Teleconnections - The North Atlantic Oscillation

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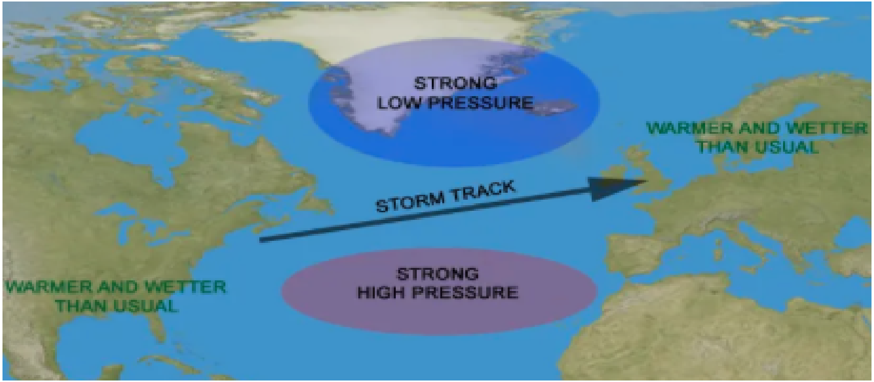
Outline

The North Atlantic Oscillation



The North Atlantic Oscillation (NAO), one of the most prominent teleconnections over the North Hemisphere, is characterized by a redistribution of mass at sea level between the Icelandic Low and the Azores High. Fluctuations from one phase to another result in significant variations in the average wind speed and direction over the Atlantic, as well as in the transport of heat and moisture between the Atlantic and neighboring continents.

Outline

2. The spatial and temporal structure of the NAO
   - One-point correlation maps
   - EOF Analysis
   - Cluster Analysis
   - NAO Index

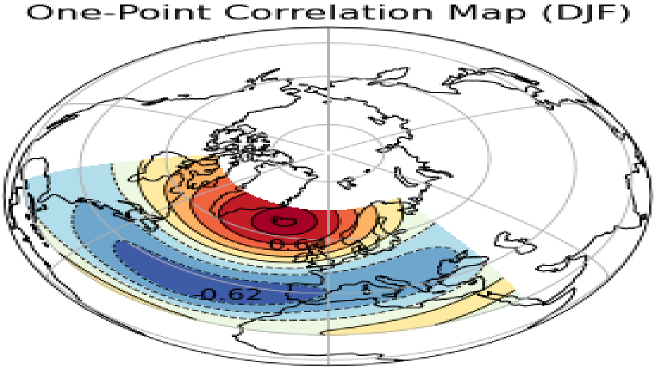
The spatial and temporal structure of the NAO

- To understand the North Atlantic Oscillation it is important to know his spatial and temporal structure.
- To examine his spatial structure will we use three methods: One-point correlation maps, EOF Analysis and cluster Analysis
- For the temporal structure we will use the NAO Index
- Idea: reproduce the methods on new data (up to 2024)

One-point correlation maps

- A one-point correlation correlates a variable at a specific location with the same variable at other locations
- Data = monthly geopotential height (on the 500 hPa) for winter season December, January and February over 1950-2024. Compute the anomalies: (individual geopotential heights year-months $-$ geopotential height time means)
- The correlation is computed using the Pearson's linear correlation coefficient calculated at every point as: $r = \frac{Cov(X,Y)}{\sqrt{Var(X)Var(Y)}}$
- where X and Y are time series of contemporaneous observations, $[(x_i, y_i); i = 1, 2, ...N]$, where we fix one of the data points, say, X, at the center of action and then compute the correlation over all Y.

One-point correlation maps



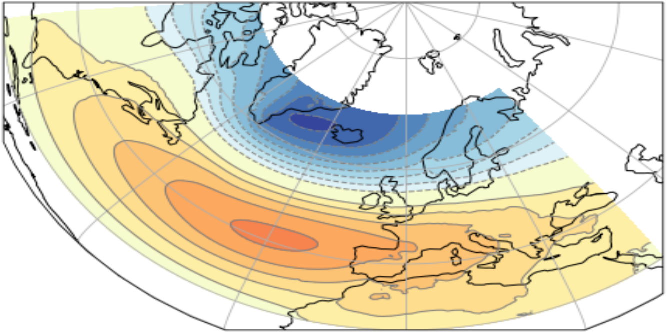
One-point correlation maps of 500 hPa geopotential heights for boreal winter (December–February) over 1950–2024. The NAO pattern is illustrated based on a reference point of 65°N, 18°W. The correlation is calculated for all points belonging to the Northern Hemisphere (20-70°N, 90W-40E)

