The impact of vertical resolution on seasonal prediction skill in new CESM2 initialized hindcast ensembles

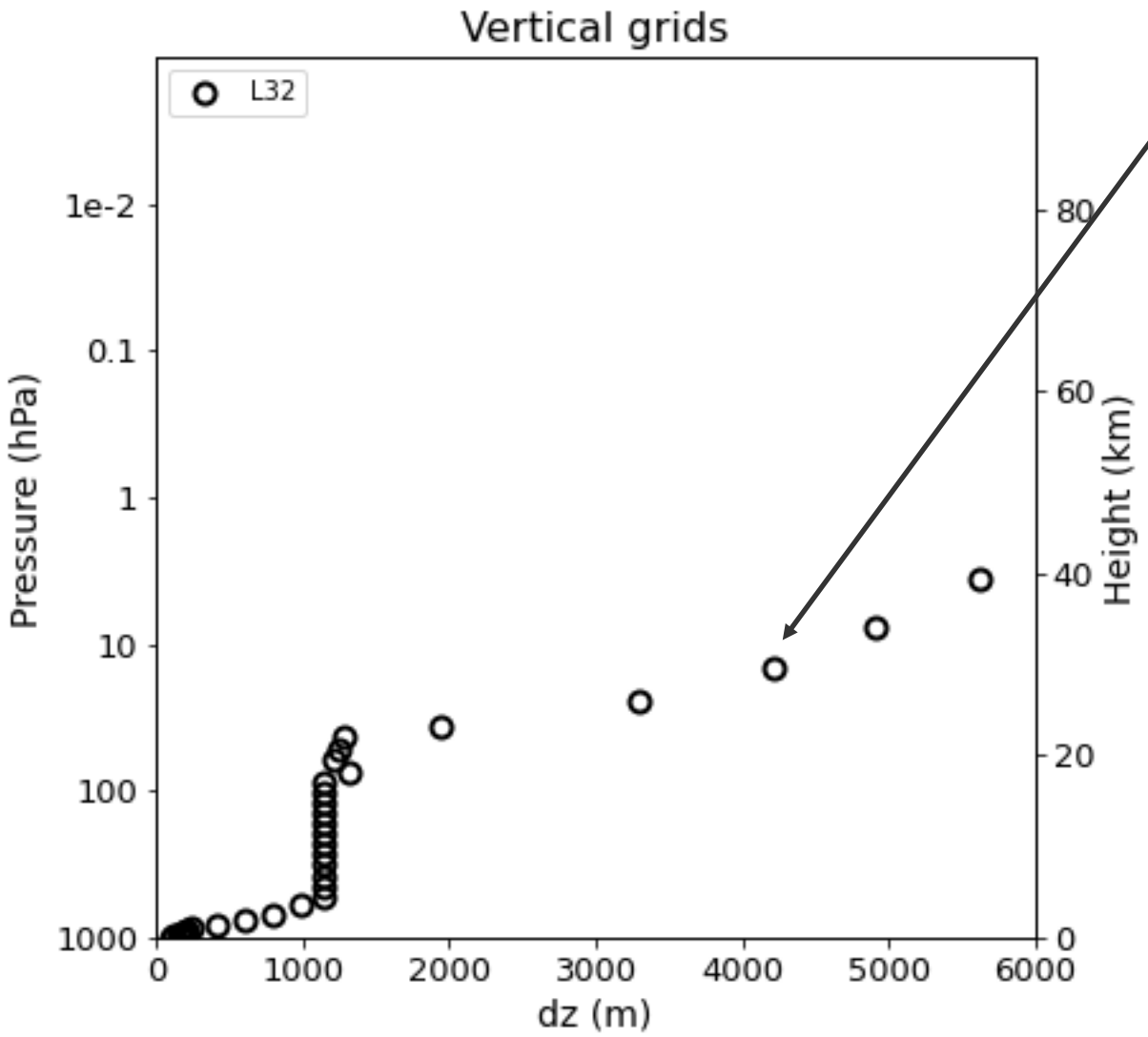
Isla Simpson[1]

Nan Rosenbloom[1], *Jim Edwards*[1], *Michael DeFlorio*[2], *Jiabao Wang*[2], *Luca Delle Monache*[2], *Nora Mascioli*[2], *Matthew Simpson*[2], *Gokhan Danabasoglu*[1], *Yuanpu Li*[1], *Peter Gibson*[3], *Patrick Mulrooney*[2], *Yaga Richter*[1], *Steve Yeager*[1]

1 = CGD NSF NCAR, 2 = CW3E Scripps Institute for Oceanography, 3 = NIWA

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Vertical grids



Standard 32 level grid of CAM6 (L32). Used in CESM2 SMYLE

Geosci. Model Dev., 15, 6451–6493, 2022
https://doi.org/10.5194/gmd-15-6451-2022

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The Seasonal-to-Multiyear Large Ensemble (SMYLE) prediction system using the Community Earth System Model version 2

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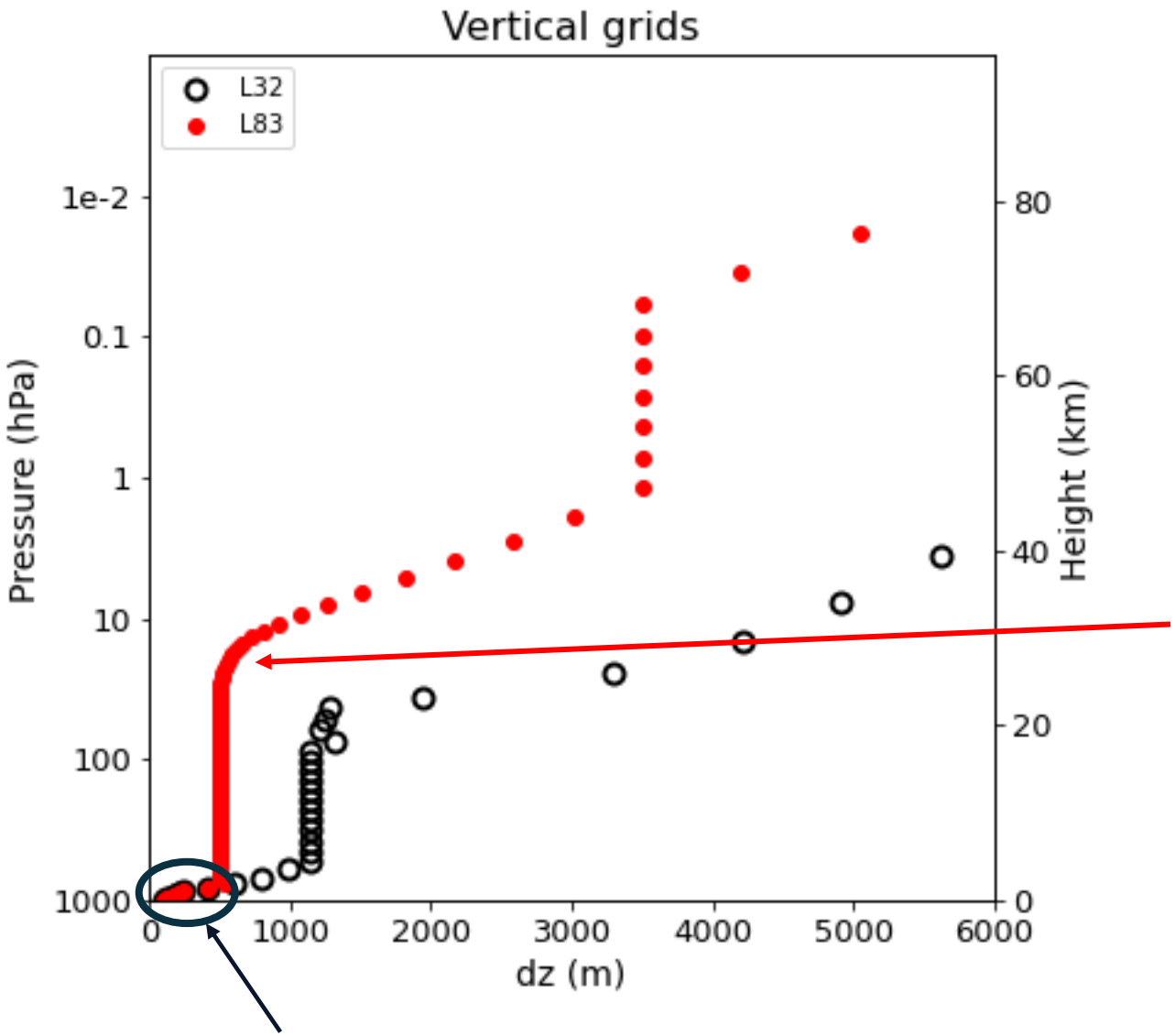

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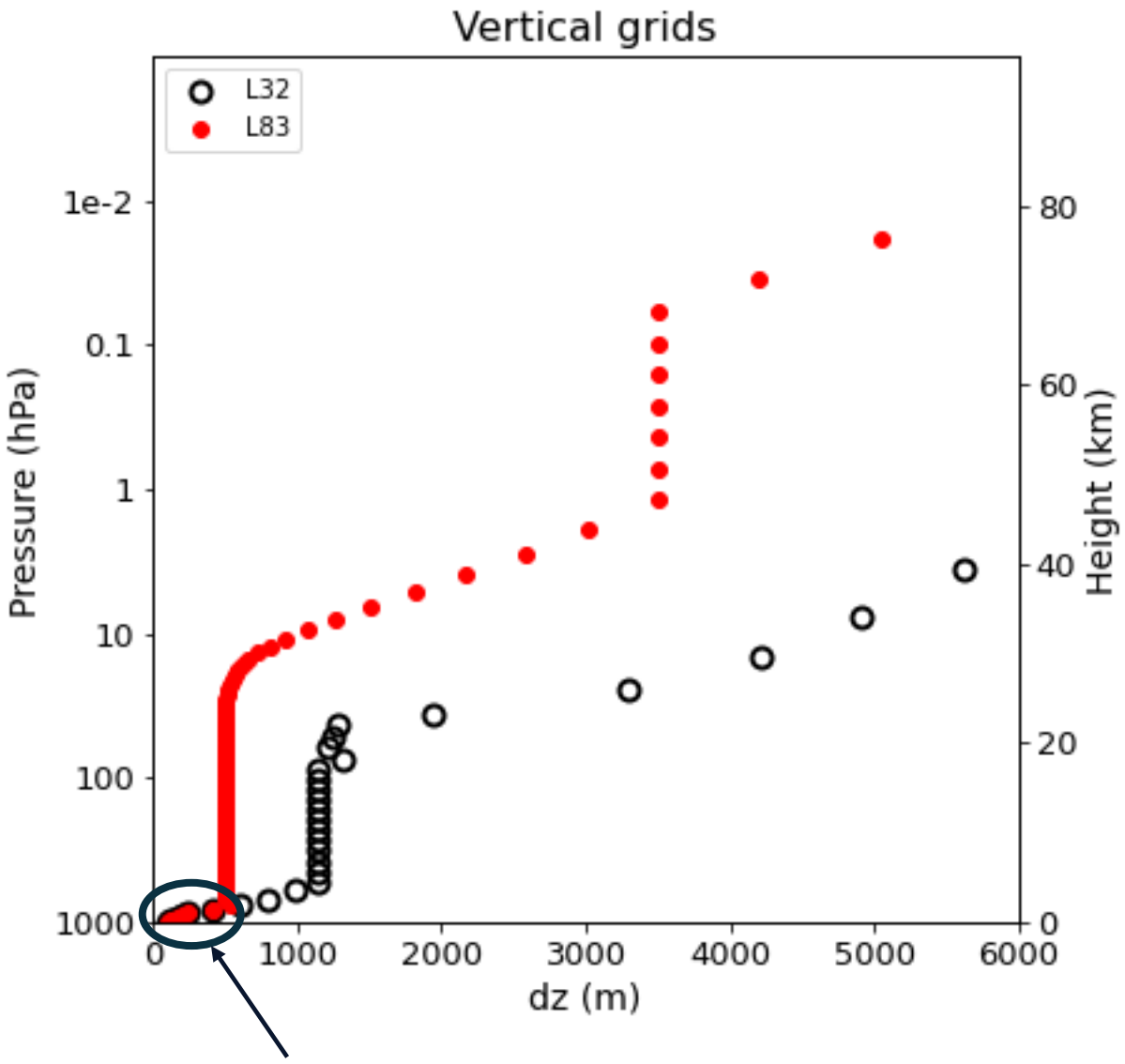
The new vertical grid of CAM7 (almost*). 83 levels (L83)

Used to produce a seasonal hindcast suite analogous to CESM2 SMYLE through collaboration with CW3E

NSF | NCAR Operated by UCAR | CW3E

* CAM7 will have a 93 level grid with additional levels in the boundary layer, which is left unchanged in the grid used here

Vertical grids



New seasonal hindcast ensembles with L32 and L83

Using CESM2

Following the same protocol as SMYLE

Except using ERA5 for atmospheric initialization

Here I'll focus on the Nov 1st initialization

Compare skill between L83 and L32

* CAM7 will have a 93 level grid with additional levels in the boundary layer, which is left unchanged in the grid used here

Skill metrics

Skill metrics

In all the analysis presented, a lead dependent climatology will be removed (model is de-drifted)

Model anomalies

$$M'(y,d,x) = M(y,d,x) - \sum_{y=1970}^{y=2020} M(y,d,x)/N$$

year day space

Observed anomalies

$$O'(y,d,x) = O(y,d,x) - \sum_{y=1970}^{y=2020} O(y,d,x)/N$$

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Anomaly correlation coefficient

$$ACC(t,x) = \frac{\sum_{y=1970}^{y=2020} M'(y,t,x)O'(y,t,x)}{\sqrt{\sum_{y=1970}^{y=2020} M'(y,t,x)^2 \sum_{y=1970}^{y=2020} O'(y,t,x)^2}}$$

1 = perfect correlation
0 = no correlation
Low or negative values are bad

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Low or negative values are bad

Mean squared skill score

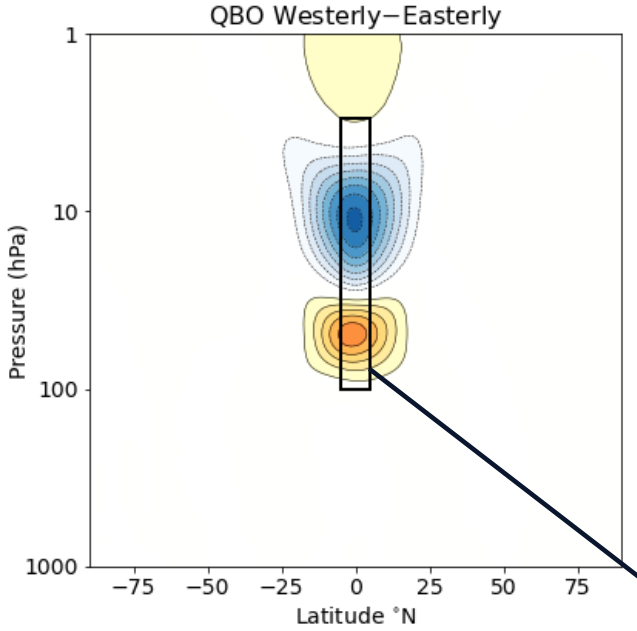
$$MSSS(t,x) = 1 - \frac{MSE_M}{MSE_O}$$

$$MSE_M(t,x) = \frac{1}{N}\sum_{y=1970}^{y=2020} (M'(y,t,x) - O'(y,t,x))^2$$

$$MSE_o(t,x) = \frac{1}{N}\sum_{y=1970}^{y=2020} O'(y,t,x)^2$$

1 = there's no error
0 = same as climatology
<0 = really bad

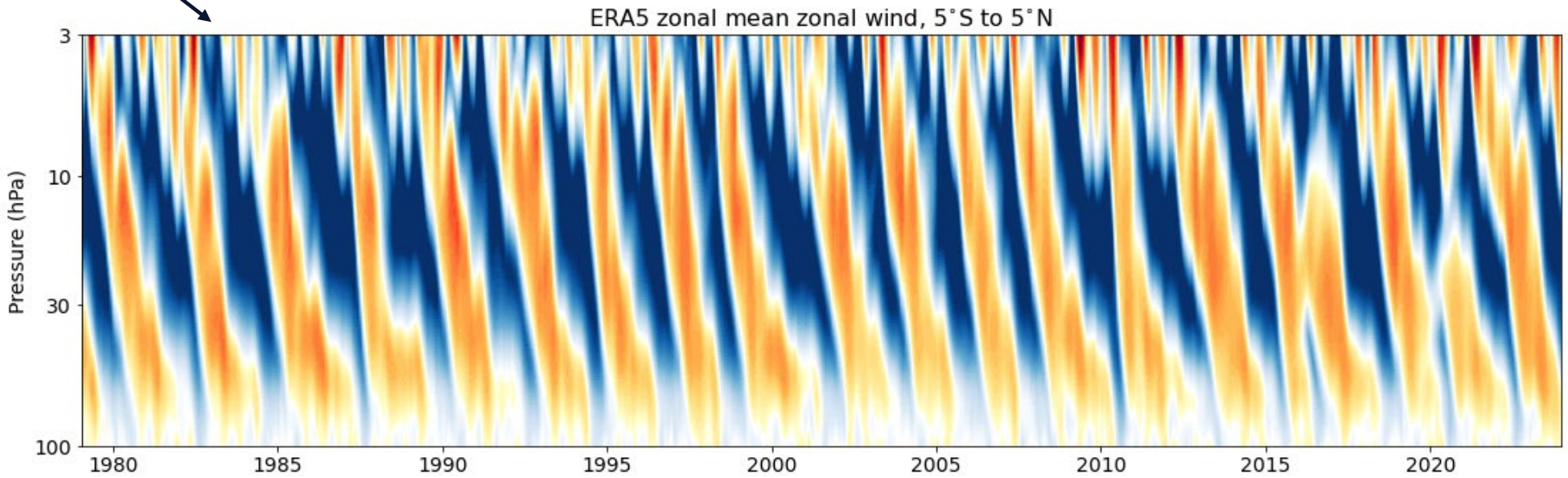
The Quasi-Biennial Oscillation (QBO)



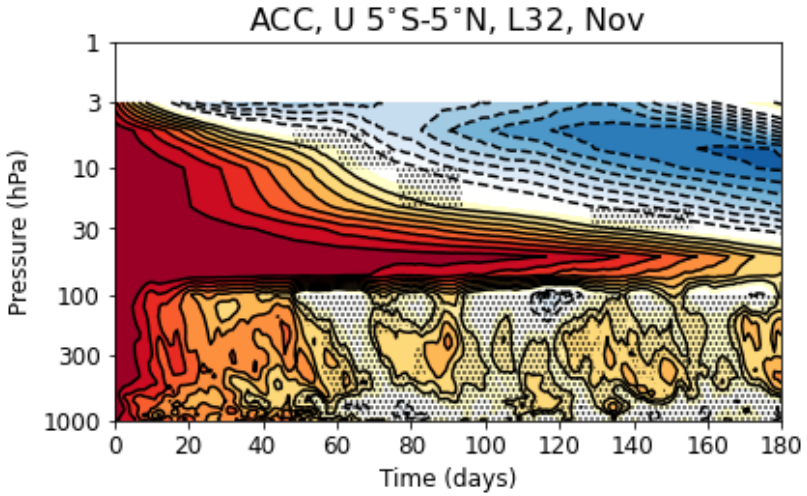
An oscillation in the equatorial zonal mean zonal wind in the stratosphere with a period of approximately 28 months

If there is predictability on seasonal timescales, it'll come from slowly varying boundary conditions for the troposphere that are predictable on these timescales. The QBO is one such boundary condition…

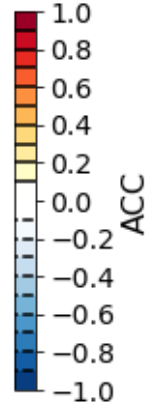
…if it has an impact on the troposphere that is sufficiently large to impact prediction skill.



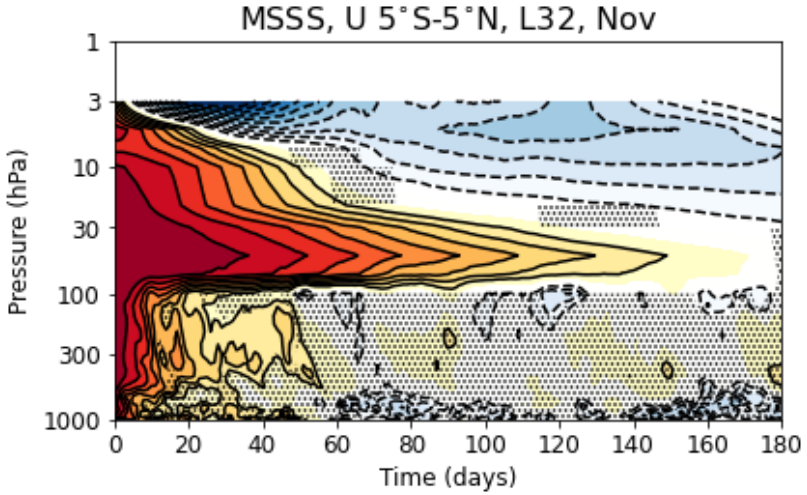
QBO skill (November initialization)



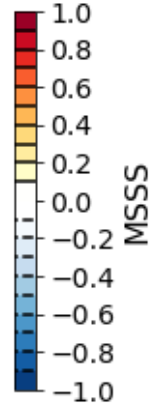
Anomaly correlation coefficient
L32 (low vertical resolution)



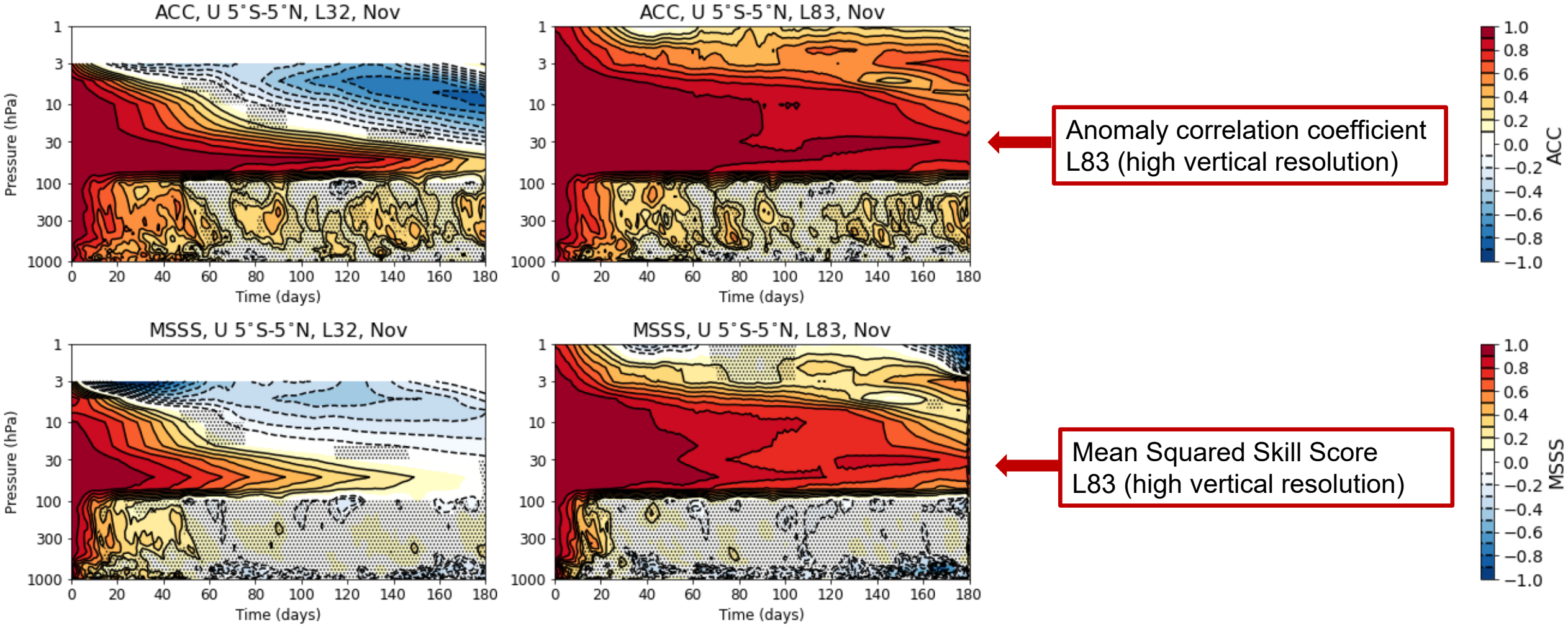
Zonal mean zonal wind, 5S-5N



Mean Squared Skill Score
L32 (low vertical resolution)



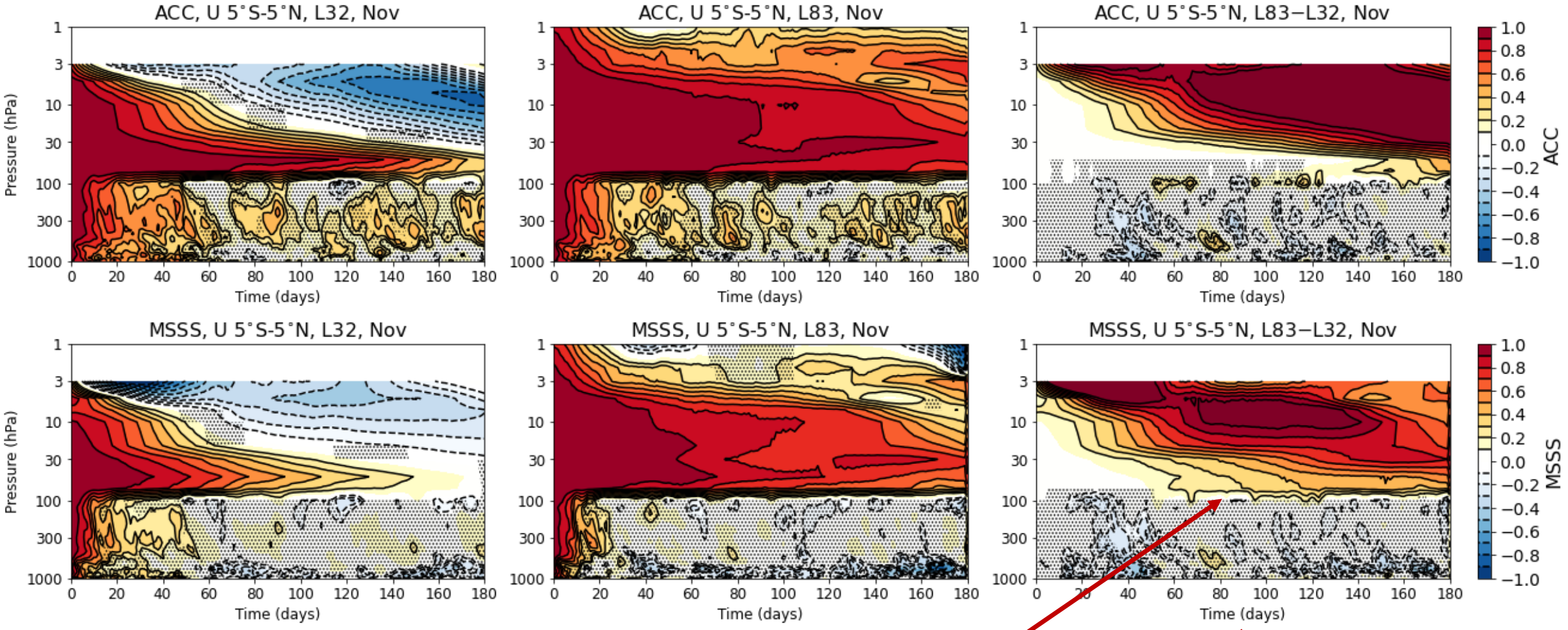
QBO skill (November initialization)



Anomaly correlation coefficient
L83 (high vertical resolution)

Mean Squared Skill Score
L83 (high vertical resolution)

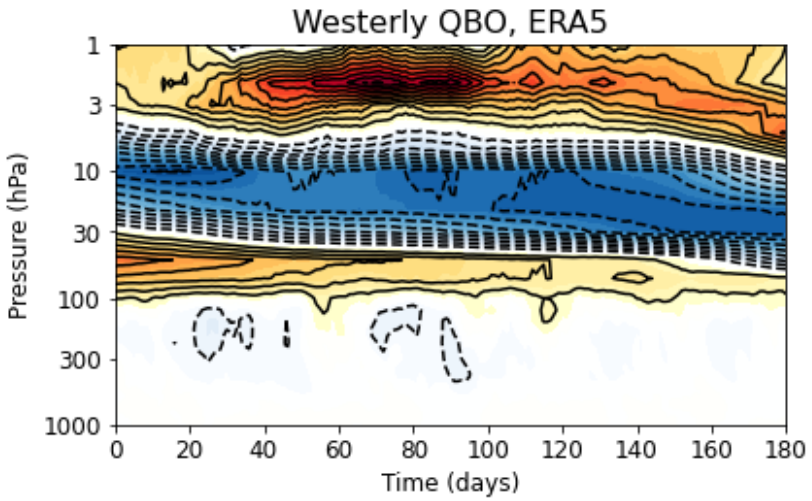
QBO skill (November initialization)



Higher skill with the high vertical resolution at longer lead times

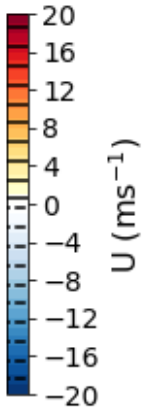
Difference

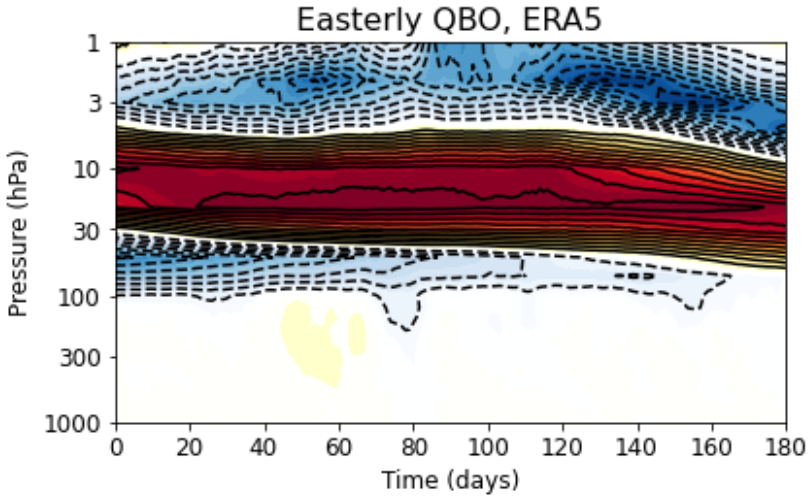
Westerly and Easterly QBO composites



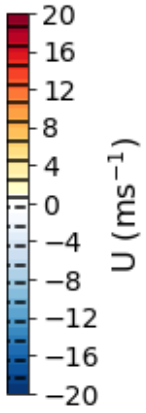
Defined as when the Nov 1st zonal mean zonal wind anomalies at 60 hPa are greater than 1 standard deviation

5S-5N zonal mean zonal wind following November 1st westerly QBO





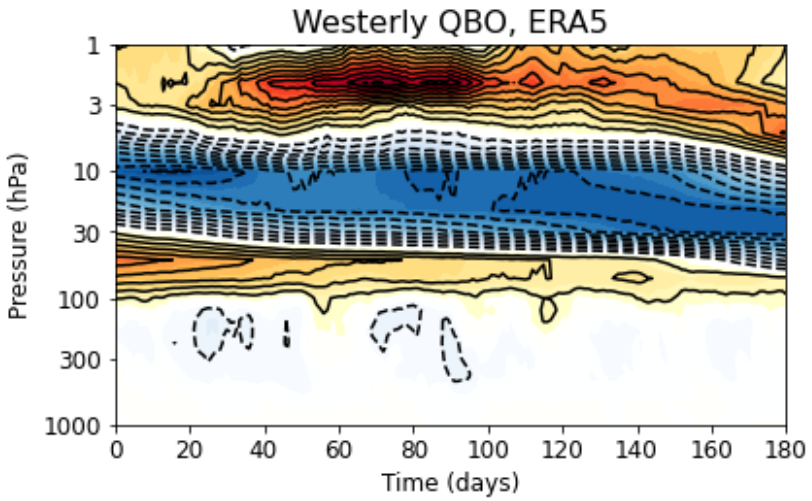
5S-5N zonal mean zonal wind following November 1st easterly QBO

