Role of the stratosphere in seasonal to decadal prediction

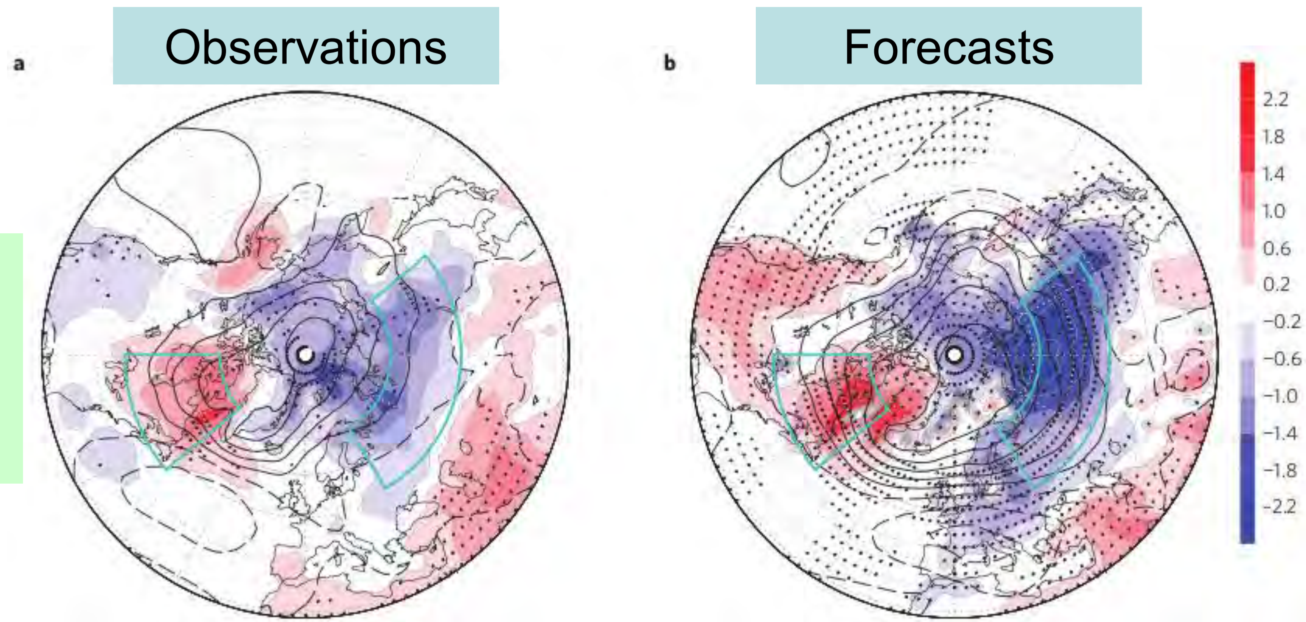
D. Smith, A. Scaife, A. Arribas, M. Athanassiadou, E. Blockley, A. Brookshaw, R.T. Clark, D. Copsey, N. Dunstone, R. Eade, E. Fiedler, D. Fereday, C.K. Folland, M. Gordon, L. Hermanson, J.R. Knight, D.J. Lea, C. MacLachlan, A. Maidens, M. Martin, A.K. Peterson, M. Vellinga, E. Wallace, J. Waters, A. Williams…

Contents

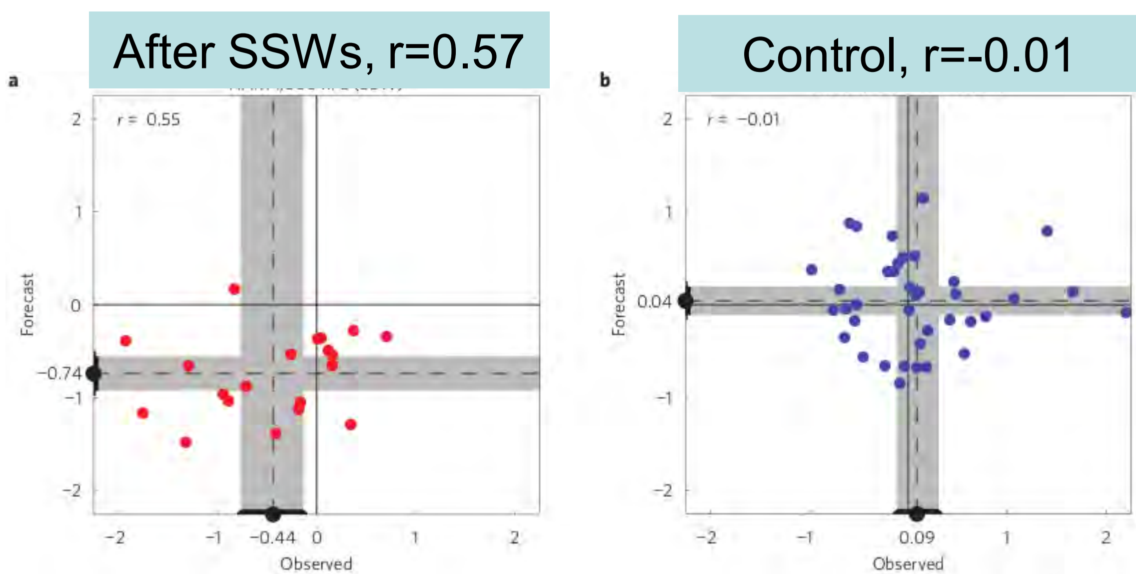
- Potential sources of skill
- Practical issues
- Seasonal forecasts of the NAO
- Decadal forecasts
- Future issues

Stratospheric warmings

SLP (contours) and surface temperature (colours) during days 16-60 after SSW



Forecast skill of NAM much higher after SSWs



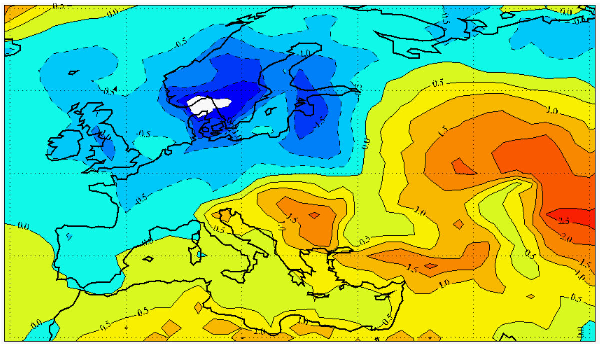
(Sigmond et al. 2013)

How Predictable are Stratospheric Warmings?

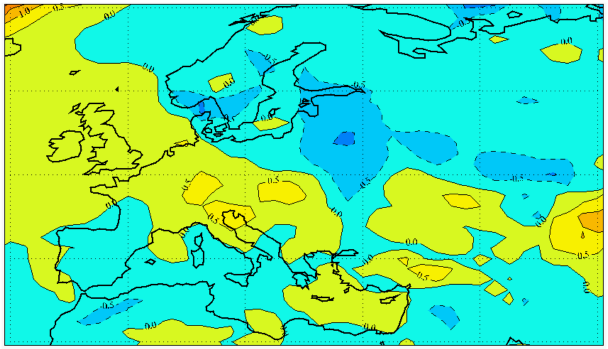
	24 Feb 1984 (Ext | Stand)	7 Dec 1987	15 Dec 1998	26 Feb 1999	Event Mean
Maximum lead time for capture (days)	13 | 5	15 | 10	12 | 12	9 | 6	**12 | 8**
Peak easterly magnitude (fraction of observed)	0.4 | 0.1	0.7 | 0.2	0.7 | 0.3	0.6 | 0.4	**0.6 | 0.3**

Improved intraseasonal prediction of European winter cold spells:

Extended



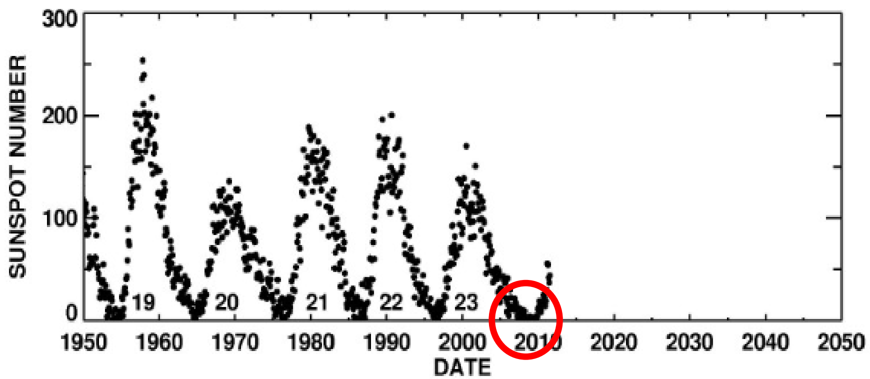
Standard



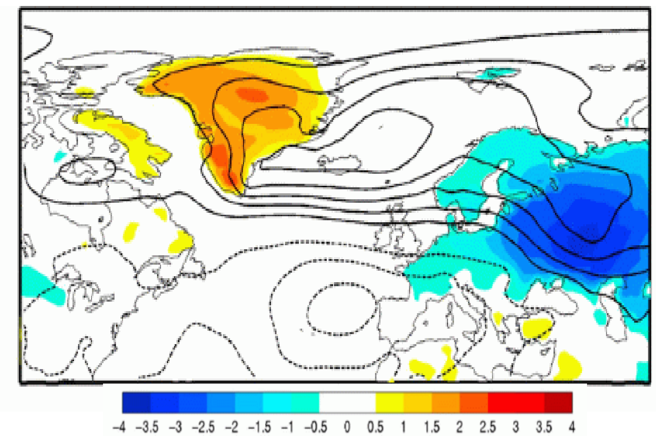
Marshall and Scaife, JGR, 2010

Solar variability

11 year solar cycle



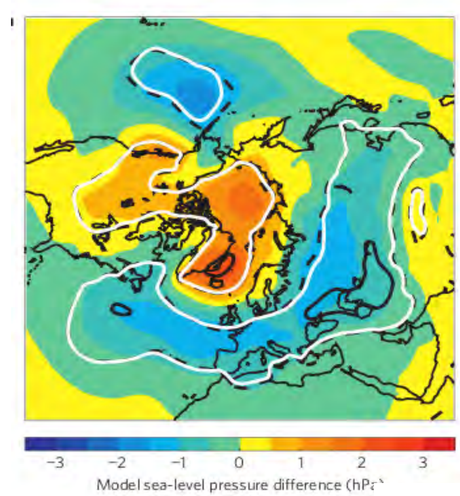
Observed surface impact



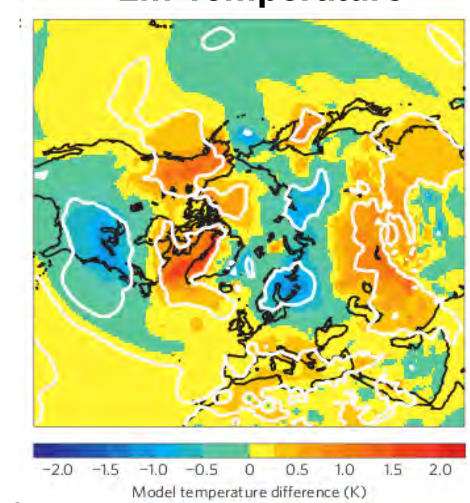
SLP (contours), temperature (colours)
Woollings et al, 2010

Modelled surface impact

Sea Level Pressure



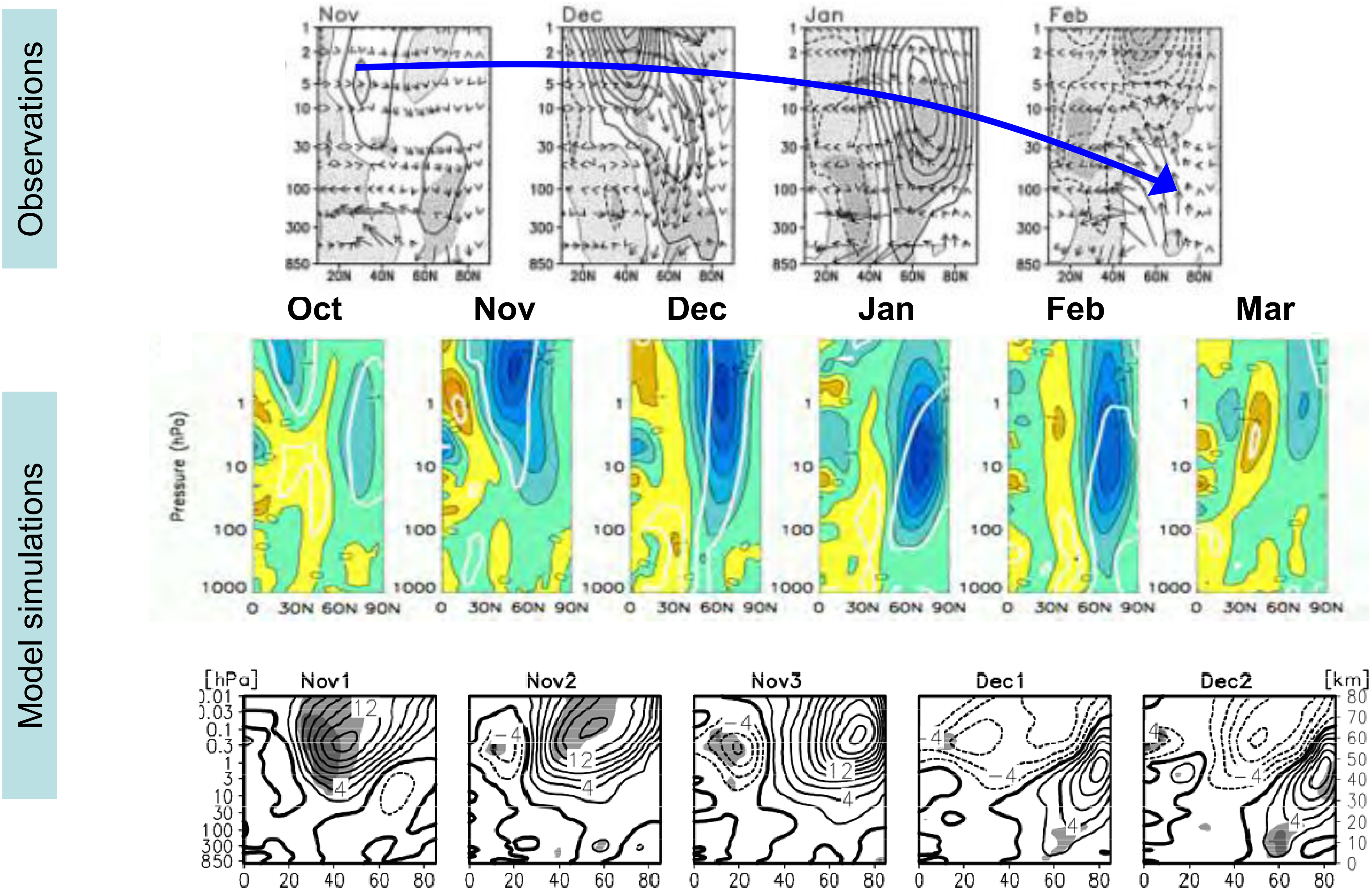
2m Temperature



Ineson et al, 2011.

Negative Arctic Oscillation / NAO at solar minimum

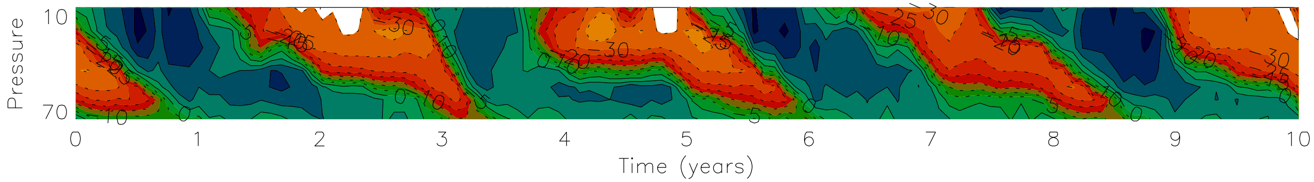
Solar Variability: downwards propagation of stratospheric polar night jet anomalies



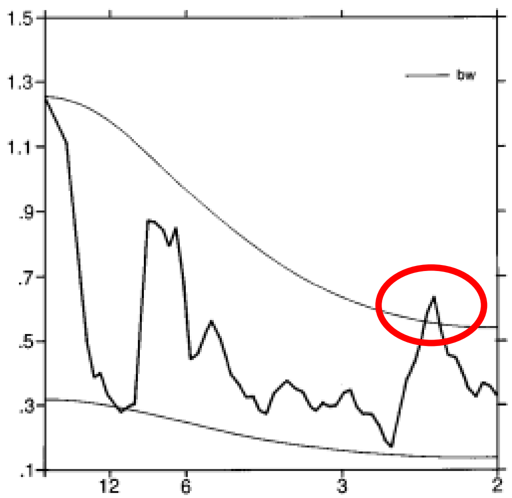
(Kuroda and Kodera 2002, Ineson et al 2011, Matthes et al 2006)

Predictability from the QBO (After Ebdon 1975)

