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A daily estimate of phase speed to explore the link between Arctic Amplification and Rossby waves

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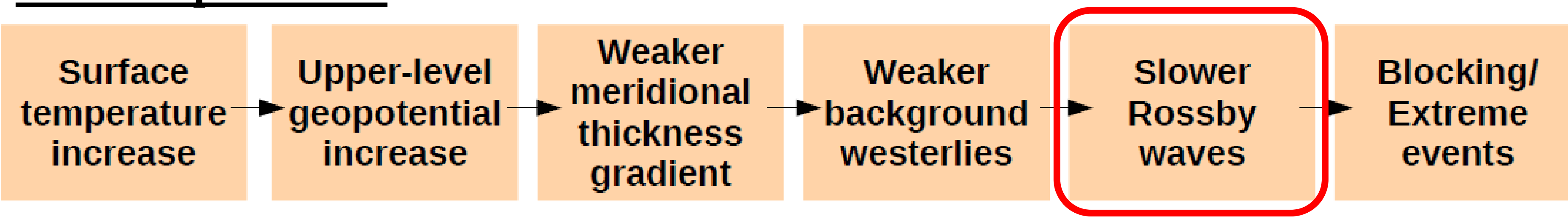
Motivation

Enhanced Arctic warming with respect to midlatitudes (Arctic Amplification) can slow down eastward Rossby wave propagation and induce extreme weather events (Francis and Vavrus 2012, Cohen et al. 2020).

Chain of processes:



How to assess whether Rossby waves have become slower?

$$c_p = \frac{\omega}{k} = \frac{\omega a \cos(\phi)}{n}$$

Problem: many waves with different ω and k co-exist in the atmosphere: how to obtain a global value?

Objectives:

1) **Develop a phase speed diagnostic accounting for midlatitude Rossby waves variability (e.g., blocking).**
2) **Assess whether Arctic Amplification impacted phase speed trends.**

Daily phase speed diagnostic

Superposition principle:

<u>Large-scale flow evolution results from a superposition of waves</u> across a broad range of wavenumbers and frequencies (and, therefore, of phase speeds).

Spectral analysis tells us how much each (n,c_p) harmonic contributes to the overall phase speed.

Phase speed metric

$$c = \frac{\sum_{n=1}^{15} \sum_{c_p=-30}^{30} S(n, c_p) \cdot c_p}{\sum_{n=1}^{15} \sum_{c_p=-30}^{30} S(n, c_p)}$$

Sum over wavenumbers and phase speeds

Spectral coefficients as weights

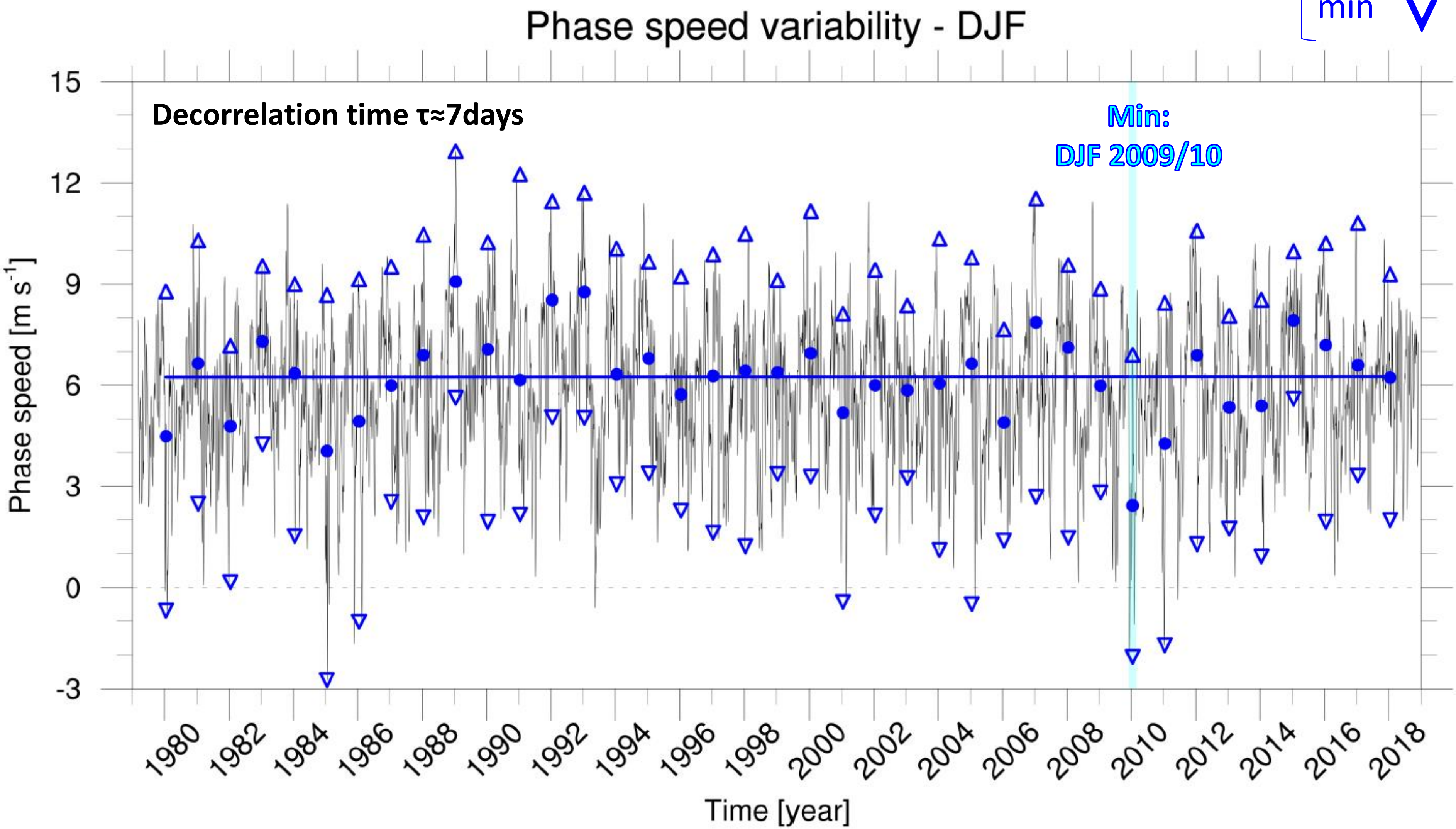
n	a-dimensional zonal wavenumber
c_p	phase speed
$S(n,c_p)$	spectral coefficients of <u>meridional wind</u> for 61 days period (37 days with tapering), as in Randel and Held (1991).

