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OESCHGER CENTRE CLIMATE CHANGE RESEARCH

Linking storm track activity and subseasonal forecast uncertainty in the North Pacific and North Atlantic

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Understanding and predicting the midlatitude storm tracks

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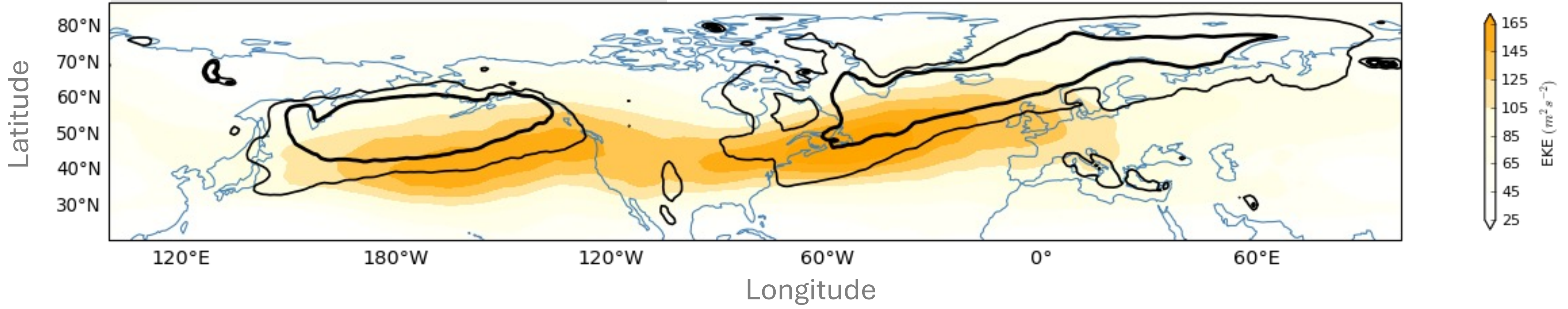
Midlatitude storm tracks: regions where extratropical cyclones occur most often.

The storm tracks are concentrated over the **North Pacific** and the **North Atlantic** and play a crucial role in Earth's climate system – transporting energy, heat and moisture from the subtropics to the Poles.

Northern Hemisphere storm track

ERA-5 (DJF, 2000-2023)

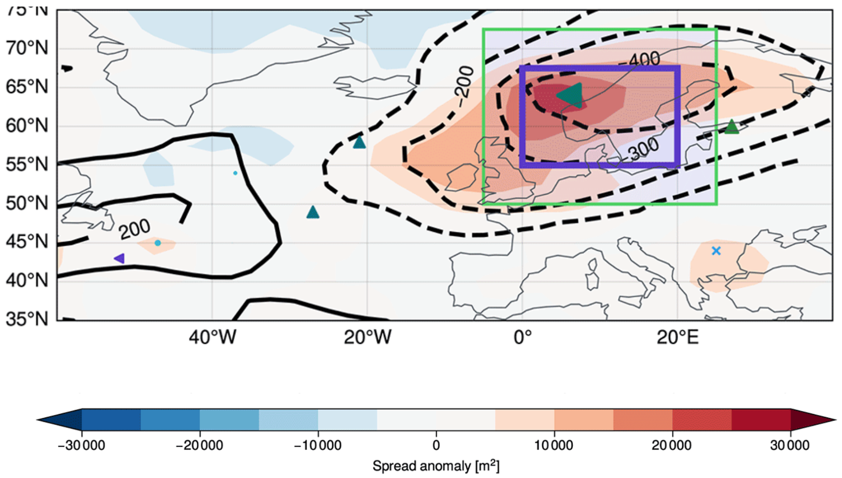


Shading: **Eddy kinetic energy (EKE)** | units: $m^2 s^{-2}$

Black contours: **extratropical cyclone frequency** | units: % (contours shown for 10% and 30%)

