Storm-Time Neutral Density Perturbation at Multiple Temporal- and Spatial-Scale During the 2015 St. Patrick Day's Storm: Data-Model Comparisons

ITIT-14

Yu Hong[1], Yue Deng[1], Lei Cai[2], Gang Lu[3], Aaron Ridley[4], Astrid Maute[5], Colin Waters[6], Cheng Sheng[1]

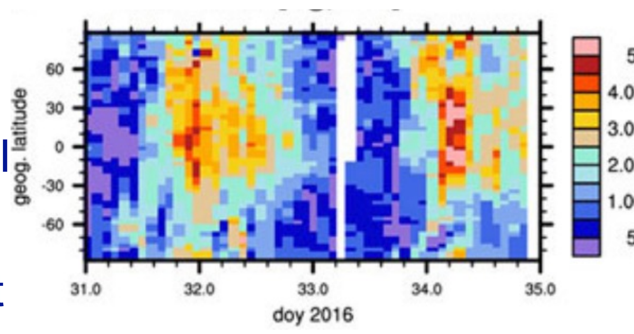
[1]UT Arlington, [2]Univ. Of Oulu, [3]NCAR/HAO, [4]Univ. of Michigan, [5]CIRES, CU Boulder [6]Univ. of Newcastle

Email: yu.hong@mavs.uta.edu

Abstract The characteristics of the density perturbations on different spatial and temporal scales have not been investigated thoroughly so far. In this study, we present a detailed model-data comparative study of the storm-time density perturbations at different scales based on GRACE-A and -B and numerical simulations from GITM. The GITM simulations are driven by the time-dependent AMPERE FACs along with the AMIE auroral electron precipitation patterns. The GRACE observations show that the neutral density perturbations at specific spatial (~250 km) and temporal (34 s) scales depend on latitude and the storm phases. In general, the GITM simulations reproduce the most salient spatial and temporal perturbations well, but the mesoscale structures are underrepresented. Moreover, to extract multi-scale from multiple spacecraft observations, we fly six virtual satellites with different temporal and spatial separations in our simulations.

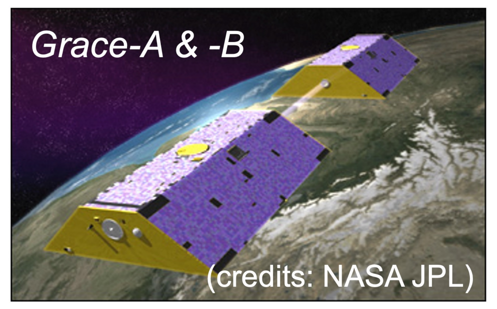
Introduction & Motivations

- **Introduction**
  - The variation & distribution of mesoscale neutral density perturbation are not known well
  - Knowledge of the dominant temporal & spatial scales of mesoscale perturbation is insufficient



[Maute et al., 2022]

- **Motivations**
  - Single satellite suffers from temporal & spatial ambiguity
  - GRACE-A & -B make it possible to separate
  - Specific separation (~30s / 250km) of GRACE-A & -B can't study other scales
  - Fly 6 virtual satellites with 'logarithmic string-of-pearl' separations in GITM simulation



Methodology: Data and Model

- ***Data***

DMSP F16 - F18	GRACE-A & -B Satellites	AMPERE FAC
○ Alt: 850 km, Dawn-Dusk	○ Alt: 370-410 km, Dawn-Dusk	○ Alt: 780km, six planes
○ Cross-track ion drift: Vy	○ Neutral density ρ	○ High-latitude FACs

- ***Model***

GITM
- ○ 6 Neutral & 5 Ion Species
- ○ Ion and neutral density, velocity and temperature
- ○ Flexible grid, can have non-hydrostatic solutions

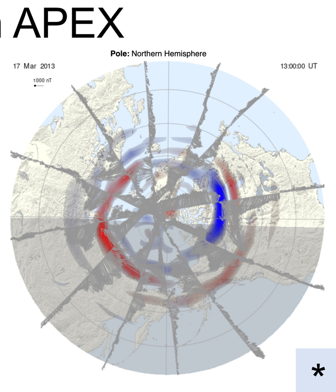
NCAR-3Dynamo (global driver)
- ○ Solves for global ionospheric j, E-field and magnetic perturbations in APEX

