Investigating Connections Between Tropical Tropospheric Convection and Thermospheric Intra-seasonal Variability of Wind and Temperature Profiles

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CEDAR 2024 SAN DIEGO, CA COUP-3 JUNE 9-14

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Introduction

Abstract

Coupling between the lower atmosphere (~0-20 km) and the thermosphere (100-500 km) on intra-seasonal (IS, ~30-90 days) time scales is an accelerating area of research that has the potential to improve the collective model of whole-atmosphere behavior. Recent research from the aeronomy community has investigated the effects of upward propagating waves originating from deep convection in the tropical troposphere on thermospheric IS variability. Convection associated with the Madden-Julian Oscillation (MJO) has been shown to modulate a range of waves including tides such as the eastward propagating diurnal tide with zonal wavenumber 3 (DE3), gravity waves, and ultra-fast kelvin waves (UFKW) which may in turn modulate thermospheric IS variability of temperature and zonal and meridional wind profiles. This work expands on previous research by incorporating temperature and wind field observations from the MIGHTI (Michelson Interferometer for Global High-resolution Thermospheric Imaging) instrument on the ICON (Ionosphere Connection Explorer) satellite and temperature data from the SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) instrument on the TIMED (Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics) satellite. TIE-GCM (Thermosphere Ionosphere Electrodynamics General Circulation Model) model data is also compared with observational results. Correlation analyses were performed between the observed and modeled data and the RMM (Realtime Multivariate MJO) index which quantifies the phase and intensity of the MJO, in addition to UFKW amplitudes DE3 tides. Correlation analysis was also performed to control for the effects of space weather, including Kp values and incoming 10.7 cm radiation flux (F10.7), in an effort to isolate instances of correlation between the RMM and thermospheric IS variability.

Sources of Data

- **ICON MIGHTI Instrument**
  - Measures zonal and meridional horizontal wind components between latitudes of 12°S - 42°N from altitudes of 91-225 km for measurements taken on green oxygen emission lines and 160-301 km for red.
    - Dataset from 12/6/2019 - 11/5/2022.
  - Measures temperature coincident with wind measurements.
  - Provides observed UFKW and DE3 tidal amplitudes.
    - Dataset from 4/4/2020 - 4/14/2022
- **TIMED SABER Instrument**
  - Temperature measurements from altitudes of 25-105 km.
  - Dataset from 1/1/2020 - 12/31/2022.
- **TIE-GCM Model Outputs**
  - Models wind vectors from a lower bound of ~97 km.
  - Includes variations on boundary specifications and parameterization of space weather impacts.
- **RMM Index, Kp Index, and F10.7 Data**
  - RMM index consists of two components which together represent the phase and intensity of the MJO.
    - Provided by NOAA earth research lab
  - Using daily average Kp index and 10.7 cm radiation flux.
    - F10.7 provided by SWPC and Kp index from GFZ

Methods

Data Binning

- Focused on MIGHTI Green winds at 100 km and Red winds at 200 km.
- Removed data with quality flags < 0.5 (caution).
- Separated data into ascending and descending nodes using the rate of change of the latitude
- Binned data into a grid by latitude* and longitude
  - Latitude bins -10° to 40° in intervals of 5°
  - Longitude bins 0° to 360° in intervals of 24°
- Averaged all data points falling into each bin each day
- Took 41-day moving averages omitting missing data
- Found Zonal Diurnal Means (ZDMs) by combining ascending and descending nodes and averaging all bins near the equator (-5° to 5° N)

**TIEGCM Zonal Diurnal Means averaged over latitudes -6.25° to 6.25° to approximately match the domain of the MIGHTI data.*