Midlatitude synoptic storms are a major source of forecast uncertainty

Association between storms and spread

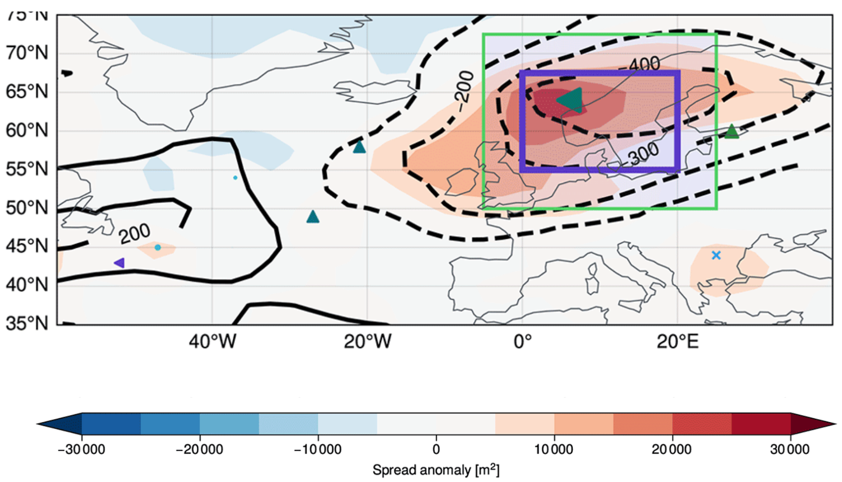


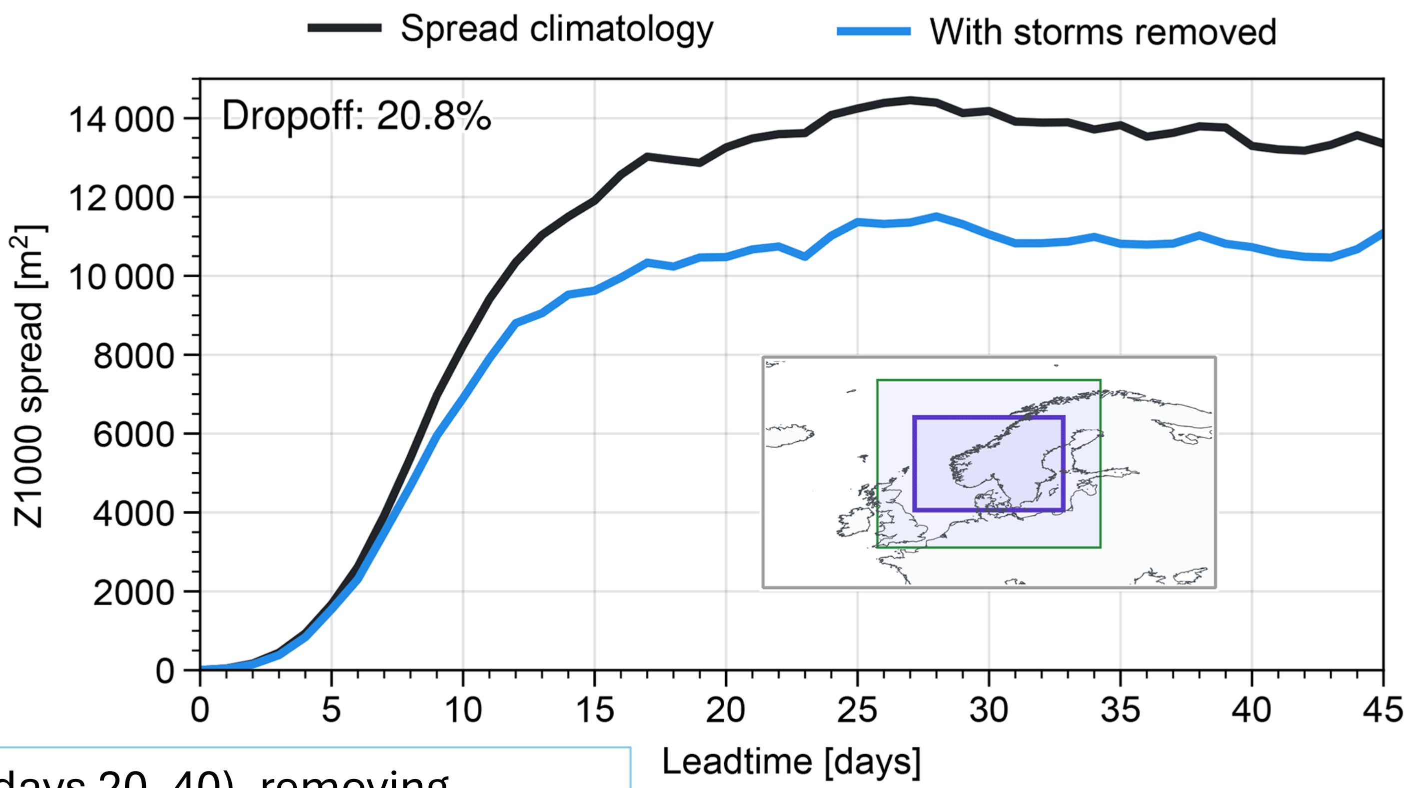
Case study of Z1000 anomalies (black contours) associated with spread anomaly (color shading). Data: ECMWF IFS reforecast initialized on 31 December 2007 (lead time day 31).

