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Modeling high-latitude ionospheric upflow and outflow

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Naval Research Laboratory

M. Burleigh's research is sponsored by the Office of Naval Research

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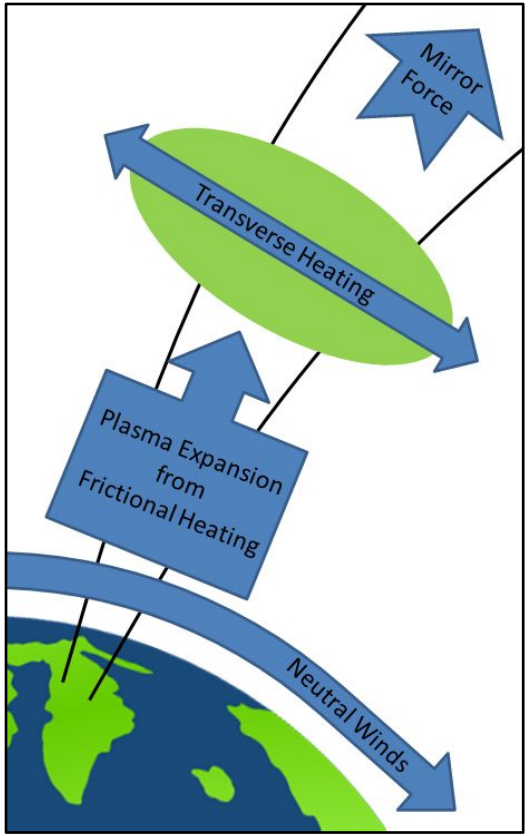
The High-Latitude Ionosphere: Upflow and Outflow



- Thermospheric winds can arise from solar forcing, plasma convection, waves, etc.
- These neutral winds may interact with the ionospheric plasma, through collisions, driving upflow or perpendicular motion.
- Other ion motion drivers, such as electric fields and auroral precipitation, may also be present and drive upflows.
- Ions may then undergo further acceleration from transverse heating by broadband ELF waves.
- At high altitudes, the mirror force may propel the ions to escape velocities, resulting in outflow to the magnetosphere.

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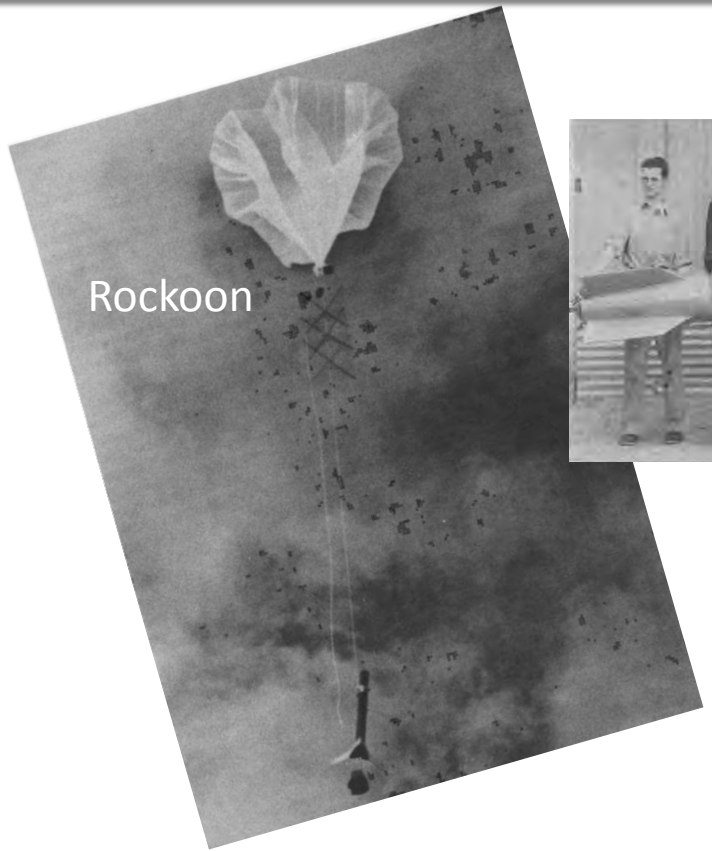
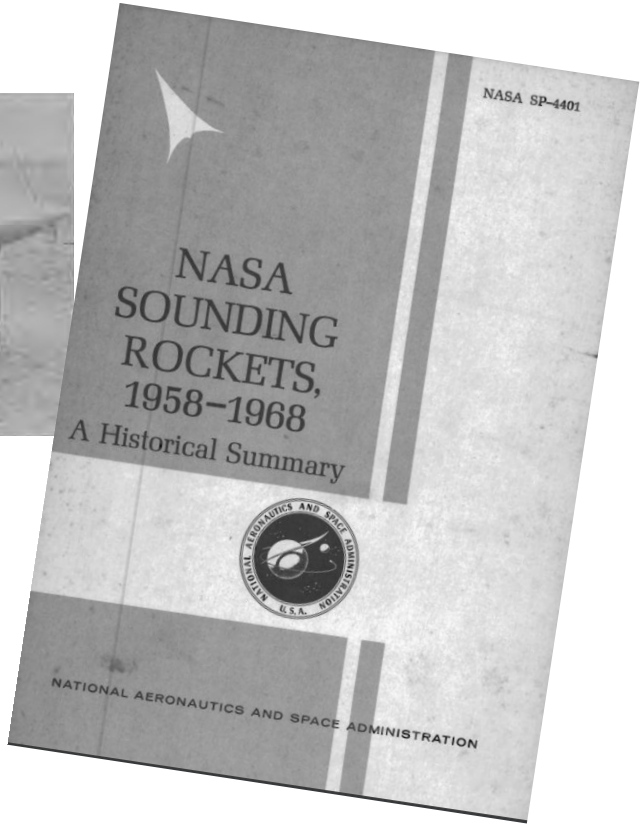
Sounding Rockets



