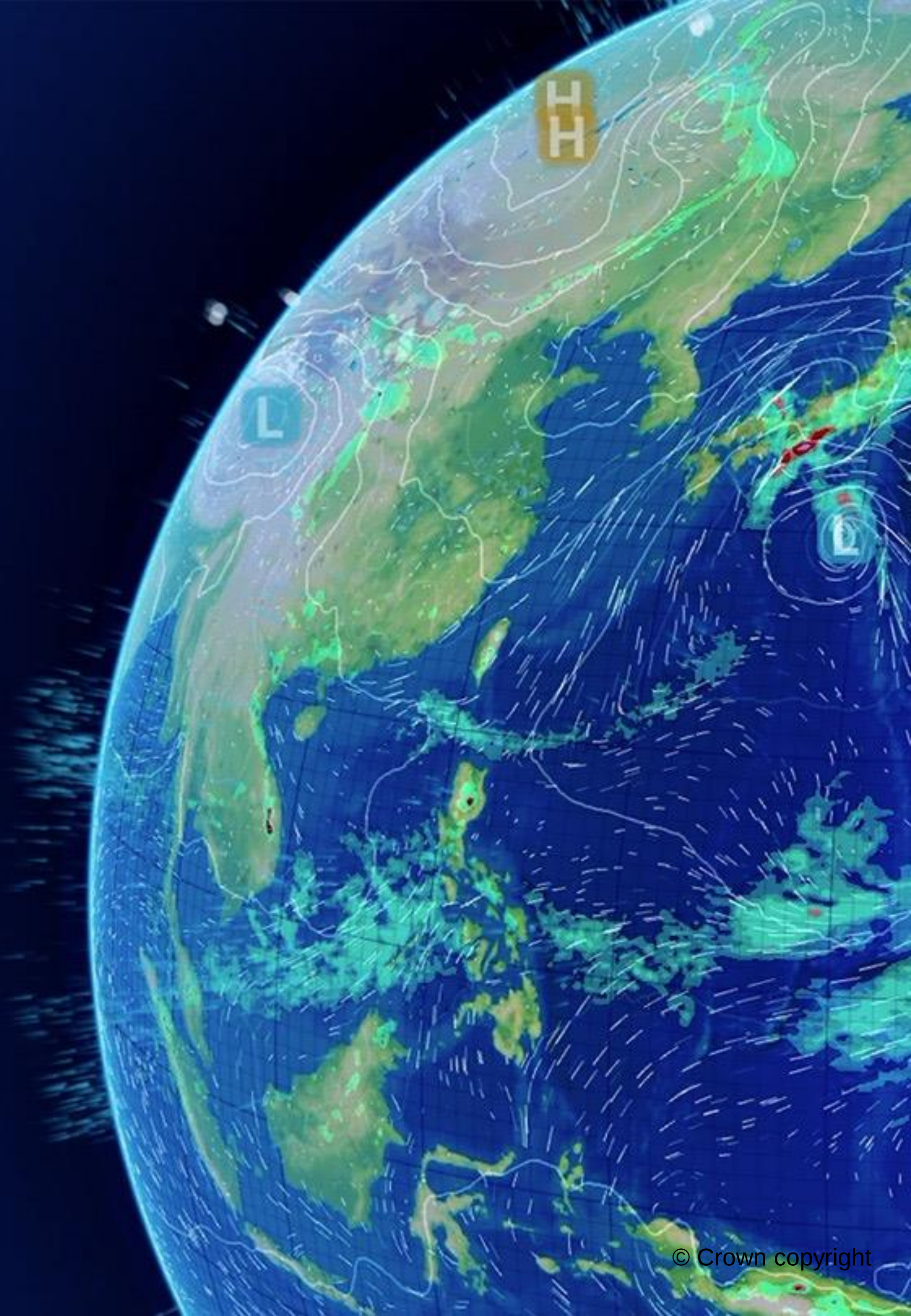
Met Office

Winter Forecast Skill

Part 1: Tropical Teleconnections



Prof. Adam Scaife

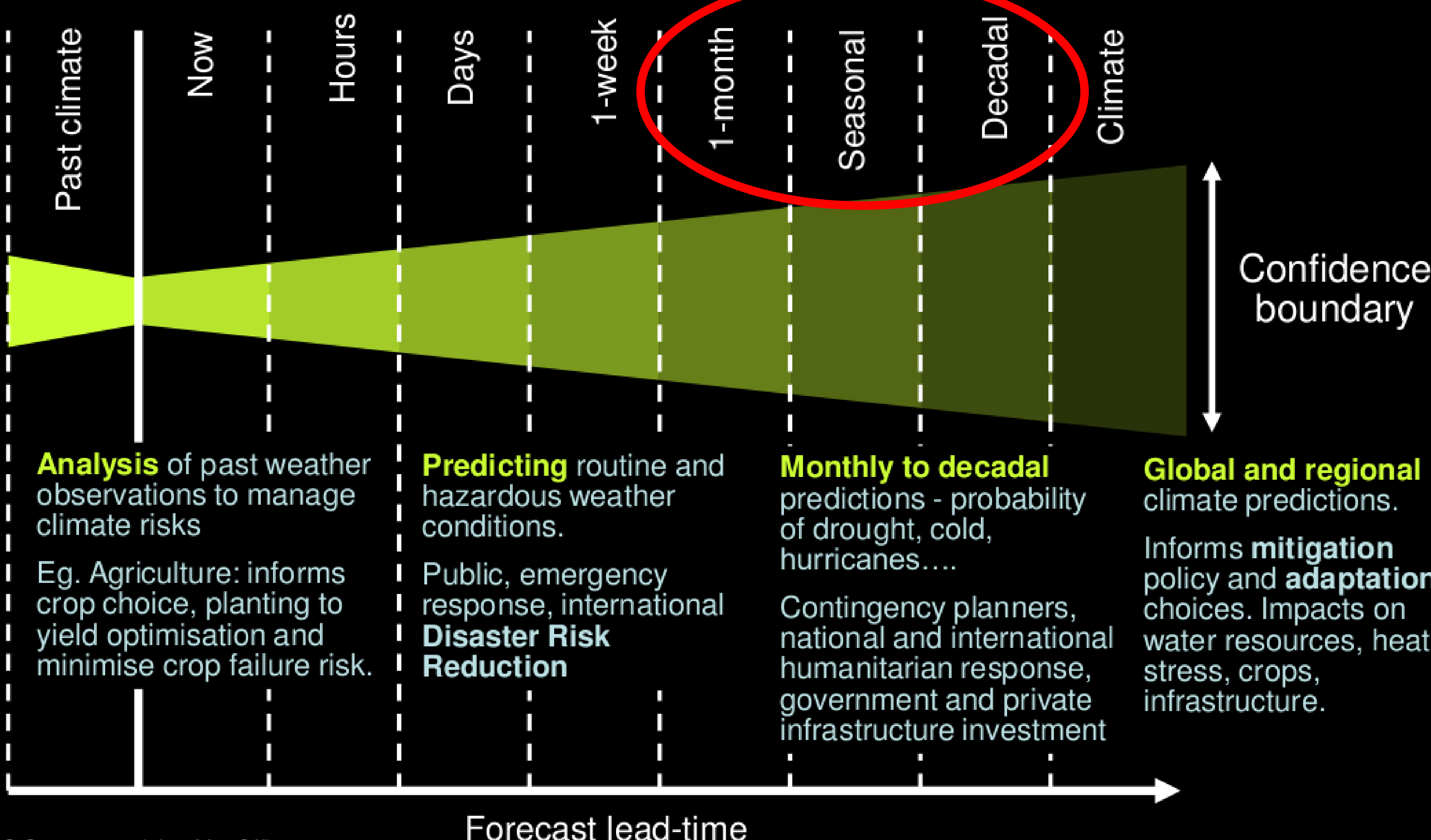
Head of Monthly to Decadal Prediction

Met Office Hadley Centre

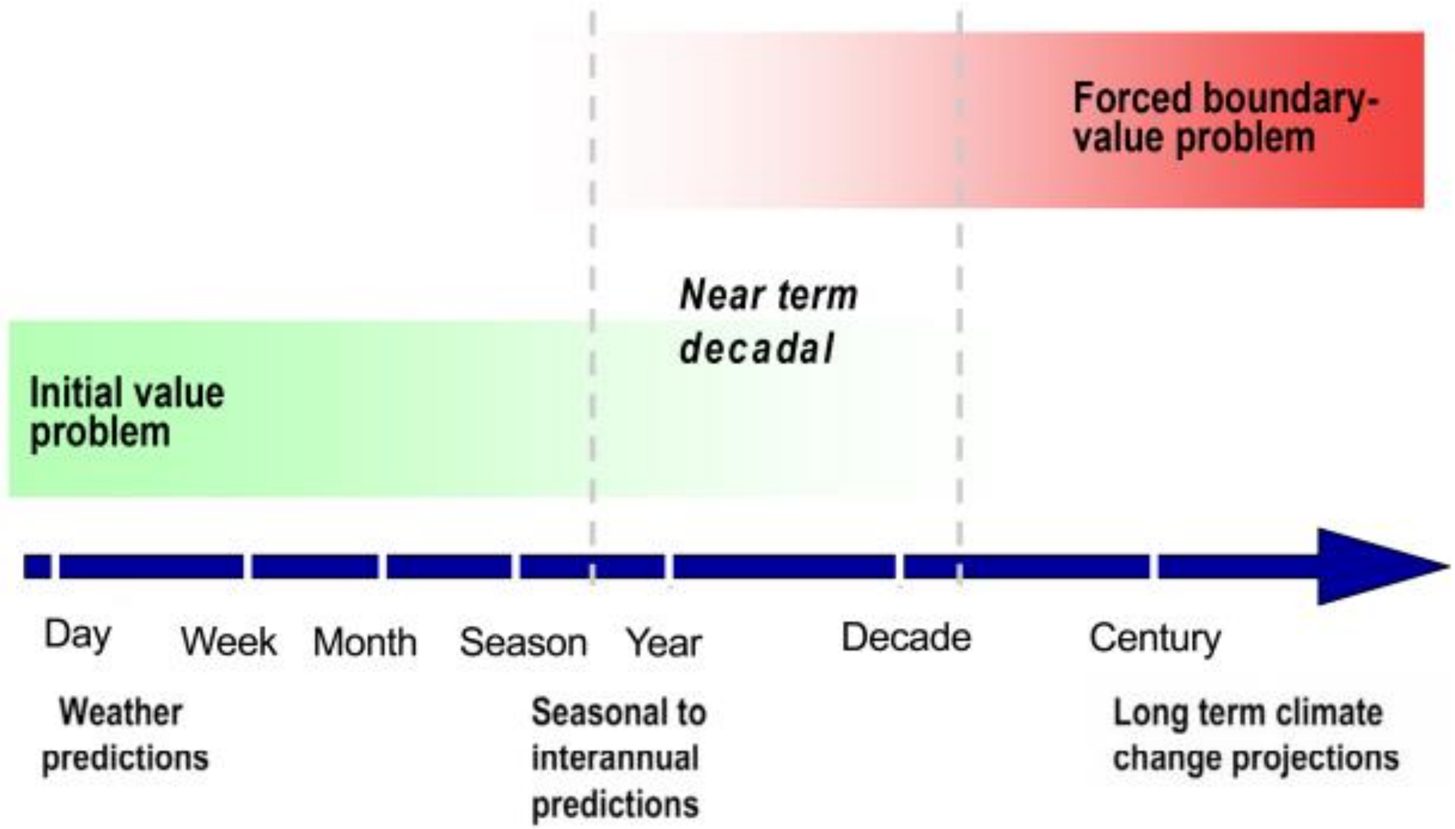
Full Implementation of Seamless Prediction: From Hours to Decades

