The influence of Arctic warming on the midlatitude jet-stream:

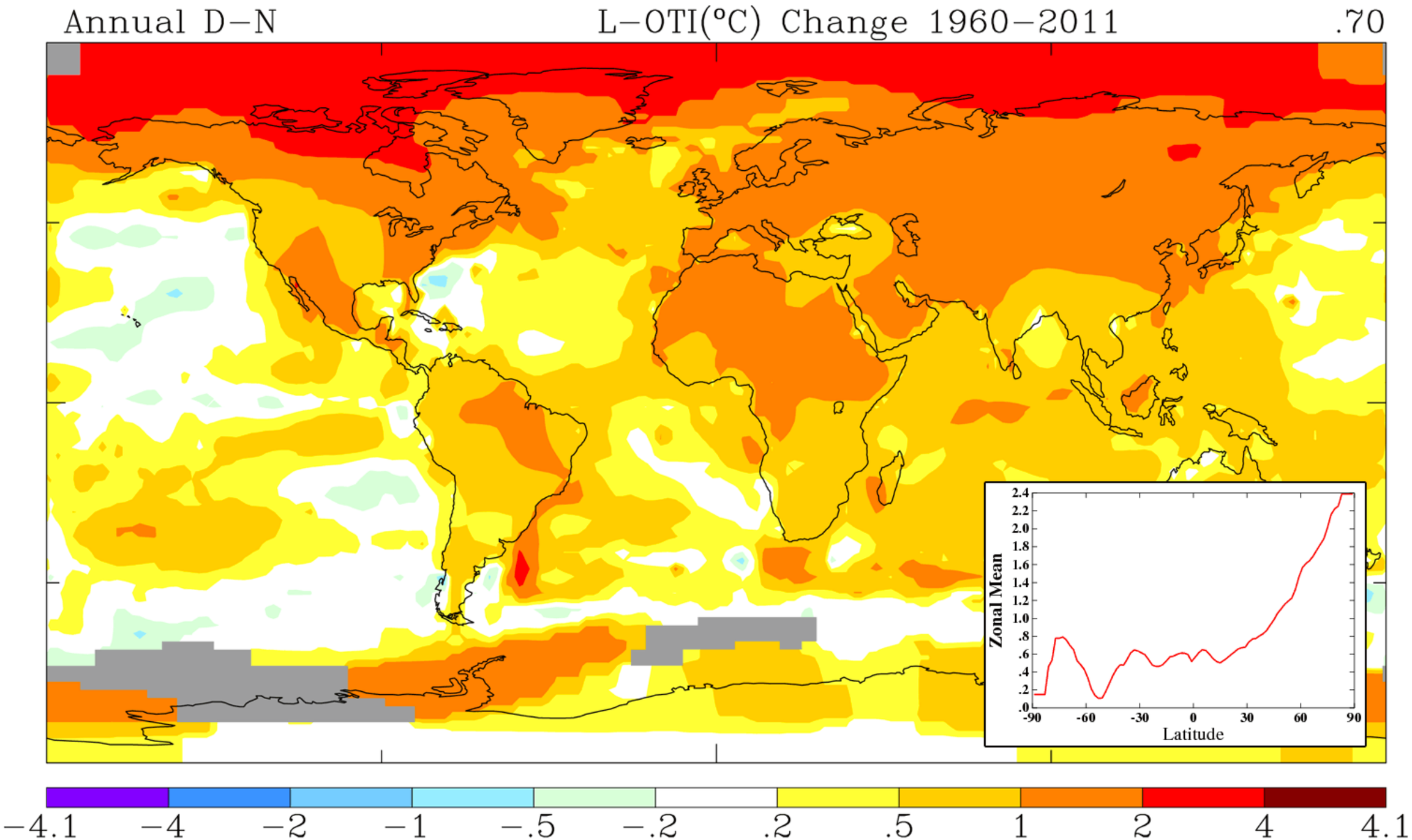
Can it? Has it? Will it?

Elizabeth A. Barnes
Colorado State University

with much help and input from my collaborators:

Marie McGraw, CSU
James Screen, U. of Exeter
Lorenzo Polvani, Columbia U.
Etienne Dunn-Sigouin, Columbia U.
Giacomo Masato, U. of Reading
Tim Woollings, Oxford

The Arctic is warming



NASA GISS

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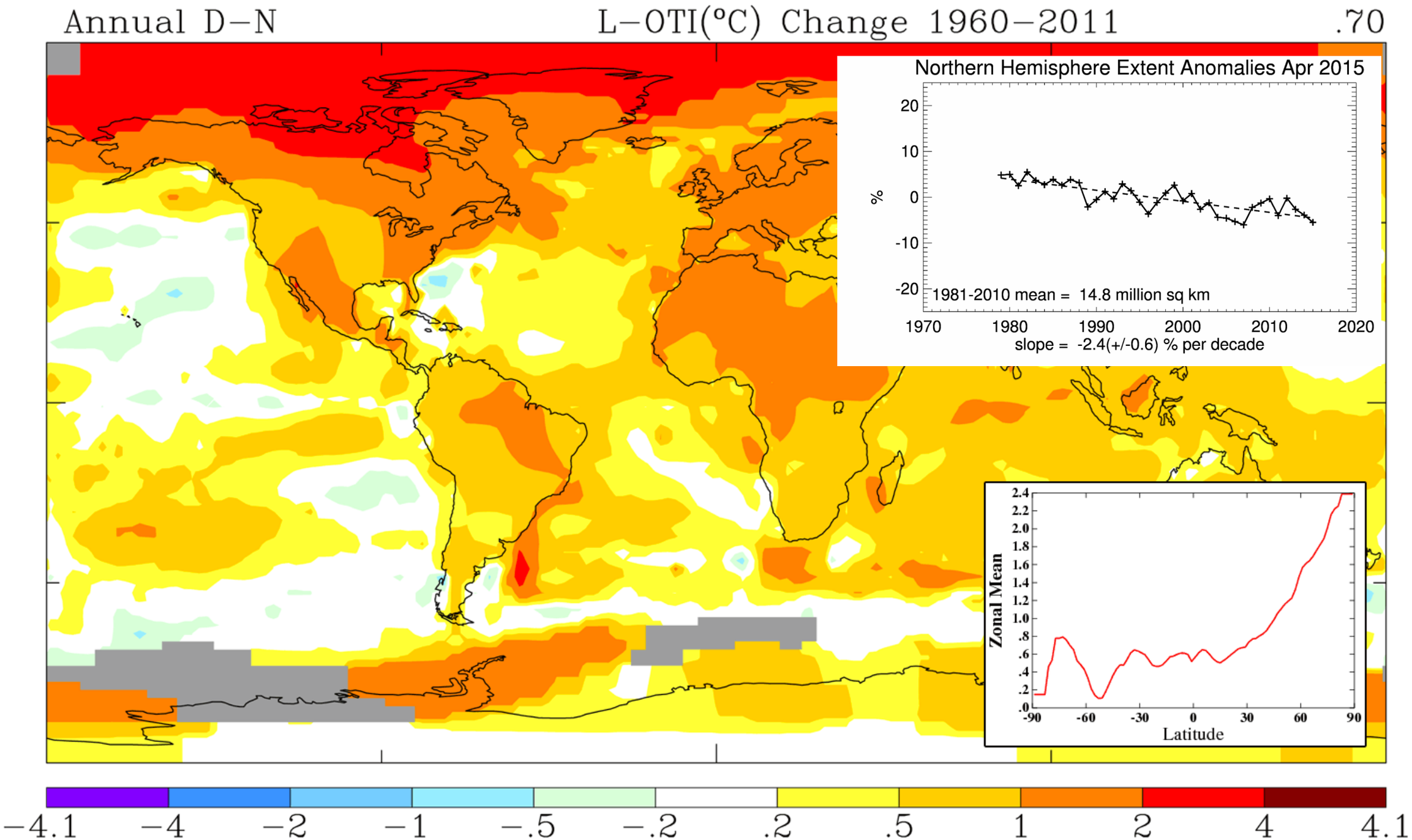
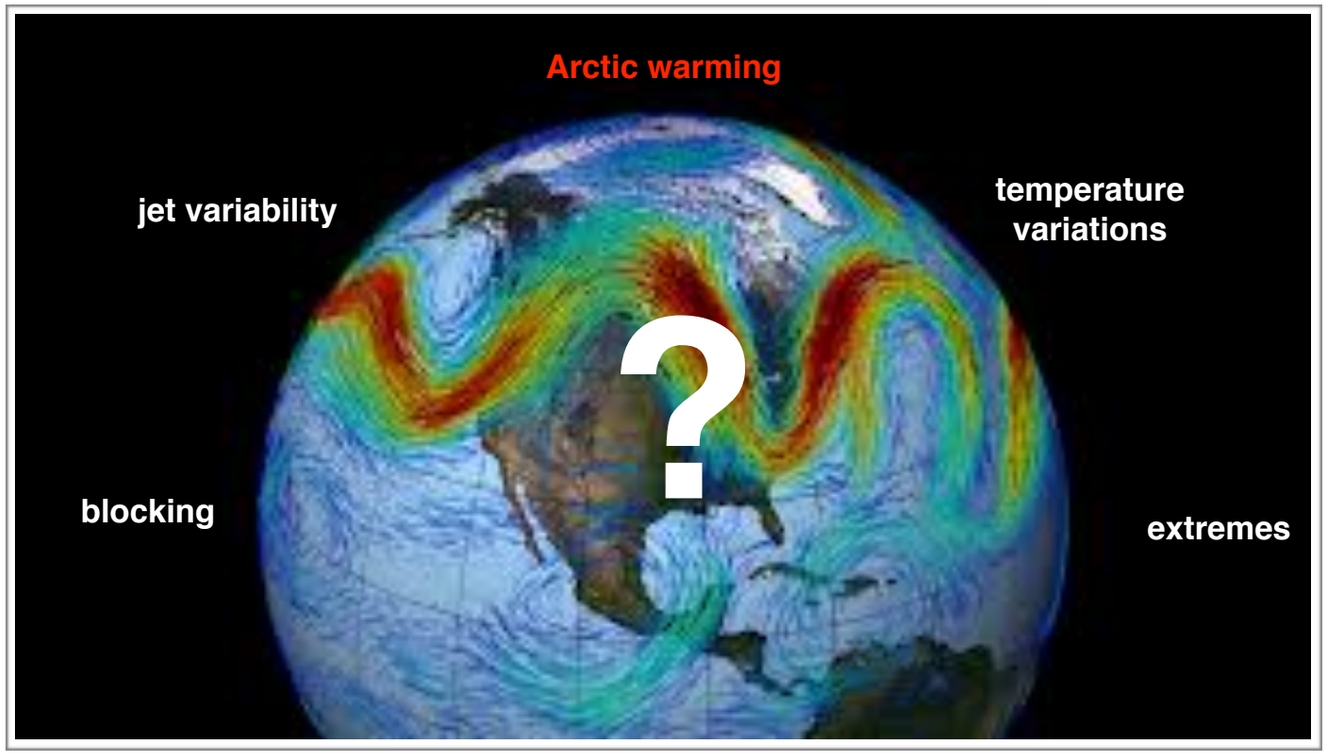


NASA GISS

Some suggested effects of Arctic warming

- slower jet-stream
- equatorward jet-stream (-NAO)
- slower wave propagation
- higher amplitude Rossby waves
- more frequent blocking

… just to name a few



Globe image from NASA/Goddard Space Flight Center Scientific Visualization Studio

3 distinct questions

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(1) **Can** Arctic warming influence the midlatitude jetstream?

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(2) **Has** Arctic warming significantly influenced the midlatitude jetstream?

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(1) **Can** Arctic warming influence the midlatitude jetstream?

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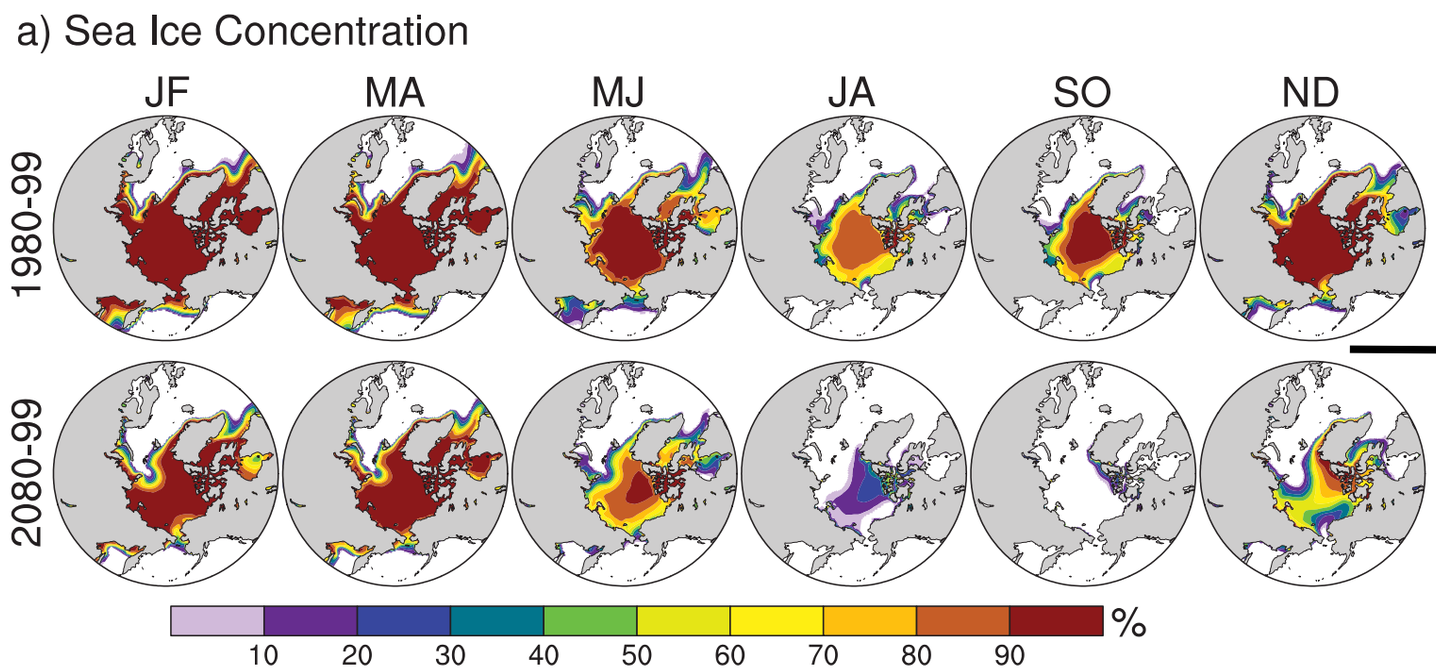
(3) **Will** Arctic warming significantly influence the midlatitude jetstream?

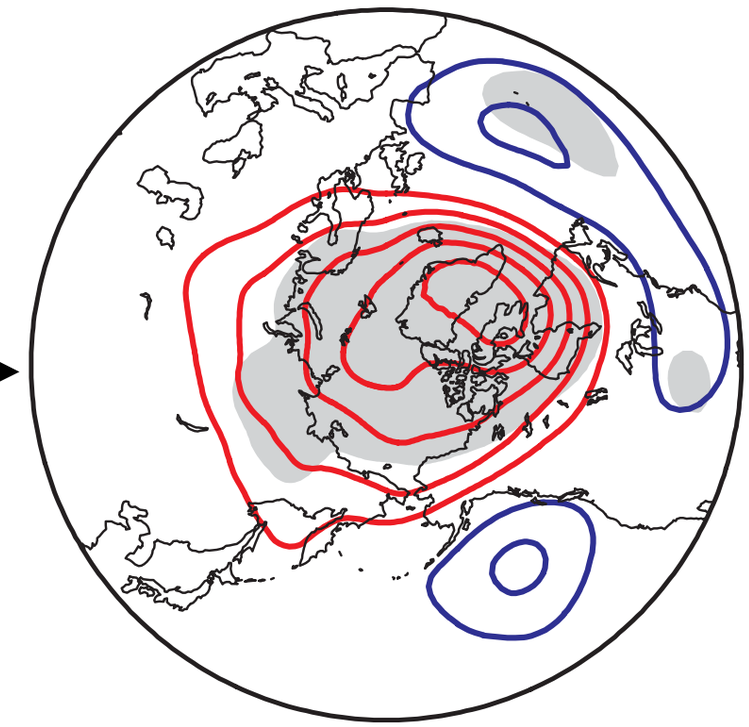
Can Arctic warming influence the midlatitude jetstream?

Model simulations & theory

Modeling evidence



500 hPa geopotential height response in Jan.-Feb.

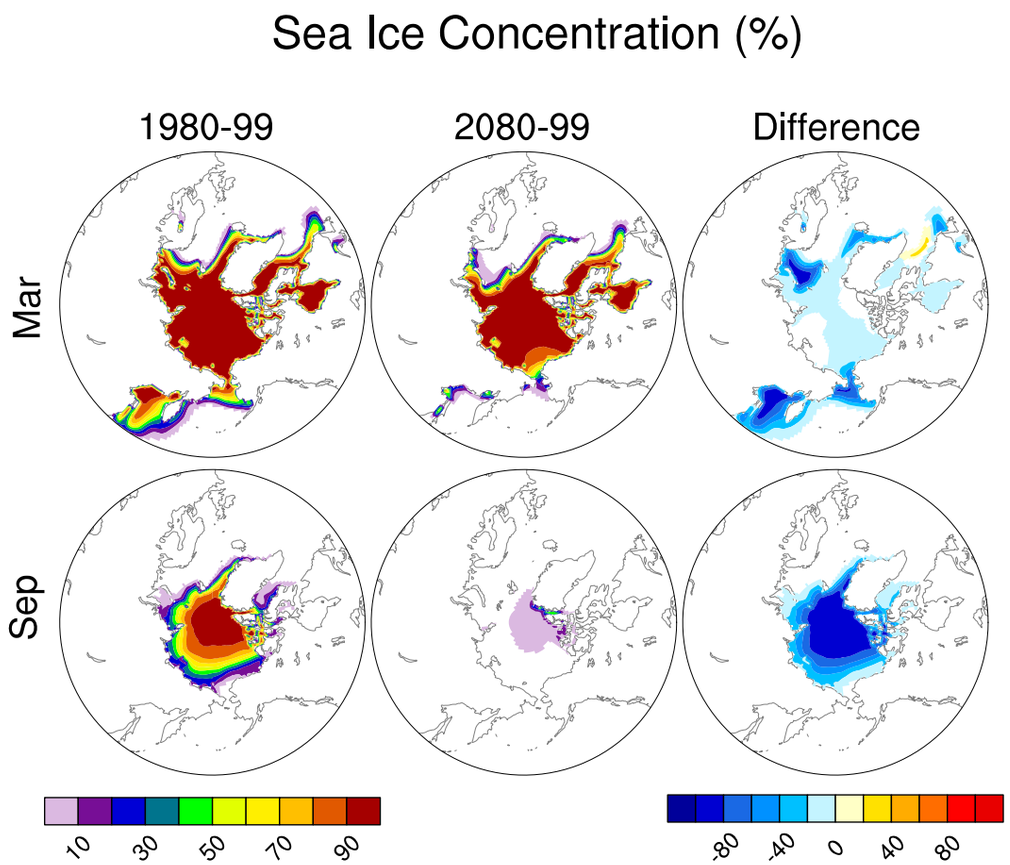


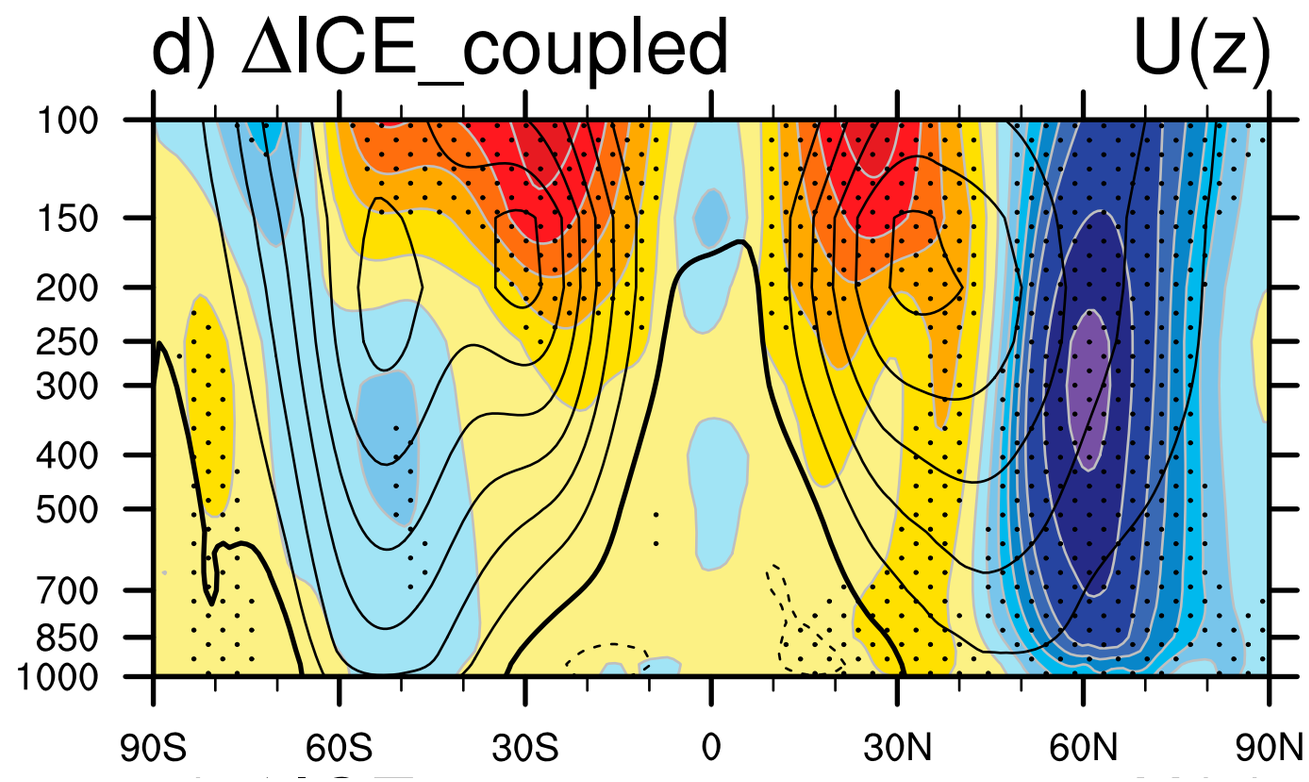
-NAO pattern
(equatorward jet shift)

dozens of atmosphere-only GCM studies have demonstrated that removing Arctic sea ice can influence the midlatitude circulation

atmosphere-only CAM3 simulations
Deser, Tomas, et al. (2010; JCLI)

Modeling evidence





-NAO pattern
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recent coupled GCM experiments also demonstrate a midlatitude response

coupled CCSM4 simulations
with additional long wave radiative fluxes in the ice model
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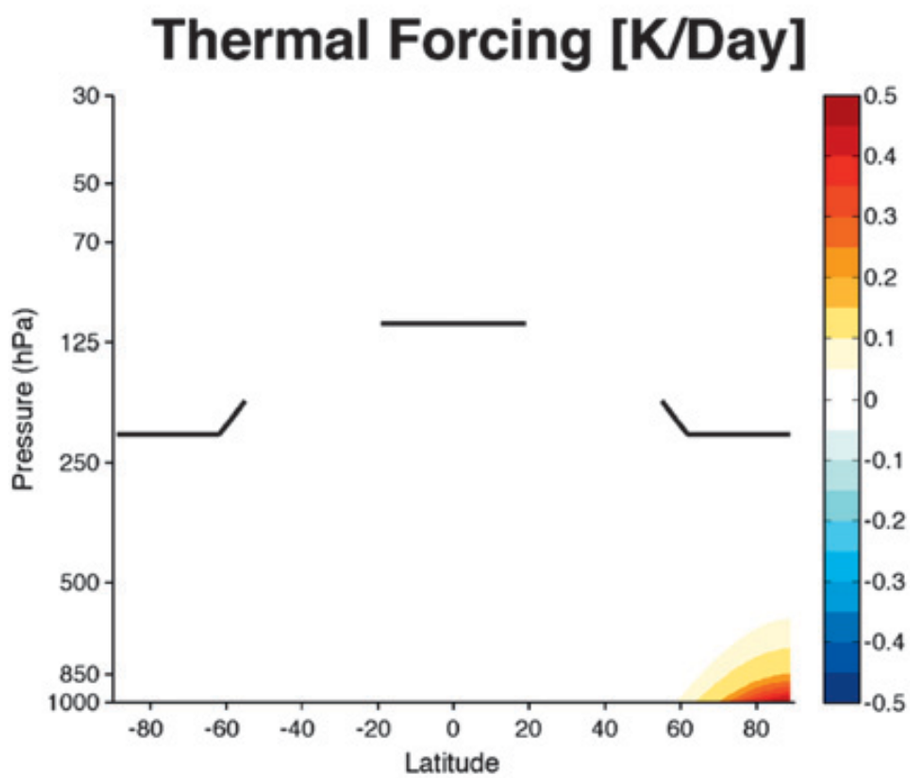
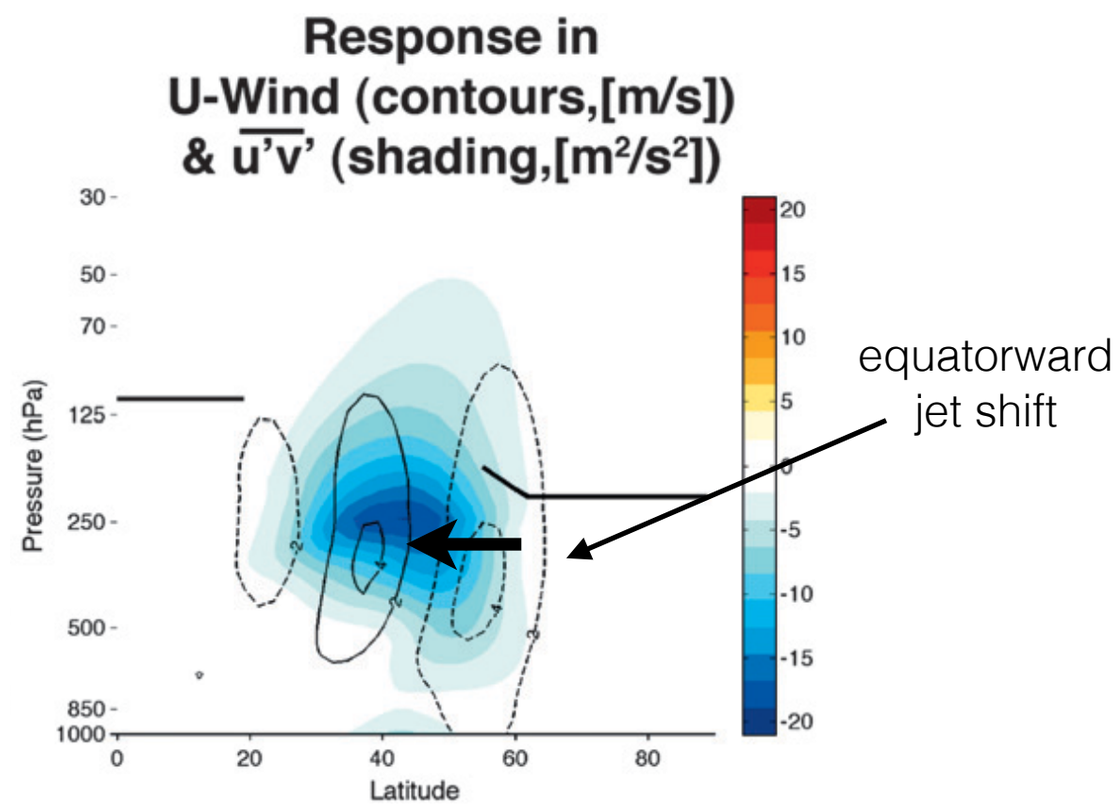


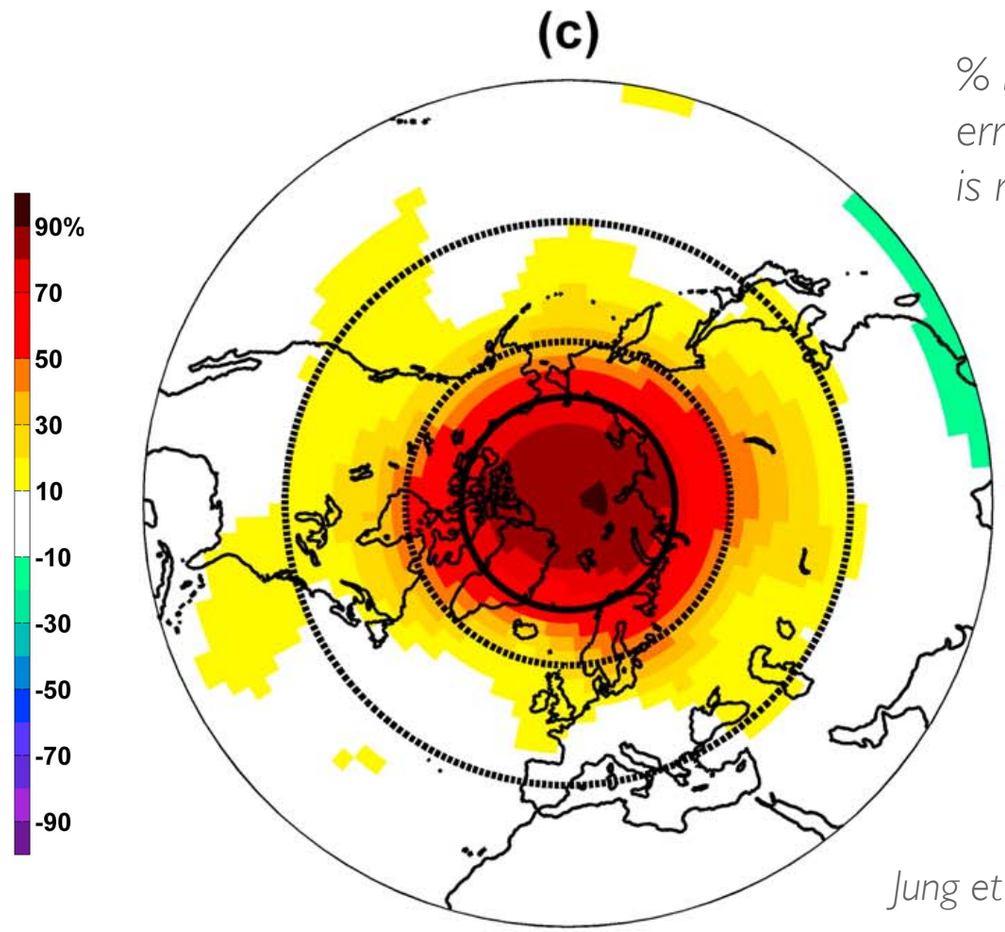
simulations of a dry, dynamical core with imposed polar surface heating under perpetual equinox conditions



Butler, Thompson et al. (2010)

idealized modeling studies with polar heating show an equatorward jet shift when polar cap is heated

Forecast approach



% reduction in RMS forecast error for days 11-30 when Arctic is relaxed toward reanalysis

Jung et al. (2014; GRL)

- Forecast experiments with ECMWF model shows that knowledge of the Arctic state can improve forecasts in mid- to high latitudes

- Lowest improvement over the oceans where atmospheric variability is large

Can it?

Can it?

- **Yes.** There is substantial model evidence of an influence.

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- but…. **How?** multiple hypotheses have been suggested:
    - reduced meridional temperature gradient
    - a more sinuous jet-stream
    - trapped atmospheric waves by a split-jet
    - locally modified storm tracks
    - weakened stratospheric polar vortex

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many open research questions!

That the Arctic **can** influence the midlatitude circulation does not imply that it **has** in a significant way, nor does it imply that it **will** in the future.

Has Arctic warming significantly influenced the midlatitude jetstream?

Observational Evidence

Headlines

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Arctic Warming is Altering Weather Patterns, Study Shows

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Rapidly Warming Arctic Leading to Deadly Extreme Weather Events

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Superstorm Sandy

A Series of Unfortunate Events?

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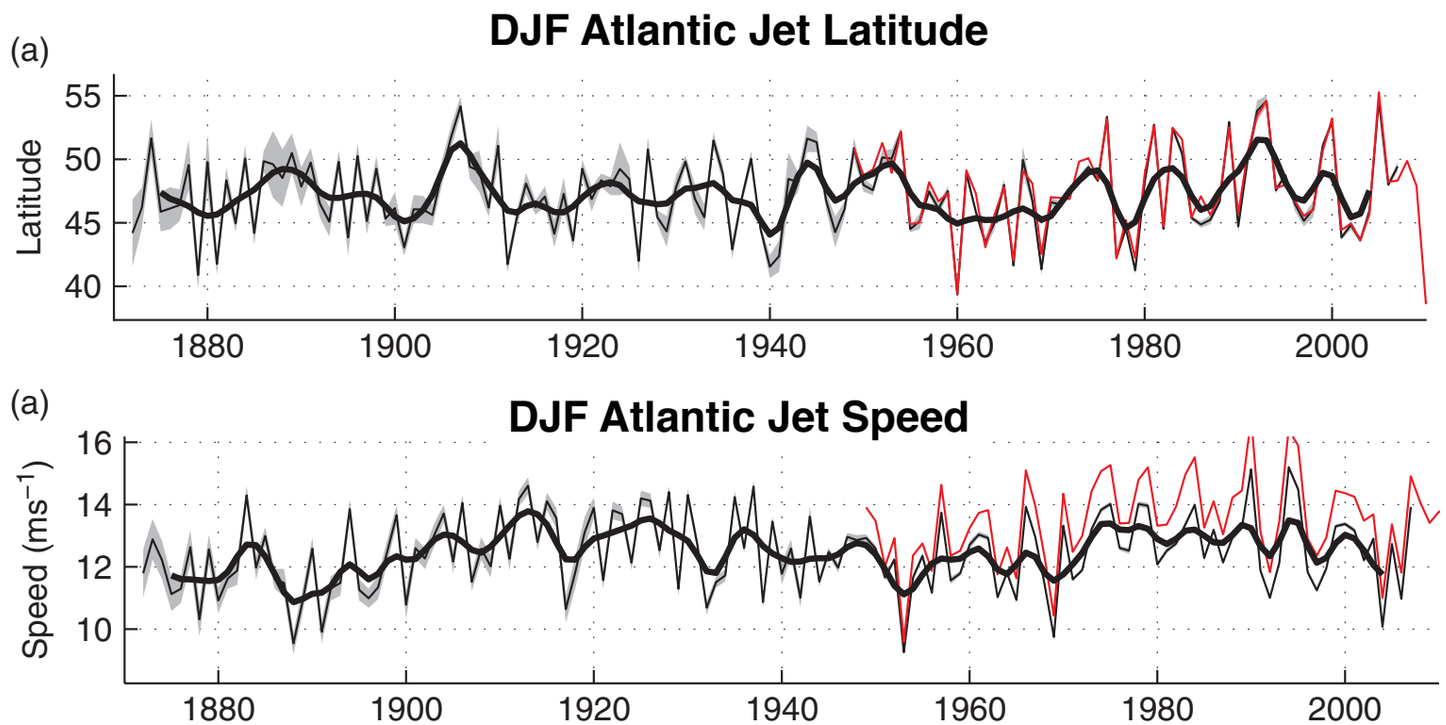
A Series of Unfortunate Events?

- the past few years have seen a large increase in the number of studies and news articles discussing present-day influences of Arctic warming on midlatitude weather
  (see for e.g., review by Cohen et al. (2014; NATGEO))

- the validity of some of these results has been questioned by other studies, but I will not go into these here.
  (e.g. Perlwitz et al. (2015), Barnes (2013; GRL), Screen & Simmonds (2013; GRL))

- instead, I will focus on internal variability….

