Zonally Symmetric Planetary Wave Signatures in F-Region Electron Density

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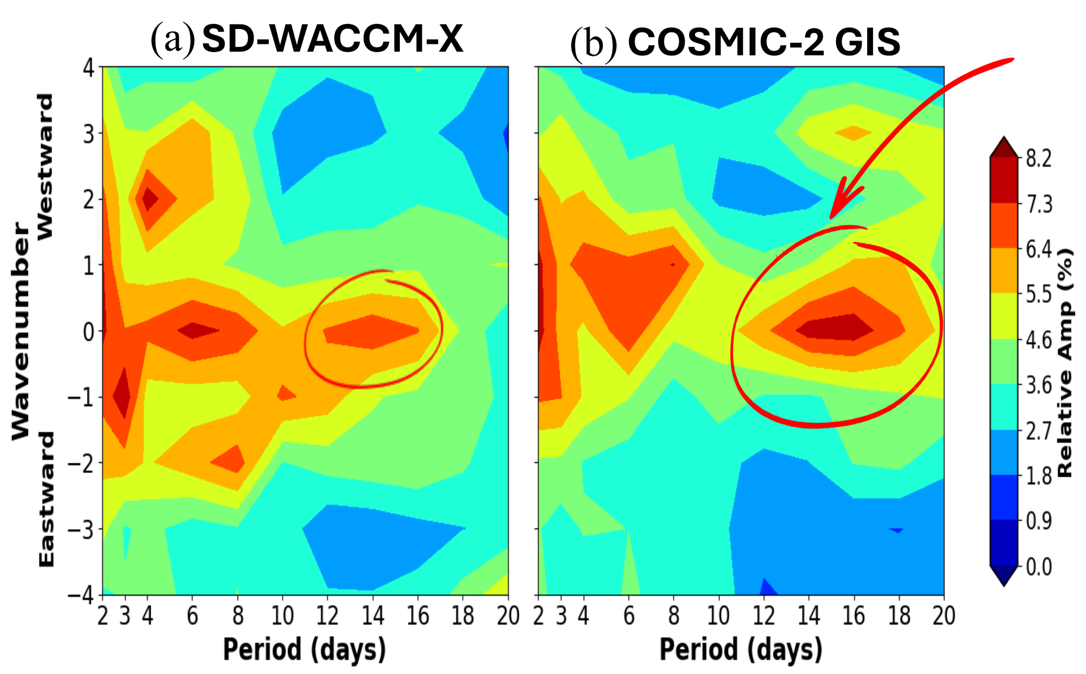
1. Abstract

Planetary waves (PWs) originating from the stratosphere and mesosphere induce significant oscillations in the F-region ionosphere at periods of 2–20 days. **Recent modeling predicts that about 30-50% of the global Ne variability occurs at PW periods. About half of this variability (roughly 15-25% of the total global Ne variability) is associated with unexpected zonally symmetric (S0) oscillations.** Using global COSMIC-2 GIS Ne observations, we find PW-period ionospheric variability consistent with these model predictions, including strong S0 oscillations. **These S0 ionospheric variations are very surprising since S0 winds at E-region dynamo altitudes do not generate electric fields (and hence vertical E×B drifts) because they do not contribute to the divergence of zonal currents.** The physical mechanism responsible for these S0 oscillations, therefore, remains unresolved. In this work, we use SD-WACCM-X nudged TIE-GCM simulations to investigate the role of Zonal conductivity gradients in driving PW S0 oscillations in F-region electron density

2. Introduction



Zonally symmetric – Breathing mode

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No zonal gradients in winds

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No zonal current divergence

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No generation of Electric field

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No E×B drift, No mapping to the F-region

- ➢ Consistent with model data.
- ➢ Half of the Ne variability is associated with S0 oscillations.
- ➢ ~30-40% of Ne variations in the ionosphere are due to PW_s.
- ➢ Tested model predictions using COSMIC-2 GIS data: **Manuscript Submitted to GRL**

Figure 1. Wavenumber versus period spectrum of relative amplitudes of PW oscillations in Ne at 300 km: (20⁰N, Avg (Mar, Apr, May)2020).

