The Impact of Stratospheric Vortex Variability and the Madden Julian Oscillation on Short Term and Intraseasonal Thermospheric O/N2 Variability in GOLD and ICON

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Introduction

O/N2: The column density ratio of atomic oxygen to molecular nitrogen.
→ Important tracer for general circulation/wave dynamics, neutral density, and the composition of the **thermosphere**.
Sensitive to: geomagnetic activity and "forcing from below."

→ Forcing from below: in-situ generated tides and upward propagating waves

Tides and gravity waves are modulated by the **polar vortex** (tracked by the **NAM** index) and the **Madden Julian Oscillation** on *day-to-day* and *intraseasonal* time scales.

GOLD and **ICON** satellites provide favorable data sampling to study the impacts of both phenomena on thermospheric O/N2.

The predictability of MJO and NAM has been demonstrated in the lower atmosphere. **Predictability of the IT via predictions of MJO and NAM** are possible if the impact of both phenomena on the IT is well characterized.

Here, we quantify the impacts of MJO and NAM on thermospheric O/N2.

O/N2, NAM Correlation

We apply a **90-day highpass filter** to GOLD O/N2 measurements from December 2018 to June 2023 at UT ~ 14:00. We correlate the O/N2 residuals with the NAM index at 10 hPa during **geomagnetically quiet** (Kp <= 2.0) **winter** (DJF) times at each lat-lon gridpoint. O/N2 is **time-lagged** by **8 days** relative to NAM.

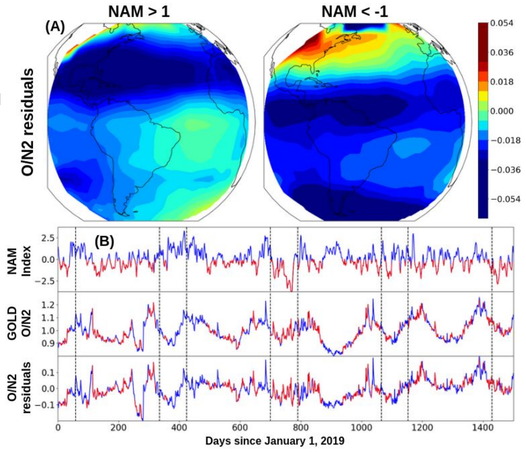
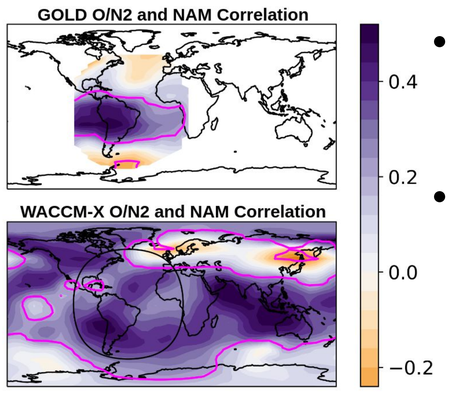


Fig. 1A: O/N2 residuals grouped together by NAM index.
Fig. 1B: NAM index at 10 hPa (first row), Mean GOLD O/N2 from +/- 20 degrees latitude (second row), 90-day high pass filtered O/N2 (third row). Dashed vertical lines demarcate winter time.

- O/N2 ratio is **depleted** at **middle and low latitudes** during **negative NAM** (relative to positive NAM).
- **Variations are small**: unfiltered O/N2 ranges from 0.8 to 1.25.



- Fig. 2A: Correlation map of GOLD O/N2 with the NAM index. The pink line encloses regions with statistically significant correlations.
- Fig. 2B: Correlation map of SD-WACCM-X O/N2 with the NAM index. The pink line encloses regions with statistically significant correlations.

- O/N2 is **positively correlated** with NAM at **low and mid-latitudes** with a maximum value of -0.54 in GOLD and -0.51 in SD-WACCM-X
- O/N2 is **negatively correlated** with NAM at **high latitudes**, with a maximum value of +0.20 in SD-WACCM-X

