Quantifying the Response of the North Atlantic Oscillation to a Wide Range of CO_2 Forcing

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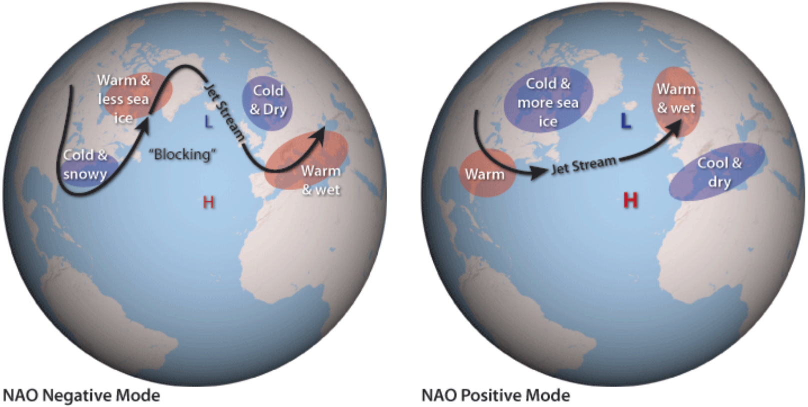
North Atlantic Oscillation (NAO)



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- The principal mode of atmospheric variability in the North Atlantic region in both winter and summer, associated with variability in eddy-driven jet

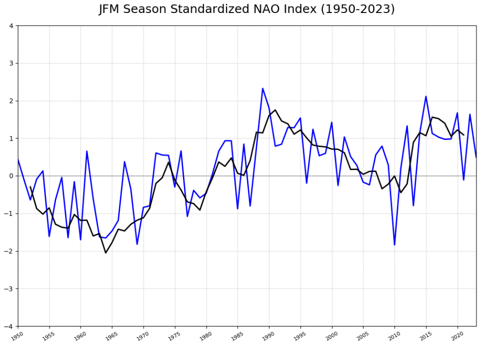
NAO trend due to GHG forcing?

Historical:

- Positive trend from 1950s to 1990s, which reversed through early 2010s.
- No clear signal due to historical GHG-caused warming.

Future:

- Some Earth System Models project a more positive NAO under high-emission 21st-century scenarios
- Signal-to-noise paradox: uncertainties persist regarding the exact response of the NAO in a warmer world



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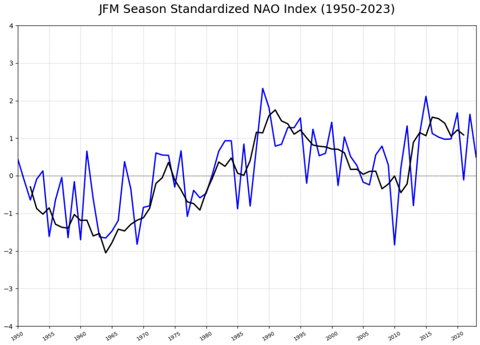

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Q1. How do the *summer* and *winter* NAO **mean state and variability** change at high CO_2?
Q2. Are there any structural changes in the NAO (e.g., spatial shift)?

Methods

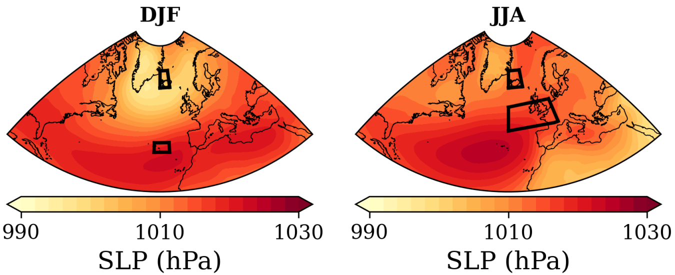
- Use **high CO_2 forcing** of 2×, 4×, and 8×CO_2 due to the signal-to-noise paradox in the North Atlantic
- Monthly data: DJF for winter, JJA for summer

Models:

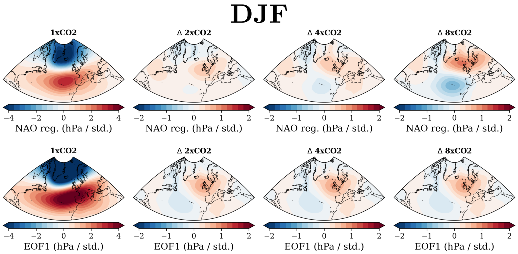
- **12** LongRun MIP models (Rugenstein et al., 2019): we utilize experiments ran for up to 1000 years to mitigate the decadal variability of the NAO
- **3** of our own models: CESM1-LE, GISS-E2.1-G, GFDL-FLOR model
- **24** CMIP6 models (mostly for 4xCO2)

NAO definition

- We define the **winter NAO** as the difference in sea level pressure (SLP) between a box over the Azores high and the Iceland low in DJF (traditional definition, e.g. Stephenson et al. 2006)
- The **summer NAO** is the SLP difference between the British Isles high and Iceland low in JJA (similar to, e.g. Dunstone et al. 2023)
- Note: results are not sensitive to the exact choice of boxes
- The NAO can also be defined as the leading EOF within the domain



NAO index regressed to SLP (upper) very similar to EOF1 (lower panels)



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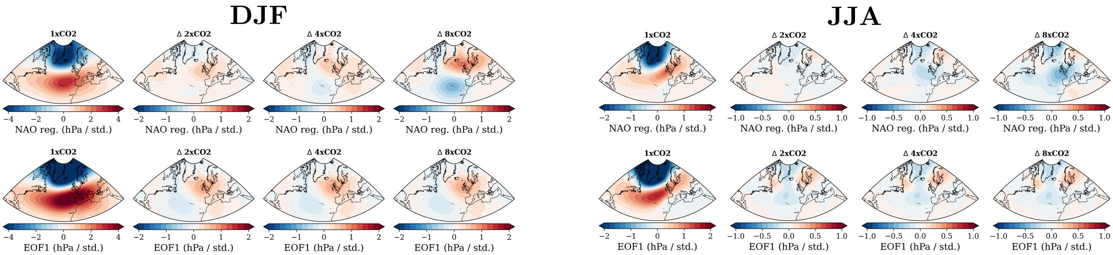
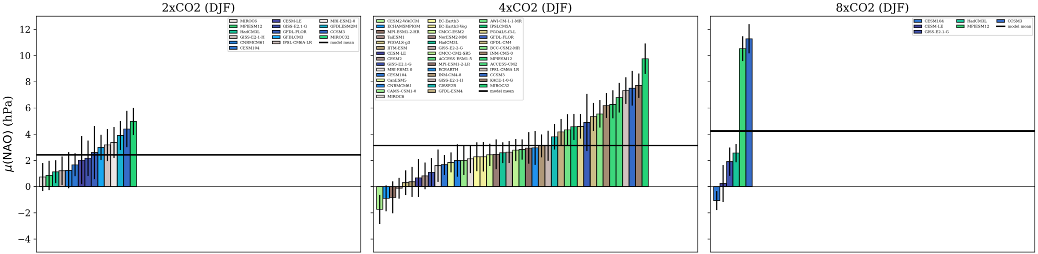


- The regression of SLP with the NAO 2-box index closely resembles EOF1, indicating that the NAO 2-box index correlates well with leading pattern of SLP variability.
- Furthermore, the changes at each CO_2 are very similar between the SLP regressed onto NAO and EOF1.
- 2-box index easier to interpret, so we use it to quantify the NAO response to higher CO_2 forcings

NAO 2-box index **mean** response in hPa

DJF



- Winter NAO becomes more positive with increasing CO_2 concentrations in almost all models.

