Exploring the Sensitivity of Auroral Current Closure to Neutral Winds Through GEMINI

DATA-24

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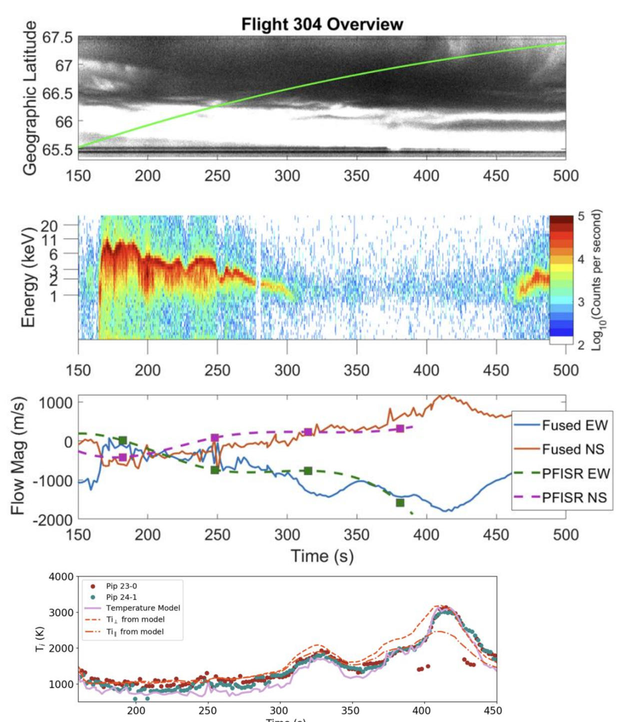
Abstract

The coupled magnetosphere-ionosphere-thermosphere (M-IT) system contains many complex interactions between neutral gas and plasma at a range of length and time scales. Many modern global circulation models use grid sizes too coarse to incorporate important aspects of small scale structures, for example those related to individual auroral features. This project uses the GEMINI ionospheric model, a physics-based, local-scale ionospheric model, to investigate the sensitivity of simulations of auroral dynamics to neutral winds model inputs. We make use of the large amount of data available from the Poker Flat Research Range (PFRR) to provide constraints for our modeling studies, specifically DASC, PFISR, SuperDARN, SDI, ESA-Swarm, sounding rockets, etc. By looking at example cases from the nightside auroral zone Swarm over Poker 2023 campaign, we will determine the effect of the neutral wind on GEMINI models by imposing varying neutral wind fields to GEMINI runs. Understanding the relationship between the neutral wind and auroral current closure is an important step in modeling mesoscale M-IT structures. Future extensions of this work will make use of fully coupled plasma-neutral extensions to these models that make use of adaptive mesh refinement to capture multiple scales of interest. Eventually these approaches will enable us to trace forcing through the IT system as it's subjected to intense, mesoscale inputs, as well as how these manifest in plasma-neutral response.

Introduction/Motivation



[Fraunberger, 2020]

