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Improved Arctic-midlatitude teleconnections via stochastic process representation

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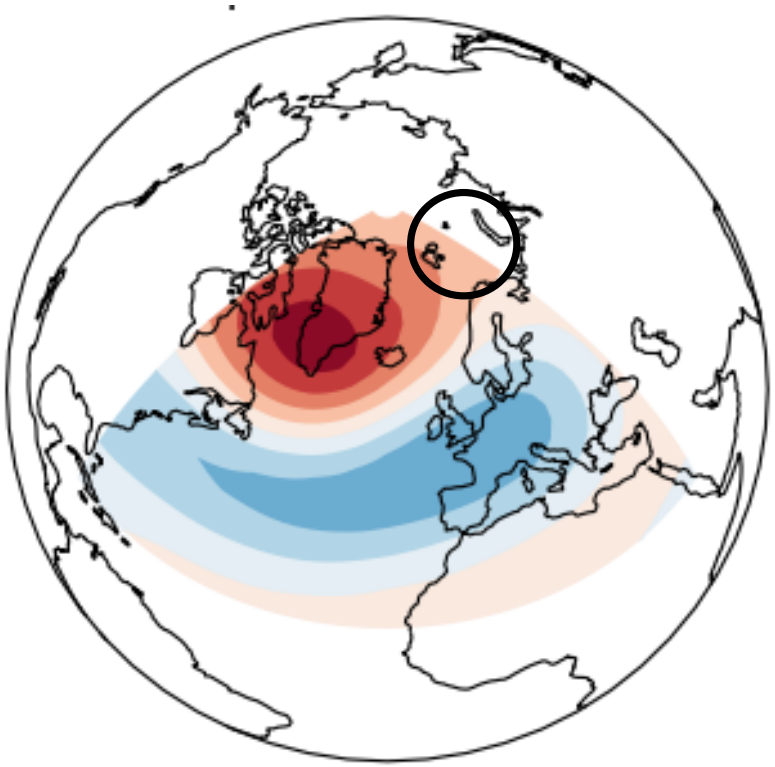
Lots of papers suggest November Barents-Kara sea-ice influences the DJF NAO…



Kim et al. (2014)
Garcia-Serrano et al. (2015)
Dunstone et al. (2016),
Kretschmer et al. (2016)
Wang et al. (2017),
Strommen et al. (2020)
etc. etc. etc.

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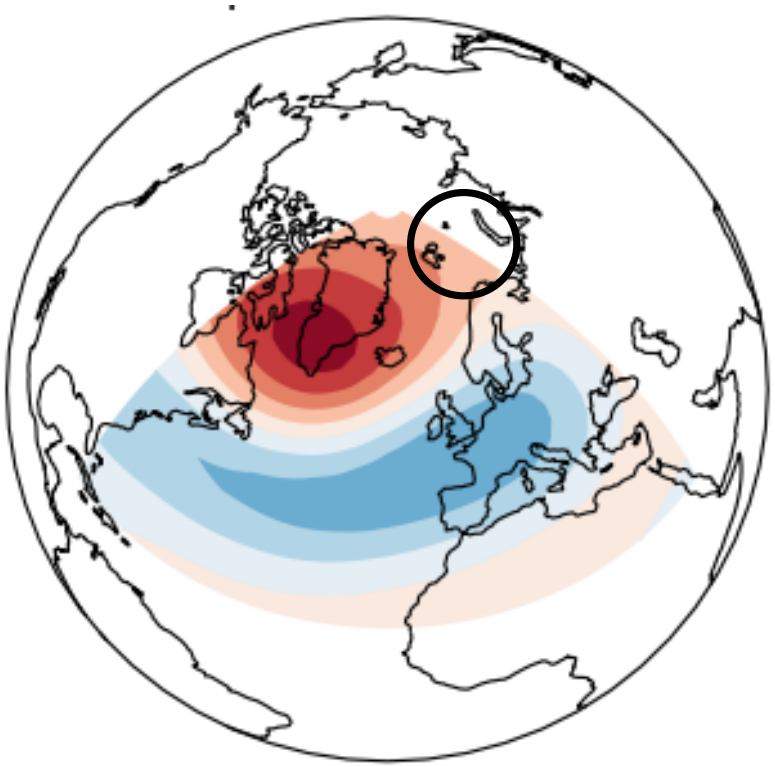
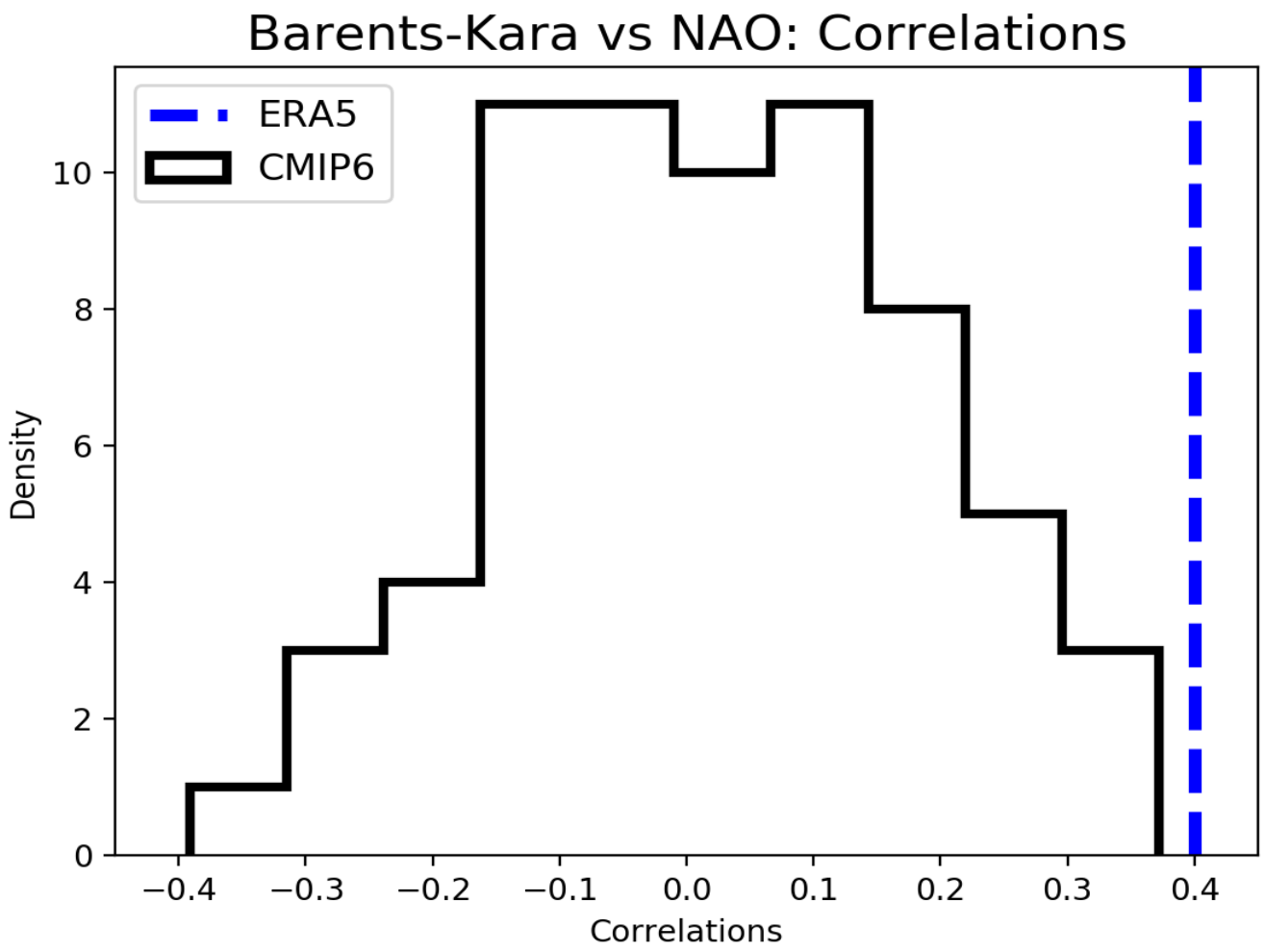
Lots of papers also suggest there is no robust teleconnection…



e.g. Screen et al. (2018)
Blackport et al. (2019, 2021)
Warner et al. (2020),
Siew et al. (2021), etc.

