Determining the Best Altitude of NAM and SAM Indices for Assessing Polar Vortex Influence on the Ionosphere-Thermosphere System

Arunima Prakash[1], V. Lynn Harvey[2], Katelynn Greer[2], Jeffery Thayer[1] and Luis Navarro[1]
[1]SWx TREC, Ann & H.J. Smead Department of Aerospace Engineering Sciences at the University of Colorado, Boulder.
[2]Laboratory for Atmospheric and Space Physics, Boulder.

Background:

What is NAM? Northern Annular Mode (NAM) is a climate pattern characterized by a seesawing pressure gradient between high and mid-latitudes and is commonly used to quantify the Arctic vortex strength. **Why is the NAM (SAM) important?** The polar vortex plays a role in the generation and modulation of gravity waves that reach the I-T, and the extent to which the waves couple to the upper atmosphere depends on vortex strength. **Currently the NAM is arbitrarily computed at the 10 hPa pressure levels in most studies.**

Science question: **What is the best altitude to compute the NAM (and SAM) altitude to predict I-T variability?**

Methodology:

- Compute NAM (and SAM) indices at all pressure levels from 100-0.015 hPa using MERRA-2
- Correlate MERRA-2 zonal mean zonal wind at 77 km, MLS temperature at 95 km and GOLD O/N_2 with 3-D NAM/SAM
- Identify the altitude where the NAM/SAM (vortex strength) is most highly correlated with variability in the upper mesosphere and thermosphere.

Data and NAM (and SAM) Derivation:

MERRA-2: NASA's Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) (Bosilovich et al., 2015) is used for this analysis. MERRA-2 is produced 4x daily, with horizontal resolution of 0.5° × 0.625° and 72 pressure levels starting from the Earth's surface to 0.015 hPa (~77 km).

MLS: NASA's Microwave Limb Sounder 5.1 temperature data are used here (Livesey et al., 2022). In the mesosphere, the vertical resolution is 7-12 km. Precision (bias) estimates for individual temperature profiles range are -9K at 0.001 hPa (~90 K).

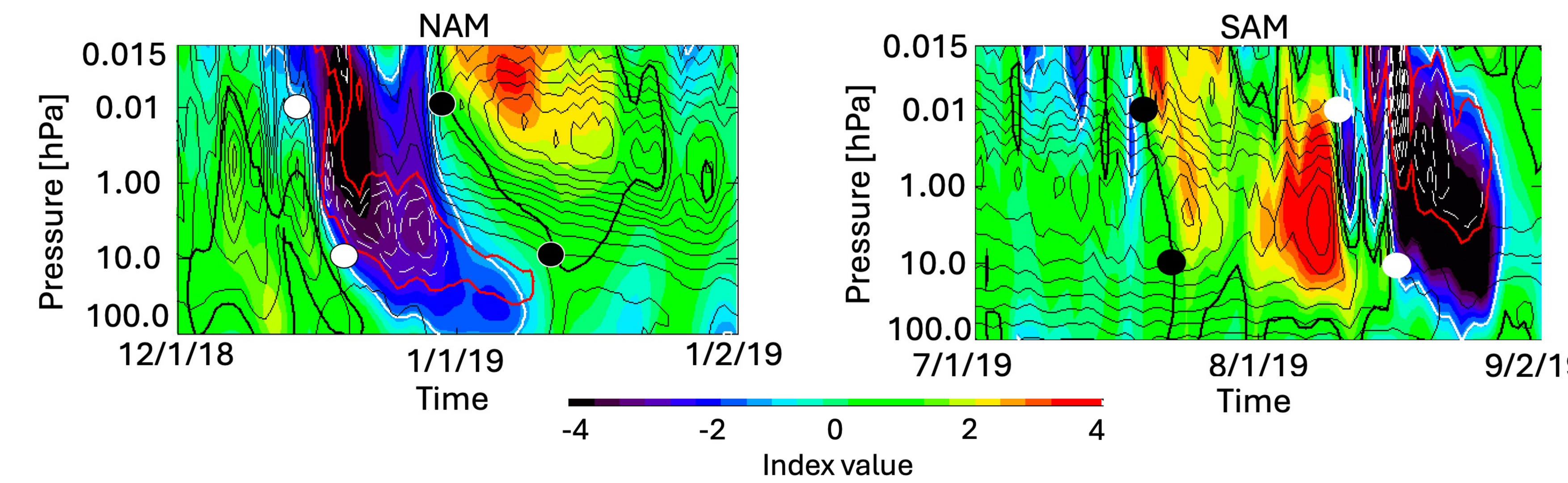
GOLD: Global-scale Observations of the Limb and Disk (GOLD) data uses Far Ultraviolet (FUV) imager instrument measuring the OI (135.6 nm) and N_2 (132-162 nm). The O/N_2 ratio is derived from OI and N_2 with spectral resolution of 0.2 nm. We use O/N_2 at 12 LT for days with $K_p < 2$ and remove the seasonal variations from the data by subtracting the following function (Oberheide et al., 2019):

