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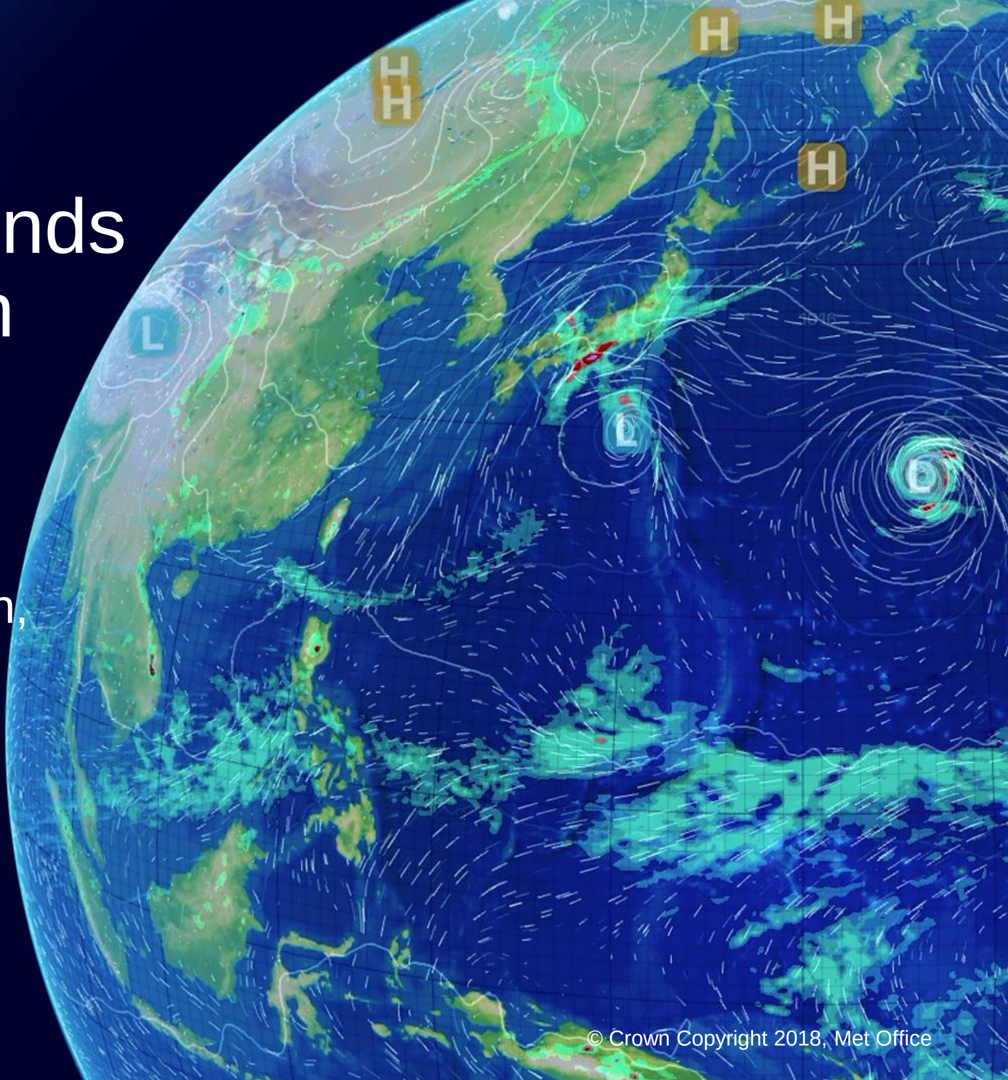
Decadal Variability & Trends with a focus on the North Atlantic Oscillation

Norway, June 2019

Rosie Eade, D. M. Smith, D. B. Stephenson, A. A. Scaife, L. Hermanson, N. Dunstone



Outline

Decadal Variability and the North Atlantic

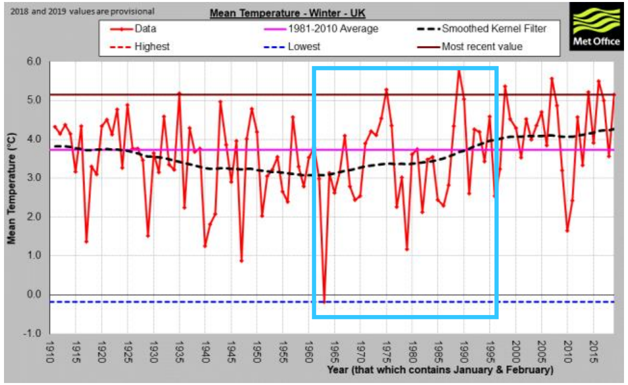
- Decadal trends in the NAO
- Decadal skill for the NAO