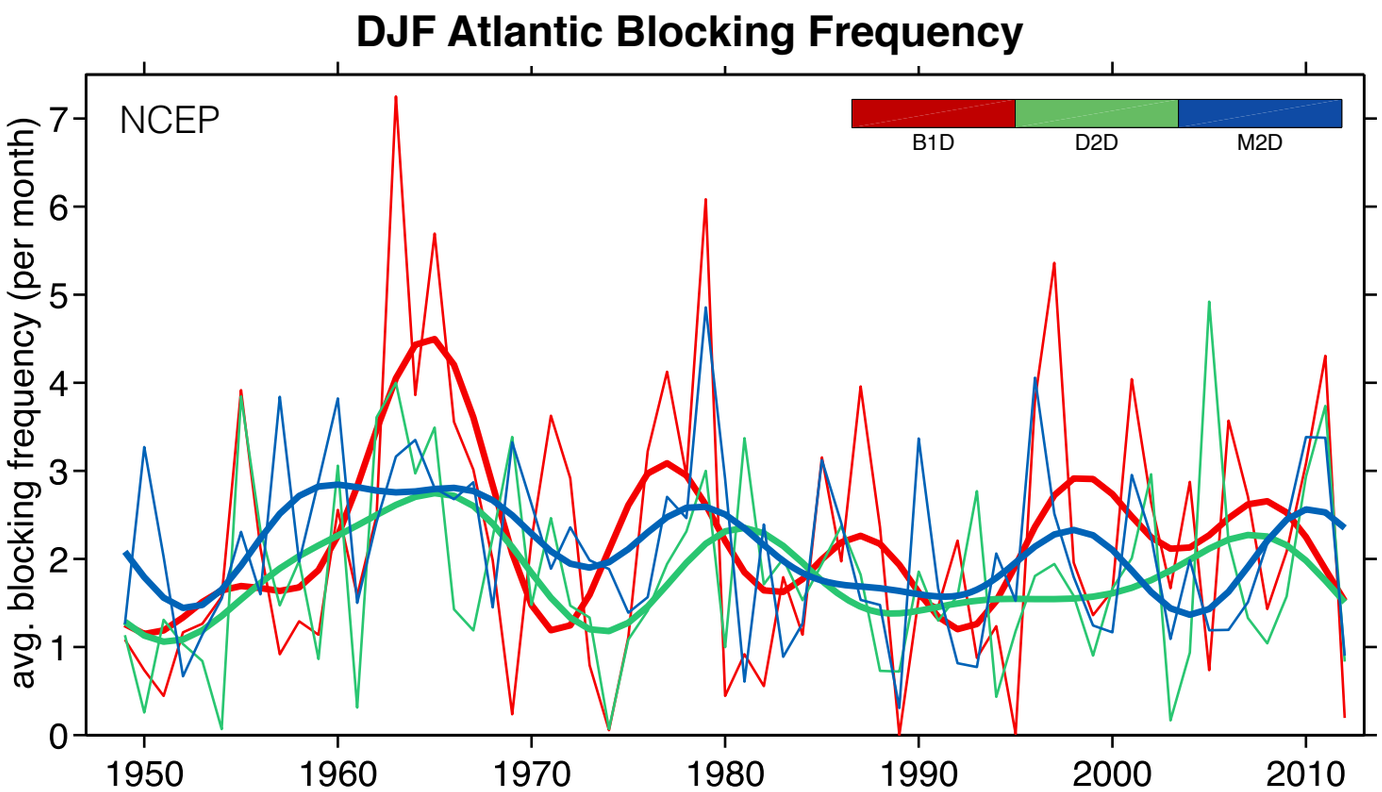
Internal atmospheric variability is large



20th Century Reanalysis jet latitude and speed
red line denote NCEP-NCAR Reanalysis
Woollings et al. (2014; QJRMS)

- Decadal variability of jet position and speed is large
- Behavior over the past decade does not appear exceptional compared to the long-term variability

Internal atmospheric variability is large

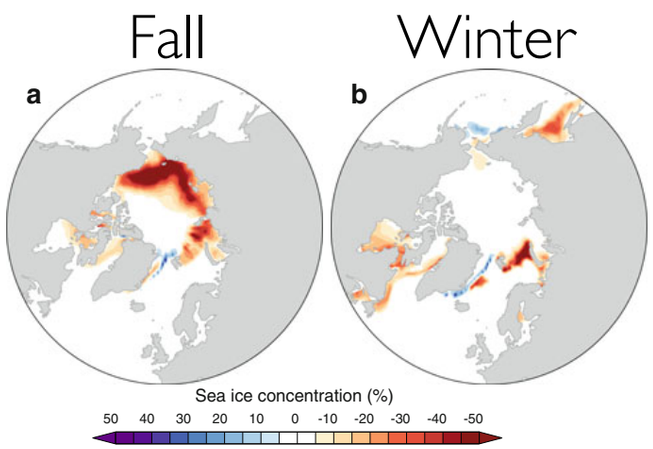


- 3 blocking identification methods
- 4 seasons
- 4 reanalyses
- 3 different time periods

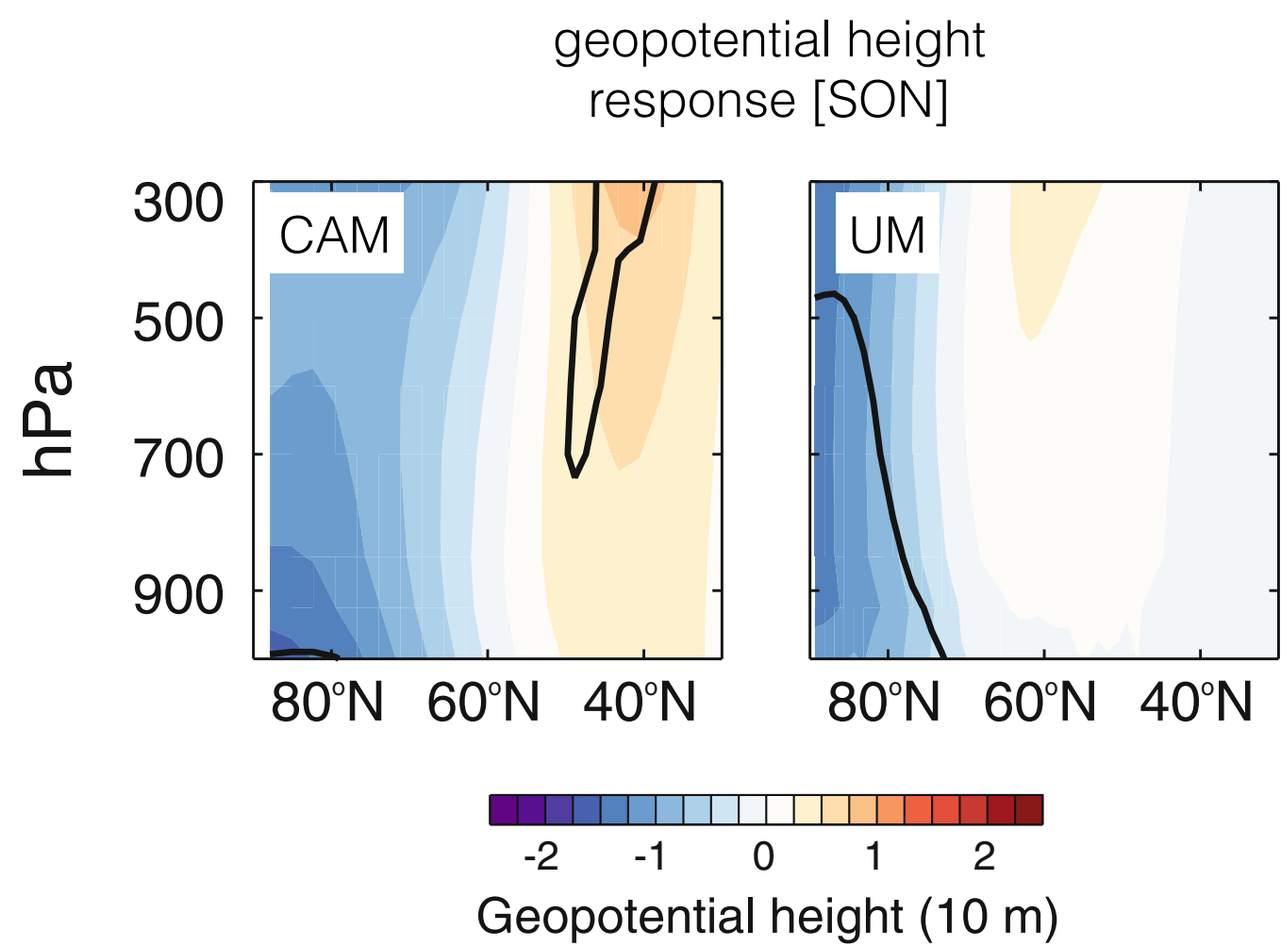
- Decadal variability of blocking frequency is very large, like jet-stream variability (the two are dynamically linked)
- Behavior over the past decade does not appear exceptional compared to the long-term variability

Barnes et al. (2014); GRL

Internal atmospheric variability is large



perturbed sea ice minus control (similar to 2009-1979)



- AMIP experiments with high and low sea-ice concentrations based on observed trends (1979-2009)
- same forcing…different response!

100 years of Unified Model
60 years of CAM
Screen, Deser et al. (2013; CDYN)

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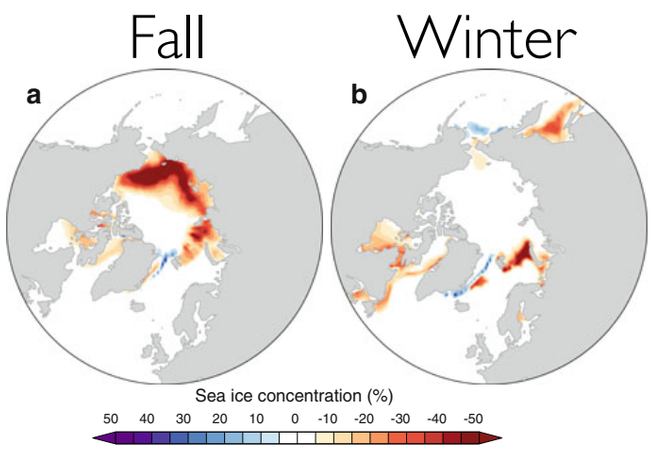

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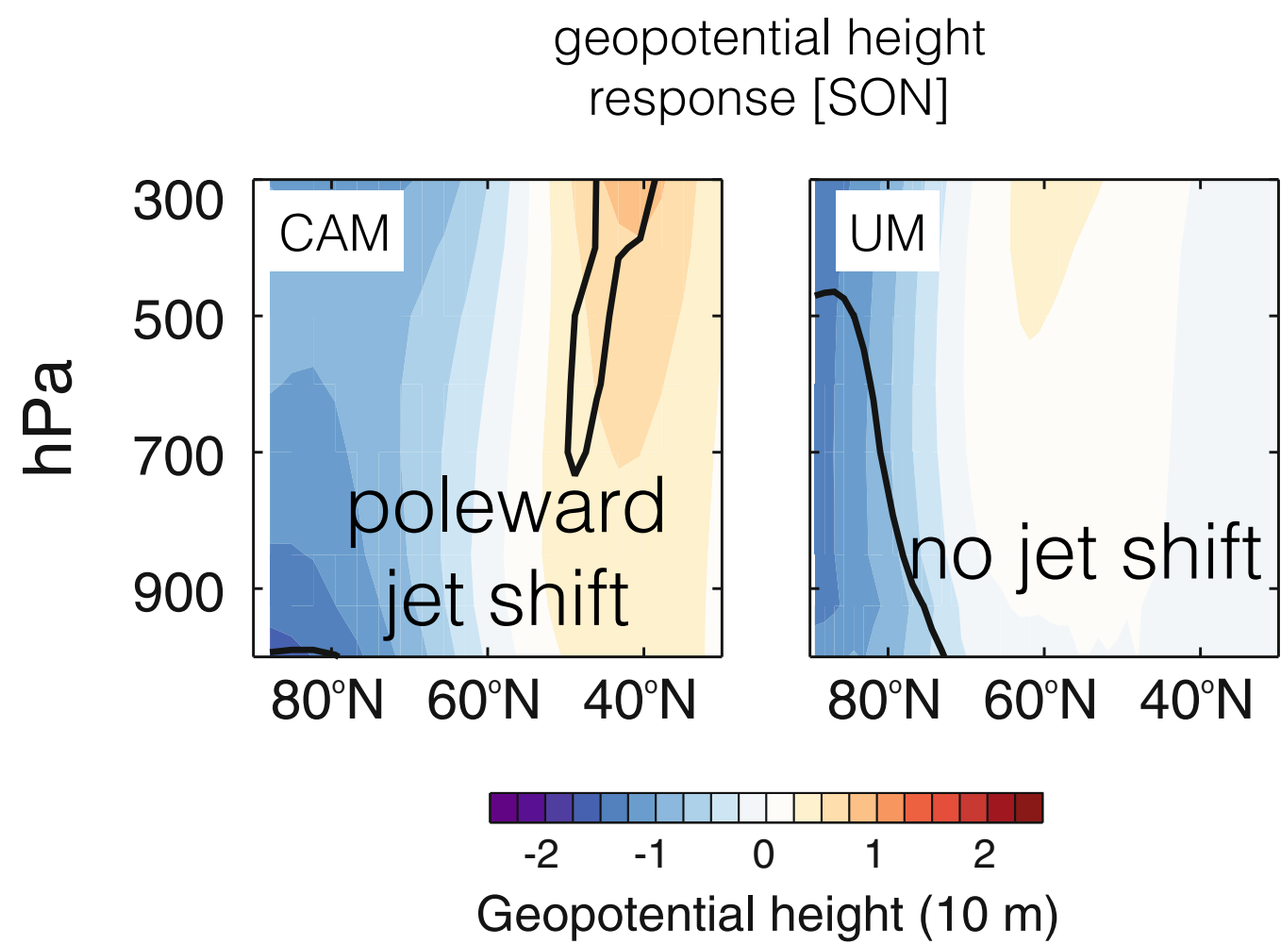

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Internal atmospheric variability is large

Table 1 Mean N_{min} for a selection of atmospheric variables

Variable	Mean N_{min}	Mean area %
Surface sensible heat flux	21.9	19.1
Surface latent heat flux	24.5	19.7
Near-surface air temperature (T_{ref})	26.0	28.9
Low cloud cover	29.9	17.5
925 hPa air temperature (T_{925})	31.1	25.7
Net surface short-wave radiation	32.6	12.9
Net surface long-wave radiation	32.8	15.2
Total cloud cover	33.3	16.5
Precipitation	40.3	11.4
Sea level pressure (*SLP*)	50.3	11.9
10 m meridional wind speed	50.7	9.0
10 m zonal wind speed	50.8	9.4
500–1,000 hPa thickness	56.1	7.0
250 hPa zonal wind speed (U_{250})	65.4	5.5
250–1,000 hPa thickness	67.6	4.7
250 hPa meridional wind speed (V_{250})	68.0	3.2
500 hPa air temperature (T_{500})	70.0	4.3
500 hPa geopotential height (Z_{500})	71.9	5.0
250 hPa geopotential height (Z_{250})	73.3	4.8

# of independent samples (e.g. yrs.)

Screen, Deser et al. (2013)

[The midlatitude circulation response to past Arctic sea ice loss] "***may be partially or wholly masked by AIV***."

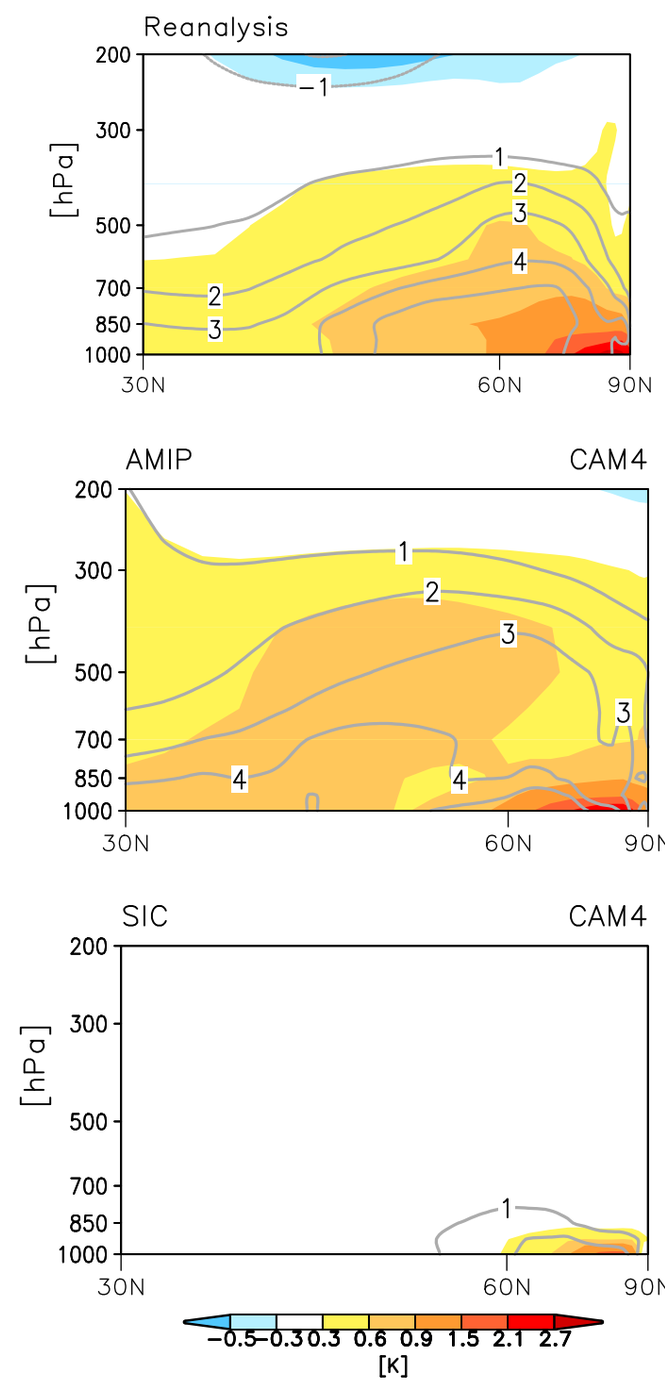
Screen, Deser, et al. (2013; CDYN)

Which way does the causality arrow point?

- It is well known that the midlatitude circulation is an important driver of Arctic climate.

- What if the mid-tropospheric Arctic warming is largely driven by processes outside of the Arctic? Causality would go the other way.

Change in OND temperatures
2003-12 minus 1979-88



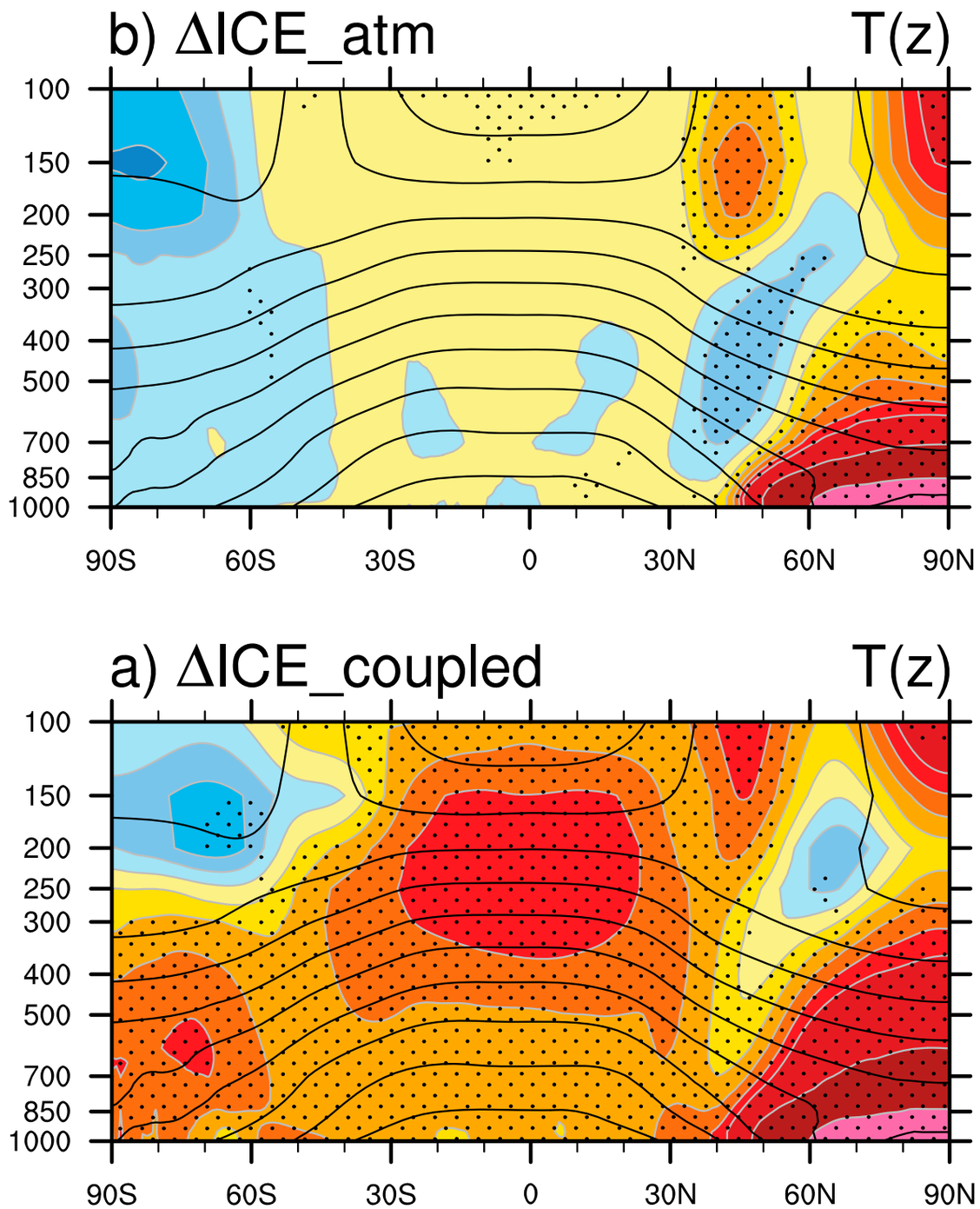
observations

model w/
observed SSTs
& radiative forcing

model contribution
of sea ice

CAM4 simulations
Perlwitz et al. (2015; JCLI)

New results from Deser et al. (2015)

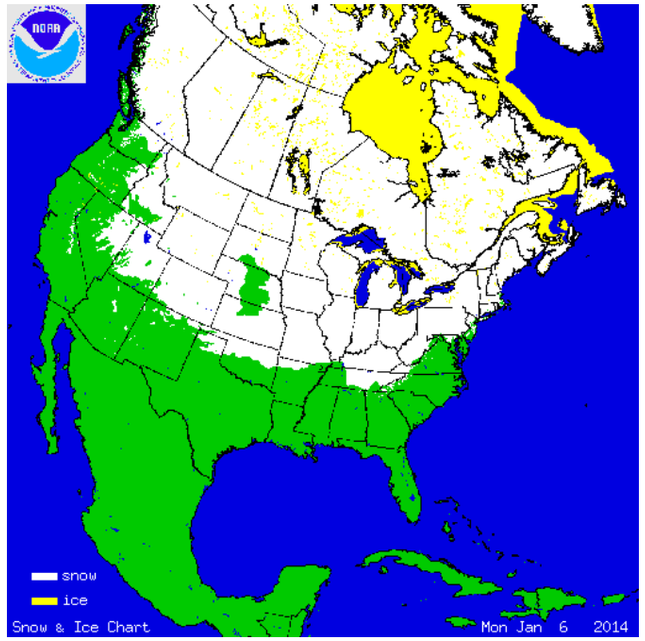


AMIP simulations may underestimate sea ice-induced warming compared to coupled simulations

coupled CCSM4 simulations with additional long wave radiative fluxes in the ice model
Deser, Tomas, et al. (2015; JCLI)

Which way does the causality arrow point?

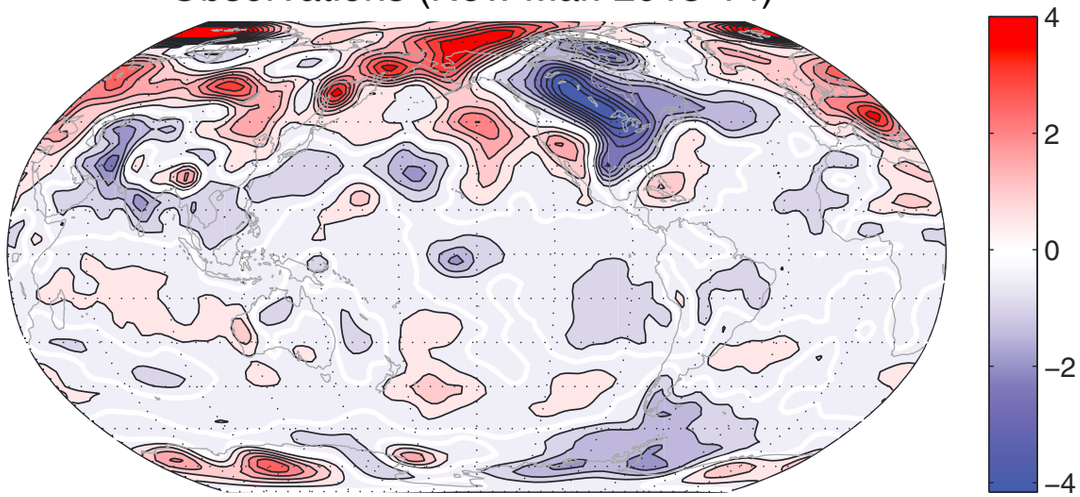
Winter of 2013-14 was unusually cold…



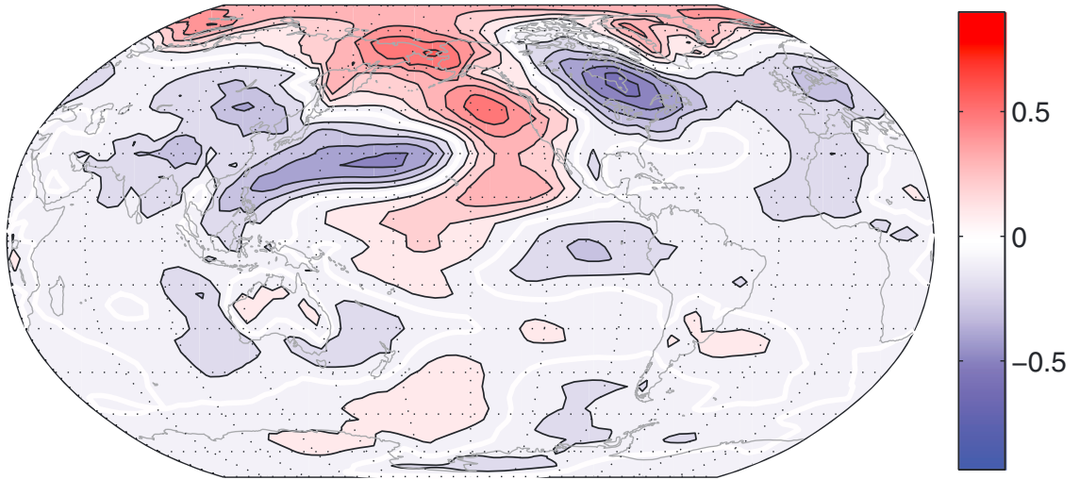
Snow cover (white)
Jan. 6, 2014

Surface Air Temperature

Observations (Nov.-Mar. 2013-14)



Regression of model ensemble onto SST pattern



- Winter of 2013-14 was very cold over the US and Canada. It has been suggested that Arctic sea ice loss may have been responsible

- However, recent work suggests that the Pacific SST's may have been the proximate cause

Hartmann (2015; GRL)

Has it?

Has it?

- **Unlikely.** The evidence to date does not support this conclusion - internal variability dominates.

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- Many challenges ahead…
    - short observational record
    - decoupling for internal variability will remain difficult
    - which way does the causality arrow point?

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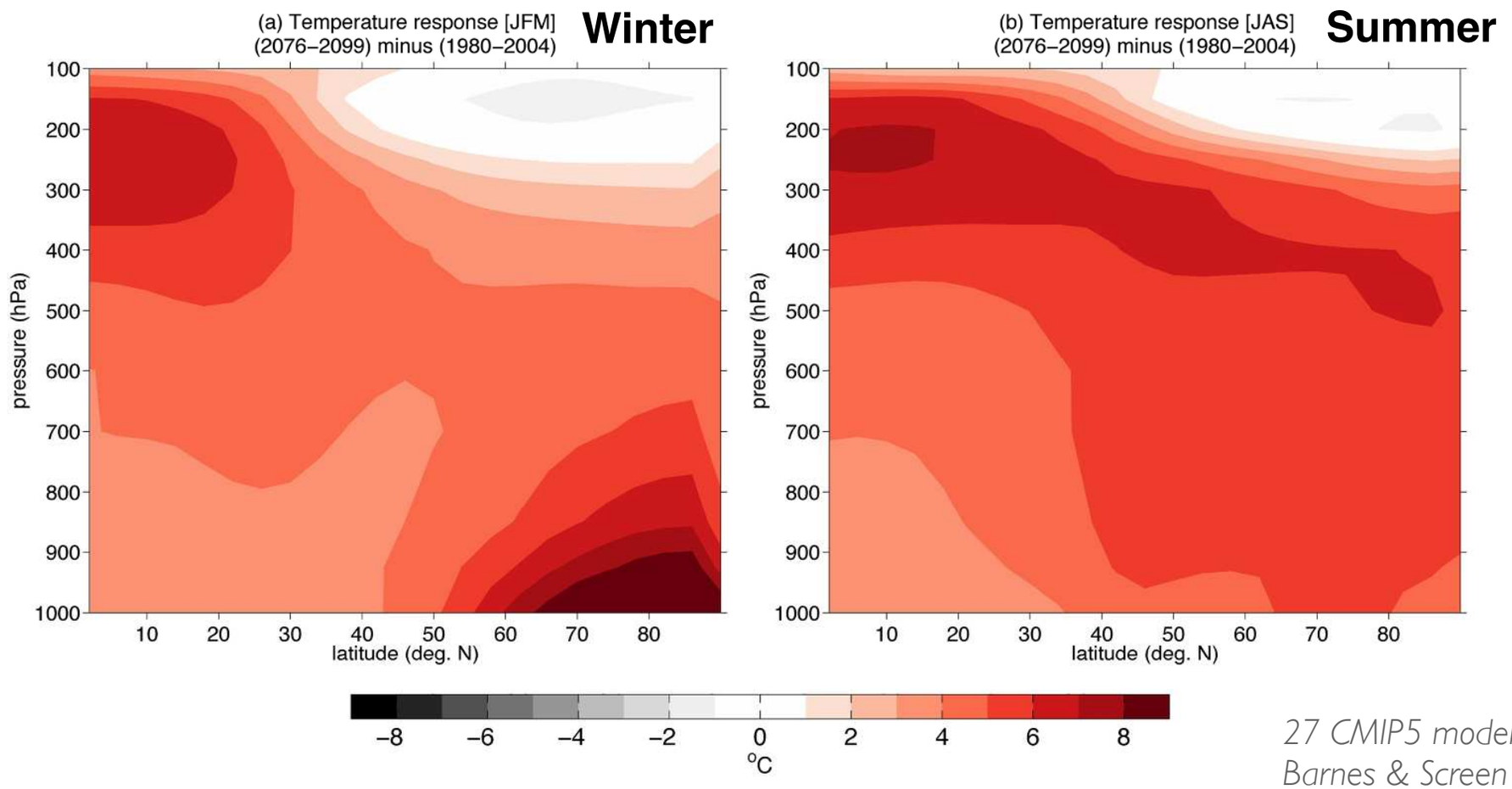
    - which way does the causality arrow point?

Models will be required to adequately answer this question.

Will Arctic warming significantly influence the midlatitude jetstream?

Future Projections

Arctic amplification under RCP8.5



27 CMIP5 models
Barnes & Screen (2015)

- Under RCP8.5, Arctic expected to warm 1.5-2 times more than the global-average by 2100

- Arctic amplification is largest in winter

One hypothesis…

As the Arctic warms and the temperature gradient decreases…

MEAN FLOW

slower winds

weaker jet

equatorward

EDDIES/WAVES

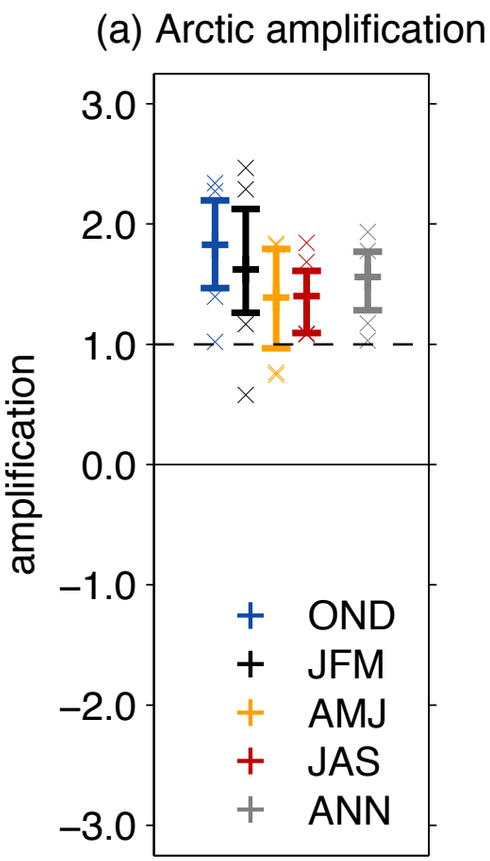
slower waves

larger amplitudes

more blocking

posed by, for example
Francis & Vavrus (2012; 2015)
Liu et al. (2012)

Near-term projections over N. Atlantic/N. America (2020-2044) - (1980-2004)



27 CMIP5 GCMs
Barnes & Polvani (2015; JCLI)

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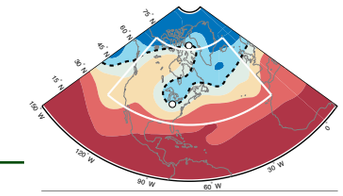

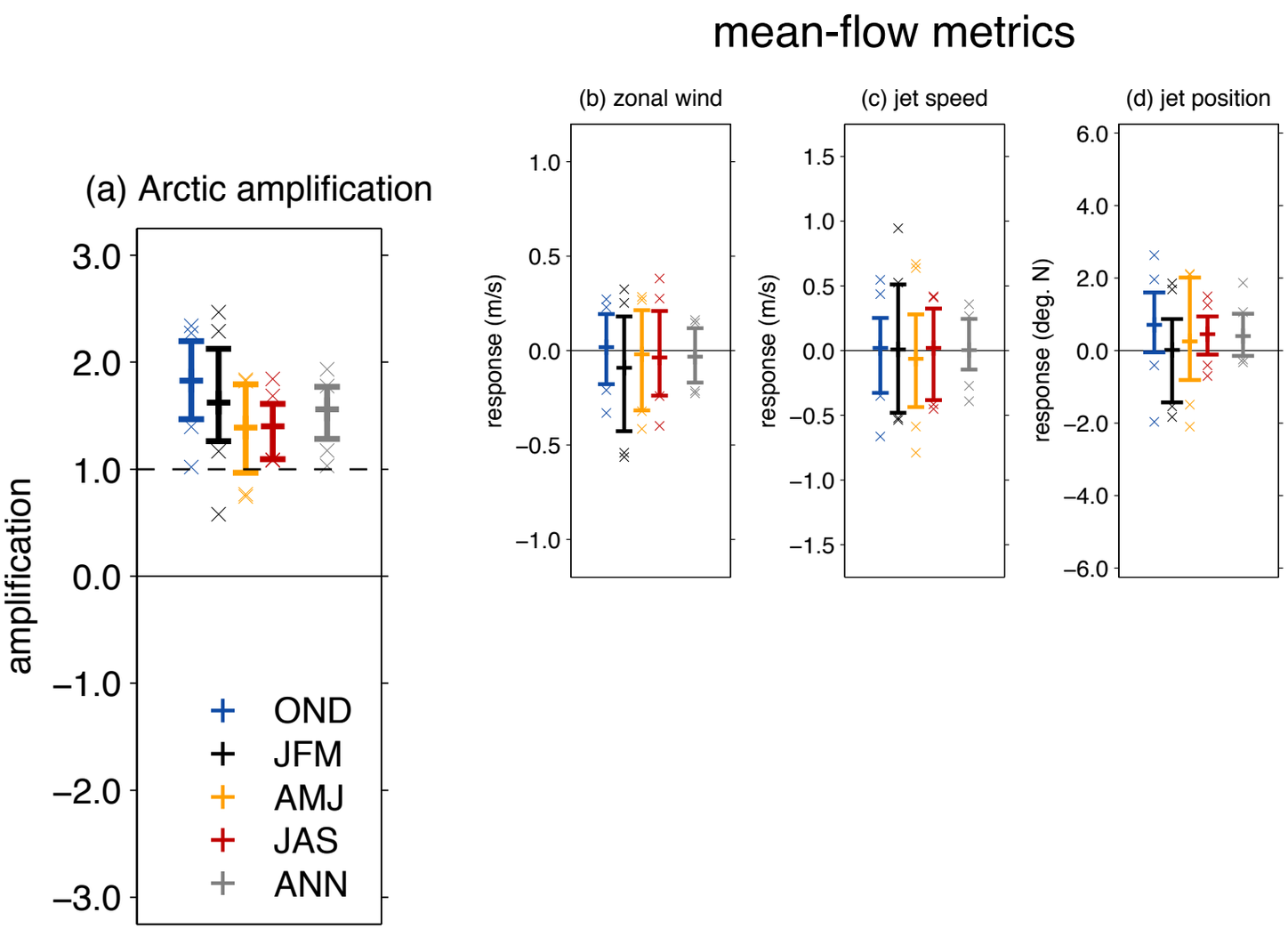

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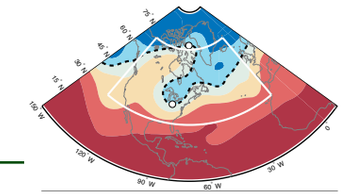