Dr. Goddard



https://history.nasa.gov/SP-4401.pdf

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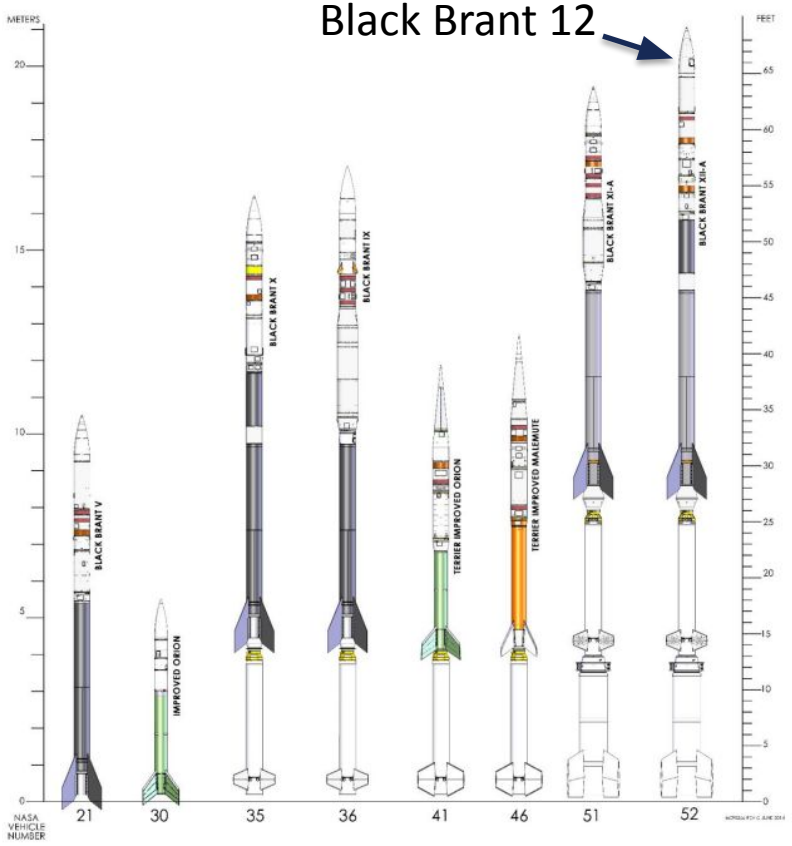
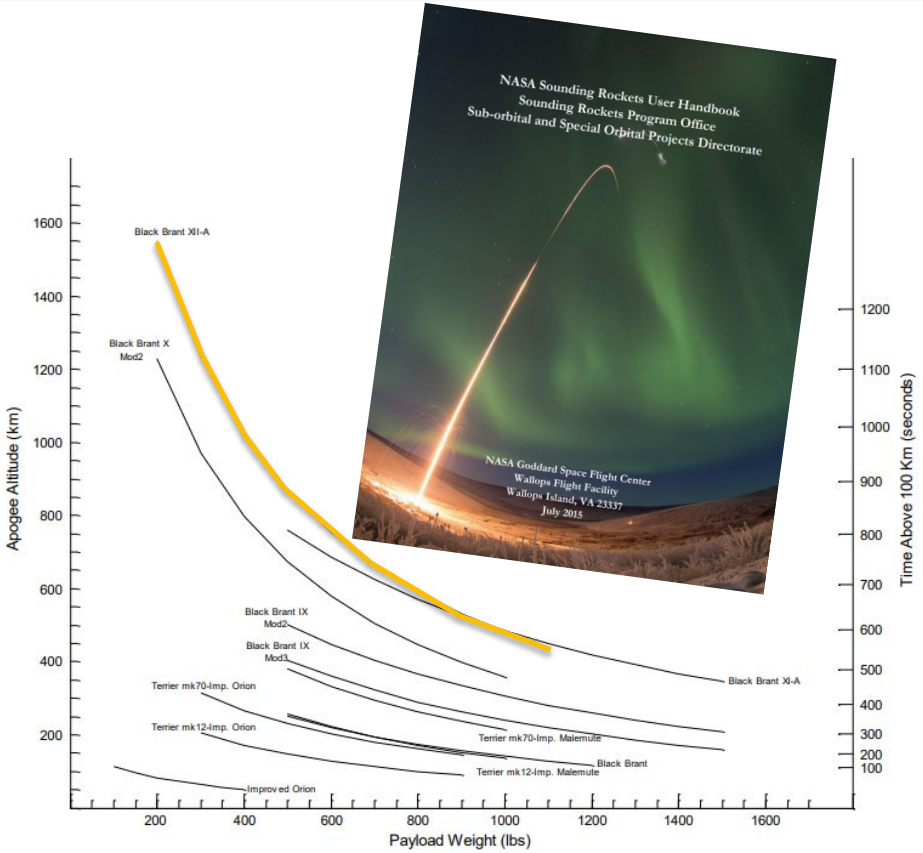
Sounding Rockets

Black Brant 12



Figures credit: NASA Sounding Rocket Handbook



https://sites.wff.nasa.gov/code810/files/SRHB.pdf

Incoherent Scatter Radar (ISR)

Madrigal: http://cedar.openmadrigal.org/

Resolute Bay ISR (RISR-N, RISR-C)

Photo credit: Craig Heinselman

Poker Flat ISR (PFISR)

Photo credit: Craig Heinselman

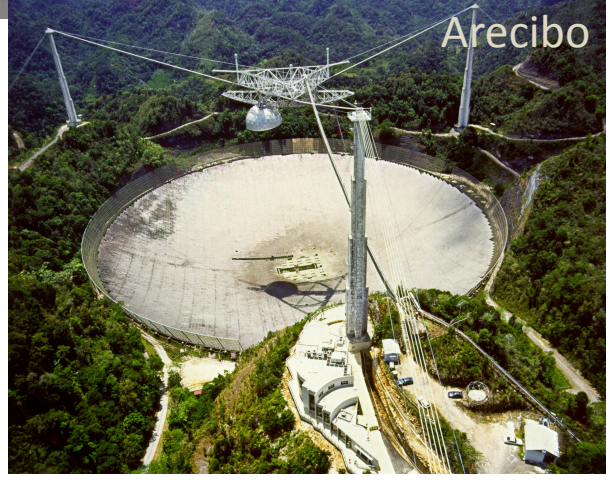
https://amisr.com/amisr/

Sondrestrom ISR

Photo credit: ThatGuyOnline

https://en.wikipedia.org/wiki/Sondrestrom_Upper_Atmospheric_Research_Facility

Arecibo



https://www.naic.edu/ao/photos-0

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The Power of Using Physics-Based Models for Science*

Why wait for an "event" to occur, hoping that instruments are turned on, in the right location, at the right time?

