Quantifying Gravity Wave–Ionosphere Coupling Over CONUS: Insights from NASA AWE Radiance and GNSS TEC Measurements

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Abstract

Atmospheric gravity waves (AGWs) play a fundamental role in the vertical coupling of the lower atmosphere and the Ionosphere–Thermosphere (IT) system, driving momentum and energy upward and inducing ionospheric variability. AGWs are also believed to seed nighttime medium-scale traveling ionospheric disturbances (MSTIDs), often linked to electrodynamic instabilities such as the Perkins instability. However, direct observations of mesospheric GW–TID coupling have been limited due to the lack of global-scale, high-resolution measurements near the mesopause. In this study, we utilize radiance measurements from NASA's Atmospheric Waves Experiment (AWE) aboard the International Space Station, providing unprecedented global coverage near ~87 km. We assess AGW–ionospheric coupling over the Continental U.S. using a swath-to-swath comparison of AWE-derived radiance variance and GNSS-based vTEC variance (5–40 min bandpass) during 2024. Strong correlations ($r > 0.7$) are observed primarily under quiet geomagnetic conditions ($Kp < 3$, $AE < 500$ nT, $Dst < -30$ nT), with enhanced coupling between 00–03 LT and during summer months, particularly July.

Science Question: How do AGW-driven perturbations manifest in ionospheric TEC variability?

Data and Methodology

NASA AWE Radiance Data

High-resolution airglow radiance observations (~87 km).

GNSS vTEC DATA

vTEC (5–40 min BP filtered) from ~2700 CONUS stations, processed by S-RAID, Embry-Riddle Aeronautical University).

AWE Radiance Variance

Pixel-wise radiance variance → 200 km circular window → GWs < 400 km in wavelength → Cloud - contamination masked → Binned to 0.25° × 0.25° grid.

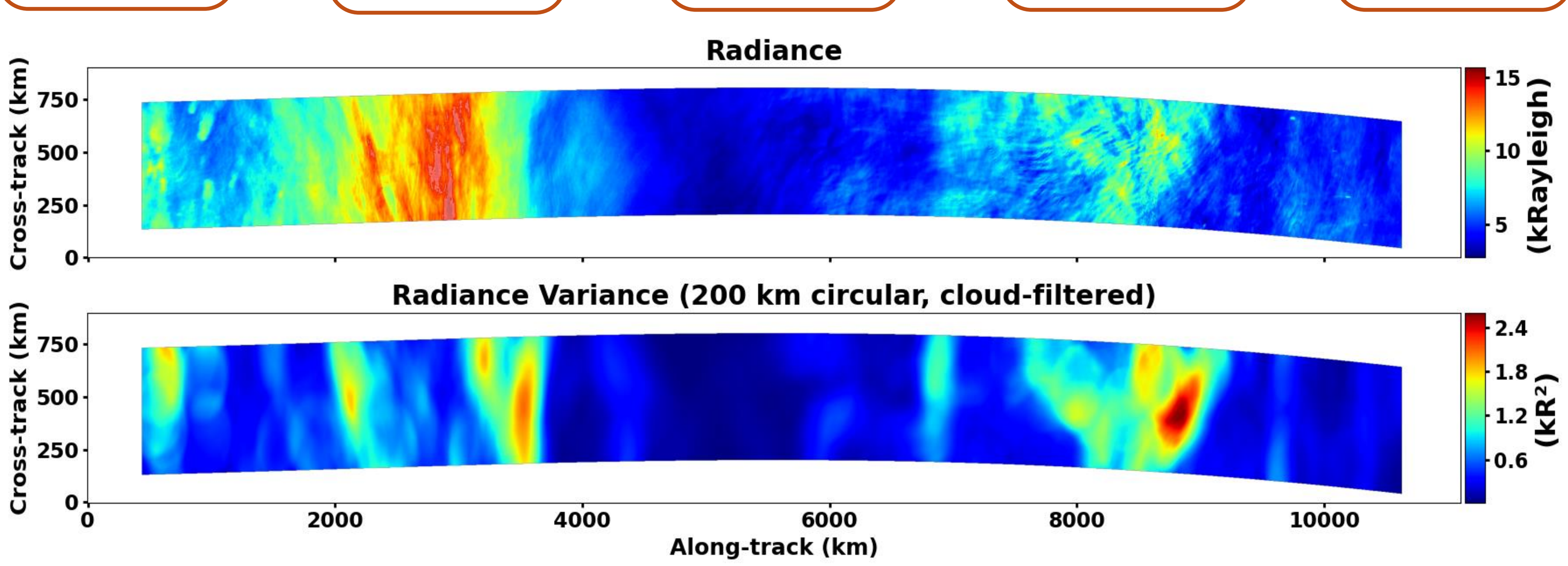

Figure 1: AWE radiance (top) and 200 km circular variance (bottom) for Jan 2, with cloud-contaminated pixels masked. Method adapted from *Zhang et al.* (2025, GRL).