Figures from Rupp et al., 2024, *WCD*

Midlatitude synoptic storms are a major source of forecast uncertainty

Association between storms and spread



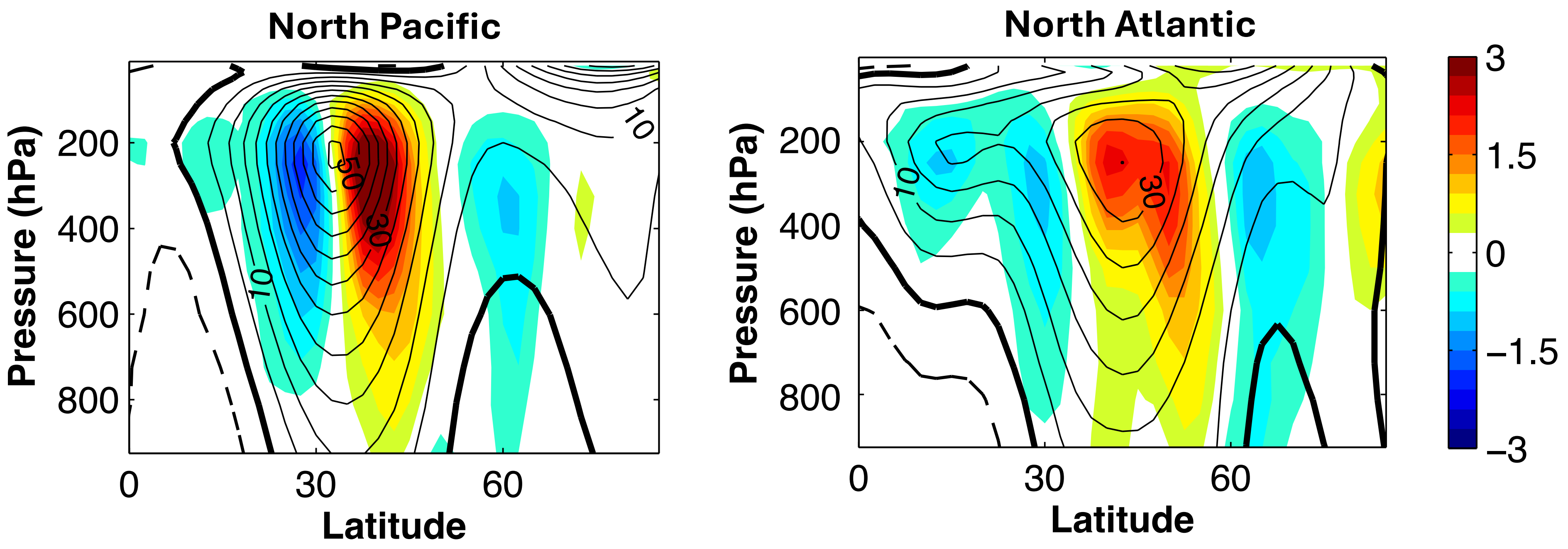


On subseasonal timescales (lead time days 20–40), removing ensemble members with storms leads to a significant drop-off (about 20%) in the spread → **storms increase the forecast uncertainty on subseasonal timescales in the Euro-Atlantic.**

Figures from Rupp et al., 2024, *WCD*

North Atlantic vs. North Pacific background flow

- **North Pacific:** a single "**thermally-driven" jet** in winter, located aloft (e.g., *Lee & Kim, 2003*)
- **North Atlantic:** two separated jets in winter, with the poleward jet (~45°N) being primarily "**eddy-driven**", generated by eddy momentum flux convergence by transient eddies *(e.g., Lorenz and Hartmann, 2003; Eichelberger and Hartmann, 2007; Li and Wettstein, 2012)*.



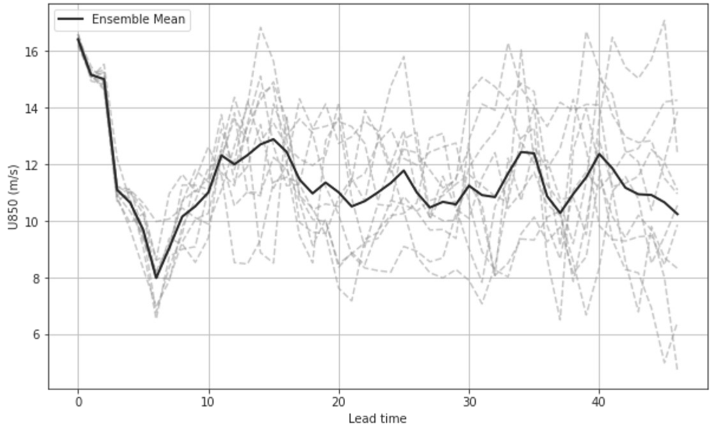
DJF zonal wind (black contours, ms^{-1}) and eddy momentum flux convergence (color, ms^{-2})
Data: ERA5 (1981-2020)

Motivation

- Processes that modify the characteristics of the storm track in the **North Pacific** and the **North Atlantic** sectors should also project on the forecast uncertainty.
- e.g., changes in **surface baroclinicity**, **strength and latitudinal position of jet stream**, and **changes in cyclone life-cycles**.

What is the relevance of these **dynamical differences** for **forecast uncertainty**?

Dynamical difference, e.g., jet characteristics → ? → Forecast uncertainty at subseasonal timescales



Data and Methods

- ECMWF IFS subseasonal reforecasts from the S2S prediction project (Vitart et al., 2017)
- January-February initializations, between 2000 to 2020
- 10-member ensembles + control
- ECMWF ERA5 reanalysis

- **Ensemble mean** is defined by averaging all ensemble members.
- **Ensemble spread** is defined as the standard deviation across the ensemble.

