Sensitivity of the Blocking-North Atlantic Oscillation Relationship to Index

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Link to paper in Climate Dynamics:

Background

North Atlantic blocking and the North Atlantic Oscillation (NAO) are key drivers of climate variability in the Northern Hemisphere, with significant implications on regional weather patterns. While these phenomena have been the subject of extensive study, recent research has revealed notable discrepancies in their observed relationship, suggesting that methodological differences, particularly in the choice of blocking indices, may influence these findings. This study aims to address these discrepancies by comparing the effectiveness of different blocking indices in capturing the complex spatiotemporal overlap between North Atlantic blocking and the NAO, highlighting the need for standardized blocking index.

Atlantic Subregions Used

Fig. 1. Atlantic sub-regions selected for analysis.

Datasets and Methods

ERA-5 reanalysis dataset (Hersbach et al. 2020) at 0.25° × 0.25° horizontal resolution was obtained from **Dec 1979 to Nov 2019** for a 40-year study. Six-hourly outputs were averaged into daily values for all variables. Potential temperature (θ) was computed on a PV = 2 potential vorticity units (PVU; 1 PVU = 10−6 km2 kg−1 s−1) surface.

Indices and Resulting Seasonal Climatologies (1980-2019)

Absolute Geopotential Height (AGP)

Davini et al., 2012

$$GHGS(\lambda_0,\phi_0) = \frac{Z_{500}(\lambda_0,\phi_0) - Z_{500}(\lambda_0,\phi_S)}{\phi_0 - \phi_S}$$

$$GHGN(\lambda_0,\phi_0) = \frac{Z_{500}(\lambda_0,\phi_N) - Z_{500}(\lambda_0,\phi_0)}{\phi_N - \phi_0}$$

$$\phi_N = \phi_0 + 15\,, \;\; \phi_S = \phi_0 - 15^\circ\,,$$

ϕ_0 is considered at each grid point from 35°-75°N and λ_0 is from 0° to 360°. Persistence criteria >4 days.

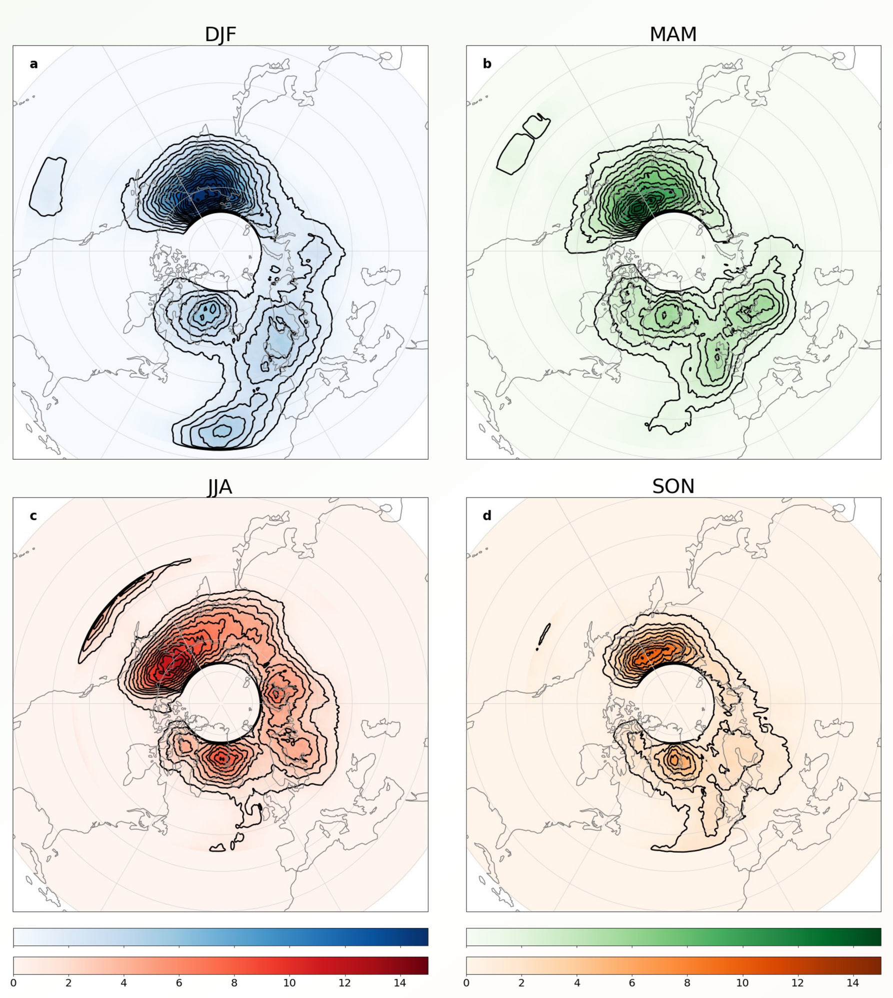

Fig. 2. Mean seasonal blocking frequency from 1980 to 2019 representing the average percent of blocked days per season when applying the absolute geopotential height (AGP) index.

