AFOSR: Multidisciplinary University Research Initiative (MURI)

Next Generation Advances in Ionosphere-Thermosphere Coupling at Multiple Scales for Environmental Specification and Prediction

The University of New Mexico

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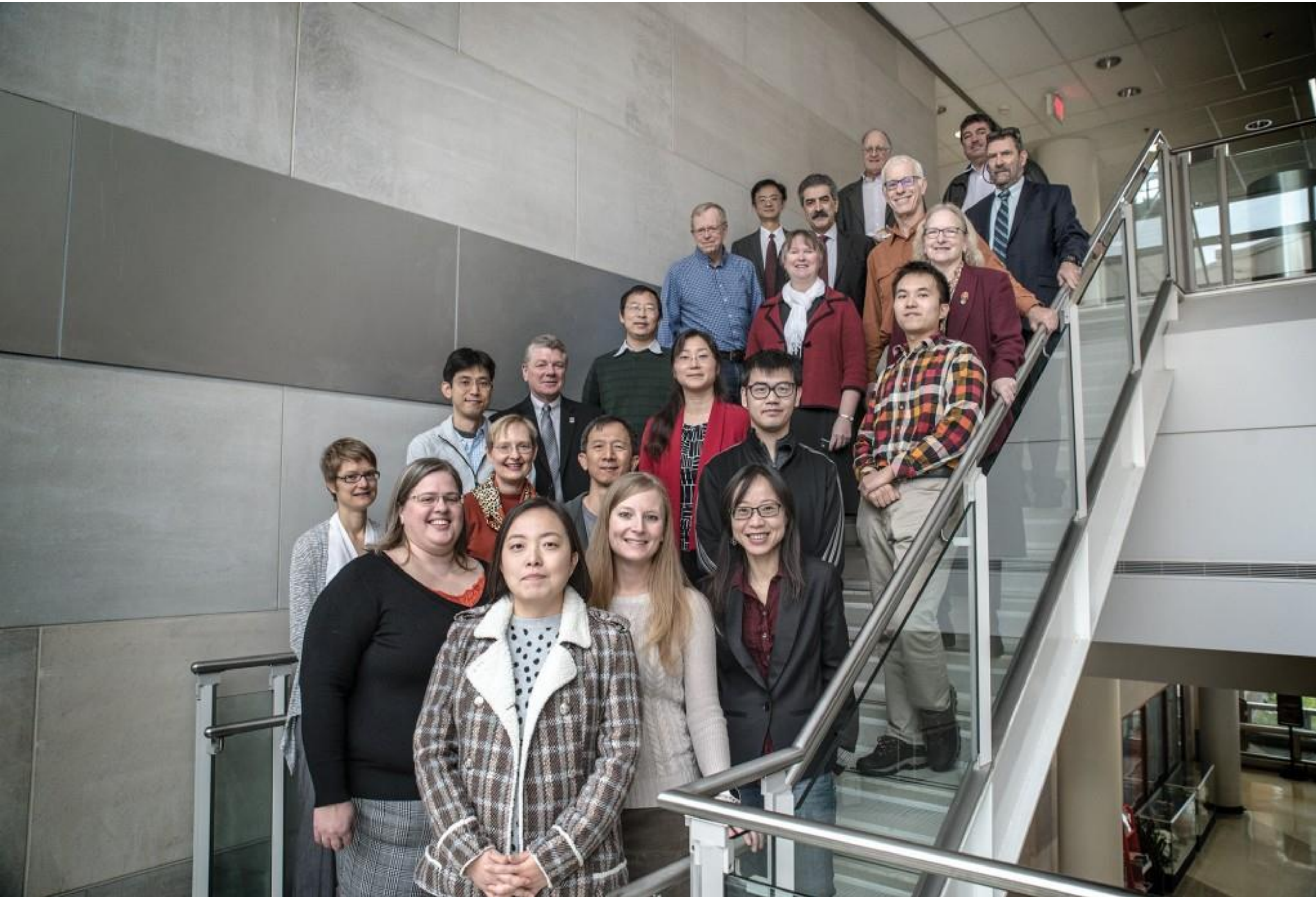
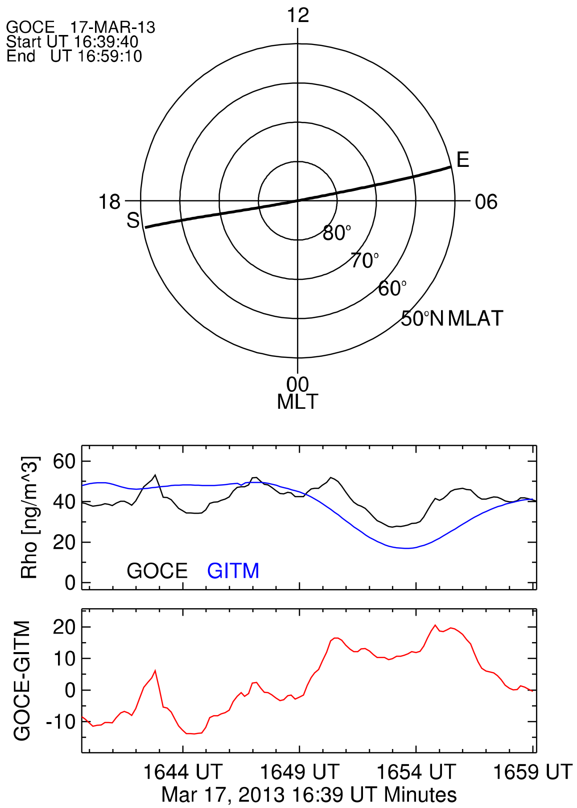
Astrid Maute, Collaborator, National Center for Atmospheric Research
Other scientists, post-docs and graduate students

Kickoff meeting: Arlington, TX on Dec 5th, 2016

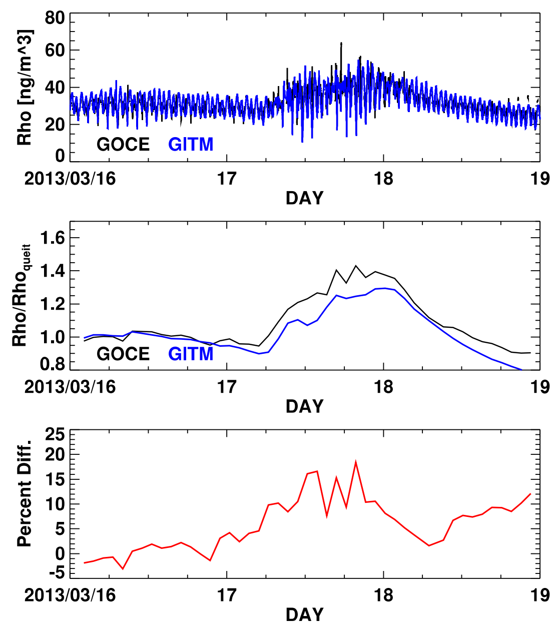


2. Objective:

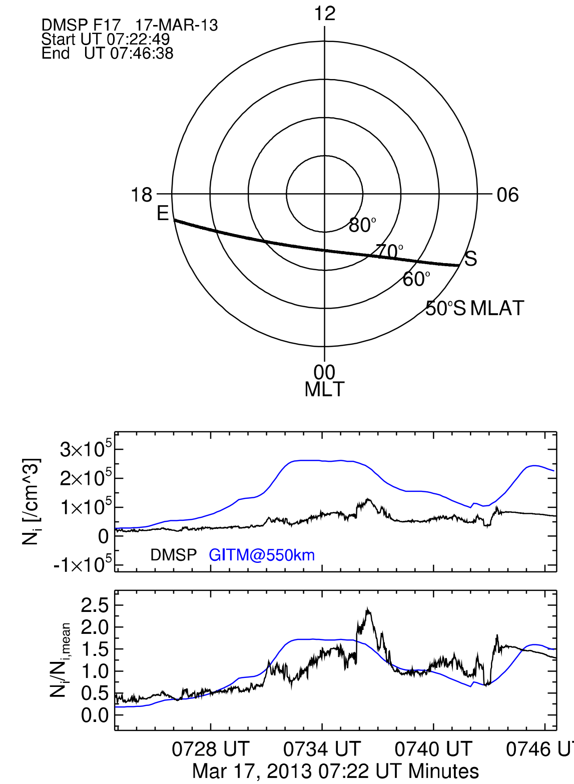
(a) Neutral density: GITM vs. GOCE along the trajectory



(b) Neutral density: GITM vs. GOCE during the whole storm period



(c) Ion density: GITM vs. DMSP



The objectives are to use new capabilities to improve the specification of the energy and momentum inputs to the system, especially at the meso-scale, and to determine how the I-T system responds to these inputs at different scales.

3. Goals:

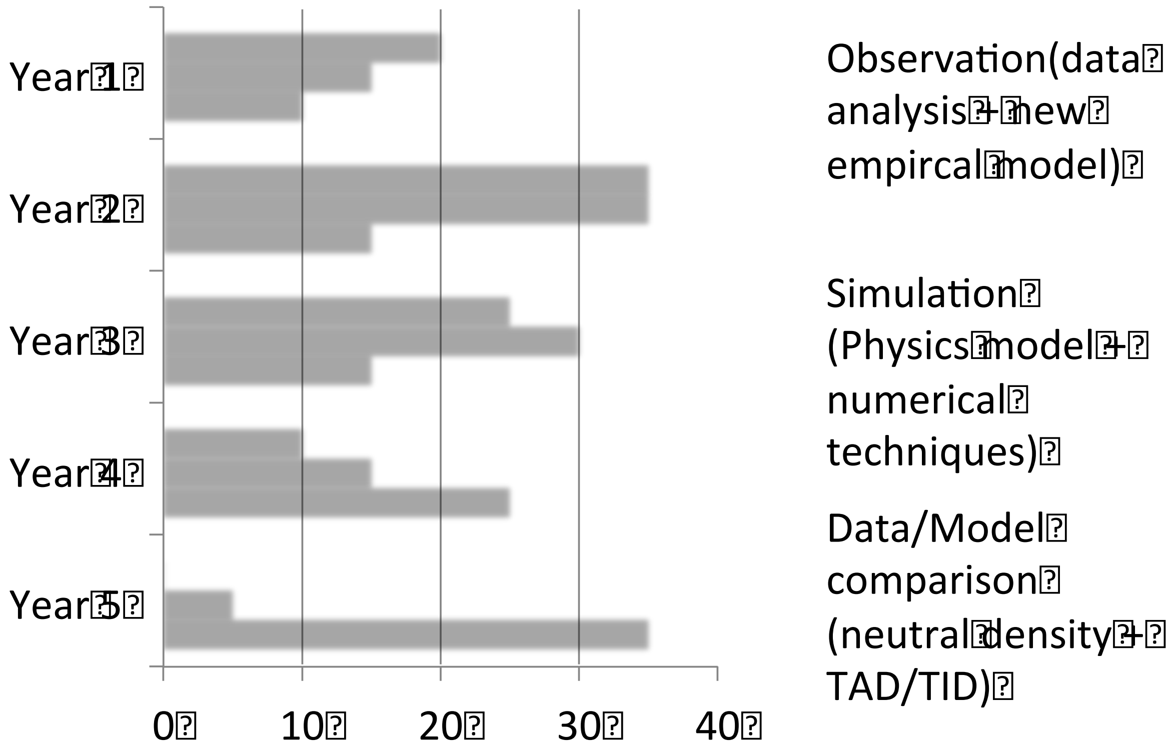
(1) discover the spatial distribution and temporal evolution of meso-scale structures in the geomagnetic forcing.

(2) develop a new model to describe the large-scale and meso-scale forcing.

(3) describe the I-T responses that result from large-scale and meso-scale energy inputs at high latitudes.

(4) understand how meso-scale structures and their influence on the I-T system are coupled to the magnetosphere.

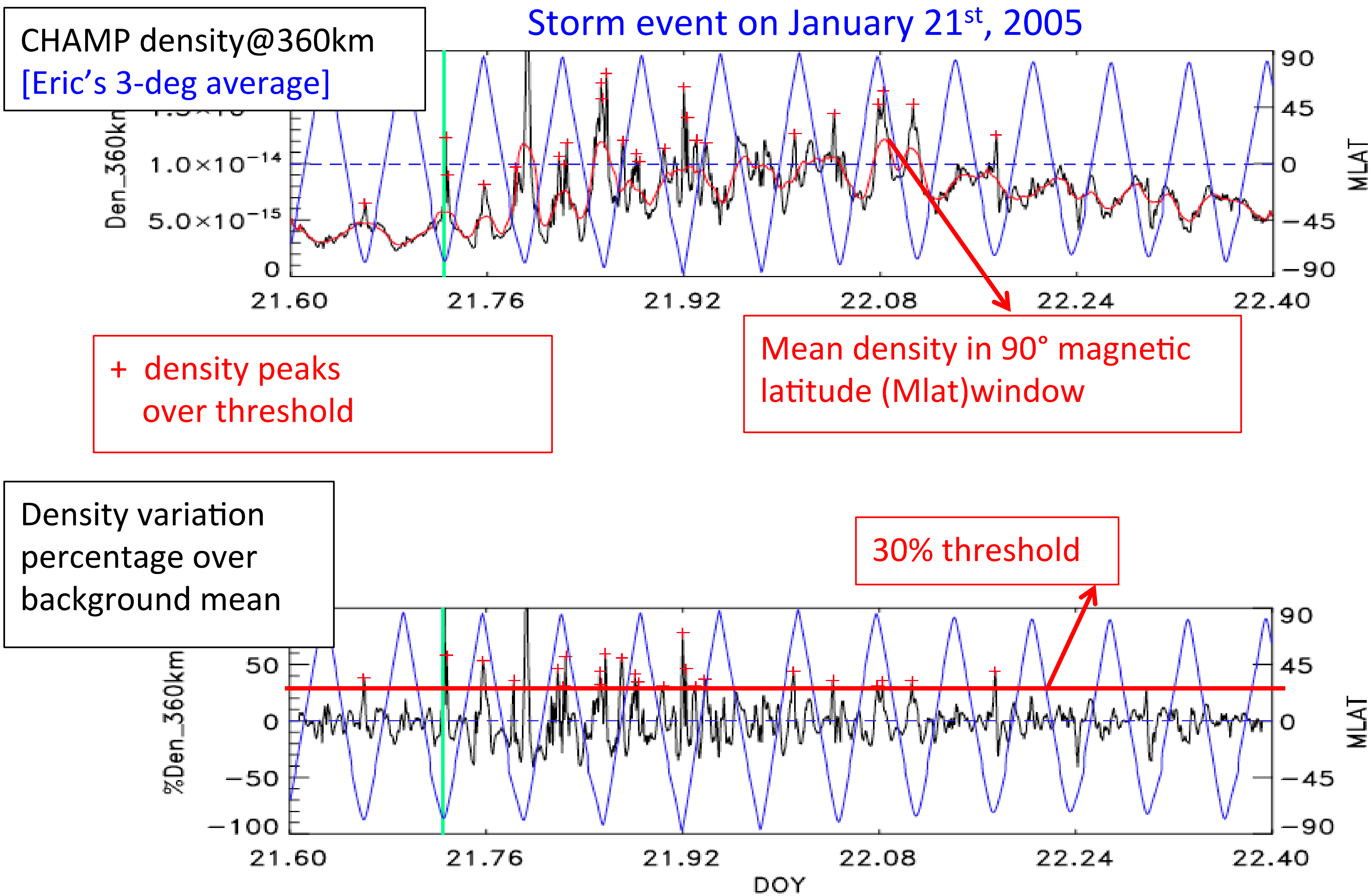
4. Schedule and Approach:



