Too weak decadal variability of the North Atlantic eddy-driven jet remains at high-resolution in CESM1

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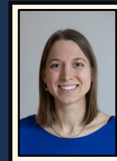

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1 Motivation

- The North Atlantic eddy-driven jet stream exhibits variability on **decadal** to multidecadal timescales, but this **variability is underestimated in current 1° GCMs.**[1]
- This makes decadal predictability a challenge![2]
- **Ocean** low-frequency variability might drive atmospheric low-frequency variability.[1]
- **High-resolution** models more adequately represent the **atmospheric heating response to SST anomalies** which can impact the large-scale atmospheric circulation.[3]

Decadal variability of the eddy-driven jets in models and reanalysis

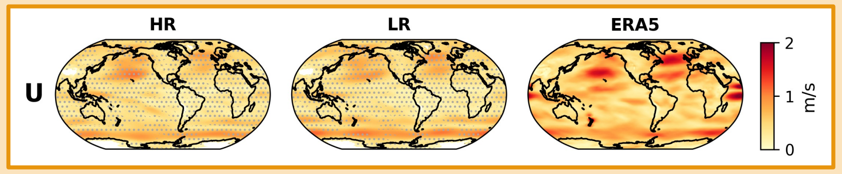


Figure 1: Standard deviation of 10-year running means of DJFM U700.

Research Questions

1) To what extent does increasing horizontal model resolution improve the representation of low-frequency variability?
2) To what extent can differences in ocean-atmosphere interactions explain differences in atmospheric low-frequency variability across datasets?

Data

- MESACLIP:
  - CESM1.3 high-resolution (HR): atmosphere 0.25°, ocean 0.1°[4]
  - CESM1.3 low resolution (LR): atmosphere & ocean 1°[4]
- ERA5 reanalysis[5]
- North Atlantic domain: 20°N to 90°N, 90°W to 40°E
- Timeseries from 1940 - 2025

4 Key take-aways:

1) Enhancing model resolution does not yield the anticipated improvements in representation of atmospheric low-frequency variability.
2) The atmospheric response to SSTs is weaker in models than in reanalysis.

These findings reinforce the hypothesis that insufficient ocean-atmosphere coupling is responsible for underestimated low-frequency variability in GCMs.

2 Atmospheric low-frequency variability

Method: **Low-frequency component analysis**[6]

- Signal-to-noise maximizing EOFs
- **Maximizes ratio of low-frequency to total variance r** in modes of variability

$$r = \frac{low-frequency\ variance}{total\ variance}$$

- Low-pass cutoff: 5 years
- Applied to normalized U700-SLP concatenated matrices

→ Yields **pattern-component pairs**

Low-frequency mode 1: North Atlantic Oscillation resembling mode

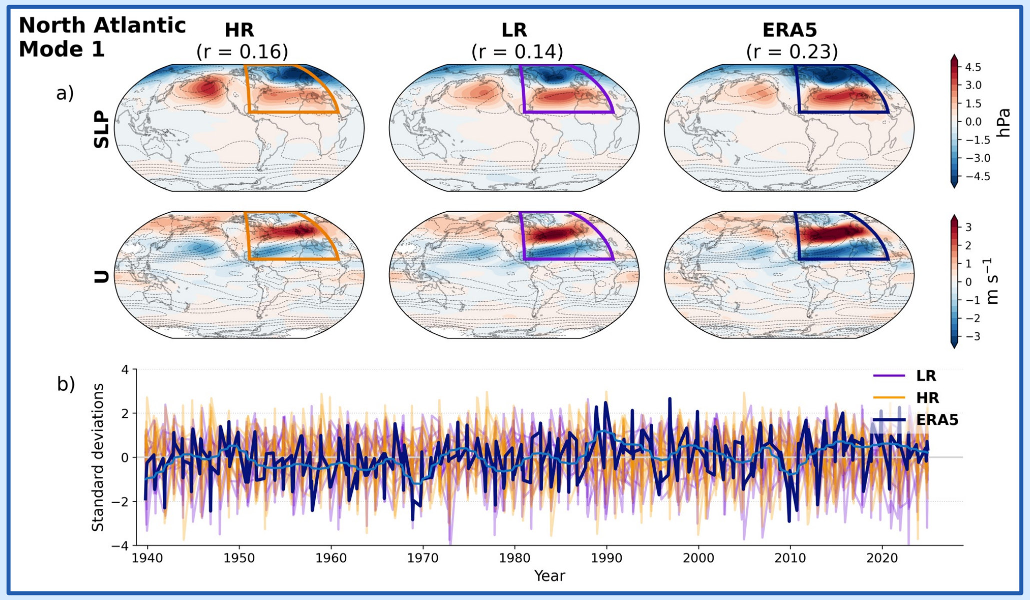


Figure 2: First mode of low-frequency variability. (a) shows low-frequency patterns, (b) shows the low-frequency components. The medium blue line represents the low-pass filtered low-frequency component of the ERA5.