Drivers of North Atlantic Variability & CMIP6 Experiments

- NAO response to reduced Arctic Sea Ice
- NAO response to Atlantic forcing

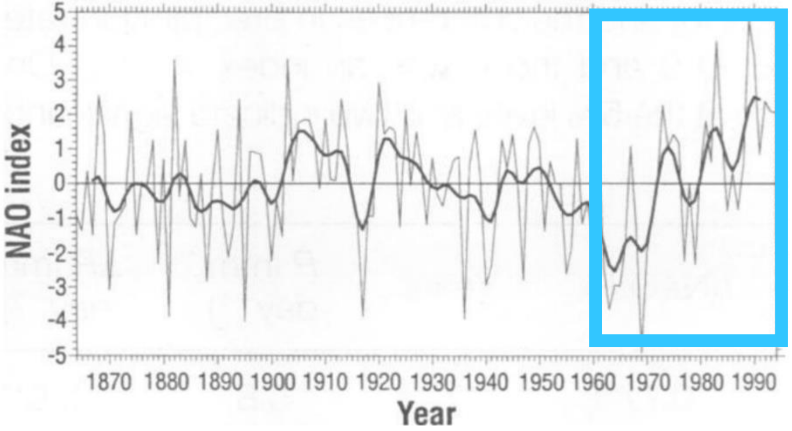
Smith et al, 2018, Geosci. Model Dev. Discuss., The Polar Amplification Model Intercomparison Project (PAMIP) contribution to CMIP6: investigating the causes and consequences of polar amplification

UK winters & NAO



The winter of 1962/63 was the coldest in the UK in over a century "The Big Freeze"
The mildest winter occurred in 1988/89

Period 1960s-1990s unusually high positive trend?



The NAO also has positive trend.

NAO known to have strong influence on European winter climate variability*.

Period 1960s-1990s unusually high +ve trend?

https://www.metoffice.gov.uk/climate/uk/summaries/actualmonthly
Hurrell, J. W., 1995, Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation, Science, 269, pp. 676 – 67
** e.g. Scaife, A.A. et al, 2008: European Climate Extremes and the North Atlantic Oscillation. J. Climate, 21, pp. 72–83*

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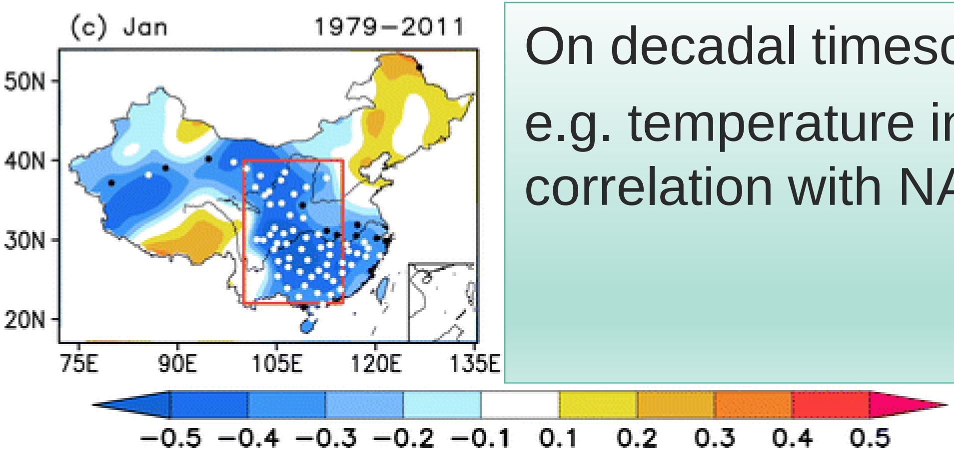
Global Climate & NAO



On decadal timescales NAO also has remote influence

e.g. temperature in South Central China, esp Jan: correlation with NAO

- Wave train spanning Arabian Sea → weakened Middle East Jet Stream in +ve NAO phase
- Downstream circulation anomalies from northern NAO centre influencing cold air movement from Siberia

Zuo et al, 2016

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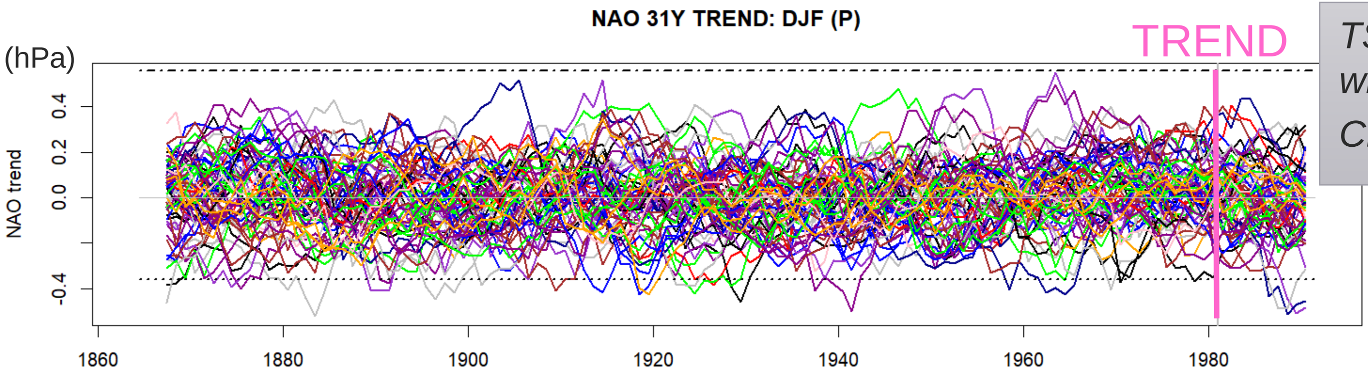
NAO in climate models

