Planetary wave signatures in F-region Electron Densities

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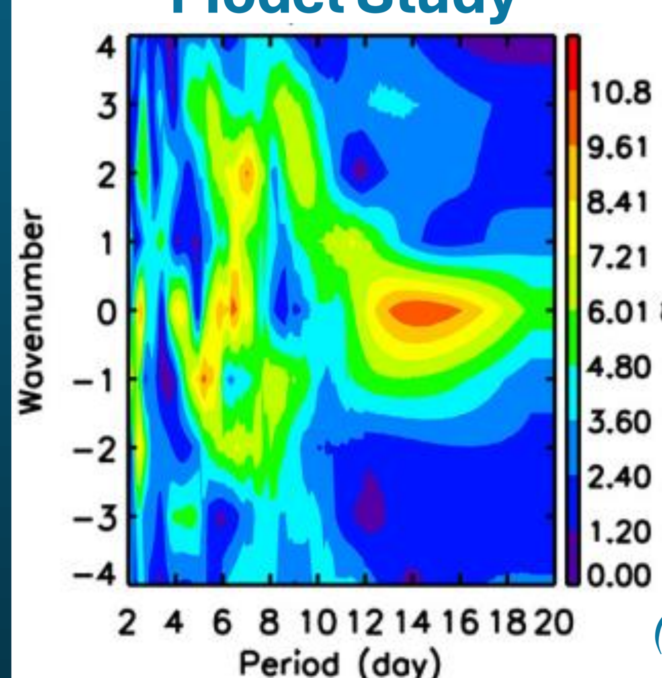
1. Abstract

Planetary waves (PWs) originating from the stratosphere and mesosphere induce significant oscillations in the F-region ionosphere at periods of 2–20 days. PW signatures in the F-region remain largely unexplored from a global observational perspective, with most studies relying on model simulations. Models predict that a key mechanism is the second order non-linear interaction between tides and PWs below 100 km to map the PW signal into the E-region, and their coupling to the ionosphere through dynamo generation of electric fields. Models also predict electron density (Ne) variability at PW periods associated with zonally symmetric oscillations (S0) that cannot be due to E-region dynamo. The mechanism remains an open question. This work aims to test these predictions using satellite data. We use electron density profiles from COSMIC-2 GIS data and temperature profiles from SABER/TIMED to delineate PW amplitudes in the F- and E-regions. We also present a wavelet filtering technique to remove solar and geomagnetic effects, allowing clearer identification of Ne oscillations purely due to planetary waves.

2. Introduction

Model Study



(Forbes et al., JGR-Space Physics, 2018)

Figure 1. *Wavenumber versus period spectrum of the ΔNe residuals at 325 km (20⁰S, 0000h)*

- ±30-50% in F-region Ne at a particular LT occurs as a result of PW-modulated tides
- Roughly half of the Ne variability at PW periods is associated with zonally symmetric (S0) oscillations.

- **Our work aims to test these model predictions of F-region ionosphere oscillation at Planetary Wave (PW) periods using observational data.**

SQ1. What are the sources of PW signatures observed in the F-region?

SQ2. What causes roughly half of the Ne variability at PW periods to be associated with Zonally symmetric (S0) oscillation?

- **Minimize solar and geomagnetic signal contamination in the F-region PWs using a wavelet filtering technique.**

3. PW-Tide Interactions

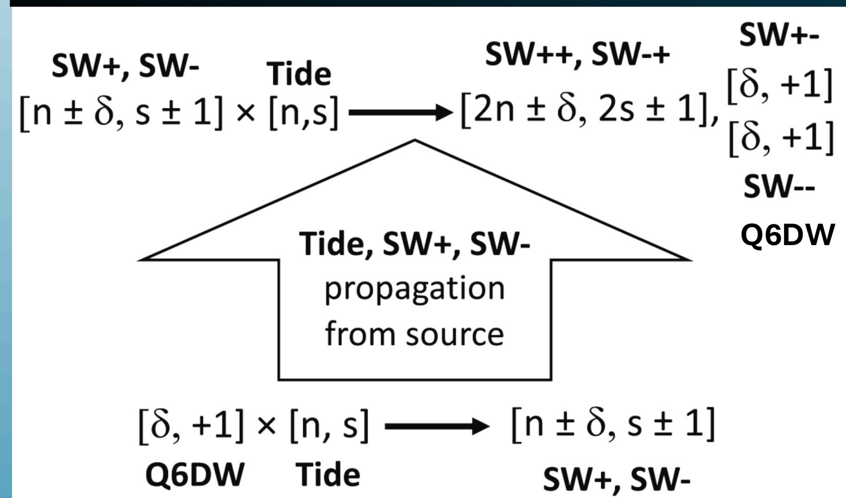


Figure 2. *Schematic representation of the multi-stage process for secondary excitation of the Q6DW above ~110 km (Forbes et al., JGR-Space Physics, 2020)*

Nonlinear interaction between tides and PW below 100 km leads to two Secondary tidal waves (SWs)

Frequencies = Sum and Difference of the primary waves - SW+, SW-

Propagate upwards (thermosphere) and interact with the same tide to produce PW

4. Data Sources

➢ COSMIC-2

Hourly GIS electron density profiles with a latitude/longitude resolution of 5 x 2.5°, and vertical resolution of 20 km.