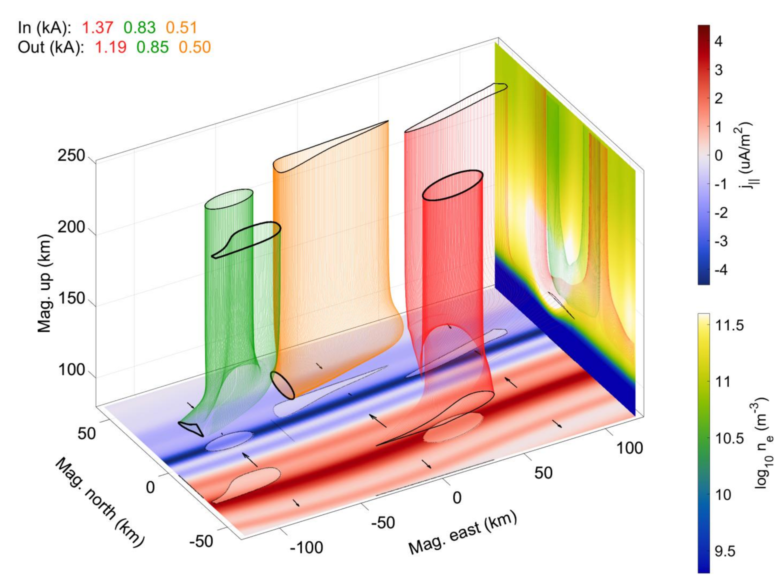
Background

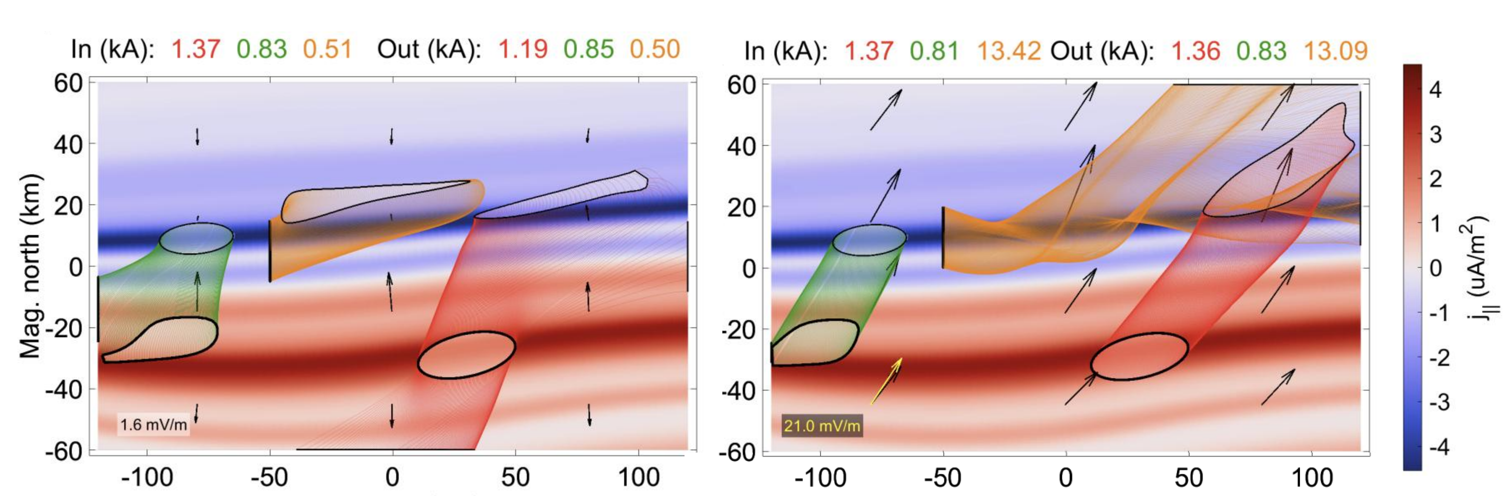
$$T_i = 16 \cdot \text{amu}/(3 \cdot k_B) \cdot \left|\mathbf{v}_{plasma} - \mathbf{v}_{neu}\right|^2 + T_n [\text{K}].$$

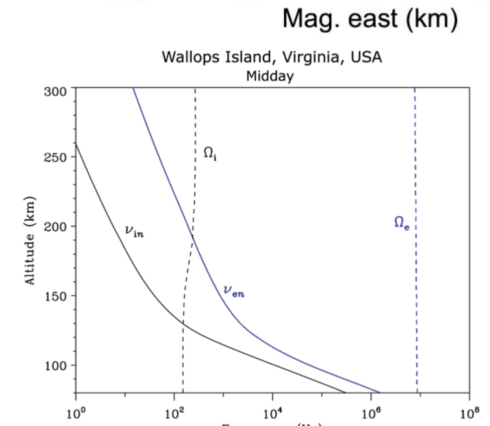
- Schunk and Sojka (1982) outlines how the ion temperature is related to the frictional heating caused by neutral winds.
- The Isinglass 304 rocket launch in 2017 [Fraunberger et al. 2020] contained a retarding potential analyzer used to determine the ion temperature. This ion temperature matched the Schunk expression, demonstrating the impact of neutral frictional heating.
- This launch, along with others, demonstrates the need for a deeper understanding for the interactions between auroral plasmas and the neutral atmosphere.

3D Arc Simulation

- 3D data driven numerical simulations of auroral arc systems have studied the sensitivity of auroral current closure to input parameters [van Irsel et al. 2025]
- The results of these simulations demonstrate that auroral arc systems are highly sensitive to changes in the background E field and these currents close at altitudes in which plasma is highly collisional with neutral gas







[Pfaff, 2012]

Goals

- Investigate the sensitivity of auroral current closure to background neutral winds
- "Study local responses of coupled plasma and neutral gases to mesoscale auroral forcing, including feedback processes" [Zettergren, 2022]
- "Study larger-scale high-latitude background plasma/wind modifications resulting from different types of auroral features" [Zettergren, 2022]

