Met Office

Atmospheric Teleconnections, the North Atlantic Oscillation and long range forecasts of European winters

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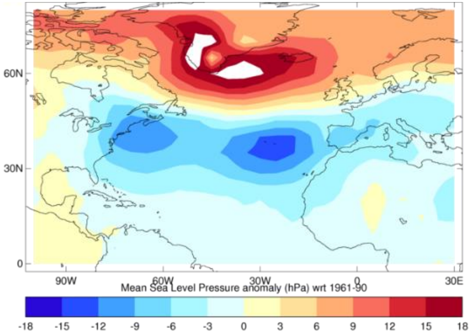
European and American winters depend on Atlantic scale weather patterns – the NAO

Pressure

Temperature

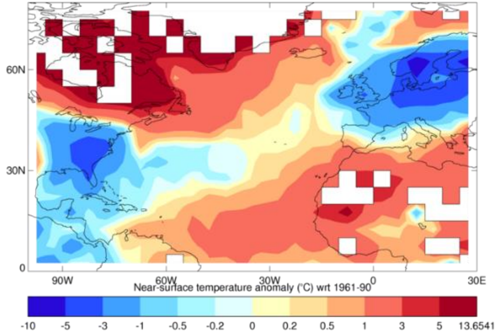
December 2010



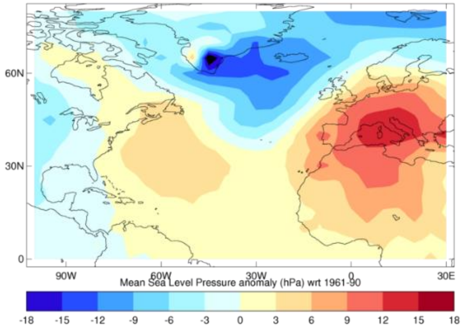
High pressure over Iceland

Weak jet stream

Cold, calm and dry



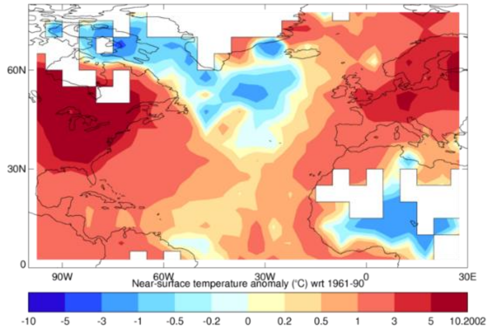
December 2015



Low pressure over Iceland

Strong jet stream

Mild, stormy and wet



Why focus on winter?

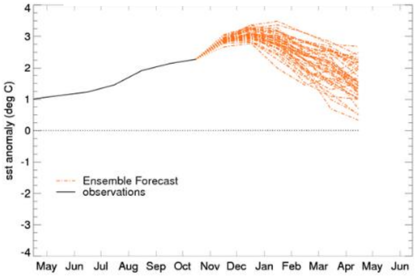
Several reasons why winter forecasts might be more skilful:

1) ENSO peaks in winter and can drive strong extratropical signals in that season

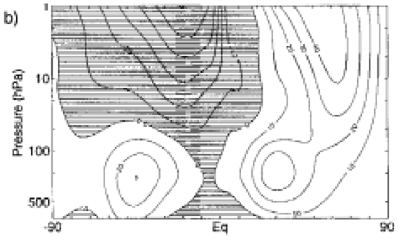
2) the stratosphere is involved but it only interacts with the troposphere in winter

3) tropical –> extratropical teleconnections are more effective in winter

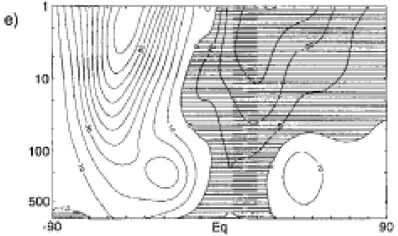
Example ENSO forecast



Winter stratosphere

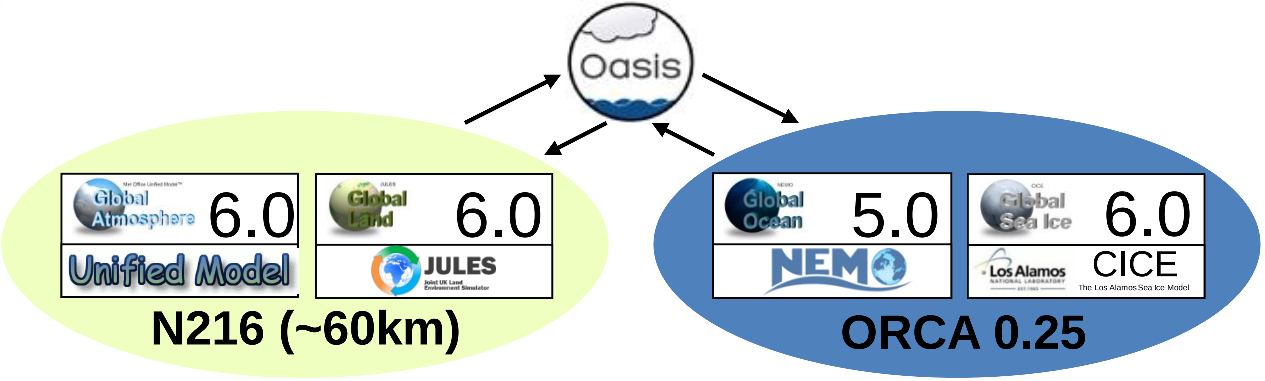


Summer stratosphere



We’ll revisit these points later

Met Office Prediction System

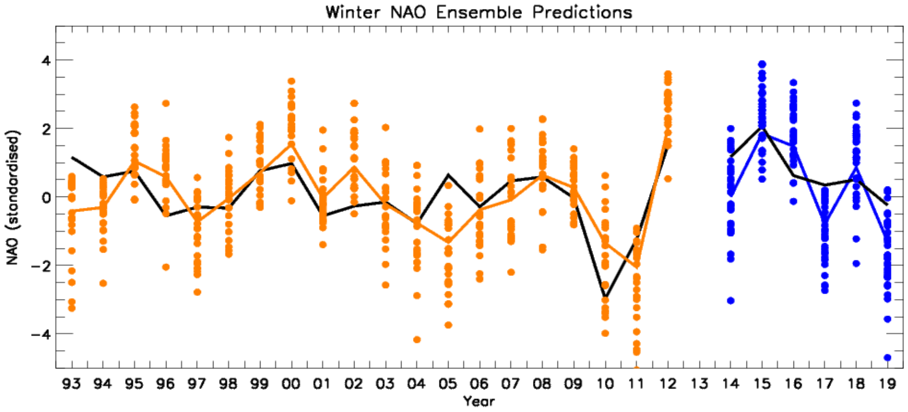


- Fully coupled model (Atmosphere-Land-Ocean-Sea Ice)
- World leading ocean resol’n + high atmosphere resol’n
- Coupled sea ice and well resolved stratosphere
- Used across timescales: monthly->seasonal->decadal

MacLachlan et al QJRMS 2015

Predictability of winter NAO
from early November

Winter seasonal predictions



Hindcast correlation = 62%

Skilful predictions of the North Atlantic Oscillation

Retrospective forecasts in orange

Real time forecasts in blue

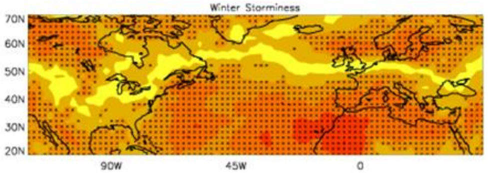
Observations in black

So where does this come from?