Low-frequency to total variance:

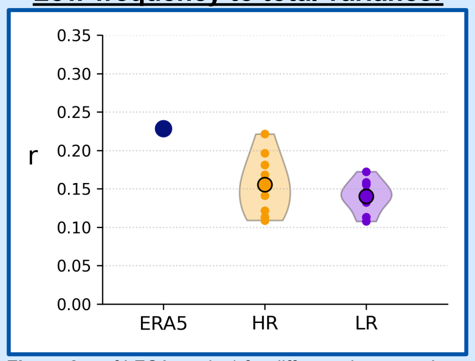


Figure 3: r of LFCA mode 1 for different data sets. Large dots: r from original LFCA. Small dots: r of ensemble members, yielded by projecting linear combinations onto ensemble member matrices.

Power spectral densities:

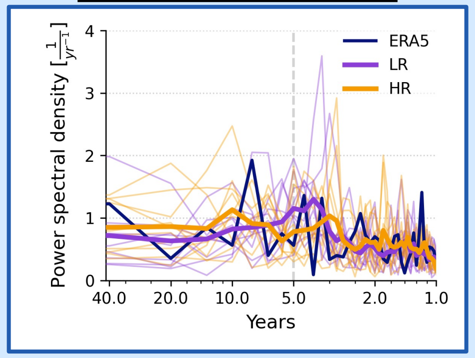


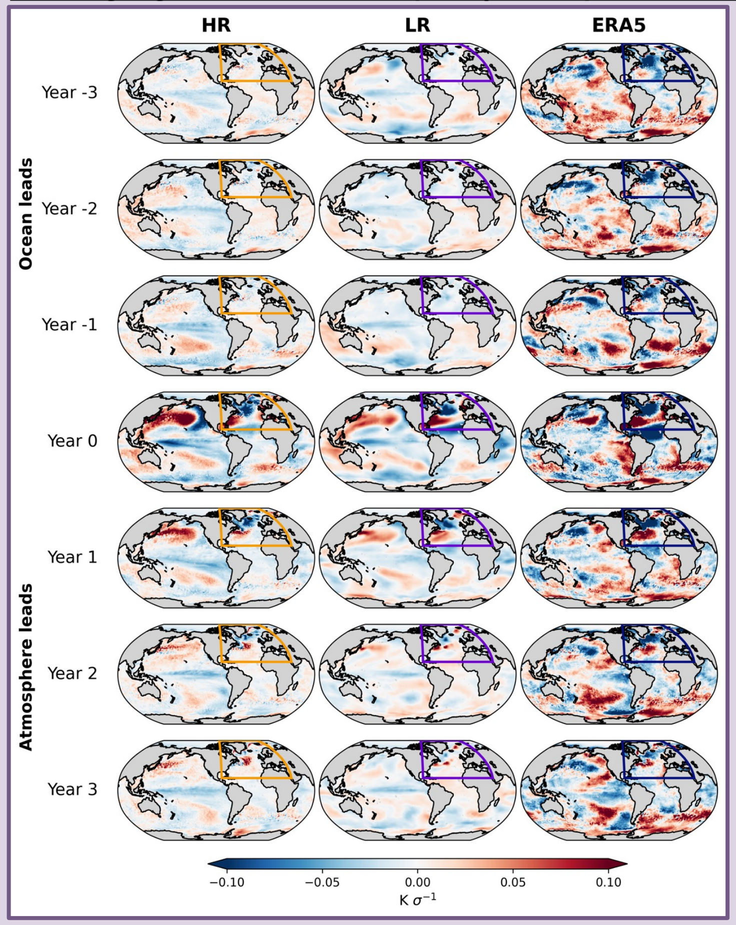
Figure 4: Power spectral densities of LFCA mode 1 for different data sets. Thick lines represent ensemble means.

3 Ocean-atmosphere interactions

Method: **Lead-lag regressions**, using ordinary least squares

- Niño3.4 linearly removed from all timeseries

Lead-lag regressions of low-frequency atmospheric timeseries onto detrended SSTs:



Ocean leads:
Pronounced reanalysis-model differences

Simultaneously:
NA: tripolar wind-driven NAO pattern
NP: PDO- teleconnection

Atmosphere leads:
NA: wind-driven SST pattern weakens

NP: teleconnection in models weakens

Figure 5: Lead-lag linear regressions of detrended SSTs onto the North Atlantic low-frequency component 1.

Model-reanalysis discrepancies are most pronounced at **negative lags**.

ERA5: negative anomalies in subpolar NA → stronger baroclinicity → might increase eddy activity → might strengthen jet stream and influence the NAO

Models: resolution might be too low to simulate vertical heat transport to upper troposphere in response to positive SST anomalies → might impede a possible large-scale response with impacts on low-frequency timescales

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