Response of the F-region ionosphere to variations in the polar stratospheric vortex

Deepali Aggarwal[1], Jens Oberheide[1] ,Nicholas Pedatella[2] ;Clemson University[1] ,UCAR[2]

1. Abstract

Space weather variability driven by lower and middle atmosphere dynamics has been studied for some time, including the effects of Sudden Stratospheric Warmings (SSW), a temporary break-up of the polar vortex in the stratosphere. However, SSW events are relatively rare, making it challenging to understand the imposed ionospheric variations statistically. In contrast, the strength of the stratospheric polar vortex for which the Northern Annual Mode (NAM) index is being used as a proxy, can help us to better understand and predict lower atmospheric impacts on the F-region ionosphere from a statistical perspective as the NAM can be predicted a few weeks in advance. In this poster, the tidal spectra of F-region ionosphere electron density obtained from hourly COSMIC-2 Global Ionospheric Specification (GIS) data assimilation are correlated with the NAM index. Previous work focused on the migrating semidiurnal tide showed a strong anti-correlation with the NAM index, consistent with a stronger E-region wind dynamo during disturbed vortex conditions. We now extend these initial results to non-migrating semidiurnal tides and diurnal tides, with emphasis on the winter months of the years 2020-2023.

2.Data and Methodology

❖ *COSMIC-2* :

- Six satellite constellation launched on 25 June 2019, 24° inclination, now at 530 km orbit height and at 60° orbit plane separation.
- Hourly GIS electron density profiles with a latitude/longitude resolution of 5 x 2.5°, and vertical resolution of 20 km using Gauss-Markov filter. GIS data poleward of 24° use GNSS data.
- Mapped into apex magnetic coordinates.
- 2-D Fourier fitting of the GIS electron density at each altitude and magnetic latitude. **Tidal spectra every day.**

❖ *NAM : Northern Annual Mode.* Index to measure for strength of polar vortex - from geopotential difference between polar and middle latitudes, at 10 hPa. Strong vortex: positive NAM index; weak vortex: negative NAM index

3. COSMIC-2 tidal spectra

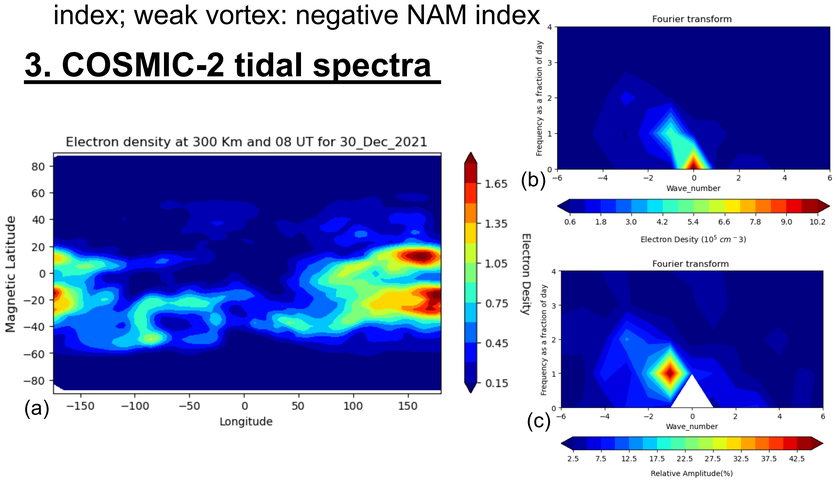

Fig 1: (a) Global distribution of electron density at UT 08, (b) Tidal electron density spectrum at 15 N magnetic latitude (c) Same but with relative amplitude (w.r.t. zonal mean at same latitude). Shown are results at 300 km for 30 Dec 2021. See Oberheide (2022) for details of tidal diagnostics.

Tidal Spectra cont.

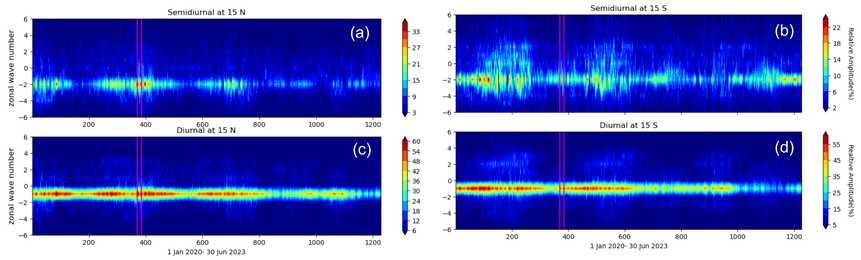

Fig 2: (a) Time evolution of (a) semidiurnal and (c) diurnal spectra at 15N at 300 km. 2020 – Jun 2023 are plotted (b),(d) Same but for 15S. Note: Negative wavenumbers are westwards propagating tides and positive wavenumbers are eastward propagating waves. Note: Purple lines indicate the SSW period

- The strongest signal comes from the migrating semidiurnal (SW2) and migrating diurnal (DW1) tides. Their variation with the NAM as a measure for the stratospheric polar vortex strength is discussed in the following sections.