Observed tropical wind oscillations

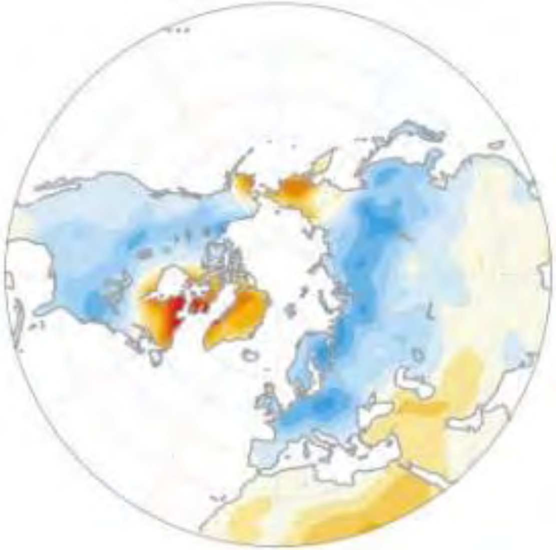


NAO Power Spectrum



Hurrel and Van Loon, 1997

Surface Temp' QBOE-QBOW

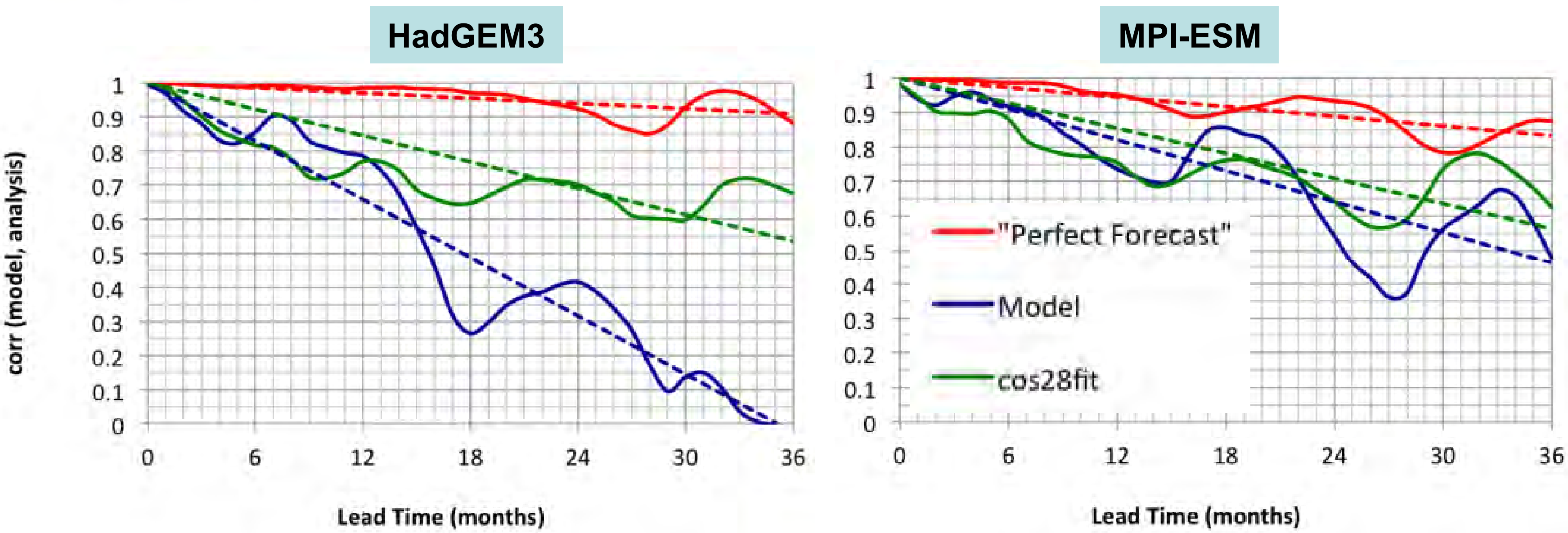


Thompson et al 2002

QBO -> extratropics -> surface NAO

Large signal in observations, potentially important

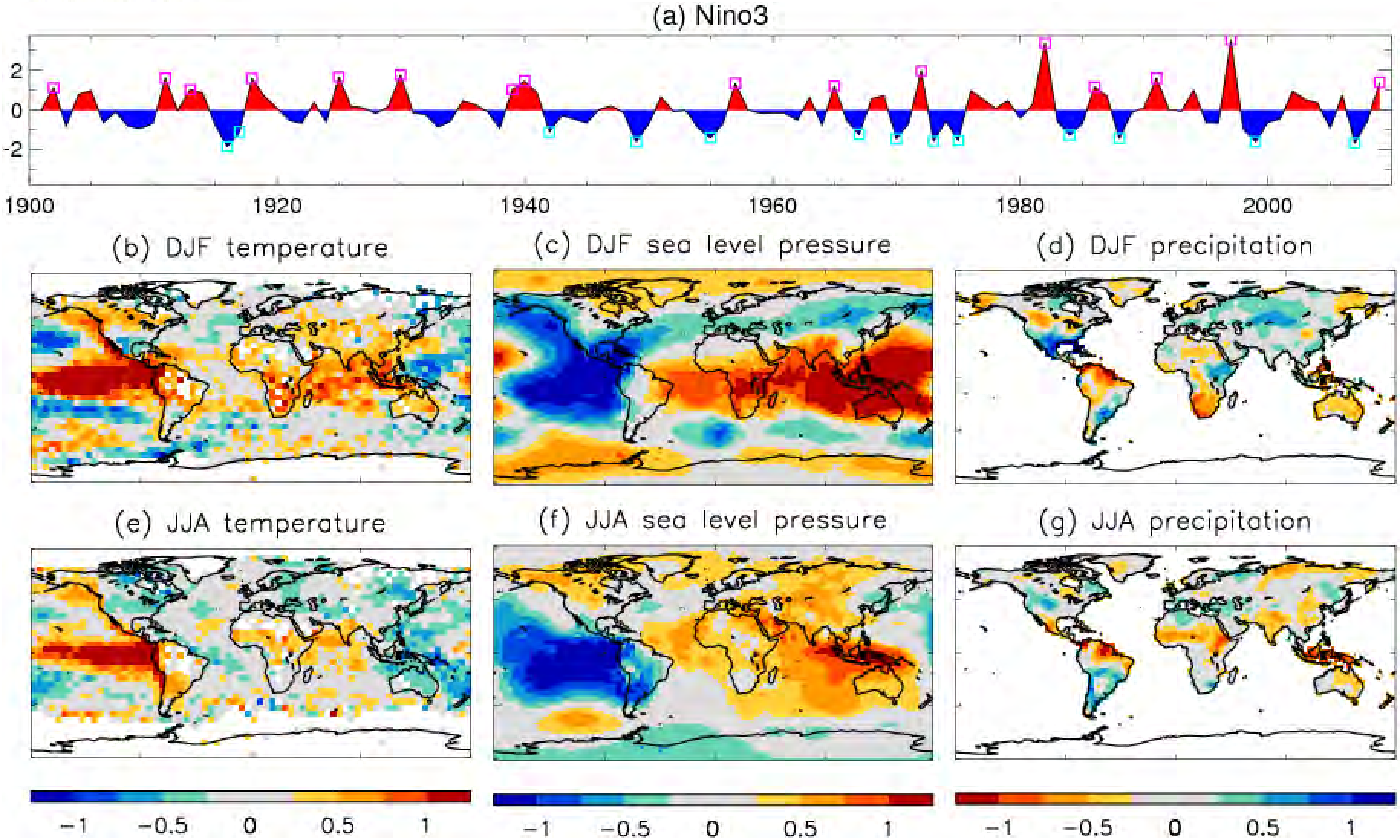
How predictable is the QBO?



- Highly predictable more than a year ahead in dynamical models
- Dynamical forecasts not quite as good as “cos28fit”
- But potential for higher skill

Scaife *et al*, submitted

El Niño Southern Oscillation (ENSO)

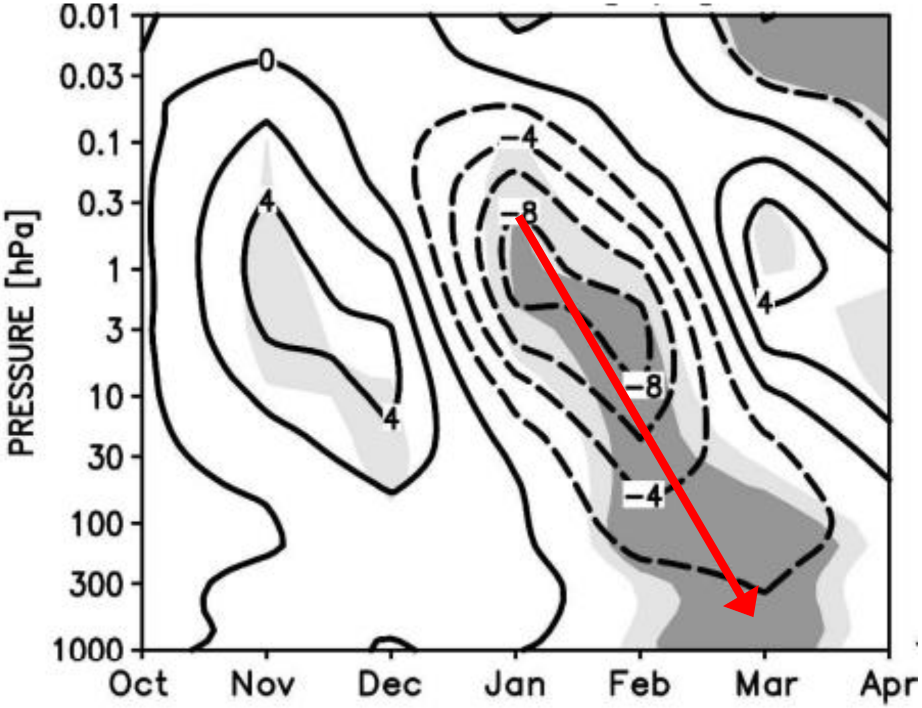


Smith *et al*, 2011

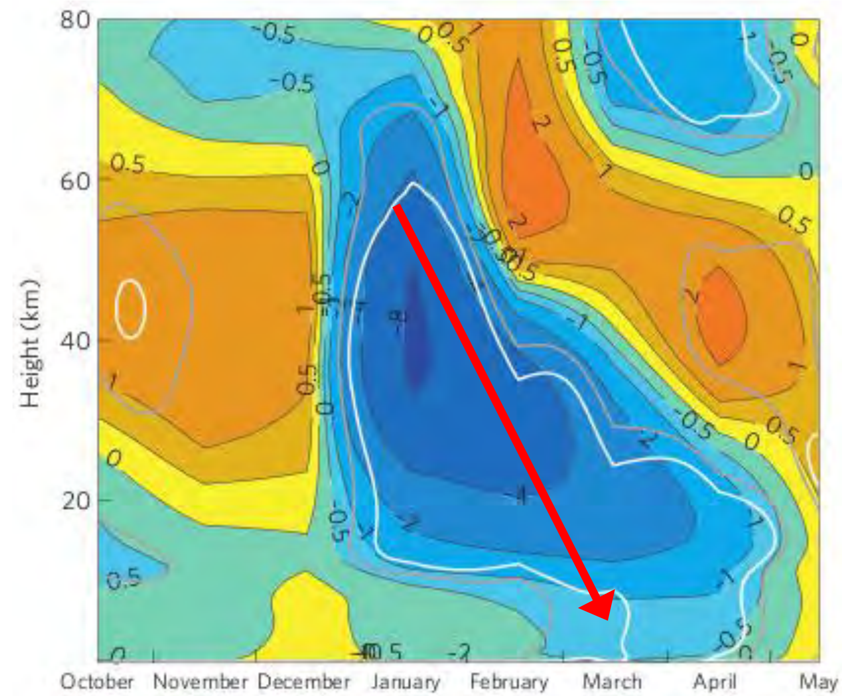
ENSO: stratospheric pathway ⇒AO

Zonal winds at 60N

ECHAM5 (Manzini et al 2006)

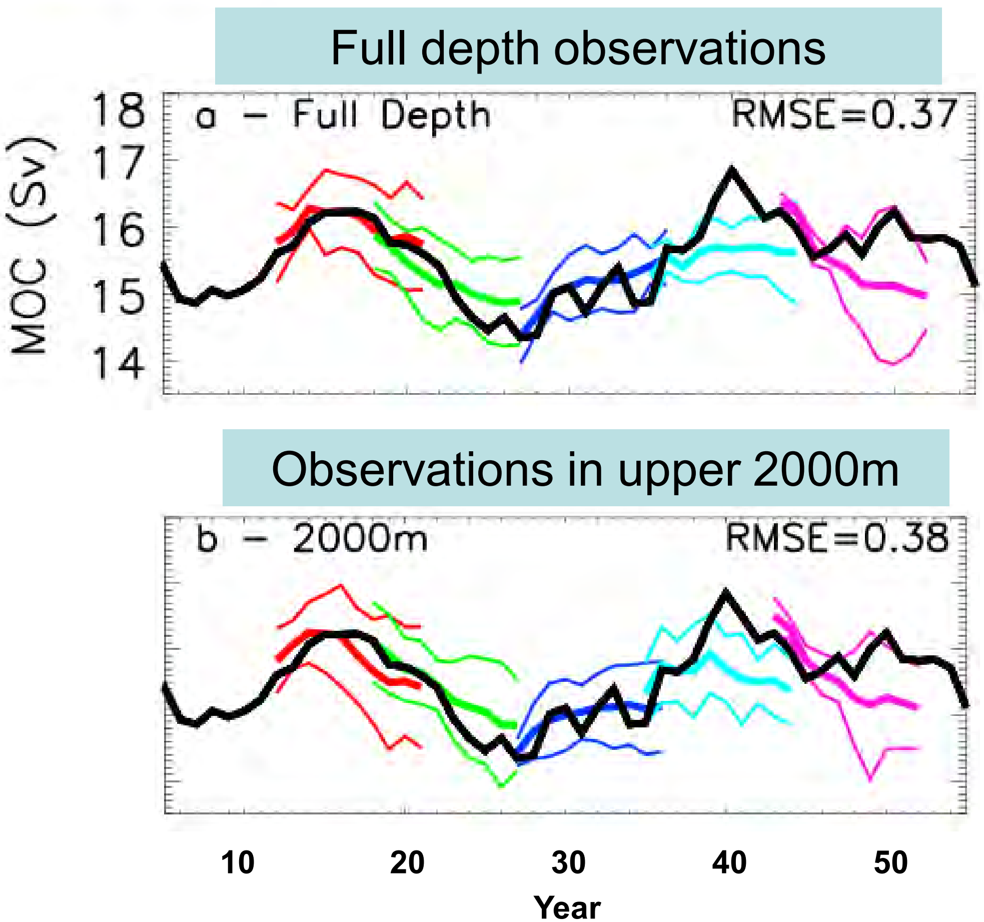


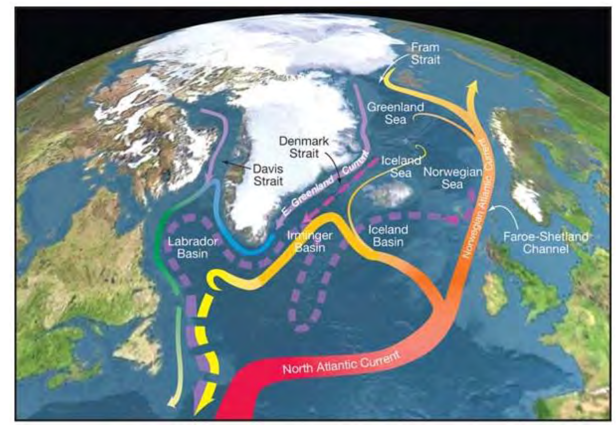
HadGEM3 (Ineson and Scaife 2009)



- **Weakening of polar vortex during El Niño, especially late winter**
- **Increased likelihood of SSW**
- **Downwards propagation**
- **Negative AO ⇒ surface climate impacts**

Idealised predictability of Atlantic overturning

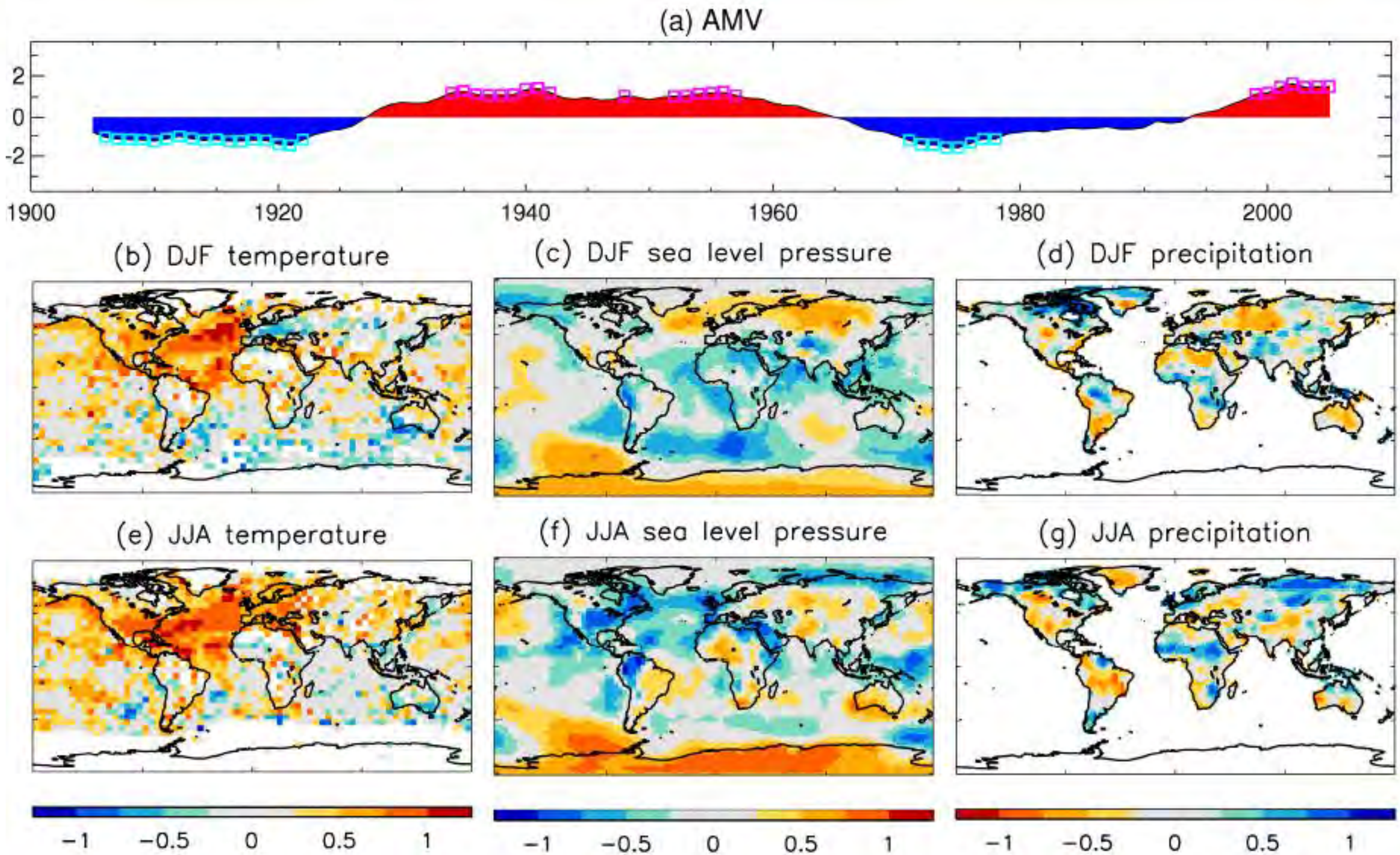




- **Many idealised experiments** suggest that North Atlantic ocean currents are potentially predictable on decadal timescales

(Dunstone and Smith 2010, also Griffies and Bryan 1997, Collins et al, Latif et al, Pohlmann et al, Msadek et al)

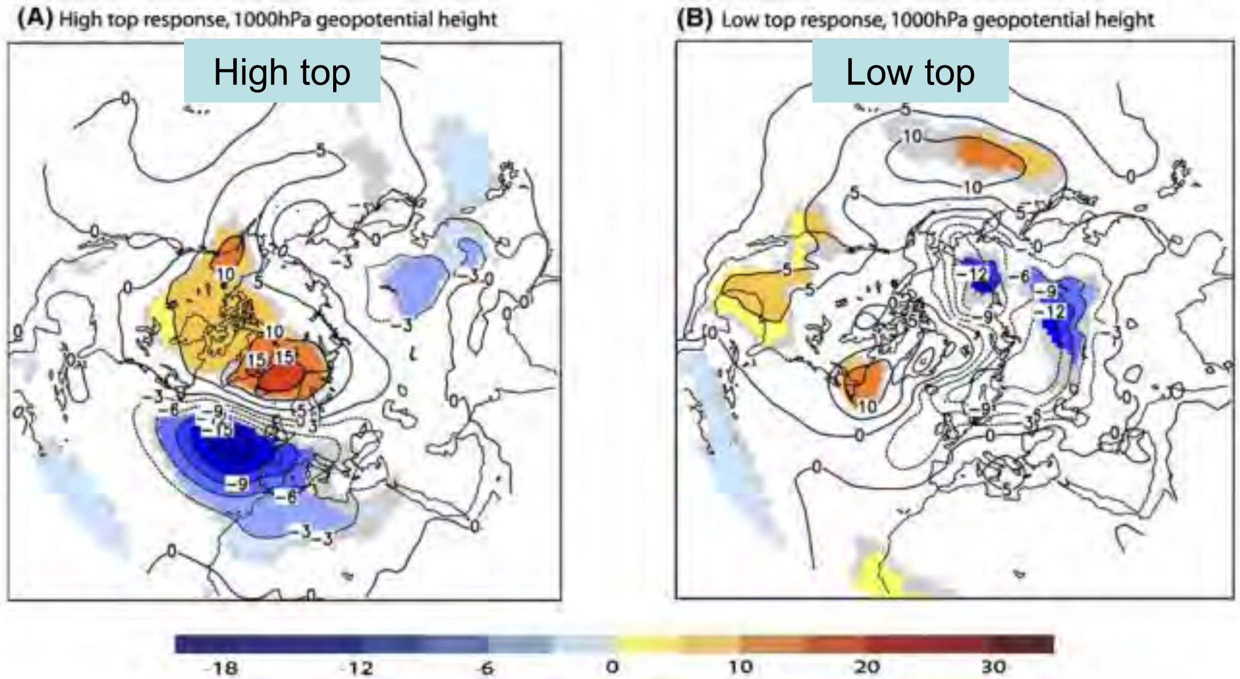
Atlantic multi-decadal variability (AMV)