➢ TIMED - SABER

Temperature profiles between 20 to 110 miles

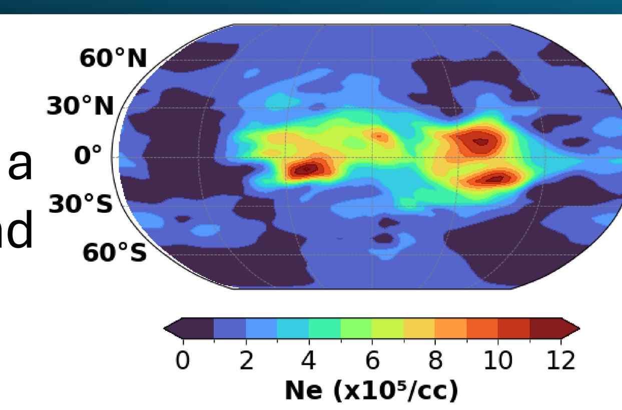


Figure 3. *Global distribution of F-region Ne at 300 km on 14 April 2020 at 17:00 UT*

5. Methodology

PW Analysis

Least square fitting method

The fit equation,

$$\sum_{s=-4}^{4} A_{s,P}\cos\left(2\pi\left(\frac{t}{P}+s\lambda\right)-\phi_{s,P}\right)$$

Where, s = zonal wavenumber and P= period

To minimize solar and geomagnetic contamination, wavelet filtering is applied to F-region Ne data.

Wavelet Filtering

STEP 1: Wavelet Transform of Ne, Kp index, and $\Delta F10.7_{rel}$

$$W_\psi f(s,\tau)=\frac{1}{\sqrt{|s|}}\int f(t)\psi^*\frac{\tau-t}{s}dt$$

STEP 2: Significant Wavelet coefficients in the smoothed wavelet spectra of the $\Delta F10.7_{rel}$, the Kp index, are set to zero in the Ne wavelet spectrum.

STEP 3: The filtered signal is reconstructed from the modified Ne wavelet spectrum by summing the real part of the wavelet transform over all scales.

$$f(t)=\frac{\delta j\,\delta t^{1/2}}{C_\delta\,\psi_0(0)}\sum_{j=0}^{j}\frac{\Re\{W_\psi(s_j)\}}{s_j^{1/2}},$$

Where, C_δ = reconstruction factor, $\psi_0(0)=\pi^{-1/4}$, s = scales, δj= 0.125

(C. Borries et al., J. Geophys, 2010; Torrence and Compo, 1998)