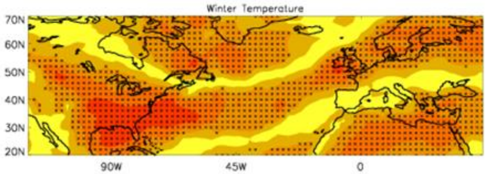
After Scaife et al, GRL, 2014

Surface weather skill

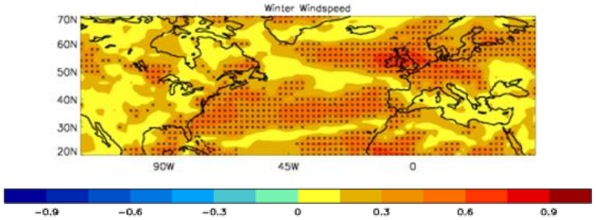
storminess



temperature



windspeed



Skill for predicting impacts: storms, temperatures, winds…

Higher skill over Europe if inferred from forecast NAO only!

Scaife et al, GRL, 2014

What is the mechanism?

Part 1

Long range forecasts do a reasonable job of simulating global rainfall

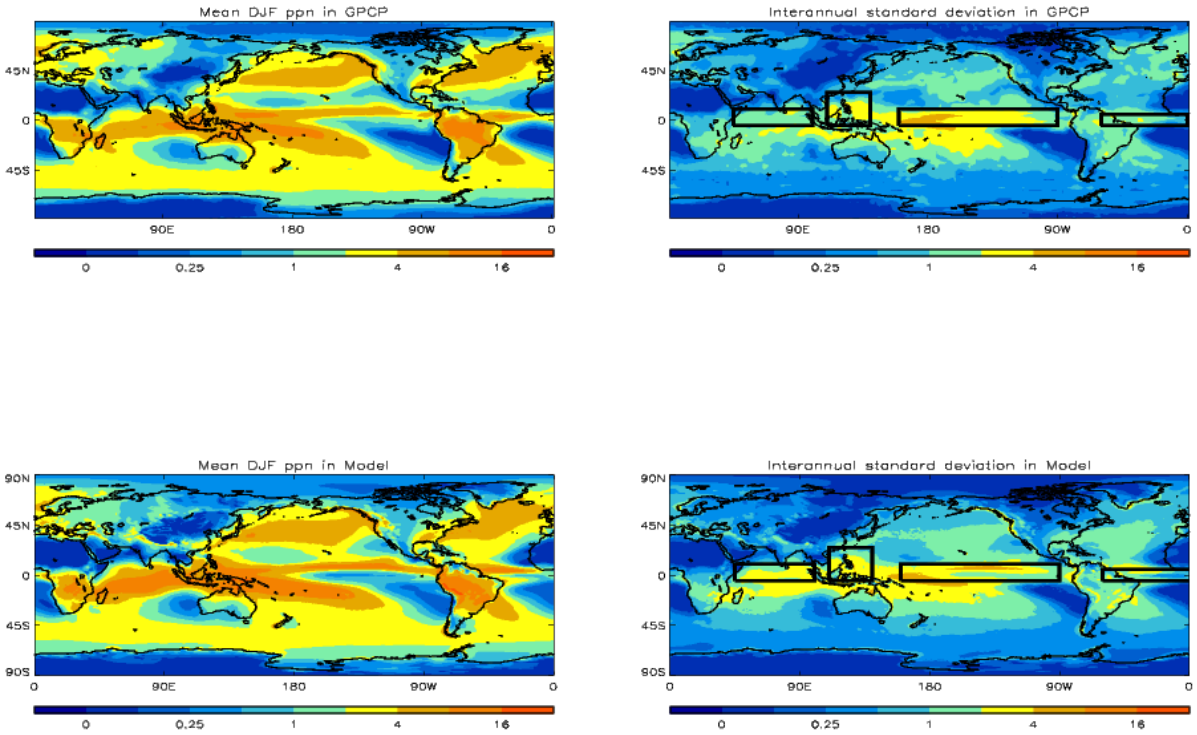
(despite what people say about rainfall in GCMs)

WINTER AVERAGE

YEAR TO YEAR VARIATIONS

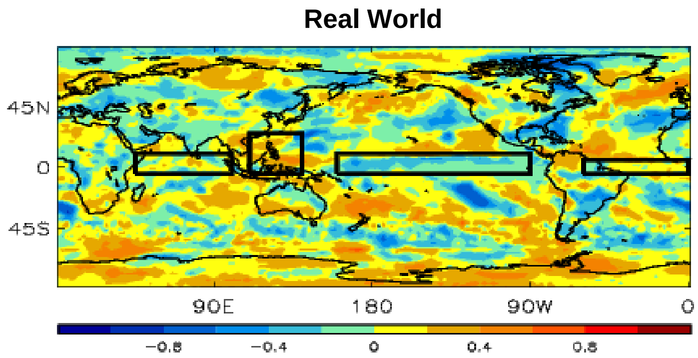
REAL WORLD

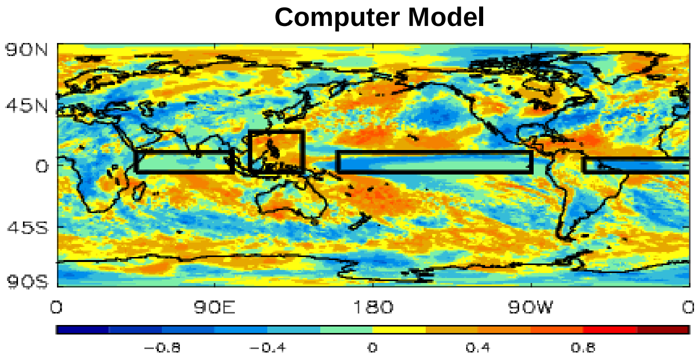
MODEL



Scaife et al., IJOC, 2018

The tropics are connected to the NAO





Correlations between winter NAO and global rainfall

Similar connections in model and observations

Some clear and common signals in the tropics

Scaife et al, QJRMS, 2017

Is tropical rainfall predictable months ahead?

Individual winter rainfall

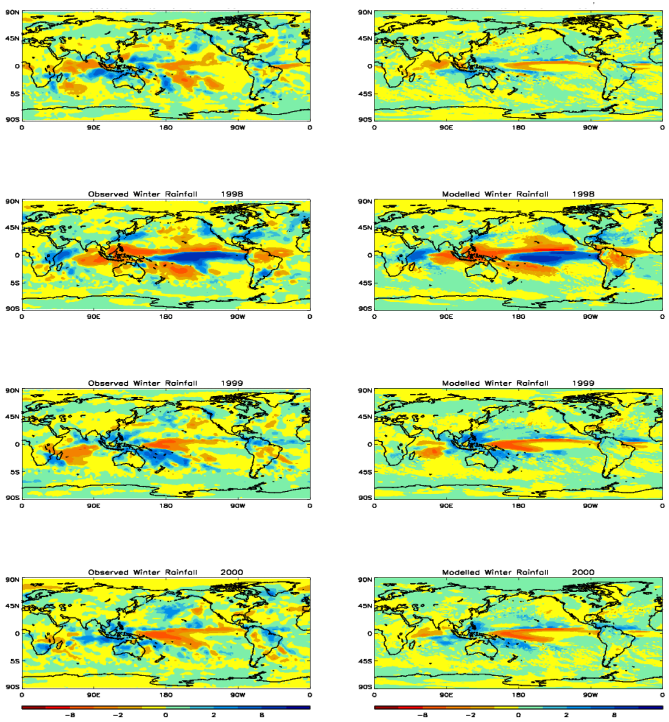
Observations | **Model**

1996/7

1997/8

1998/9

1999/0



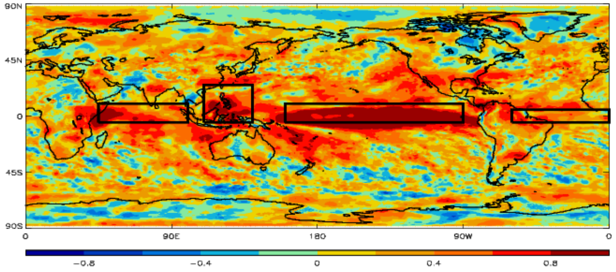
Tropical rainfall shows good prediction skill

