Transient Forcing of Ionospheric Outflow

M. Burleigh[1], M. Zettergren[1], K. Lynch[2]

[1]Embry-Riddle Aeronautical University, [2]Dartmouth College

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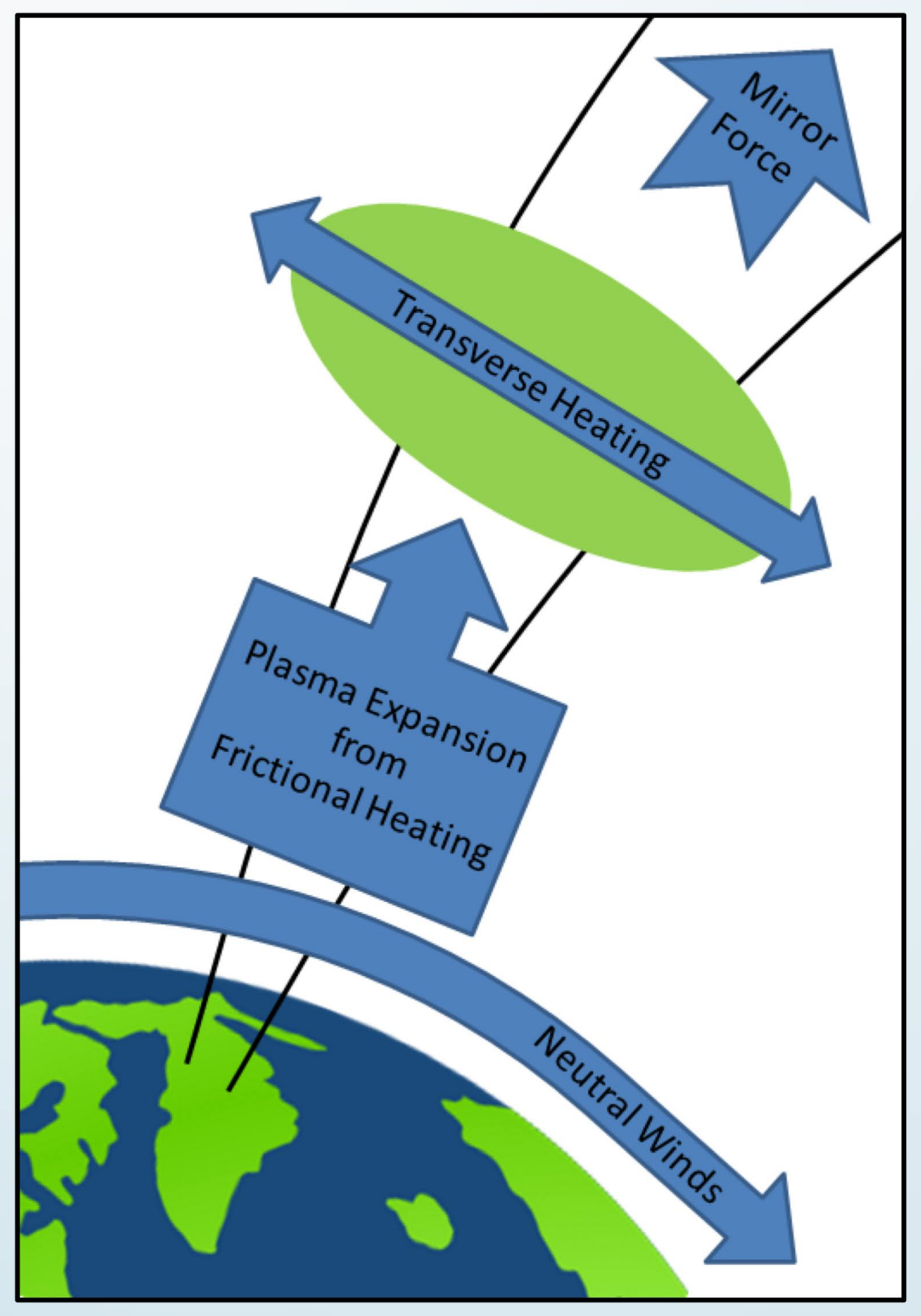
1. Introduction – High-Latitude Ion Upflow/Outflow



Ionospheric plasma is transported to high altitudes (ion upflow) in response to a variety of plasma heating and uplifting processes.