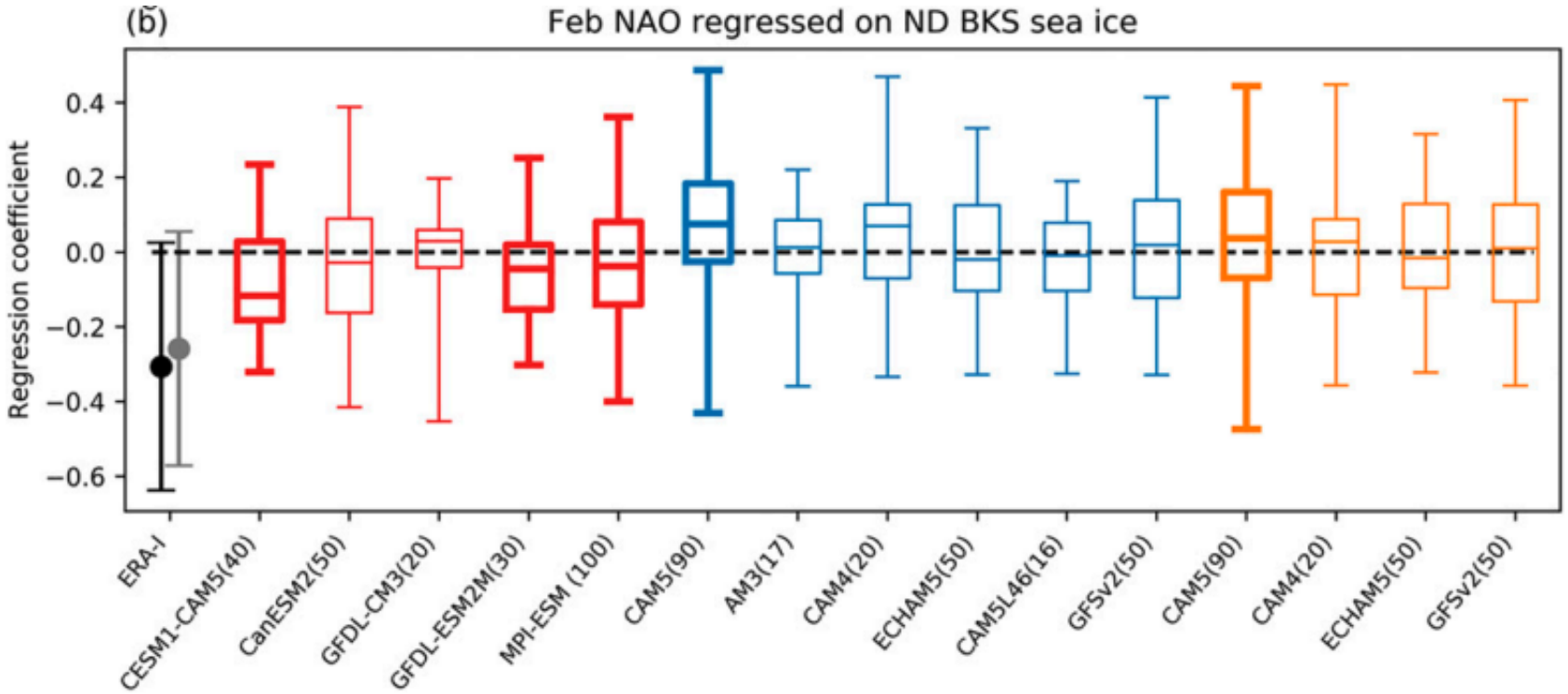
Why so controversial? Because climate models show no consistency!



- November sea ice vs DJF NAO index
- Coupled CMIP6/HighResMip models with observed forcing.
- ~70 simulations (1980-2015).
- **Models are consistent with a mean-zero null hypothesis.**
- **But also: obs is significantly diff from models.**

Why so controversial? Because climate models show no consistency!

Blackport and Screen (2021)



Even individual models have big ensemble spread *(Blackport and Screen 2021)*

Large decadal variability in models!

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Two ways to interpret this:

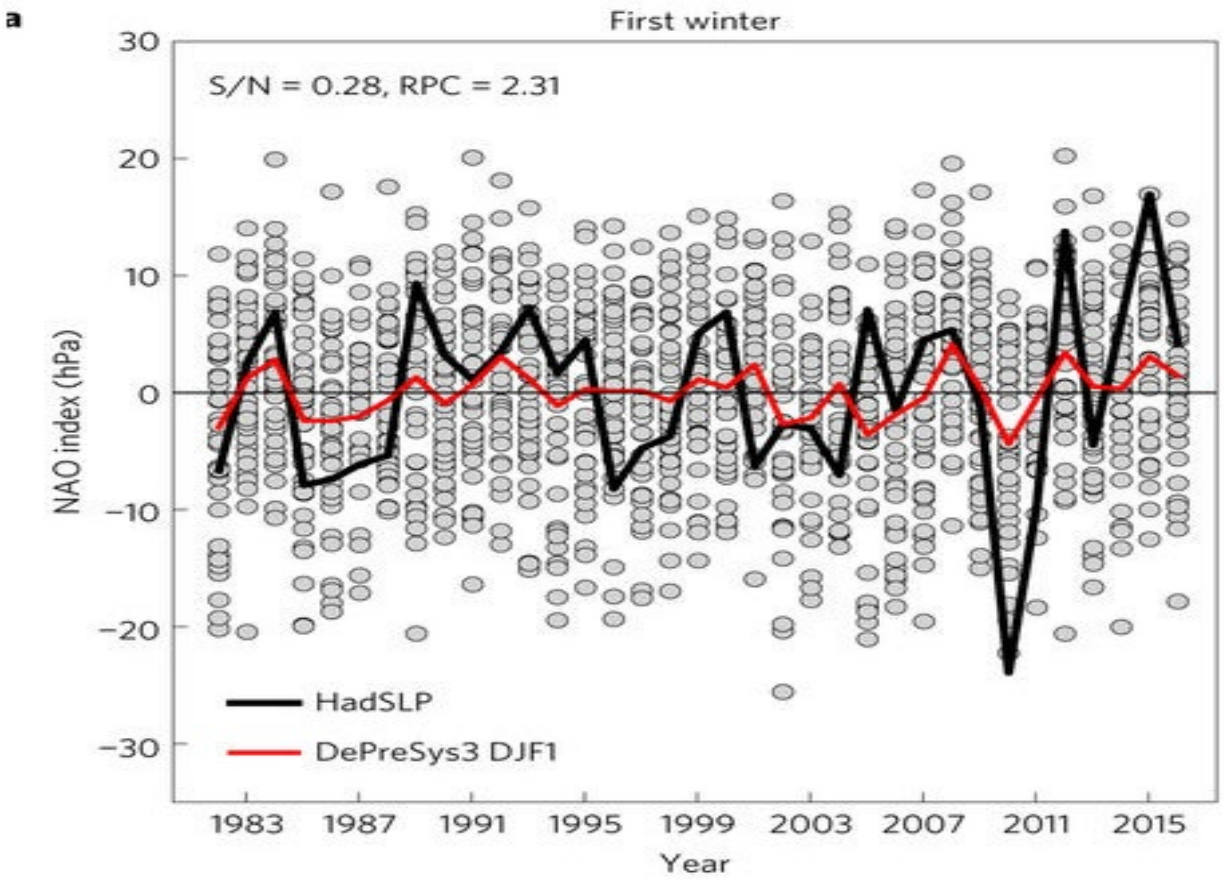
1. **The models are fine**: the observed teleconnection is unlikely but ultimately random atmospheric variability

   (e.g. Warner et al. 2020, Blackport and Screen 2021, etc.)