Daily phase speed diagnostic

Daily phase speed evolution from Feb. 1979 to Aug. 2018

Blue line is linear regression (trend is absent, $p<0.01$).

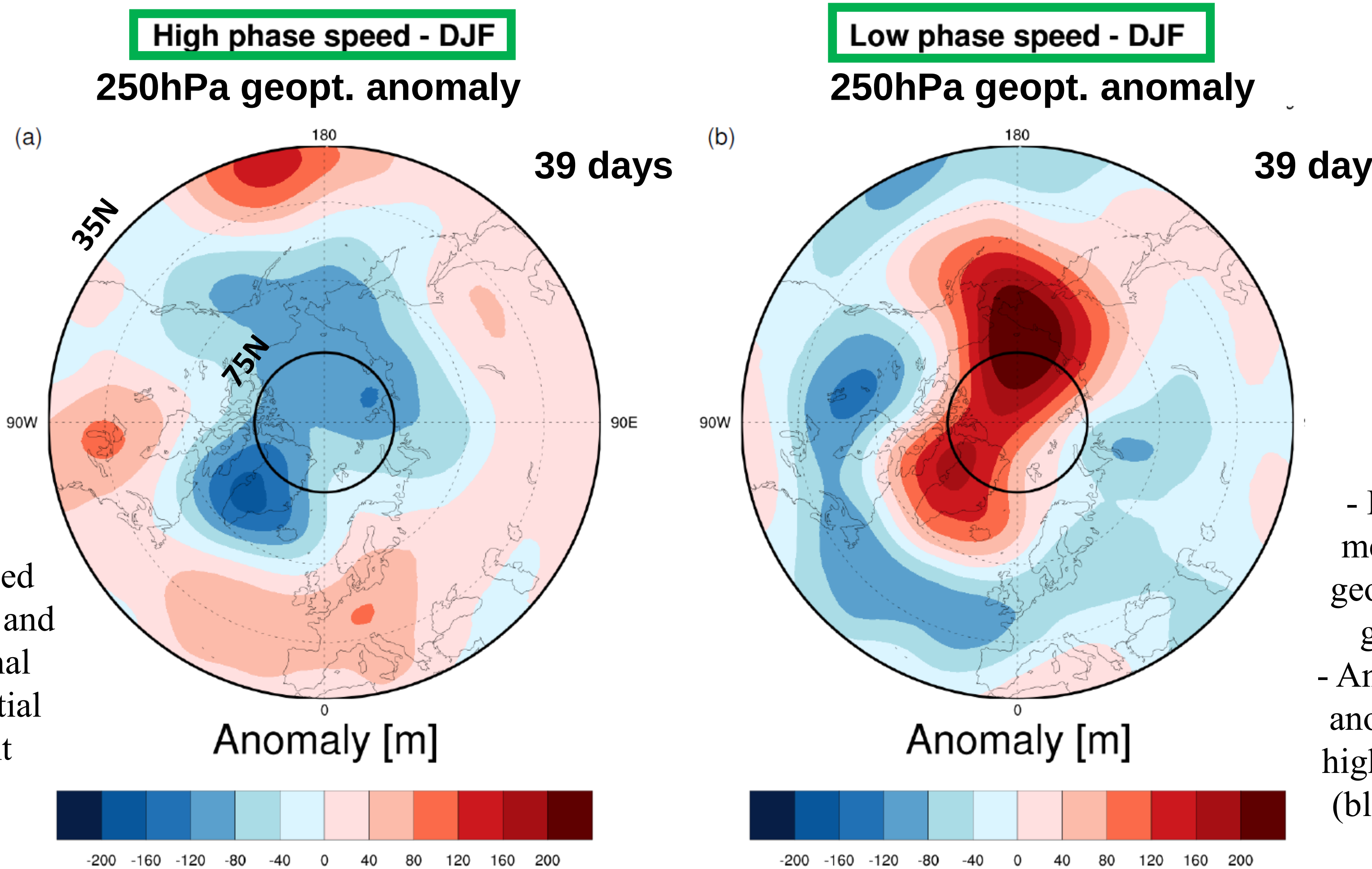
Seasonal: max △, mean ●, min ▽



Large-scale circulation during high/low phase speed days

DJF 1979/80→2017/18 (39 winters): composite for the day of maximum and minimum phase speed in each winter.

Low phase speed days correspond to anomalously high blocking activity [(hyperlink)](#) and to extreme temperature events over midlatitudes, especially in winter [(hyperlink)](#).