-PV/+θ

Pelly and Hoskins (2003); Masato et al. (2012)

A 2-D instantaneous wave breaking index, B,

$$B_i = \bar{\theta}_i^n - \bar{\theta}_i^s \;\; \rightarrow \;\; \bar{\theta}_i^n = \frac{2}{\Delta\phi}\int_{\phi_0}^{\phi_0+\Delta\phi/2} \theta_i \, d\phi \quad \bar{\theta}_i^s = \frac{2}{\Delta\phi}\int_{\phi_0-\Delta\phi/2}^{\phi_0} \theta_i \, d\phi$$

ϕ_0 is considered at each grid point from 40°-75°N at each longitude with $\Delta\phi$ = 30°. Identified reversals were classified by the direction of breaking (DB):

$$DB = \bar{\theta}_{i-1} - \bar{\theta}_{i+1} \qquad \bar{\theta}_i = \frac{\bar{\theta}_i^n + \bar{\theta}_i^s}{2}$$

Positive DB values indicate anticyclonic wave breaking, and negative cyclonic. A centroid based tracking algorithm was then applied, following Masato et al. (2012), to identify events lasting > 4 days.

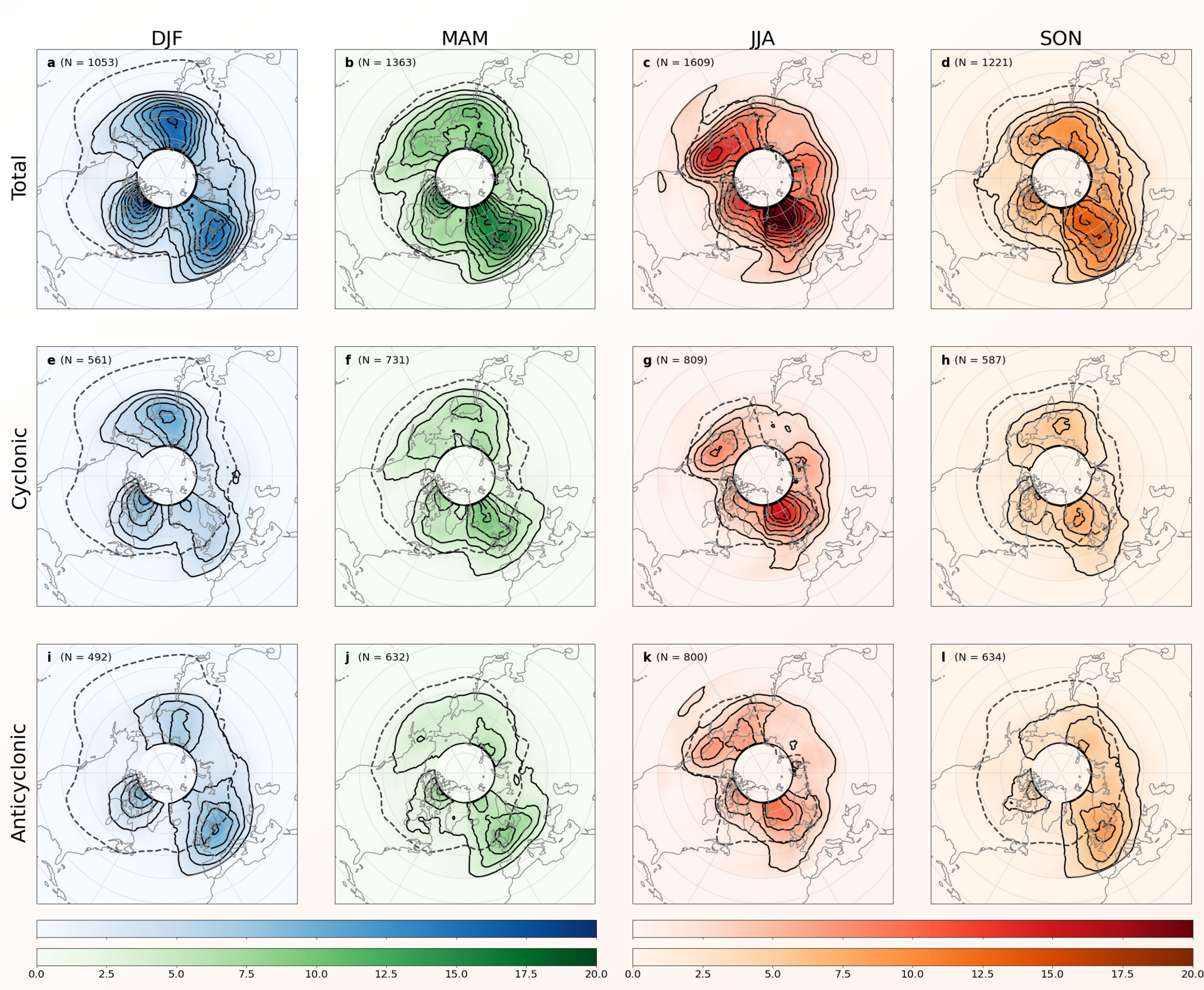

Fig. 3. Mean seasonal blocking frequency from 1980 to 2019 representing the average percent of blocked days per season in totality (**a–d**) and those driven by cyclonic (**e–h**) and anticyclonic (**i–l**) wave breaking. Contours are every 0.02. N = number of total blocking events, over the 40-year study. The dashed line represents the CBL or seasonal climatology of maximum EKE by latitude