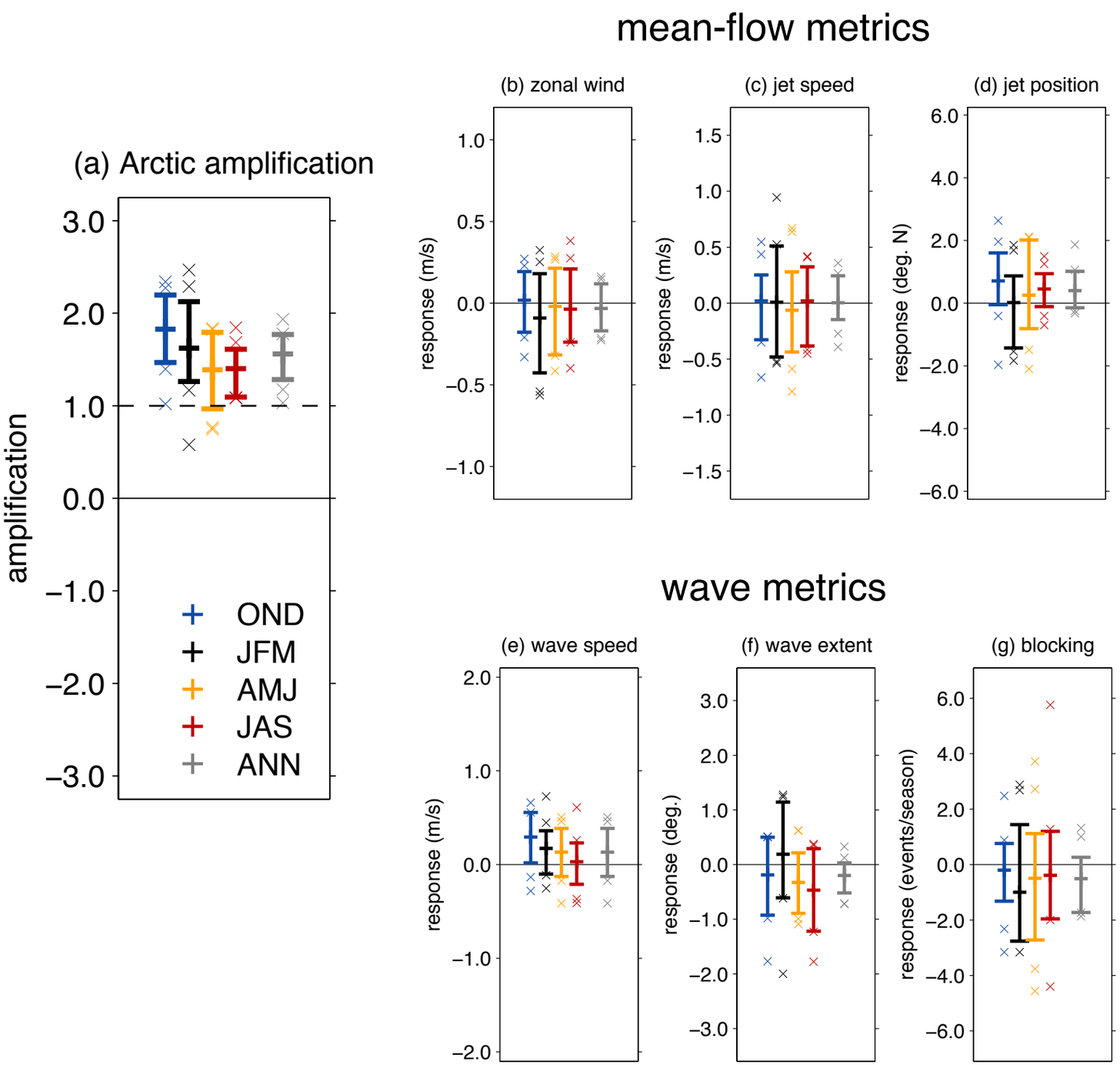

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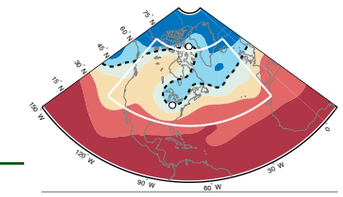

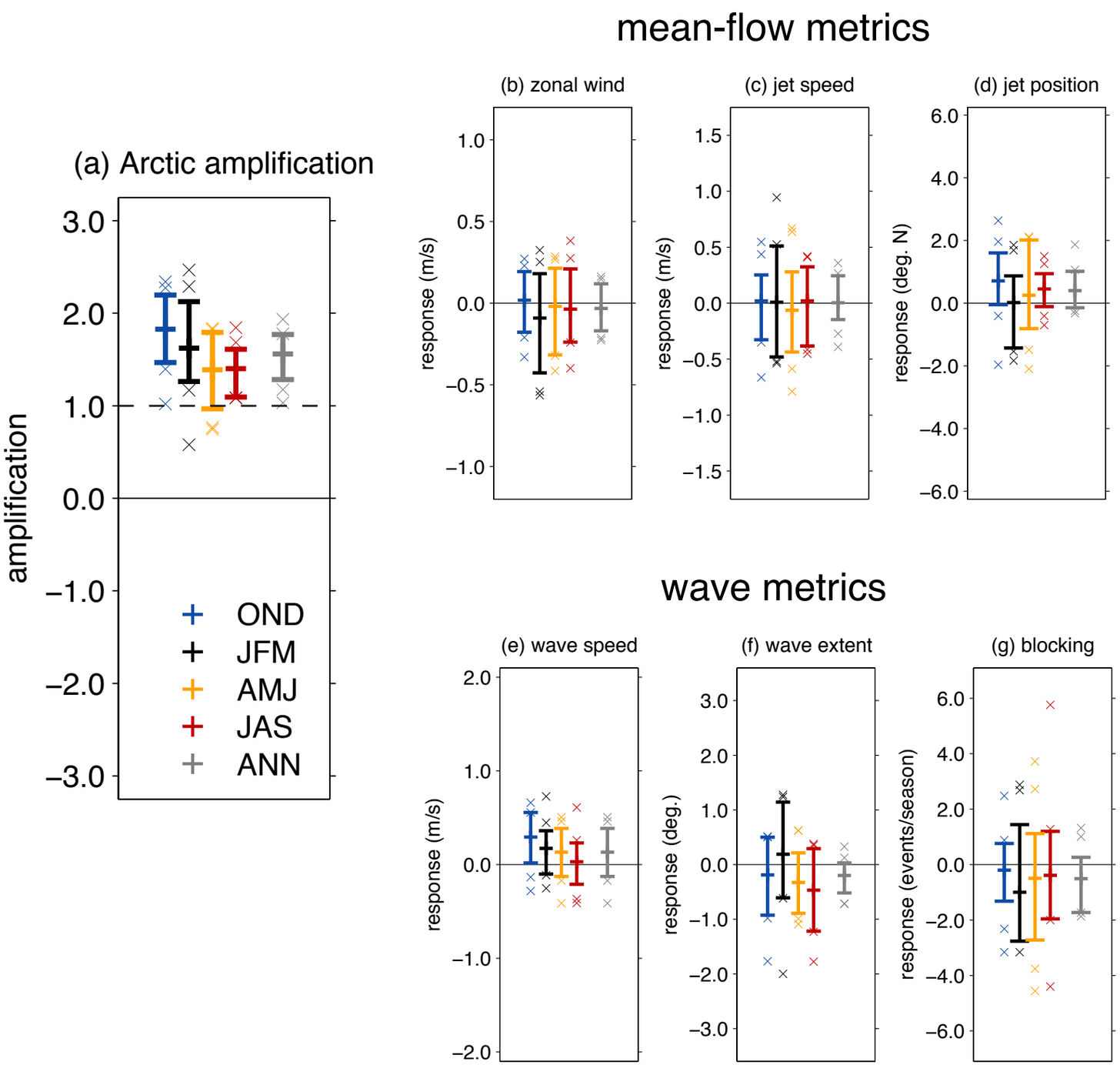

No consensus in the circulation response

27 CMIP5 GCMs
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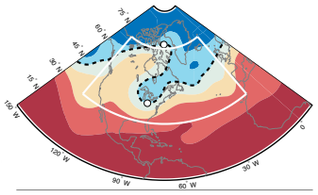

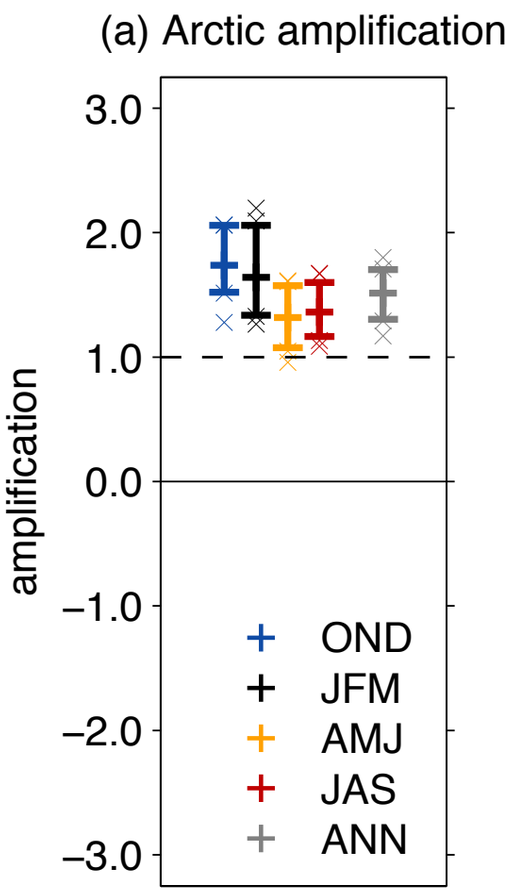

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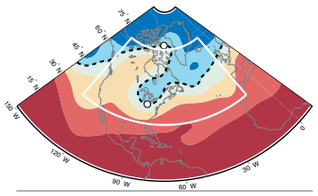

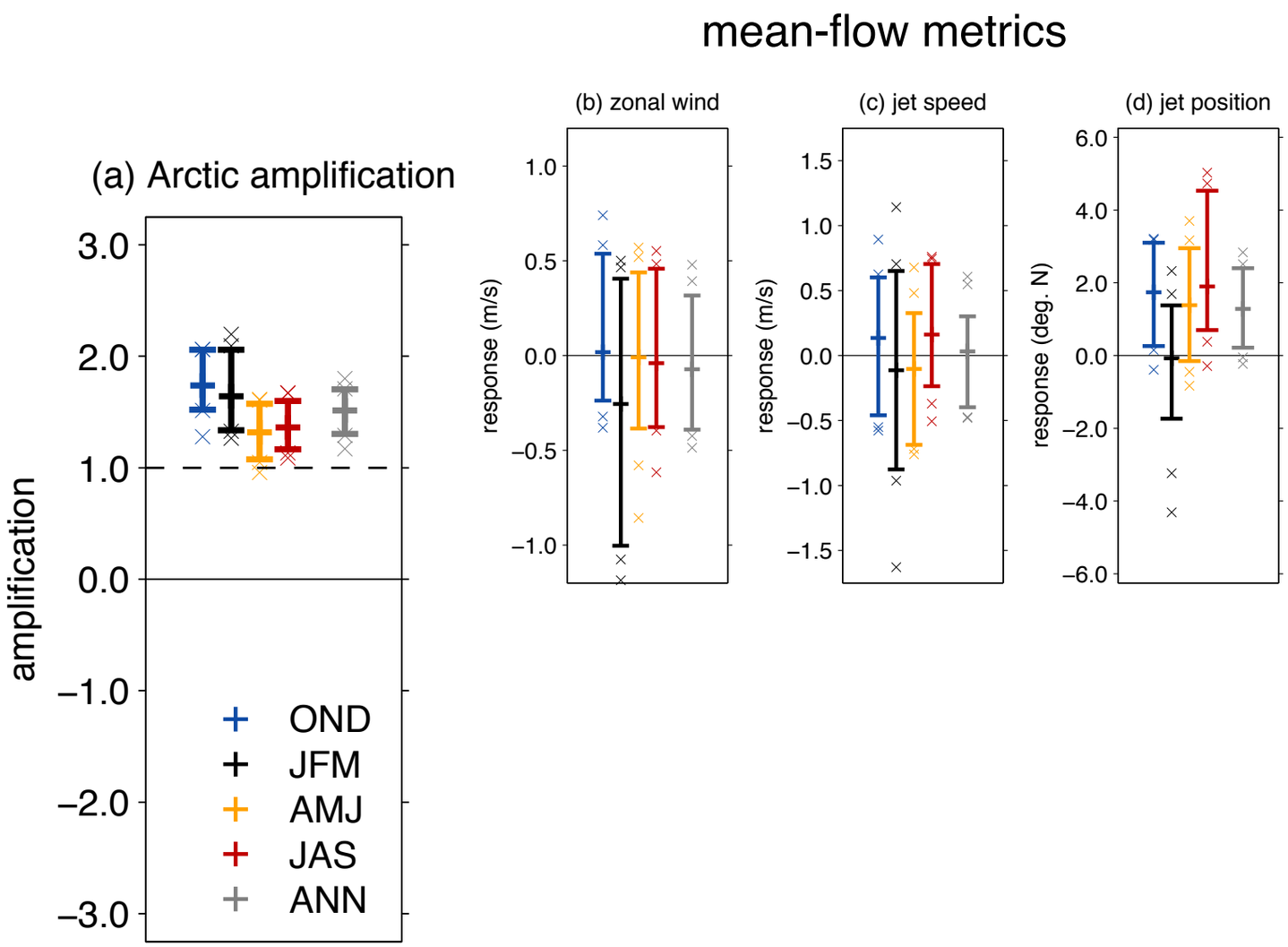

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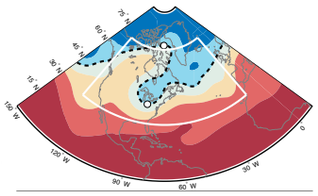

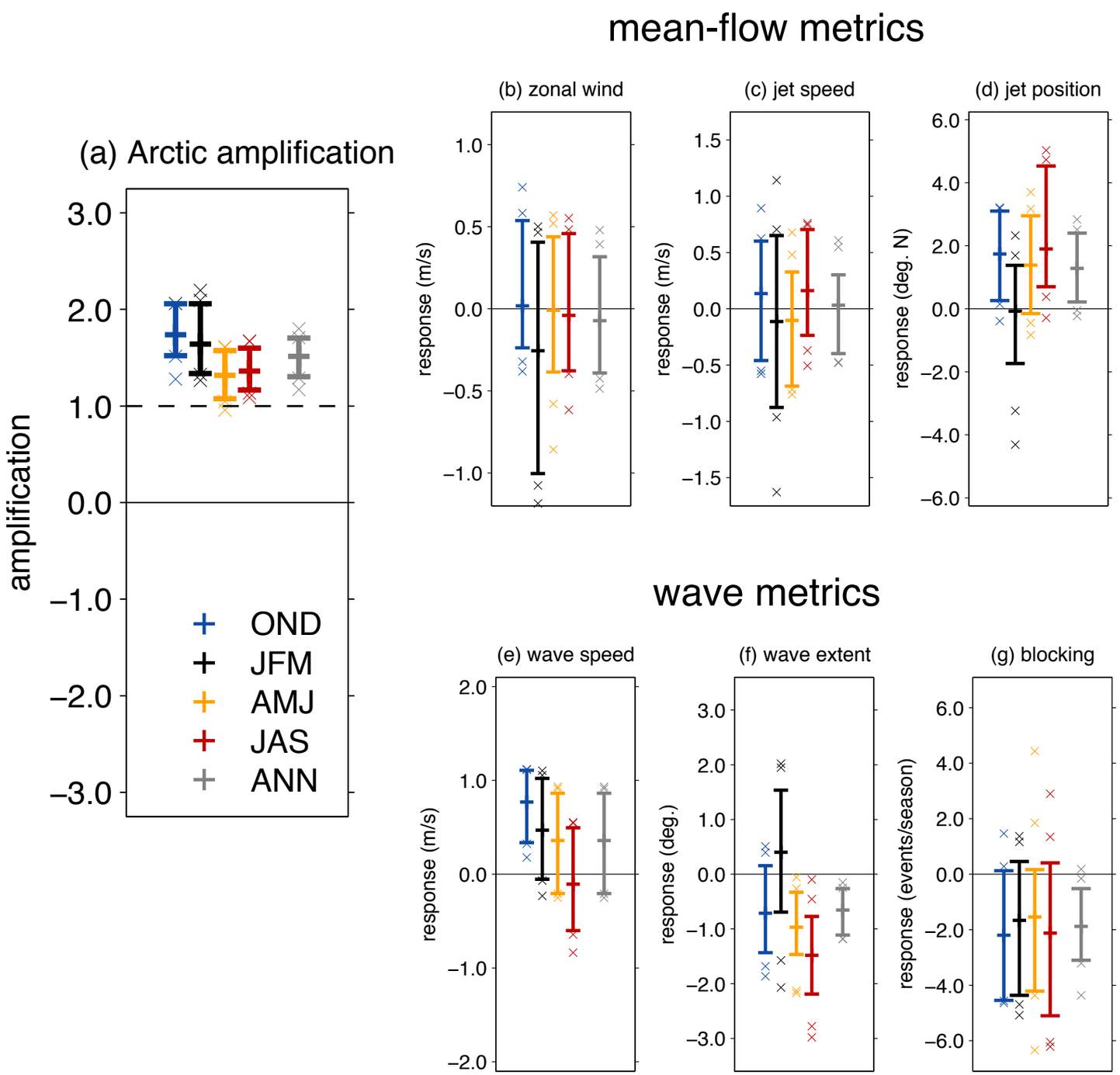

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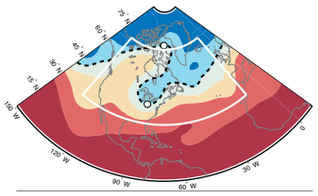

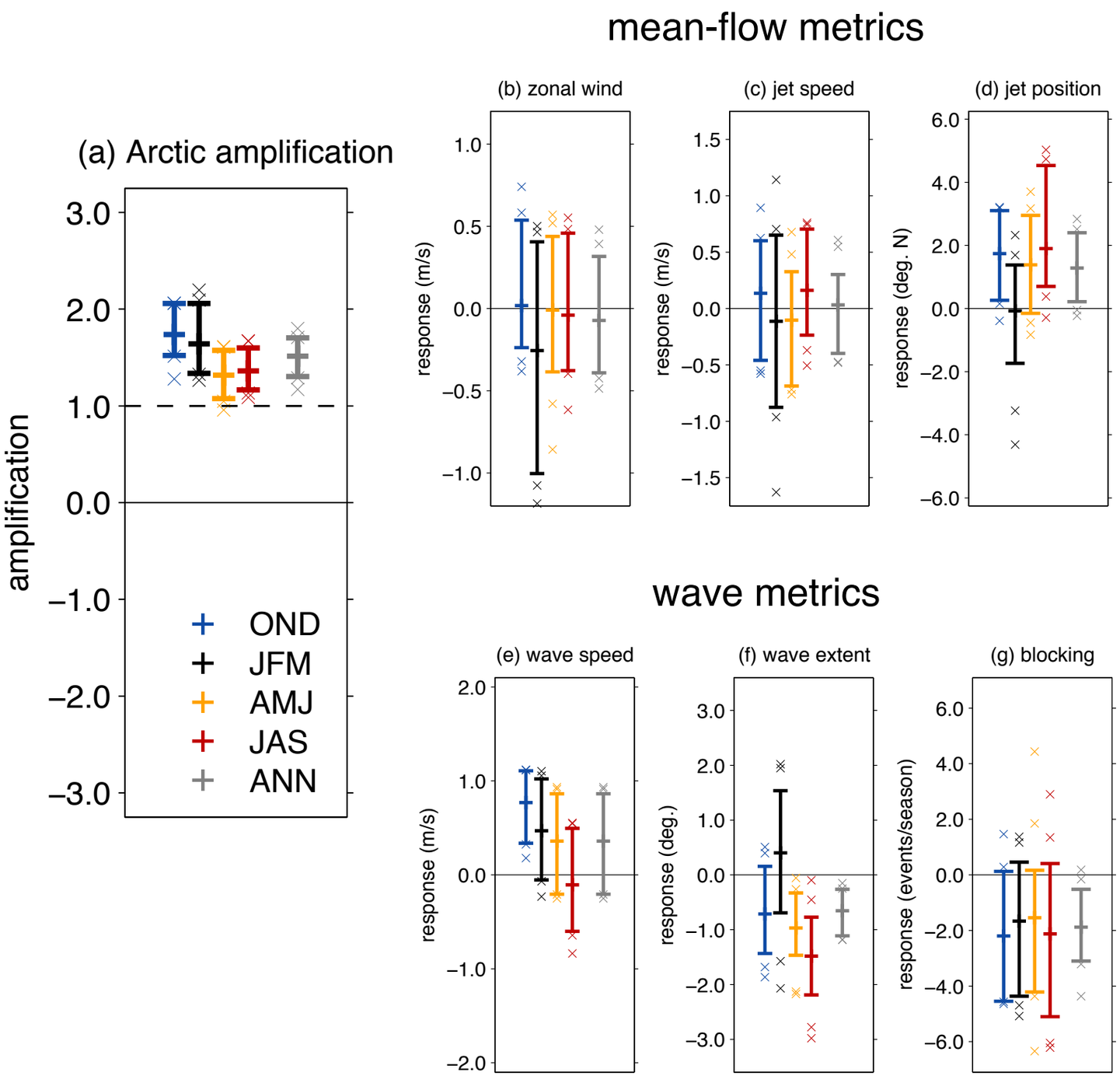

<u>No consensus</u> in the circulation response or response is of the <u>opposite sign</u> to that hypothesized

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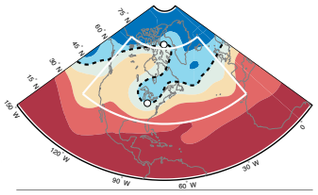
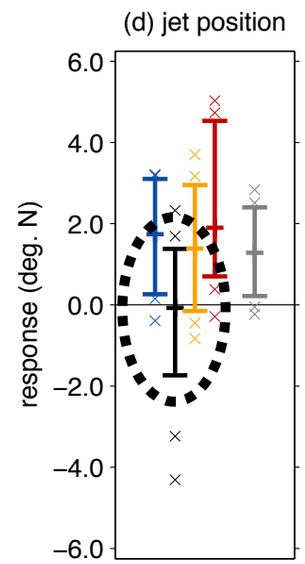
Barnes & Polvani (2015; JCLI)

Long-term projections over N. Atlantic/N. America (2099-2076) - (1980-2004)



mean-flow metrics

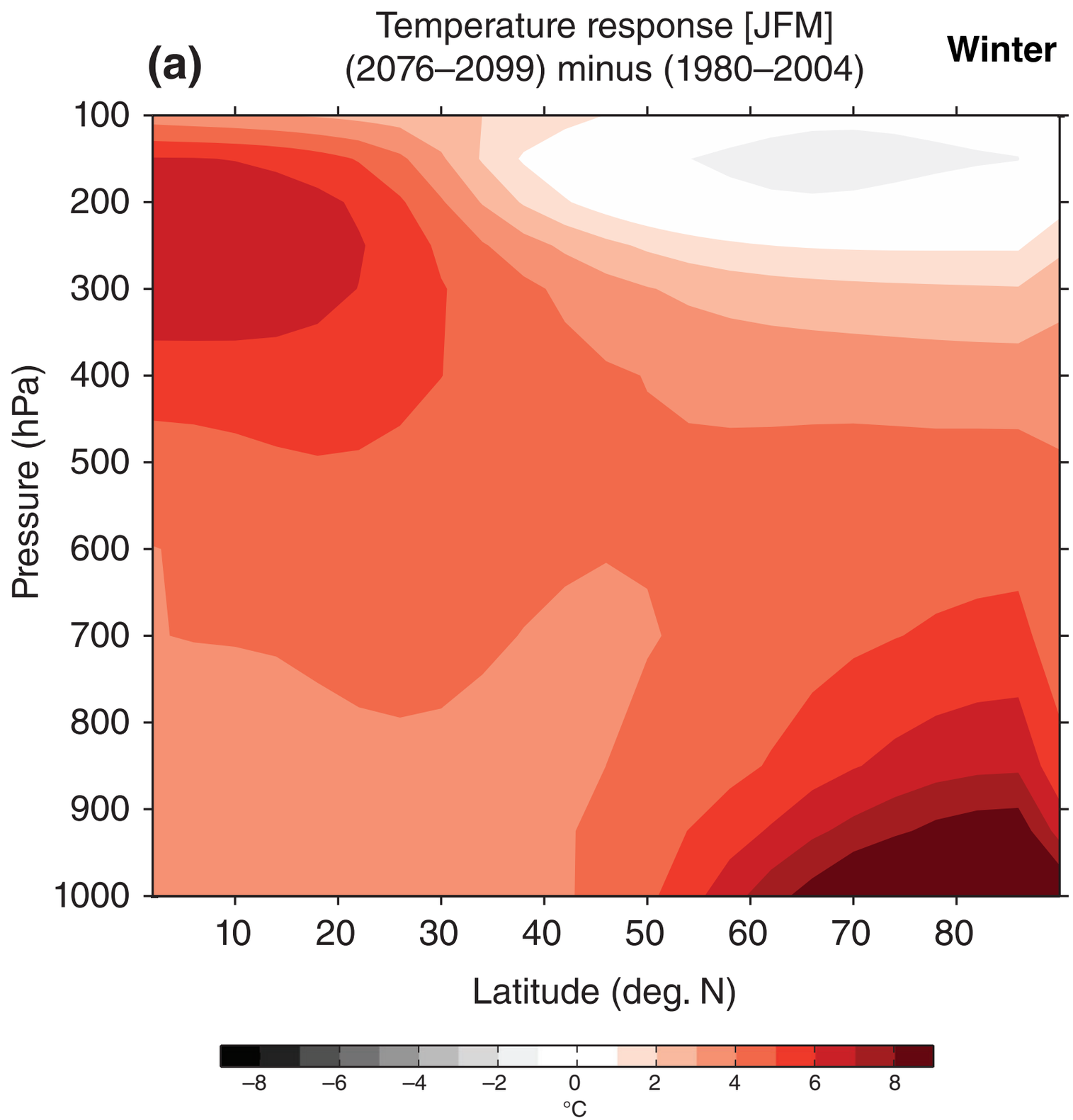


What is different about winter?

27 CMIP5 GCMs
Barnes & Polvani (2015; JCLI)

Tug-of-war

- Decrease in surface temperature gradient
- Increase in upper-level temperature gradient
- Who wins this tug-of-war?
  (see discussion" in Held (1993; BAMS))



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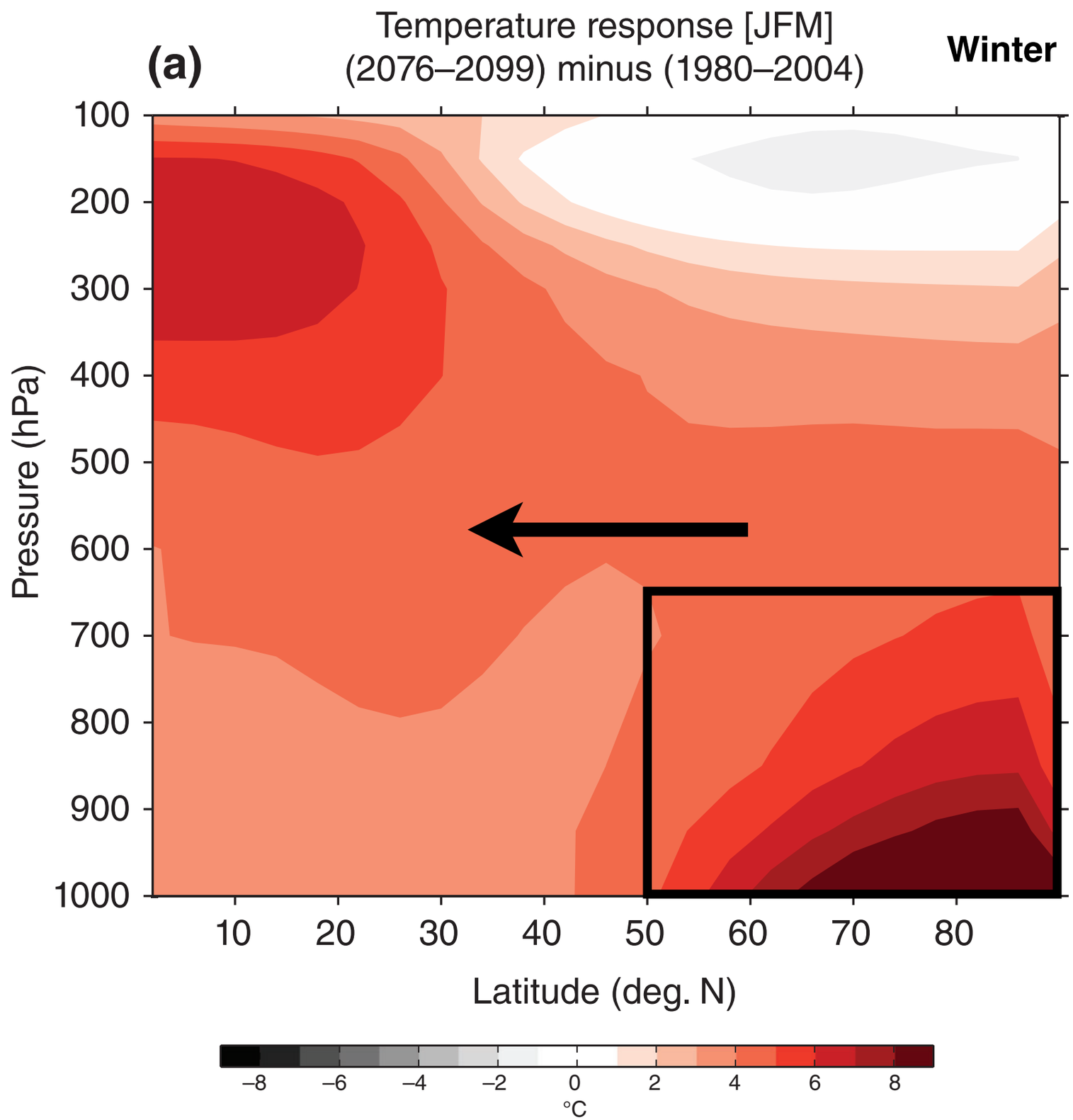

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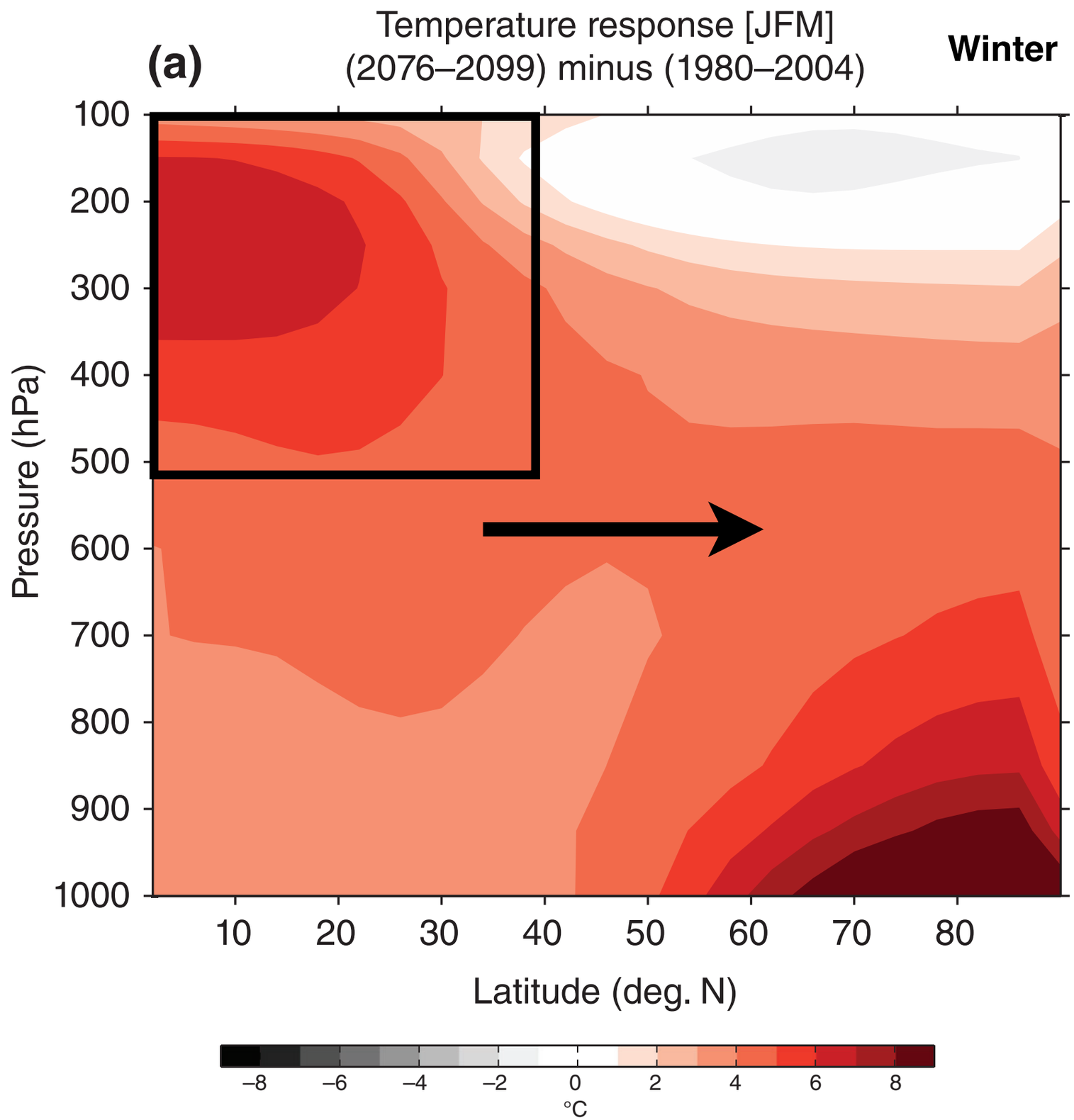

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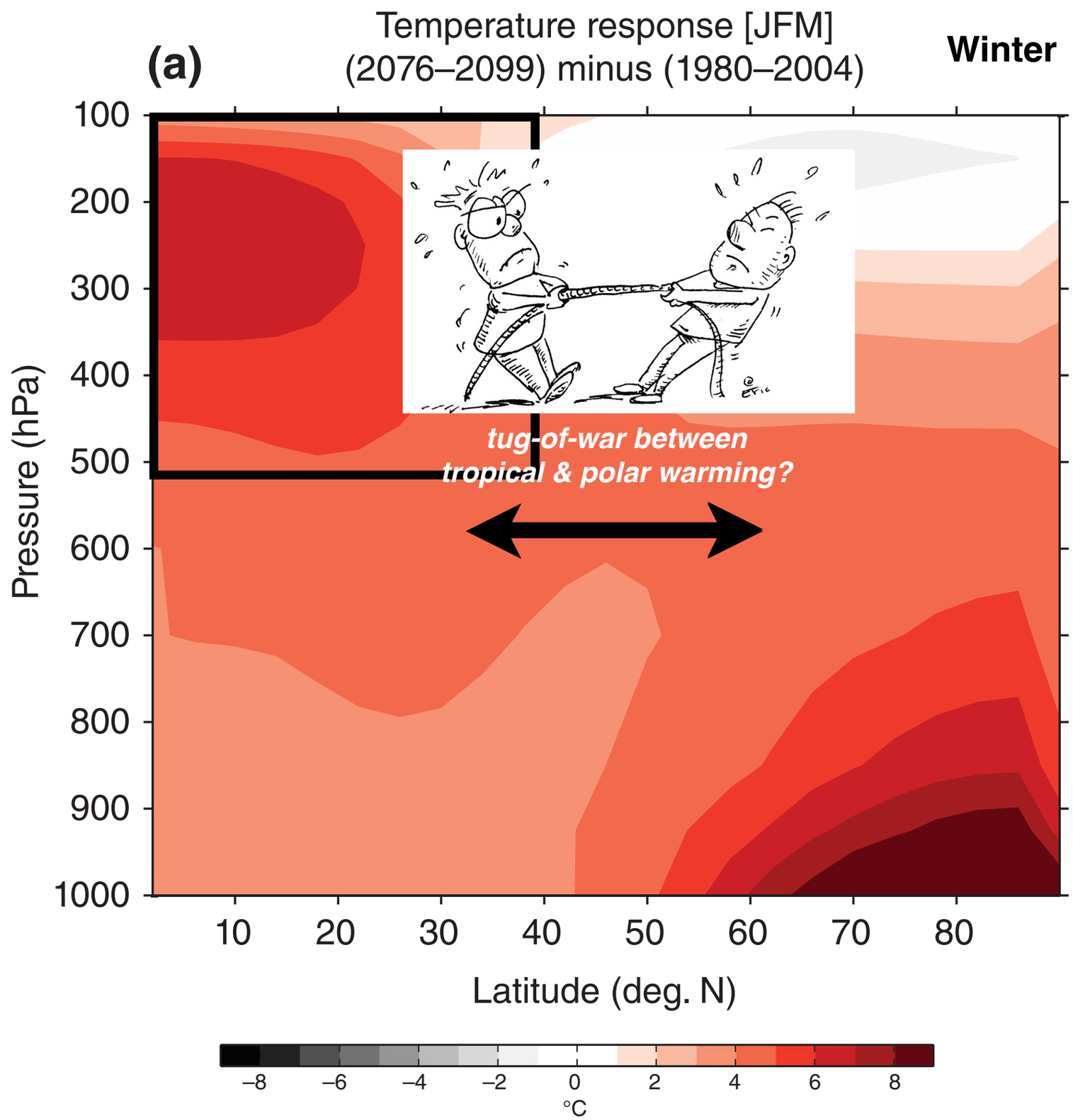
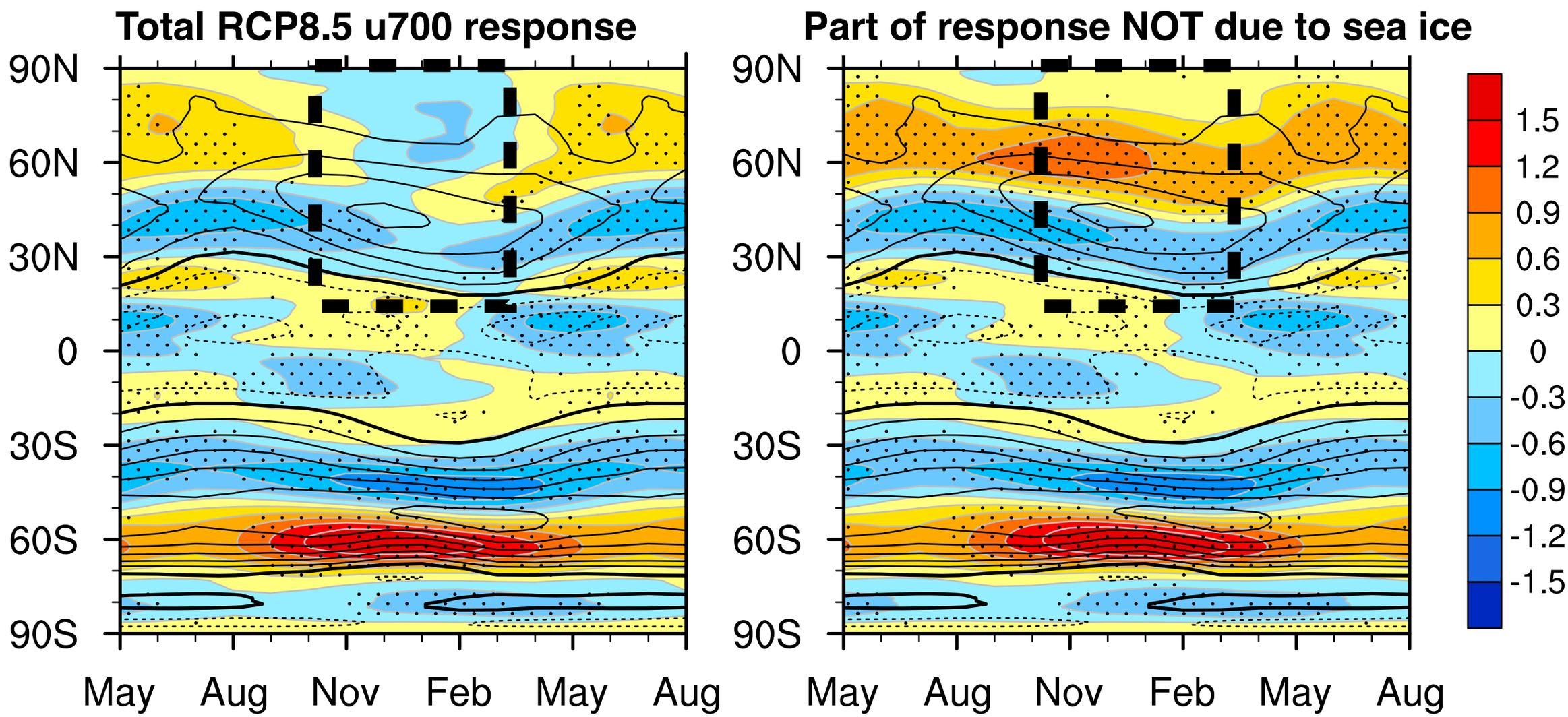


Tug-of-war between tropics and pole



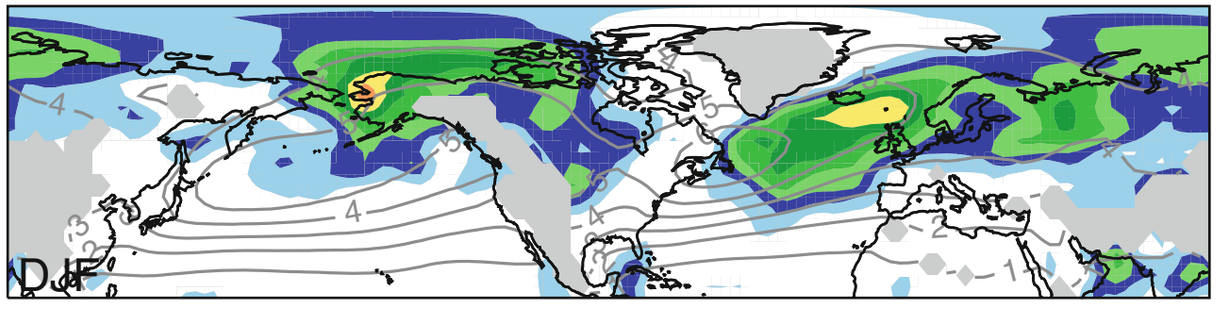
- In CCSM4, the sea ice loss effects appears to cancel the poleward shift of the jet
- In other CMIP5 models, the poleward shift “wins”

coupled CCSM4 simulations
with additional long wave radiative fluxes in the ice model
Deser, Tomas, et al. (2015; JCLI)

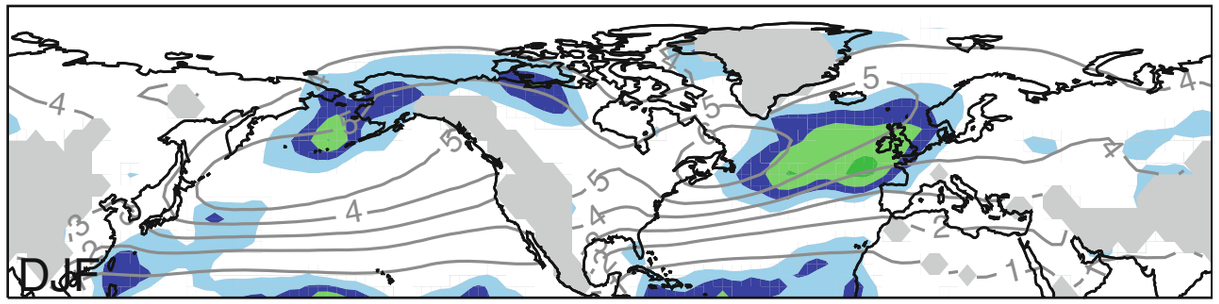
Will it modulate?