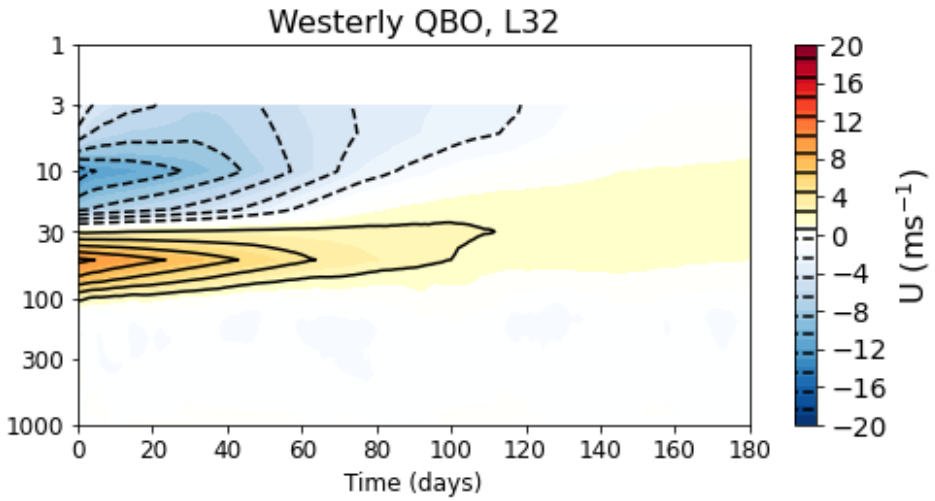


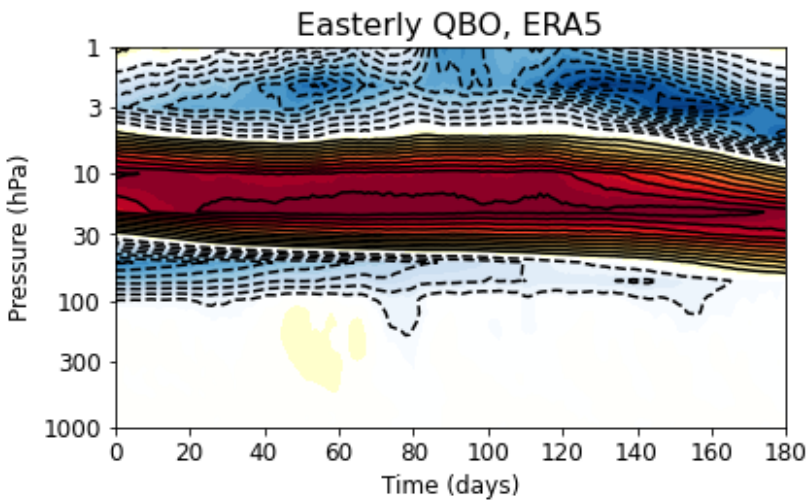
Defined as when the Nov 1st zonal mean zonal wind anomalies at 60 hPa are less than -1 standard deviation

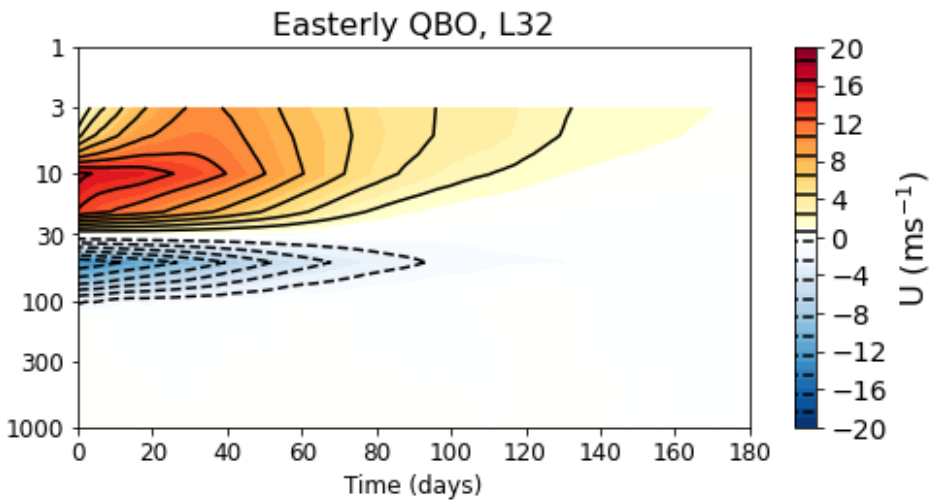
ERA5

Westerly and Easterly QBO composites









ERA5

L32

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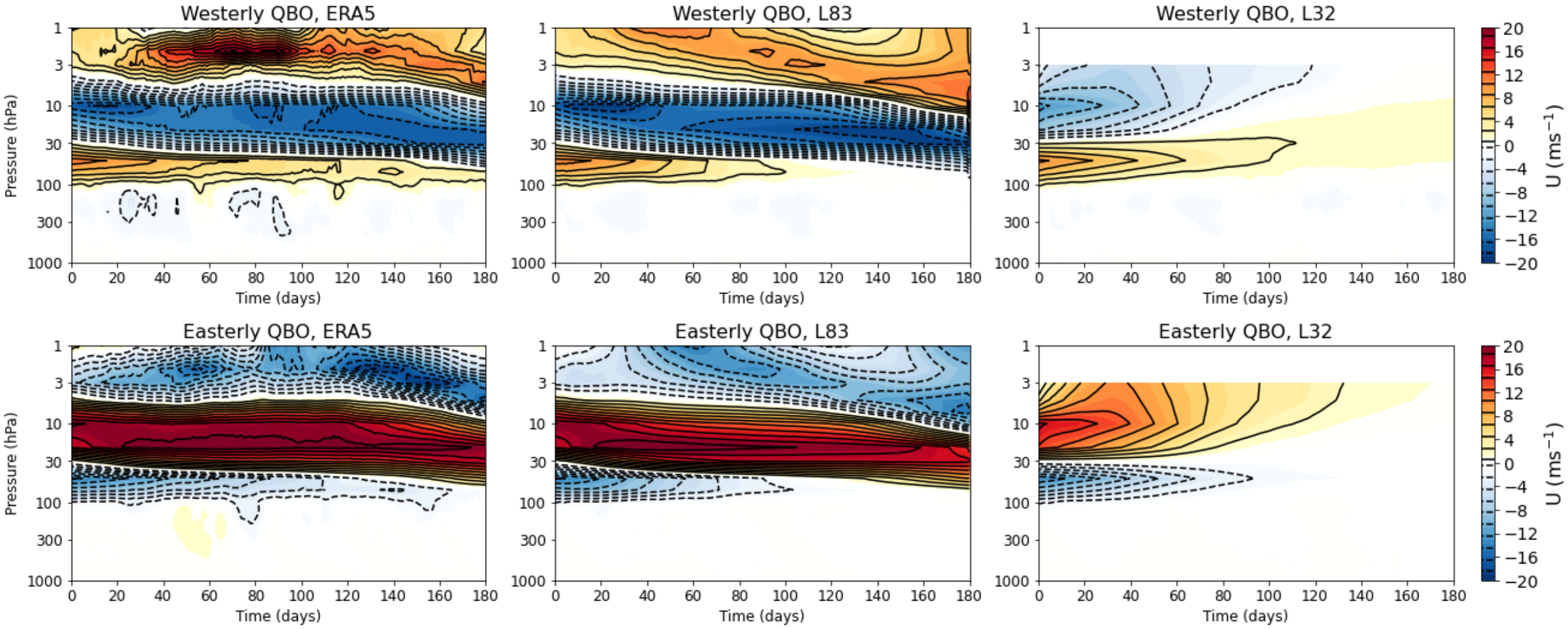
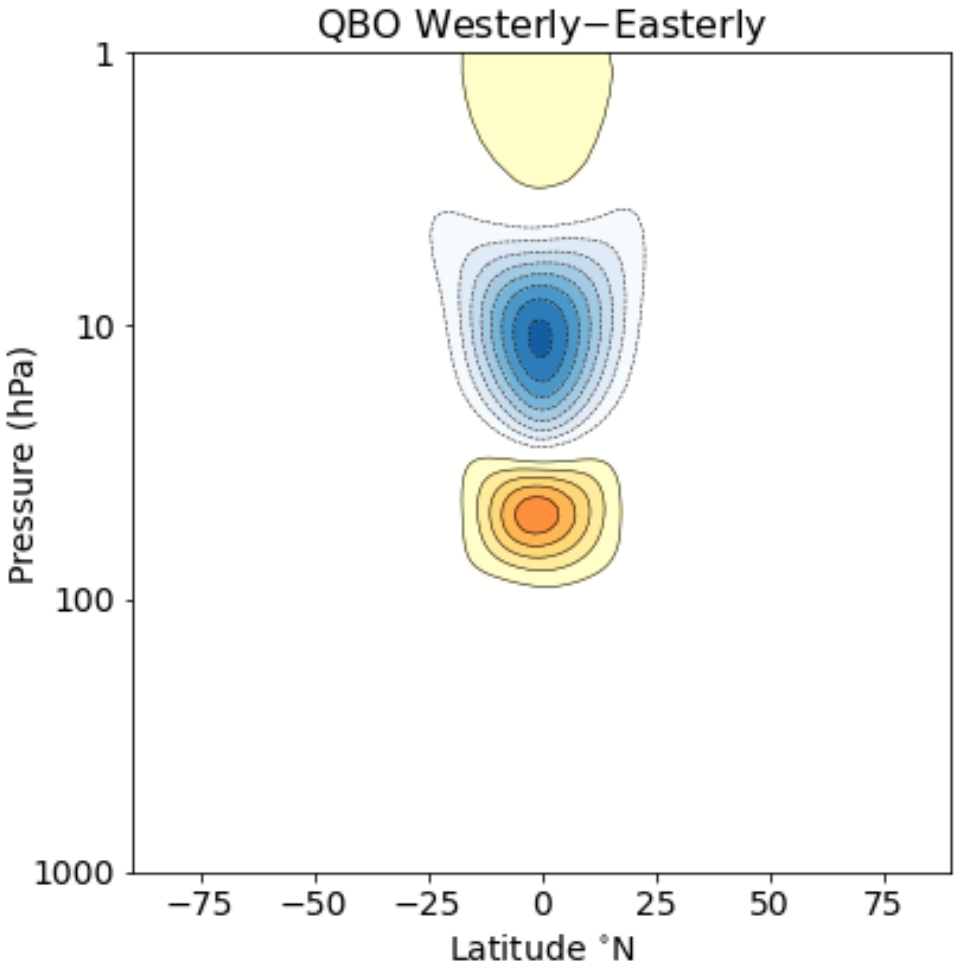


Now that we can predict the QBO, how does that impact skill in other things?

Focusing on features that have been argued in prior literature to be connected to the QBO:



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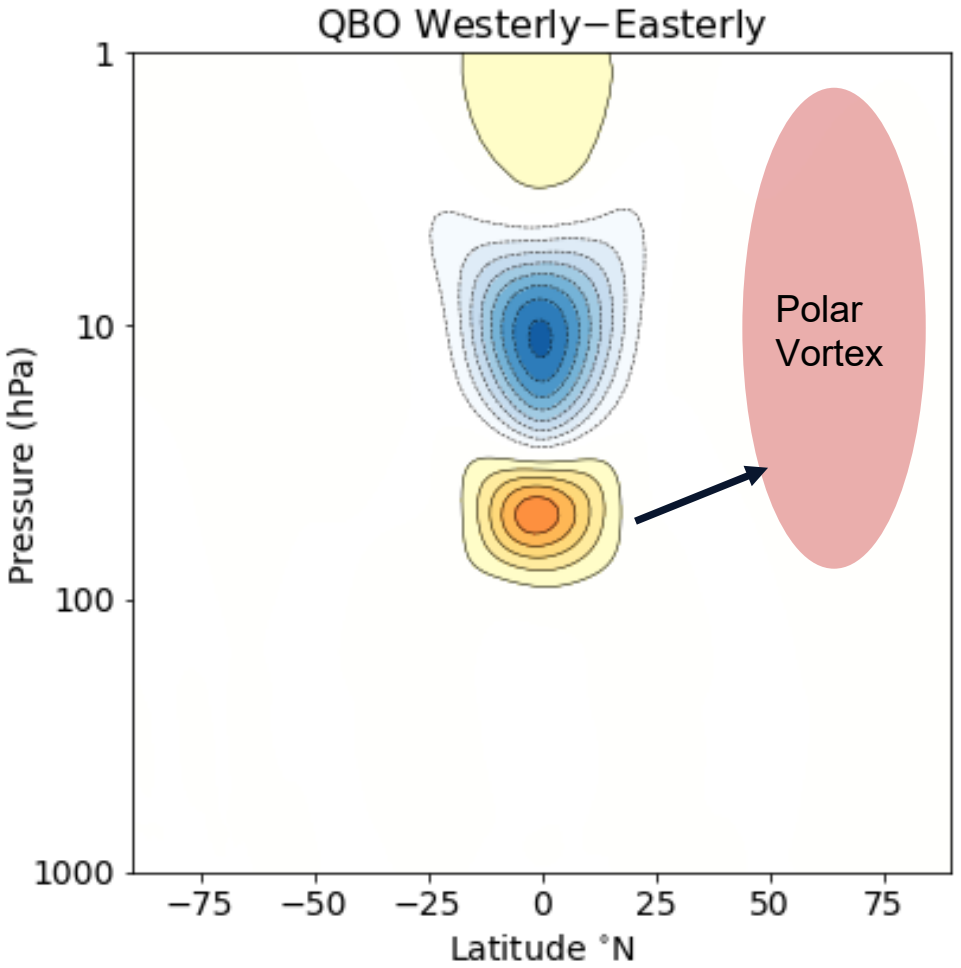

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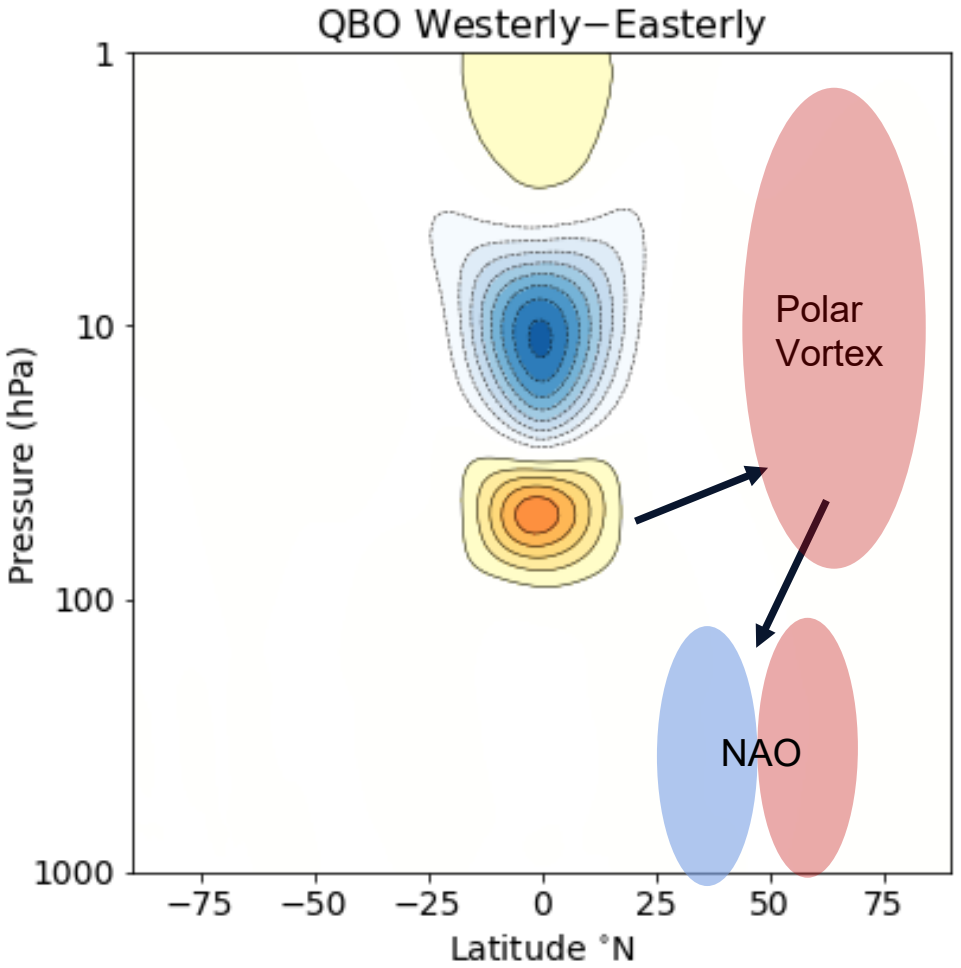

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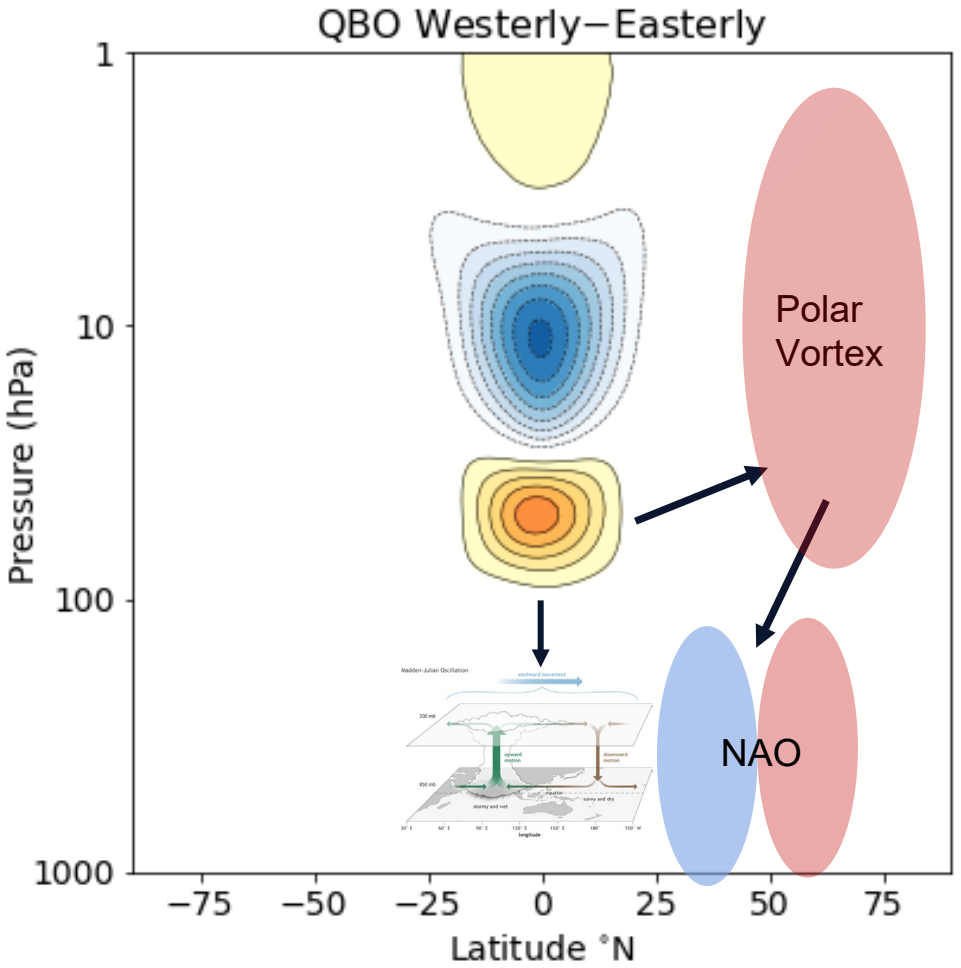

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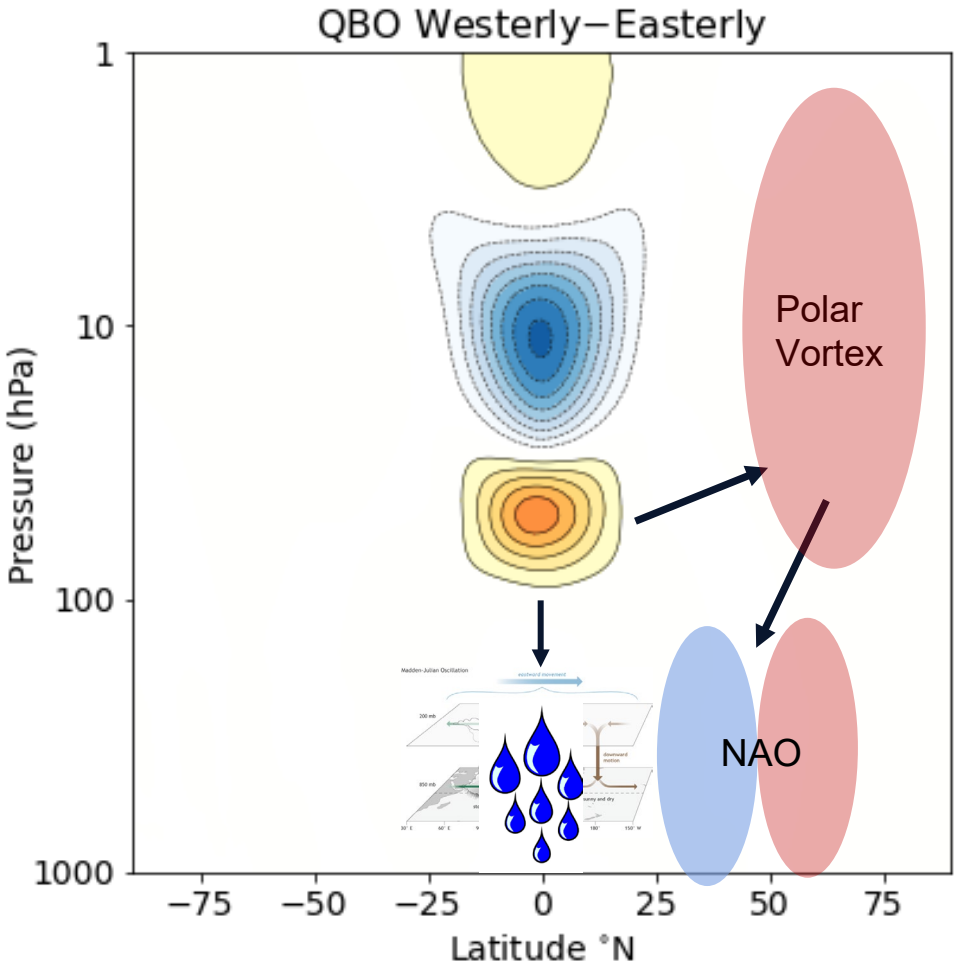

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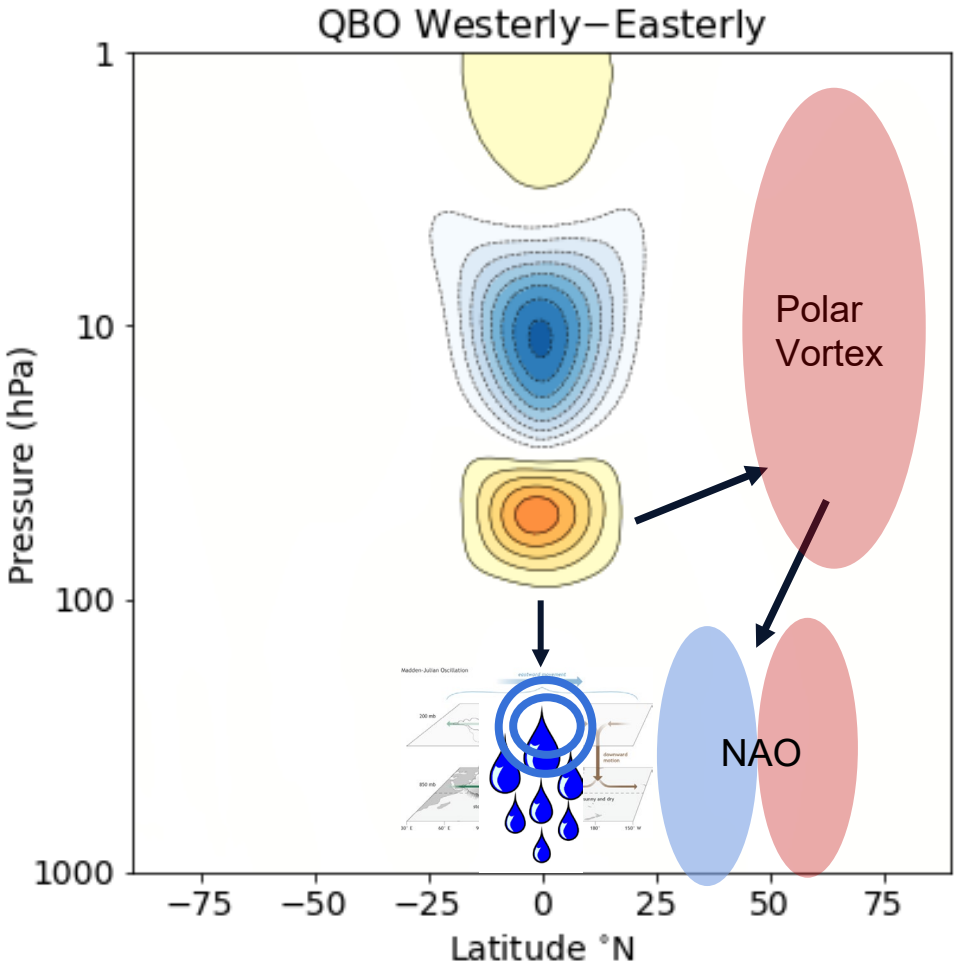

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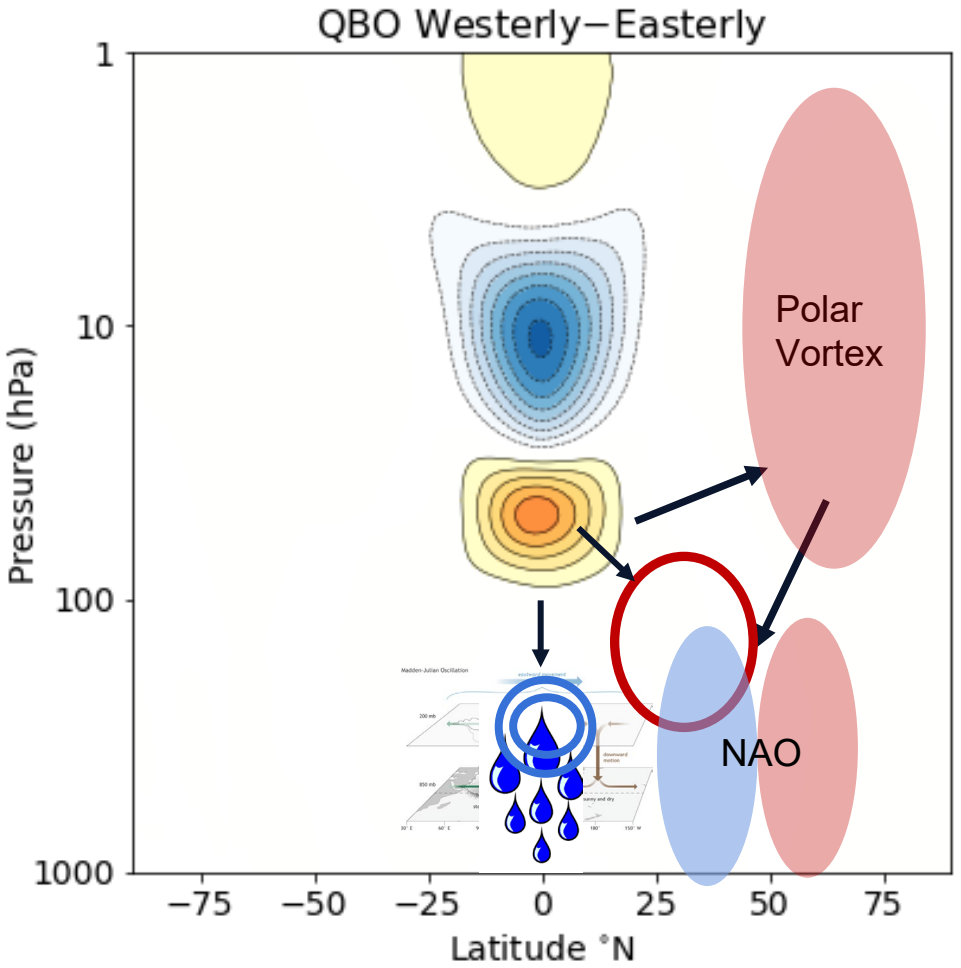
- Sub-tropical jet in the Pacific sector
  e.g. Garfinkel and Hartmann (2011)



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- ~~Tropical Precipitation~~ No skill improvement
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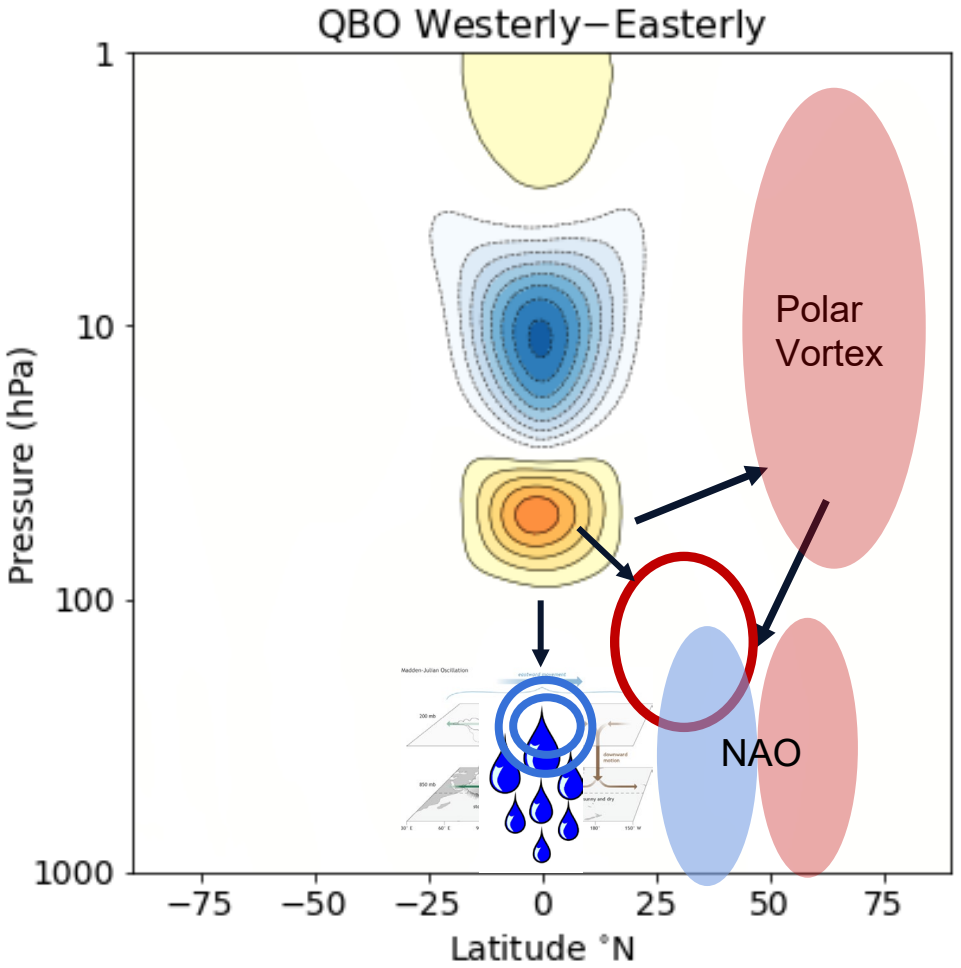