- DC electric fields frictionally heat the ion population resulting in anisotropic increases in ion temperature that cause large pressure gradients which push the ions outward and upward.
- Soft electron precipitation heats F-region electrons creating electron pressure gradients which increase the ambipolar electric field and drives ion upflows.
- Ions may undergo further acceleration from transverse heating by broadband ELF waves.
- At high altitudes, mirror force propels ions to escape velocities and results in outflow to the magnetosphere.

Despite processes being generally well-known, **ion outflow is difficult to predict due to the myriad of processes acting over a large range of altitudes, physical regimes, and time scales**.

2. Anisotropic Ionospheric Fluid Model - GEMINI-TIA

- Solves time-dependent, nonlinear transport equations for the conservation of mass, momentum, parallel and perpendicular energy for six ion species.
- Includes electrons with an isotropic description.
- Contains chemical and collisional interactions with the neutral atmosphere, NRL-MSISE-00.
- Includes photoionization and electron impact ionization.
- Utilizes an electrostatic current continuity equation to self-consistently describe auroral effects.

This model is used to examine the effects of transient energization on ionospheric upflow/outflow during the ISINGLASS sounding rocket campaign. GEMINI-TIA is well suited to ingest ground based measurements and in-situ data including, but not limited to, particle precipitation, DC electric fields, and transverse heating from BBELF waves.