Percentage of effort in each category (%)

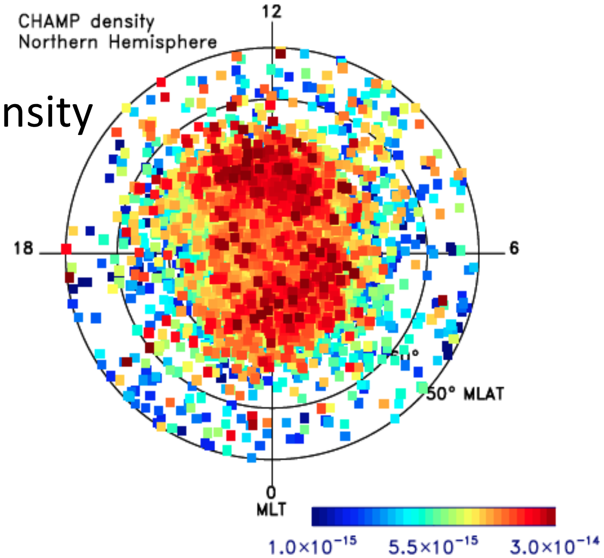
5. Progresses in last ~2 year:

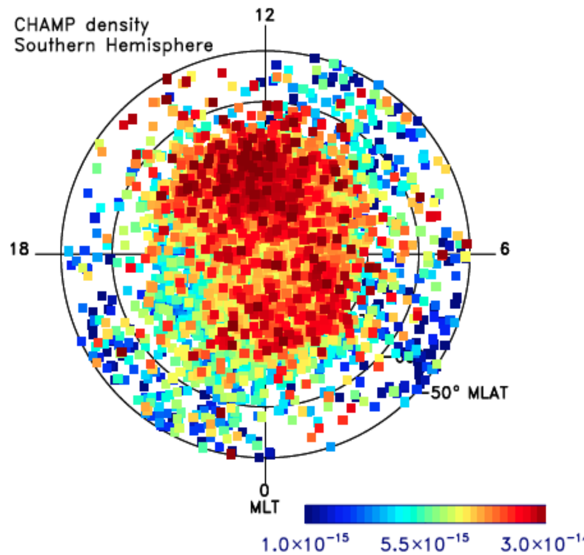
5.1 Neutral density variation:

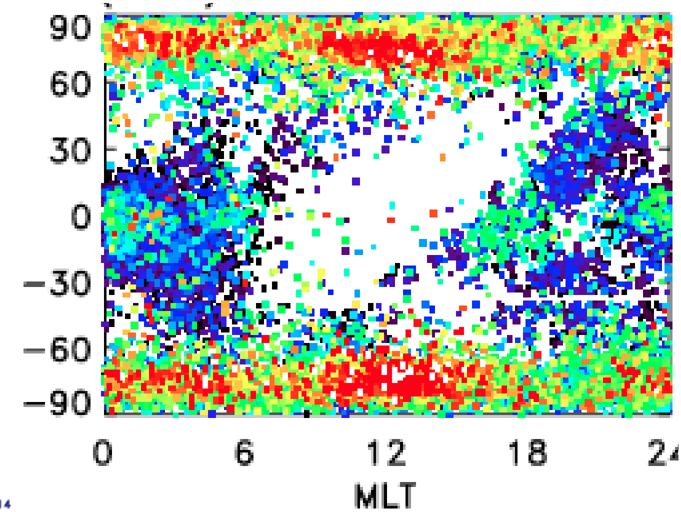


CHAMP 30% peaks from 2001-2010

Density

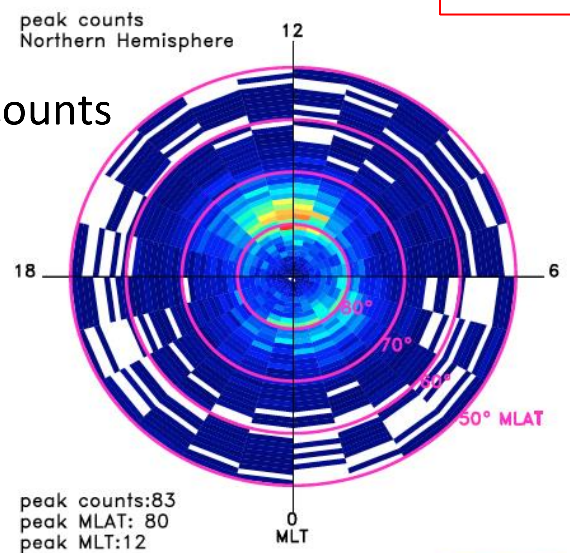


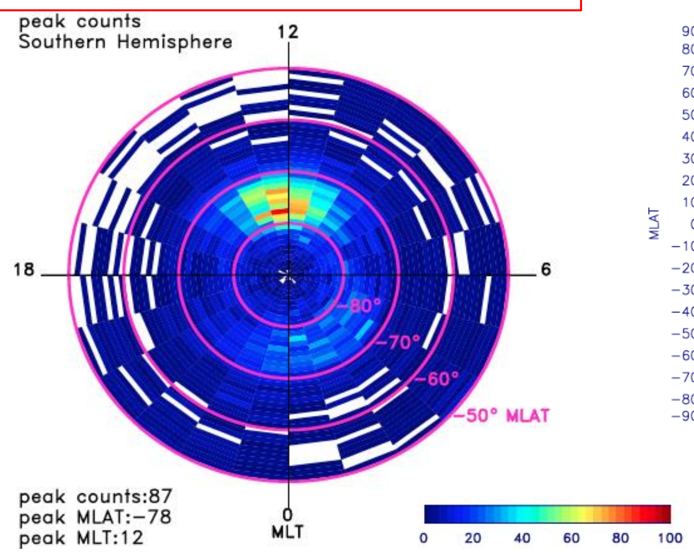


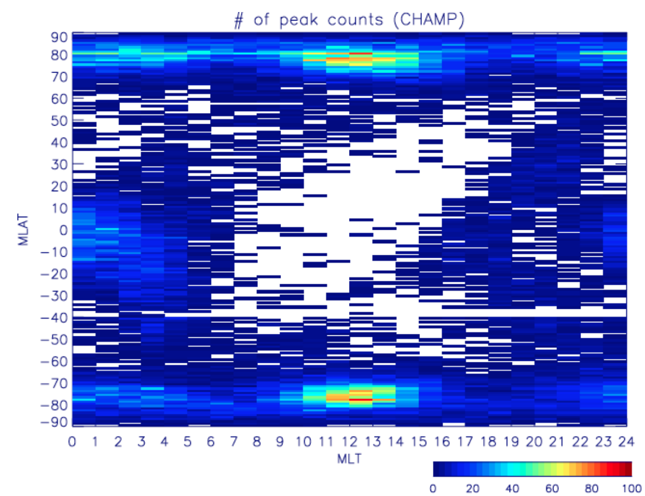


1° MLAT×1MLT binned CHAMP data

Counts



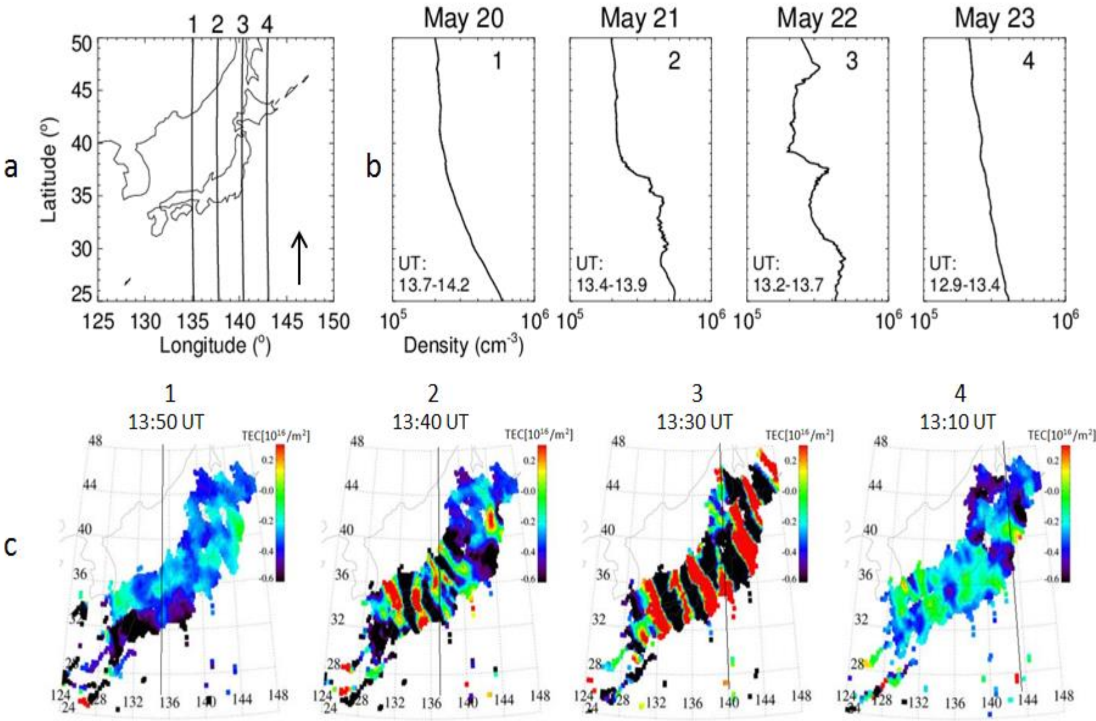




5.2. Traveling Ionospheric Disturbances (TIDs) and irregularity

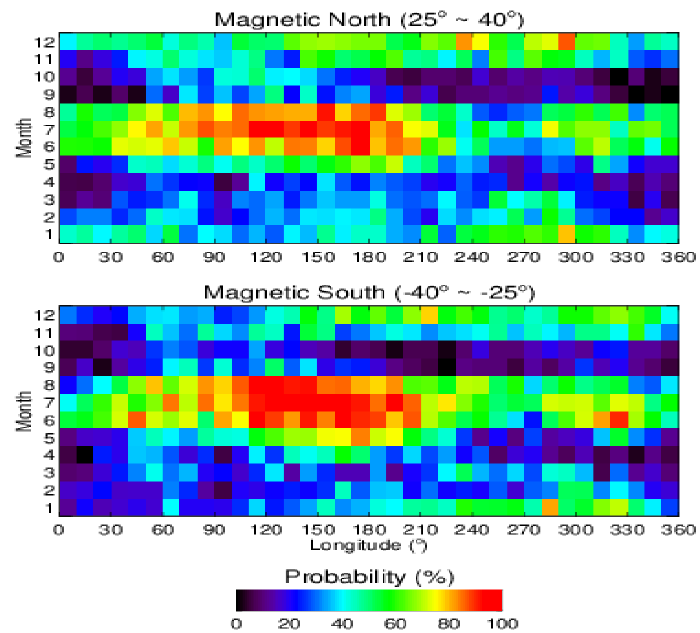
Swarm satellite observations

Coincidence of irregularities and MSTIDs



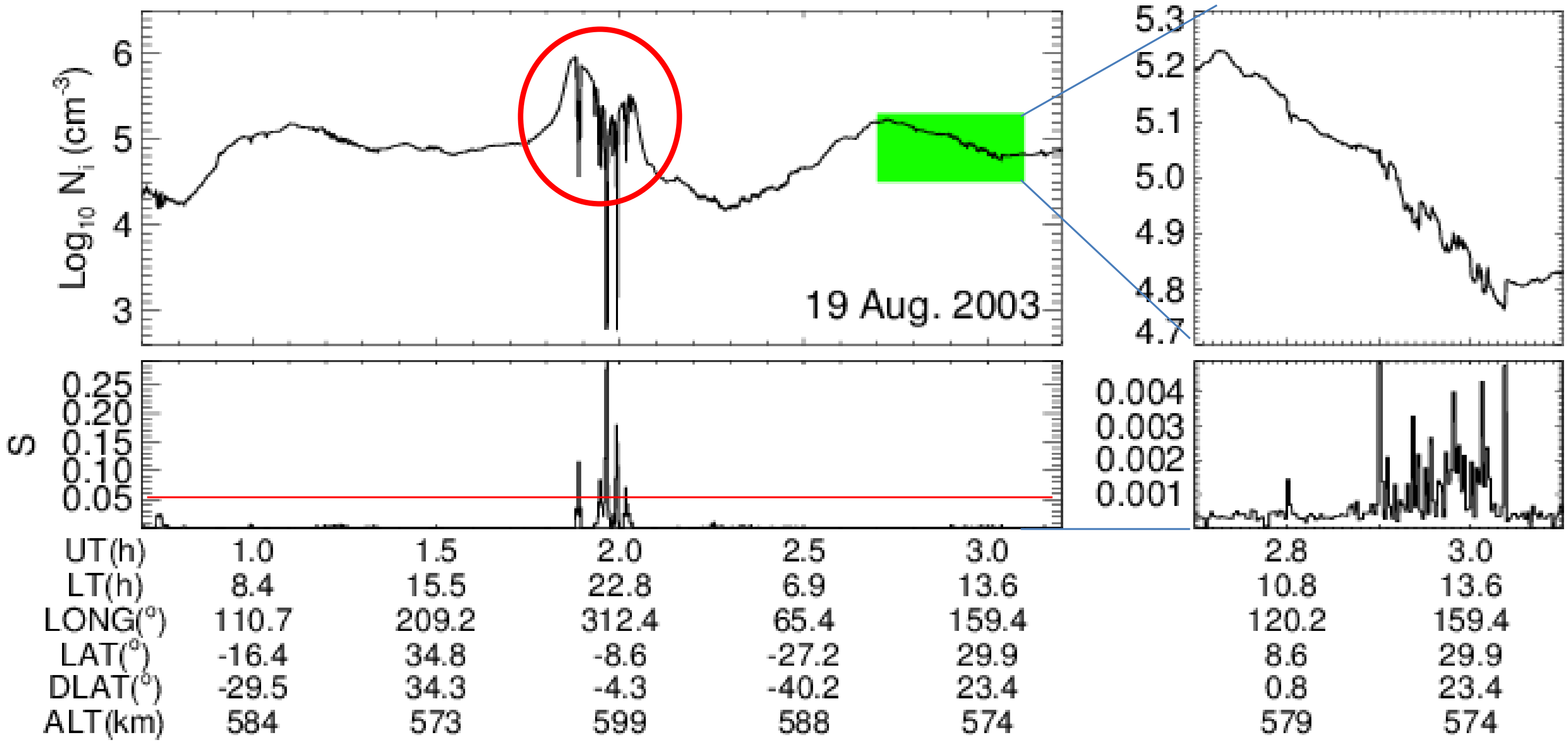
[Kil and Paxton, GRL, 2017]

MSTID (irregularity) distribution seen by Swarm



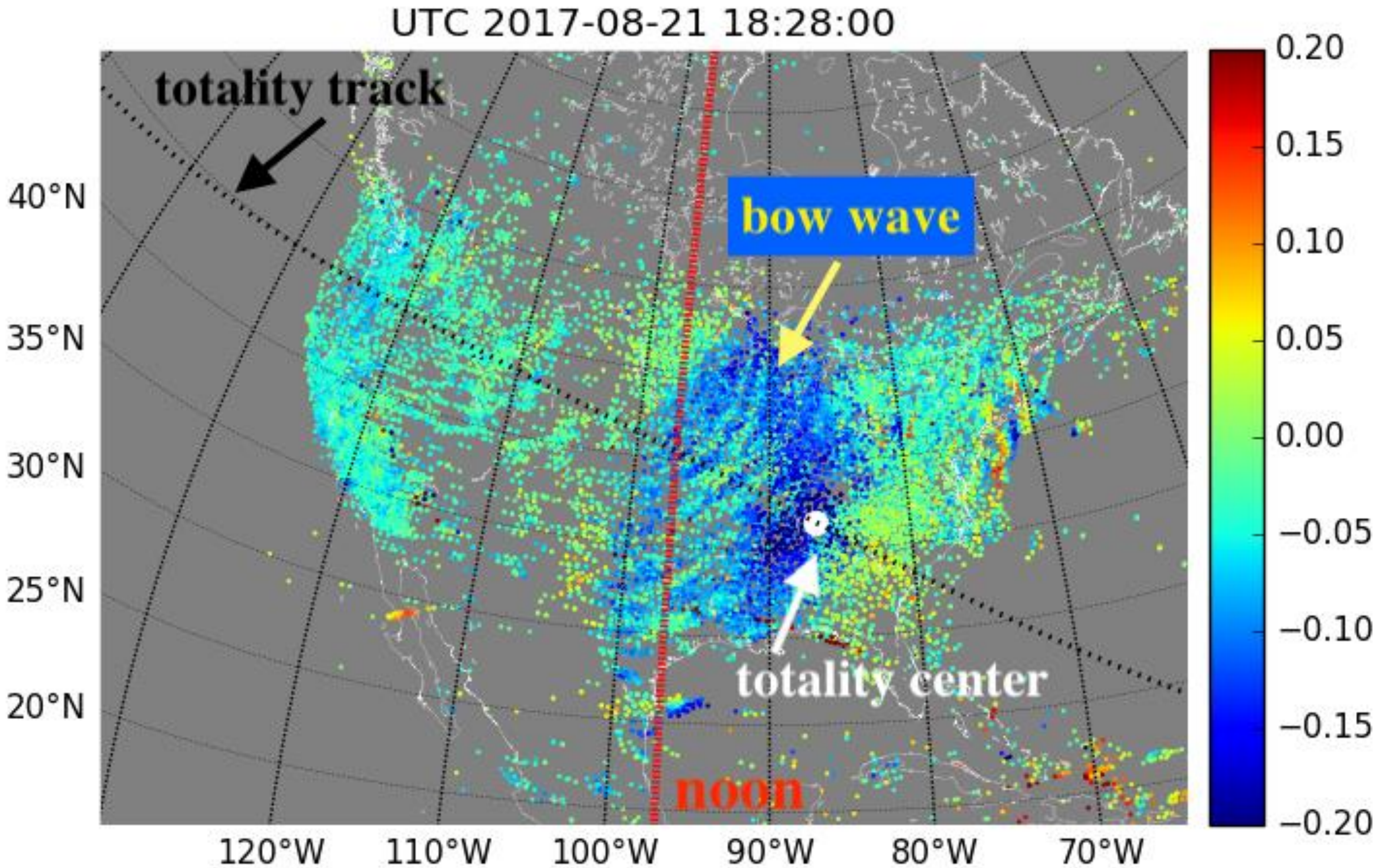
ROCSAT-1 satellite observations of dayside ionospheric irregularity

- So far, people have focused on the detection of the irregularities at night from satellite observations using large detection criteria.
- Daytime irregularities are not detected by this criterion.



$$S = 100 \times \left[\frac{1}{n-1}\sum_{i=0}^{n-1}(\log_{10} N_i - L_i)^2\right]^{1/2} \Big/ \left[\frac{1}{n}\sum_{i=0}^{n-1}\log_{10} N_i\right] \qquad n = 10$$

Ionospheric bow waves induced by the eclipse

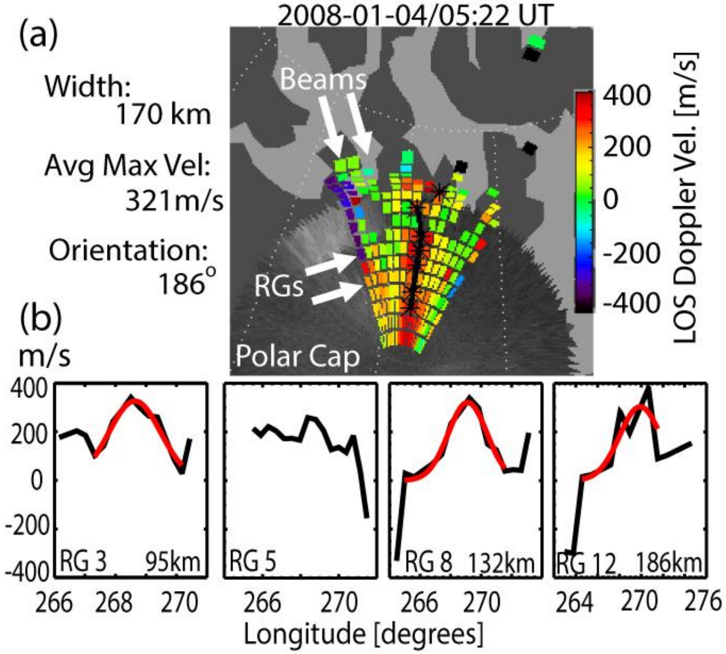


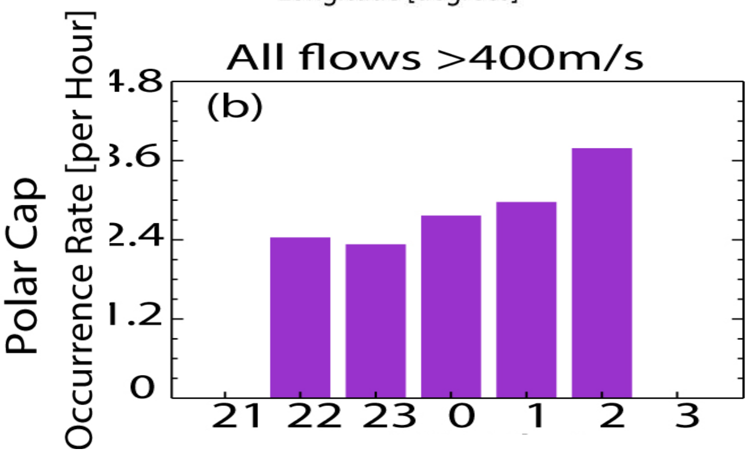
- **Traveling at typical GW speeds (~250 m/s)**
- **Trailing the eclipse totality**
- **V-shaped wave fronts, evolving in time & space**

Zhang et al. (2017), GRL featured

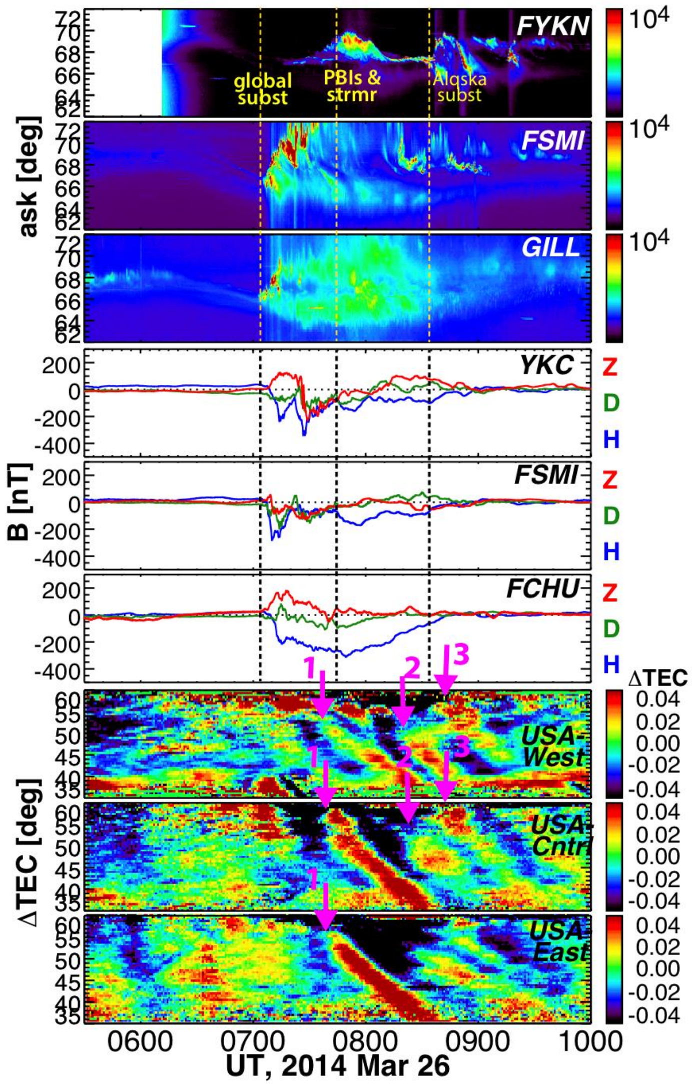
CEDAR Eclipse Session (Friday AM)