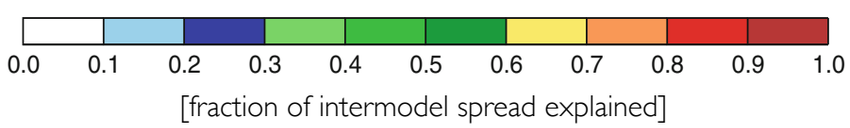
Variance explained of storm track response by N. Atlantic temperature gradients

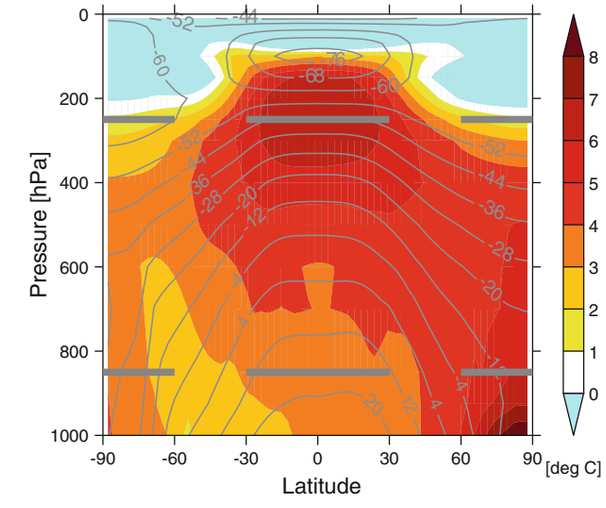
850 hPa



250 hPa







temperature response under RCP8.5 (1976-2005) - (2070-2099)

CMIP5 model analysis
storm track = variance of 2-6 dy. SLP
Harvey, Shaffrey et al. (2013)

- In the N. Atlantic, 850 hPa gradient explains over 50% of variance
- Northern Hemisphere winter intermodel spread requires both 850hPa and 250hPa changes to explain the model storm track responses in winter

Will it?

Will it?

- **Perhaps…**but not in the way some current hypotheses suggest.

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- There is evidence of Arctic amplification **modulating** the future jet response, but not determining the net response

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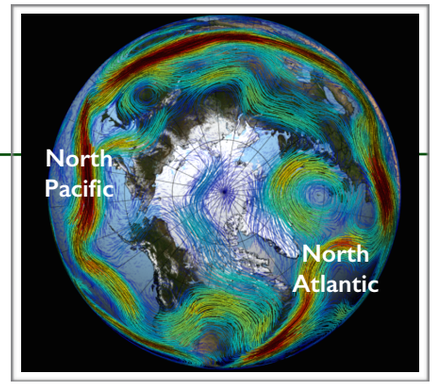
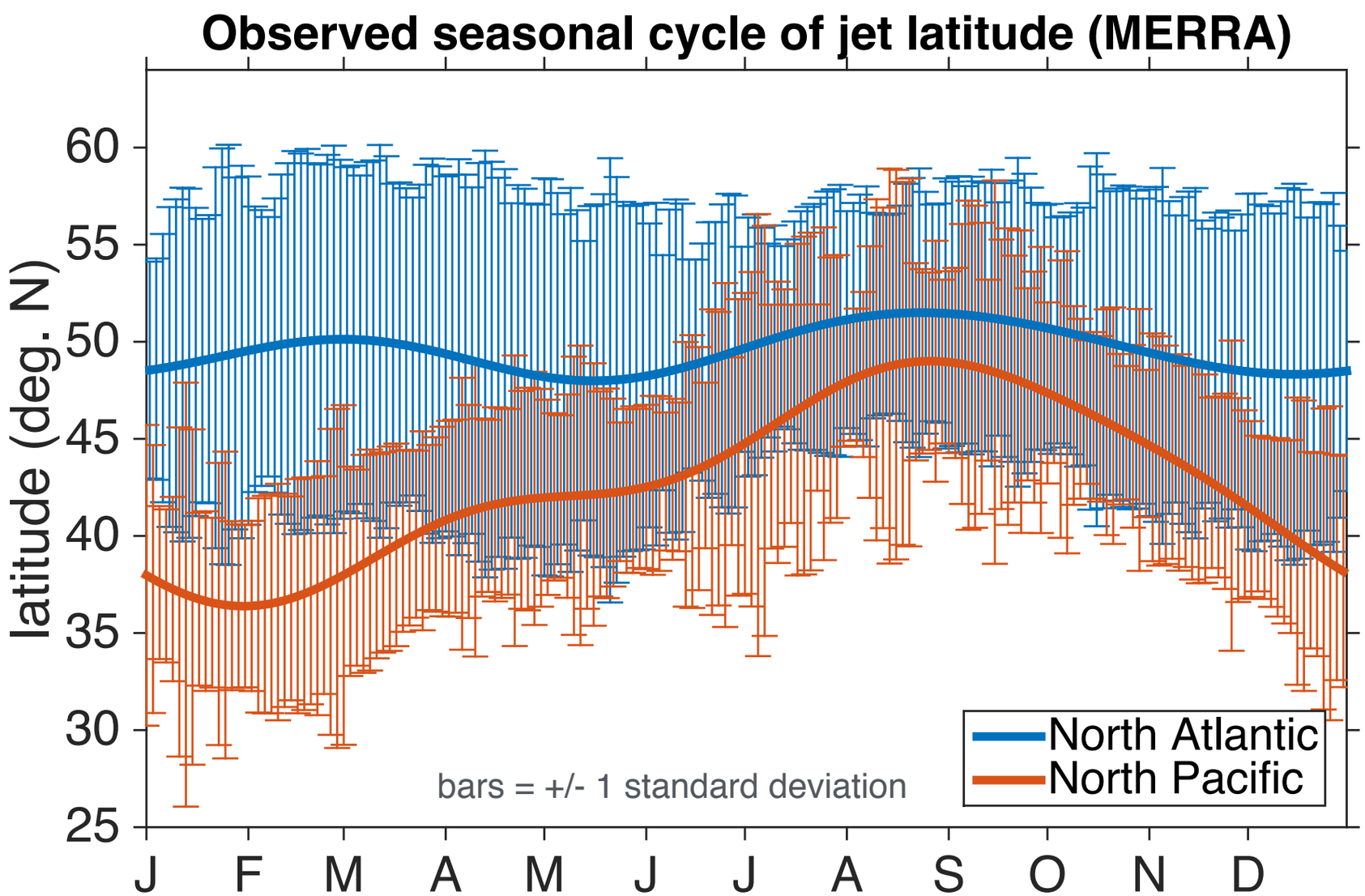
Next steps…

1. Clearly separate "**Can it?"** from "**Will it?".** We must consider the *relative importance* of Arctic warming compared to other factors.
2. Simplified modeling experiments are a good place to start understanding the "**How?"**

Seasonality of the tug-of-war





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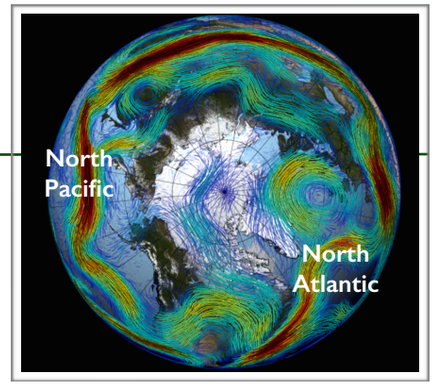

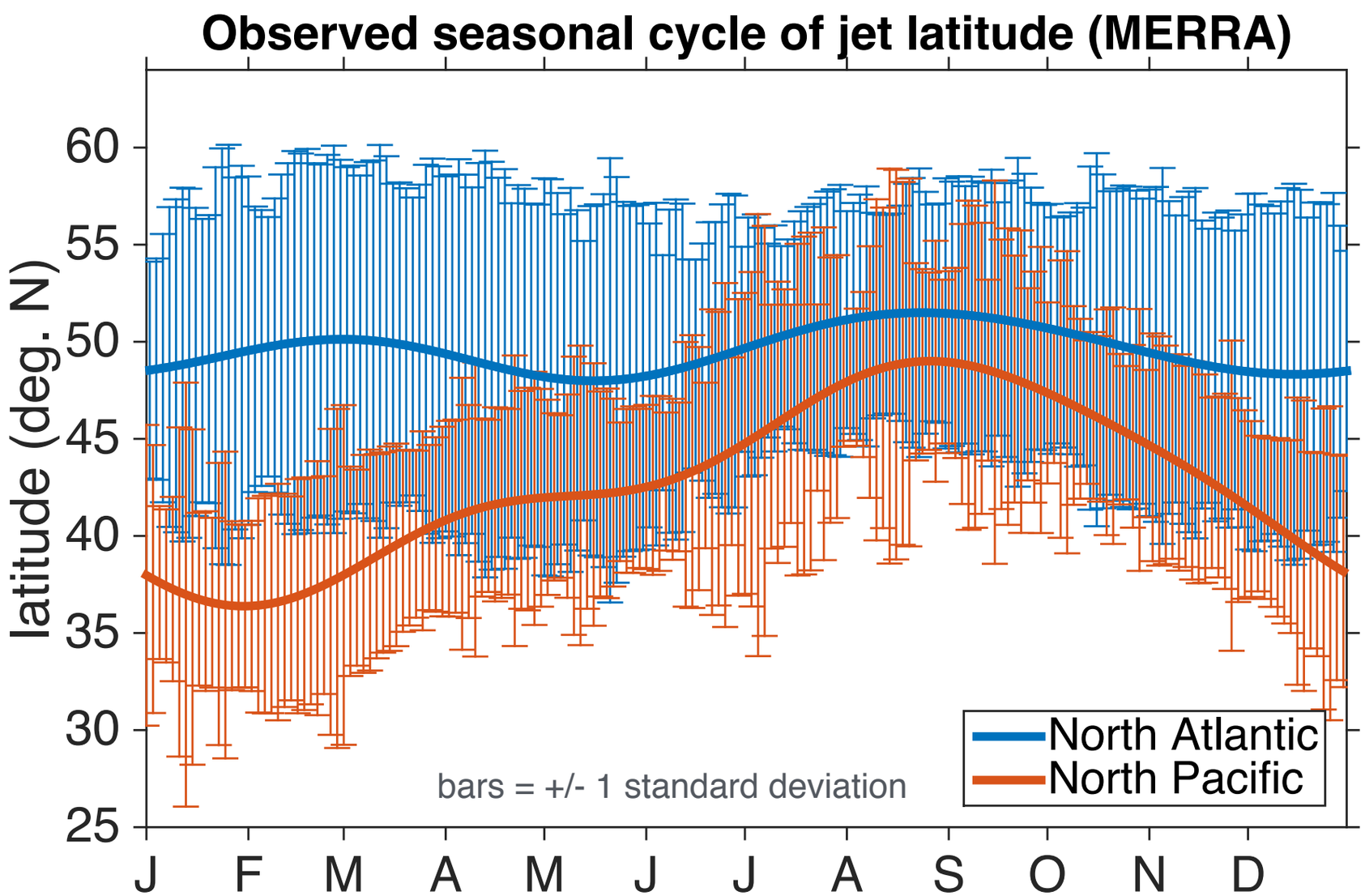

In my group at CSU, we are investigating the seasonality of the circulation response to tropical and polar warming….

Wrap-up

Conclusions

(1) **Can** Arctic warming influence the midlatitude jetstream?

(2) **Has** Arctic warming significantly influenced the midlatitude jetstream?

(3) **Will** Arctic warming significantly influence the midlatitude jetstream?

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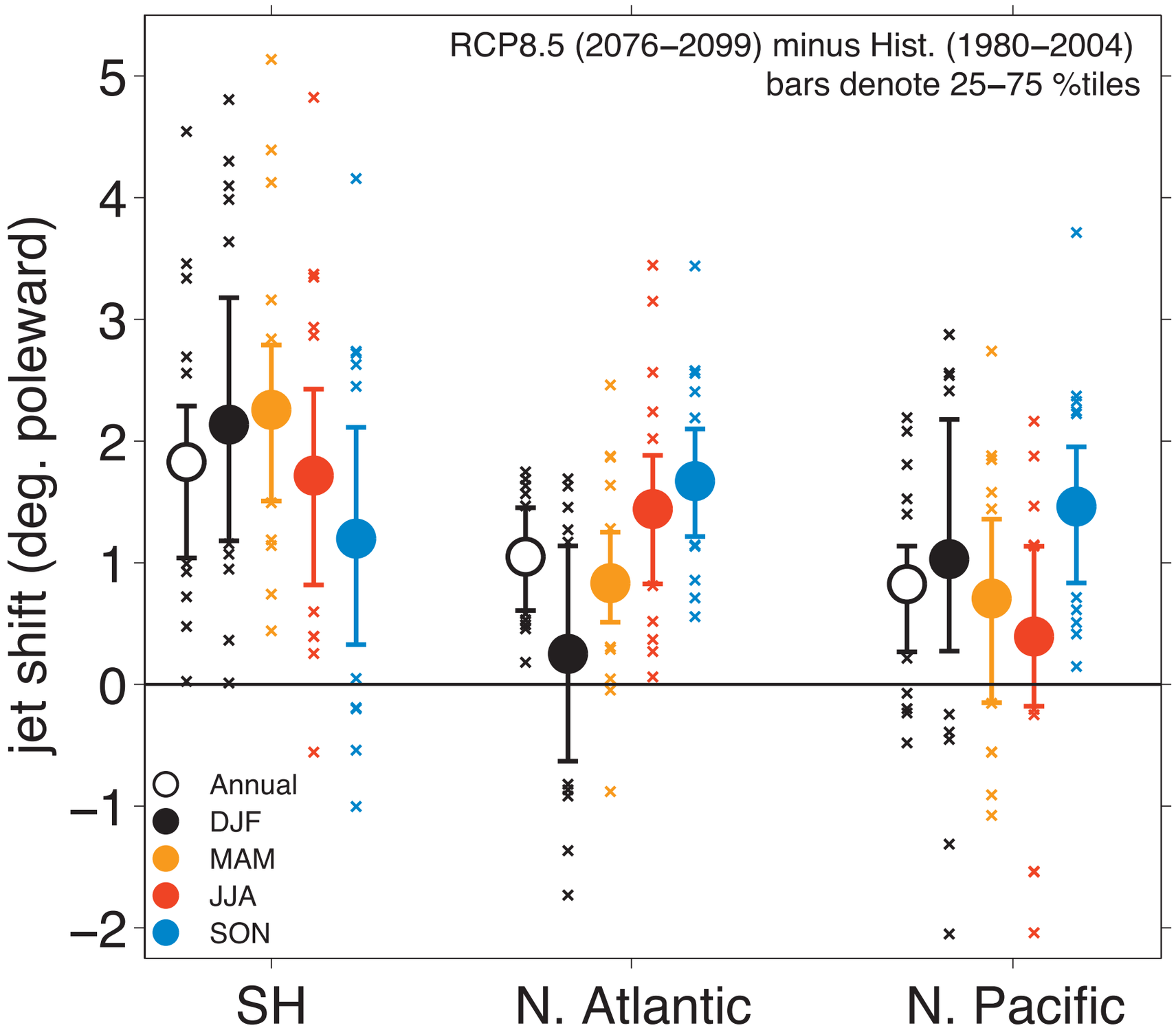
Perhaps…but not in the way some current hypotheses suggest.

The midlatitude circulation is **noisy** and **complex** - as we continue to investigate a possible link with Arctic warming we must keep in mind that **the Arctic does not and will not act in isolation**.

EXTRA SLIDES

Seasonality of future jet shifts

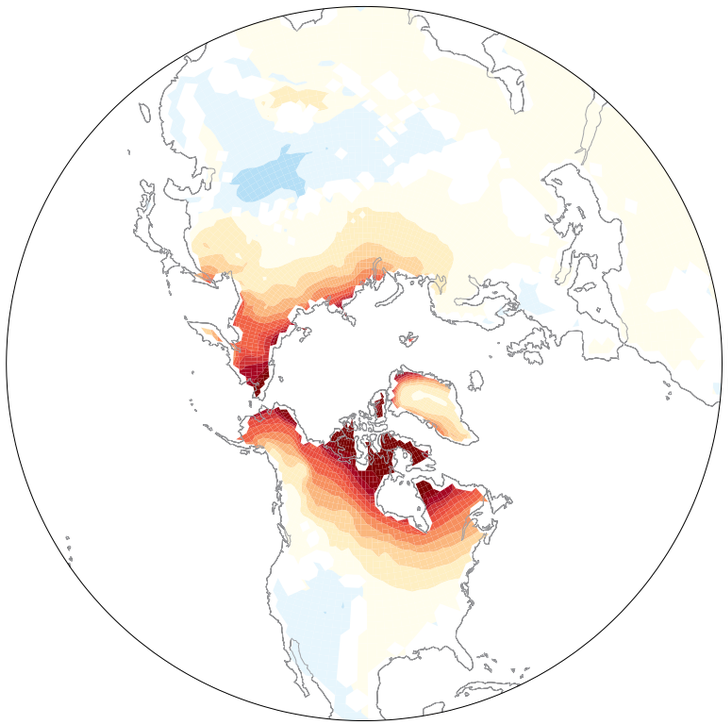


Seasonality of future jet shifts

Midlatitude temperature variance

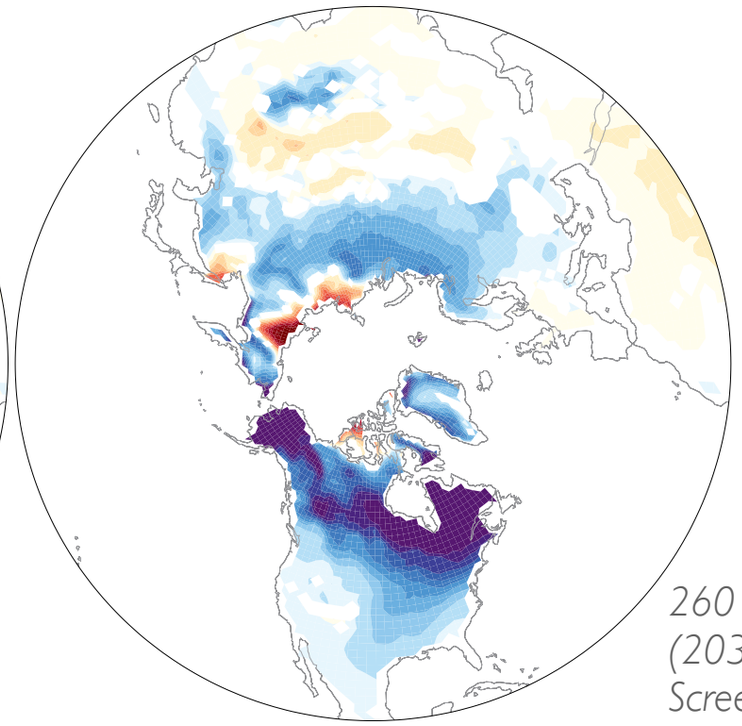
temperature response

a) HadGAM2 mean



variability response

b) HadGAM2 standard deviation

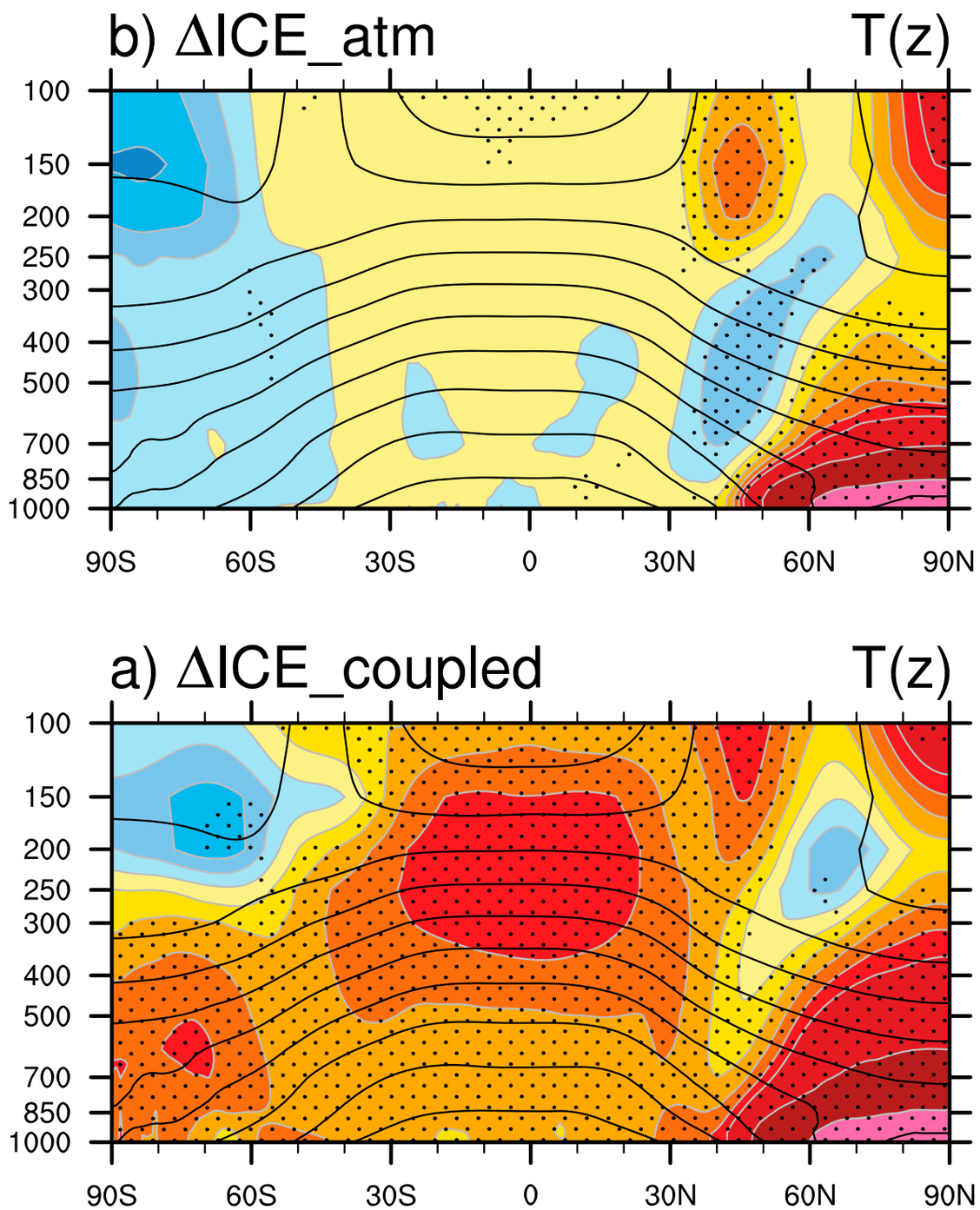


260 years of forced sea ice experiments
(2030-2049) - (1980-1999)
Screen et al. (2015; BAMS)

- temperature variance in midlatitudes *decreases* when sea ice decreases and the Arctic warms more than the surrounding areas

- theory suggests a decrease in variance when equator-to-pole temperature contrast decreases *(see also Schneider et al. (2014; JCLI) for more details and CMIP5 results)*

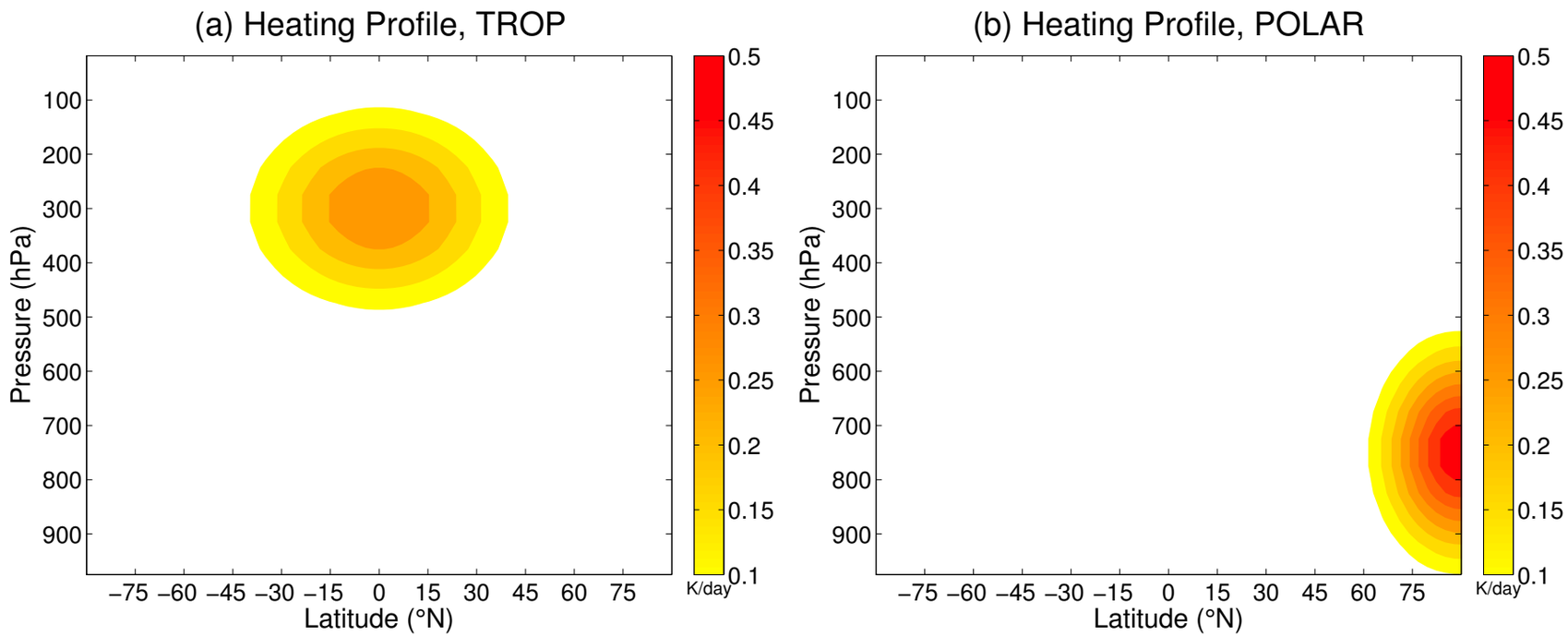
Coupled vs. AMIP simulations

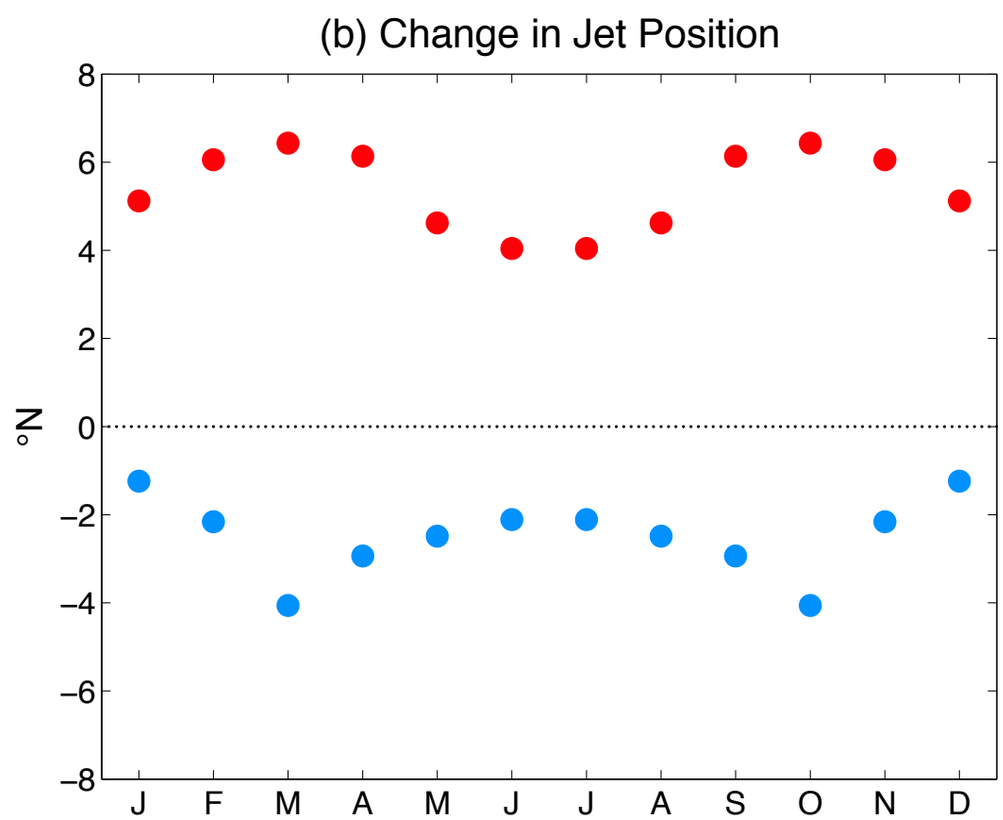


AMIP simulations may underestimate sea ice-induced warming

coupled CCSM4 simulations with additional long wave radiative fluxes in the ice model
Deser, Tomas, et al. (2015; JCLI)

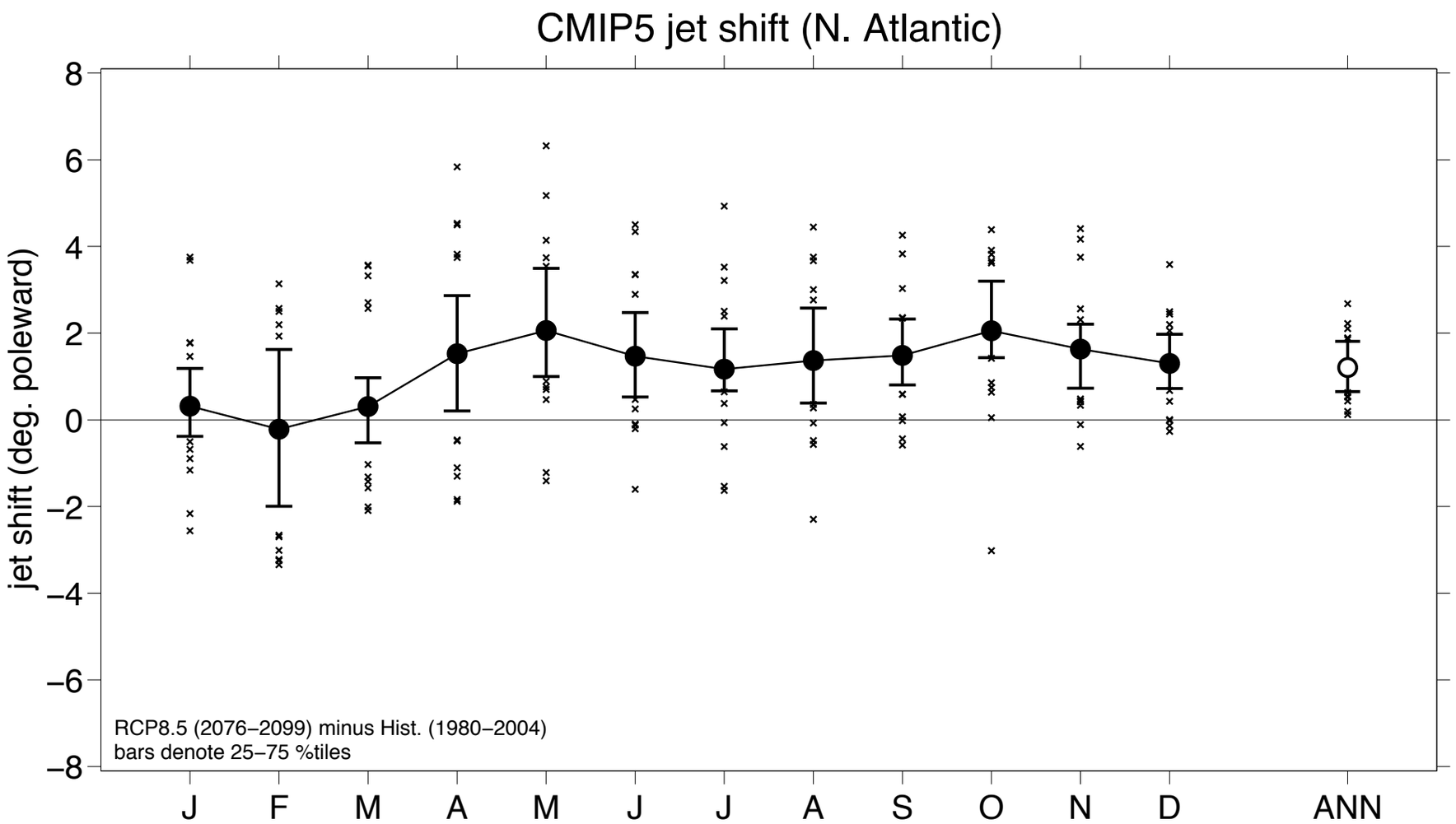
Seasonality of jet-stream response to heating





idealized modeling results
McGraw and Barnes (2015; submitted)

