Tidally-Driven Intra-Seasonal Oscillations in the Thermosphere from TIEGCM/ICON and Potential Connections to the Madden-Julian Oscillation

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ABSTRACT

Recent evidence has revealed that strong coupling between the troposphere and the thermosphere (>100 km) occurs around intra-seasonal (IS, ~30-90 days) timescales. The Madden-Julian Oscillation (MJO), a dominant source of IS variability in tropical tropospheric convection and circulation, can influence the generation and propagation characteristics of solar tides and has been proposed as an important driver of thermospheric IS oscillation (ISOs). However, the sparsity of satellite observations in the `thermospheric gap' region (ca. 100-300 km), and thus numerical models incapable of accurately characterizing this region, has hindered our ability to improve our understanding of the fundamental processes at play. In this work, an Ionospheric Connection Explorer (ICON)-adapted version of the Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) with lower boundary tides based on Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) observations is used to quantify and characterize the impact of the upward-propagating tidal spectrum on thermospheric ISOs and reveal connections to the MJO. Thermospheric background zonal winds are shown to exhibit prominent (> ±10-20 m/s) tidally-driven IS oscillations, largest at low latitudes (30°S-30°N) in the 110-150 km altitude region and strongly (r=0.6) correlated with DE3 variability. Furthermore, IS variability in thermospheric DE3 amplitudes is found to share about 45% variance with the Real-time Multivariate MJO series 1 (RMM1) index. This study demonstrates that vertically propagating solar tides play a leading role in connecting IS variability from the lower atmosphere (below ~100 km) to the thermosphere and indicates the MJO to be the most likely contributor to this whole-atmosphere teleconnection.

TIEGCM/ICON NUMERICAL EXPERIMENTS

- The ICON observatory was launched on 11 October 2019 into a 27° low inclination orbit near 590 km (*Immel et al., 2018*[1]). MIGHTI measures neutral winds (daytime, 94-300 km; nighttime 94-109 km and 210-300 km).
- The TIEGCM describes self-consistently the IT dynamics/energetics/chemistry.
- TIEGCM here is driven near the 97 km LB by ICON Hough Mode Extension (HME) tides (*Maute et al., 2023*[2])
- The model background is based on HWM07 and MSISE00 and the HME tidal fitting uses 41-day running windows.
- The TIEGCM cases examined are *Run 1 with ICON HME tides (24/12h) at LB*, *Run 2 with no tides at the LB*, and *Run 3 with tides but const. GPI (Kp=X, F10.7=71 sfu)*.
- Prominent 45-90-day intra-seasonal (IS) variability is observed in the tropospheric OLR and RMM1 (likely MJO-connected), not found in Kp and F10.7 (***Figure 1***).