GNSS TEC Variance

GNSS vTEC variance is computed using 200 km BallTree-based local variance and then spatially binned to a 0.25° grid.

Correlation Analysis

- 429 AWE swaths from Jan, Feb, Mar, May, Jul, Sep, and Nov 2024 with CONUS overlap were analyzed.
- For each swath, a 2-hour forward window was scanned to find the best GNSS epoch using z-score normalized 2D spatial correlation, applying ±3° spatial shifts to align mesospheric and ionospheric wave patterns.

Results: AWE–GNSS Swath Comparisons

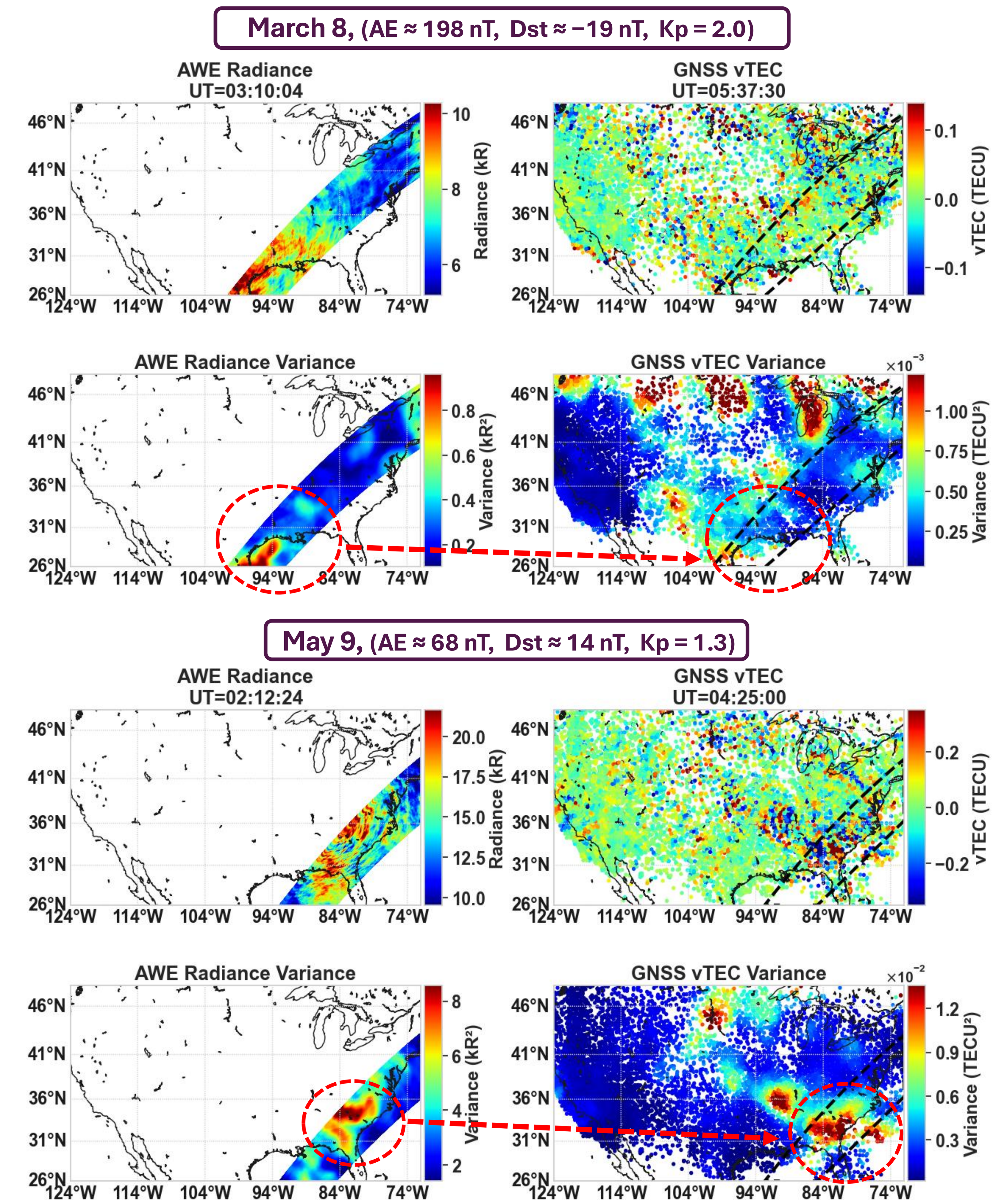

Figure 2: AWE radiance, radiance variance, GNSS vTEC, and vTEC variance for two example swaths under quiet conditions. GNSS data shown at the best-correlated epoch identified via 2D spatial alignment.