2. **The models are biased/wrong:** the observed correlation is unlikely to be random

   (Mori et al. 2019, Strommen et al. 2022)

Evidence for model biases from seasonal forecasts



`Signal-noise-paradox' *(Dunstone et al. 2016)*

- There is predictability of winter NAO, even 1 year out!
- But the signal is strangely weak in forecasts: `signal-to-noise paradox'
  (Smith et al. 2018)
- **And not all forecast models have skill!**
  (Baker et al. 2018)
- Is sea ice a highly persistent source of skill which models underestimate?

What are models doing wrong?

Unresolved variability and missing processes

- **Do many models have no robust teleconnection because they are missing crucial sea ice variability?**
  (Mori et al. 2019)
- If so, can we improve matters using stochastic schemes?
- We tested in EC-Earth3 using stochastic sea-ice/ocean schemes.

Stochastic sea-ice/ocean schemes

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- Developed by **Stephan Juricke**
- **NEMO** and **LIM** models, coupled to **EC-Earth3**
    - Sea-ice strength parameter P*
    - Various parts of NEMO (eddy kinetic energy, mixing strength, …)
- Both tendency and parameter perturbations
- All perturbed with multiplicative noise (similar to SPPT).

Our experiments

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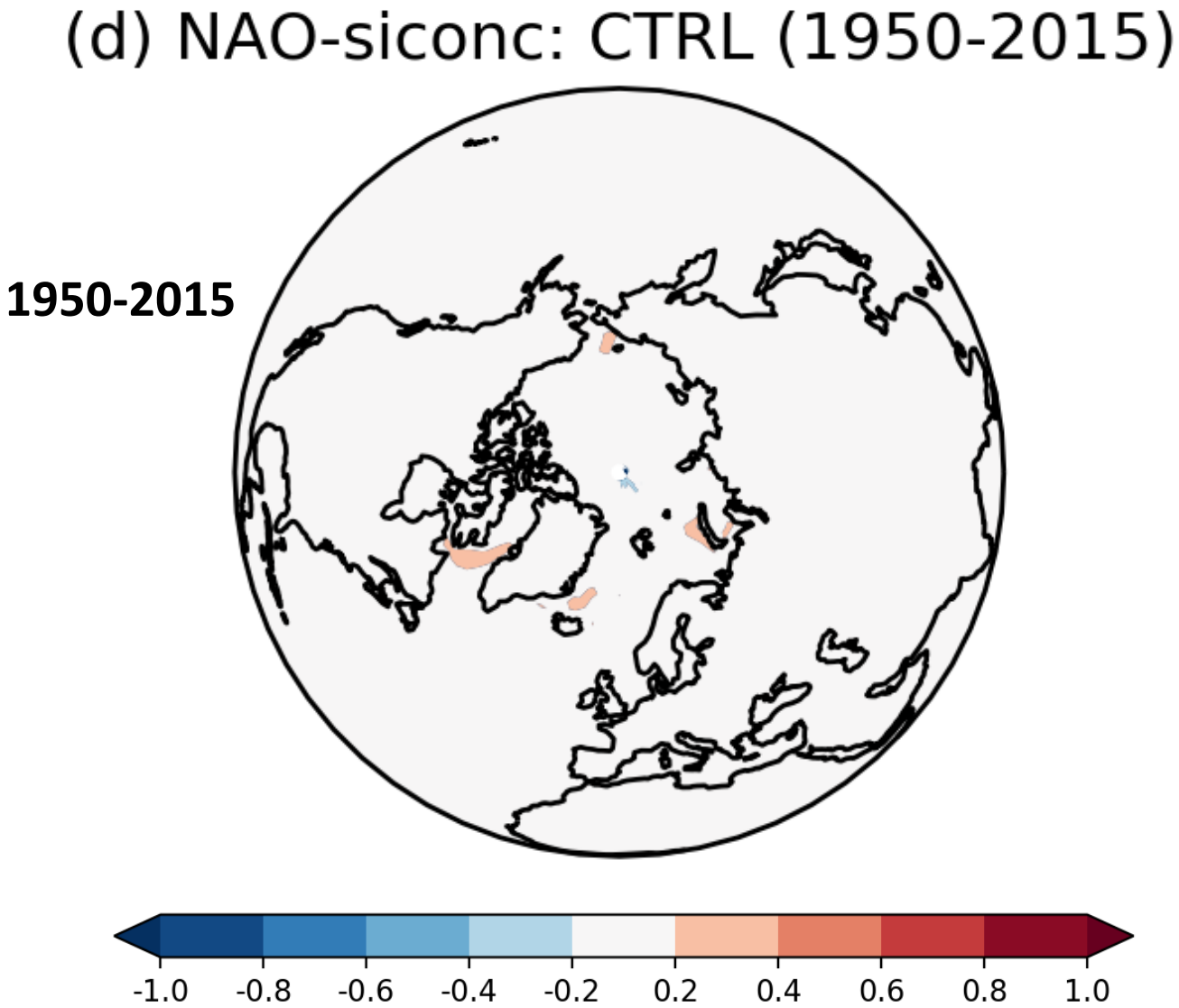
- **CTRL** = default model (no stochasticity)
- **OCE** = with stochastic schemes turned on
- 6 ensemble members covering 1950-2015
- Atmosphere resolution = ~80 km (T255)
  Ocean resolution = 1 degree
- In addition: 3 `AMIP' simulations
  (prescribed HadISST ice/SSTs)

