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Seasonal Prediction of Wintertime North Pacific Blocking: What Are We Capturing and Missing?

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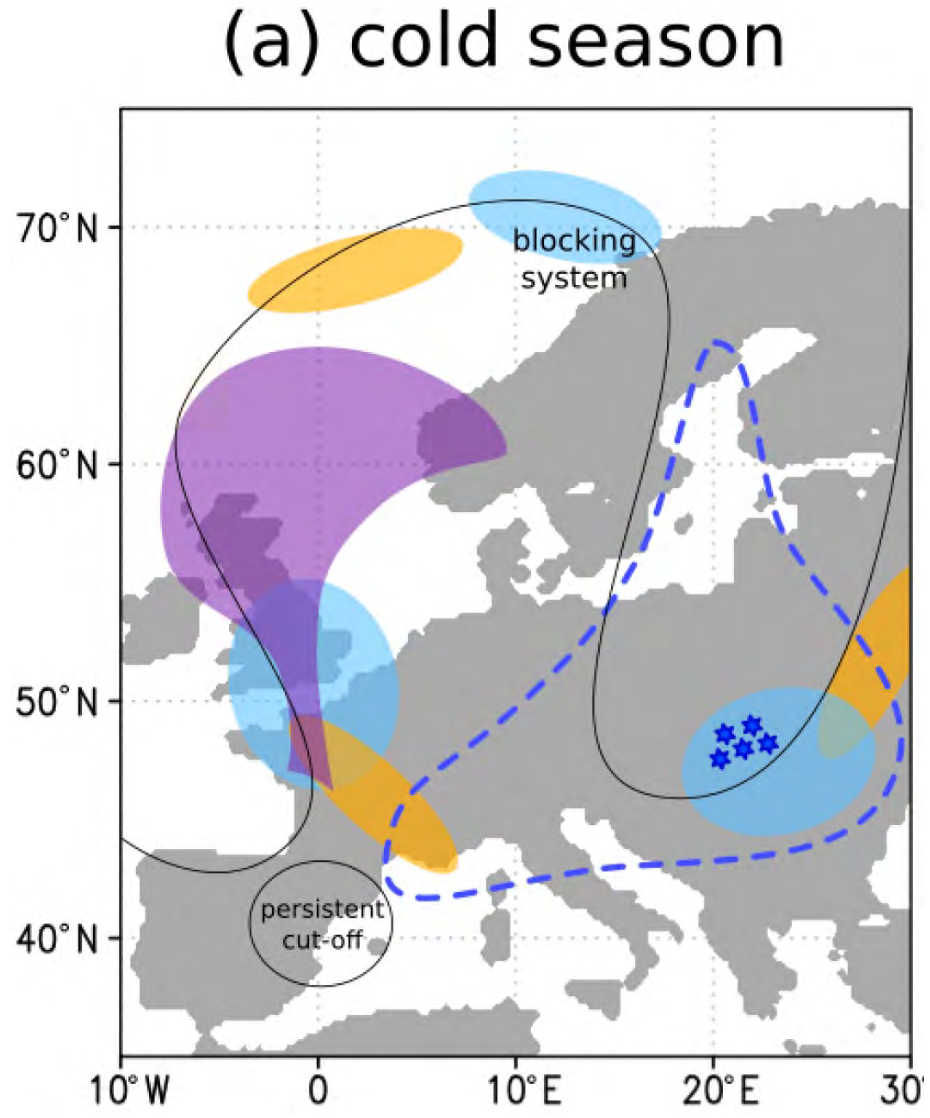
Wintertime Blocking-Cold extreme

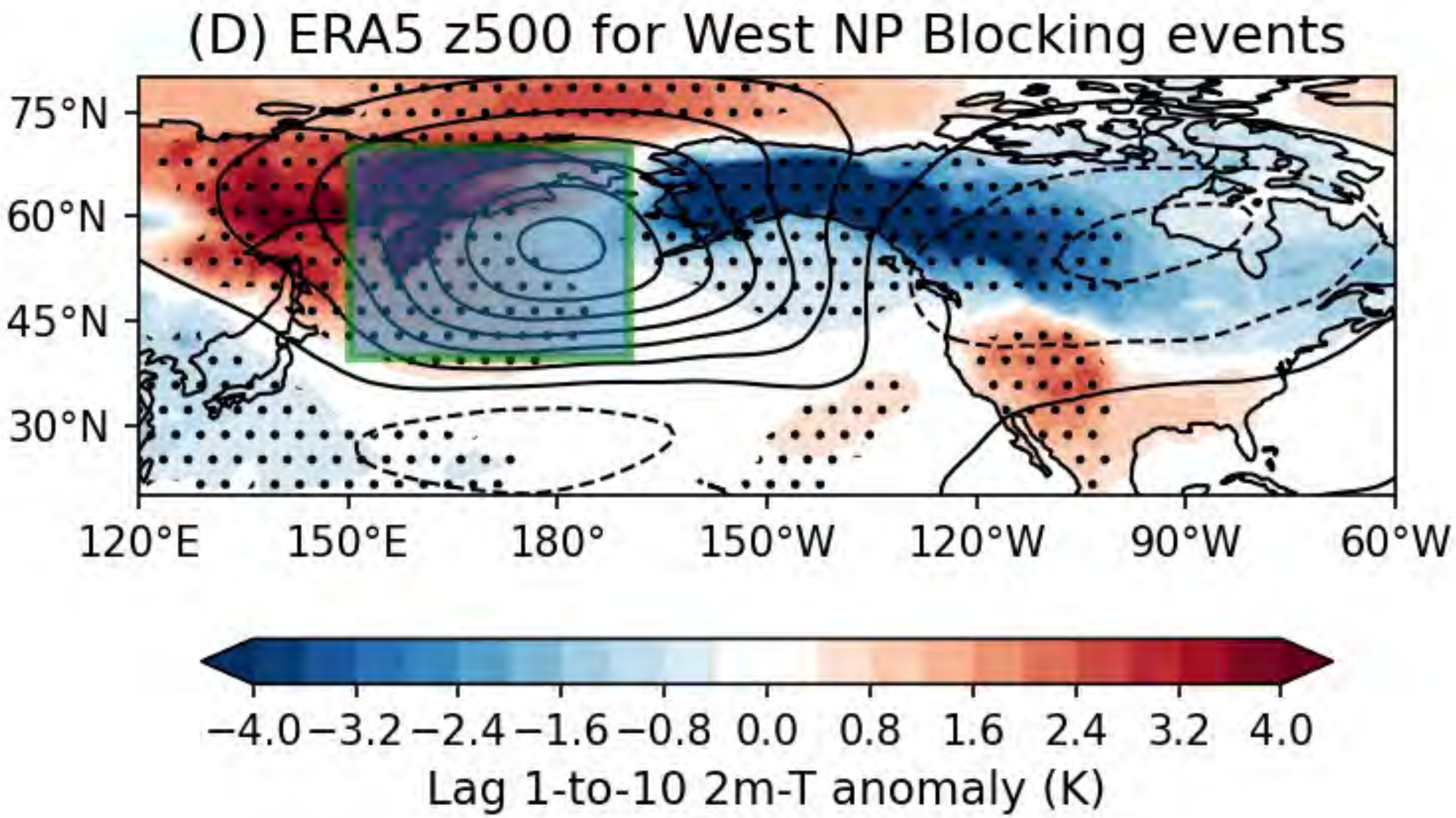


- During cold season blocking events, low-temperature anomalies tend to be observed at the eastern flank of the blocking system, sometimes accompanying snowstorms.

- This downstream influence contributes to the occurrence of cold extremes over many different regions, including East Asia, North America, and Europe.

Kautz et al. (2022)

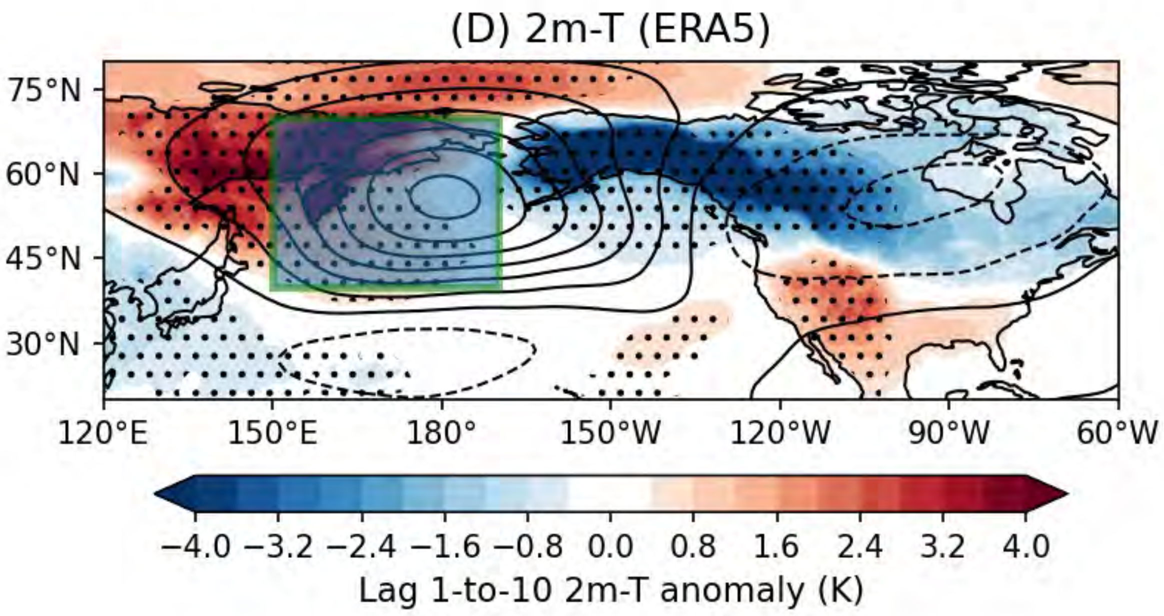
Wintertime North Pacific Blocking-North American Cold extreme