DJF Greenland Blocks: AGP v. –PV/+θ

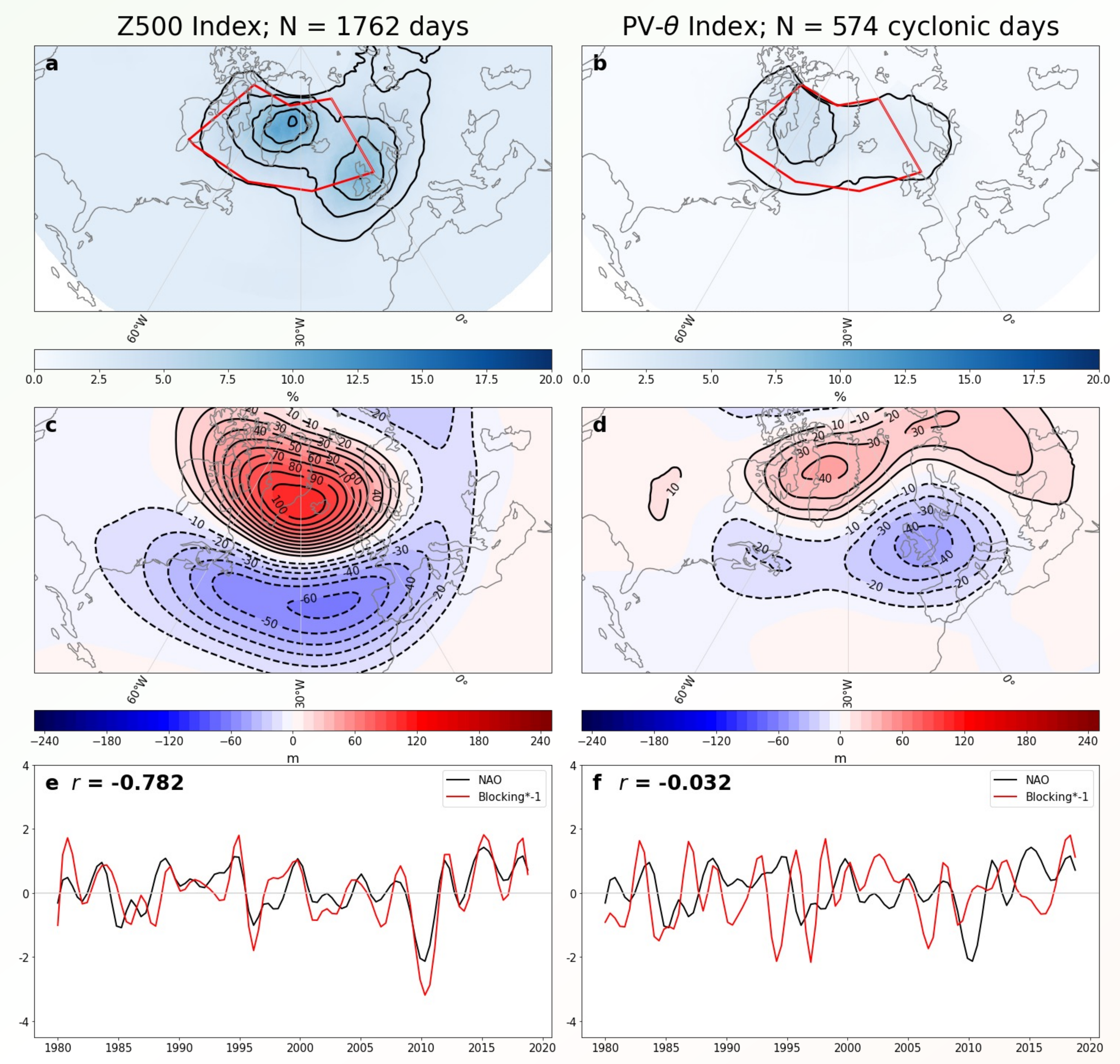

Fig. 4. **a**, **b** Blocking frequency, **c**, **d** daily 500mb geopotential height composites and **e**, **f** correlation of the normalized blocking count with the NAO over the region 55°–75°N, 0°–80°W derived by the **a**, **c**, **e** AGP index and **b**, **d**, **f** PV–θ index, considering only cyclonic cases.

- AGP index = higher correlation values of seasonal blocking and NAO than PV-θ index over Greenland area
- Indices are measuring different blocking events
- Suggested sensitivity to:
  - study period
  - subregion
- Vertical structure?
