Madden-Julian Oscillation Influence on Ionospheric Tides: Insights from COSMIC-2, SABER, and TIEGCM Simulations

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1. Abstract

MJO drives variability in ionospheric tides, linking tropospheric weather to space weather. COSMIC-2 GIS electron density shows MJO enhances DE3 by ~15% and modulates other tidal modes. SABER temperature tides (~110 km) show no lag with COSMIC-2 tides (~300 km), highlighting E-region dynamo coupling. Limited observations of the coupling processes motivate the use of TIEGCM, forced by SD-WACCM-X tides (with/without MJO), to separate contributions from plasma transport, photochemistry, and electrodynamics. Results reveal that electrodynamics—primarily the E-region dynamo—is the dominant driver, with field-aligned winds also critically contributing to F-region plasma redistribution.

➢ **Science Goal: Quantify how recurring tropical weather drives F-region ionospheric variability through tidal modulation.**

2. Introduction (MJO)

- Most important **recurring** tropical intraseasonal variability.
- Period: **30-96 days**.
- Direction: Eastward propagating.
- **Source of DE3 tides in troposphere** (Latent heat energy).
- Predictable ~ 2 weeks (RMM index).

3. Data Sources and Methodology

Observational Datasets

➢ **COSMIC-2 GIS:**
- Assimilated data using COSMIC-2 (RO) Radio Occultation, GNSS data poleward 24°, IRI model and Gauss-Markov filter.
- **Hourly electron density profiles** (5°x2.5°x20 km). 2-D Fourier fitting.
- **Tidal spectra every day.**

➢ **SABER:**
- Hough Mode Extension temperature tides.

Model Datasets

➢ **SD-WACCM-X:**
- Specified dynamics WACCM-X version v2.1 simulation with nudging of (MERRA-2) data from the surface up to ~50 km. **Tidal spectra every day.**

➢**TIEGCM:**
- **Lower boundary Nudged:** SD-WACCM-X tides from U, V, Z3, T.
- Run1: Tides with MJO, Run2: Tides without MJO.

MJO Extraction

COSMIC-2, SABER, SD-WACCM-X
↓
2-D FFT => Daily tides
↓
(30-96 days) Bandpass & eastward propagating filter => MJO

Nudging TIEGCM

Run1: Tides w MJO
Run2: Tides w/o MJO
↓
TIEGCM
↓
F-region tides and coupling mechanisms

➢ Model isolates MJO impact where global observations are limited, quantifying key coupling processes and advance predictive capability.

4. Results: Observed MJO Signal in DE3

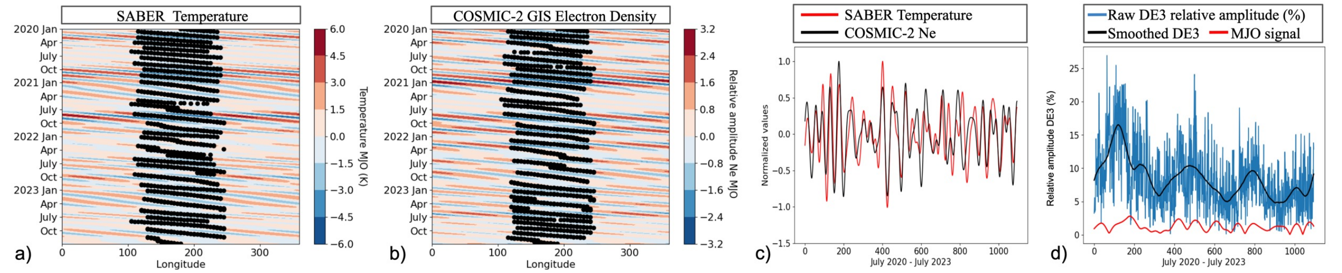

Figure 1: (a) SABER MJO signal (~110 km, 0°). (b) COSMIC-2 electron density (~300 km,15N); black dots shows the temporal phases of the extracted MJO signal. (c) Normalized **SABER** & **COSMIC-2 GIS** at 0° longitude. (d) DE3 amplitudes: **raw**, **smoothed**, and **MJO signal** (🚀 submitted to GRL).

