Understanding the Madden-Julian Oscillation's Impact on Ionospheric Space Weather with COSMIC-2 Data

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1. Abstract

This study aims to investigate how the Madden-Julian Oscillation (MJO) influences space weather in the F-region ionosphere by utilizing data from the COSMIC-2 satellite constellation. The mechanism involves the MJO inducing changes in global-scale waves via modulation of convective forcing, stratospheric gravity waves (GW) drag, and mean winds. These alterations depend upon various factors, including the season, magnitude, and phase (location) of the MJO. The response of ionospheric tides to the MJO is likely from either modulation of the E-region dynamo or direct upward propagation of tides. Our findings indicate that the MJO influences tides in mesosphere/lower thermosphere dynamics and in EIA electron density. These insights are relevant for enhancing predictability of ionospheric space weather on intraseasonal timescales.

Science Goal: Global response of F-region ionosphere (~300 km) to recurring weather variability in the tropical troposphere (~10 km).

2. Introduction

- **MJO (Madden Julian Oscillation):**
  - Intraseasonal variability in tropical atmosphere.
  - Sources: Latent heat energy.
  - Period: 30-96 days
  - Eastward at 4-8 m/s.
  - Phase: 1-8, indicates the location of maximum convection.

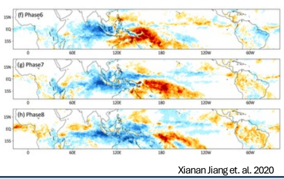

Figure1: Evolution of TRMM rainfall anomalies with MJO phases.

3. Data used and tidal extraction

- **COSMIC-2:**
  - Hourly GIS electron density profiles with a longitude/latitude resolution of 5° x 2.5°, and vertical resolution of 20 km using Gauss-Markov filter.
  - 2-D Fourier fitting of the GIS electron density at each altitude and magnetic latitude. **Tidal spectra every day.**
- **SD-WACCM-X:** Specified dynamics (SD) WACCM-X version v2.1 simulation with nudging of (MERRA-2) data from the surface up to ~50 km.
- **SABER:** HME temperature tides.

*Relative amplitude (%): Amplitude of DE3 w.r.t. zonal mean

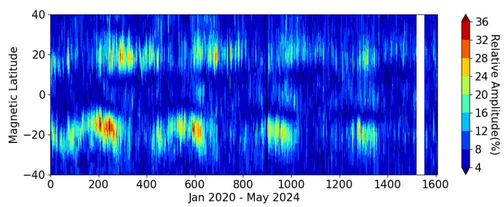

Figure 2: DE3 (Diurnal non-migrating eastward propagating tide) time series vs magnetic latitude at 300 km in electron density.

4. Methodology

Electron density (ionosphere) and temperature (MLT) tides ➡ **Band-pass and eastward propagating filter**

(MJO) Hovmoeller plots

5. Results : MJO signal in DE3 (MLT~95 km and Ionosphere ~300 km)

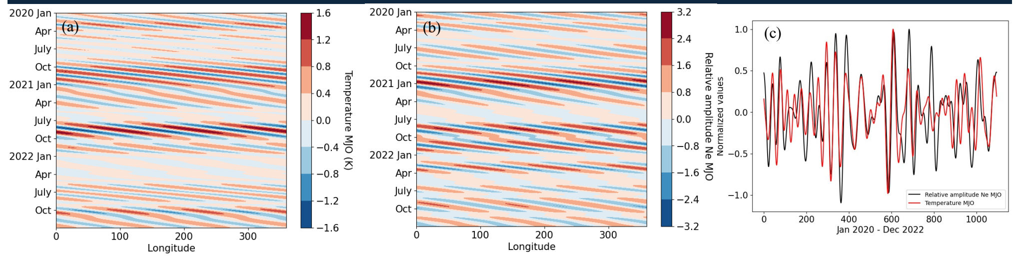

Figure 3: (a) MJO signal in temperature tides from SABER for the years 2020-2022 around the equator. (b) Same but for electron density from COSMIC-2 at 15N magnetic latitude. (c) Normalized values of SABER temperature at longitude 0 deg and **COSMIC-2 electron density** at longitude 80 deg.

6. Quantitative analysis

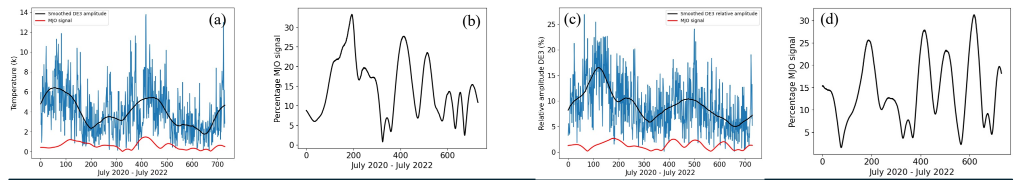

Figure 4: (a) Comparison between **DE3 amplitude** and MJO signal for SABER, (c) same as (a) but for COSMIC-2 ; (b) and (d) are the percentage MJO signal in SABER and COSMIC-2, respectively.

7. Statistical analysis- SD-WACCM-X (Temperature ~ 110 km and electron density ~300 km)

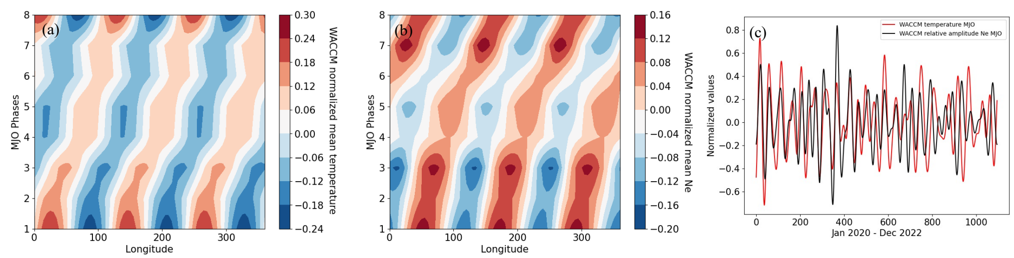

Figure 5: Average characteristics of the tidal MJO-response from SD-WACCM-X as a function of MJO-phases/locations, retrieved from years 2002–2022 (winter only: Dec, Jan, Feb, March) of Hovmoeller time series of DE3. (a) temperature, (b) electron density, (c) normalized values of WACCM temperature at longitude 0 deg and **WACCM electron density** at longitude 30 deg, similar to Figure 3c.

8. Conclusions

- For the first time, the response of the Madden-Julian Oscillation (MJO) signal in the ionosphere has been established using COSMIC-2 electron density measurements.
- The MJO signal structure in the neutral Mesosphere and Lower Thermosphere (MLT) aligns well with the ionosphere's electron density for the non-migrating tide DE3. **Modulation is ~30% of the mean tidal amplitude.**
- The **likely cause** for the connection between the tropospheric MJO phenomenon and the F region ionosphere is the **E-region dynamo.**
- Model (SD-WACCM-X) is in agreement with the observations which can be utilized for statistical analysis.
- **Predictability potential of ionospheric space weather variability due to recurring tropospheric weather.**

This work was supported through NASA's LWS program, grant 80NSSC22K1010.
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