CMIP5 **historical** simulations DON'T fully capture NAO decadal variability



TS of DJF 31-year moving window trend NAO

CMIP5 Historical models (64 sim)

Obs NAO Max trend: 0.56hPa/year (20CR)

- No CMIP5 models has trend > Obs Max
- Don't get timing of 1960s positive trend

…

How unusual is the 1960s-1990s observed NAO trend?

A Single Trend

Compare against statistical model: Red noise

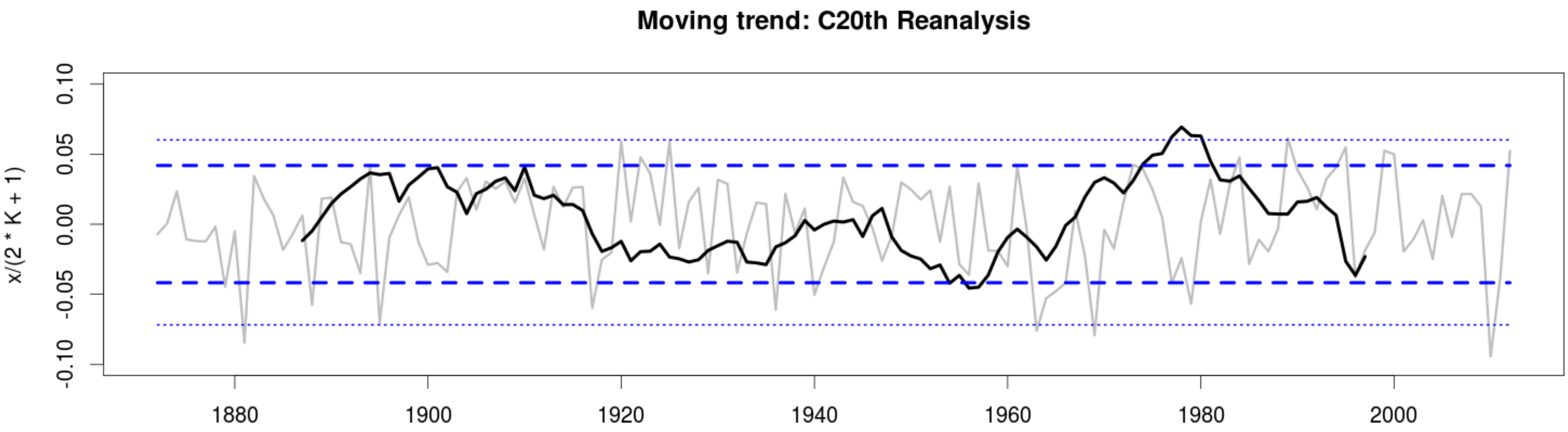
Simulate NAO time-series from **AR1 process** (1000 sims of 31 years), Observed $\rho = 0.14$

- Distribution of trends → 95% Confidence intervals (in blue) (and range)

Obs NAO Max trend: 0.064 (*standardised*)

=> ***Very unusual*** event? (no sims have greater trend)

* BUT *this period has been picked by eye as an* ***extreme trend***



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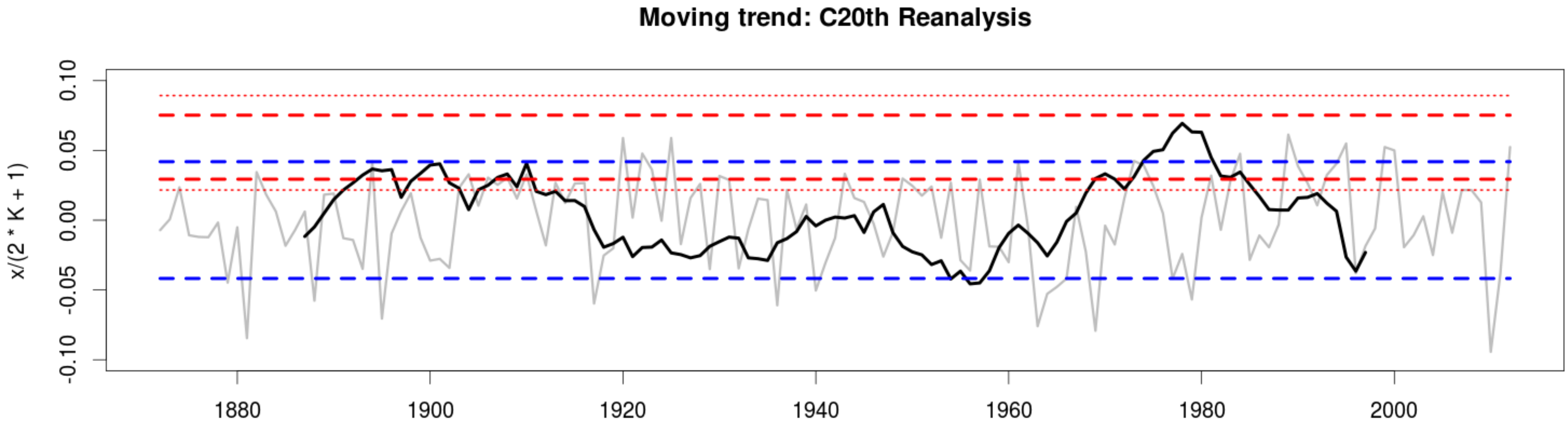
An Extreme Trend