➢ **~15%** DE3 variability at 300 km**; SABER-COSMIC-2 alignment → E-region dynamo dominates.**

5. TIEGCM MJO Signal in DE3

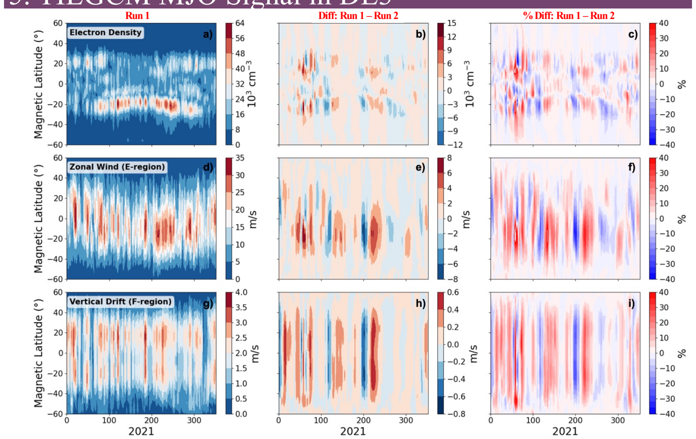

Figure 2: Columns: MJO (Run1), (Run1-Run2) Diff and Relative Diff (%). Rows: Ne (~300 km), zonal winds (~110 km), vertical drift (~300 km).

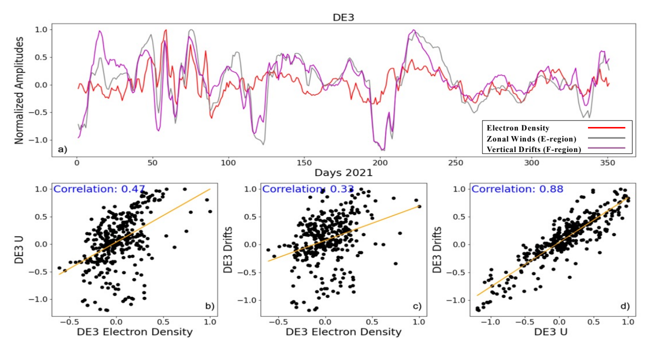

Figure 3: (a) Normalized DE3 for **Ne**, **zonal winds**, and **vertical drifts** (15° N; from Fig. 2, Column 2) (b) Wind–Ne, (c) Drift–Ne, (d) Drift–wind correlations.

➢ E-region dynamo leads MJO-ionosphere coupling **(Ne–wind: 0.47, Ne–drift: 0.32)**, but plasma transport and photochemistry might contribute.

6. Coupling Mechanisms

O^+ continuity equation *Transport of plasma

$$\frac{\partial O^+}{\partial t} = Prod. - Loss + Amb\_diff + Trans\_wind + Trans\_E\times B$$

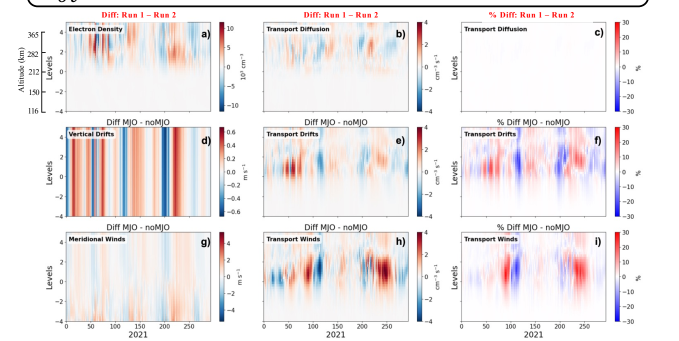

Figure 4: Cols 1–2: Diff, 3: Rel. Diff (%). (a,d,g): Ne, drifts, meridional winds. (b,e,h): Plasma transport by ambipolar diffusion, drifts, winds.

➢ Preliminary Result*: For DE3 **drifts dominate**, but wind-driven (field-aligned) transport also contributes, especially during seasonal transitions.

7. Conclusions

- **~15% MJO-driven variability** detected in DE3 tidal amplitude.
- **No lag** between MJO signal in SABER DE3 (110 km) and COSMIC-2 Ne (300 km) → **strong electrodynamic link**.
- **TIEGCM reproduces MJO signatures** in E-region zonal winds, vertical drifts, and F-region electron density.
- **E-region dynamo** likely mediates the coupling; Correlations: **Ne–zonal wind: 0.47, Ne–vertical drift: 0.32**.
- **Vertical drifts dominate** plasma transport; field-aligned winds also contribute.
- Results highlight the potential for **MJO-based predictability** of ionospheric variability.

Next steps: Analyze other tides and impacts on ionospheric mean state.

Observational results from SABER and COSMIC-2 GIS (Figure 1) are included in a submitted manuscript: ***Geophysical Research Letters* (2025GL115481).**
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