5.3. Meso-scale convection and influence on the I/T



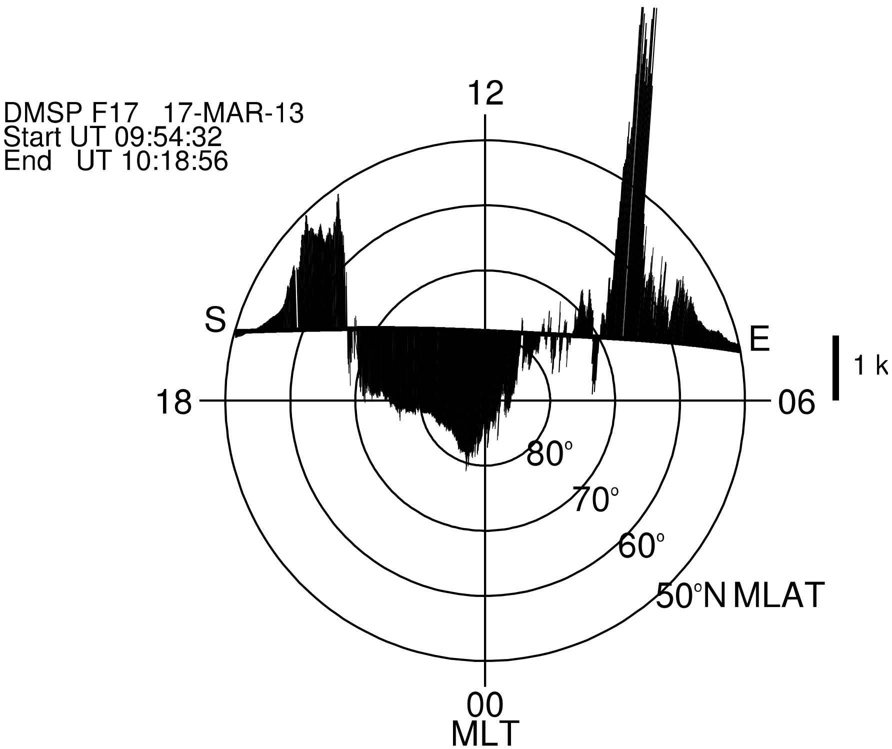


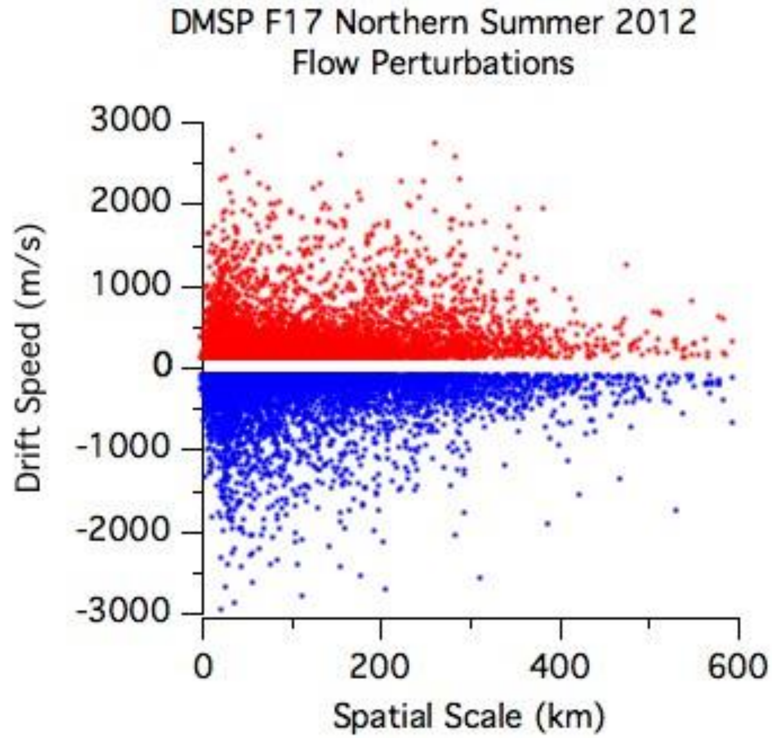
[Gabrielse, et al., 2018]

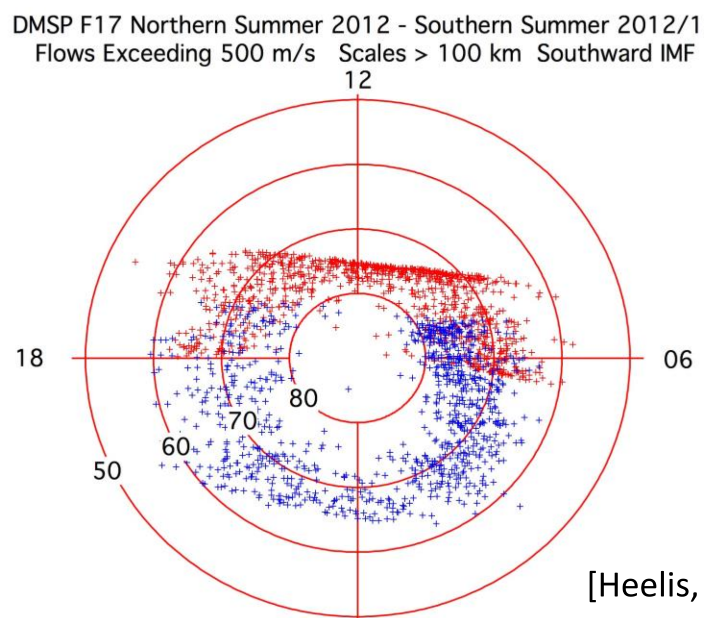


Polar cap flow structures – UCLA + MIT

(a) DMSP





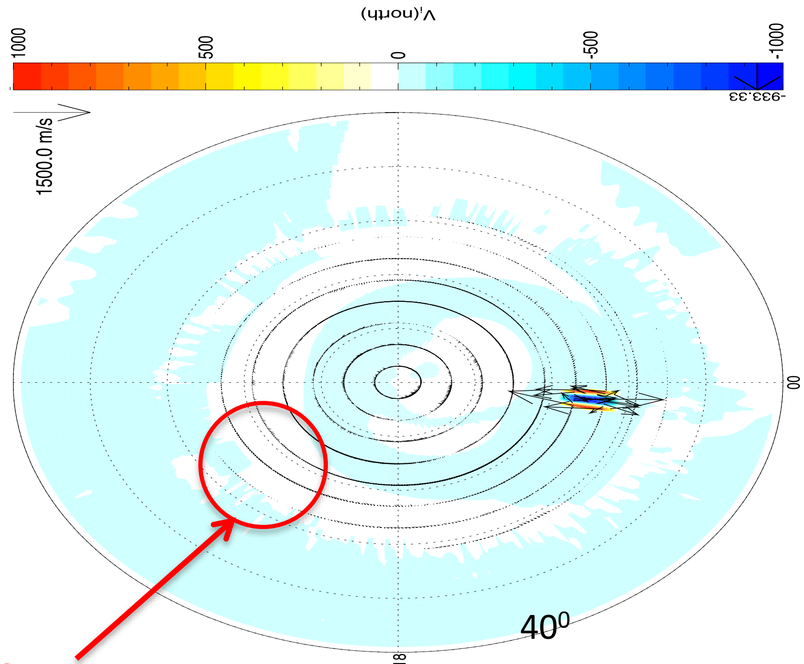


Sub-grid plasma flow – UTD

[Heelis, et al., 2018]

GITM simulation: Influence on I/T

Difference Vi @ 300km

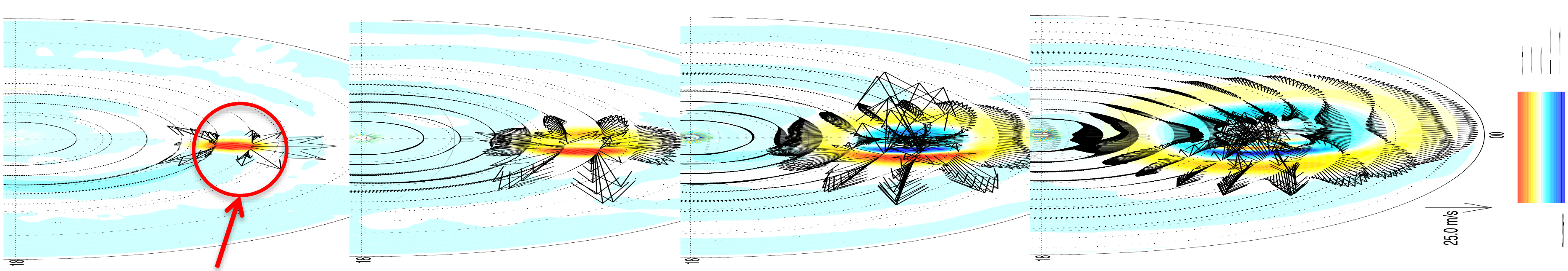


Fast flow

Rho (%) + Vn (horizon)@ 300km

[Deng, et al., 2018]

5 min 15 min 30 min 50 min

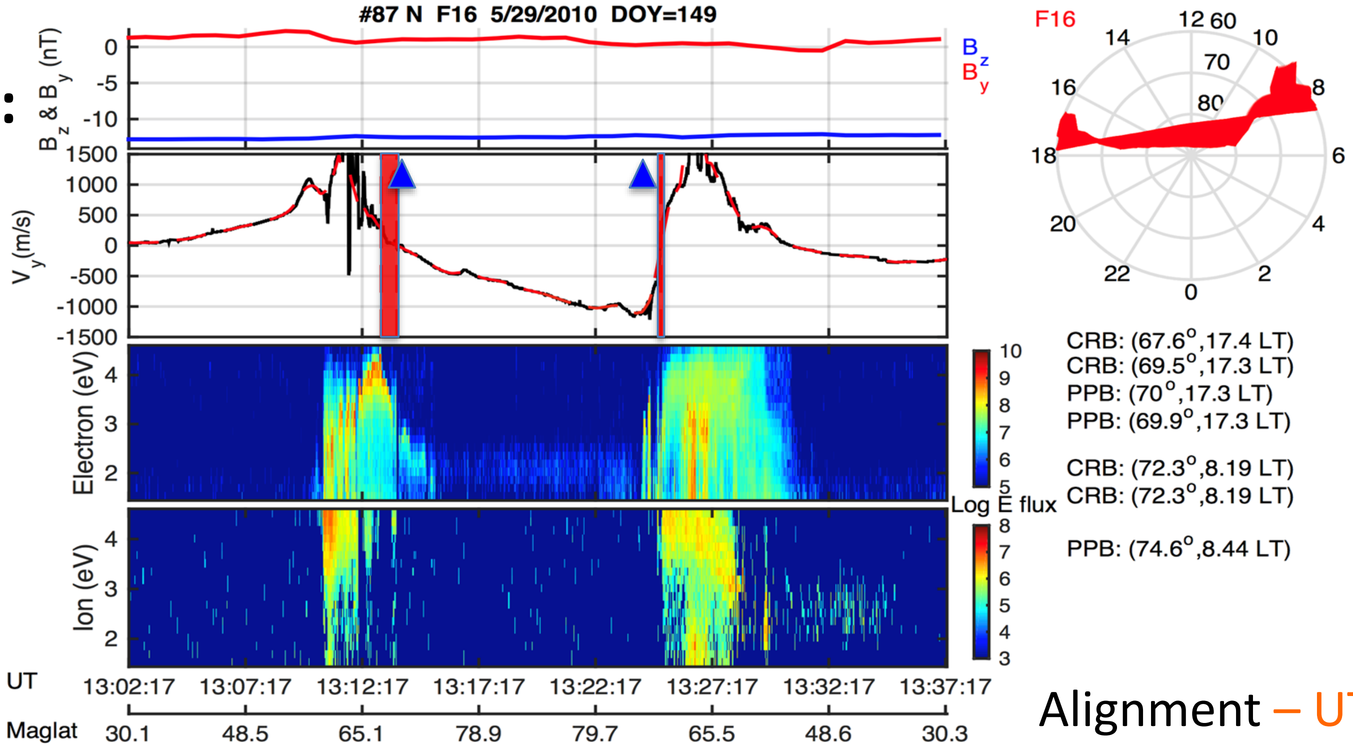


Rho @ 300km ↑ by 8%.

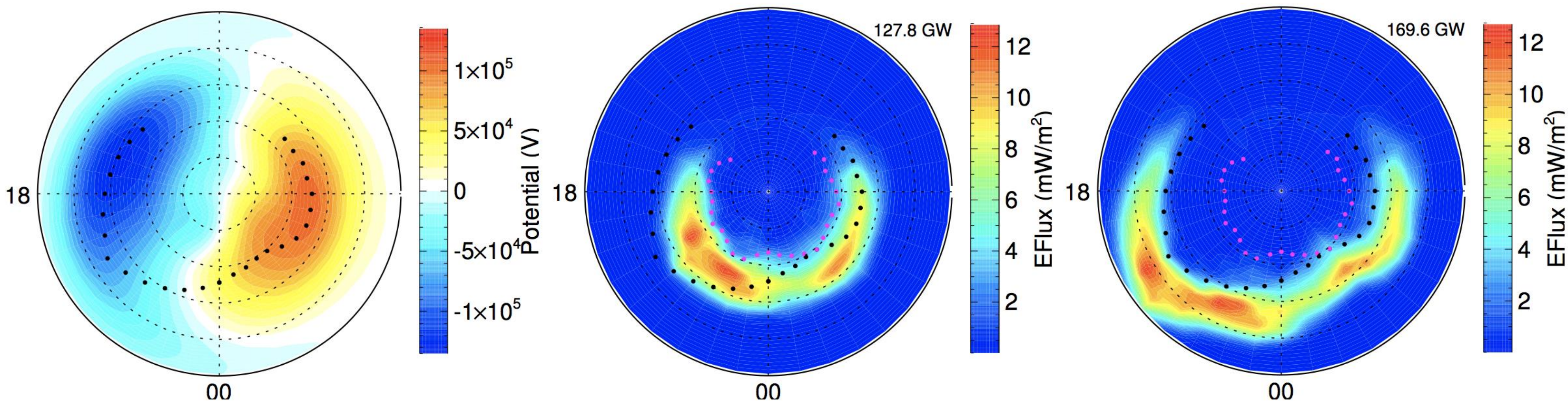
Influence on thermosphere – UTA

5.4 Correlation of ion convection and particle precipitation

Alignment:



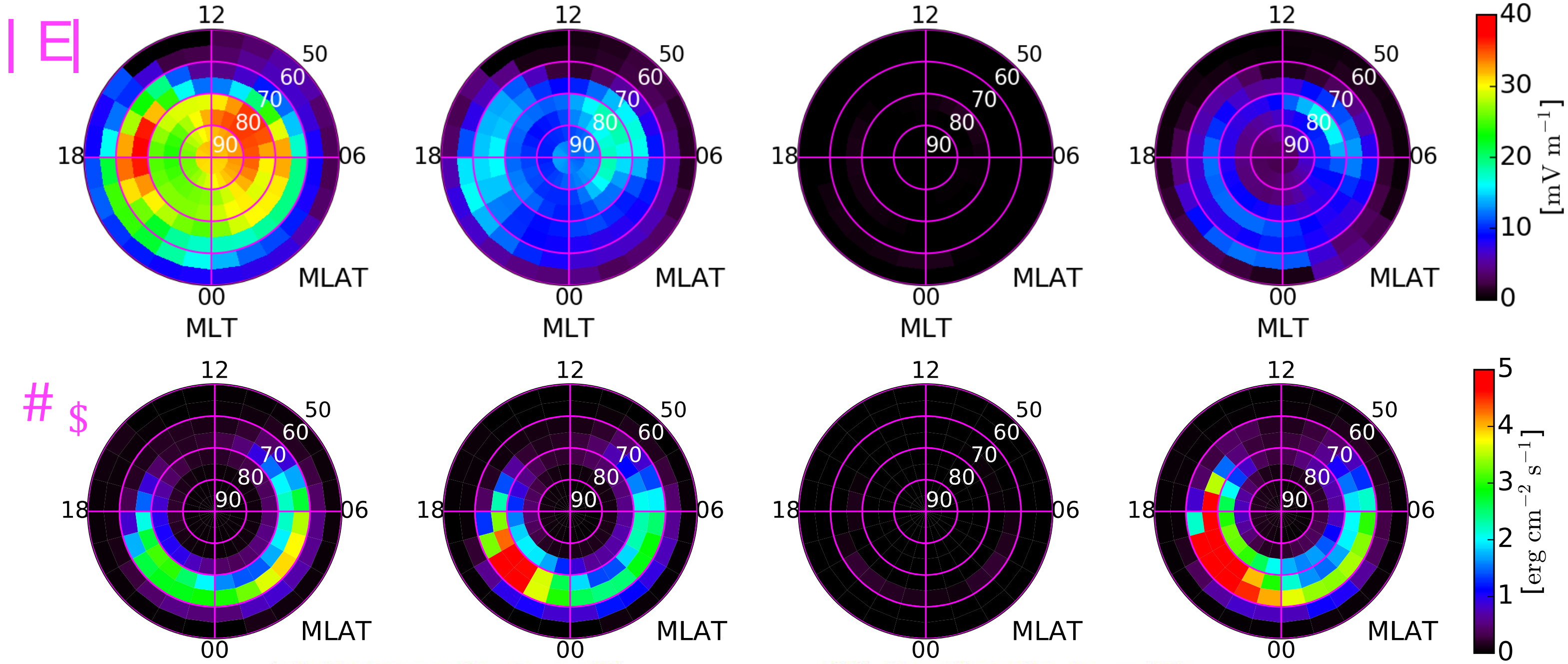
Alignment – UTD + UTA



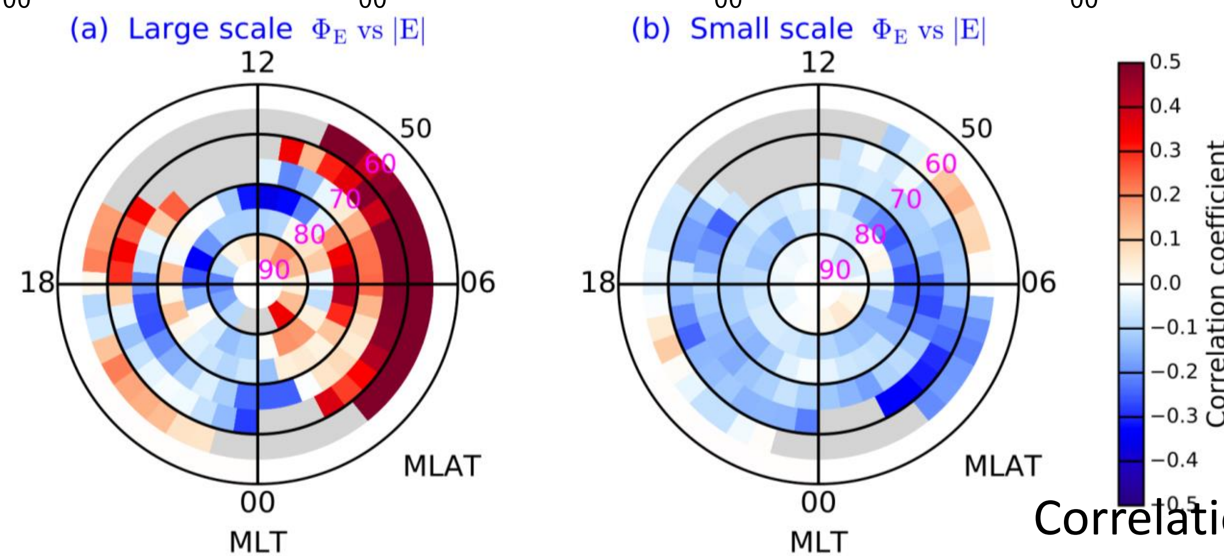
Binning (5° - , A. x 500 km - , . •

Large-scale | Small-scale

Mean | Std.)dev. | Mean | Std.)dev.



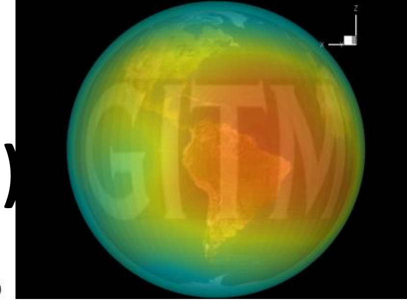
- I- F (E
- **Large·**
  - Ḟ) I
  - Φ''
- **Small**

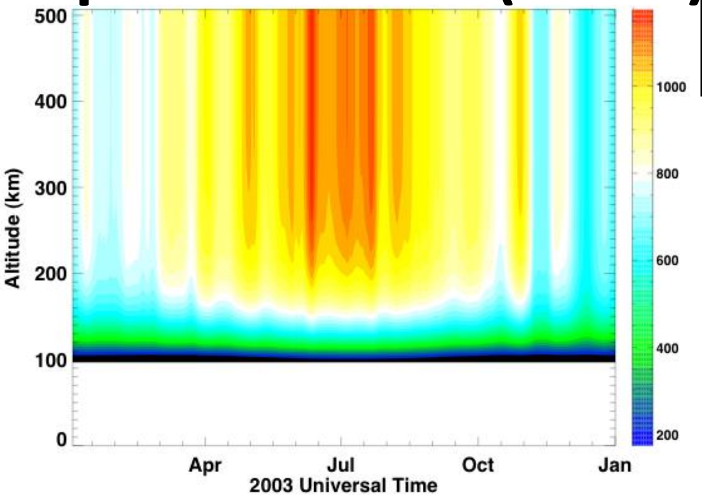


d; i5ht.

Correlation – UTA+HAO

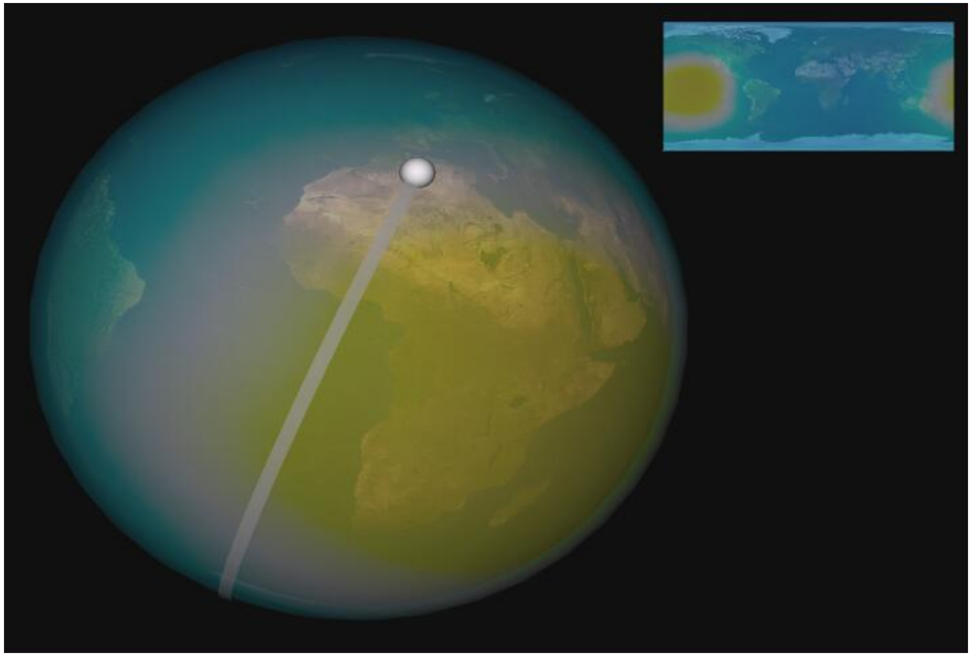
5.5 Physics-Based Model Simulation: Global Ionosphere-Thermosphere Model (GITM)





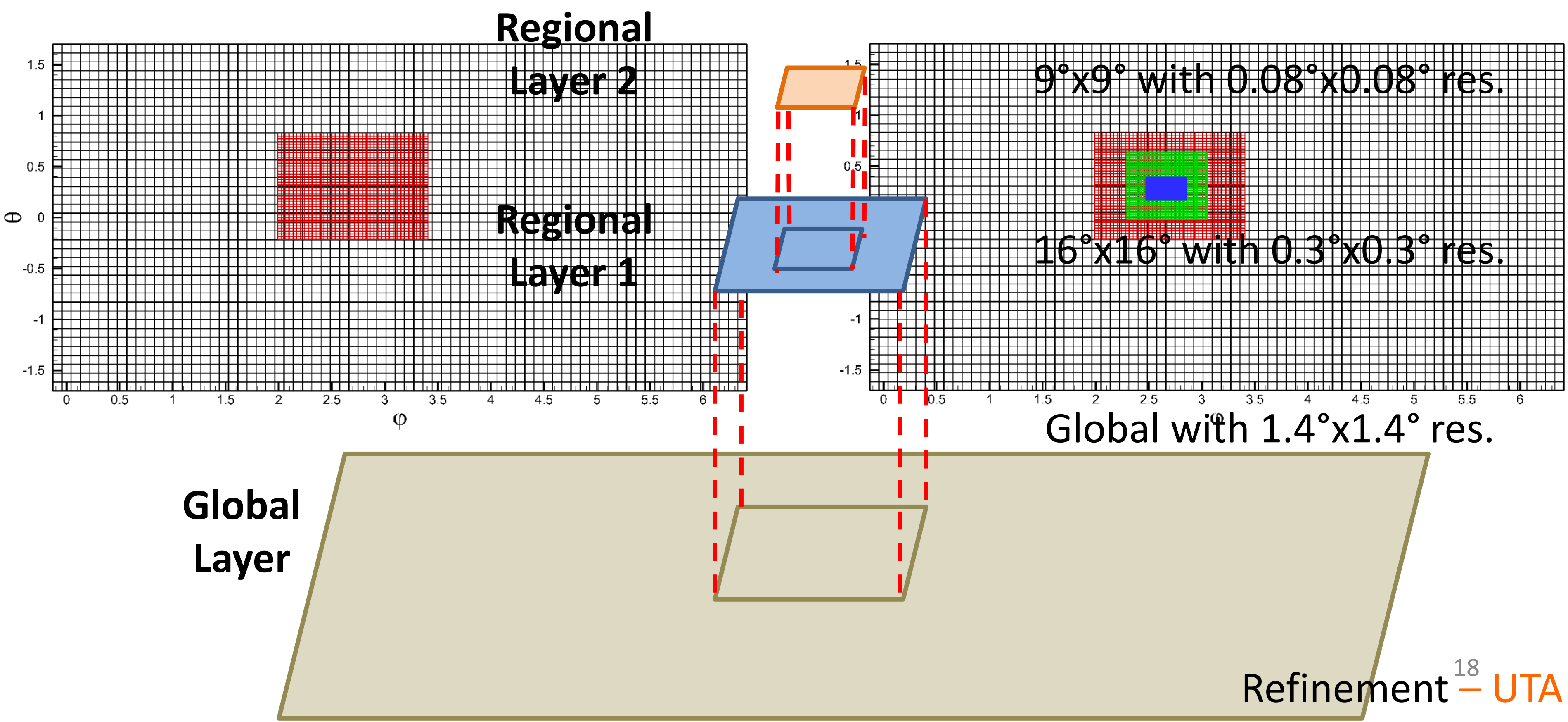
GITM Features:

- **Flexible grid resolution**
- **Can have non-hydrostatic solutions**
  - **Coriolis**
  - **Vertical Ion Drag**
  - **Non-constant Gravity**
  - **Massive heating in auroral zone**
- **Runs in 1D and 3D**
- **Solves in altitude coordinates**
- **Vertical winds for each major species with friction coefficients**
- **Non-steady state explicit chemistry**
- **Variety of high-latitude and Solar EUV drivers**
- **Fly satellites through model**
- **Time step: 2 seconds**



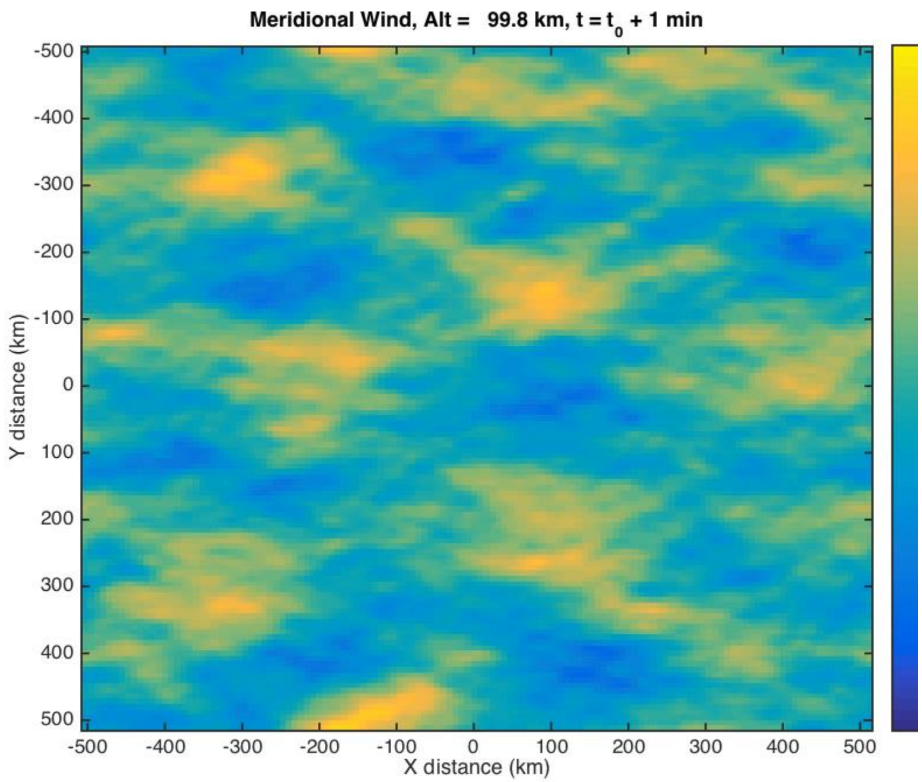
Local refinement

- Objective: Coarse-grid global layer provides more realistic boundary conditions to finer-grid regional layer(s).
- 3-layer set-up for a regional grid refined to 0.08°x 0.08°