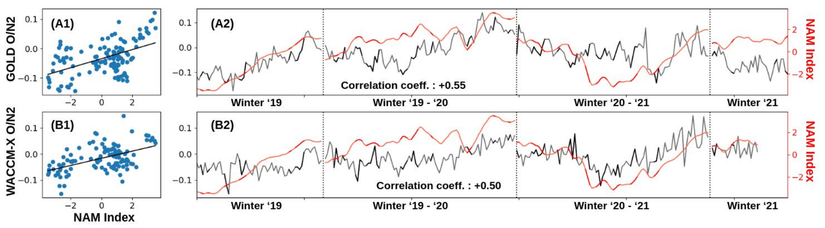
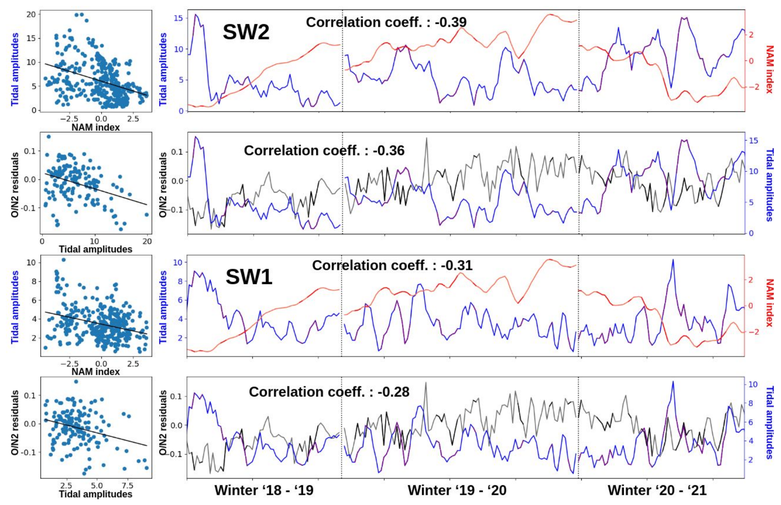


Fig. 3A1 and A2: GOLD O/N2 as a function of the NAM index with a line of best fit. GOLD O/N2 residual time series plotted with the NAM index. Fig. 3B is the same, except for WACCM-X O/N2.

Relationship between O/N2, NAM, and Tides



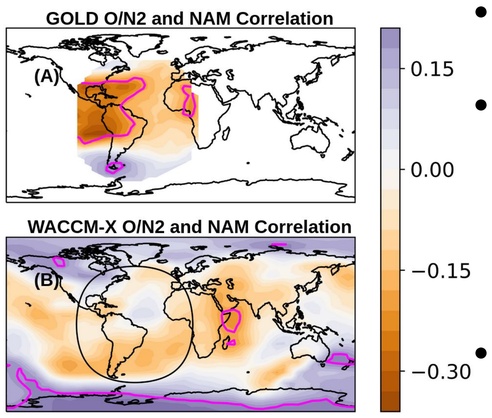
Westward Migrating Tides:

Negative NAM = Weak Polar Vortex
→**increasingly westward** zonal mean **zonal background winds**
→**enhancements** in **DW1** and **SW2** at low- and mid- latitudes
(hence: negative correlation between NAM and tides)
→dissipation of enhanced tides
→**poleward transport** of [O] poor air from low- to high-latitudes
→decrease in O/N2 ratio at low latitudes
(hence: positive correlation between NAM and O/N2)

Nonmigrating Tidal Components:

Interactions between **SPWs** and **migrating tides** give rise to **nonmigrating tides**
(e.g., SPW1 + SW2 = SW1, SW3,
in general: SPW + migrating tide = stationary tide)
→enhanced SPWs cause the weakening of the polar vortex
→enhanced migrating tides strengthens stationary tides
(hence: negative correlation between NAM and tides)

Short term O/N2, NAM Correlation



- Fig. 5A and B: Similar to Fig. 2, except using a 30-day high pass filter
- < 30 day O/N2 perturbations are **negatively correlated** with NAM at **low and mid-latitudes** with a maximum value of -0.36 in GOLD and -0.24 in SD-WACCM-X
- O/N2 perturbations are **positively correlated** at high latitudes

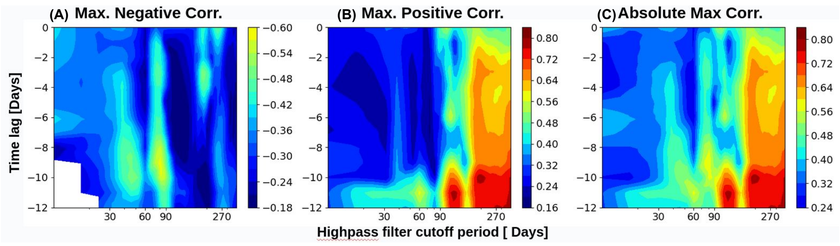


Fig. 6A: Maximum anti-correlation between GOLD O/N2 and the NAM index for various high pass filters and time lags. 6B: maximum correlation, 6C: absolute maximum correlation.