Met Office

Global coupled modelling on all timescales



Seasonal and Decadal Prediction is a mixed initial/boundary value problem



Boer et al, 2016

What causes the difference between this:

December 2010

Image courtesy of Channel 4

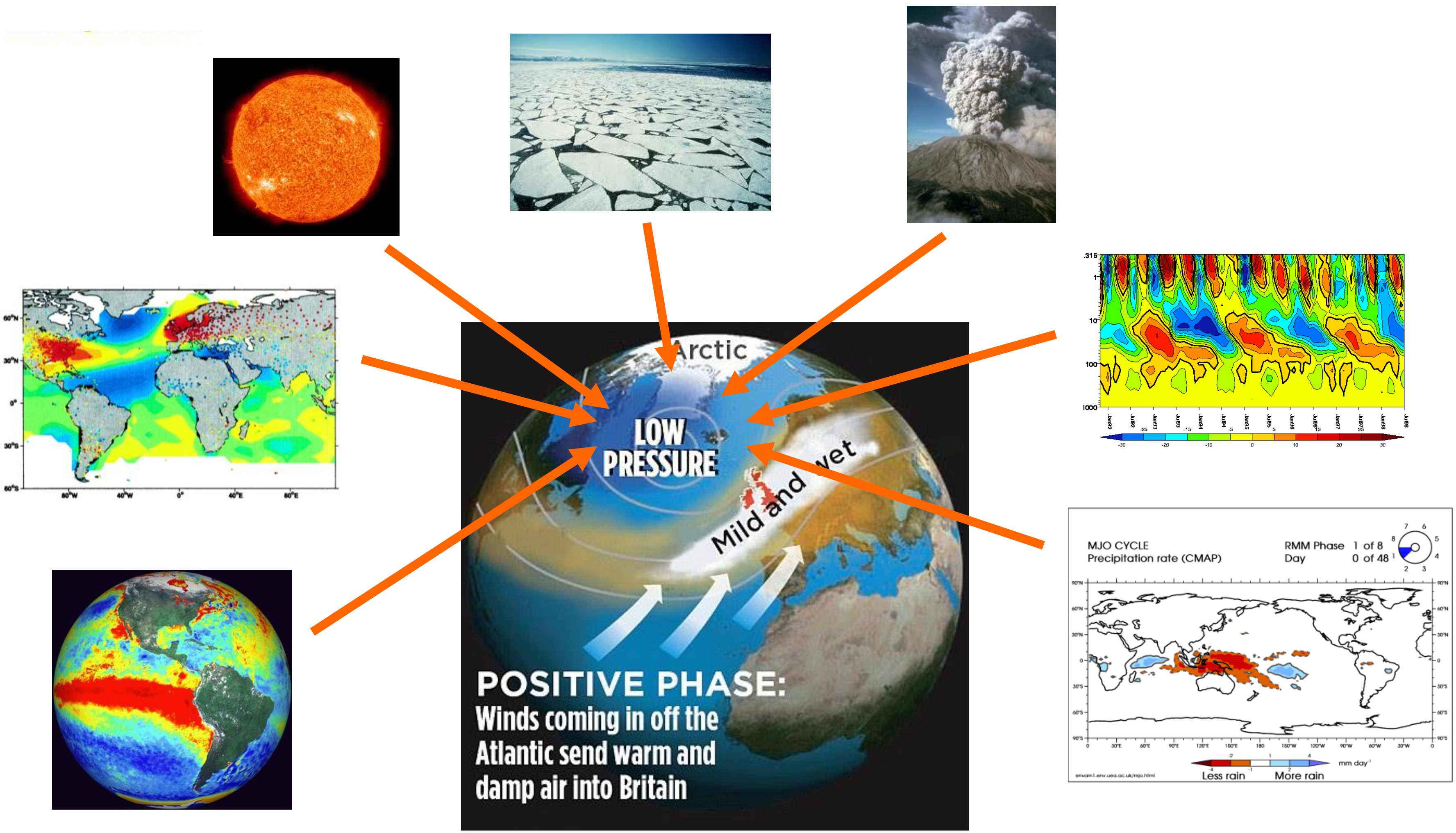
...and this:

December 2015

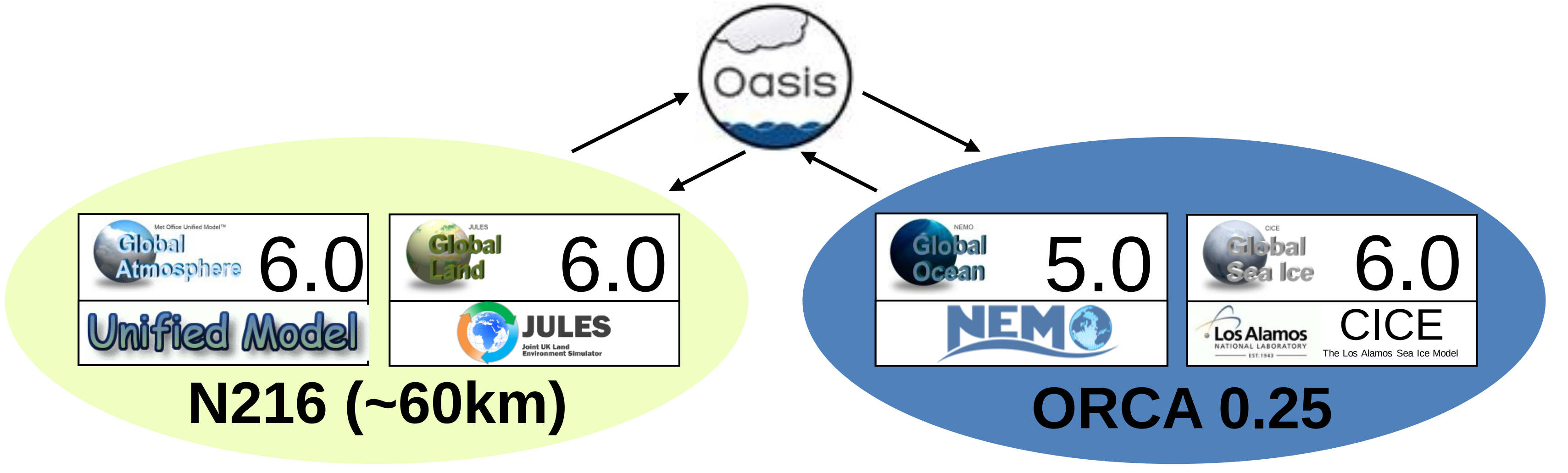
Image courtesy of The Telegraph Newspaper

North Atlantic Oscillation

(single most important factor for UK winters and responds to many drivers)



Seamless Monthly, Seasonal and Decadal Predictions



Fully coupled model (Atmosphere-Land-Ocean-Sea Ice)

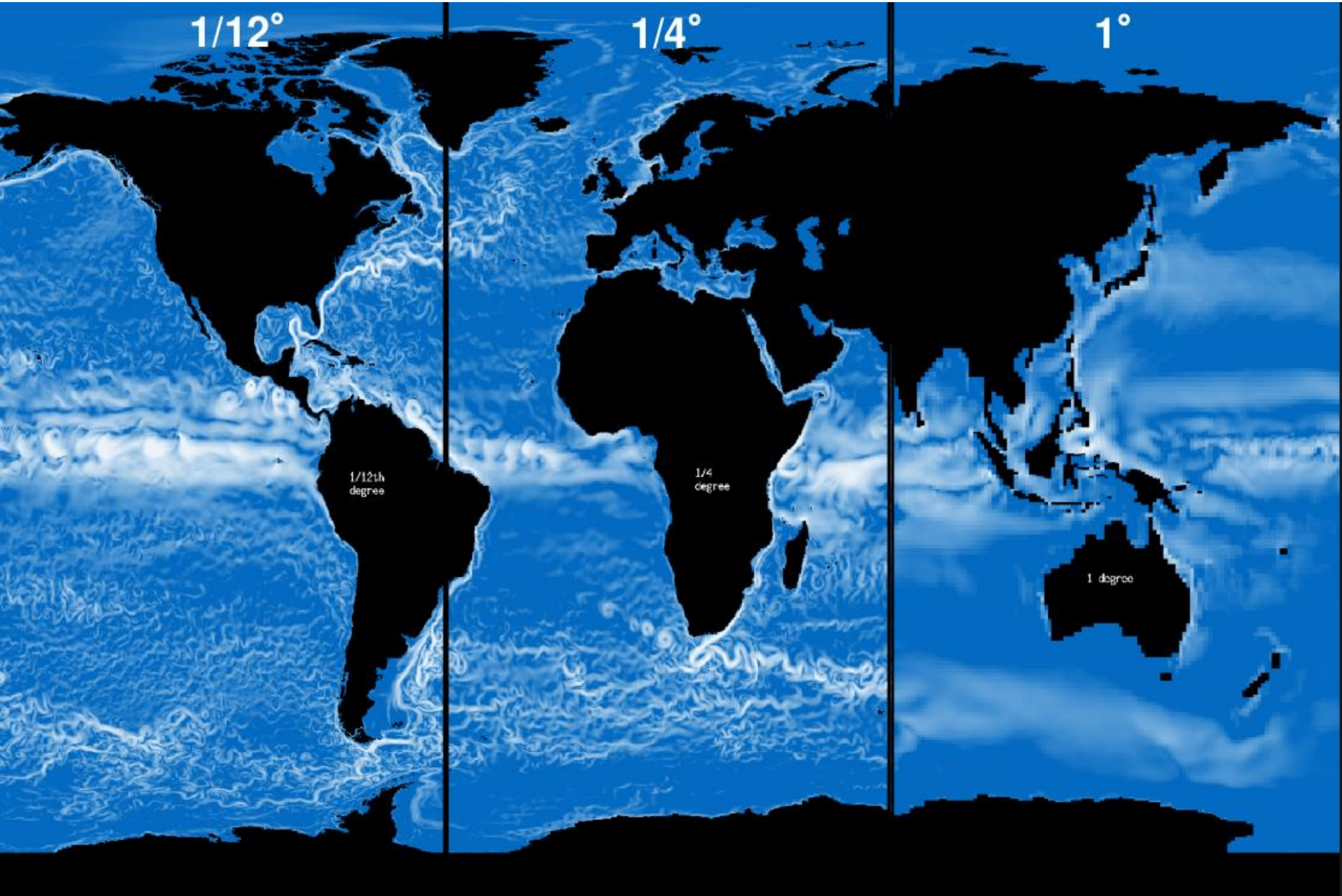
World leading ocean resol'n + high atmosphere resol'n

