An impact of Arctic sea-ice on the stratospheric polar vortex?

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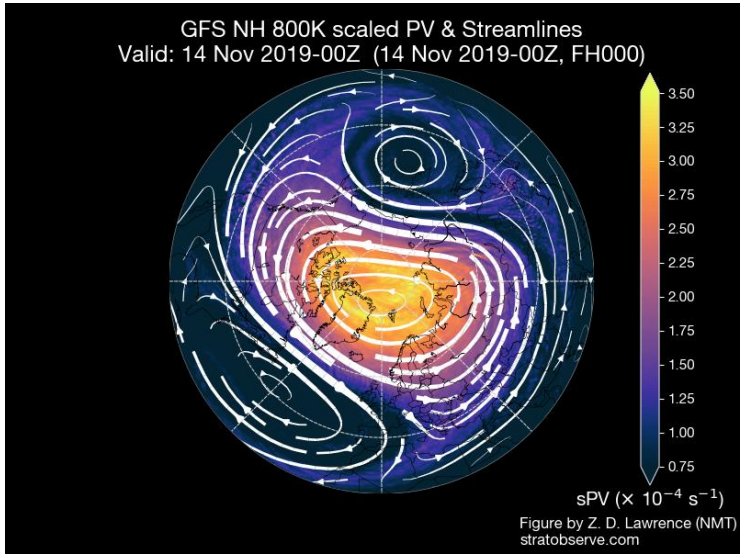
With thanks to John Fyfe (CCCma), Darryn Waugh (Johns Hopkins), Lorenzo Polvani (Columbia)

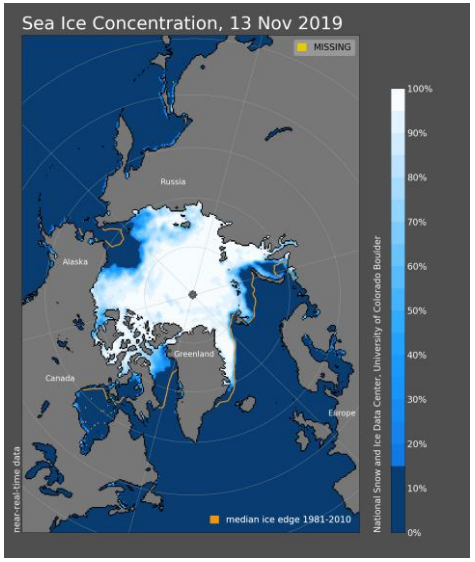
ECMWF Workshop on Stratospheric predictability and impact on the troposphere, 19 November 2019.

Sea-ice-stratospheric polar vortex connection

This talk

Impact of sea-ice anomalies on the stratospheric polar vortex (and subsequent impacts on surface, inc. midlatitudes)





Karen Smith et al., J. Climate, 2018

Impact of stratospheric polar vortex variability on sea-ice

Outline: Impact of Arctic sea-ice on the stratosphere

Can it? Previous modelling studies with perturbed sea-ice

Has it? Large ensemble analysis (Seviour, 2017)

Will it? Model sensitivities and uncertainties (Ryan Bedford, Bristol Master's project, 2019)

With credit to Barnes and Screen, 2015

Can it?

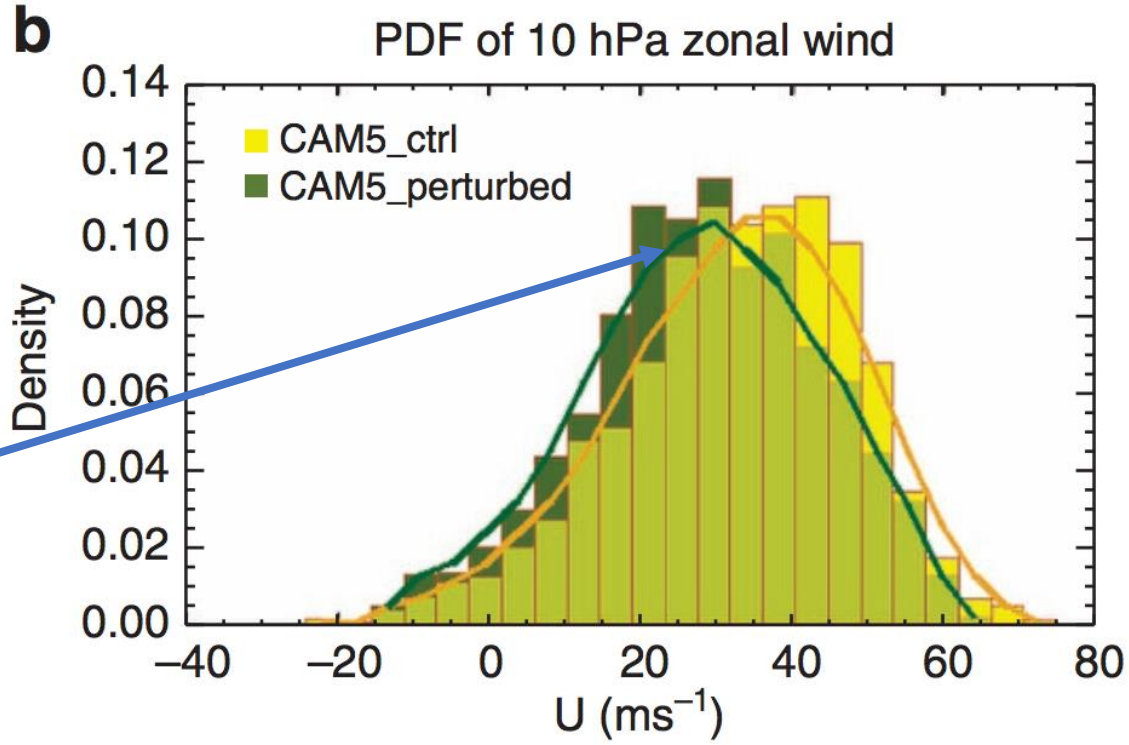
(Can changing sea-ice impact the stratospheric polar vortex?)

Simulations with perturbed sea-ice

Weakening of the stratospheric polar vortex by Arctic sea-ice loss

Baek-Min Kim[1], Seok-Woo Son[2], Seung-Ki Min[3], Jee-Hoon Jeong[4], Seong-Joong Kim[1], Xiangdong Zhang[5], Taehyoun Shim[4] & Jin-Ho Yoon[6]

Reduced sea-ice simulations result in a weaker stratospheric polar vortex.



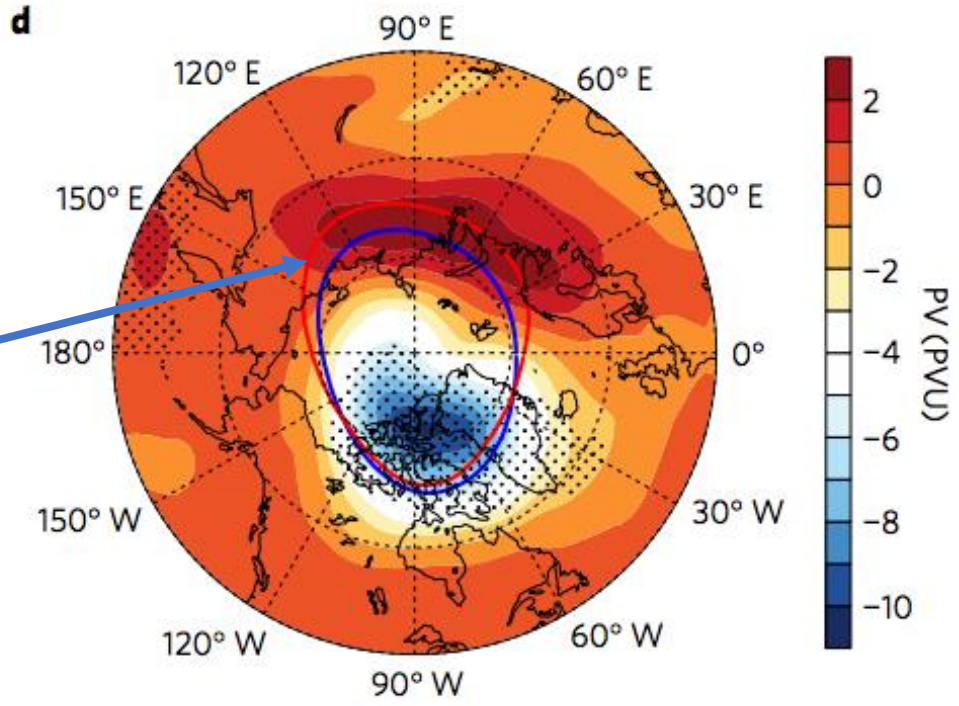
Kim et al. 2014

Simulations with perturbed sea-ice

Persistent shift of the Arctic polar vortex towards the Eurasian continent in recent decades