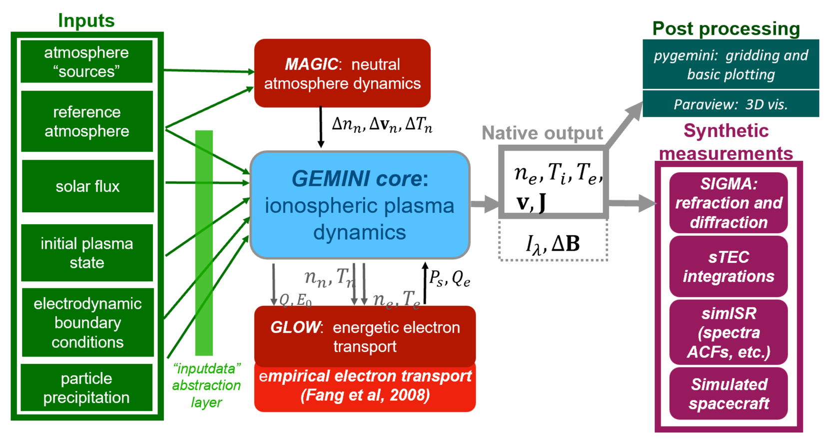
GEMINI + MAGIC

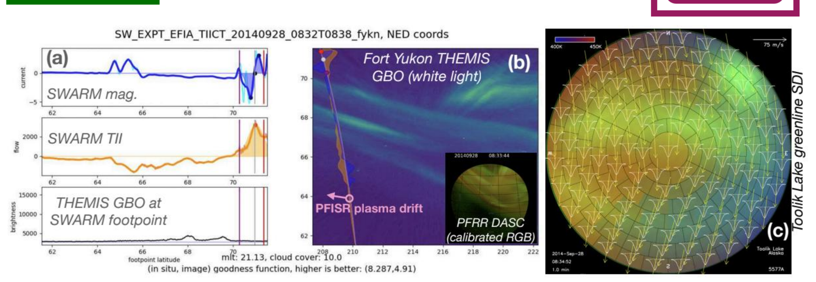
Models

- **GEMINI:** "GEMINI [Zettergren & Semeter 2012] solves for static current continuity to account for changes in model parameters impacting conductivities as it steps forward in time. It is driven with top-boundary precipitation maps of energy flux and characteristic energy covering impact ionization (Fang et al., 2008)." [van Irsel, 2024, MITC10]
- **MAGIC:** "MAGIC [Snively, 2013; Zettergren and Snively, 2015b] solves the 3D nonlinear compressible Navier-Stokes equations using a finite-volume method based upon modified Clawpack routines [LeVeque, 2002] and implemented via the f-wave method [Bale et al., 2003]." [Zettergren, 2022]

Coupling

- The project goal is to two-way couple the GEMINI model to the MAGIC neutral model allowing for large- and small-scale auroral energy source effects of both the plasma and neutral atmosphere.
- It is challenging to define ionospheric inputs that will produce physical results, as such we need observational data to define model inputs in various conditions
- Using imagery data, we can extract maps of both auroral precipitation energy flux and characteristic energy, and from in-situ measurements we can define fields and flows.
- Communication frameworks are being developed, but these simulations do not utilize MAGIC

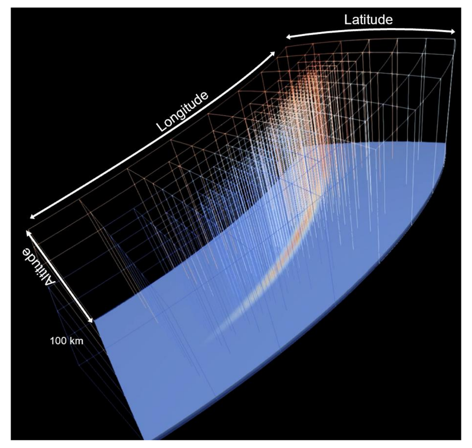




[Zettergren, 2022]

AMR

- A key goal of this multi-year project is to simulate plasma and neutral populations on both large- and meso-scales.
- The computational method that will be used to accomplish this is adaptive mesh refinement, which works to dynamically modify the mesh size to focus computation in areas requiring more precision.