- Enhanced westerlies and meridional geopotential gradient

- Reduced meridional geopotential gradient
- Anticyclonic anomalies at high latitudes (blocking ?)

Riboldi et al. 2020, in review (GRL)

Arctic Amplification and phase speed trends (1)

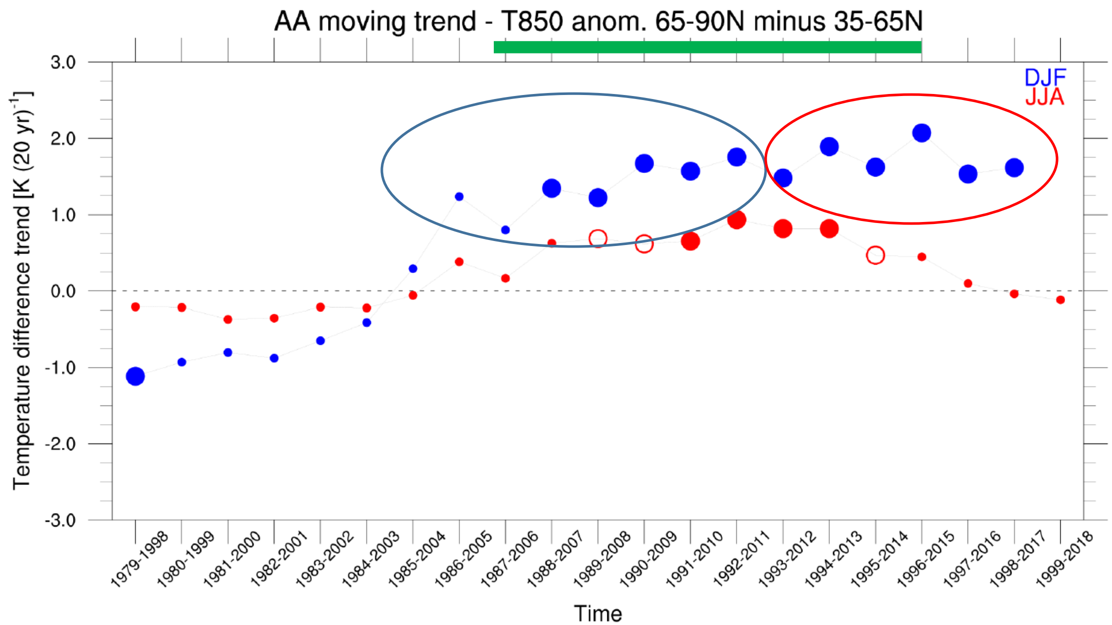
p-value > 0.95 ●
p-value > 0.90 ○

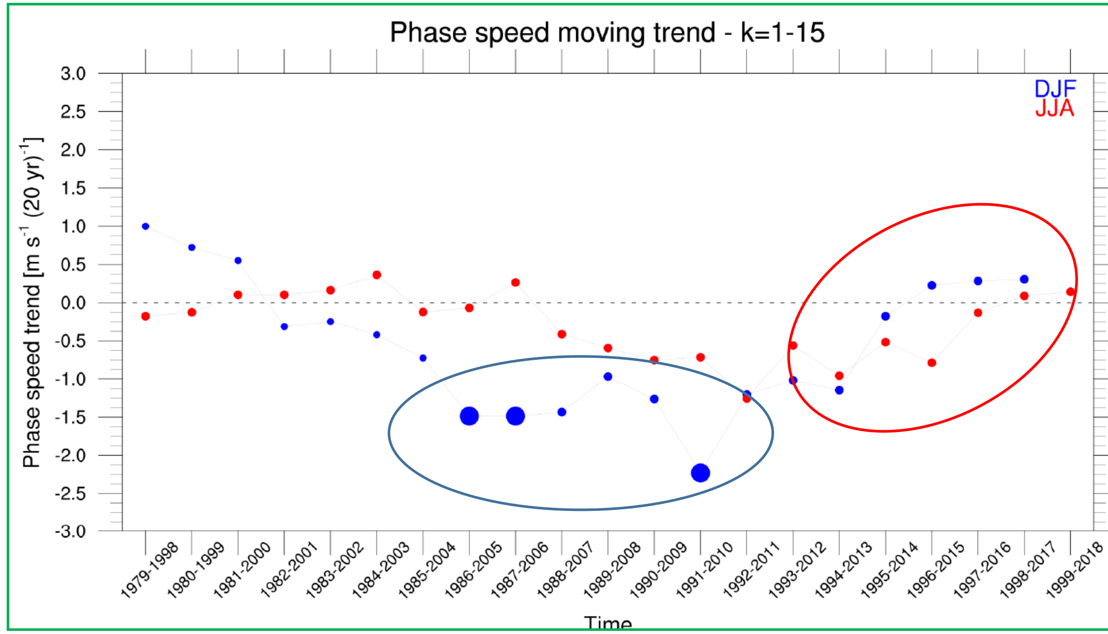
Trends over consecutive 20-year periods: T850 anom difference <u>vs</u> phase speed

- Day-to-day Pearson correlation
  r (*c*, T850 anom.) = -0.39

- <u>Arctic-to-midlatitude T850 difference (hyperlink)</u> consistently increasing since 1988-2007 period (Arctic Amplification).

- <u>No corresponding phase speed trend.</u> Significant negative trend in 1991-2010 period (likely because of extreme 2009/2010 winter).