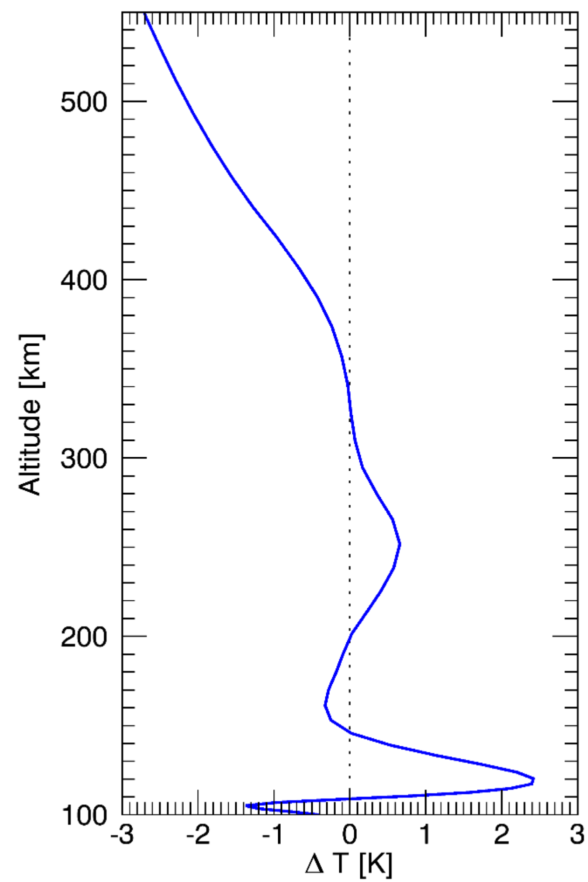


Stochastic Gravity Wavefields (SGWs)

- Gravity wave ray-tracing in the Fourier domain
- Frequency components: 5 evenly spaced values between $\widehat{\omega}_{min} = 2f$ (f = Coriolis frequency) and $\widehat{\omega}_{max} = N/\sqrt{5}$ (N = buoyancy frequency).
- Domain is about ~10°x10° in Utah (41°N, 247°E).
- Simulation local time is 1 pm and season is June 11th



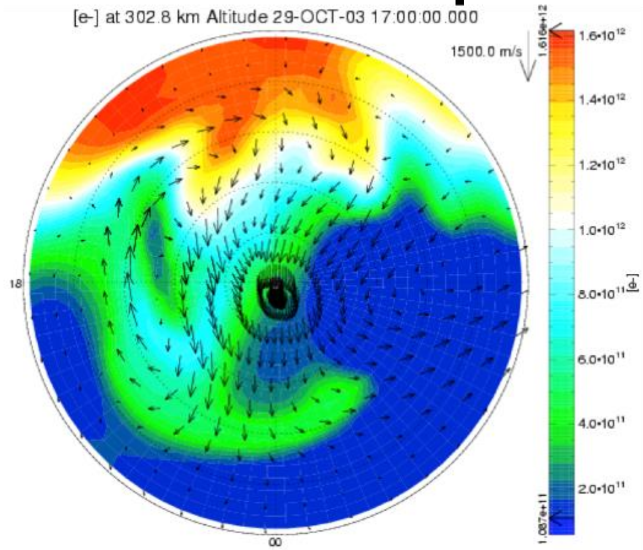
Change from 3x ➔ 6x $\Delta T_{forcing}$ (2x Increase)



Drob *et al*. [2013]

Couple GITM with NCAR 3D electrodynamics model

■ Global Ionosphere Thermosphere Model



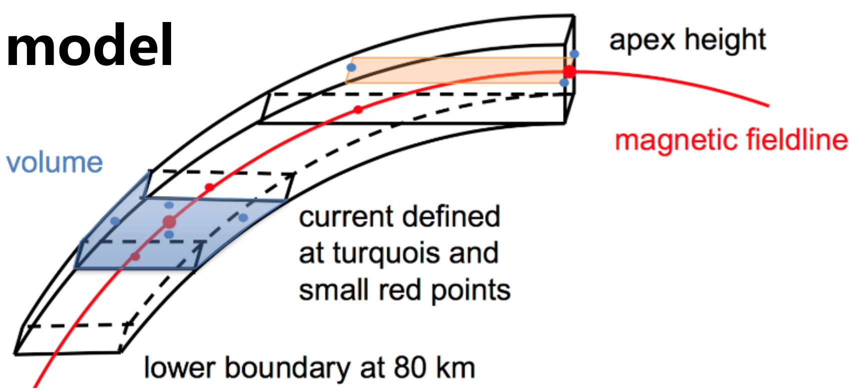
solves for:

- 6 Neutral & 5 Ion Species
- Ion and neutral density, velocity and temperature
- Flexible grid resolution
- Can have non-hydrostatic solutions

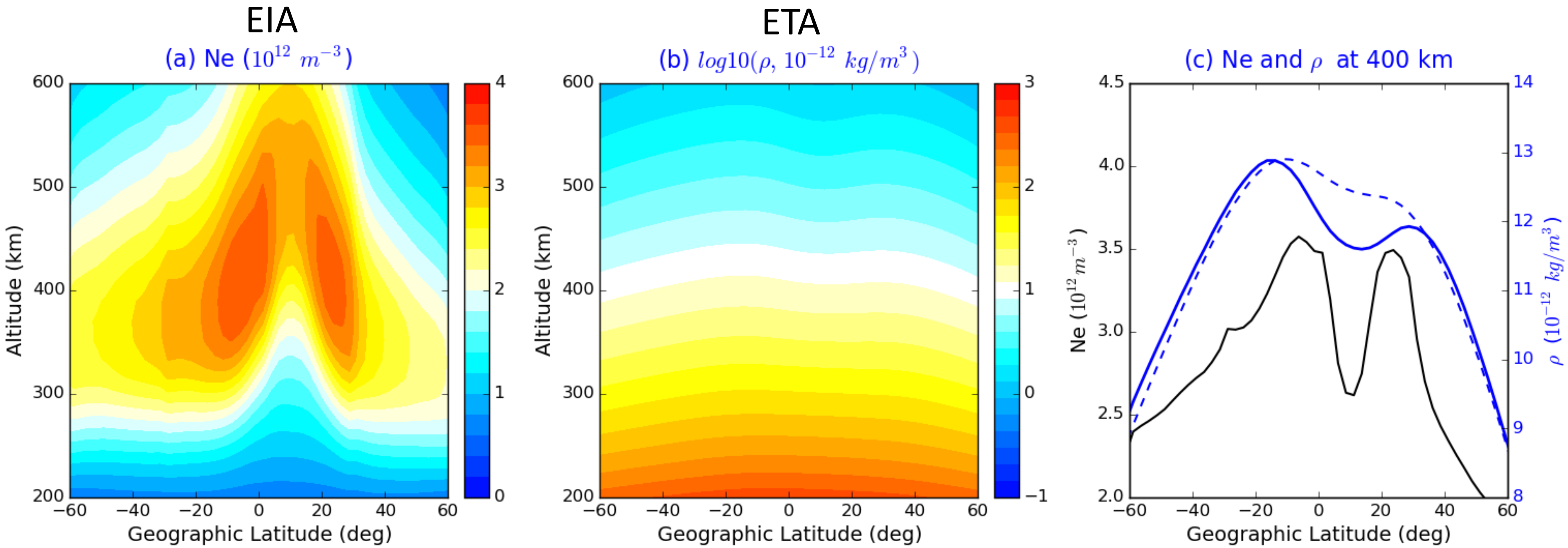
Ridley, A., **Deng, Y.,** and Toth, G. (2006), *J. Atmos. Solar-Terr. Phys.*, 68, 839-864.

■ NCAR 3D electrodynamics model

- Solves the neutral dynamo along the magnetic field lines
- Capable to solve the 3-D currents.

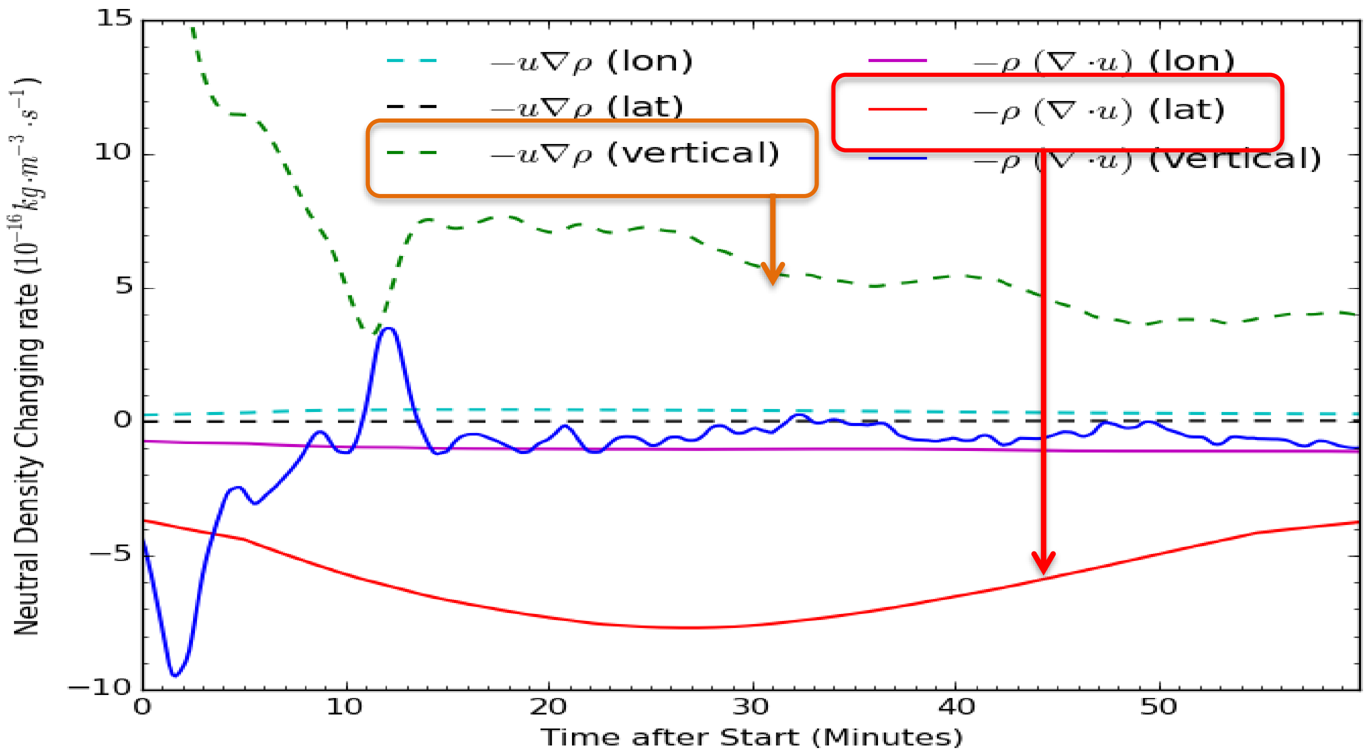


Maute and Richmond 2016, SSR



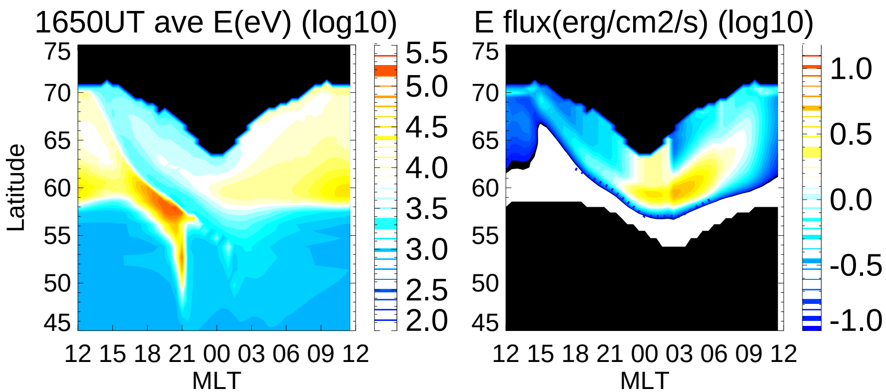
Continuity Equation:

$$\frac{\partial n}{\partial t} = -\boldsymbol{u} \cdot \nabla\rho - \rho\,(\nabla \cdot \boldsymbol{u})$$