AMIE (high-latitude driver)
- ○ Auroral electron precipitation

$$\nabla\cdot(\Sigma\cdot(\mathbf{E}+\mathbf{U}\times\mathbf{B})) = -\mathbf{J}_\parallel$$

Conductance — Neutral wind — FAC pattern

Eq 1. FAC-driven procedure



[JHU/APL]

- ***Logarithmic string-of-pearl***

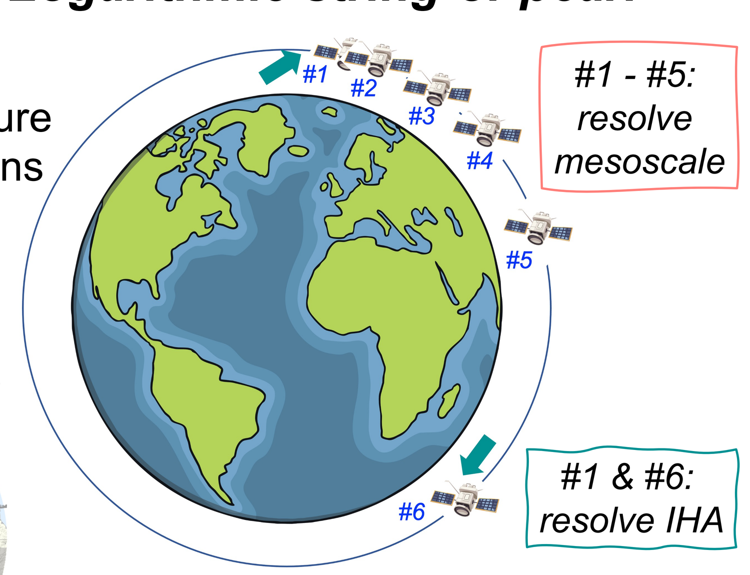


Fig 1. Illustration of satellite orbit

* *Temporal*: $\rho_i(t)$ - $\rho_j(t+\Delta t)$ fixed location
* *Spatial*: $\rho_i(t)$ - $\rho_j(t)$ at the same time