Jiankai Zhang[1], Wenshou Tian[1]*, Martyn P. Chipperfield[2], Fei Xie[3] and Jinlong Huang[1]

Simulations with reduced sea ice (Barents-Kara sea) show shift of vortex towards Eurasia

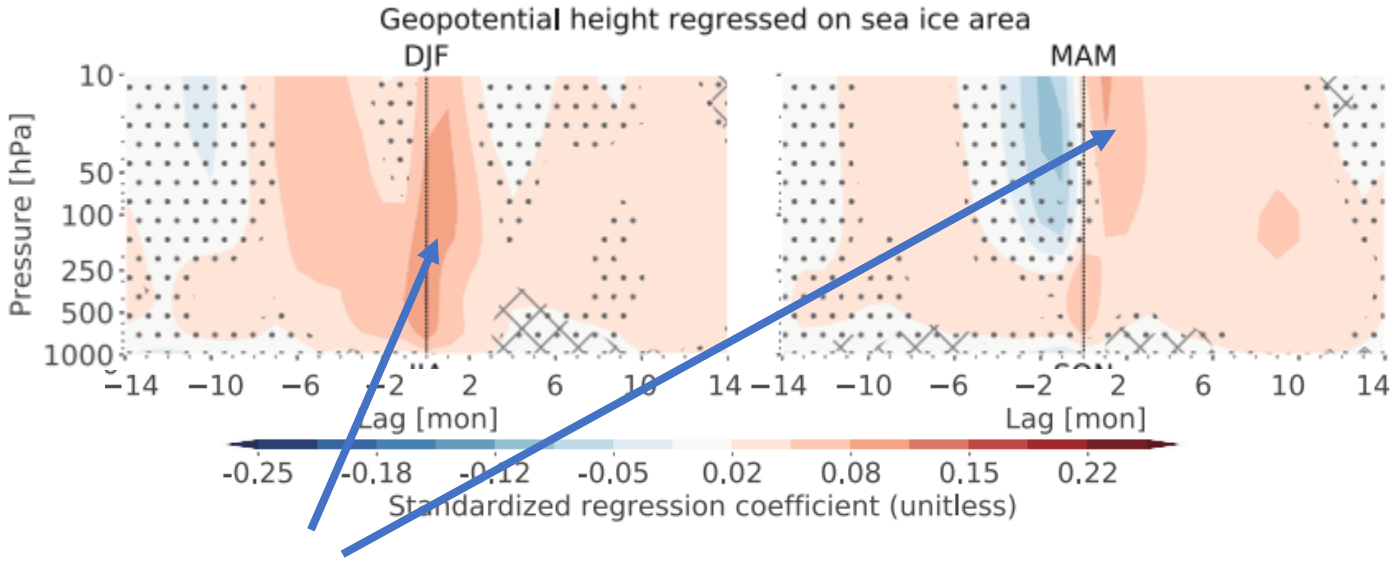


Zhang et al. 2016

Lag-correlations in models

Atmospheric Precursors of and Response to Anomalous Arctic Sea Ice in CMIP5 Models

Michael KELLEHER and James SCREEN*

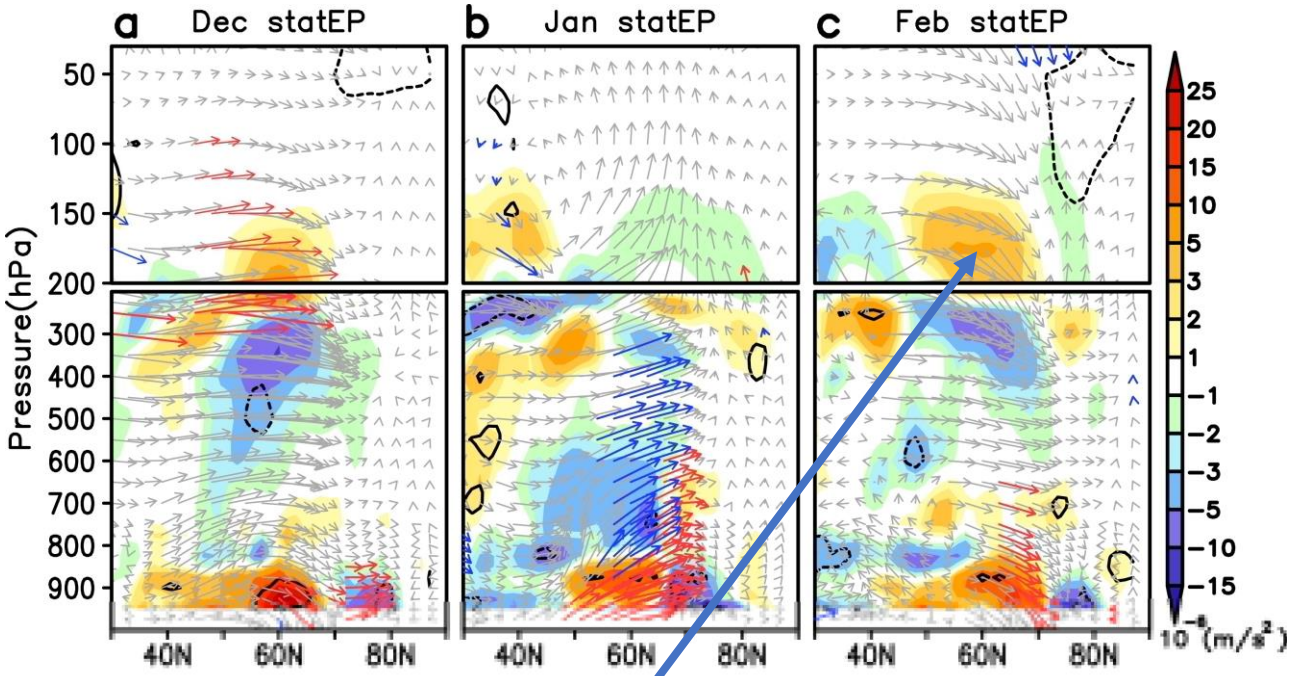


Positive ice-leading correlations of stratospheric GPH in model control simulations

Kelleher and Screen 2018

Proposed mechanisms

Stationary EP-flux/divergence, low-high Barents-Kara SIE



Yang et al, 2016

Several studies (modelling/observational) have proposed enhanced upward planetary wave propagation associated with low sea-ice extent. Particular sensitivity in Barents-Kara sea.

Washington Post

Capital Weather Gang • Analysis

Polar vortex shifting due to climate change, extending winter, study finds

Scientific American

Dreaded Polar Vortex May Be Shifting

As the Arctic wind pattern migrates toward Europe it could allow frigid air to descend upon the U.S.