Able to predict year to year changes

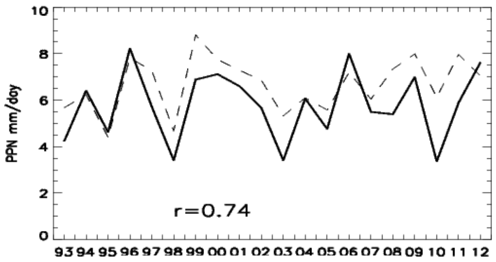
Predictable signals in all ocean basins

Tropical rainfall is predictable months ahead

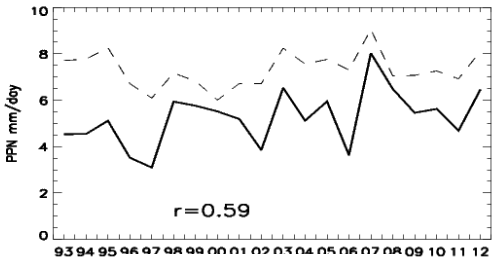
Forecast skill for winter rainfall



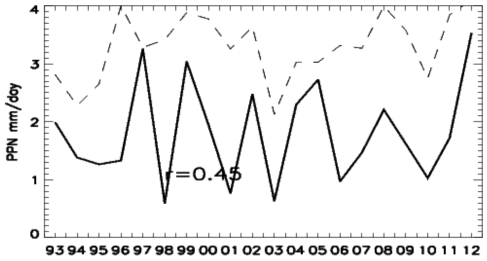
West Pacific



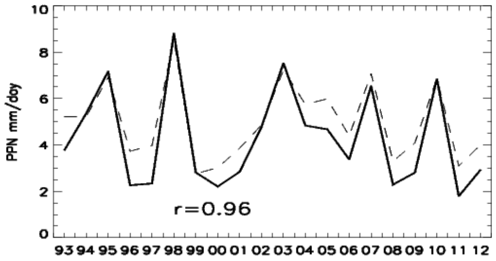
Indian Ocean



Atlantic



East Pacific



Tropical rainfall variations are well predicted months in advance

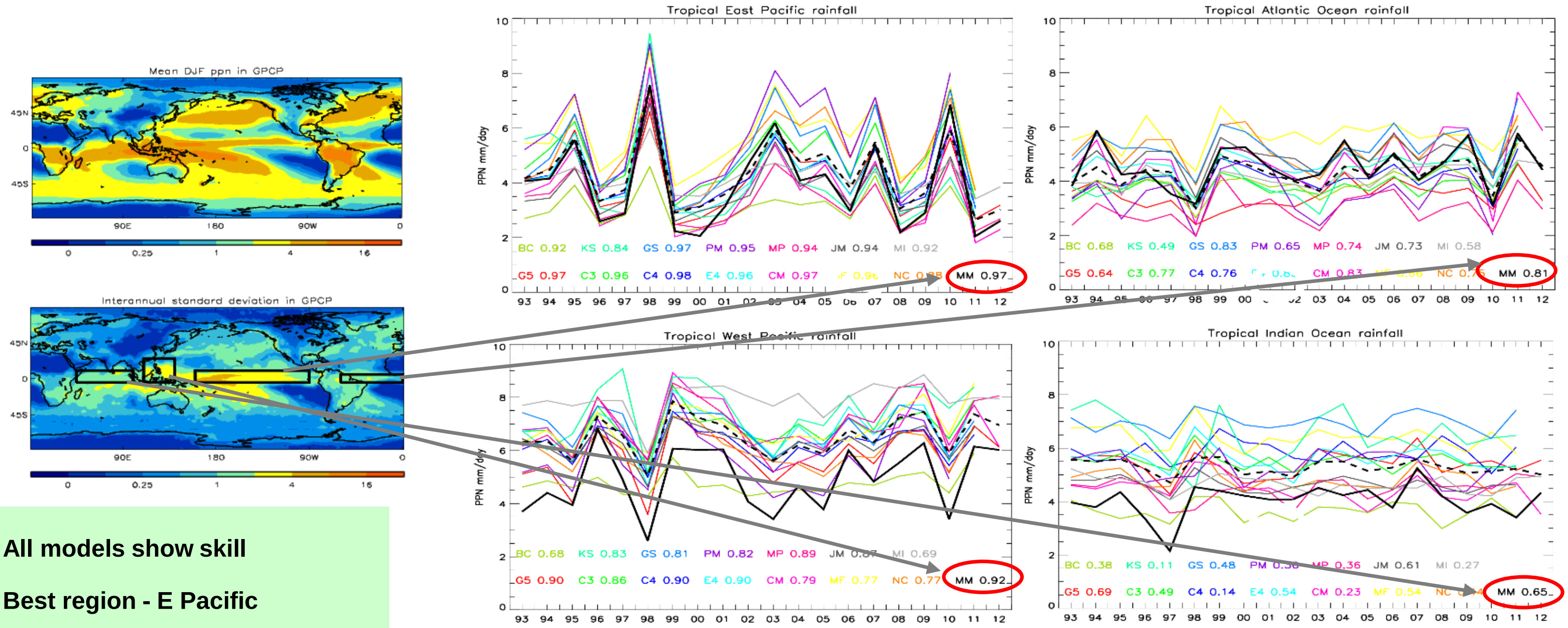
Predictions and observations agree on *amplitude*

Tropical precipitation is highly predictable out to months ahead

Best region - E Pacific **Worst region – Atlantic**

Scaife et al, QJRMS, 2017

High Skill in Tropical Rainfall for Multiple Models



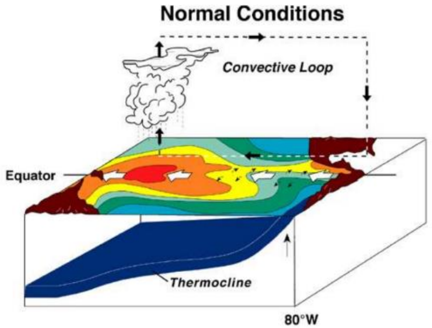
All models show skill

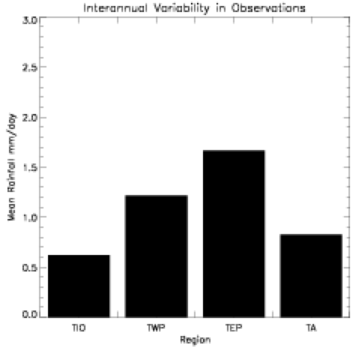
Best region - E Pacific

Worst region – Indian Ocean

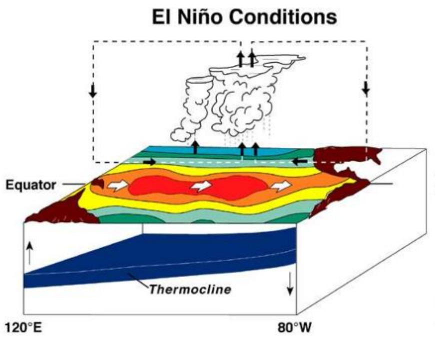
Scaife et al, IJC, 2019

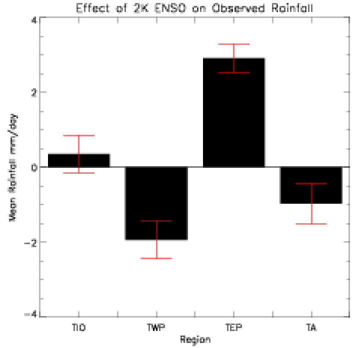
El Niño effects explain which regions are most predictable