What about the benefits of being able to fill in the blanks between data measurements to see the ionospheric response as a whole?

Wouldn't it be nice to be able to deconstruct the ionosphere into the basic processes that are responsible for its current state?

How cool would it be to reproduce past ionospheric events as well as predict the future?

*A model is only as good as its underlying rules and assumptions

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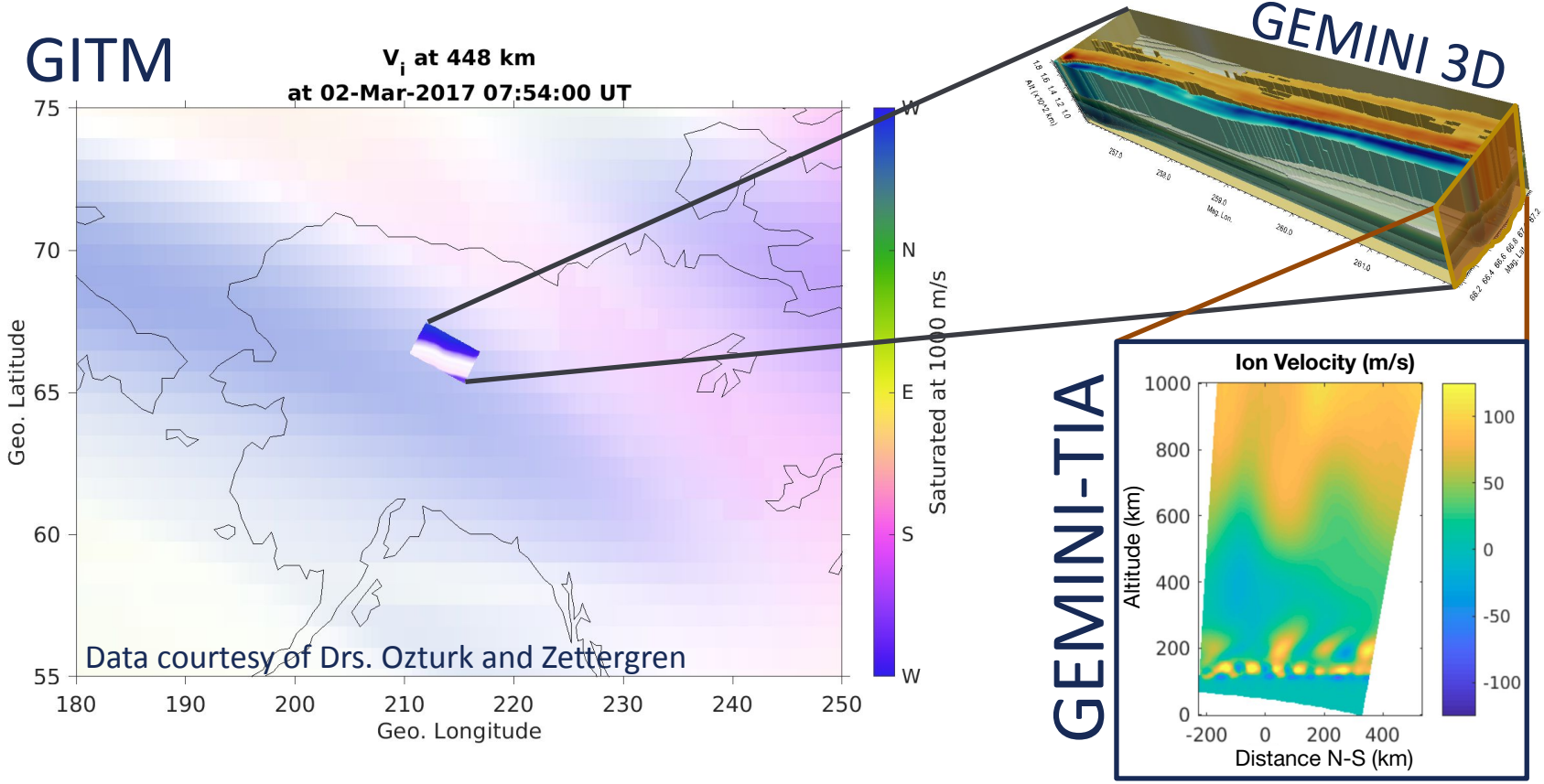
Global vs. Local Ionospheric Modeling