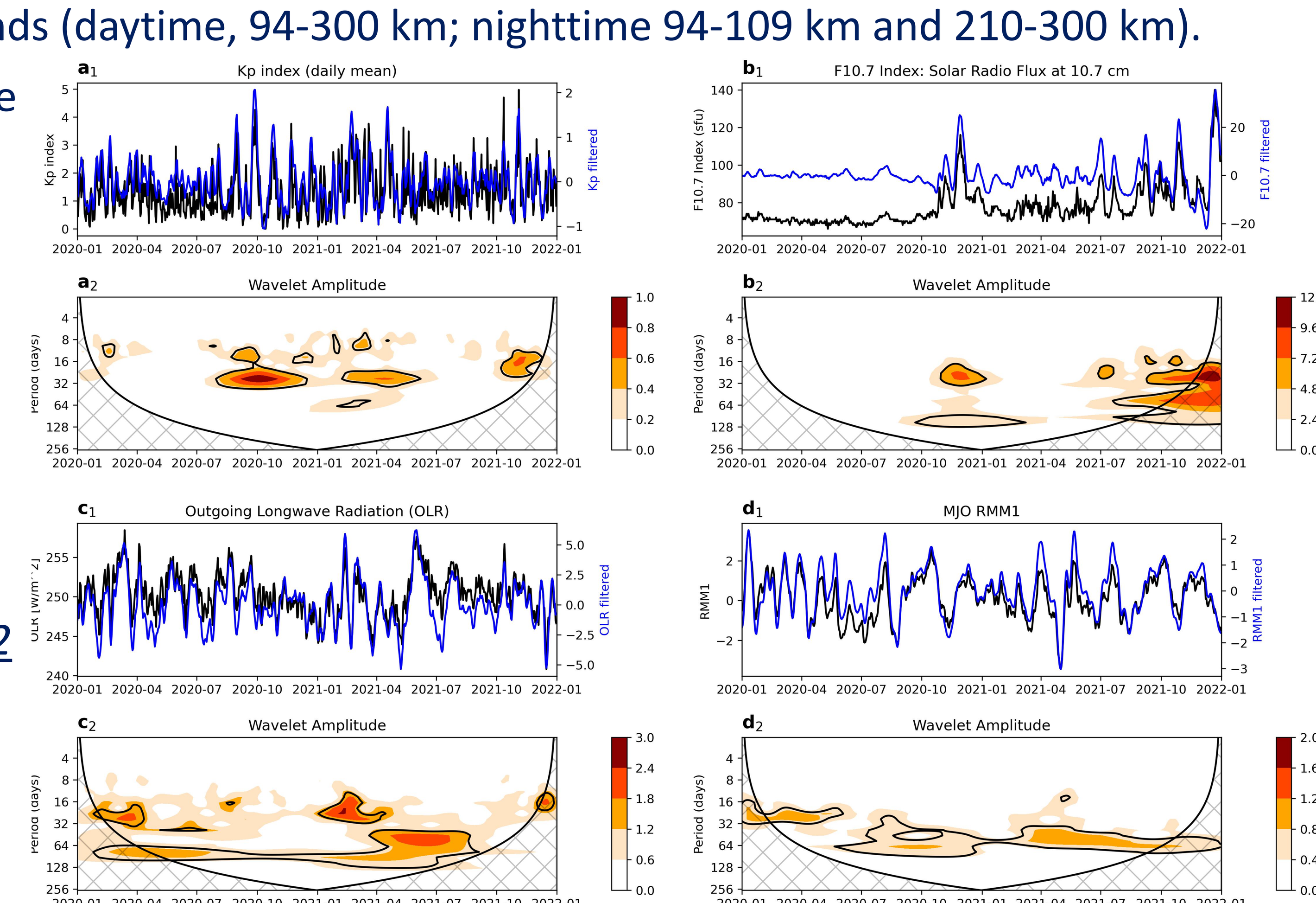

Figure 1. *(a_1)-(d_1) Time series of Kp, F10.7, OLR (15°S-15°N mean), RMM MJO index. (a_2)-(d_2) Morlet wavelets of the time series in (a_1)-(d_1).*

