Analyzing the Impact of North Atlantic Pressure Systems on Extreme Weather Events in the Azores

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Abstract

Climate change is increasing the frequency and intensity of extreme weather events globally as well as in the Azores Islands, Portugal. The weather patterns of the Azores Islands influence the weather and climate patterns of Western Europe and beyond. Understanding the dominant pressure systems in the eastern North Atlantic Ocean is key to predicting the climate of Western Europe which also helps to predict future trends in extreme events in the Azores archipelago. In this study, we aim to describe the potential trends and relationships between the occurrence of extreme events, global weather indices, the Azores High-pressure system (AH), and the Icelandic Low-pressure system (IL), specifically with respect to the surface areas of the pressure systems. Area was determined using pressure thresholds calculated from mean and standard deviation values obtained from 1980-2024 MERRA-2 sea-level pressure data in the North Atlantic sector and correlated against the global climate indices. Our result shows the changes of the area of Azores High is highly correlated with the North Atlantic Oscillation (NAO). Further links between the area components of the pressure systems and atmospheric variables will be investigated in the future, with the hope of including GNSS and atmospheric reanalysis data to create a system by which future trends in extreme events in the North Atlantic can be predicted.

Background

- The Azores Islands are located 900 miles off the west coast of Portugal, in the center of the region where the Azores High typically establishes itself.
- Pressure systems have very large impacts on local and regional climate.
- Azores High (AH): large region of higher pressure in the eastern North Atlantic (NA) that rotates anti-cyclonically and is associated with a dry and calm atmosphere.
- Icelandic Low (IL): large region of lower pressure just above the AH that rotates cyclonically and is associated with a moist and dense atmosphere.

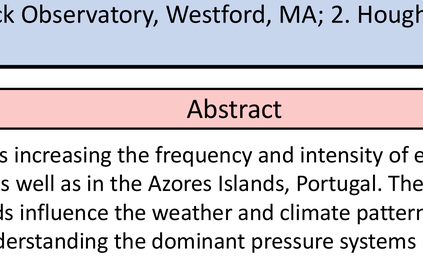

Fig. 1: North Atlantic sector outline (red is Azores Islands, 'H' is AH location, 'L' is IL location).

- Recent research has shown the growth of the AH when it comes to the frequency of extremely large events, based on sea-level pressure.[1]
- Others have identified a change in extreme events in the Azores region – specifically relating to the forecasted increased number of >20mm rainfall days.[2]
- Explore potential relationship between pressure system expansions and extreme weather occurrences.

References

[1] Cresswell-Clay, Nathaniel et al., "Twentieth-century Azores High expansion unprecedented in the past 1,200 years." *Nature Geoscience*, vol. 15, no. 7, July 2022, pp. 548-553

[2] Carvalho, Fernanda R. et al., "Climate change and the increase of extreme events in Azores." *Climate Change Management*, 2022, pp. 349- 365.

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Methods and Data

- Utilize NCEP/NCAR and MERRA-2 data to analyze potential sea-level pressure (SLP) and precipitable water content (PWC) trends in the NA sector.
- Use empirical orthogonal function analysis and fast Fourier transforms (FFTs) to locate spatiotemporal patterns.

Variable/Index	Type	Location	Time Resolution	Lat/Lon Resolution
SLP	MERRA-2	NASA's GES DISC	hourly	0.5° x 0.625°
PWC	NCEP/NCAR Reanalysis 1	NOAA's PSL	daily	2.5° x 2.5°
NAO	Standard PSL	GCOS WG-SP	monthly	N/A
MEI	Standard PSL	GCOS WG-SP	monthly	N/A

Table 1: Data types and specifications.

North Atlantic Sector Sea-Level Pressure

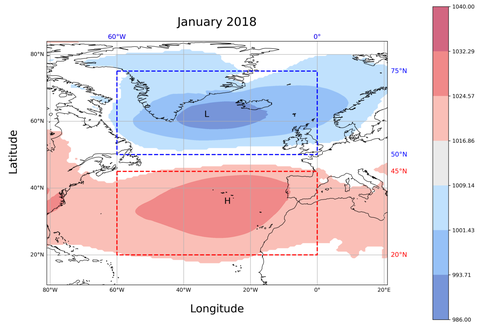

Fig. 2: North Atlantic sector sea-level pressure contour plot for January 2018.