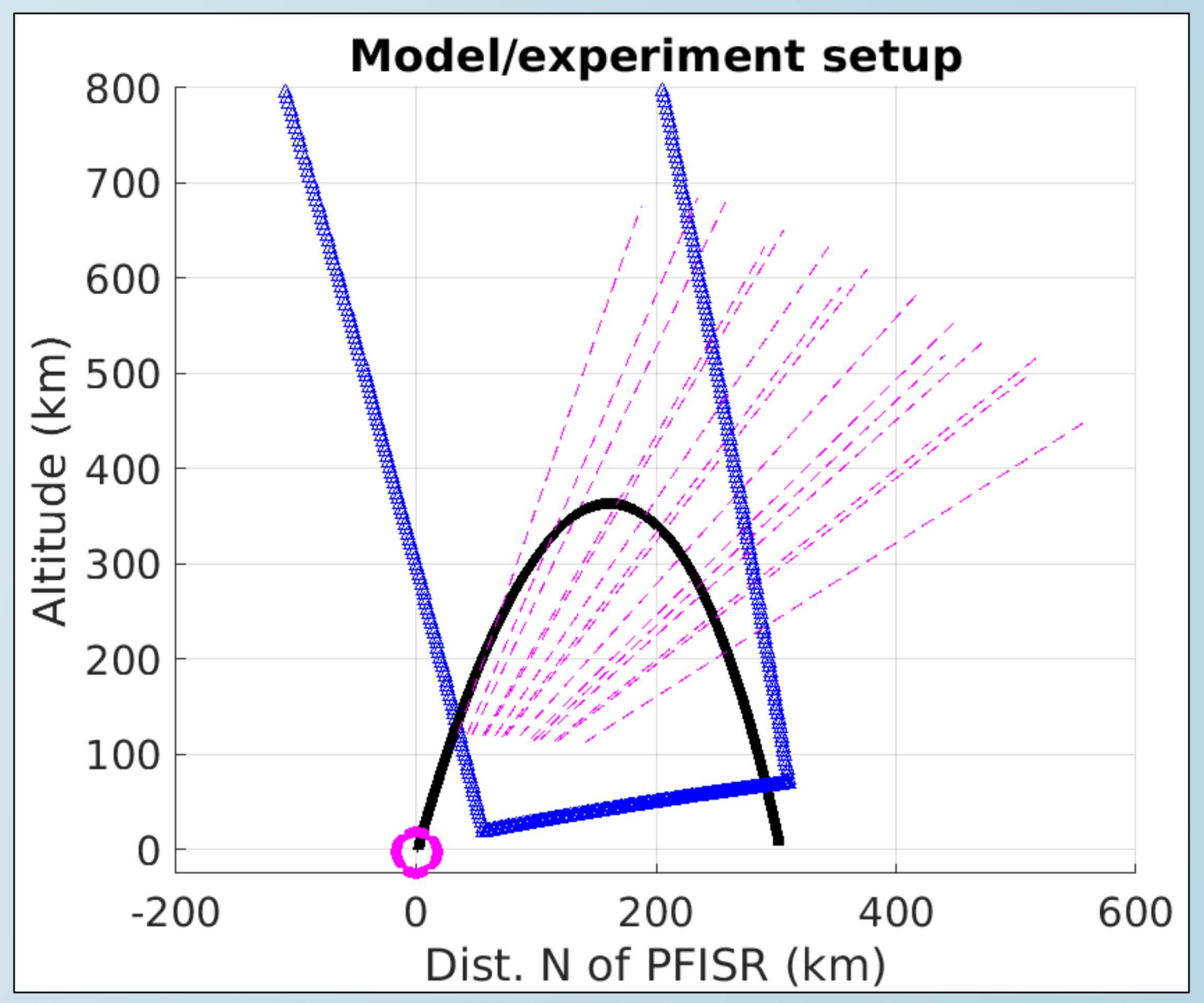


Figure 1) The spatial relationship between the model grid (outlined in blue triangles), PFISR (magenta circle), PFISR beams (magenta dashed lines), and the sounding rocket trajectory (black line). The all-sky camera field-of-view is not shown here.

3. Energization of Ionospheric Upflow and Outflow

- ISINGLASS B, launched from the Poker Flat Rocket Range at 7:50 UT (22:50 LT) on March 2, 2017, flew through aurora during a substorm expansion.
- An alternative to using in-situ rocket measurements to drive the ionospheric model is to use PFISR DC electric field (DCE) measurements and all-sky camera precipitation measurements.
- There is a trade-off between the two data sets (in situ vs. ground). **In situ data provides high cadence, moving, point measurements while the ground data provides a lower resolution, spatially *and* temporally evolving data set**.

