The importance of stratospheric initial conditions for winter NAO predictability and implications for the signal-to-noise paradox.

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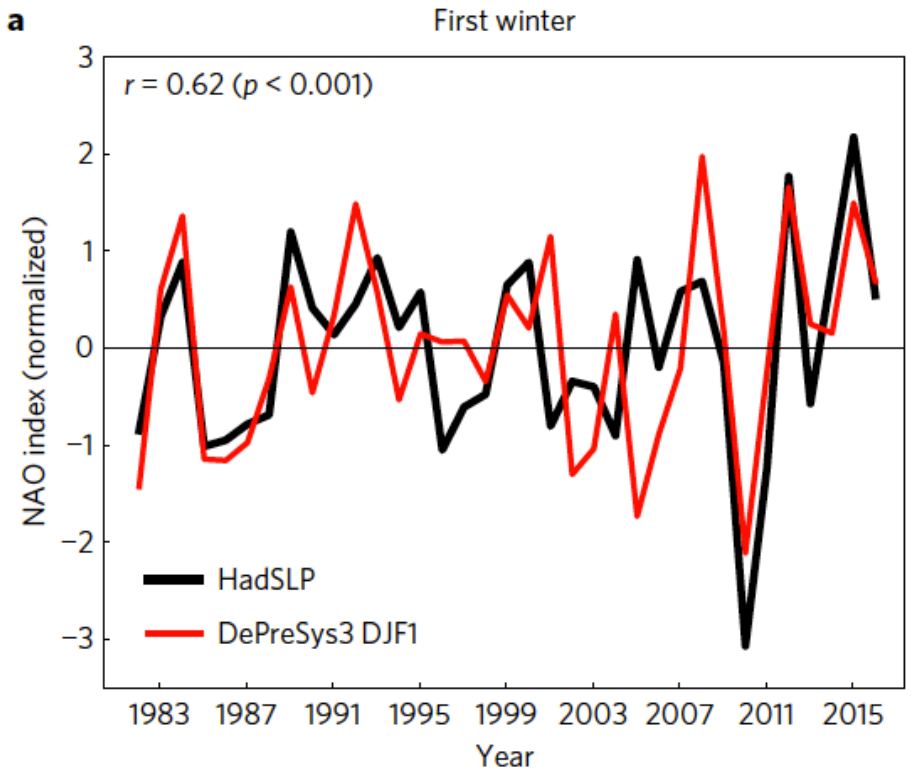
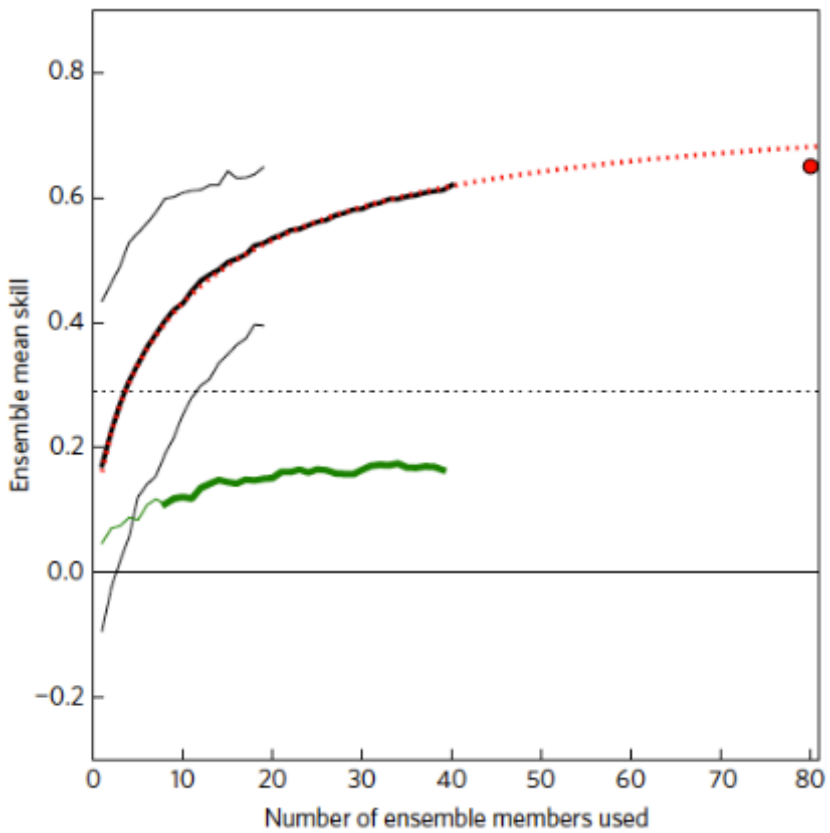
“Are atmospheric initial conditions important for seasonal forecasts of the winter North Atlantic Oscillation?”

Winter NAO hindcast skill

1. Seasonal hindcast skill of the wintertime North Atlantic Oscillation (NAO) has been demonstrated (e.g. in the Met Office systems GloSEA5 & DePreSys3).

2. However, these hindcasts seem to exhibit a weak predictable signal – referred to as a **“signal-to-noise paradox”**.





From Dunstone et al. (2016).

Model setup

Three experiments performed using the ECMWF IFS (c41r1):

- Prescribed SST and sea-ice at surface (from HadISST).
- Initialised on 1st November and run through DJF winter.
- T255 horizontal resolution, 91 vertical levels.
- Initialised for 50 years, 1960-2009.
- 51 ensemble members (49 members in “Shuffled IC” run).

Hindcast experiments

1. ERA-40/Int IC experiment:

- Initial condition taken from the ERA-40 dataset (1960-1978) and ERA-Interim dataset (1979-2009).

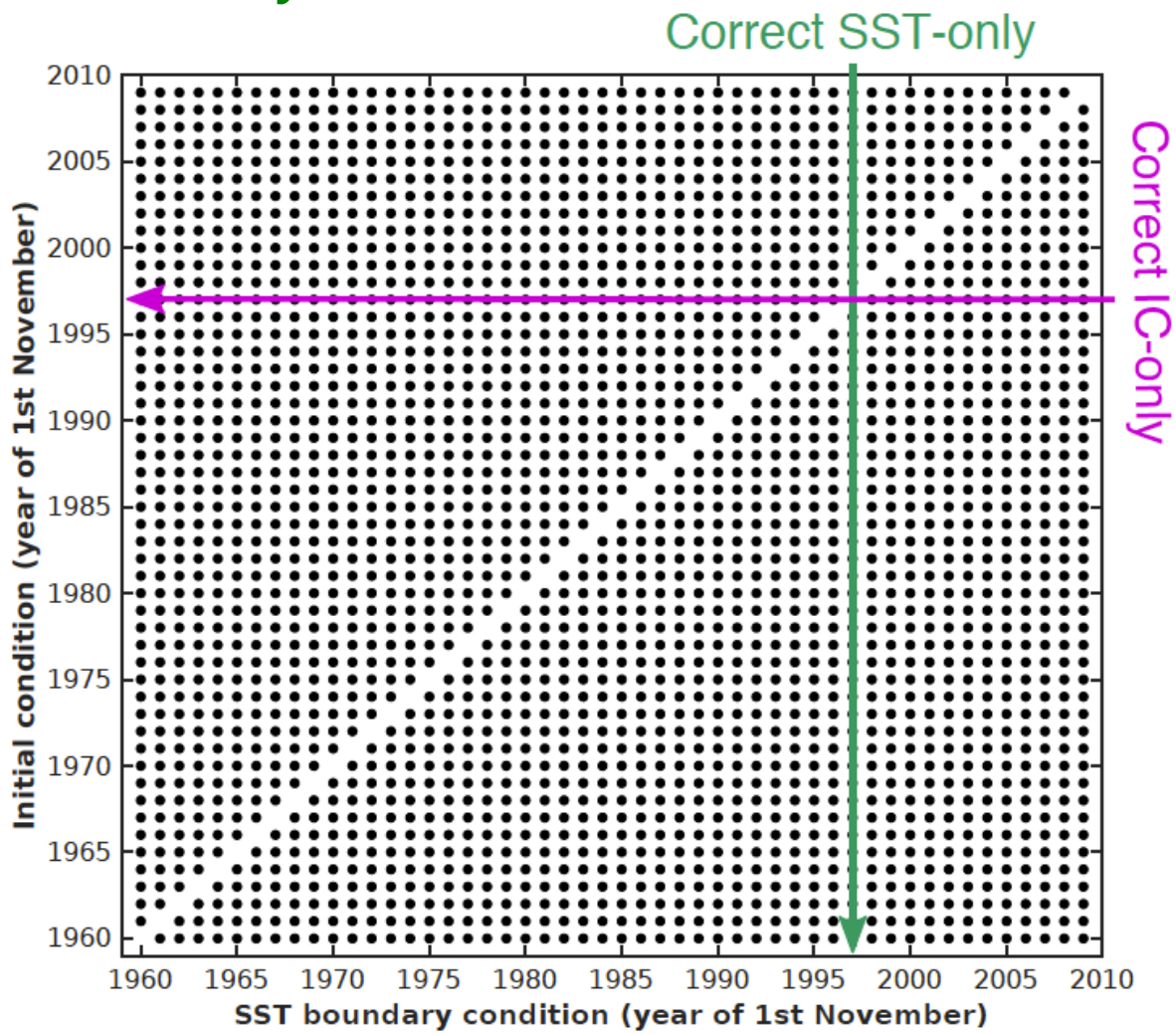
2. ERA-20C IC experiment:

- Initial condition taken from the ERA-20C dataset (1960-2009).
- ERA-20C assimilates only surface observations.
- Therefore differs from ERA-40 and ERA-Interim in upper-troposphere and stratosphere.

Hindcast experiments

3. Shuffled IC experiment:

- Initial condition taken ERA-40/Interim from all years not corresponding to the SST boundary condition.
- See schematic:

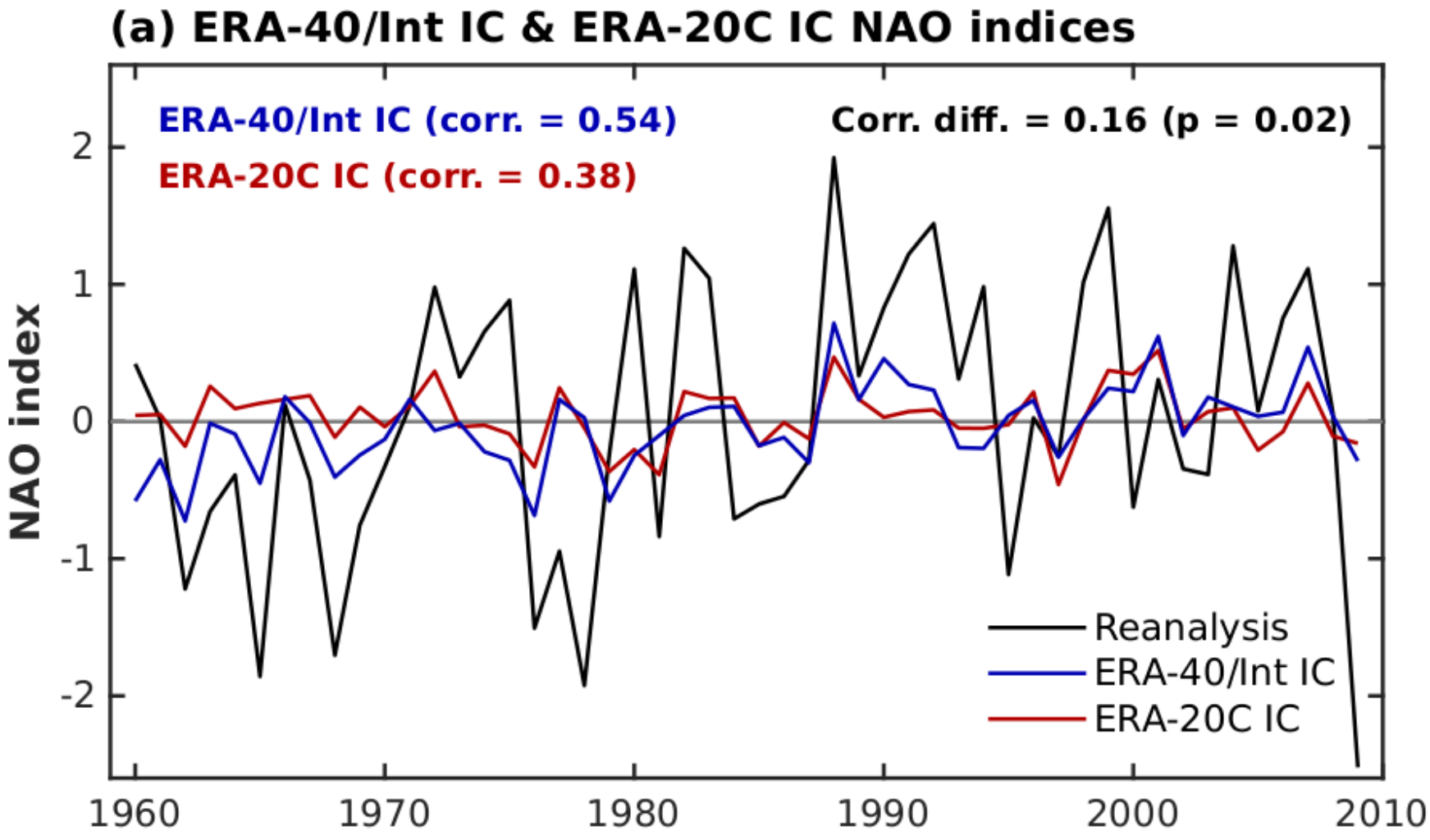


Each point represents a single ensemble member in the Shuffled IC experiment.