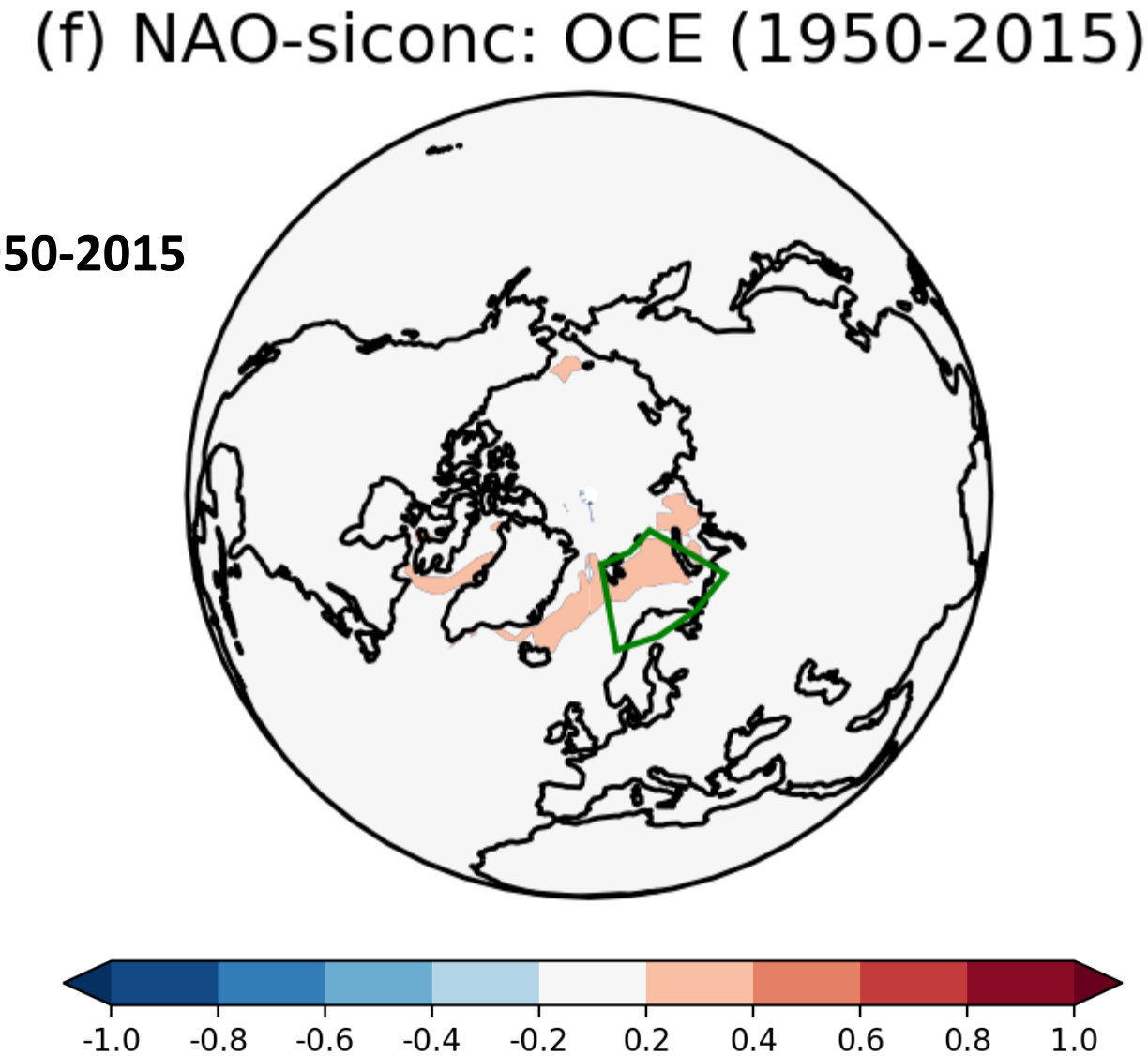
DJF NAO index vs Nov sea ice



Correlate DJF NAO index with November sea ice concentration at each gridpoint.

In CTRL, there is nothing…over either full time period or modern period

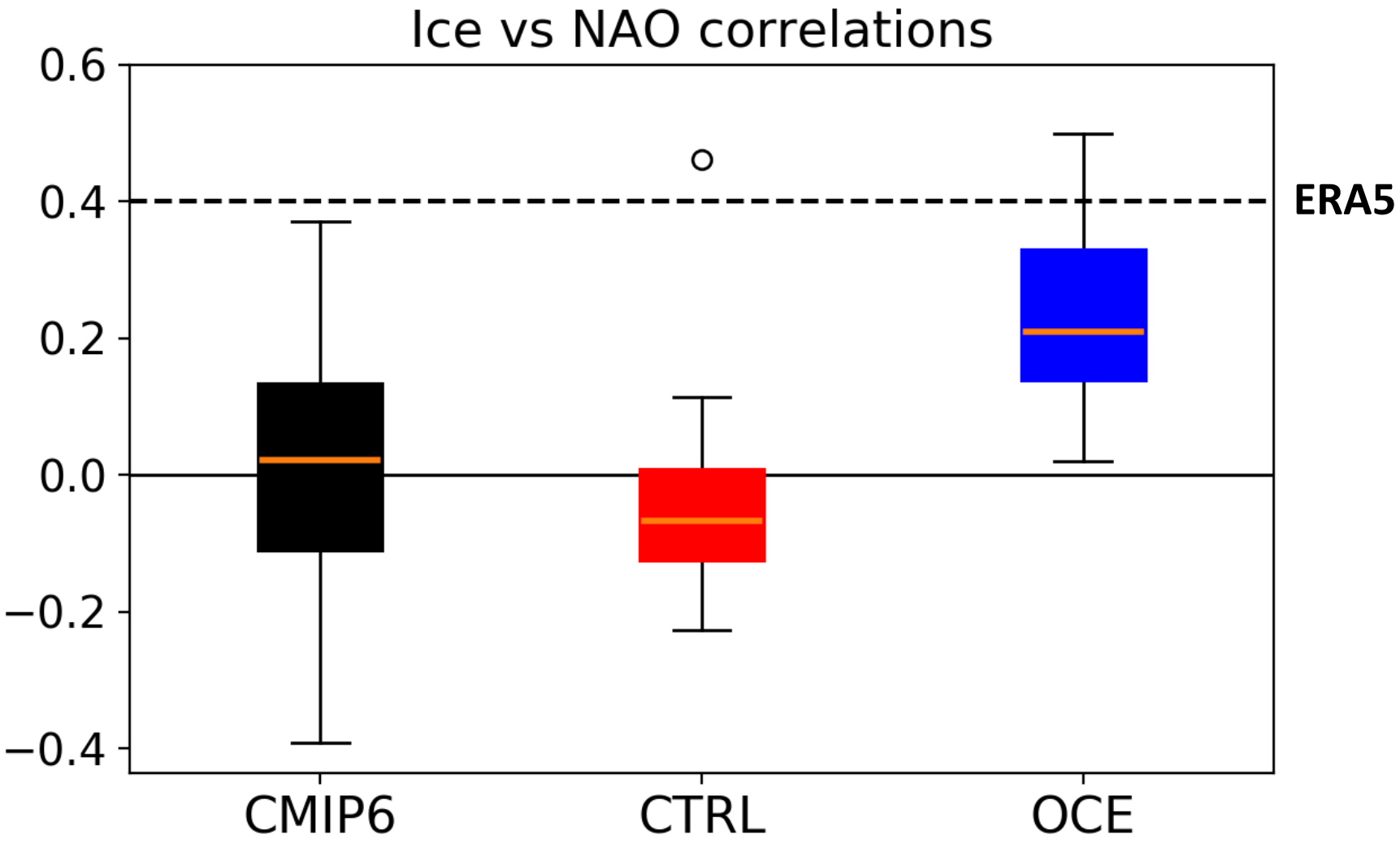
DJF NAO index vs Nov sea ice



Correlate DJF NAO index with November sea ice concentration at each gridpoint.

Turn on stochasticity and a signal emerges in Barents-Kara sea…it's bigger and larger in extent when using full time period