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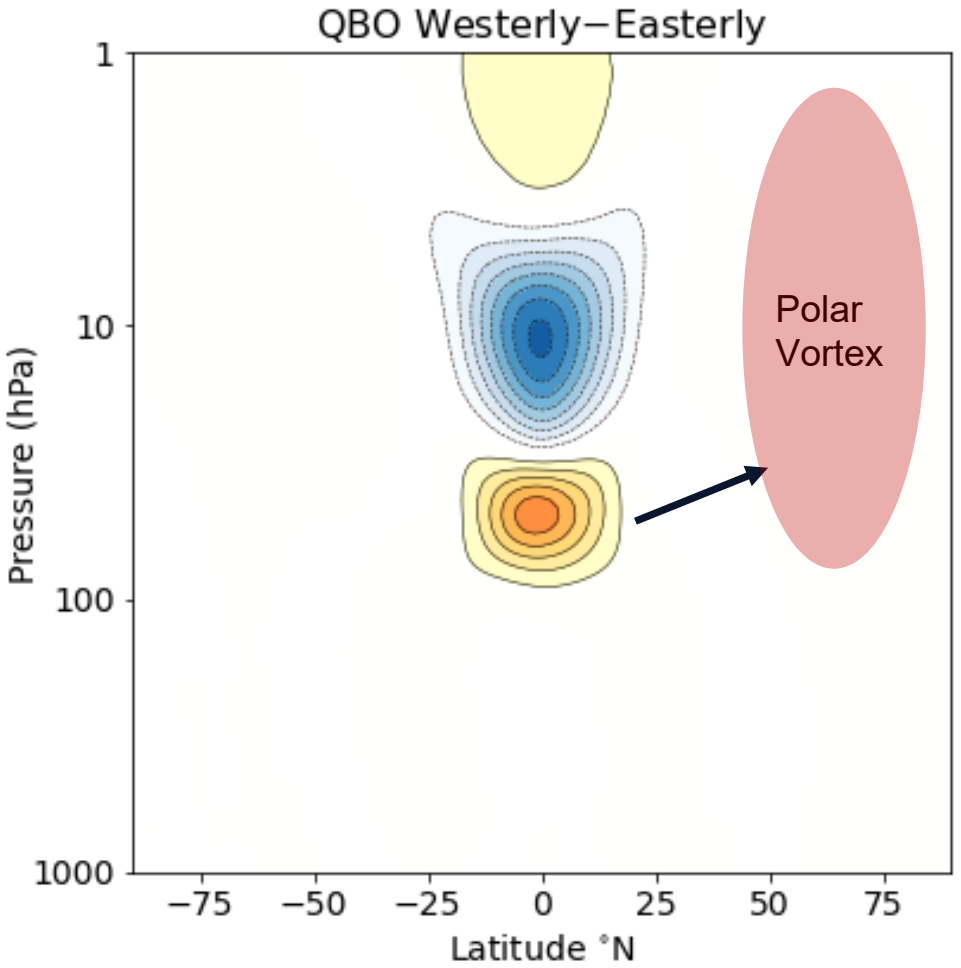
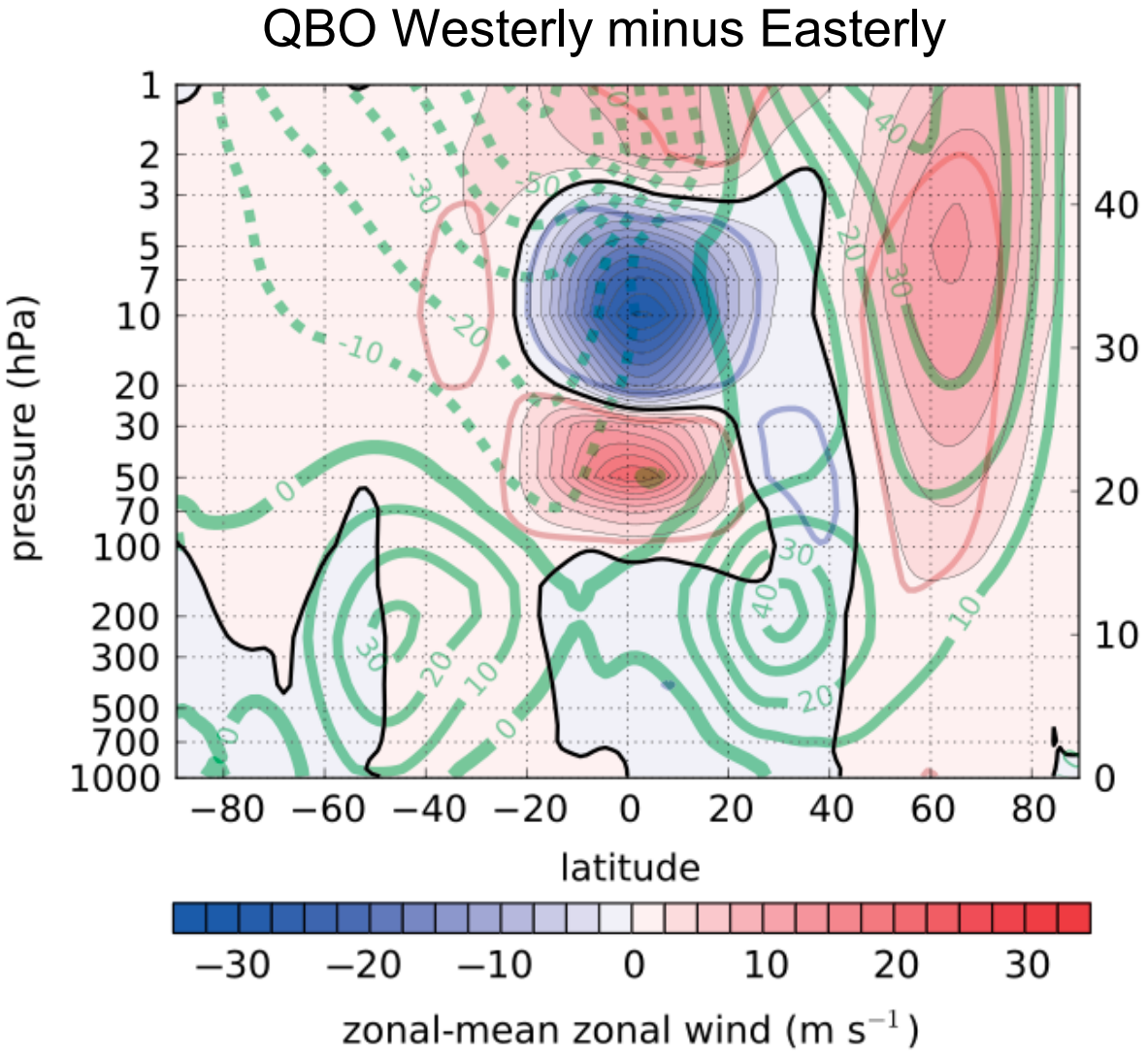


The Holton -Tan Effect

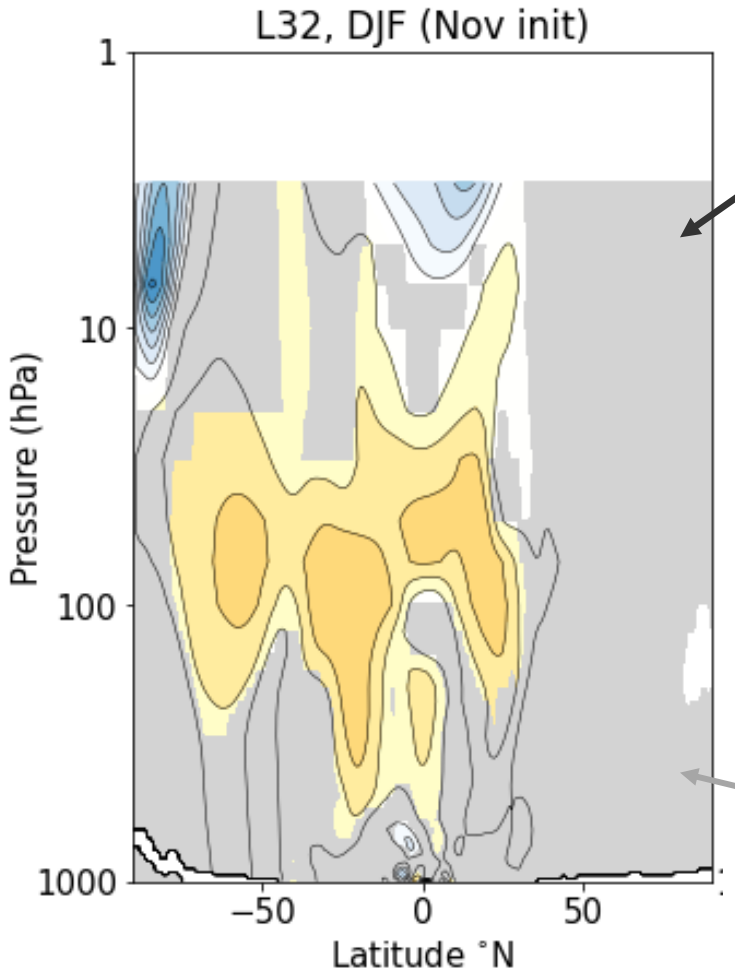
Holton and Tan (1980)

During westerly QBO, the NH polar vortex is stronger than during easterly QBO.



Anstey and Shepherd (2014)

DJF zonal mean zonal wind skill, November Initialization

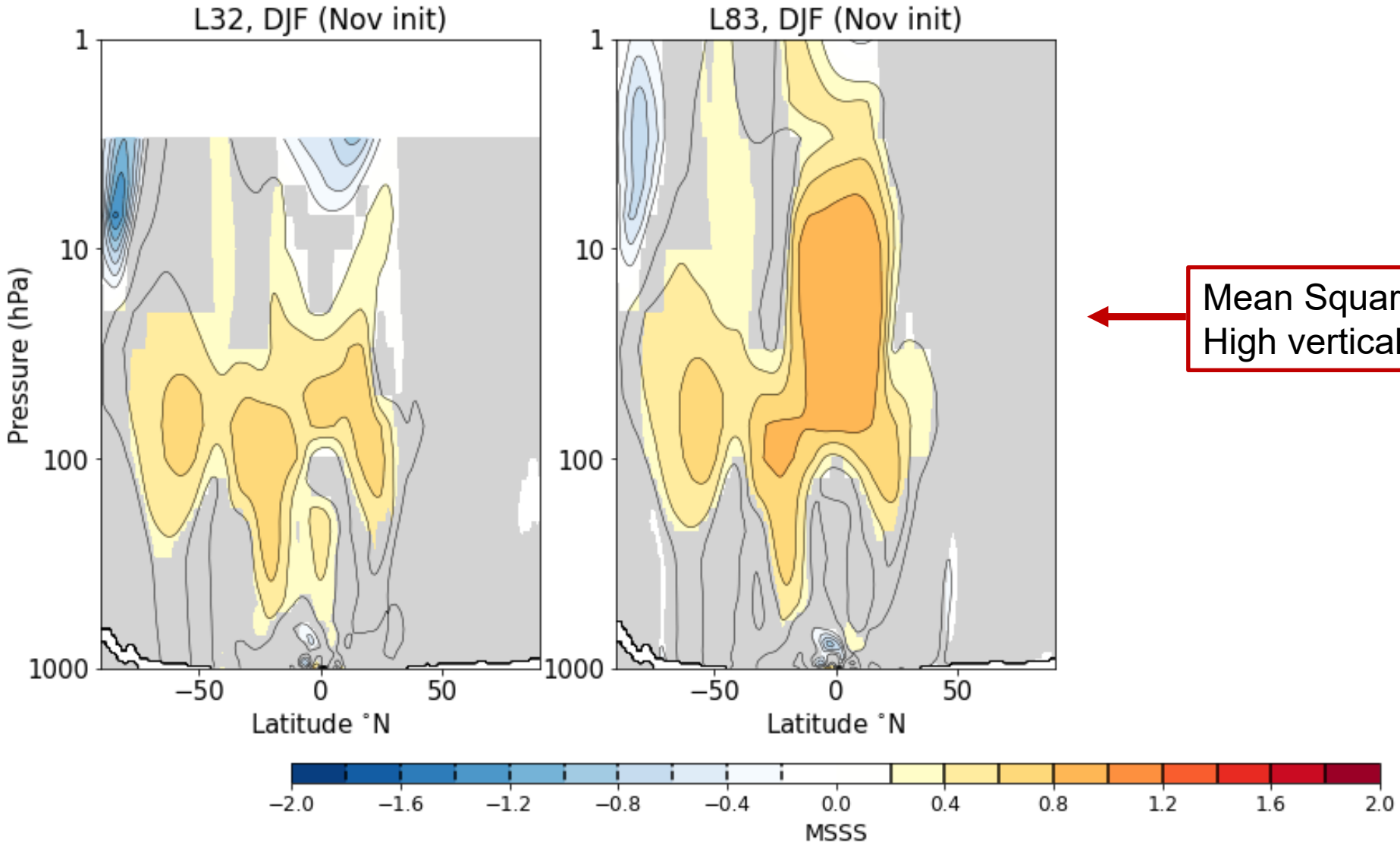


No skill in the NH winter polar vortex

Mean Squared Skill Score
Low vertical resolution (L32)

Gray = not significantly different from zero at the 95% confidence level bootstrapping both ensemble members and years

DJF zonal mean zonal wind skill, November Initialization



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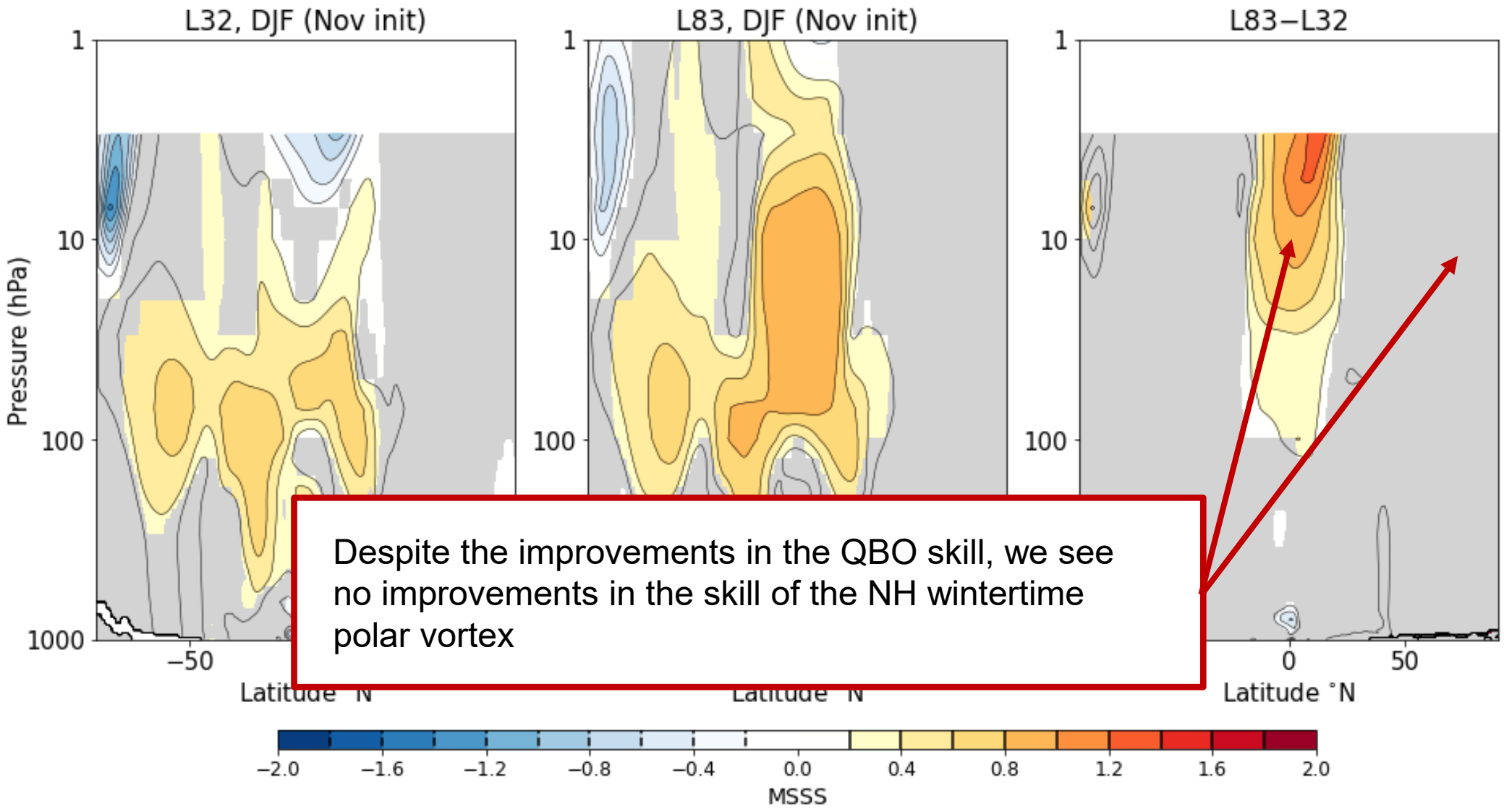
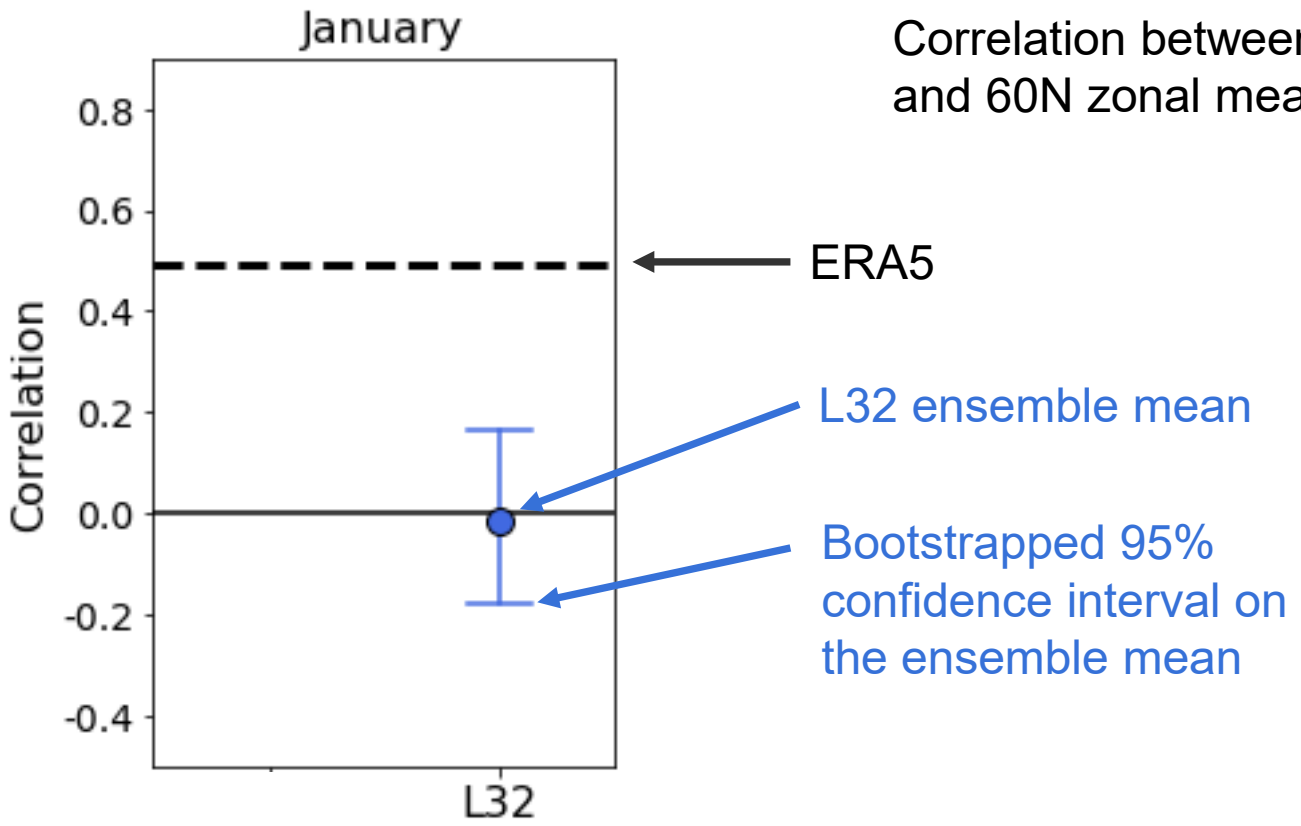


Despite the improvements in the QBO skill, we see no improvements in the skill of the NH wintertime polar vortex

The Holton -Tan Effect

January of the November initialization

Correlation between 5S-5N zonal mean zonal wind at 50hPa and 60N zonal mean zonal wind at 10 hPa



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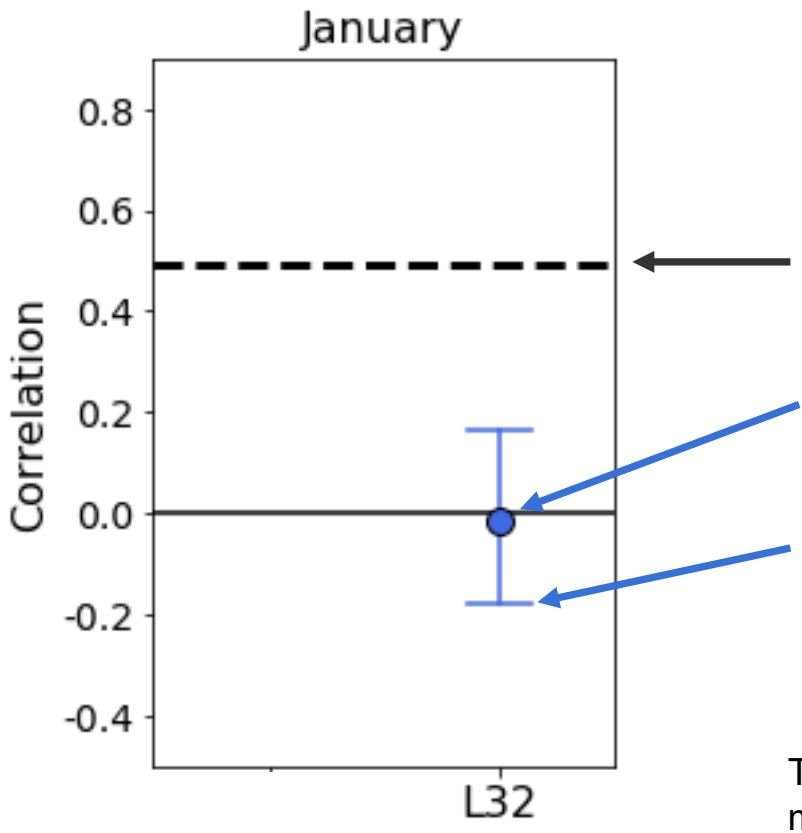

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ERA5

L32 ensemble mean

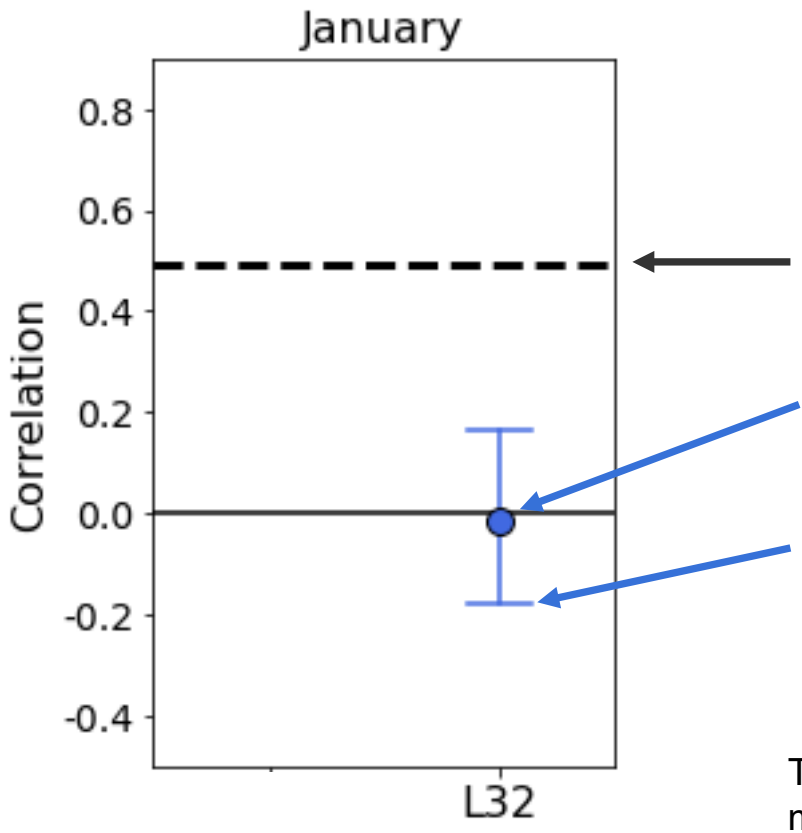
Bootstrapped 95% confidence interval on the ensemble mean

The initialized predictions give us an opportunity to quantify the uncertainty in single member samples (like the obs)

The Holton -Tan Effect

January of the November initialization

Correlation between 5S-5N zonal mean zonal wind at 50hPa and 60N zonal mean zonal wind at 10 hPa



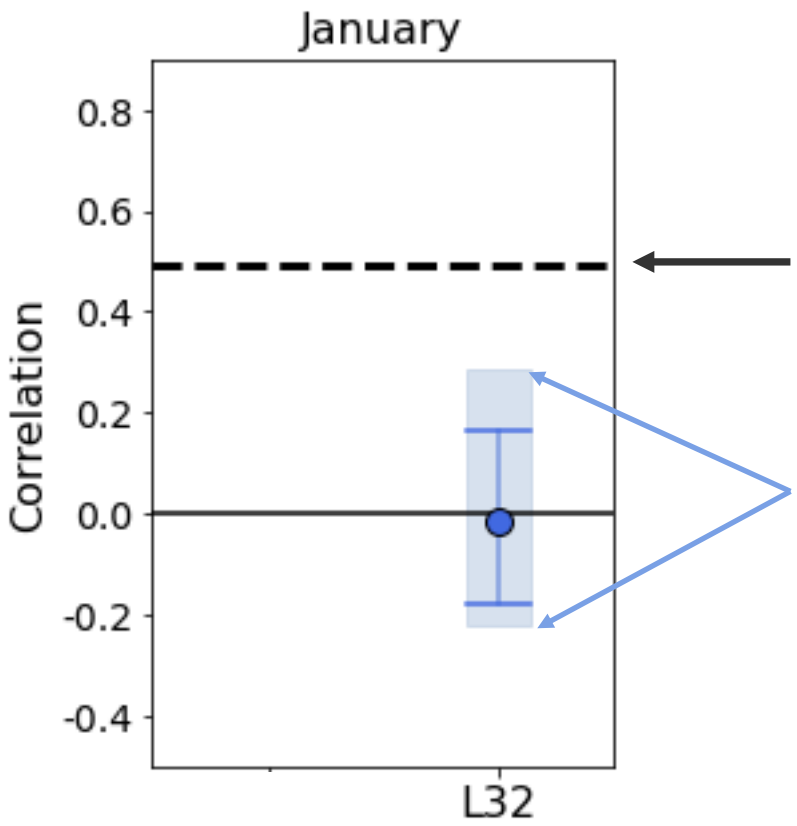
ERA5

L32 ensemble mean

Bootstrapped 95% confidence interval on the ensemble mean

The initialized predictions give us an opportunity to quantify the uncertainty in single member samples (like the obs)

The Holton -Tan Effect



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ERA5

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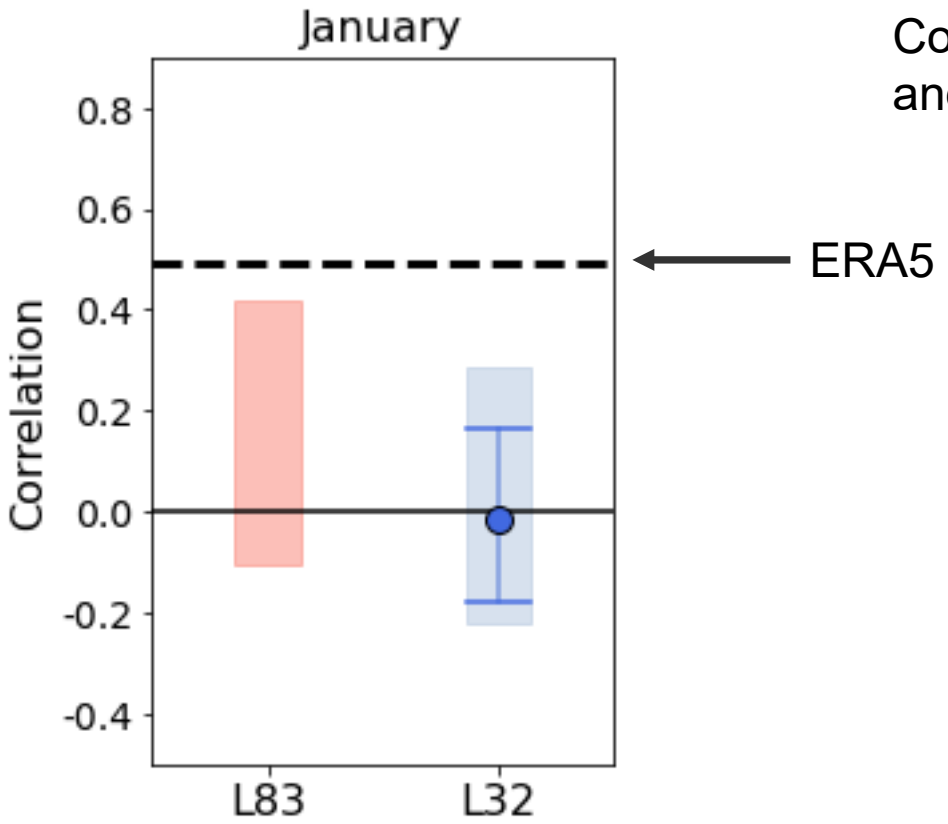

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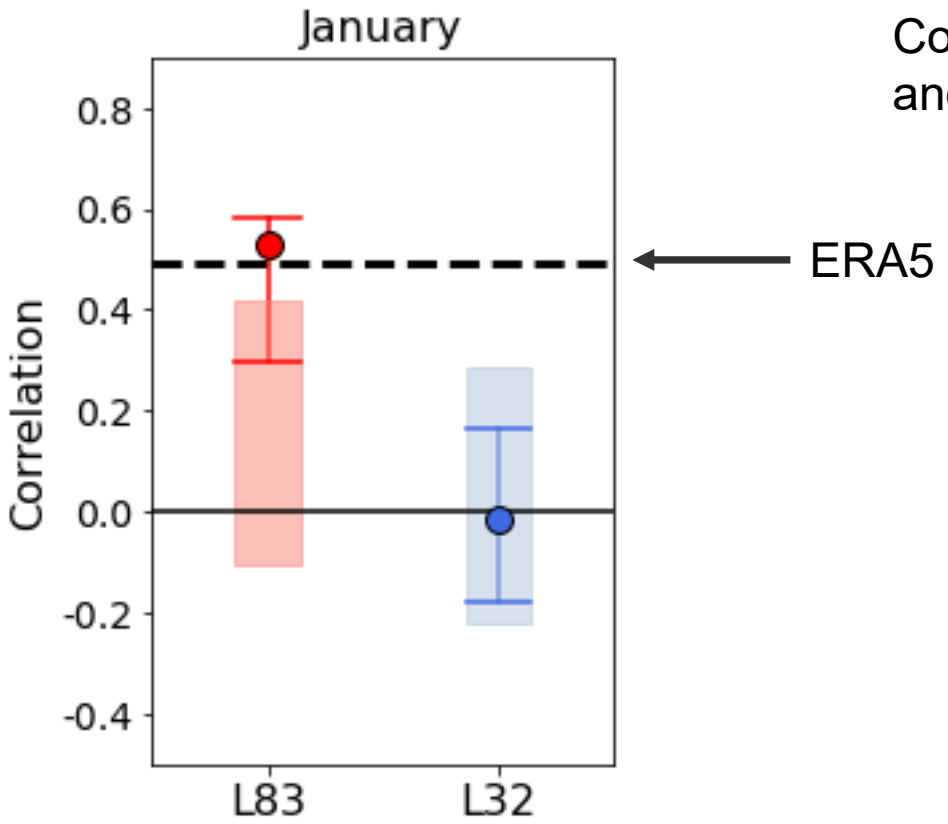

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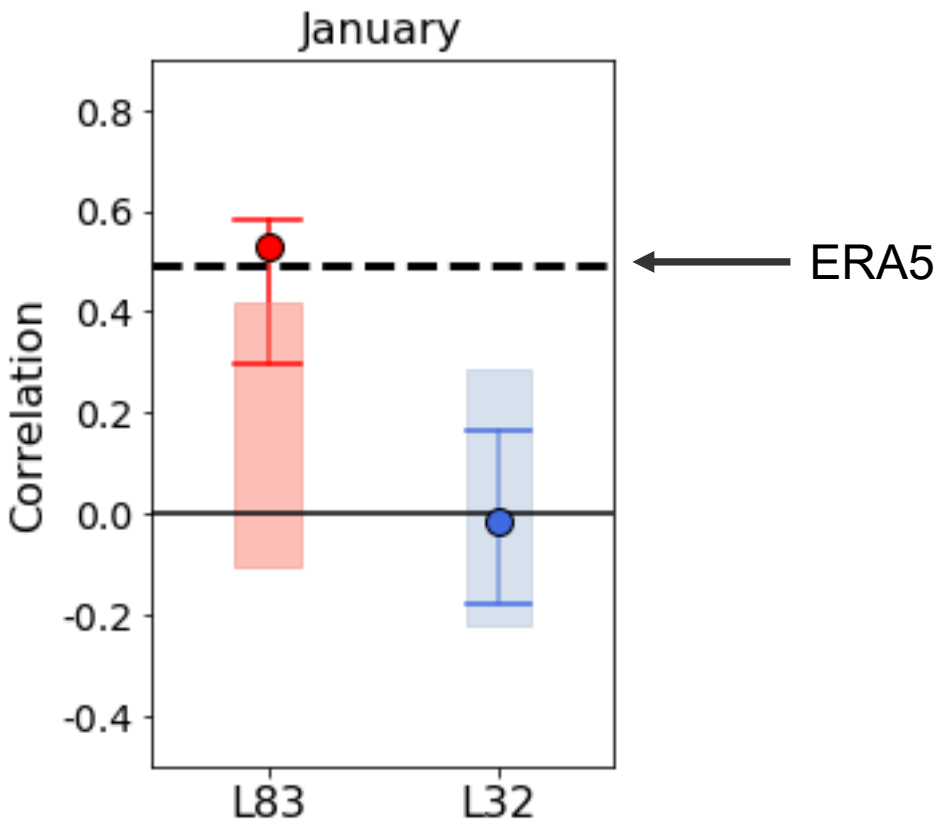
If the ensemble mean of L83 has a correlation between the QBO and the polar vortex that's similar to obs, and we're predicting the QBO well, why don't we see an increase in skill?