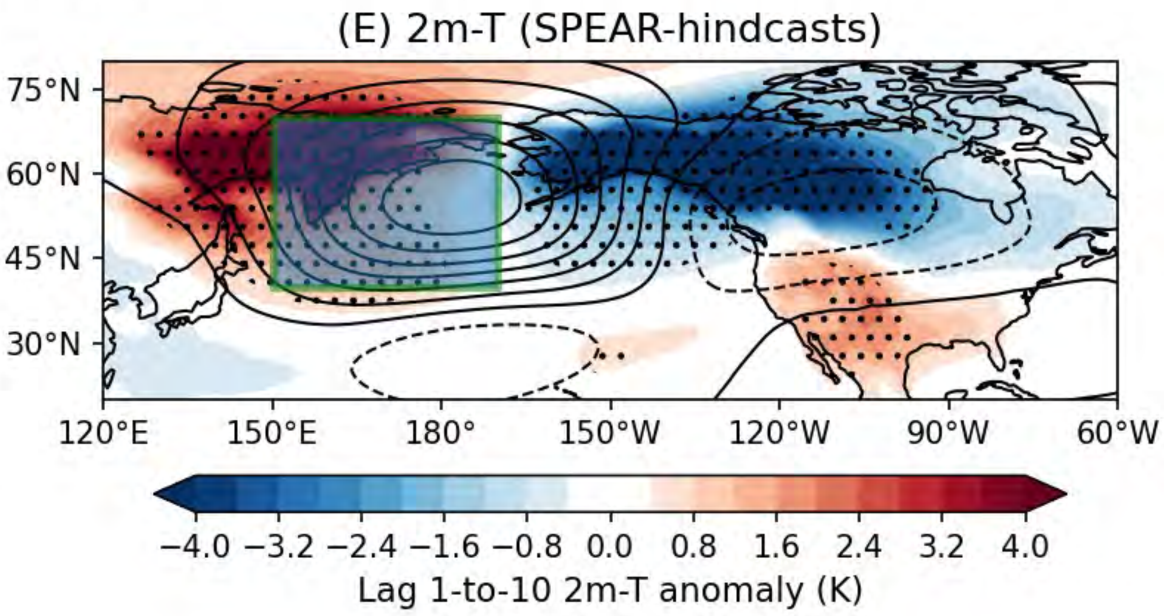
- North Pacific blocking induces cold temperature anomalies over Alaska and northwestern Canada

Wintertime North Pacific Blocking-North American Cold extreme linkage is well captured by seasonal model forecasts

ERA5



GFDL-SPEAR hindcasts



- As far as model captures the North Pacific blocking frequency well, its downstream impact is likely to be well represented.

How skillful can we predict the wintertime North Pacific blocking frequency using seasonal hindcasts?

GFDL-SPEAR Seasonal Forecast System

GFDL-SPEAR
(Delworth et al. 2020)

- GFDL's coupled climate model optimized for seasonal-to-multidecadal climate prediction and projection.
- **50 km** for atmosphere (AM4) / land (LM4), **1°** for sea ice (SIS2) and ocean components (MOM6).

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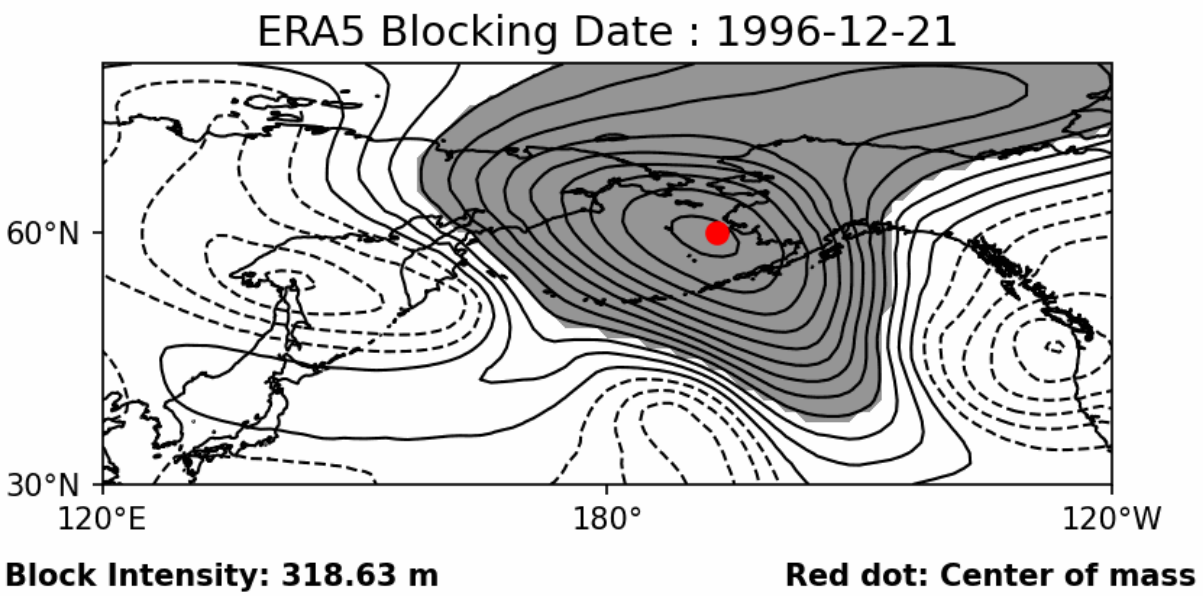
Prediction
(Initial value problem)
observations
↓
SPEAR assimilation & initialization system
↓
SPEAR model
↓
Seasonal predictions, Decadal predictions

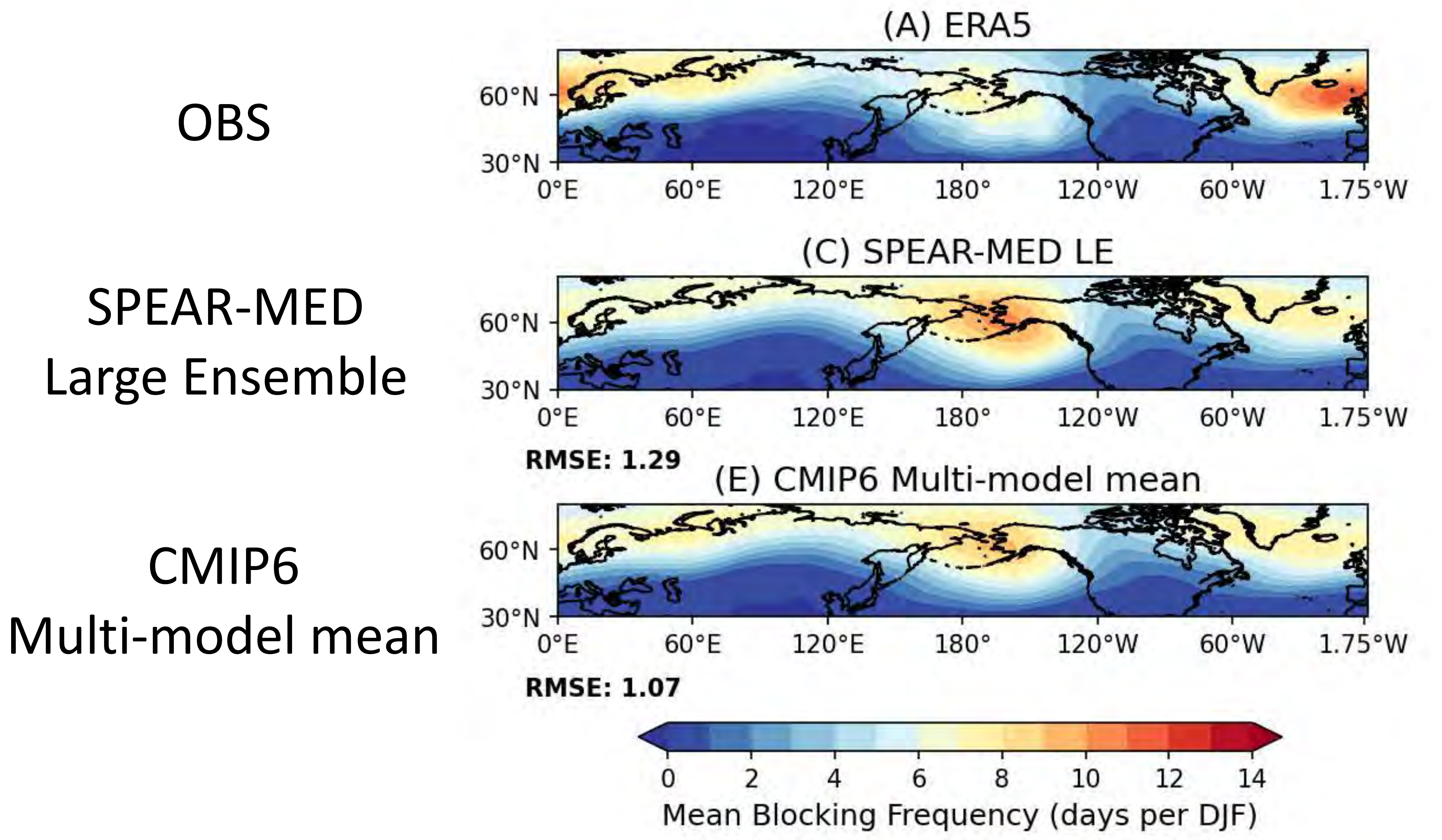
- SPEAR seasonal forecast system has 15 ensemble members that are initialized on the first day of each month and integrated for 12 months afterwards.