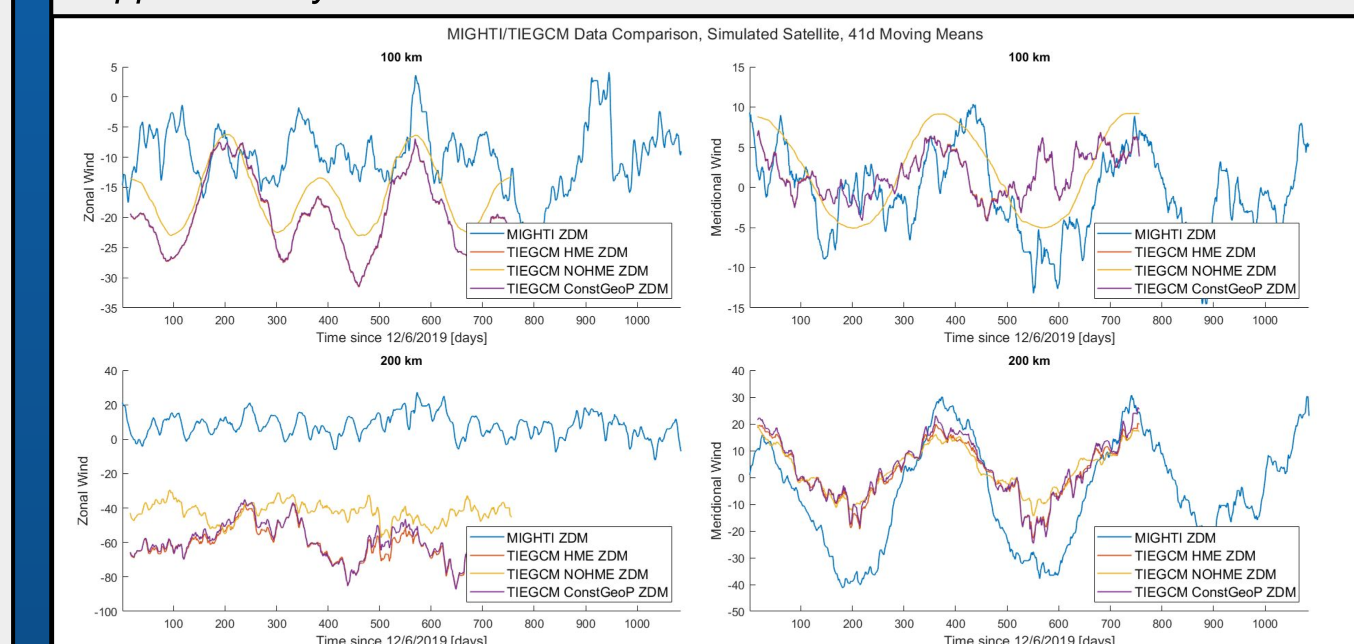


Figure 1: Time series of binned MIGHTI ZDMs compared with equivalently binned TIEGCM model output ZDMs using Hough Mode Extension boundary conditions & space weather parameterization on/off.

Correlation Analysis

- MIGHTI Data Gaps filled with Linear Interpolation
- 5-day moving average applied to smooth data before correlation calculated
- Found correlation coefficients for each day by comparing variables in a 192-day window centered on each day
  - Looked for strong correlations with RMM amplitude concurrent with weak correlations with F10.7 and Kp index
- Included a variable number of "offset days" between the variables being compared to account for time required for disturbances to propagate
  - Maximum of 4 offset days
  - Greatest R-value taken which has $P < 0.05$
- Found correlation with time between MIGHTI observations/ TIEGCM outputs and UFKW/DE3 data, and between Kp/RMM/F10.7 indices and UFKW/DE3 data.

Wavelet Analysis

- Created wavelet scalograms to search for repeating oscillations.
  - Oscillations of similar periods occurring simultaneously may indicate coupling between two variables.
  - 95% confidence contours.
  - Future analysis will include wavelet coherence.