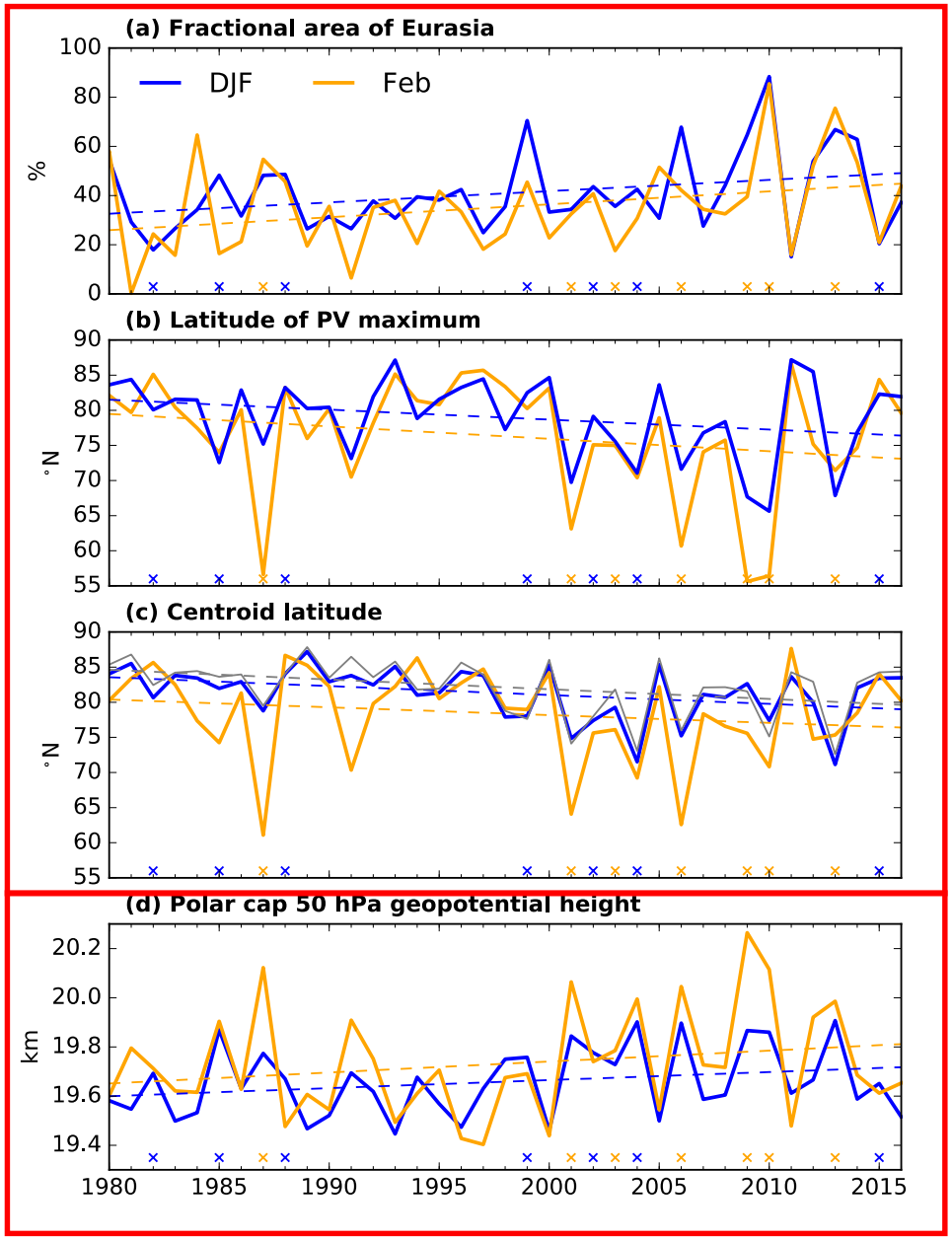
Has it?

(Has changing sea-ice impacted the stratospheric polar vortex?)

Trends in vortex location and strength

location

strength

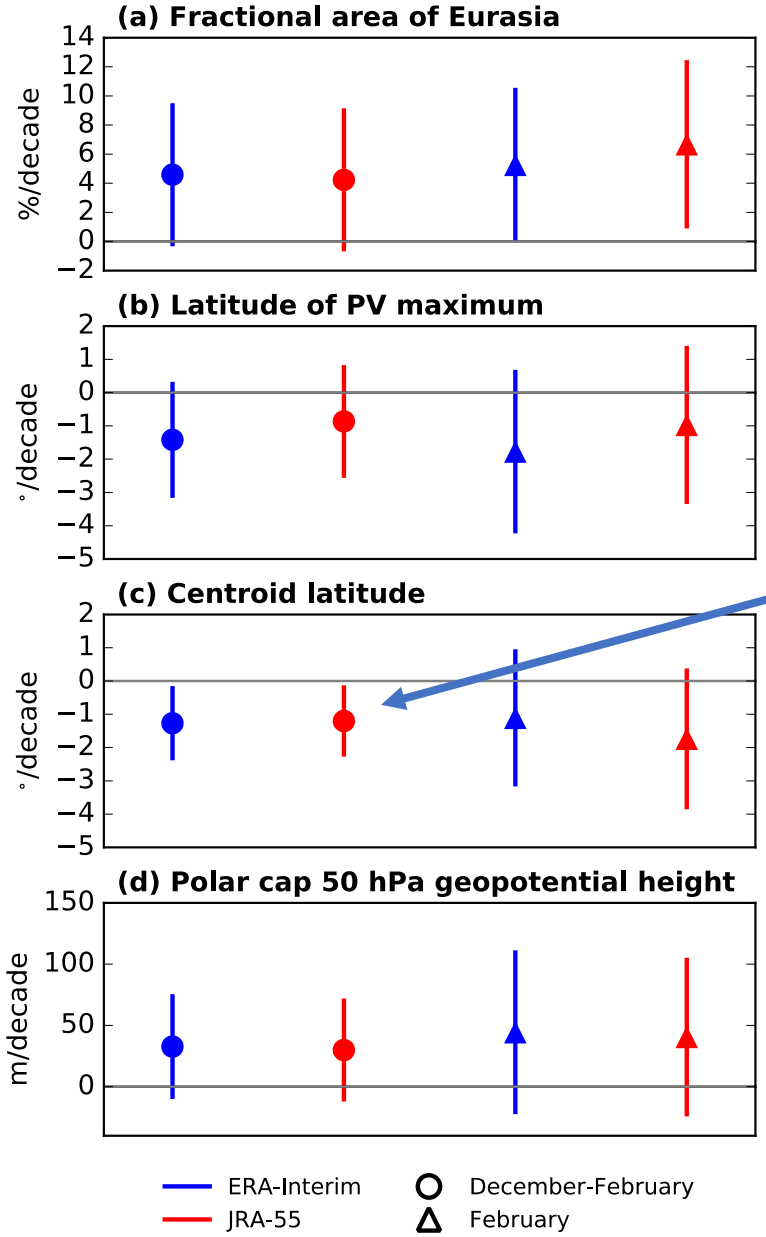


ERA-Interim time series.

Both DJF and Feb time series shown (some studies suggest significant trends only in Feb).

Large increase in variability from 1990s to 2000s along with increase in SSW frequency.

Trends in vortex location and strength



Trends and uncertainty (95% range of *t*-test).

ERA-Interim and JRA-55

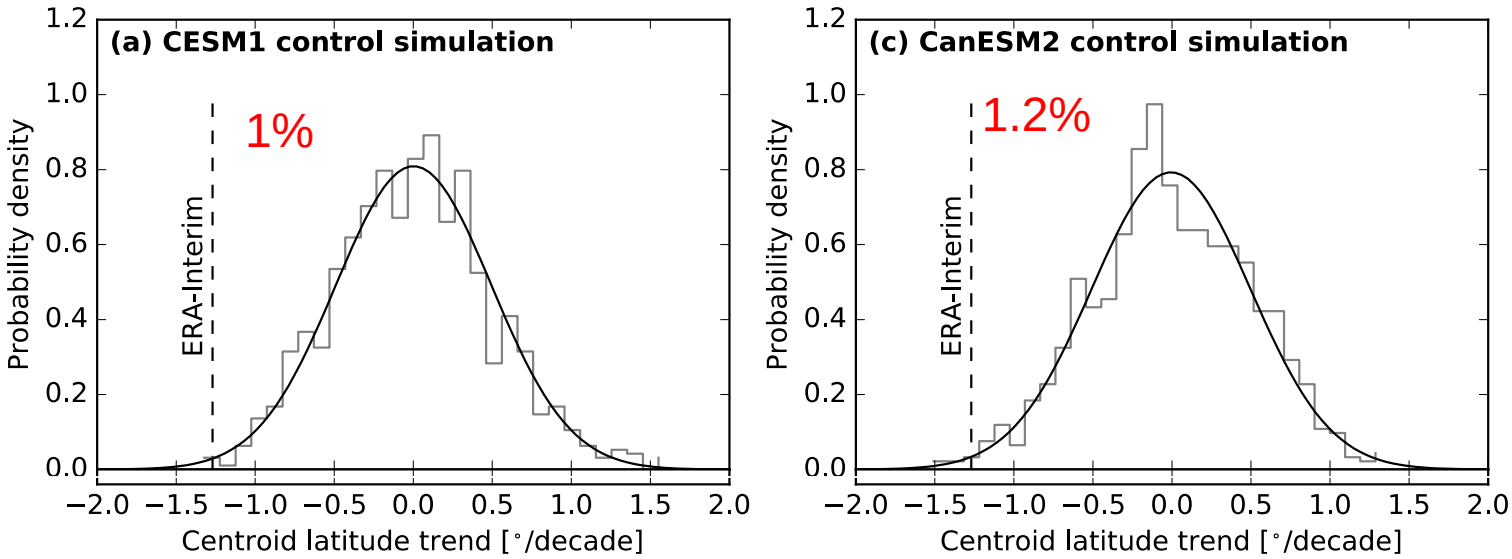
Only quantity with significant trend in both reanalyses is DJF centroid latitude.