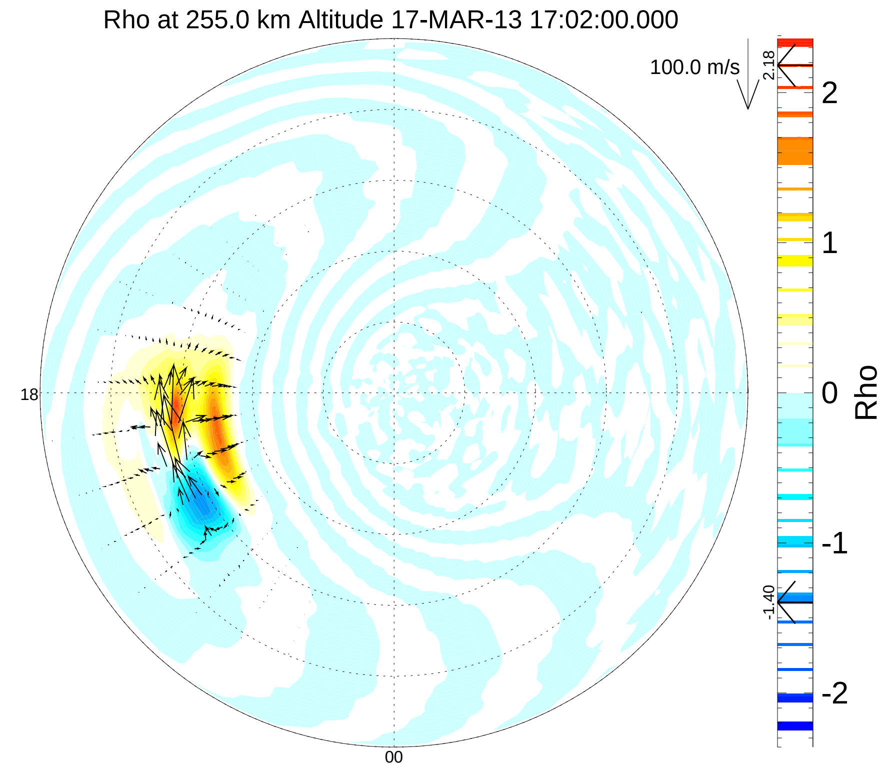


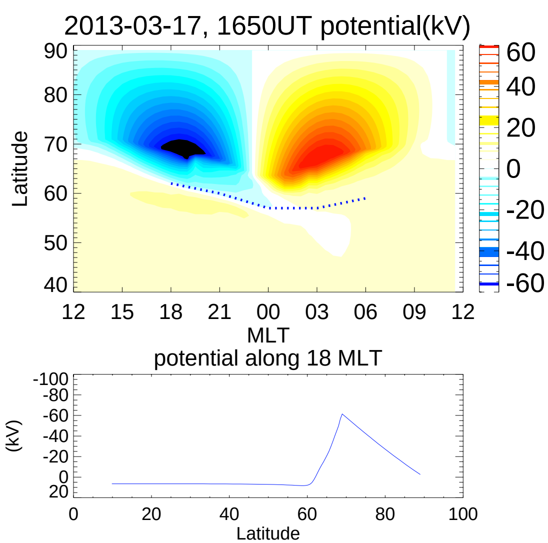
[Zhu et al., 2017]

GITM/UCLA-RCM coupling



➢This is the electron precipitation energy flux and average energy from RCM model. In the figure we label the aurora boundary by the blue dash line

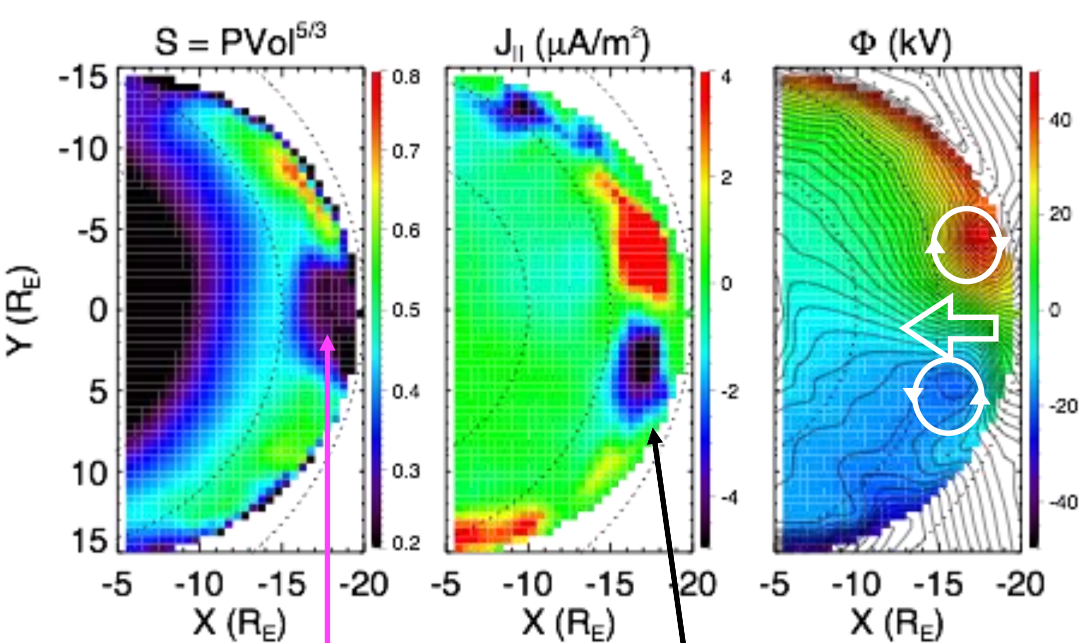




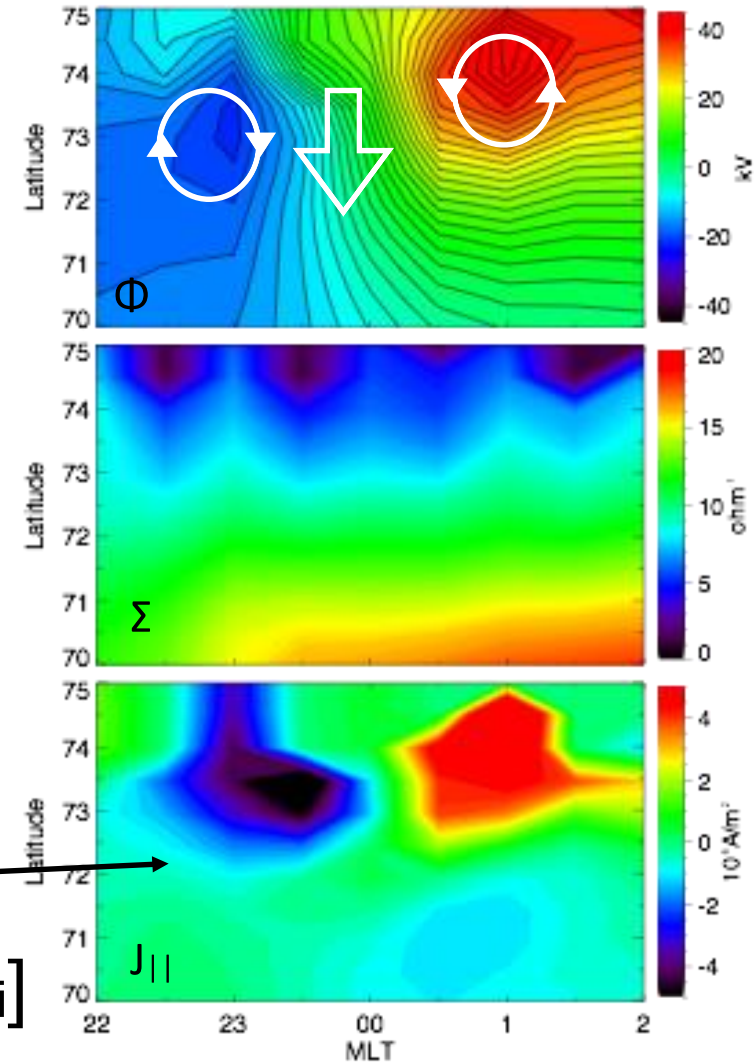
1. GITM/RCM two-way coupling;
2. Mechanism study
3. Event study

M-I coupling of bursty flow

magnetosphere



ionosphere



initiating a busty flow by
a local (~1 MLT wide) decrease of
S (density up temperature down) for 10 min

$$(\nabla Vol \times \nabla S)\cdot \mathbf{b}/Vol^{5/3} = J_{||}$$

$$J_{||} \cdot (B_i/B_{eq})\cdot sin(I) = -\nabla_i\cdot[\Sigma\cdot\nabla_i\Phi_i]$$

current continuity

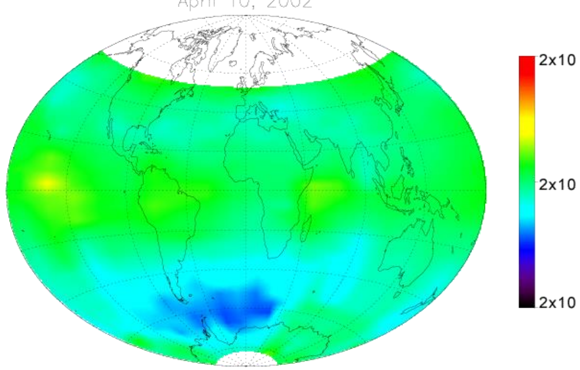
5.6 Nitric Oxide

Nitric Oxide is the most important storm time cooling mechanism in the lower thermosphere:

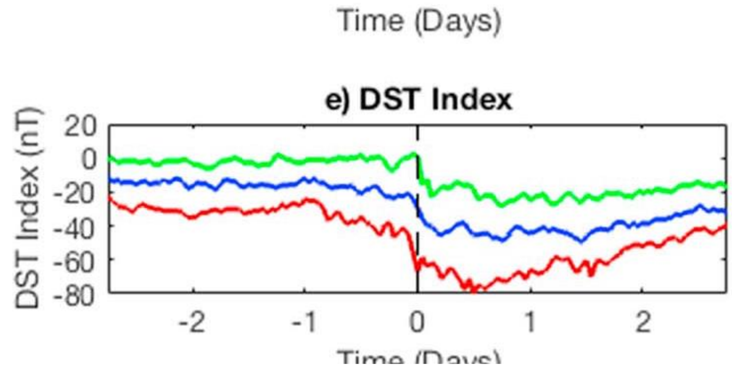
— Infrared cooling in the 5.33 μm band—thermostat effect

— Controls temperature in the critical 120 km region

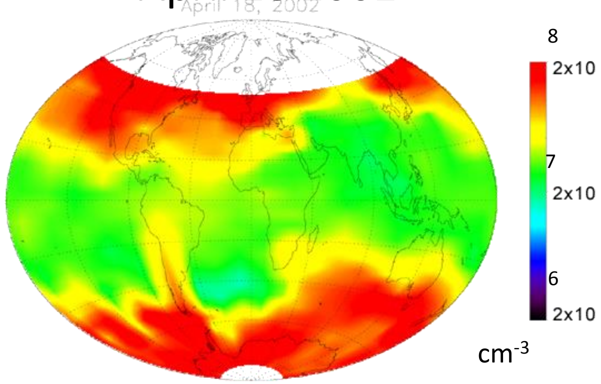
April 10 2002

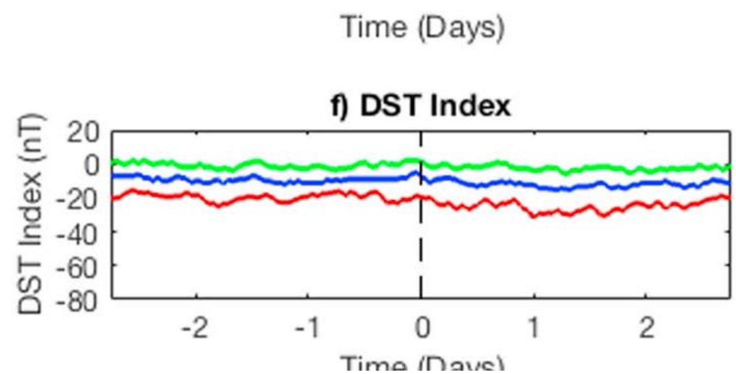


[Knipp et al., 2017]