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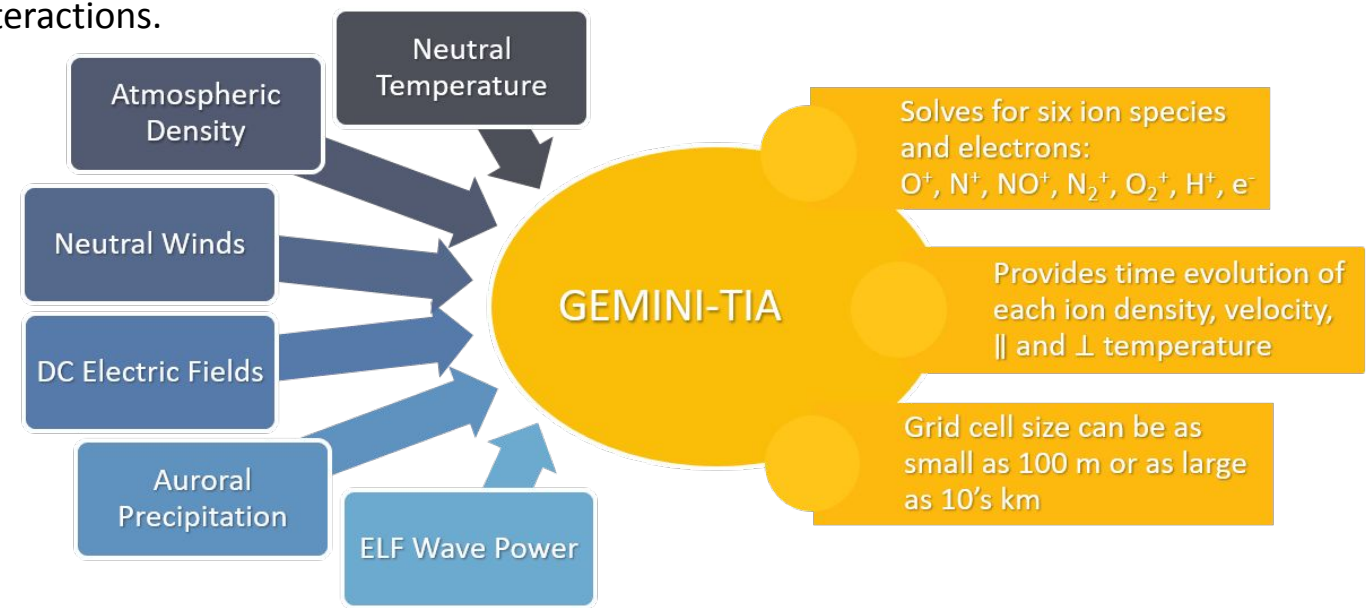
What is GEMINI-TIA?

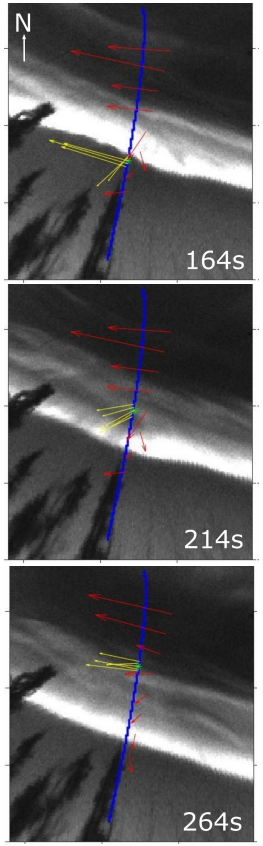
The **G**eospace **E**nvironment **M**odel for **I**on-**N**eutral **I**nteractions with **T**ransverse **I**on **A**cceleration (**GEMINI-TIA**) is a **2.5D multi-fluid ionospheric model** based on a bi-Maxwellian distribution that incorporates ionospheric chemistry and transport needed to simulate ionospheric dynamics (>80km), including possible effects of low-altitude wave-particle interactions.



Well suited for **ingesting sounding rocket and ISR campaign data for investigations into ionospheric dynamics**.

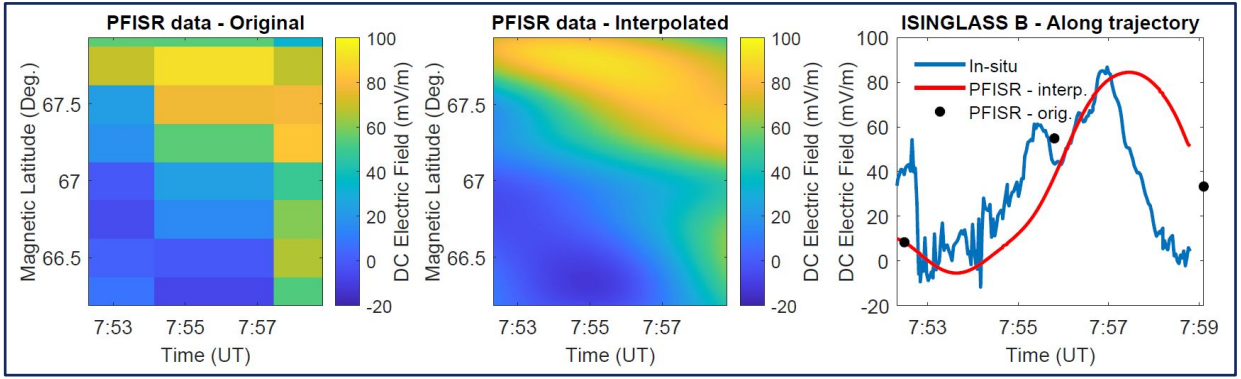
Burleigh and Zettergren, 2017 - doi:10.1002/2016JA023329

Ground-based vs. In-Situ Data for Data-Driven Modeling

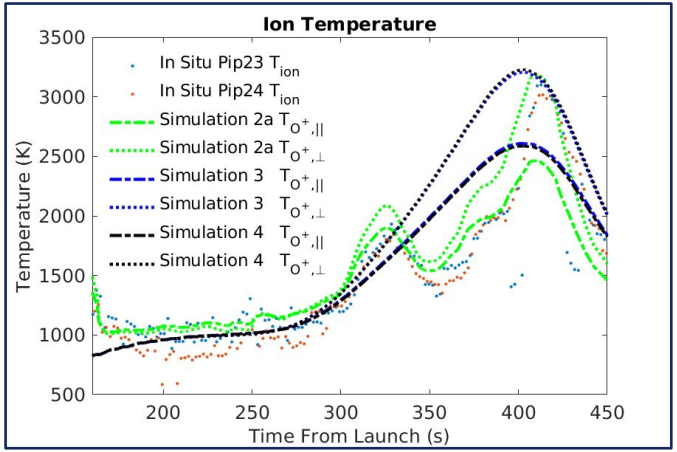


ISINGLASS

Launched 2017



Model-data comparison of O^+ temperature along trajectory



Pip23 & Pip24 are in-situ data, Simulation 2a is rocket data driven, Simulation 3 &4 are ground data driven.

