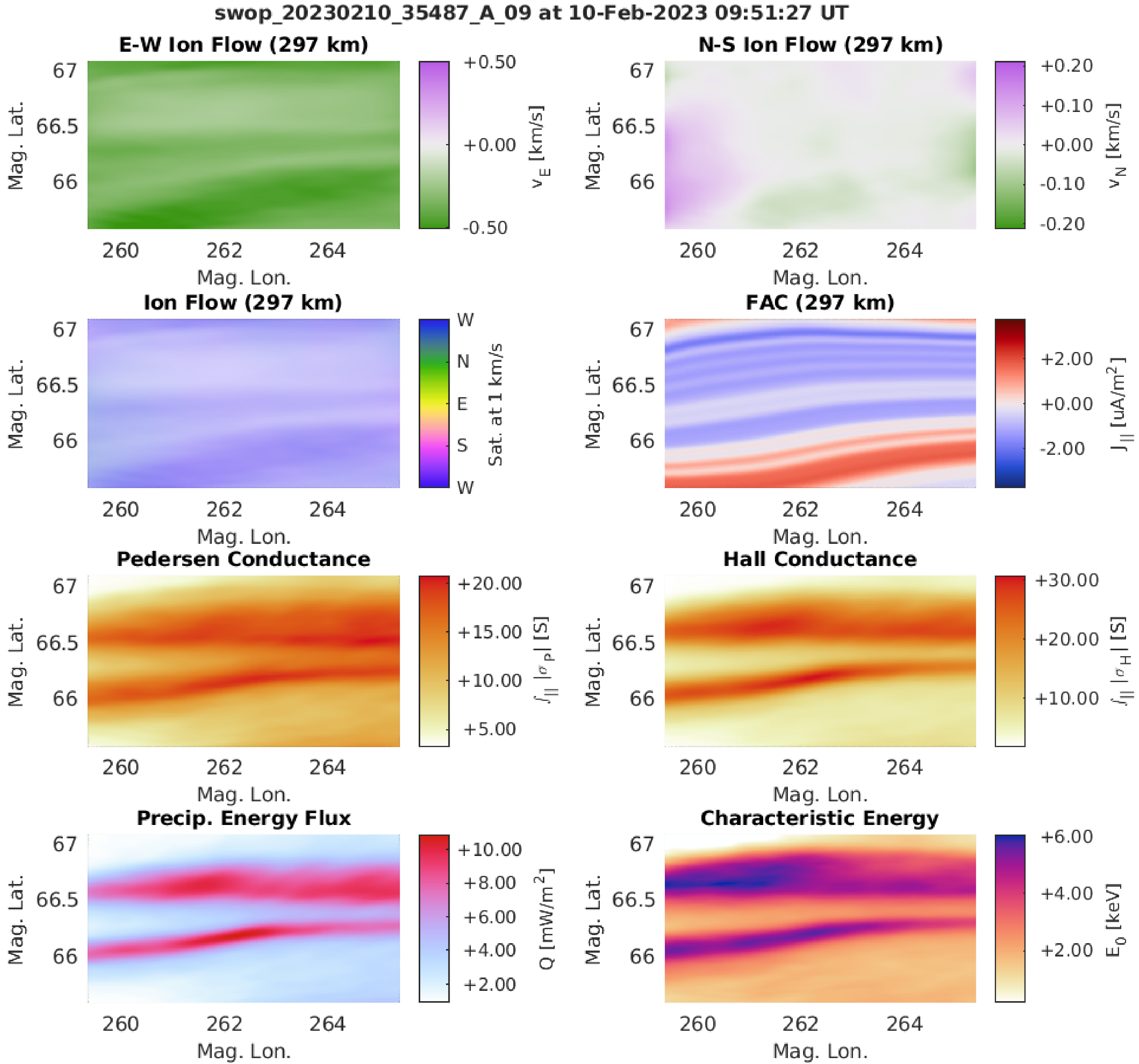
E-W Ion Flow (297 km)
N-S Ion Flow (297 km)
Ion Flow (297 km)
FAC (297 km)
Pedersen Conductance
Hall Conductance
Precip. Energy Flux
Characteristic Energy
Mag. Lat.
Mag. Lon.