$$F\left(Seasonal_{O/N_2}\right) = c_0 + mt + a_1 \sin\left(\frac{2\pi}{t\tau_1}\right) + a_2 \sin\left(\frac{4\pi}{t\tau_2}\right)$$

Calculating NAM (and SAM) (Gerber and Martineau, 2018)**:**

1. Calculate daily geopotential height $Z(t,\lambda,\phi,p)$
2. Smooth the annual daily time series and subtract from $Z(t,\lambda,\phi,p)$ to get anomalous height $Z'^{(t,\lambda,\phi,p)}$
3. Compute global mean geopotential height $\bar{Z}'^{global}$ and boreal polar cap heights $\bar{Z}'^{NH}$ and $\bar{Z}'^{SH}$
4. Compute raw NAM and SAM: $-(\bar{Z}'^{NH} - \bar{Z}'^{global})$ and $-(\bar{Z}'^{SH} - \bar{Z}'^{global})$
5. Compute NAM and SAM: $\frac{-(\bar{Z}'^{NH} - \bar{Z}'^{global})}{\sigma_{RAW\ NAM}}$ and $\frac{-(\bar{Z}'^{SH} - \bar{Z}'^{global})}{\sigma_{RAW\ SAM}}$

Is 10 hPa the best altitude for using NAM and SAM?



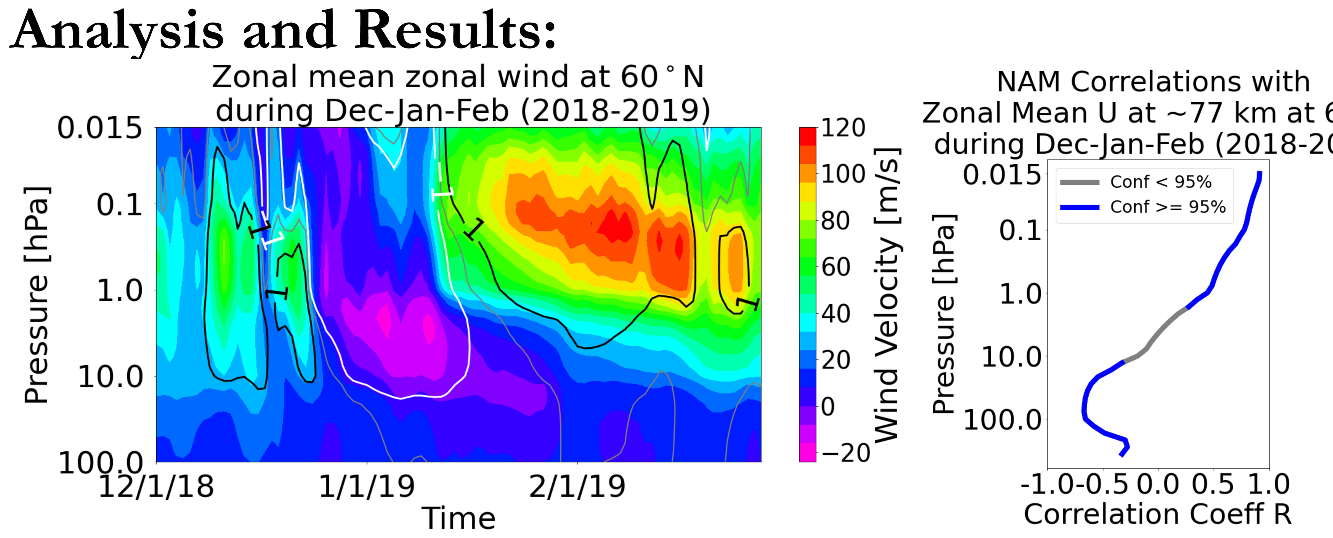
NAM and SAM indices at different pressure levels are shown in this figure with thick white contour line corresponding to -1 and thick black contour line +1. Zonal mean zonal wind at 60° N (and S) latitude contour lines are overlaid with their velocities (black for positive and dashed white for negative).