Results

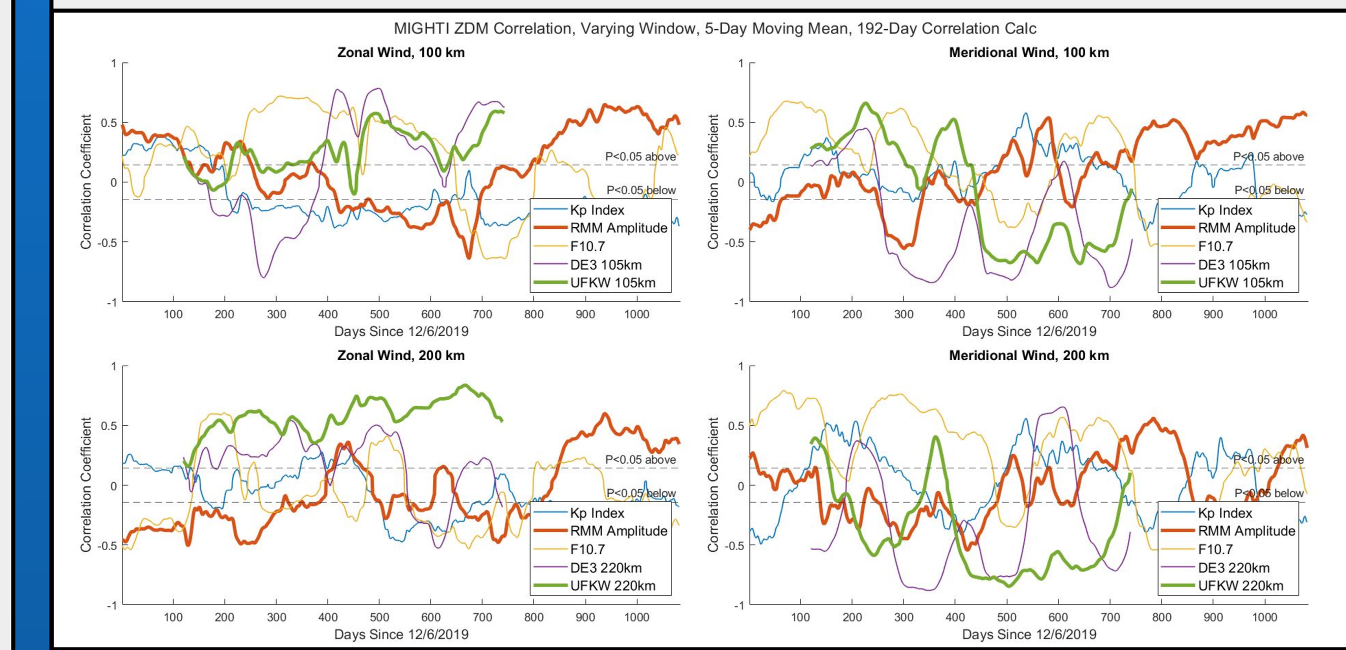


Figure 2: Correlation between MIGHTI zonal diurnal mean wind components and Kp index, RMM amplitude, F10.7, DE3 tides, and UFKW at 100 km and 200 km MSL. Statistically significant data outside dashed lines.