[Zettergren, AGU2024]

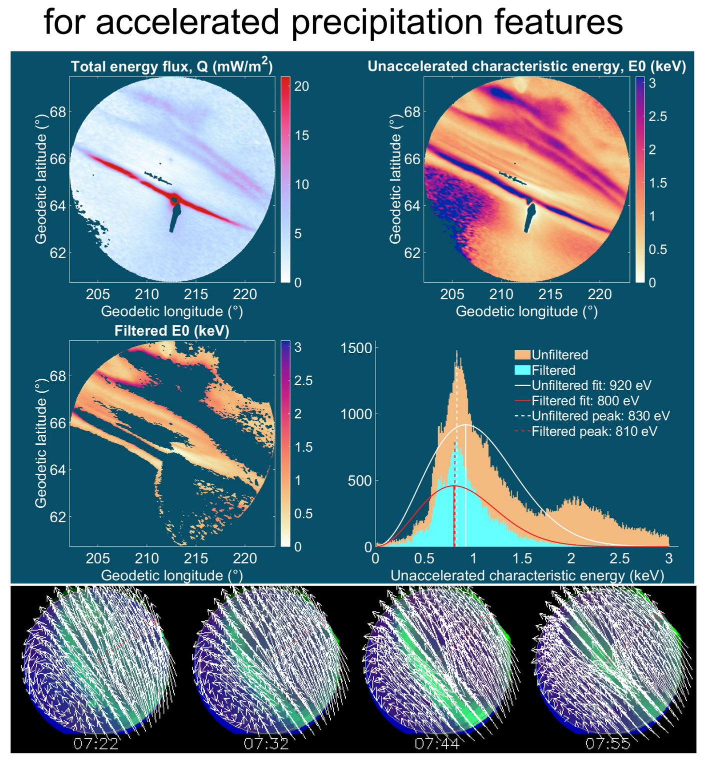
DASC + SDI + HWM

Instruments and Models

- **DASC:** Poker Flat Research Range Digital All Sky Cameras [UAF/GI DASC, 2023]
- **SDI:** Alaska Scanning Doppler Imagers [UAF/SDI, 2023]
- **HWM14:** Horizontal Wind Model [Drob et al. 2015]

DASC Inversions

- Alongside ESA's SWARM TII instrument, DASC imagery is used to create the 2D flow driver map which is used as input for GEMINI.
- Following the process from Clayton et al. (2021), the DASC imagery is inverted assuming an unaccelerated Maxwellian population which provides maps of (a) total energy flux and (b) the characteristic energy. Next, assuming the auroral acceleration potential drop goes to 0 outside the arc, the largest energy fluxes are removed, and the peak of the resulting distribution is the source region characteristic energy. Separately the in-arc regions are fit for accelerated precipitation features



SDI and HWM Data

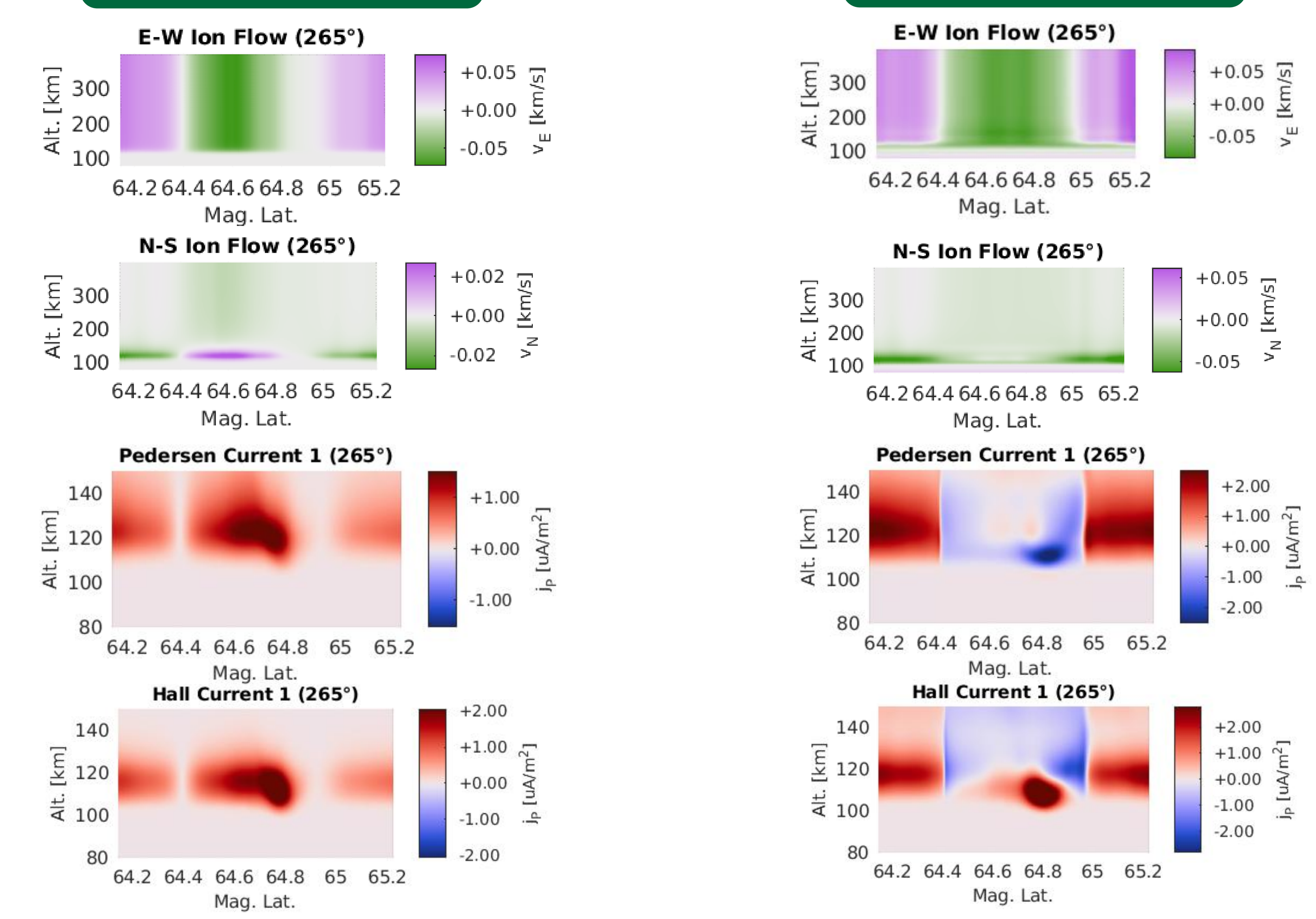
- The coupling of GEMINI and MAGIC is still underway, so initial testing has been done by driving GEMINI with uniform neutral wind profiles
- The SDI data provide neutral wind and neutral temperature maps by measuring red and green airglow, which can be used to construct neutral wind profiles.
- HWM14 is an empirical model based on data from ground-based and satellite instruments and will generate a neutral wind profile as a function of latitude, longitude, time, and Ap index.