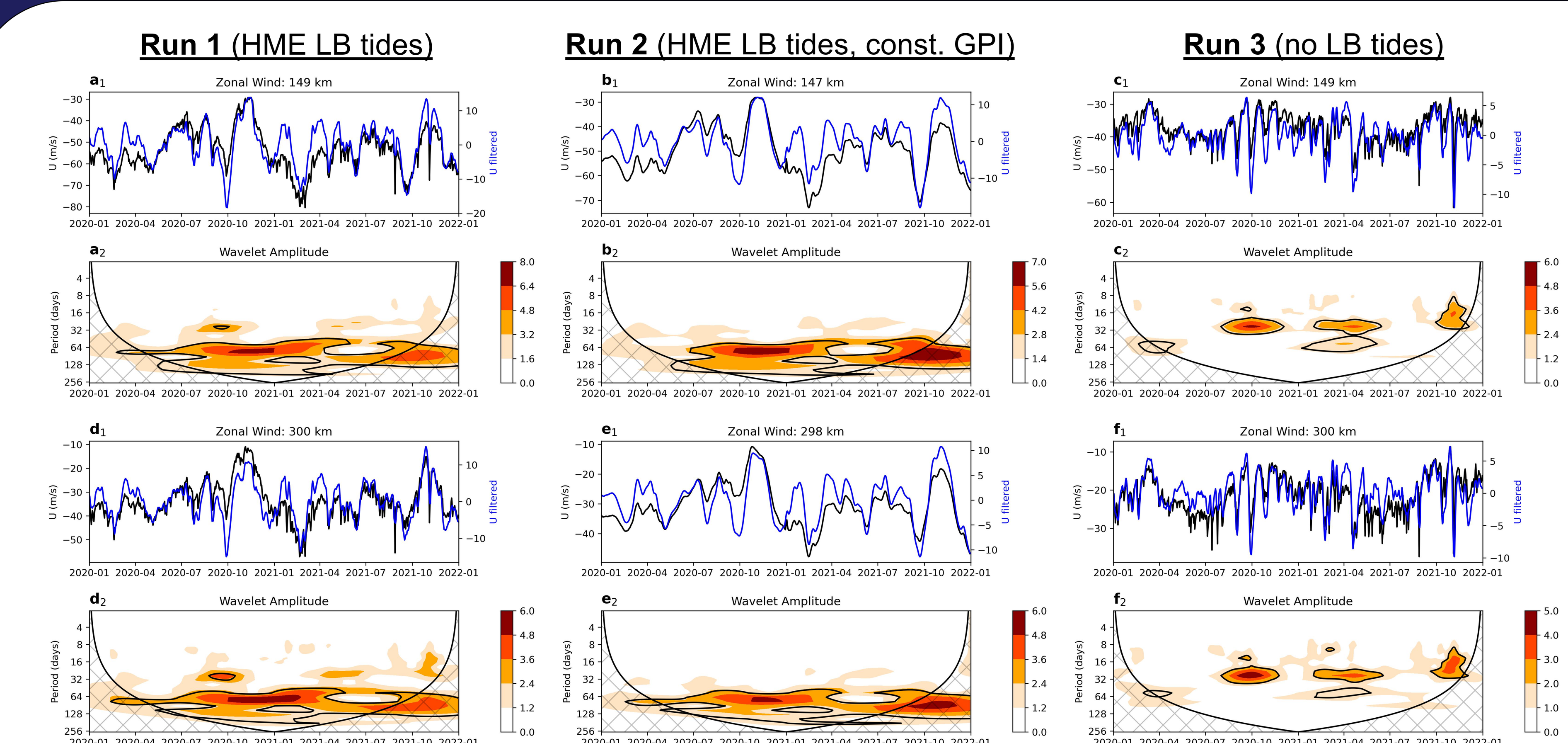

Figure 2. *Time series of ZDM zonal winds near 15°S-15°N and 150 km for Run-1 WeiHmeV2r1 (a_1), Run-2 WeiHmeV2r1_conGeop (b_1), and Run-3 WeiWoHmeV2r1 (c_1). (a_2)-(c_2) show the corresponding Morlet wavelets. (d_1)-(f_1) and (d_2-f_2) show similar depictions near 300 km altitude.*

- Zonal/diurnal mean (ZDM) zonal winds for *Run-1* show large ~60-day IS variability of ±15 m/s (***Figures 2a$_1$-2d$_1$***) closely resembling similar periodicities in RMM1 (*Figures 1d$_1$-1d$_2$*).
- The time series and wavelet of *Run 2* display large IS variability (as in *Run 1*) but lack variability near 27 days associated with solar and geomagnetic effects (as these are const.).
- *Run 3* contains negligible IS variations near 60-100 days indicating that the ±15 m/s ZDM zonal wind IS variability in *Run 1* and *Run 2* are largely associated with the LB tides.
- ***Figure 3*** shows the *alt-doy* & *lat-doy* structure of the ZDM zonal winds and their filtered variations from the difference field (*Run 1 - Run 3*) that isolates the LB tidal contributions.
- The tidally-induced mean wind *ISOs* generally maximize in the lower thermosphere near 110-130 km altitude where upward-propagating tidal components undergo significant dissipation imparting their energy, momentum, and temporal variability to the background, however, they retain large values even above with variations > ±15 m/s near 400 km.
- The IS variability is most prominent within about ±20° latitude, with strong doy-dependency and dominant equatorially symmetric and asymmetric latitude structures that alternate throughout 2020-2021 pointing to the combined effect of different tidal components.