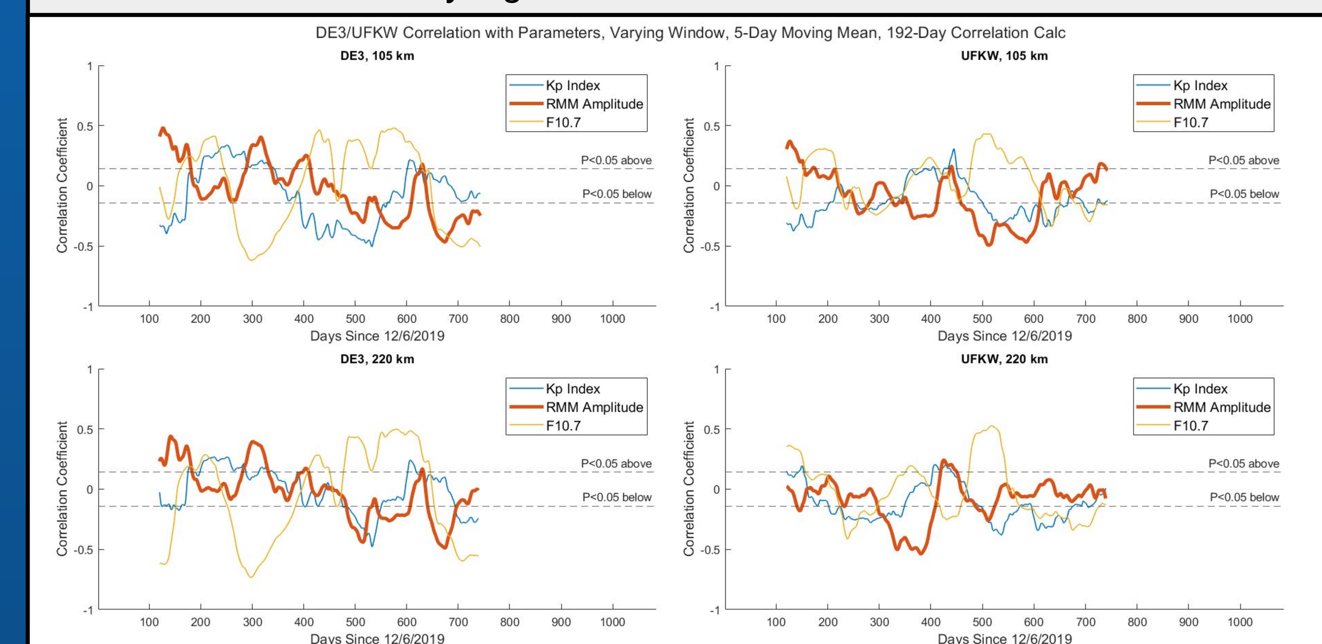


Figure 3: Correlation between DE3 tides/UFKW and Kp index, RMM amplitude, and F10.7. Statistically significant data outside dashed lines.