Can be averaged over members with the ***same SST boundary conditions*** or members with the ***same initial conditions***:

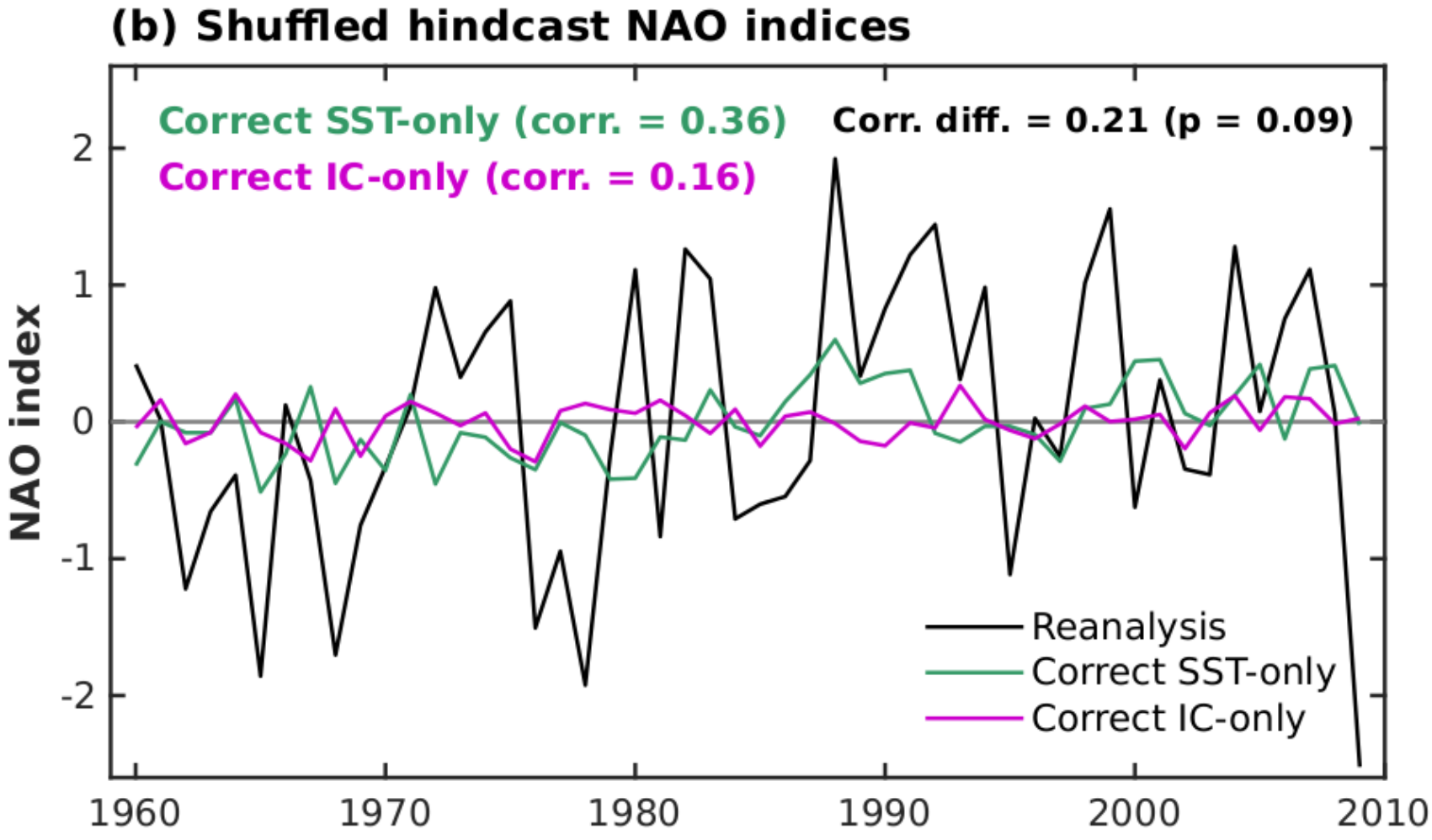
- **Correct SST-only**
- **Correct IC-only**

Winter (DJF) NAO ensemble mean hindcast skill



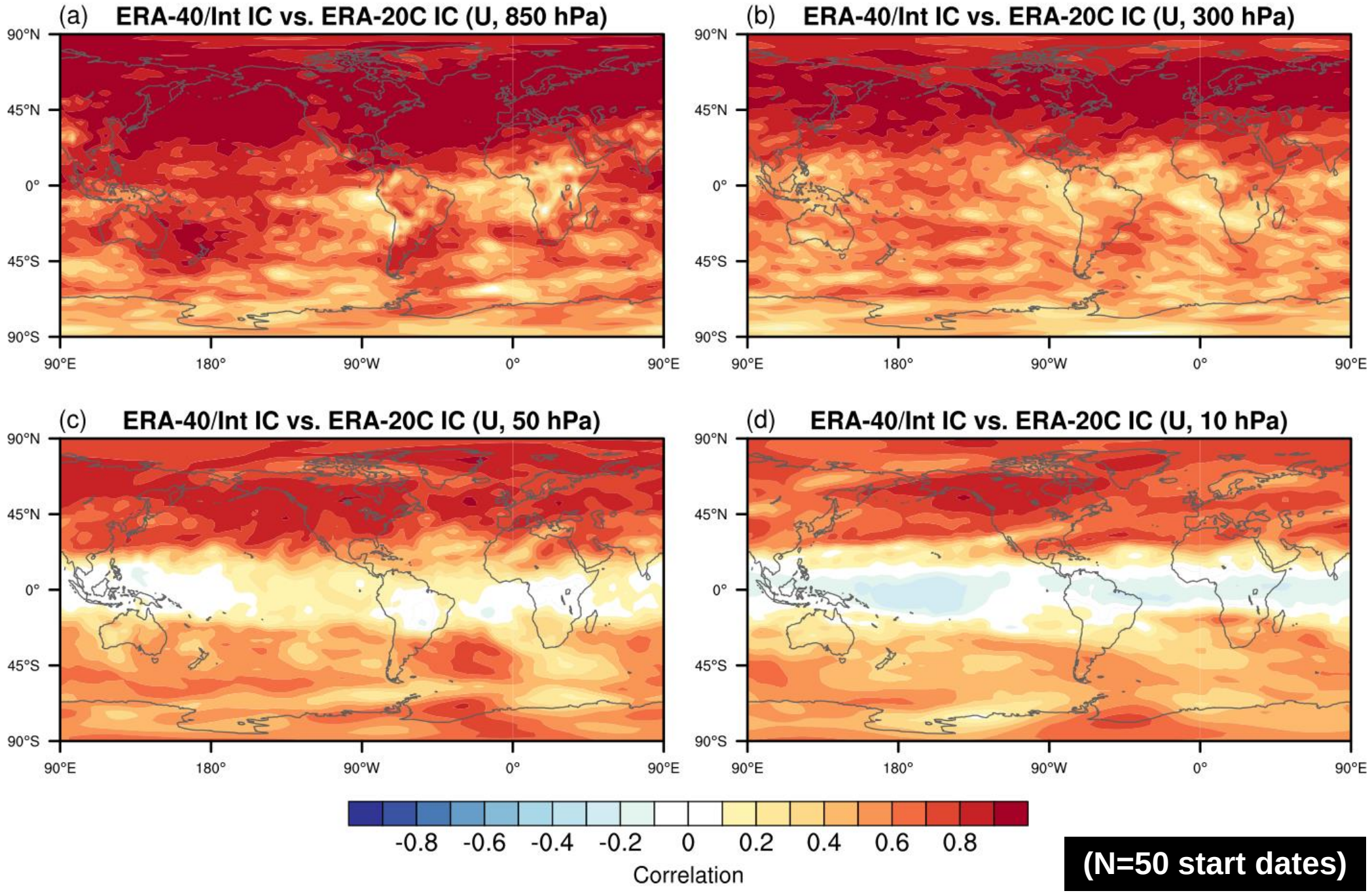
NAO hindcast is more skillful in the ERA-40/Int IC experiment than than the ERA-20C IC experiment.

Winter (DJF) NAO ensemble mean hindcast skill



Hindcast with only SSTs and shuffled IC is not significantly less skillful than the ERA-20C IC experiment.

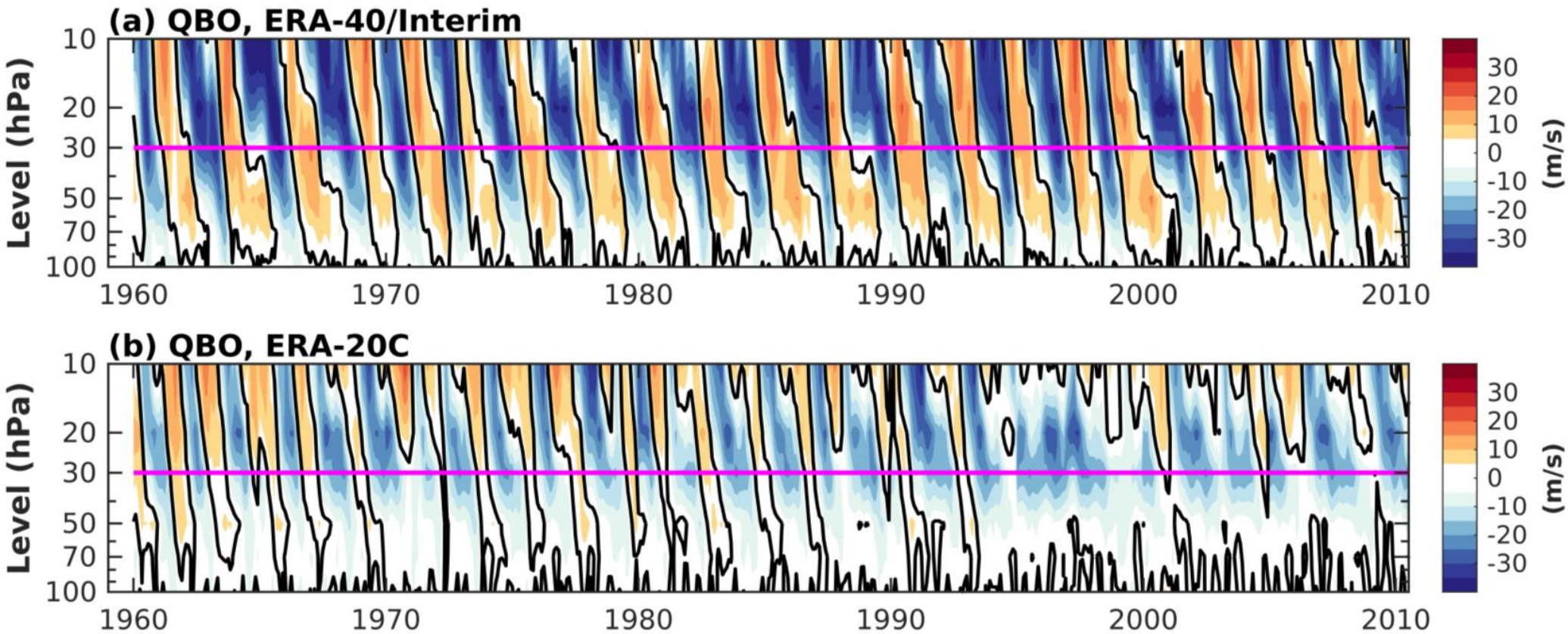
Initial conditions comparison (1st November, 1960-2009)



(N=50 start dates)