- The rocket detects the arc boundary location more clearly than the lower resolution PFISR data
- Ground data driven simulations capture the general shape of upflow and contain both time and space variability, but at the loss of fine-scale details.
- Simulations driven by ISINGLASS flow and precipitation data reproduce in-situ ion temperature measurements better than ground-based data

Burleigh et al. 2022 - doi:10.1002/2021JA030242

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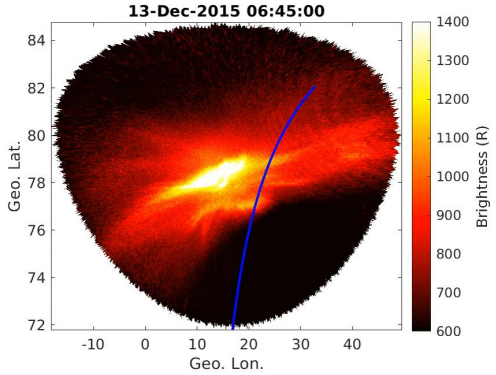
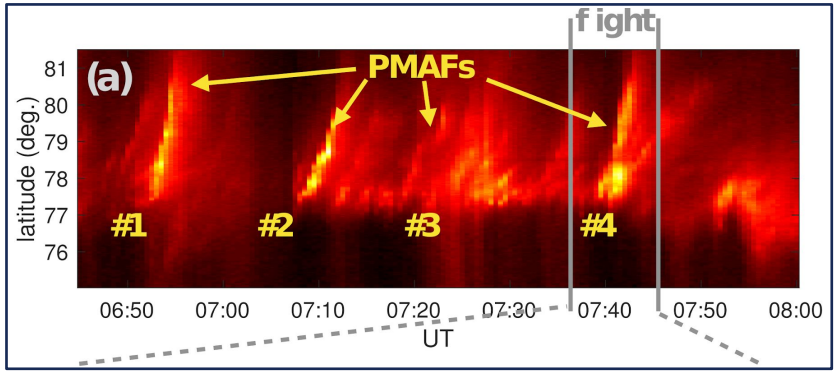
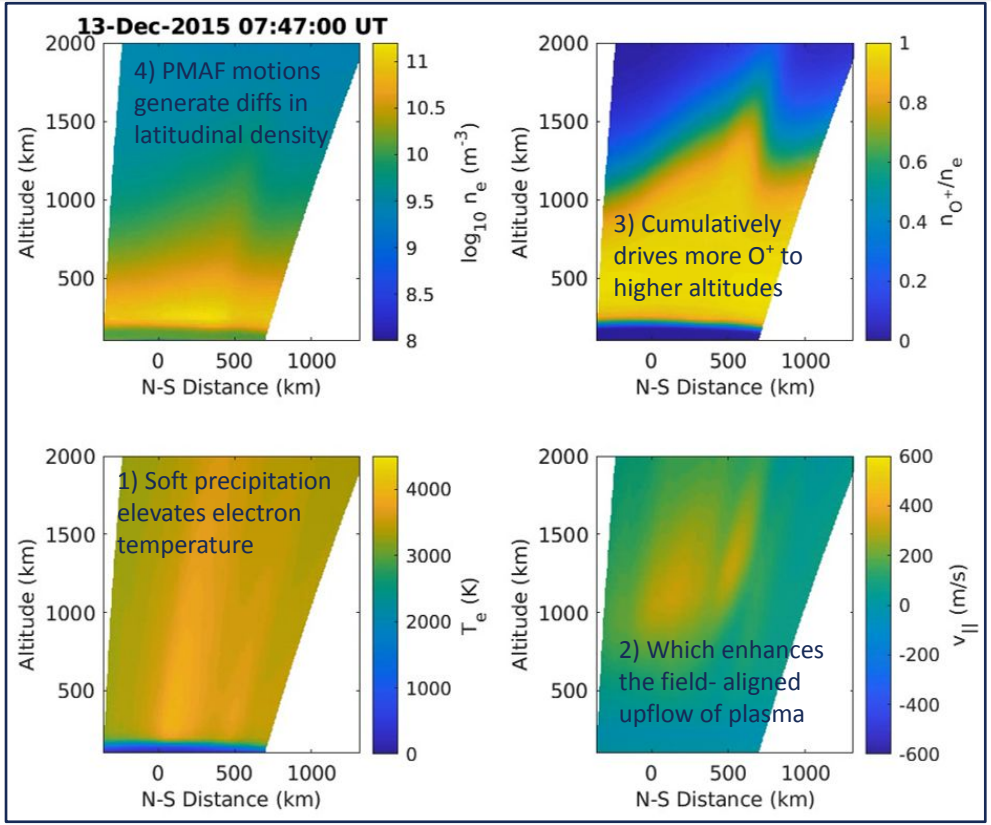
Impacts of Auroral Variability via Data-Inspired Modeling