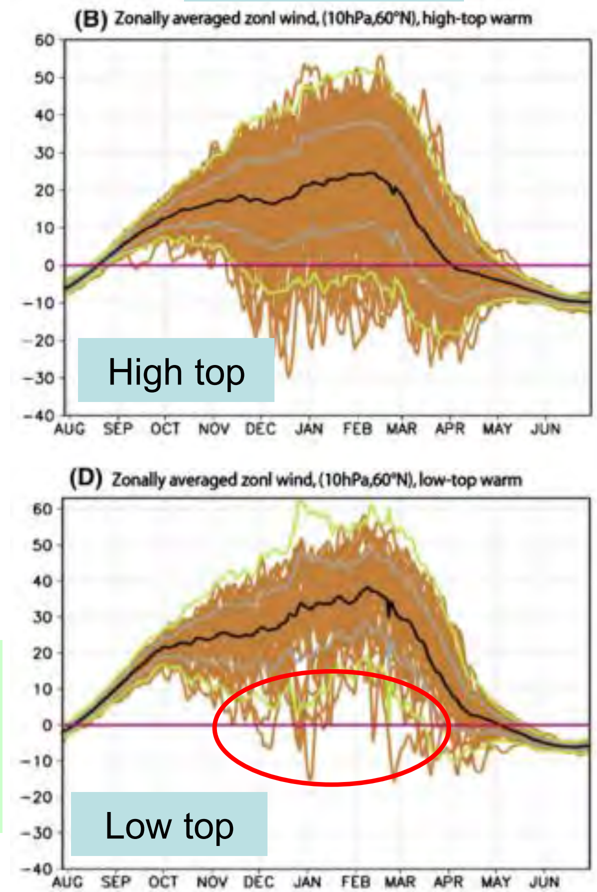
Smith *et al*, 2011

Response to warm AMV

1000hPa geopotential height response



Zonal wind



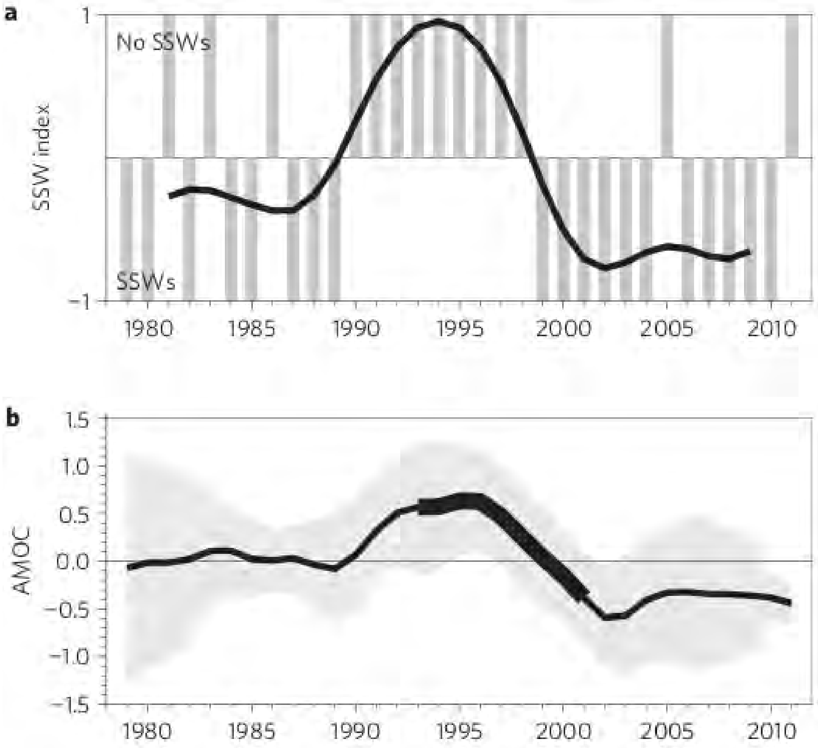
Negative AO response to warm AMV only in high top model…

…due to an increase in SSWs, not simulated in low top model

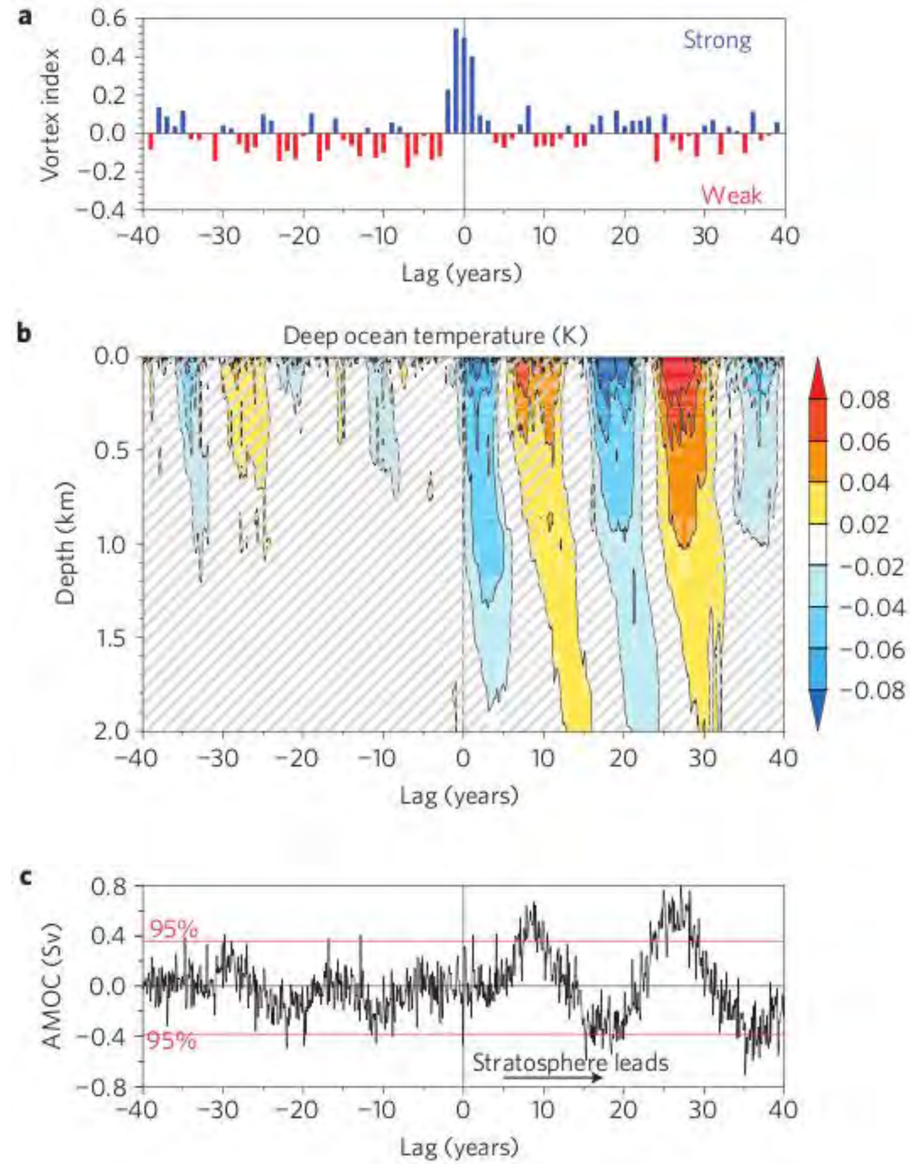
Omrani *et al*, 2013

SSWs driving Atlantic overturning

Observations



Model simulations

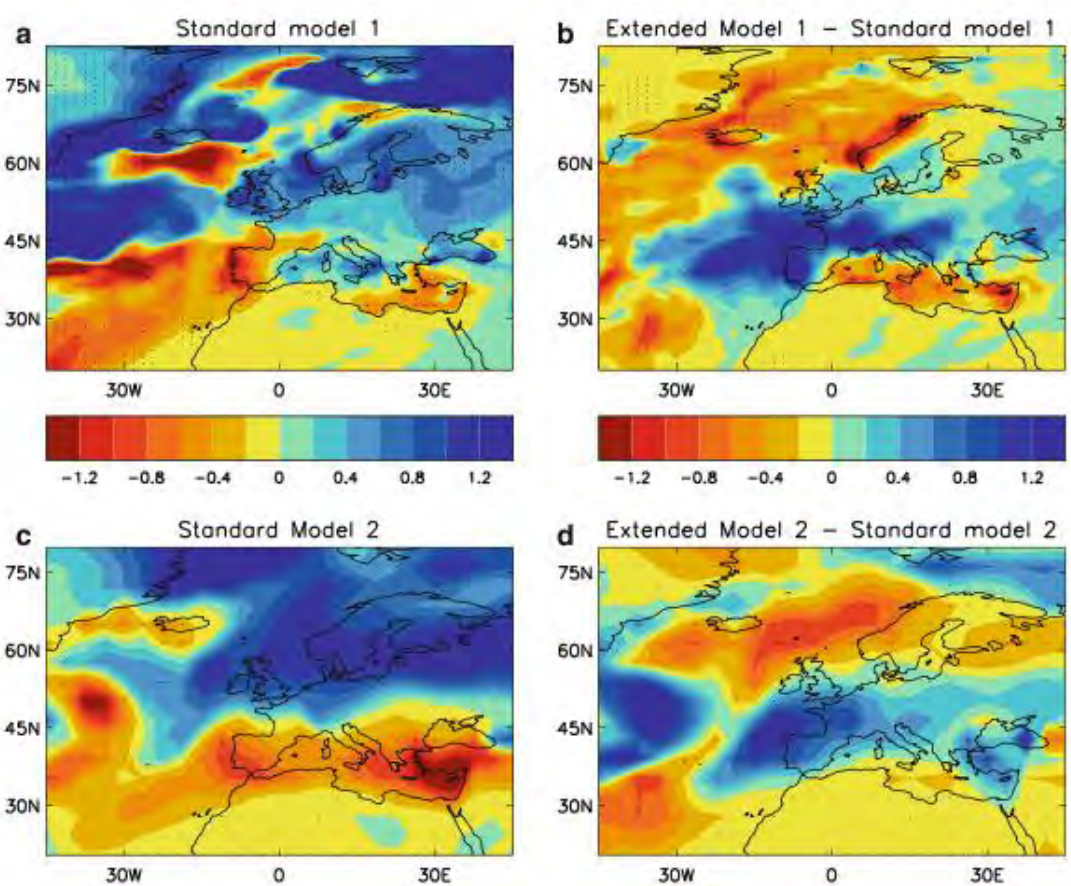


Low frequency variations in SSWs induce deep ocean signals and modulate the Atlantic overturning

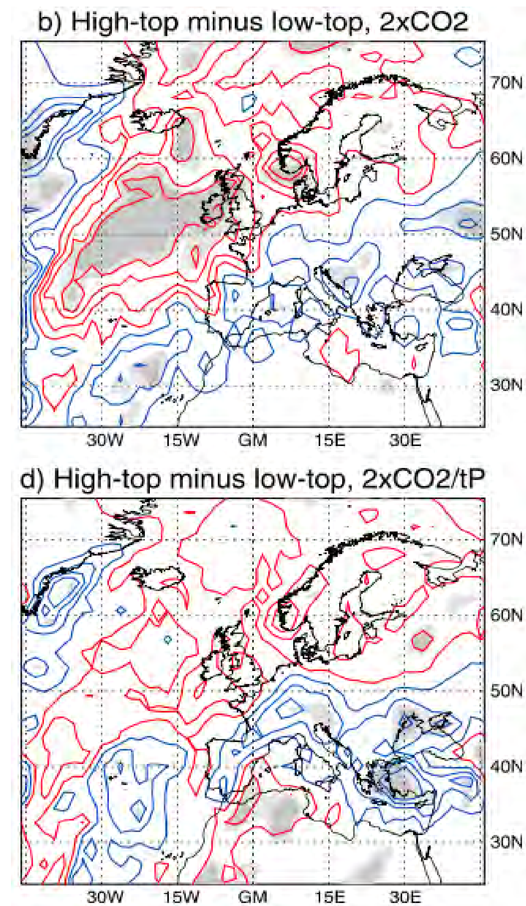
Reichler *et al*, 2012

Greenhouse gases

- Robust multi-model response when stratosphere is well resolved
- Smaller decrease of Arctic SLP
- Large differences in rainfall over Europe

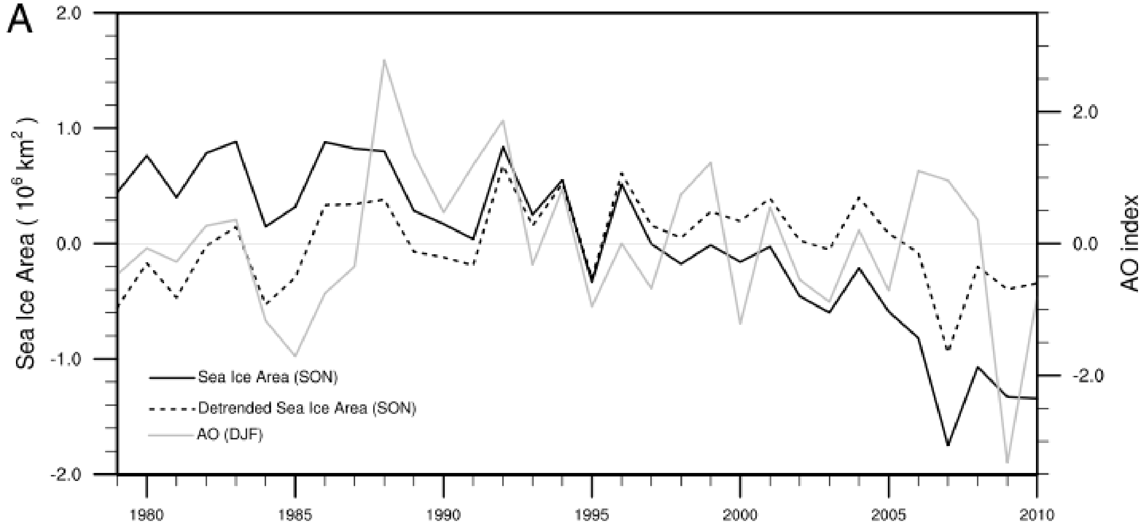


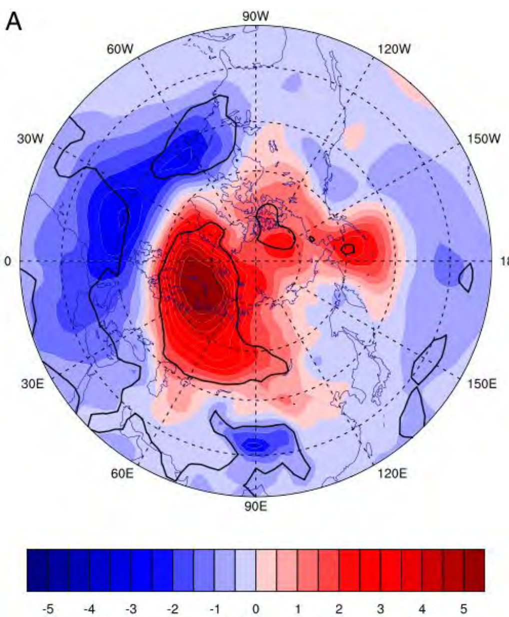
Scaife *et al*, 2011



Karpechko and Manzini, 2012

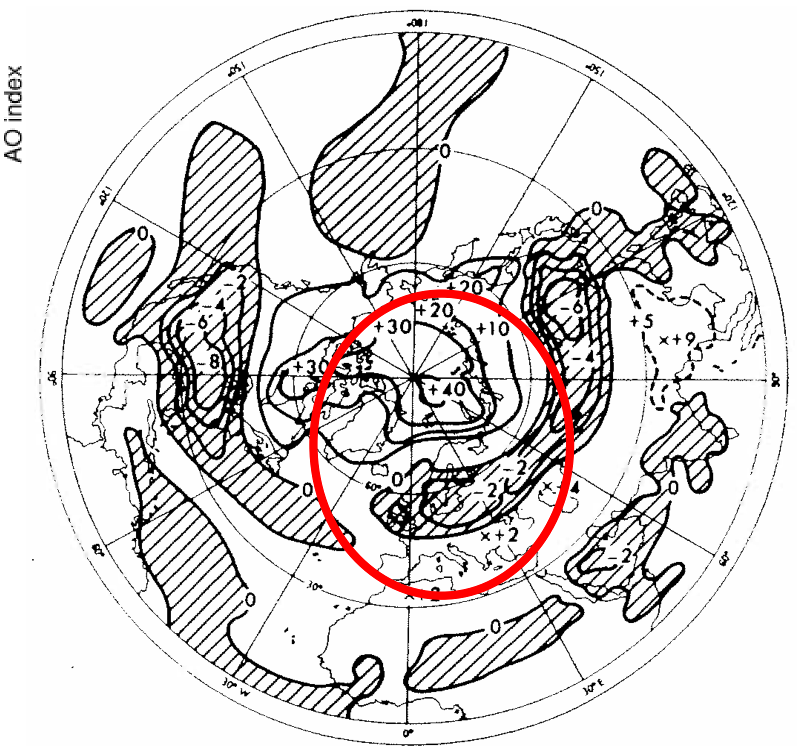
Arctic sea ice: potential impact on AO





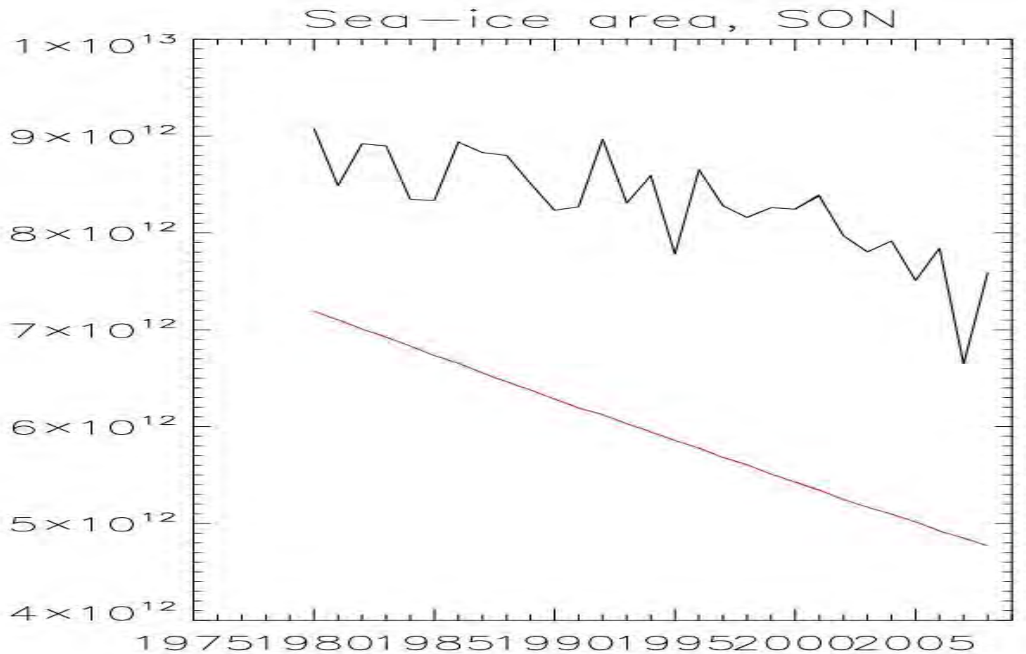
Regression of Arctic sea ice and mslp

Liu *et al*, 2012



Newson, R.L., 1973. Response of a general circulation model of the atmosphere to removal of the Arctic ice-cap. Nature, 241, 39-40.