- GITM simulation validation

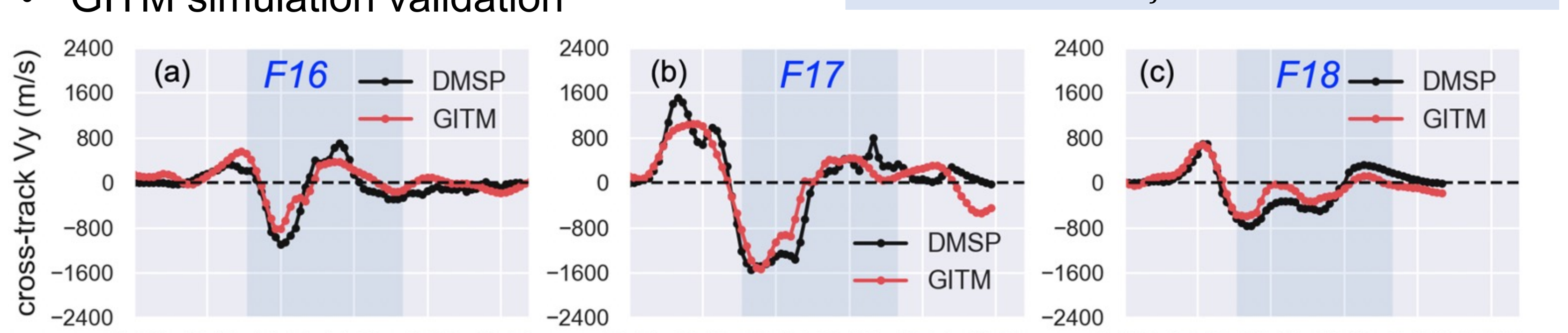
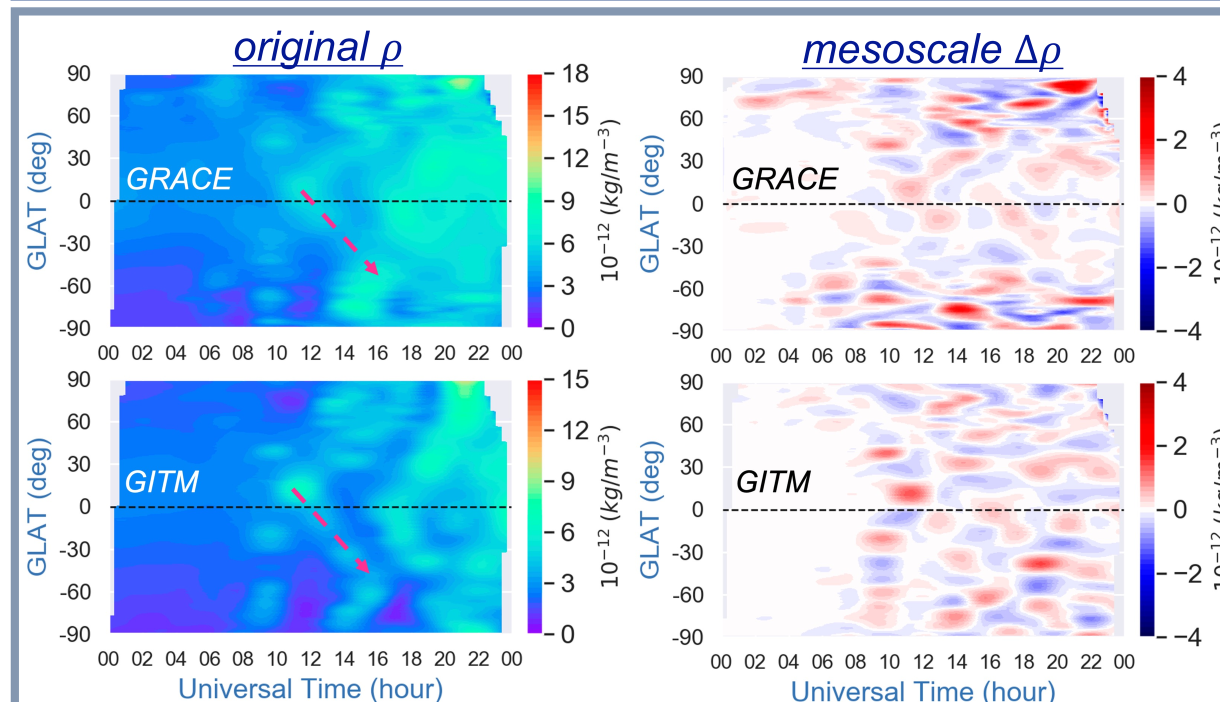


Fig 2. Comparisons of cross-track ion drift Vy between DMSP F16-18 and GITM simulations