EOF Analysis

- Empirical Orthogonal Function (EOF) analysis is also used to identify and analyze dominant patterns of variability in spatial and temporal datasets.
- Idea: reduce a dataset with many variables to a smaller set of new variables, which are linear combinations of the original ones, chosen to capture the maximum possible variability of the original data.
- Given multiple observations of a ($K \times 1$) data vector **x**, PCA finds (M x 1) vector **u**, which are linear combinations of the elements of **x** and capture most of the information from the original data
- There are few steps by performing this EOF analysis:
- Data = mean sea level pressure (on the 500 hPa) for winter season December, January, February and March over 1940-2024.
- Anomalies calculation, covariance matrix, eigenvalue decomposition.
- The first principal component, is obtained as the projection of the anomalies vector onto the first eigenvector
- This first EOF explains the most variance, followed by the second, and so on

EOF Analysis

EOF SLP hPa) DJFM 1940-2024: 35.8

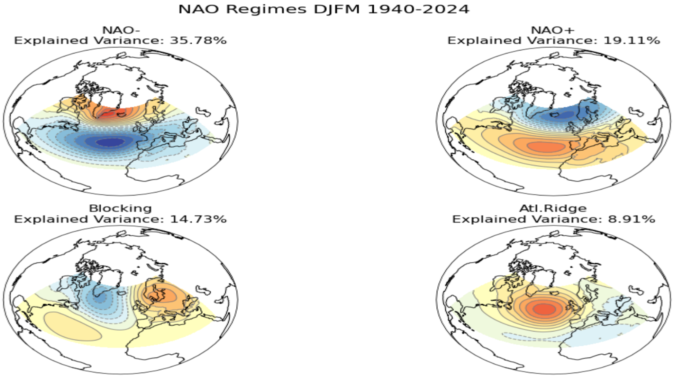


Leading empirical orthogonal functions (EOF 1) of the seasonal mean sea level pressure anomalies in the North Atlantic sector (20°–70°N, 90°W–40°E), and the percentage of the total variance they explain. The patterns are displayed in terms of amplitude (hPa), obtained by regressing the hemispheric sea level pressure anomalies upon the leading principal component time series.

Cluster Analysis

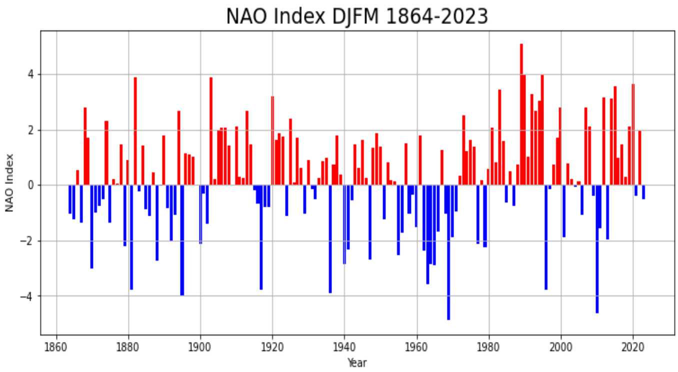
- The Cluster Analysis is a non-linear approach used to group similar data points into clusters based on their similarities.
- Here it is used to identify distinct atmospheric patterns (NAO patterns in this case) with similar pressure characteristics.
- The algorithm groups in this case the monthly SLP maps into a small number of representative states (or regimes) according to an objective criterion of similarity.
-The step by performing the cluster analysis are:
- Data = mean sea level pressure data for winter season December, January, February and March over 1940-2024.
- Anomalies Calculation, k-means clustering on the PCs (4 clusters)
- Given a prescribed number of clusters k, the overall goal of the algorithm is to find a partition P of the data points into k clusters $C_1, C_2, \ldots, C_k$ that minimizes the sum of the variances within the clusters.

Cluster Analysis



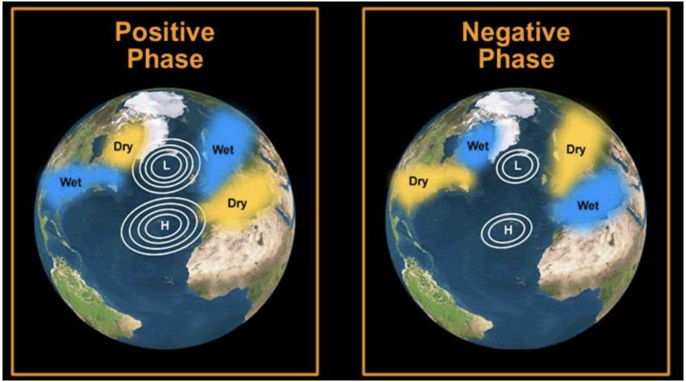
Boreal winter (December–March) climate regimes in sea level pressure (hPa) over the North Atlantic domain (20°–70°N, 90°W–40°E) using monthly data over 1940–2024. The percentage at the top right of each panel expresses explained variance of each cluster.