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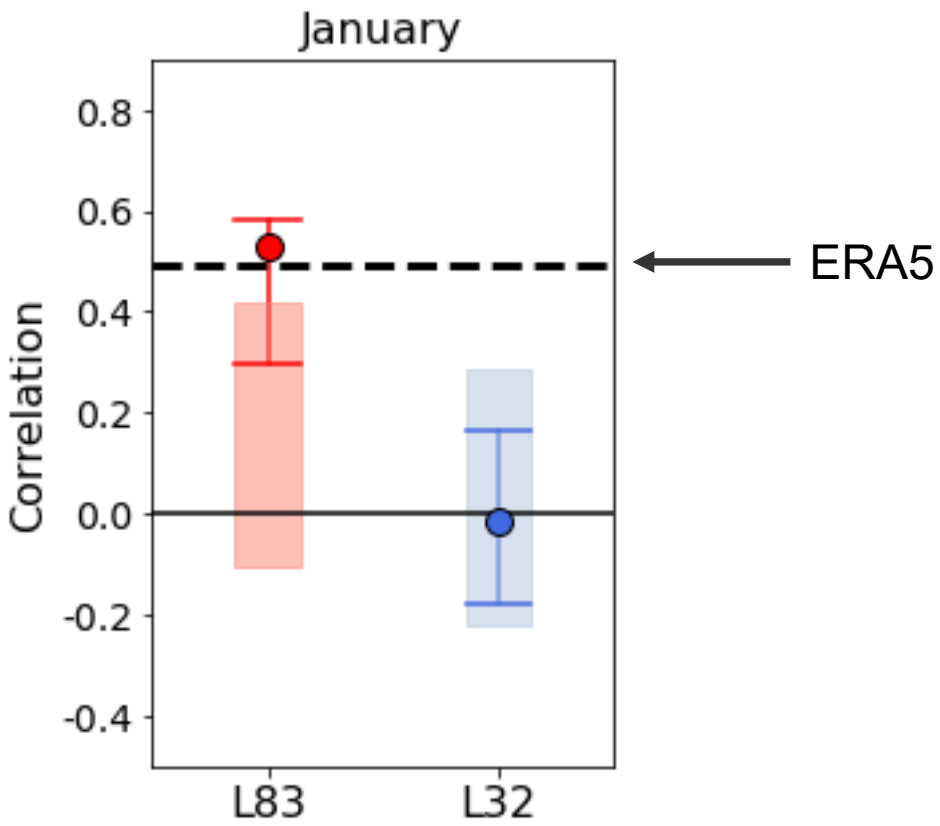
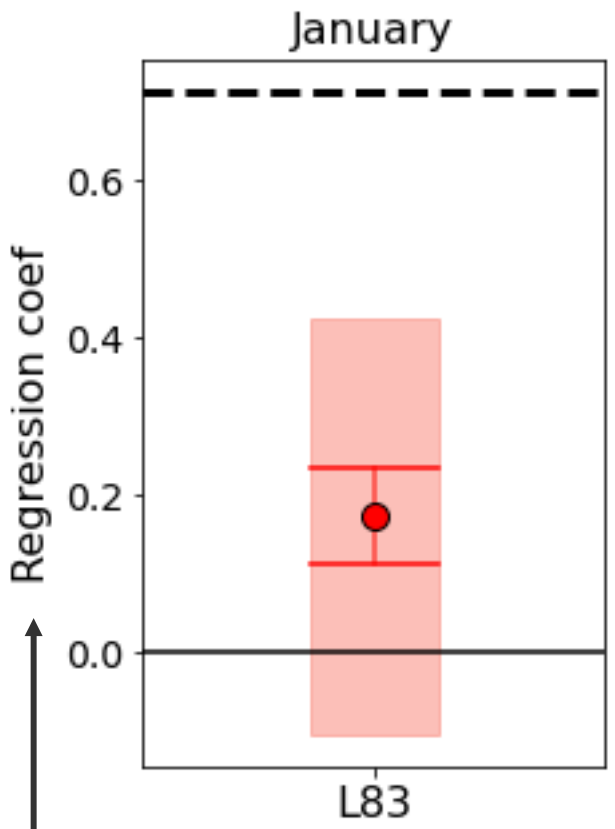


ERA5



Signal-to-noise problem in the model?

Polar vortex = a + b x QBO

Now that we can predict the QBO, how does that impact skill in other things?

Focusing on features that have been argued in prior literature to be connected to the QBO:

- Northern Hemisphere Polar vortex (Holton-Tan effect)
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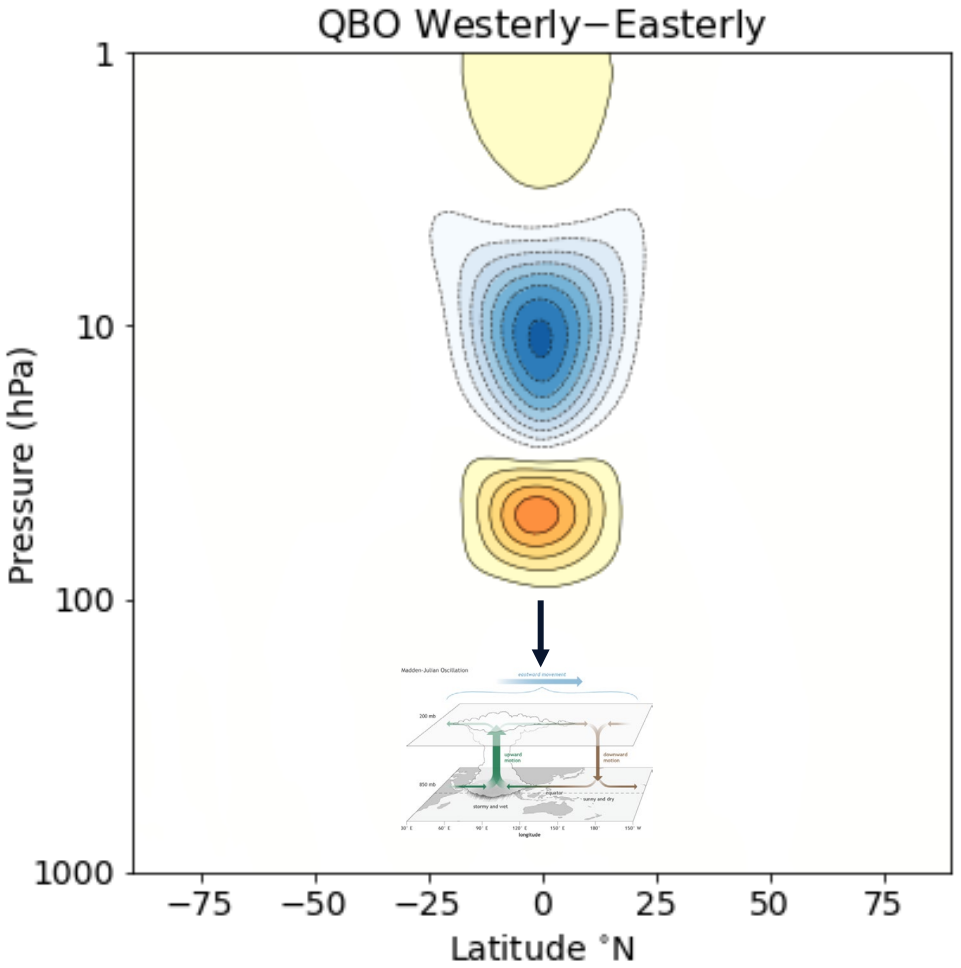
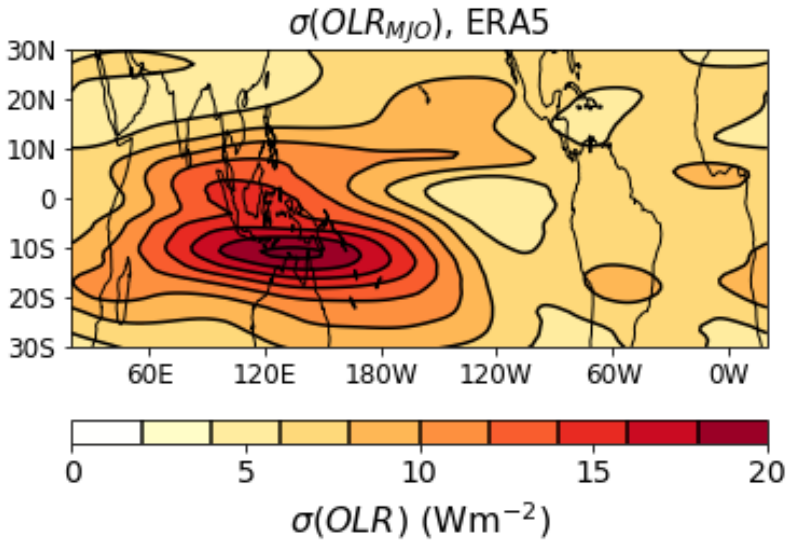


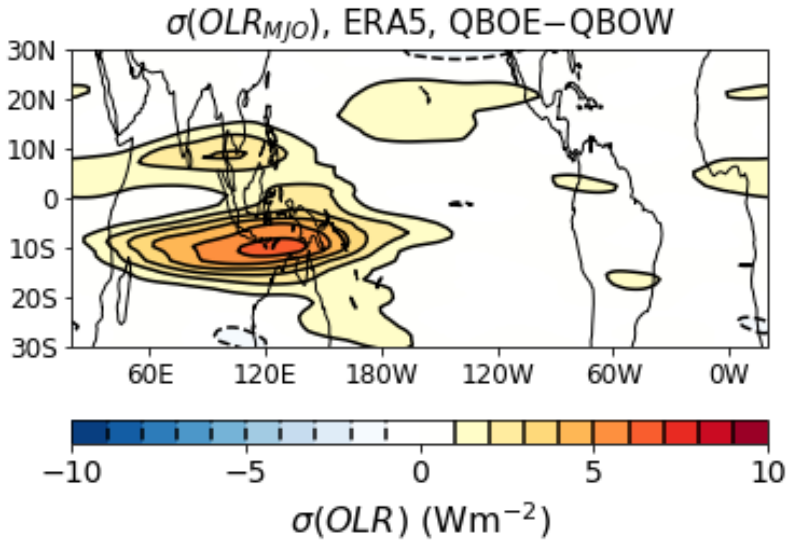
QBO-MJO connection

Following the analysis of Yoo and Son (2016)

DJF standard deviation of MJO filtered OLR (zonal wavenumbers 1-5, periods 20-100 days)



Climatology



Difference between QBO easterly and QBO westerly

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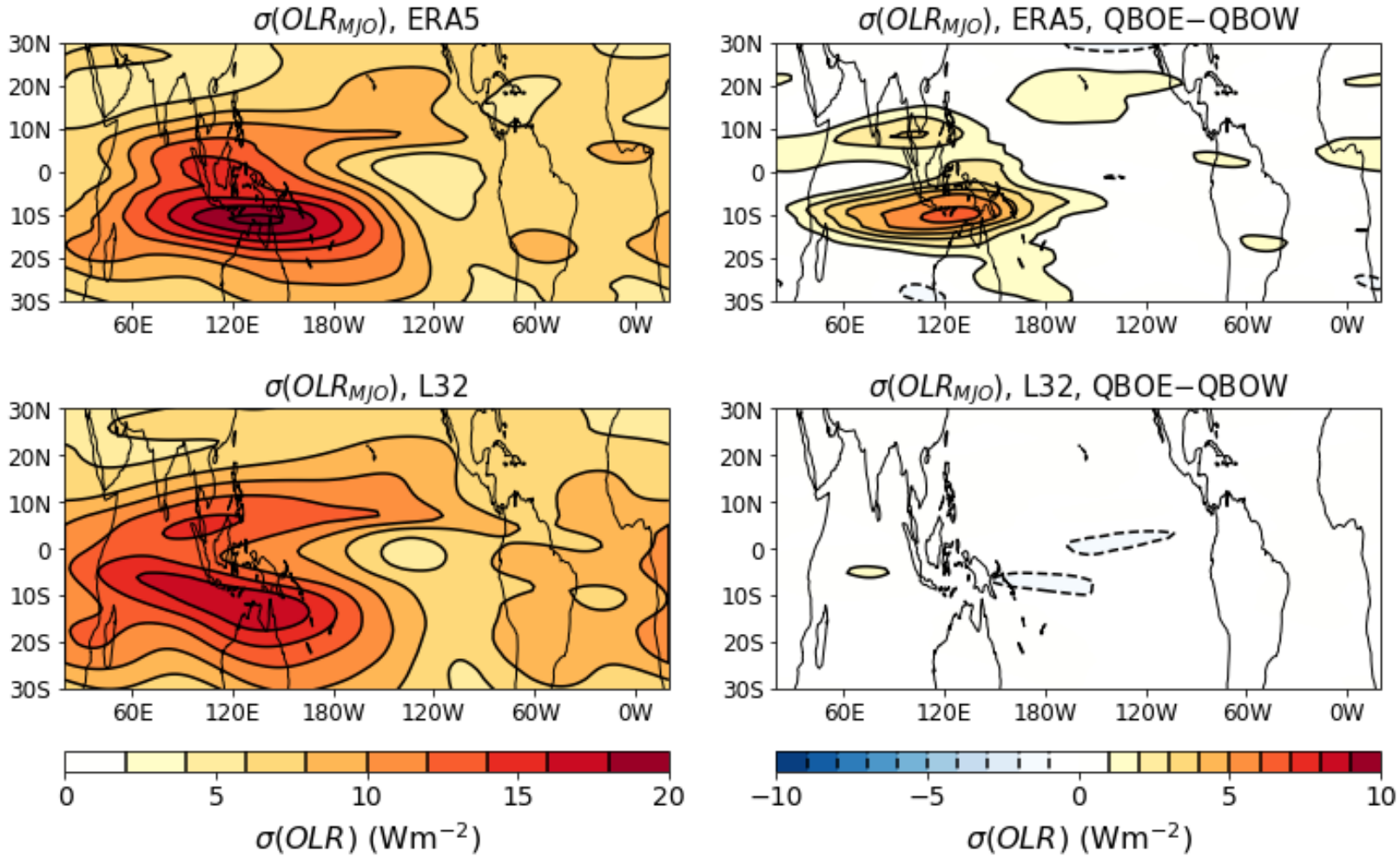
L32 ➡



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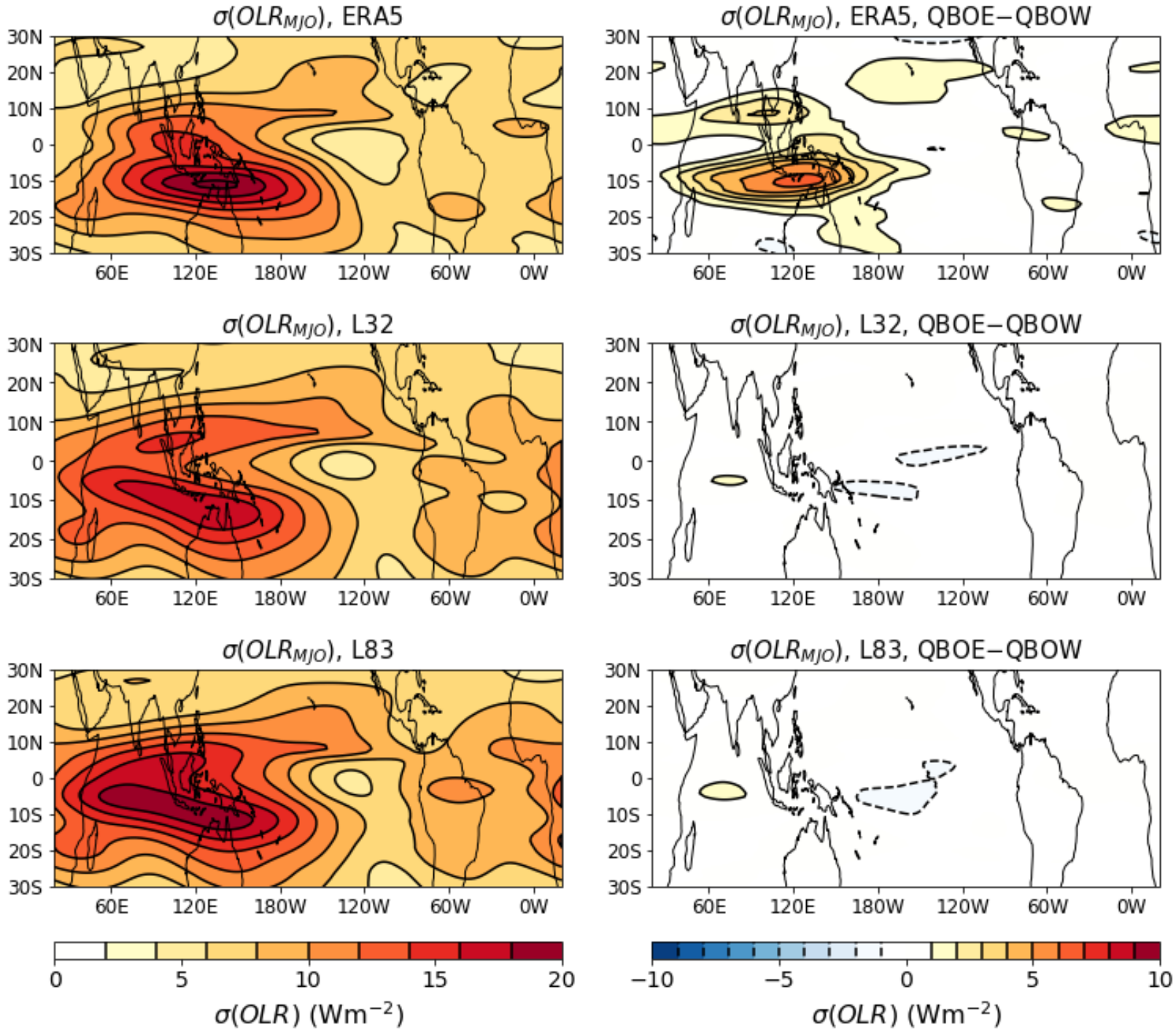
L32 →

L83 →



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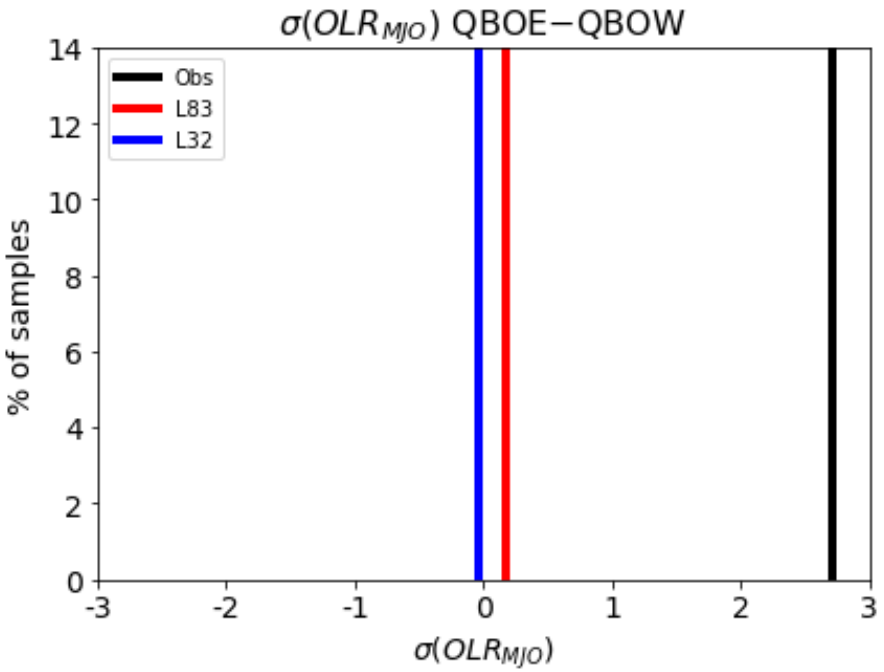
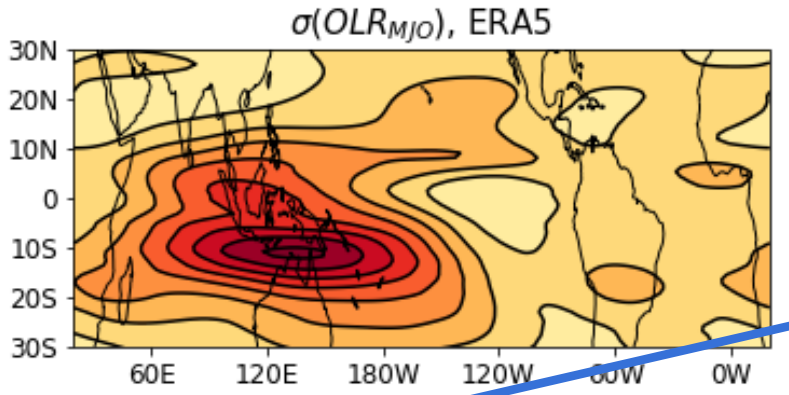
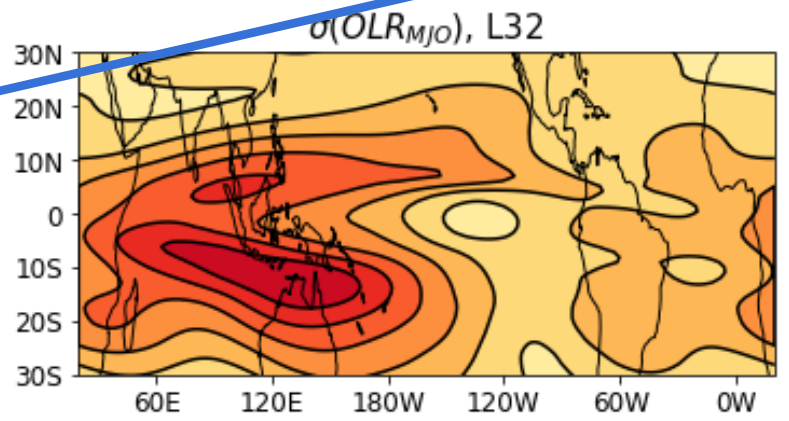
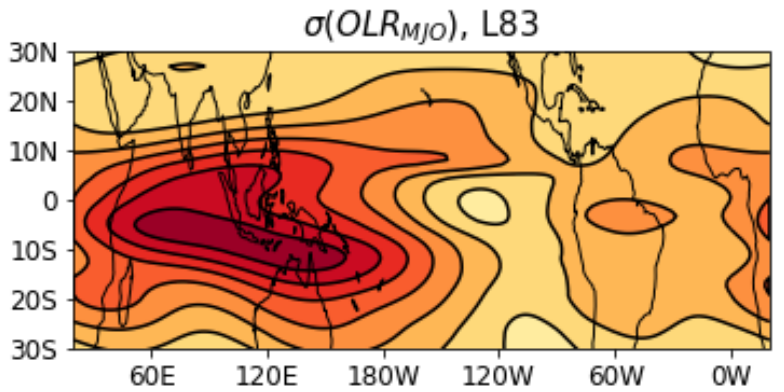
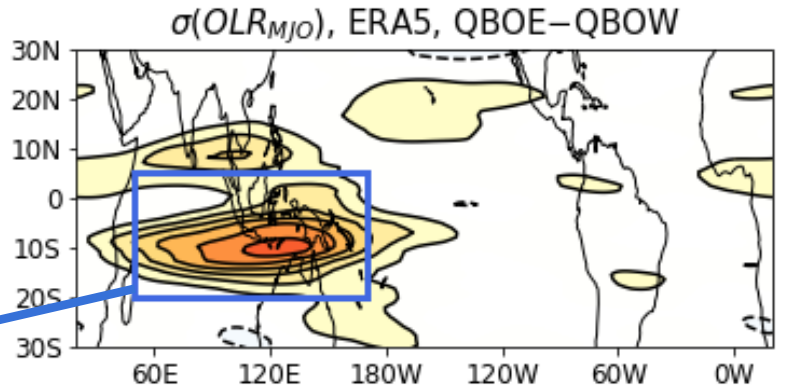
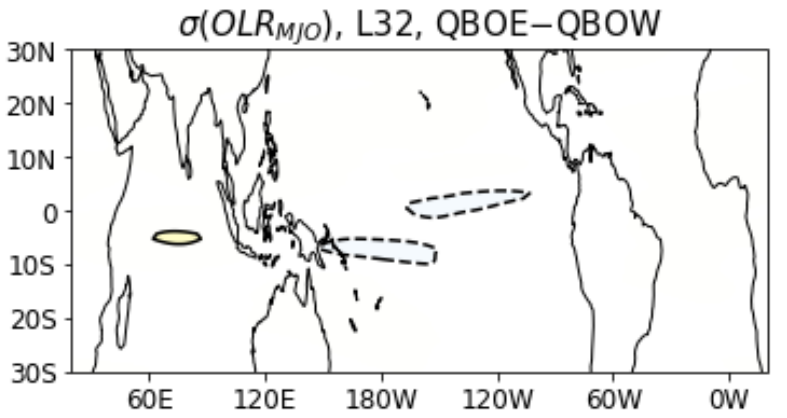