  - Cross-sectional analysis suggests not
- Different indices picking up on different portions of the flow field?
  - Could be – PV-θ misclassifying as jet streaks or identifying reversal NW of anticyclone center
- Is it an index threshold problem?
  - Could be – AGP was least like PV* and Z* results in Pinherio et. al (2019).

Duration by NAO Tercile

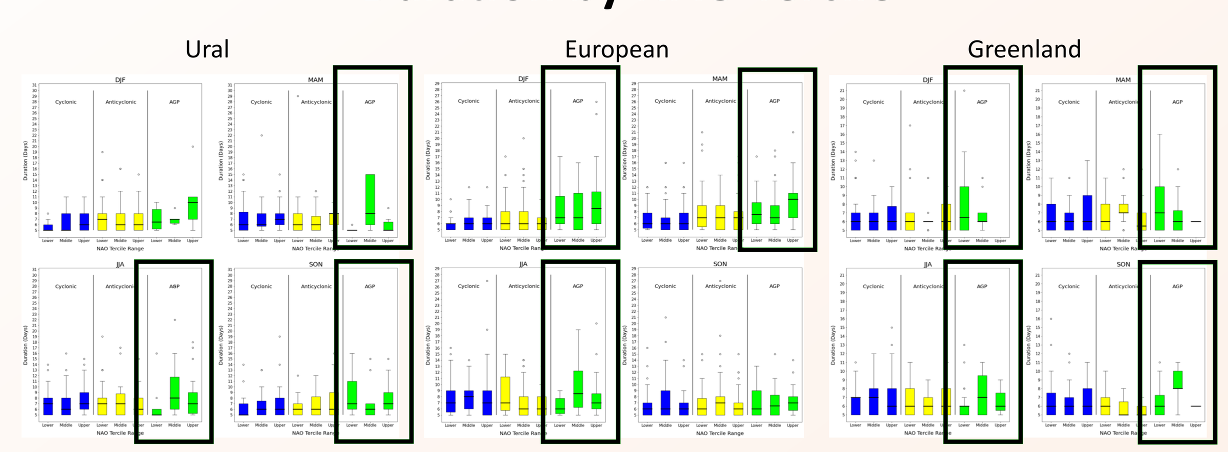

Fig. 5. The duration of blocking events by AGP and classified PV–θ index produced blocking events by season for the North Atlantic subregions based on the NAO tercile at blocking onset.

- AGP Blocks have a longer duration than PV-θ blocks across most seasons and subregions.