Result-1: Data-Model Comparisons

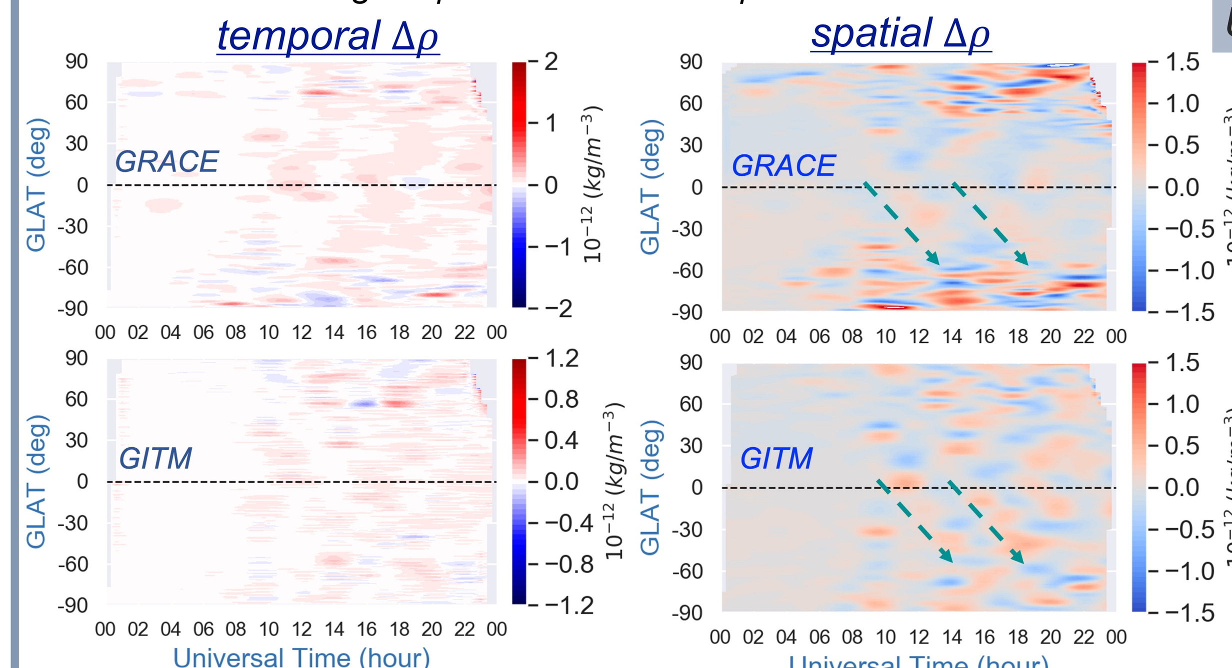


Along GRACE-A track

In general, GITM simulations reproduce the most salient temporal and spatial perturbations

Remove ~30 degree latitudinal ρ structure

Fig 3. Comparison between GRACE and GITM simulation extracted along GRACE orbit for original ρ and mesoscale $\Delta\rho$



Using GRACE-A & -B

Temporal: ~ 30s

Mesoscale neutral density perturbation can distribute in all the latitudes, and has finer structures in polar regions

Spatial: ~ 250km

Fig 4. Similar to Fig.3 but for temporal and spatial variation of mesoscale $\Delta\rho$

Result-2: Temporal variation of virtual satellites

- *#1 - #5 virtual satellites fly-over the same location at different times: $\Delta\rho$*