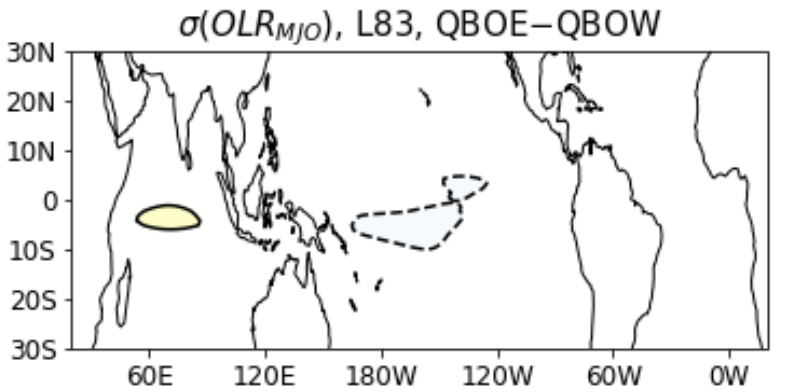


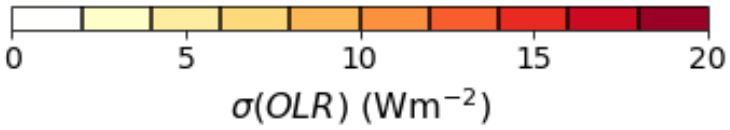


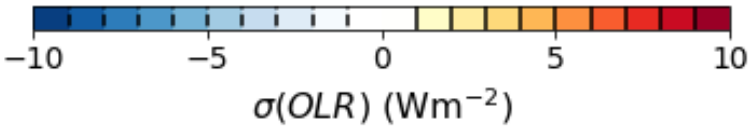




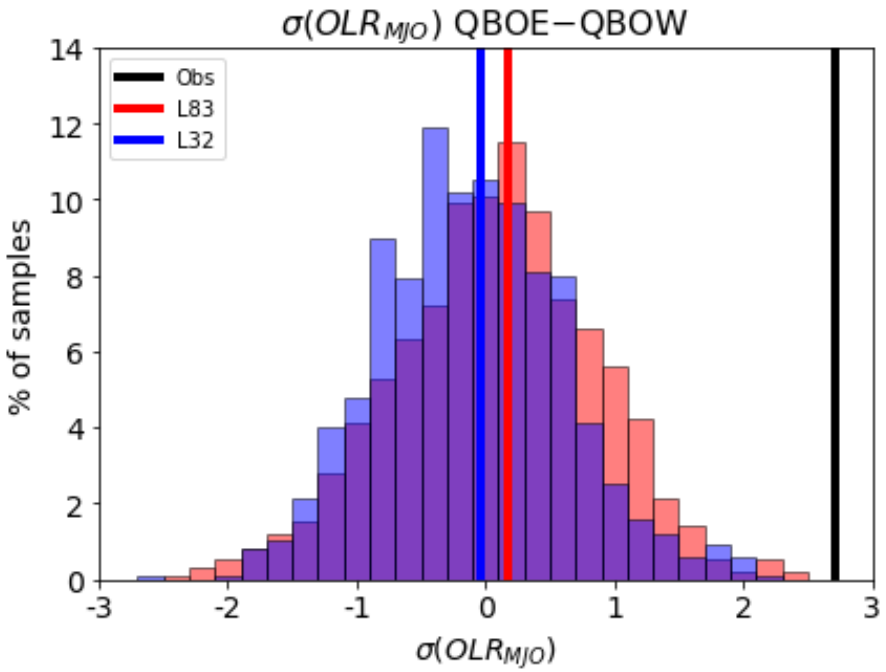


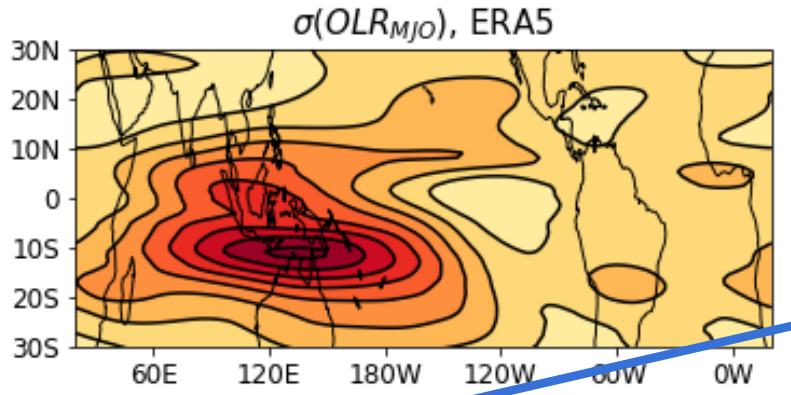


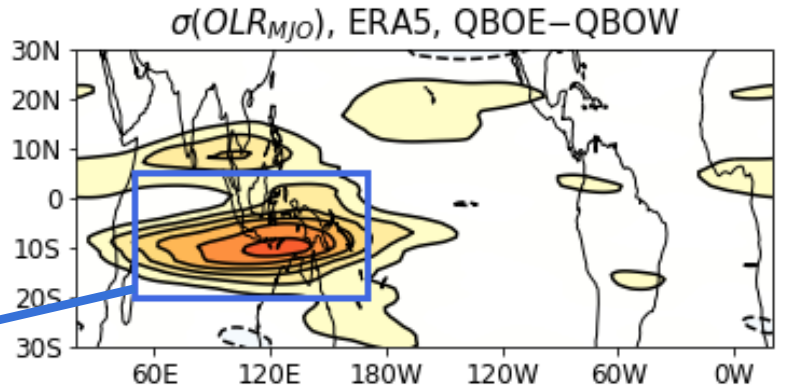


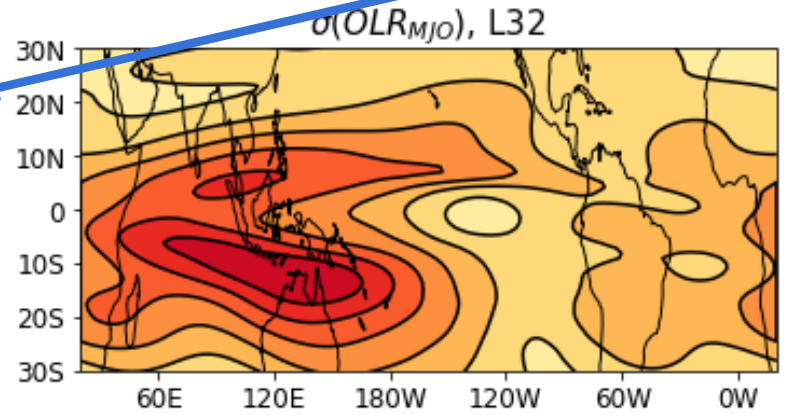


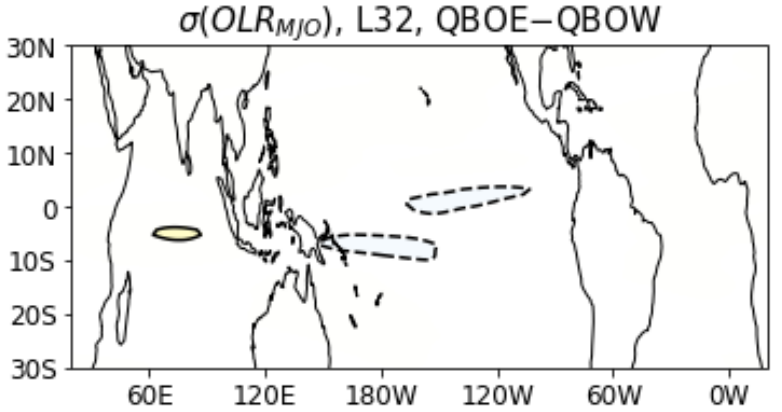
QBO-MJO connection

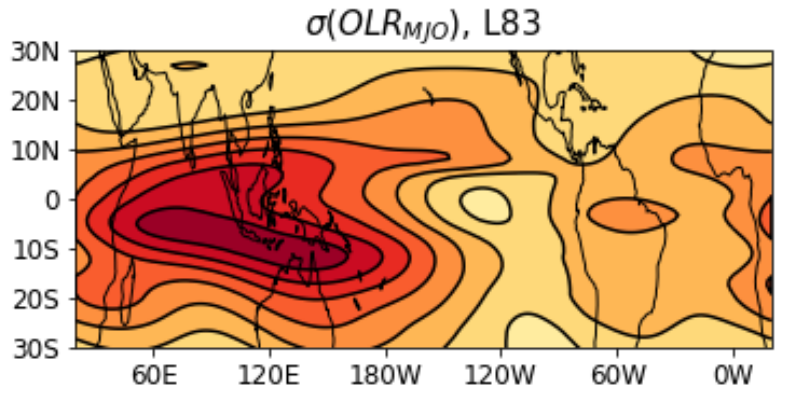


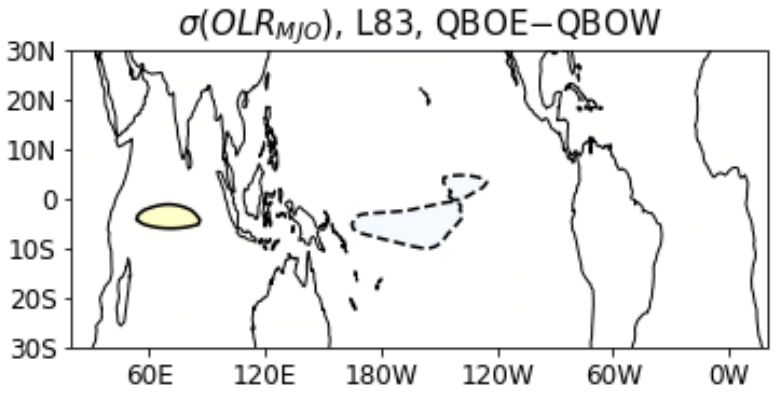


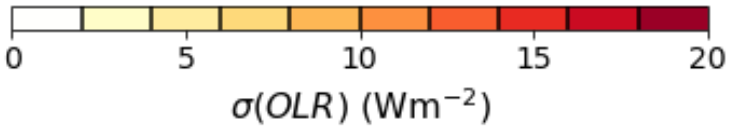


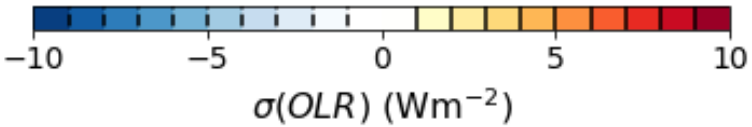












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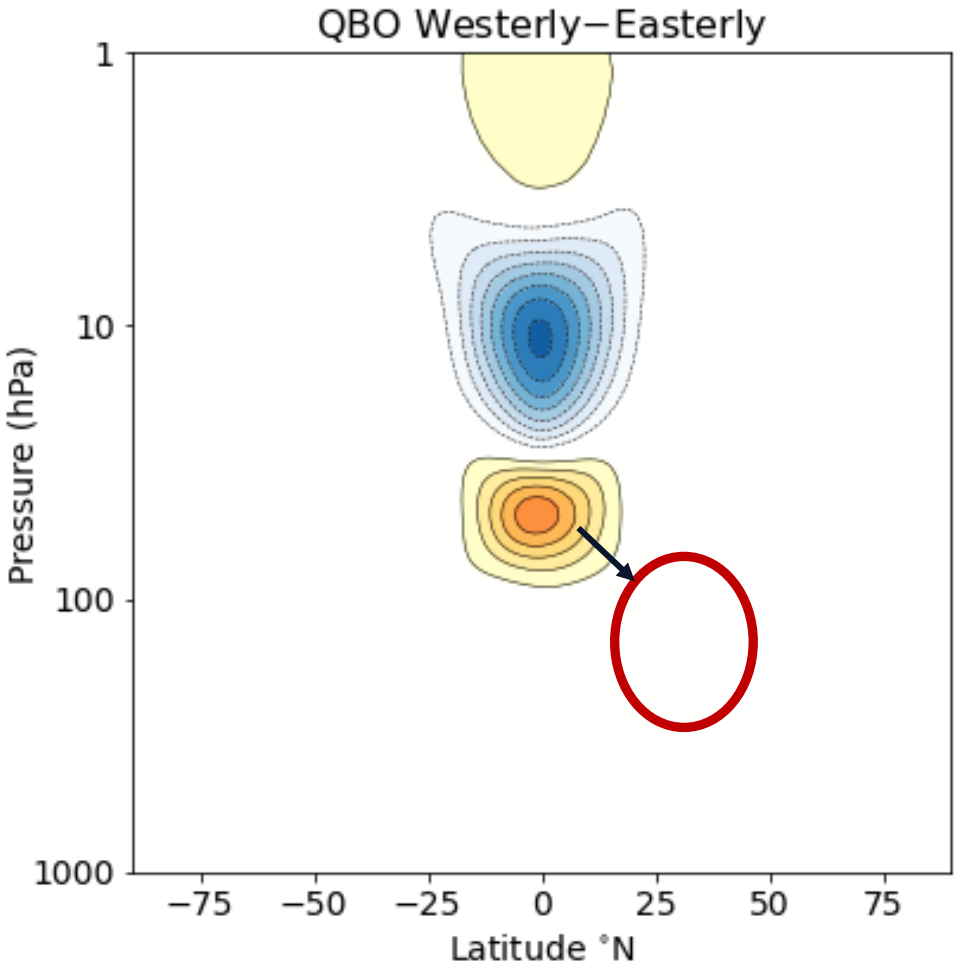
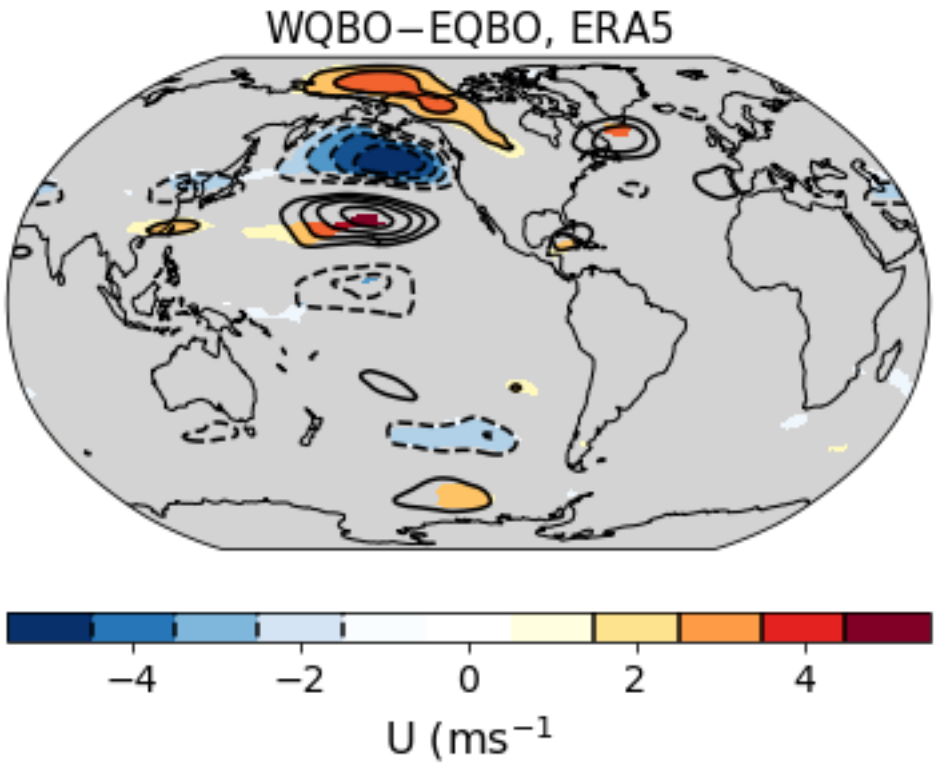


Connections between the QBO and the westerlies in the Pacific sector



DJFM ERA5 upper tropospheric zonal wind averaged (400 hPa to 100 hPa average).

QBO Westerly – QBO Easterly

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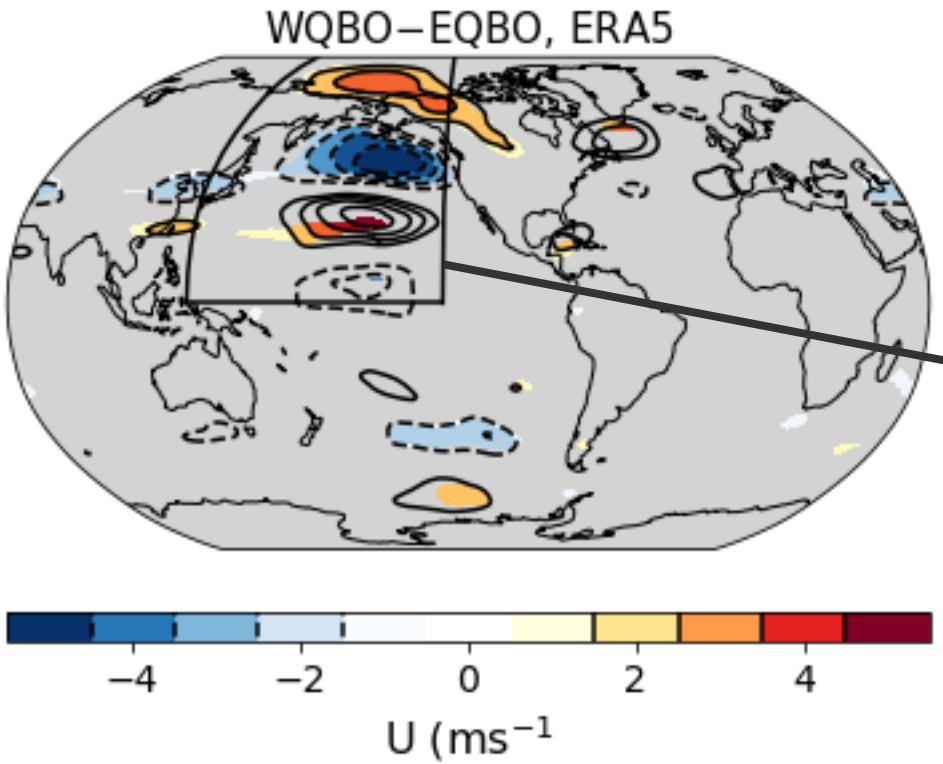
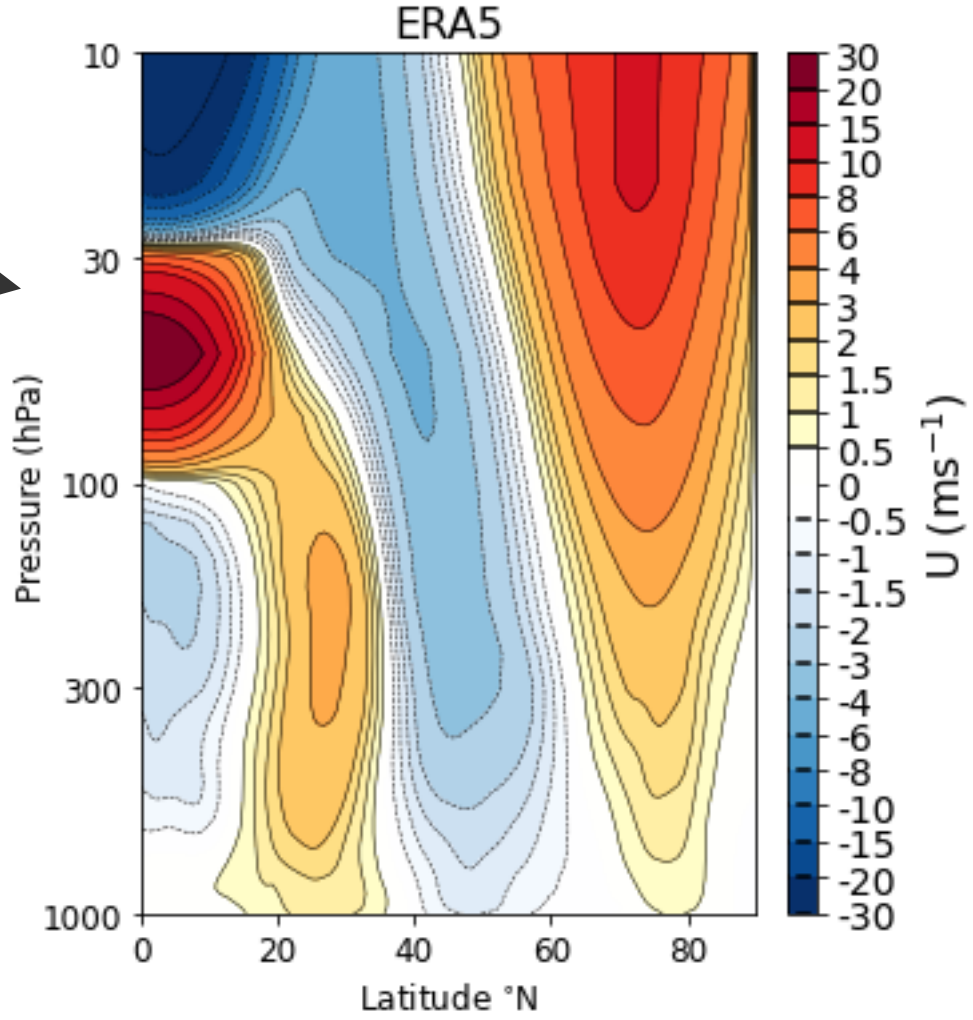
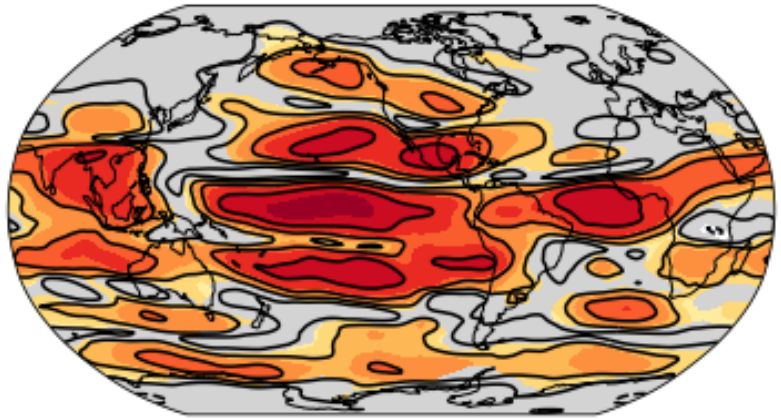


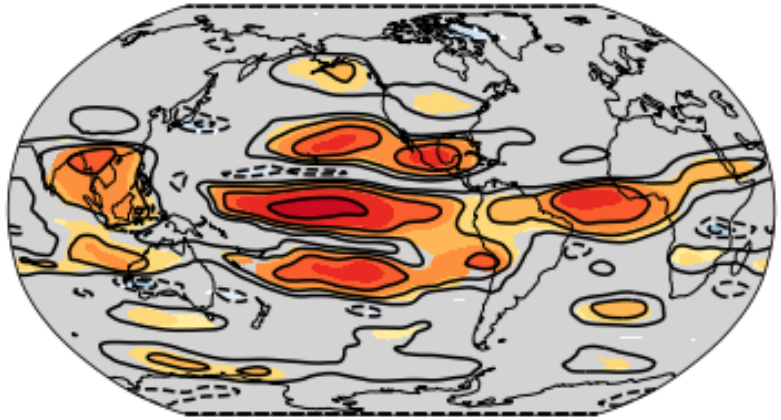


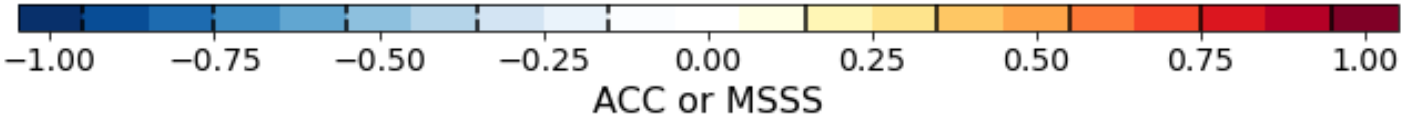
Skill of upper tropospheric zonal wind in the Pacific sector

ACC, L32



MSSS, L32





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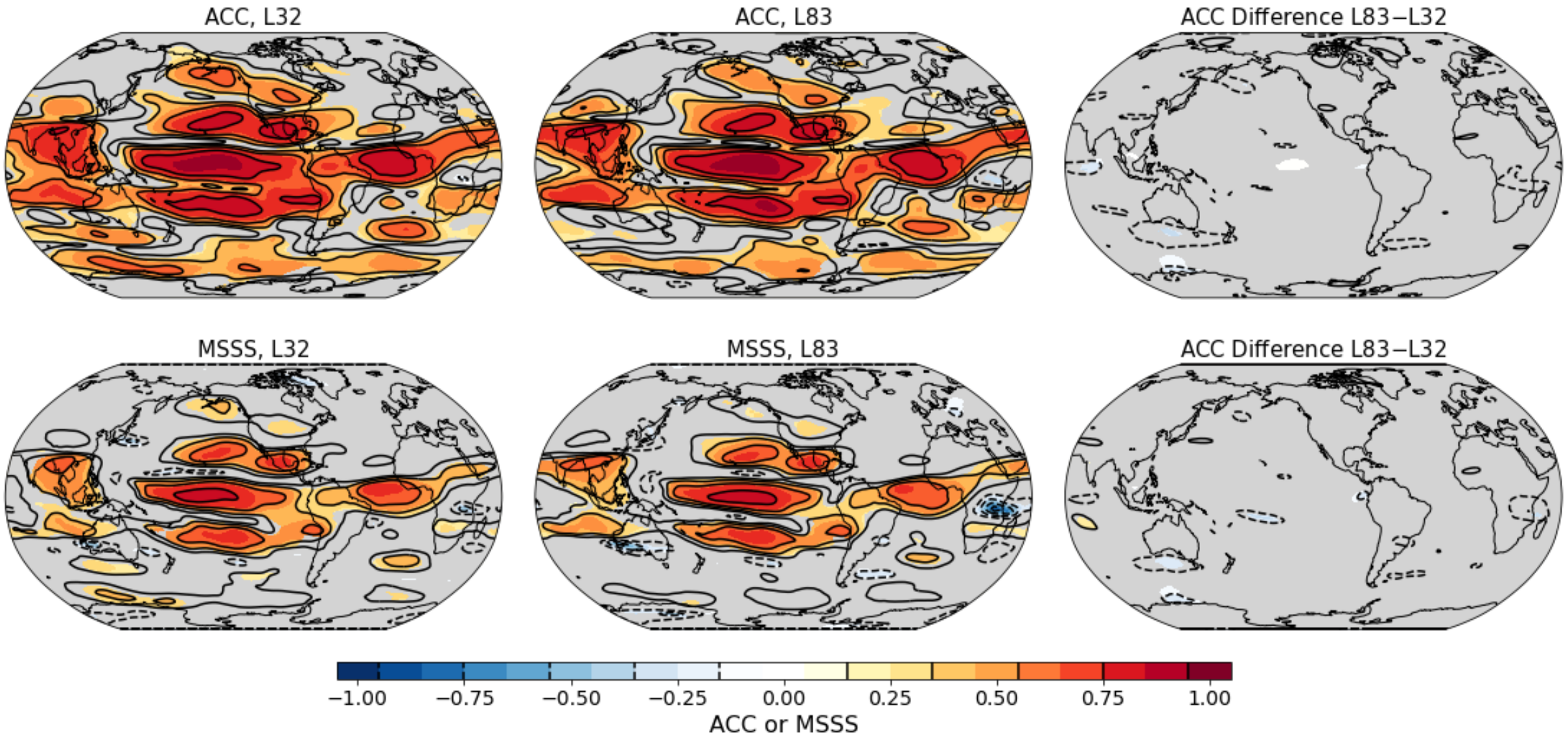
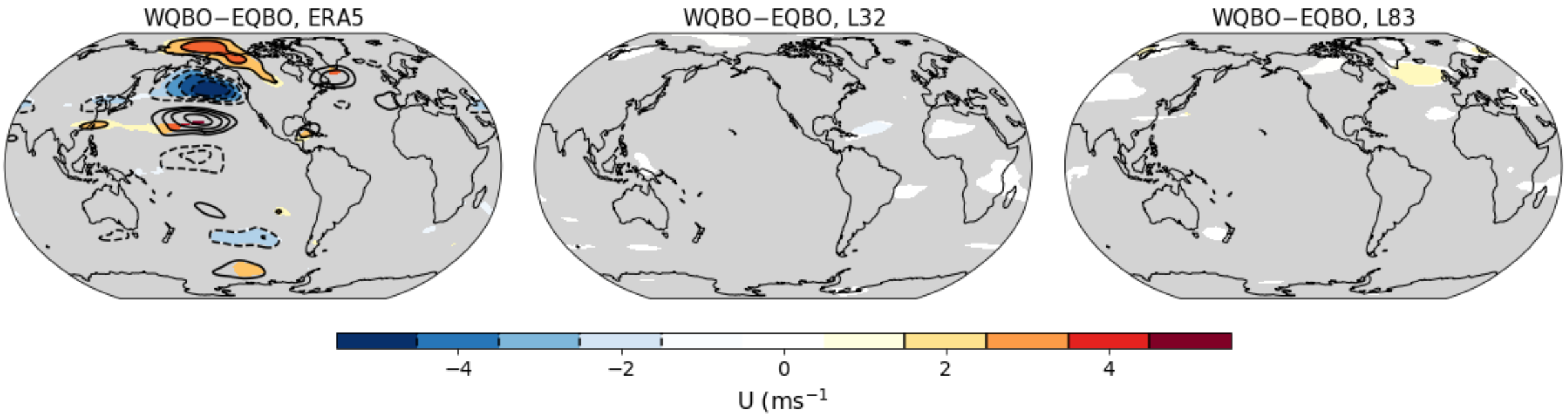


Composites of QBO westerly minus QBO easterly



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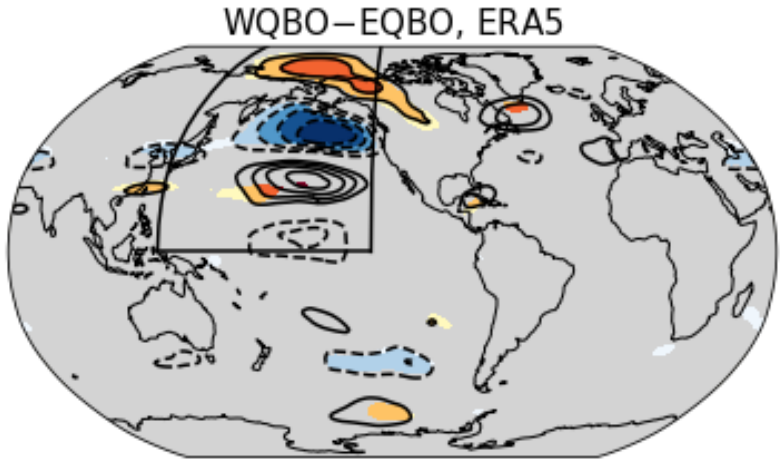
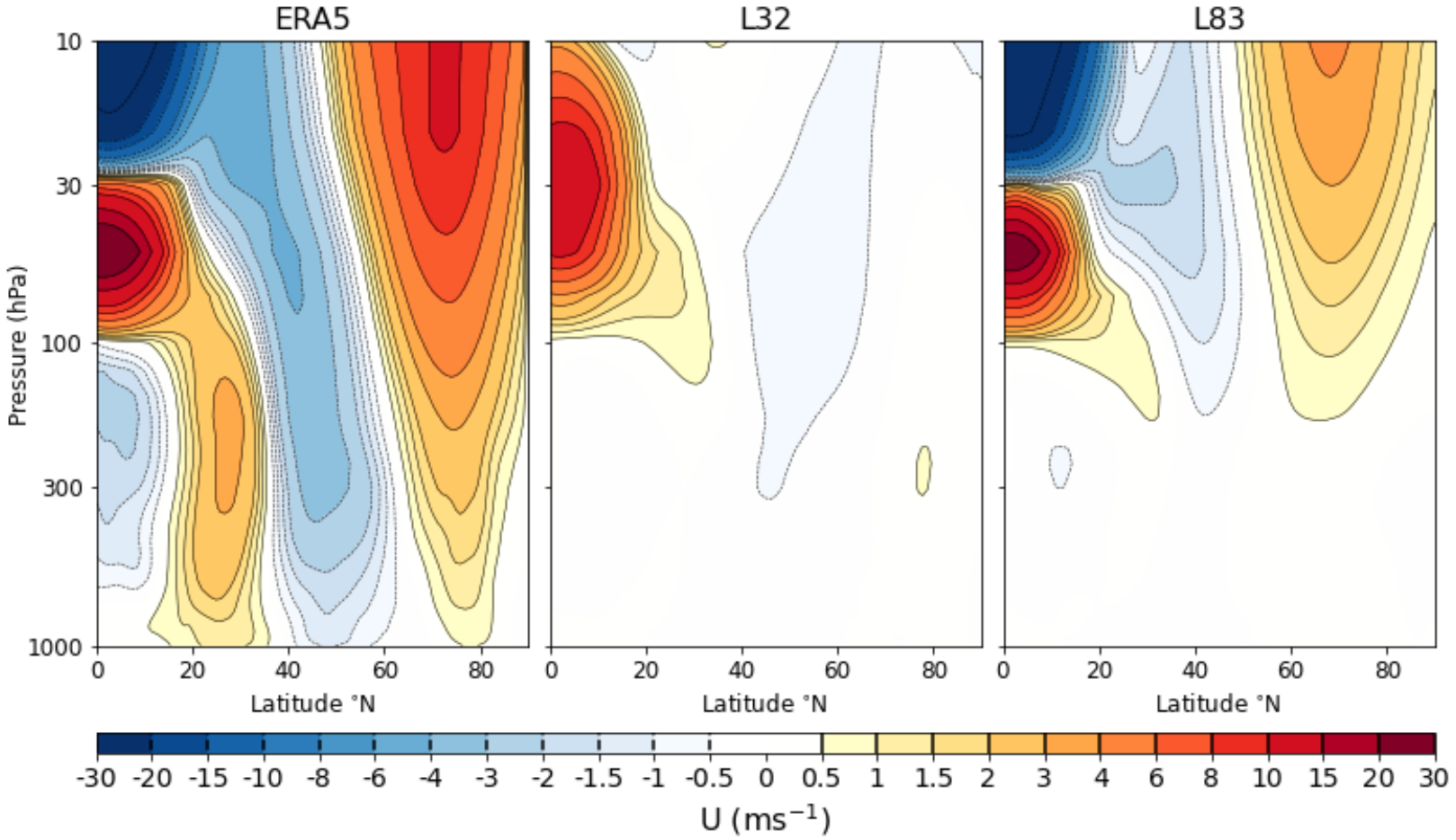
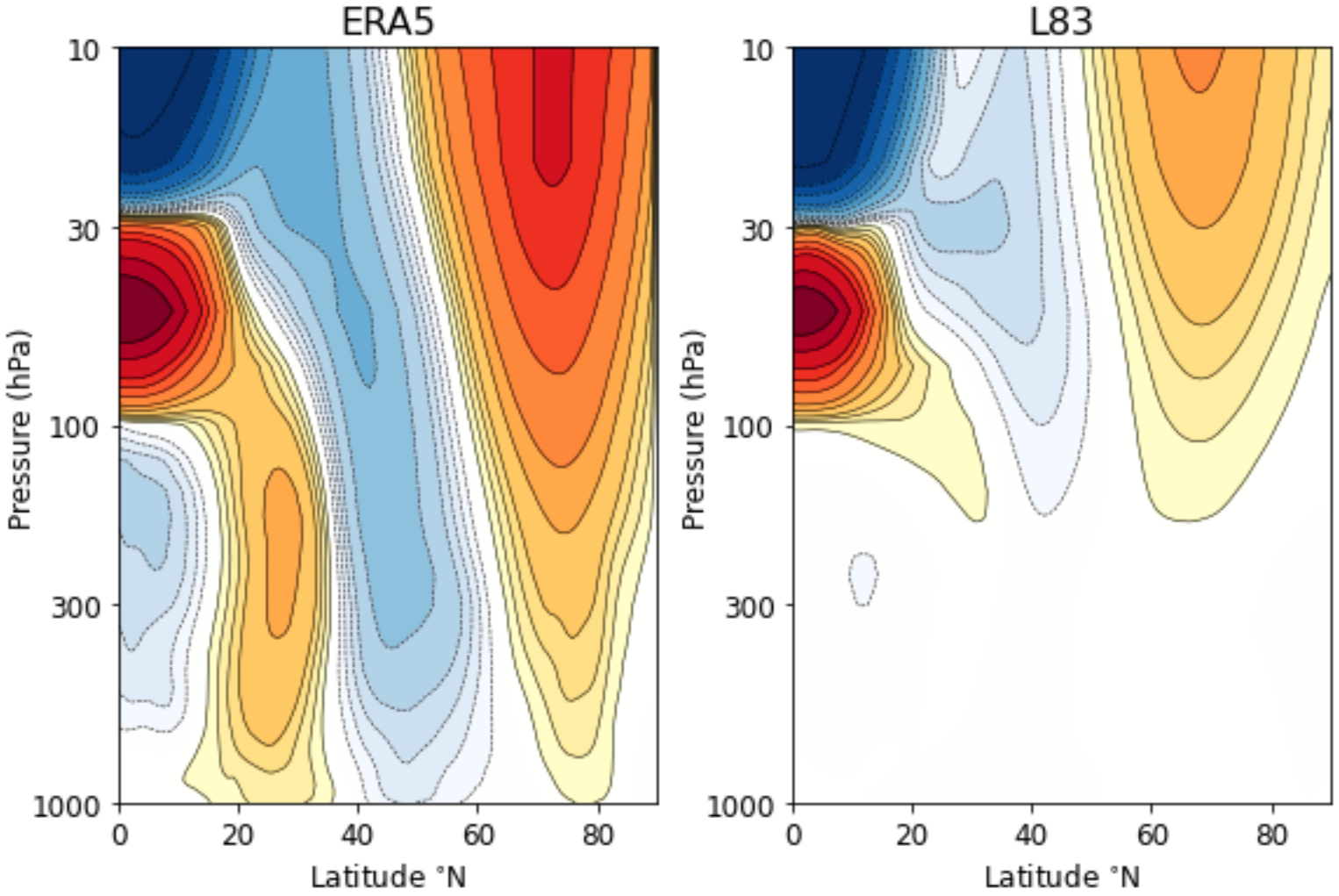


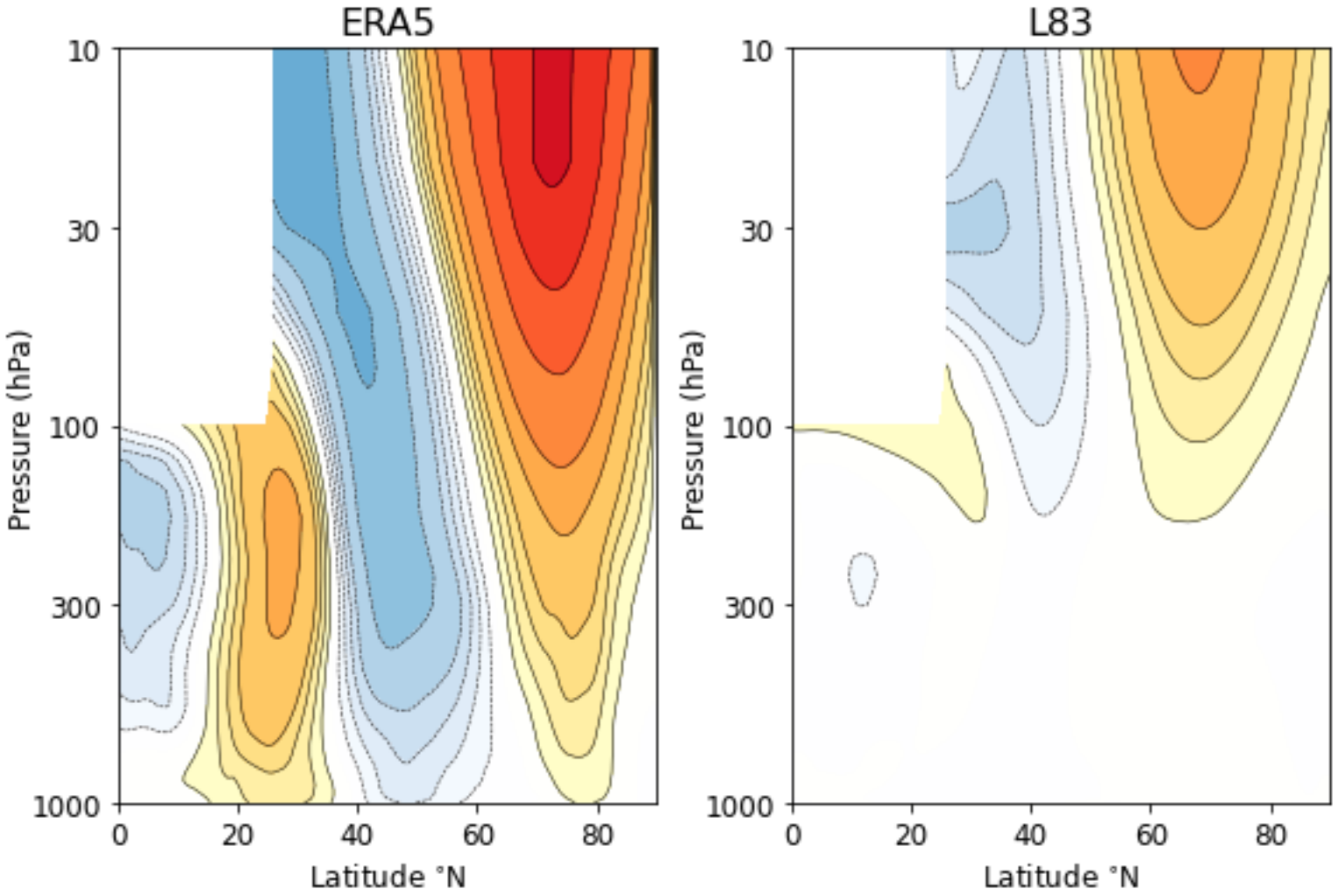


Signal-to-noise issues in the Pacific teleconnection?