Coupled sea ice and well resolved stratosphere

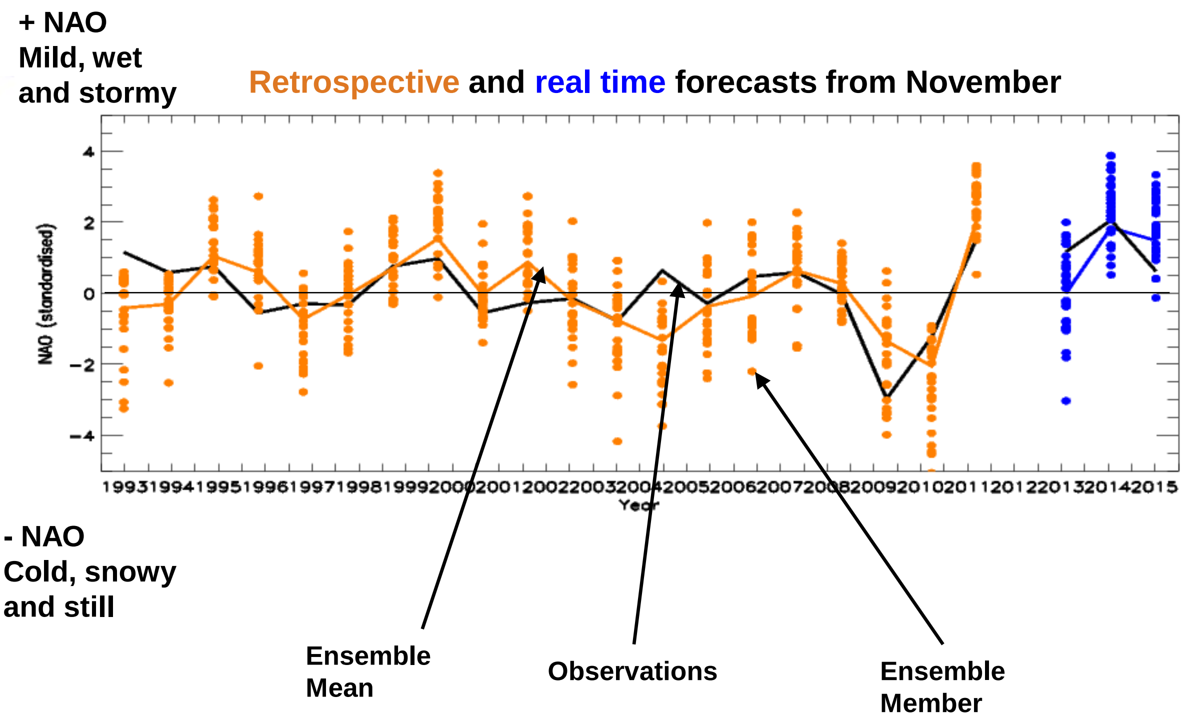
Used across timescales

MacLachlan et al QJRMS 2015, Scaife et al GRL 2014

Benefit of increased ocean resolution



Skilful predictions of the NAO



Our original tests are shown in orange and indicate a correlation skill of 62%

More ensemble members => more skill and ~0.8 may be possible

So far so good with real time forecasts...

Scaife et al GRL 2014

Where does this come from?

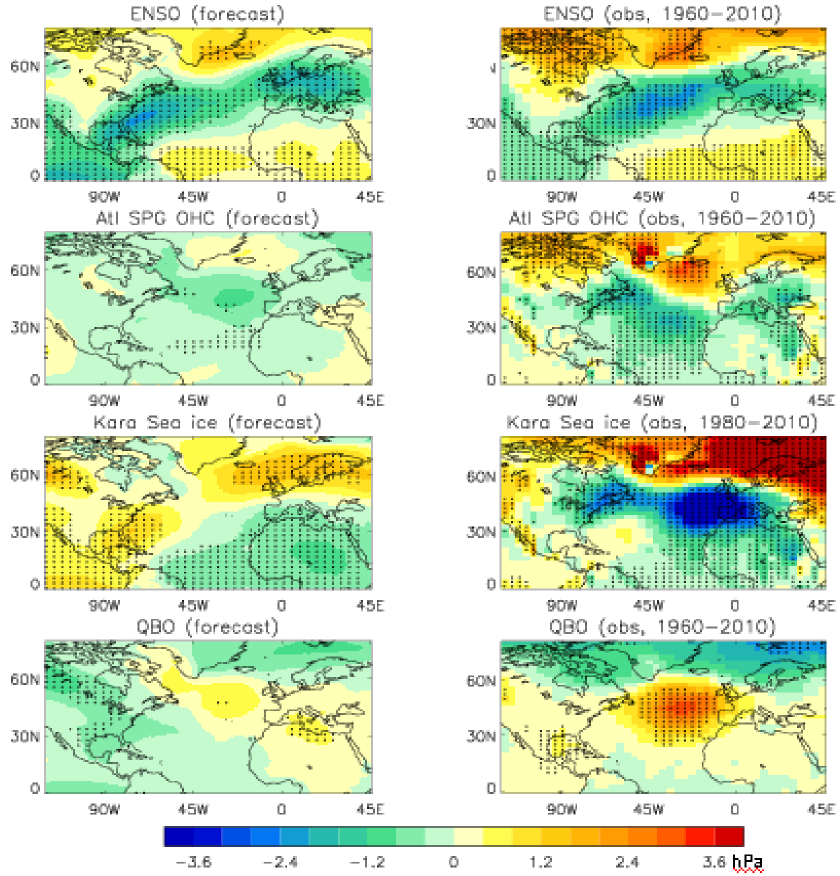
Sources of predictability

El Nino – La Nina

Warm – Cold N Atlantic

Low – High Kara Sea Ice

Wly – Ely QBO



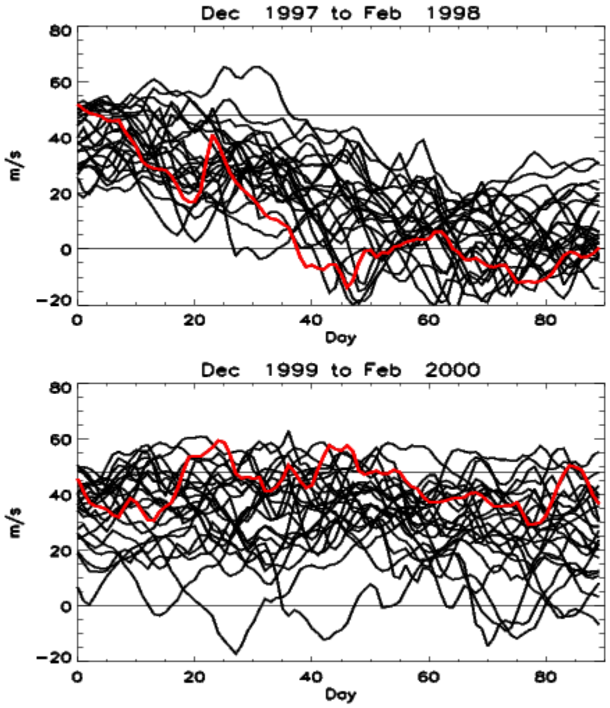
Some from El Niño Southern Oscillation (Toniazzo and Scaife 2006, Bell et al 2009, Ineson and Scaife 2009)
Some from Atlantic (Rodwell and Folland 1999, Folland et al 2002, Scaife et al 2011)
Some from Sea Ice (Pethoukov and Semenov 2011, Mori et al 2014)
Some from Quasi Biennial Oscillation (Boer and Hamilton 2009, Marshall and Scaife 2009, Scaife et al 2014)

This gives a correlation of ~0.5 (25% variance) – what about the rest?

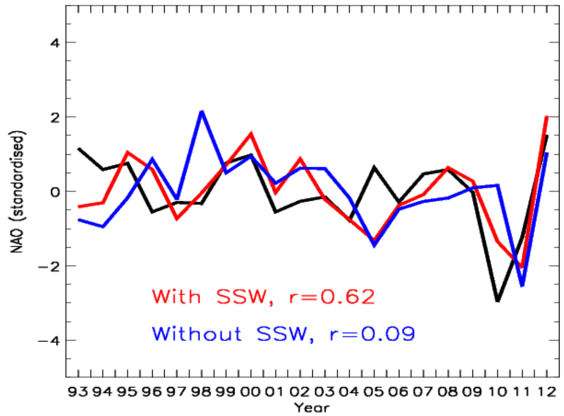
Scaife et al GRL, 2014

The stratosphere is involved

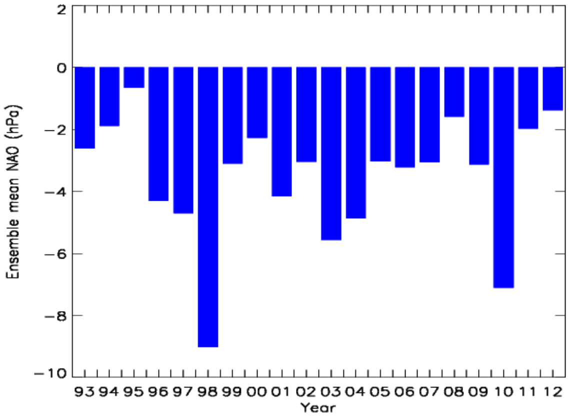
Sudden stratospheric warming risk



NAO skill depends on SSW



Effect varies from year to year



Probabilistic skill for sudden stratospheric warmings

Well beyond traditional predictability horizon of ~2 weeks

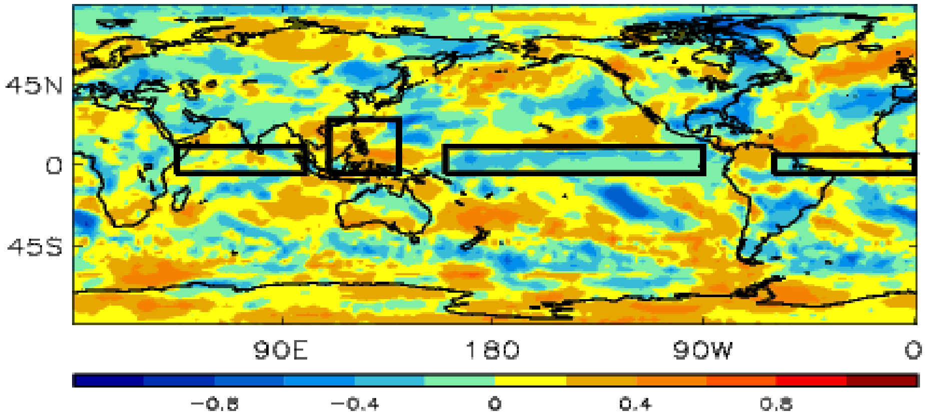
NAO skill is conditional on inclusion of these events