DJF Blocking Composite Analysis by Atlantic Subregion and Index

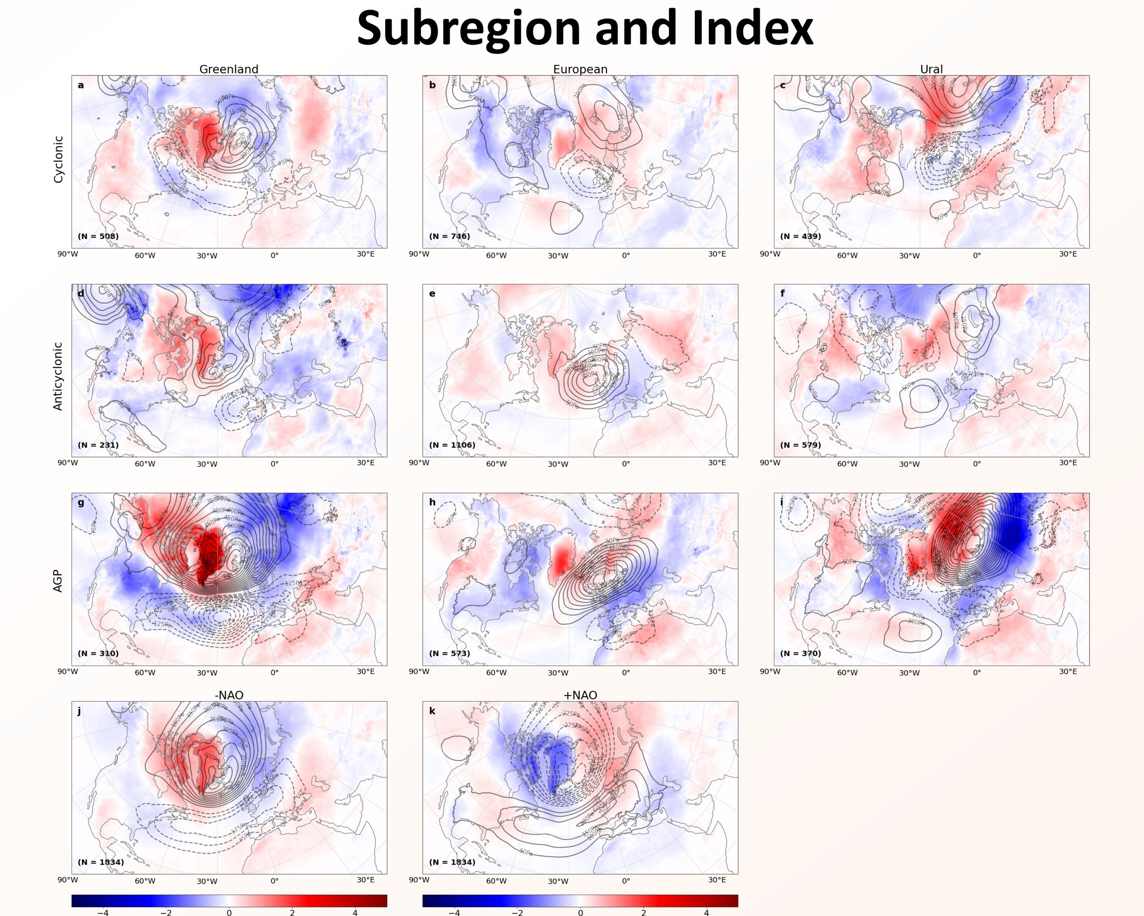

Fig. 5. DJF composites of anomalous Z500mb (black contours), precipitation (brown-green shading), and SSTs (blue-red shading) during all blocked days within a given subregion, by index and for the PV–θ blocks, by classification. Classified cyclonic PV–θ blocks by the Greenland, European, and Ural regions are in panels **a–c**, **d–f** for PV–θ anticyclonic blocks by subregion, and **g**, **h** for AGP blocks. Daily NAO composites are also provided for context and comparison in (**k**). N represented the number of days included in the composite.