- On **intraseasonal time scales and longer**, O/N2 is **correlated** with O/N2, but anti-correlated on shorter time scales

Madden Julian Oscillation

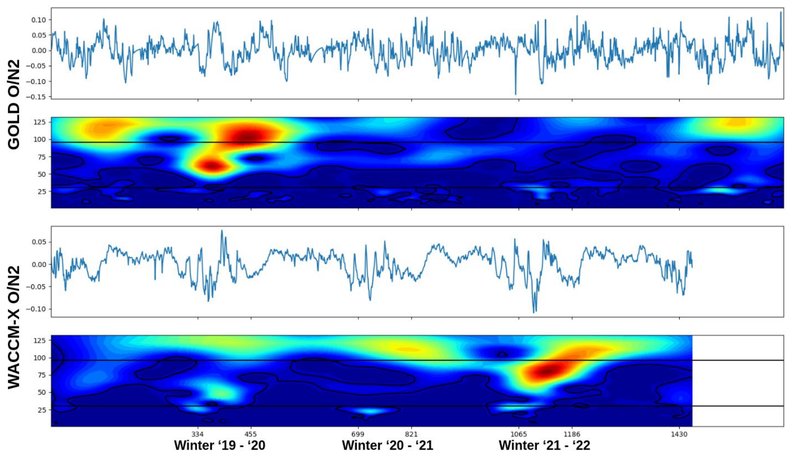


Fig. 7: 120-day high-pass filtered O/N2 from GOLD (top row) and SD-WACCM-X (third row), with the corresponding wavelets (second and fourth rows.) The black vertical lines demarcate the regions with MJO periods (between 36 and 90 days)

- **Strong MJO periodicity** is observed during **winters**, especially Winter 2018-2019 in GOLD and SD-WACCM-X and Winter 2020 - 2021 in SD-WACCM-X

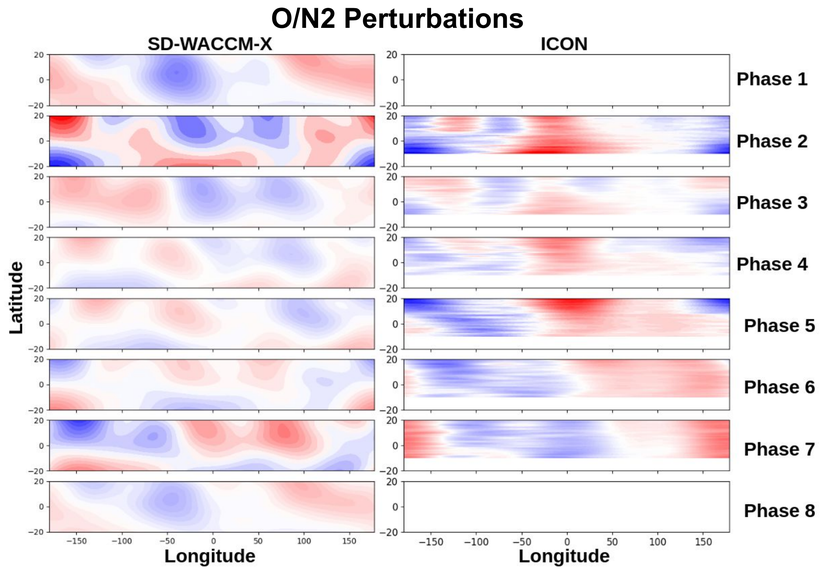


Fig. 8: SD-WACCM-X (left) and ICON FUV (right) O/N2 perturbations grouped together by phase after filtering for MJO signals via a 2D Fourier transform

- MJO events are defined as times in which at least **5 consecutive days** have an **MJO RMM index >= 1**.
- Analysis is restricted to winter times (**DJFM**)
- **Eastward propagating structures** are clearly visible in both SD-WACM-X and ICON
- Opposite Phases are inverses of one another (e.g., phases 2 and 6, phases 3 and 7)

Conclusions

- The influence of the polar vortex on the thermosphere is demonstrated by the strong correlation of O/N2 with the NAM index
- The O/N2 ratio is strongly correlated with NAM on intraseasonal time scales, while being significantly anti-correlated with NAM on short (<30 days) time scales
- Salient MJO signals are identified in ICON and SD-WACCM-X, which contributes the intraseasonal variability of O/N2
- Anti-correlations between NAM and various tidal components provide evidence for the mechanism of polar vortex influence on the IT, which is summarized in the green box

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