MODELING ANALYSES

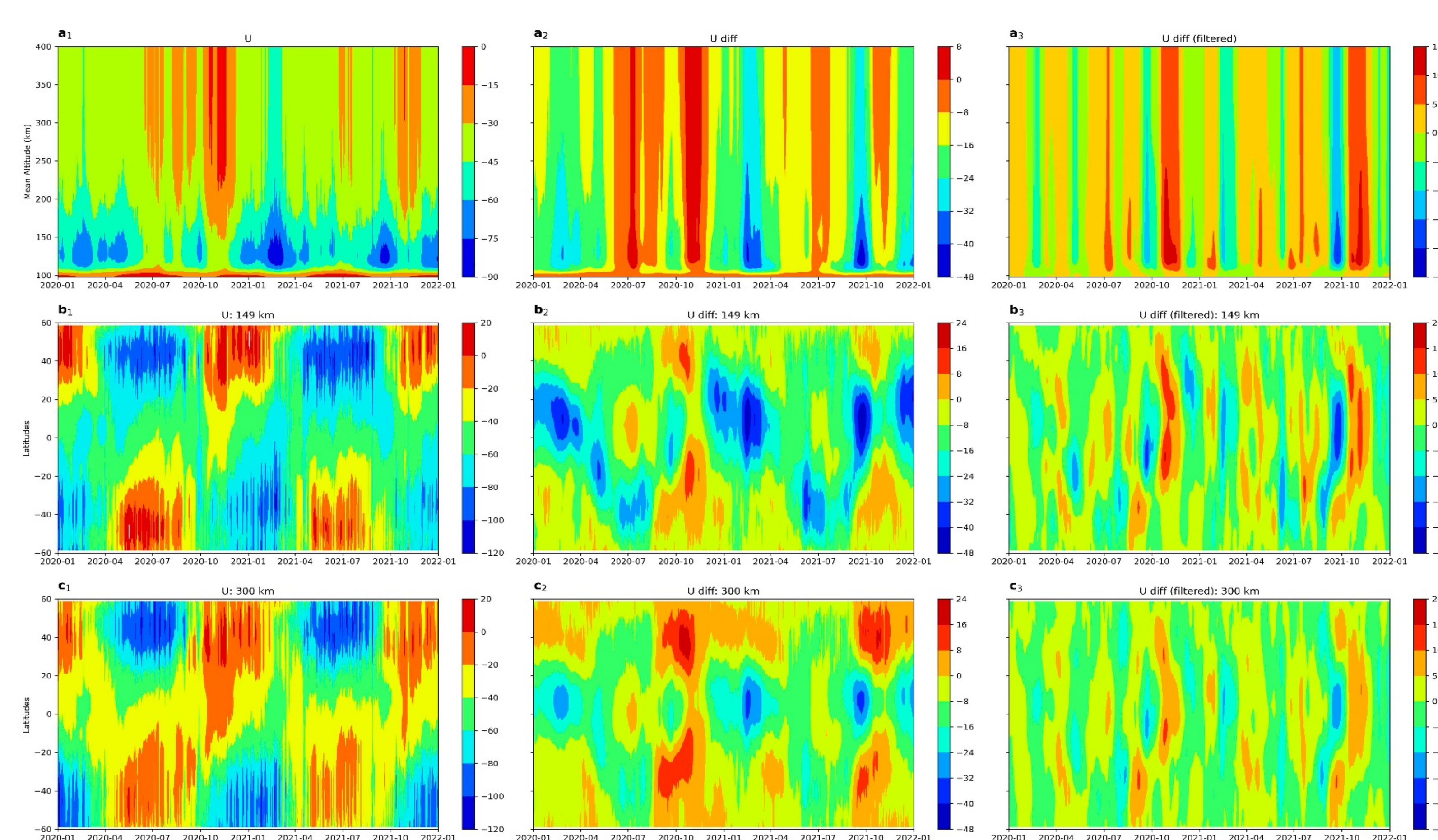

Figure 3 *Altitude-doy contours of ZDM zonal wind (m/s) near 15°S-15°N from Run 1 (a_1) and from Run 1 - Run 3 (a_2). (a_3) 5-90-day filter is applied to (a_2). (b_1)-(b_3) Latitude-doy contours at ~150 km. (c_1)-(c_3) Latitude-doy contours at ~300 km.*

- The vertical structure of zonal wind DE2, DE3, DW1, and SW2 amplitudes from *Run 1* (***Figure 4***) show well-known seasonal effects and large IS variability consistent with the mean wind IS variations (ref. *Figures 2-3*).
- In-situ tidal generation (DW1, SW2) and propagation (DE3, DE2) are found.

