The Space Weather Operational Readiness Development Center

Storm-time comparisons between the neutral atmosphere response and LSTADs/LSTIDs generated in GITM, TIEGCM, and SAMI3 simulations

Aaron Bukowski

Aaron Ridley, Ari Gottesman, Sreelakshmi Jayaraman, Chen Wu

Daniel Welling, Yuxi Chen,

And the rest of the SWORD Team

Track 1: Coupled model development

outline

- Introduce:
  - Models: physics then empiricals
  - Why not put Emery & Heelis into Electrodynamics (licensing & “complexity”)
  - Storms: 2013-03-17, 2015-06-23. equinox & solstice, low F107, moderate intensities
- GITM FTA vs TIEGCM FTA; show eFlux/temp disagreement, HP_actual vs HP_input
- Runs done: gitm FTA/FRE, tiegcm Emery/fta/ftaONLY/fre
  - (mention DNF’s, only have SAMI from a few…)
- Movies:
  - TEC, e- @ 150/450 km / hmf2
  - Rho/NO/(?) @ 150/350/450 km
- Plots of:
  - Mean density
  - Mean temperature, TEC (over americas)
- SAMI3 outputs from what we have, TEC movie, longitude/localtime slices
- Takeaways:
  - TIEGCM can be run with any pot/aur model (and amie)
  - Gitm & tiegcm are similar (?)
  - See github for more!!!

Physics models used

GITM

- Non-hydrostatic
  - "up" = "altitude"
- Flexible resolution (set by # of CPUs)
  - 4x1 lon x lat, 60 altitudes with ~0.3 scale-height spacing
- 2D Dynamo, APEX field-line integration
- "SWMF" (framework)
- Finite difference

TIEGCM

- Hydrostatic
  - "up" = "pressure"
- Resolution determined before compiling
  - 1.25^o horizontal, zitop=7
  - ~110 pressure levels
- 2D Dynamo, APEX integration
- "MAGE" framework
- Spectral scheme

SAMI3

- Field-aligned ionospheric grid
- Does not model neutrals, only ions
  - MSIS & HWM by default, TIEGCM and GITM here
  - 1-way coupled every 5 minutes
  - Densities decrease hydrostatically, velocities constant above model domain
- 3D-dynamo
- Finite volume

All results are presented on *(Latitude, Longitude, Altitude)* grids

Executive Summary

Goals

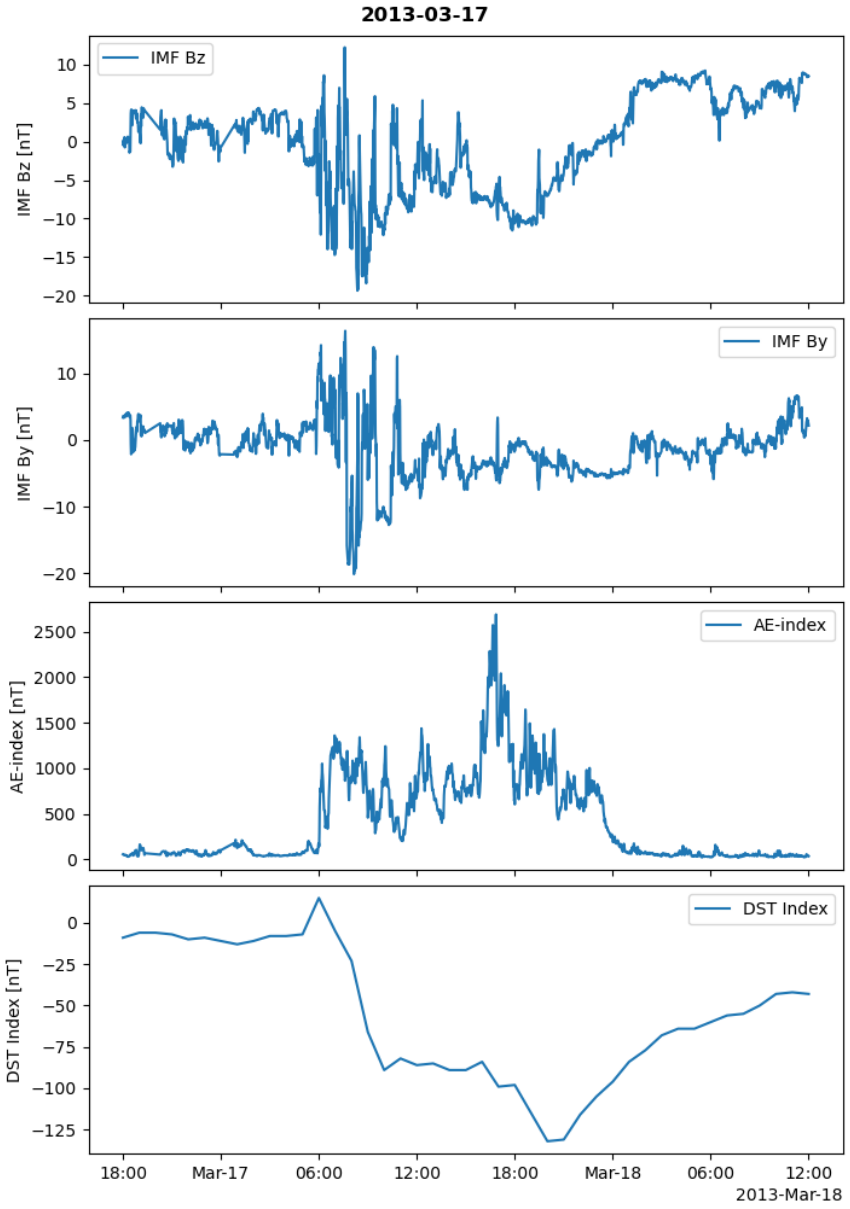
- Run GITM & TIEGCM using the ***exact*** same:
  - Drivers (potential & aurora)
  - Indices (F107, IMF, AE/HP, etc.)
- Similar:
  - Dates (initialization for TIEGCM >> GITM)
  - Horizontal resolution
- Use default settings when possible & appropriate
- Look at general model behavior & LSTADs/LSTIDs
- Drive SAMI3 using outputs of both
  - *Proof of concept*