Quasibiennal Oscillation (QBO) in the hindcast experiments

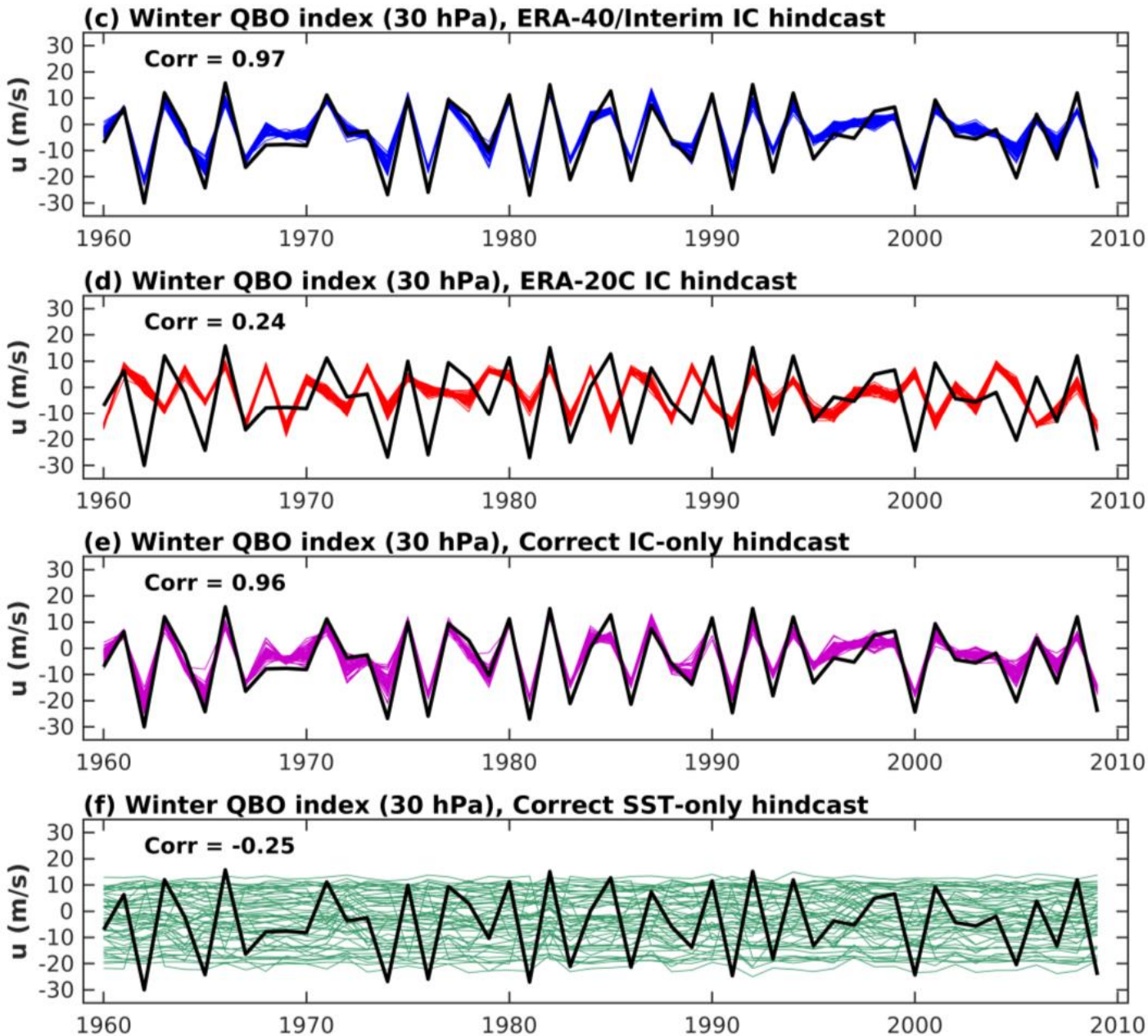
Zonal mean zonal winds along the equatorial lower-stratosphere in the two reanalysis datasets.



We define simple QBO index at 30 hPa (where the QBO exhibits largest correlation with NAO in both observations and all hindcast experiments).

Quasibiennal Oscillation (QBO) in the hindcast experiments

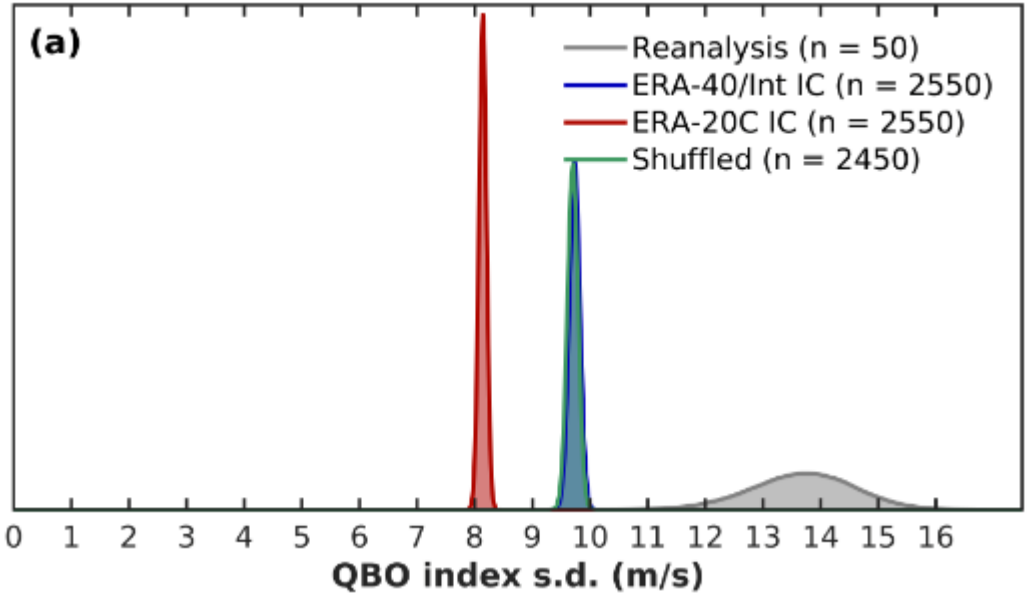
DJF QBO indices at 30 hPa in hindcast experiments (reanalysis in black).

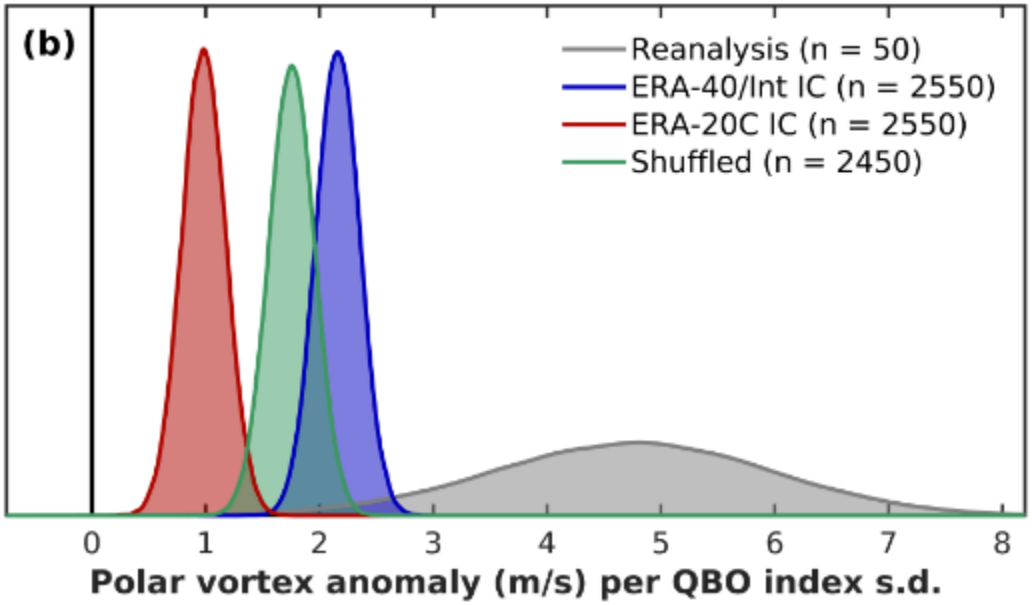


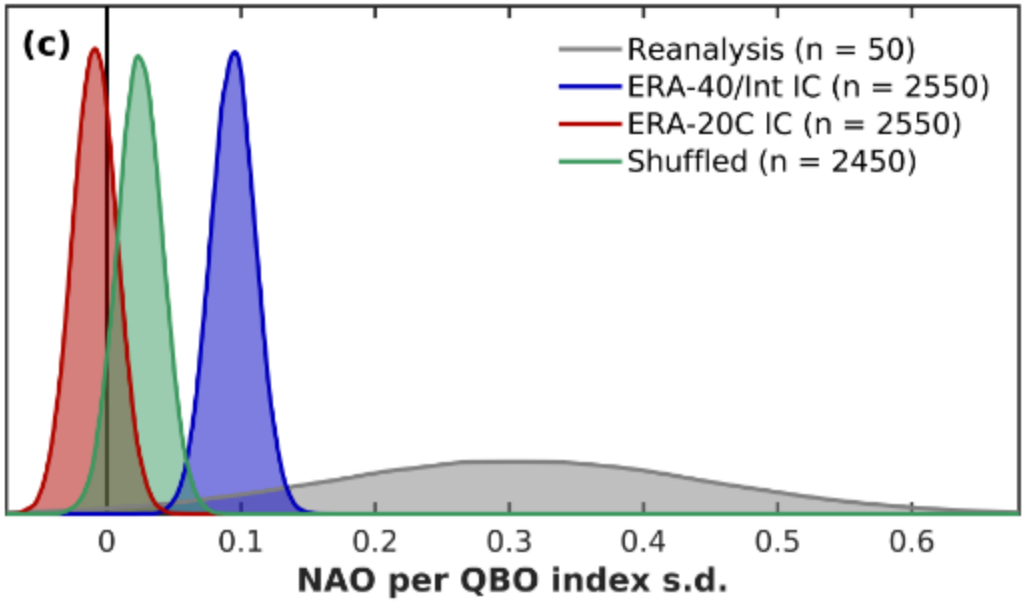
QBO teleconnection to polar vortex and NAO

Bootstrapped estimates of the QBO amplitude and regression in the hindcast experiments and reanalysis.

(a) Amplitude of the QBO index
(b) Polar vortex index (65N, 10hPa)
(c) NAO index







QBO influences the stratospheric polar vortex (i.e. the Holton-Tan relationship) but is relatively weak in the hindcasts – also a weak NAO link.

NAO hindcast skill from the QBO teleconnection

We estimate the QBO contribution to the NAO hindcasts by linearly regressing out the influence of the QBO from each ensemble member.

We then recompute the NAO hindcast skill (below).

Hindcast skill:

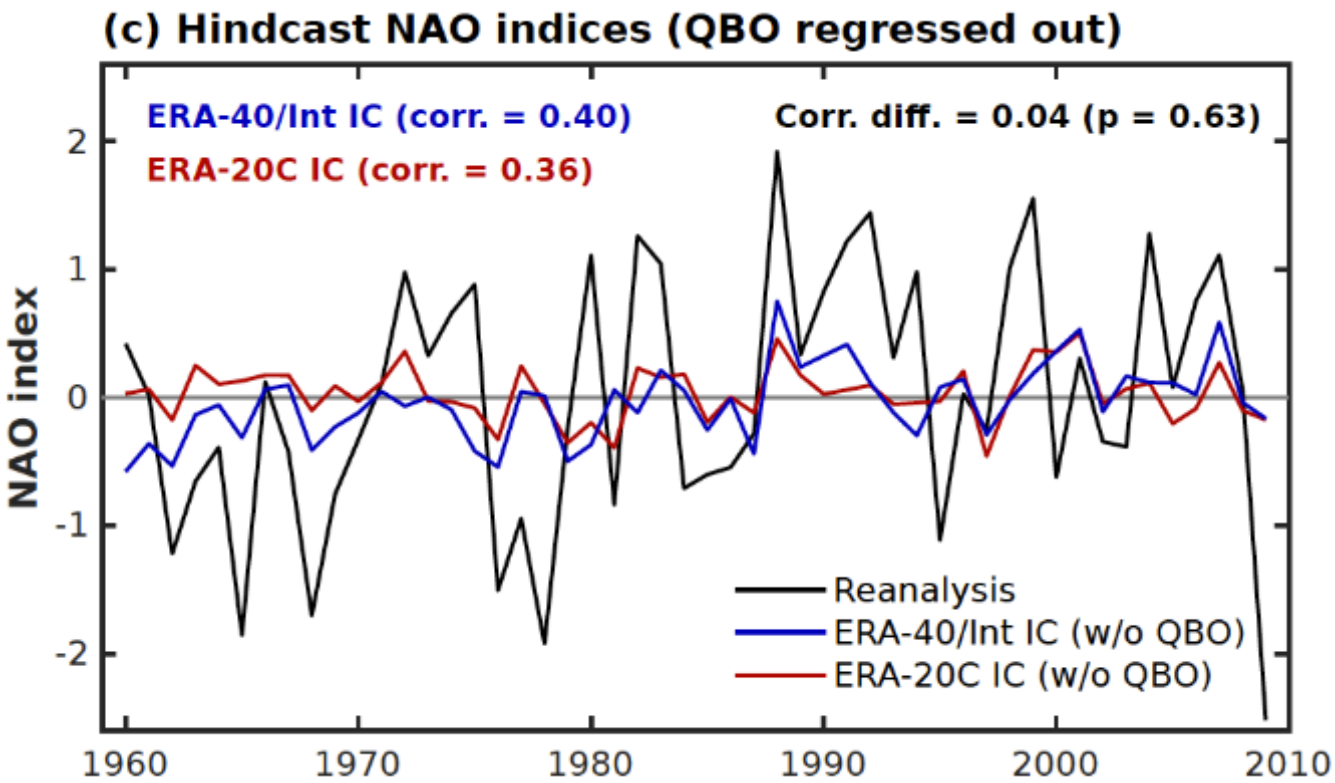
ERA-40/Int IC (corr. = 0.54)

ERA-20C IC (corr. = 0.38)

Hindcast skill (without QBO):

ERA-40/Int IC (corr. = 0.40)

ERA-20C IC (corr. = 0.36)



The NAO hindcast skill difference is reduced substantially and is no longer distinguishable.