Variability in different regions





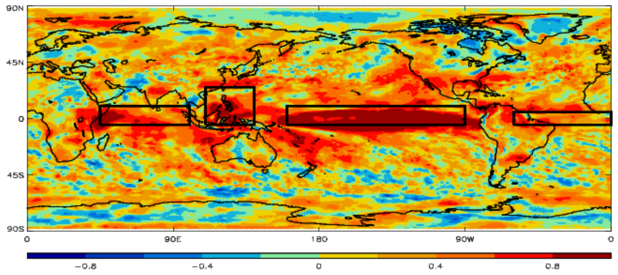
Effect of El Nino

TEP > TWP > TAT > TIO

Scaife et al., IJC, 2019

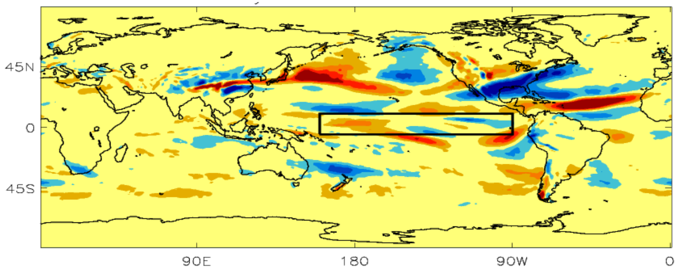
Tropical rainfall -> predictable vorticity sources

Tropical rainfall skill



Rossby Wave Source Anomalies

$$S = -\nabla \cdot (v_d \zeta)$$



Tropical rainfall shows good prediction skill

Able to predict year to year changes

Encouraging correlations in all basins

Preferred source regions

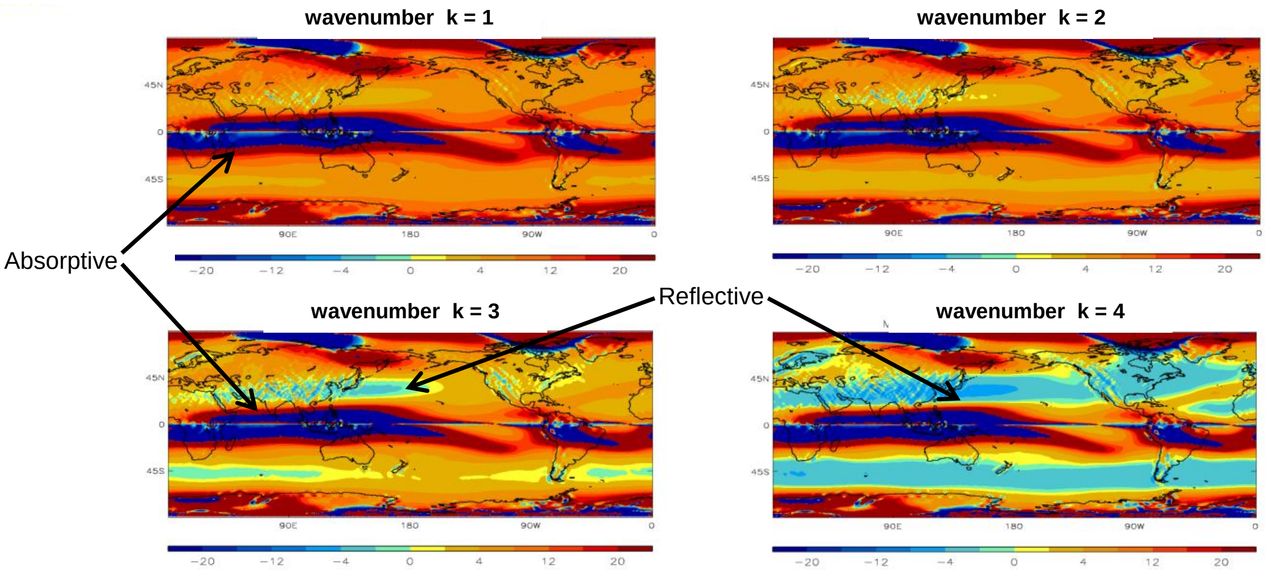
Fluctuate with forcing from other regions

Sources located at edge of jets where vorticity is large

Scaife et al, QJRMS, 2017

Rossby wave propagation

Meridional wavenumber squared ($10^{13}m^{-2}$) $\{ (\beta-\bar{u}_{yy})/\bar{u} - k^2 \}^{1/2}$



Orange and red – propagation allowed

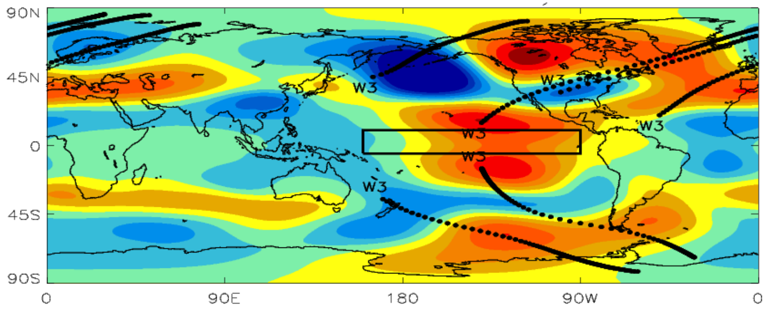
Dark blue regions are easterly winds – absorption of all waves

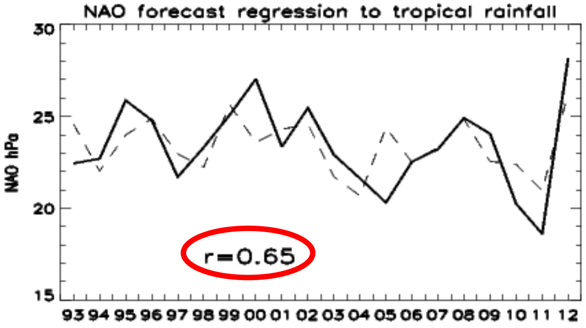
Light blue regions – reflection of short waves

Scaife et al, QJRMS, 2017

Tropical rainfall -> vorticity sources -> Rossby waves -> NAO

Teleconnections as Rossby waves





Poleward and eastward propagation of Rossby waves

Rays intersect main centres *from a few common sources*

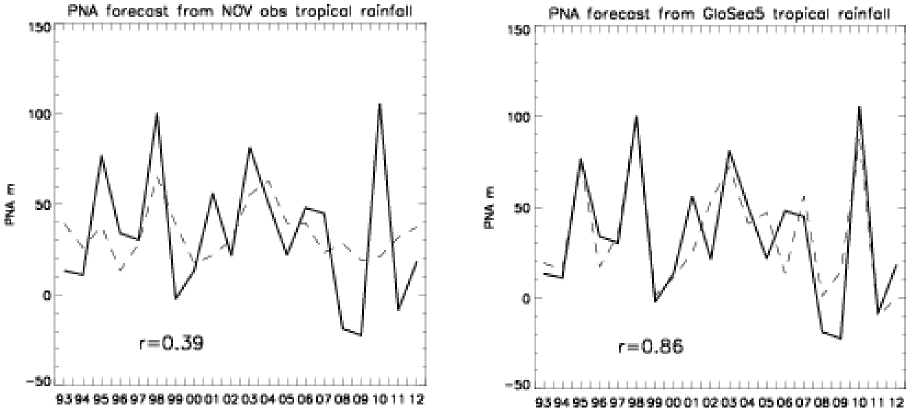
Wave 2, 3 mainly responsible as wave 4 rarely propagates