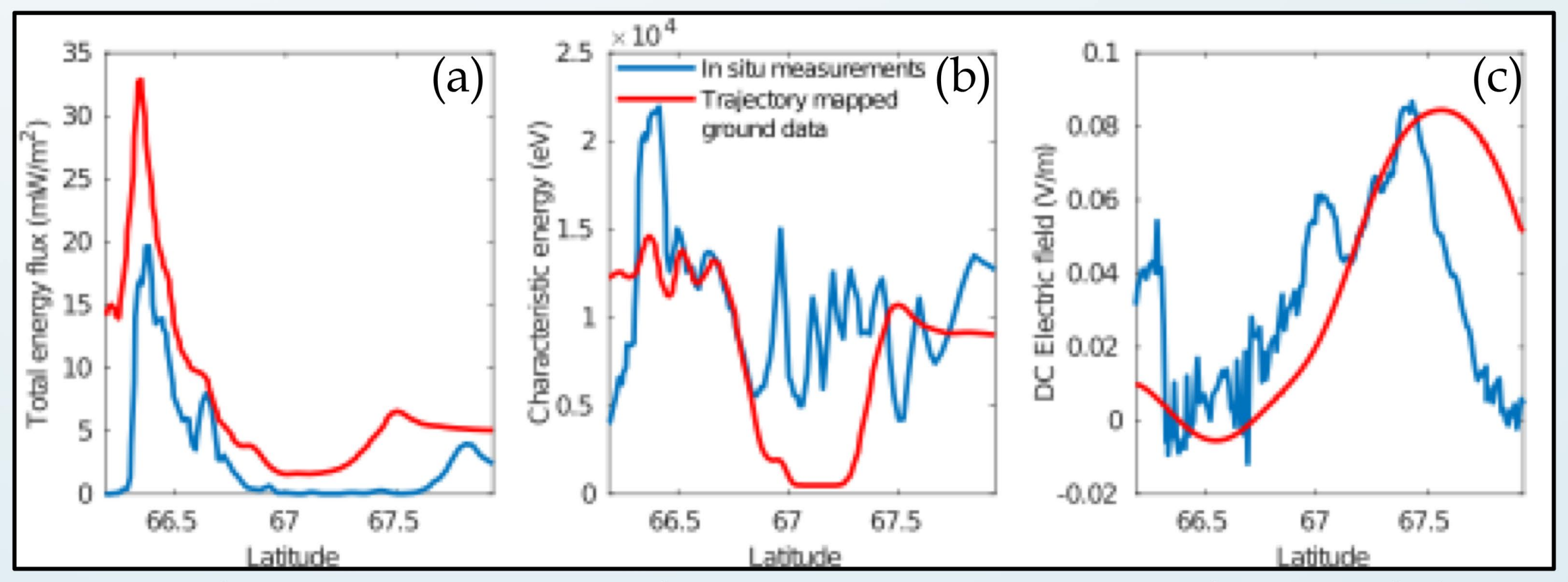


Figure 2) Compare in situ data to trajectory trace of ground data.

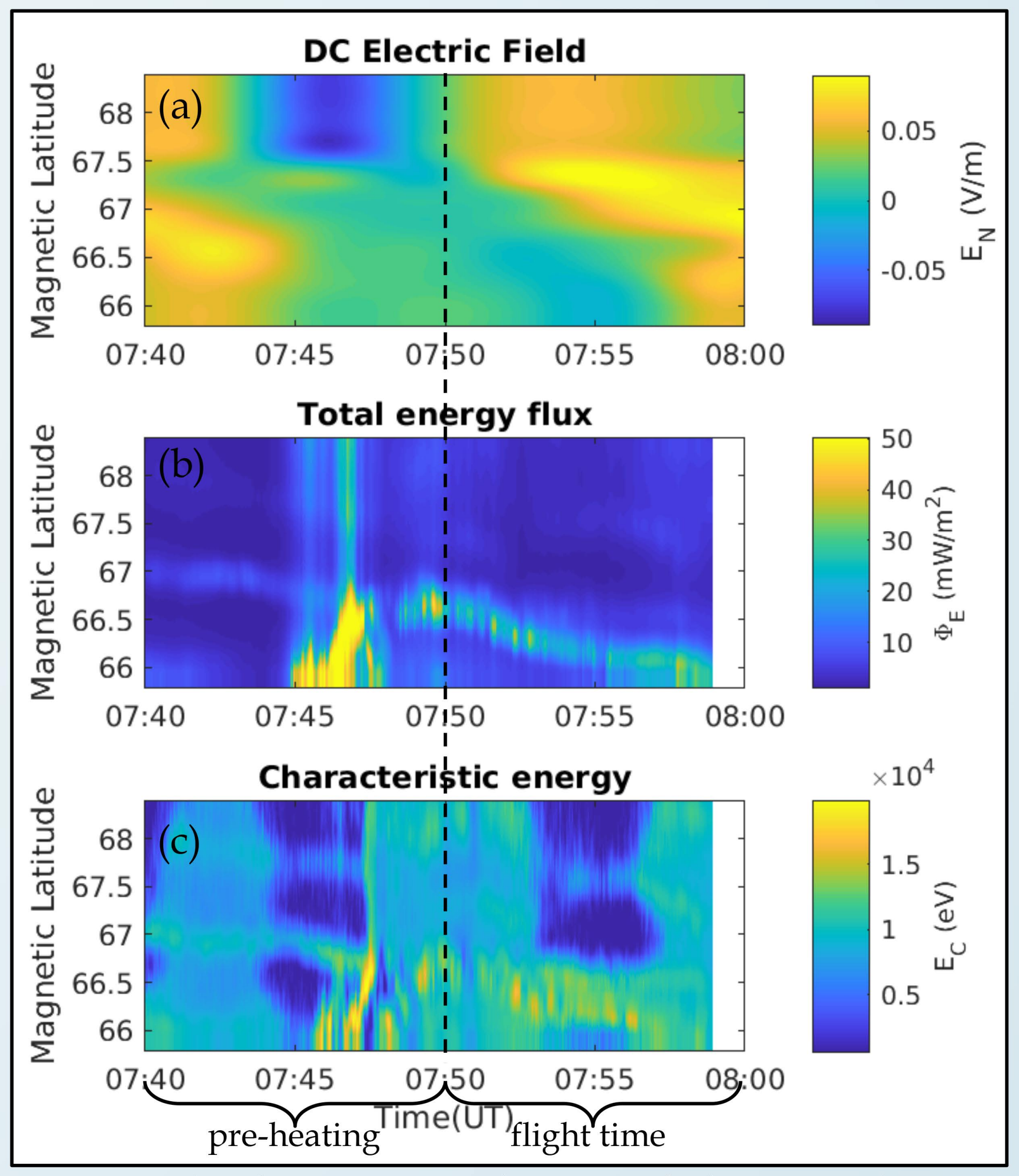


Figure 3) The time evolution of the DC electric field from PFISR (panel a) and the total energy flux (panel b) and characteristic energy (panel c) from an all-sky camera mapped to model grid.