Signal-to-noise of the NAO in these hindcast experiments

Following previous studies we analyse the "ratio of predictable components", or RPC, defined as follows:

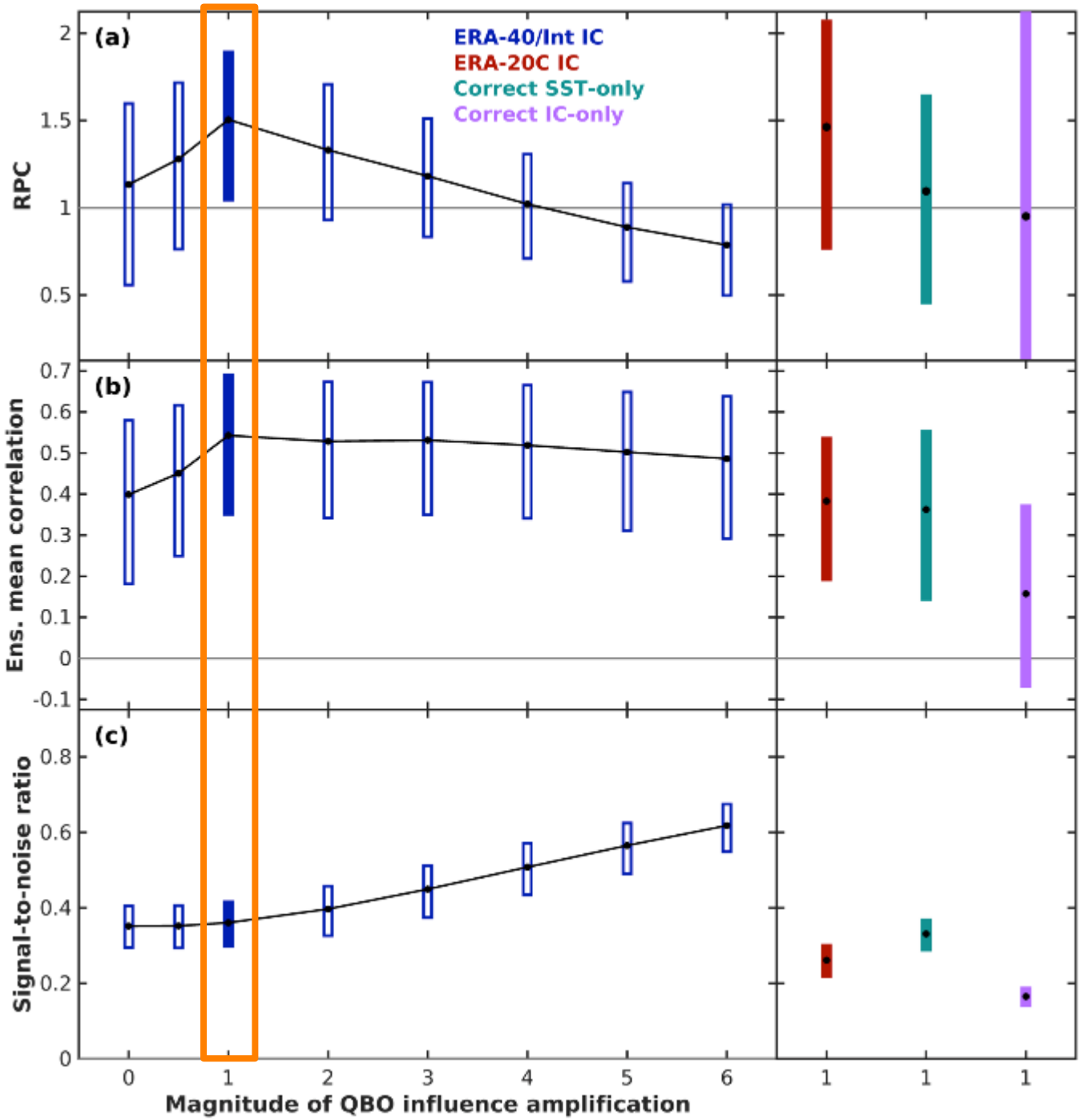
$$RPC = \frac{r}{\sqrt{\sigma^2_{ensmean} / \sigma^2_{total}}}$$

- **The numerator, *r*, is the ensemble mean hindcast correlation skill.**
- **The denominator is the signal-to-noise ratio.**

Signal-to-noise of the NAO in these hindcast experiments

$$RPC = \frac{r}{\sqrt{\sigma^2_{ensmean} / \sigma^2_{total}}}$$

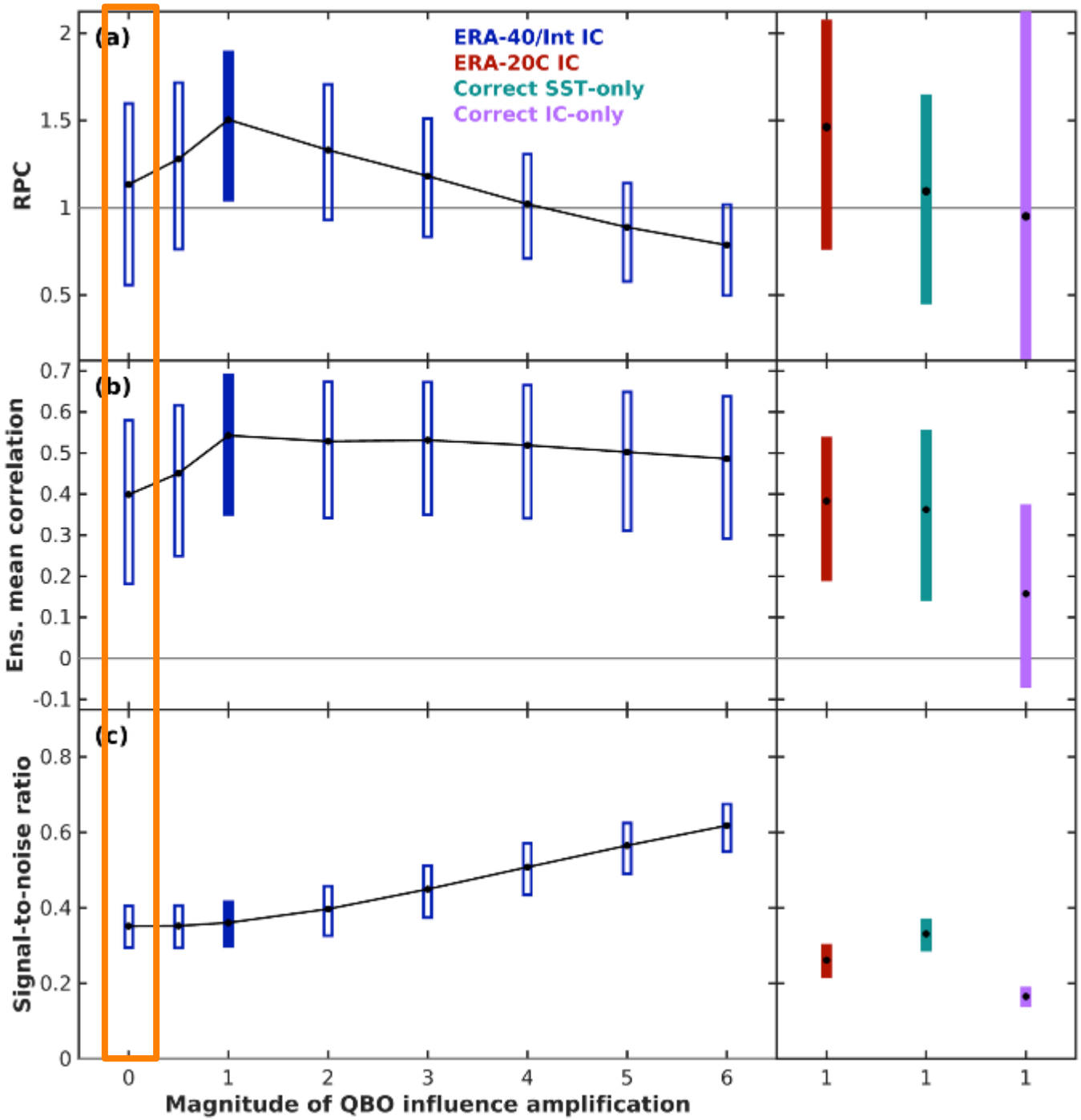
RPC is significantly greater than 1 in the ERA-40/Int IC experiment.



Signal-to-noise of the NAO in these hindcast experiments

$$RPC = \frac{r}{\sqrt{\sigma^2_{ensmean} / \sigma^2_{total}}}$$

Removing the QBO via linear regression reduces the RPC towards 1.