Simulate NAO time-series from **AR1 process** (1000 sims of 150 years), Observed $\rho = 0.14$

- Note dependence of trends in consecutive windows
- Distribution of max moving-31-year trend (from each 150-years)
  → 95% Confidence intervals (in red) (and range)

Obs NAO MAX trend: 0.064 (*standardised*)

=> ***Moderately unusual*** event? *(6.7% of sims have greater max trend)*

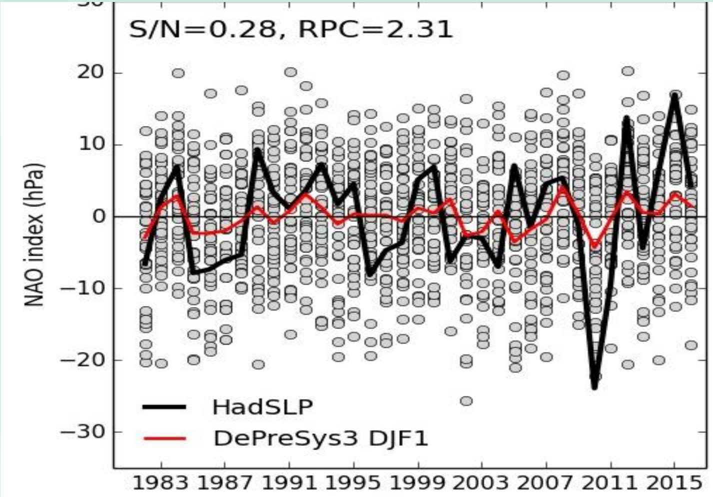


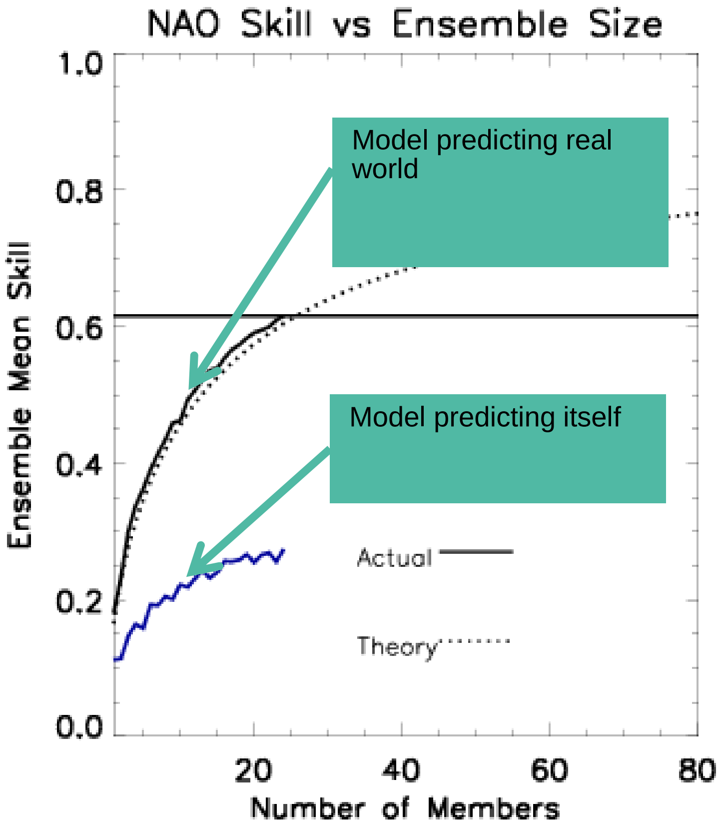
NAO Signal-to Noise Paradox

Skilful seasonal predictions (**initialised**)

BUT signal-to-noise ratio of ensemble forecast is smaller than expected by statistical relation

Model can predict the real world better than itself





Scaife et al 2014, Eade et al 2014, Siegert et al 2015, Dunstone et al 2016, Scaife and Smith 2018