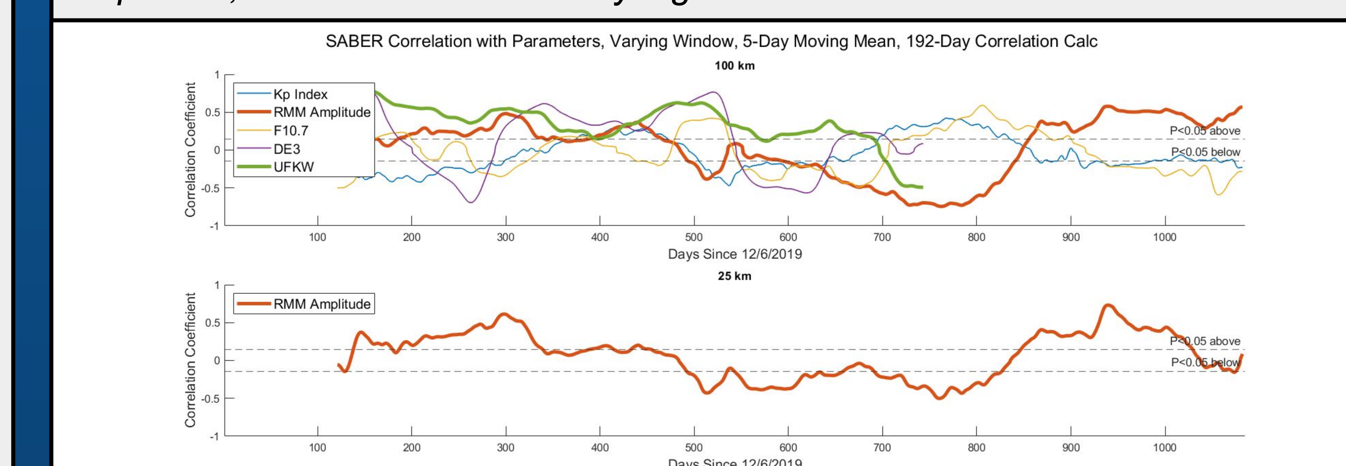


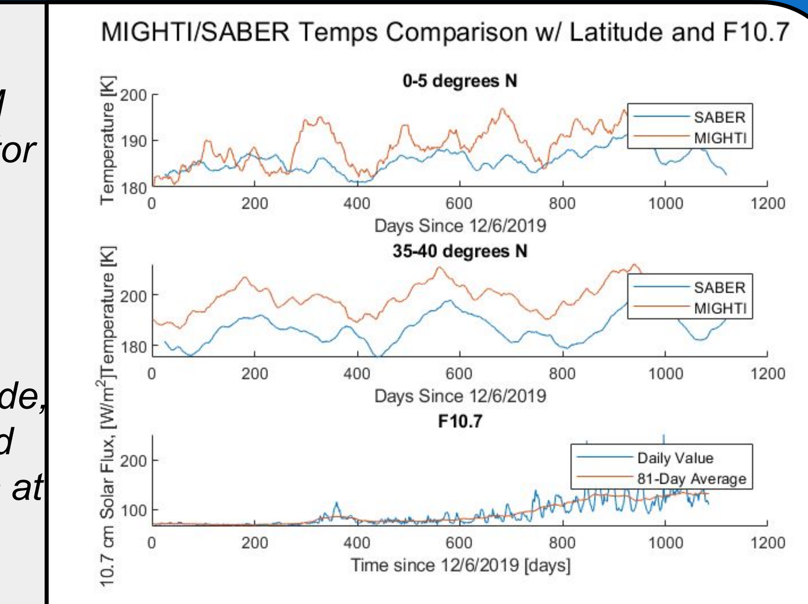
Figure 4: Correlation between SABER temperatures and Kp index, RMM amplitude, F10.7, UFKWs, and DE3 tides at 25 km and 100 km. Statistically significant data outside dashed lines