Signal-to-noise issues in the Pacific teleconnection?

Pattern correlation
~0.75



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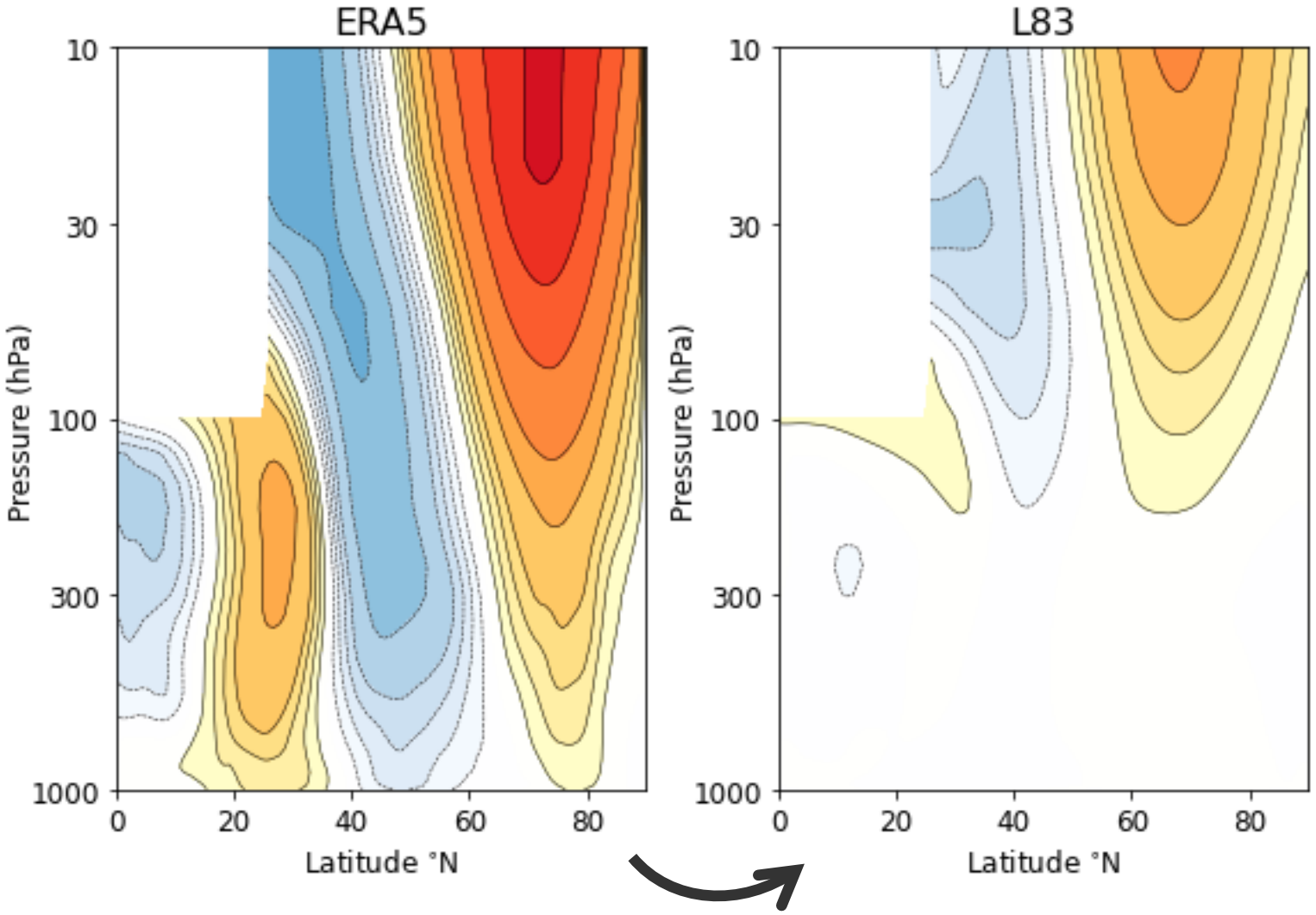

Regress the ERA5 pattern onto the L83 pattern

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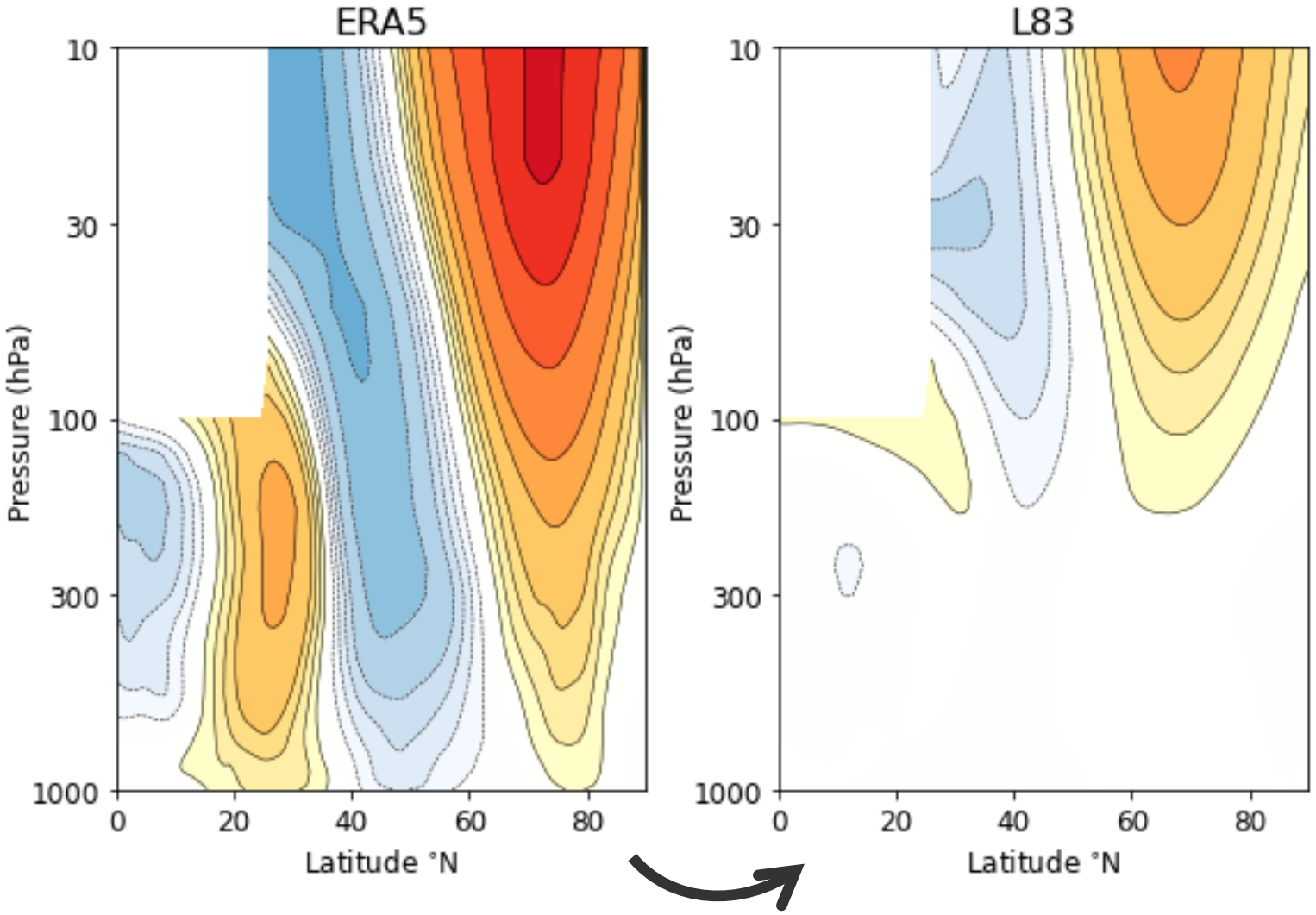

Regress the ERA5 pattern onto the L83 pattern

Is that regression coefficient greater than you can get with single member timeseries from the L83 ensemble?

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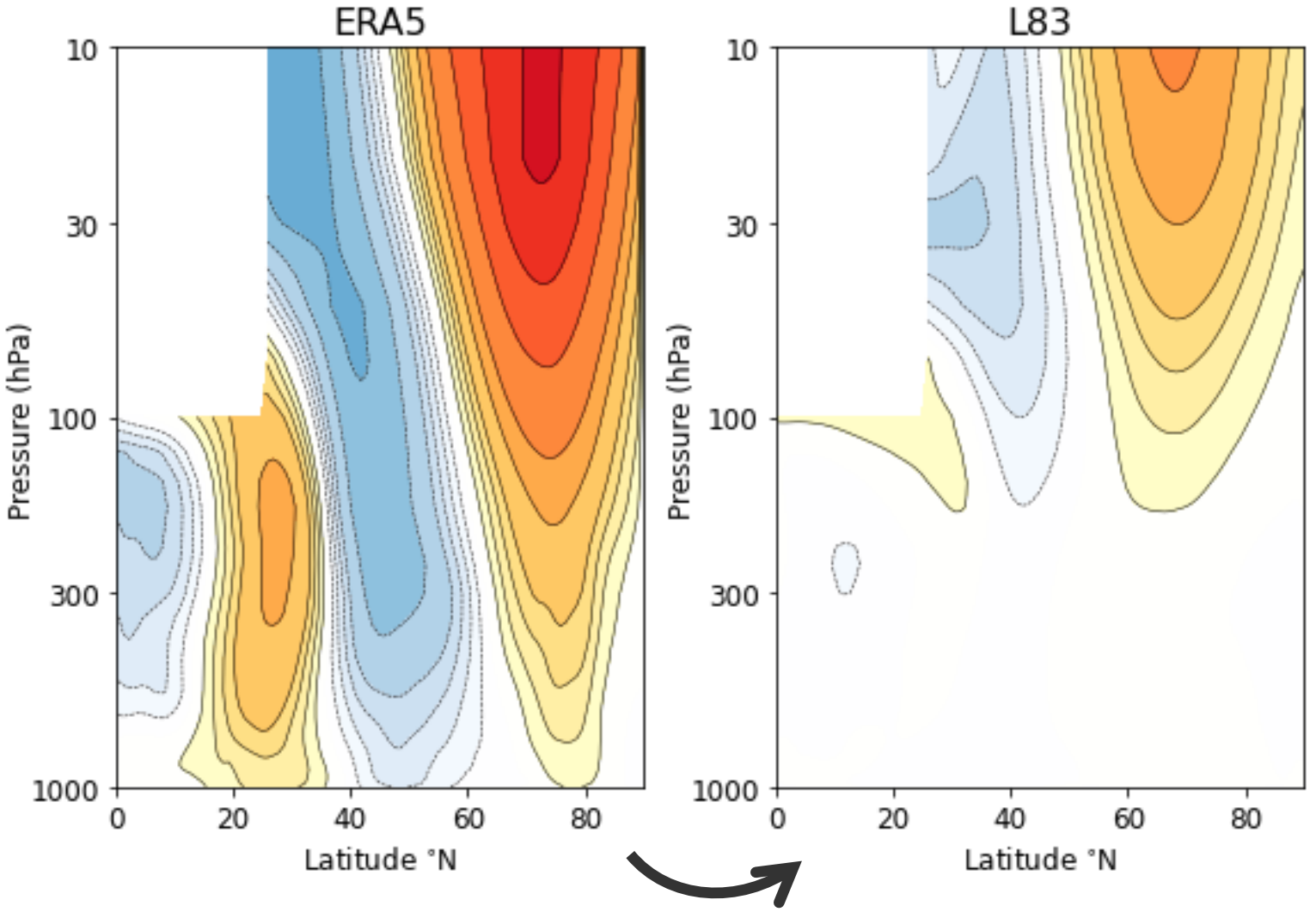

Kind of like a signal-to-noise paradox metric but based on the teleconnection pattern

Regress the ERA5 pattern onto the L83 pattern

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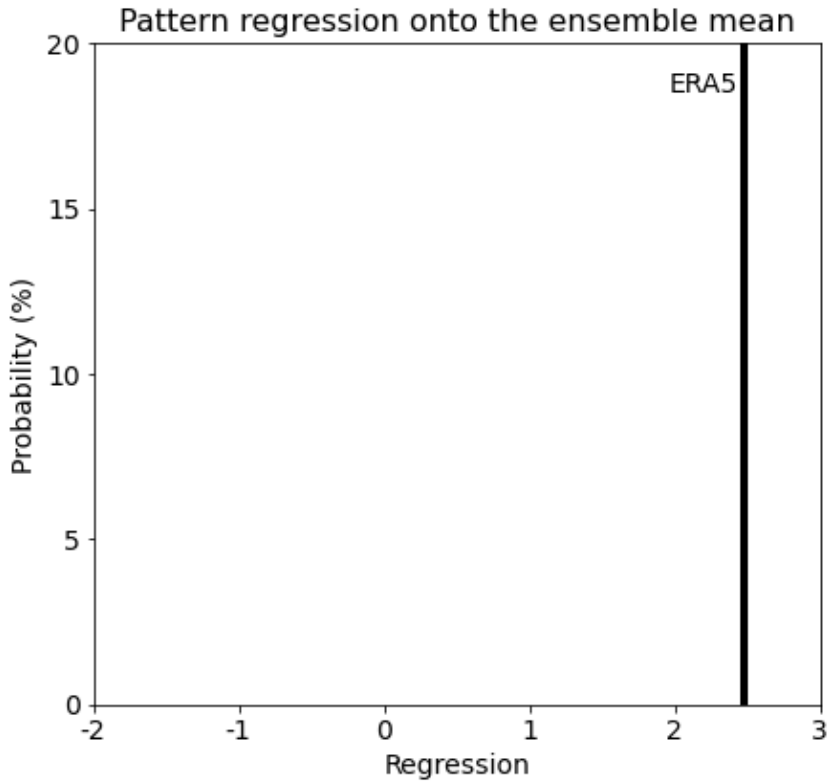
Signal-to-noise issues in the Pacific teleconnection?



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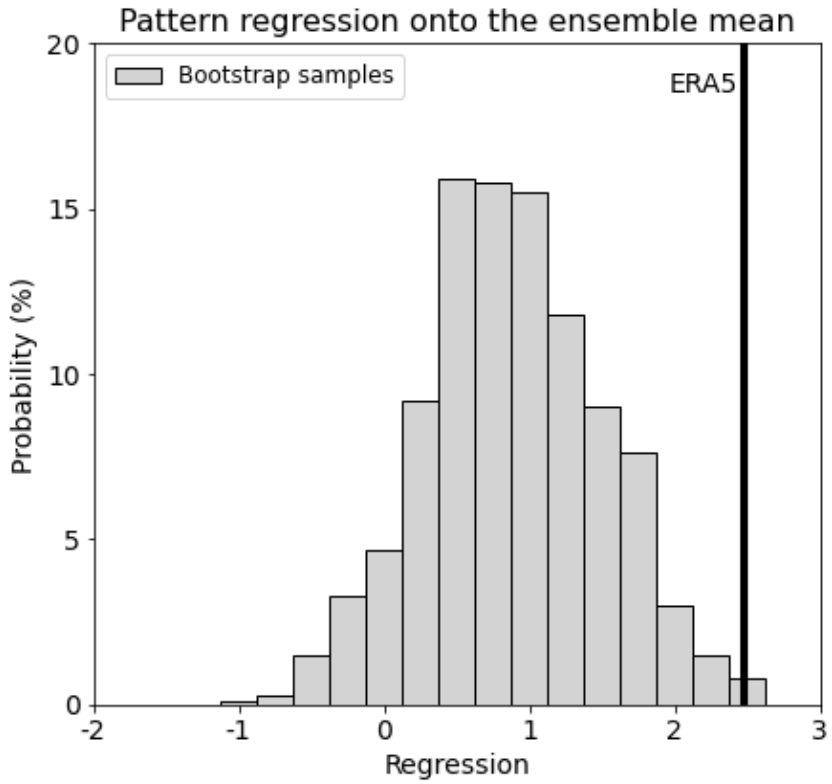


Conclusions

- Two new seasonal hindcast ensembles with CESM2 will become available soon (L32 and L83)

  (3 initialization dates: Nov 1st, Sept 1st, Feb 1st, 1970-2020)

- L83 has much improved skill in the prediction of the QBO compared to L32

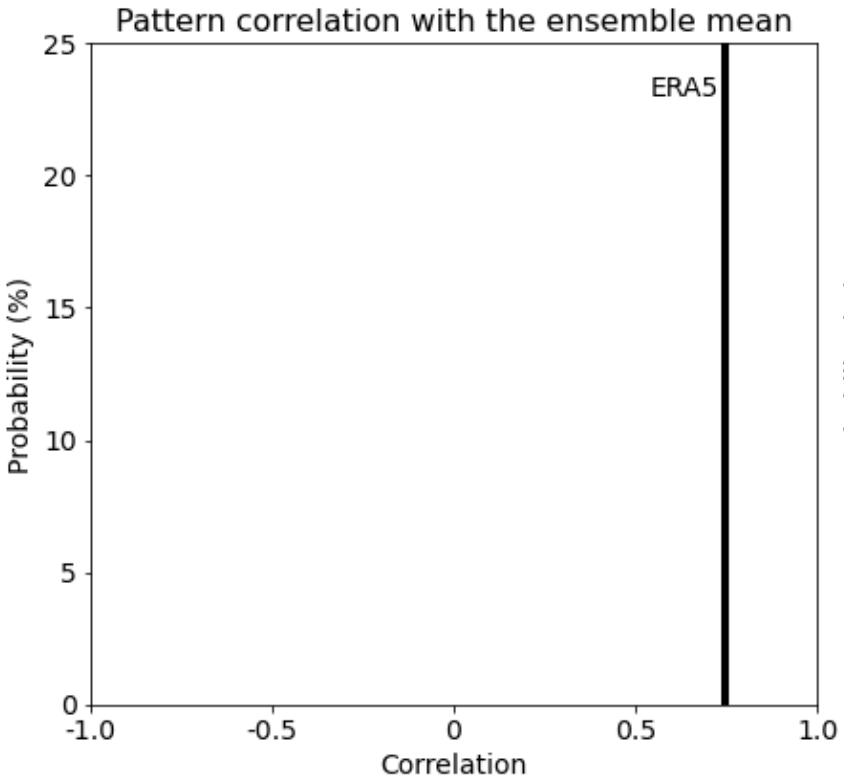
- Unfortunately this doesn't lead to substantial improvements in skill in many other features.

- There are, however, indications potential signal-to-noise issues in the model. The observed connection between the QBO and the NH polar vortex and circulation in the Pacific sector may be stronger than what the model represents → there may be more skill to be gained.

- This dataset can be used to probe the impact of vertical resolution on hindcast skill further

- It can also be used to try to understand why we don't capture the QBO-MJO connection, since it has a good representation of the QBO.

Signal-to-noise issues in the Pacific teleconnection?



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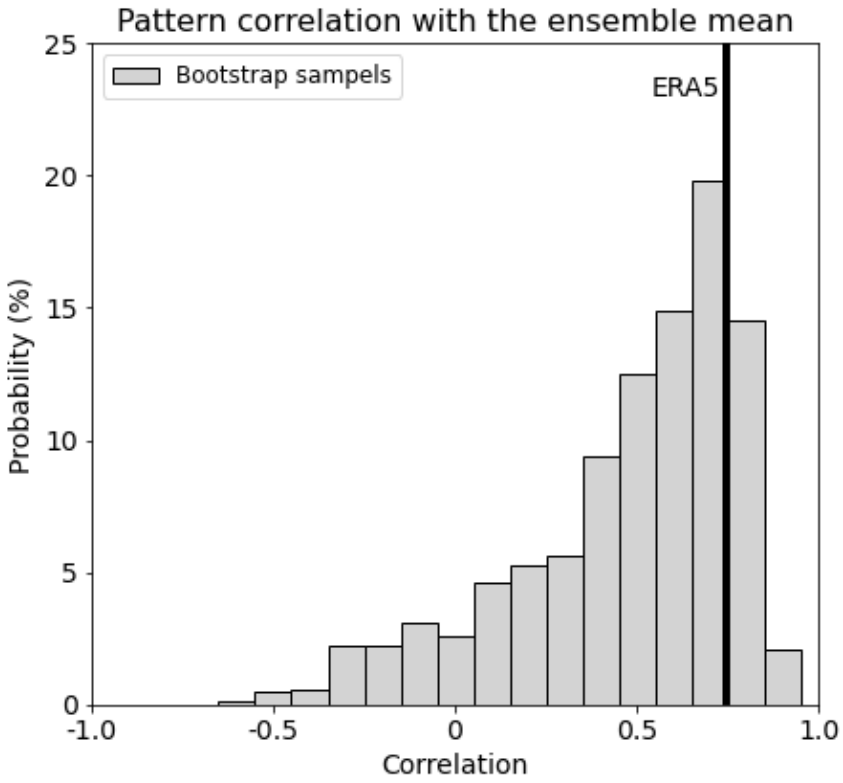
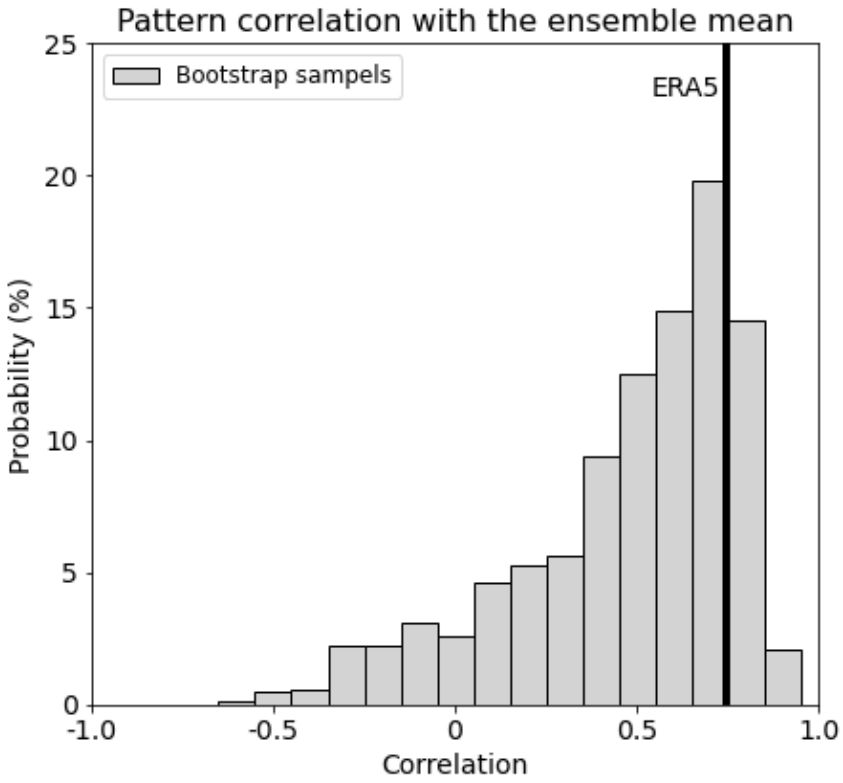
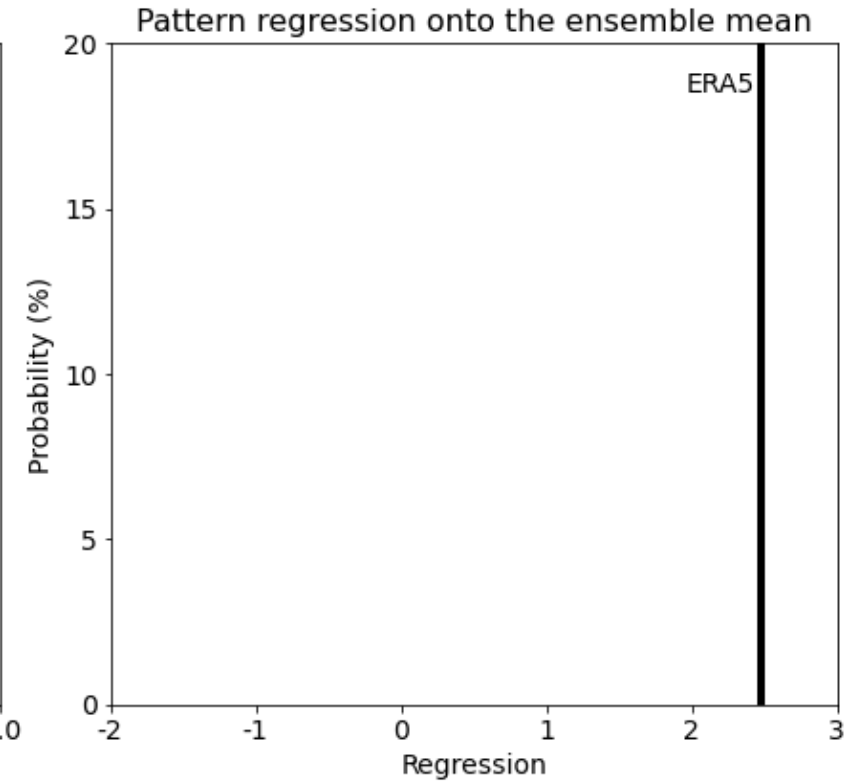


Signal-to-noise issues in the Pacific teleconnection?