Results

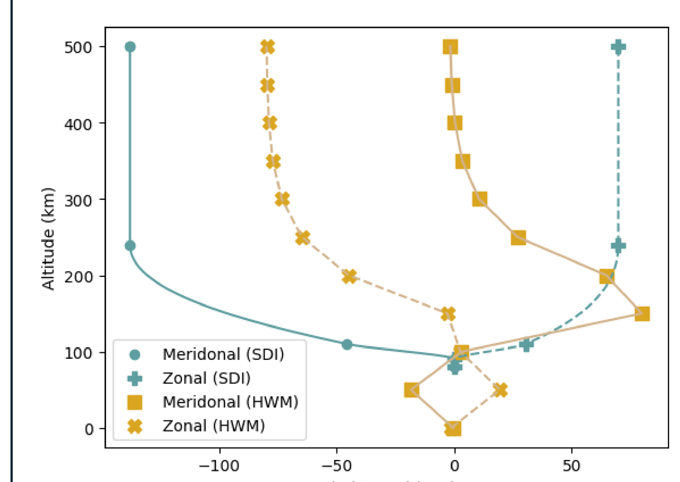
Simulations

- GEMINI contains information on the neutral atmosphere whether or not a background wind profile is defined.
- Results of running GEMINI simulations without (left) and with (right) defined neutral winds as generated by the Horizontal Wind Model (2014):

No Wind | **HWM14**



Errors



- There is the potential for significant errors in these results, although they show that with the addition of a moderate neutral wind profile the current and ion flow are dramatically changed.
- One major source of error is that the HWM14 generated wind profile varies greatly from the measured SDI profile.
- Additionally, the SDI profile has not been correctly altitude adjusted.
- In the future, MAGIC will be two-way coupled and will be used to determine the neutral wind profiles

Conclusions and Future Work

- Initial results show significant change to both low altitude ion flow and Hall/Pedersen currents. However, the neutral wind input from HWM14 significantly differs from the measured neutral wind profile from the SDI data.
- When constructing neutral wind profiles, these red and green emissions are assumed to be at static altitudes, however the height of these airglows can change based on ionospheric conditions.
- Using the DASC inversion method, altitudes of the red and green airglow can be extracted, which will then be used to refine the neutral wind profiles.
- Work has been done to compare neutral wind measurements to HWM14 [Branning et al. 2022], and other models are being developed for high-latitude winds [HL-TWIM Dhadly et al. 2019]
- To better reflect realistic conditions, we aim to repeat these simulations with altitude corrected SDI profiles.

References and Acknowledgments

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