Shifts of the North Atlantic jet-stream by 2100



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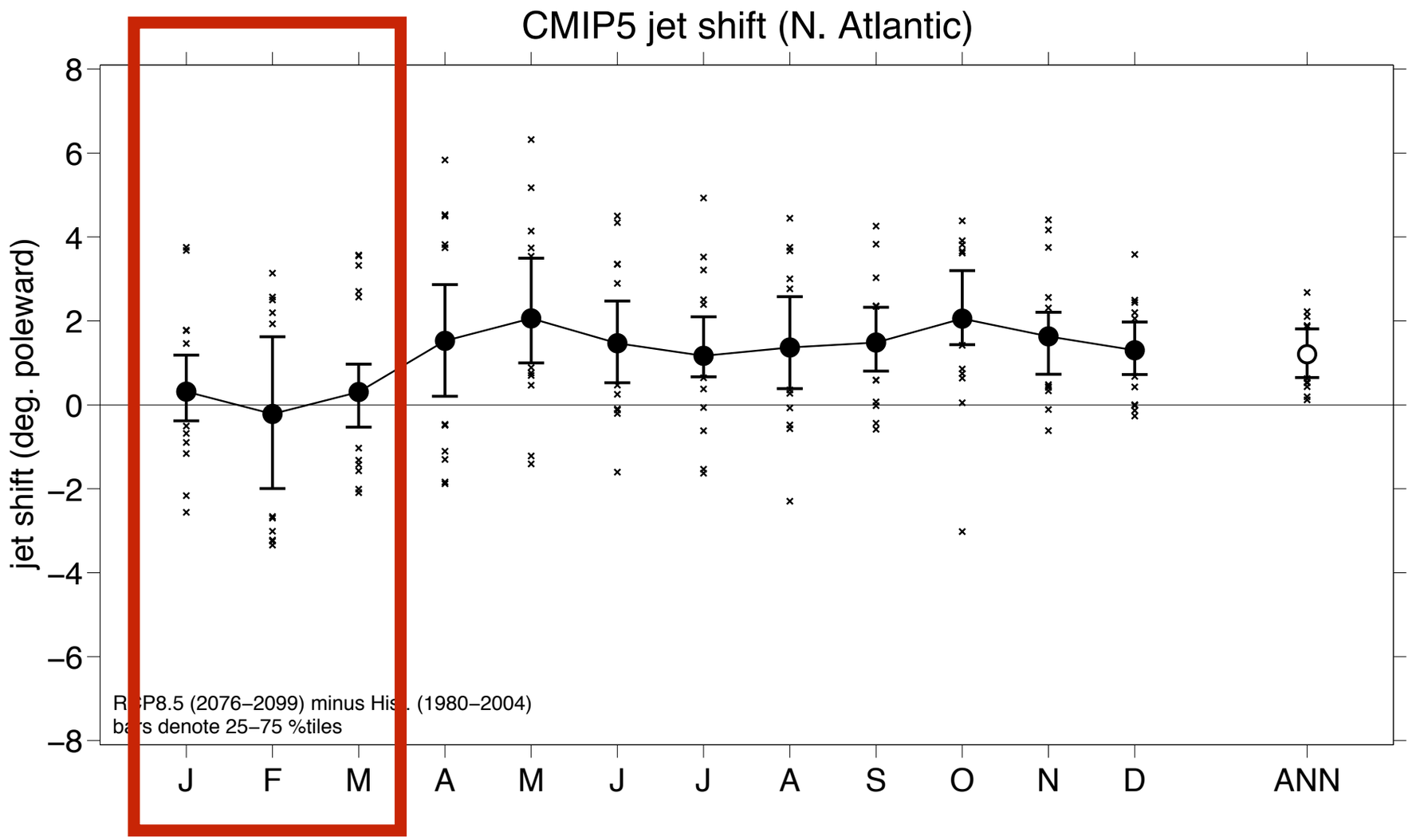

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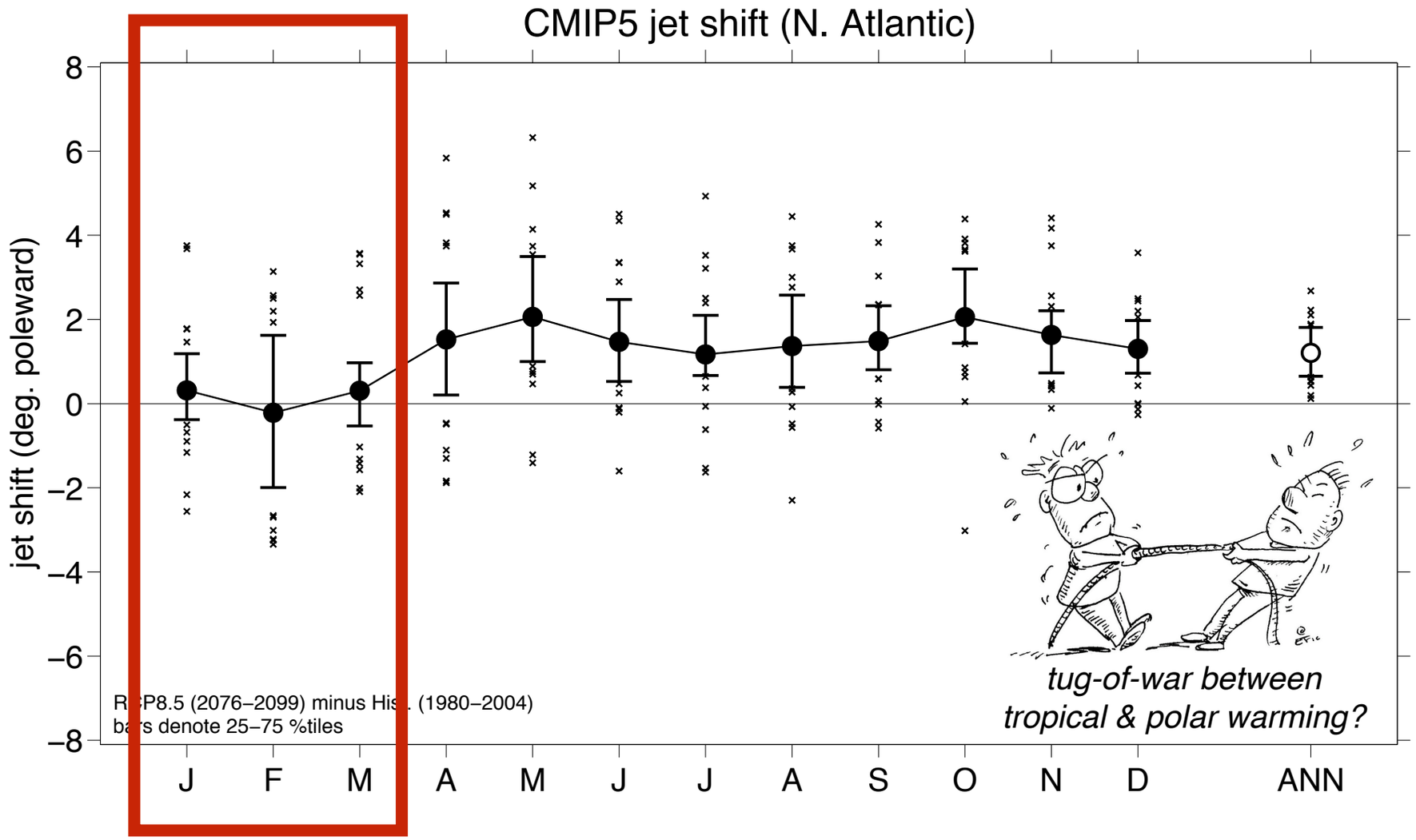

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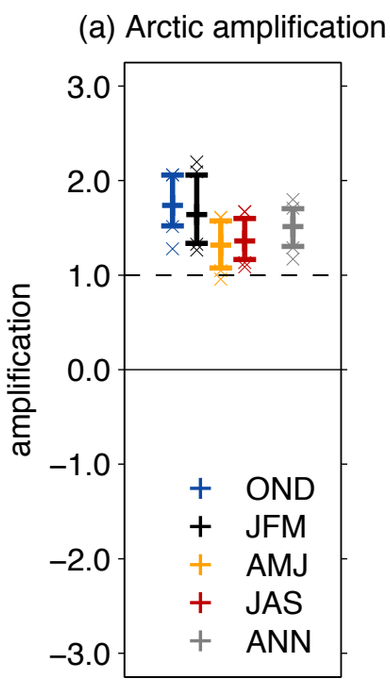

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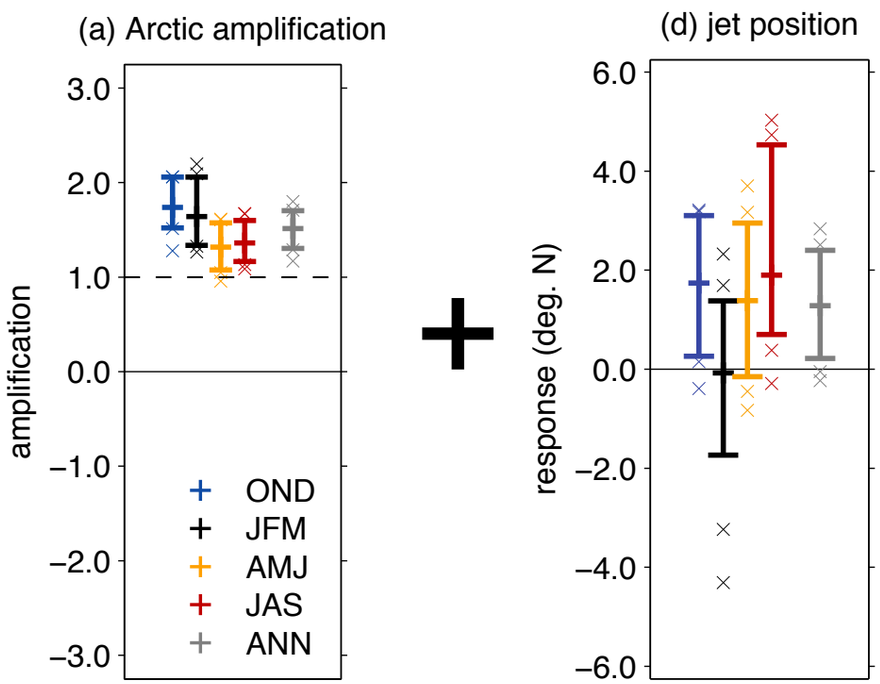

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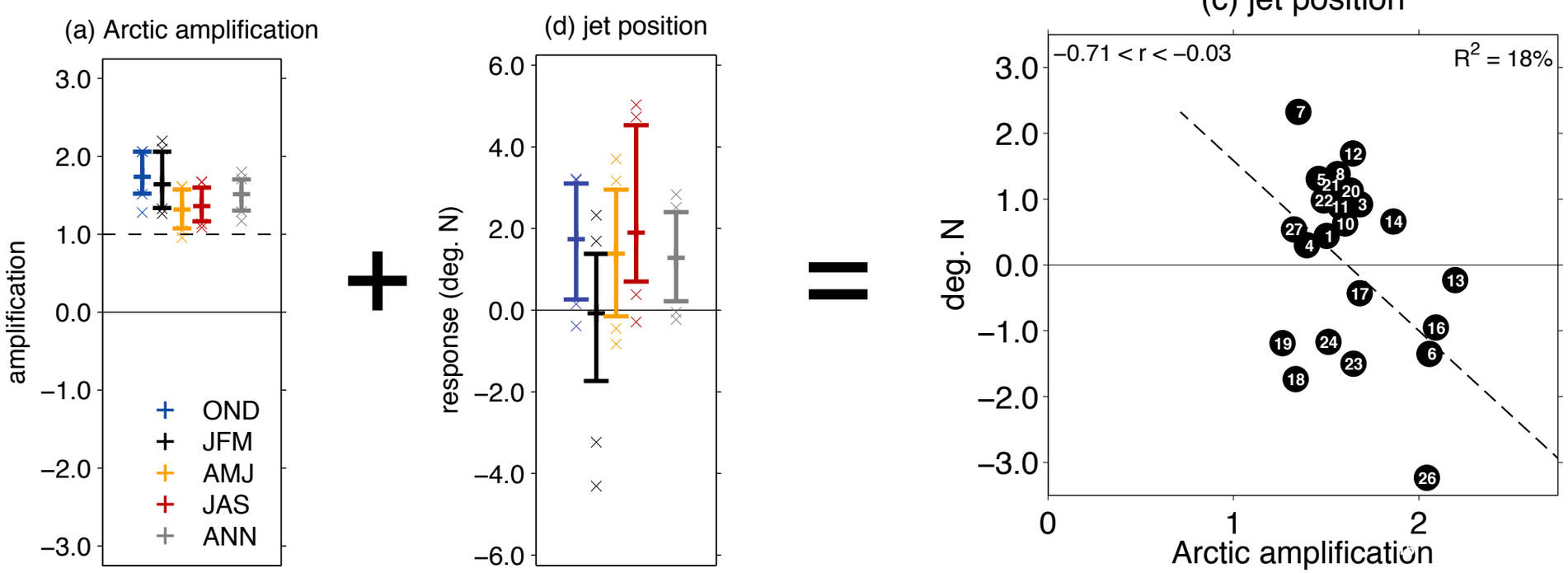

JFM only
1 dot = 1 GCM
Barnes & Polvani (2015)

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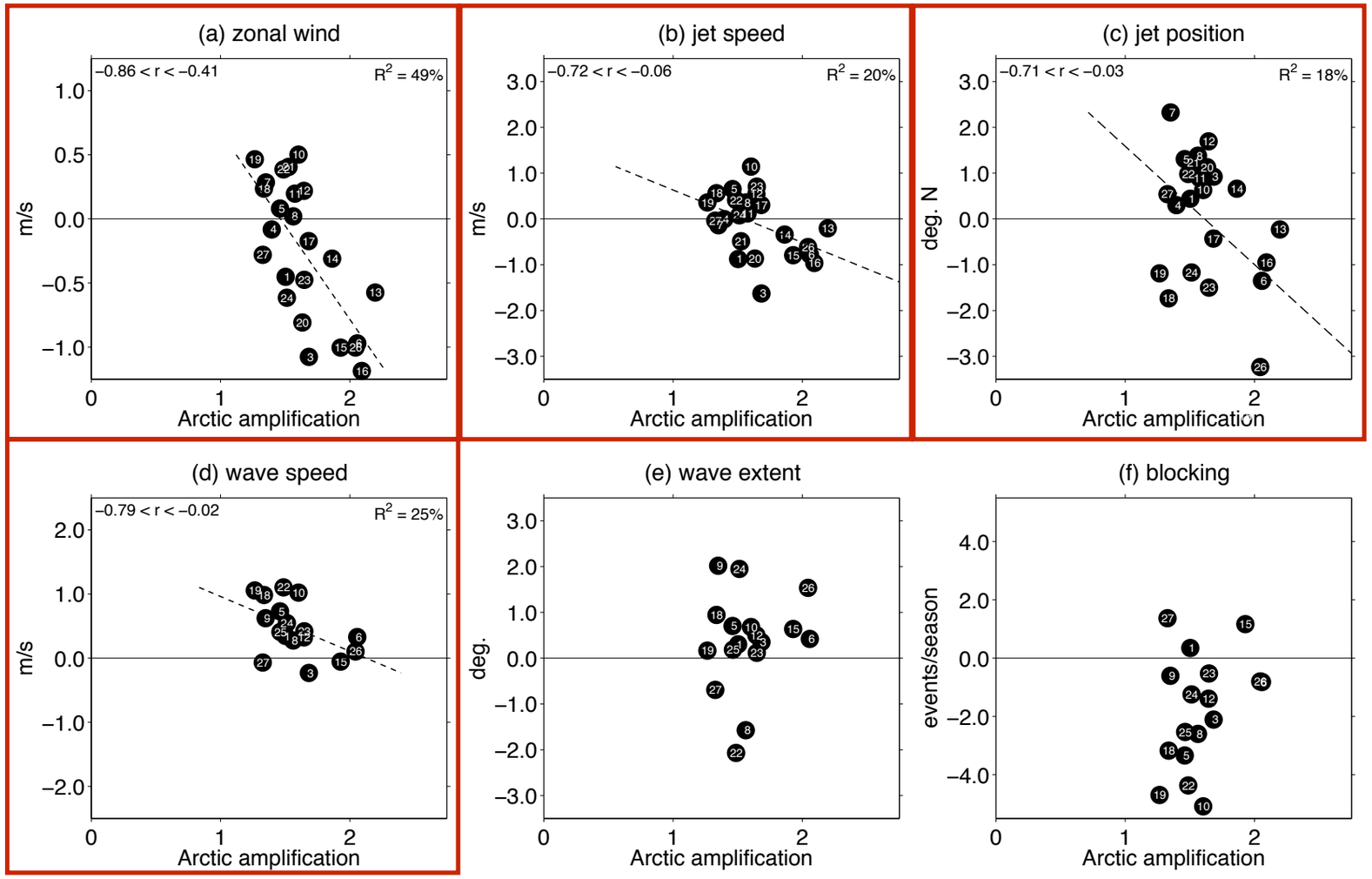


mean-flow metrics

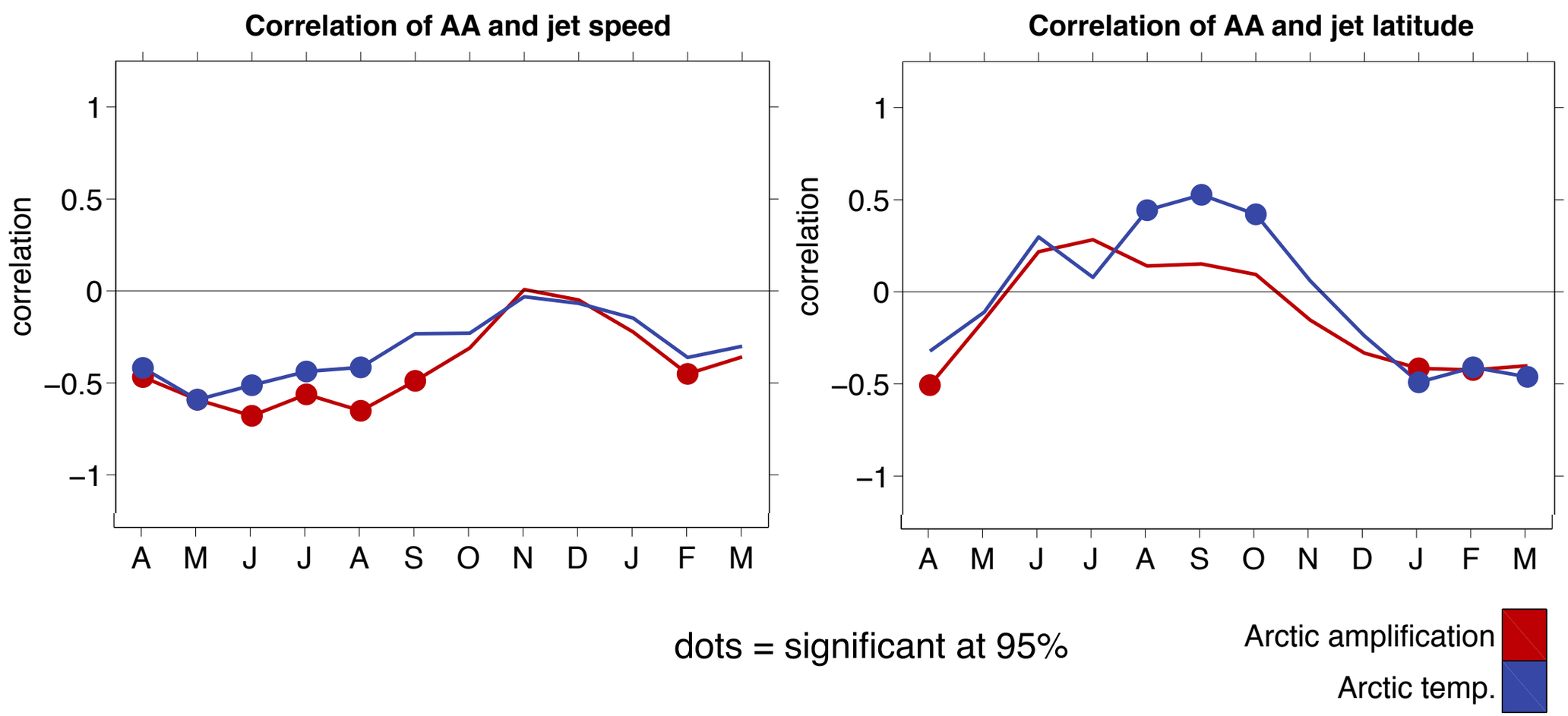
wave metrics

JFM correlations
Barnes & Polvani (2015)

- Zonal wind over the hemisphere is well correlated with Arctic warming in all seasons *(Harvey et al. (2013) and Haarsma et al. (2013) demonstrate strong correlations between zonal wind and tropospheric heating)*

- Weak relationships are found for the other metrics

Will it modulate?



- Correlations between Arctic amplification and the jet-stream are seasonally dependent - and strongest in spring and summer

- These results suggest a possible role for the Arctic to *modulate* the future response, but not determine the *net response*

Barnes & Polvani (2015)

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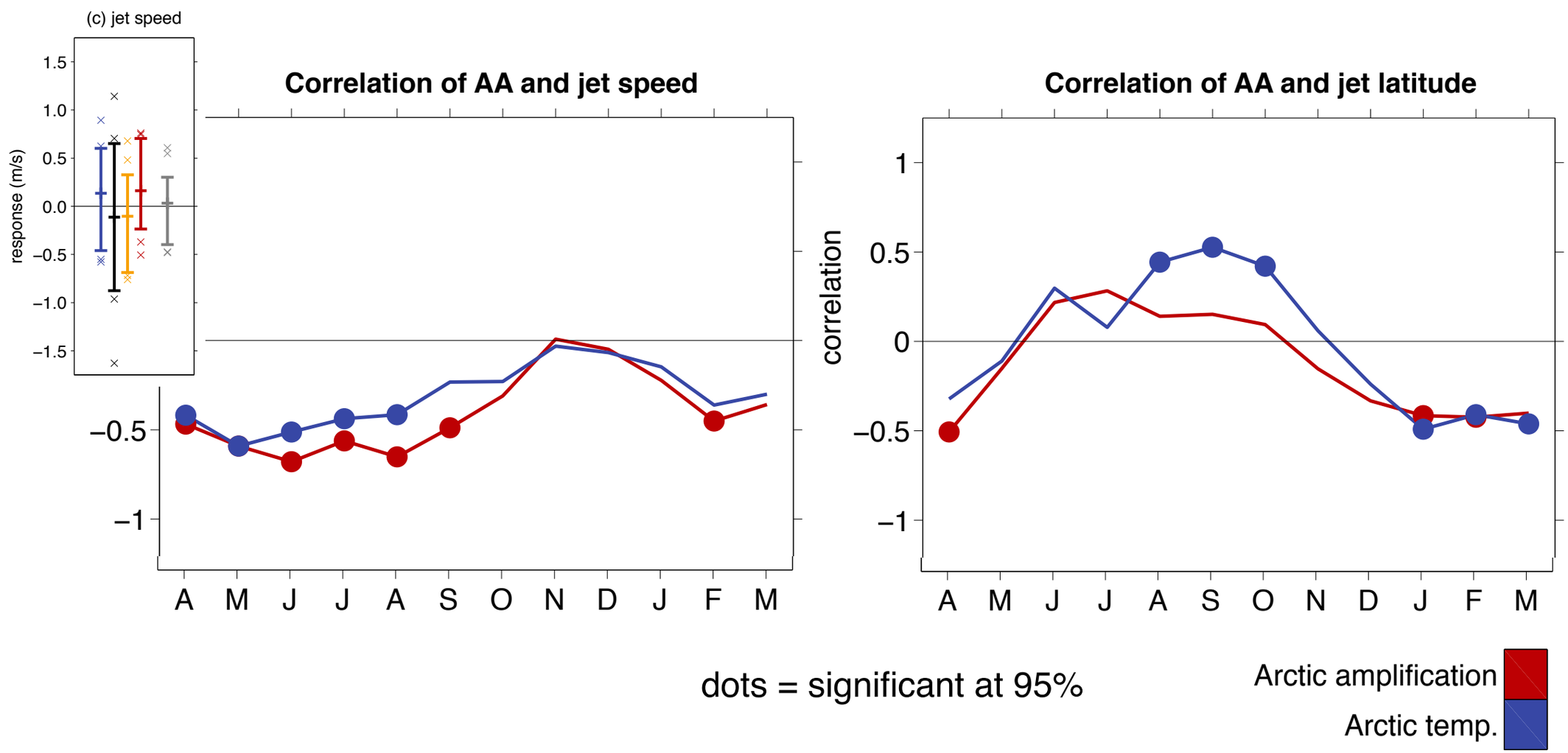

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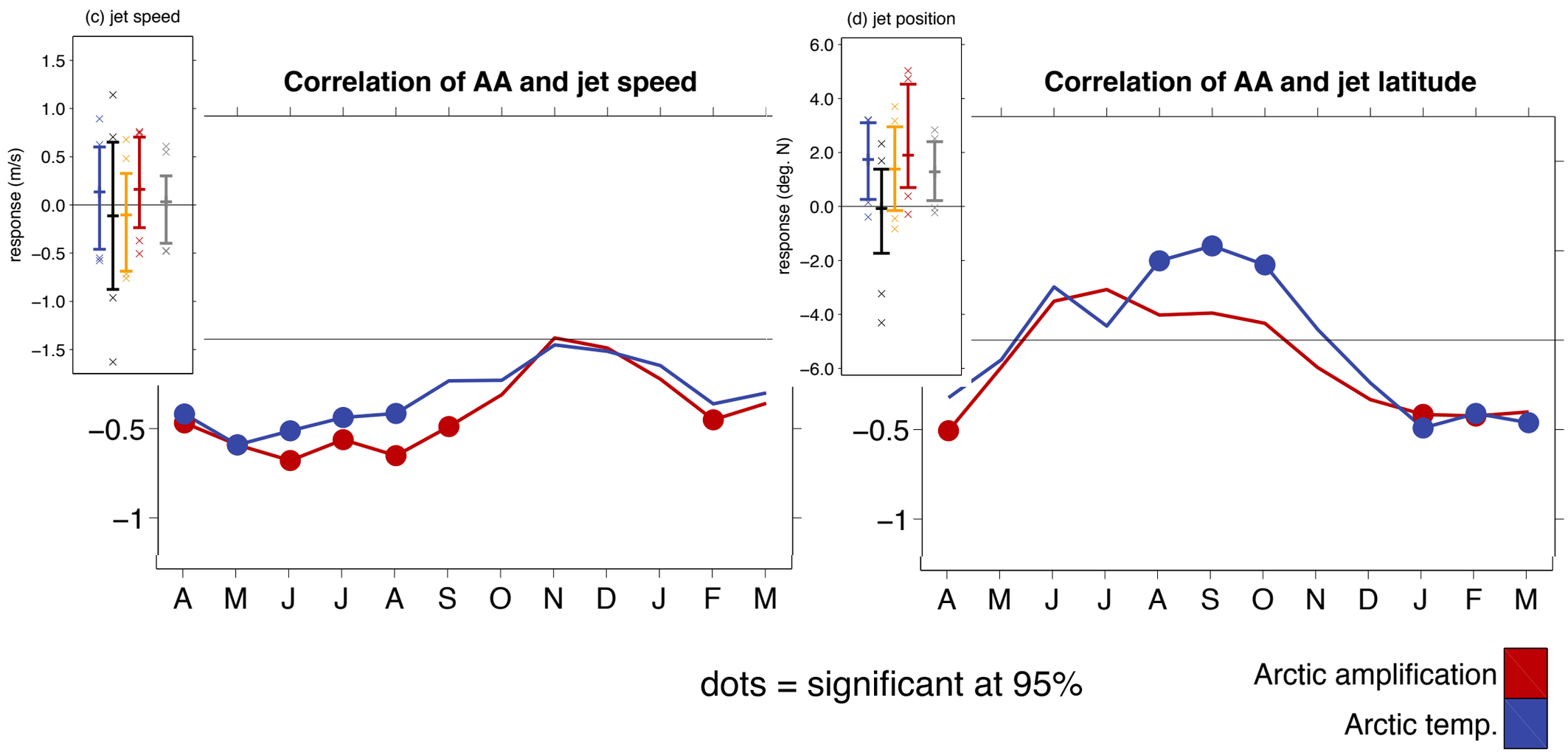

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Public belief

INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **34**: 1723–1728 (2014)
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(wileyonlinelibrary.com) DOI: 10.1002/joc.3796

RMetS
Royal Meteorological Society

Short Communication

Arctic warming and your weather: public belief in the connection

Lawrence C. Hamilton[a]* and Mary Lemcke-Stampone[b]
[a] *Department of Sociology, University of New Hampshire, Durham, NH 03824, USA*
[b] *Department of Geography, University of New Hampshire, Durham, NH 03824, USA*

If the Arctic region becomes warmer in the future, do you think that will have **major effects**, **minor effects** or **no effects** on the weather where you live?

[1500 interviews of New Hampshire residents]

Hamilton and Lemcke-Stampone (2013; IJC)

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[1500 interviews of New Hampshire residents]

major effects:	**60%**
minor effects:	**29%**
no effects:	**5%**
don't know:	**6%**

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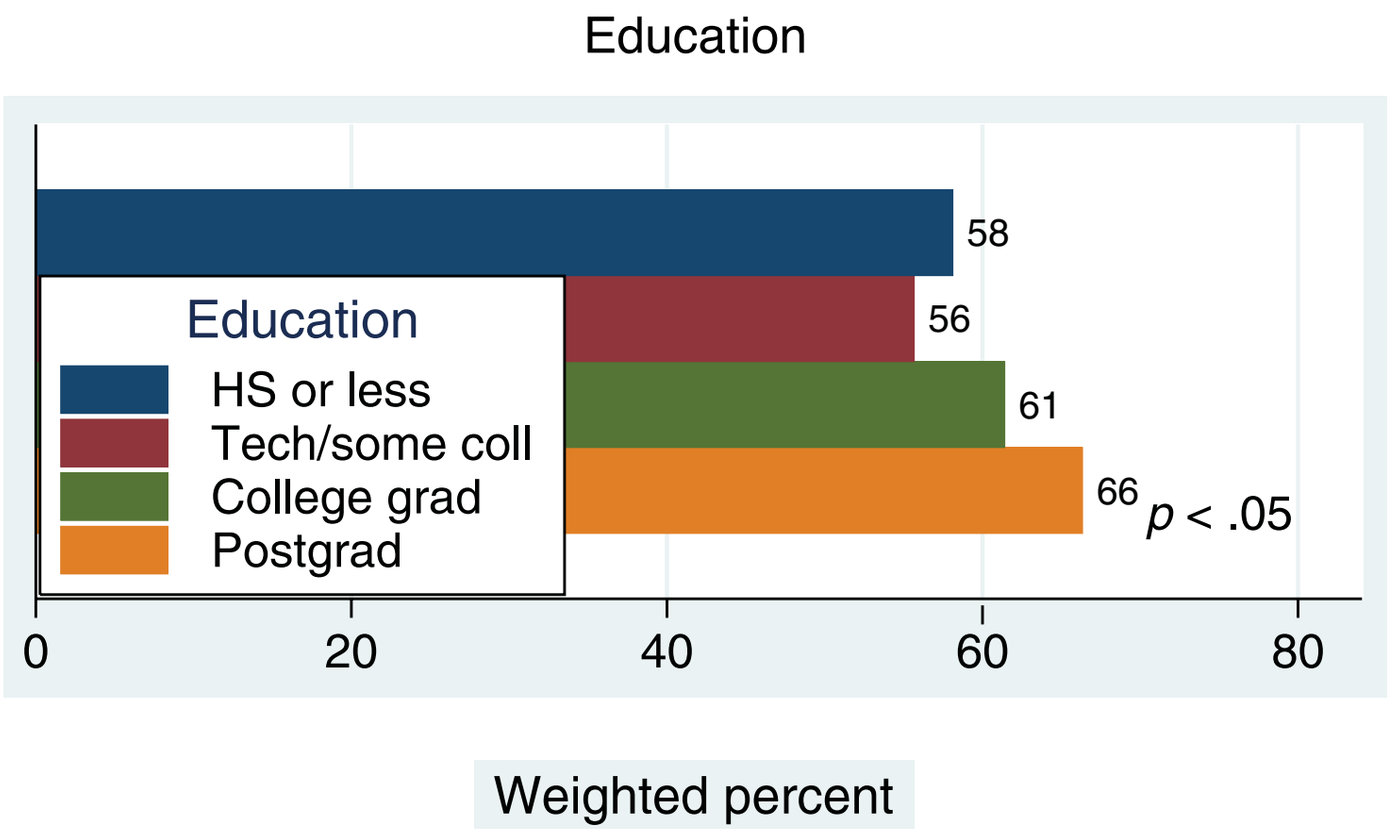

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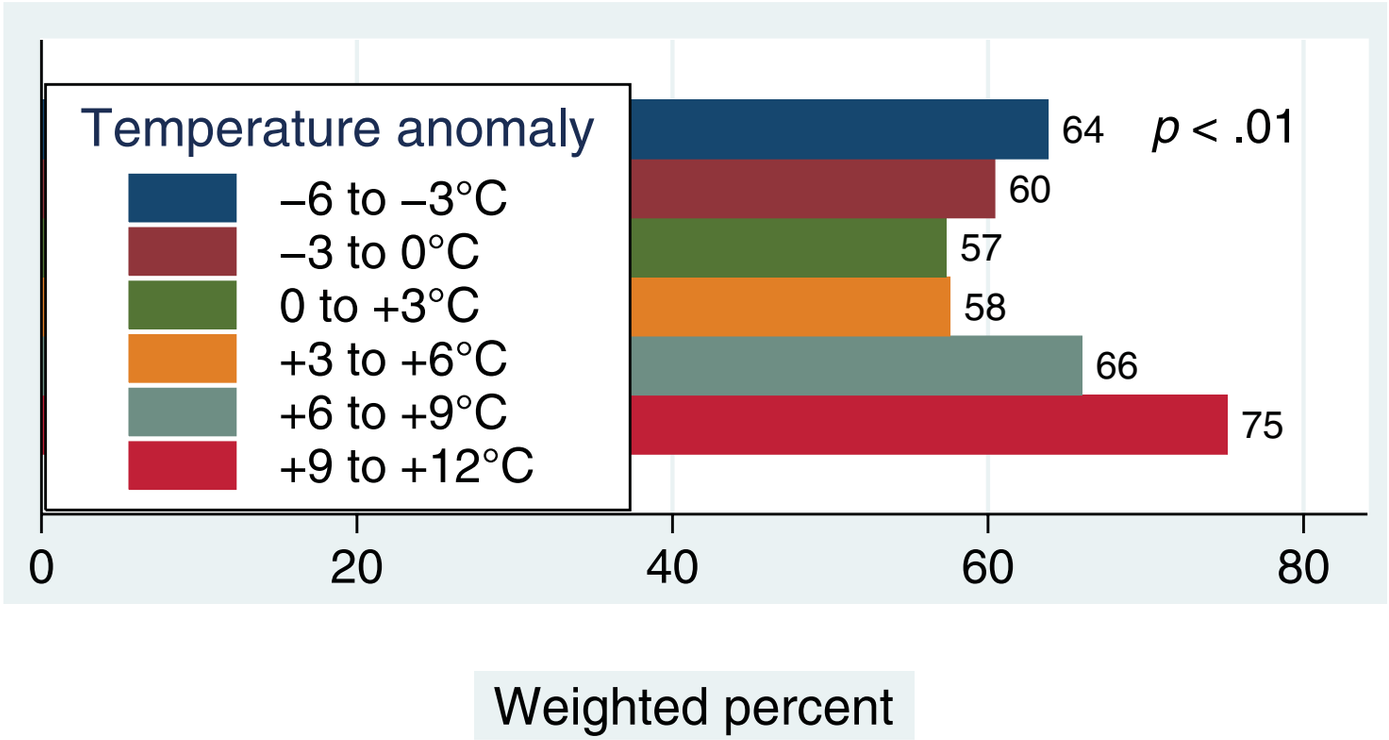
Average temperature anomaly interview day and day before