Two simulations are discussed here. The first simulation uses the ground based measurements as inputs from 7:50 to 8:00 UT (the time of the rocket flight) do drive an ionospheric response. Initial conditions are generated by running the model for 24 hours in a quasi-steady state mode to initialize plasma parameters. The second simulation also uses the ground measurements as inputs from 7:50 to 8:00 UT. Initial conditions are created by first running the model for 23 hours and 50 minutes in a quasi-steady state and then "pre-heated" with the ground measurements from 7:40 to 7:50 UT. The differences between these two simulations are discussed below.

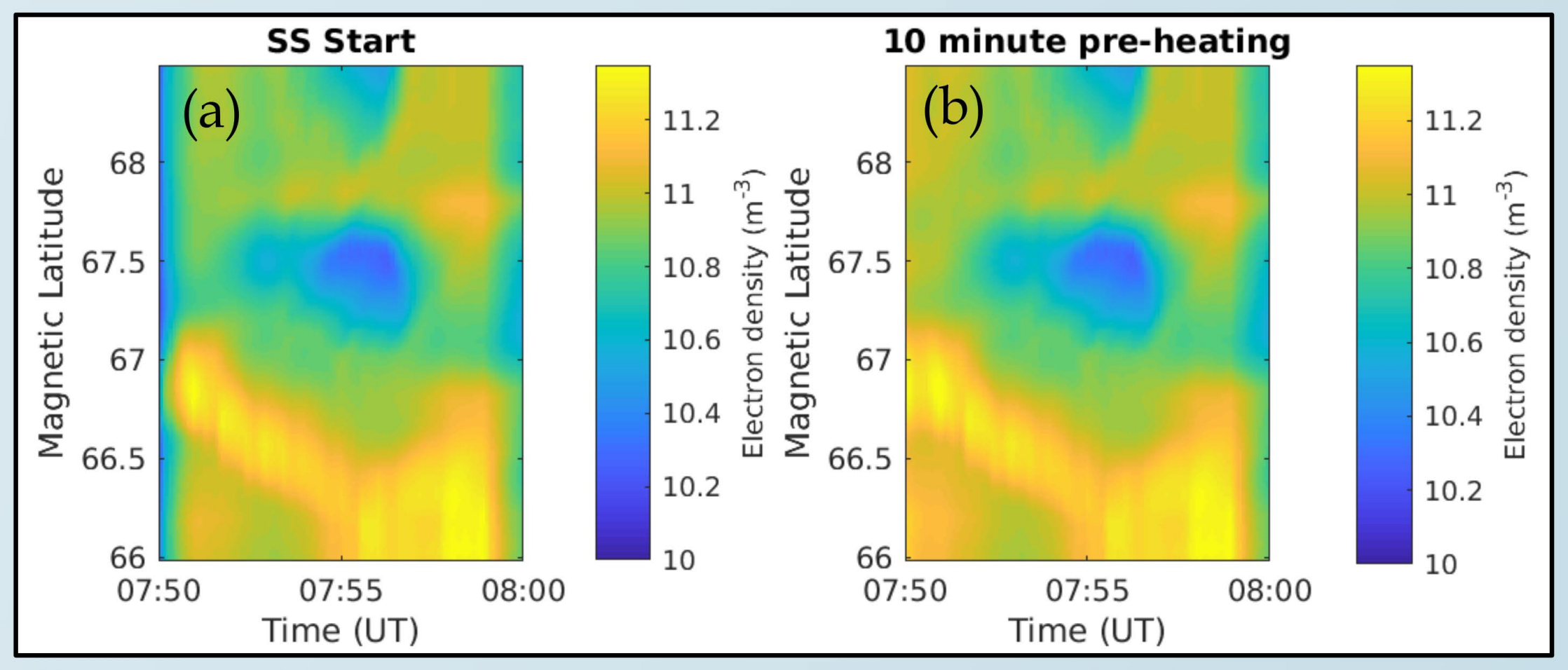


Figure 4) E region density response (125 km).