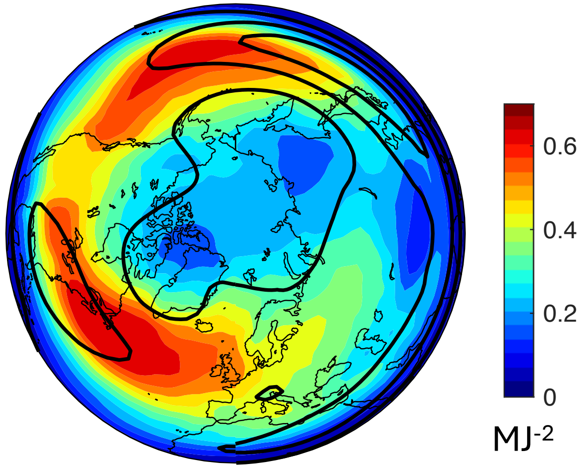
To define the storm track, we use eddy kinetic energy (EKE):

$$EKE = \frac{1}{2g}\int (u'^2 + v'^2)dp$$

EKE is computed by bandpass filtering of the zonal and meridional wind fields with a cutoff period between 3-8 days (synoptic timescale).

Jet latitude index (JLI) is computed by calculating the daily maximum of the zonally averaged zonal wind (15°-75°N) (following Woollings et al., 2010).

Climatology of vertically-integrated EKE (ERA5, 1981-2020)



North Atlantic: 280°-360°E
North Pacific: 140°-220°E

Relationship between EKE ensemble spread and mean (Pacific+Atlantic)

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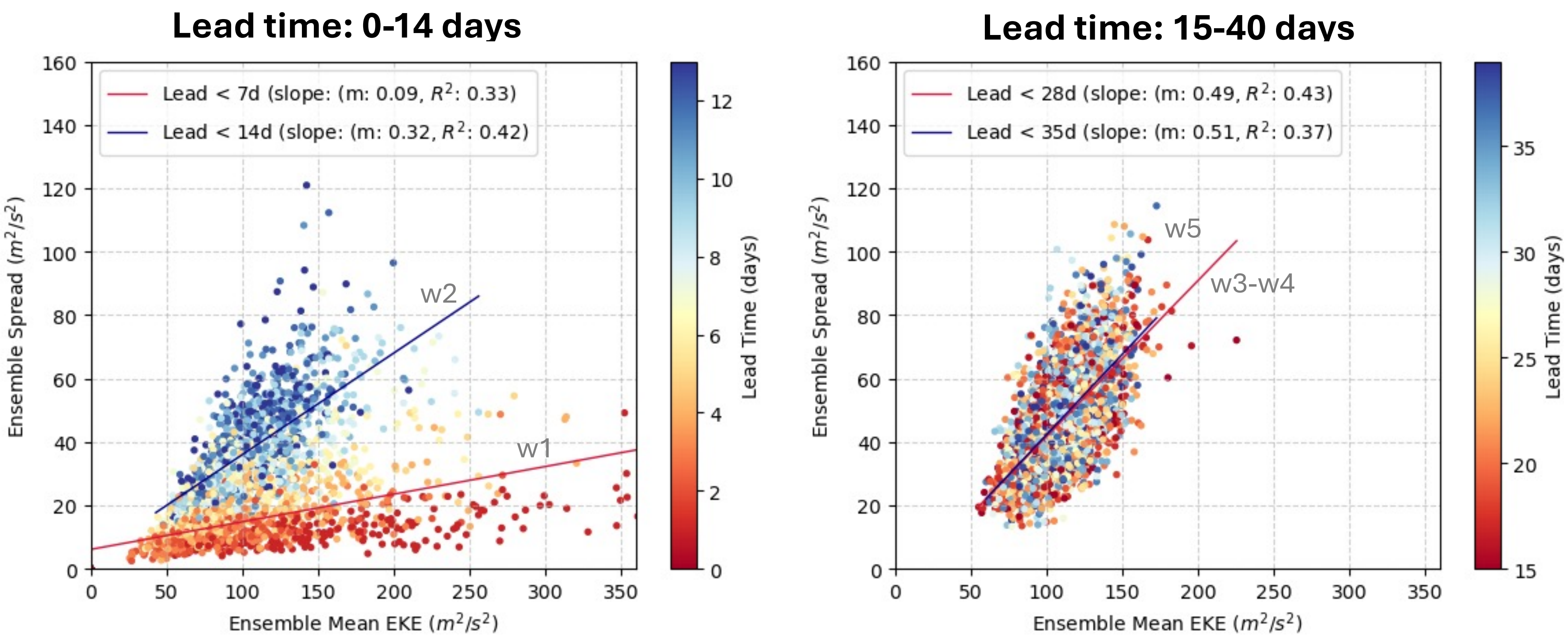


- **EKE ensemble spread is found to be linearly related to the ensemble mean.**
- Slope varies with lead time:
  - Up to 14 days, steeper slope for longer lead times (dark blue) vs. short lead time (red).
  - Beyond 14 days, spread-mean relationship remains rather similar.