Riboldi et al. 2020, in review (GRL)

Arctic Amplification and phase speed trends (2)

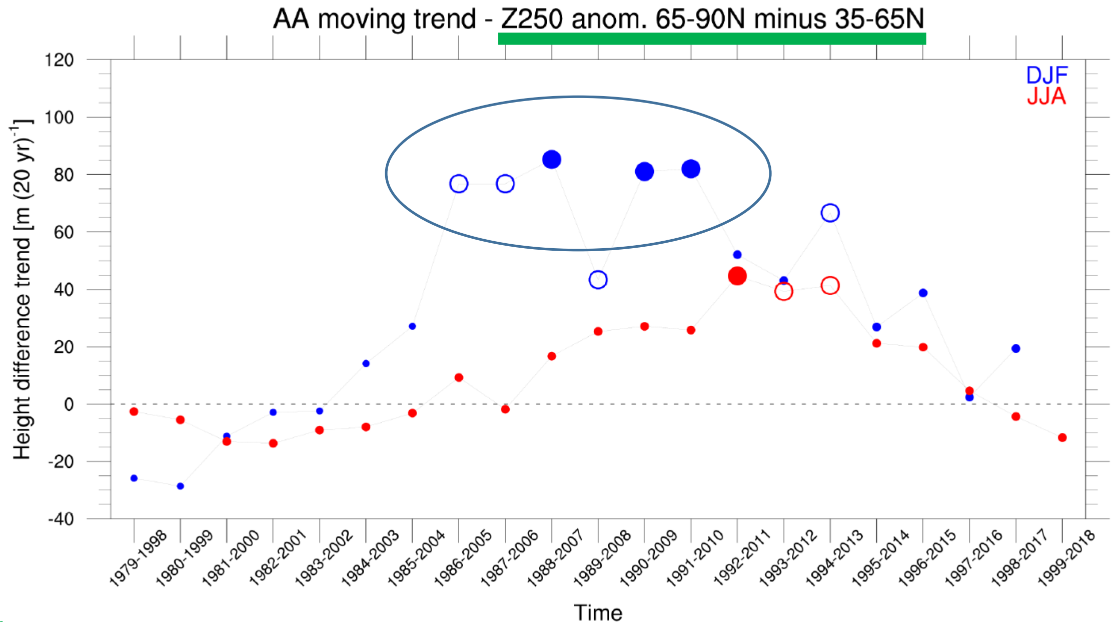
p-value > 0.95 ●
p-value > 0.90 ○

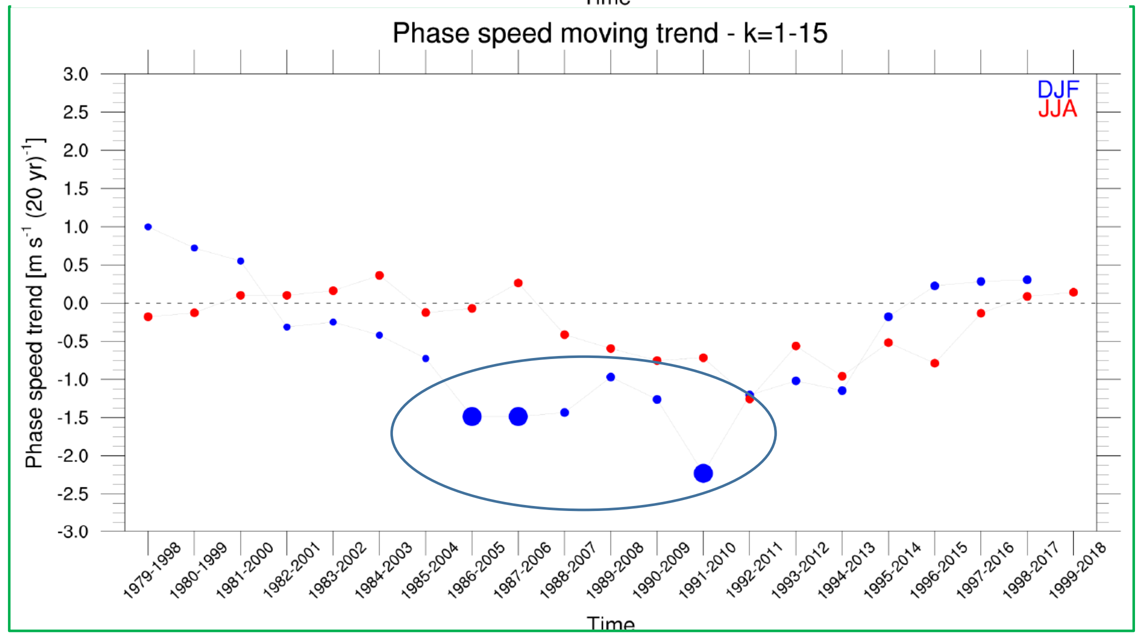
Trends over consecutive 20-year periods: Z250 anom difference <u>vs</u> phase speed

- Day-to-day Pearson correlation $r(c, \text{Z250 anom.}) = \mathbf{-0.70}$

- [Arctic-to-midlatitude Z250 anomaly (hyperlink)] trends occur in similar periods as phase speed trends.