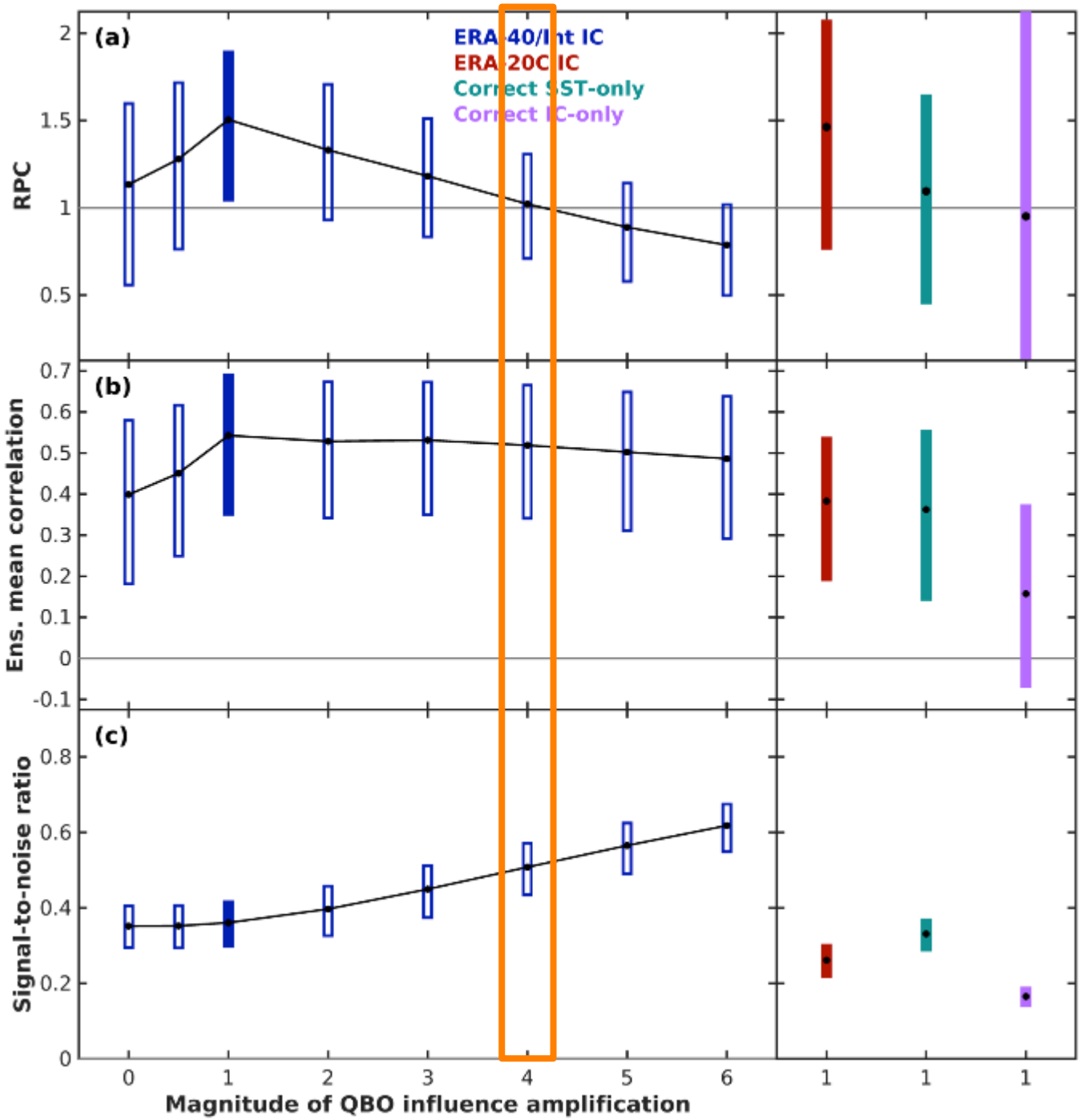


Signal-to-noise of the NAO in these hindcast experiments

$$RPC = \frac{r}{\sqrt{\sigma^2_{ensmean} / \sigma^2_{total}}}$$

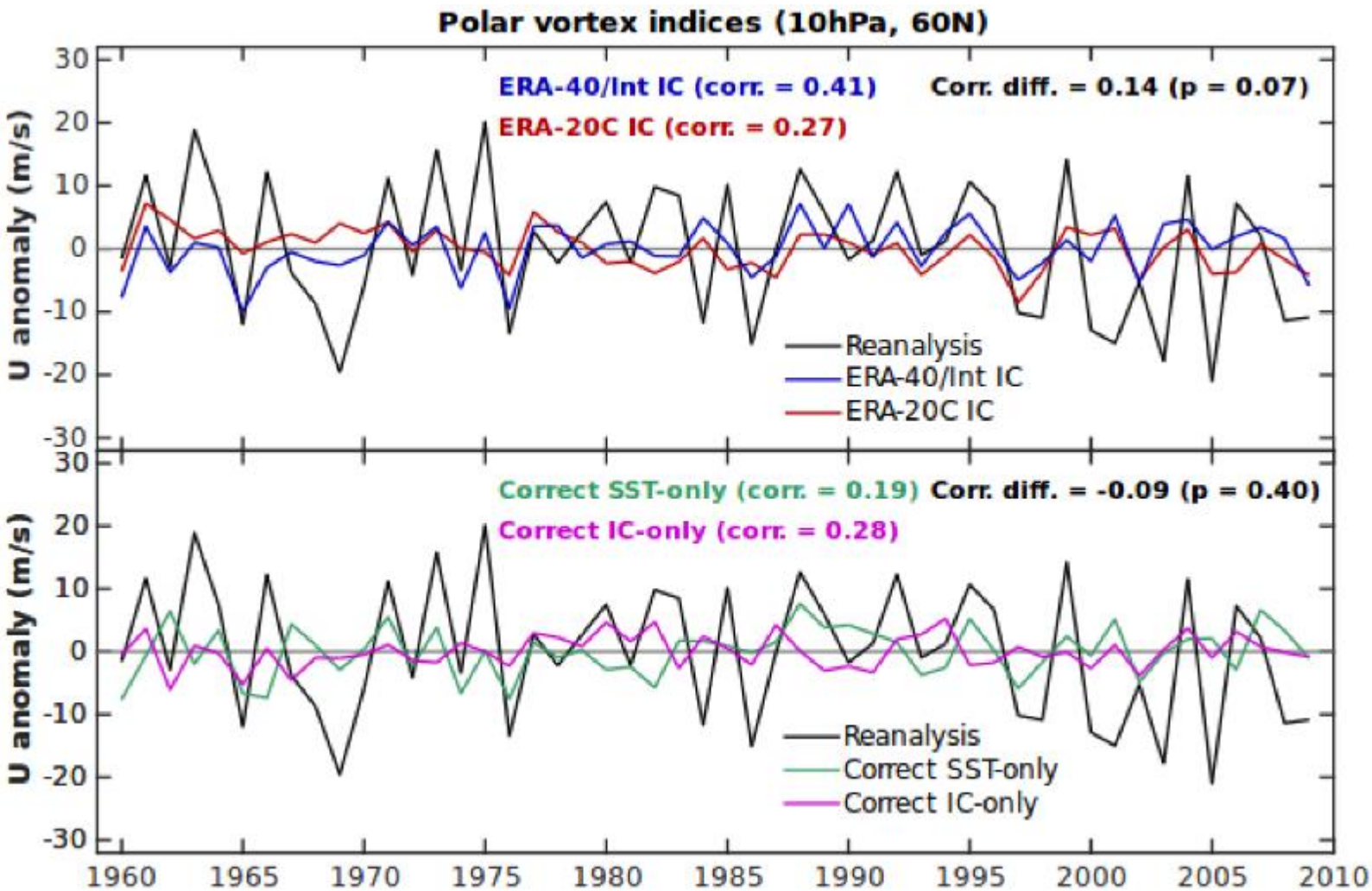
We can also amplify the QBO contribution using a simple linear regression.

RPC reduces to 1 when the QBO influence is 4 times the amplitude.



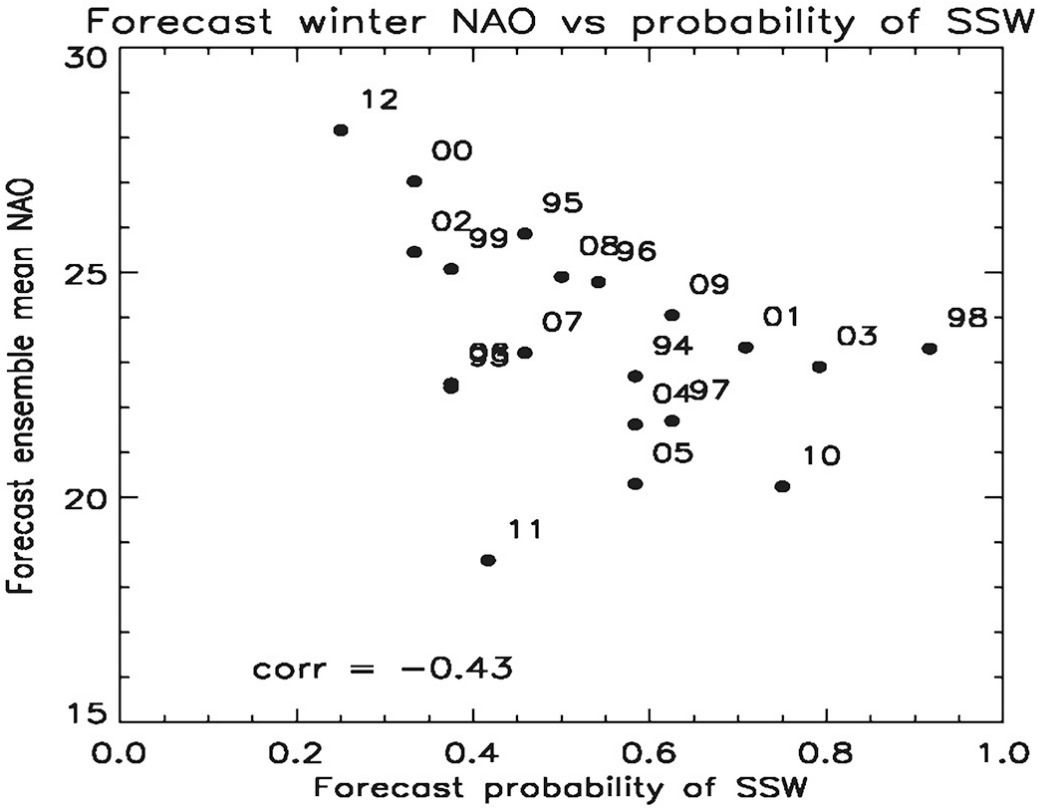
Skill of the winter polar vortex strength

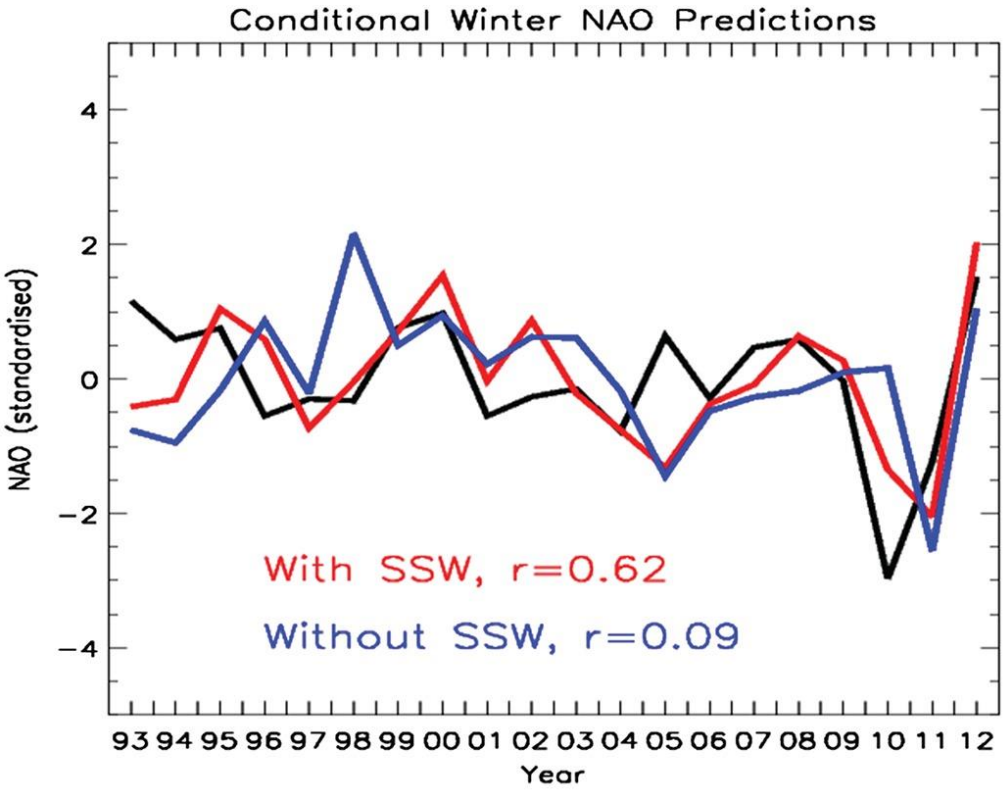
The ERA-40/Int initial condition increases the skill of the polar vortex strength in the hindcast, consistent with the Holtan-Tan effect:



Is the skill linked to Sudden Stratospheric Warmings?

In the Met Office GloSEA5 model, much of the skill in winter NAO has been linked to sudden stratospheric warmings:

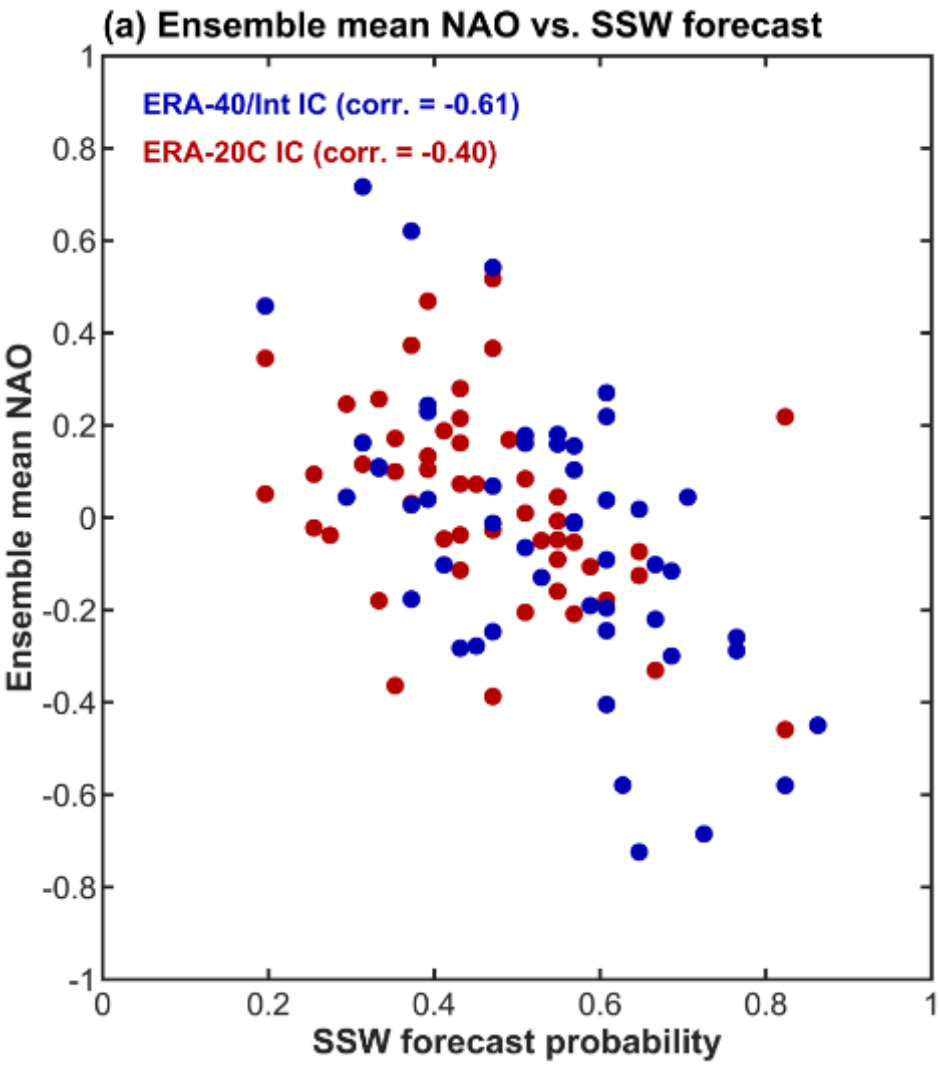


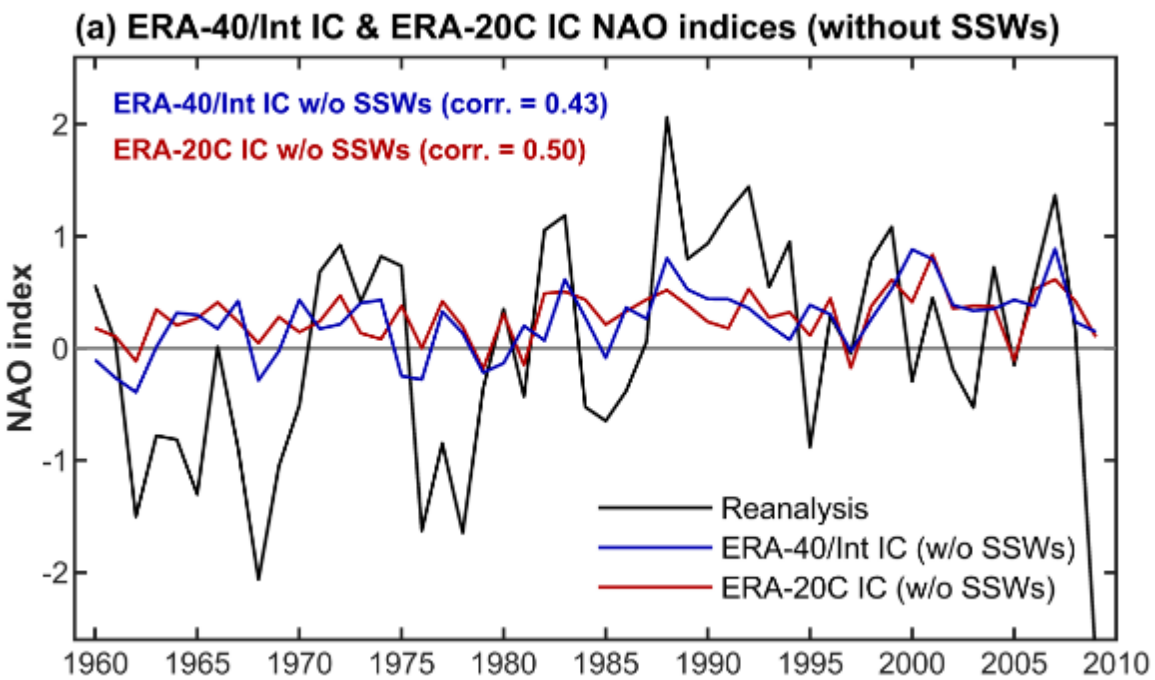


From Scaife et al. (2015).

Is the skill linked to Sudden Stratospheric Warmings?

The same analysis in the experiments analysed here, however, does not show a similar dependence on SSWs:





However, neither of the ensembles actually exhibit significant skill in forecasting observed SSW events.

Ongoing work: tropical stratosphere relaxation experiments

Aim: To understand why the stratospheric initial condition (i.e. QBO) seems to be responsible for the weak predictable signal.

We performed an pair of (24 member) experiments:

1. CONTROL:

- Initial condition taken from the ERA-40 dataset (1960-1978) and ERA-Interim dataset (1979-2009) **but with 60 levels** ☹

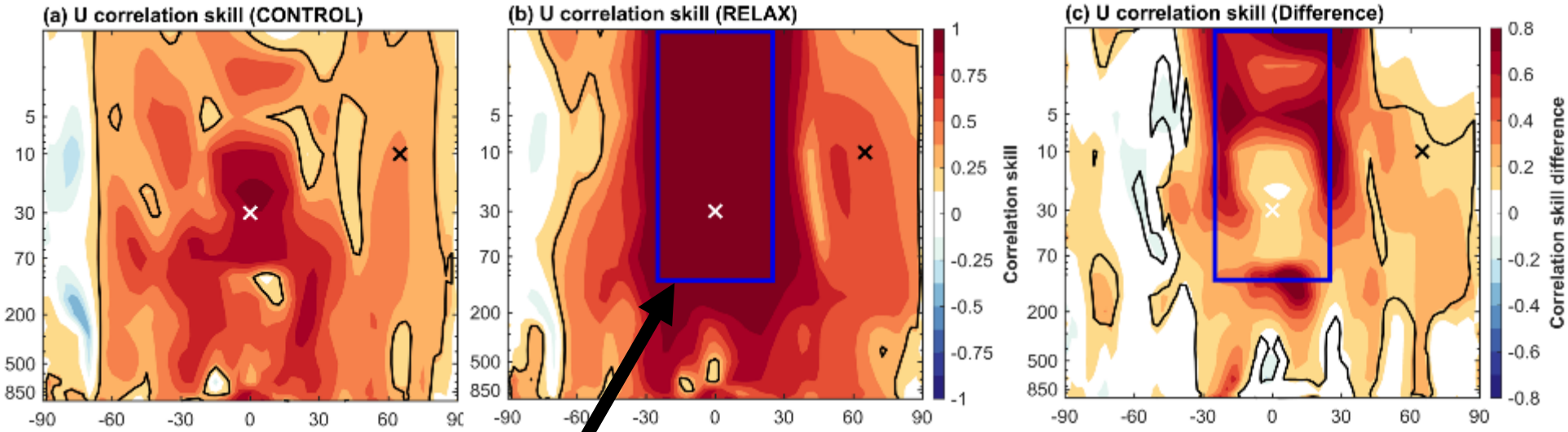
2. RELAX:

- As in CONTROL but with relaxation towards reanalysis in the tropical stratosphere (levels ~ 100 hPa and above, 25S-25N).

Ongoing work: tropical stratosphere relaxation experiments

CONTROL **RELAX** **Difference**

Corr. skill

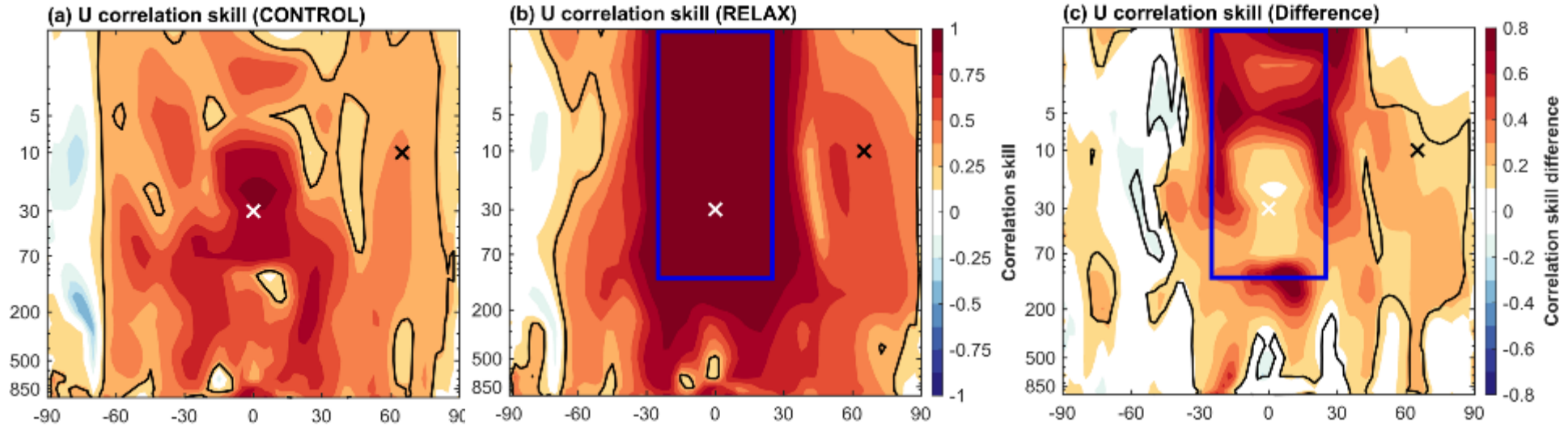


Relaxation region

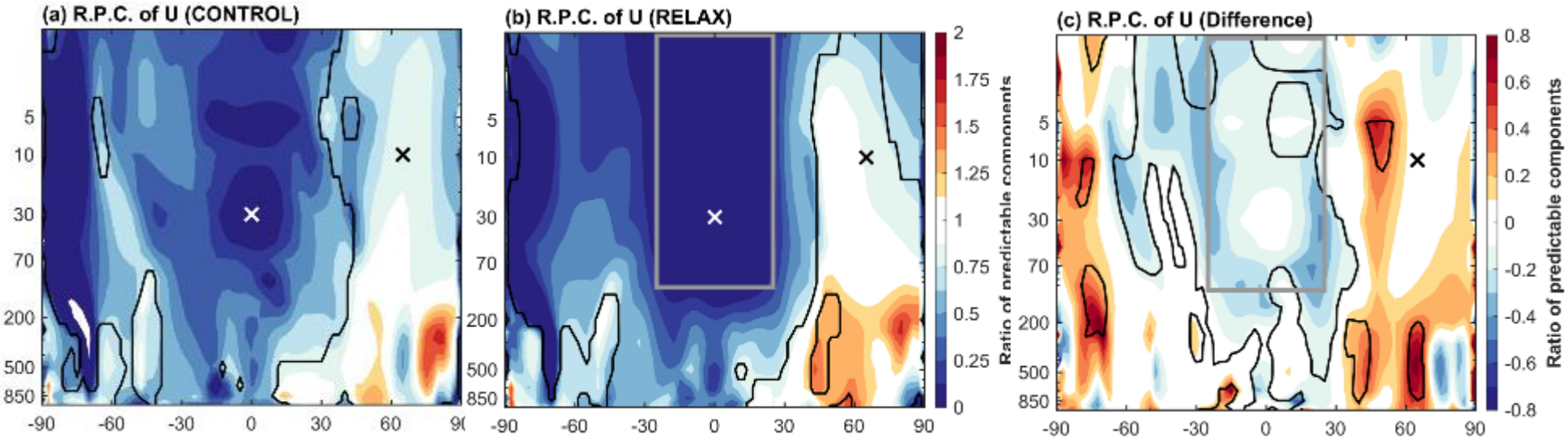
Ongoing work: tropical stratosphere relaxation experiments

CONTROL **RELAX** **Difference**

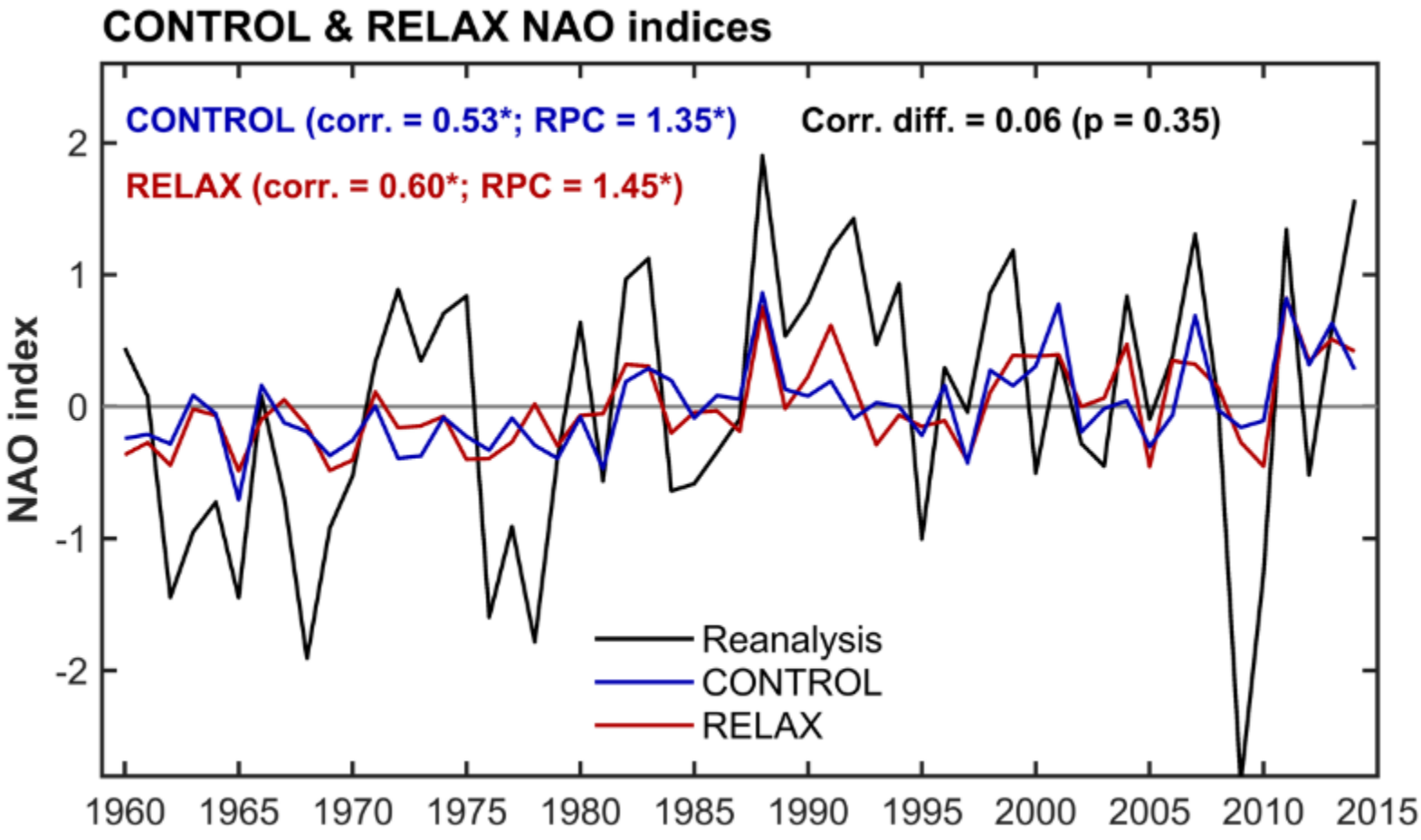
Corr. skill



RPC



Ongoing work: tropical stratosphere relaxation experiments



Skill increases slightly in the RELAX experiment but RPC > 1 and also increases – is the downward influence too weak?