How likely are these trends in:

i. Unforced (control) simulations?

ii. Historical forcing simulations?

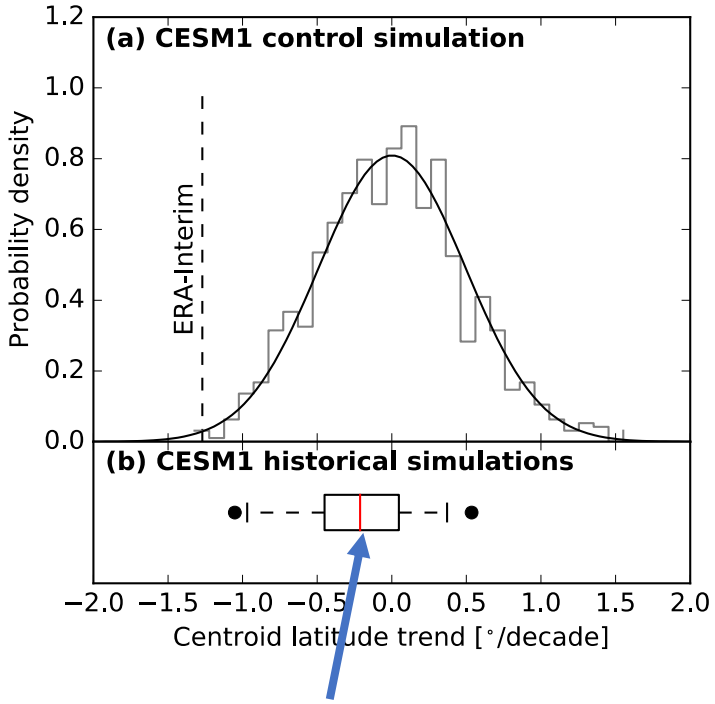
37-year centroid latitude trends

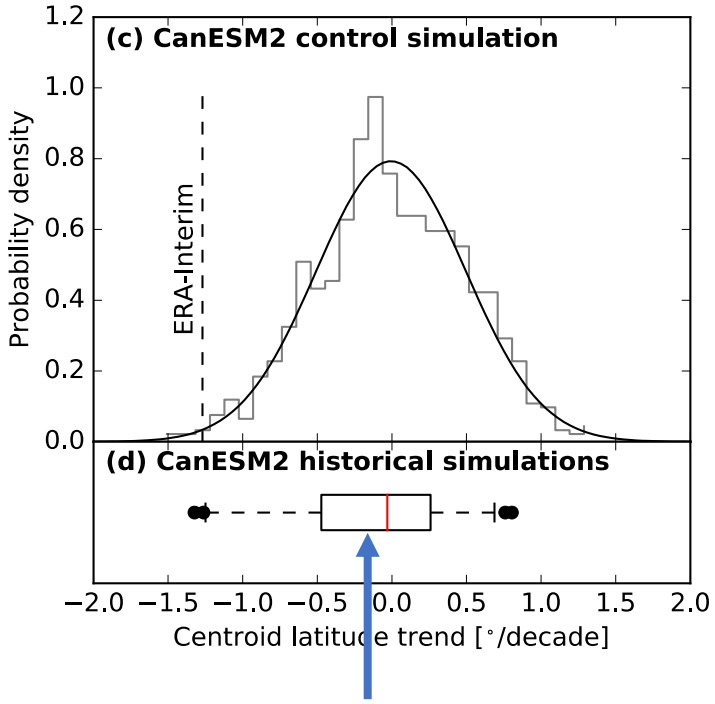


Trends as large as observed are unlikely (~1%) in unforced simulations.

How about in large ensembles of historical simulations (35 members for CESM1, 50 members for CanESM2)?

37-year centroid latitude trends



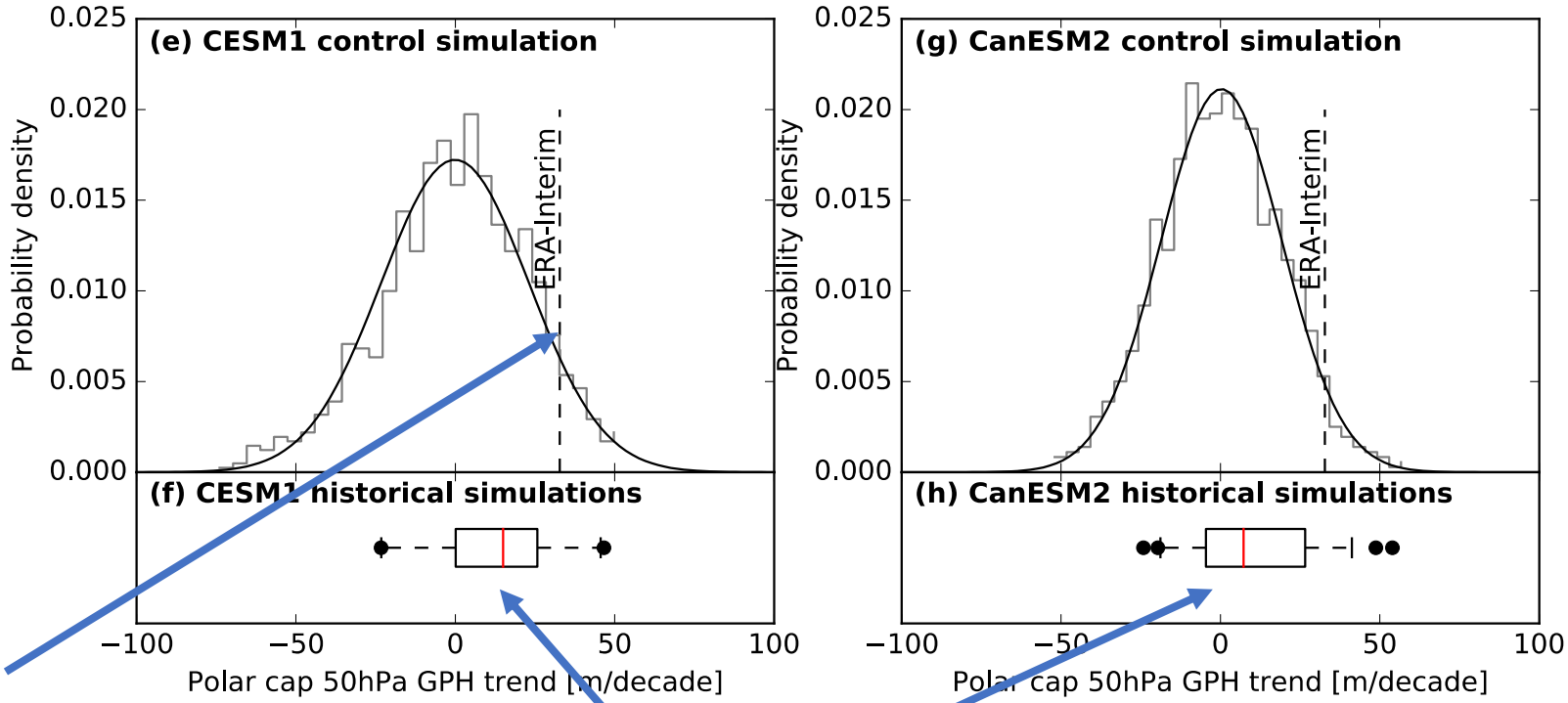


CESM1: Distribution shifted towards more diaplaced vortex (K-S p=0.01). No ensemble members as strong as observed trend.