RENU2

Launched 2015





Burleigh et al., 2019 - doi:10.1029/2018GL081886

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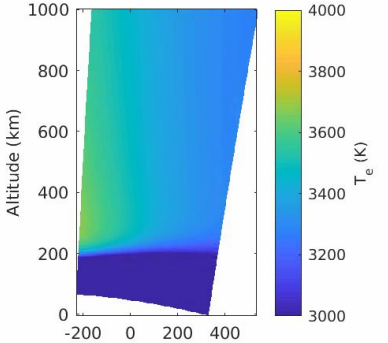
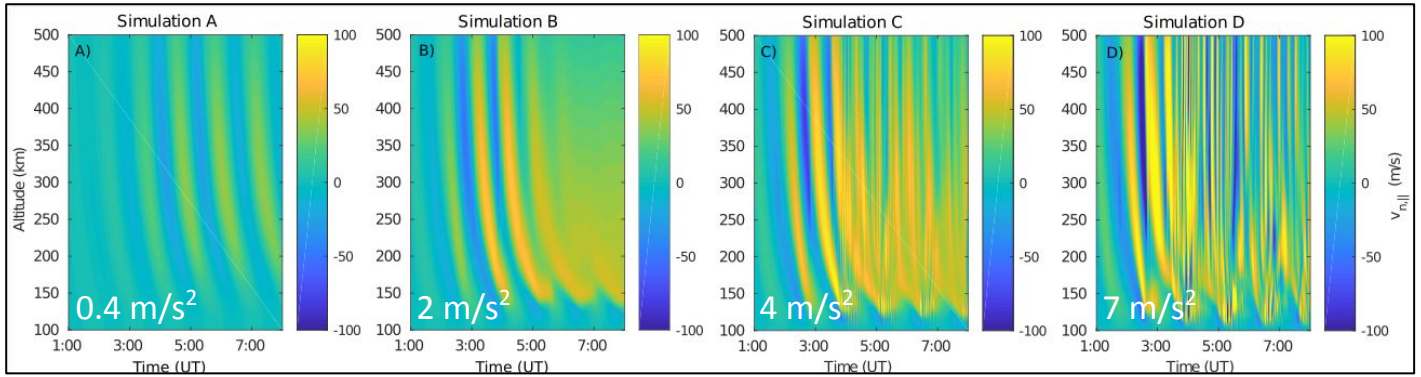
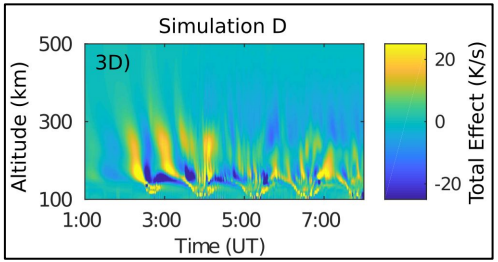
Gravity Wave Effects via Data-Inspired Modeling





1) Gravity wave breaking modulates ion densities and drives periods of large field-aligned ion flows
2) Increase in mean flow increases ion densities >300 km
3) Changes in ion density affects:
   - Ionospheric collision frequency (cooling)
   - Photoionization effects (heating)
4) The total heating and cooling effects modify the electron temperature (T_e)
5) T_e increases conduct quickly up geomagnetic field lines and can **drive ion upflow at altitudes well above initial disturbances**.



Burleigh et al., 2018 - doi:10.1029/2018GL081886

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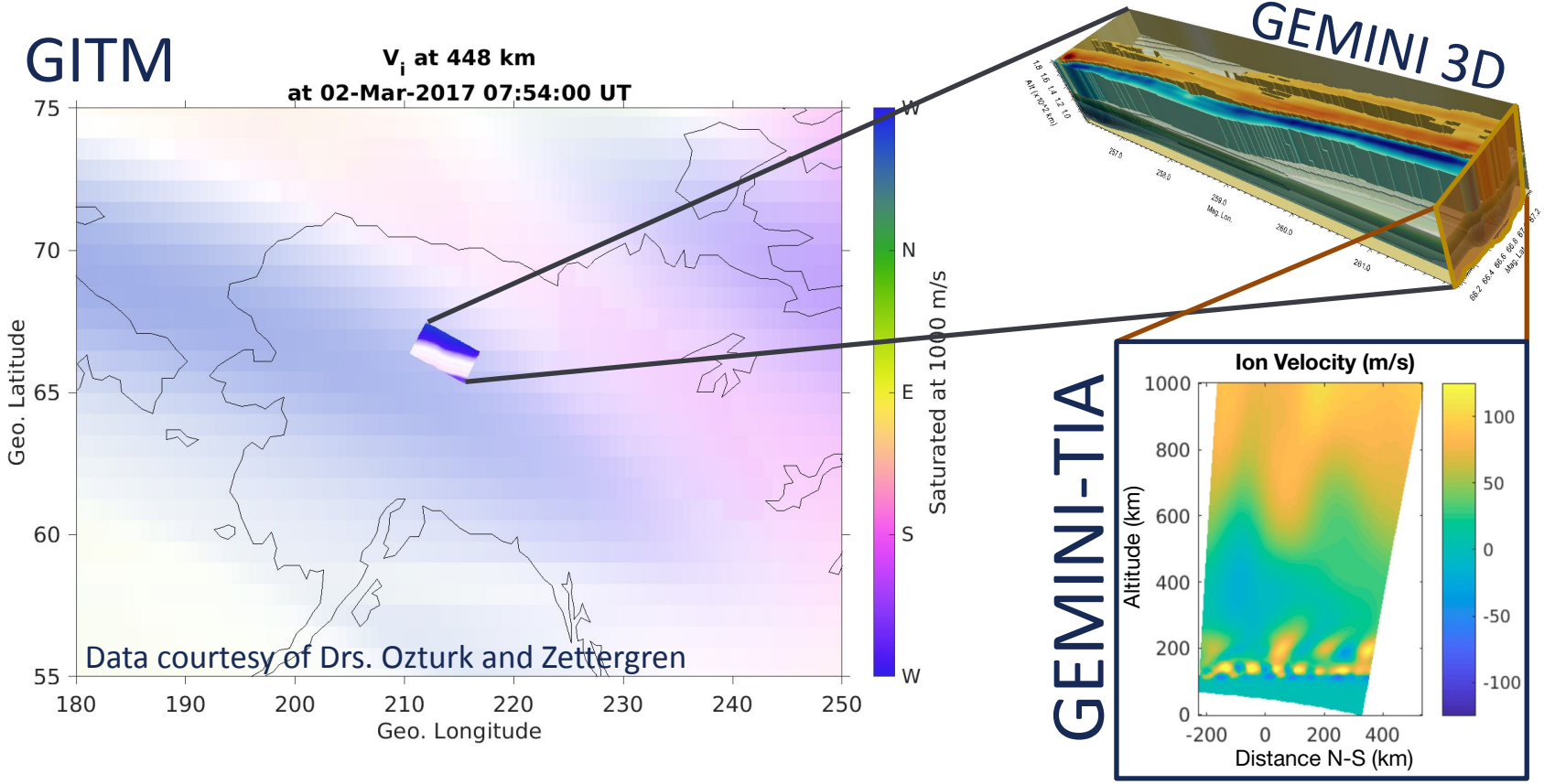
Global vs. Local Ionospheric Modeling