Key points

1. Wintertime NAO skill is improved in seasonal hindcast experiments initialised with reanalysis that assimilates upper-atmosphere observations (i.e. ERA-40/Interim).

2. This improved skill seems largely due to the correct QBO initial conditions.

3. The QBO-NAO teleconnection in the model is weaker than in observations.

4. The weak QBO-NAO teleconnection results in an "underconfident" ensemble… a **signal-to-noise "paradox"**.

5. The skill is not linked to SSWs in the ensembles, unlike in some other systems.

6. Relaxing the tropical stratosphere towards reanalysis does not alleviate the signal-to-noise issue.

Key points

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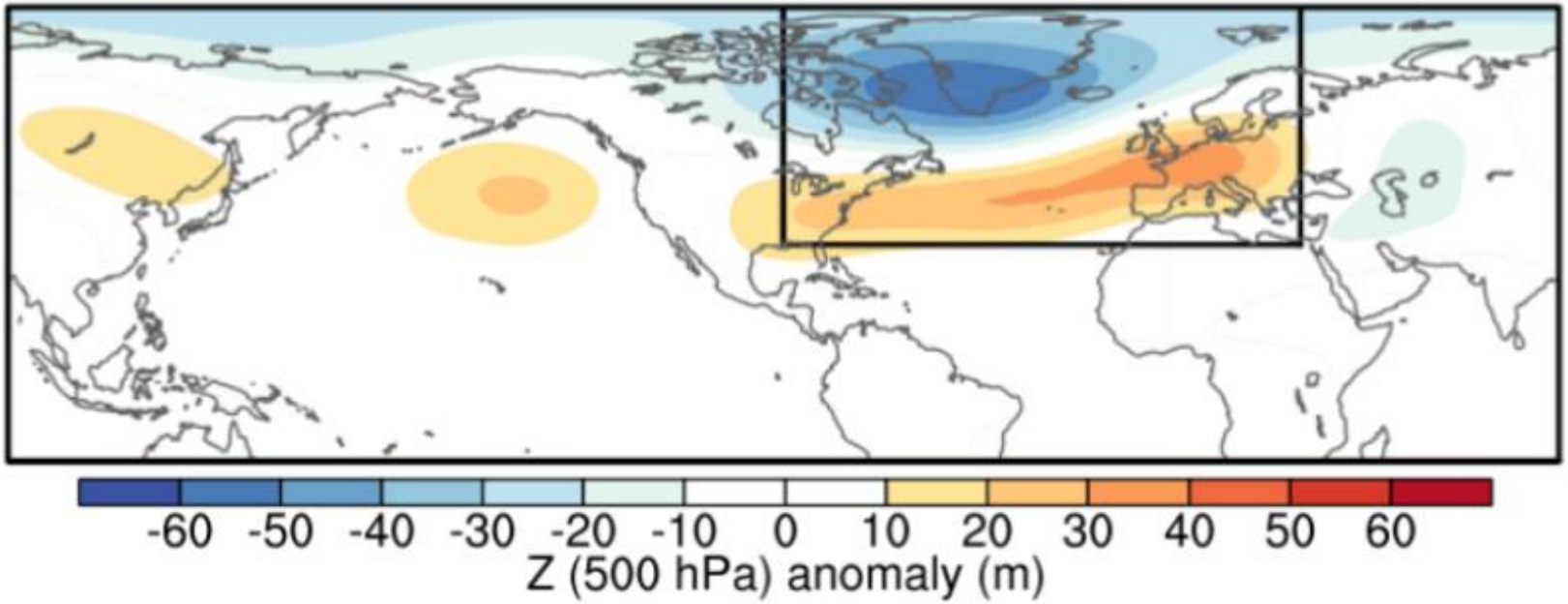
Thanks.

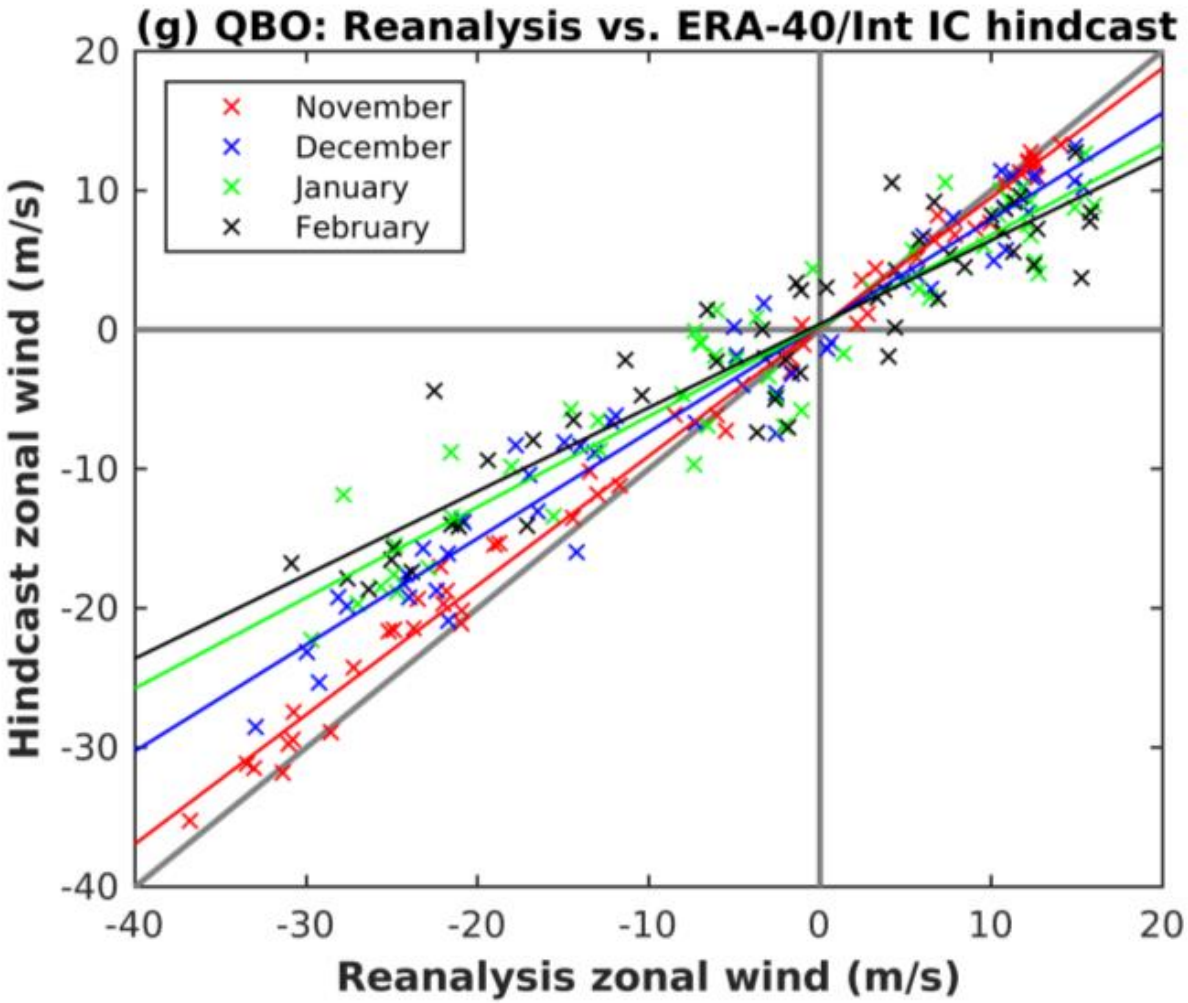
Spare tyres

Winter (DJF) NAO ensemble mean hindcast skill

Winter NAO pattern (1st EOF Z500, ERA-40/Interim)

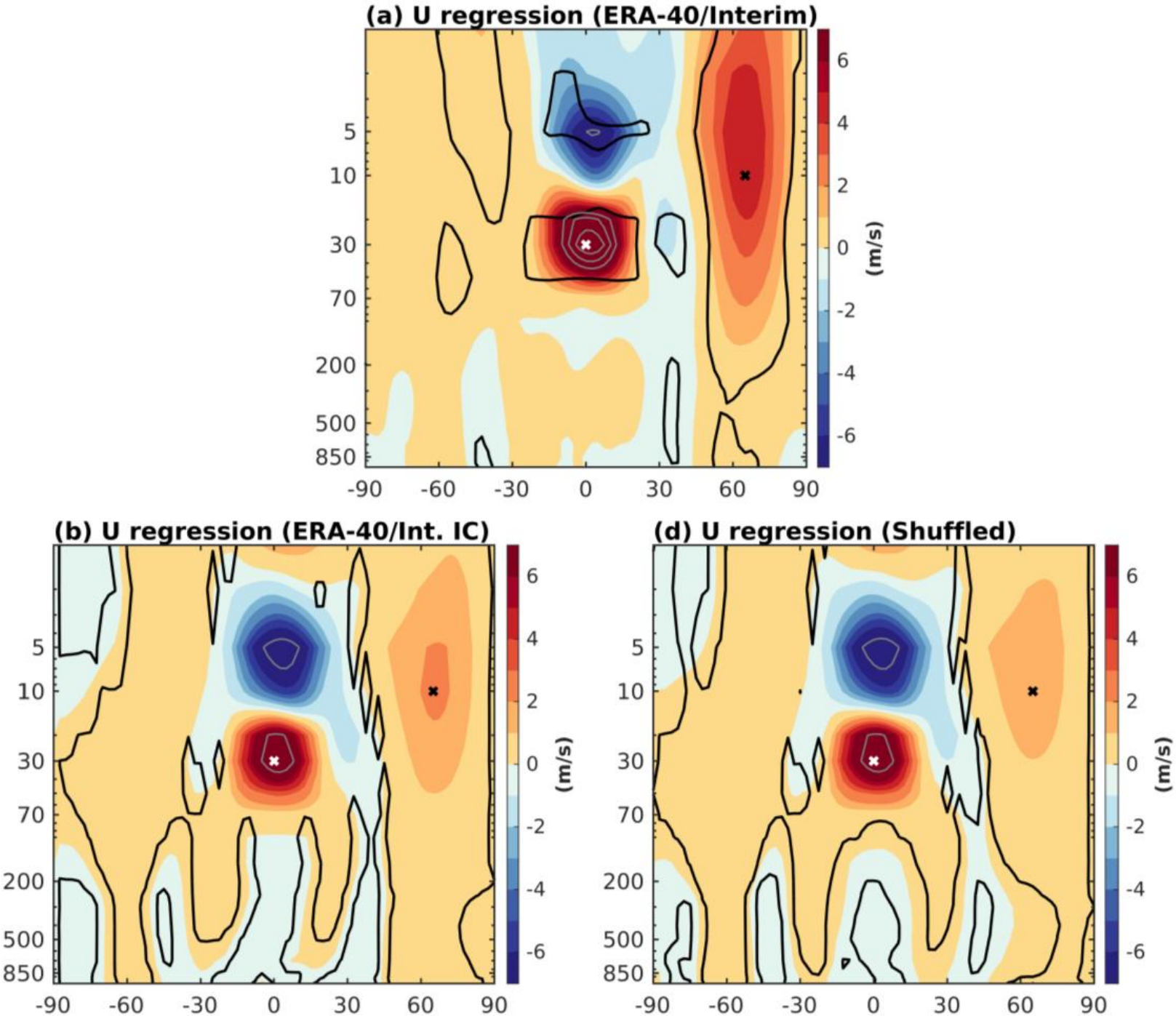


Amplitude of QBO in the hindcast experiments



The equatorial zonal winds associated with the QBO weaken substantially as the simulations progress through the winter.