6. Results: 1 (Wavelet Filtering)

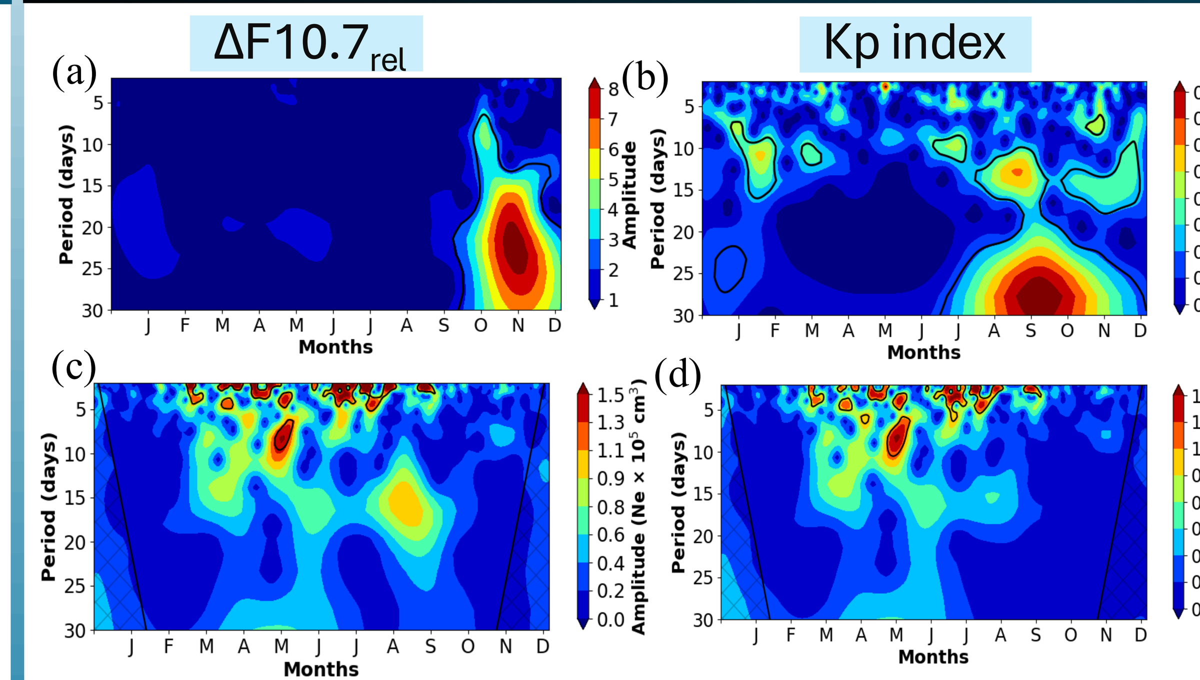


Figure 4. *Wavelet amplitude spectra of **(a)** $\Delta F10.7_{rel}$ **(b)** the Kp index, **(c)** F-region Ne at 75°W, 20°N, and **(d)** the corresponding filtered Ne signal for 2020. Shadings encapsulated by black lines are 95% significant amplitudes.*

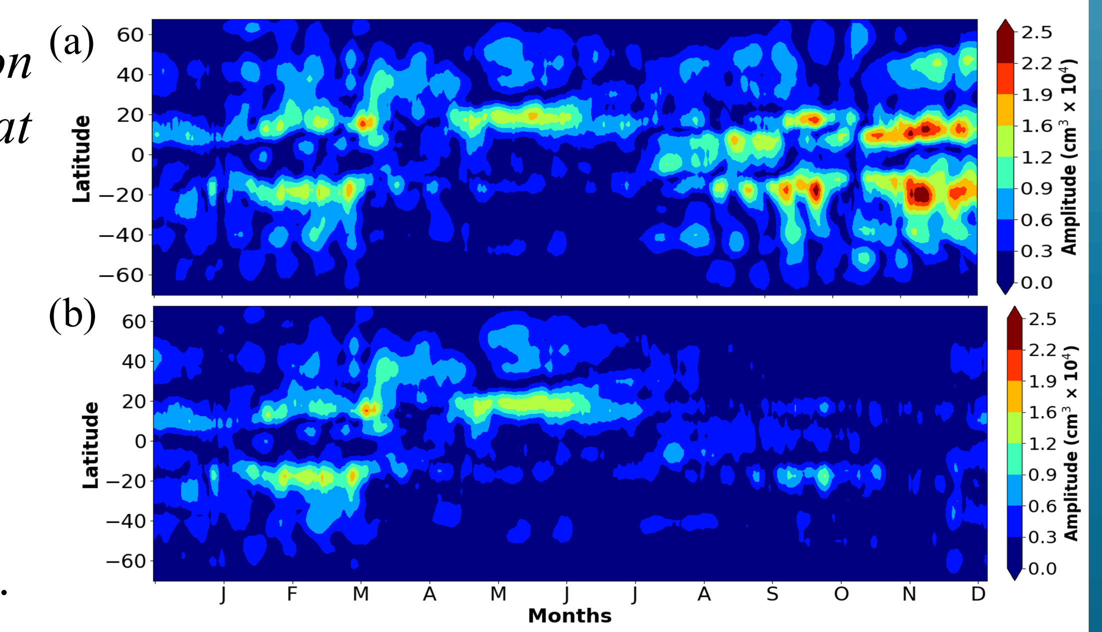


Figure 5. *Latitude–time variation of the **Q16DW1** in F-region Ne at 300 km for 2020.*
(a) *Amplitude spectrum derived from raw Ne data.*
(b) *Amplitude spectrum derived from filtered Ne data (Solar and geomagnetic effects removed using wavelet filtering).*