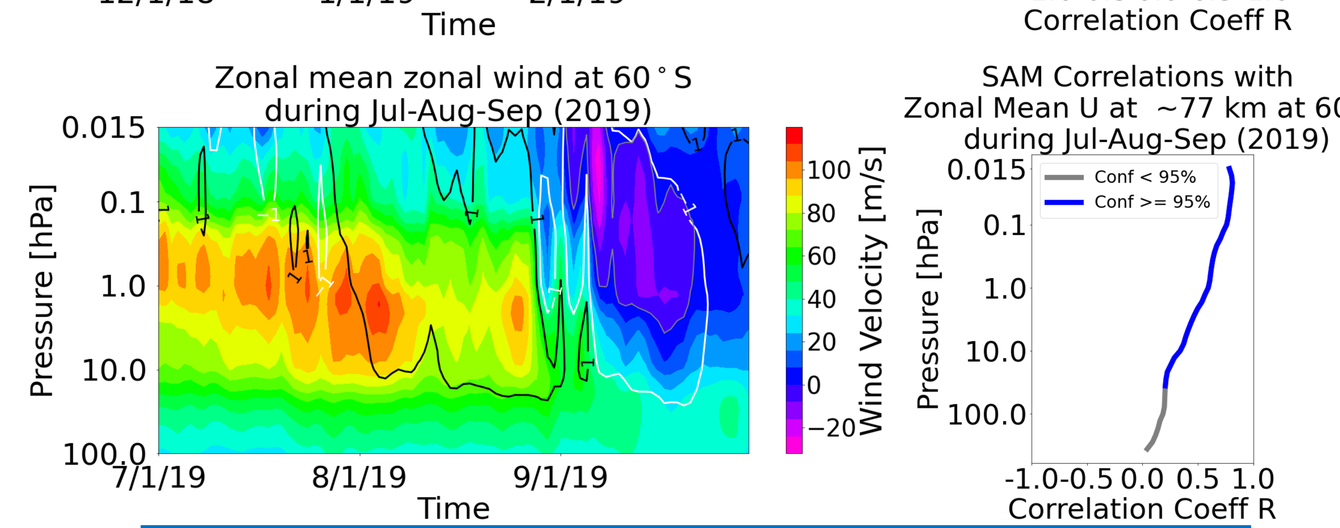
These contour plots clearly indicate that there is more to NAM and SAM at various pressure levels than just at 10 hPa. Zonal mean zonal winds show a clear correlation with NAM and SAM. **We need to consider altitude variations when choosing the NAM and SAM levels!**

NAM	Weak Onset Date ○	Strong Onset Date ●
At 0.1 hPa	12-22-18	1-14-19
At 10 hPa	12-28-18	1-31-19
Delay	**6 days**	**17 days**