What was done

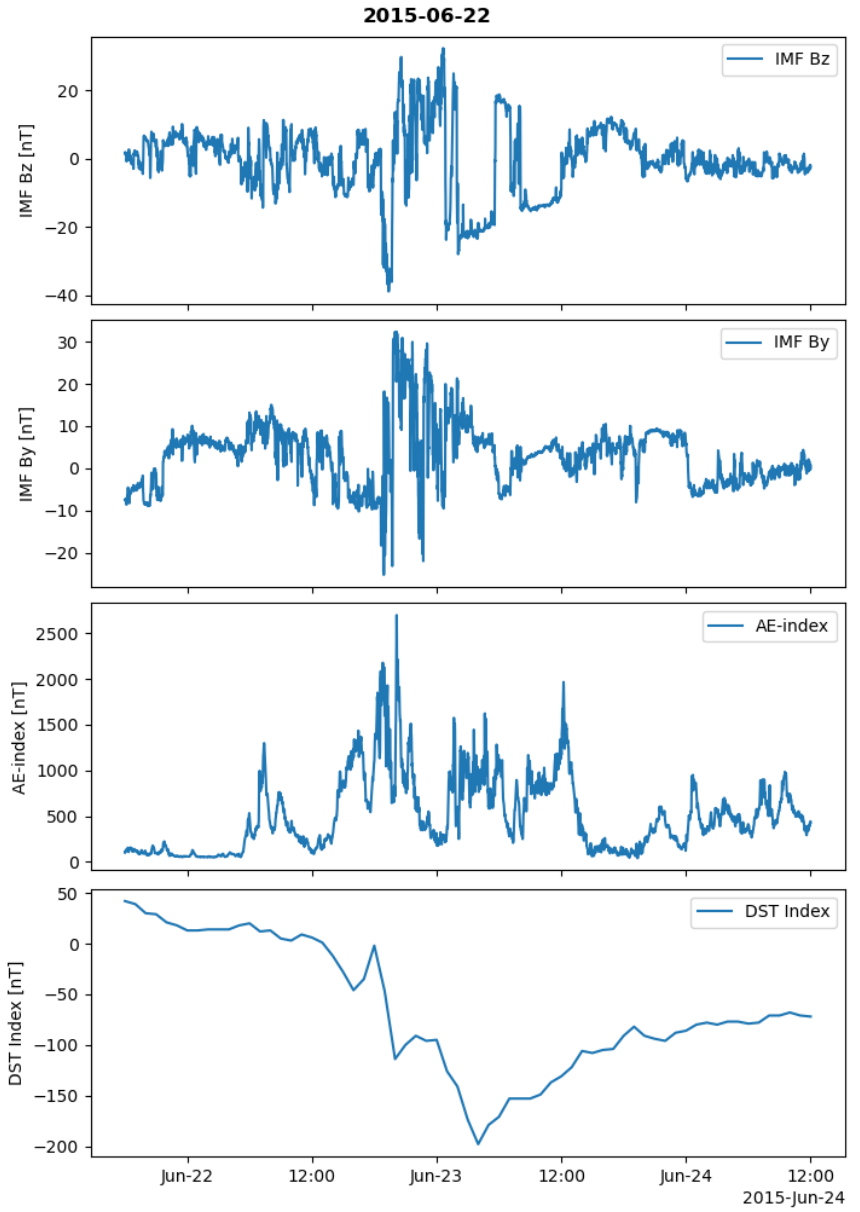
- Did not disturb standalone, prior, model behavior
  - Results are reproducible & open-source
- Need a model-agnostic Electrodynamics library
  - We made one!

  https://github.com/GITMCode/Electrodynamics.git
  - Currently works with GITM, TIEGCM, IPE
  - Implementation in a new model *can* also include readers for relevant indices
- Two storms:
  - FTA/FRE + Weimer for both GITM & TIEGCM
  - Emery + Weimer for TIEGCM (baseline, default)
  - ** not all shown **

Storms Analyzed



- One solstice storm, one equinox
- Both have:
  - Relatively low F10.7 (<80)
  - Strong IMF By
  - A somewhat “standard signature”



Empirical Electrodynamics Models

"Electrodynamics" / "MILE"

TIEGCM (NCAR)