Blocking Detection

- We adapted the MIX approach (Dunn-Sigouin and Son 2013) that captures persistent, quasi-stationary blocking systems retaining both meridionally reversed gradients and large amplitudes.
- Period: 1991/92-2020/21 DJF



Wintertime Blocking Climatology (1991/92-2020/21)

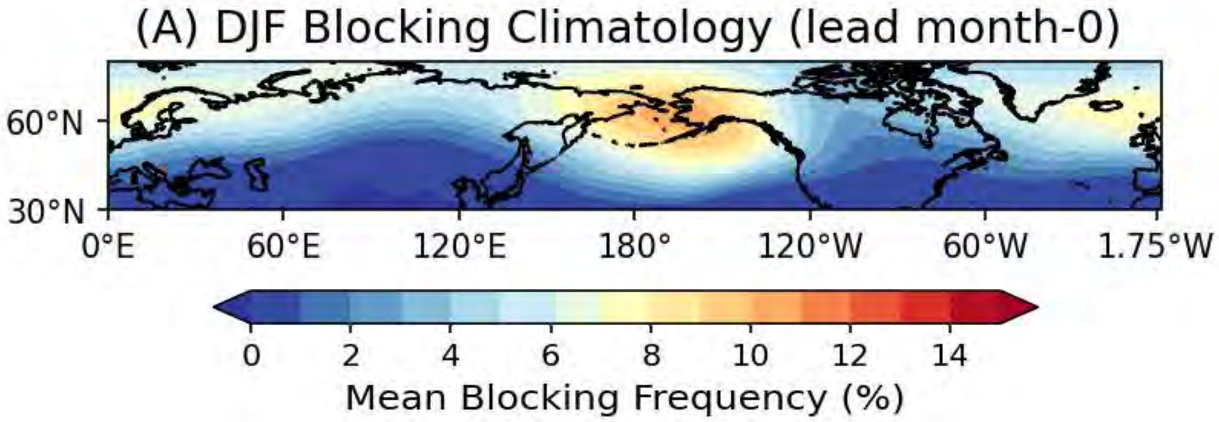


- Approximately 200 out of 2700 days are blocked over the North Pacific Ocean (ERA5)

Seasonal prediction skills from SPEAR hindcasts

DJF Climatology in hindcasts

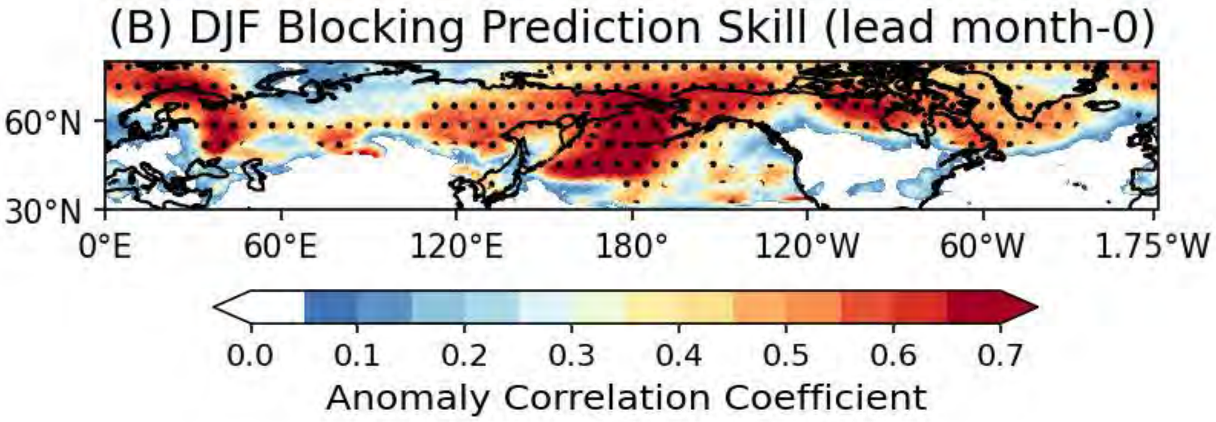
December 1st Initialization



- Biases are weaker in magnitudes, albeit spatially similar to those in SPEAR-MED

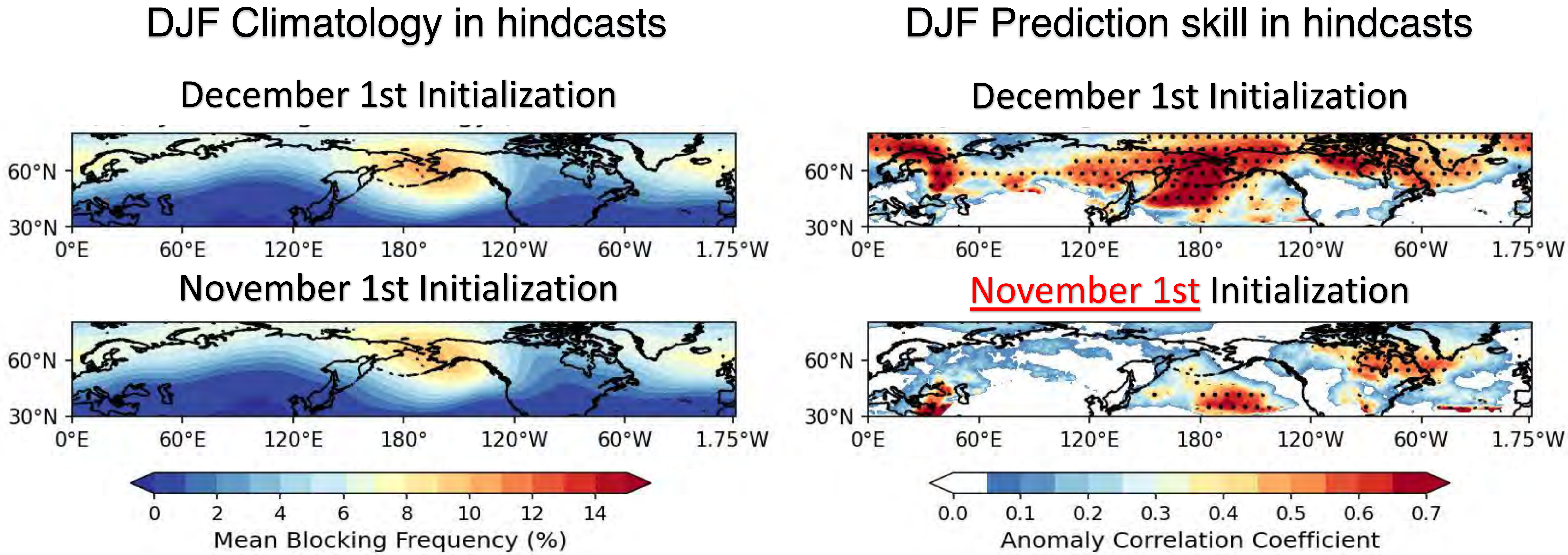
DJF Prediction skill in hindcasts

December 1st Initialization



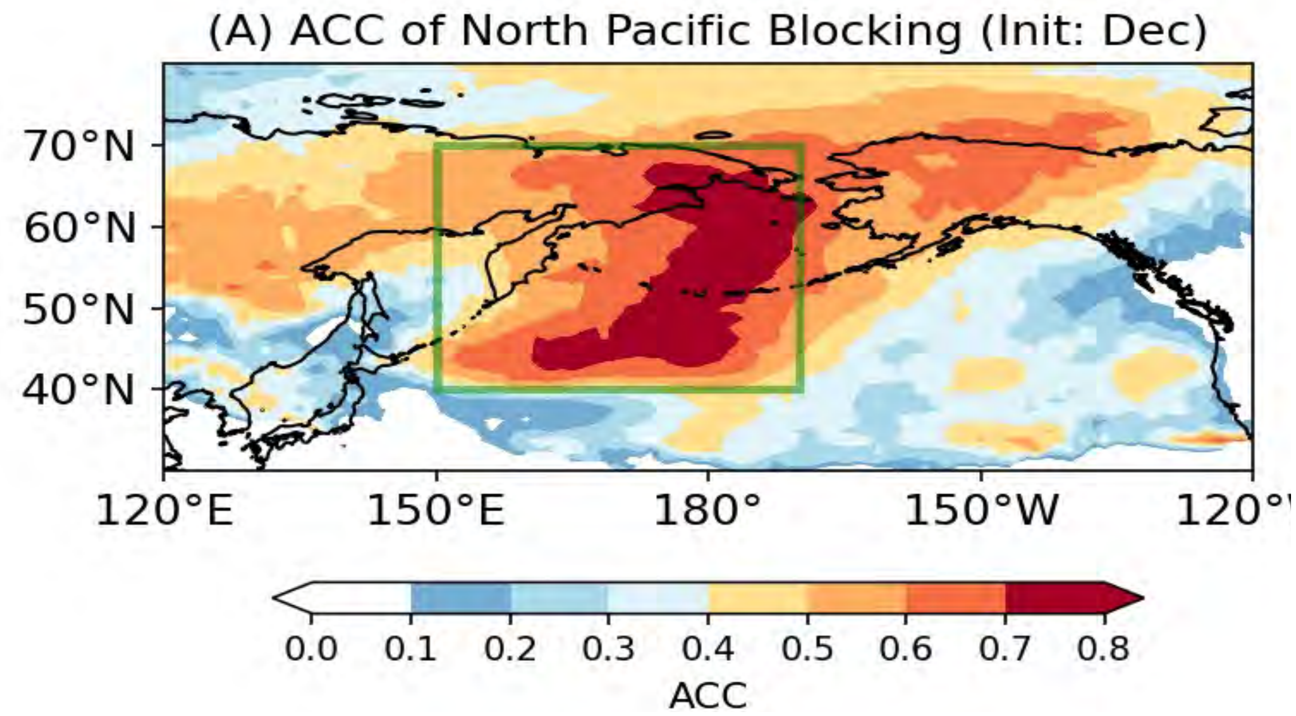
- Good skills (ACC > 0.7) are found over the North Pacific, Greenland, and northern Europe