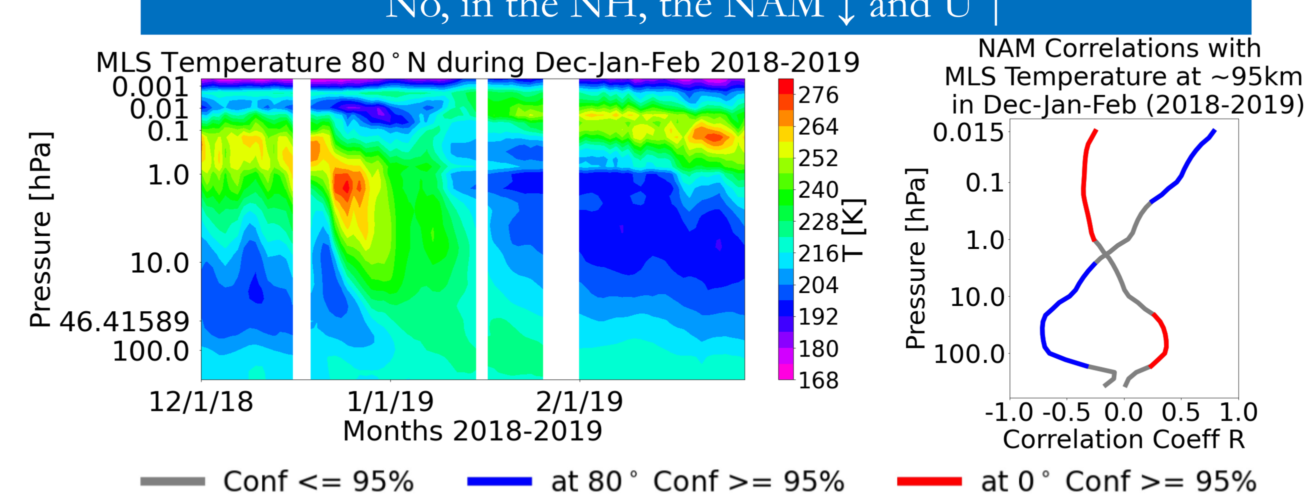
SAM	Weak Onset Date ○	Strong Onset Date ●
At 0.1 hPa	8-29-19	7-29-19
At 10 hPa	9-7-19	8-2-19
Delay	**9 days**	**4 days**

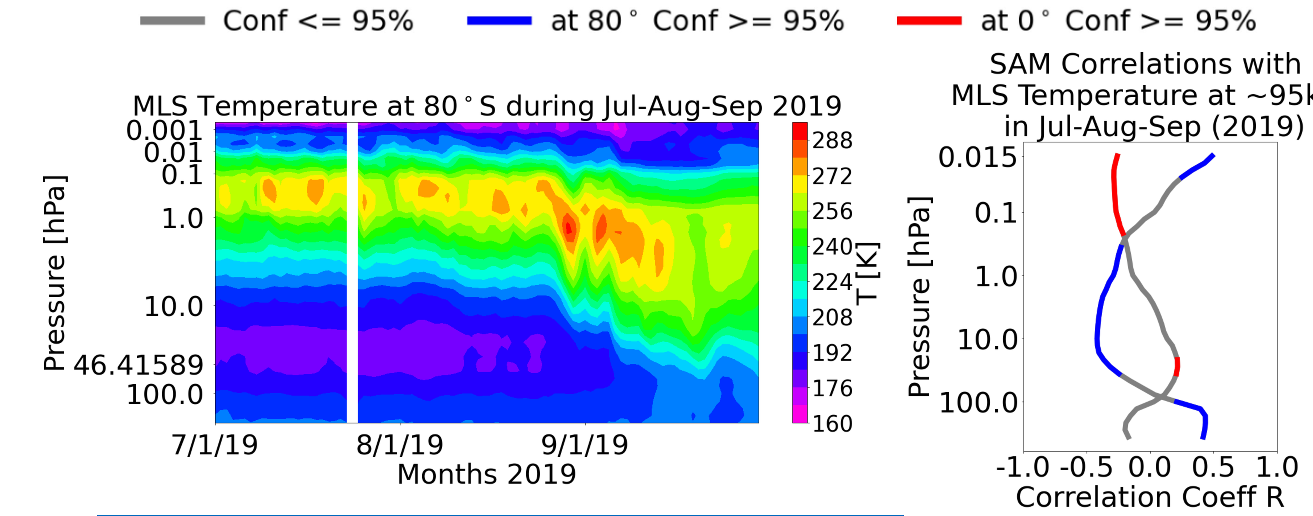
Analysis and Results:



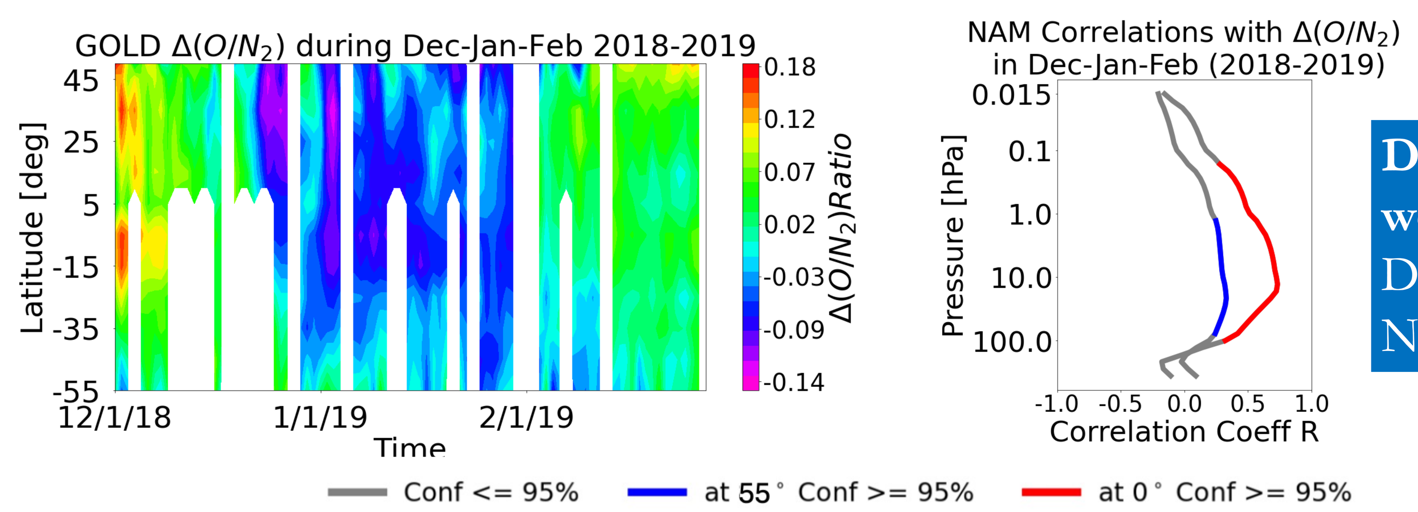


Do we see what we expected? Yes! In the SH SAM ↓ & U ↓ & No, in the NH, the NAM ↓ and U ↑