Sea ice experiments



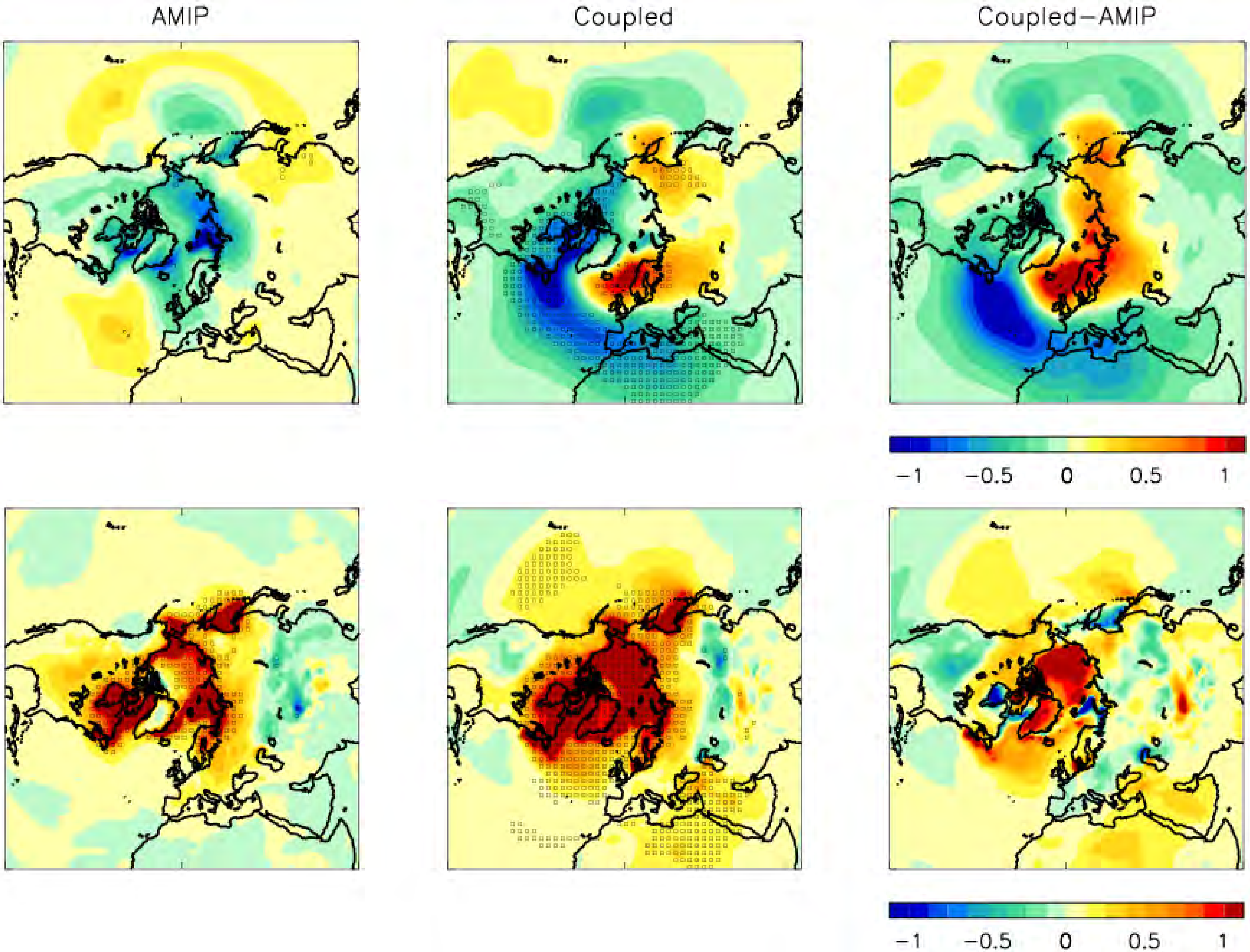
- **30 year period 1979 to 2009**
- **Control: use observed Arctic sea ice**
- **Perturbed: use reduced Arctic sea ice, obtained by projecting the 30 year trend**
- **10 ensemble members (300 simulated years)**
- **AMIP: atmosphere model forced by observed SST (set to 0°C where sea ice removed)**
- **COUPLED: fully coupled model, constrained by observed temperature and salinity below 200m**

(Smith et al. in prep)

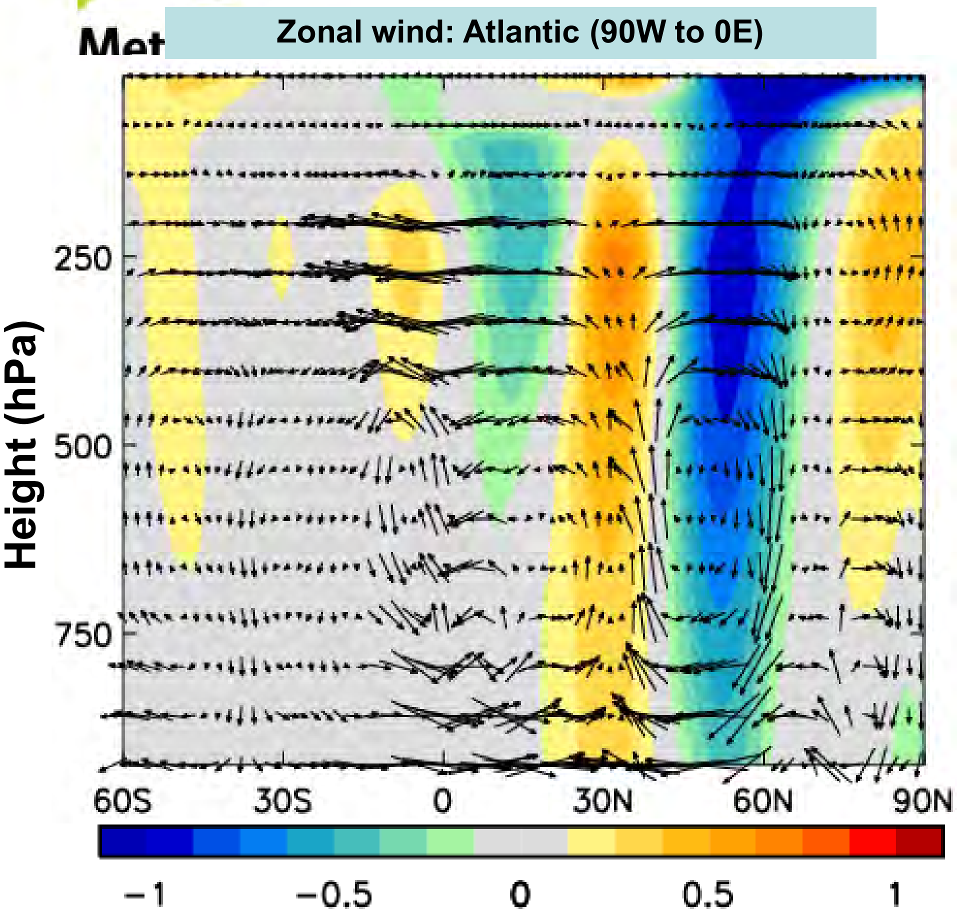
DJF: low ice minus control

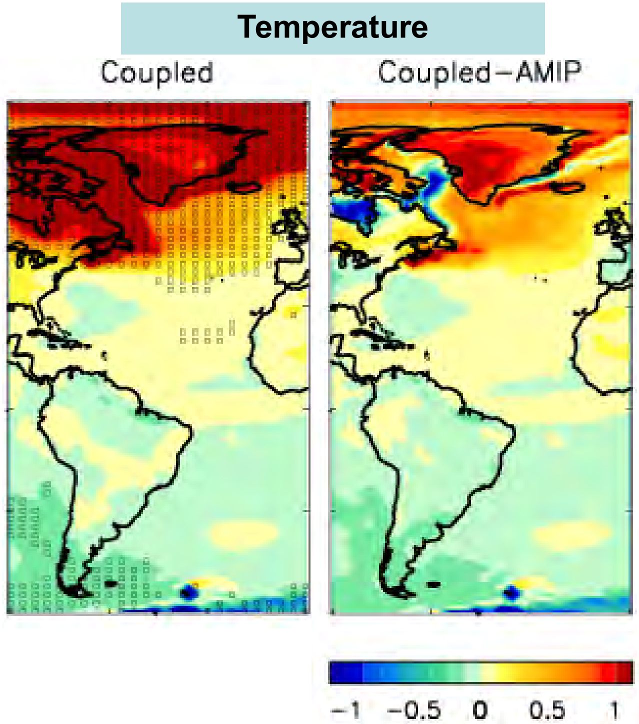
Pressure

Temperature



DJF





- **Weakening of westerly jet (only in coupled simulations)**
- **Anomalous Ferrel circulation**
- **Negative NAO**

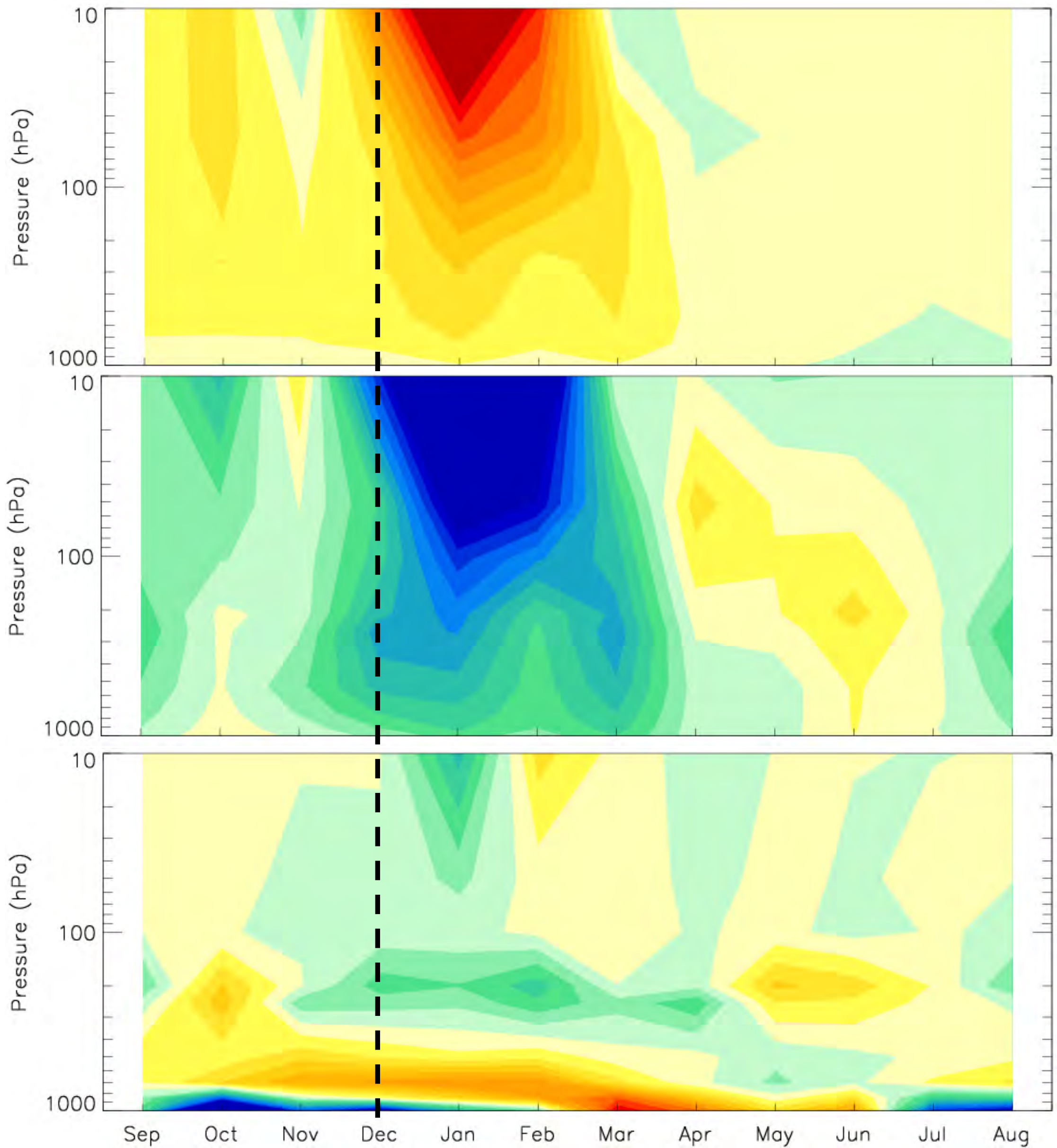
$$u_t = v^*(f - u_y) + w^* u_z + \nabla \cdot \vec{F} + X$$

zonal wind change	meridional advection	vertical advection	EP flux divergence	gravity waves

Arctic geopotential height 60N to 90N

Zonal wind at 60N

EP flux divergence at 60N

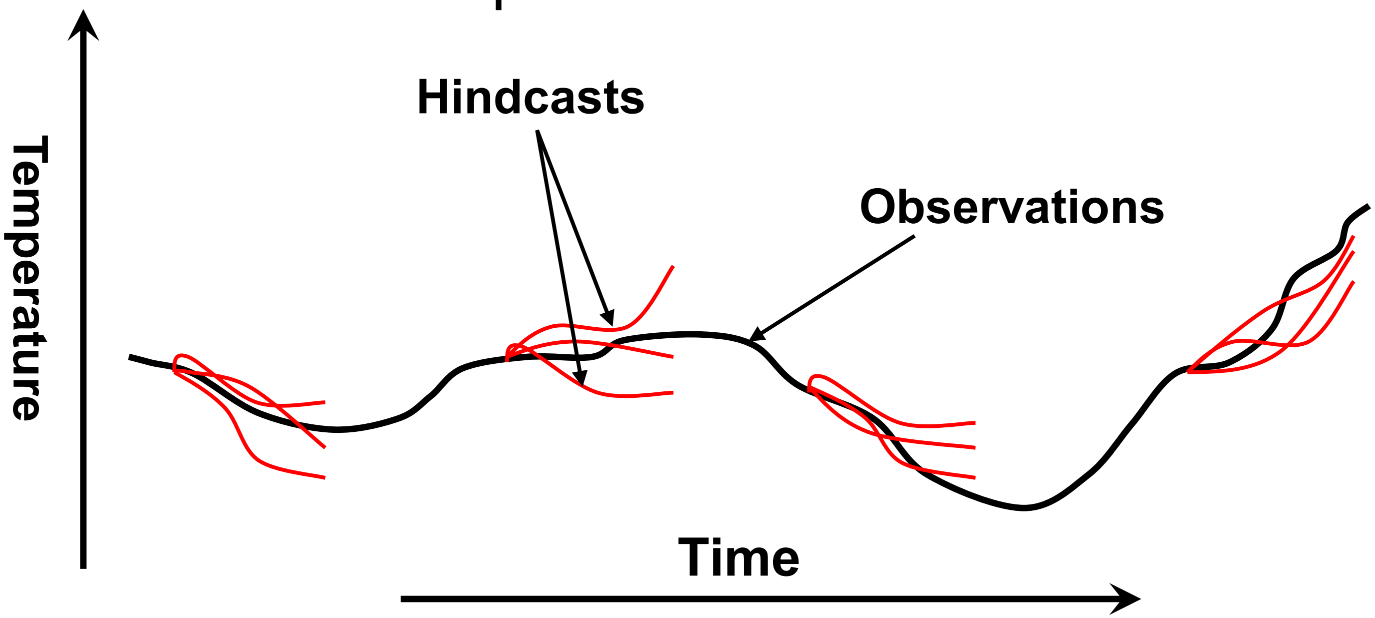


Contents

Hindcasts to assess skill

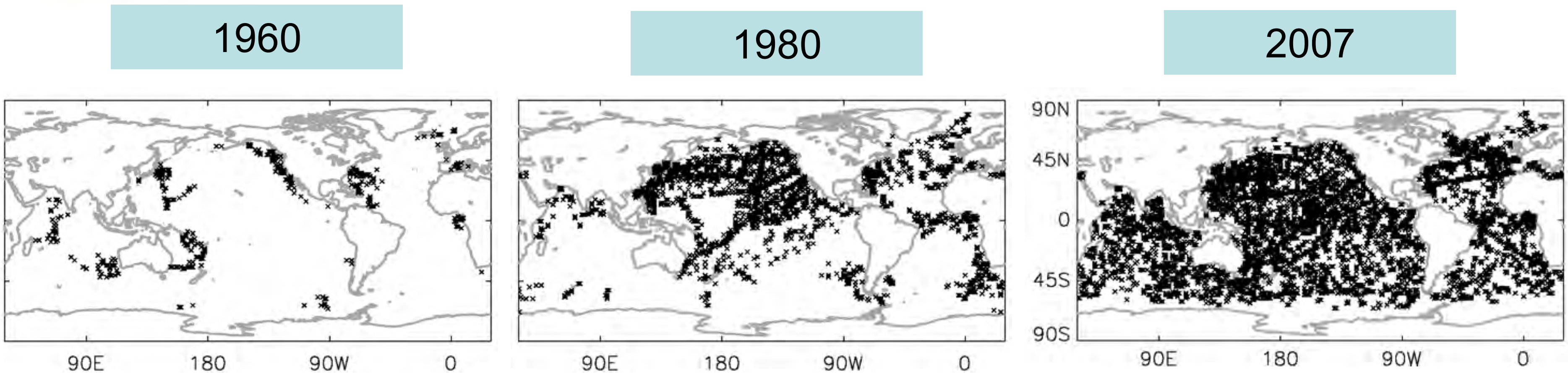
Ensembles to sample uncertainties:
• Uncertainties in the initial conditions
• Model errors

An optimistic view:



Perform historical tests ("retrospective forecasts" or "hindcasts" to assess likely skill and correct biases

Sub-surface ocean observations

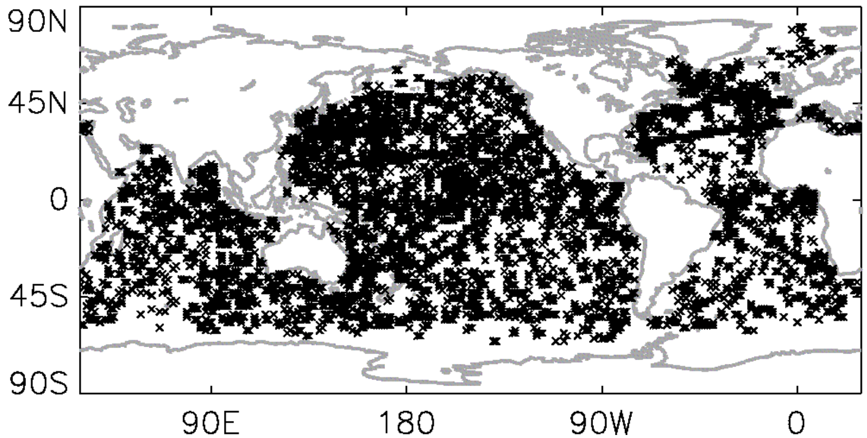


- Need historical tests to assess likely skill of forecasts
- Far fewer sub-surface ocean observations in the past