Both

	FTA (Wu et al 2010)	Emery Roble & Ridley (2008, 1987)	FRE (Fuller-Rowell & Evans, 1987)	Heelis (1982)	Weimer (2005)	Ovation ** (Newell, 2009)
Outputs	*Aurora* Diffuse e- (eFlux, avgE)	*Aurora* (Diffuse e-, cusp, soft e-, drizzle) +SAPS	*Aurora* Diffuse e- (eFlux, avgE)	*Potential*	*Potential* +FACs *Auroral boundaries*	*Aurora* Diffuse e-, Wave/BB e-, Mono e-, Ion diffuse
Inputs	AU, AL	IMF, HP/Kp	HP	ctpoten (CPCP), Boundaries (Kp, IMF, *Emery*)	IMF	IMF, HP **

*** some OVATION & AMIE features from Electrodynamics are not available for TIEGCM ****

Runs Done

	2013-03-17	2015-06-23
GITM	Weimer + FTA Weimer + FRE	Weimer + FTA Weimer + FRE
TIEGCM	Weimer + Emery Weimer + FTA Weimer + FRE Weimer + FTA **	Weimer + Emery Weimer + FTA Weimer + FRE Weimer + FTA**

*** Without cusp, drizzle, soft e-*

- **Weimer05 used in all runs**
- **TIEGCM run with internal vs external Weimer produce potentials <2% different**
- **CAVEATS:**
  - **(Not all TIEGCM runs finished)**
    - Some NetCDF/HDF5 write errors
    - Some physics errors (dynamo??)
  - **SAMI3 results only shown from GITM…**

Heelis and Emery / Roble & Ridley Inter-dependency

Why not put TIEGCM empirical IE into Electrodynamics

- Licensing
- Outputs from auroral model depend on which potential model is used & which indices were provided
- Heelis (potential) can only be used with Emery aurora

Sequence of events (each dt) in TIEGCM, from advance.F:

- Get HP (calculate if not given)
- Aurora_cons()
  - Read ctpoten (CPCP) if Weimer, calculate if Heelis
  - Determine auroral & potential boundary
- Run potential models
  - Weimer overwrites auroral boundary & writes ctpoten
  - Heelis reads auroral boundary
- (from dynamics): Run Aurora
  - Read boundary, ctpoten, power
  - Deposit all precipitation
- Dynamo (use potential)

Electrodynamics TIEGCM implementation

Default code pathways are all unchanged!

Everything new is guarded with pre-processor directives

- Let original TIEGCM code run, change values before they're used
  - Bypassing native Weimer calls leaves null values in arrays, blocks SAPS, etc.

Run electrodynamics
Just pass indices

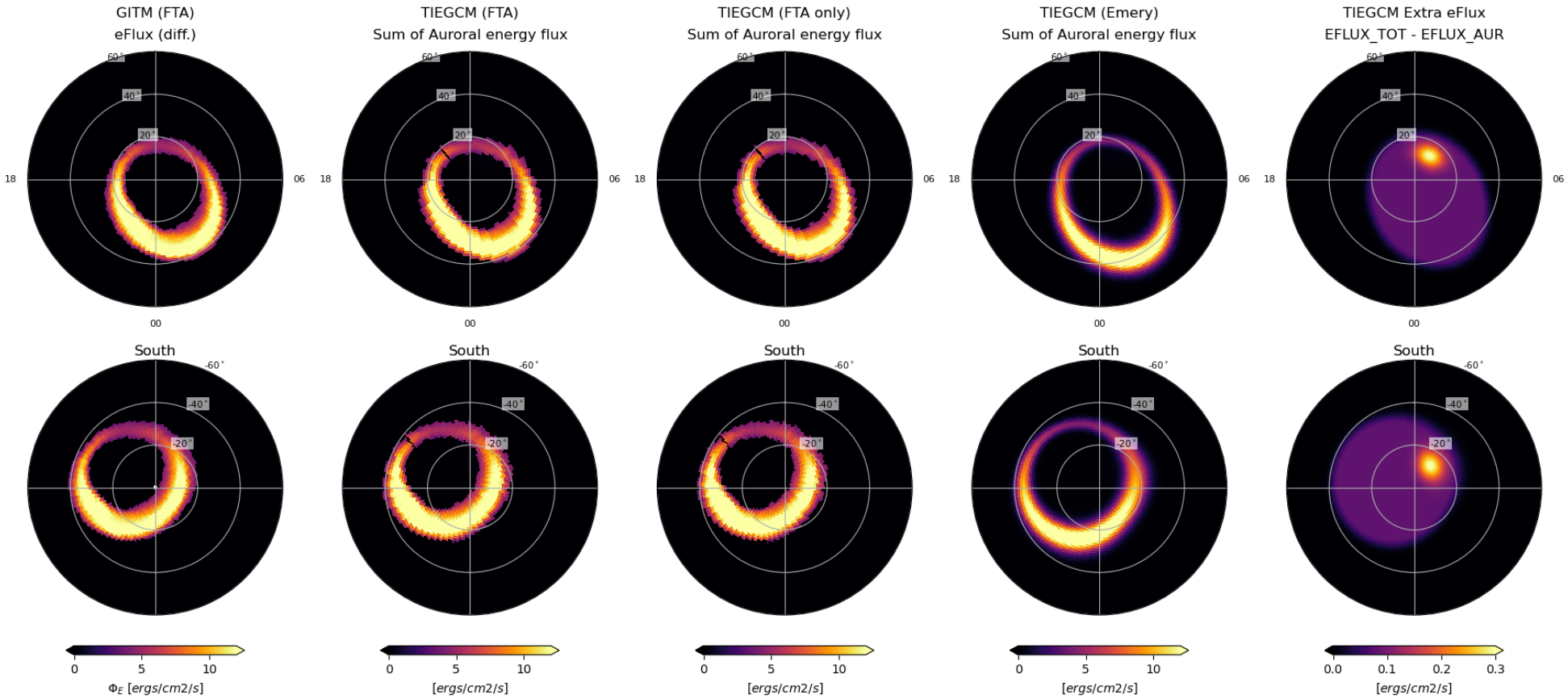
Insert new potentials & aurora here!!