The prediction skill sharply drops with increasing lead time



- Consistent with Davini et al. (2021) which used ECMWF S5 seasonal forecasts with one-month lead, and found a small rank correlation skill, 0.12, for the North Pacific sector

High prediction skills in the western North Pacific Ocean



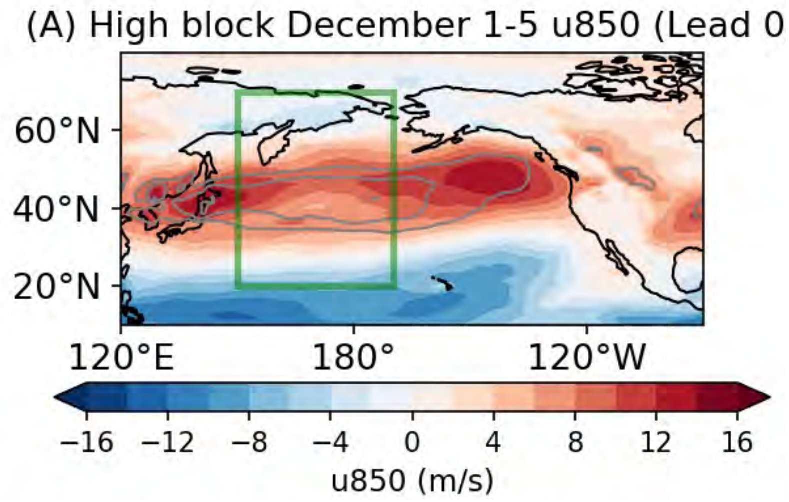
December 1st initialization

1. The intensity and location of the low-level jet are rectified by initial conditions (also upper-level jet), which helps simulating the block onset variability

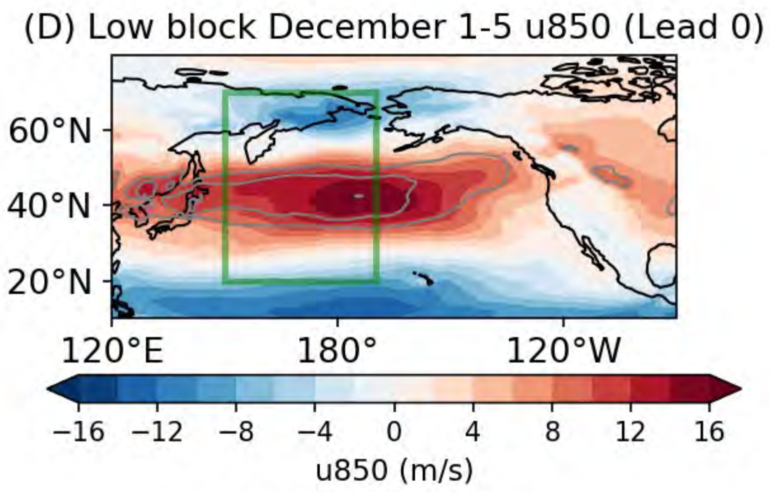
2. In addition, ENSO teleconnection provided by initial conditions also play an important role in simulating teleconnection-driven blocking anomalies.

Composites of lower-tropospheric winds (u850) during December 1st-5th from December 1st initialization

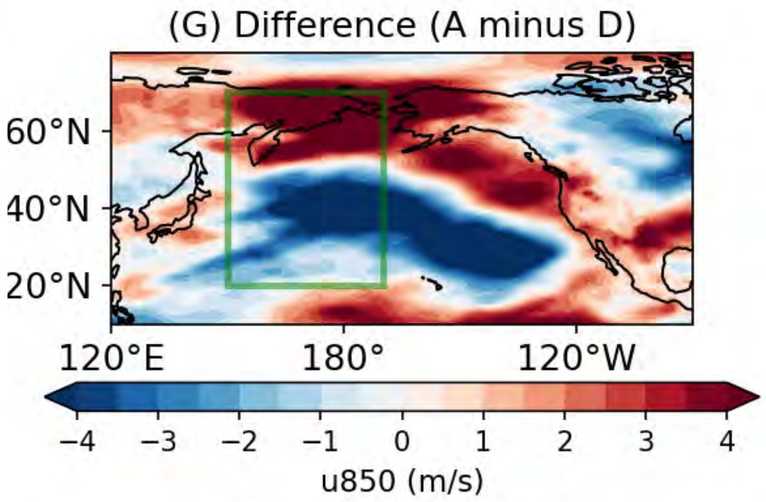
High blocking winters



Low blocking winters



Difference

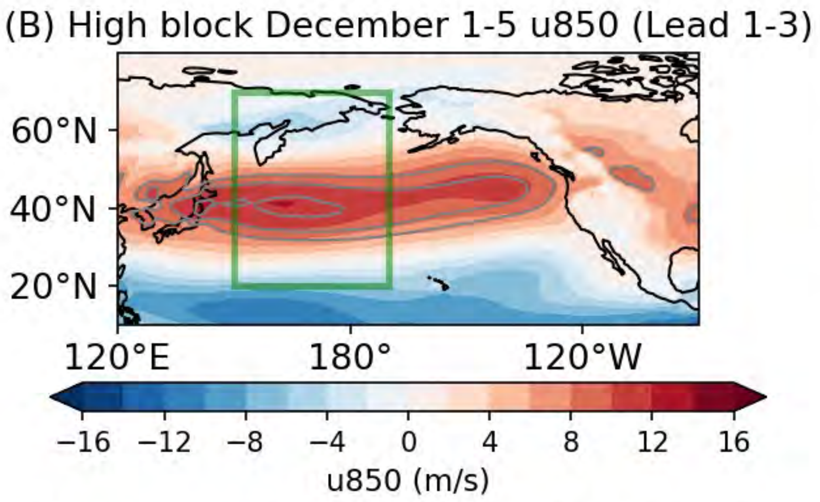


Anticyclonic circulation feature

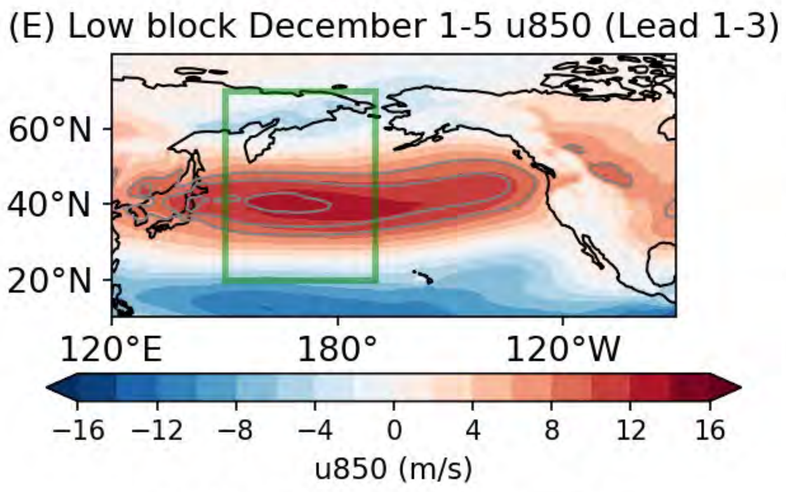
* Blocking winters identified from ERA5 reanalysis

Composites of lower-tropospheric winds (u850) during December 1st-5th from initializations in lead time (i.e., Sep 1st-Nov 1st average)