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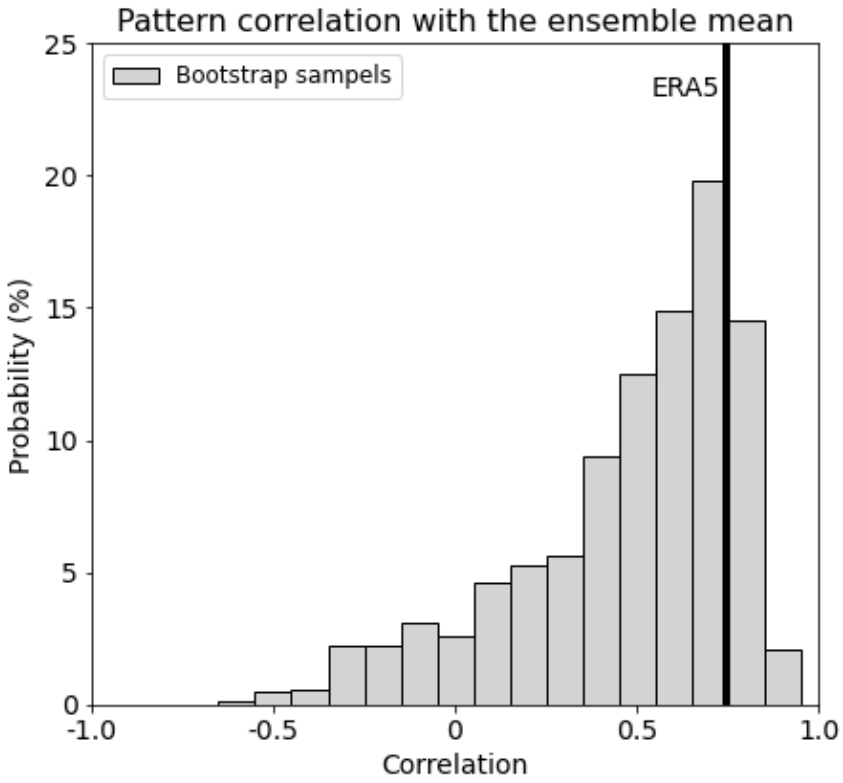

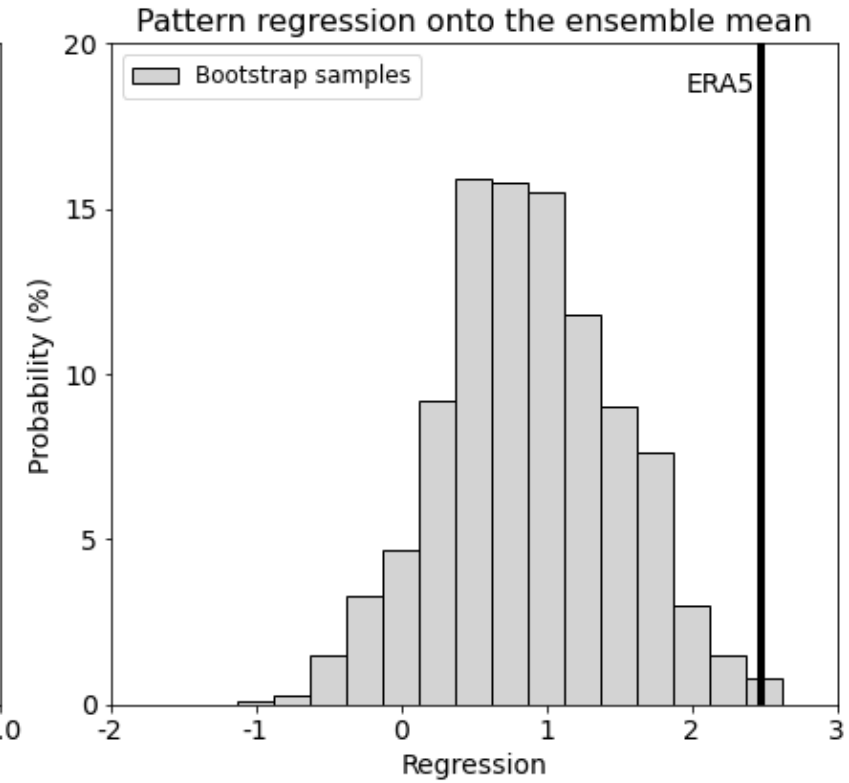

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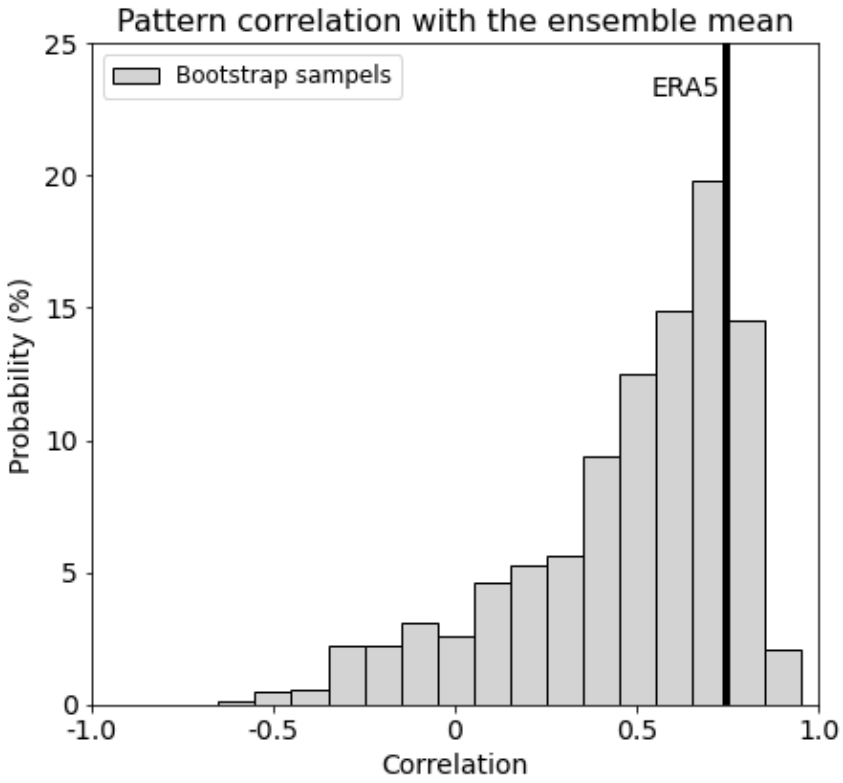

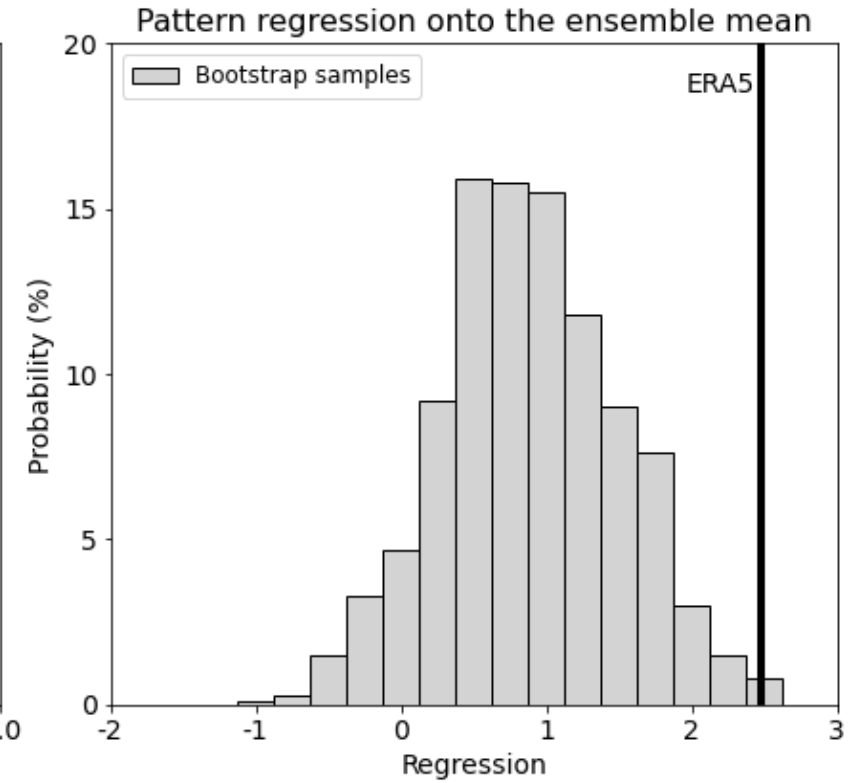

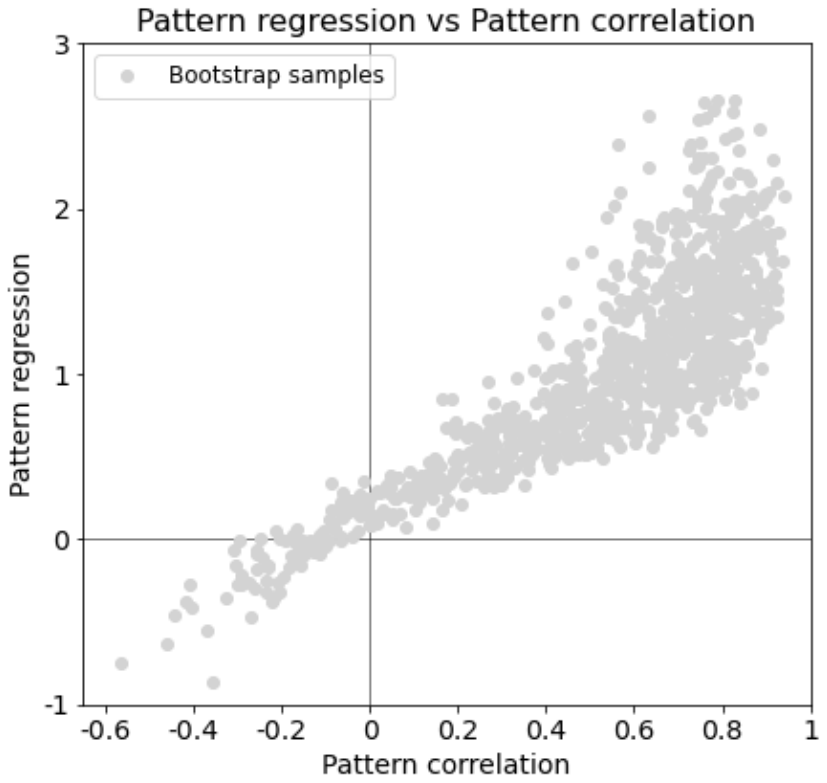

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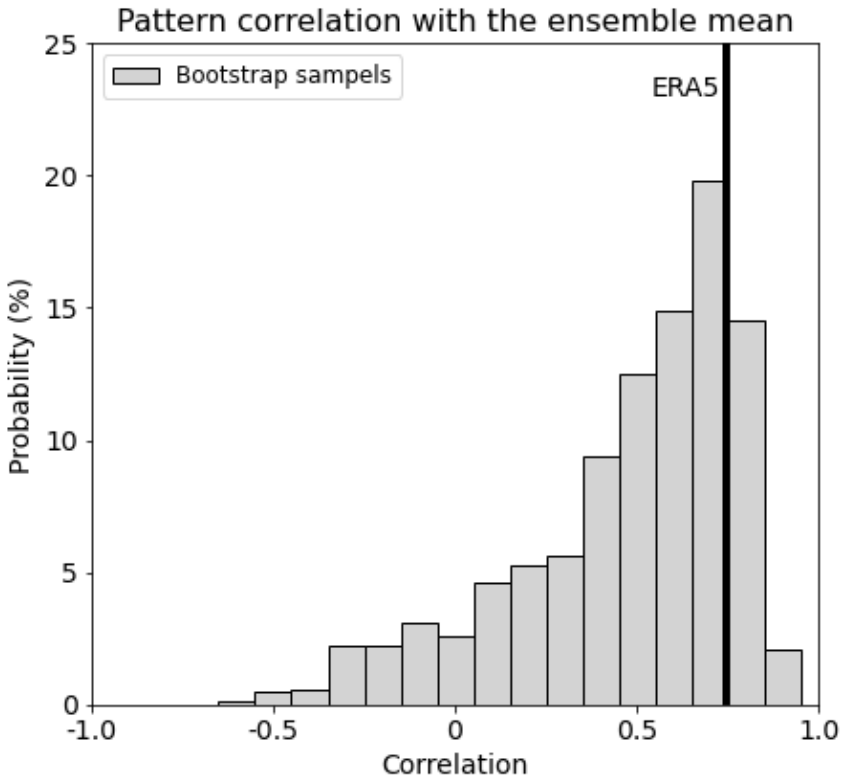

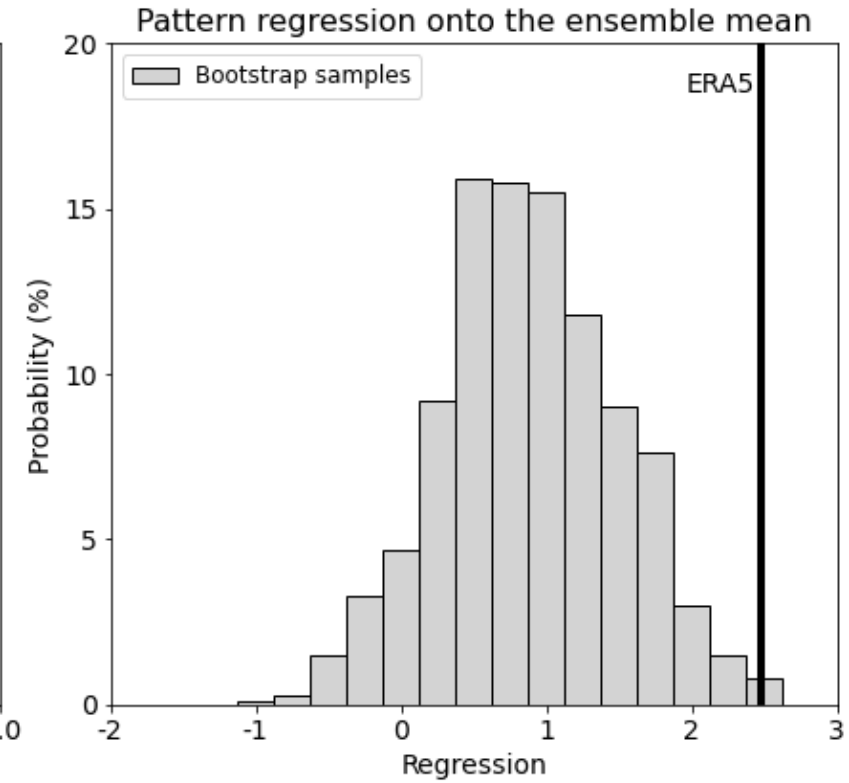

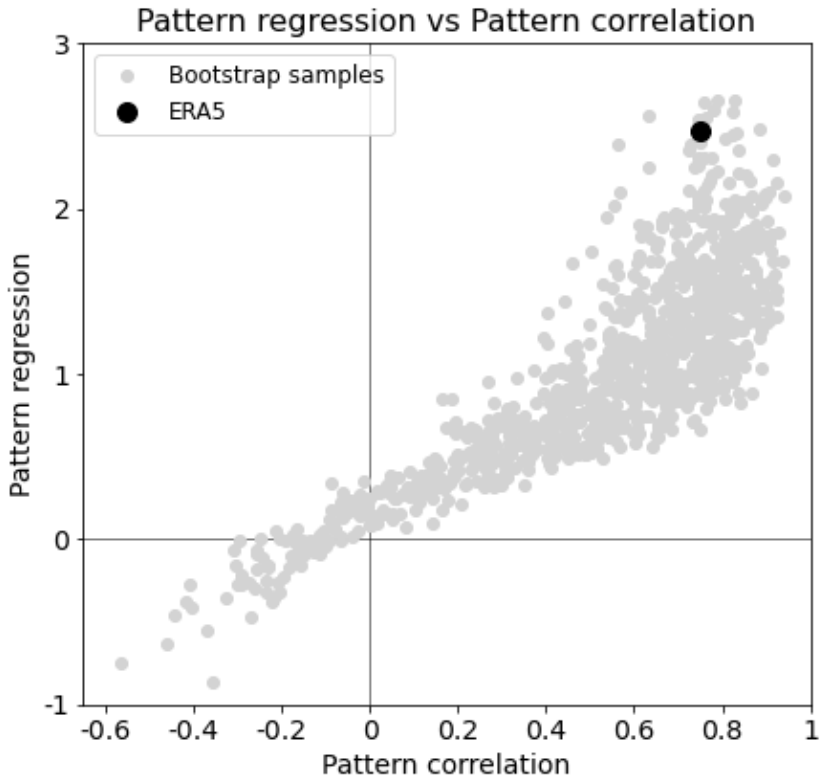

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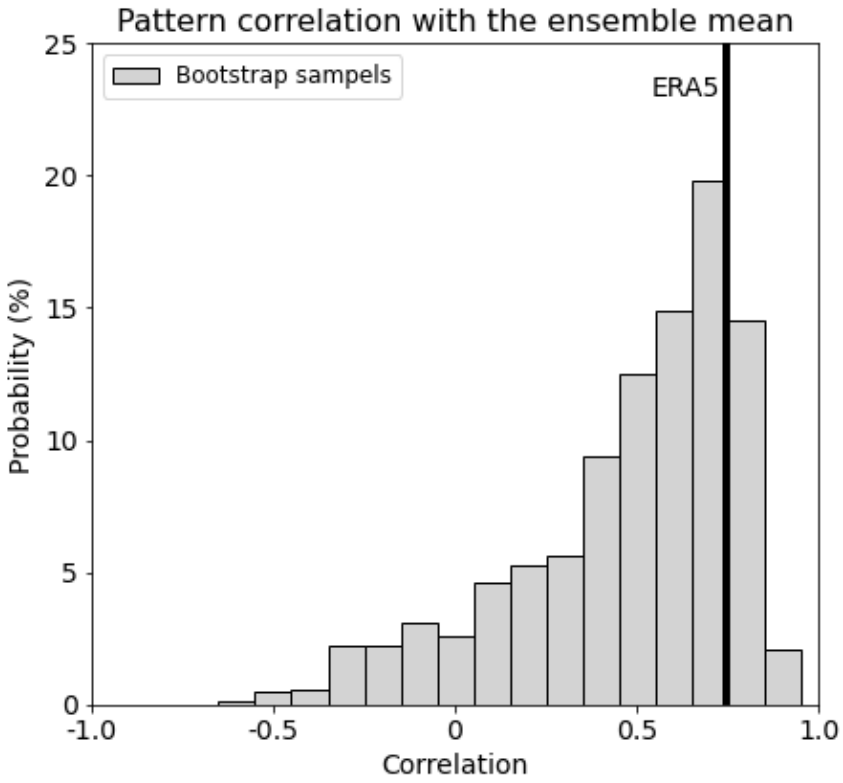

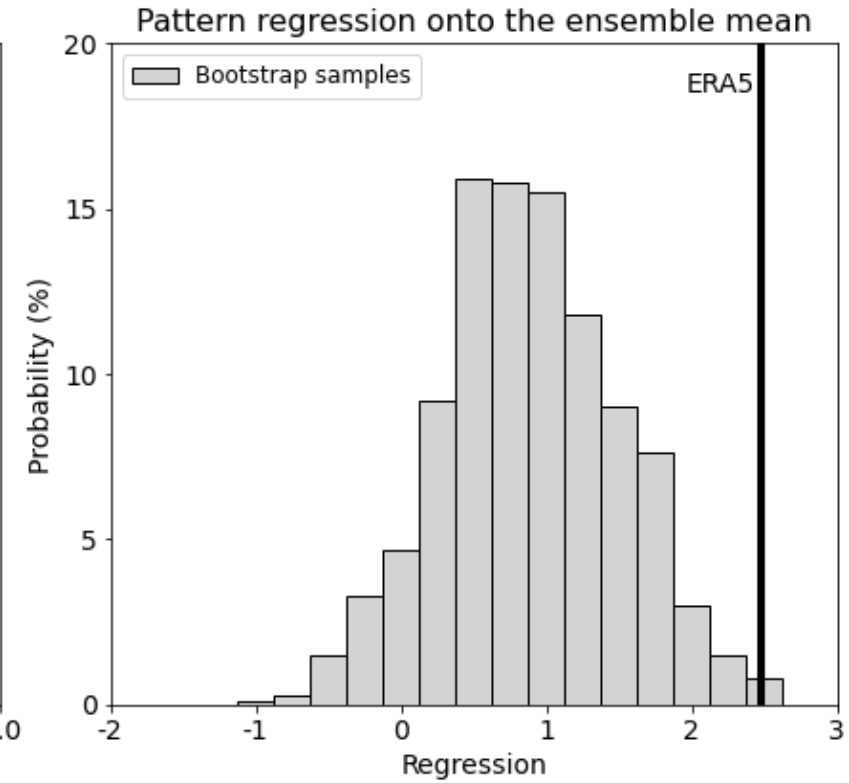

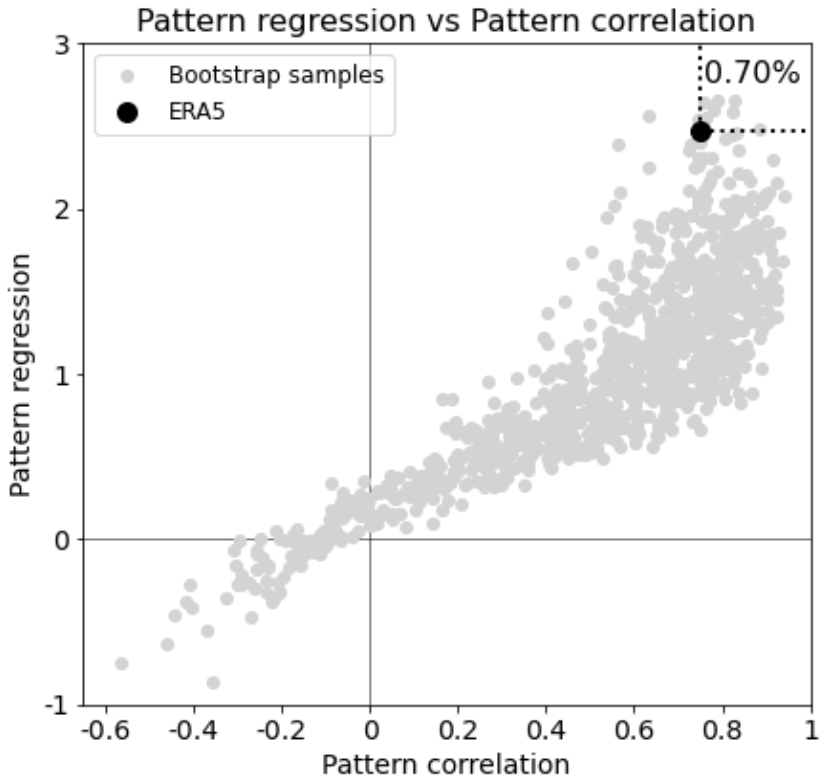

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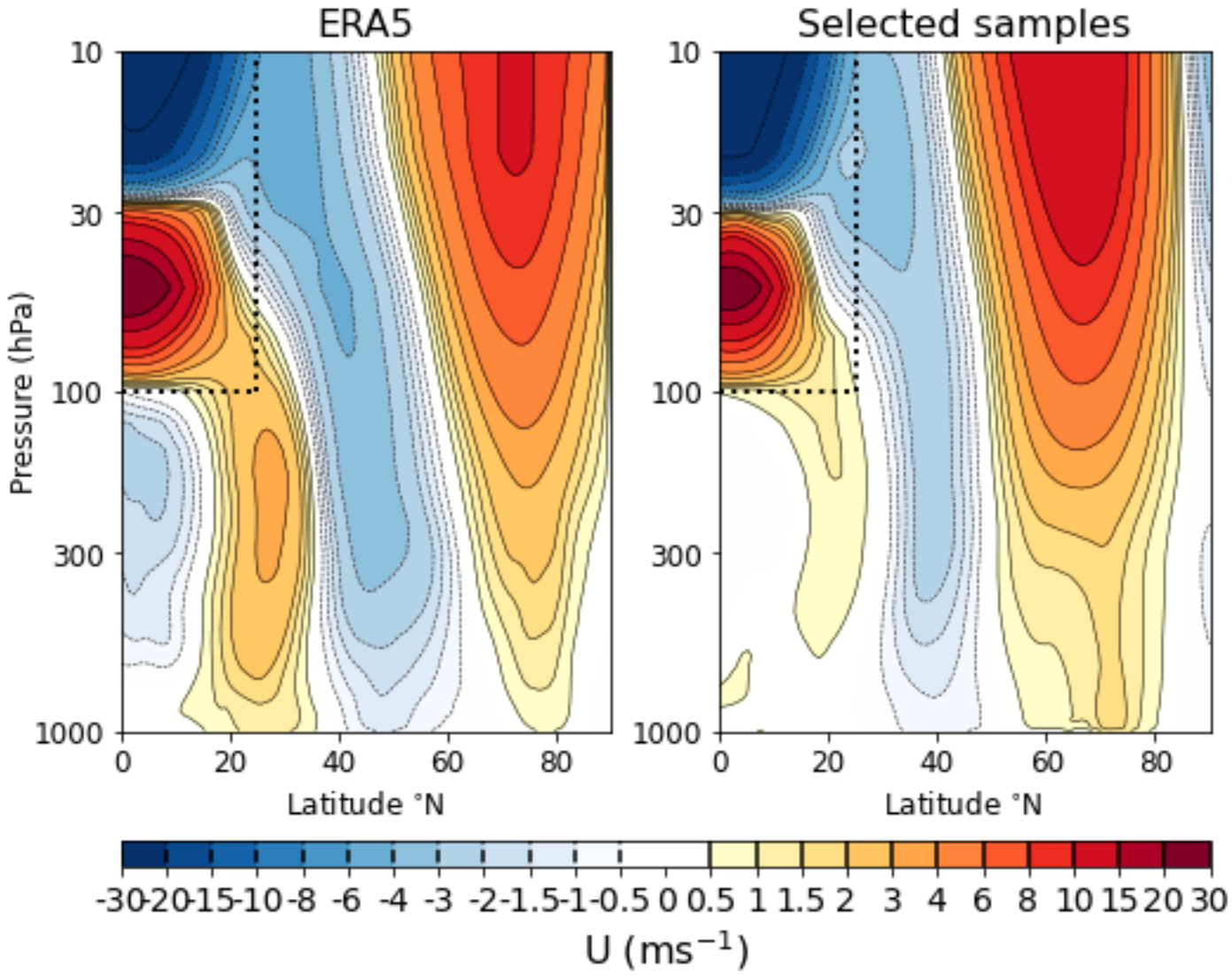

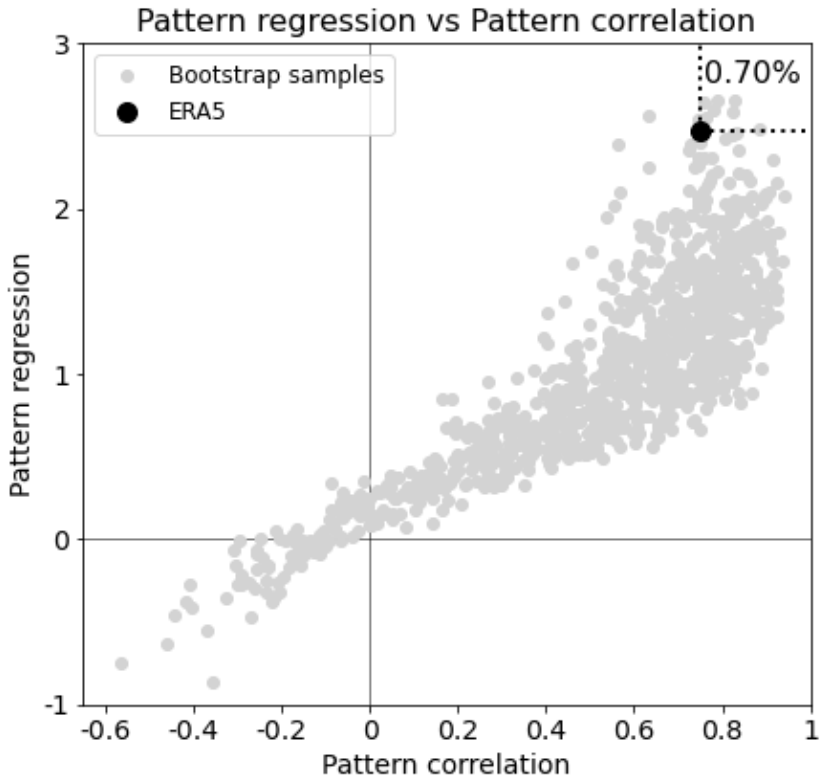

Experimental Design

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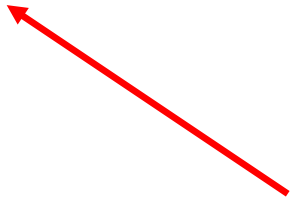

Because of this, we ran a new L32 ensemble as well initialized with JRA55. Can be used in combination with the original CESM2 SMYLE to augment ensemble size or to explore the impact of initializing from this different reanalysis.

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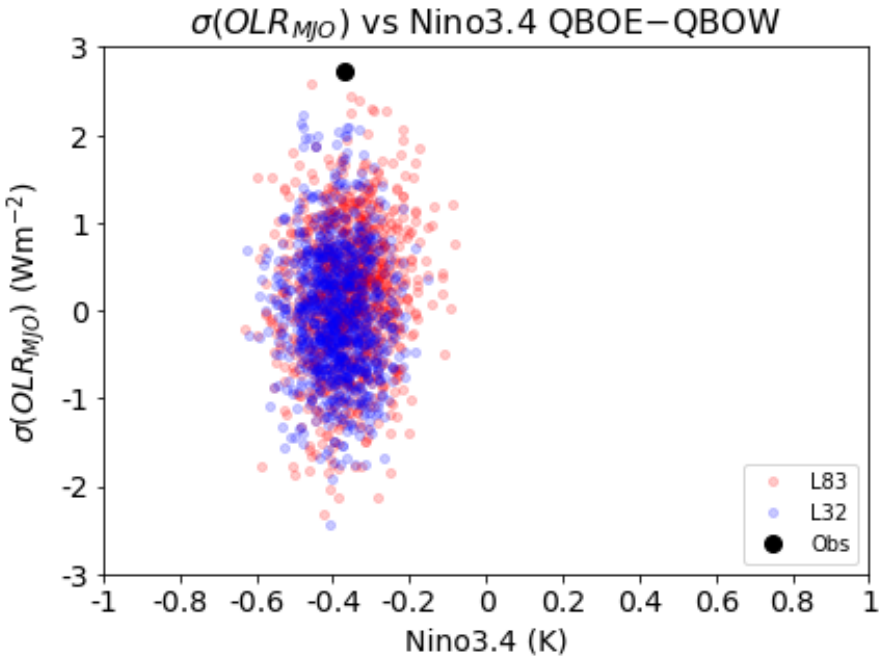
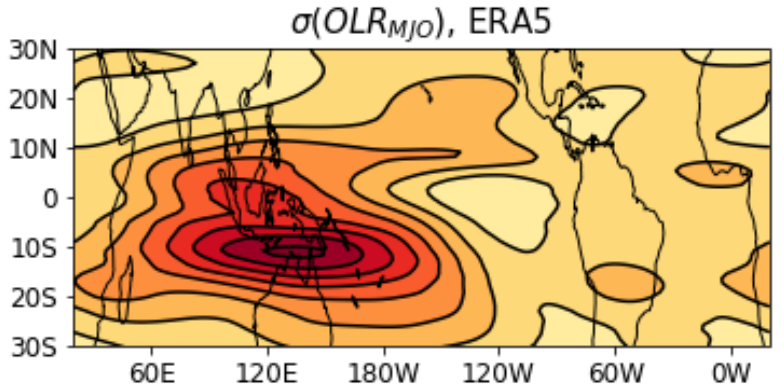
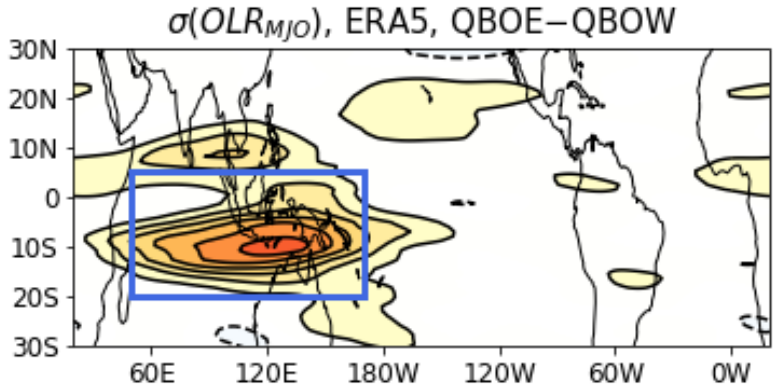
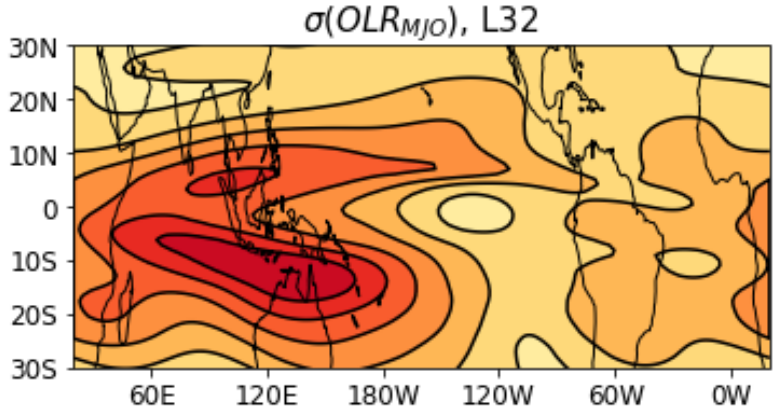
Here, we'll compare the prediction skill between the L32 ensemble and the L83 ensemble, with a particular focus of the impact of the Quasi-Biennial Oscillation (QBO) which is much better represented in L83