Sequence of events (each dt) in TIEGCM, from advance.F:

- Get HP (calculate if not given)
- Aurora_cons()
  - Read ctpoten (CPCP) if Weimer, calculate if Heelis
  - Determine auroral & potential boundary
- Run potential models
  - Weimer overwrites auroral boundary & writes ctpoten
  - Heelis reads auroral boundary
- (from dynamics): Run Aurora
  - Read boundary, ctpoten, power
  - Deposit precipitation
- Dynamo (use potential)

Auroral Driving

- eFlux *nearly* identical between GITM & TIEGCM
  - RIGHT: TIEGCM ($eFlux_{TOTAL} - eFlux_{AURORA}$)
- FTA produces substantially more eFlux than Emery



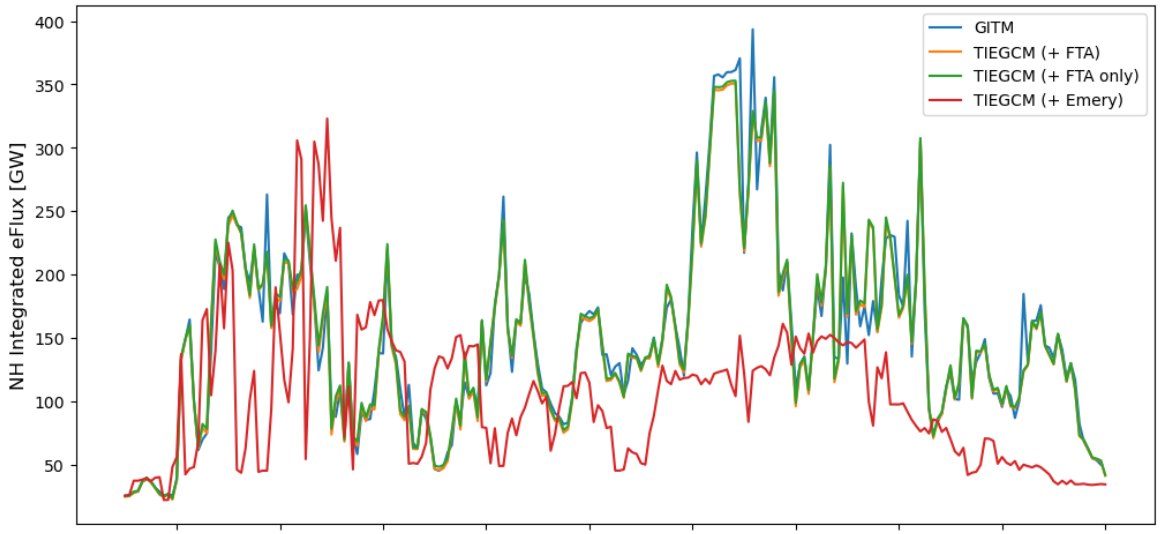
Why turn off TIEGCM extra precip?

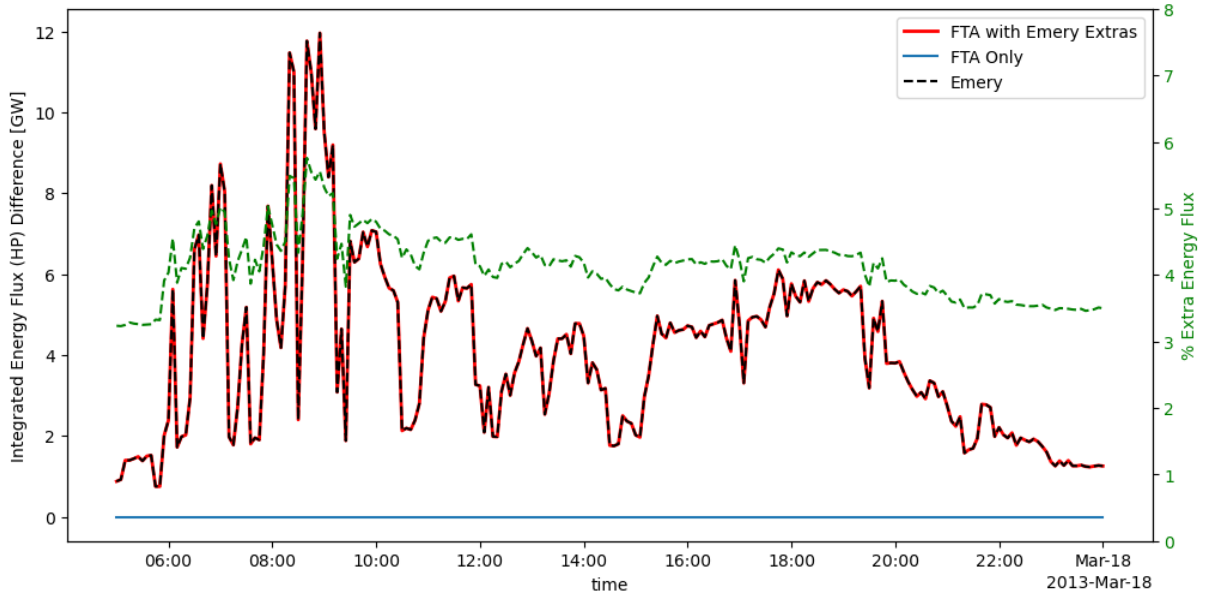
$HP_{in} = HP_{out} = HP_{"aurora"} \leq HP_{deposited}$