What causes roughly half of the Ne variability at PW periods to be associated with zonally symmetric (S0) oscillation?

Hypothesis: Zonal asymmetries in conductivities

3. Data Source

➢ TIE-GCM

- Thermosphere-Ionosphere Electrodynamics General Circulation Model
- Lower-atmosphere variability nudged with hourly SD-WACCM-X (a whole atmosphere model constrained by meteorological reanalysis)
- Variables used: Hall and Pedersen conductivity, Vertical drifts, Ne profiles, zonal and meridional winds

4. Methodology

PW Analysis in local time

Least square fitting method

$$\sum_{s=-4}^{4}\left[C_{s,\tau}\cos\left(2\pi\left(\frac{t_{UT}}{\tau}+s\lambda\right)\right)+S_{s,\tau}\sin\left(2\pi\left(\frac{t_{UT}}{\tau}+s\lambda\right)\right)\right]$$

$$Where,\quad C_{s,\tau}=A_{s,\tau}\cos\phi_{s,\tau}\,,\; S_{s,\tau}=A_{s,\tau}\sin\phi_{s,\tau}$$

s = zonal wavenumber and τ = period

- **For each location, the chosen local time (t_{LT}) is converted into the corresponding universal time via $t_{UT}=t_{LT}-\frac{\lambda_{geographic}}{15}$**

5. Hypothesis

Is E-region conductivity the primary driver of S0 oscillations?

From Ohm's law, Zonal current, $J_x^W=\sigma_H uB+\sigma_P vB\sin I$

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Around Dawn (5LT to 7LT) and dusk (17LT to 19LT) σ changes rapidly

Setting zonal gradients of the E-region conductivities to zero

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Enhancement of vertical drift disappears

Liu et al., JGR-Space Physics, 2010

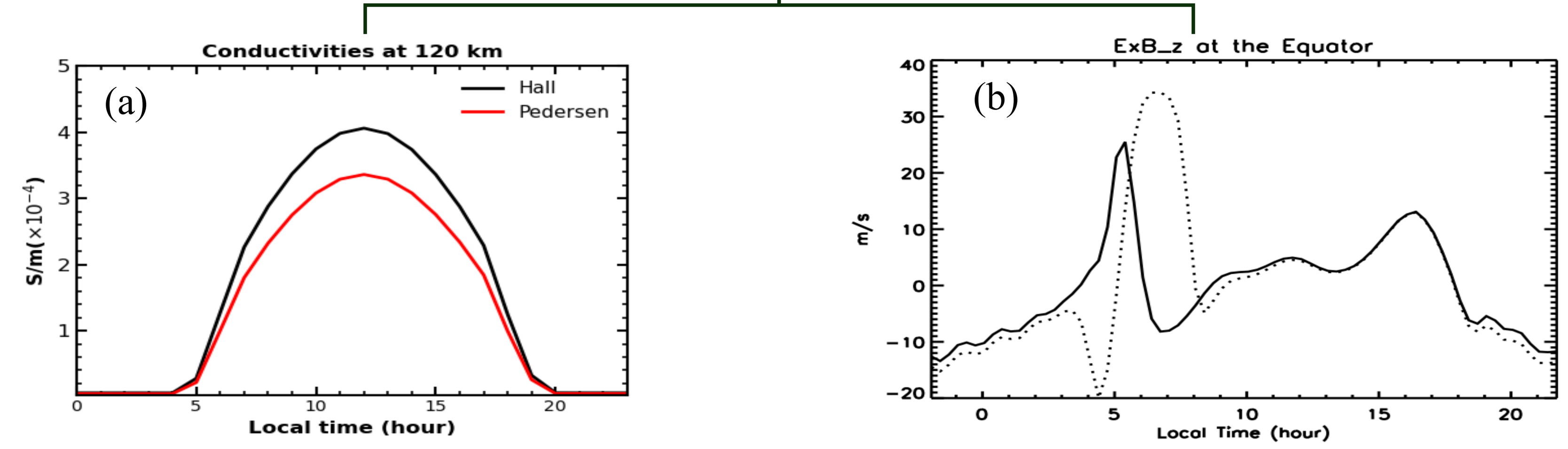

Figure 2. (a) Conductivities at 120 km from TIE-GCM (2020) (b) Vertical ion drift from TIME-GCM simulations. Solid: control run; dotted: run with E-region zonal conductivity gradients removed between 4–8 LT.