Scaife et al ASL, 2016

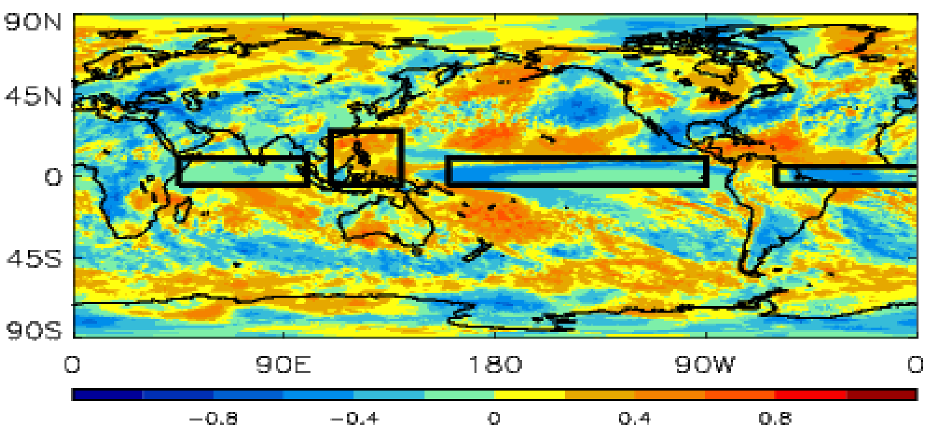
Where else could predictability come from?

Tropical rainfall....

Observed NAO versus Precipitation correlation



Modelled NAO versus Precipitation correlation



Similar connections in model and obs!