OCE is different from CTRL/CMIP6



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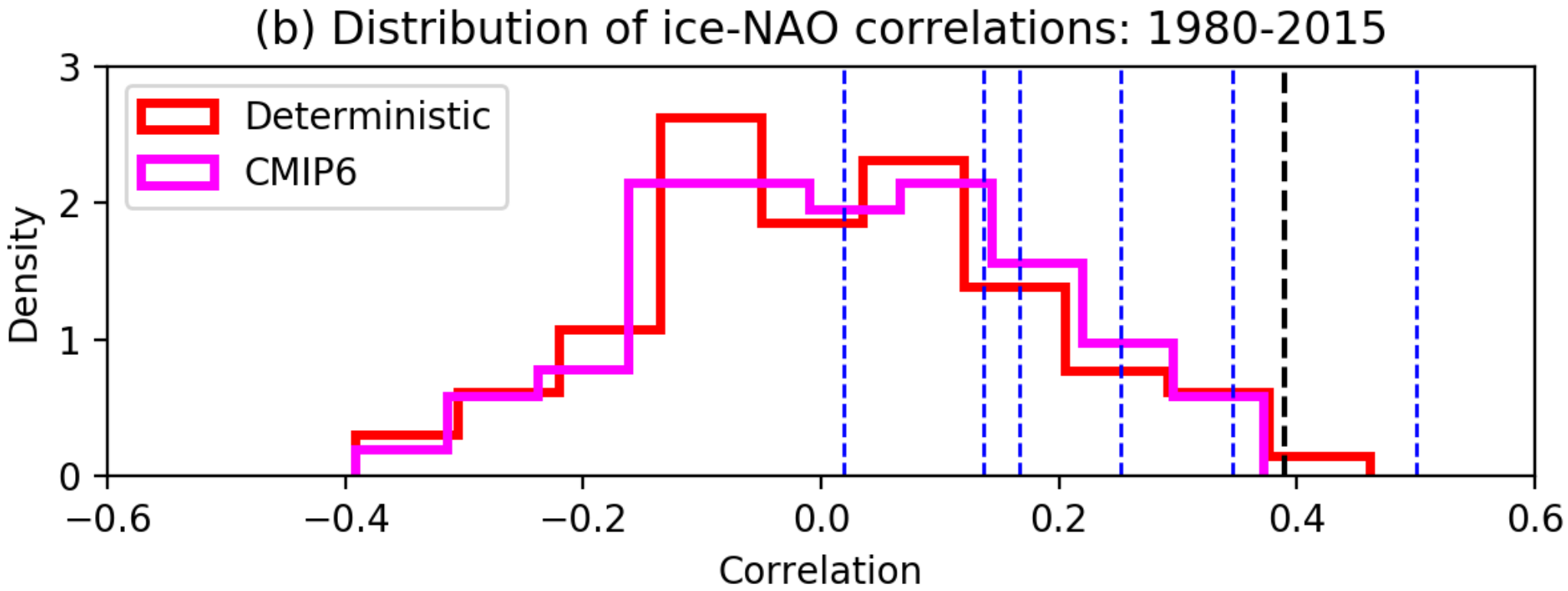
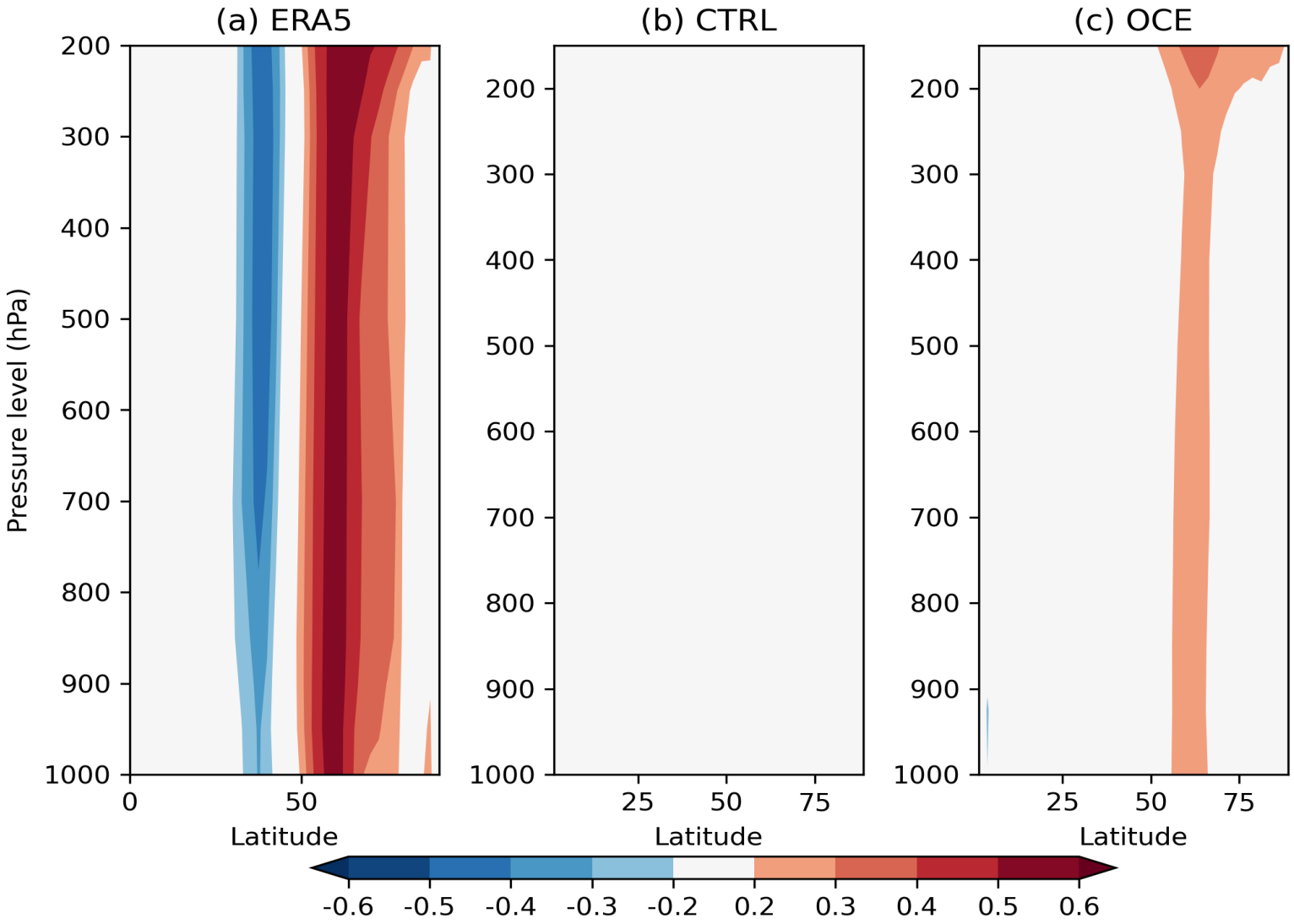
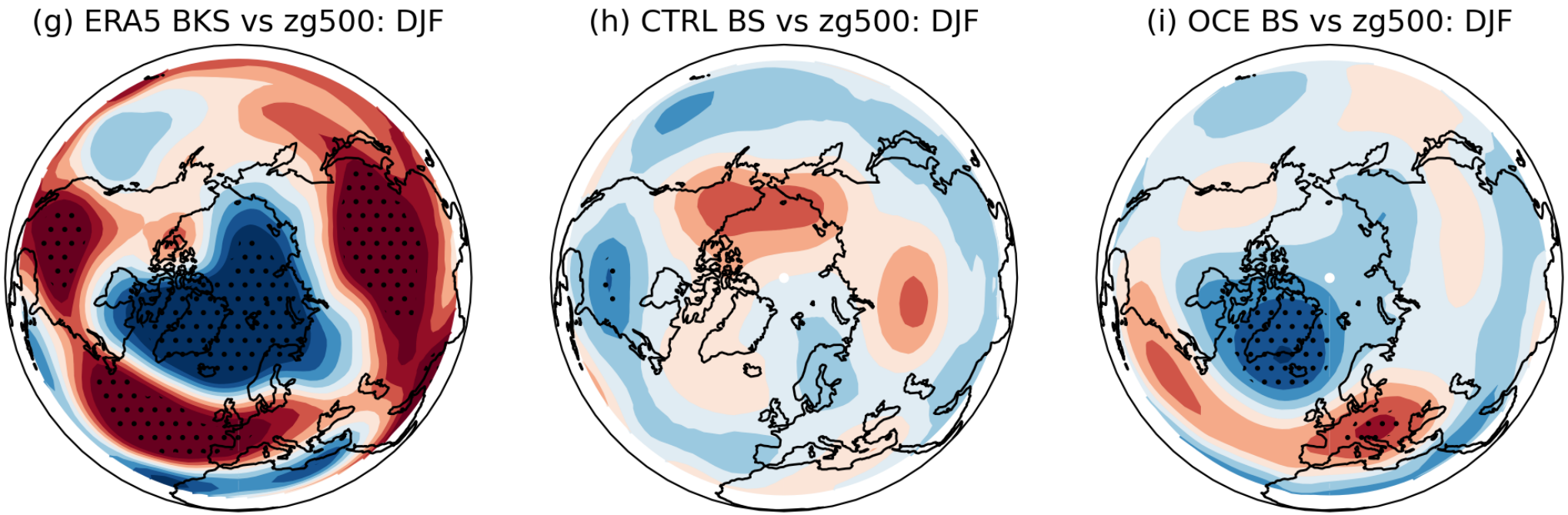


OCE is not a random draw from the mean-zero CMIP6 distribution
→ the teleconnection is probably a real feature of OCE