Zonal asymmetries in Conductivity

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Modify wind-driven currents

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producing current divergence

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generating polarization electric fields

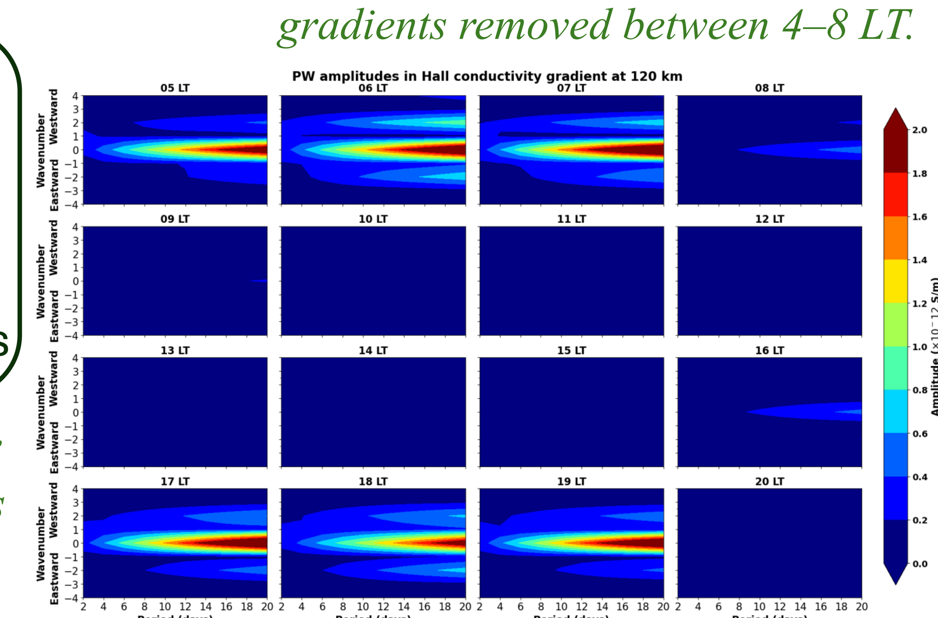

Figure 3. LT variation of Wavenumber v/s period spectrum of PW oscillations in Hall conductivity gradient at 120 km: (20⁰N, Avg (Mar, Apr)2020).