CanESM2: Mean near 0, historical distribution not different from control (K-S test).

Both models: historical ensemble member with opposite sign trend to observed.

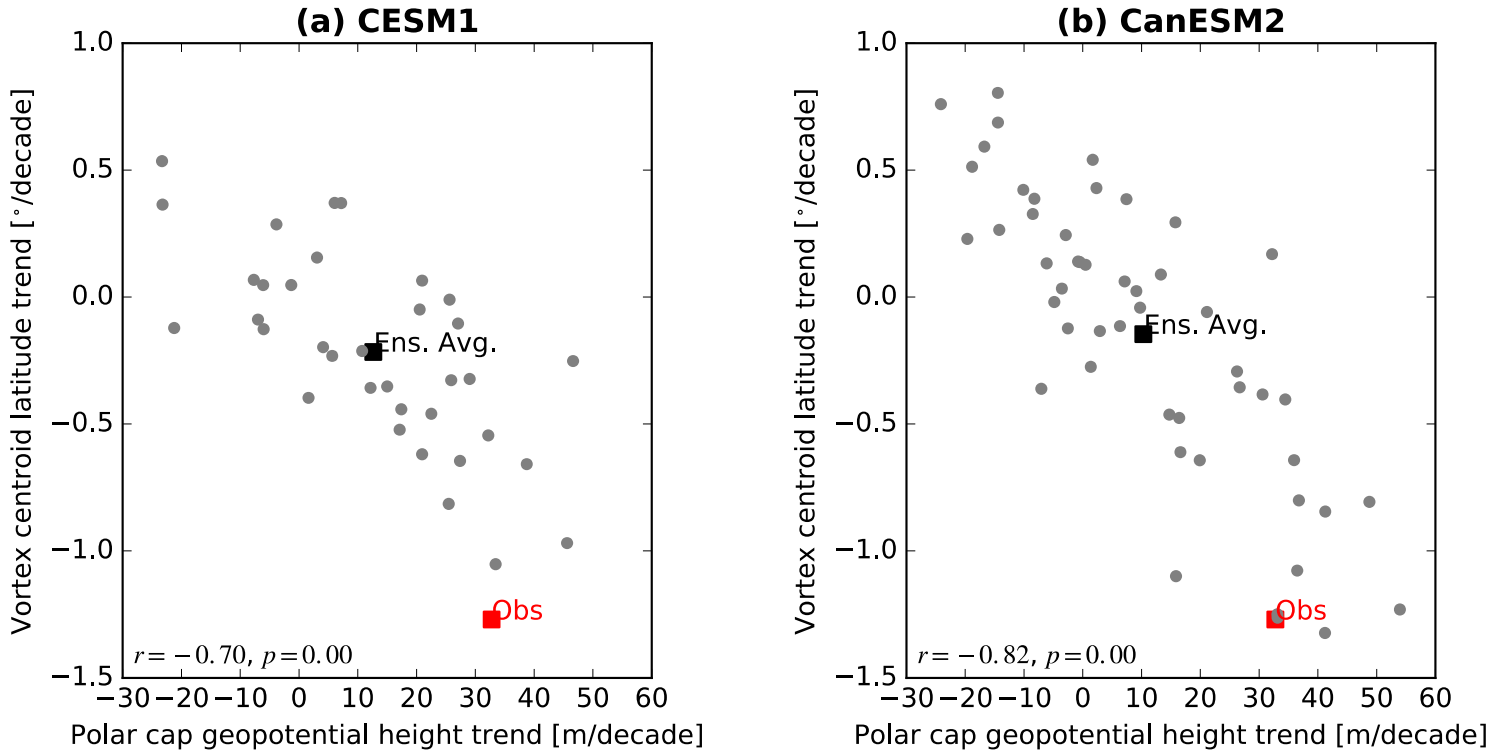
37-year 50 hPa polar cap GPH trends



Observed 50hPa GPH trends less extreme

Small shift in ensemble mean towards weaker vortex. (greater in CESM1)

Relation between centroid latitude and GPH trends

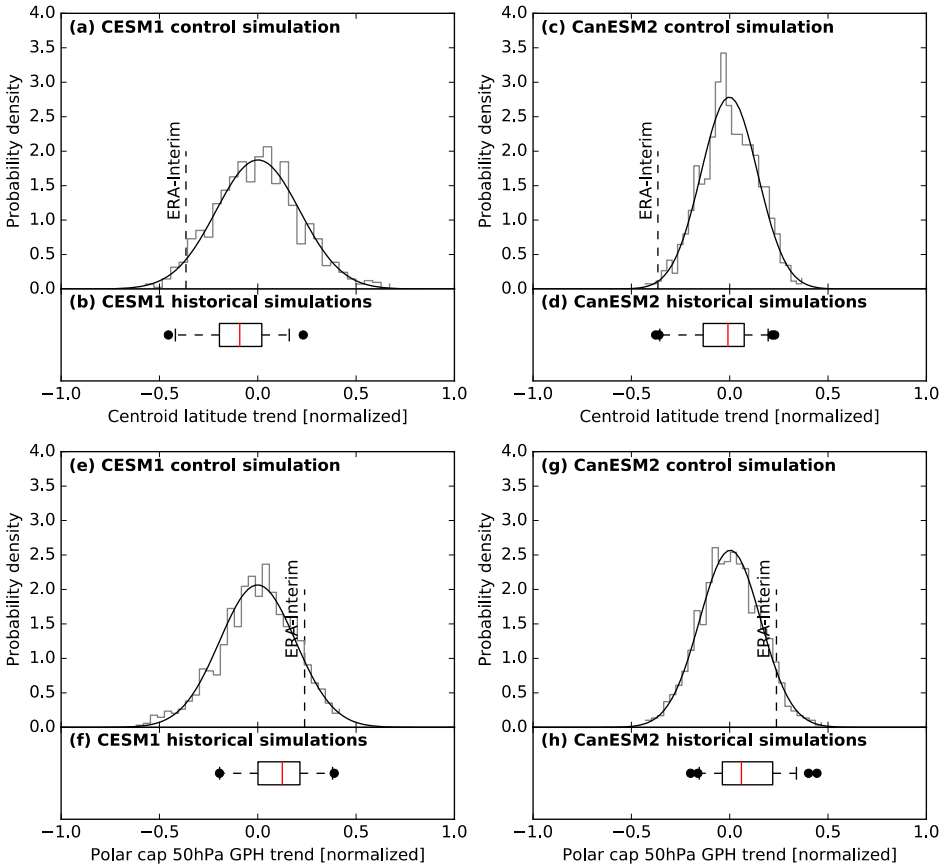


Signal-to-noise

Neither model is ‘high-top’ so might expect too little variability (Charlton-Perez et al. 2013).

Can instead look at trends in terms of ‘signal to noise’.