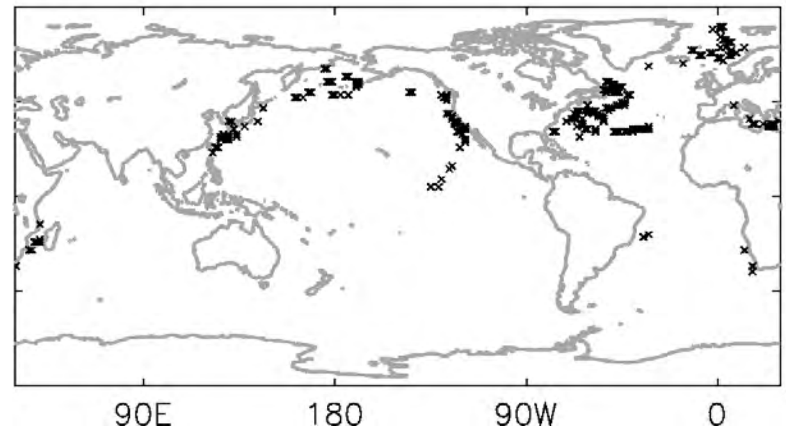
Met Office
Hadley Centre

Temperature at 300m : June 2007 from 1960 observations

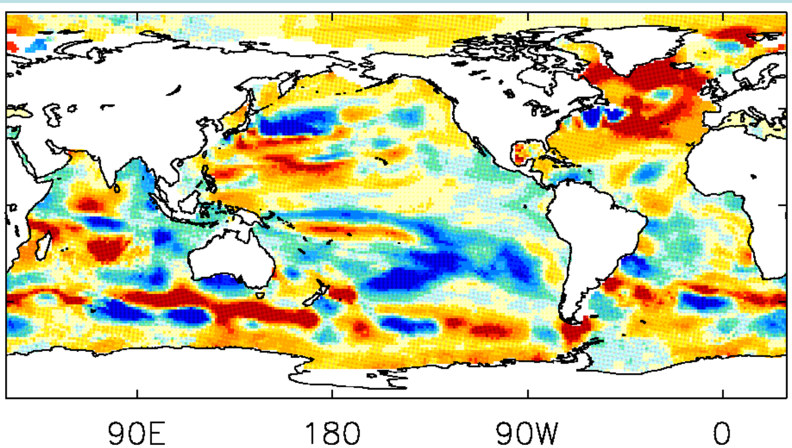
June 2007 obs

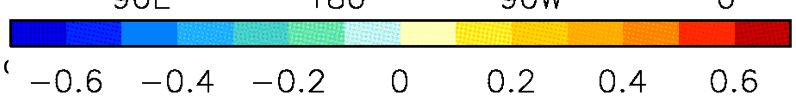


June 1960 obs

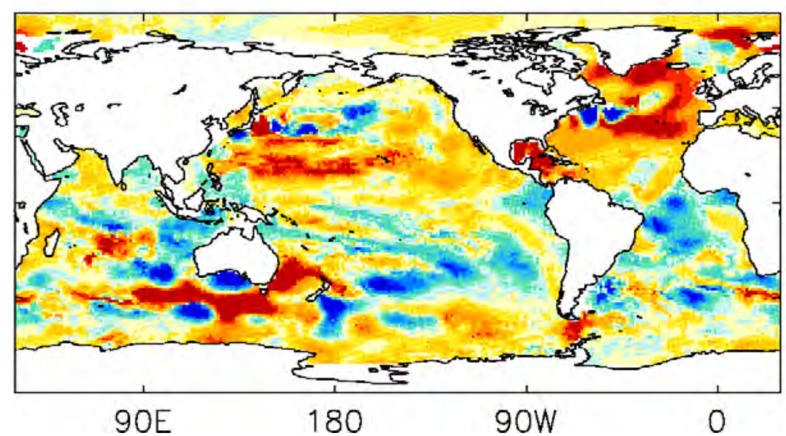


Analysis using all obs

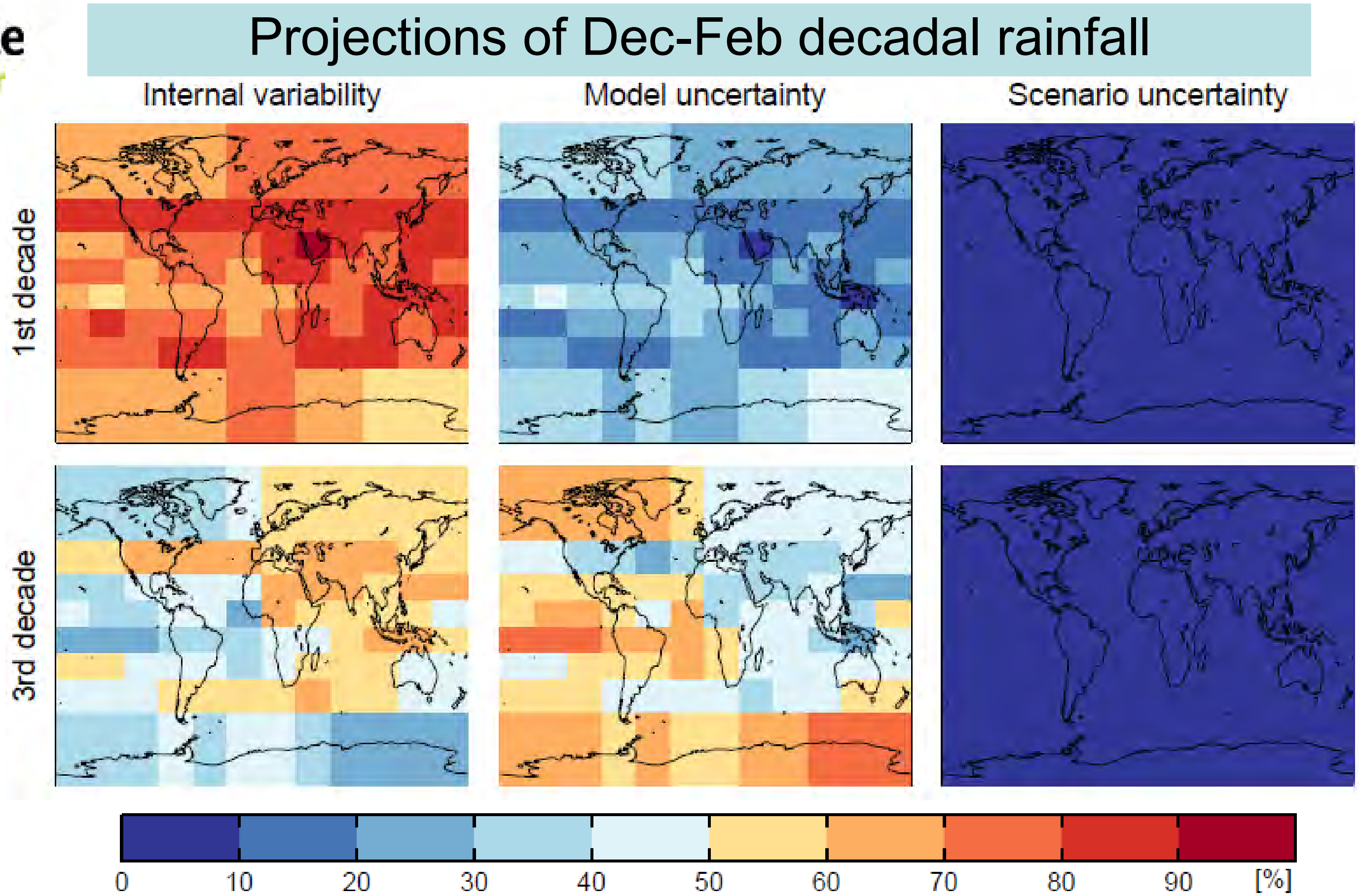




Analysis using sub-sampled (1960) obs



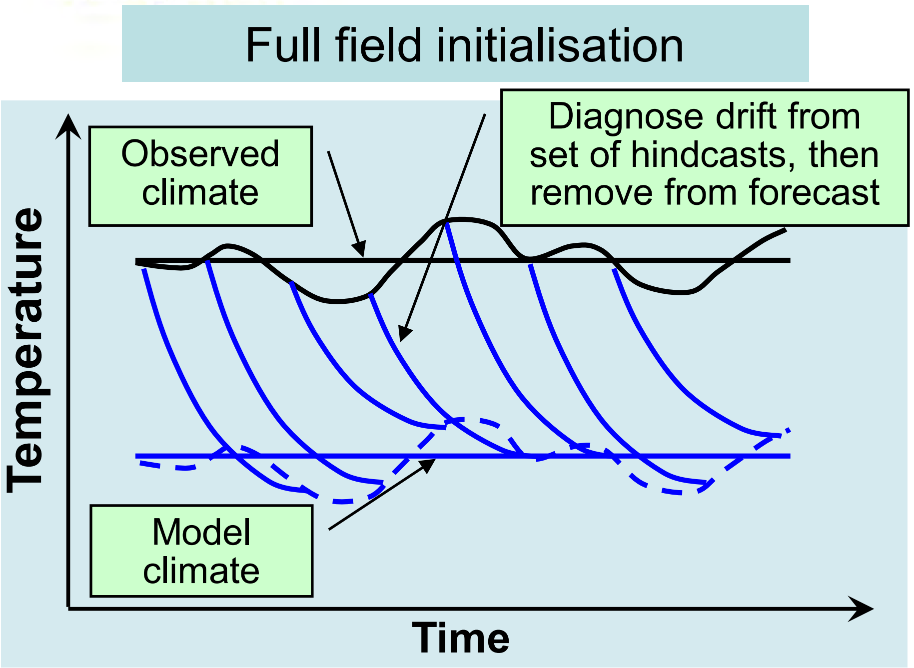
Uncertainties

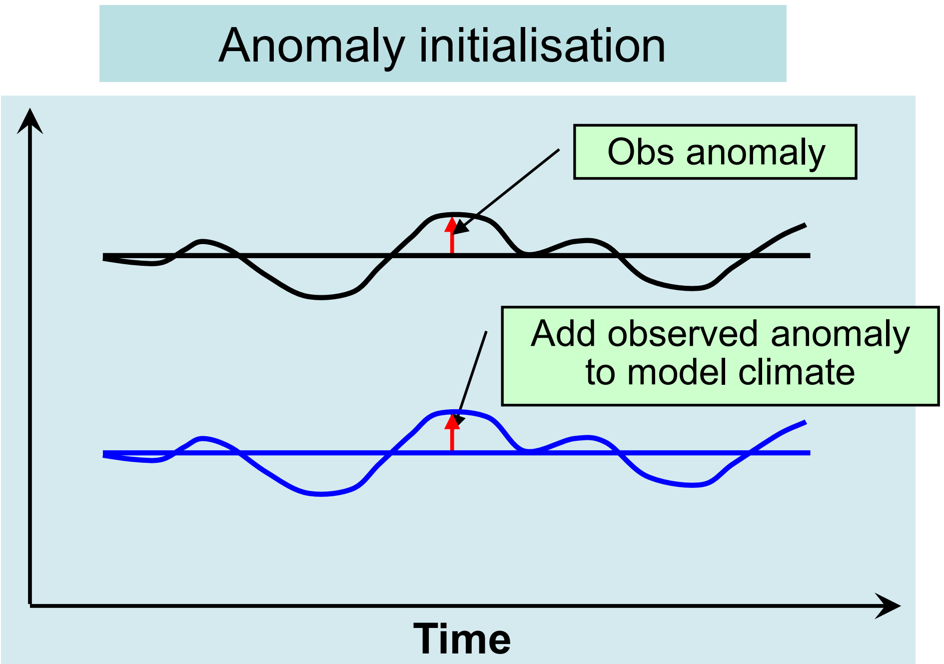


- Large uncertainties in model response to external forcing
- Need multi-model ensembles
- and to understand physical mechanisms

(Hawkins and Sutton, 2011)

Models are imperfect: Dealing with model bias

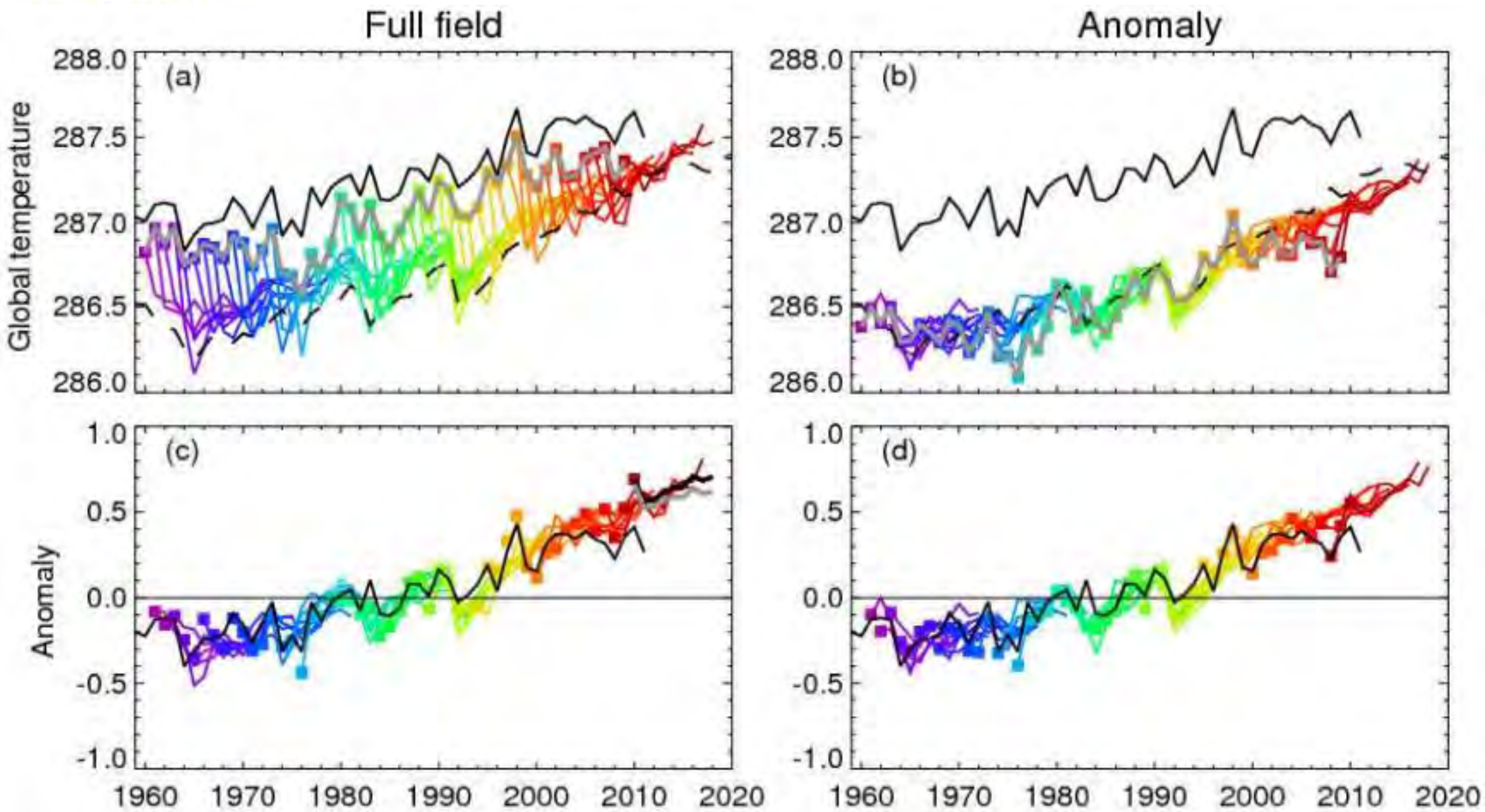




- Routinely used in seasonal forecasting
- Ideally need large hindcast set, sampling multiple phases of variability
- Non-linearity?

- Needs model to be spun-up, together with simulation of recent period
- Observed anomalies could be in wrong location relative to model features
- Non-linearity?

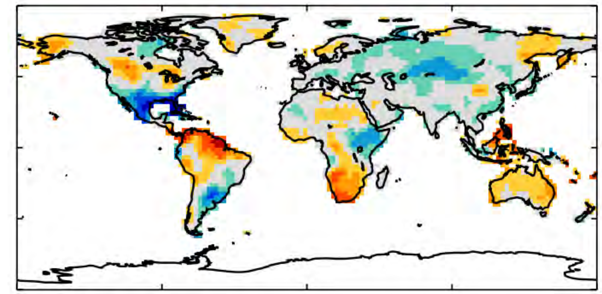
Correcting the bias/drift



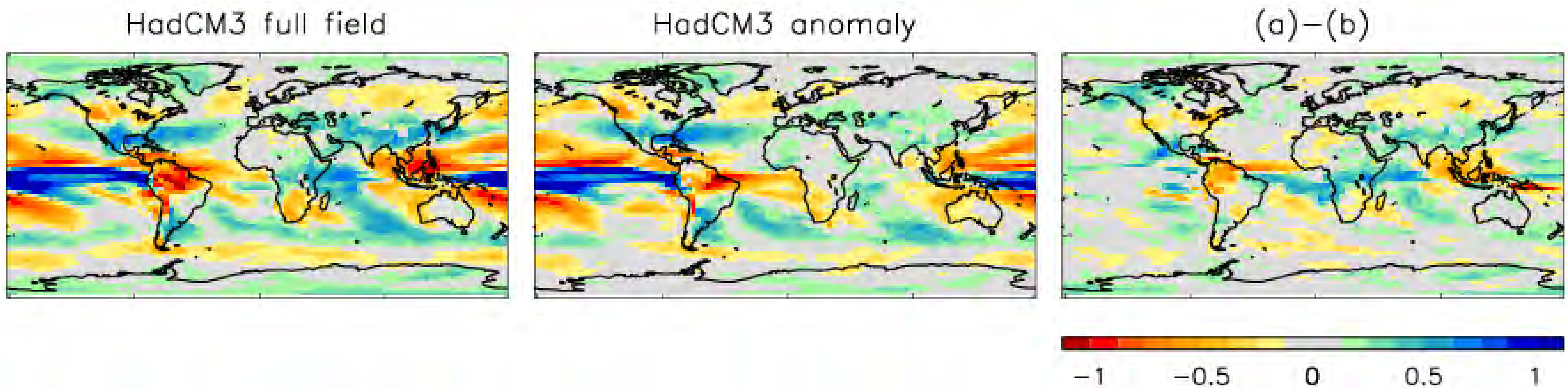
(Smith et al. 2013)

DJF precip
(months 2-4)

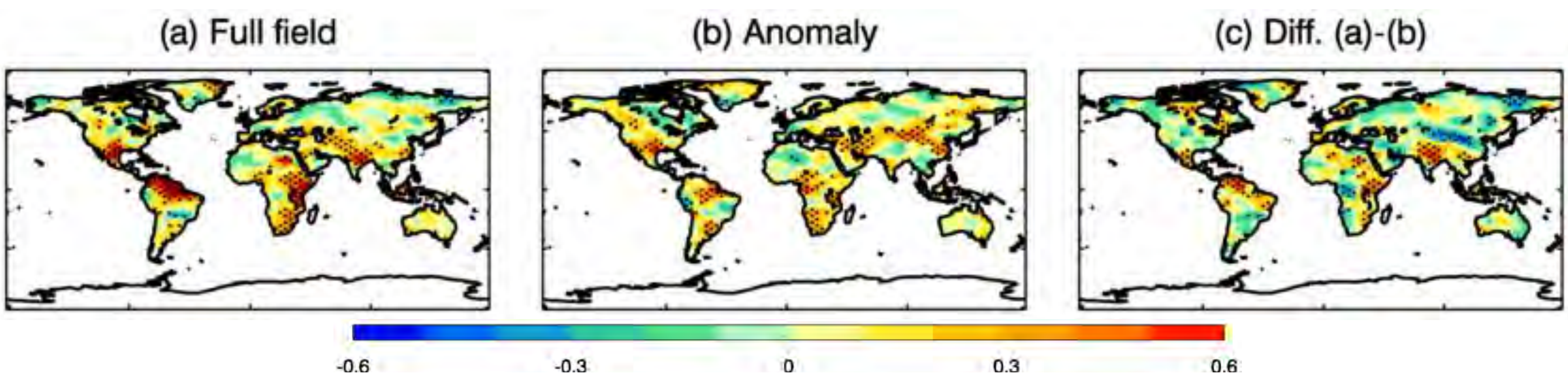
Observed Nino composite



Model composites



Hindcast skill

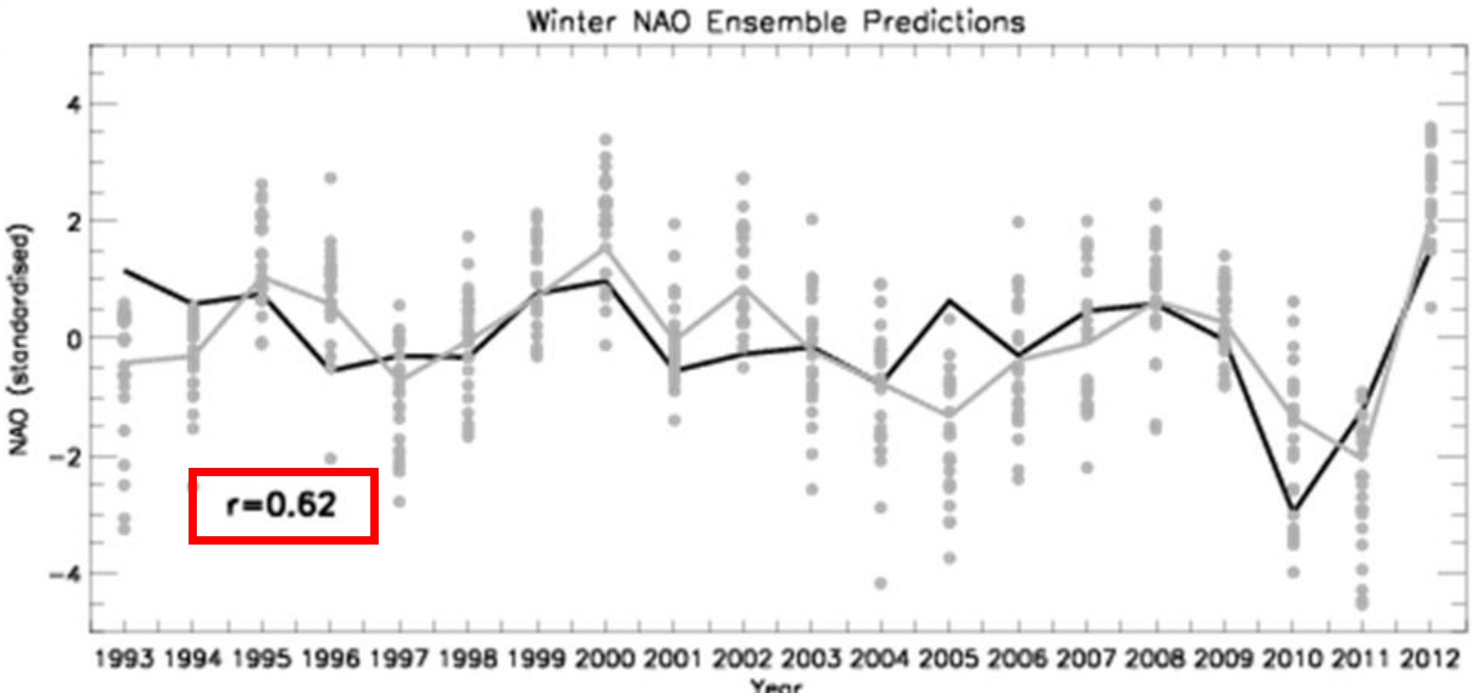


(Smith et al. 2013)