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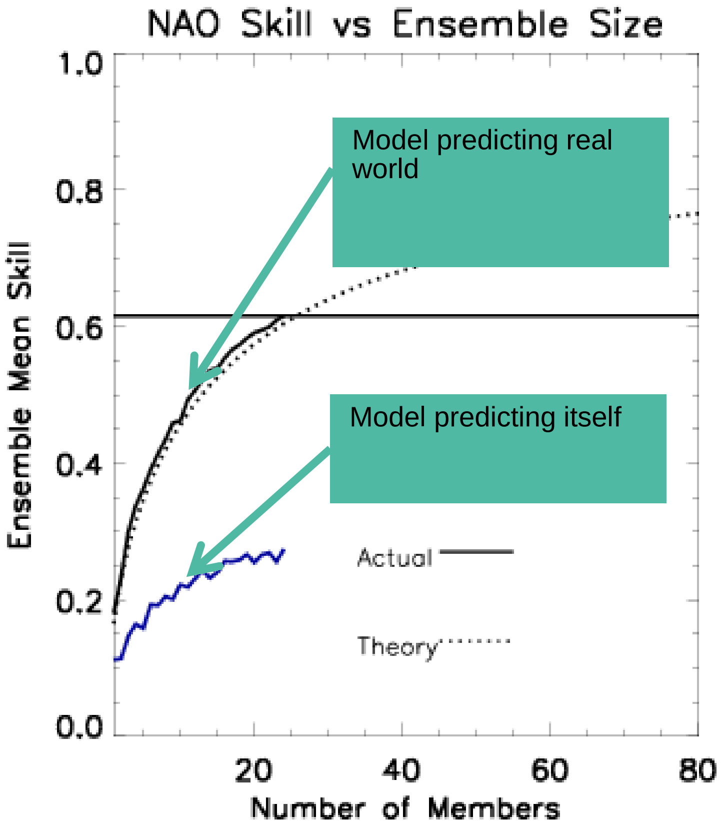
$$RPC = \frac{PC_{obs}}{PC_{\mathrm{mod}}} \geq \frac{r}{\sqrt{\sigma^2_{\mathrm{ens\_mean}} / \sigma^2_{\mathrm{ens\_members}}}}$$

Should ~ 1 for perfect model

But for NAO is ~ 0.6/0.3 = 2



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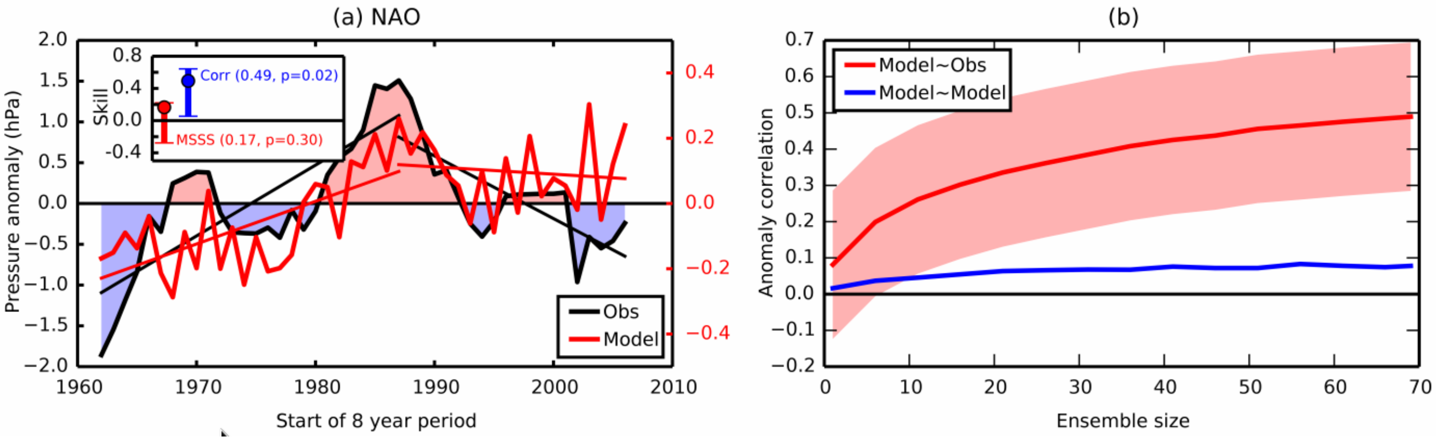
Initialised Hindcasts: years 2-9: NAO (annual)



Signal-to-noise paradox

Skilful predictions of NAO
BUT
Signal-to-noise ratio of ensemble forecast is smaller than expected by statistical relationship.
→ Model predicts real world better than itself

$$RPC = \frac{PC_{obs}}{PC_{mod}} \geq \frac{r}{\sqrt{\sigma^2_{ens\_mean} / \sigma^2_{ens\_members}}}$$

~ 1 for perfect model

- Forecast signal similar to observations
  - increase from 1960s to 1990s, slight decrease thereafter
- Predicted signal has very small amplitude → **MSSS positive but not significant**
- **Correlation is significant (r = 0.49, p = 0.02)**
- Correlation of *ensemble mean* is much higher with *observations* than with *individual model members* → **RPC > 6**