CESM1 interannual variability < ERA-I

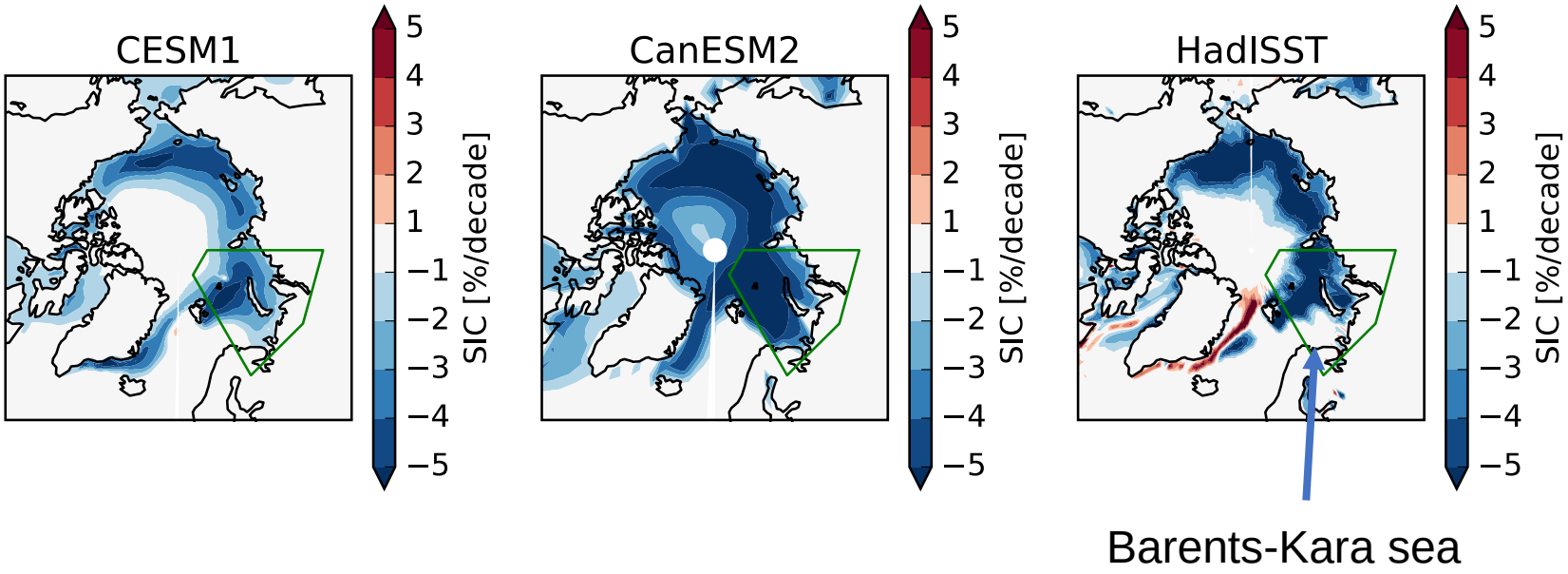


CanESM2 interannual variability > ERA-I

Overall little impact on results when taking account of variability biases.

Impact of sea-ice

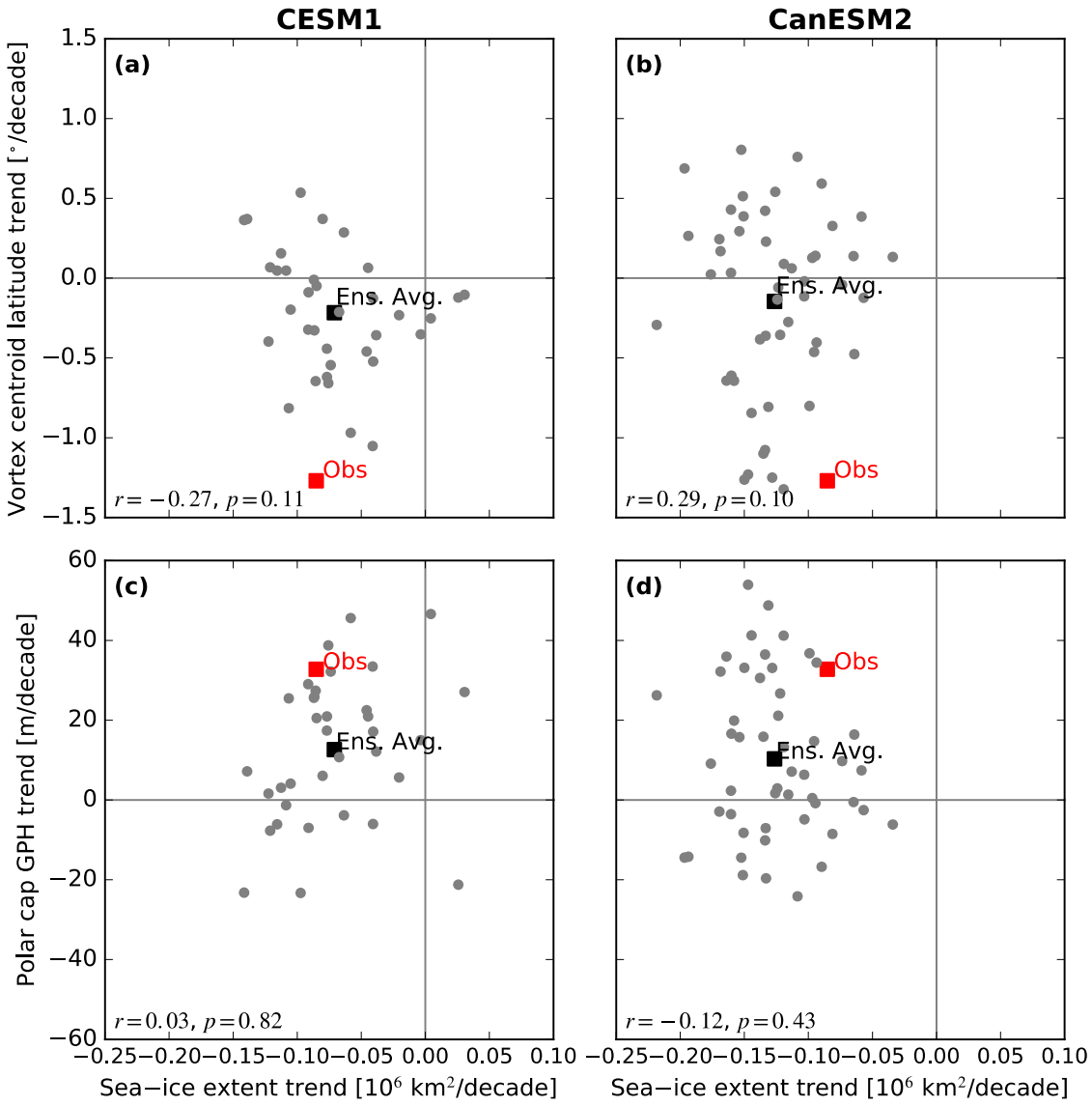
1980-2016 trends



Both models show similar patterns of sea-ice loss as observed. CanESM2 sea-ice decline slightly stronger than observed, CESM1 slightly weaker.

Perhaps ensemble members showing greater sea-ice decline also show greater stratospheric trends?

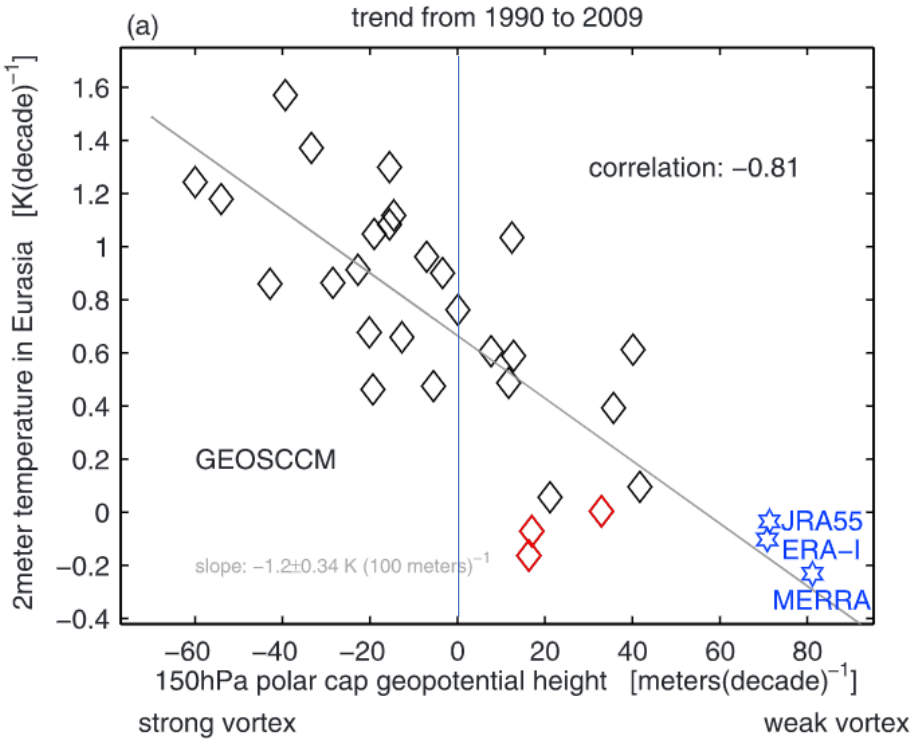
Impact of sea-ice



Several ensemble members lie close to observations, but several have opposite-sign trends.