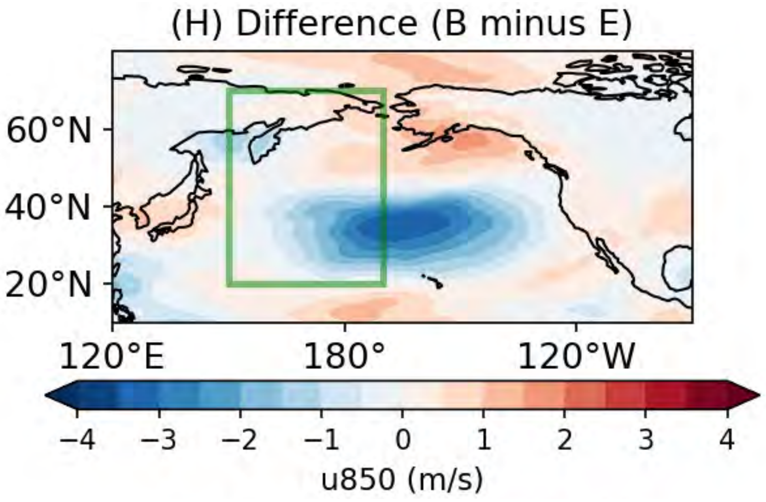
High blocking winters



Low blocking winters



Difference

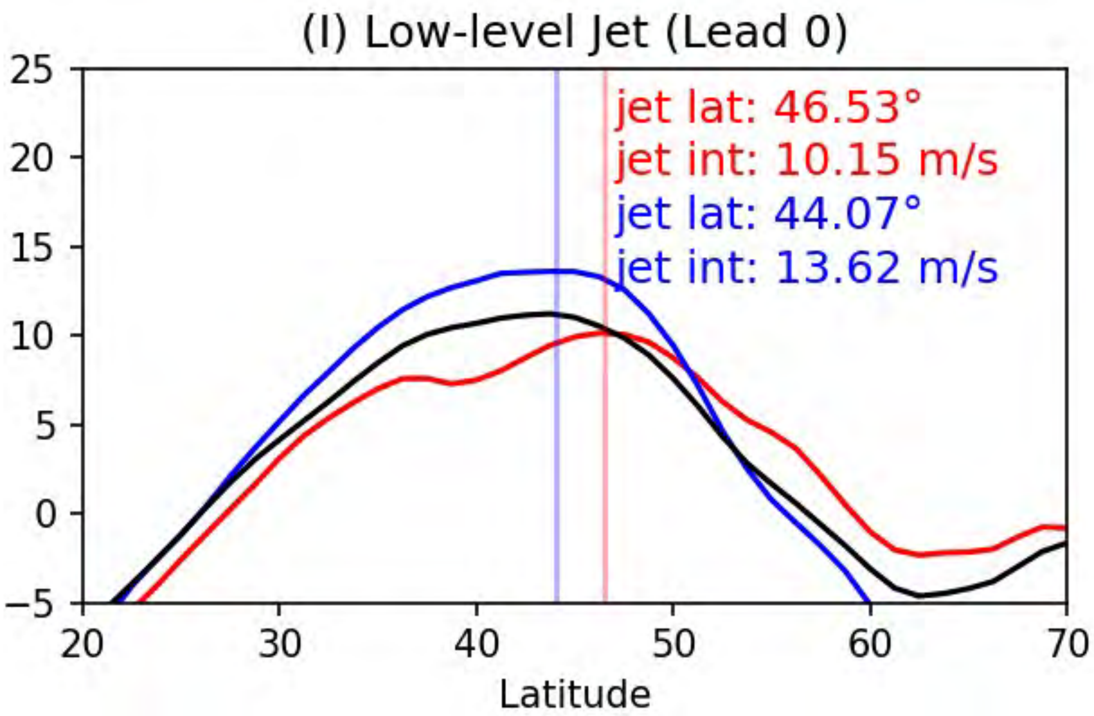


Much weaker differences between two groups

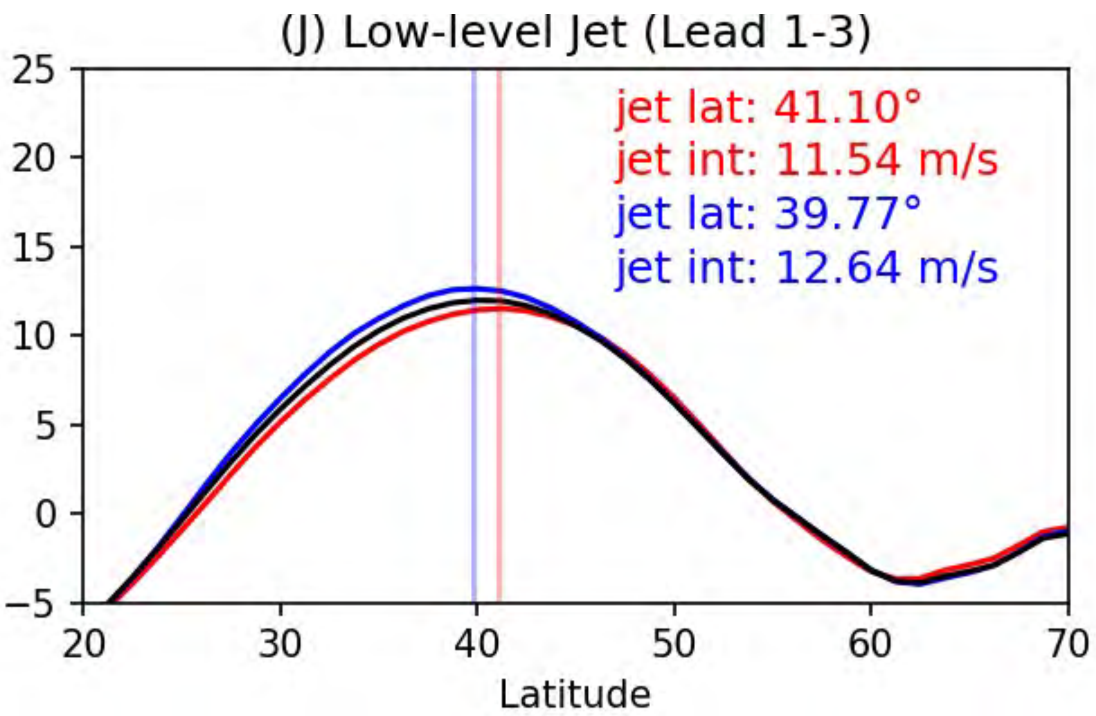
* Blocking winters identified from ERA5 reanalysis

The contrasting features of low-level jet (**u850**) during high and low blocking winters

December 1st Initialization



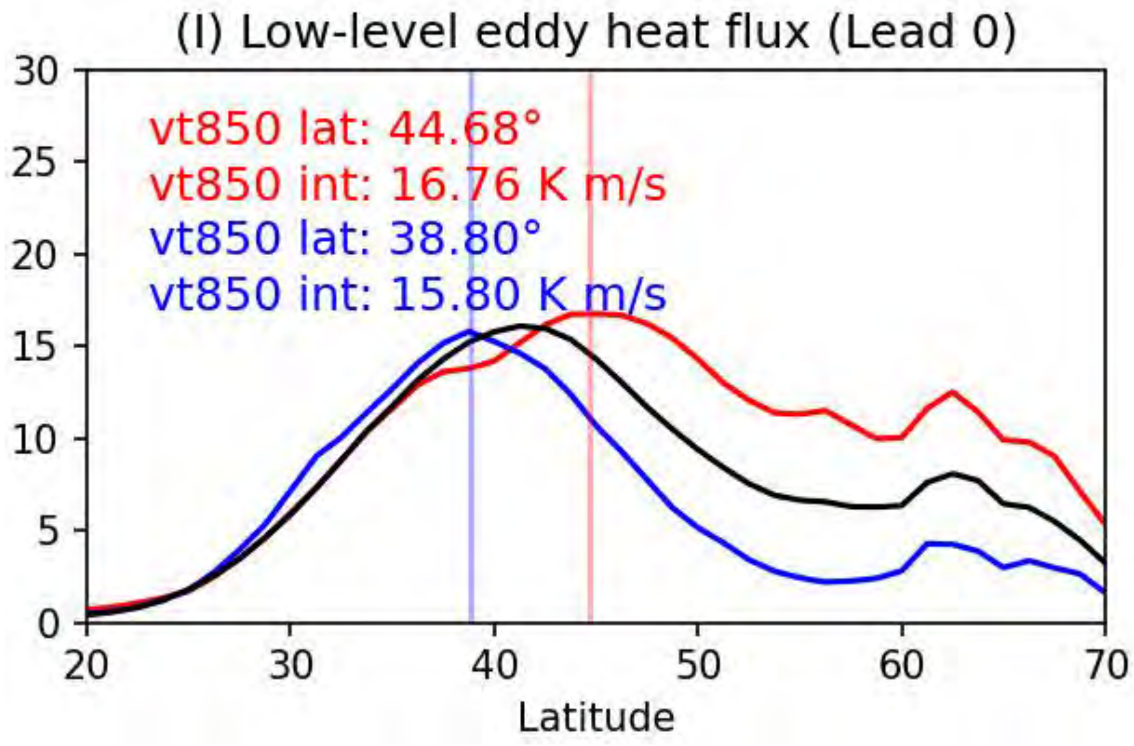
Average of September 1st-November 1st Initialization