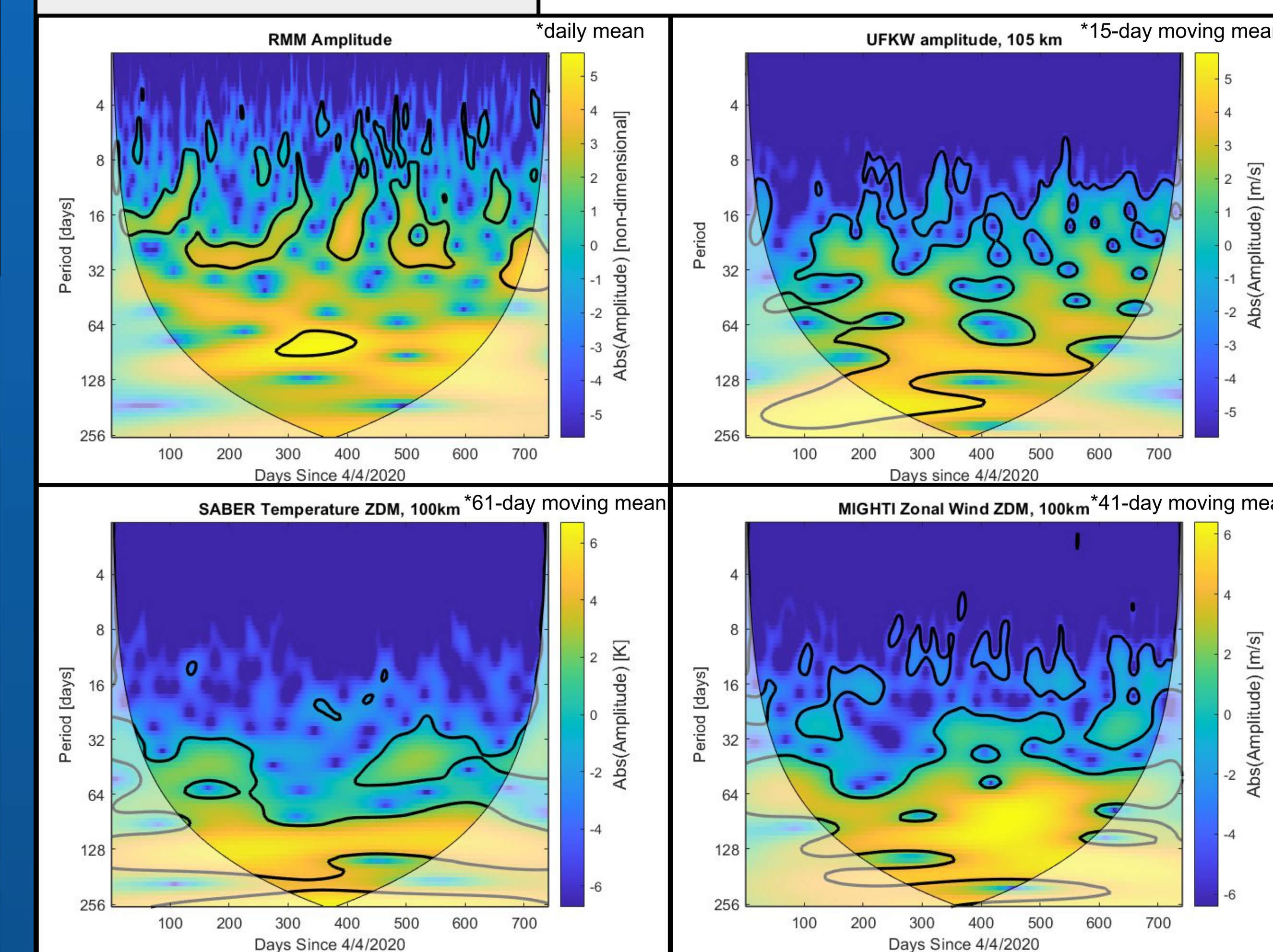
Observations

- Zonal winds at 200 km appear strongly correlated with UFKWs, to a greater extent than at 100 km.
  - Meridional winds at 200 km are instead negatively correlated with UFKWs, more strongly than at 100 km.
- Wind components experience intraseasonal periods of significant correlation with RMM amplitude at 100 & 200 km.
- Ultra-fast kelvin waves and DE3 tides display strong seasonal variability which is reflected in the correlations.
  - Correlation between RMM and UFKWs is mostly negative and only significant for 2 IS periods
- SABER temperature correlation with RMM is mostly consistent from 25-100 km.
  - SABER temperature correlation with RMM is opposite to that of Kp and F10.7 for 3 periods of >100 days.

Figure 5: Comparison of MIGHTI and SABER ZDM temperatures at the equator and the mid-latitudes alongside F10.7.

Figure 6: Morlet wavelet scalograms of RMM amplitude, UFKW amplitude, SABER temperatures, and MIGHTI zonal wind ZDMs at 100 km. 95% confidence contours.





- MIGHTI consistently overestimates temperatures compared to SABER by up to 10℃, regardless of F10.7 or latitude.
- RMM amplitude oscillates on IS periods b/w days 280-420.
  - These periods are also present in UFKW & MIGHTI zonal ZDMs, less so in SABER ZDMs.
  - Long-period oscillations may represent sat. precession.

Summary

- Investigated the effects of tropical tropospheric convection associated with the **MJO** on intraseasonal variations of **wind and temperature profiles** in the thermosphere.
  - Improved understanding may help **improve models, forecasting for orbit calculations & re-entry.**
- Utilized **ICON MIGHTI, TIMED SABER & TIE-GCM** outputs.
- Binned satellite data to create ZDMs of wind & temperature.
- Compared MIGHTI and TIE-GCM wind profiles
  - **Strong agreement on 100-200 km meridional winds.**
  - Agreement on oscillation period only for zonal winds.
- Calculated correlation coefficients with time between RMM amplitude, control variables (Kp index, F10.7), and dependent variables (temperature and wind components).
  - Found IS periods of **correlation coefficients up to 0.6** between RMM and wind components.
  - RMM effect on temperature **consistent from 25-100 km.**
- Analysis of wavelet scalograms revealed that **RMM amplitude, UFKW amplitude, and MIGHTI 100 km zonal wind ZDMs share IS oscillations** of 64-96 day periods.
- In **ongoing work**, focusing on specific periods of correlation, and modeling the latitudinal structure of DE3 tides & UFKWs through Hough Mode Extensions (HMEs).