Tropical rainfall can also explain a fair proportion of NAO skill

Introduces predictable signals to the extratropics

Scaife et al, QJRMS, 2017

Tropical rainfall => PNA

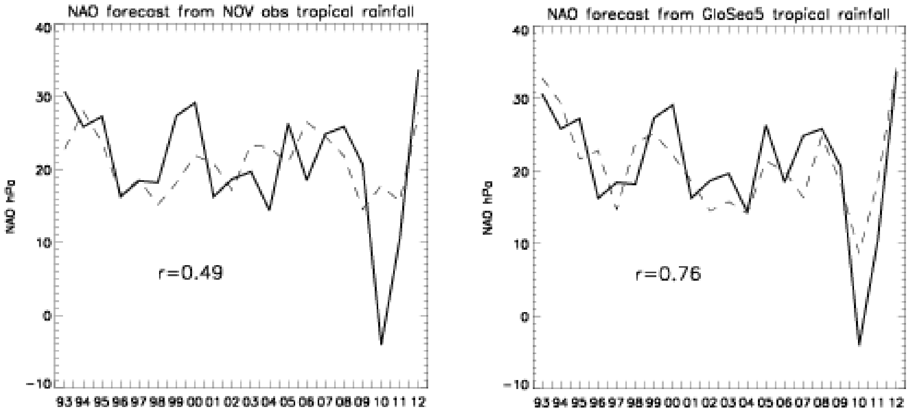


Observed rainfall => Observed PNA

Modelled rainfall => Observed PNA

Scaife et al, IJC, 2019

Tropical rainfall => NAO



Observed rainfall => Observed NAO

Modelled rainfall => Observed NAO

Rainfall regression gives better prediction than forecast NAO!

Scaife et al, IJC, 2019

Outstanding errors: Inter-basin teleconnections

	TEP-TWP	TEP-TA	TEP-TIO	TWP-TA	TWP-TIO	TA-TIO
Observed	-0.89	-0.62	+0.41	+0.61	-0.30	-0.07
Modeled	-0.96, -0.24	-0.85, 0.16	-0.67, 0.75	-0.09, 0.83	-0.65, 0.64	-0.69, 0.75
No. models spanning obs.	6/14	10/14	9/14	12/14	11/14	11/14

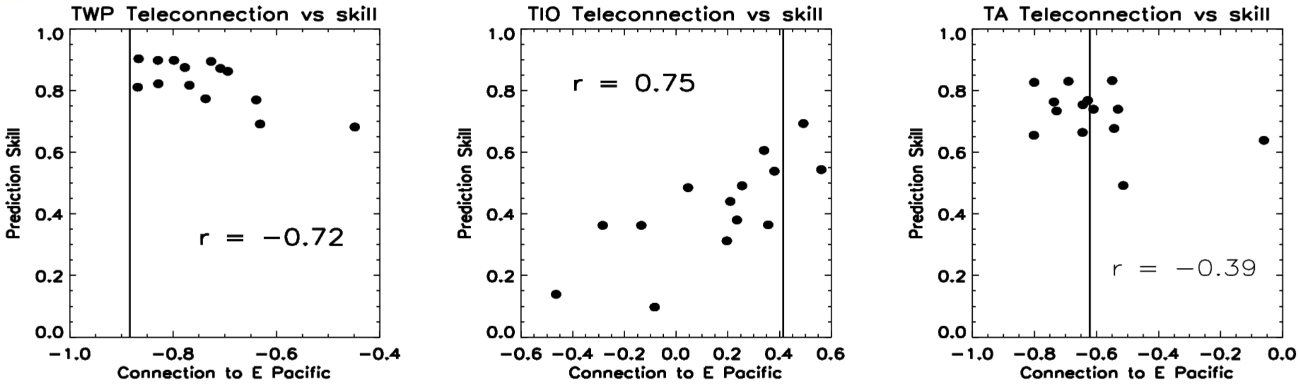
Inter-basin connections can be reproduced by the full multi-model ensemble in all cases

However, not all models are able to reproduce inter-basin connections

Surprisingly, the E Pacific connections are worst represented

Scaife et al, IJC, 2019

Inter-basin teleconnections may be important for skill



Tropical W Pacific and Indian Ocean have weak teleconnections to Tropical E Pacific in models

Stronger inter-basin connections => more skill

This may be important (rather than mean bias) for improved predictions

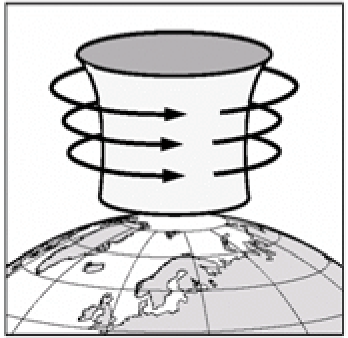
Scaife et al, IJC, 2019

What is the mechanism?