El Niño => -ve NAO

West Pacific rain => +ve NAO

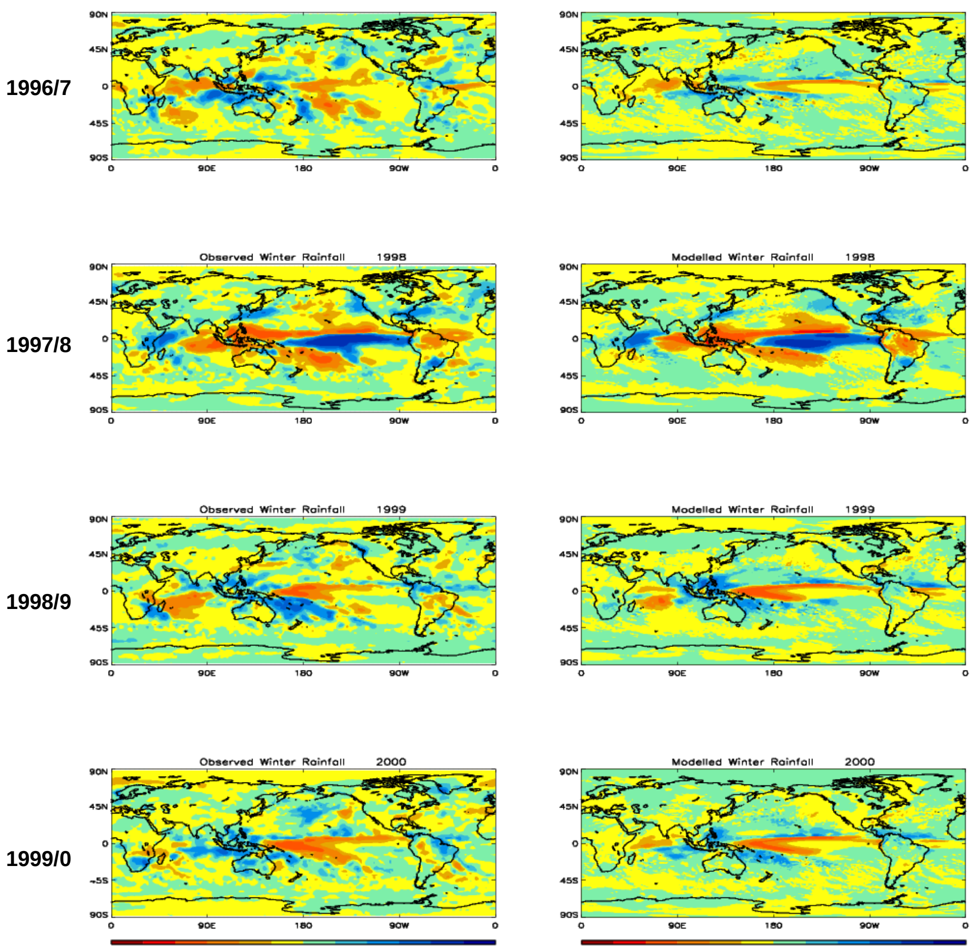
Interesting tropical Atlantic signals

Scaife et al, QJRMS, 2016

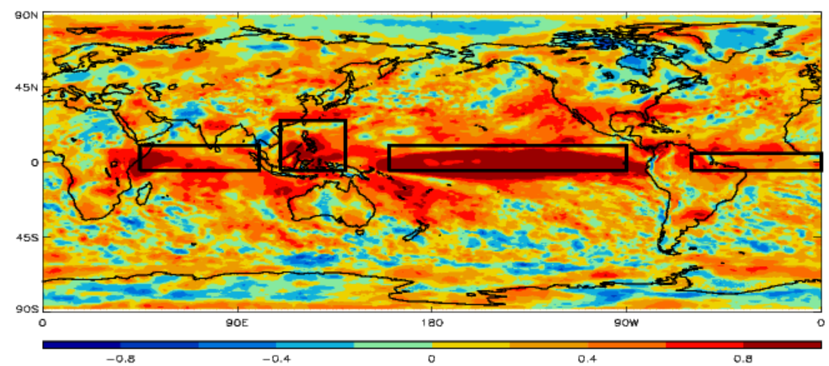
Tropical rainfall – some good news

Individual winter rainfall

Observations | **Model**



Interannual correlation skill



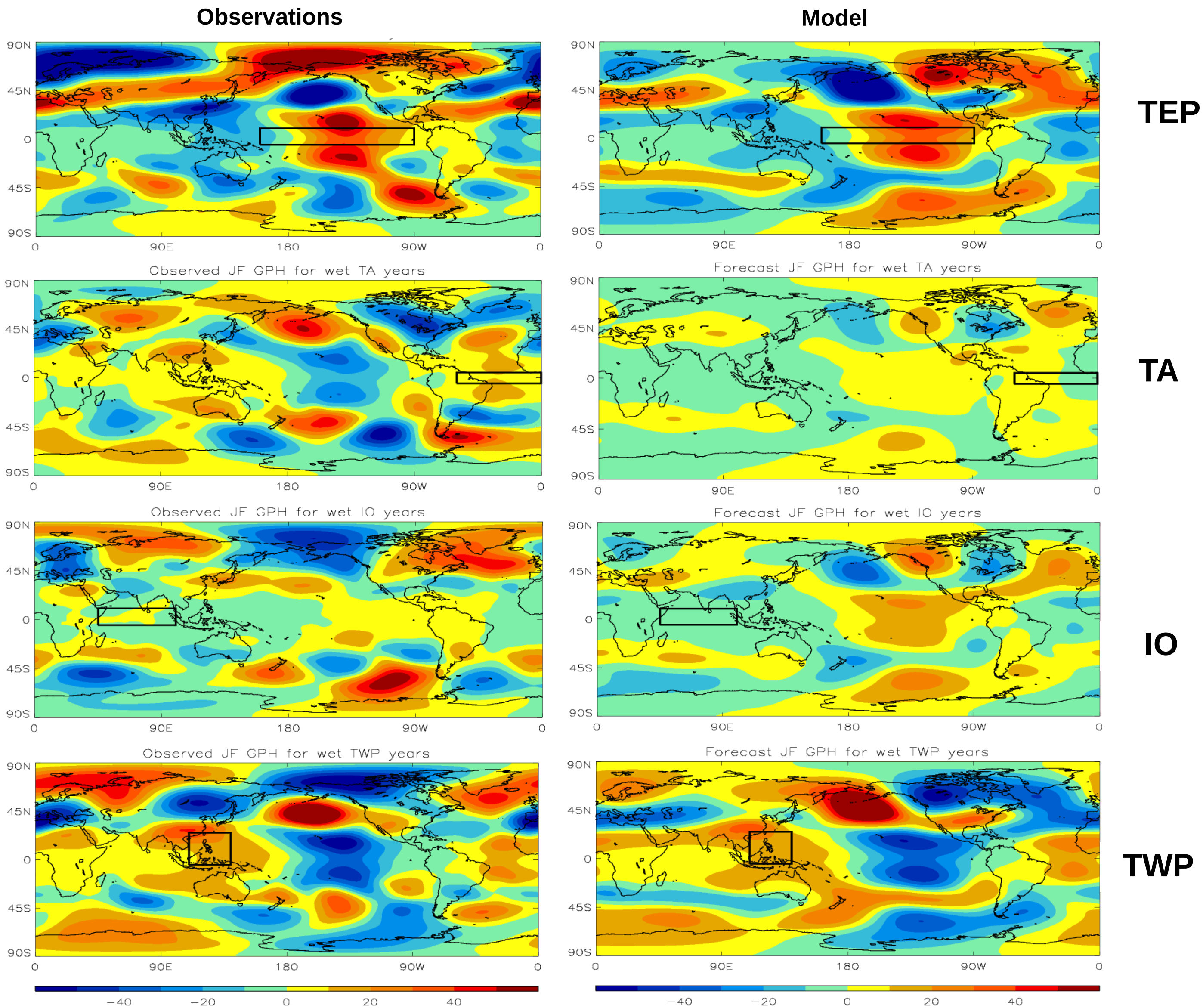
Tropical rainfall shows good prediction skill

Able to predict year to year changes

Encouraging correlations in all basins

Scaife et al, QJRMS, 2016

Wavelike teleconnections to tropical rainfall



Symmetrical about the equator as expected

Composites ~50m

Similar in model and obs

Regional detail different

Tropical Atlantic?

Largest signals not always local

We need a mechanism for extratropical signals...

Scaife et al, QJRMS, 2016

Wave Propagation

Met Office
Hadley Centre

Wave Dispersion Relation: $$\omega = \bar{u}k - \frac{(\beta - \bar{u}_{yy})k}{(k^2 + l^2)}$$

Group velocity: $c_g = \frac{\partial\omega}{\partial k}, \frac{\partial\omega}{\partial l}$ and assume stationary waves $\omega = 0$

Group velocity: $c_{gx} = \frac{2\bar{u}^2k^2}{(\beta - \bar{u}_{yy})}$ $c_{gy} = \frac{2\bar{u}^2k\,\{(\beta-\bar{u}_{yy})/\bar{u} - k^2\}^{1/2}}{(\beta - \bar{u}_{yy})}$

Eastward propagation is faster for shorter wavelengths (high k)

Meridional propagation stops at zero wind lines – *absorption*

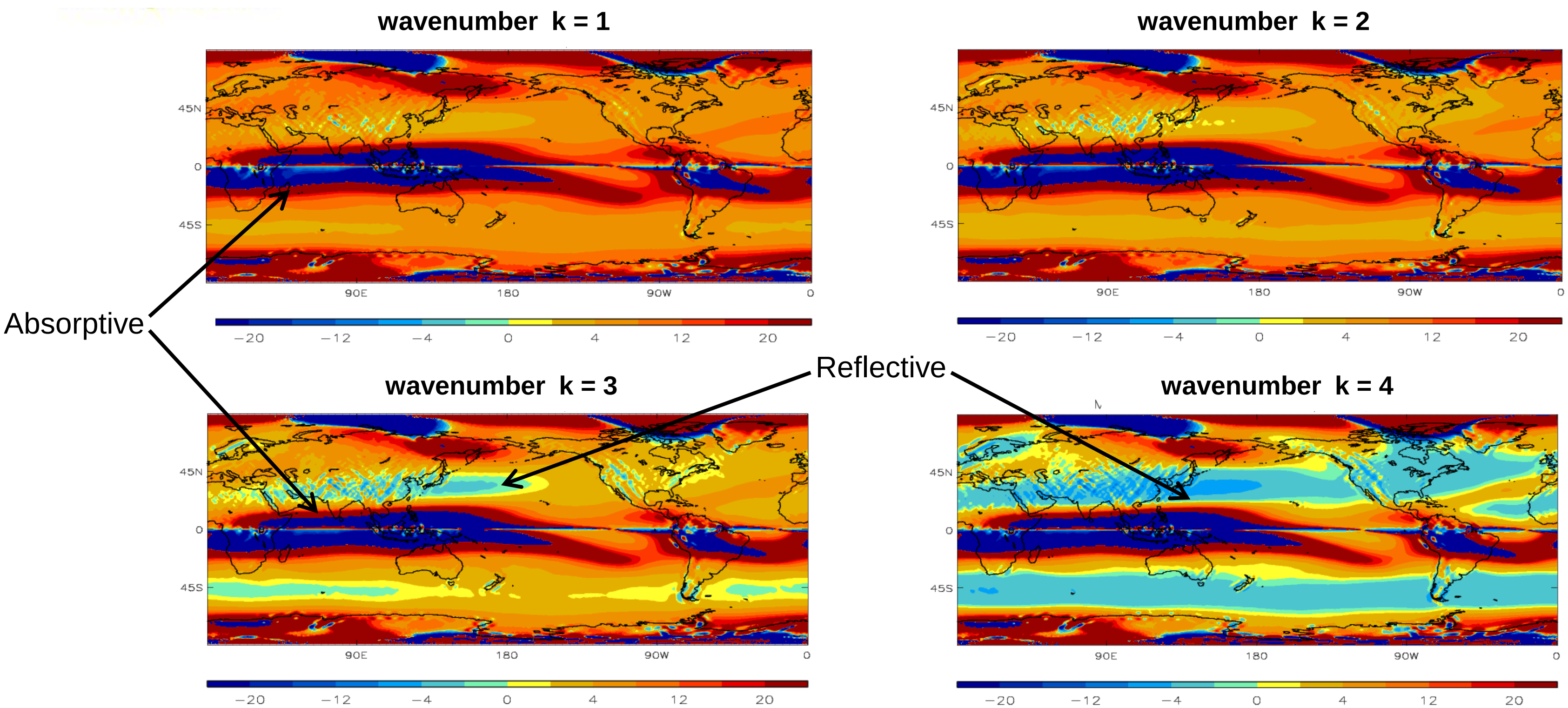
Meridional propagation stops in strong winds - *reflections*

Meridional propagation is easier for longer wavelengths (low k)

Curvature of the wind field can *in principle* prevent propagation

Rossby wave absorption and reflection

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

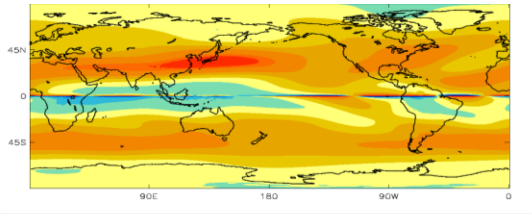
Light blue regions – reflection of short waves