6. Results

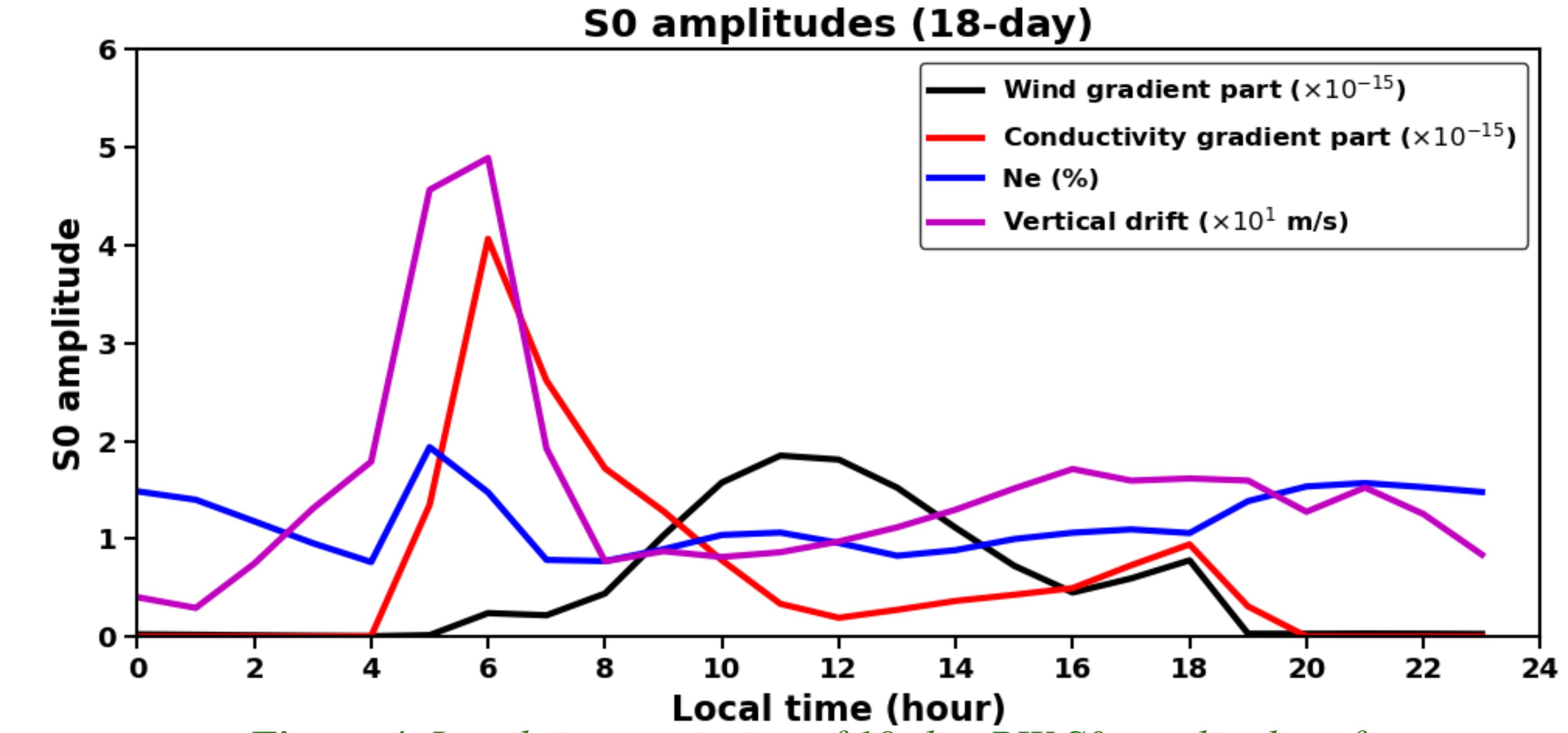

Figure 4. Local-time variation of 18-day PW S0 amplitudes of conductivity-gradient contribution (red, 120 km) and wind-gradient contribution in zonal current divergence (black, 120 km), vertical drift (pink, 300 km), and F-region relative Ne (Relative to 27-day running mean, blue, 350 km) from TIE-GCM at 20⁰N averaged over March–April 2020

S0 Oscillations

Conductivity gradient contribution to Zonal Current divergence, $-uB\frac{\partial\sigma_H}{\partial x}+vB\sin I\frac{\partial\sigma_P}{\partial x}$

Wind gradient contribution to Zonal Current divergence, $-\sigma_H B\frac{\partial u}{\partial x}+\sigma_P B\sin I\frac{\partial v}{\partial x}$

vertical E×B drifts

S0 conductivity - Peaks at 4-8 LT and16-19 LT

S0 winds – No zonal current divergence No vertical E×B drifts

Contributes to F-region Ne variability

Key point: **Dawn/dusk conductivity gradient peaks align with S0 drift, highlighting the role of conductivity in S0 oscillations.**

8. Conclusions

- ➢ Zonal conductivity gradients appear to play an important role in generating S0 oscillations.
- ➢ Dawn/dusk conductivity-gradient peaks align with S0 vertical drift, linking E-region to F-region Ne variability.
- ➢ Another possible mechanism for S0 oscillations is ion–neutral coupling associated with the offset between the geographic and magnetic poles and will be investigated in future work.

References

- H.-L. Liu, W. Wang, A. D. Richmond, and R. G. Roble. "Ionospheric variability due to planetary waves and tides for solar minimum conditions". In: *Journal of Geophysical Research: Space Physics* 115.A6 (2010). url: https://agupubs.onlinelibrary.wiley.com/doi/abs/10. 1029/2009JA015188.
- Baiju, S., J. Oberheide, X. Lu, and D. Aggarwal, "Planetary Wave Signatures in F-Region Electron Density from COSMIC-2 Global Ionospheric Specification" Geophys. Res. Lett., 2026GL123835, submitted, 2026