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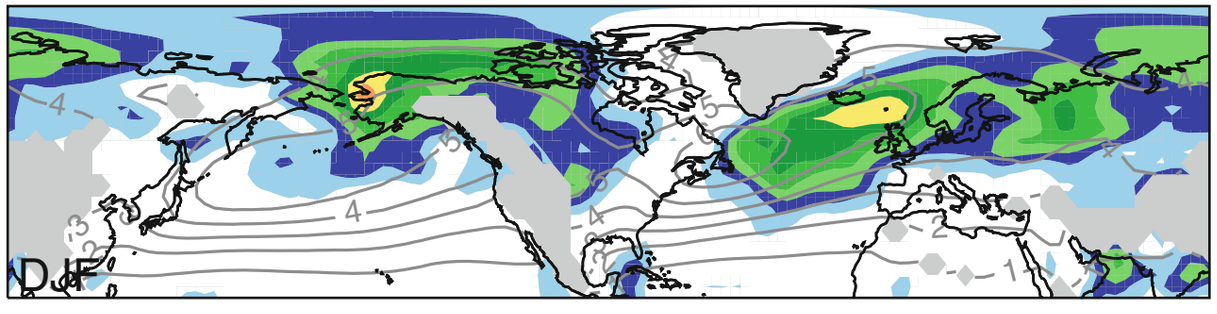
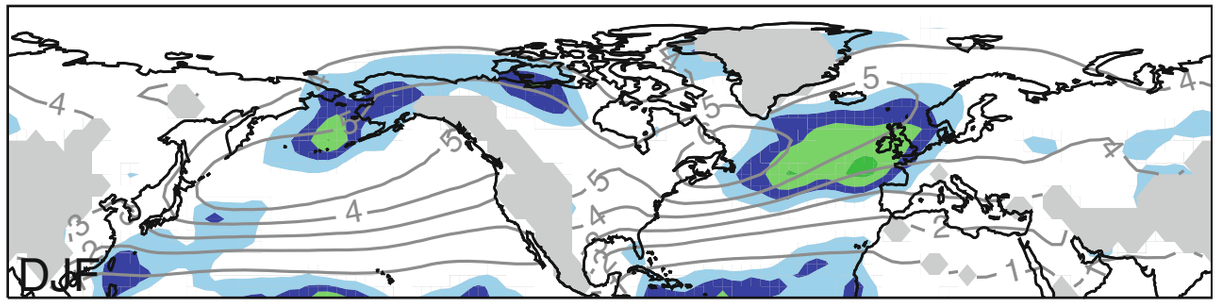
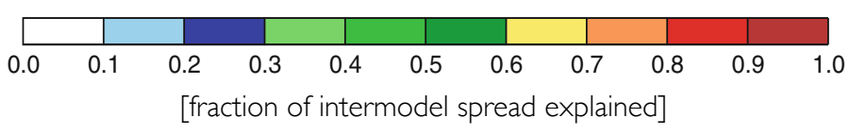
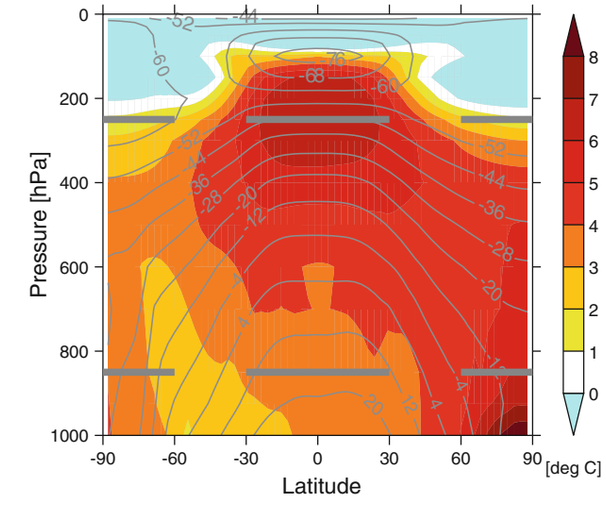


250 hPa







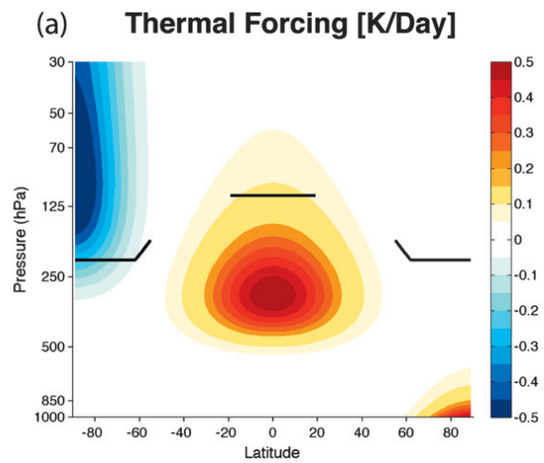
temperature response under RCP8.5 (1976-2005) - (2070-2099)

CMIP5 model analysis
storm track = variance of 2-6 dy. SLP
Harvey, Shaffrey et al. (2013)

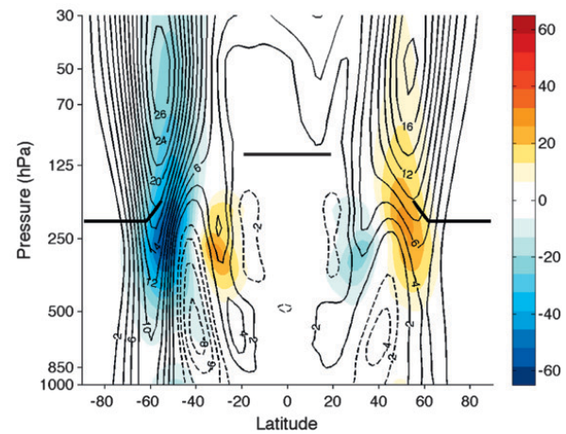
- In the N. Atlantic, 850 hPa gradient explains over 50% of variance
- Northern Hemisphere winter intermodel spread requires both 850hPa and 250hPa changes to explain the model storm track responses in winter

Nonlinear response

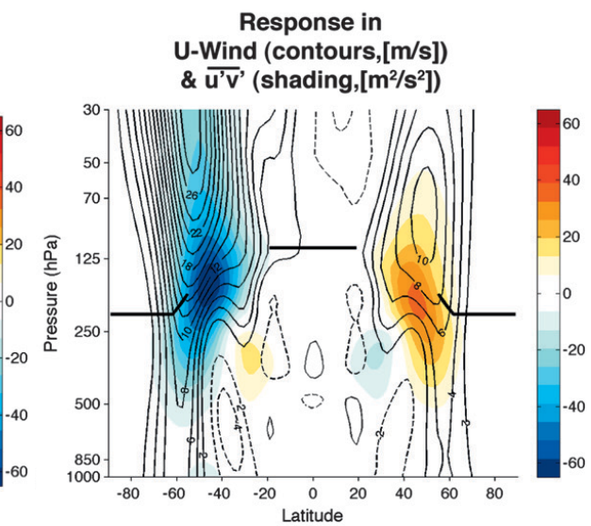
simulations of a dry, dynamical core imposed heating under perpetual equinox conditions
Butler, Thompson et al. (2010)



3 thermal forcings



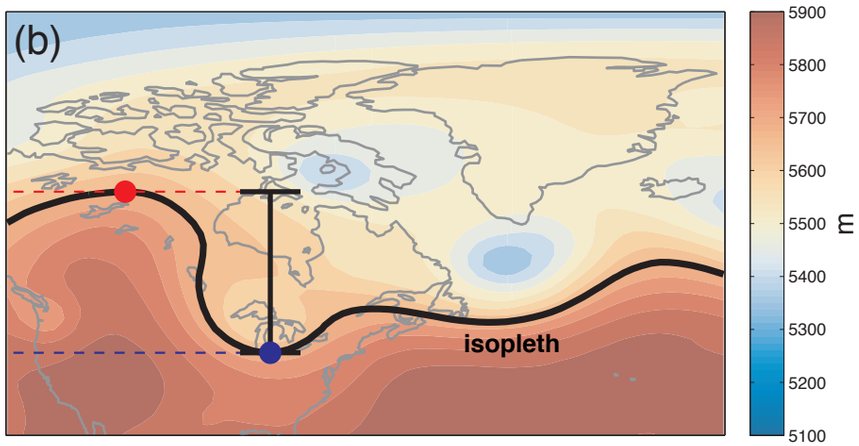
sum of individual forcing responses



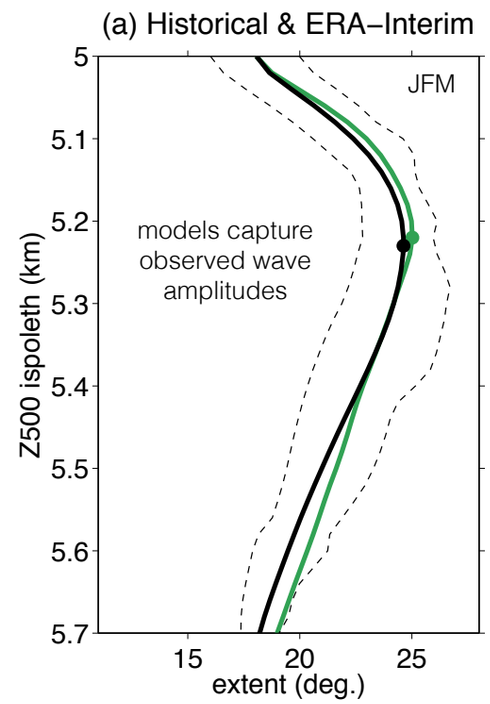
total response

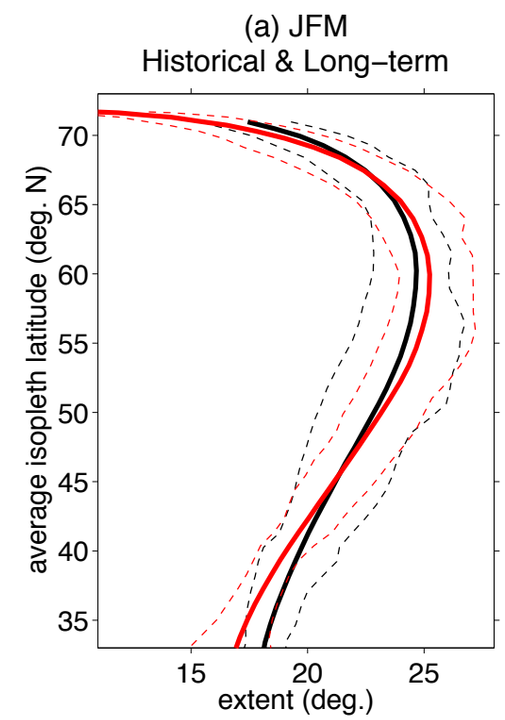
- Ultimately, jet shifts poleward
- Even if the tropics “win”, response may be modulated by Arctic warming

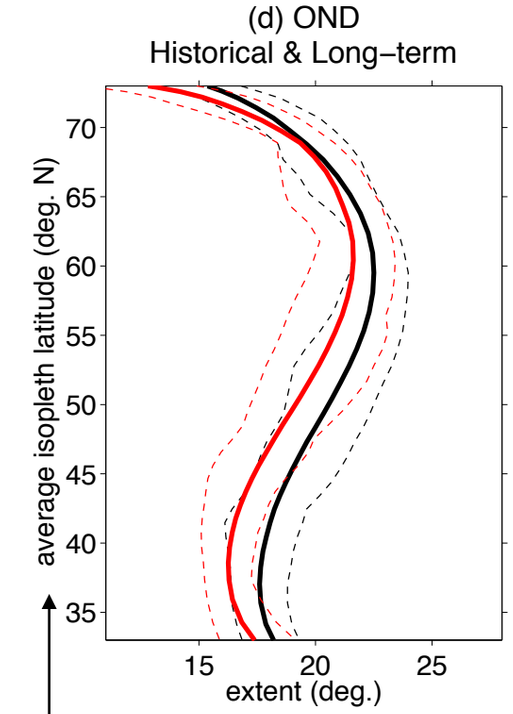
Jet “waviness”



Barnes (2013)







average latitude

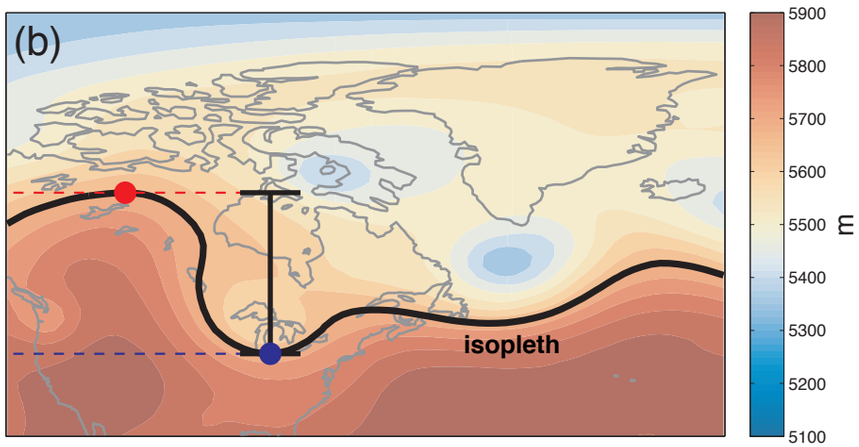
ERA–Interim (1980–2004)
CMIP5 (1980–2004)
CMIP5 (2020–2044)
CMIP5 (2076–2099)
Hypsometric approx.

- Has been suggested that wave amplitude increases with Arctic amplification
  (Francis & Vavrus (2012; GRL))

- However, models show *decreases* or no clear change over North America and the North Atlantic

Barnes & Polvani (2015; JCLI)

Wave amplitudes in the future



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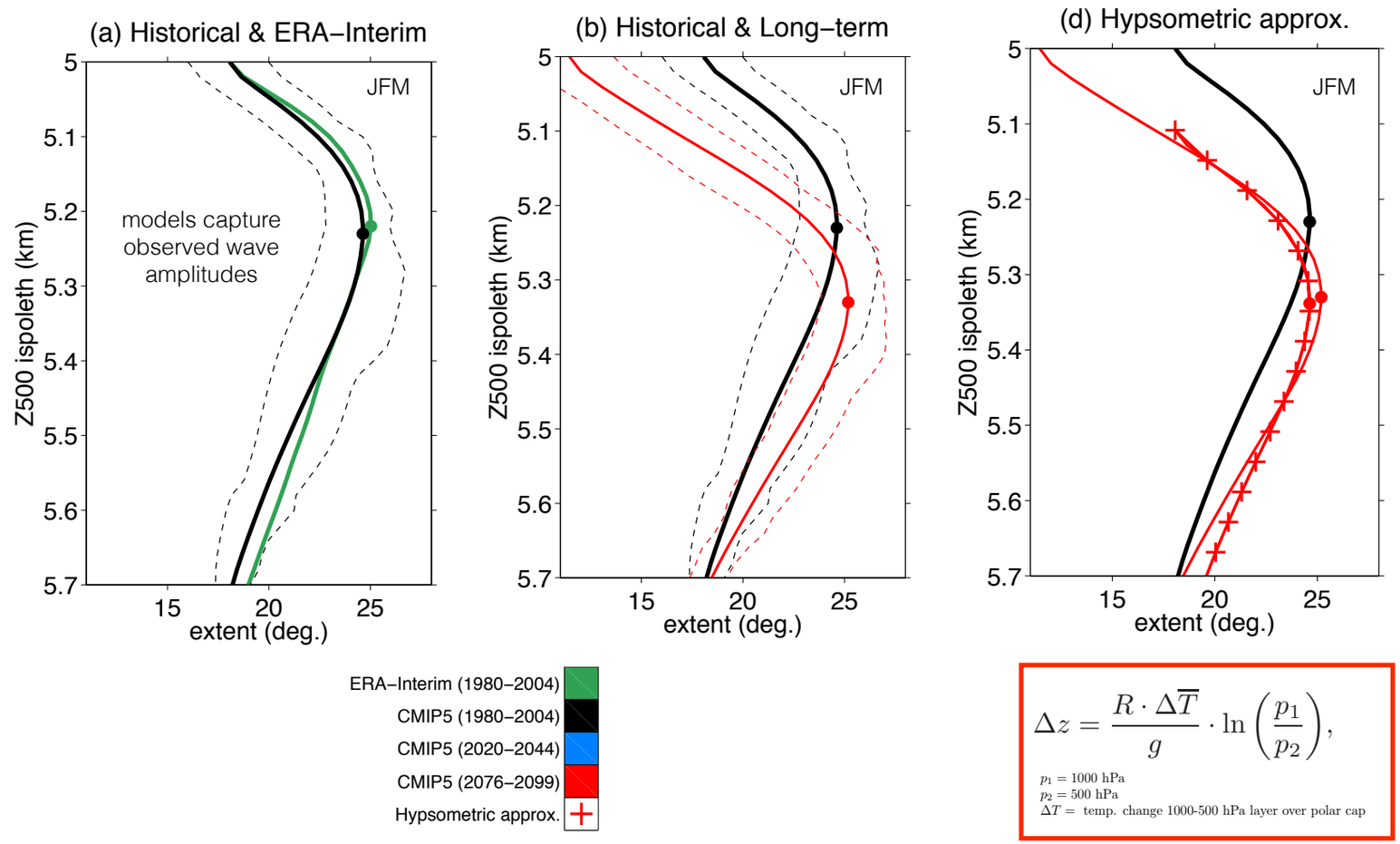

$$\Delta z = \frac{R \cdot \Delta \overline{T}}{g} \cdot \ln\left(\frac{p_1}{p_2}\right),$$

$p_1 = 1000$ hPa
$p_2 = 500$ hPa
$\Delta T =$ temp. change 1000-500 hPa layer over polar cap

- Has been suggested that wave amplitude increases with Arctic amplification
  (Francis & Vavrus (2012; GRL))

- Let's look further into the CMIP5 wave amplitude response

- other seasons show decreases everywhere

Barnes & Polvani (2015; JCLI)

Some challenges

(1) **Can** Arctic warming influence the midlatitude jetstream?

(2) **Has** Arctic warming significantly influenced the midlatitude jetstream?

(3) **Will** Arctic warming significantly influence the midlatitude jetstream?

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regional v.s. hemispheric impacts

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what metrics?
what weather?

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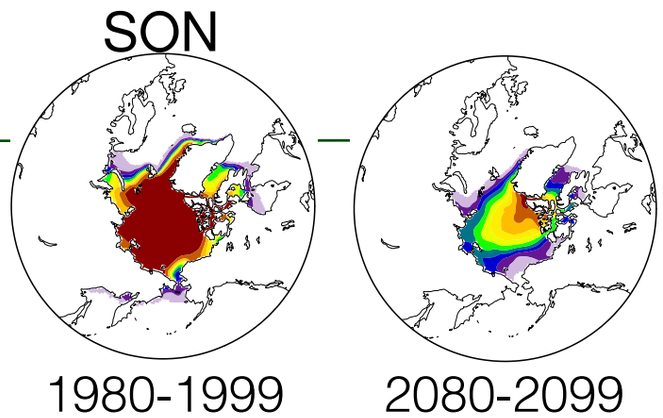
can models capture the relevant processes?

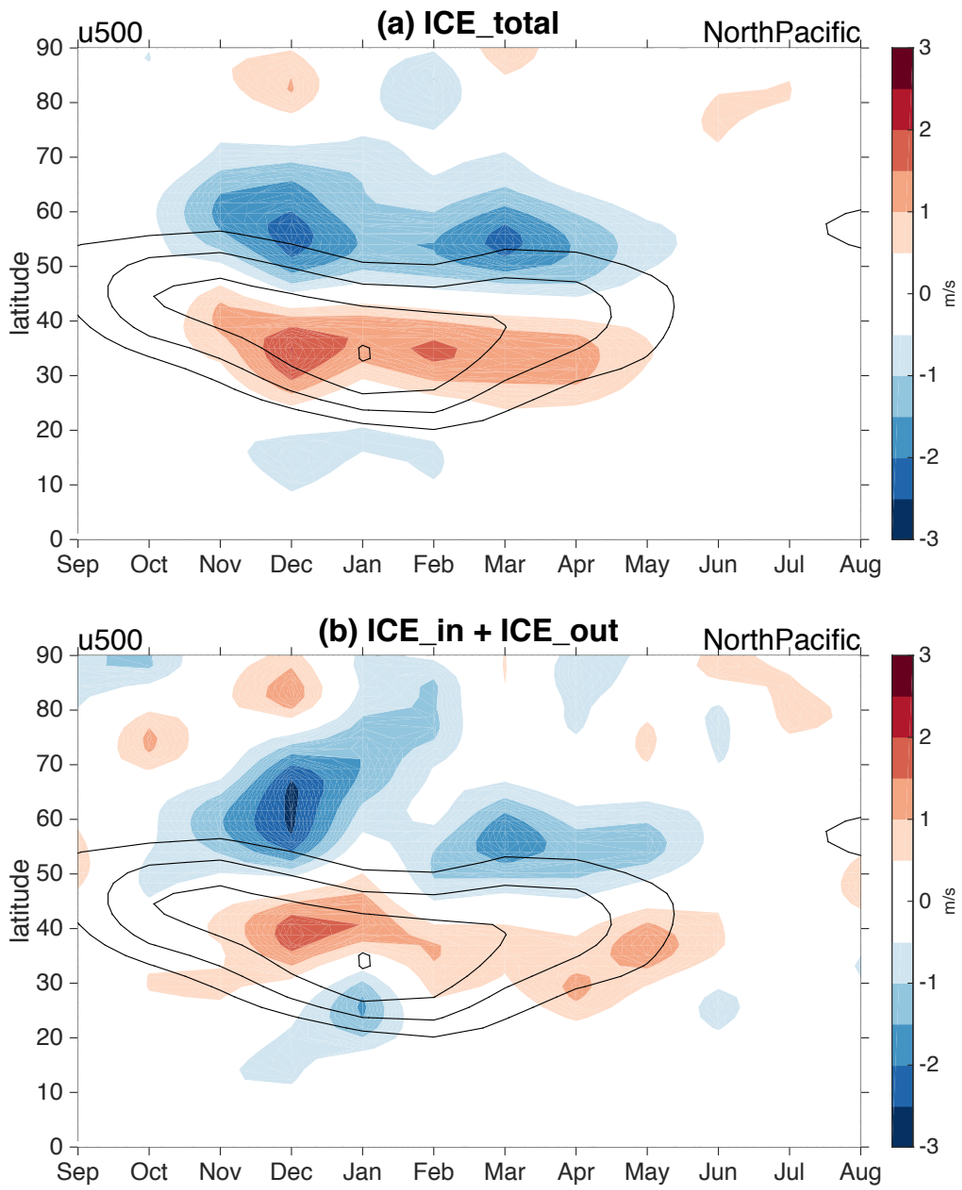
what is the net response?

nonlinearity complicates simplified experiments

Nonlinear response

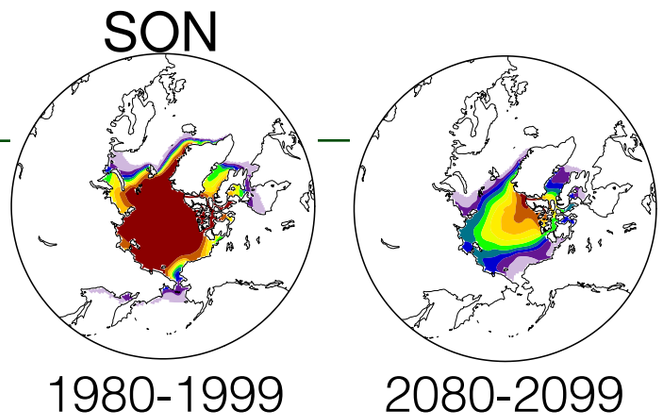


North Pacific jet response to sea ice loss **inside** and **outside** of the Arctic circle.



based on 160-year WACCM simulations of Sun et al. (2015; JCLI)

Nonlinear response



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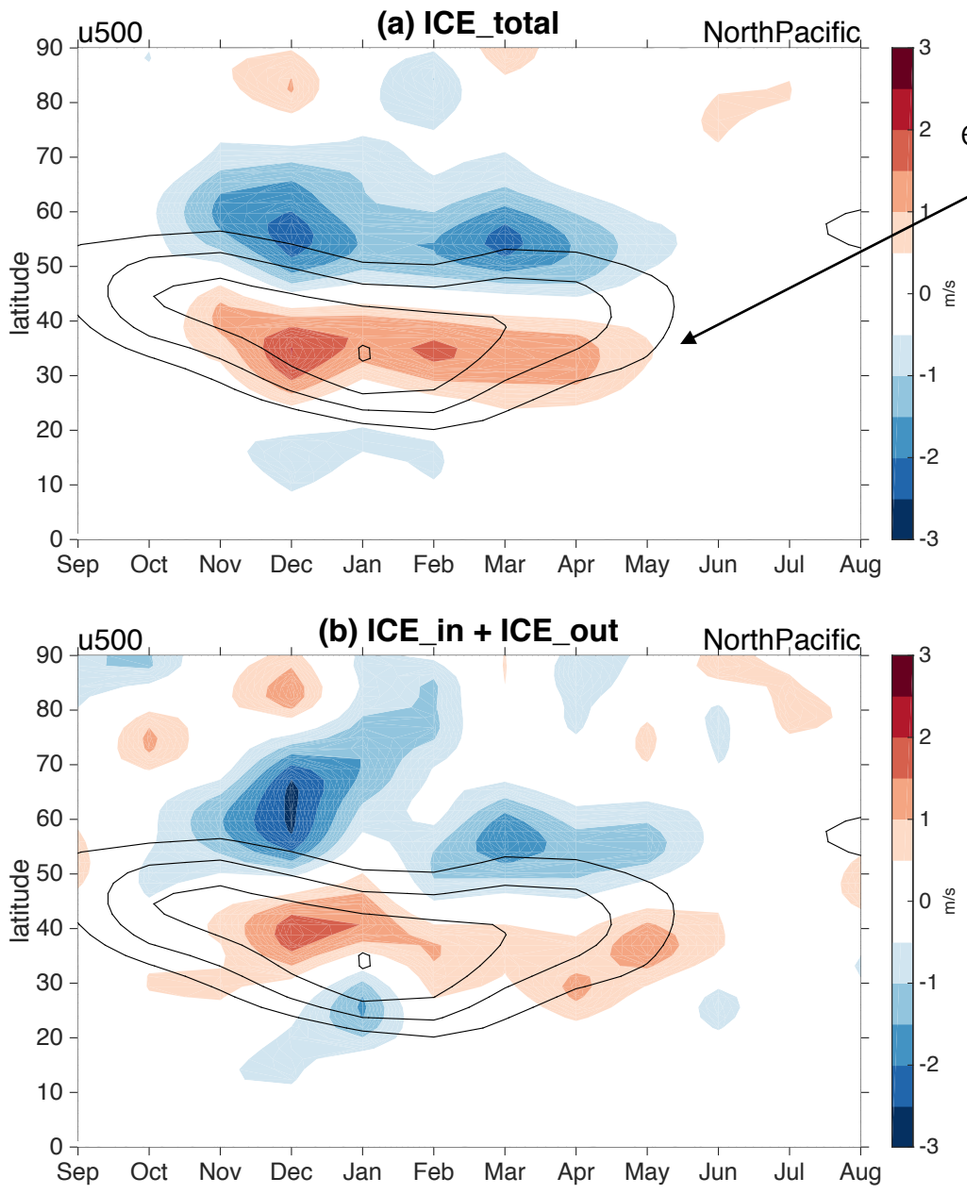
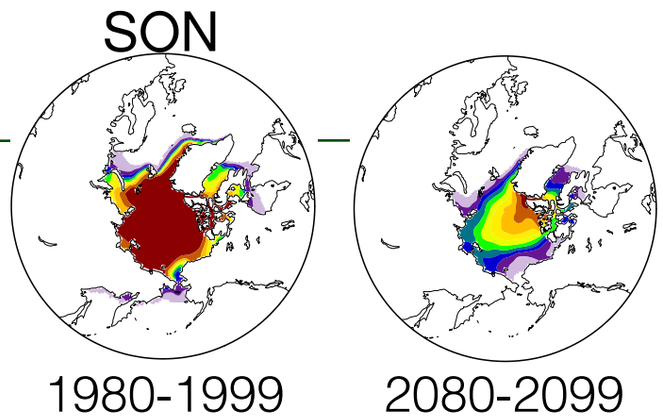


jet shifts further equatorward for total forcing

based on 160-year WACCM simulations of Sun et al. (2015; JCLI)

Nonlinear response



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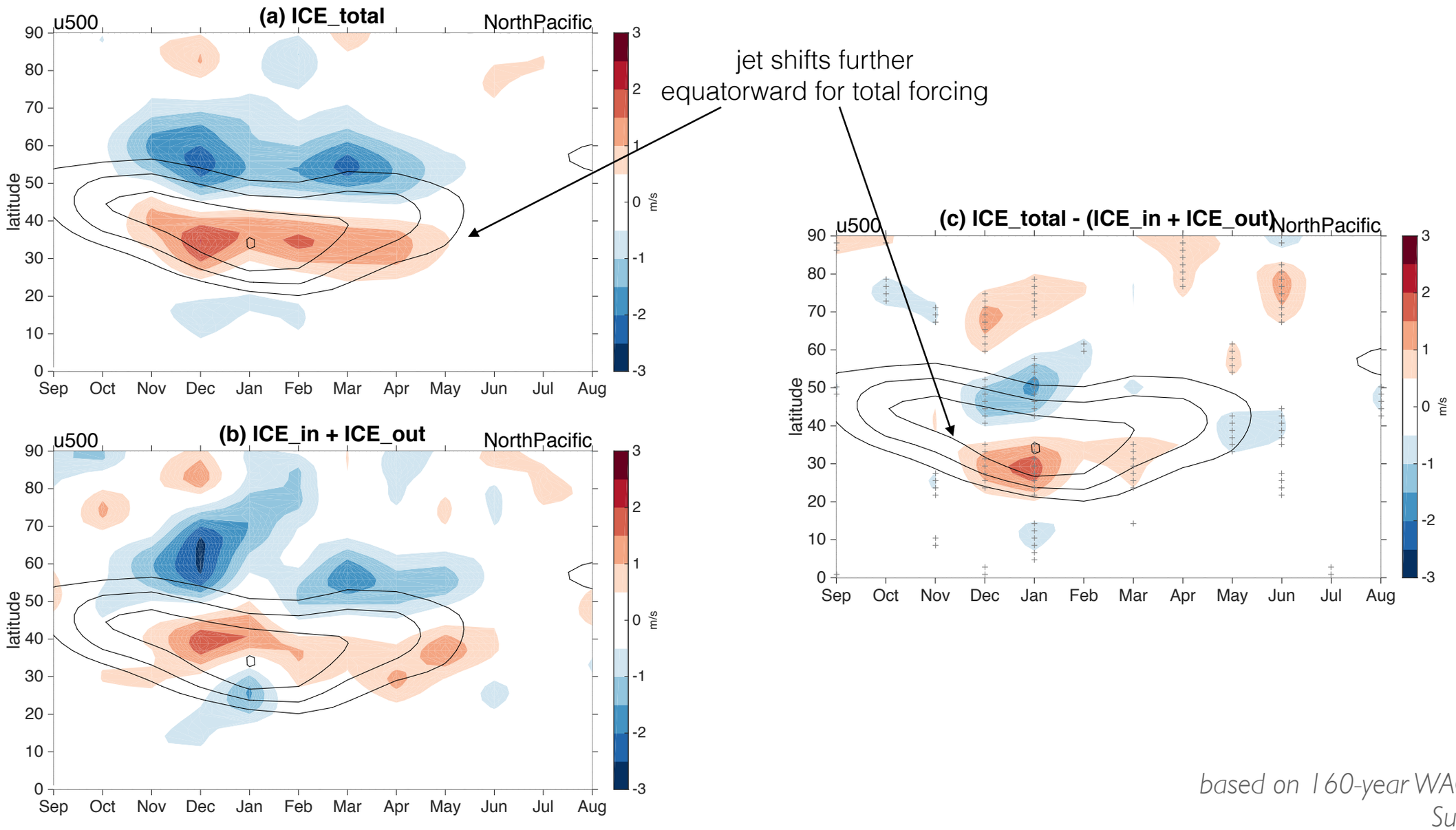
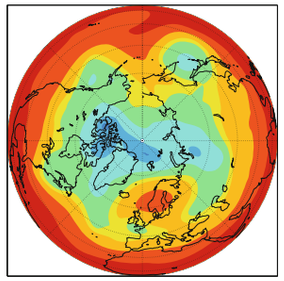
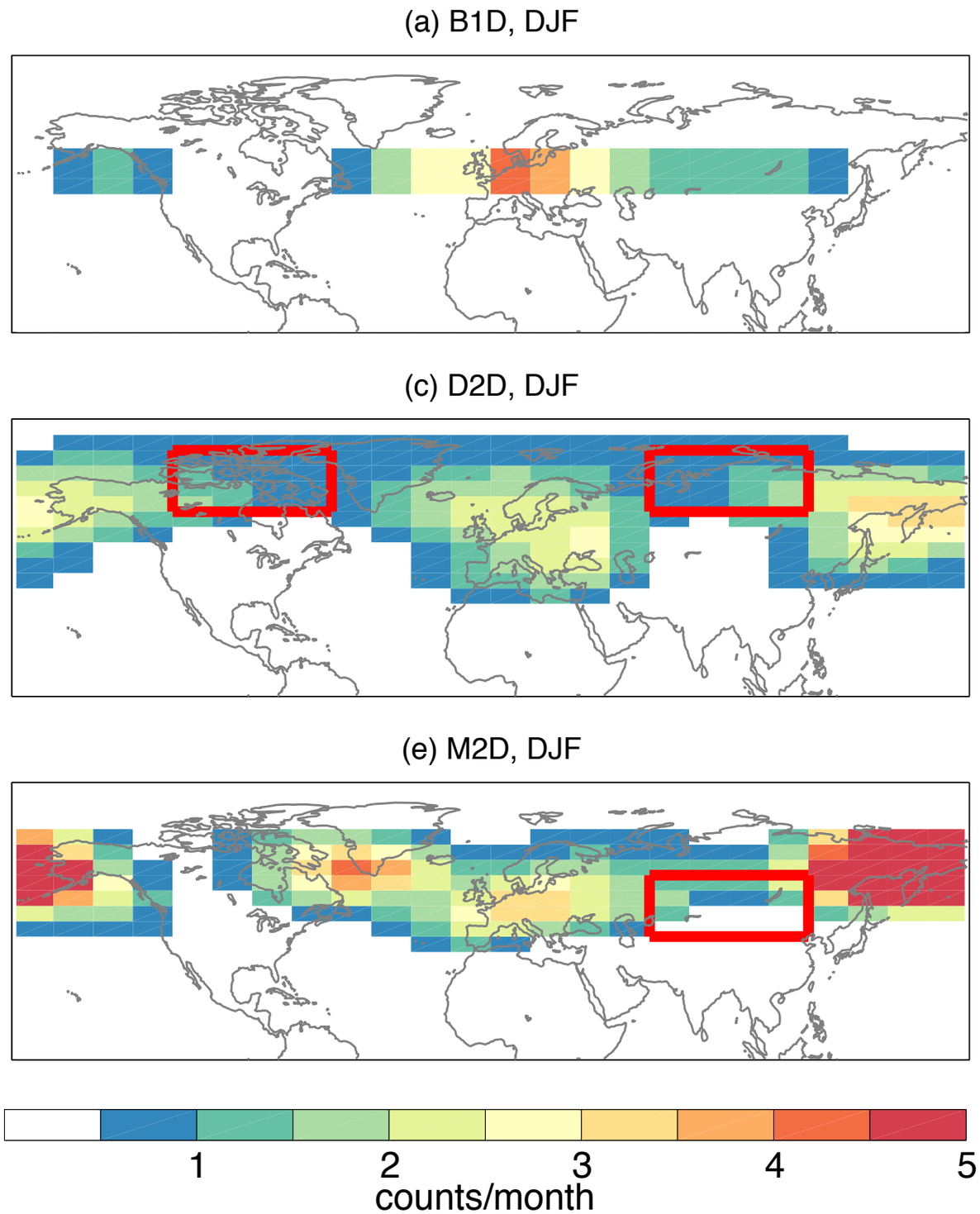


based on 160-year WACCM simulations of Sun et al. (2015; JCLI)

Has blocking frequency shown positive trends?



example blocking high 500 hPa Z anomaly



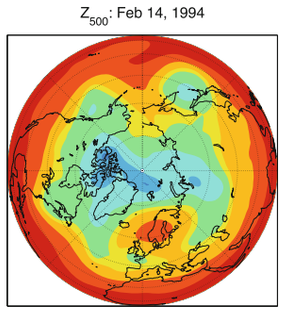
- 3 blocking identification methods
- 4 seasons
- 4 reanalyses
- 3 different time periods

3 different blocking metric climatologies

B1D: Barnes et al . (2012)
D2D: Dunn-Sigouin et al. (2013)
M2D: Masato et al. (2013)