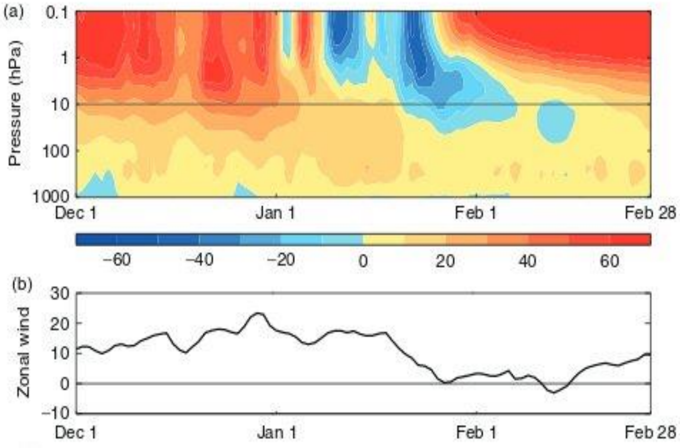
Part 2

The stratosphere and winter 2005/6

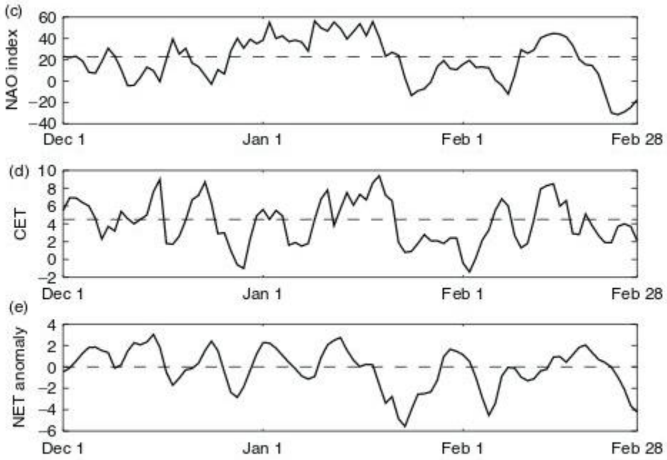
Stratospheric Polar Vortex



Stratospheric Winds



North Atlantic Oscillation and temperature

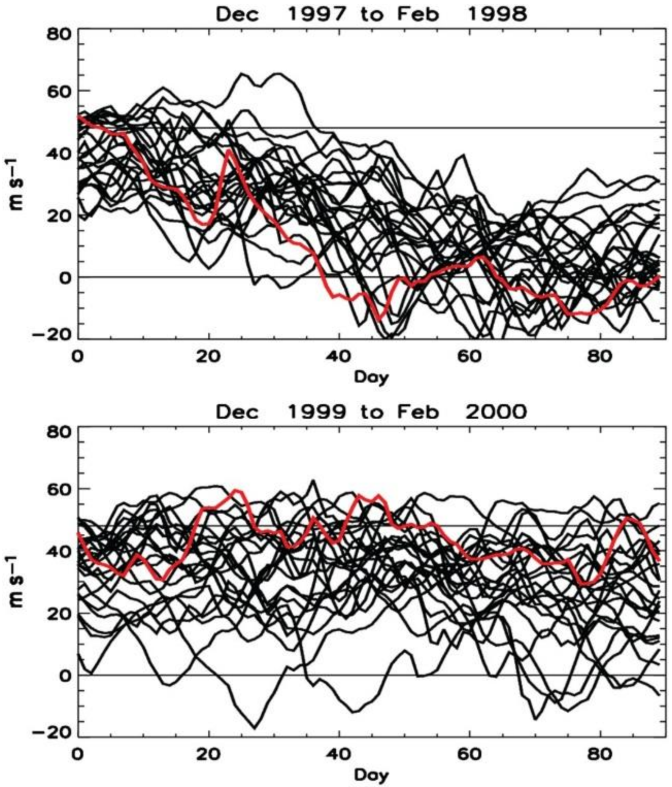


Easterly winds can occur episodically in the stratosphere

They can burrow down to the troposphere, resulting in severe cold

Scaife and Knight, 2008

Long range predictability of the stratosphere



Easterly winds in the stratosphere can be predicted months ahead

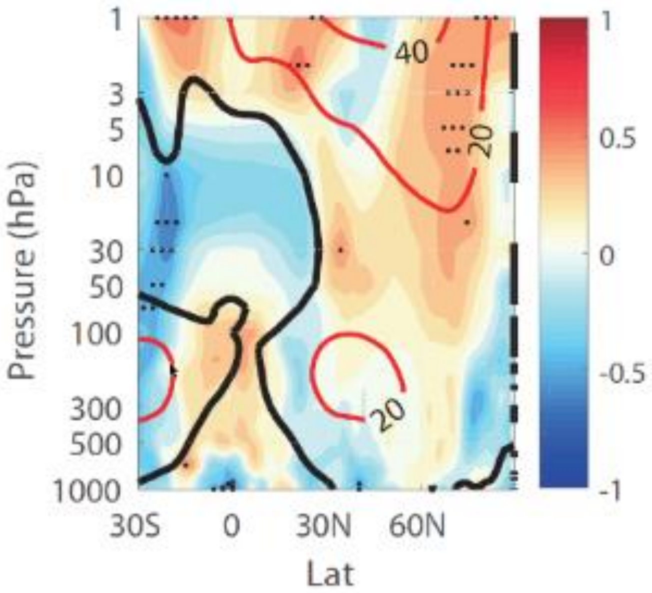
Sudden Stratospheric Warmings are predictable on *seasonal* timescales

At least in a probabilistic sense

Scaife et al, ASL, 2016

A Role for Initial Atmospheric Conditions

Initial zonal mean wind and forecast NAO



Initial winds correlate with predicted winter NAO

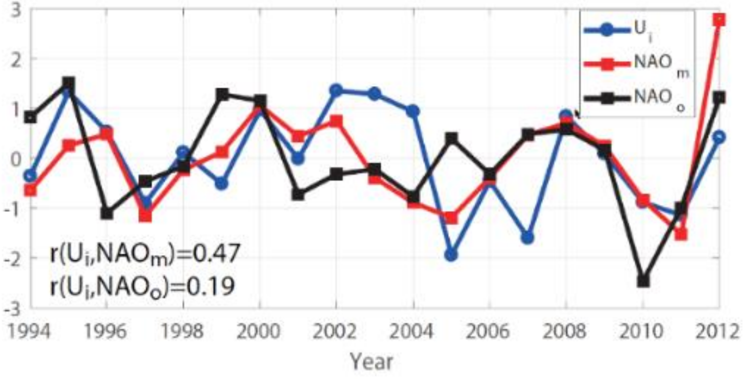
Sign is as expected: westerly wind anomaly => +NAO

Suggests predictability from initial atmospheric conditions

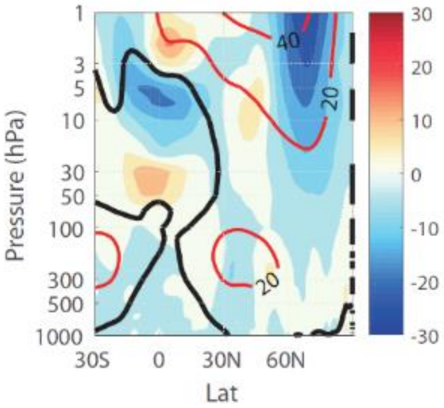
Nie et al, ERL, 2019

A Role for Initial Atmospheric Conditions

Initial wind, forecast NAO, observed NAO



1 Nov 2004



Initial conditions => ~20% of forecast NAO variance

Smaller than tropical rainfall (>50%) but likely important

Add these together => most of predictability explained!

Note 2004/5…

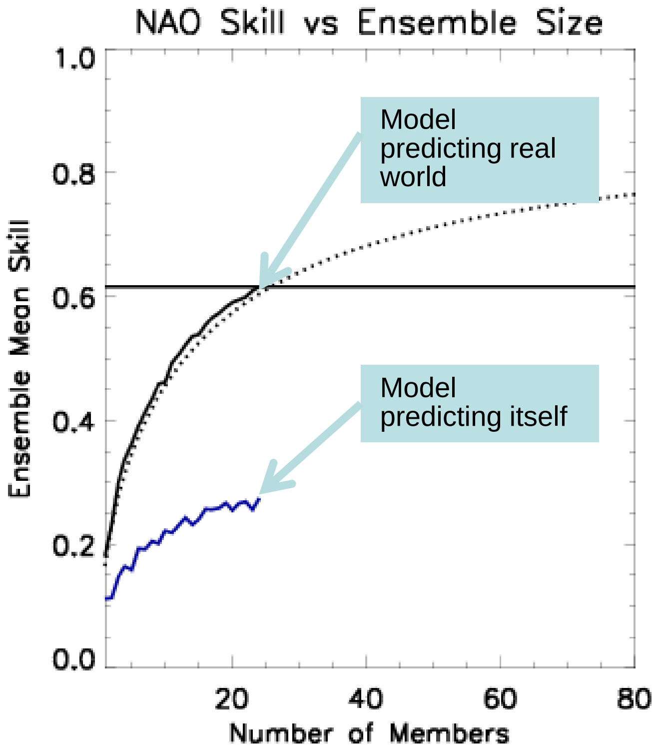
2004/5 is the most easterly initial condition case in the hindcast

Suggests the stratosphere drove the model but not the obs in this particular winter