Sat. at 1 km/s
W
N
E
S
W



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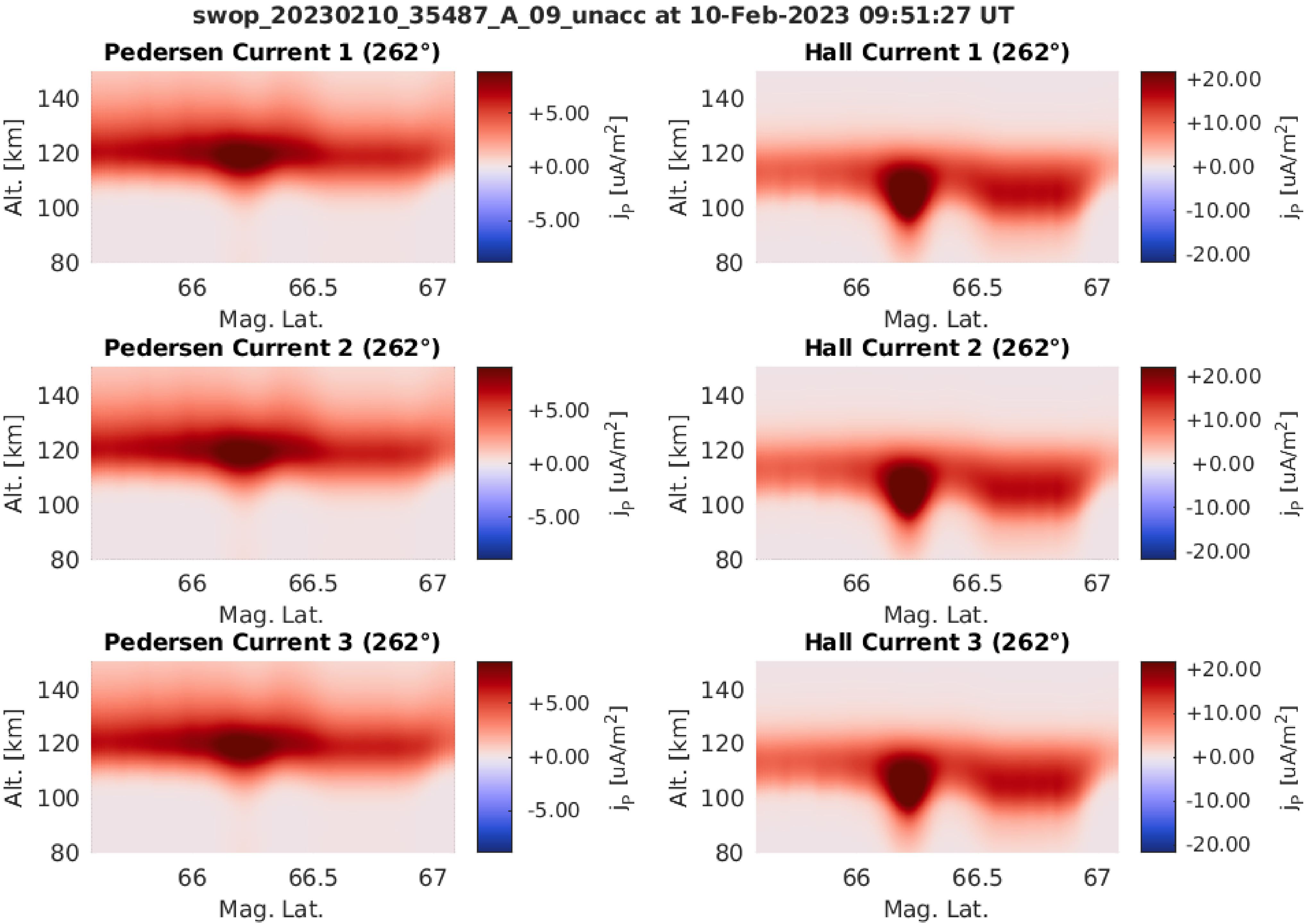
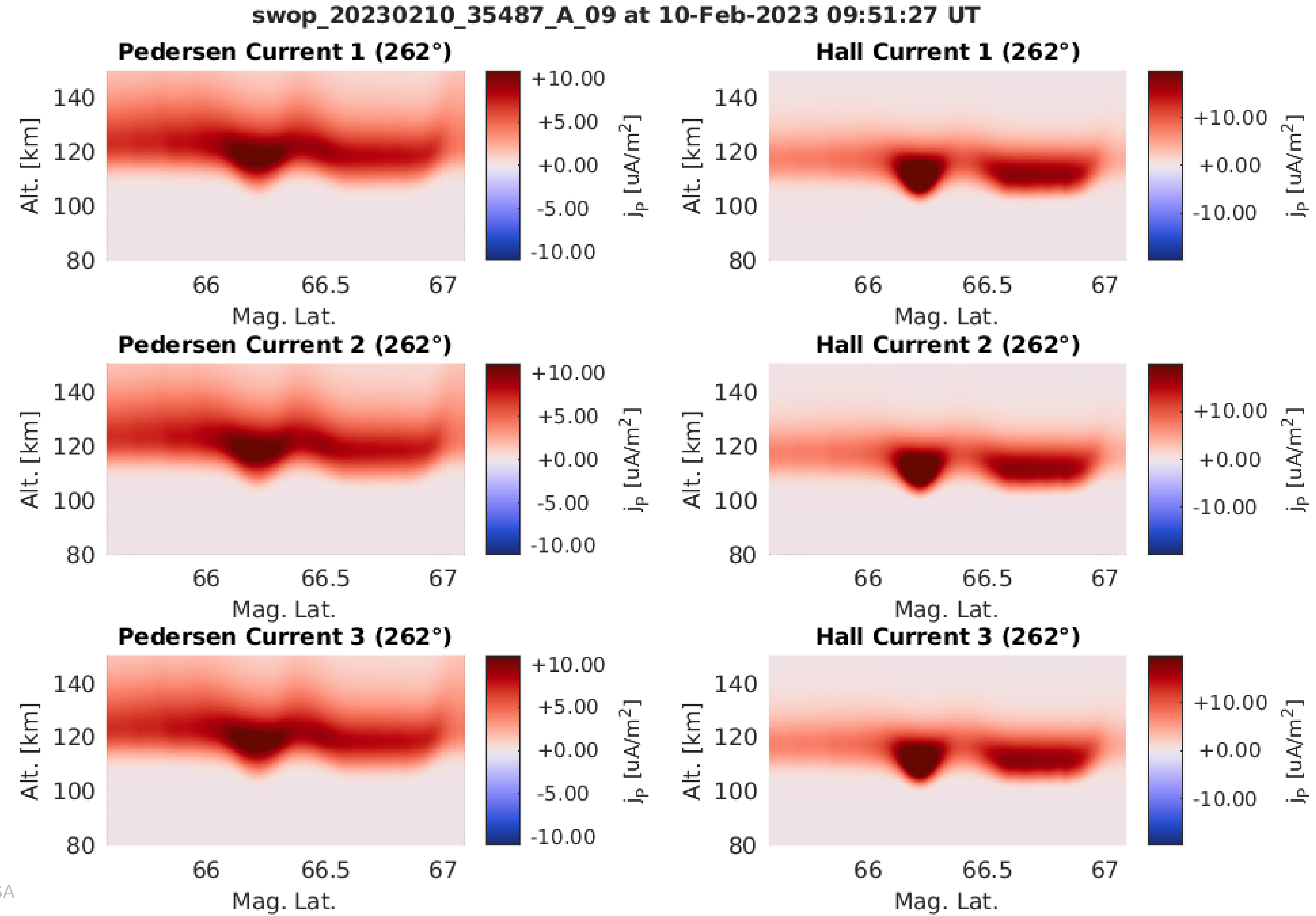
E-W Ion Flow (297 km)
N-S Ion Flow (297 km)
Ion Flow (297 km)
FAC (297 km)
Pedersen Conductance
Hall Conductance
Precip. Energy Flux
Characteristic Energy
Mag. Lat.
Mag. Lon.
v_E [km/s]
v_N [km/s]
Sat. at 1 km/s
W
N
E
S
W
J_|| [uA/m^2]
Q [mW/m^2]
E_0 [keV]


swop_20230210_35487_A_09_unacc at 10-Feb-2023 09:51:27 UT
Pedersen Current 1 (262°)
Hall Current 1 (262°)
Pedersen Current 2 (262°)
Hall Current 2 (262°)
Pedersen Current 3 (262°)
Hall Current 3 (262°)
Alt. [km]
140
120
100
80
66
66.5
67
Mag. Lat.
+5.00
+0.00
-5.00
+20.00
+10.00
-10.00
-20.00
jp [uA/m2]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Pedersen Current 1 (262°)
Hall Current 1 (262°)
Pedersen Current 2 (262°)
Hall Current 2 (262°)
Pedersen Current 3 (262°)
Hall Current 3 (262°)
Alt. [km]
Mag. Lat.
j_P [uA/m^2]
+10.00
+5.00
+0.00
-5.00
-10.00
140
120
100
80
66
66.5
67