NAO 2-box index **mean** response in hPa

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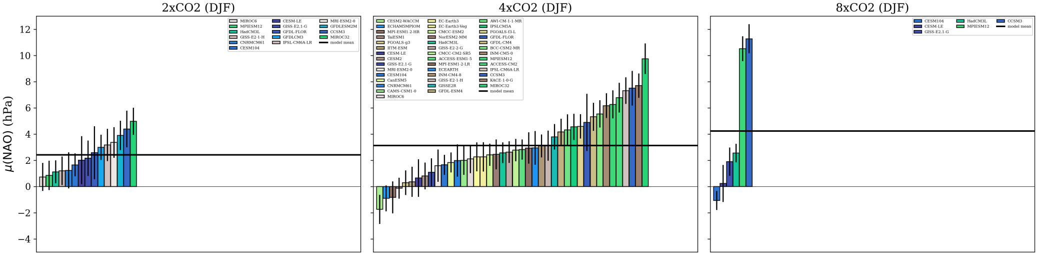

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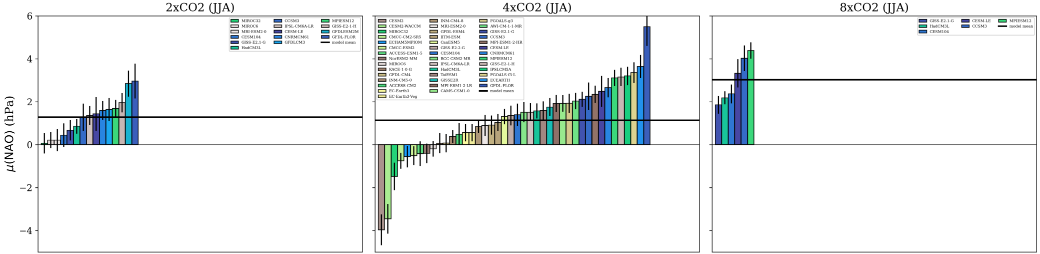
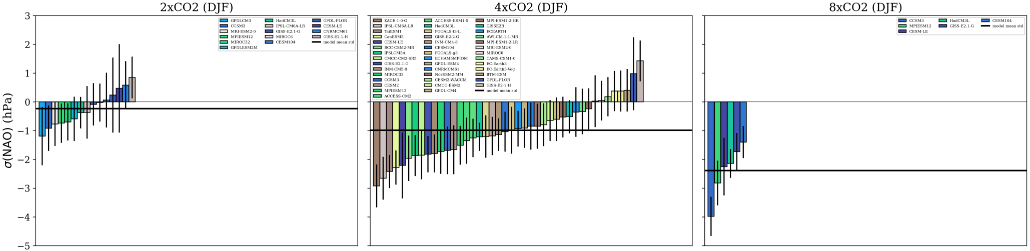
JJA



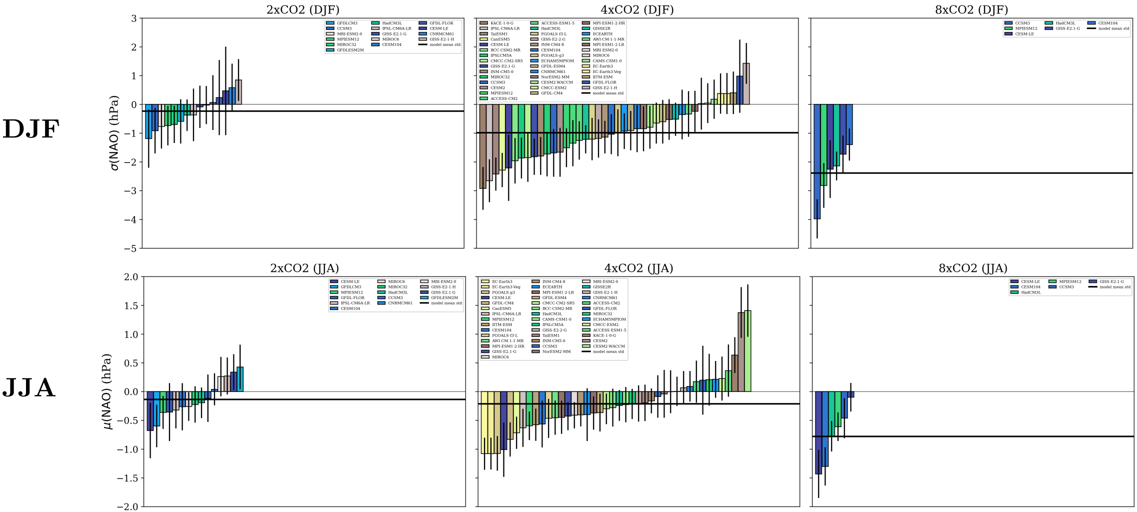
- Summer NAO also becomes more positive in most models.