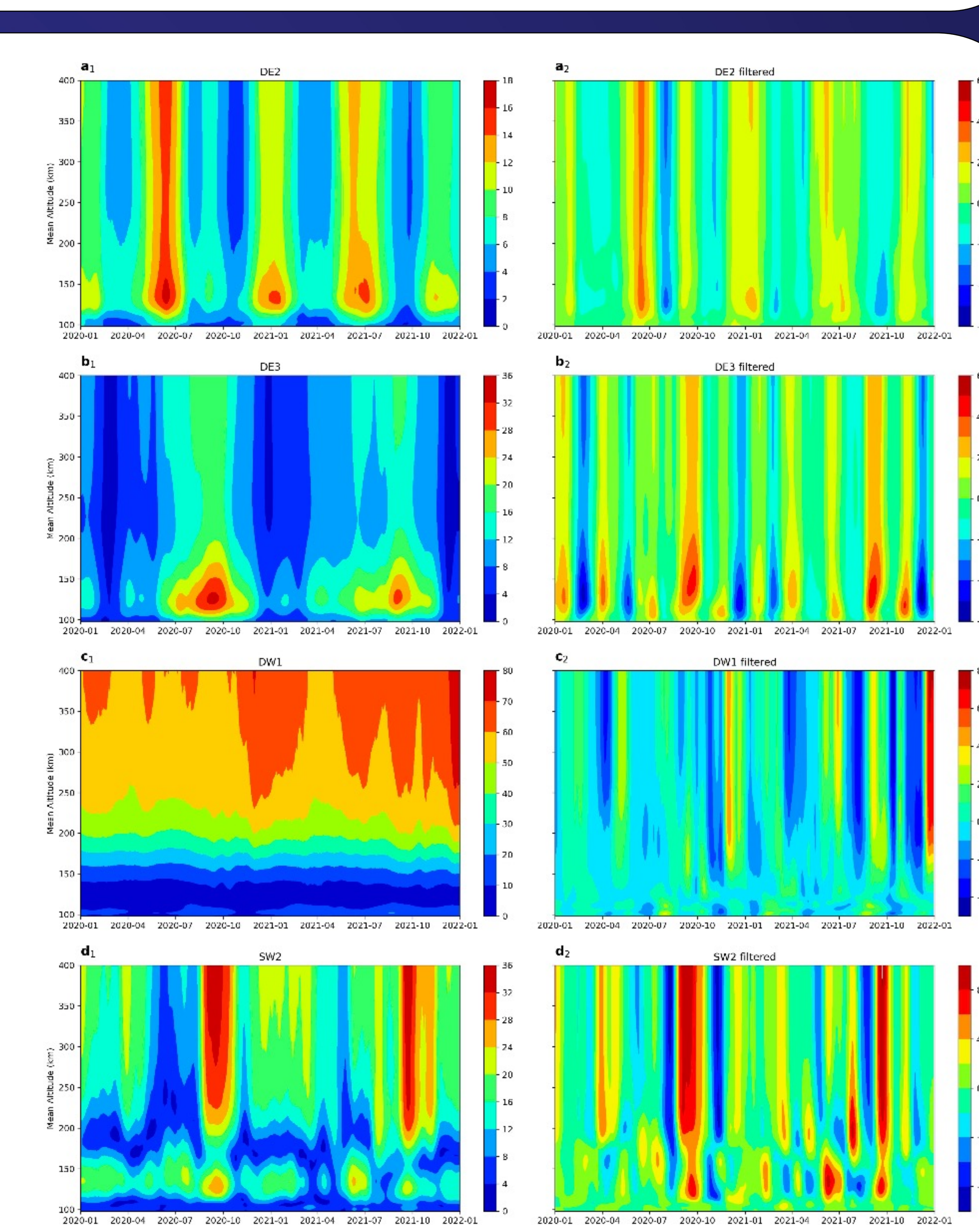

Figure 4 *(a_1)-(d_1) Altitude-doy contours of DE2, DE3, DW1, and SW2 zonal wind amplitudes near 15°S-15°N for Run 1 and their filtered amplitudes (a_2)-(d_2).*

CONCLUSIONS

- This study indicates that ***the lower thermospheric diurnal/semidiurnal tides play a crucial role in generating dynamical variability in the background thermospheric winds (±20 m/s) around IS time scales*** with a likely connection to the MJO (not shown here). Follow-on work will assess ionospheric impacts.
- TIEGCM/ICON is an excellent model for characterizing the impact of E-region tides on the thermosphere, however, unaccounted waves (higher-order tides, UFKWs, PWs) likely introduce important uncertainties.
- Combined modeling/observational studies are set to characterize MJO impacts on the whole atmosphere.

Results Based on JGR Manuscript Currently Pending Submission.

References

[1] doi:10.1007/s11214-017-0449-2

[2] doi:10.3389/fspas.2023.1147571

Acknowledgments

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