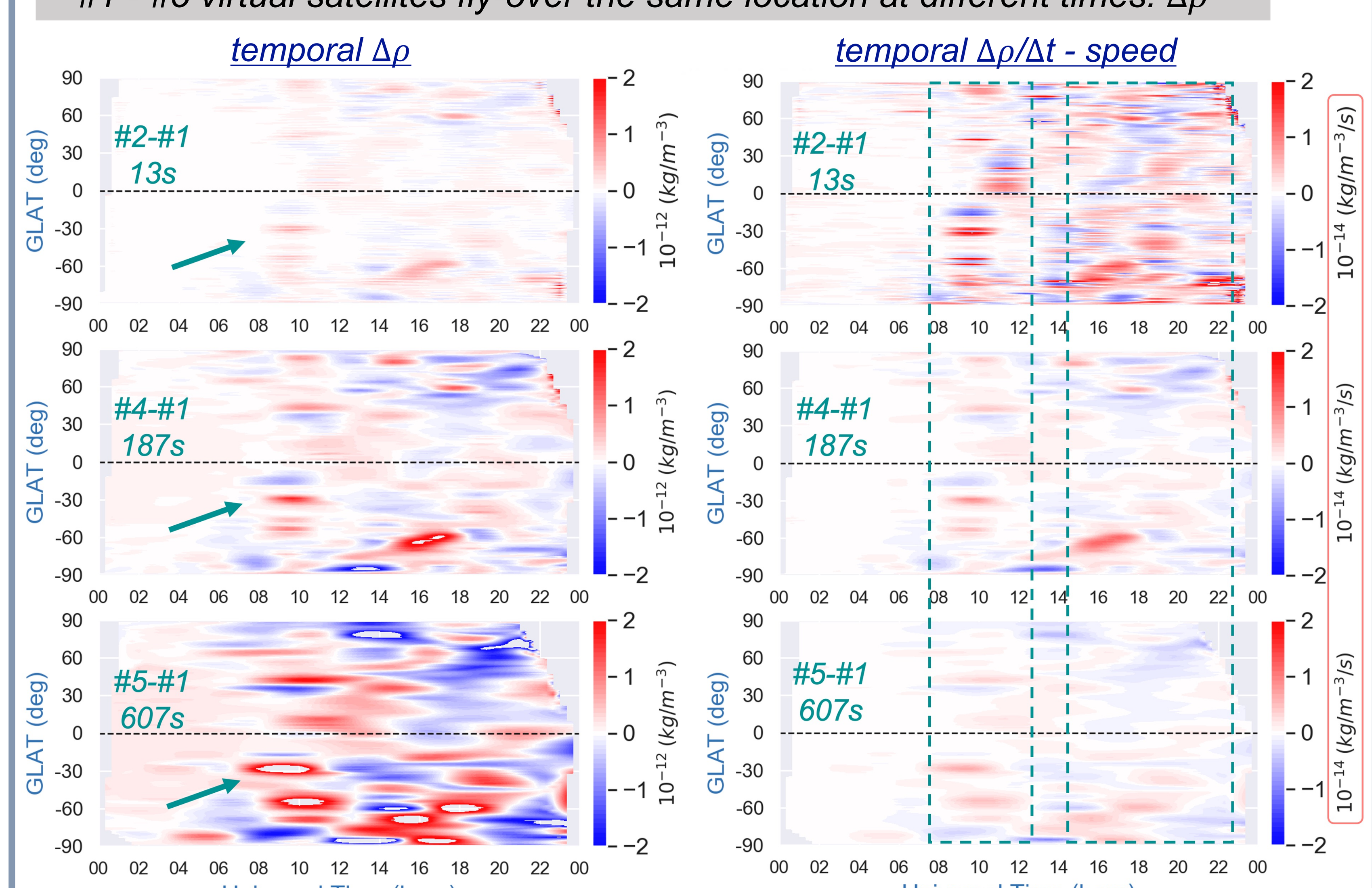


Fig 5. Temporal variations of simulated mesoscale perturbation $\Delta\rho$ derived from #1 - #5 satellites

- ○ *The magnitude and size of perturbations $\Delta\rho$ increase over times, from 13s to 607s*
- ○ *$\Delta\rho/\Delta t$ mainly due to advection, also has storm response (two periods)*
- ○ *Smallest time (13s) has the biggest value, implying transient dynamics are important*

Acknowledgements: NSF, AFOSR MURI and NASA GDC Mission

Result-3: Spatial variation of virtual satellites

- *#1 - #4 virtual satellites derived different spatial scales at given time: $\Delta\rho$*