The signal reaches the stratosphere

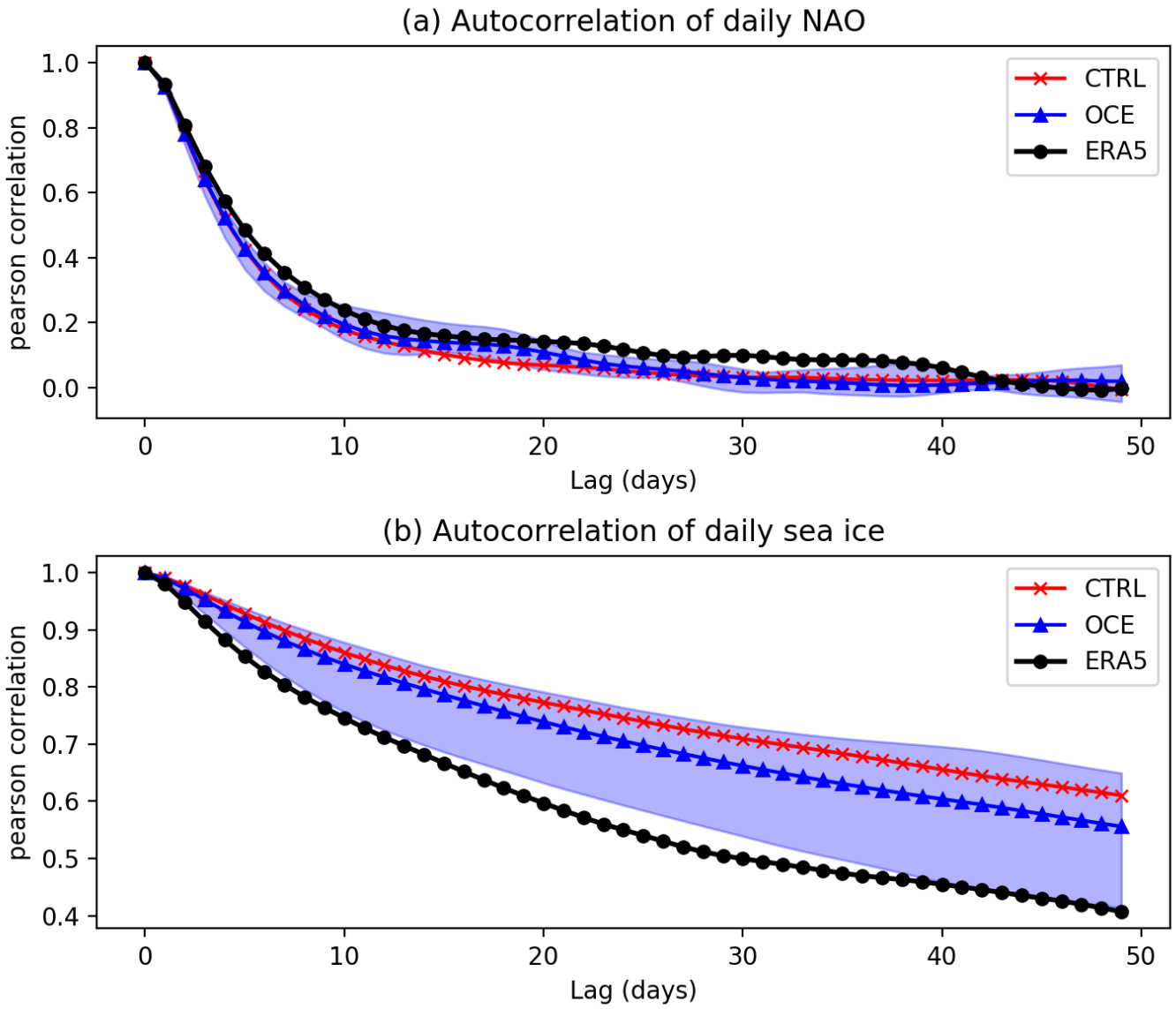


In CTRL the initial anomaly fizzles out…

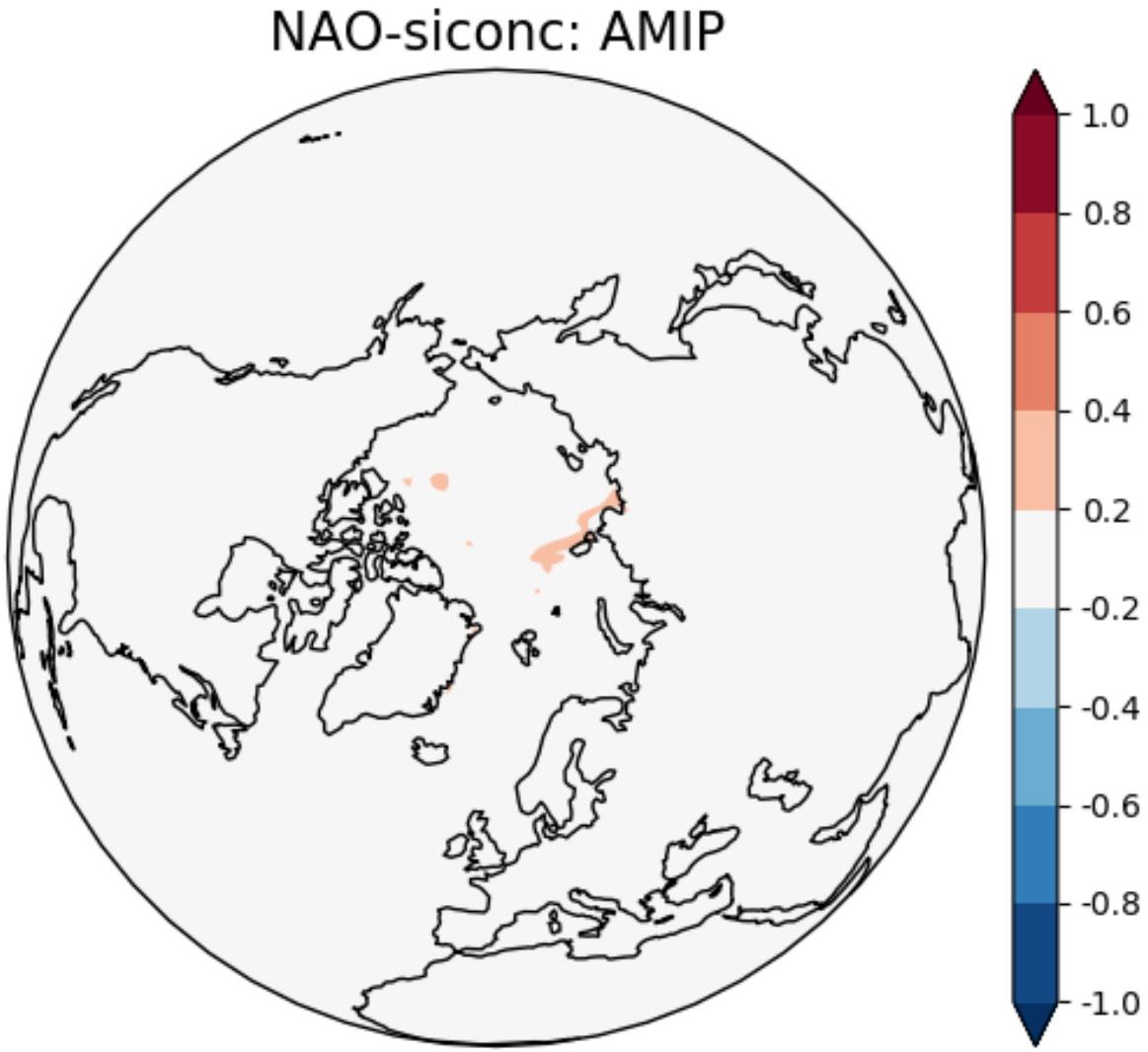


DJF anomaly in CTRL is essentially a weaker version of the November anomaly.

But it’s not due to autocorrelation



And it’s not purely the mean state!



Our AMIP ensemble has perfect SSTs and sea ice…

But doesn’t have a teleconnection.