Contents

Seasonal predictability of the NAO

Retrospective winter forecasts



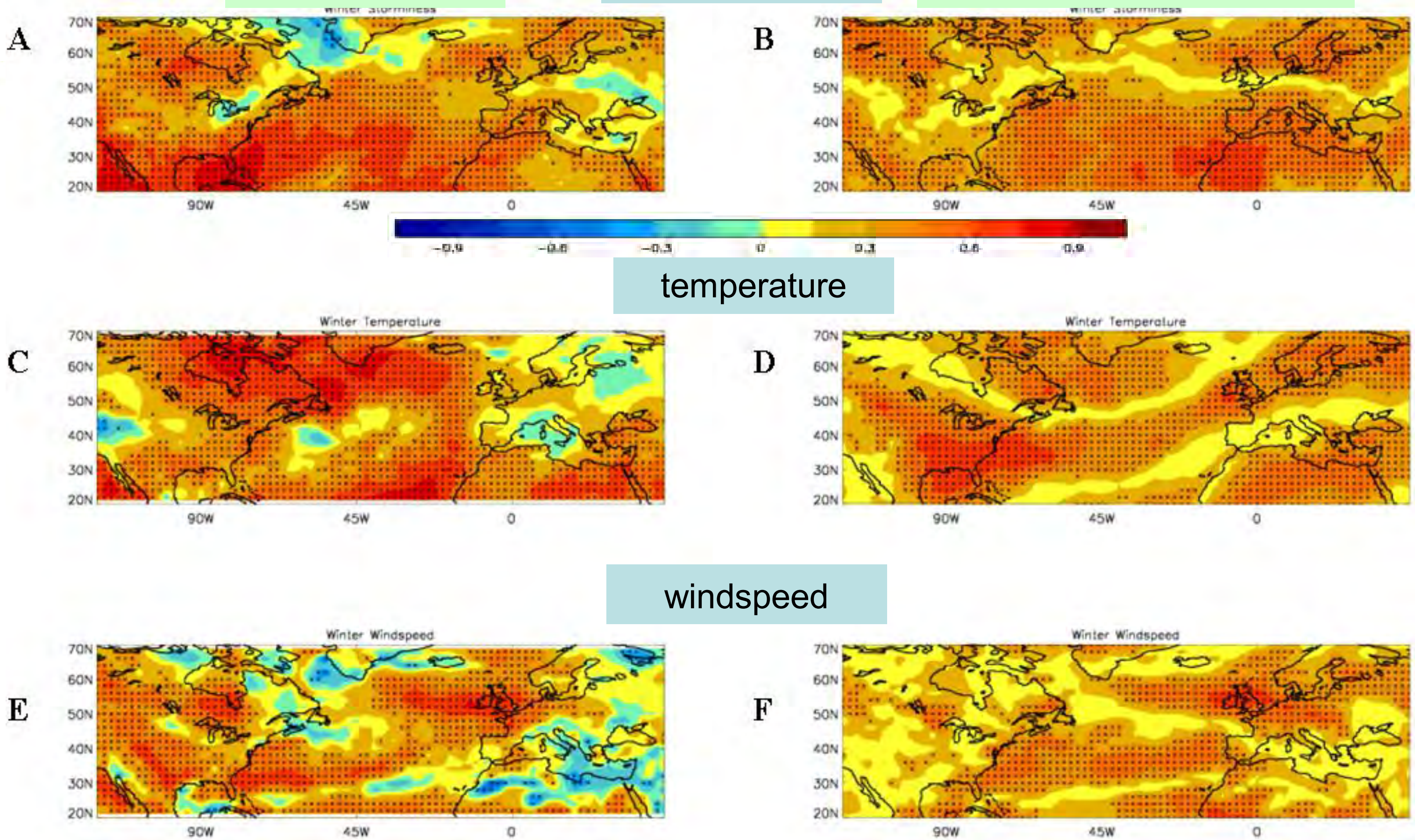
NAO skill r~0.6 (c.f. ECMWF 0.16, NCEP 0.25: not stat. sig.)

Significant at the 98% level

(Scaife et al. submitted)

Surface weather forecast skill

Raw model | storminess | From NAO forecast



- Skill for predicting impacts ⇒ storms, temperatures, winds
- Higher skill over Europe if inferred from forecast NAO
  - ➢ model NAO teleconnections not perfect?

Scaife et al, submitted

Met Office
Hadley Centre

NAO sources of skill

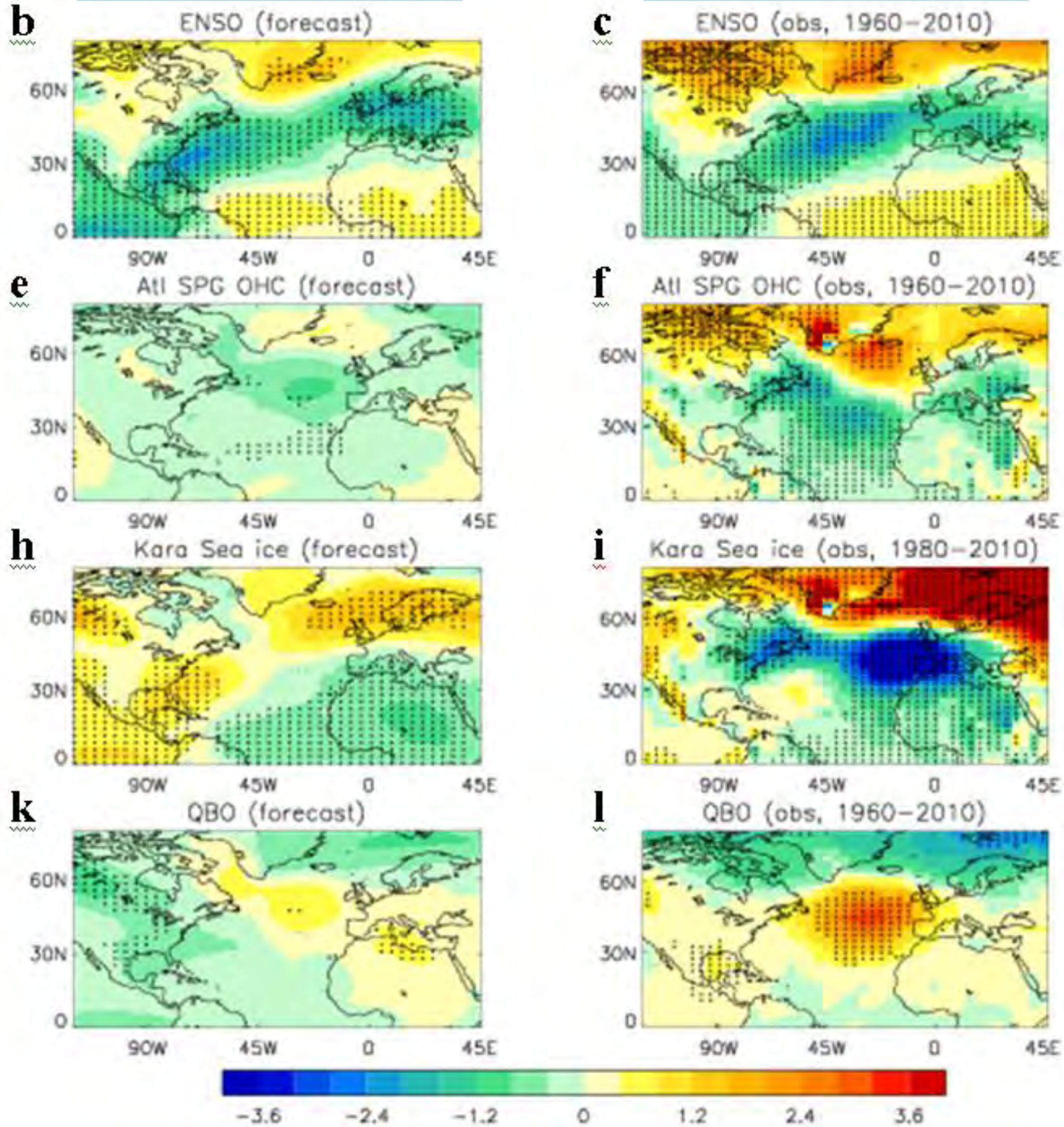
Model | Observations

ENSO

Atlantic SST

Kara sea ice

QBO

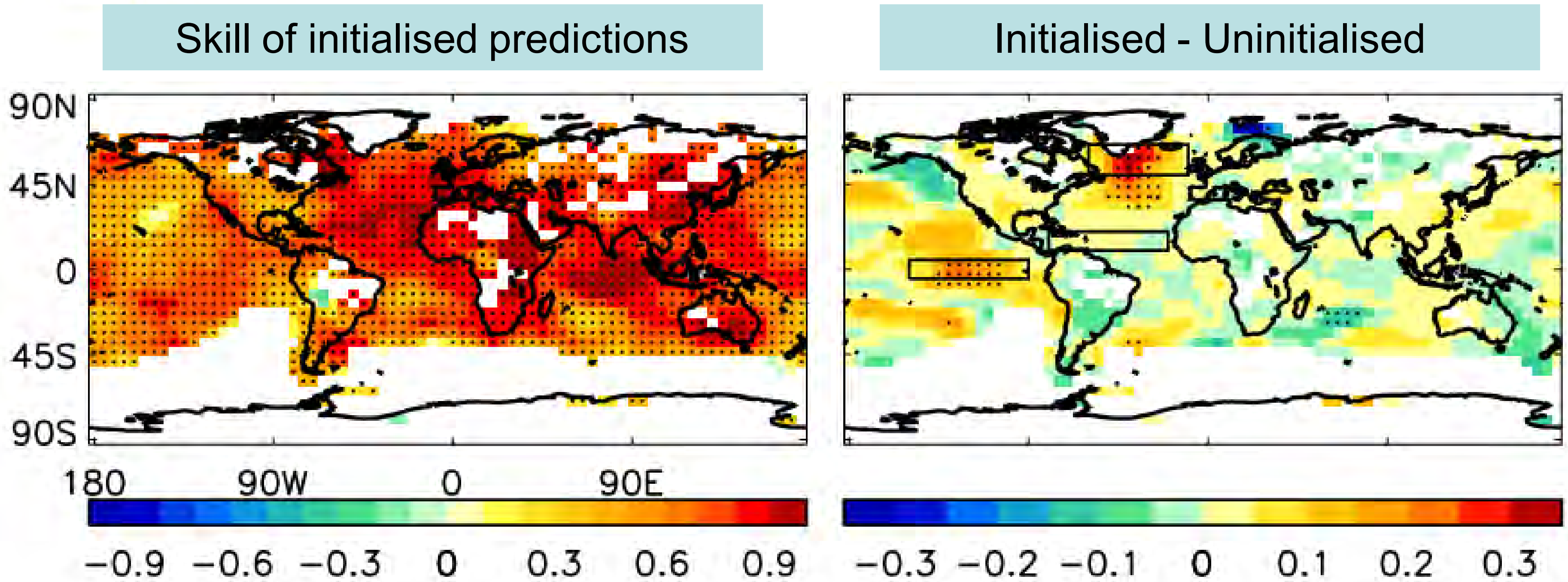


(Scaife et al. submitted)

Contents

- Potential sources of skill
- Practical issues
- Seasonal forecasts of the NAO
- Decadal forecasts
- Future issues

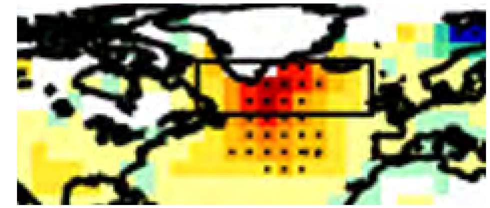
Surface temperature predictions (five year means)



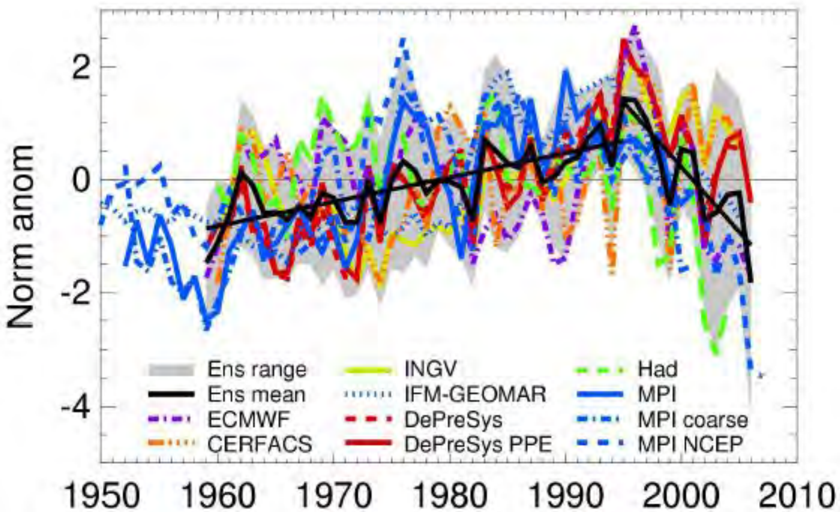
- Skilful almost everywhere (positive correlations)
- Mostly due to external forcing
- Initialisation gives improved skill mainly in North Atlantic and tropical Pacific

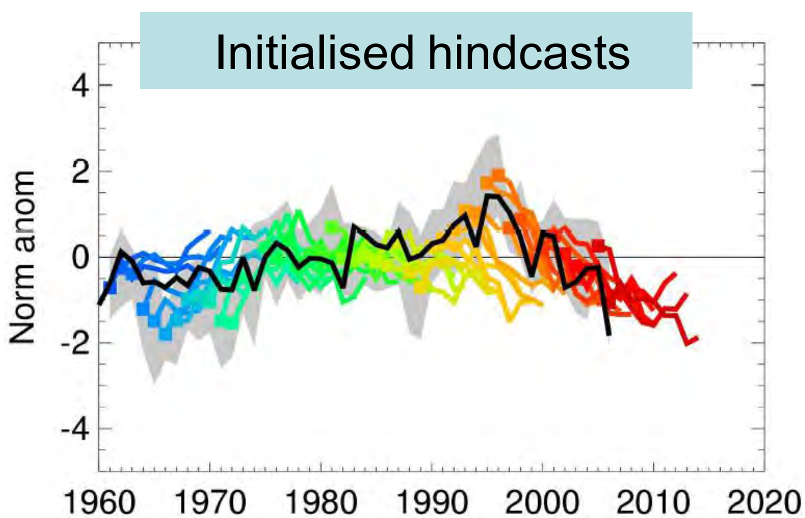
(Smith et al. 2010)

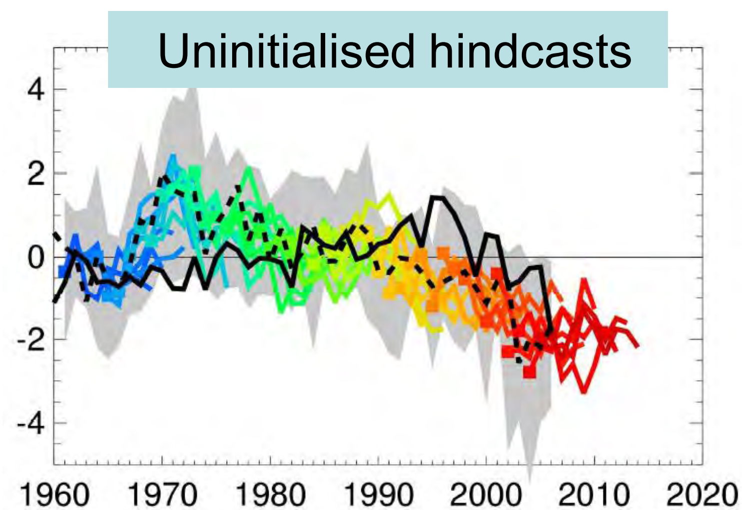
Physical basis for improved skill



- No historical observations – must rely on models
- Consistent signal: increase from 1960 to 1995, decrease thereafter
- Agrees with related observations
- Some skill in initialised predictions, but not in uninitialised predictions







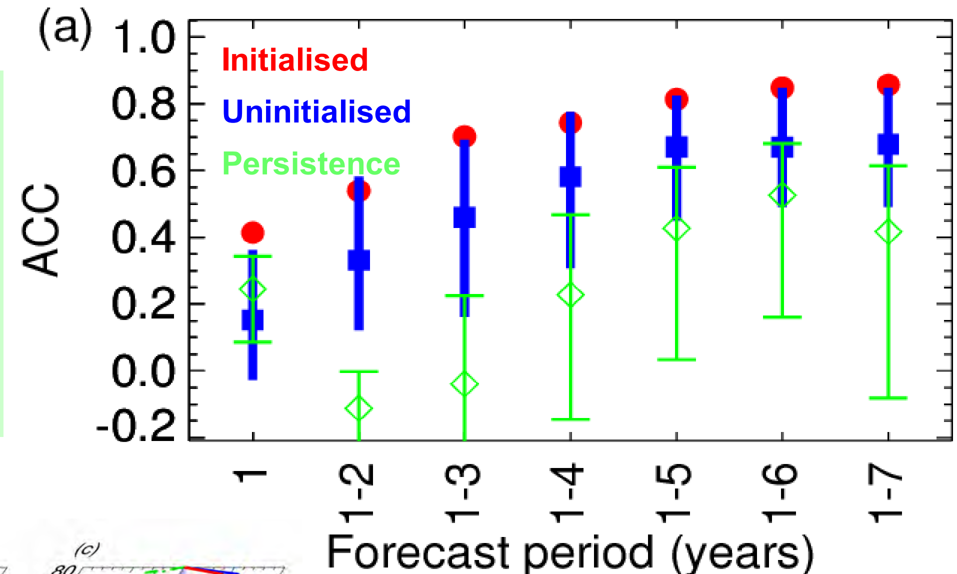
(Pohlmann et al. 2013)