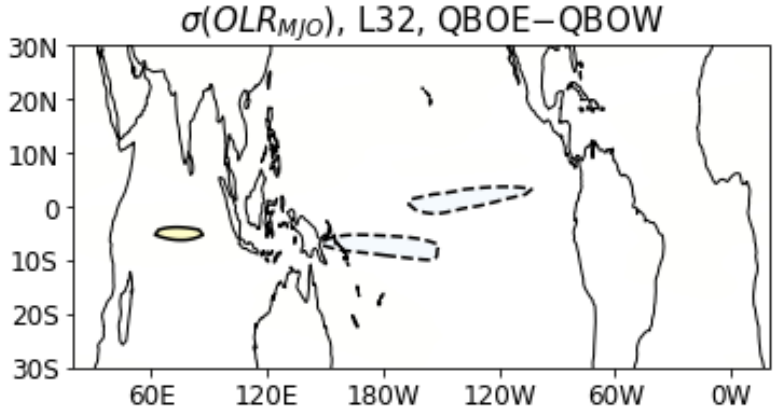
QBO-MJO connection

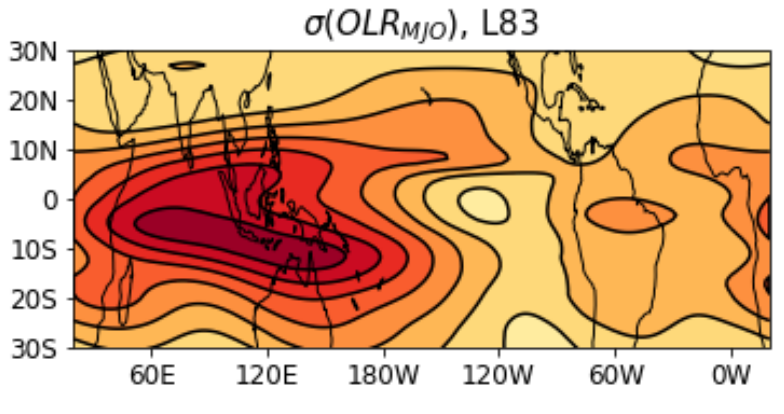


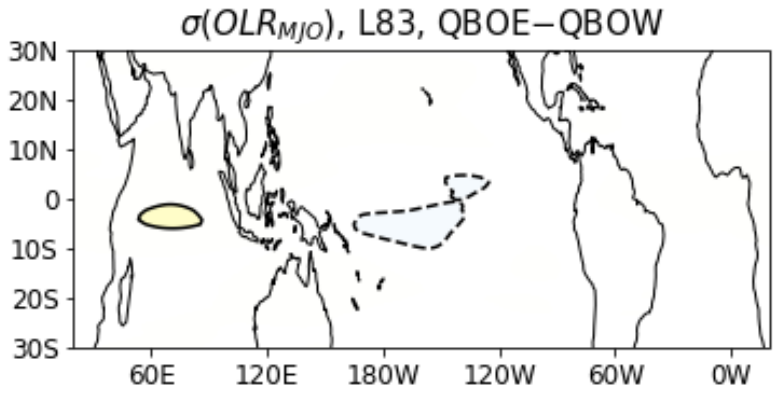


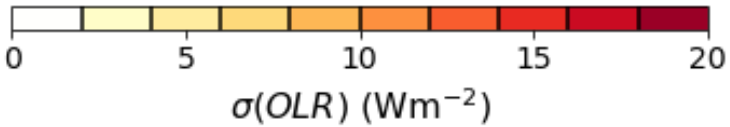


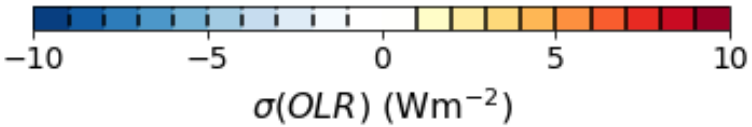






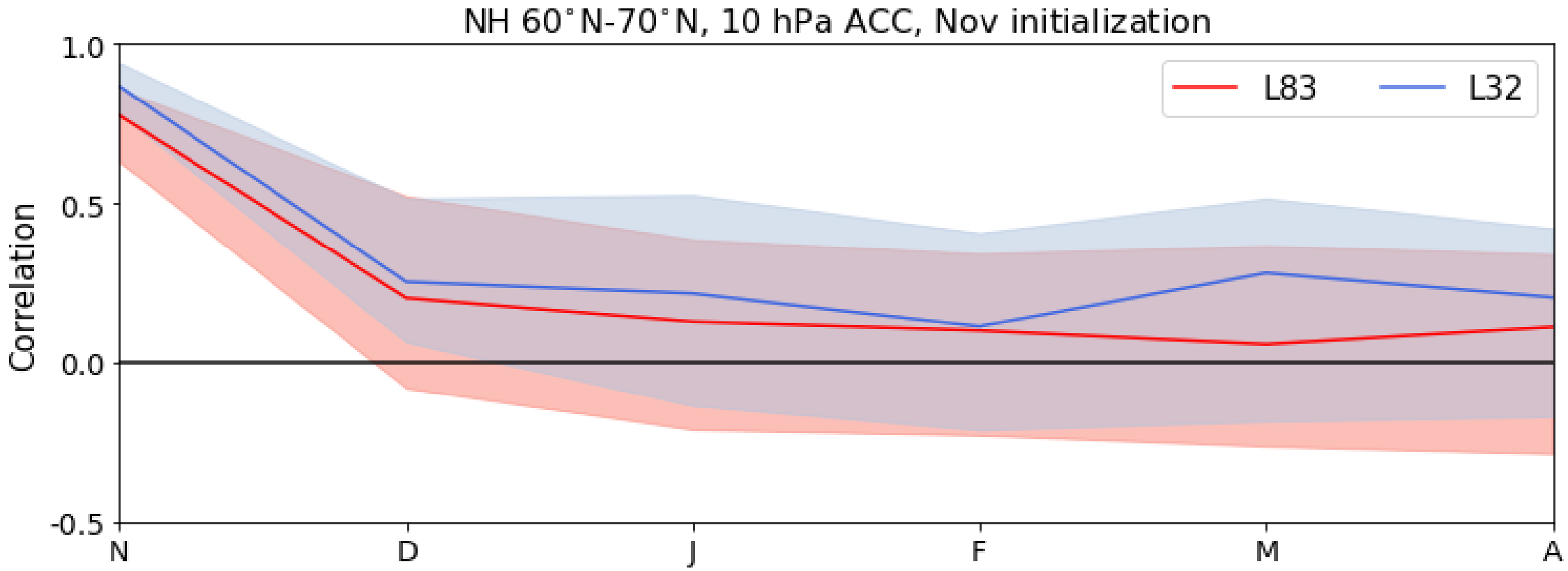




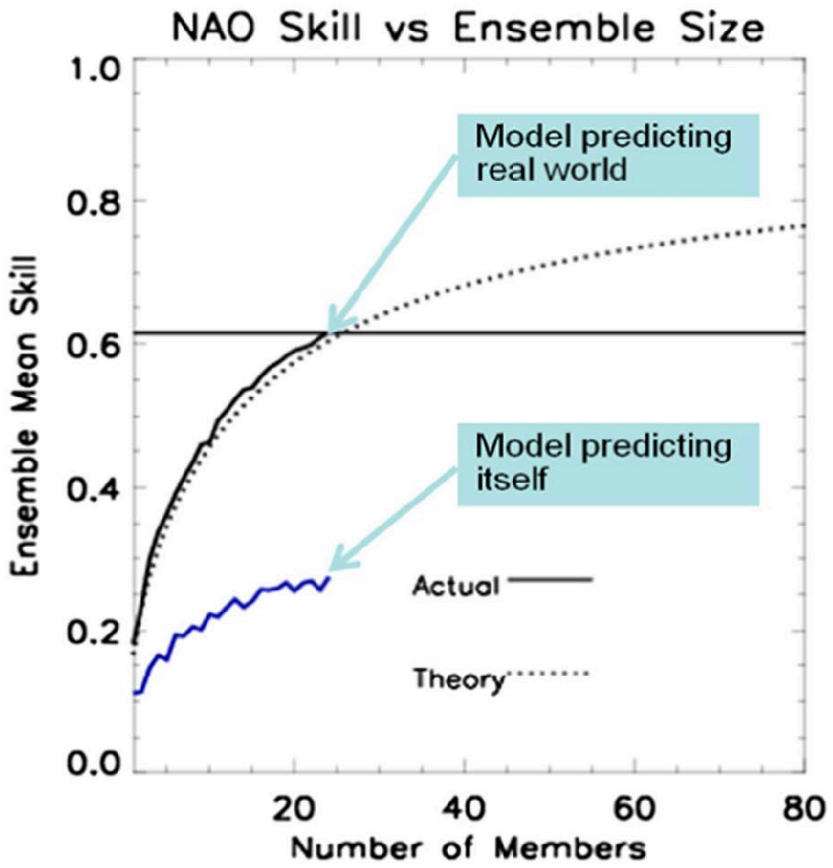


DJF zonal mean zonal wind skill, November Initialization

Anomaly correlation coefficient for 10 hPa 60N-70N zonal mean zonal wind for each month following the November 1st initialization



Signal-to-noise paradox in the NAO?



Scaife and Smith (2018)

UK Met Office model

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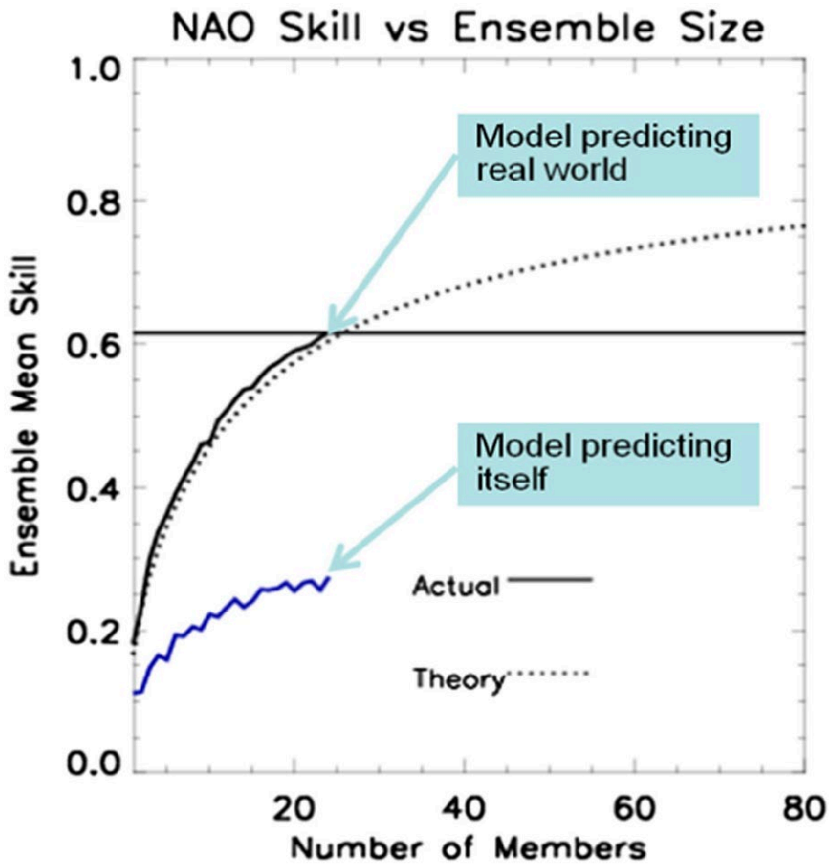

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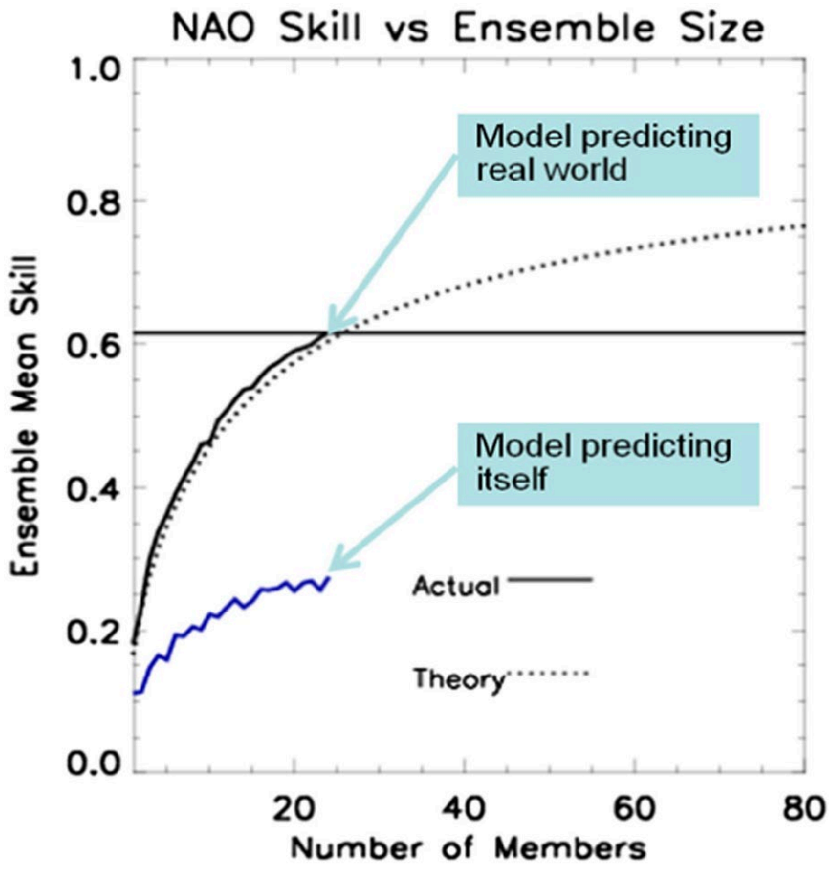
Now we have 60 members of initialized predictions with CESM

20 from original SMYLE
20 L32 from this project
20 L83 from this project

Signal-to-noise paradox in the NAO?



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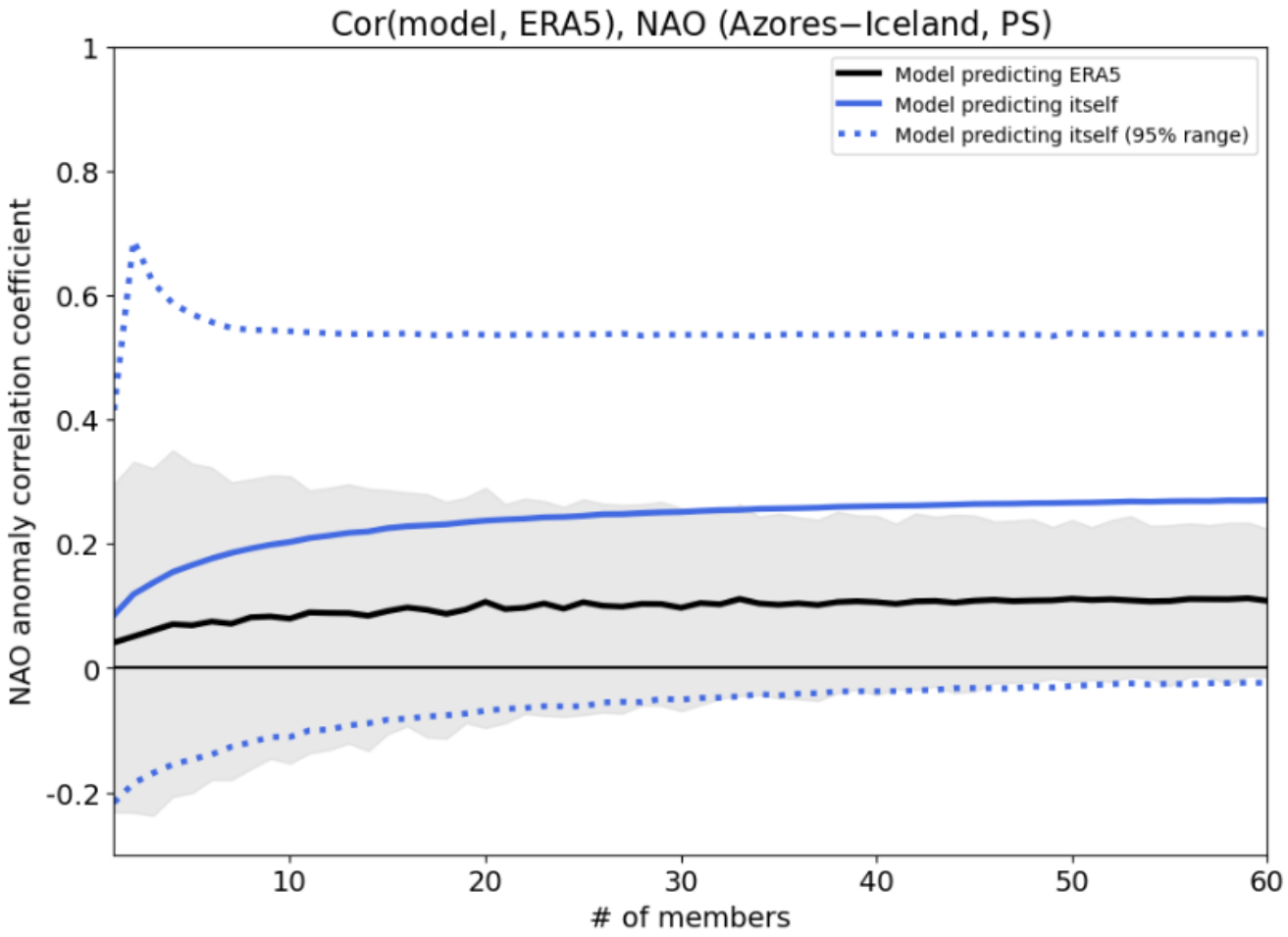
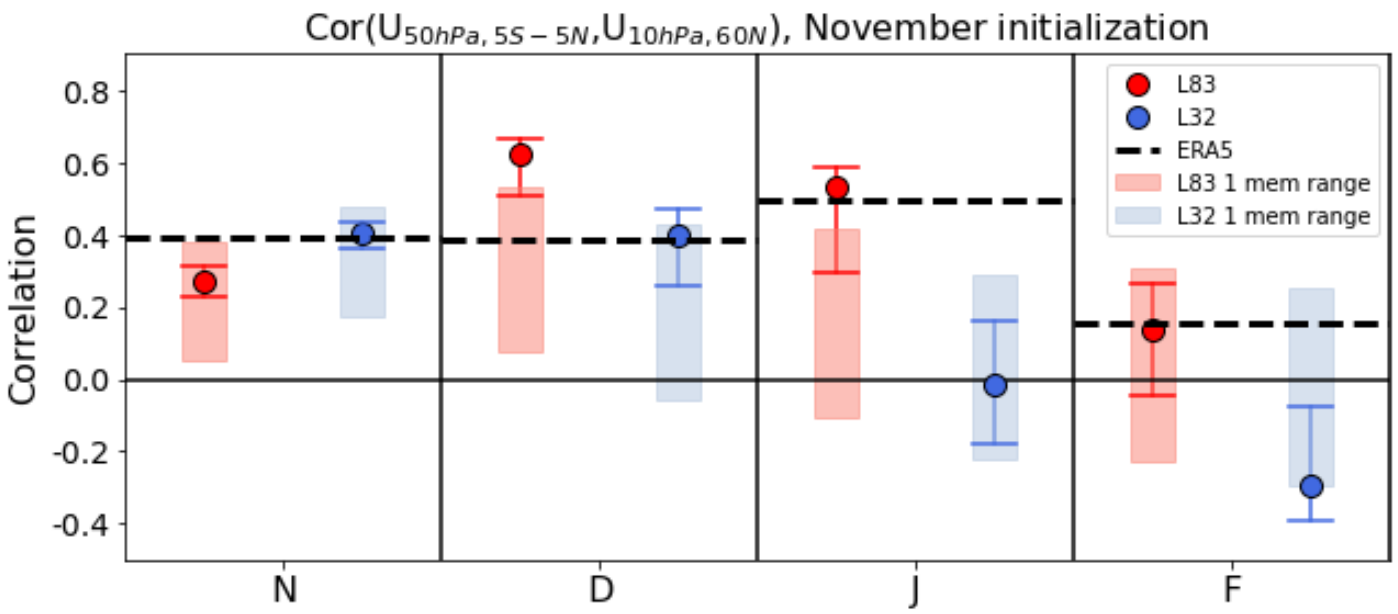
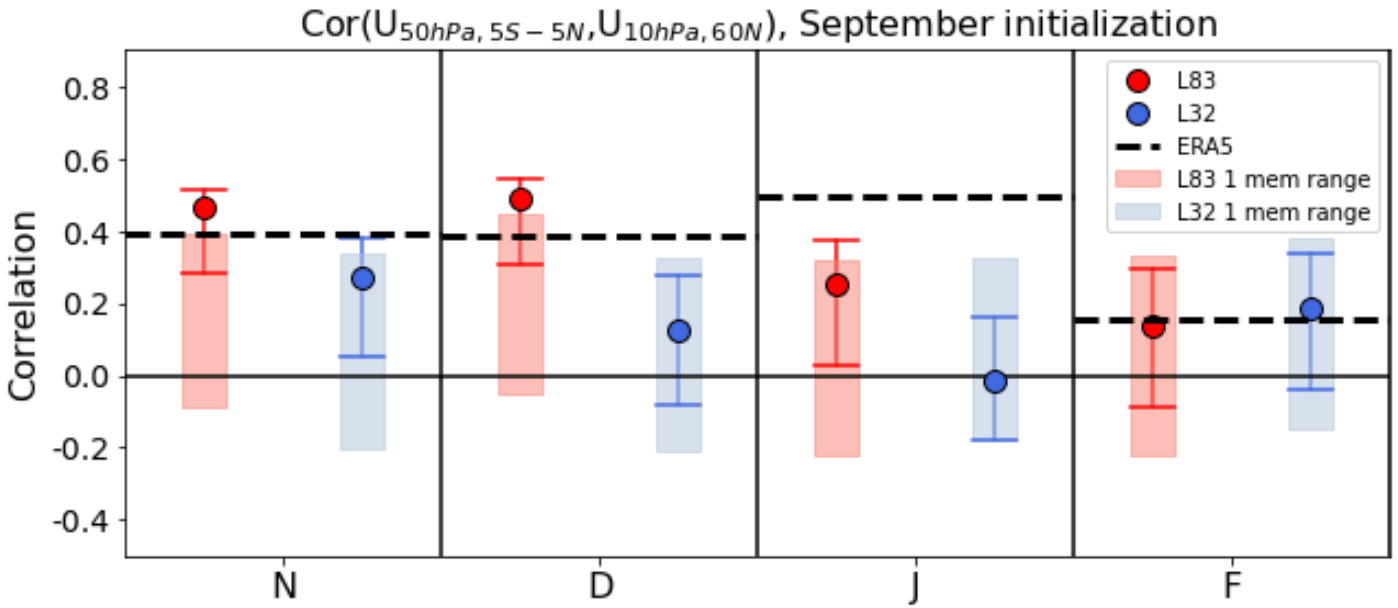


The Holton -Tan Effect

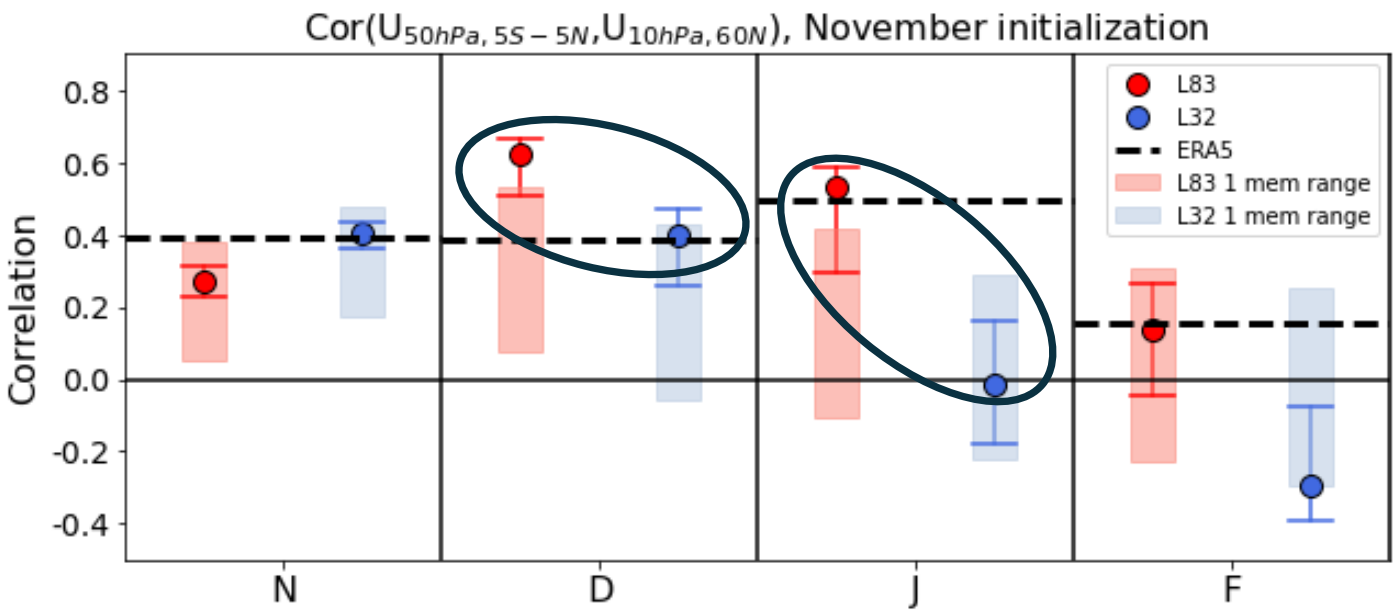


November initialization

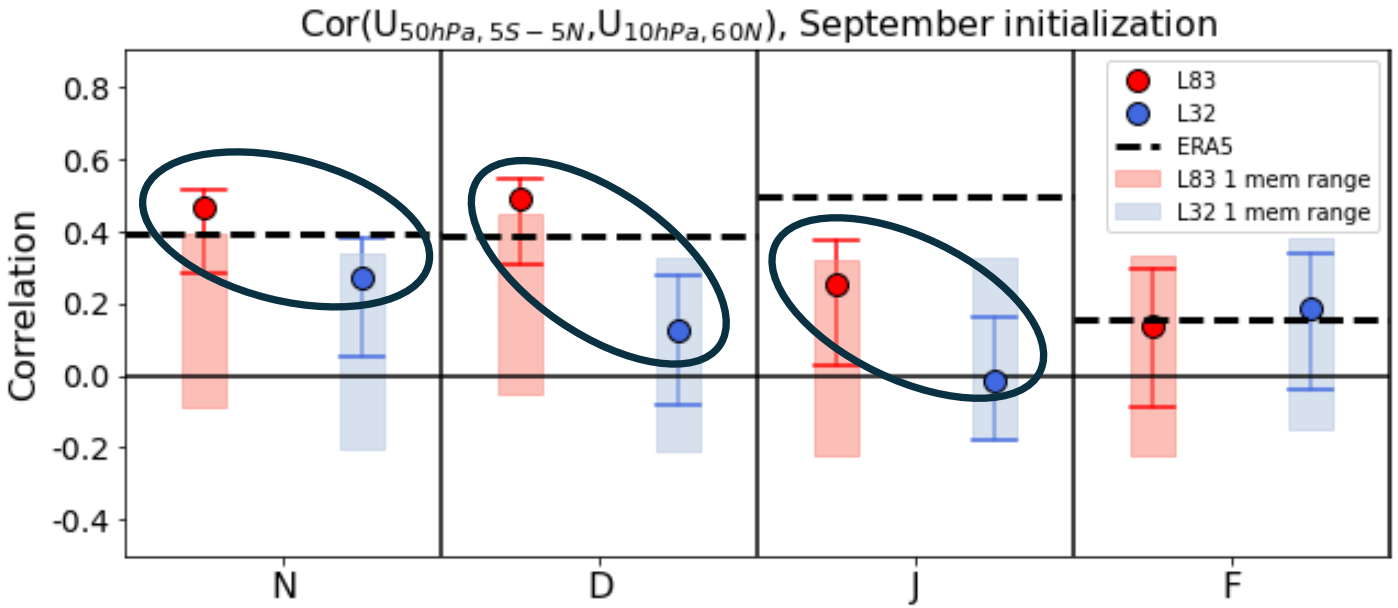


September initialization

The Holton -Tan Effect



November initialization



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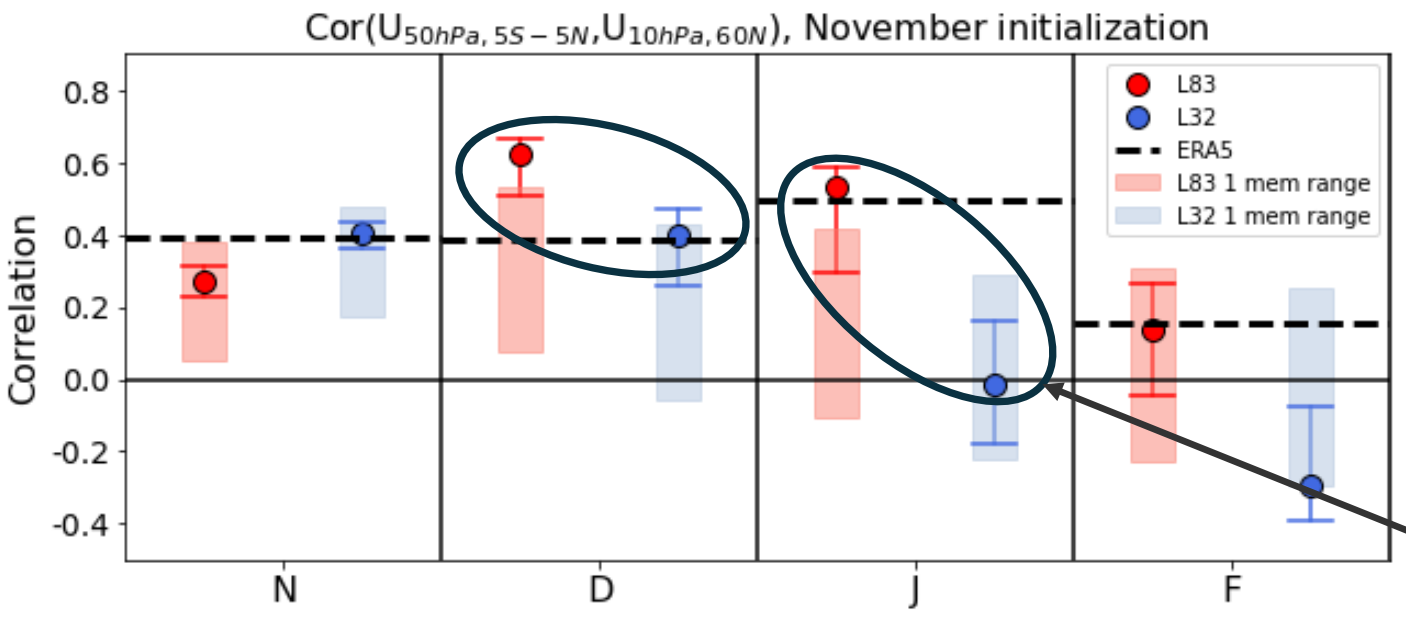
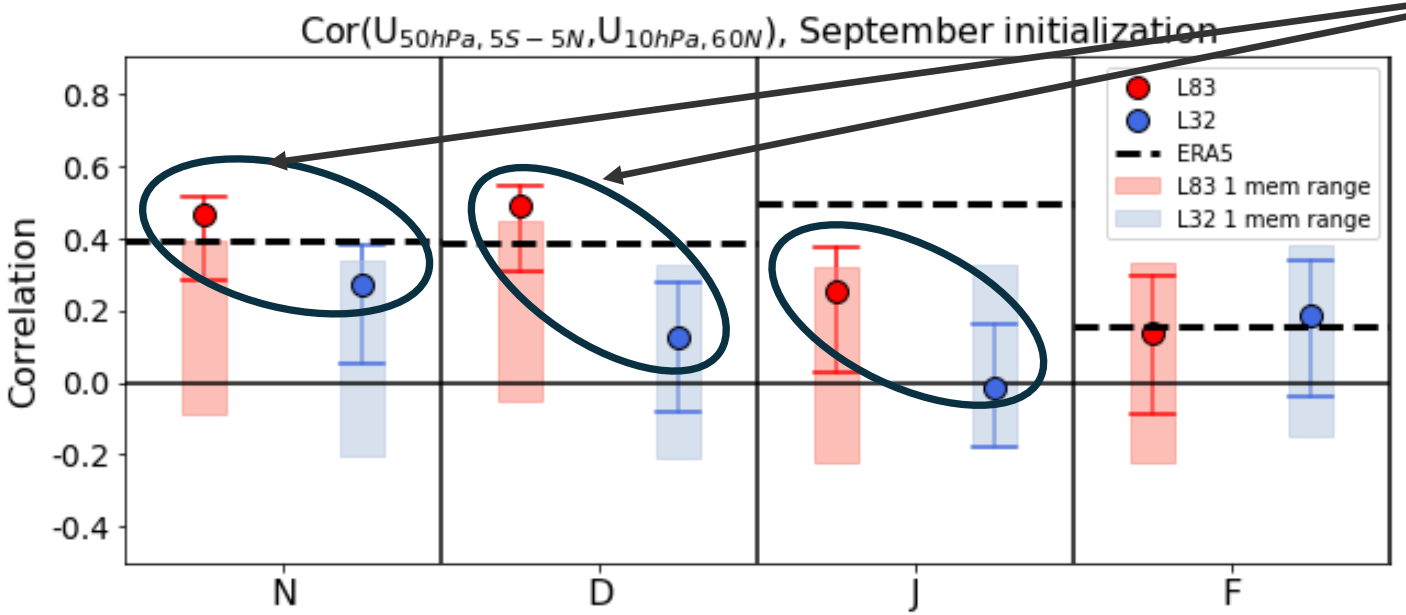


November initialization

Signal-to-noise issues???



September initialization

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