No correlation between sea-ice trends and vortex location/strength trends.

Similar evidence in GEOSCCM ensemble



Garfinkel et al. 2017

"Stated another way, there is substantial internal variability in the polar lower stratosphere, and the apparent trend since 1990 in Eurasian surface temperatures may be just a byproduct of one specific manifestation of this chaotic decadal variability."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The polar vortex is running wild—and it may not be because of climate change
It bends, it twists, and scientists are split on what's causing it.

Impact of Large Ensembles

'Forced response' trends shown to be consistent with internal climate variability using Large Ensembles:

NH surface response to volcanic eruptions: Polvani et al. 2019

NAO trends: Deser et al. 2017

US 'warming hole': Banerjee et al. 2017

Tropical expansion: Grise et al. 2019

…

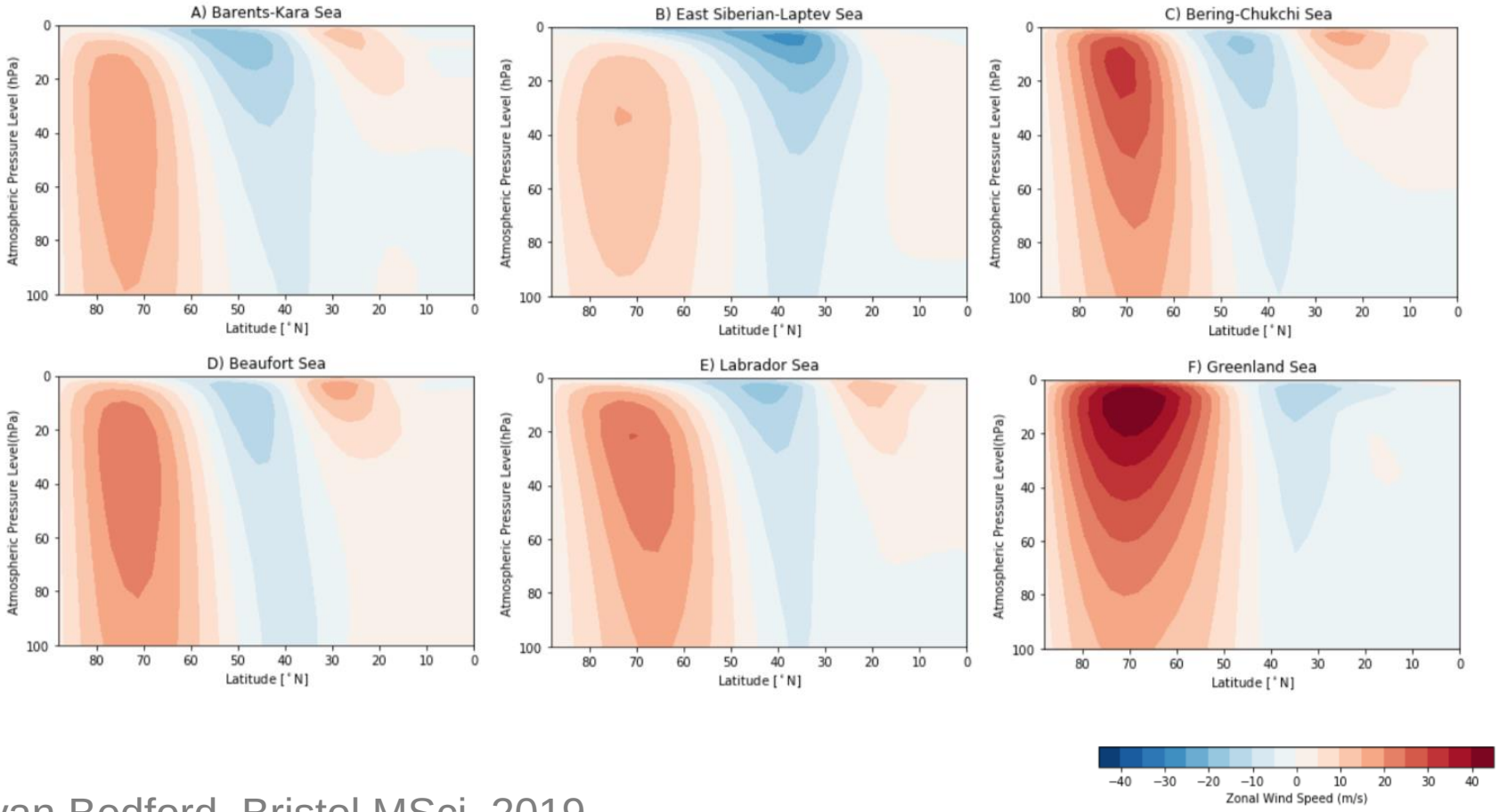
Will it?

(Will changing sea-ice impact the stratospheric polar vortex?)

Uncertainty due to spatial patterns of future sea-ice change

Spatial pattern of sea-ice changes

- Intermediate-complexity AGCM (Isca – Vallis et al. 2017)
- Impose regional sea-ice loss.



Ryan Bedford, Bristol MSci, 2019

Spatial pattern of sea-ice changes

Simulation with simultaneous loss in all regions.

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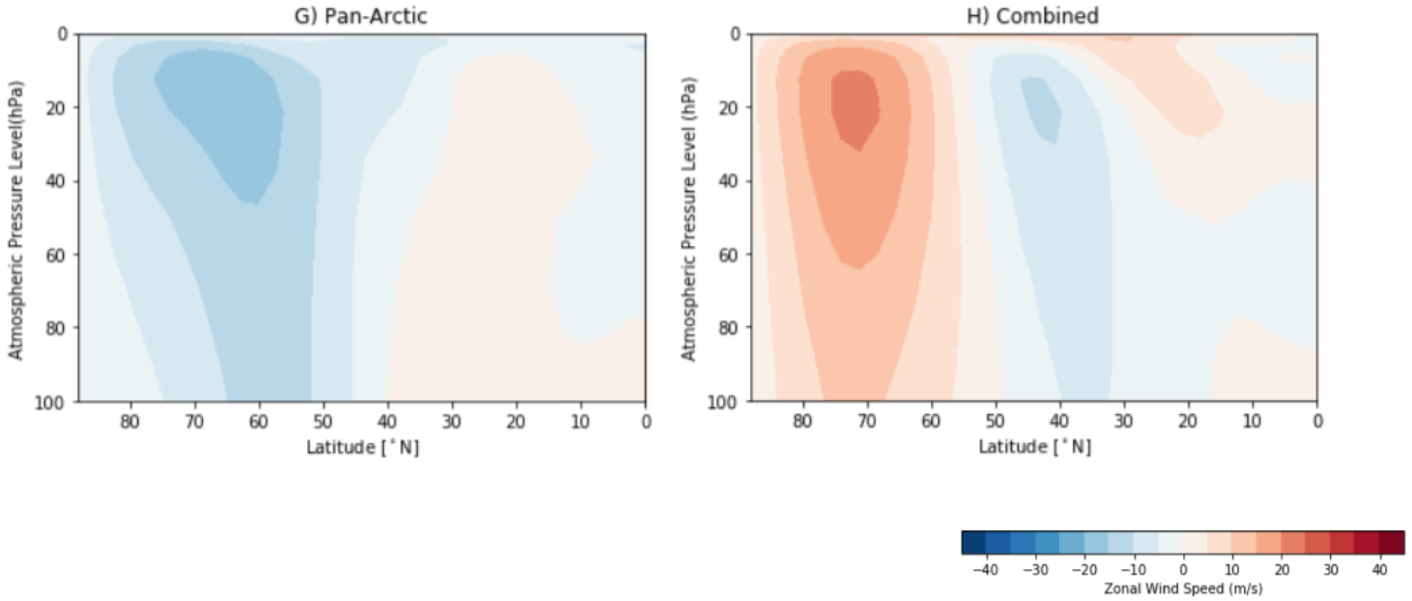
Linear addition of regional changes