Emery Aurora includes Cusp, drizzle, soft e-

AND diffuse e-

- Each are constant or HP-dependent
- eFlux vaiarble only contains diffuse e- precipitation (what Electrodynamics writes)
- 1-1 auroral driver comparisons mean they should be toggled **off**
  - *All are minor contributors ->*





Effects of the auroral differences

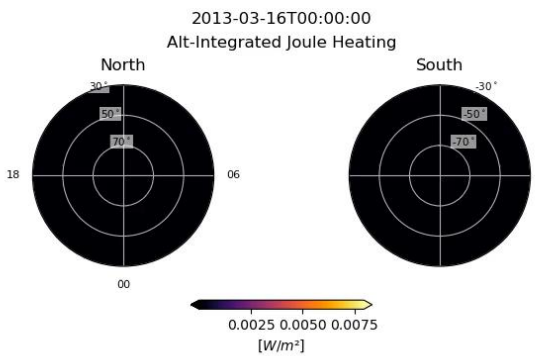
Runs from left to right:

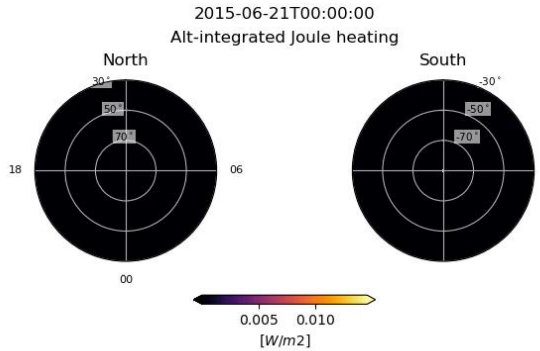
GITM + FTA

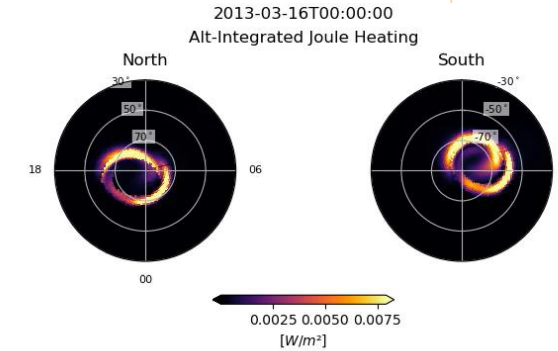
TIEGCM + FTA

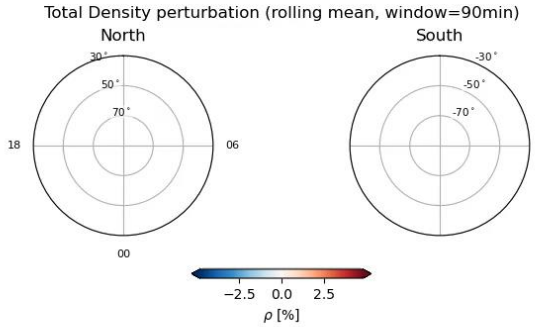
+ Emery extras

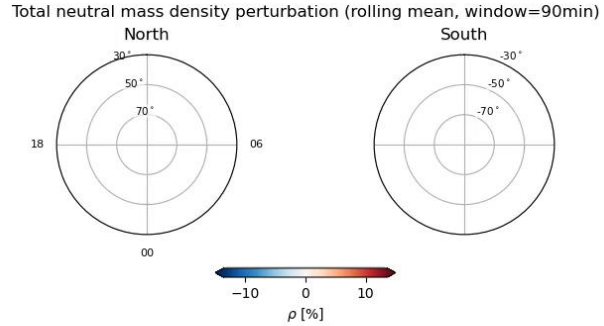