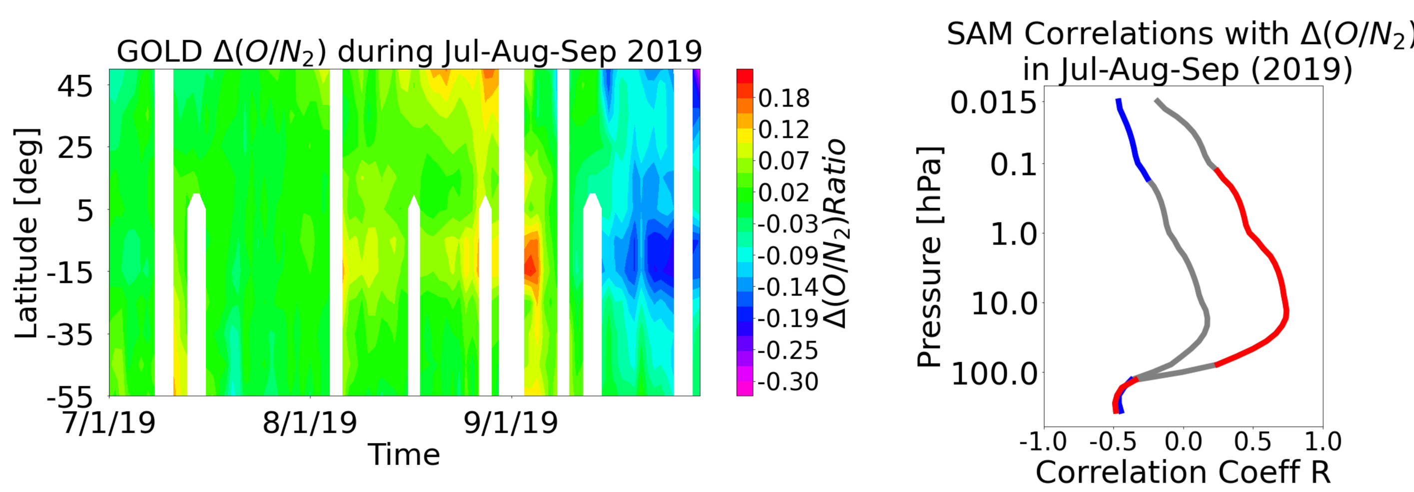


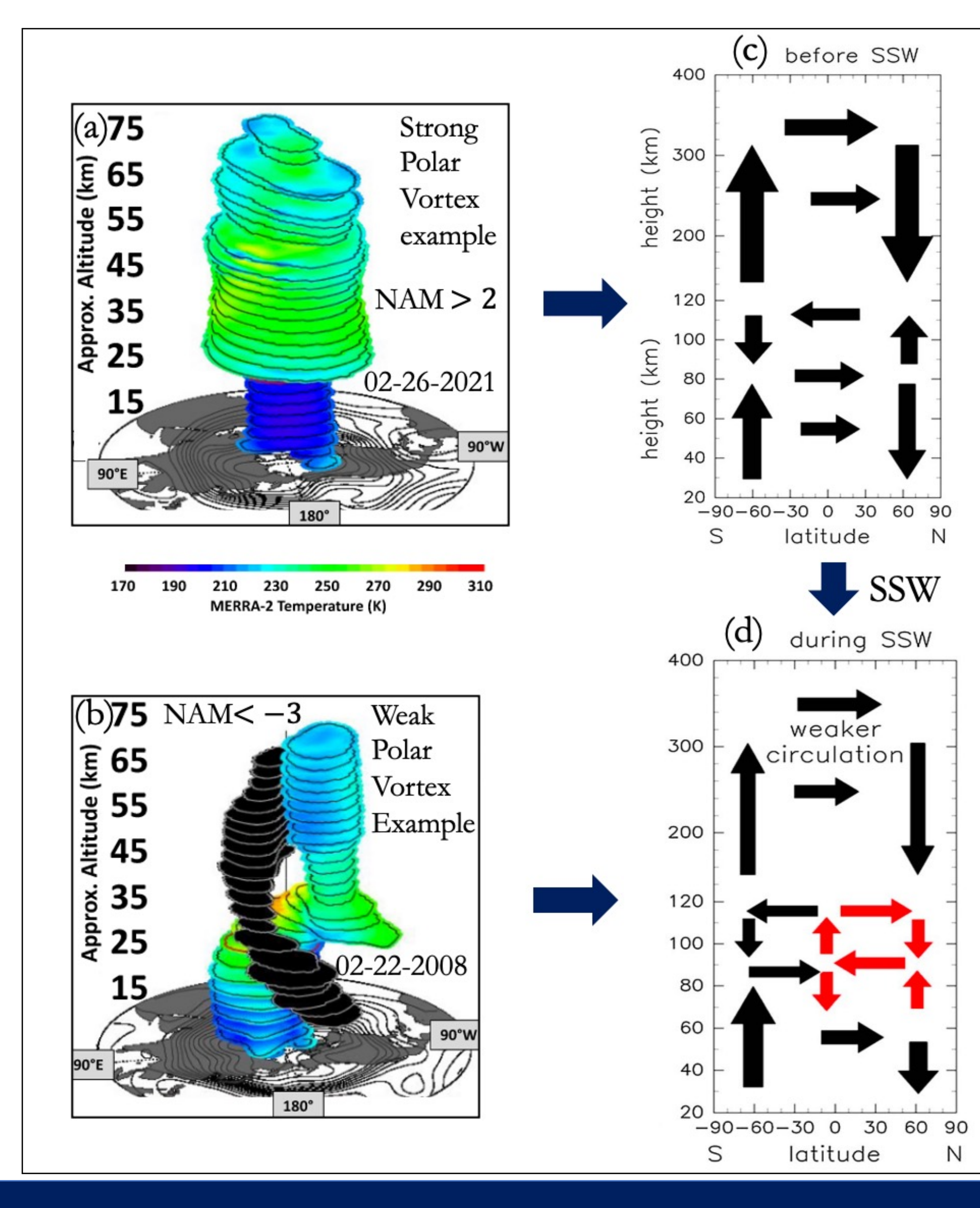


Do we see what we expected? Yes! During SSW, NAM ↓ T at 75-80 km ↓ T at 95+ km ↑



Do we see what we expected? Yes! During SSW, NAM ↓ O/N_2 ↓





This figure shows how weak and strong polar vortex affects O/N_2, T and U. There are two figures combined, on the left (a) and (b) are taken from figure 2 of Greer et al., 2023 and right (c) and (d) are taken from figure 6 of Miyoshi et al., 2015.

Impact on O/N_2
SSW causes enhancement in migrating SW2
Tidal dissipation changes zonal mean circulation
Atomic O↓ in lower thermosphere
O/N_2 ↓ in thermosphere

Impact on U
SSW causes GW drag ↓
2 cell circulation formed
Meridional circulation reversed
NAM follows Zonal Mean zonal wind flow

Impact on T
SSW causes GW drag ↓
2 cell circulation formed
Meridional circulation reversed
T ↓ in mesosphere
T ↑ in lower thermosphere

Conclusions and key takeaways!

- Correlation between vortex strength & variability in the upper mesosphere and thermosphere maximizes in the lower stratosphere.

Choice of altitude for NAM – it depends!

Parameter for Correlation with NAM	Correlation Value (Confidence %)	Level and altitude of Maximum Correlation
O/N_2 at 55° N	0.33 (99.7%)	30 hPa (~24 km)
O/N_2 at 0°	0.73 (100%)	15 hPa (~29 km)