- Electron impact ionization drives increases in E region densities
- Within 2 minutes the simulations have similar E region densities (within 4%)
- Pre-heating has minimal influence here
- Model uses Fang et al 2008 parameterization

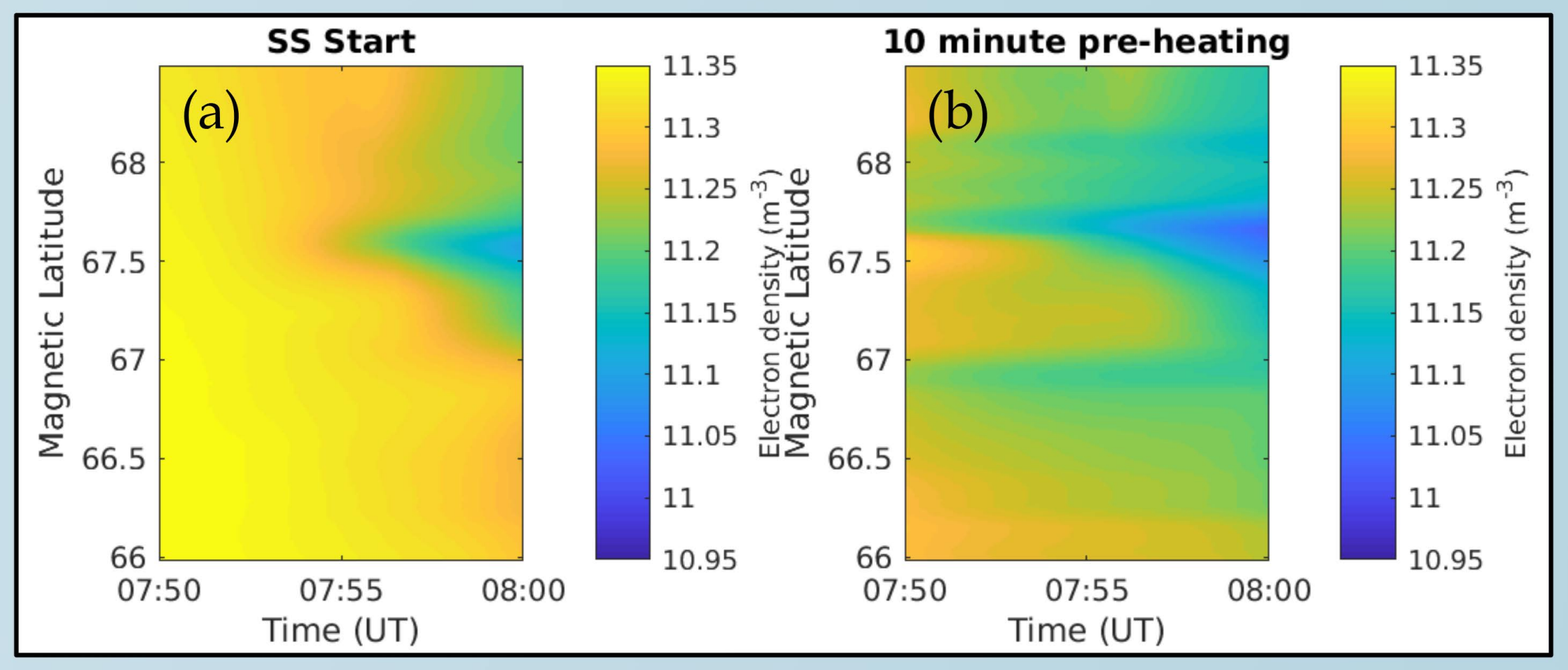


Figure 5) F region density response (310 km).