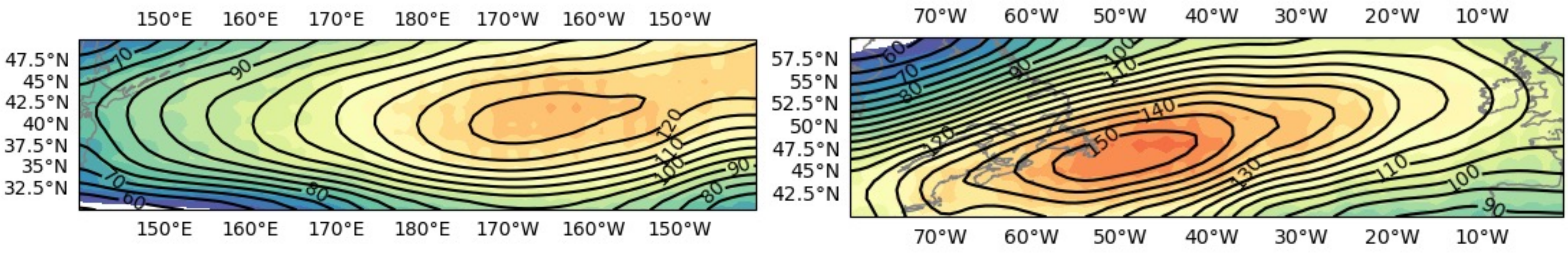
EKE at 300 hPa; Data: ECMWF subseasonal reforecasts

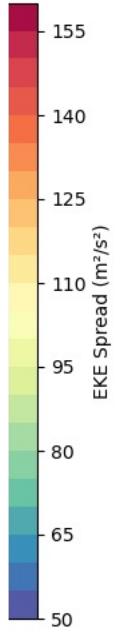
North Atlantic: 280^{o}-360^{o}E
North Pacific: 140^{o}-220^{o}E

Ensemble spread is largest over the storm track peak regions

EKE ensemble **spread** (color) vs. **mean** (in black)

Pacific **Atlantic**





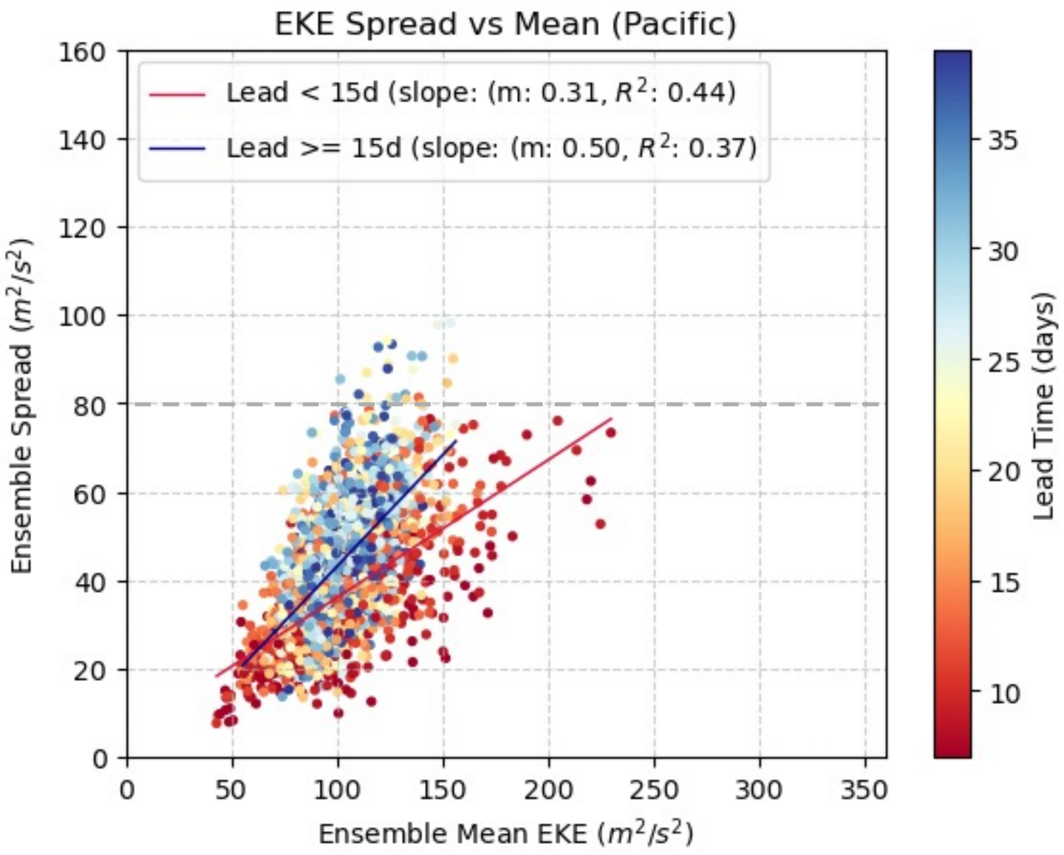
- Strong geographical association between **storm track EKE** and **forecast spread**
- For January-February initializations, EKE spread in the North Atlantic is larger compared to the North Pacific, and is located more poleward and westward.
- In both basins, the stronger EKE is, the larger is the spread.