T at ~95 km 80° N	-0.71(100%)	50 hPa (~21 km)
T at ~95 km 0°	0.37 (99.9%)	80 hPa (~18 km)
U at ~77 km & 60° N	-0.67 (100%)	80 hPa (~18 km)

Choice of altitude for SAM – it depends!

Parameter for Correlation with SAM	Correlation Value (Confidence %)	Level and altitude of Maximum Correlation
O/N_2 at 55° S	0.17 (86.7%)	20 hPa (~27 km)
O/N_2 at 0°	0.74 (100%)	15 hPa (~29 km)
T at ~95 km 80° S	-0.42 (99.9%)	10 hPa (~32 km)
T at ~95 km 0°	0.22 (96.1%)	40 hPa (~22 km)
U at ~77 km & 60° S	0.81 (100%)	0.03 hPa (~73 km)

Future work

- Extend the analysis to more years with low geomagnetic activity.
- Look at TEC correlations with NAM (and SAM).
- Time lag analysis between NAM (and SAM) and O/N_2 ratio, T, and U.

Selected References:

1.Bosilovich et al., 2015. https://gmao.gsfc.nasa.gov/pubs/docs/Bosilovich803.pdf
2.Gerber and Martineau, 2018. https://doi.org/10.5194/acp-18-17099-2018
3.Greer et al., 2023. https://doi.org/10.1029/2023JA031797
4.Livesey et al., 2022. https://mls.jpl.nasa.gov/data/v5-0_data_quality_document.pdf
5.Miyoshi et al., 2015. https://doi.org/10.1002/2015JA021894
6.Oberheide et al., 2019. https://doi.org/10.1029/2019GL086313
7.Pedatella and Harvey, 2022. https://doi.org/10.1029/2022GL098877

Contact information: Arunima.Prakash@Colorado.edu

This work is funded by NASA-ECIP 80NSSC23K1066