- <u>Phase speed trend follows evolution of Z250 gradient, rather than of T850.</u>





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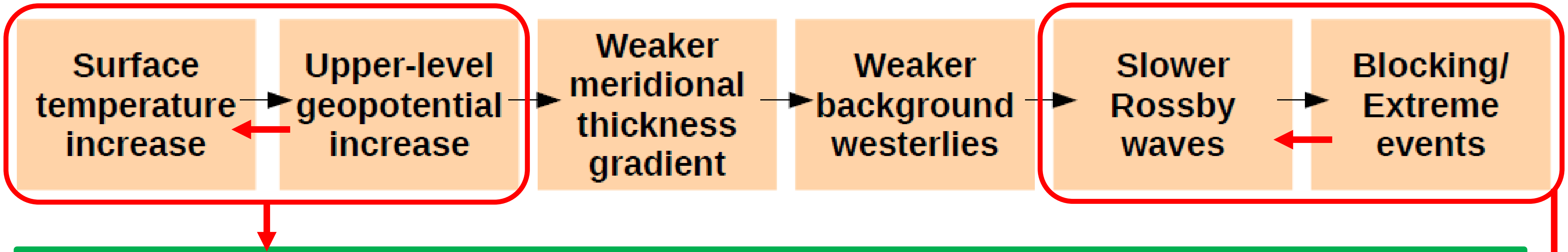
Conclusions



- **Reduction of low-level meridional T gradient not related to reduction in Rossby wave phase speed.**

  Apparent thermal wind violation, but consistent with eddy-driving of the polar jet.

  Extratropical variability has affected phase speed more strongly than Arctic Amplification.

- **Conversely, Rossby wave phase speed correlates well with upper-level geopotential gradient and blocking activity.**

  Upper-level processes modulate Rossby wave phase speed, rather than low-levels.

  Atmospheric blocking, related to meridional geopotential gradient reversal, can modulate phase speed variability.

Thanks for your attention!

Bibliography

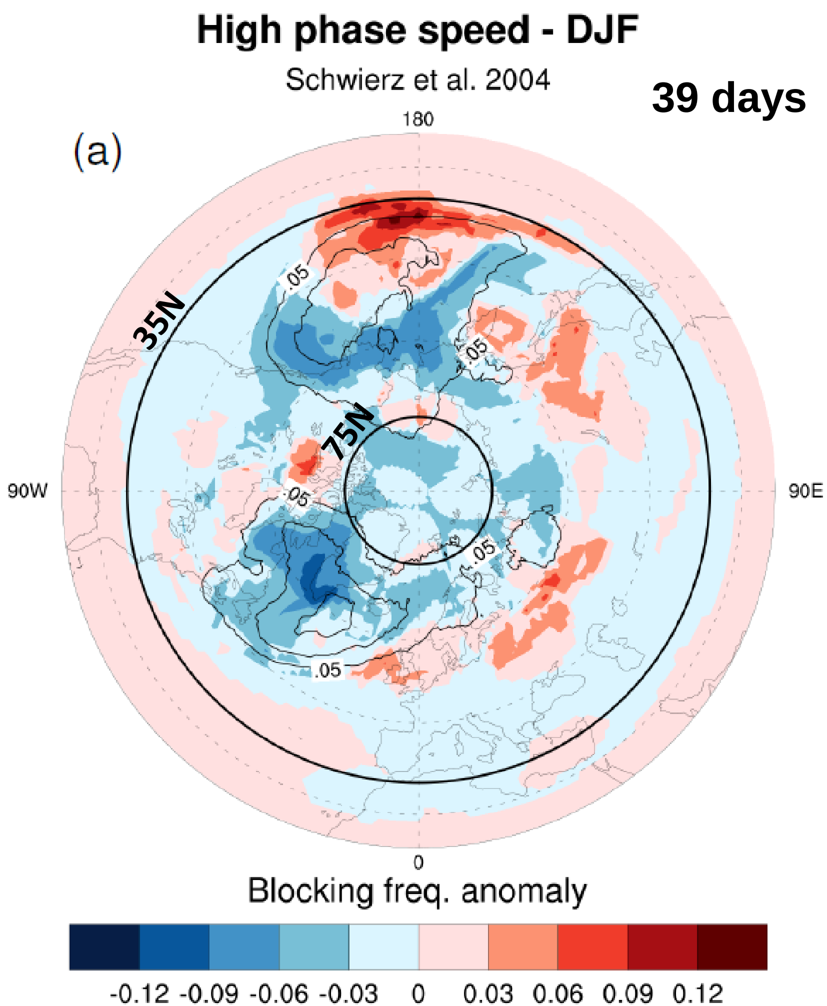
- Francis, J. A., and Vavrus, S. J. (2012), Evidence linking Arctic amplification to extreme weather in mid-latitudes, *Geophys. Res. Lett.*, 39, L06801, doi:10.1029/2012GL051000.