Scaife et al, QJRMS, 2016

Ray Tracing **(see Hoskins and Karoly, 1981)**

Group velocity: $c_{gx} = \dfrac{2\bar{u}^2k^2}{(\beta - u_{yy})}$ $\quad c_{gy} = \dfrac{2\bar{u}^2k\,\{(\beta - \bar{u}_{yy})/\bar{u} - k^2\}^{1/2}}{(\beta - \bar{u}_{yy})}$

$k = 2\pi/\lambda$ $\quad \beta = \dfrac{2\Omega\cos\phi}{a}$ $\quad \bar{U} =$



Calculate local group velocity C_g

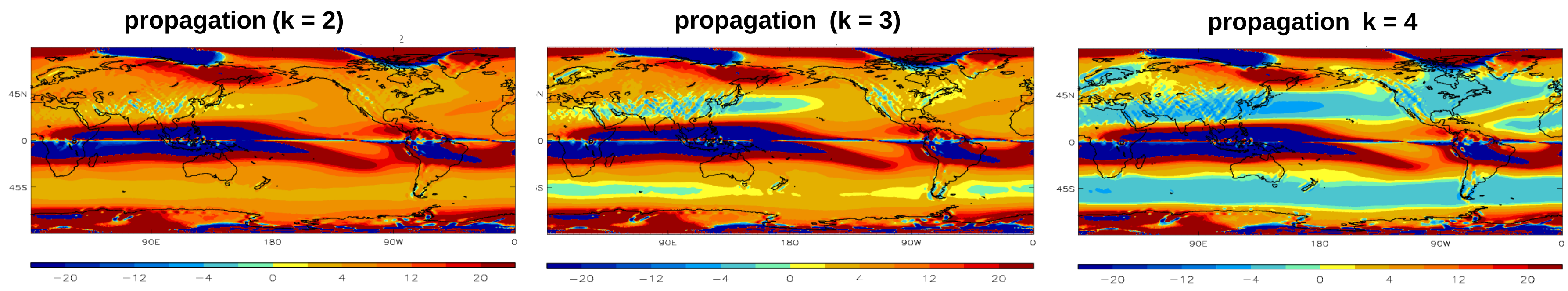
Discretise with a timestep of 2h

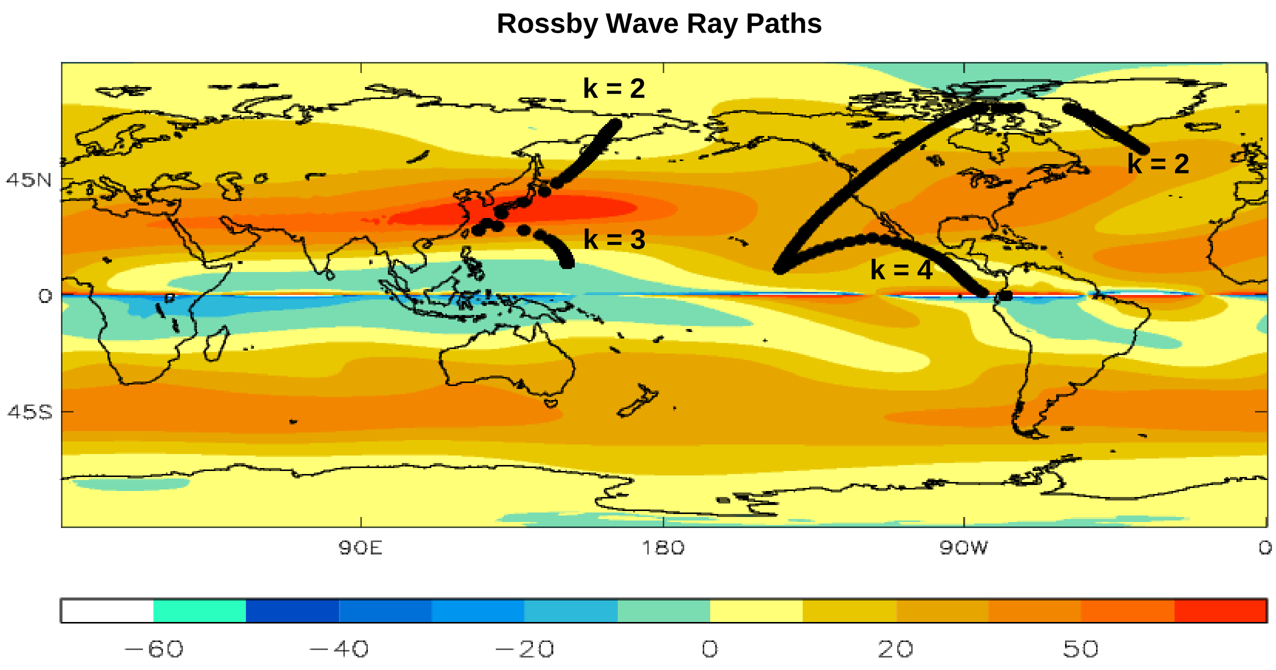
Calculate new ray position in spherical coordinates

Recalculate C_g

And so on.....

Rossby Wave Rays





<u>From the W Pacific:</u>

Wave2 propagates

Wave3 reflects

<u>From the E Pacific:</u>

Wave2 propagates

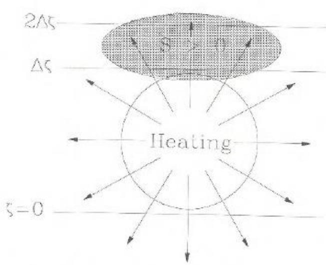
Wave4 reflects

Seems to be working...