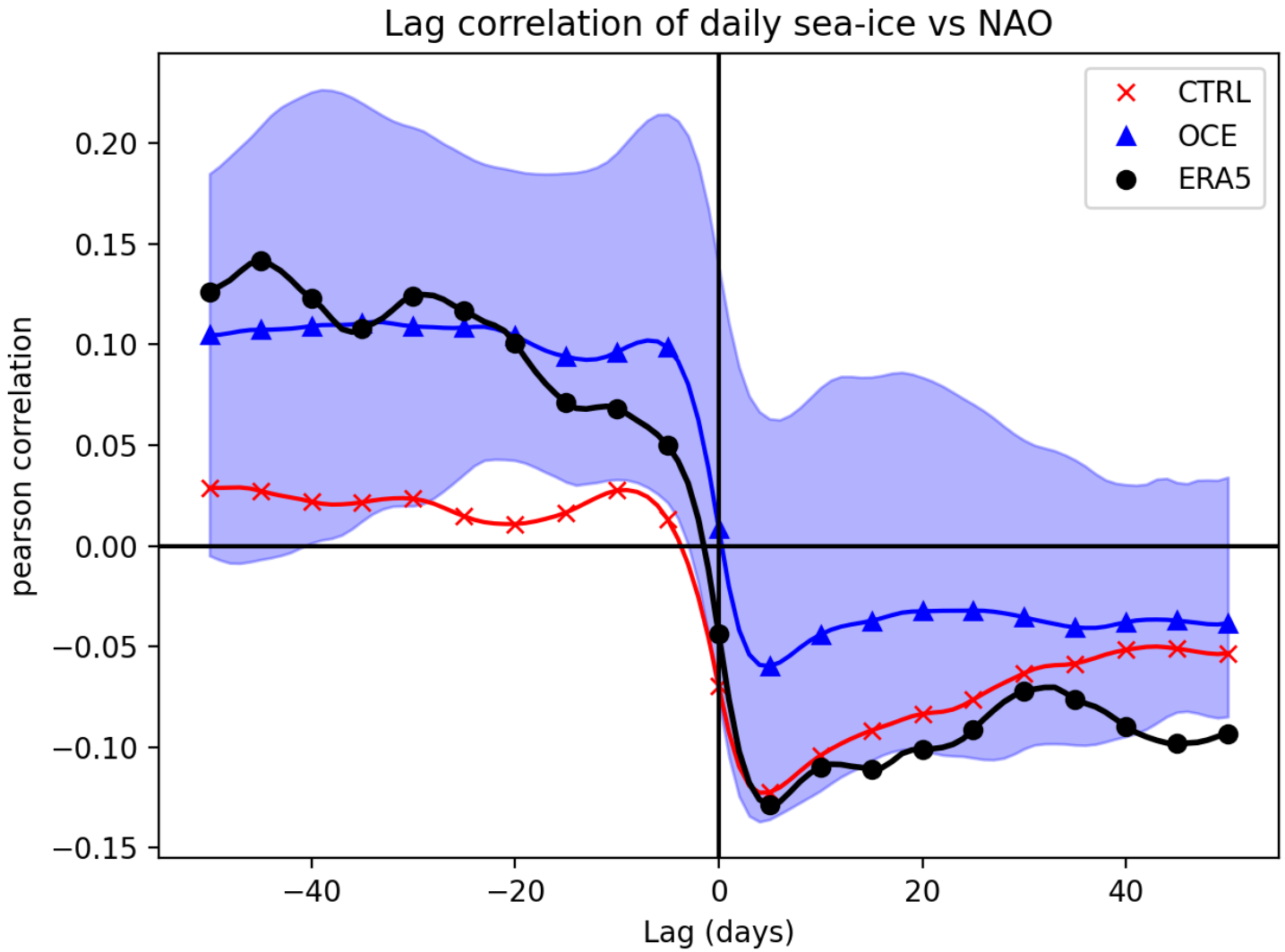
AMIP models generally have weaker teleconnections.

(Blackport and Screen 2021)

Coupling must matter!

(Strong et al. 2009, Deser et al. 2016, Mori et al. 2019)

Ice-NAO coupling is better in OCE



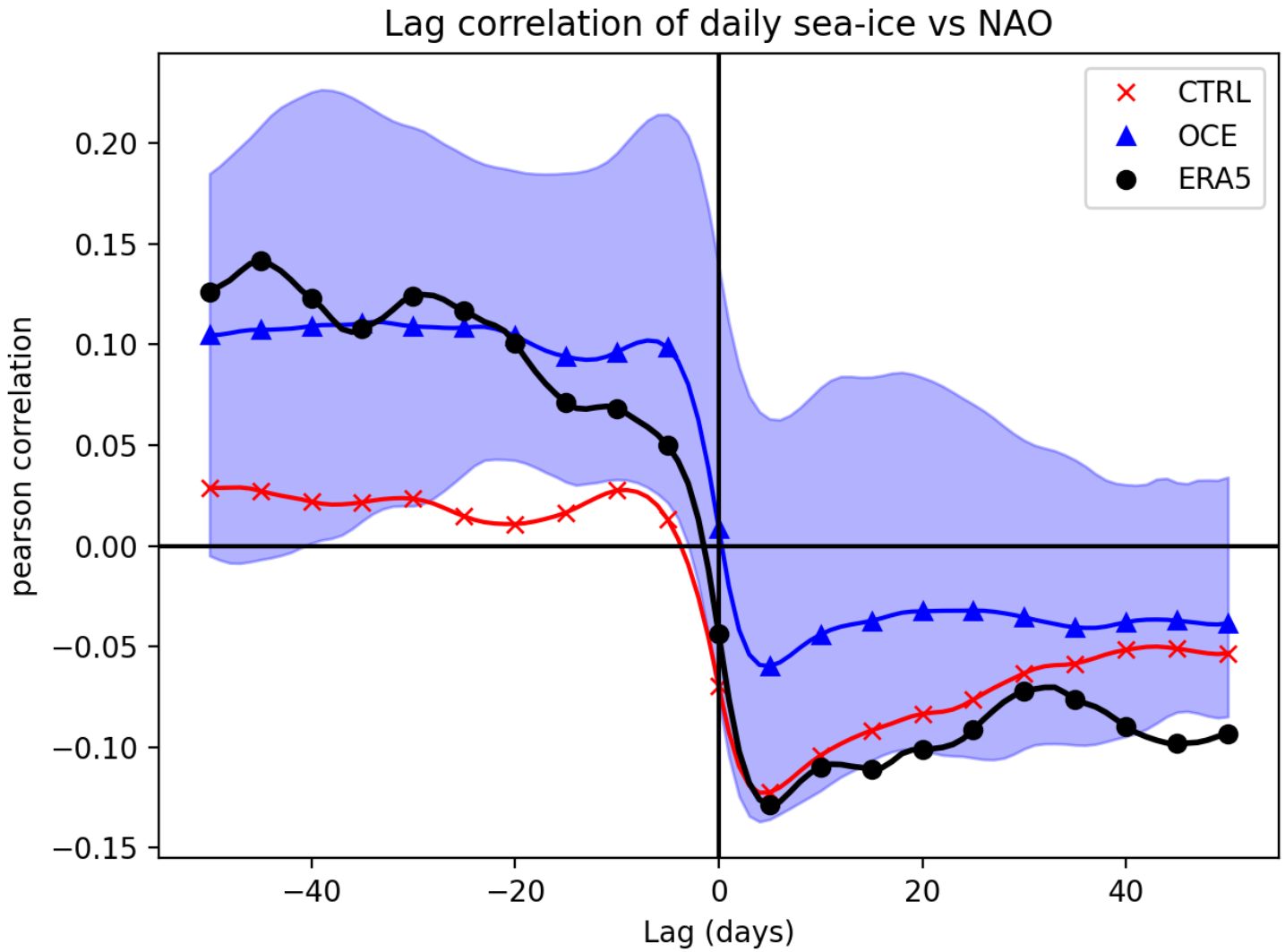
Is all relevant ice-NAO dynamics captured by the daily coupling?

Test using **Linear Inverse Model** (LIM)

$$\frac{d}{dt}\mathrm{NAO} = a \cdot \mathrm{NAO} + b \cdot \mathrm{ICE} + \epsilon_{\mathrm{NAO}},$$

$$\frac{d}{dt}\mathrm{ICE} = c \cdot \mathrm{NAO} + d \cdot \mathrm{ICE} + \epsilon_{\mathrm{ICE}}.$$

Ice-NAO coupling is better in OCE



Is all relevant ice-NAO dynamics captured by the daily coupling?