TIEGCM + FTA

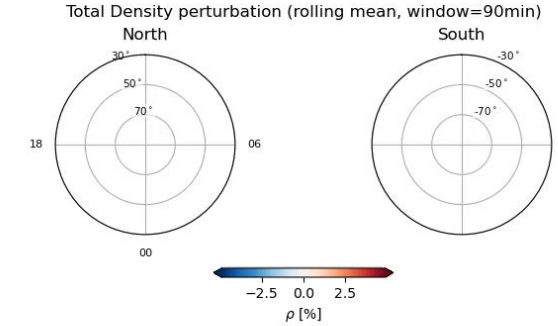


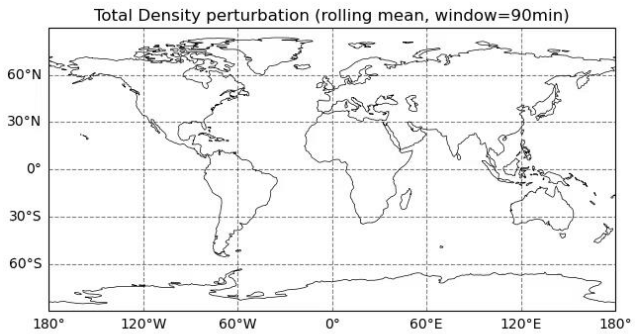


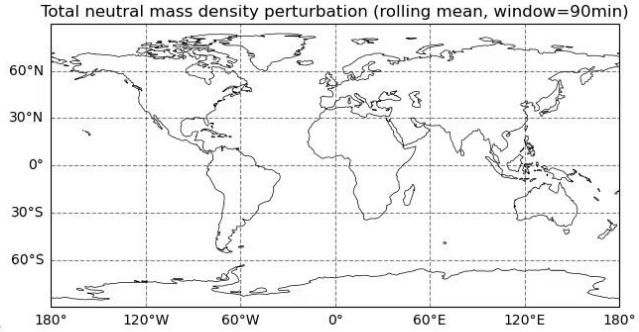


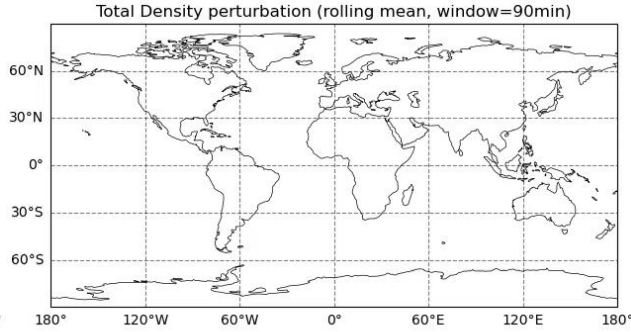






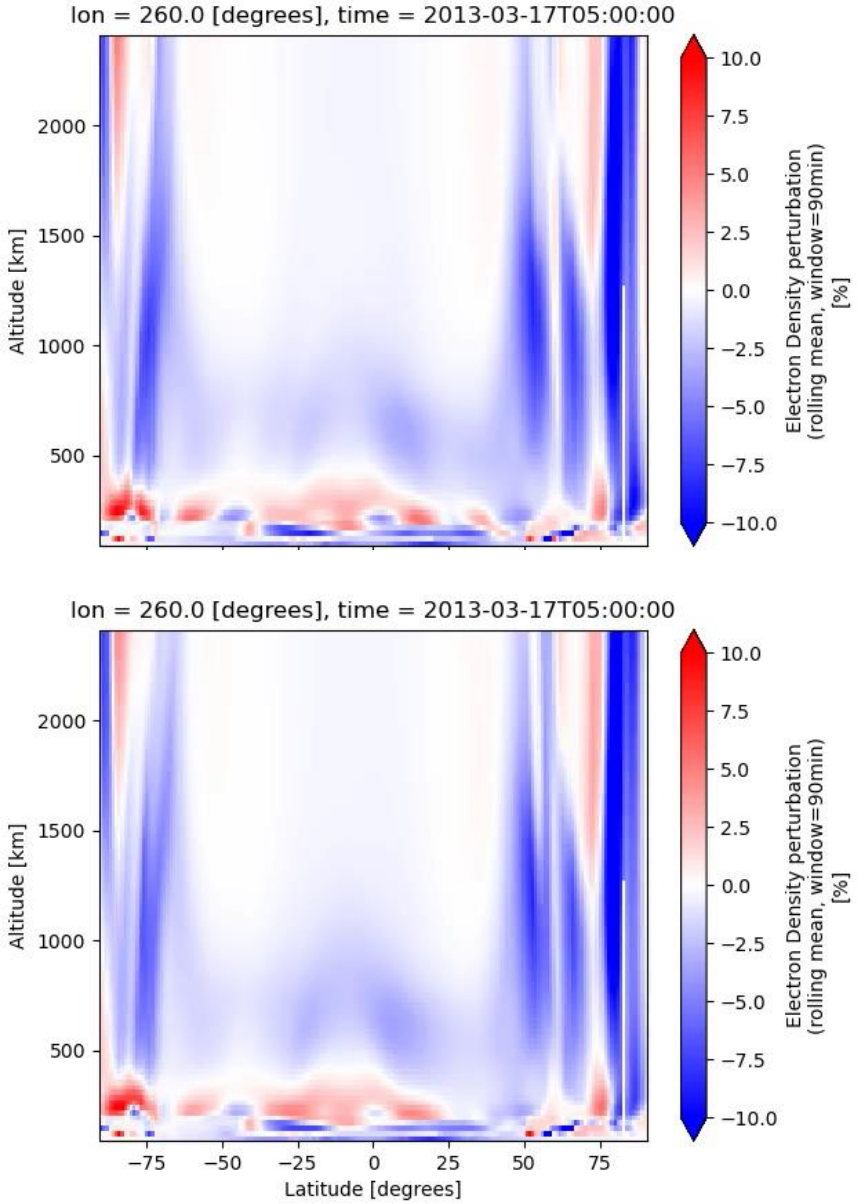






LSTIDs in SAMI3

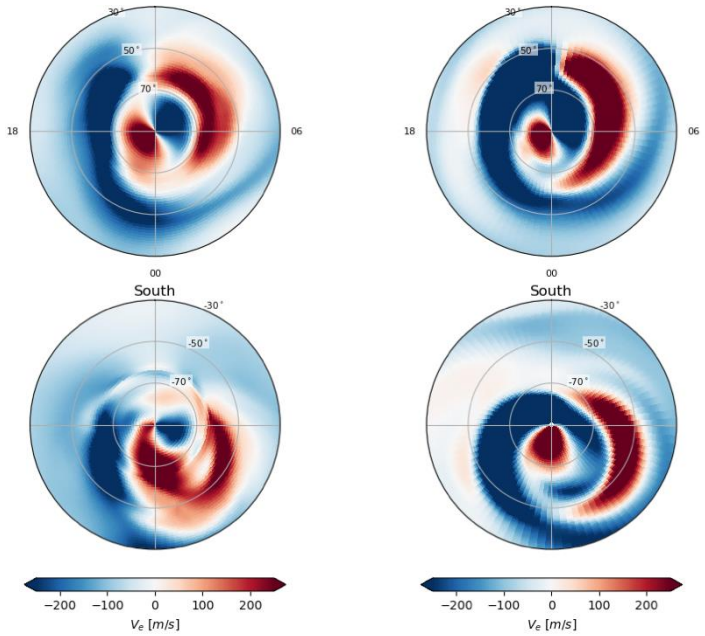
- GITM only extends to ~800 km in this storm
- Ion-neutral collision frequency (drag) is negligible at this point
- LSTIDs do not “propagate”; they are the ionospheric signature of waves in the neutrals
- Magnetic field lines are equipotential, so LSTID signatures are present beyond the topside