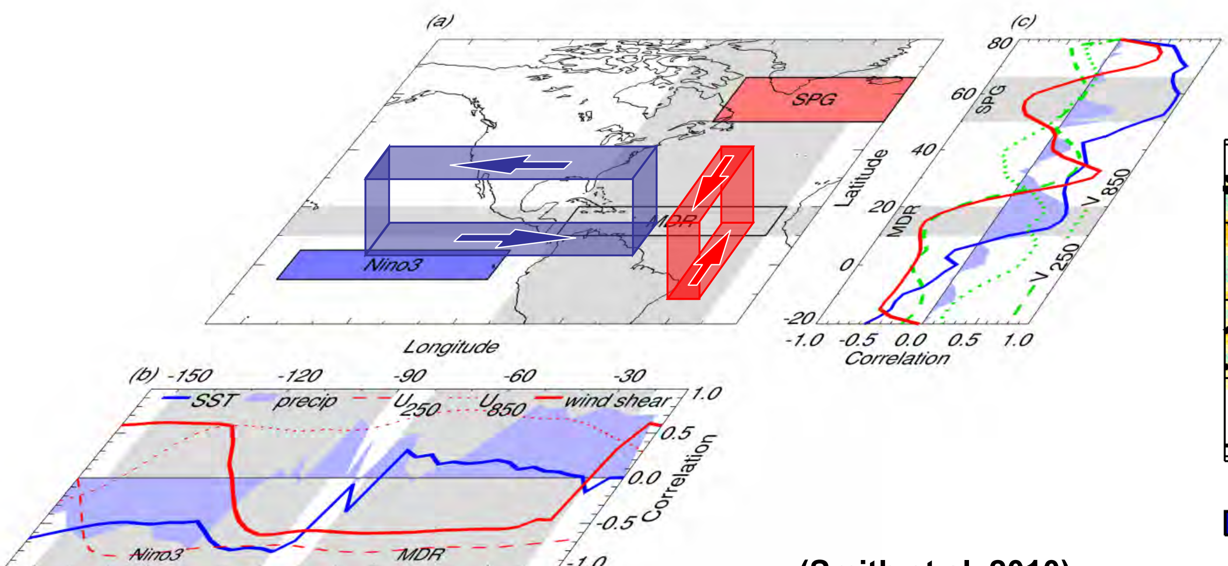
Met Office
Hadley Centre

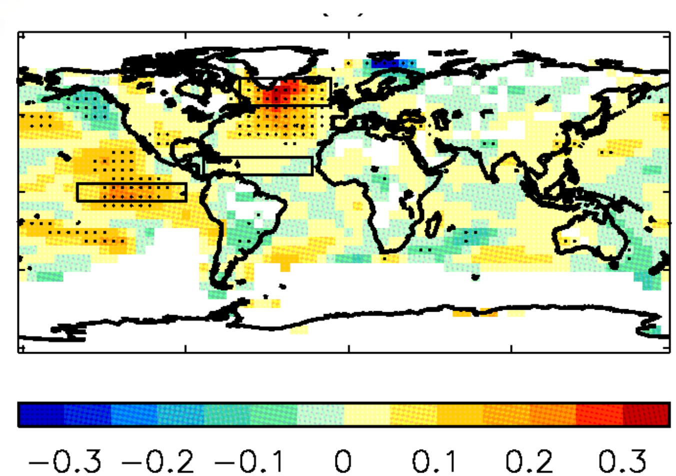
Atlantic tropical storm predictions

Met Office
Hadley Centre

- Skill from both initialisation and external forcings
- Improved through initialisation
- Consistent with remote influences from improved SST predictions

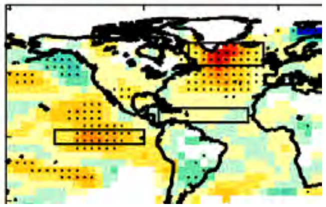


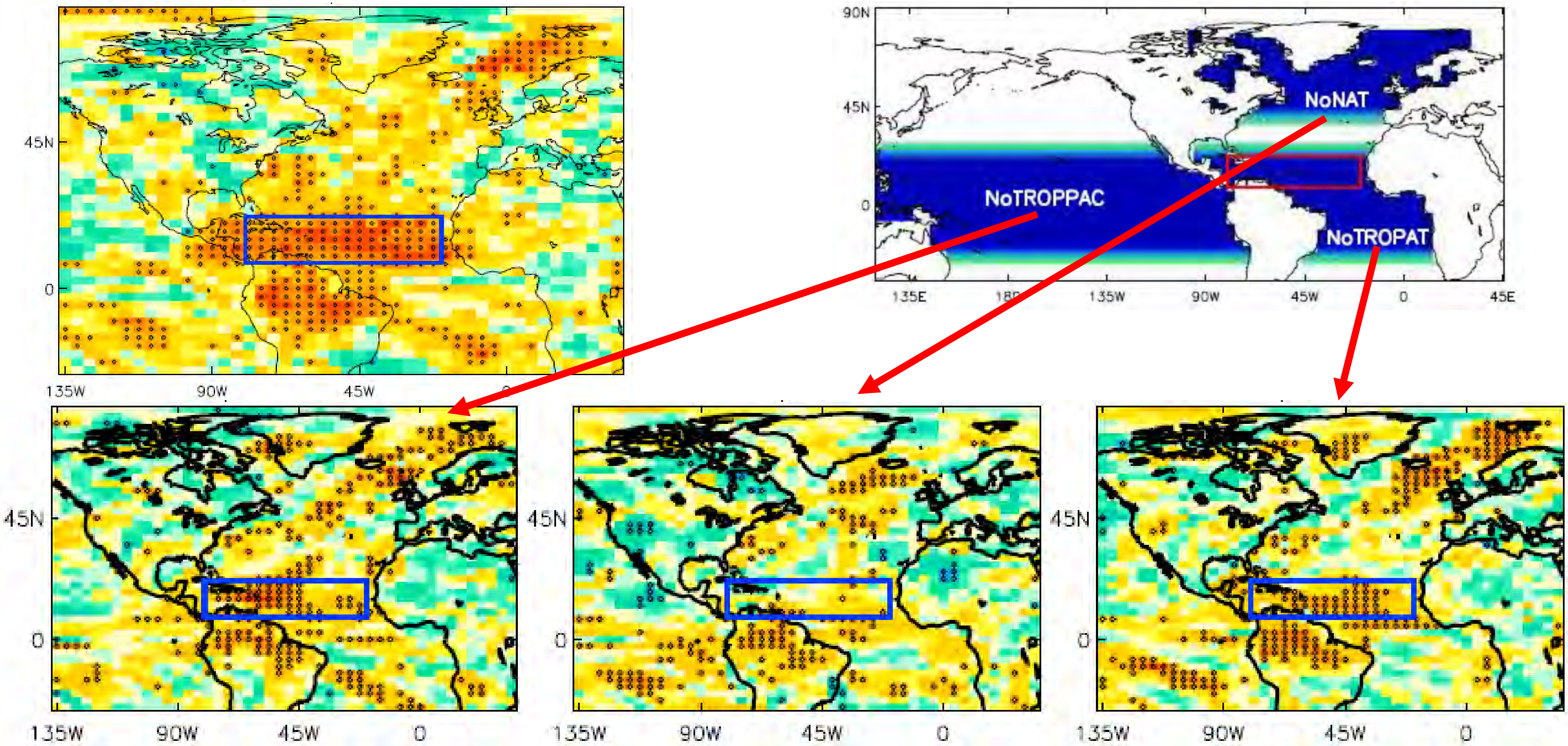




(Smith et al. 2010)

Remote influences on tropical Atlantic atmosphere





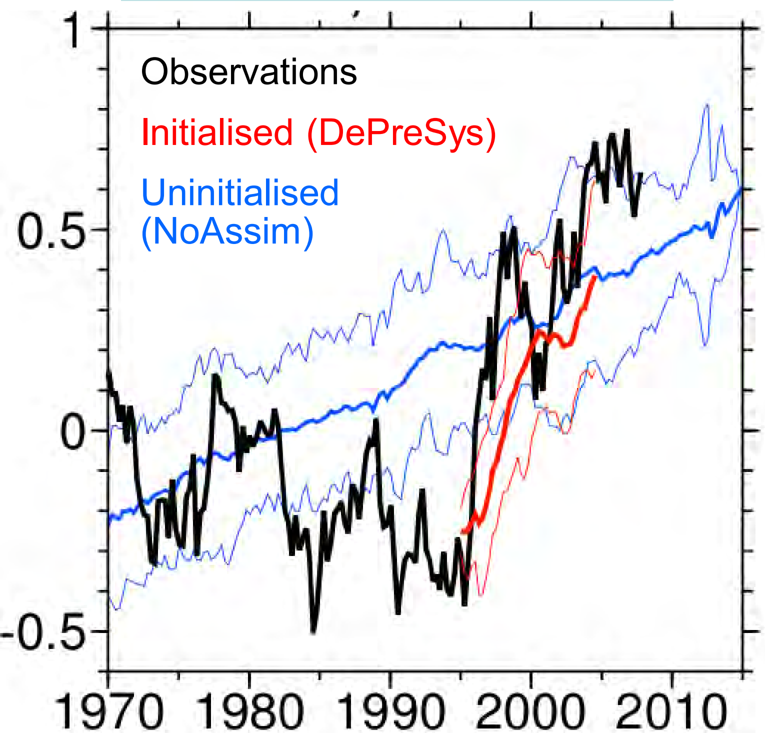
- Idealised predictions of rainfall 2 – 5 years ahead
- Tropical Atlantic atmosphere is relatively predictable
- Skill originates from sub-polar North Atlantic

Dunstone et al, 2011

North Atlantic sub-polar gyre (SPG)

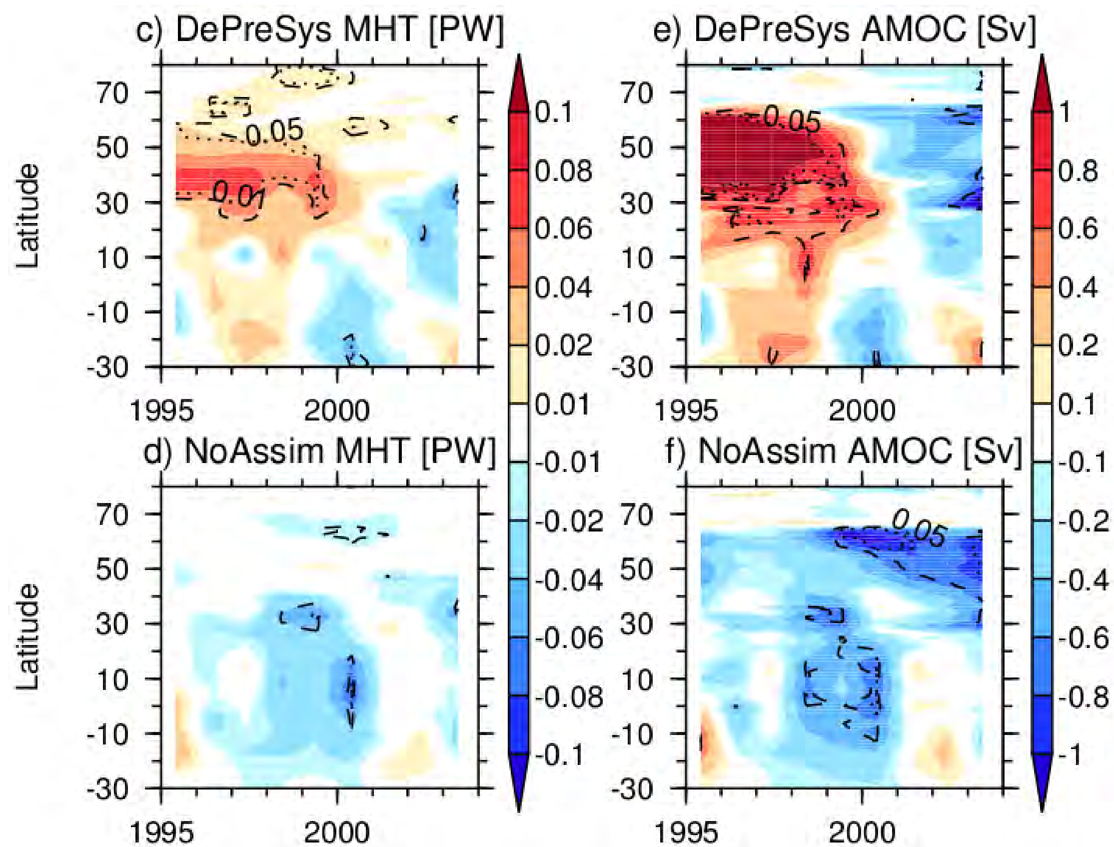
Met Office
Hadley Centre

SPG 500m temp



Meridional heat transport

Overturning circulation



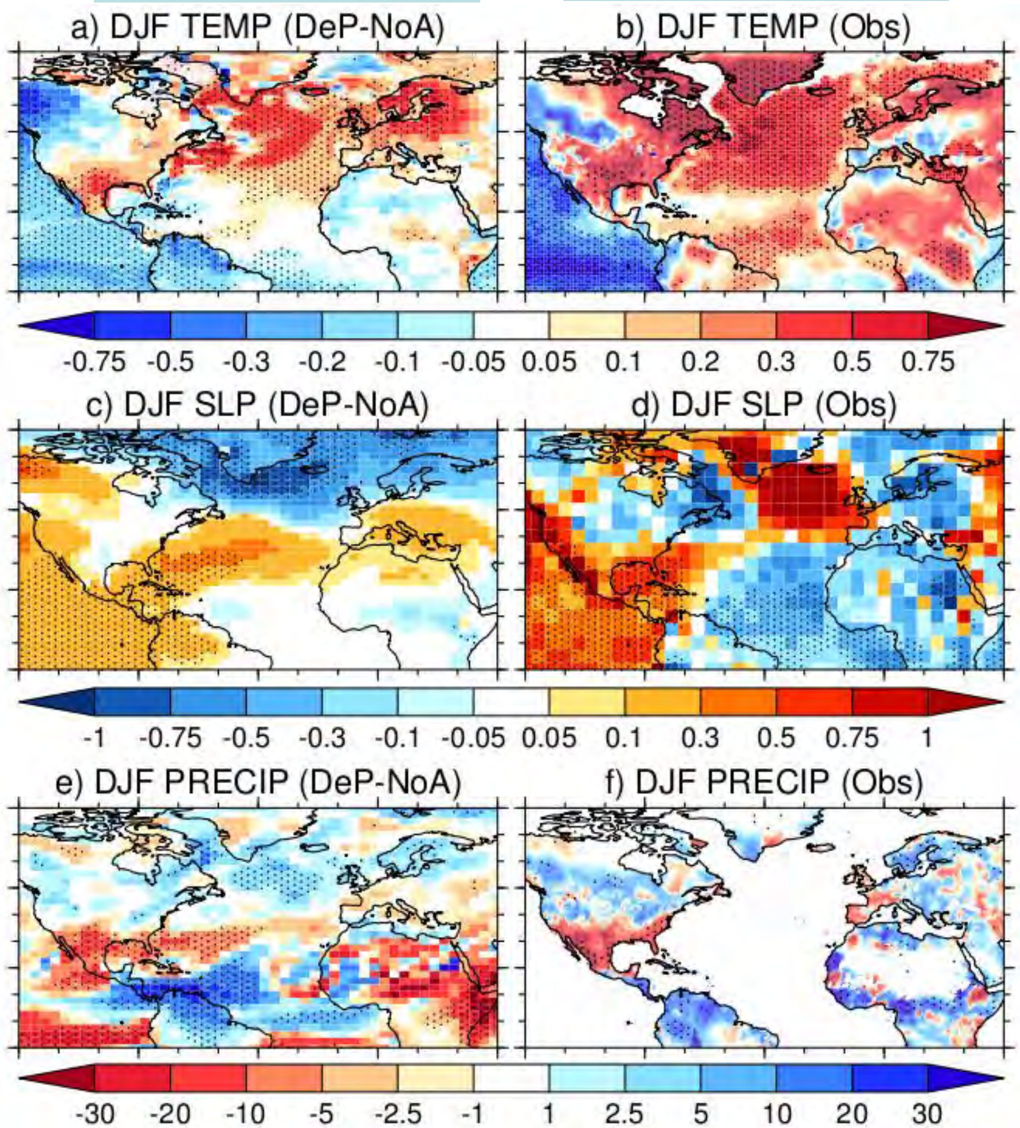
• Improved skill for 1995 rapid warming results from initialisation of increased Atlantic overturning circulation and meridional heat transport

(Robson et al. 2012, also Yeager et al. 2012)

Impacts of 1995 SPG warming

Model

Observations



Temperature

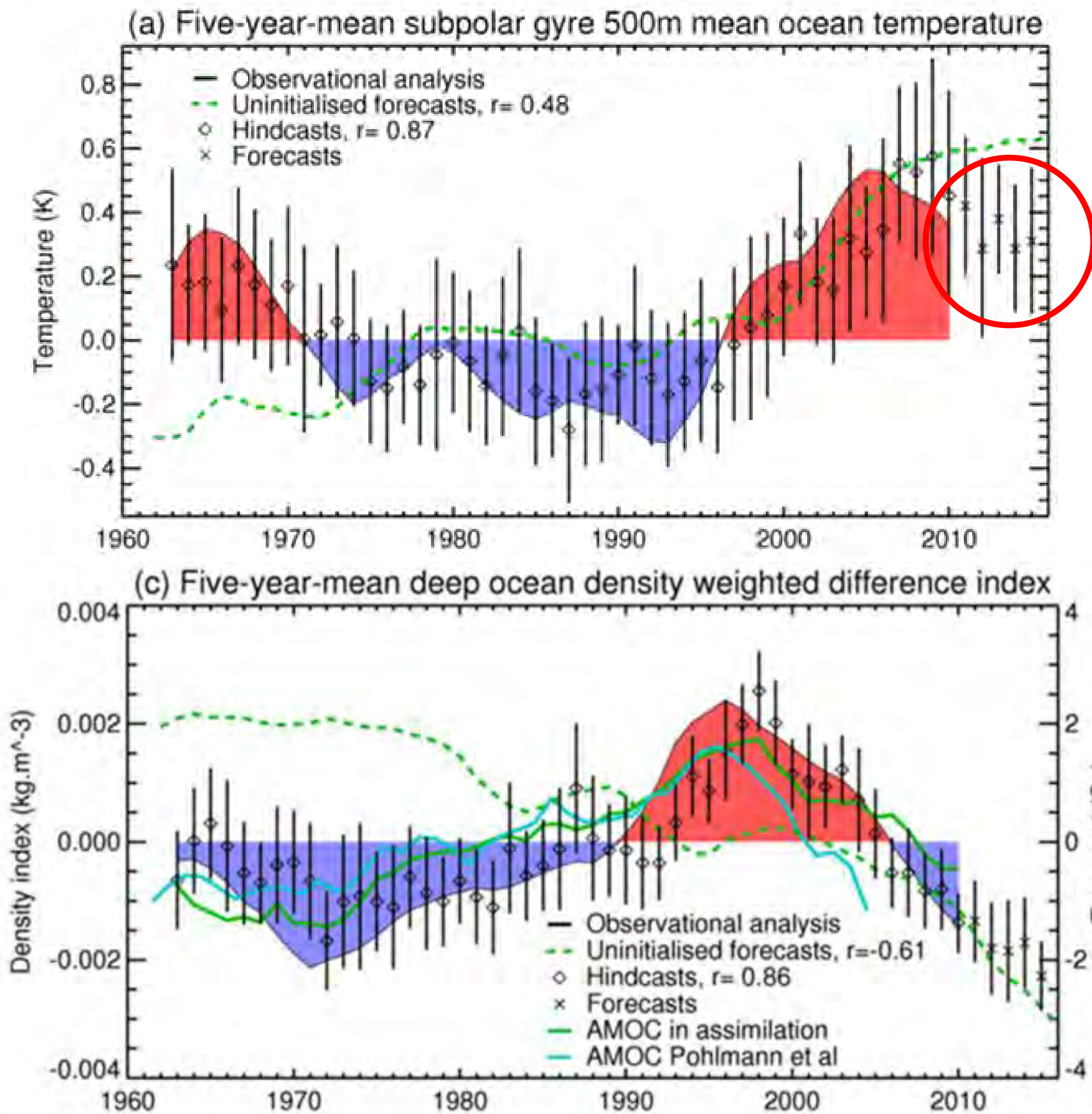
Pressure

Precipitation

(Robson et al. 2013)