Nie et al, ERL, 2019

An unresolved paradox

A Signal to Noise Paradox in Seasonal Prediction

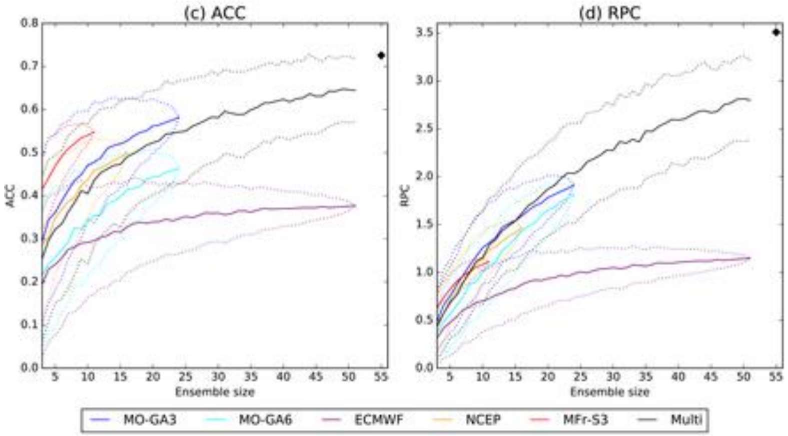


Skill rises slowly with ensemble size

Undermines basis of ensemble prediction

Members NOT alternate realisations of obs

Not a simple problem of incorrect spread



Scaife and Smith, npj Clim. Atm. Sci., 2018

Baker et al., G.R.L., 2018

Ratio of predictable components

Ratio of predictable components: RPC = r / (σ_{em}/σ_{tot})

should be 1 but is actually > 1

Correlation higher than predictable proportion of variability

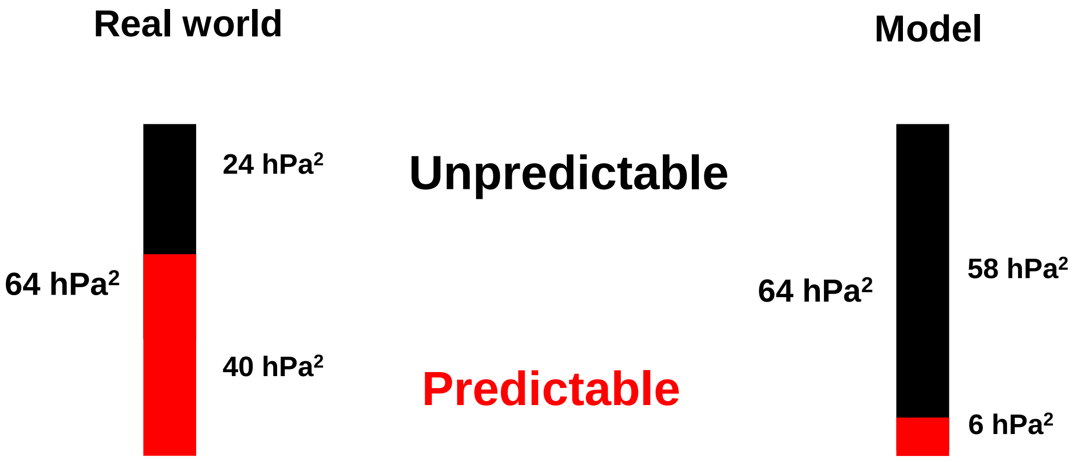
Correlation	**r = 0.6**	
Ensemble *mean* variability	**σ_{em} = 2.3hPa**	
Ensemble *member* variability	**σ_{tot} = 8hPa**	**σ_{obs} ~ 8hPa**

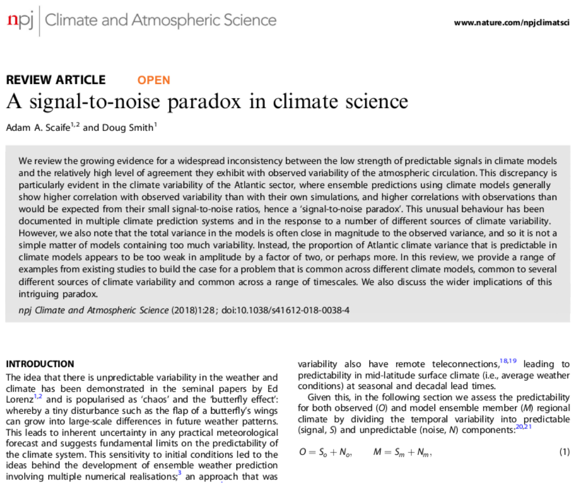
RPC = 2.2

because *signal* is too small: "Signal to Noise Paradox"

Eade et al, GRL, 2014

A simple interpretation of what’s going on





npj | Climate and Atmospheric Science www.nature.com/npjclimatsci

REVIEW ARTICLE OPEN

A signal-to-noise paradox in climate science

Adam A. Scaife[1,2] and Doug Smith[1]

We review the growing evidence for a widespread inconsistency between the low strength of predictable signals in climate models and the relatively high level of agreement they exhibit with observed variability of the atmospheric circulation. This discrepancy is particularly evident in the climate variability of the Atlantic sector, where ensemble predictions using climate models generally show higher correlation with observed variability than with their own simulations, and higher correlations with observations than would be expected from their small signal-to-noise ratios, hence a ‘signal-to-noise paradox’. This unusual behaviour has been documented in multiple climate prediction systems and in the response to a number of different sources of climate variability. However, we also note that the total variance in the models is often close in magnitude to the observed variance, and so it is not a simple matter of models containing too much variability. Instead, the proportion of Atlantic climate variance that is predictable in climate models appears to be too weak in amplitude by a factor of two, or perhaps more. In this review, we provide a range of examples from existing studies to build the case for a problem that is common across different climate models, common to several different sources of climate variability and common across a range of timescales. We also discuss the wider implications of this intriguing paradox.

npj Climate and Atmospheric Science (2018)1:28 ; doi:10.1038/s41612-018-0038-4

INTRODUCTION

The idea that there is unpredictable variability in the weather and climate has been demonstrated in the seminal papers by Ed Lorenz[1,2] and is popularised as ‘chaos’ and the ‘butterfly effect’: whereby a tiny disturbance such as the flap of a butterfly’s wings can grow into large-scale differences in future weather patterns. This leads to inherent uncertainty in any practical meteorological forecast and suggests fundamental limits on the predictability of the climate system. This sensitivity to initial conditions led to the ideas behind the development of ensemble weather prediction involving multiple numerical realisations;[3] an approach that was

variability also have remote teleconnections,[18,19] leading to predictability in mid-latitude surface climate (i.e., average weather conditions) at seasonal and decadal lead times.

Given this, in the following section we assess the predictability for both observed (*O*) and model ensemble member (*M*) regional climate by dividing the temporal variability into predictable (signal, *S*) and unpredictable (noise, *N*) components:[20,21]

$$O = S_o + N_o, \qquad M = S_m + N_m, \tag{1}$$

Forecasts appear to have about the right amount of variability

BUT

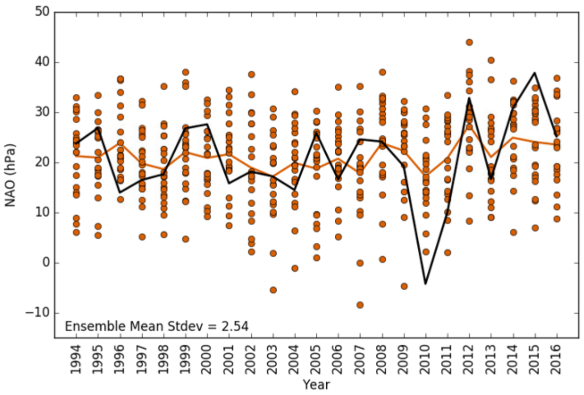
The *proportion* of variability that is predictable appears to be less in models

Is horizontal resolution important?