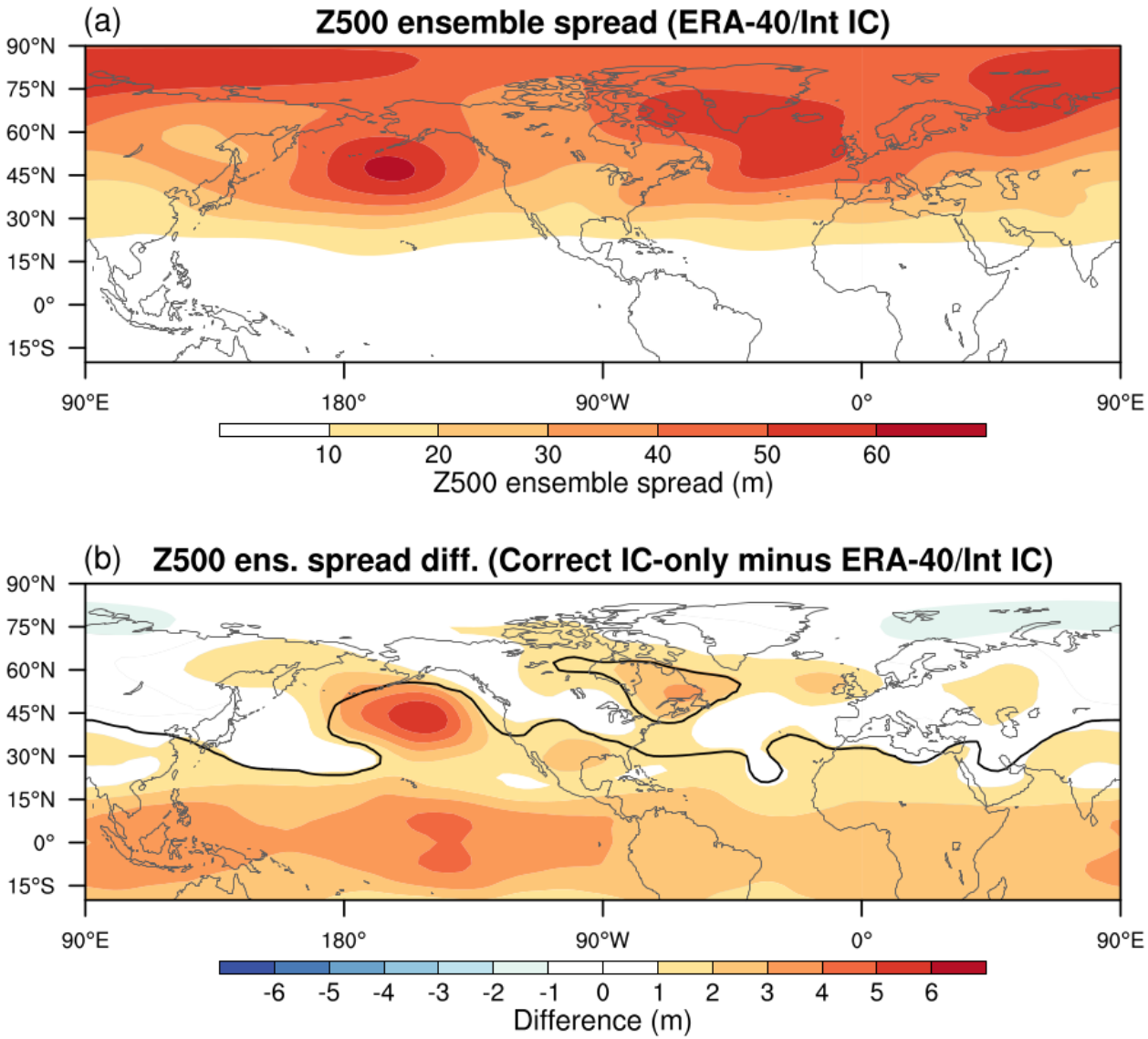
QBO teleconnection to extratropics



Why the weaker teleconnection in the Shuffled experiment?

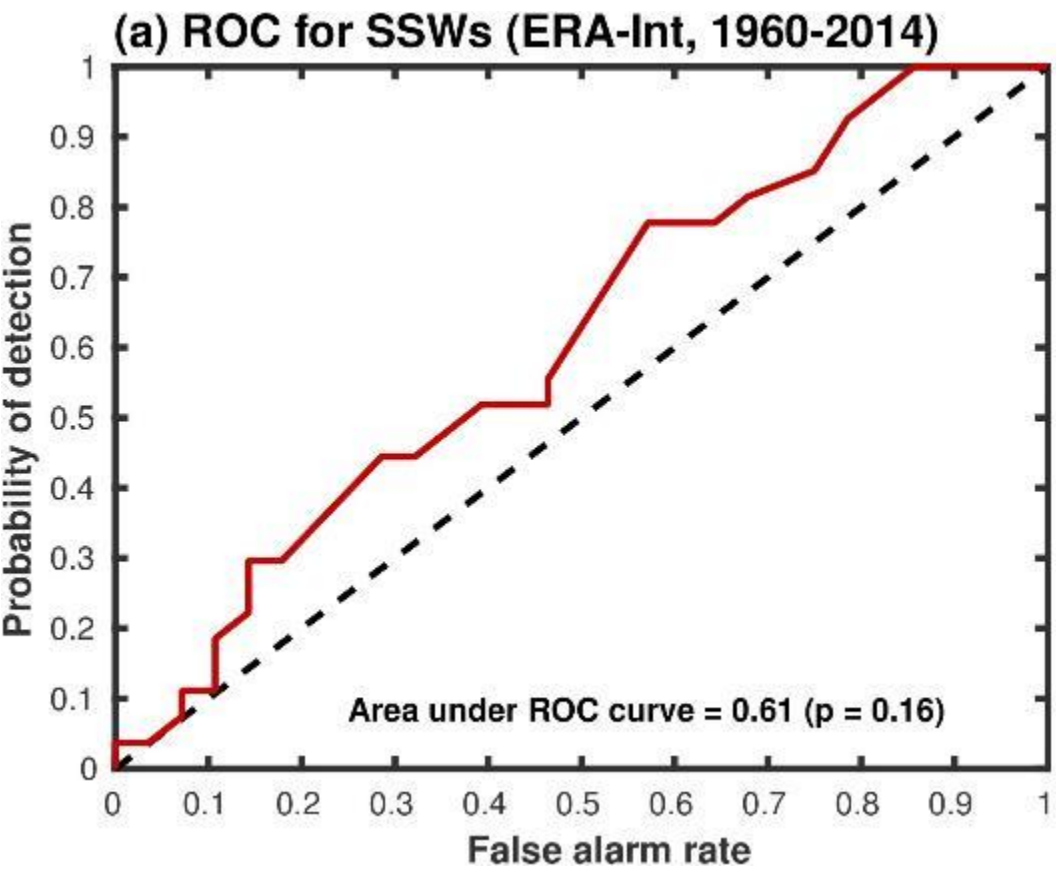
Z500 (DJF) ensemble spread averaged over the hindcast period.

Larger ensemble spread in the Shuffled experiment due to the wide variety of surface boundary conditions.

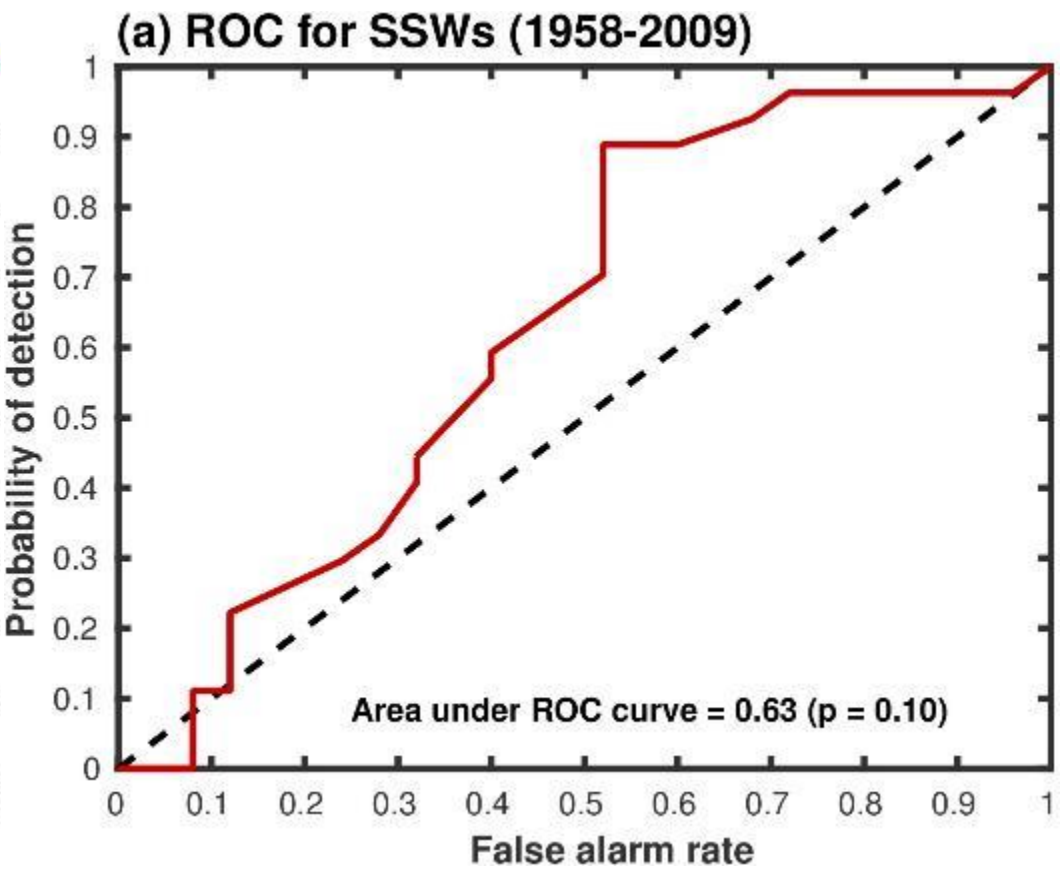


Skill of Sudden Stratospheric Warmings?

ERA-40/Int IC experiment

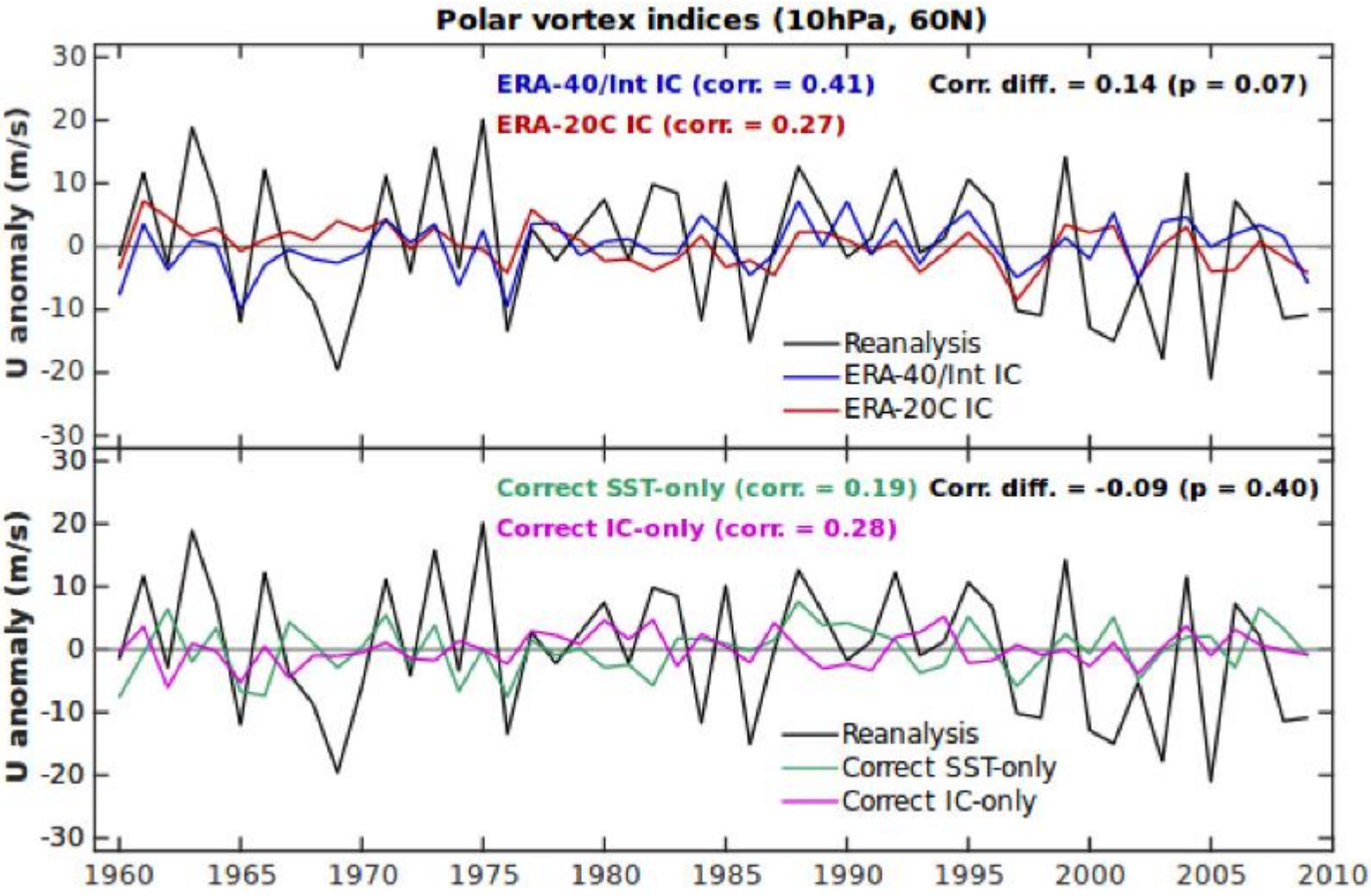


ERA-20C IC experiment



ROC curves of SSW events during (DJF) show no significant skill for either ensemble.

Teleconnection to the polar vortex



Holton-Tan effect