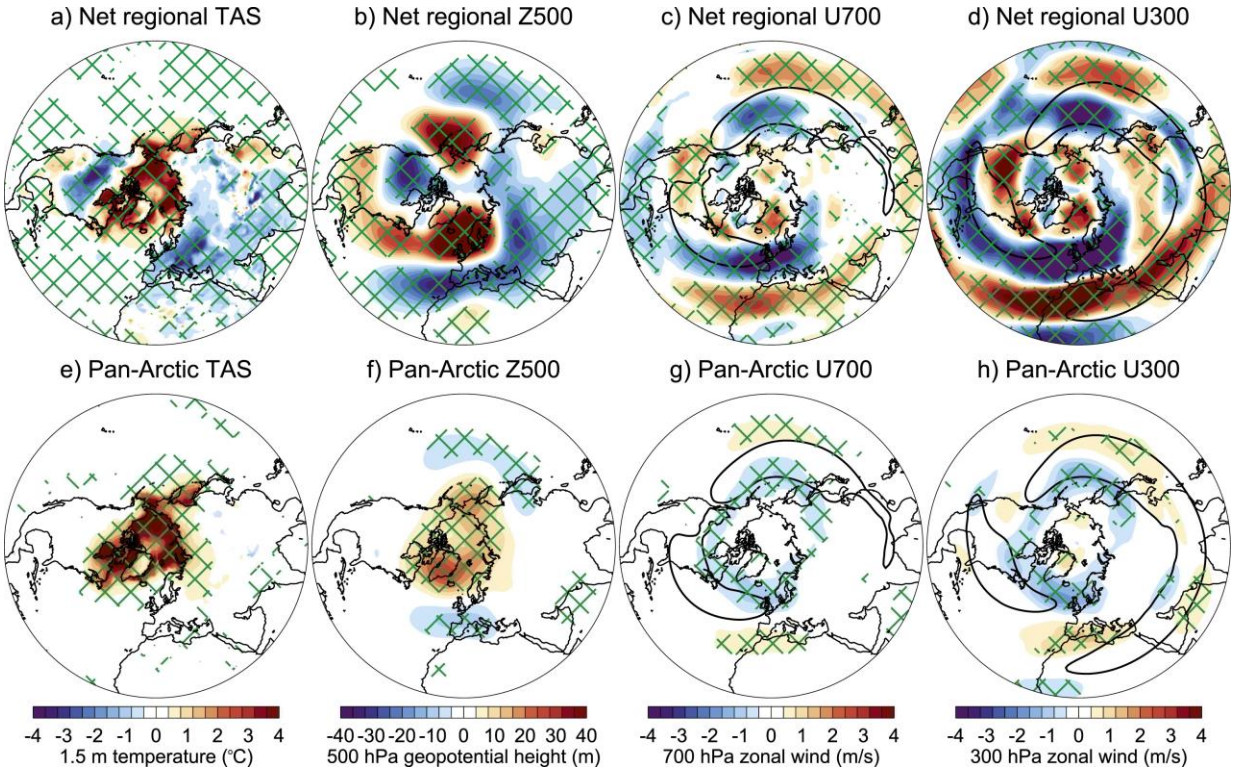
Response to regional sea-ice changes is very **nonlinear**.

Ryan Bedford, Bristol MSci, 2019

Similar results in upper-troposphere

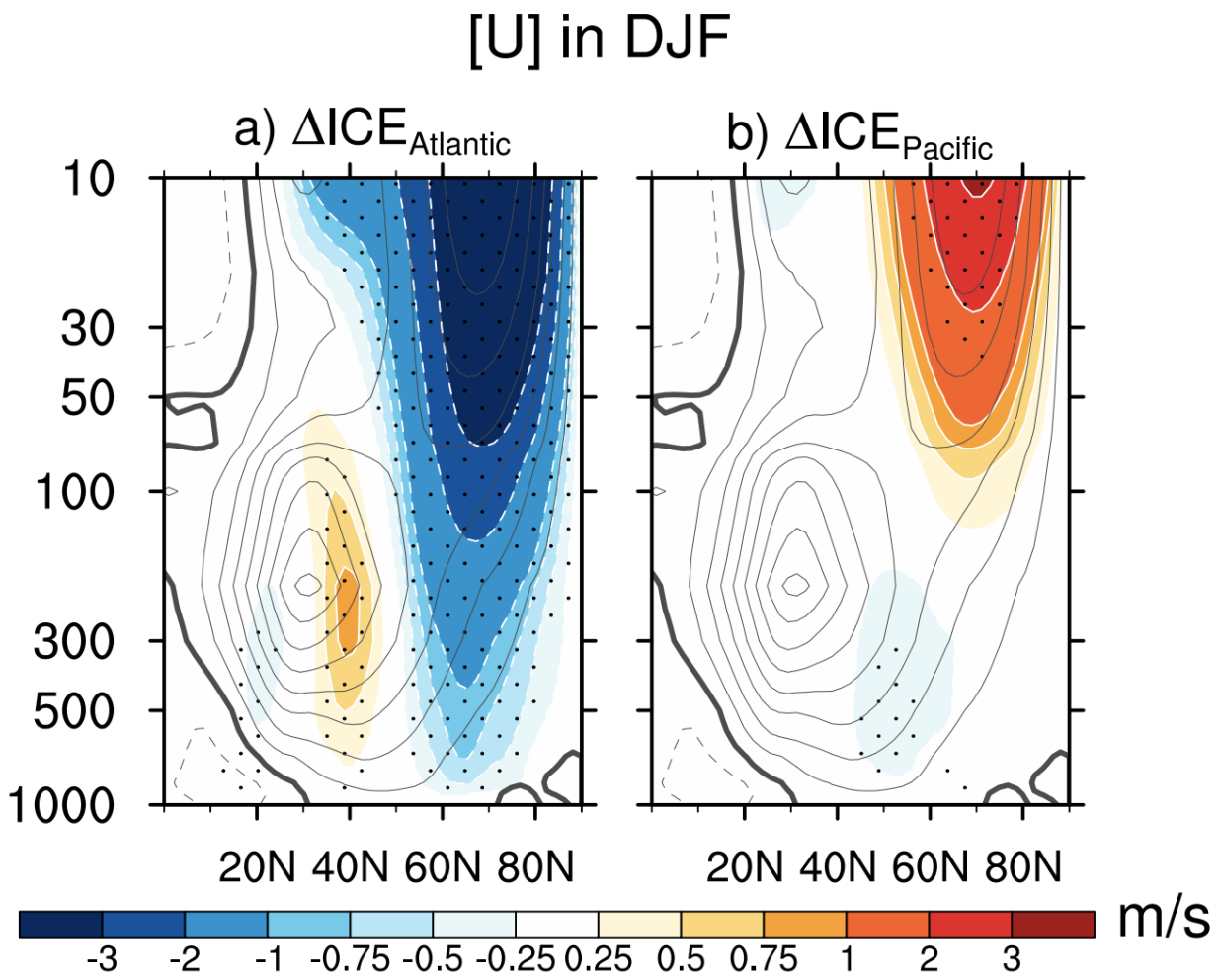
Linear addition of regional changes

Simulation with simultaneous loss in all regions.



Screen 2017

Spatial pattern of sea-ice changes



Opposite sign response to Atlantic and Pacific sector sea-ice changes.

Sensitive to background state (stationary wave pattern)?
- Test using Isca

Sun et al. 2015

Summary: Impact of Arctic sea-ice on the stratosphere

Can it?

Yes: Modelling studies suggest changing sea-ice can impact upward planetary-wave propagation and hence vortex strength and location

Has it?

Probably not: Many observed trends are not statistically-significant. No evidence that sea-ice decline has significantly increased the likelihood of weakening/shift of the vortex (Seviour, 2017; Garfinkel et al. 2017).

Will it?

Maybe: Highly sensitive to spatial pattern of sea-ice loss. Also no strong evidence for changes in vortex strength/variability in future (e.g. Ayarzagüena et al. 2018).