NAO 2-box index **variability** response in hPa

DJF

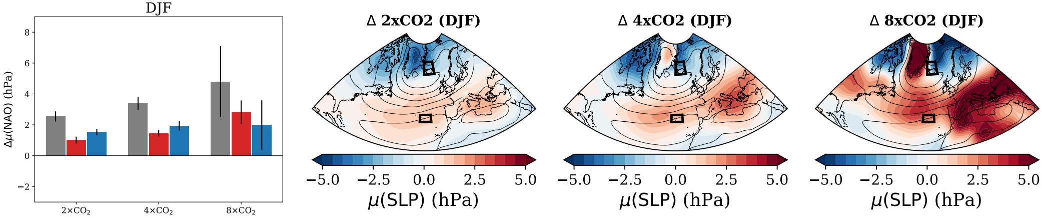


NAO 2-box index **variability** response in hPa



- Variability decreases at higher CO_2 forcing in most models in winter and summer.

NAO (2-box) **mean** response decomposed to High and Low



- Positive shift in multi-model winter NAO (2-box index) is roughly equally due to the strengthening of both the Azores high (red) and the Iceland low (blue)

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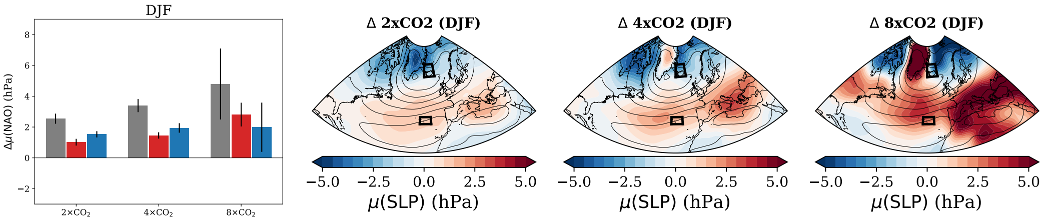

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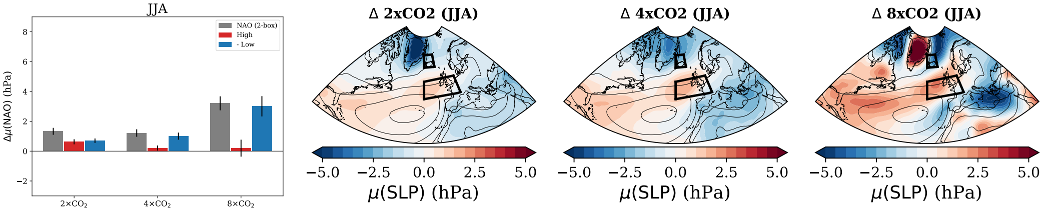
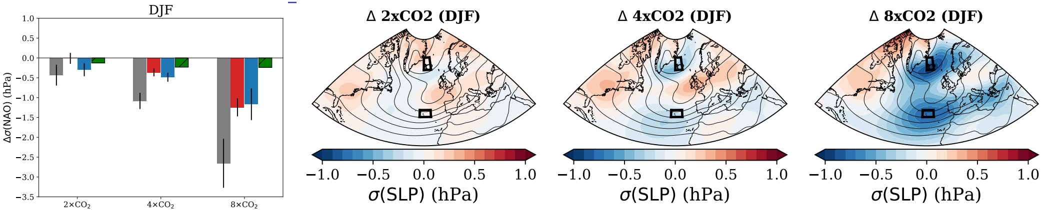


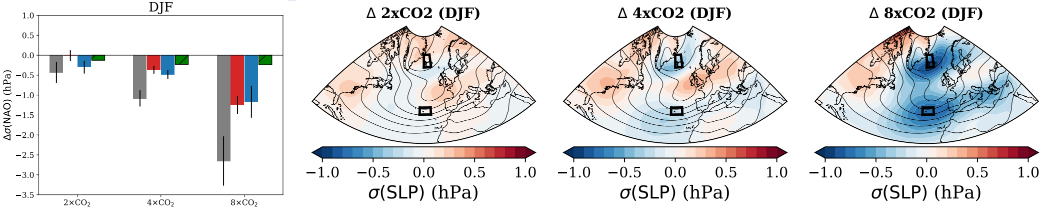
- Positive shift in multi-model summer NAO is primarily due to a deepening Iceland Low

NAO (2-box) **variability** response decomposed to High and Low



- The multi-model decrease in winter NAO variability is roughly equally due to a decrease in variability of both the Azores high (red) and the Iceland low (blue).