EKE ensemble spread and mean are averaged over lead times 15-30 days. Data: ECMWF subseasonal reforecasts

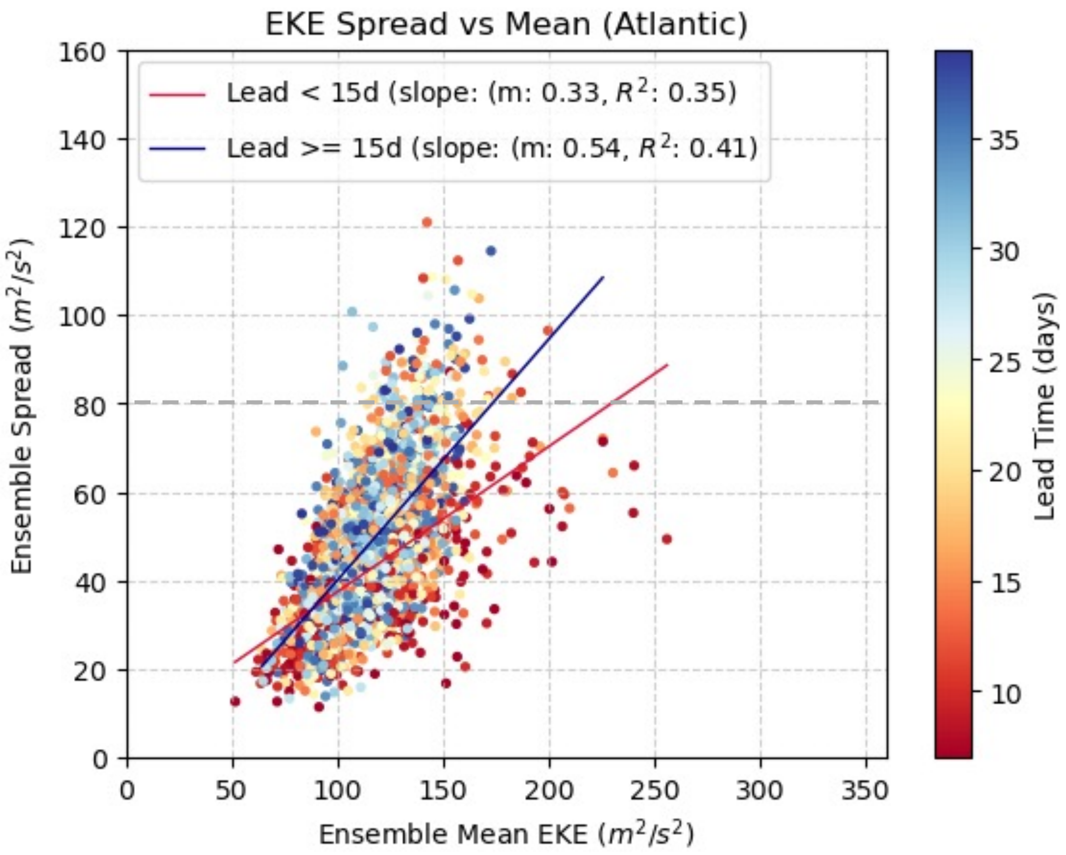
North Atlantic: 280°-360°E
North Pacific: 140°-220°E