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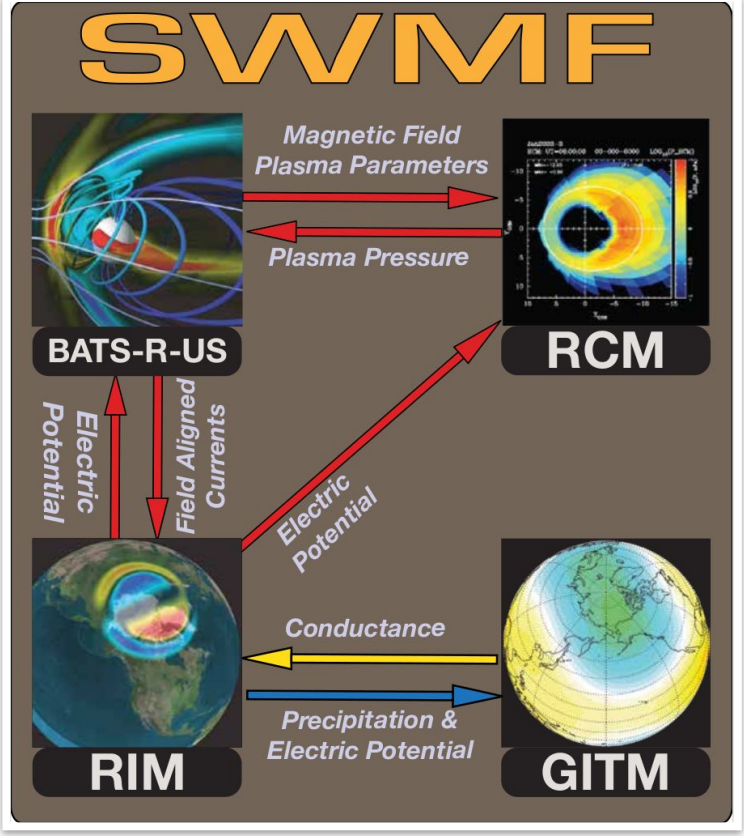
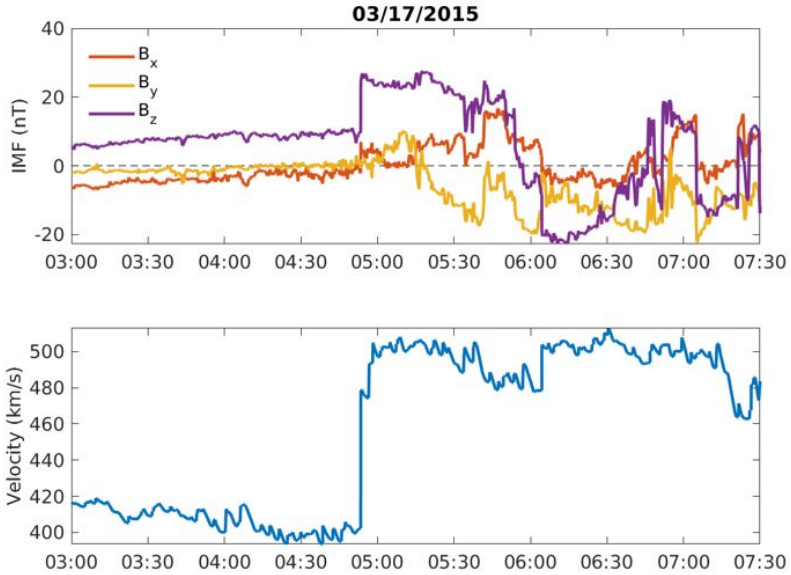
Global Ionospheric Modeling and Magnetospheric Impacts



2015 St. Patrick's Day Storm



Burleigh et al., IN PROGRESS

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2015 St. Patrick's Day Storm – Ionospheric Conductance