- DCE drives F region density cavities through temperature sensitive chemistry
- Density differences > 35% persist to the end
- **Pre-heating has a lasting influence here**
- Frictional-heating driven upflow generated above the cavity altitude (not shown)

4. Conclusions

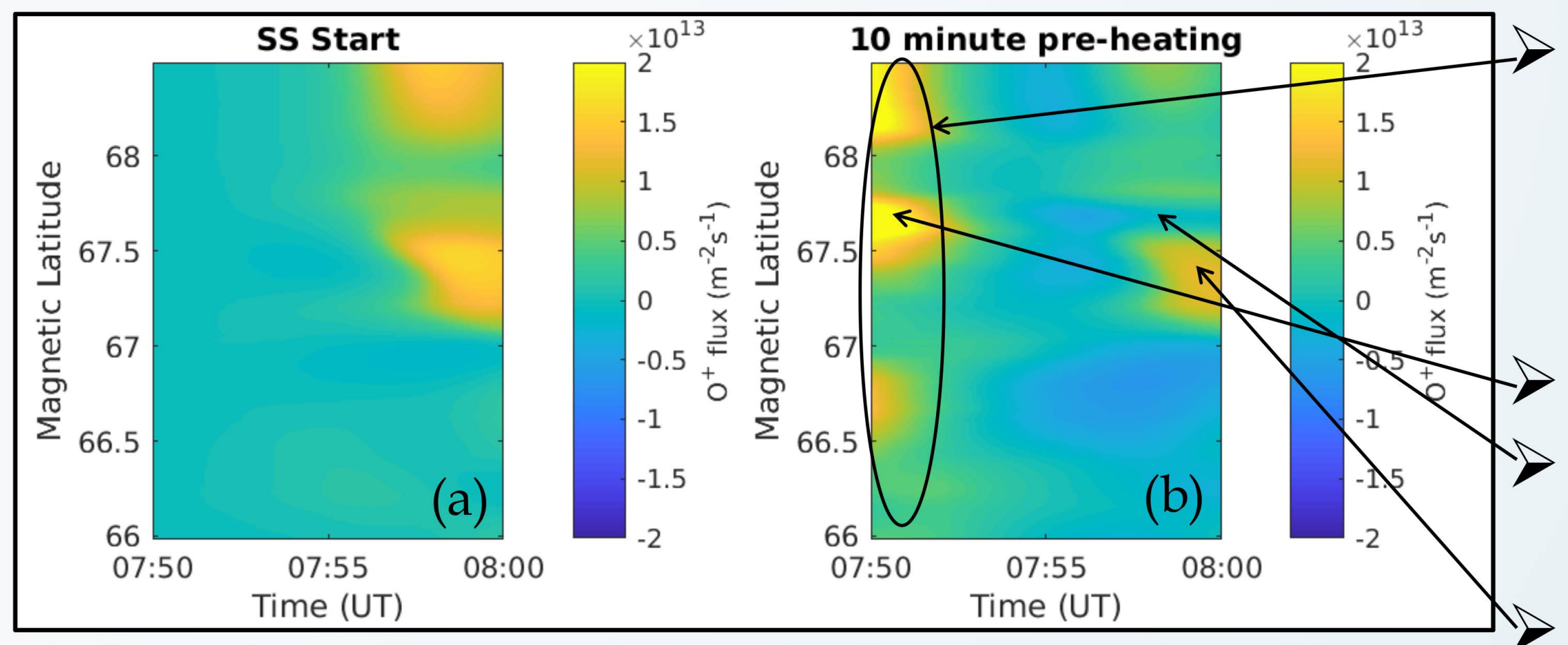


Figure 6) Evolution of the O$^+$ flux, minus steady state background conditions to remove diurnal variations, at 1000 km over the duration of the simulation.