Relationship between EKE ensemble spread and mean: Pacific vs. Atlantic

Pacific



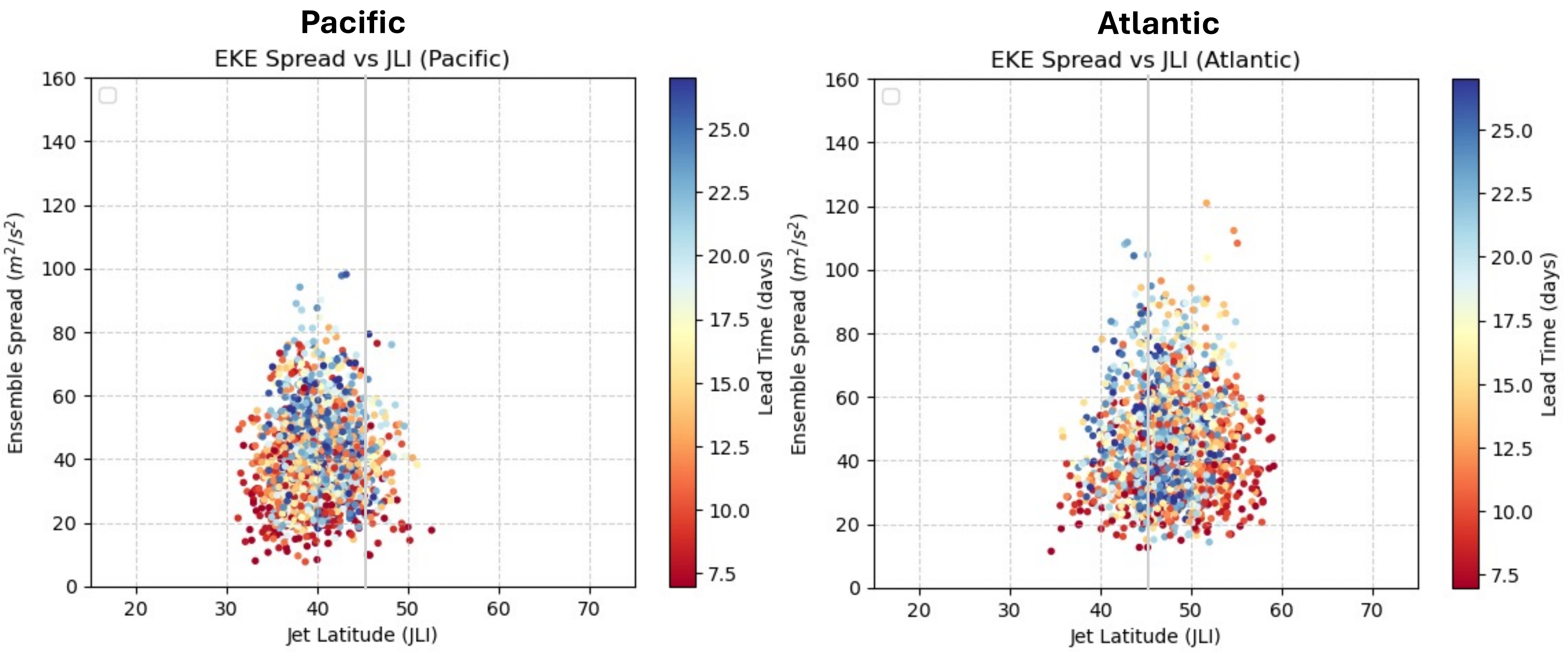
Atlantic



- Periods of enhanced storm activity are linked to higher forecast uncertainty.
- Spread-mean coupling varies between **Pacific** and **Atlantic**: higher storm-related spread in the Atlantic

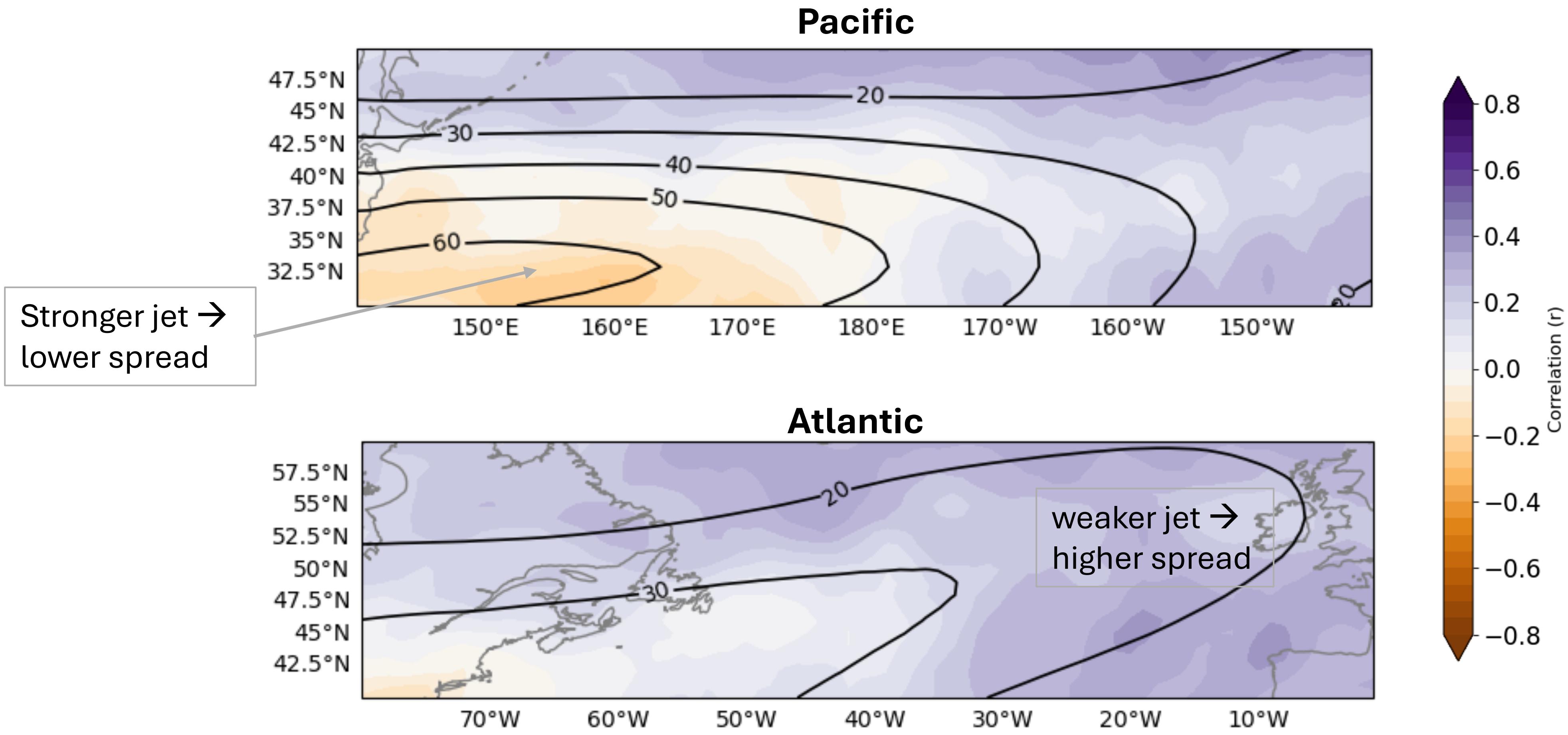
Jet latitude is based on daily maximum of the zonally averaged zonal wind (15°-75°N)