Spatial Correlation Analysis

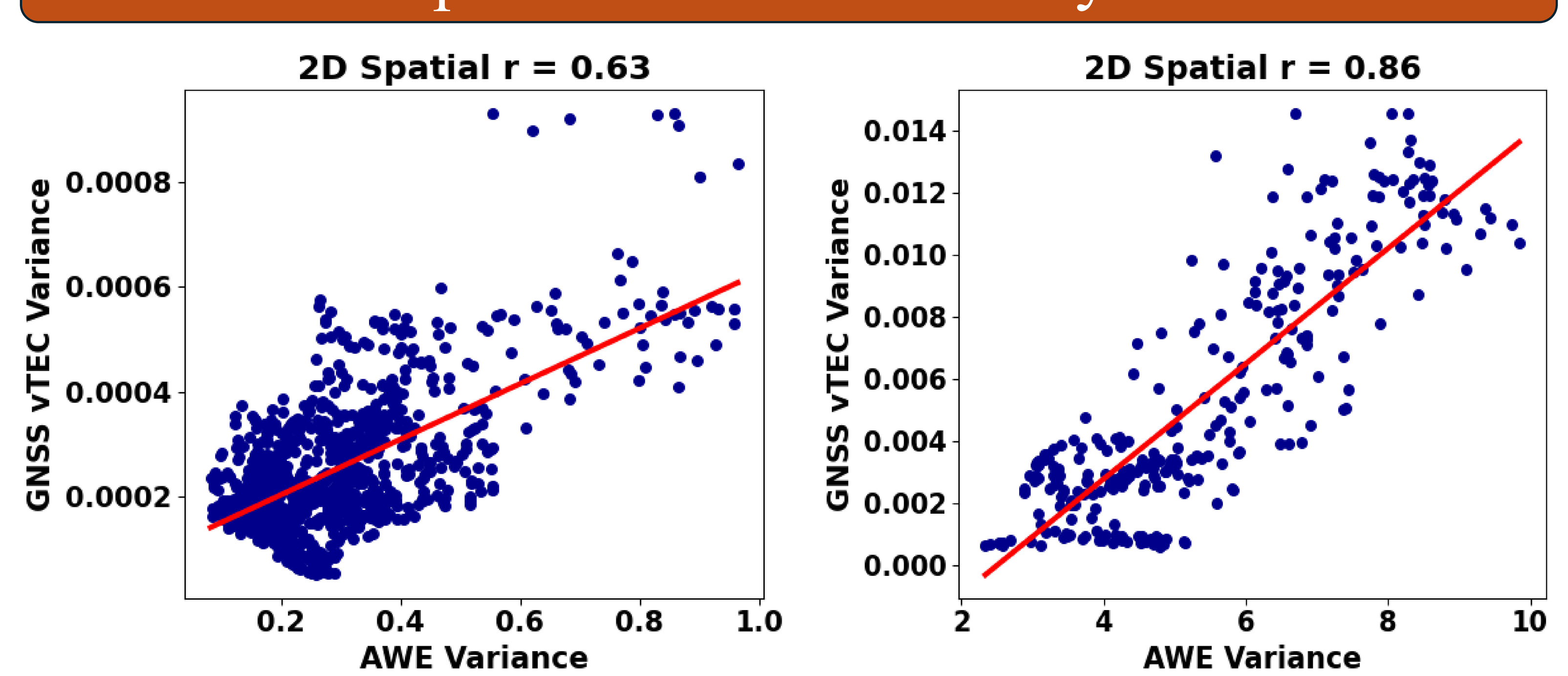

Figure 3: Pixel-wise correlation between AWE radiance variance and GNSS vTEC variance for the **two swaths shown in Figure 2**. The number of points is limited by the swath footprint and valid GNSS coverage.