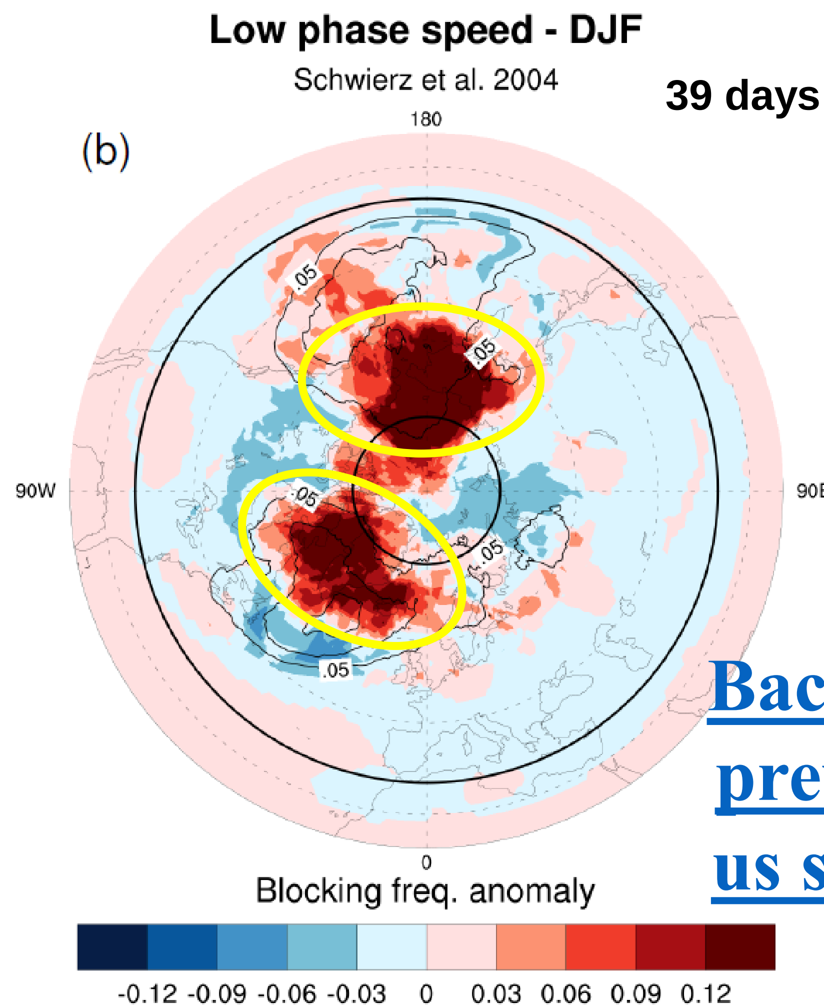
- Cohen J., Zhang X., Francis J., et al. ARCTIC CHANGE AND POSSIBLE INFLUENCE ON MID-LATITUDE CLIMATE AND WEATHER: A US CLIVAR White Paper. *US CLIVAR Rep*. (2018) doi:10.5065/D6TH8KGW

LINKED SLIDES

Atmospheric blocking during high/low phase speed days

Low phase speed occurrence is linked to positive blocking frequency anomalies at the end of the storm tracks (consistent across blocking indices).





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Blocking diagnostics from ETH Zürich (Sprenger et al. 2017).

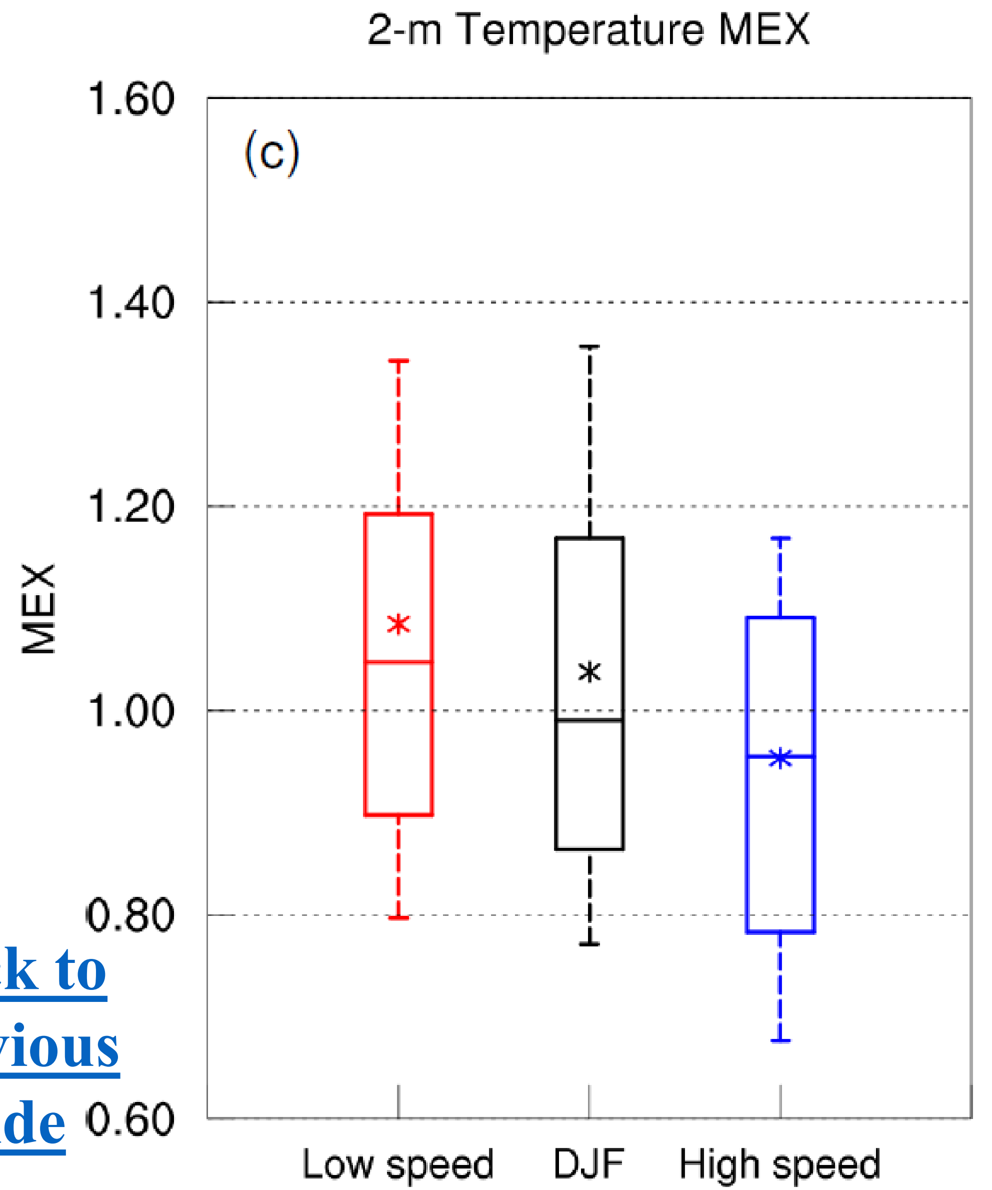
Riboldi et al. 2020, in review (GRL)