April 18 2002

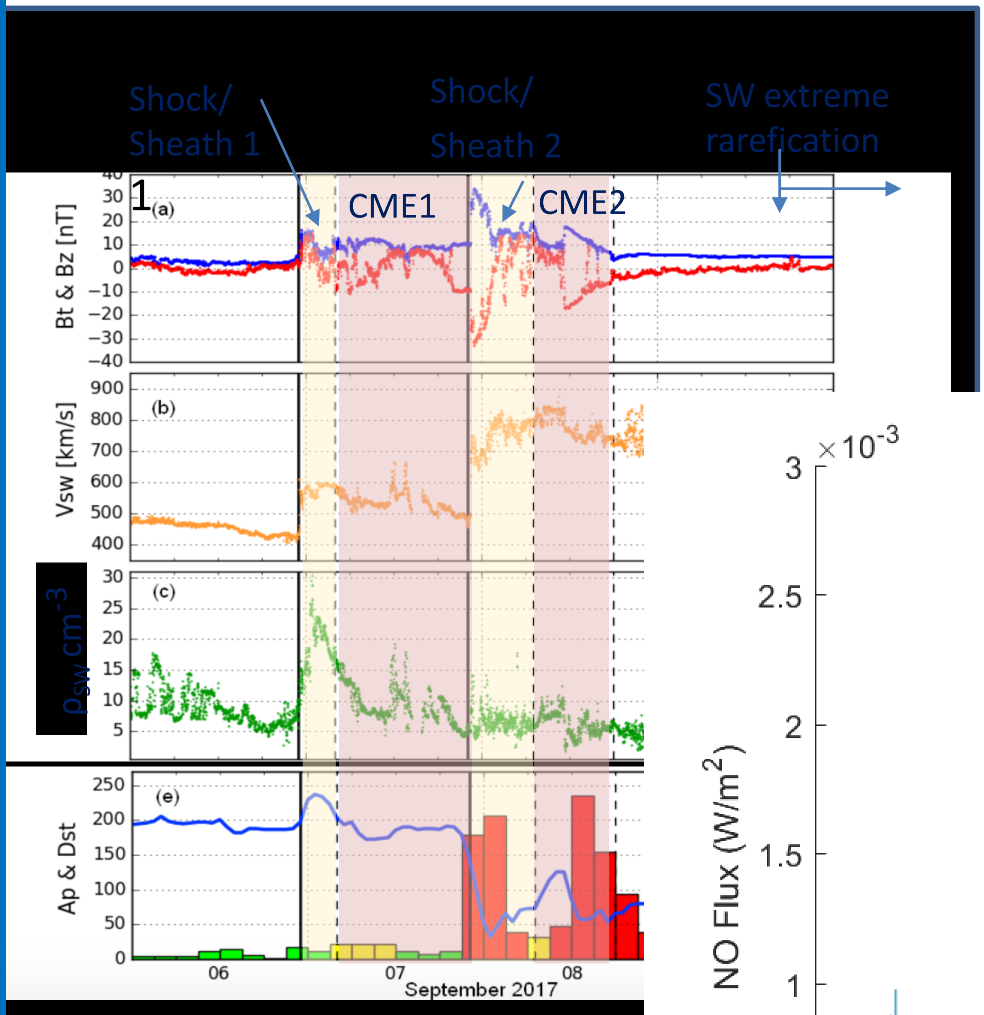


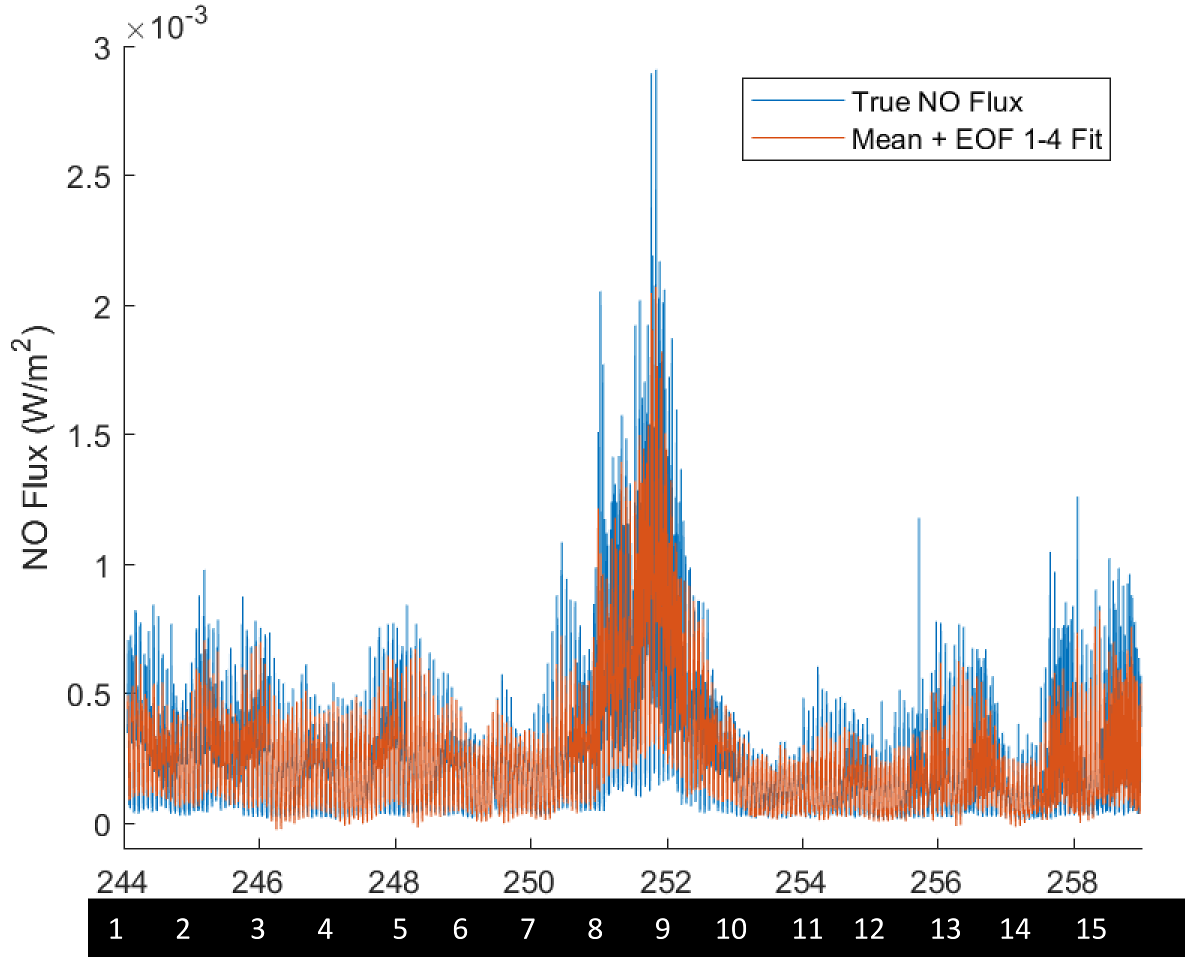


Courtesy of Scott Bailey Virginia Tech

NO cooling – CU+UTA

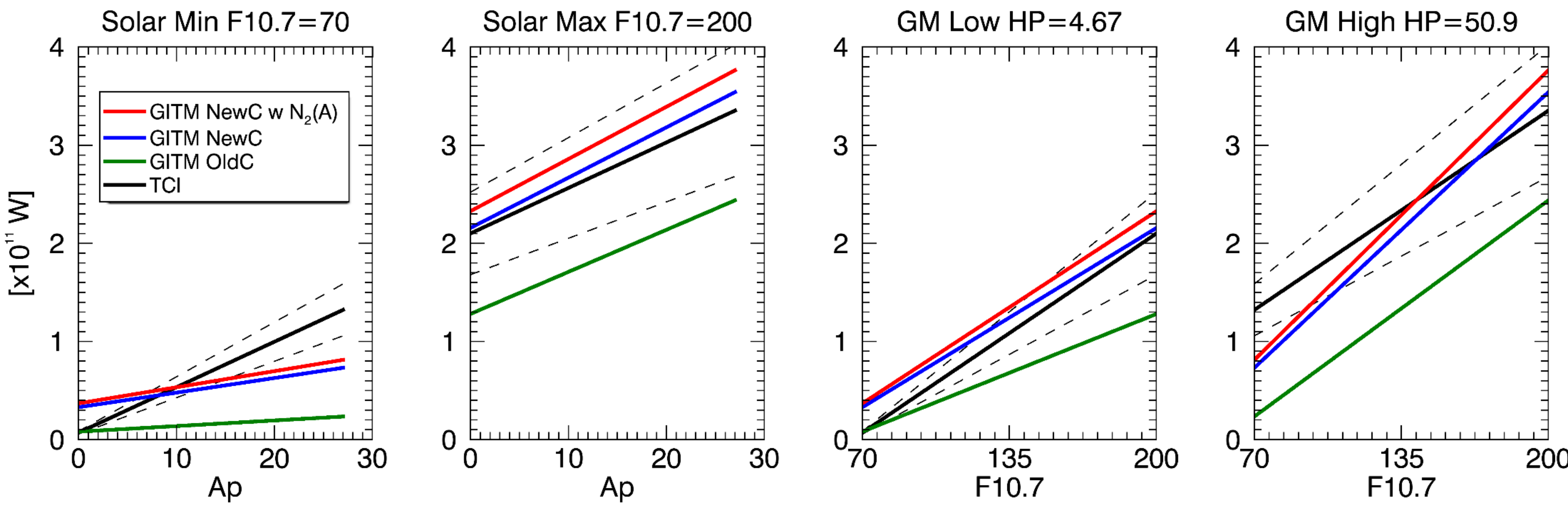
September 2017 Storm NO Flux reconstruction



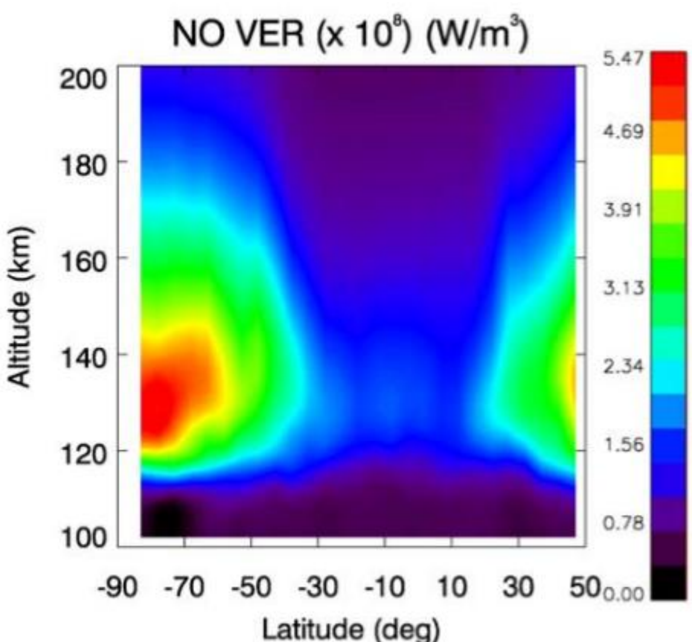


NO Emission: Multiple linear regression of14-year SABER measurements [Mlynczak et al., 2016]

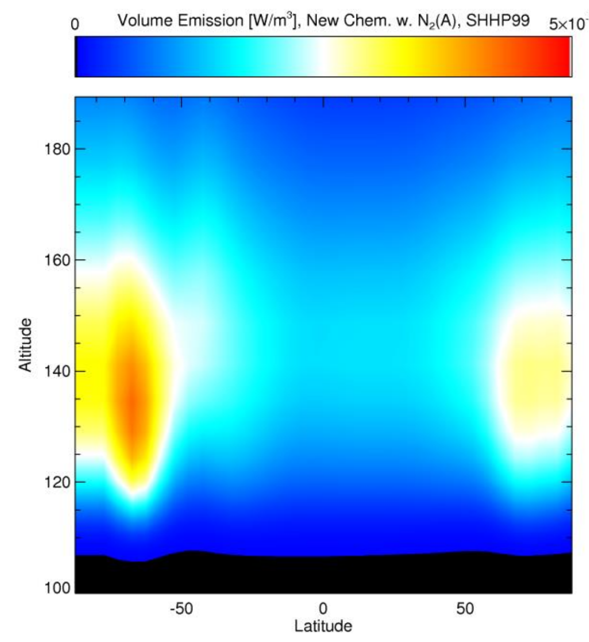
$$NO = -1.024 + 1.562 \times 10^{-2} \times F_{10.7} + 4.637 \times 10^{-2} \times Ap - 4.013 \times 10^{-3} \times Dst$$



SABER:

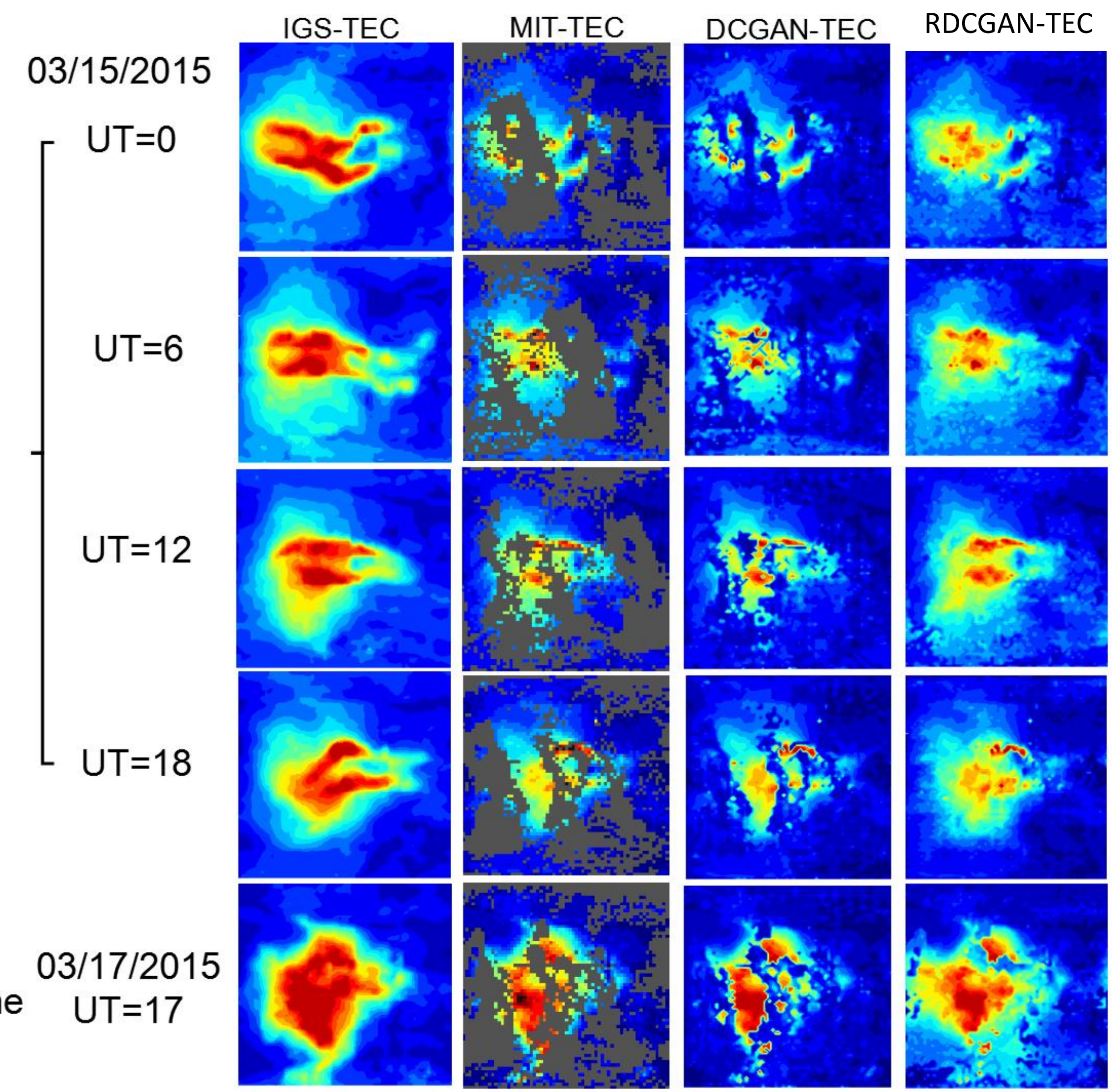


GITM:



[Lin et al., 2018]

6. Deep learning for TEC maps: data completion



- Traditional DCGAN can not work for TEC map completion
- The result generated by RDCGAN can shows satisfactory ionospheric peak structures at different times and geomagnetic conditions.

5. Summary:

- MURI is a team project including effort in data analysis, data assimilation, empirical model and theoretical model.
- The progresses we have made include:
  - Ionospheric and atmospheric disturbances;
  - Meso-scale convection and influence on the I/T;
  - Electrodynamics;
  - Improvement of physics-based model;
  - No chemistry;
  - Deep learning;