- Upflows reach this altitude in ~4 minutes
- **Pre-heating alters the initial conditions, which modify the ionospheric response**
  - E region density differences last <2 min.
  - F region density differences last >10 min.
- O$^+$ flux from a sheer driven upflow
- Sheer end results in downflow that overcomes subsequent upflow from DCE
- **Much of the ion source population has been already been uplifted resulting in a smaller response to the subsequent DCE.**

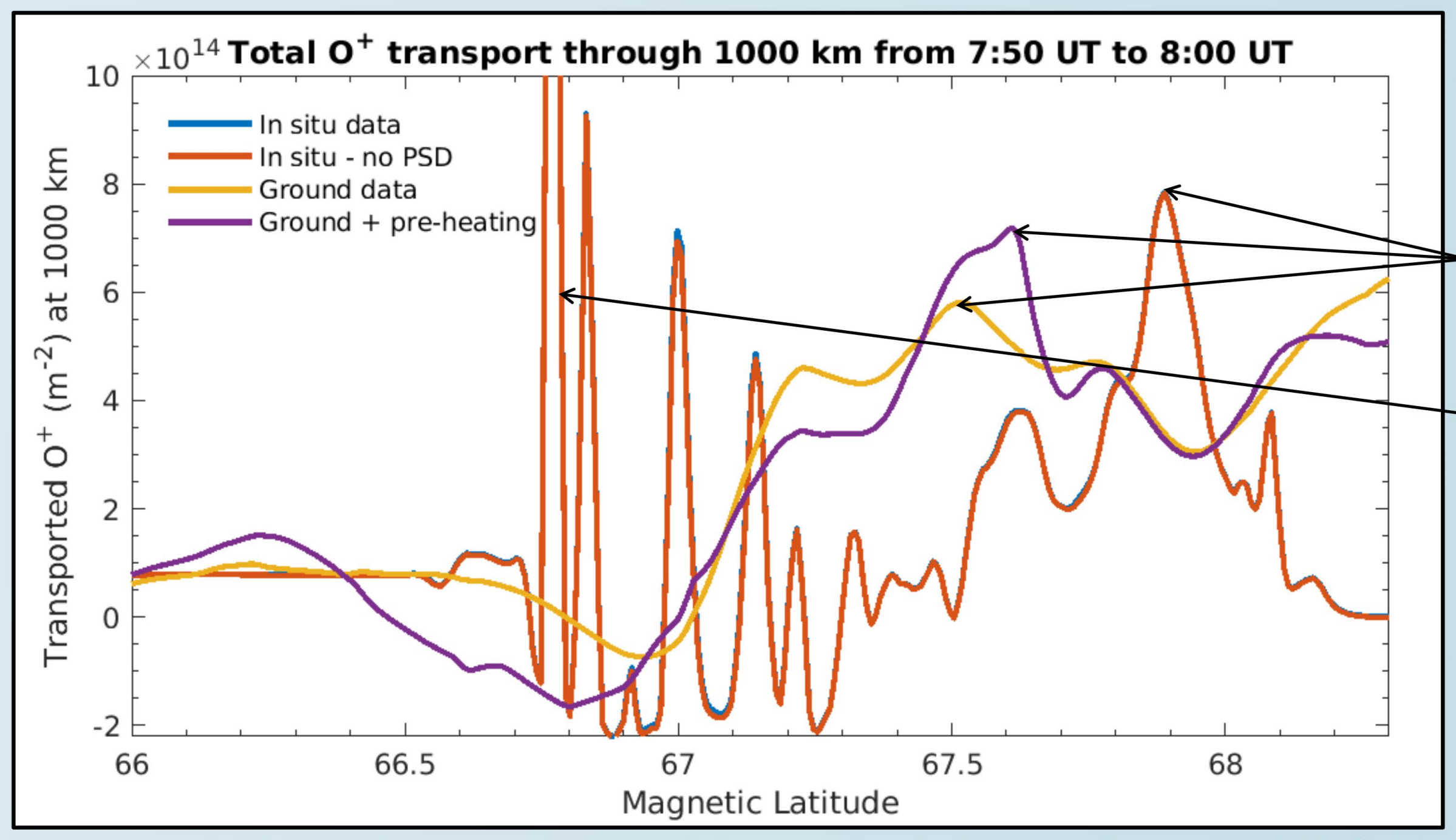


Figure 7) Total O$^+$ transported by end of simulation at 1000 km.

For further comparison, simulations driven by in situ data, held constant for the duration of the flight, have also been run with no pre-heating.

- The location of maximum O$^+$ transport is dependent on energy source variability.
- Artificially stable sheer in the in situ data driven simulations overestimates the total number of O$^+$ ions transported through 1000km.
- **Realistic spatiotemporal variability is important when accurately determining the location and amount of upflow and potential outflow to the magnetosphere.**

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