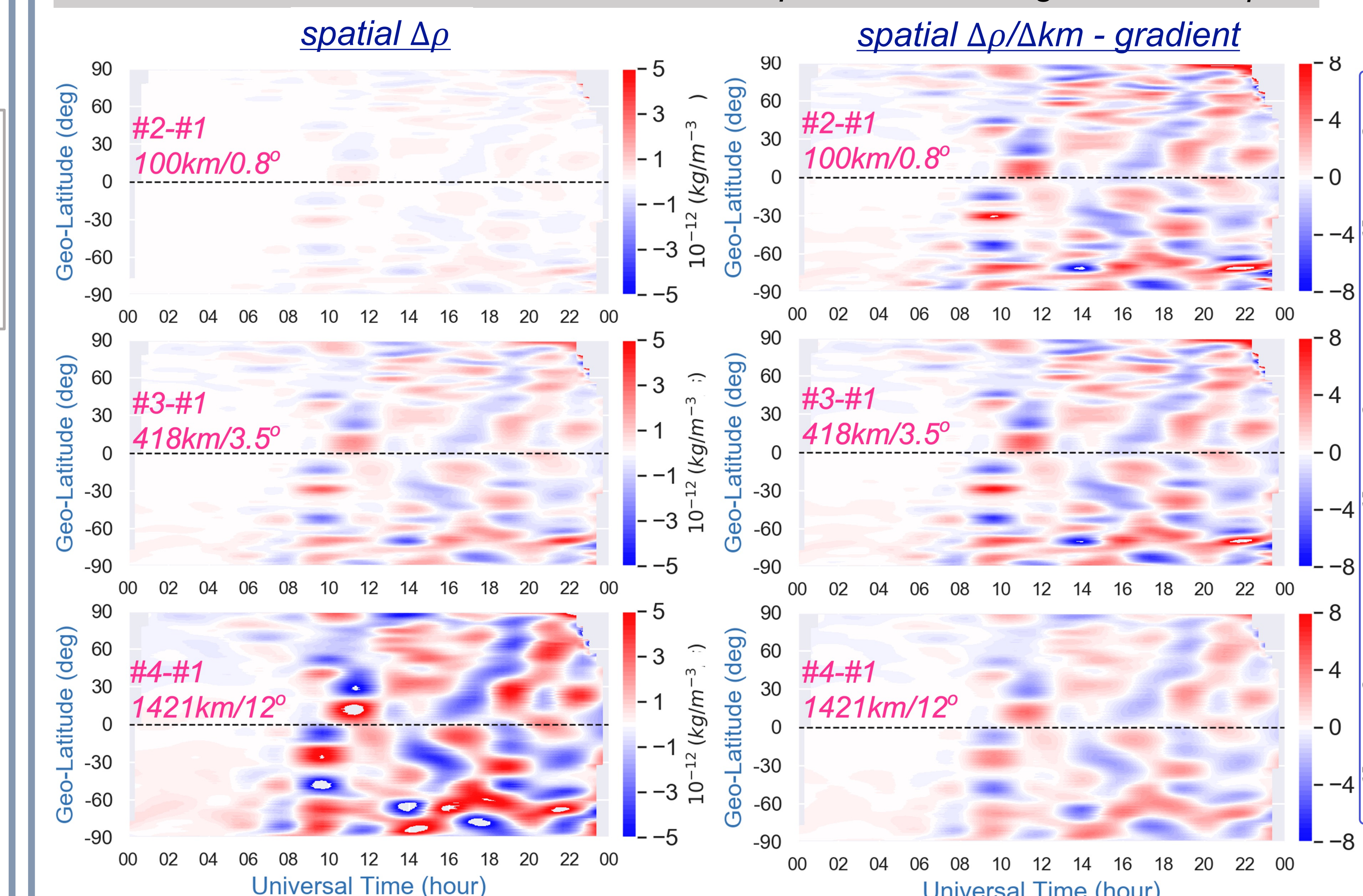


Fig 6. Spatial variations of simulated mesoscale perturbation $\Delta\rho$ derived from #1 - #4 satellites

- ○ *$\Delta\rho$ increases with distance; $\Delta\rho/\Delta km$ decreases with distance*
- ○ *Spatial variation (~12deg) is more static than temporal variation (~187s)*