7. Results: 2 (Observed PW Spectra)

➢ E-region Temperature

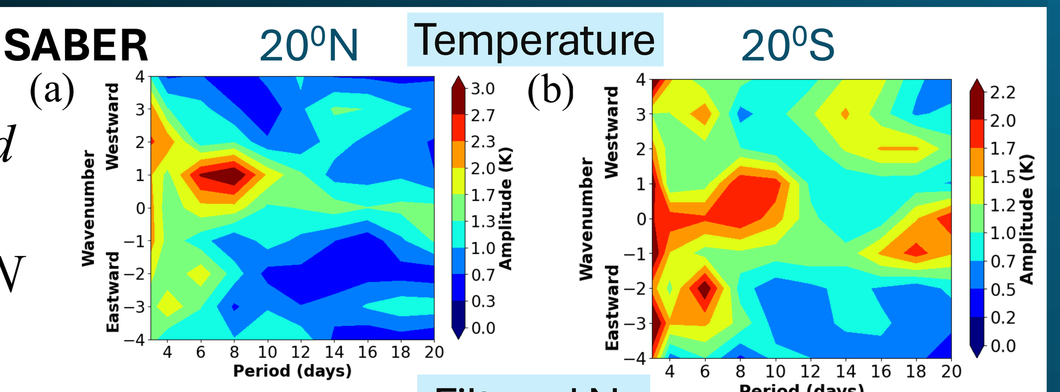


Figure 6. *Wavenumber v/s period spectra of PW oscillations in temperature at 100 km at **(a)** 20°N & **(b)** 20°S (April 2020)*

➢ F-region Electron density

- Consistent with model data
- The majority of Ne variability is associated with S0 oscillations
- ~30-40% of Ne variations in the ionosphere are due to PW_s

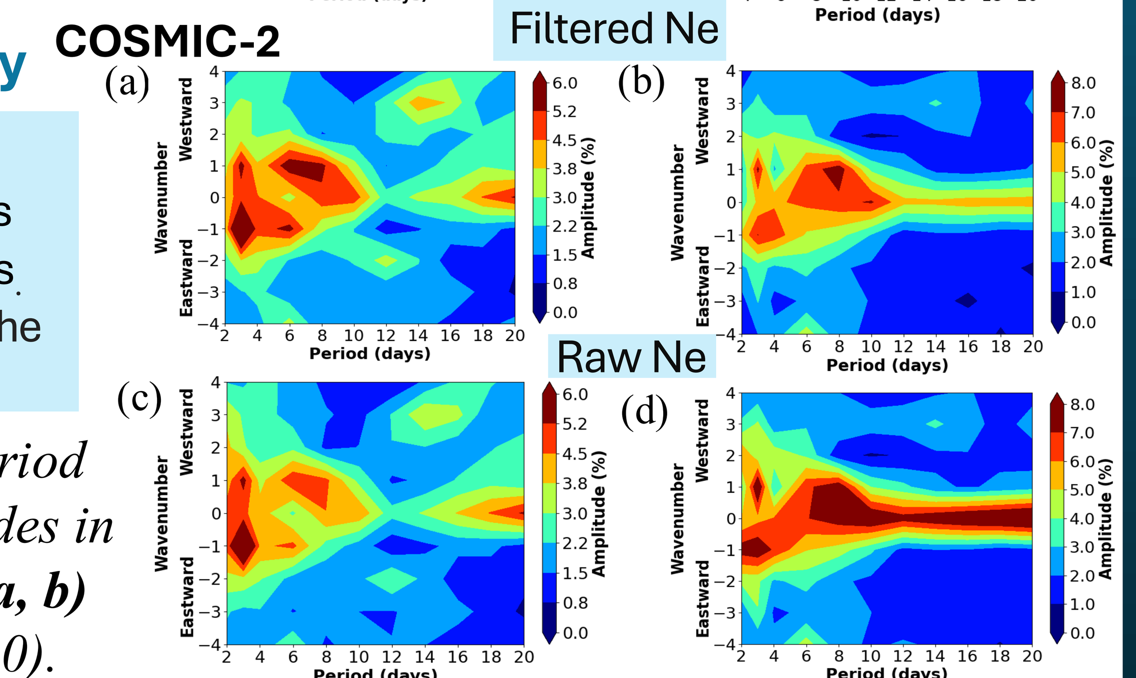


Figure 7. *Wavenumber v/s period spectra of PW relative amplitudes in Ne at 300 km: using filtered **(a, b)** and raw **(c, d)** Ne (April 2020).*

8. Conclusions and Future steps

- **Model Consistency:** The observational results align well with model predictions.
- ~30-40% of observed Ne variations are linked to planetary wave activity, with S0 oscillations playing a major role.
- **Solar Variability:** Solar signals contribute to PW oscillations in the ionosphere to some extent, but they are not the sole driving factor.
- **S0 Oscillations:** They are possibly due to conductivity, though the exact mechanisms remain unclear and need further investigation.

Future Steps: Better understand the drivers behind zonally symmetric oscillations and investigate more about the PW-tide interactions.