NAO (2-box) **variability** response decomposed to High and Low



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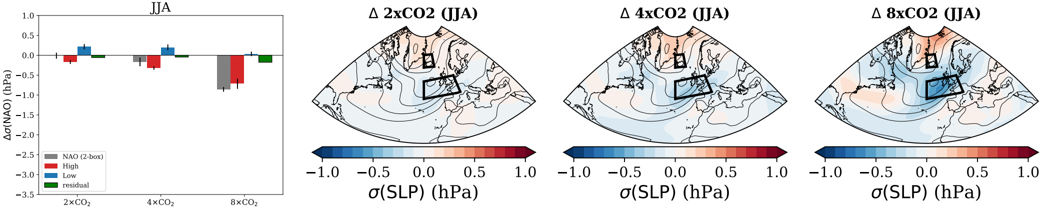
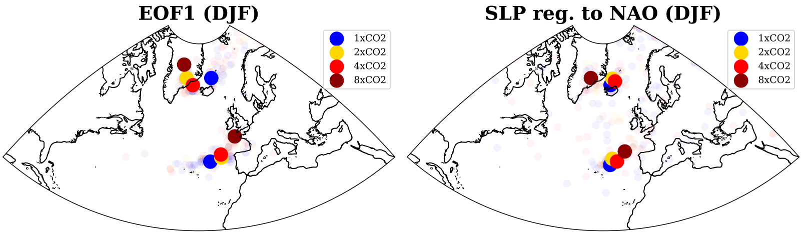


- The multi-model NAO decrease in variability in JJA is primarily due to a decrease in variability in the British Isles.

Spatial shift of NAO



- The Azores High node of the winter NAO shifts slightly northeast (in both EOF and 2-box definitions)

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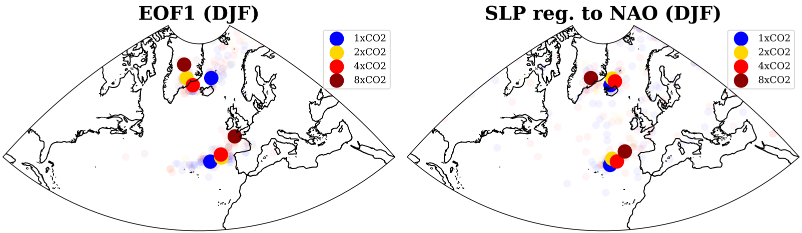

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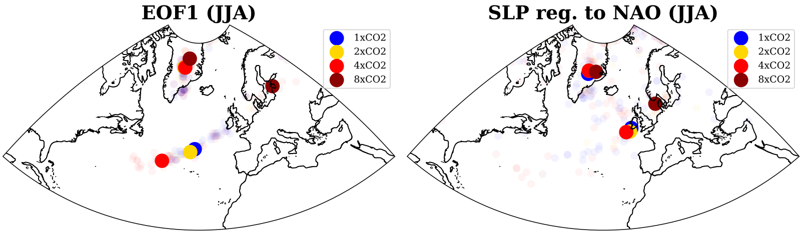

- Similar but clearer northeast shift in summer

Summary

- The North Atlantic Oscillation (NAO) becomes **more positive** in both winter and summer at high CO_2 forcings
- Meanwhile, the **NAO variability decreases** in both winter and summer
- NAO mean is more positive, but variance is decreased, so **extremes** may not scale linearly with the mean
- The spatial structure of NAO changes, with the summer low shifting northeast. Capturing magnitude of change more challenging; fixed 2-box method may **underestimate** changes.

Thank you!