Barnes et al. (2014); GRL

Blocking trends sensitive to time period



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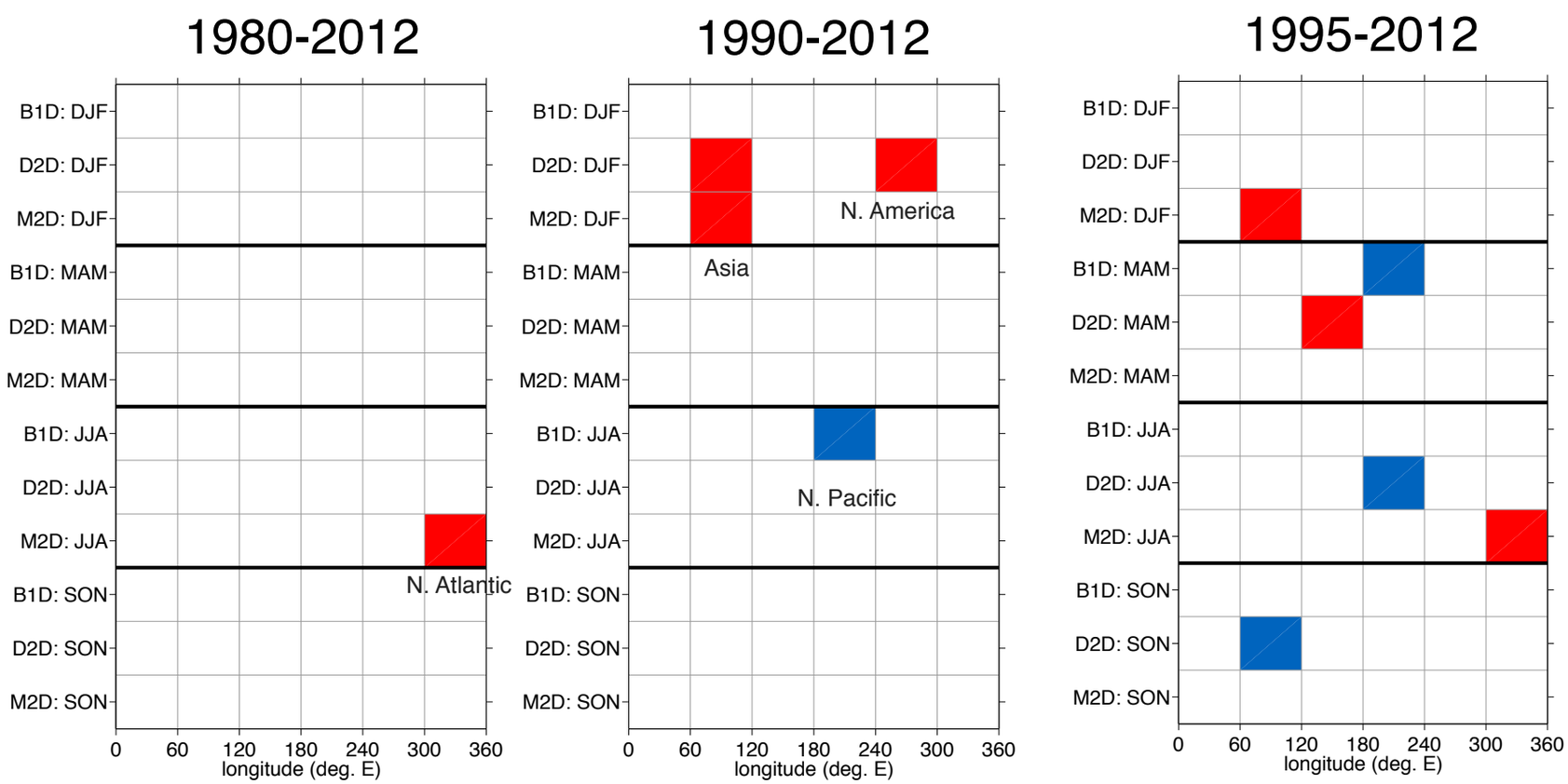


at least 3 of 4 reanalyses show significant positive trend at 95% confidence

at least 3 of 4 reanalyses show significant negative trend at 95% confidence

*expect **0-5** blocks per reanalysis and index by chance alone*

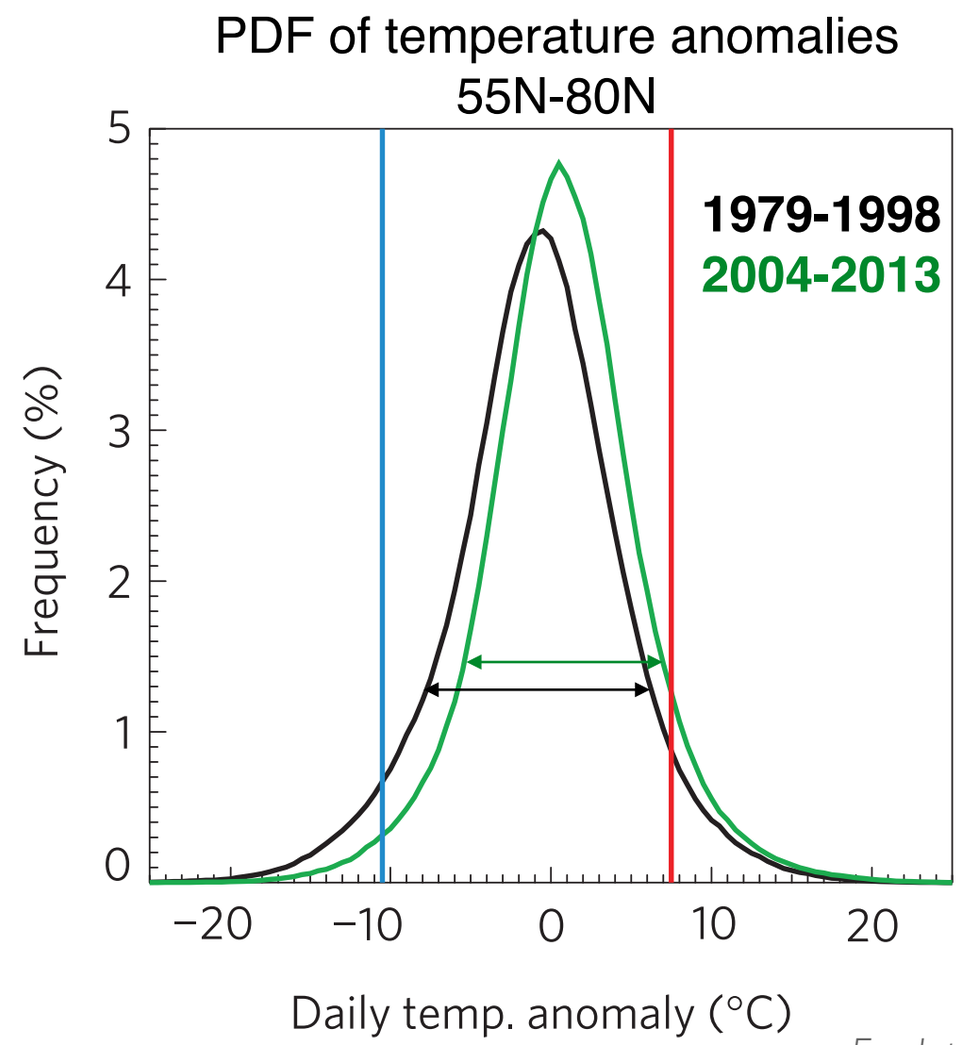
- Trends are very sensitive to the exact time period chosen
- Different results are obtained for different reanalyses and metrics
- No clear signal of increased blocking frequency emerges

Barnes et al. (2014); GRL

Observed midlatitude temperature variance

- recent work suggests that temperature variance in midlatitudes has *decreased* in recent decades

- consistent with theory: a decrease in variance when equator-to-pole temperature contrast decreases
  (see also Schneider et al. (2014; JCLI))



Era-Interim, autumn
Latitudes 55N-80N
Screen (2014; NATCC)

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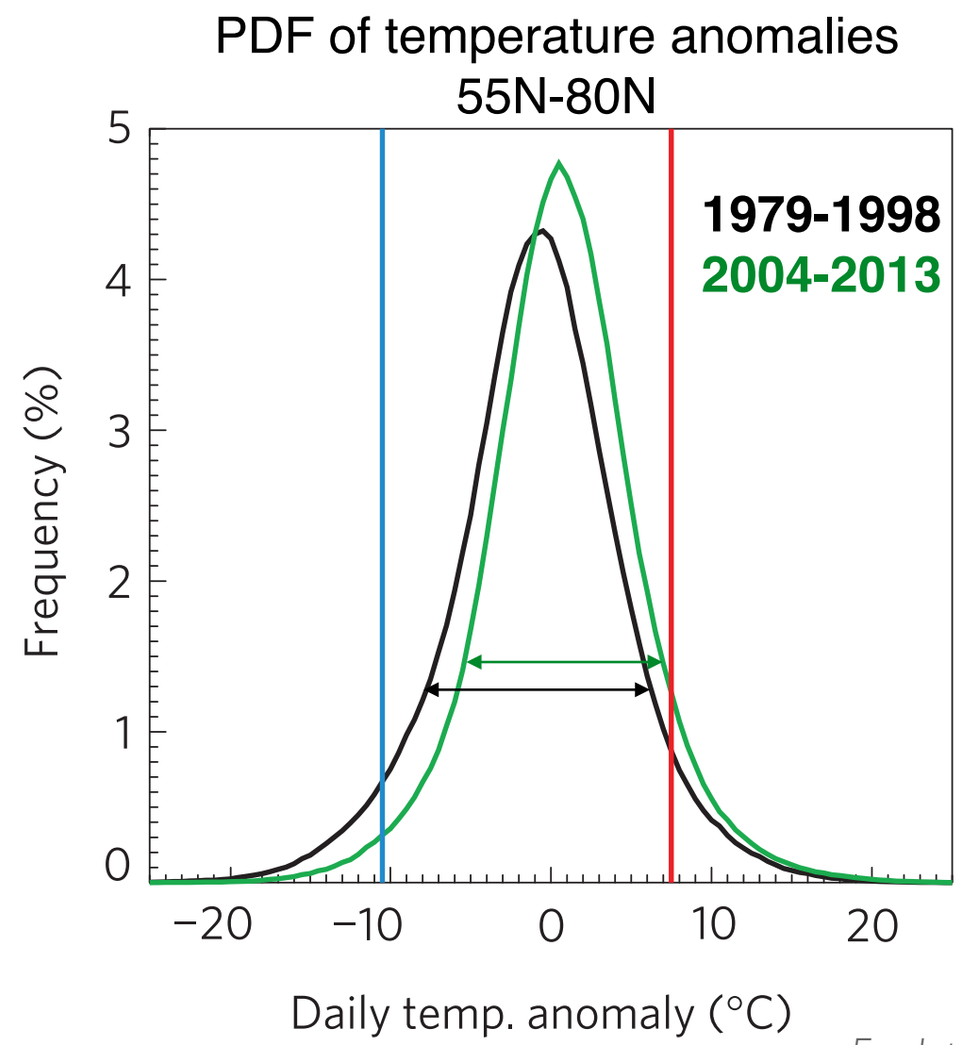

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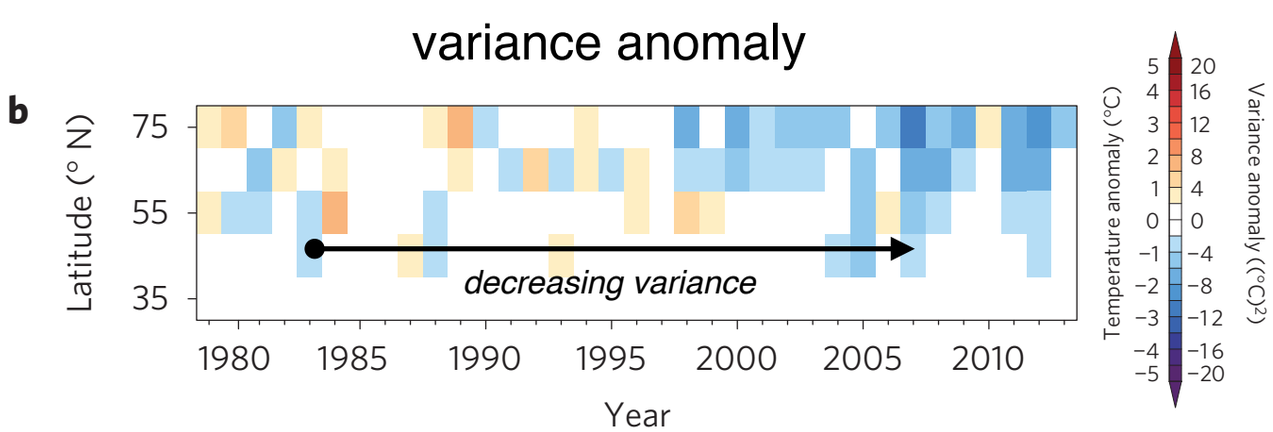
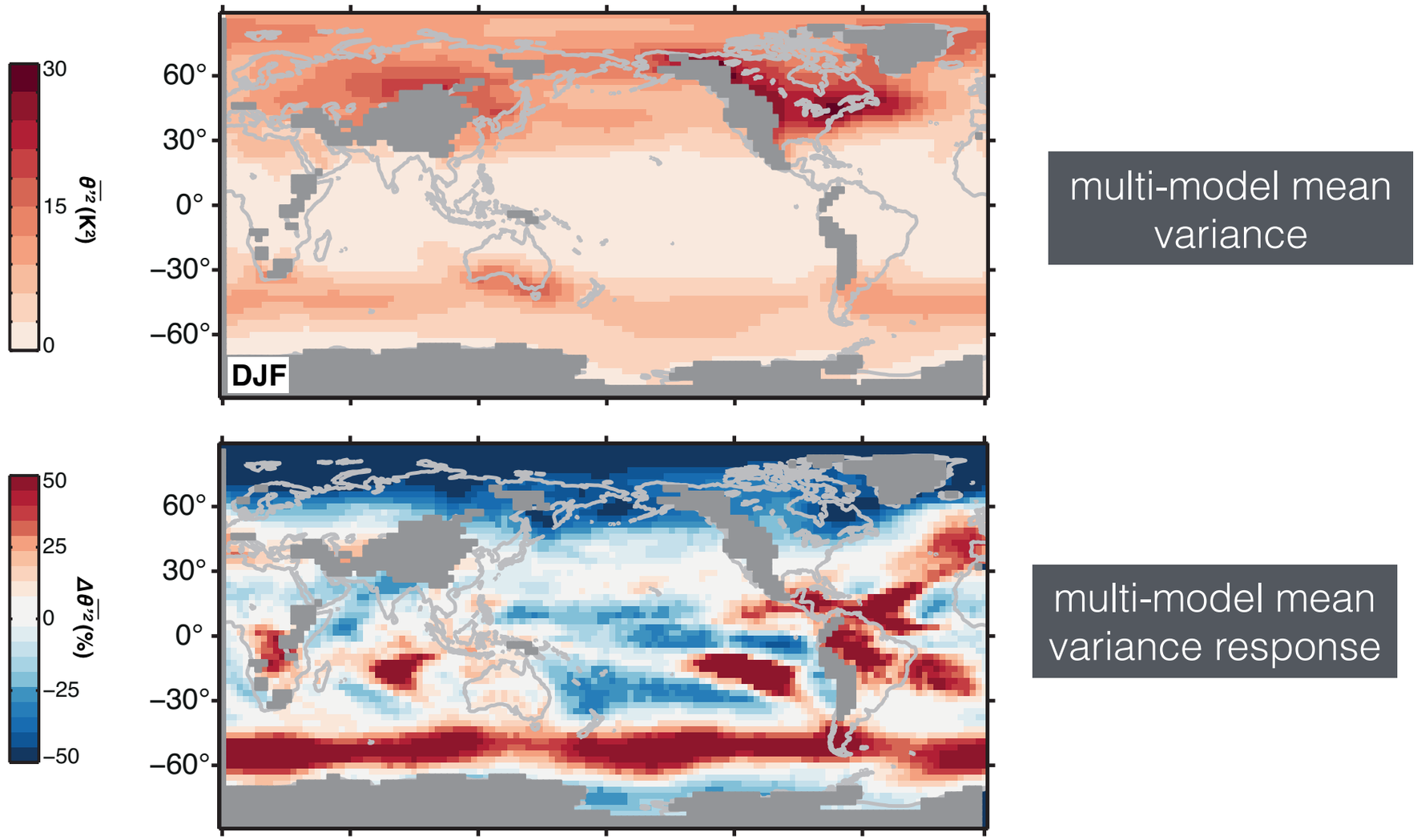


Midlatitude temperature variance



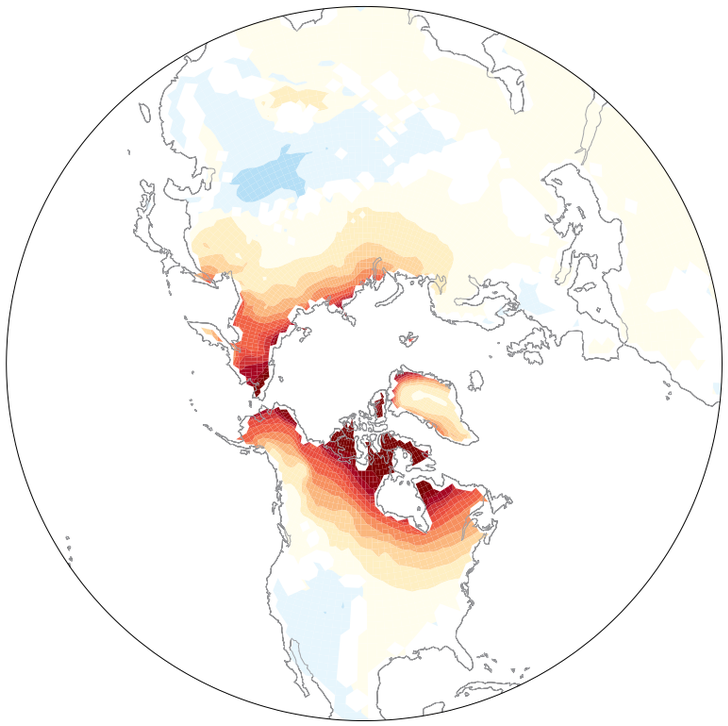
RCP8.5 potential temperature differences (2080-2099) - (1980-1999)
Schneider et al. (2014; JCLI), Fig. 6

- CMIP5 models show decreased temperature variance at high latitudes in the future due to decreased near-surface temperature gradient

Midlatitude temperature variance

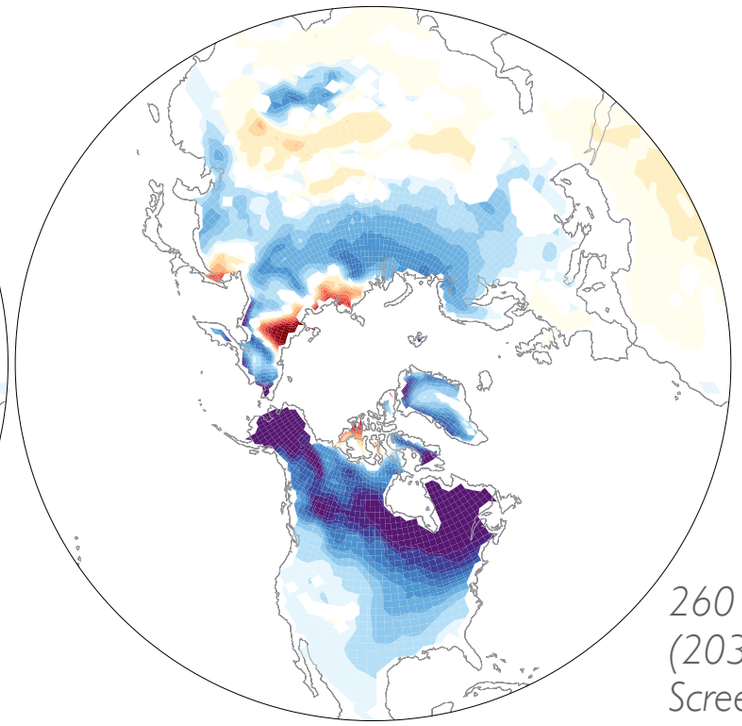
temperature response

a) HadGAM2 mean



variability response

b) HadGAM2 standard deviation

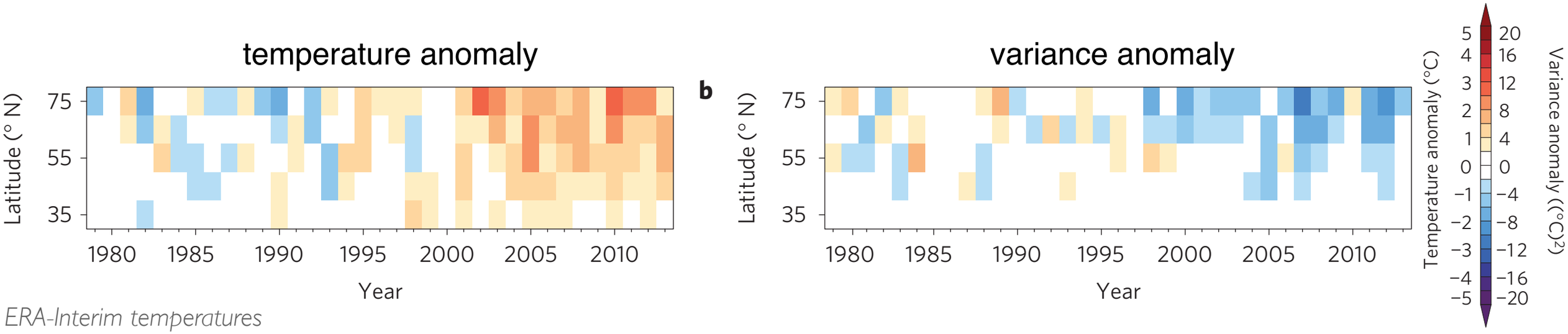


260 years of forced sea ice experiments
(2030-2049) - (1980-1999)
Screen et al. (2015; BAMS)

- temperature variance in midlatitudes *decreases* when sea ice decreases and the Arctic warms more than the surrounding areas

- theory suggests a decrease in variance when equator-to-pole temperature contrast decreases *(see also Schneider et al. (2014; JCLI) for more details and CMIP5 results)*

Observed midlatitude temperature variance

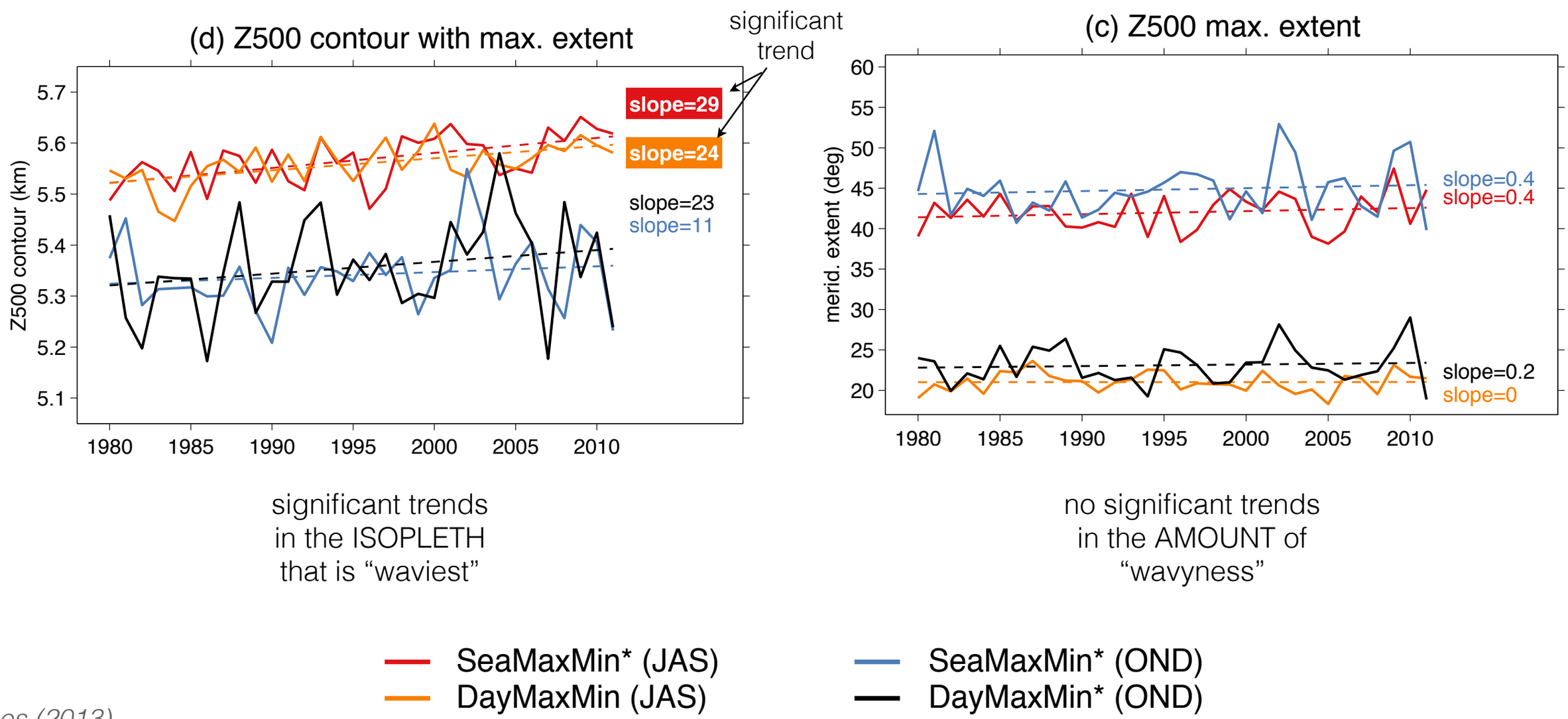


ERA-Interim temperatures
Screen (2014; NATCC), Figure 1

Arctic amplification and Rossby-wave scales

Barnes (2013) suggest that trends in wave extents may not be robust if

1. daily wave extents are analyzed instead of seasonal maxima and minima
2. a larger range of isopleths are analyzed: *namely, a poleward shift of the isopleths with Arctic amplification may appear as a change in wave extent when a narrower range is used instead*



significant trends
in the ISOPLETH
that is "waviest"

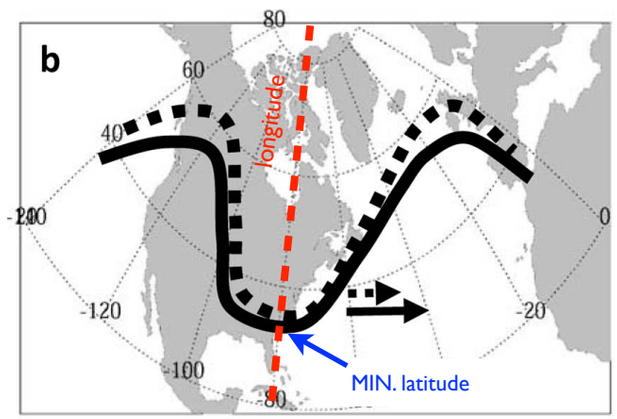
no significant trends
in the AMOUNT of
"wavyness"

Barnes (2013)

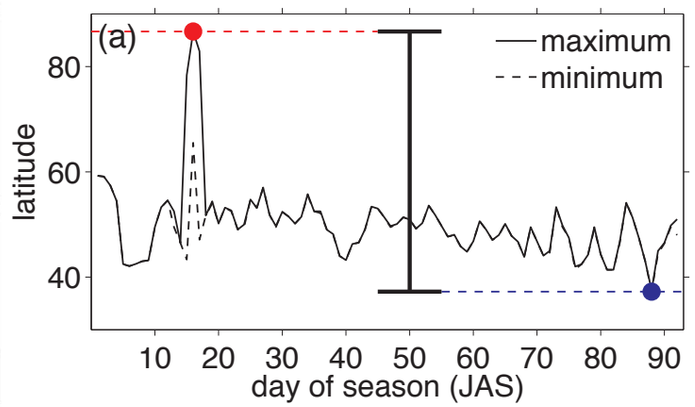
Wave amplitudes in the future

SeaMaxMin

following Francis & Vavrus (2012)

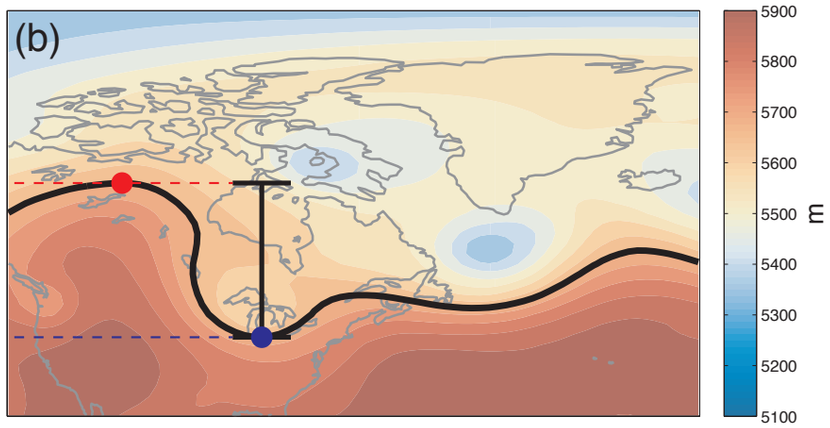


Francis & Vavrus, (2012)



Barnes (2013)

DayMaxMin



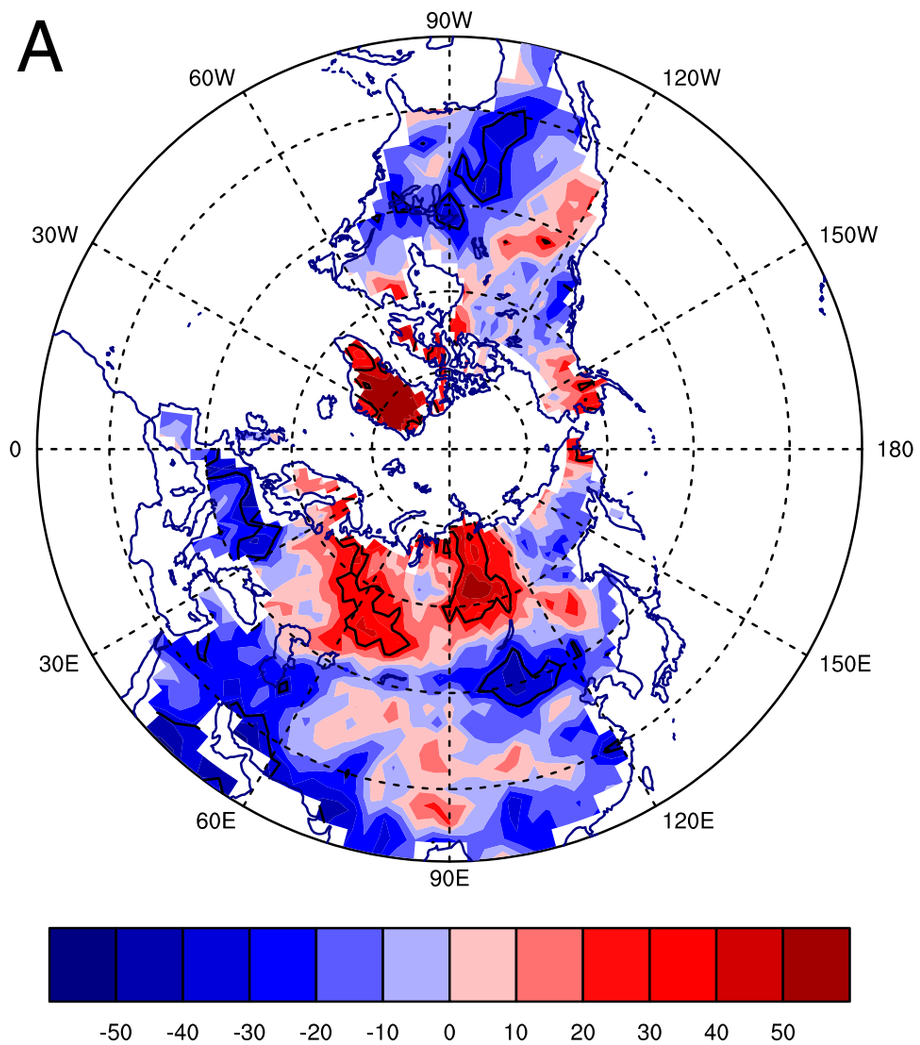
Barnes (2013)

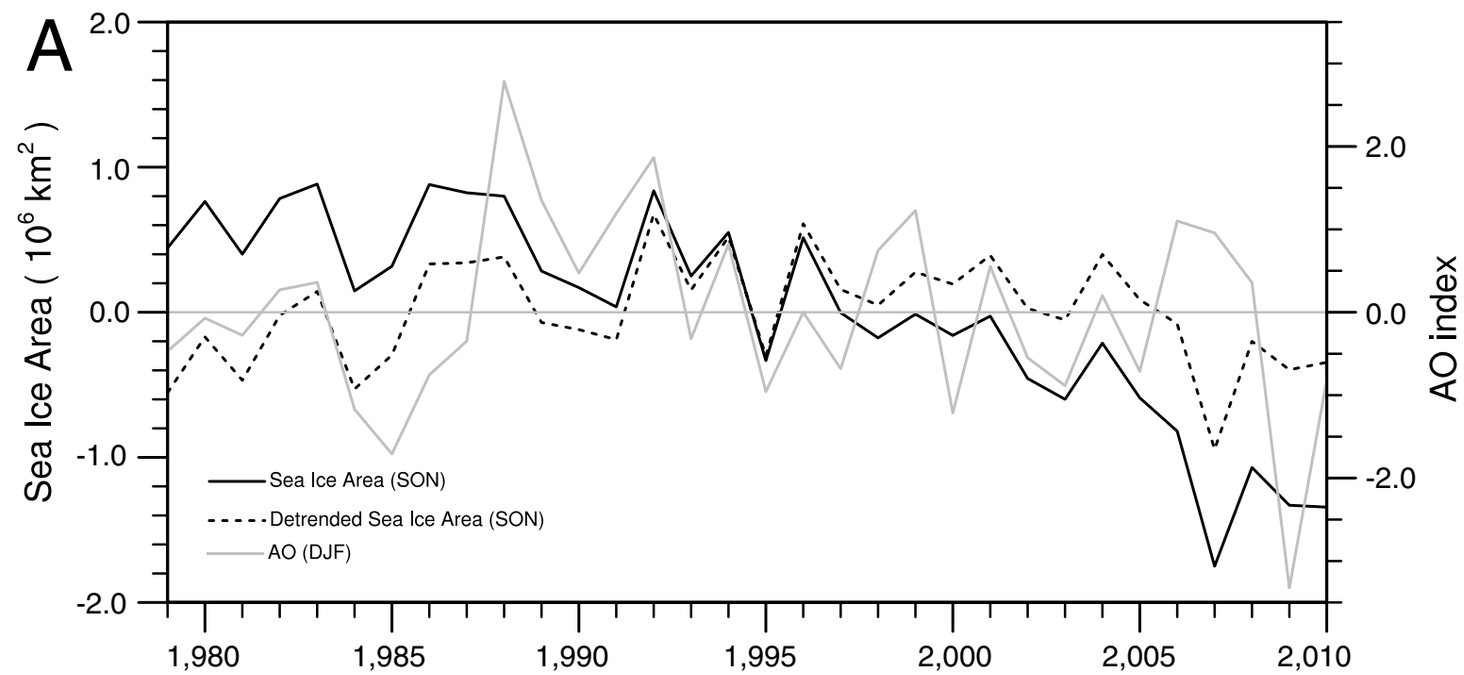
- DayMaxMin = a simple wave extent metric
- calculate wave extents using both metrics for 3 isopleths, then average over the domain and the season when applicable
- <u>IMPORTANT:</u> *both* metrics appear to have problems

Barnes (2013)

Correlation in the observations

correlations over the short data record can be hard to interpret in the face of internal variability

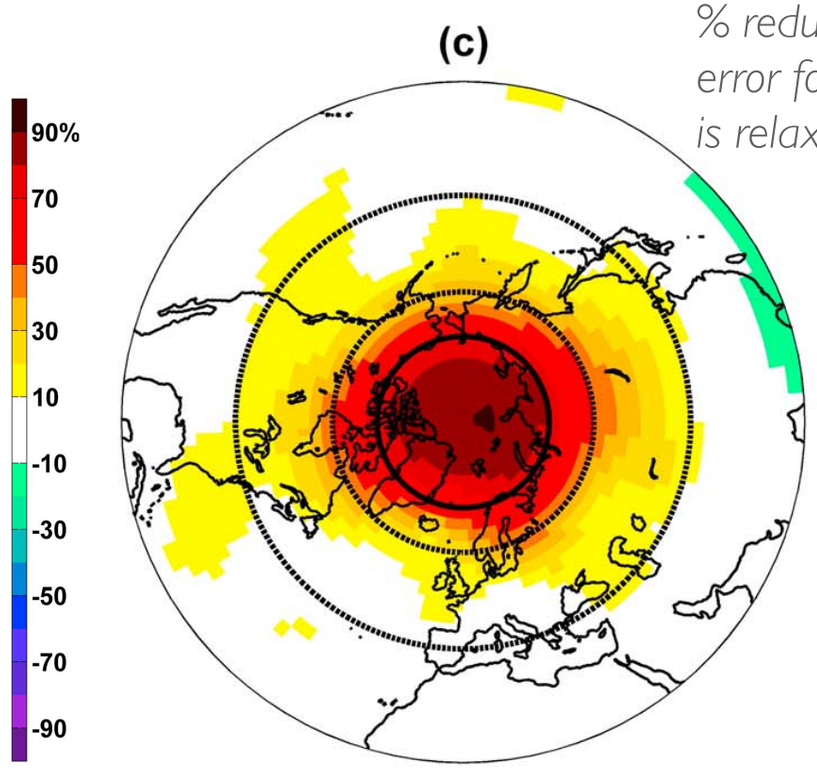




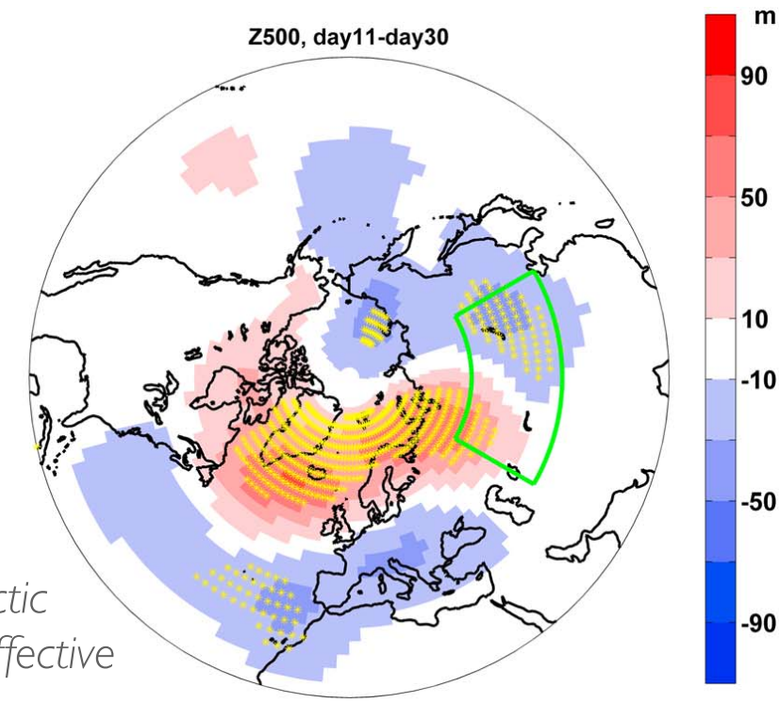
percent change in DJF blocking due to reduced Arctic sea ice calculated from linear regression of blocking and detrended SON Sea Ice Area