- Differing signals in variables found across classification, subregion, season, index
  - Usefulness of:
    - Breakdown into subregion
    - Classification into cyclonic and anticyclonic
- Blocks appear as both standalone features and of larger scale planetary flow
- AGP Greenland panel and –NAO near identical across seasons
- AGP most intense

Correlation of NAO Index + Blocked Days

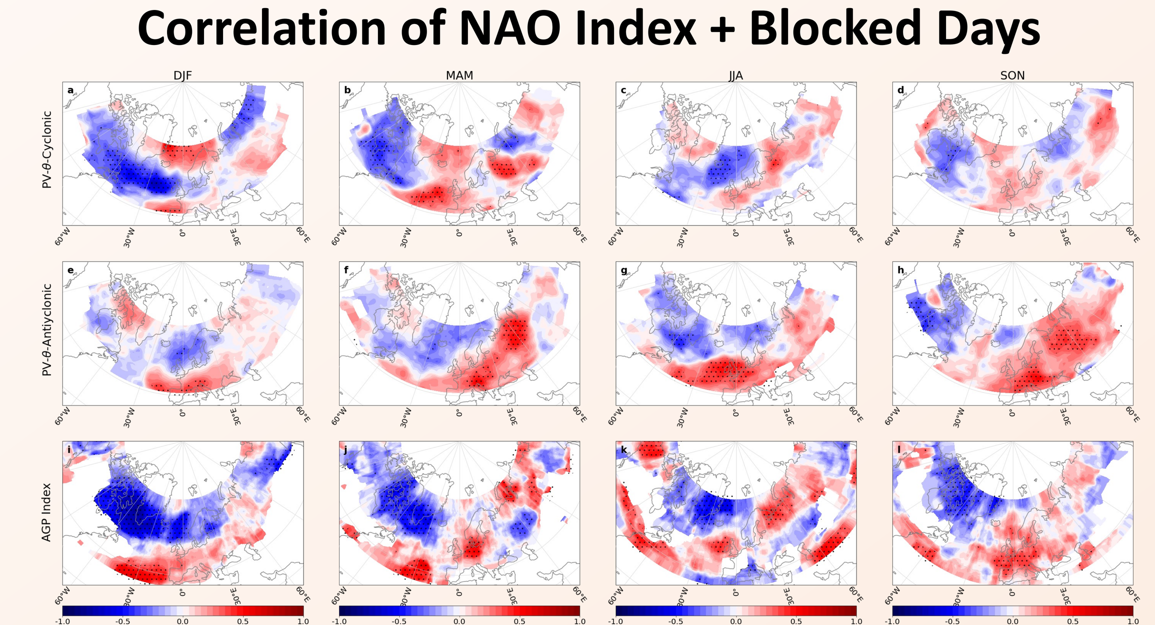

Fig. 6. Spatial correlation (shading) of the seasonal North Atlantic Oscillation index with cyclonically **a–d** and anticyclonically **e–h** driven normalized blocked days derived from the PV–θ index and **i–l** from the AGP index by season from 1980 to 2019 across all seasons in the North Atlantic sector.

- DJF Greenland Blocking: AGP v. Cyclonic –Max of -0.7 correlation with NAO is with DJF cyclonic blocking
- Larger area of increased negative DJF correlation values for AGP index -PV/+θ
- Seasonality of both blocking types emerging into a negative west, positive east correlation pattern
- Cyclonic more significant west, anticyclonic more significant east

Conclusions

- **Index Sensitivity:** The choice of blocking index significantly influences the observed correlation between seasonal blocking and the NAO, with the AGP index showing higher correlation values with the NAO over the Greenland area.
- **Different Blocking Events:** The AGP and PV-θ indices measure different types of blocking events, which contributes to the discrepancies in correlation with the NAO.
- **Factors Affecting Sensitivity:** The sensitivity of the blocking-NAO relationship is influenced by the study period, subregion, and potentially the vertical structure, although cross-sectional analysis suggests the latter may not be a significant factor.
- **Flow Field Interpretation and Threshold:** Different indices may capture (or fail to due to index threshold) different aspects of the flow field, with the PV-θ index potentially misclassifying jet streaks or identifying reversals northwest of the anticyclone center as shown in Pinherio et. al (2019).
- **Variable Signals:** Signals in variables such as frequency, duration, and composites vary across classification, subregion, season, and index.
- **Duration of Blocking Events:** AGP blocks tend to have a longer duration than PV-θ blocks across most seasons and subregions.
- **Seasonal and Regional Correlation Patterns:** Seasonality and regional differences emerge in the blocking-NAO correlation pattern, with cyclonic blocking being more significant in the west and anticyclonic blocking more significant in the east.
- **Methodological Consistency:** The lack of consistency in blocking methodology and definitions of blocking events may be contributing to discrepancies in studies of blocking-NAO variability.
- **Recommendations for Future Research:** A more consistent methodology that captures multiple forms of blocking, such as the one proposed by Sousa et al. (2021), is recommended to improve understanding of the blocking-NAO relationship.