Ensemble spread vs. jet latitude (U850)



- **Pacific:** sharp increase in spread with latitude.
- **Atlantic:** spread is higher for jet latitudes around 45°N, and lower for equatorward or poleward latitudes.
- At subseasonal lead times, the range of jet latitudes becomes narrower, and spread higher.

Correlation between EKE ensemble spread and the jet stream:



- Correlation between **EKE ensemble spread** and **zonal wind (U300) ensemble mean** is negative at the jet core region, particularly in the Pacific, and positive in the exit region.

Correlation coefficient (color shading) and U300 ensemble mean (black contours); Data: ECMWF subseasonal reforecasts;

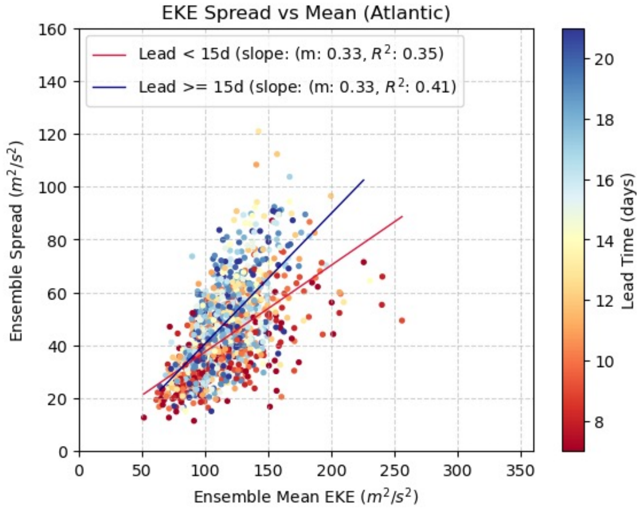
Summary

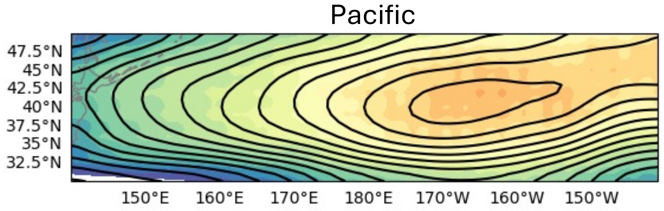
- We find a robust linear, positive relationship between ensemble mean and spread of EKE in both the Pacific and Atlantic sectors, suggesting the contribution of synoptic-scale storms for reliable forecasts.

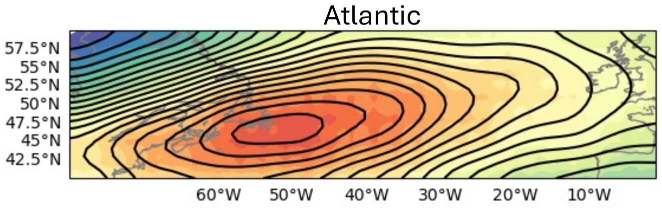
- **Variance scales with the mean:** periods of enhanced storm activity are associated with larger forecast uncertainty.

- Spread-mean coupling varies between **Pacific** and **Atlantic**: higher storm-related spread in the Atlantic for lower-level jet latitude at 45N, suggesting a non-trivial role of synoptic storms in affecting forecast uncertainty.

- Large-scale variation of the storm track, such as those associated with teleconnections (e.g., stratospheric polar vortex, e.g., Speath et al. 2024) are expected to modulate ensemble spread and thereby induce **flow-dependent variations** in predictability.







These findings highlight the relevance of **storm track diagnostics** and **EKE-based spread metrics** as promising tools to improve forecast accuracy and enhance early warning capabilities for high-impact midlatitude storms.

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