- AH: values > $[mean_{data} + (0.5 \times std_{data})]$
- IL: values < $[mean_{data} - (0.5 \times std_{data})]$
- Filters out all SLP values in 1 std around the mean.[1]
- Idea that extreme highs could be correlated with extreme lows.

Empirical Orthogonal Function (EOF) Analysis

- EOF analysis attempts to study variable spatial patterns as they evolve with time by decomposing a set of data through matrix eigenvalue computations.

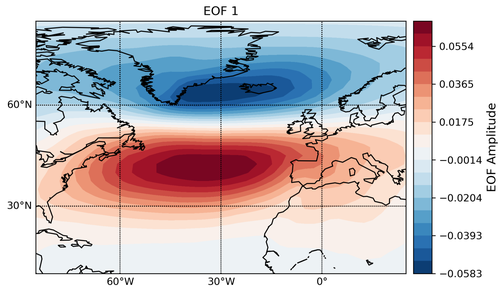

Fig. 3: North Atlantic sector sea-level pressure first EOF eigenvector (variance fraction of ~0.175).

- The AH and IL are visible through the spatiotemporal pattern the EOF analysis discovered.
- Evidence that the presence of a larger AH corresponds to a larger IL.

Areas/Volumes Azores High and Icelandic Low

- SLP thresholds and a world surface area array were used to identify area and volume of AH and IL within respective regions.

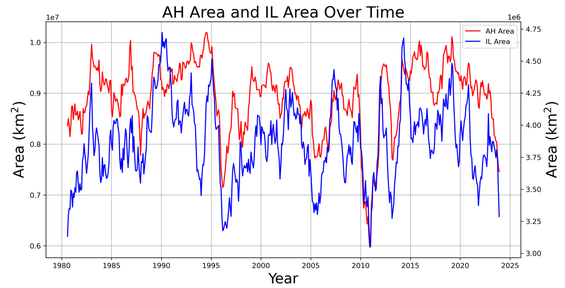

Fig. 4: AH and IL areas over time.

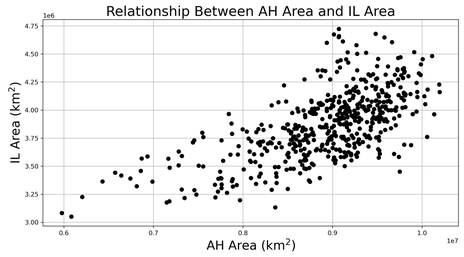

Fig. 5: AH area plotted against IL area.

- FFTs resulted in no seasonally significant high- or low-frequency variations.
- Pearson's R statistical test on Figure 5 and volume equivalent:
  - $r = 0.64, 0.63$
  - $p < 0.05$
- Positive correlation.

<u>A few possible explanations:</u>

1. Rossby wave propagations
2. Conservation of atmospheric angular momentum
3. Teleconnections

Azores Islands Precipitable Water Content

- Determined threshold for extreme PWC days exactly like the SLP threshold.

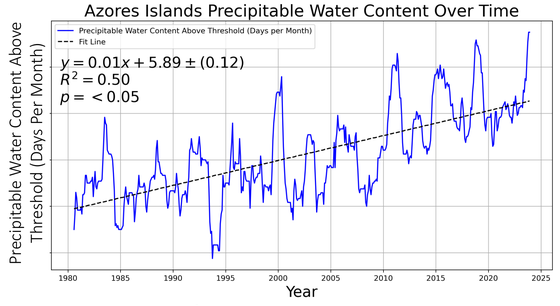

Fig. 6: Extreme PWC (above 23.39 $\frac{kg}{m^2}$) days per month in Azores region (37-40°N, 32-25°W).

- Increase in PWC over the Azores Islands.
- Coupling with increasing >20mm days = complicated lower and upper atmosphere dynamics.

Final Comments

Summary

- The Azores High and Icelandic Low are positively correlated with respect to area and volume, but there exists no evident change in time over the past few decades of either parameter thus far.
- The number of extreme precipitable water content days over the Azores Islands is increasing over time.

Future

- Investigate variables such as humidity and wind speed in the Azores region.
- Use more focused fast Fourier transforms and EOFs to attempt to identify seasonal and yearly variations in the AH and IL parameters.
- Filter out potential low- and/or high-frequency variations to locate general trends.
- Continued research on how to define 'extreme events' in this region.