Not well distinguished if there is a lead time in forecast initialization

The lower tropospheric eddy heat flux during high and low blocking winters

December 1st Initialization



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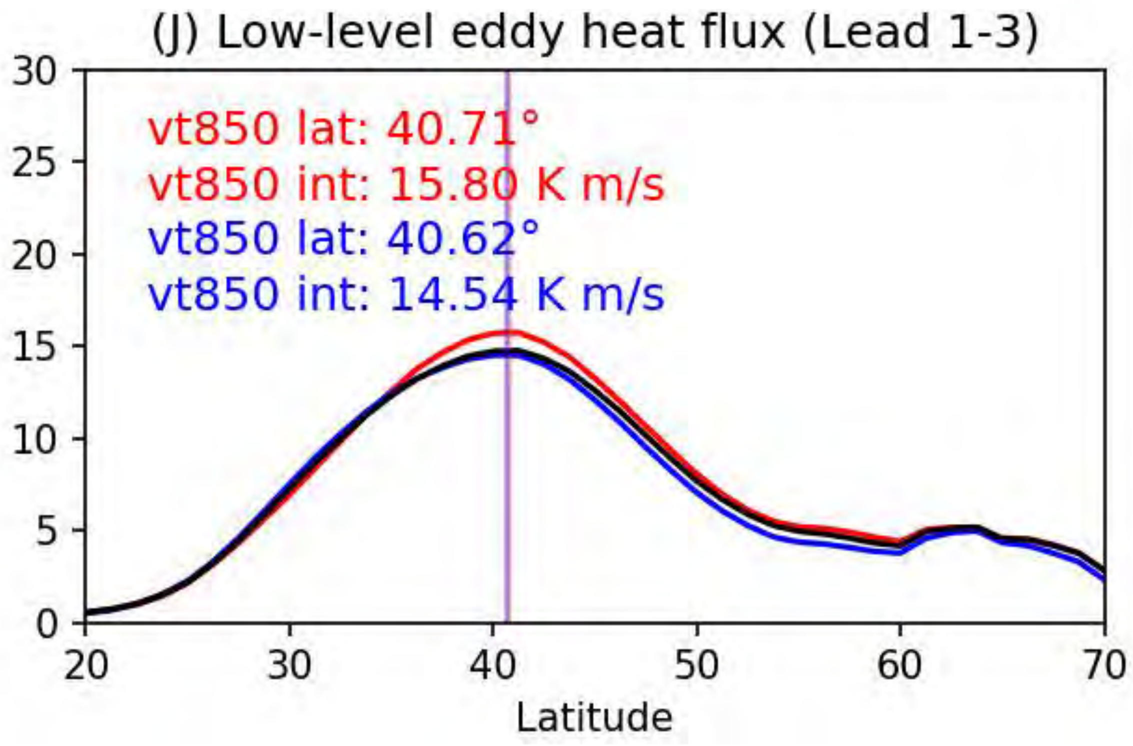
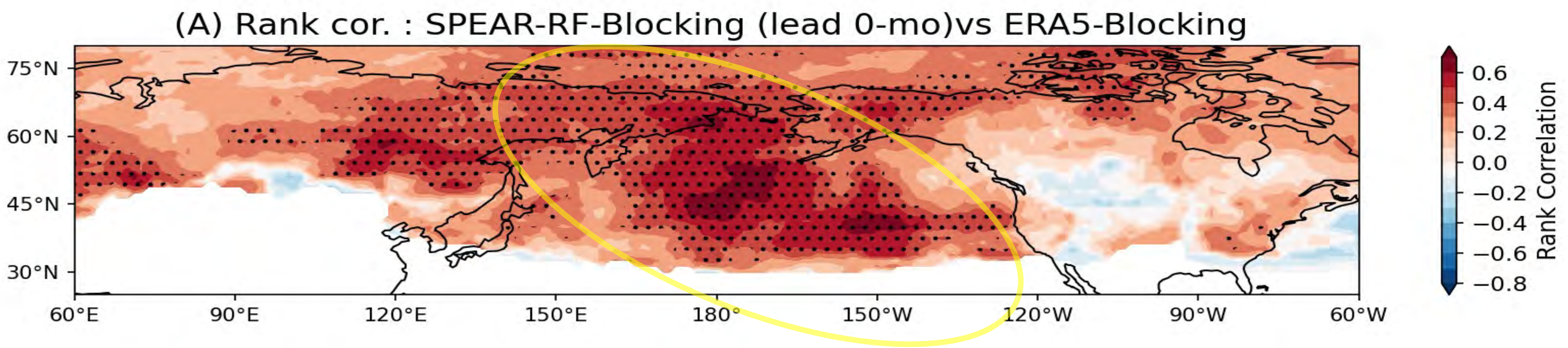


Barely distinguished if there is a lead time in forecast initialization

Also, ENSO provides some predictability of North Pacific blocking

Rank correlation between
SPEAR blocking (December 1st init.) vs ERA5 blocking



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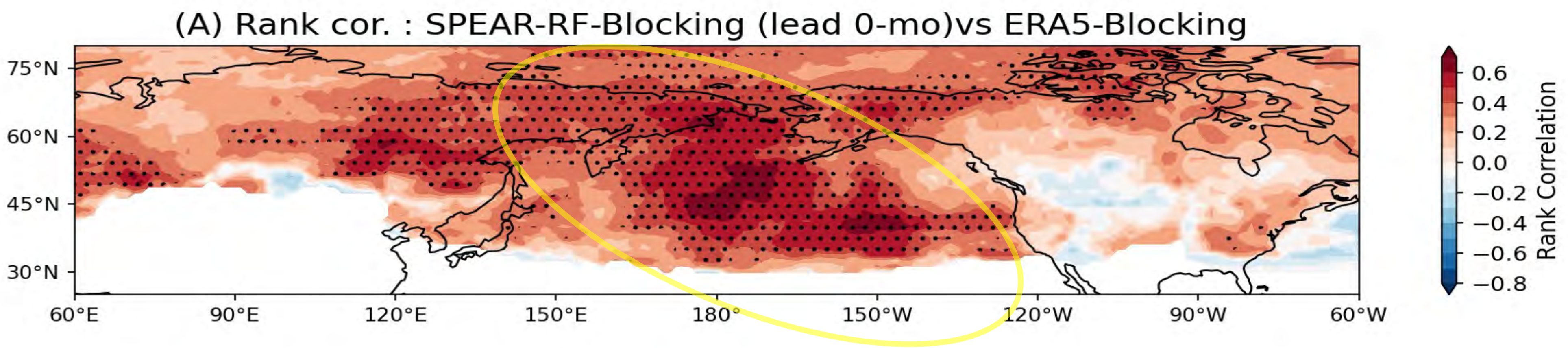
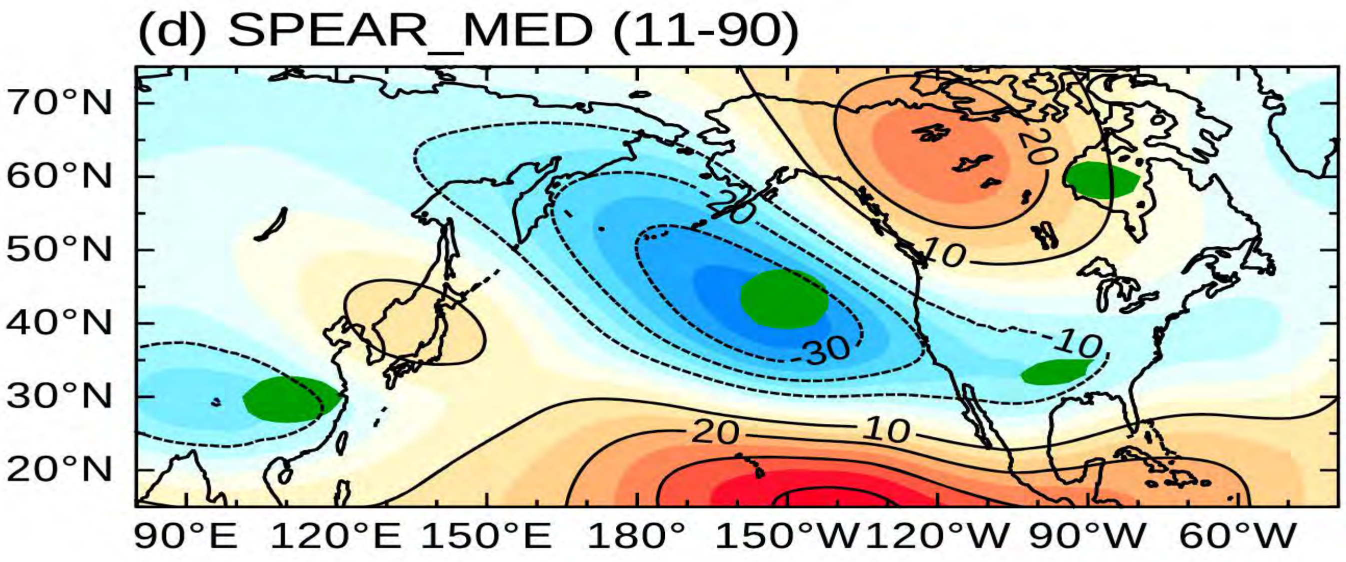


ENSO teleconnection simulated by SPEAR

SPEAR-MED 200-hPa Z regressed onto Nino3 index for DJF (Delworth et al. 2020)



Hypothesis: Seasonal prediction based on **the ENSO-blocking relationship** might be more skillful for longer lead months

- To use the observed ENSO-blocking relationship, we construct a hybrid statistical-dynamical model, based on linear multivariate regression.

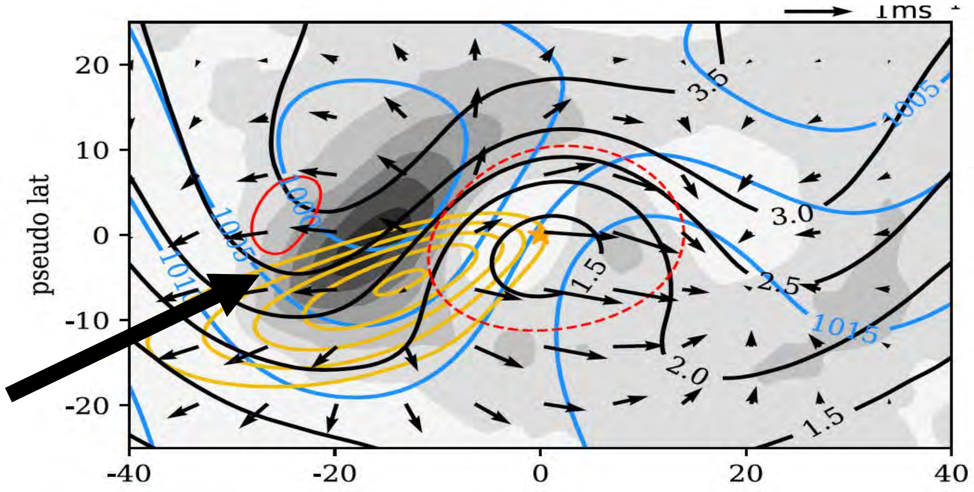
- Two predictors: Nino3.4 and upstream precipitation from SPEAR hindcasts with different initialization months.

$$block_{hybrid,m} = a_{nino34}\, x_{fc\_nino34,m} + b_{precip}\, x_{fc\_precip,m} + c_{offset}$$

- The regression coefficients a_{nino34}, b_{precip}, and c_{offset} are derived by regressing the hindcast Nino 3.4 index and upstream precipitation at lead 0 month onto the observed NP blocking frequency

Upstream precipitation as a predictor of the North Pacific blocking

Blocking-centered composites (onset stage of blocking)



Latent heating

Steinfeld and Pfahl (2019)