3. SW2 time evolution

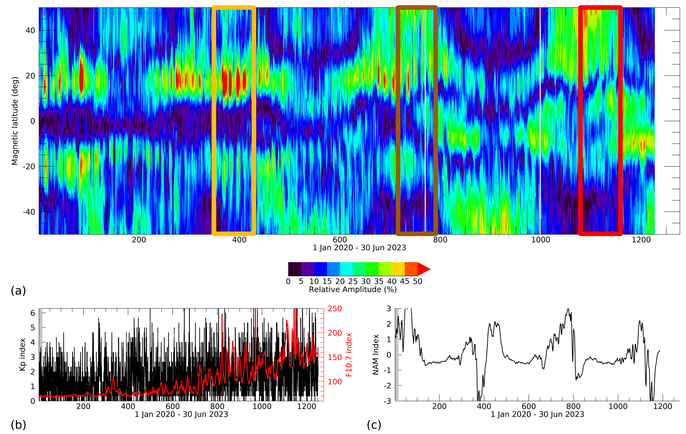

Fig 3 (a) Relative Amplitude SW2 2020 - June 2023, (b) kp-index (black), F10.7 (red), (d) NAM index. **Note: 15 Dec 2020 -01 March 2021, 15 Dec 2021 - 01 March 2022, 15 Dec 2022 - 01 March 2023.**

- The increase in solar flux produces more semi-annual changes in low latitude SW2 which is expected from O/N2 increases.
- Solar and lower atmosphere forcing compete to the right of the brown box but SW2 up to brown box more likely to be driven by E-region dynamo.
- We will only use data in orange and brown box for the following correlations.

4. Response to polar vortex strength

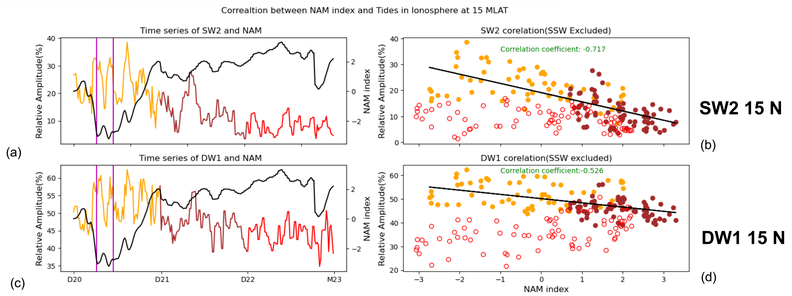

Fig 4: (a) SW2 relative amplitude for winters of 2020-2023 **15 Dec 2020 -01 March 2021, 15 Dec 2021 - 01 March 2022, 15 Dec 2022 - 01 March 2023.** at 300 km and 15 N magnetic latitude. The black line is the NAM at 10hPa. (b) Correlation of relative amplitude with NAM index (**excluding the SSW period 04 - 19 Jan21**). (c) & (d) Same but for DW1. Note: Purple lines indicate the SSW period, red circles are the excluded (high solar flux) data points for 2022/23.

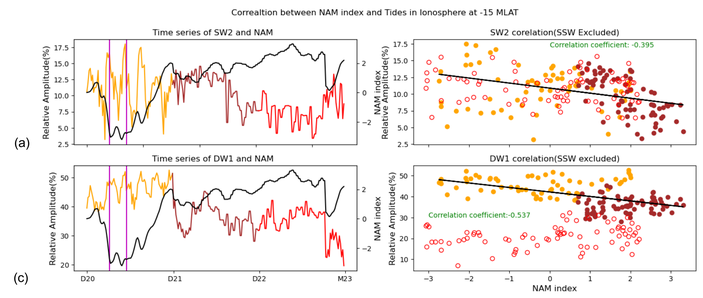

Fig 5: Same as Fig 4 but for 15 S magnetic latitudes.

- Strong anti-correlation between NAM and tidal components **in both hemispheres** at EIA latitudes when the solar flux is quite low.
- This suggests tidal wind variations in the E-region dynamo are the main driver (see interpretation below).
- The correlation coefficient between NAM at 10 hPa and SW2 is -0.717, and DW1 has a correlation coefficient of -0.526, when the 2020/21 SSW is excluded.
- The corelations increase if SSW is included : -0.744 for SW2 and -0.584 for DW1 as expected.

Interpretation

- Strength of polar vortex changes E-region zonal wind SW2. Weaker vortex = larger tides (Fig. 6)
  - E-region dynamo then transmits tidal signal into F-region (both hemispheres)
  - Response to vortex strength masked by in-situ tidal forcing during increased solar activity.

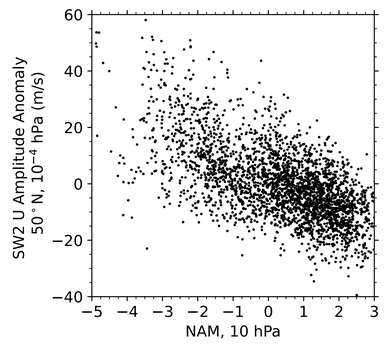

Fig 6: From (Pedatalla and Harvery, 2022) SD-WACCM-X daily SW2 amplitude anomaly in zonal wind at 50°N and 10−4 hPa versus the daily Northern Annular Mode (NAM) at 10 hPa. Results are restricted to the time period of 15 December to 1 March.

Conclusions

- Strength of NH stratospheric polar vortex strongly modulates F-region tides at EIA latitudes.
- Strong anticorrelation of -0.72 for SW2 (SSW excluded, low F10.7)
- DW1 also increases during weak polar vortex conditions but overall effect is smaller because DW1 is more sensitive to solar flux.
- COSMIC-2 GIS data are a powerful tool to study whole atmosphere tidal coupling on “weather” timescales.
- Nonmigrating tidal results: Talk on June 29 at 14.26-14:38 PDT, Room West Coast.

References:
- Oberheide, J. (2022). Day-to-Day Variability of the Semidiurnal Tide in the F-Region Ionosphere During the January 2021 SSW From COSMIC-2 and ICON. *Geophysical Research Letters*, *49*(17), e2022GL100369.
- Pedatella, N. M., & Harvey, V. L. (2022). Impact of strong and weak stratospheric polar vortices on the mesosphere and lower thermosphere. *Geophysical Research Letters*, *49*(10), e2022GL098877.

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Contact: deepala@clemson.edu