Precipitation Energy Flux

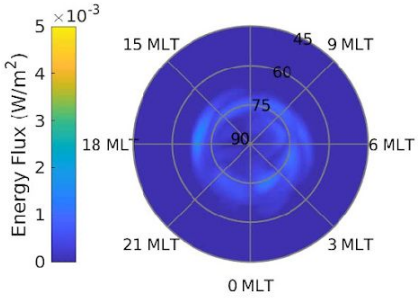
Potential

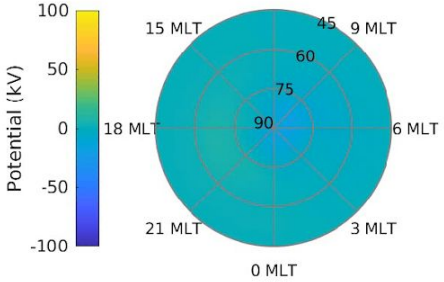
Hall Conductance

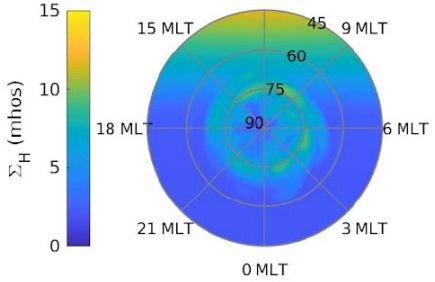
Pedersen Conductance

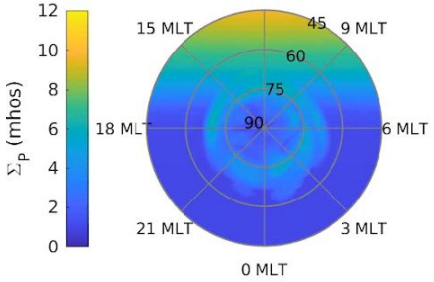
17-Mar-2015 01:00:00

Empirical

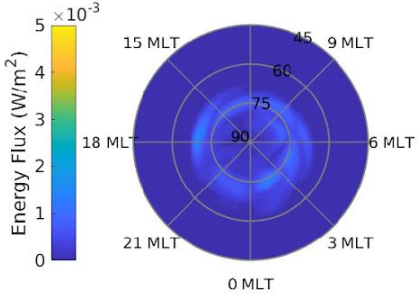


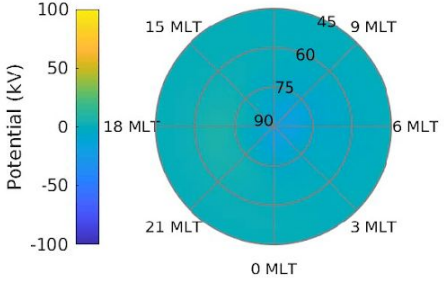


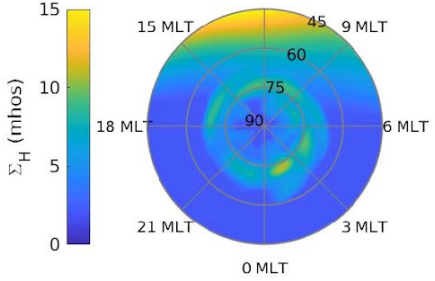


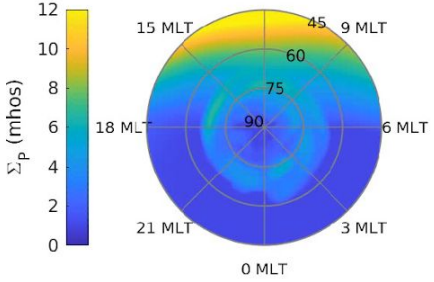


2-way









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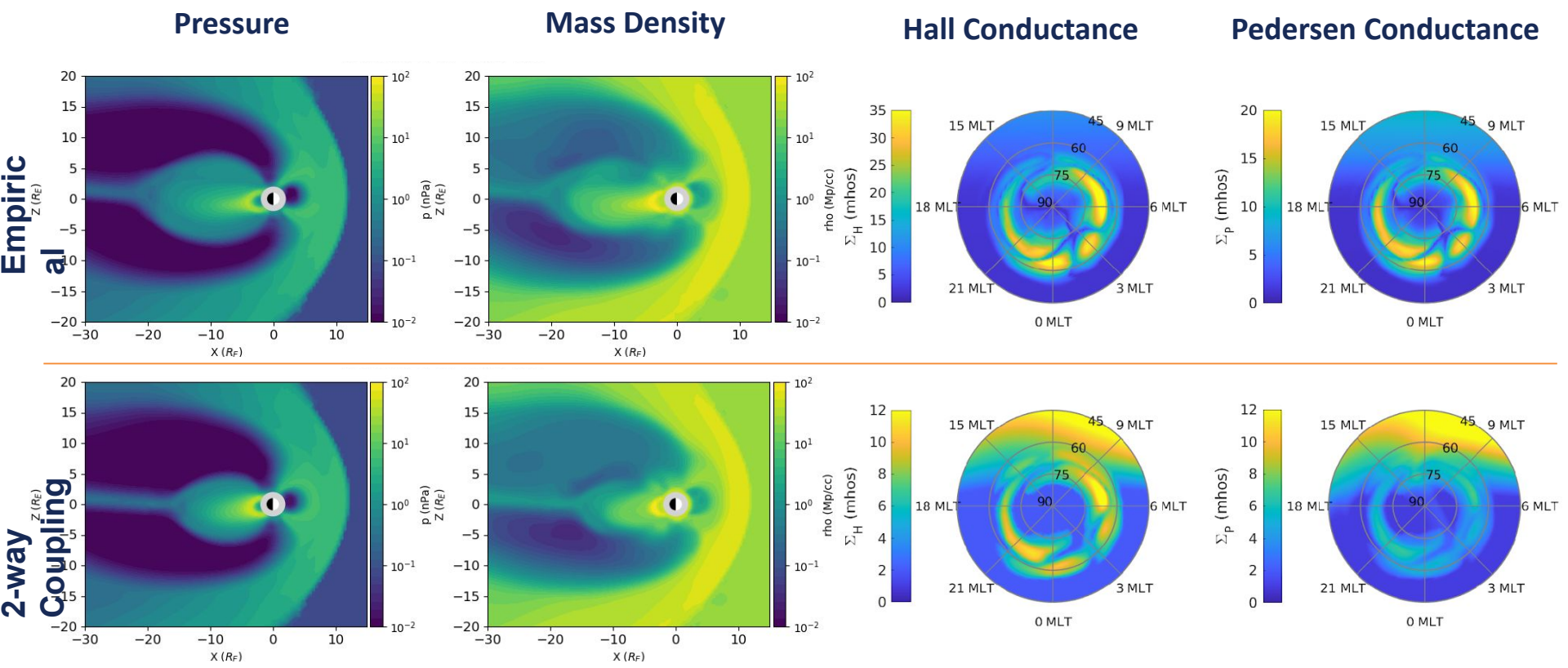
2015 St. Patrick's Day Storm – Ionospheric Conductance



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Final Thoughts

- GEMINI-TIA is well suited for ingesting sounding rocket and ISR campaign data for investigations into ionospheric dynamics.
- Realistic spatiotemporal variability is critical when determining the location, duration, and amount of upflow and potential outflow to the magnetosphere.
- Auroral activity, DC electric fields, and atmospheric gravity waves can all increase topside transport and yield a larger response to transverse wave heating.
- What happens in the near-past impacts what happens in the present which modifies what is possible for the future (i.e. hysteresis is important).