Statistical Analysis

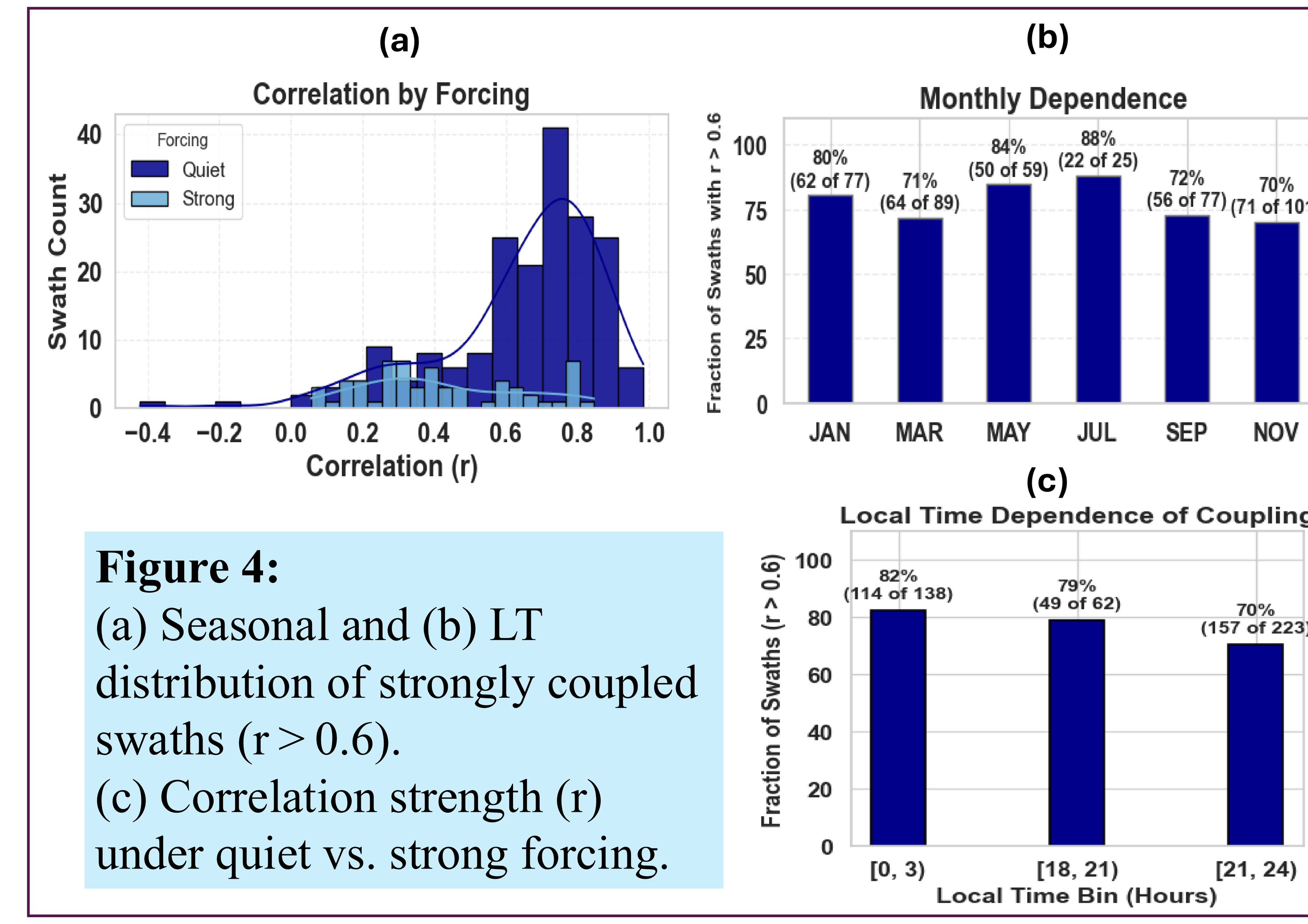

Figure 4:
(a) Seasonal and (b) LT distribution of strongly coupled swaths ($r > 0.6$).
(c) Correlation strength (r) under quiet vs. strong forcing.

Conclusions

- Over 70 percent swaths show strong correlation under quiet conditions; strong forcing yields weaker, variable correlation.
- Coupling peaks during 00–03 LT and in July, consistent with summer nighttime MSTID climatology in prior studies.
- Some high-correlation swaths also occur under strong forcing, suggesting additional factors influence coupling.
- Further work is needed to isolate GW impacts from **Perkins instability** and other ionospheric instabilities.

Results are limited to nighttime observations and months with sufficient CONUS coverage.

Future Work

Investigate the **global climatology** of AGW–TID coupling, focusing on how **seasonal drivers** and background atmospheric conditions modulate wave propagation and ionospheric response.

References

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- *Shiokawa, K., Otsuka, Y., Ihara, C., Ogawa, T., & Rich, F. J. (2003). Ground and satellite observations of nighttime medium-scale traveling ionospheric disturbance at midlatitude. Journal of Geophysical Research: Space Physics, 108(A4),1145.*

Acknowledgements

We thank Jiarong Zhang (Utah State University) and Björn Bergsson (Embry-Riddle Aeronautical University) for GNSS data support and collaboration.

The work is supported by NASA grants 80NSSC22K0018, NNX17AG10G, 80NSSC22K1010, 80NSSCK19K0810, and NSF grants CEDAR-2431688, AGS-2149695, and CAREER-1753214.