Smith et al, 2019

CMIP6-PAMIP

Research funded as part of APPLICATE project, Grant number 727862

Simulations to assess the **impact of Arctic sea ice** on climate.
- Set of large ensemble experiments, **AMIP** and Coupled
- 14 months (from 1st April 2000), **75 members**, Met Office model HadGEM3 N216

Different combinations of **prescribed global SIC and SST fields**
pdSST_pdSIC present day (Pre Industrial GMT +0.57°C GMT)
pdSST_fuArcSIC future sea-ice in Arctic, rcp8.5 (Pre Industrial GMT +2°C)
fuBKSeasSIC, **fuOkhotskSIC**

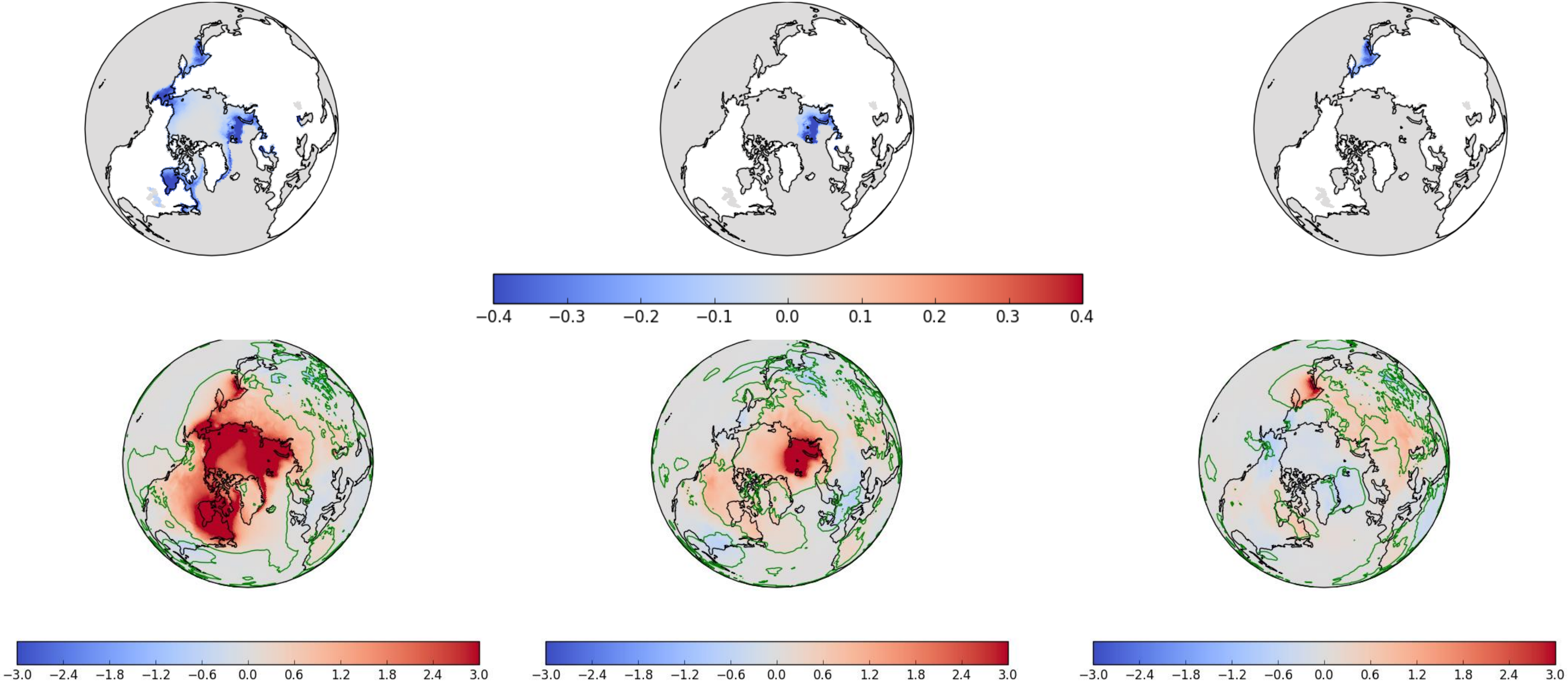
→ Estimate contribution of SIC reduction to polar amplification
- Arctic SIC reduction in different regions may have different impacts
- Projections of SIC show different rates of loss in different regions → impacts may vary over time

Smith et al, 2018, Geosci. Model Dev. Discuss., The Polar Amplification Model Intercomparison Project (PAMIP) contribution to CMIP6: investigating the causes and consequences of polar amplification