Test using **Linear Inverse Model** (LIM)

1. Teleconnection in ERA5/OCE accounted for by continuous ice-ocean-atmosphere coupling.
2. **This coupling fails in the CTRL simulations.**

So what goes wrong in CTRL?

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Three ways CTRL can fail LIM hypothesis:

1. Remote ice/SST adjustments are crucial and these are worse in CTRL due to worse ice-ocean-atmosphere coupling

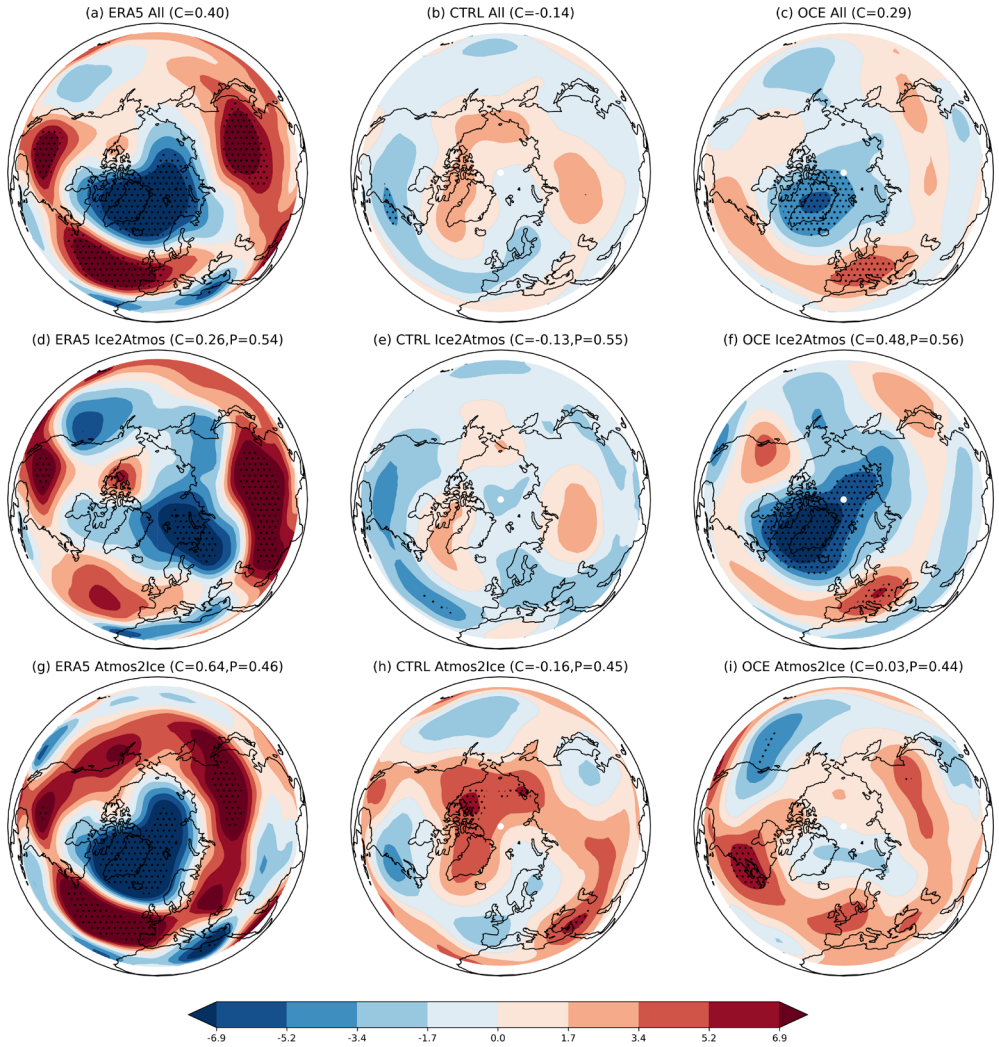
2. The evolution of the initial anomaly is systematically disrupted by some other unrealistic variability in CTRL but not OCE
   (e.g. from excessive ENSO signals)

3. Ice edge is misaligned with the storm track in CTRL but not OCE.

Maybe all the above?

It's <u>not</u> that the initial heatflux anomaly is much weaker in CTRL

Are you sure it's not random variability?



- We carry out Blackwell et al. (2019) analysis to test if it's all due to atmospheric forcing.
- Teleconnection in OCE is mostly accounted for by years when the ice is forcing the atmosphere.

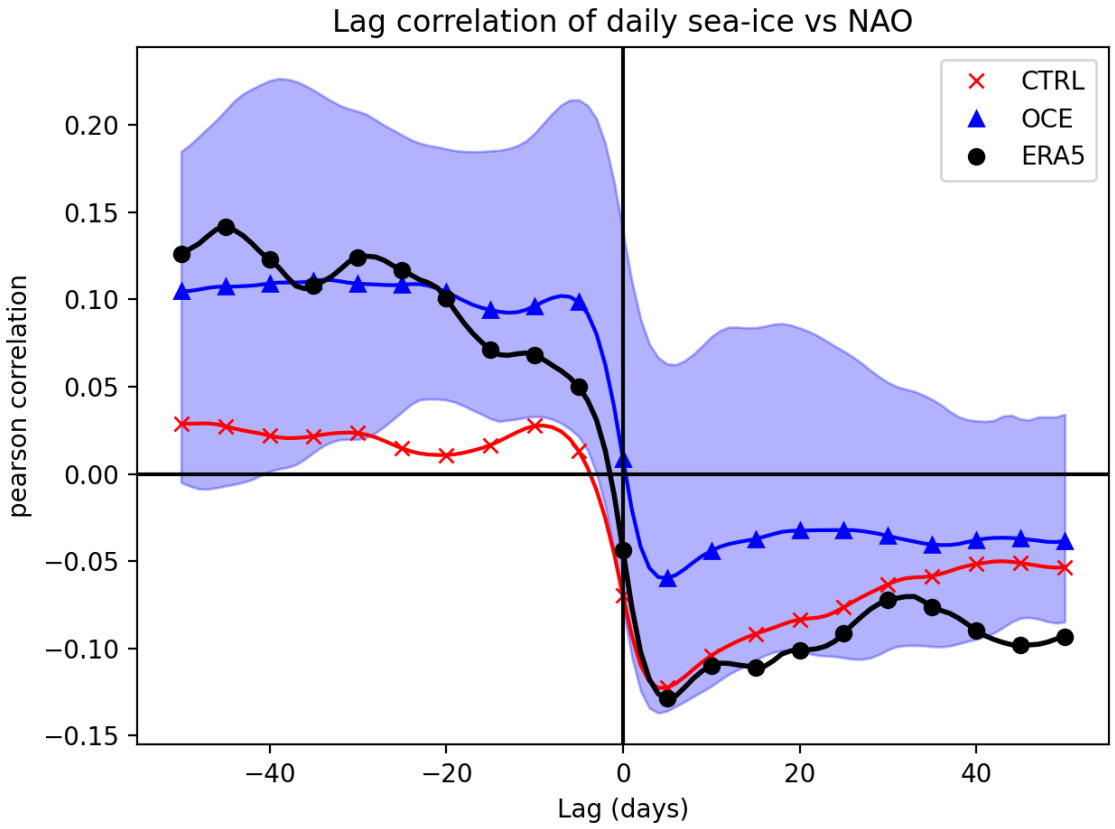
Stochasticity as `damage mitigation'?

Deterministic models?

- We don't understand the exact mechanisms…
- But deterministic forecasts are often `overconfidently wrong'
- Stochasticity → sometimes get the shape in the right hole
- Matters more where variability is great

(e.g. ice edge formation)

Summary



- Stochastic sea-ice and ocean schemes lead to a teleconnection comparable to ERA5.
- Improved ocean/ice-atmosphere coupling seems to be crucial mechanism.
- Suggests weak inter-model consensus is due to model biases in surface coupling.
- **You might get better teleconnections by adding stochastic sea-ice/ocean schemes to your model.**