Liu et al. (2012; PNAS)

Forecast approach



% reduction in RMS forecast error for days 11-30 when Arctic is relaxed toward reanalysis



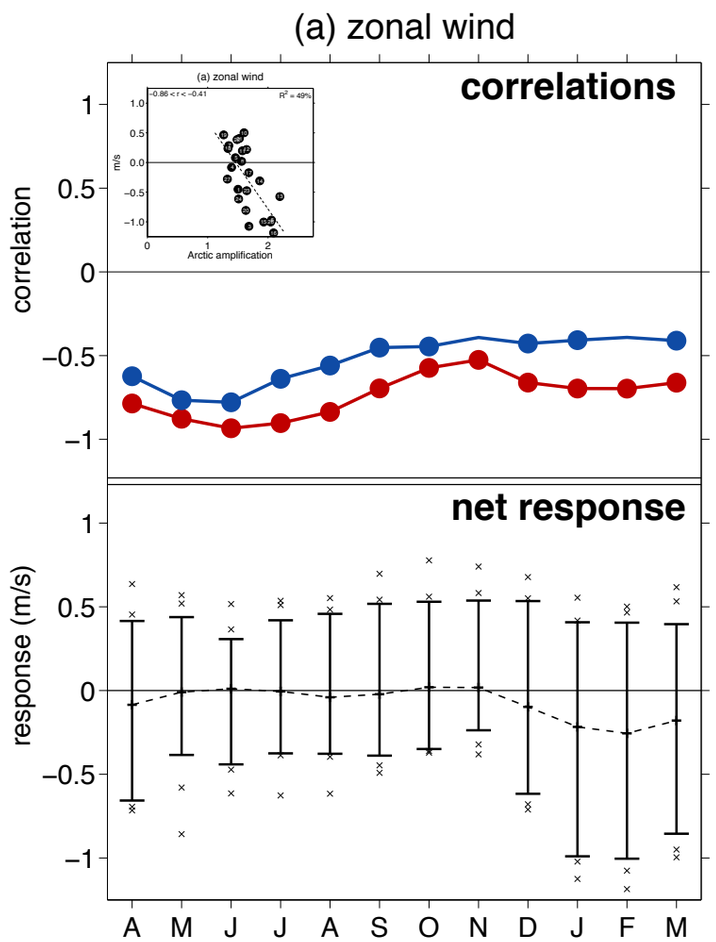
Z500 anomalies when Arctic relaxation is particularly effective over days 11-30

Jung et al. (2014; GRL)

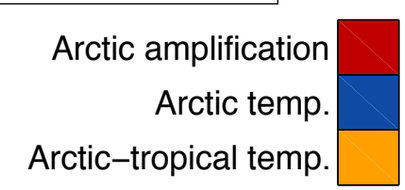
- Forecast experiments with ECMWF model shows that knowledge of the Arctic state can improve forecasts in mid- to high latitudes

- Lowest improvement over the oceans where atmospheric variability is large

Seasonality of mean-flow/AA correlations



results for Arctic-tropical temp. similar to AA
Barnes & Polvani (2015)



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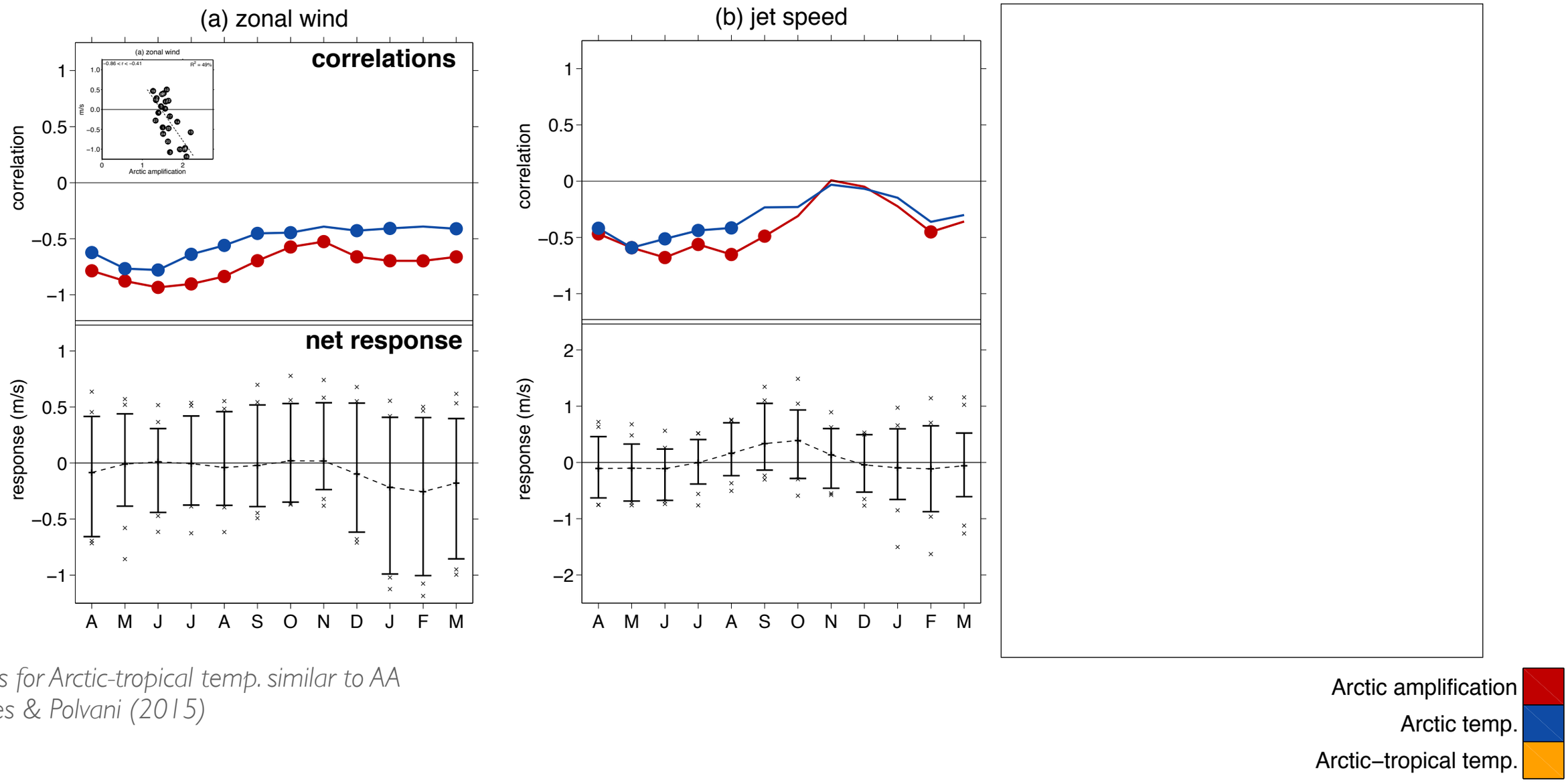

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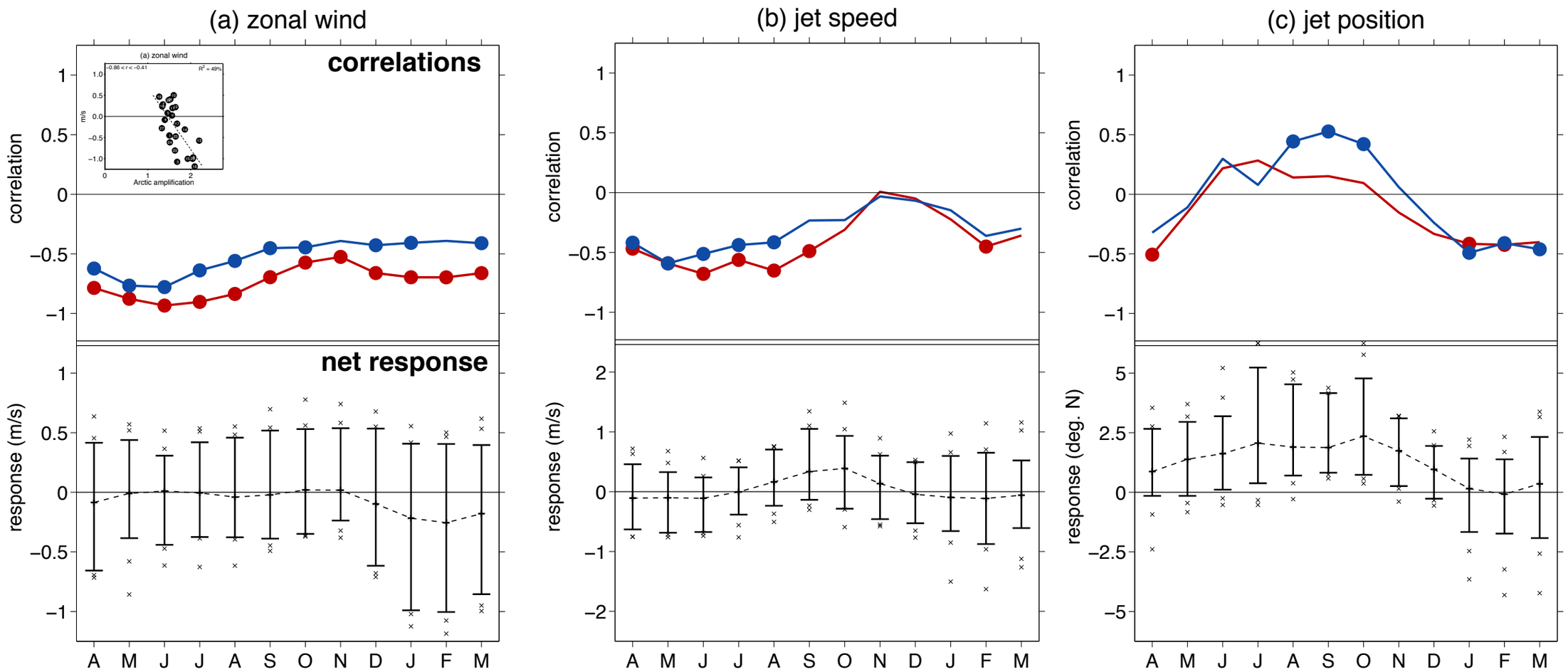

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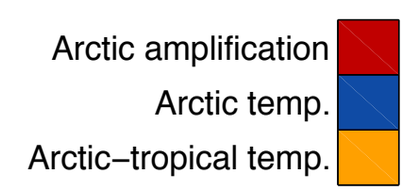

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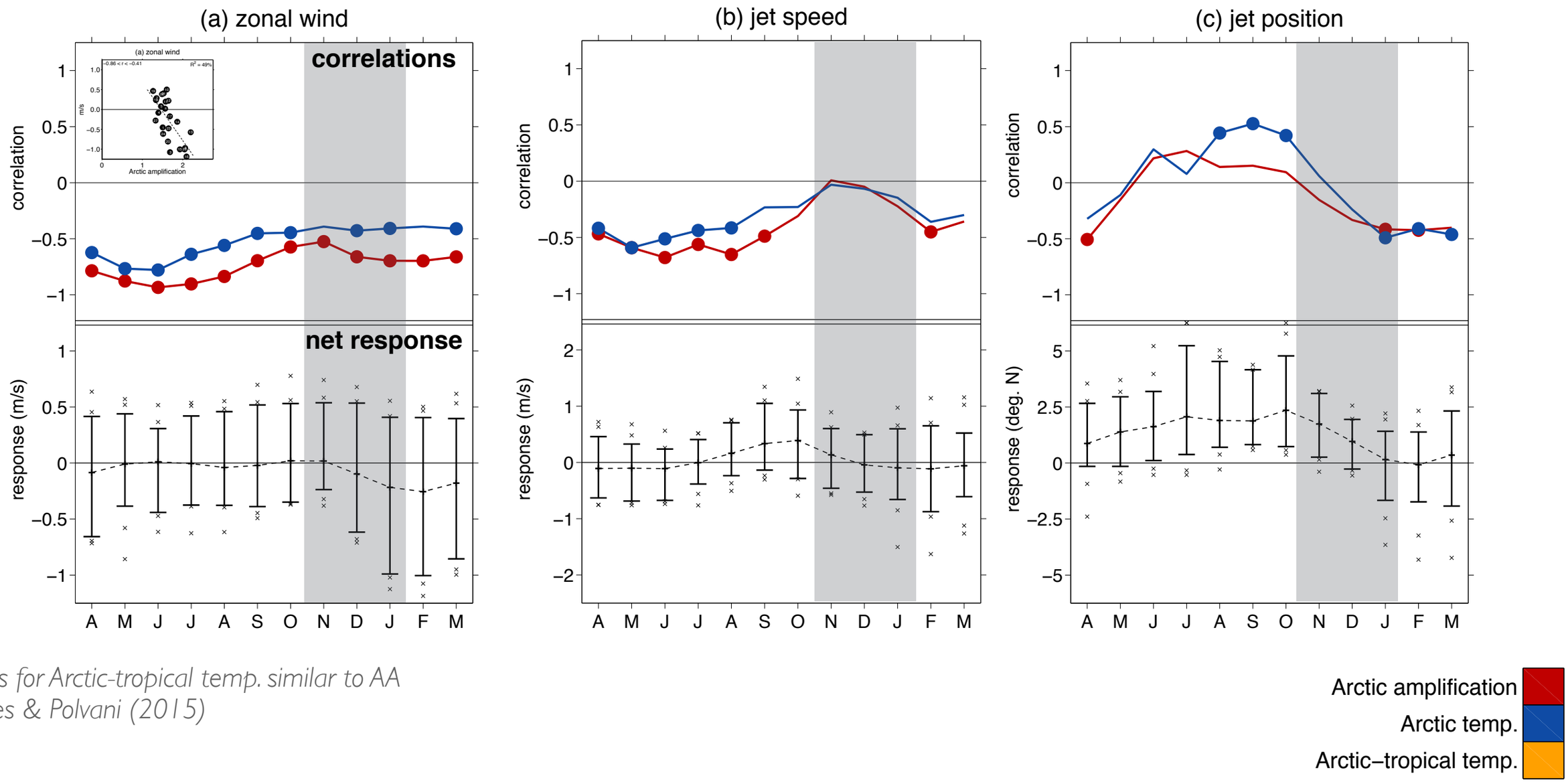

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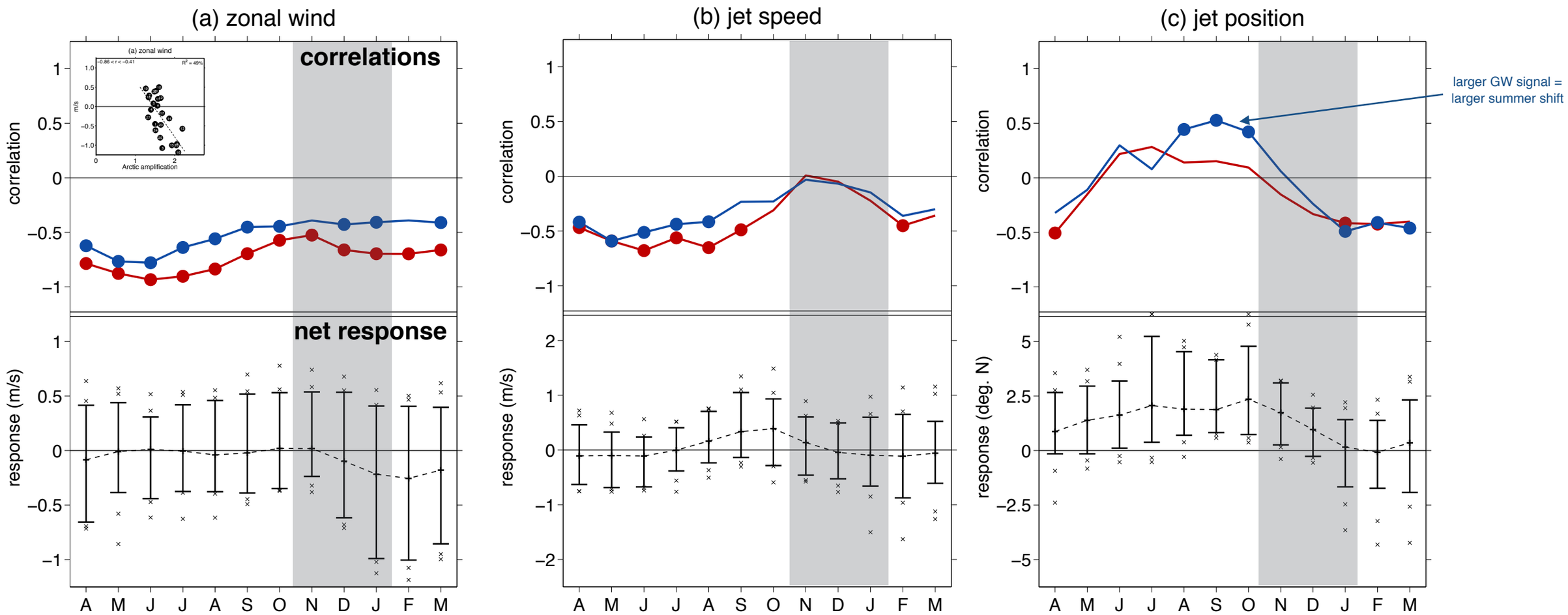
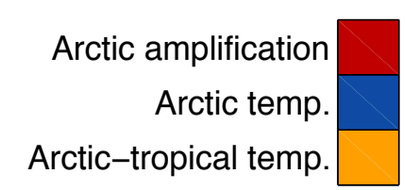
Barnes & Polvani (2015)

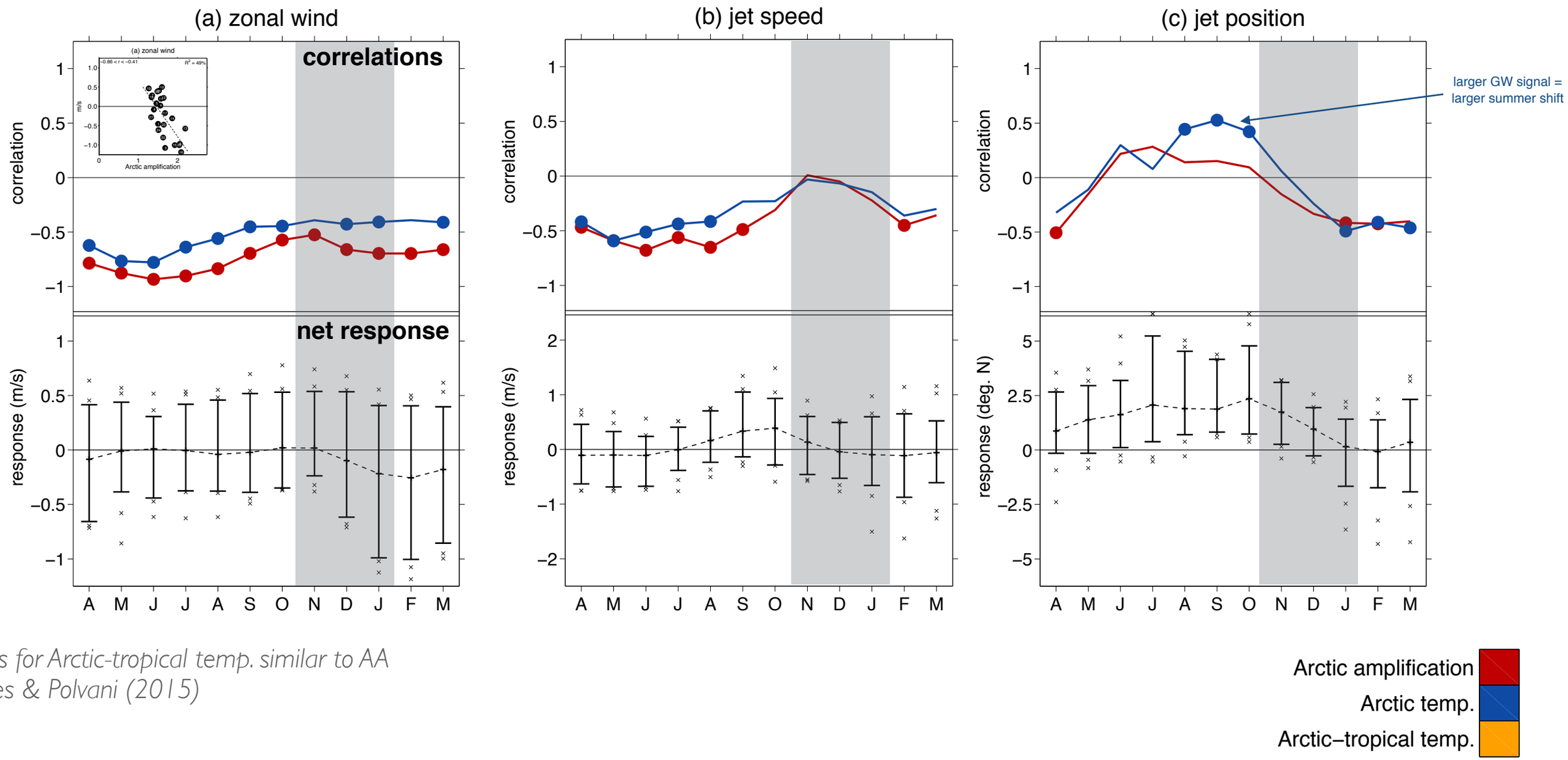
Seasonality of mean-flow/AA correlations



results for Arctic-tropical temp. similar to AA
Barnes & Polvani (2015)

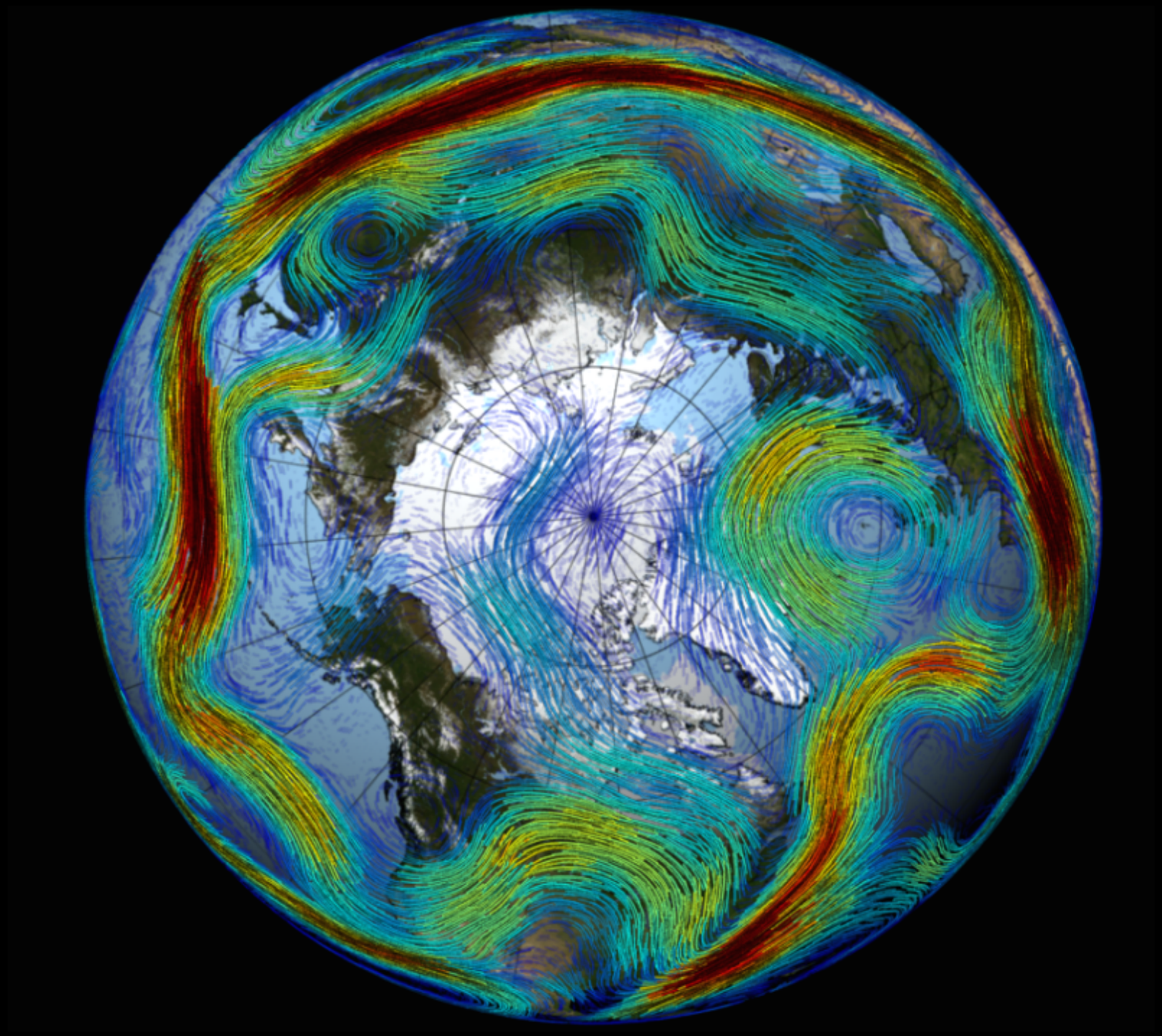


Seasonality of mean-flow/AA correlations



results for Arctic-tropical temp. similar to AA
Barnes & Polvani (2015)

Key Point:
These correlations do not communicate the net response in the future - they suggest a potential for Arctic amplification to modulate the response



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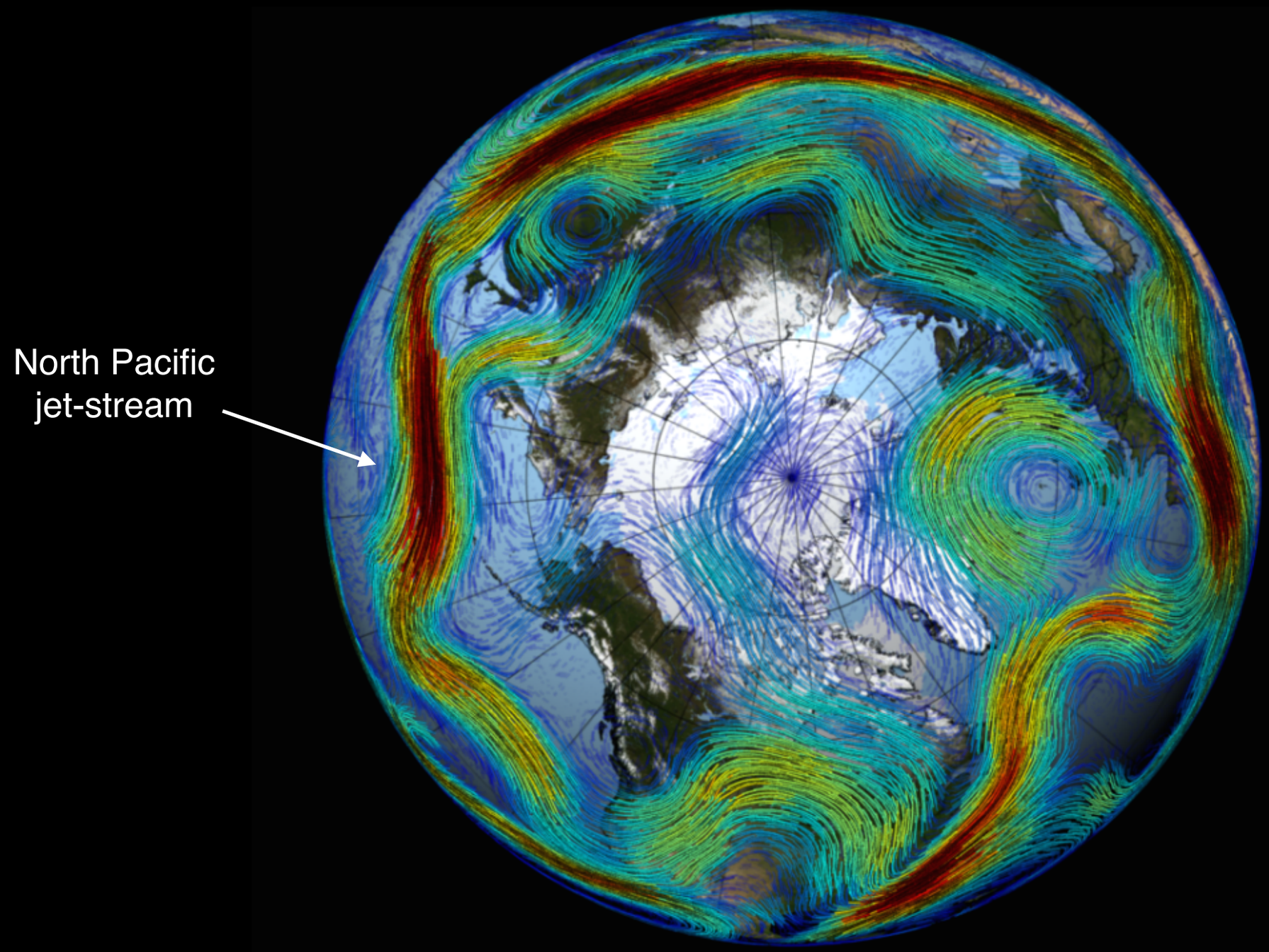

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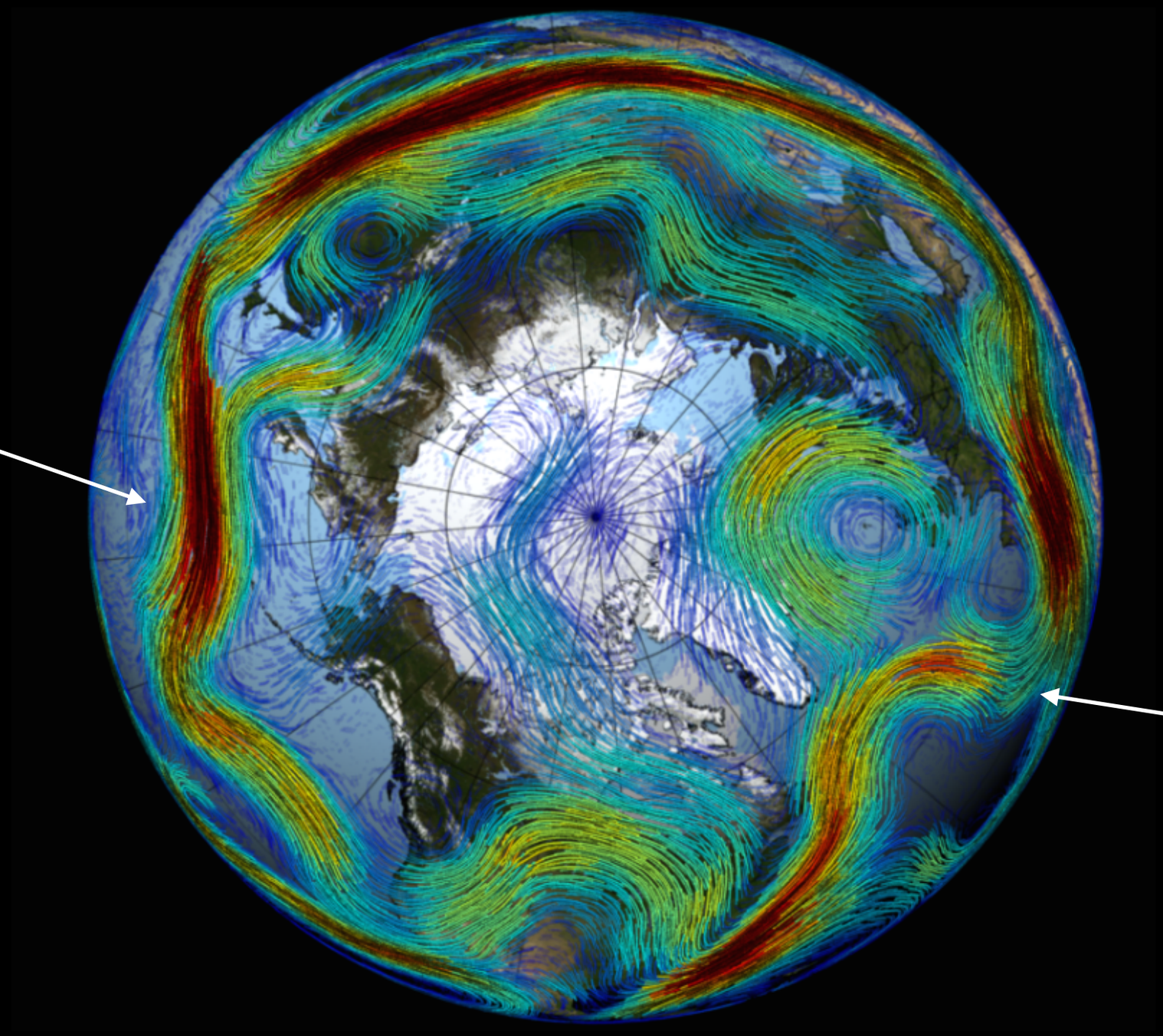

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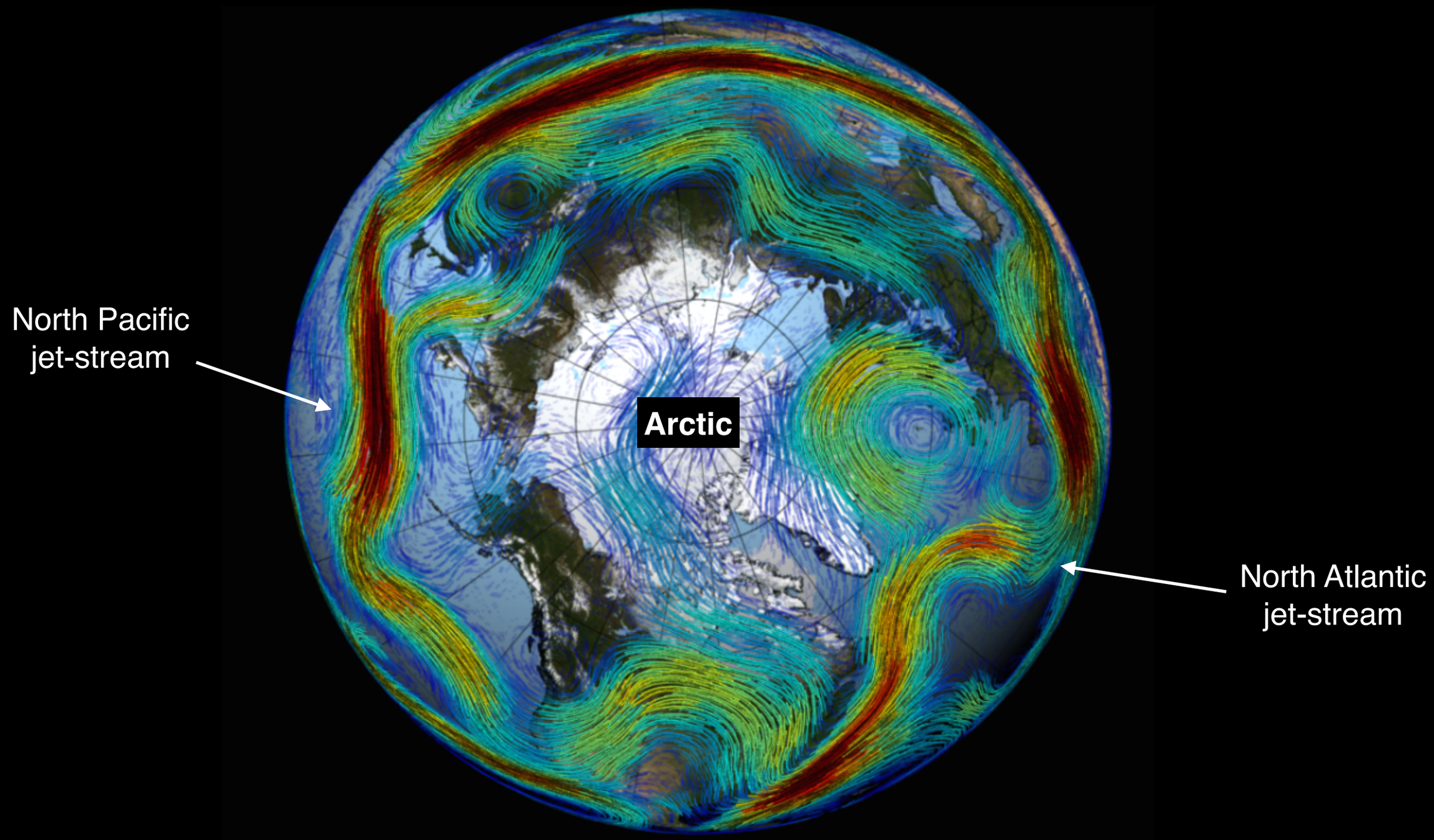

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