Reduced Arctic Sea Ice

Sea Ice Concentration: Future - Present Day DJF

Arctic | Barents/Kara Seas | Sea of Okhotsk



SAT: Local warming near surface

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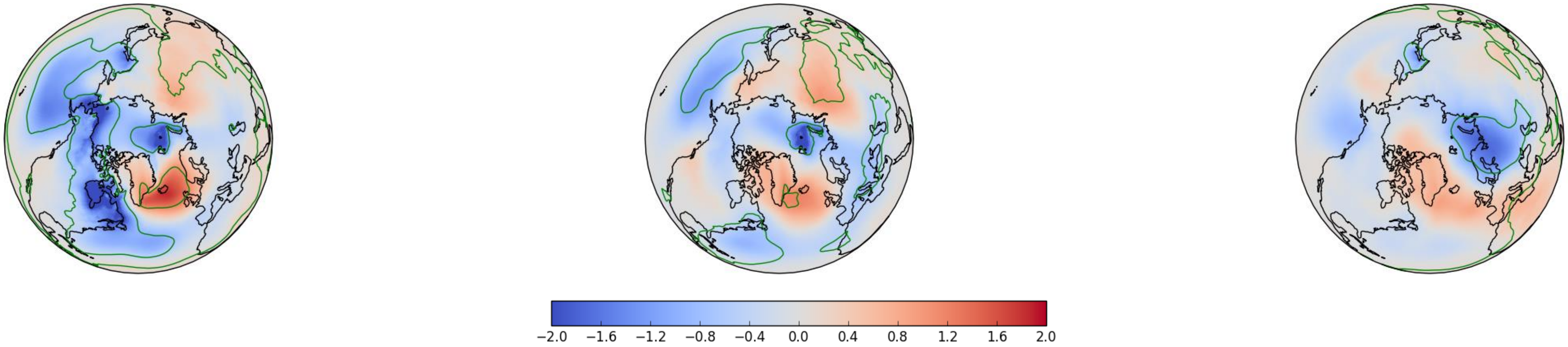
Reduced Arctic Sea Ice

MSLP: Future - Present Day DJF

Arctic | Barents/Kara Seas | Sea of Okhotsk



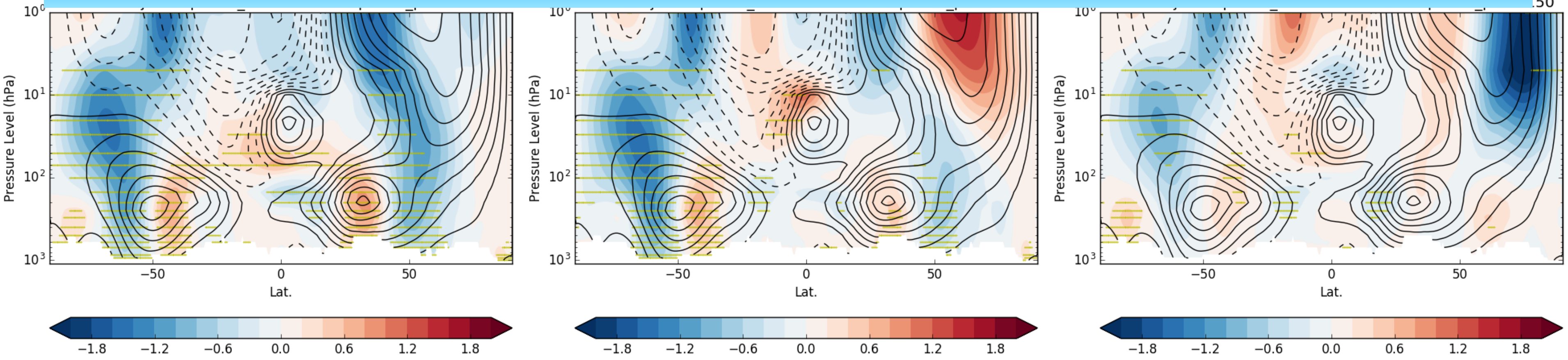
Increase around Iceland suggests tendency towards negative NAO

- Also decrease in central/western North Atlantic
- Similar responses for all 3 regions
- Not significant for Sea of Okhotsk, but sig. decrease over Siberia

Reduced Arctic Sea Ice

Zonal mean U-wind: Future - Present Day DJF

Arctic | Barents/Kara Seas | Sea of Okhotsk



Increase on equatorward side of tropospheric jet suggests equatorward shift

- Not significant for Sea of Okhotsk
- Also see fairly symmetric response in southern hemisphere