Predicted cooling of SPG

- SPG predicted to cool…
- …in response to weakening of Atlantic overturning
- Likely to cause climate impacts around the Atlantic basin
    - ➢ wetter winters and dryer summers in Europe?
    - ➢ fewer hurricanes?
    - ➢ less Sahel rainfall?
- Need improved models to further assess these impacts

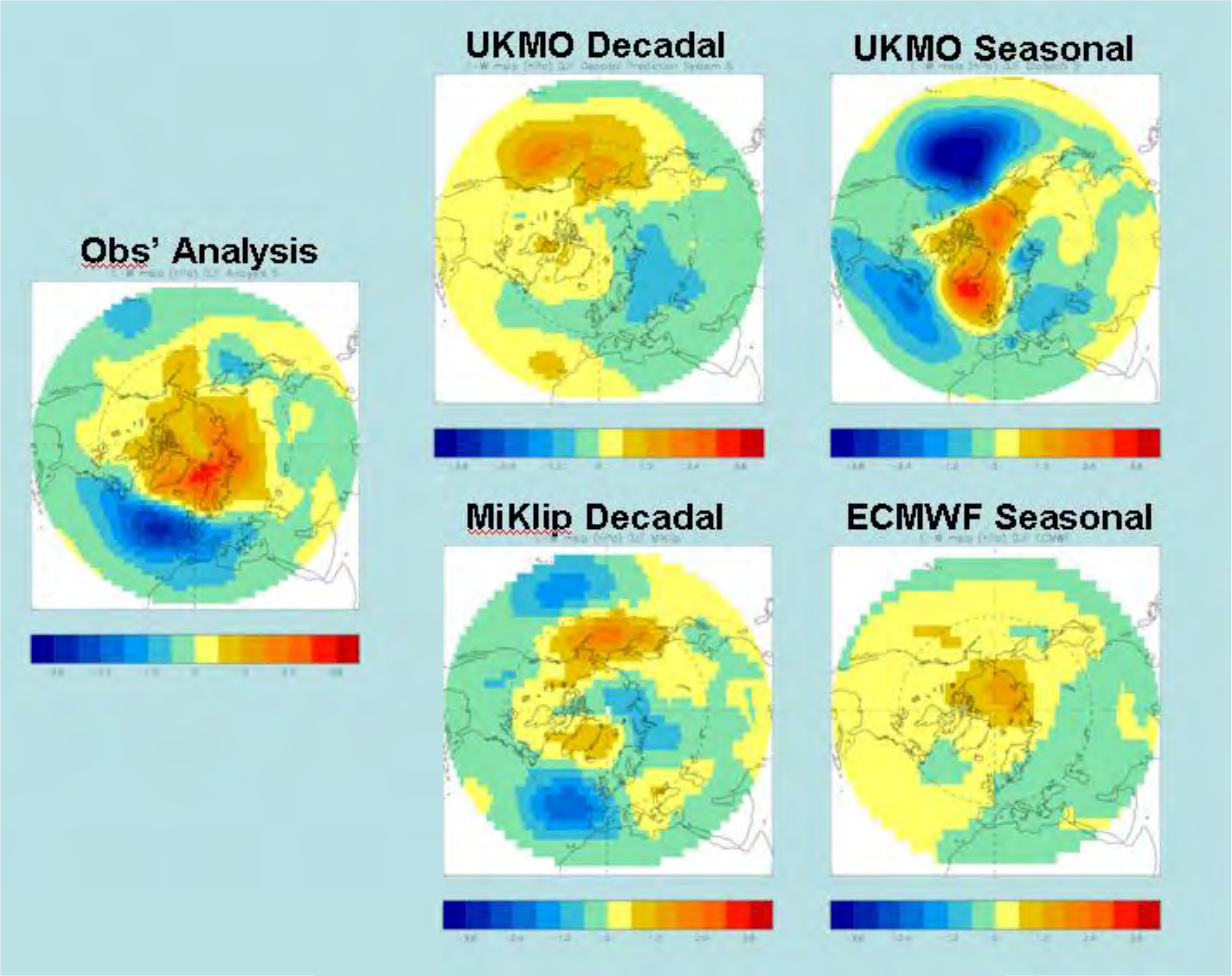


(Hermanson *et al*, submitted)

Contents

- Potential sources of skill
- Practical issues
- Seasonal forecasts of the NAO
- Decadal forecasts
- Future issues

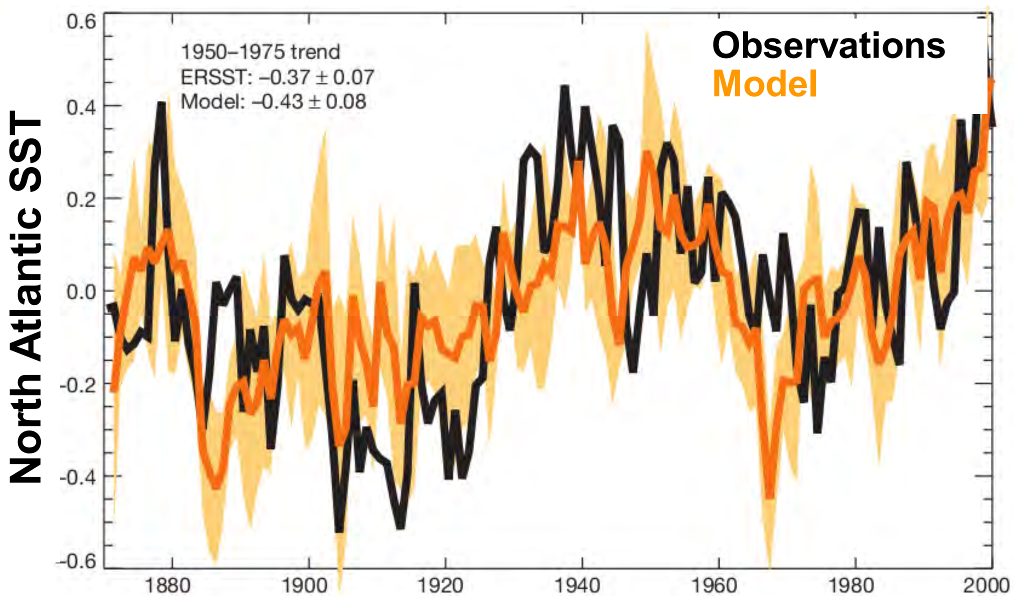
QBO teleconnection



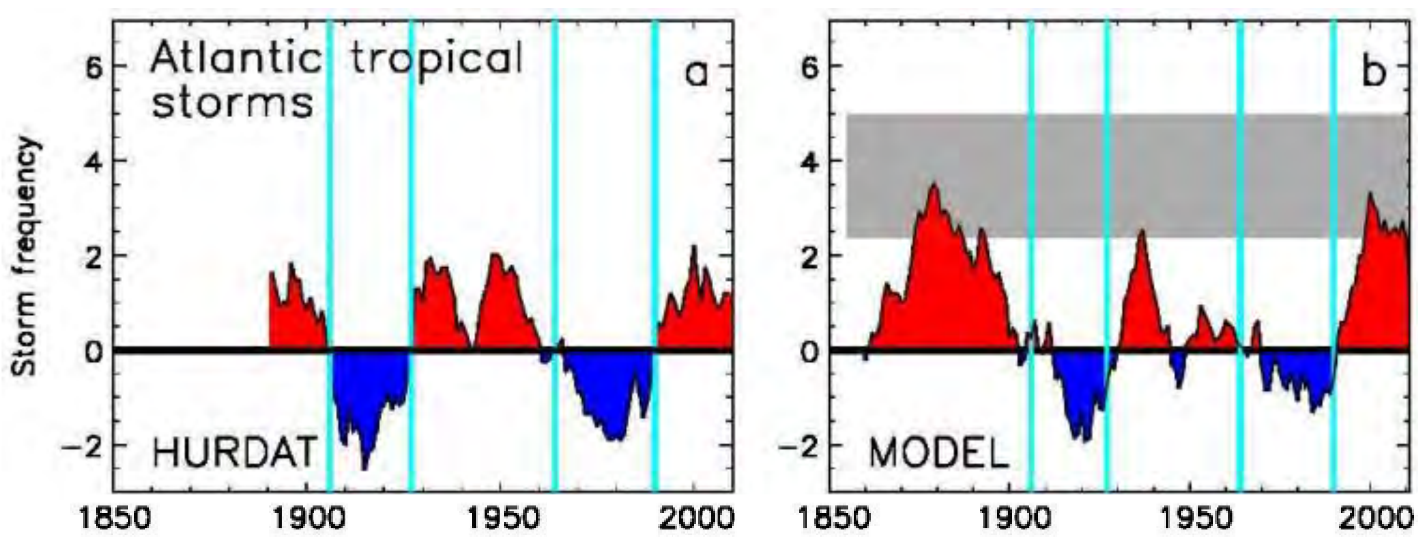
Scaife *et al*, submitted

See poster by Adam Scaife et al

Potential role of aerosols…

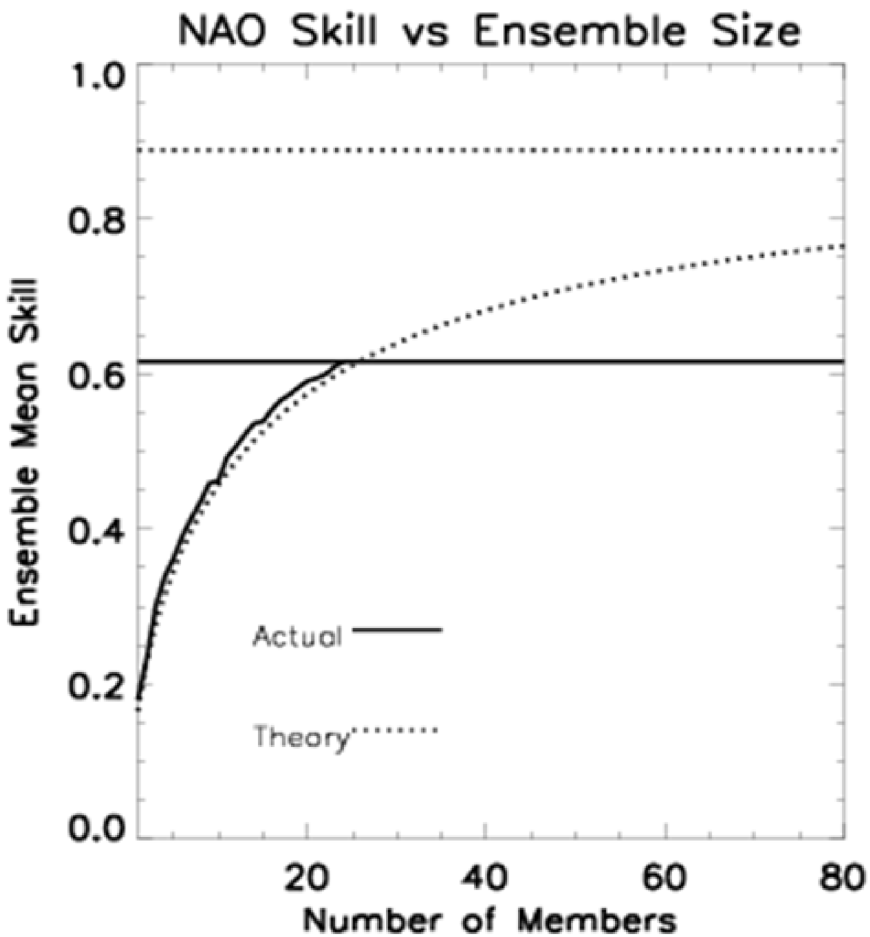


Booth et al., 2012



Dunstone et al., 2013

Effect of ensemble size on NAO skill

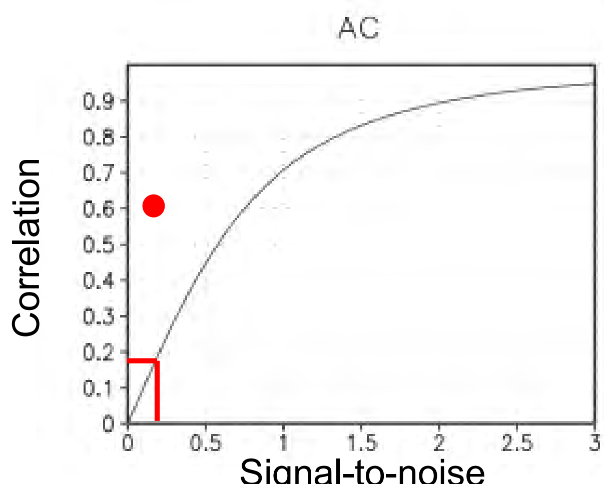


Increasing ensemble size increases correlation

Signal to noise is small ~0.2

Mismatch between correlation and signal-to-noise ratio

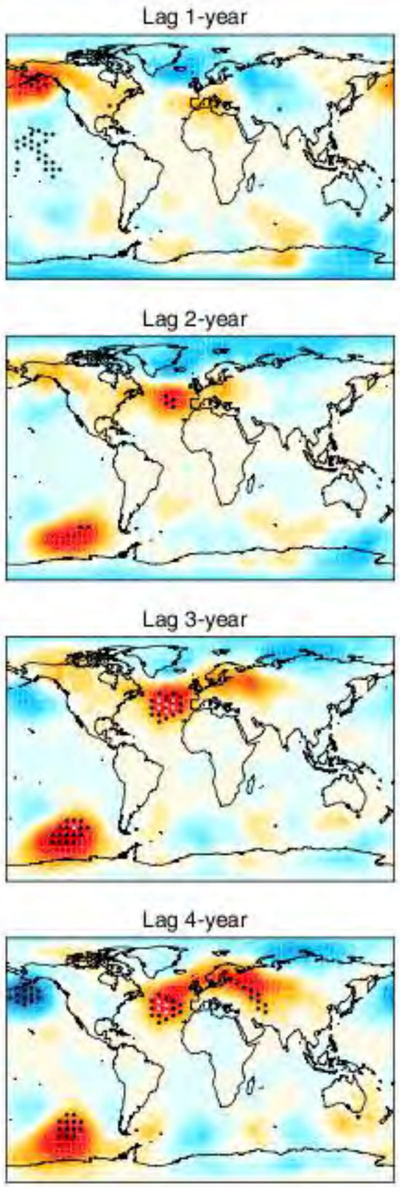
Atmosphere response to SST too weak?



Kumar 2009

Lagged response to solar forcing

Observed SLP



Gray et al, JGR, 2013

Signal builds up year on year…

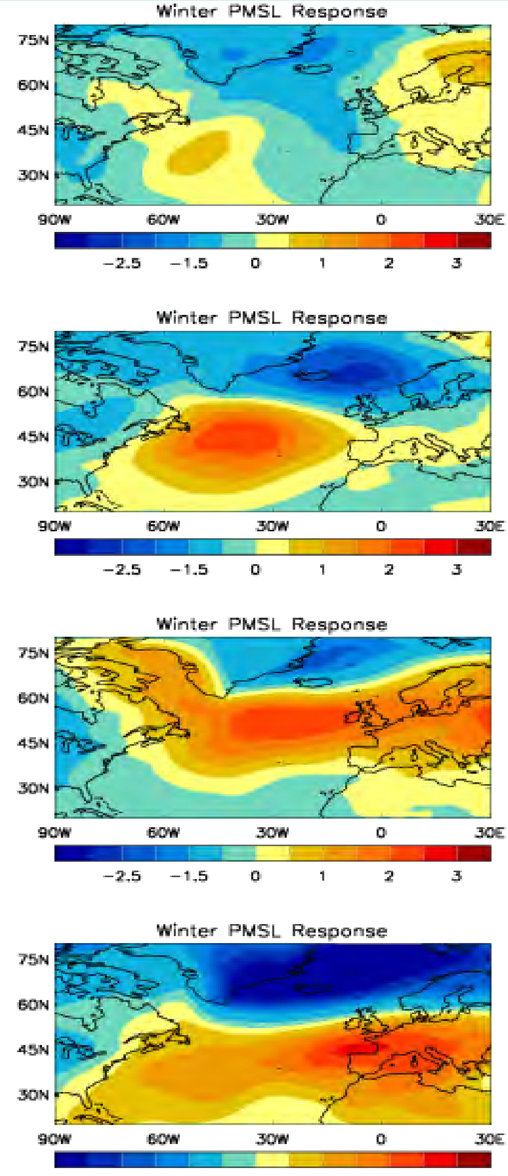
Model simulations

Year 1

Year 2

Year 3

Year 4



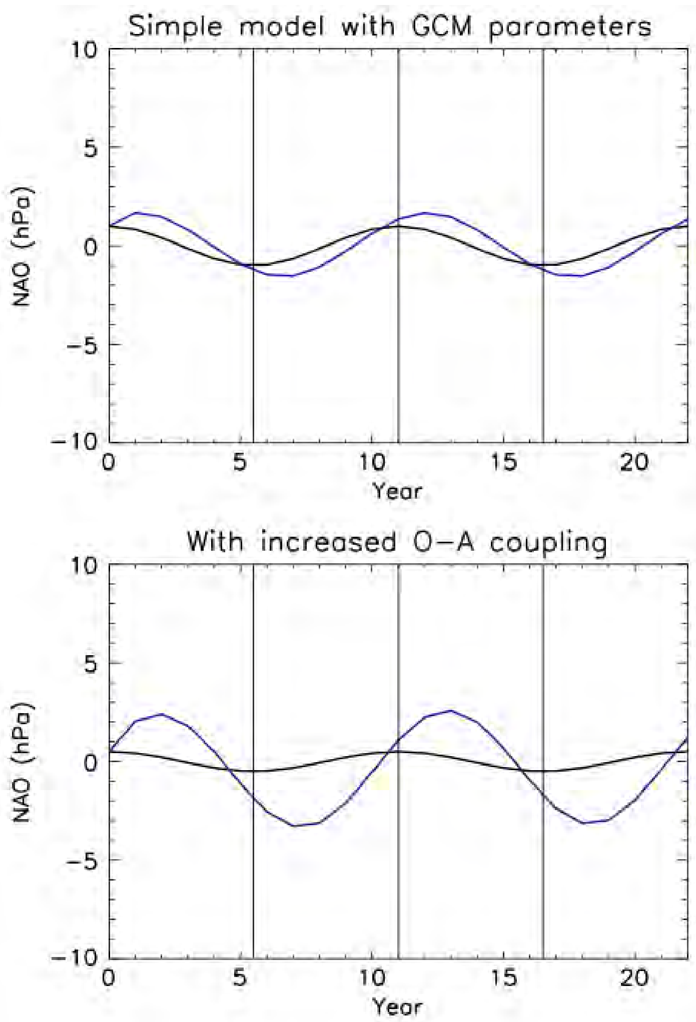
Scaife et al, GRL, 2013

Is ocean-atmosphere interaction too weak?

Simple model

$$SST(y) = \alpha \cdot NAO(y) + \beta \cdot SST(y-1)$$

$$NAO(y) = F \cdot S(y) + \gamma \cdot SST(y)$$



Simple model with GCM coefficients => no lag

Requires increased O-A coupling to achieve observed lag

See poster by Adam Scaife et al

Scaife et al, 2013

Summary

- Stratosphere is important in many sources of seasonal to decadal predictability
  - ➢SSWs, QBO, ENSO, solar, Atlantic SST, sea ice, CO2
- Emerging evidence that NAO is highly predictable a month ahead
- Decadal predictions skilful for North Atlantic SSTs
  - ➢predicted cooling due to weakening overturning
- Atmosphere response to SSTs may be too weak in models