Extreme temperatures during high/low phase speed days

Midlatitude EXtreme (MEX) index: Areally averaged (over N gridpoints between 35°N and 75°N) squared standardized 2-m temperature anomalies (see also Coumou et al. 2014).

$$MEX(x,t) = \frac{1}{N}\sum_{i}^{N}\left(\frac{x_i(t) - \overline{x_i(t)}}{\overline{\sigma}(x_i(t))}\right)^2$$

Low phase speed → high MEX values → stronger/more extended temperature anomalies than normal.



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MEX definition:

Coumou D., Petoukhov V., Rahmstorf S., Petri S., Schellnhuber H. J.: *Quasi-resonant circulation and extreme weather* PNAS, (2014) DOI: 10.1073/pnas.1412797111

Arctic Amplification and phase speed trends

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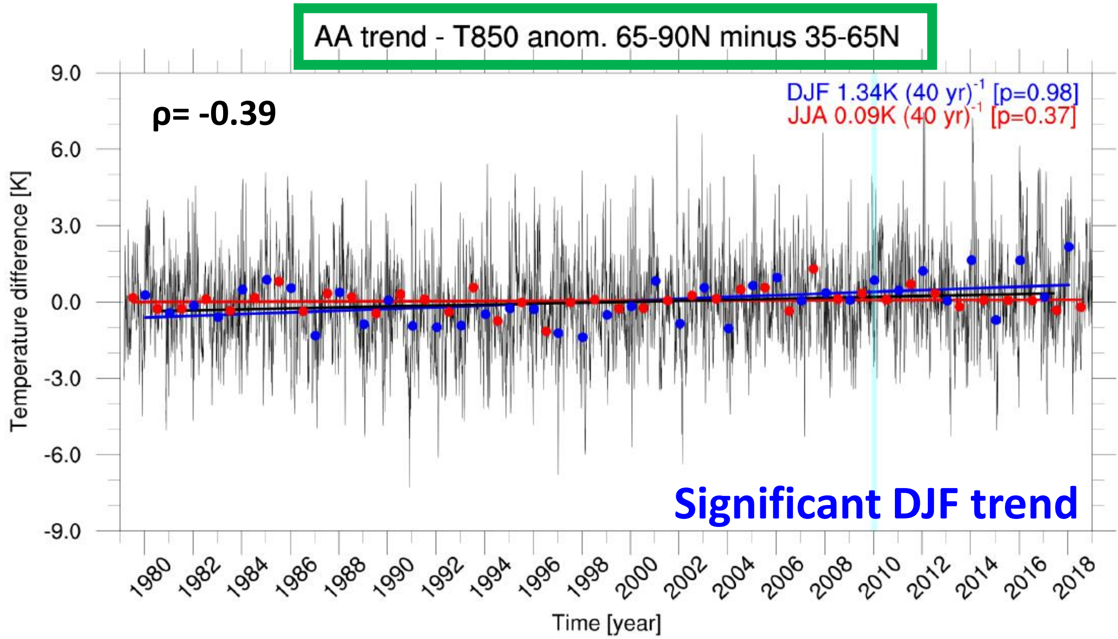
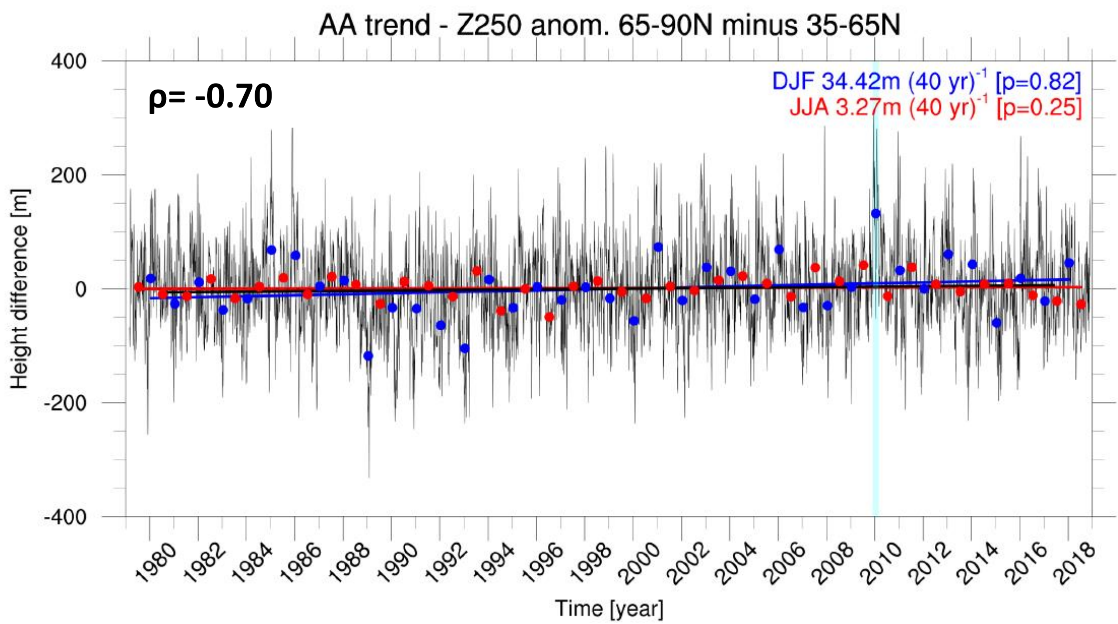
Two different Arctic Amplification metrics:

1) **Thermal metric:** 850hPa temperature anomaly difference (65°N-90°N minus 35-65°N)

2) **Dynamical metric:** 250hPa geopotential anomaly difference (65°N-90°N minus 35-65°N)





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Arctic Amplification and phase speed trends

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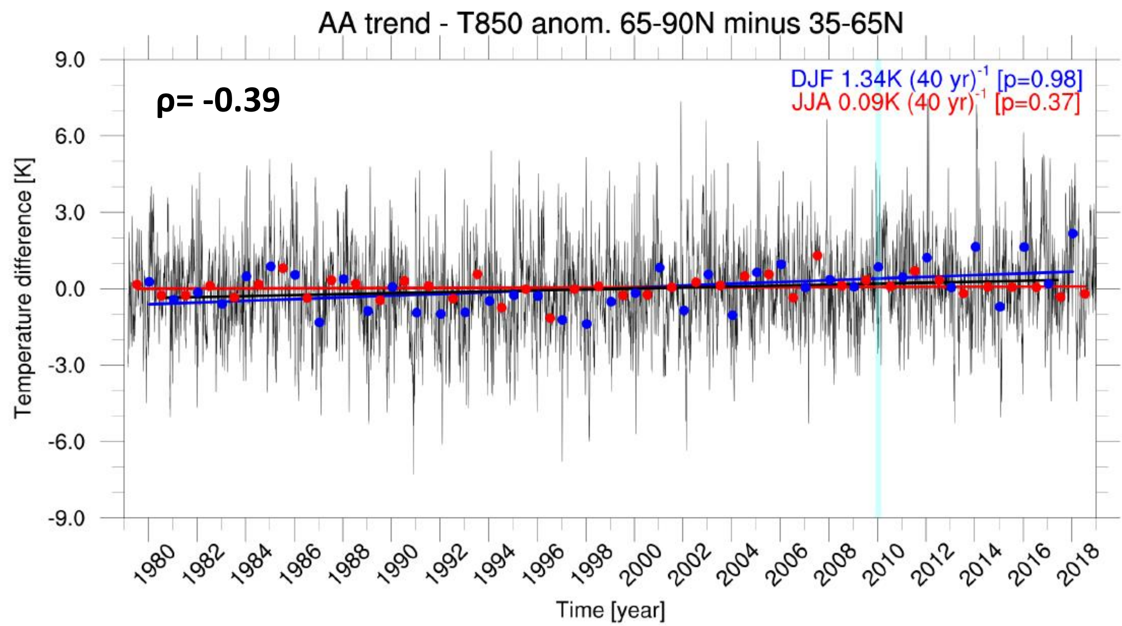

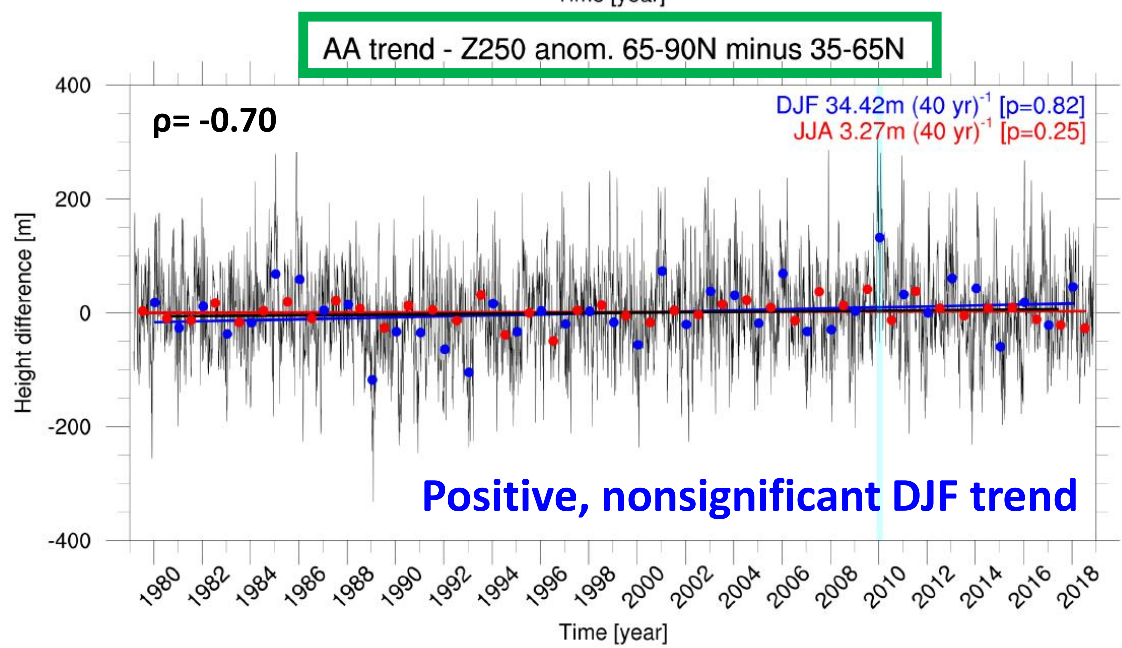

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