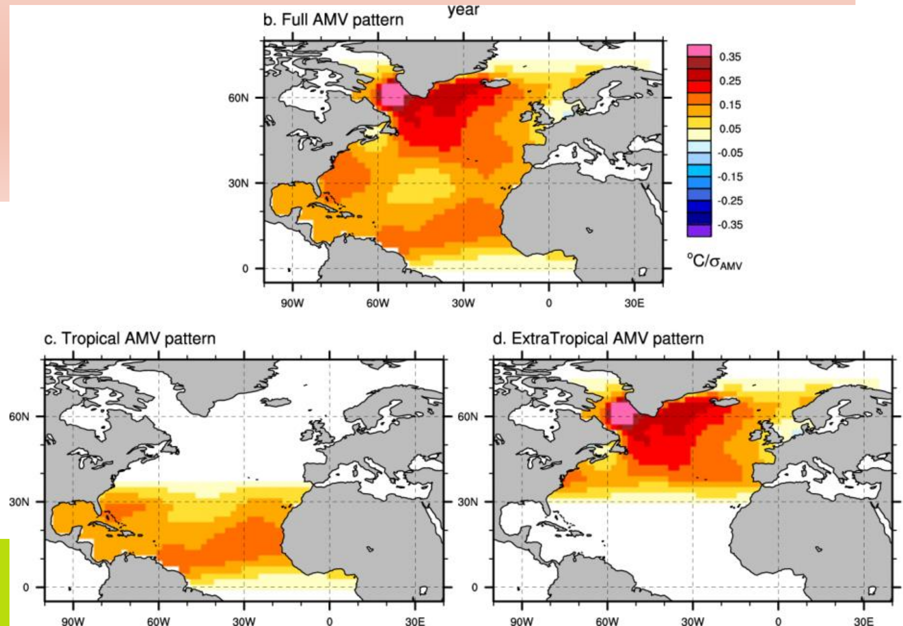
…

R. Eade, D. Smith

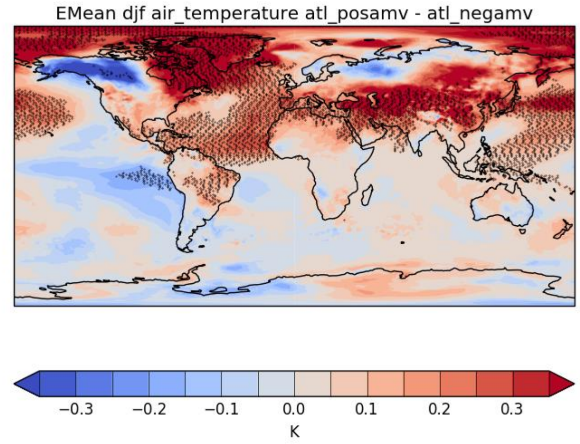
CMIP6-DCPP AMV/PDV

Simulations to assess the impact of Atlantic and Pacific decadal variability on climate.

- Coupled simulations, nudged by +/- AMV/PDV SST patterns
- 10 years, 25 members from different initial conditions representing different phases of AMV/PDV
    - salinity nudging so density conserved
    - nudging of sub-regions (extra-)tropics



CMIP6-DCPP AMV

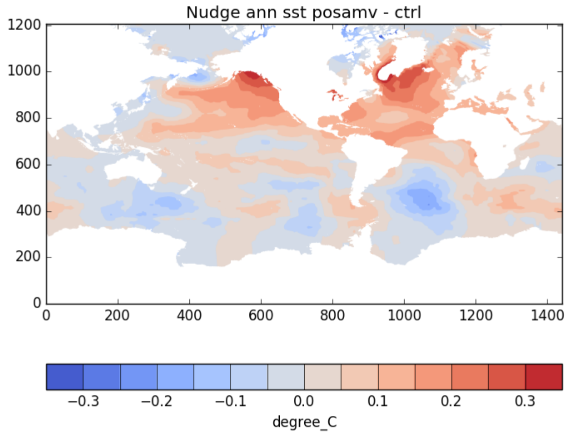


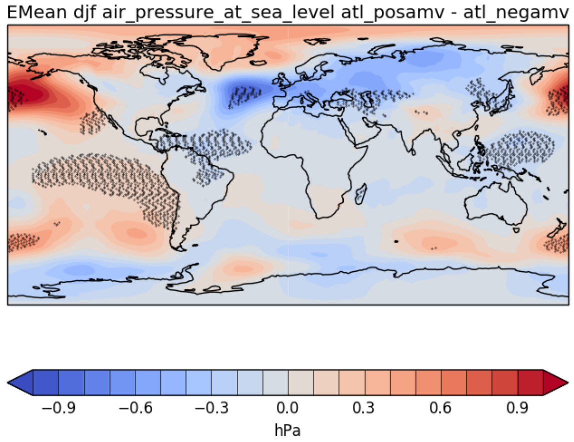
DJF Mean SAT response

Pos AMV – Neg AMV

Nudging field for MO Model

(+ appropriate mask)





DJF Mean MSLP response

Pos AMV – Neg AMV

- Warming over N Hemi. Land
- Reduced pressure in North Atlantic ~ NAO southern node (slight increase over Iceland) → tendency for -ve NAO

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Summary

Decadal Variability and the North Atlantic

- 1960s – 1990s Obs +ve NAO Trend
- Extreme trend: Moderately unusual compared to AR1 model simulations
- Very unusual compared to historical GCM simulations
- Initialised hindcasts simulate obs +ve NAO trend, followed by down-turn
    - But Signal-to-noise ratio issue => hard to detect, weak signal, need large ensemble

Drivers of North Atlantic Variability & CMIP6 Experiments

- Reduced sea ice in Arctic leads to a tendency for negative NAO; more extreme –ve events
- Related westward shift of the northern centre
- Equatorward shift of the jet
- Similar response for sub-region experiments but Sea of Okhotsk has weaker response (noting this is a smaller region of sea ice loss)

- Positive AMV leads to a tendency for negative NAO

Future:

- Investigate mechanisms
- Investigate response in southern hemisphere