Upstream precipitation as a predictor of the North Pacific blocking

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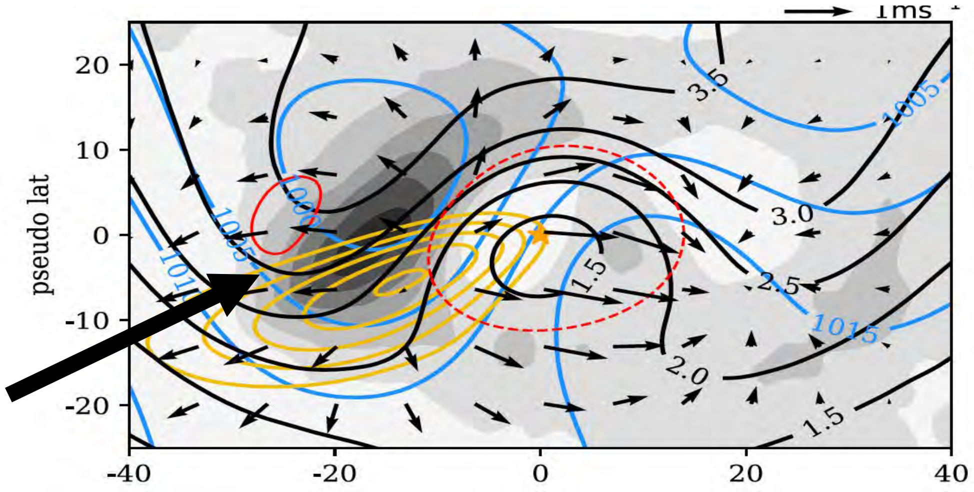
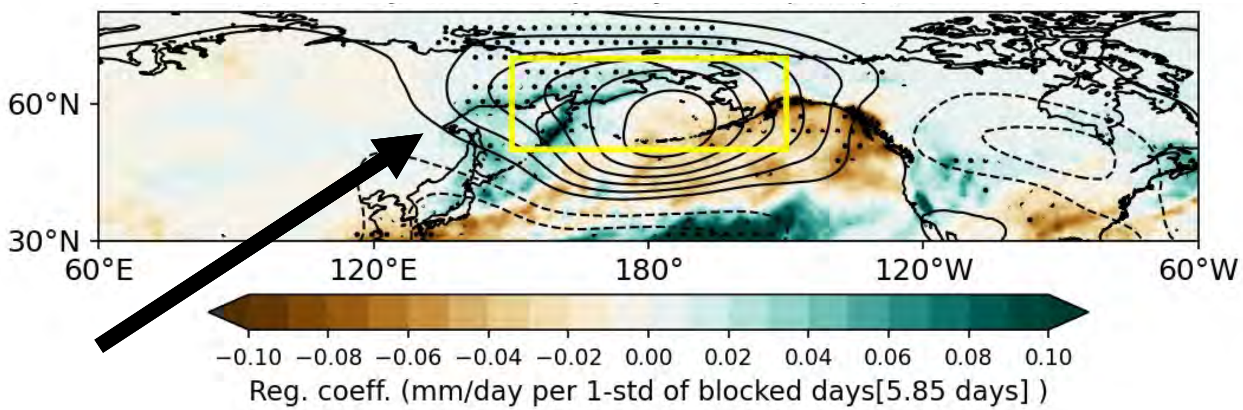


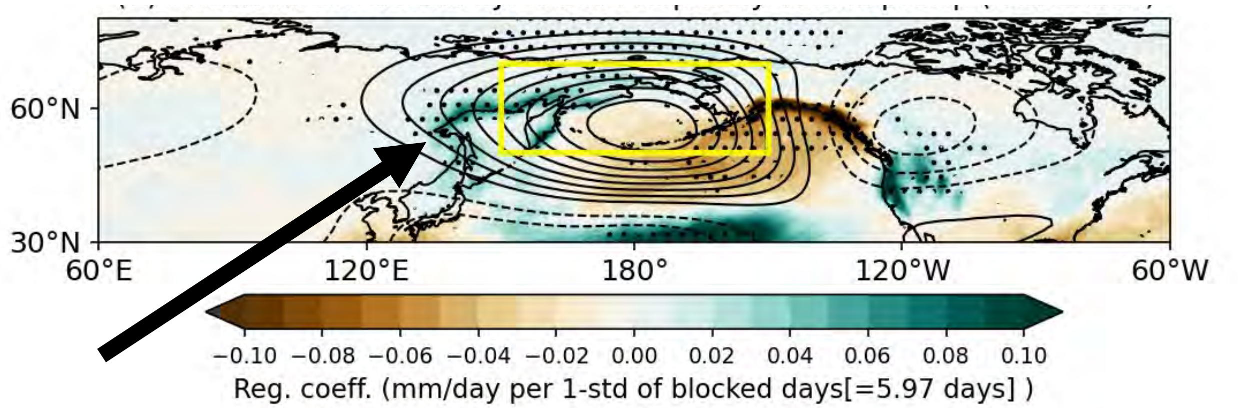
Latent heating

Steinfeld and Pfahl (2019)

Blocking Frequency vs Precipitation Regression (ERA5)



Blocking Frequency vs Precipitation Regression (SPEAR)

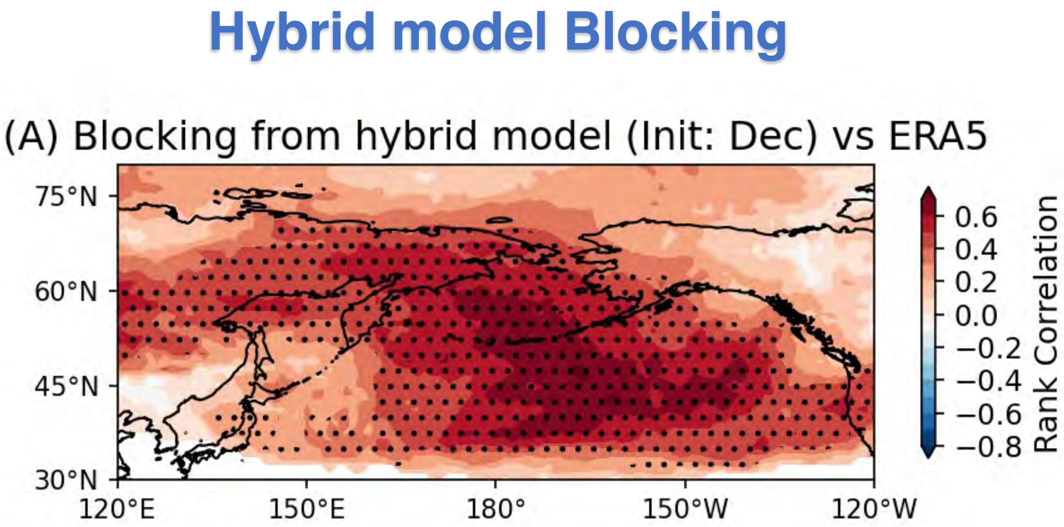


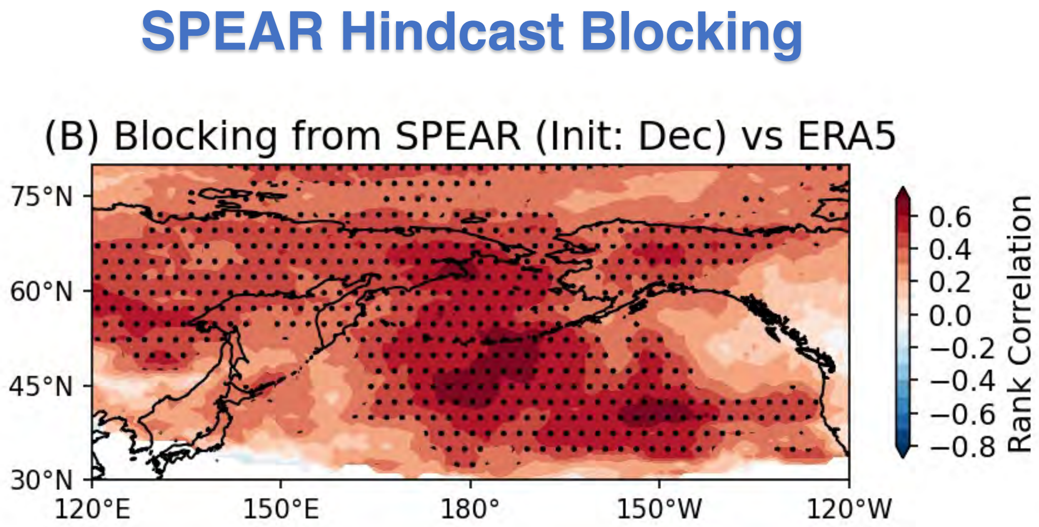
- Enhanced latent heat release at the upstream of blocking systems

Yes, the hybrid dynamic-statistical model provides higher prediction skills for longer lead months

Metric: Rank correlation

Dec. Init.