NAO Index



Normalized indices of the mean winter (December–March) NAO constructed from sea level pressure data. The index is based on the difference of normalized sea level pressure between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland. The average winter sea level pressure data at each station were normalized by division of each seasonal pressure by the long-term mean (1864–2023) standard deviation.

Positive and negative phase of the NAO



The NAO is in his positive phase when both the Icelandic low and the Azores high are stronger than average and in his negative phase when they are weaker than average

Outline

3. The implications of the NAO for our climate
   - Temperature, wind speed and direction
   - Storm and precipitation
   - Ocean and Sea Ice

Implications of the NAO

The NAO plays a critical role in shaping climate patterns across the North Atlantic and surrounding areas. Its phases can lead to significant variations in temperature, precipitation, and weather extremes, influencing ecosystems, human activities, and natural resources.

Temperature, wind speed and direction

- During the positive phase of the North Atlantic Oscillation (NAO), the atmospheric pressure difference between the Icelandic low and the Azores high intensifies
- stronger-than-usual westerly flow across the North Atlantic during the winter months. Consequently, relatively warm, and moist maritime air is transported over much of Europe and extends across Asia.
- Milder winter conditions across the continent, often resulting in higher temperatures and increased precipitations
- Meanwhile, stronger northerly winds over Greenland and northeastern Canada transport cold air southward, which leads to a decrease in both land temperatures and sea surface temperatures (SST) in the northwest Atlantic.
- The stronger clockwise circulation around the subtropical Atlantic high-pressure center during this phase of the NAO significantly impacts other regions.

Storm and precipitation

- NAO signals can also be observed in winter precipitation patterns and in the intensity and path of storms over the North Atlantic.
- During the positive phase of the NAO, storm activity in the Atlantic shifts northeast. Furthermore, the positive phase is typified by more intense and frequent storms
- During the NAO-, a weak subtropical high and a weak Icelandic Low prevail, resulting in a reduced pressure gradient and in fewer and weaker winter storms with a more wets-east trajectory, while moist air is brought into the Mediterranean and cold air into northern Europe
- Changes in the mean flow and storminess associated with swings in the NAO index lead to significant changes in the transport and convergence of atmospheric moisture, impacting the distribution of evaporation and precipitation

Ocean and Sea Ice

- Fluctuation in the SST and the strength of the NAO are related
- Tri-polar structure: a cold anomaly in the subpolar North Atlantic, a warm anomaly in mid-latitudes, and a cold anomaly in subtropical regions
- Persistent SST anomalies over longer periods also are related to consistent anomalous SLP patterns, including the NAO, reflecting the ocean's response to long term atmospheric variability.
- The reduction of the Arctic Sea ice is one of the most prominent indicators of climate change

Outline

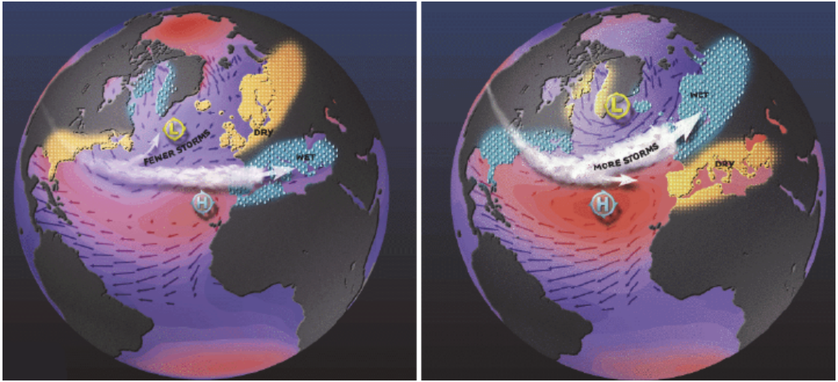
4 Conclusion

Conclusion

- Develop adaptative strategies
- Accurate weather forecasting and climate prediction
- Open issues
- External forcing

Discussion

The North Atlantic Oscillation



Time series mean sea level pressure anomalies