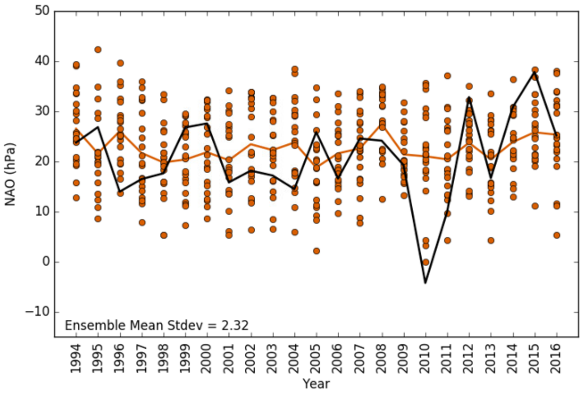
NAO Predictions

Standard Resolution (0.83deg)
vs
Higher Resolution (0.33deg)

Standard



Higher



Ensemble mean standard deviation does not improve with resolution

Signal to noise ratio does not increase with resolution

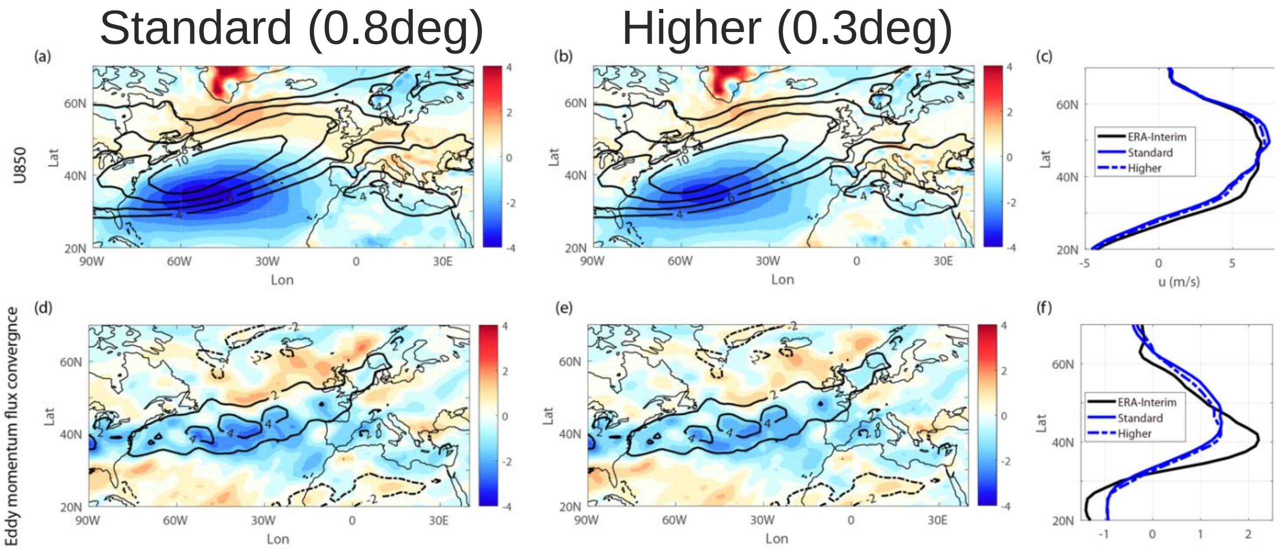
Signal to noise paradox is not resolved by doubling resolution

Scaife et al, ASL, 2019

Is horizontal resolution important?

Synoptic Eddy Feedback

$$F_y = -\frac{\partial(\overline{u'v'})}{\partial y}$$



Eddy feedback is weaker than in reanalysis

Barely improves with doubling resolution

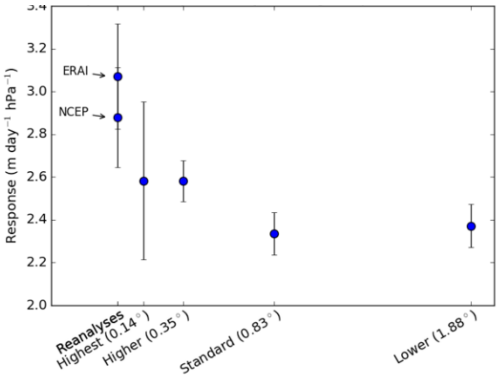
Scaife et al, ASL, 2019

Is horizontal resolution important?

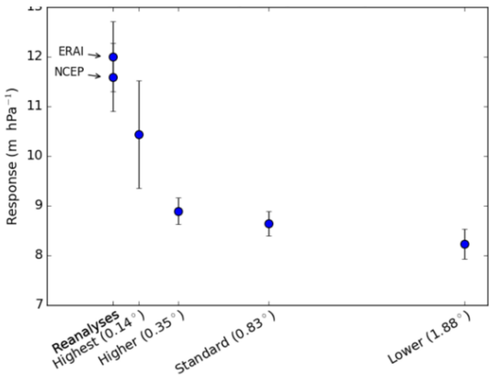
Eddy Feedback

$$F_v = -\frac{f}{g_o}\nabla^{-2}\left(\nabla.\overline{\mathbf{V}'\zeta'}\right)$$

Vorticity forcing per hPa of NAO



Upper Tropospheric GPH per hPa of NAO



Eddy feedback onto NAO starts to improve at 4x resolution

Impacts deep NAO signals throughout troposphere

Scaife et al, ASL, 2019

Eddies and filaments at higher resolution:

Taylor Identity: $\overline{\mathrm{v}'q'} = -\frac{\partial}{\partial y}\left(\overline{u'v'}\right)$

http://www-hc/~hadru/nao_n512/vort300_djf2007_atl_4up.mp4

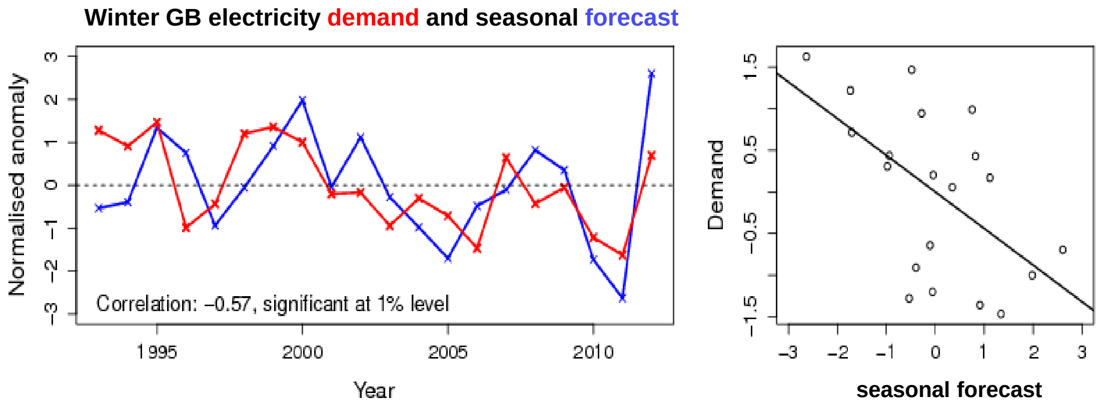
Meridional mixing of potential vorticity = convergence of eddy momentum flux

Strengthens deep NAO signals in the troposphere

Animations courtesy of Ruth Comer

Climate Services

Applications: energy



Both energy demand and supply are skilfully predicted

Could be used to predict likely winter demand

Best forecast is based on regression to ensemble mean NAO

Clark et al, ERL, 2017

Summary

Skilful seasonal prediction of winter North Atlantic Oscillation continues

Originates largely from the tropics and the stratosphere

There is an outstanding signal to noise paradox

This affects ensembles from all models as far as we are aware

Applications should use the multimodel mean and recalibrate before use