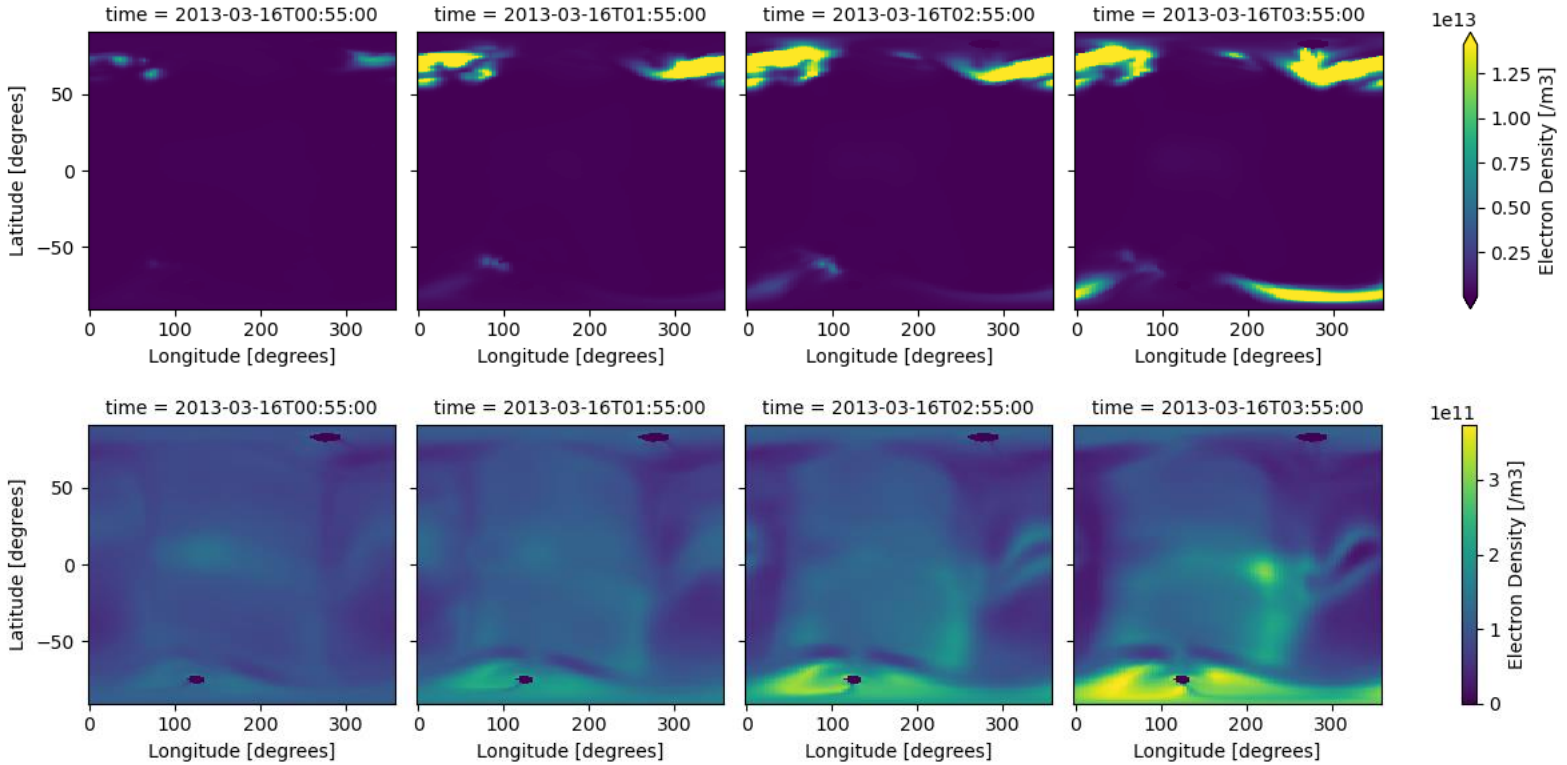


Why no SAMI3 runs with TIEGCM?

- SAMI3 did not survive!
- Likely due to neutral winds in the lower thermosphere <200 km

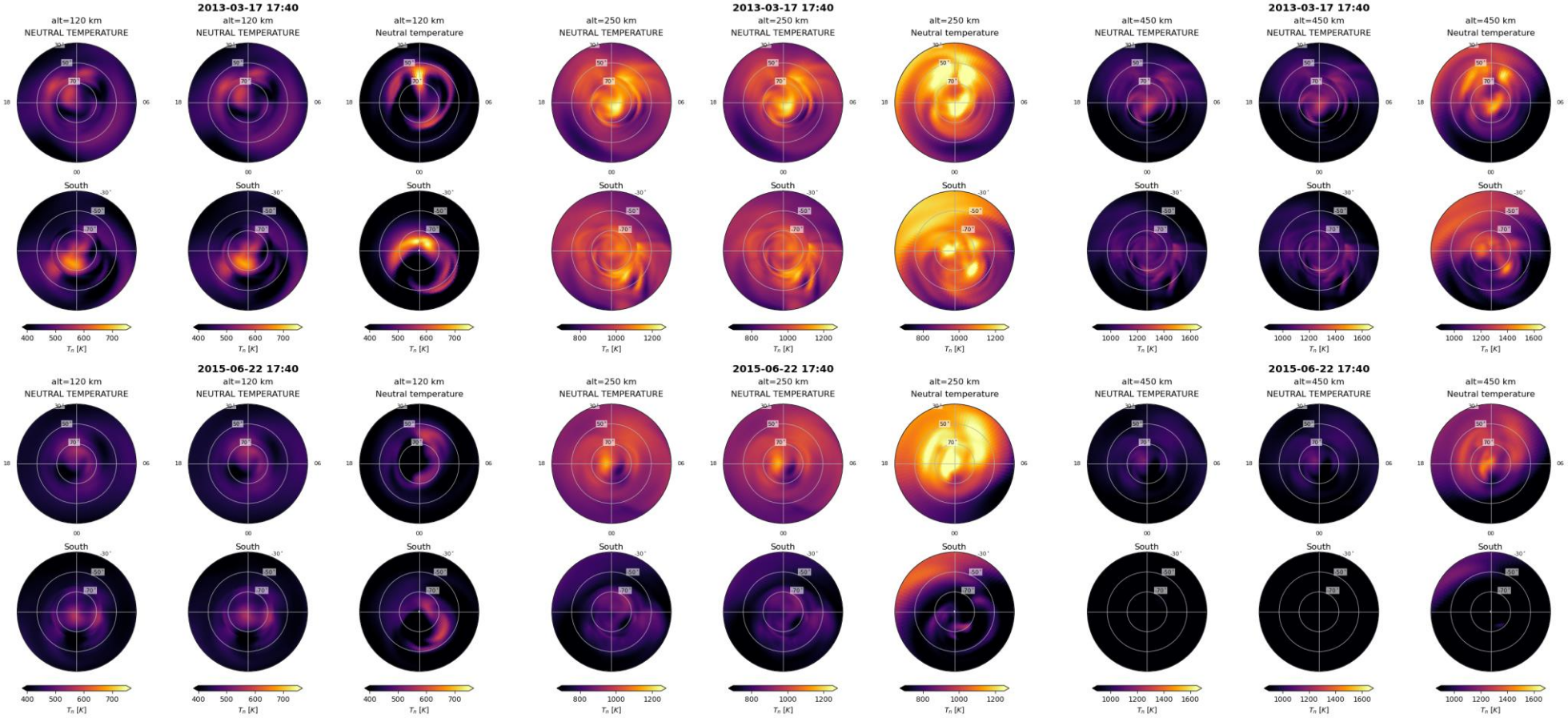
Eastward winds from TIEGCM, GITM @ 150 km:





Left -> right (TIEGCM + FTA + extras, TIEGCM + FTA, GITM) @ 120, 250, 450km

- GITM gets hotter & stays hotter than TIEGCM
- TIEGCM cools faster with altitude; less hemispheric asymmetry in Solstice storm



Conclusions

- We have created methods for 1-1 model comparisons with the exact same IE Drivers
- LSTADs in TIEGCM and GITM appear differently
- Further validation is now possible!

Thanks!!

Scan for TIEGCM Fork

Electrodynamics available in other Repositories of GITMCode