GDC mission: Multi-satellite applications

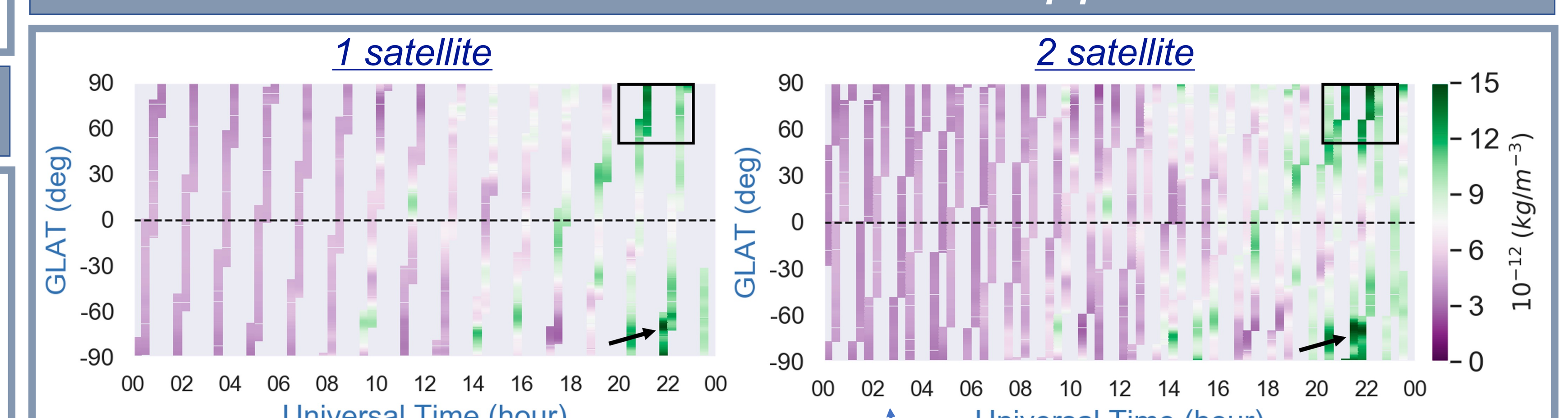
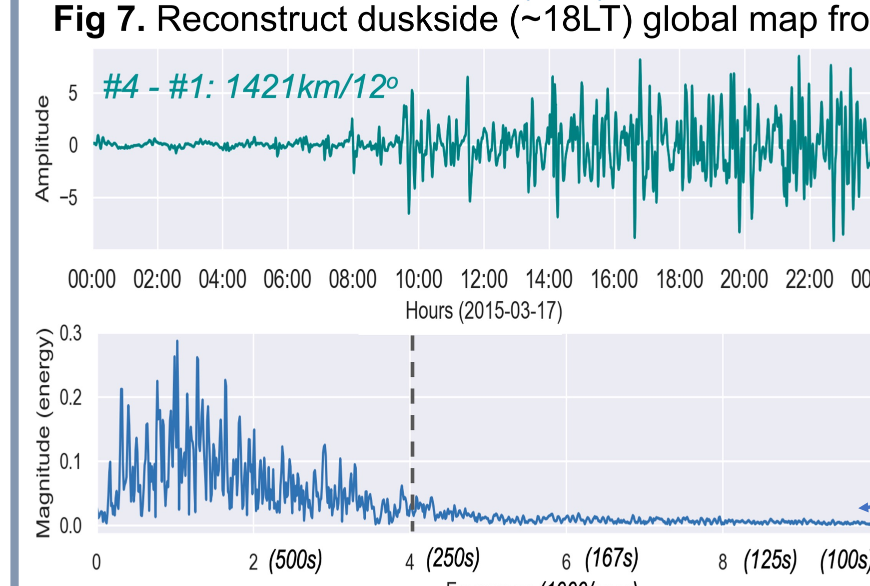


Fig 7. Reconstruct duskside (~18LT) global map from single and two satellites from GITM simulation



Better global map with more satellites

In this case, a separation of ~12° has a cut-off frequency is ~4, which means ~20°, about twice the relationship

The closer, the finer $\Delta\rho$ can be studies

Fig 8. Direct difference between #4 and #1 (top) and spectral analysis with FFT (bottom)

Summary

- ***GITM simulations reproduce the most salient spatial and temporal ρ well***
- ***By combining 6 satellites which share the same orbit, time-space is separated:***
  - ○ *$\Delta\rho$ increases with time & space, but its speed $\Delta\rho/\Delta t$ & gradient $\Delta\rho/\Delta km$ will decrease*
  - ○ *Spatial variation (< 12°) is much more static than temporal variation (< 187s)*
- ***More comprehensive global map can be obtained, e.g., TAD and more diverse scales can be investigated (~2 x satellite separation) with more satellites***

COMING SOON

Hong et al., (2023) Storm-Time Neutral Density Perturbations at Multiple Temporal- and Spatial-Scales During the 2015 St. Patrick Day's Storm: Data-Model Comparisons, Space Weather, to be submitted