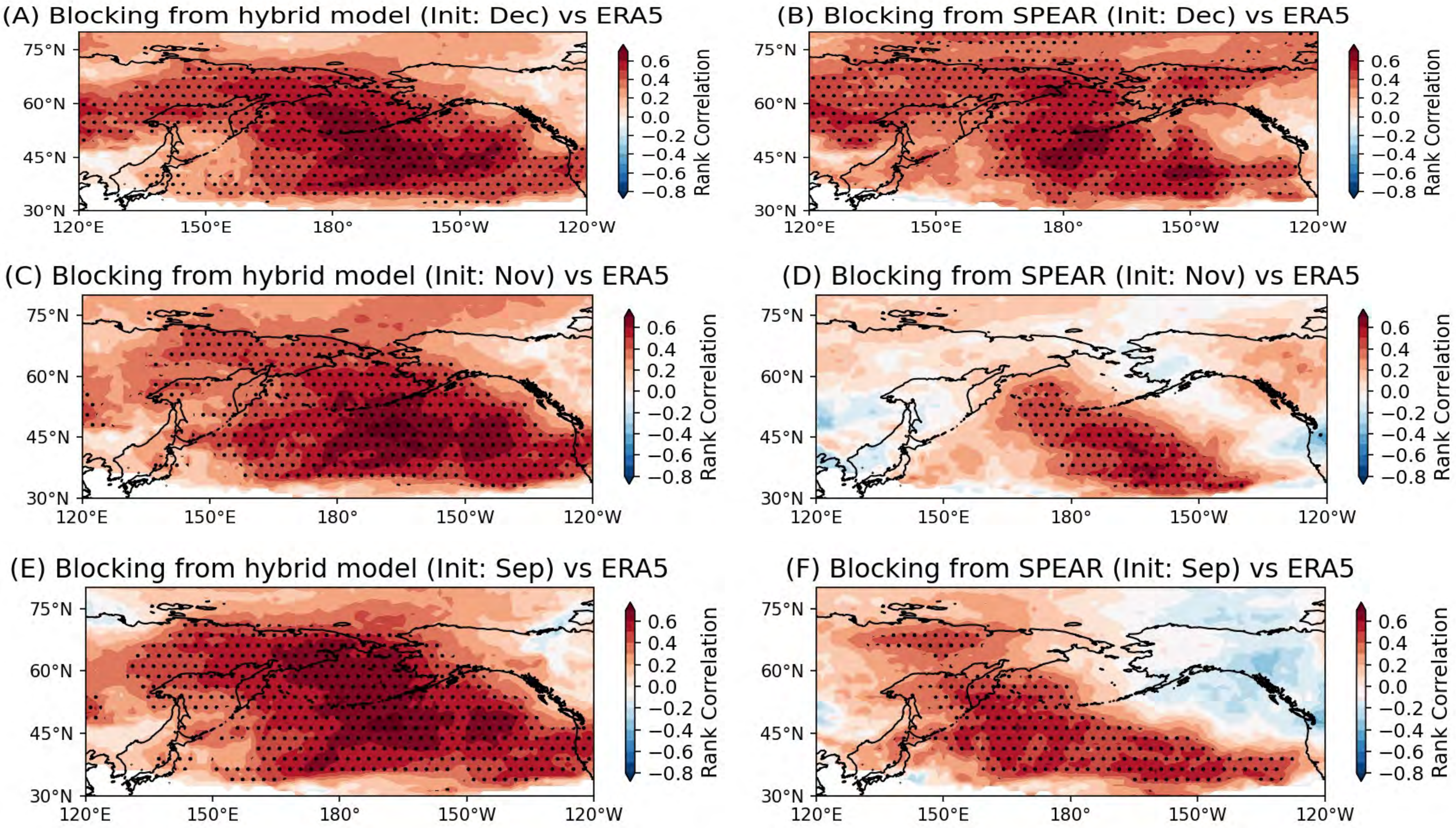
- For December initialization (no lead month), correlation skills are comparable, but for high-latitude blocking frequency, SPEAR hindcast blocking (direct output) has higher skills

Hybrid model skills | SPEAR Hindcast skills

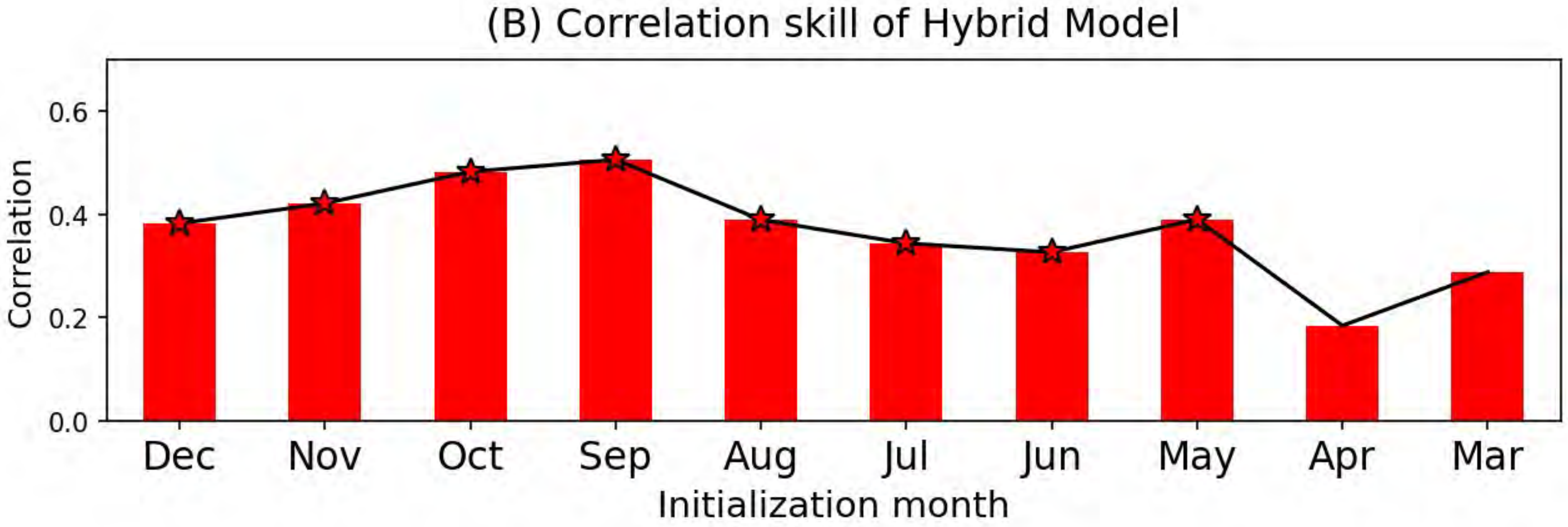
Lead month: 0
(Dec 1st. Init.)

Lead month: 1
(Nov 1st. Init.)

Lead month: 3
(Sep 1st. Init.)



Correlation skills from the hybrid model blocking are well maintained until lead months up to 7



* Star indicates the statistical significance at 5% level

Conclusions

- SPEAR hindcasts can provide skillful predictions of wintertime North Pacific blocking frequency due to atmospheric predictability sources and tropical SSTs associated with ENSO, particularly when there is no lead time.
- SPEAR hindcasts with lead months rapidly lose prediction skill for North Pacific blocking due to the model drift of atmospheric mean states, which are crucial for representing the variability in blocking frequency.
- A hybrid statistical-dynamical model based on the ENSO-blocking linkage is proposed as a potential means to enhance seasonal prediction skills for North Pacific blocking, extending up to lead times of 7 months.

A hybrid approach for skillful multiseasonal prediction of winter North Pacific blocking (Park et al., *in GFDL internal review)*

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BLOCKING & EXTREME WEATHER IN A CHANGING CLIMATE

Thank you. Questions?

A hybrid approach for skillful multiseasonal prediction of winter North Pacific blocking
(Park et al., *in GFDL internal review)*

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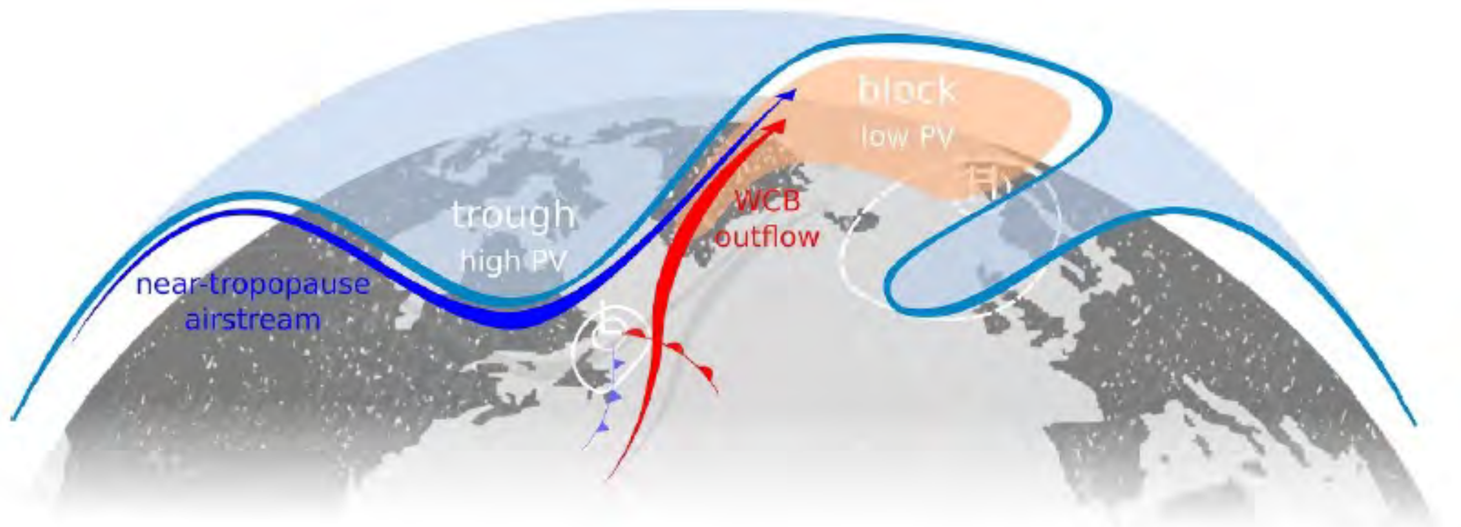
Dry and moist processes that contribute to the formation and maintenance of atmospheric blocking



Steinfeld et al. (2022)

- Dry process: Transport of low PV along the amplified upper-level jet
- Moist process: Transport of low PV in ascending warm conveyor belt airstreams with strong latent heating