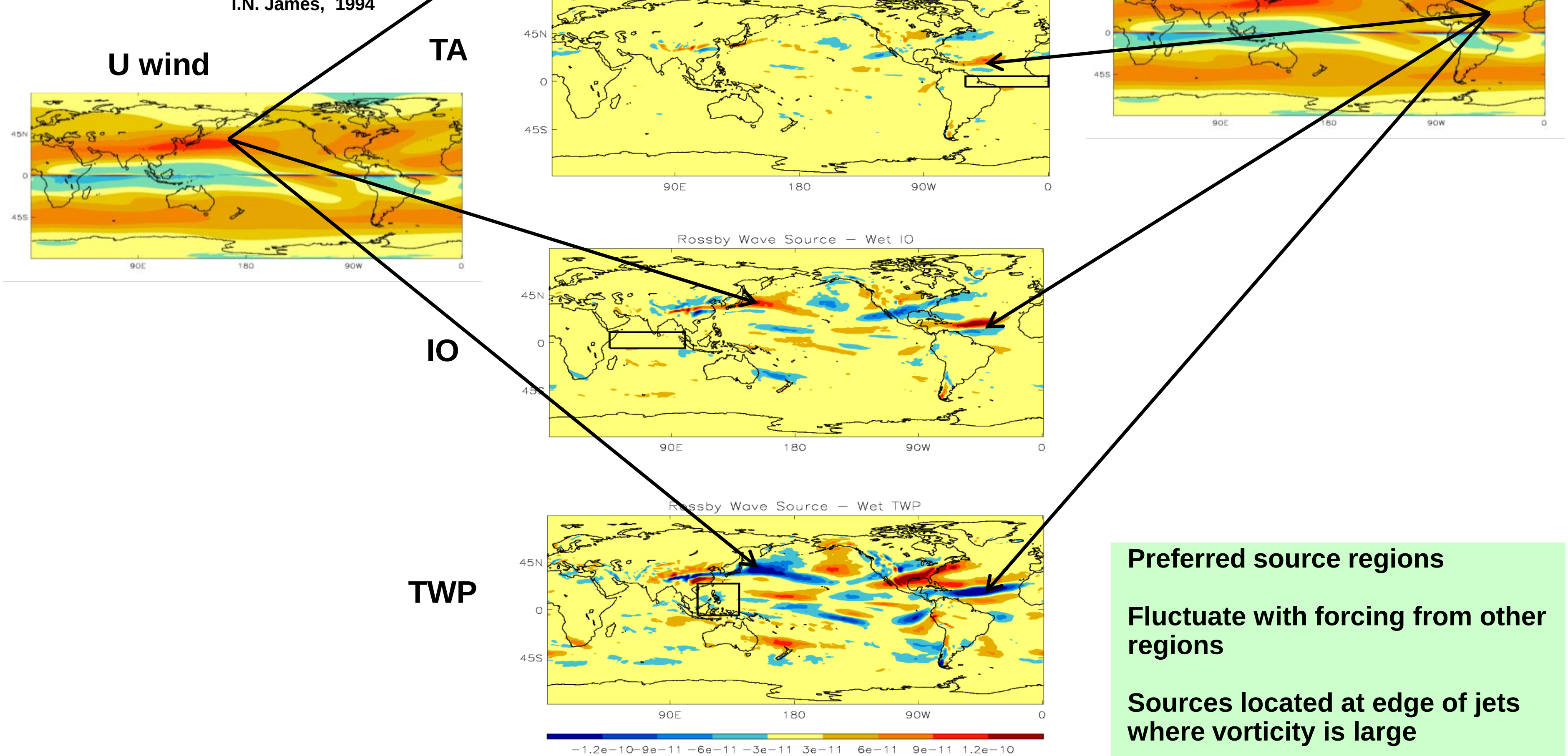
Scaife et al, QJRMS, 2016

Rossby Wave sources

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



I.N. James, 1994



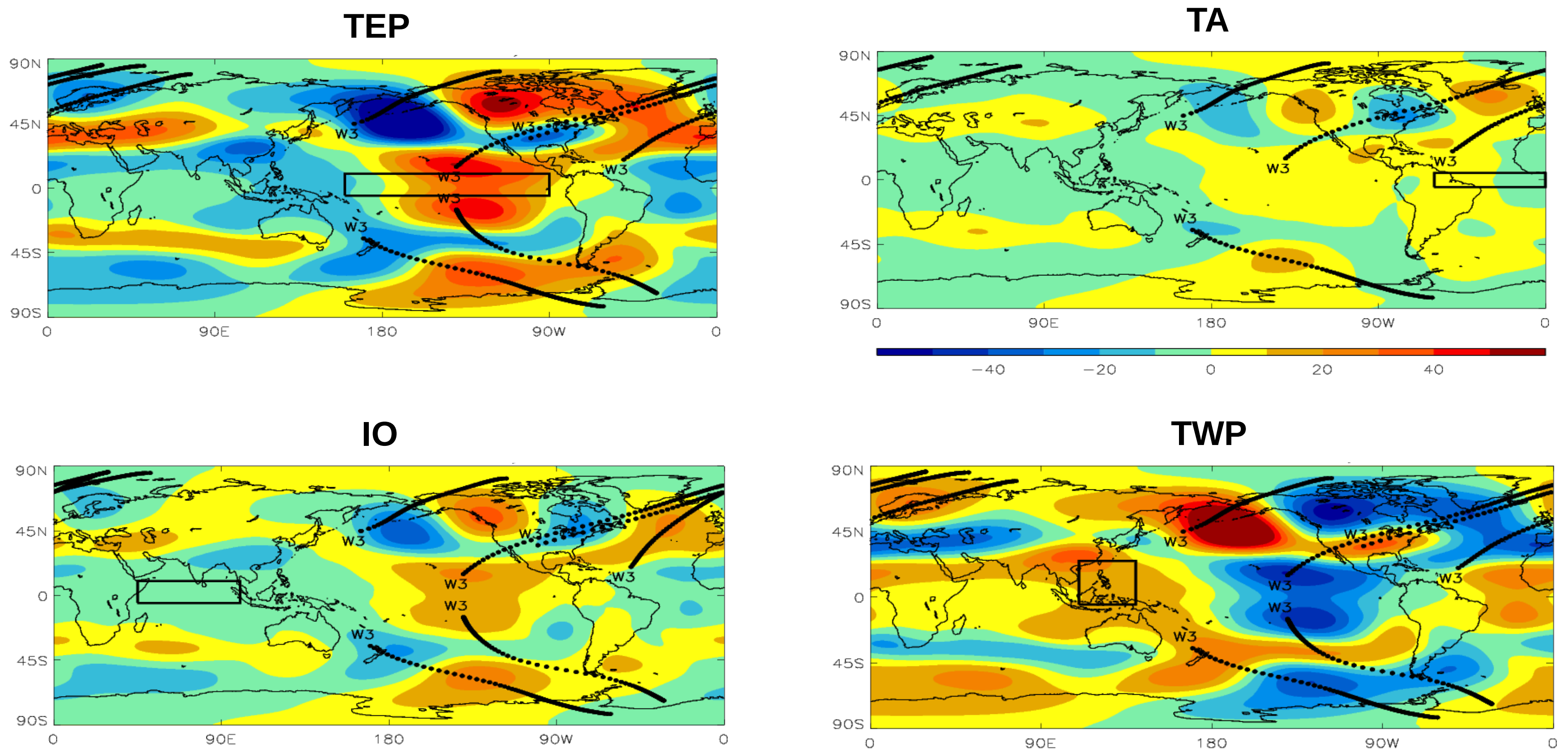
Preferred source regions

Fluctuate with forcing from other regions

Sources located at edge of jets where vorticity is large

Scaife et al, QJRMS, 2016

Teleconnections as Rossby Waves



Rays intersect main centres *from a few common sources*

Wave 2, 3 mainly responsible as wave 4 rarely propagates

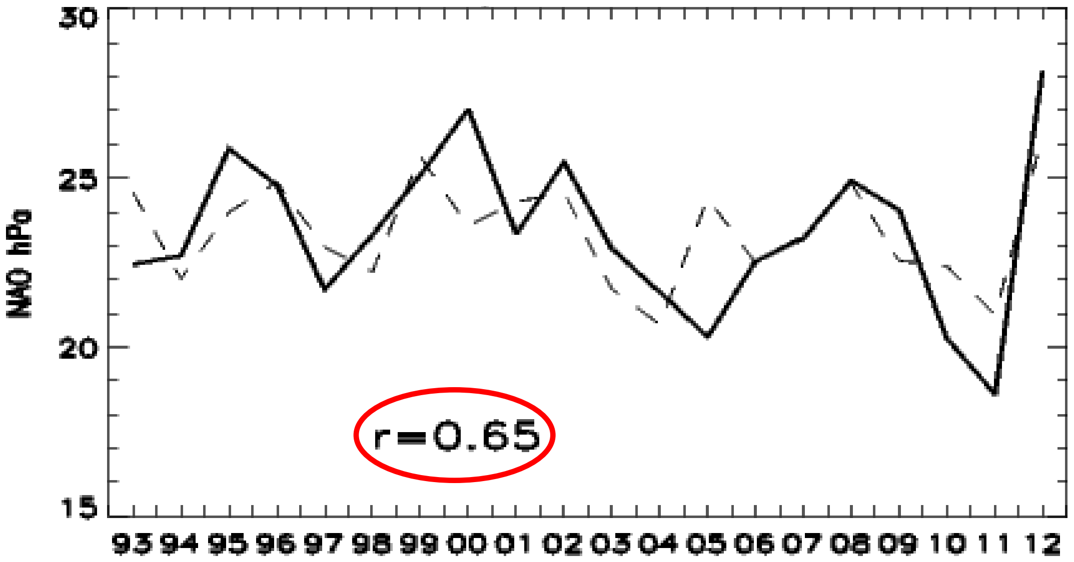
We have a theory for the teleconnections from tropical rainfall

But can this also explain the NAO forecast skill?

Scaife et al, QJRMS, 2016

Explaining forecasts of the NAO

Multiple linear regression to tropical ppn



Our four regional rainfall series explain a sizeable fraction (~40%) of forecast variance

The Atlantic is most important (but may indirectly represent other regions)

Note the 2004/5 winter which is not reproduced.....

Scaife et al, QJRMS, 2016

Met Office

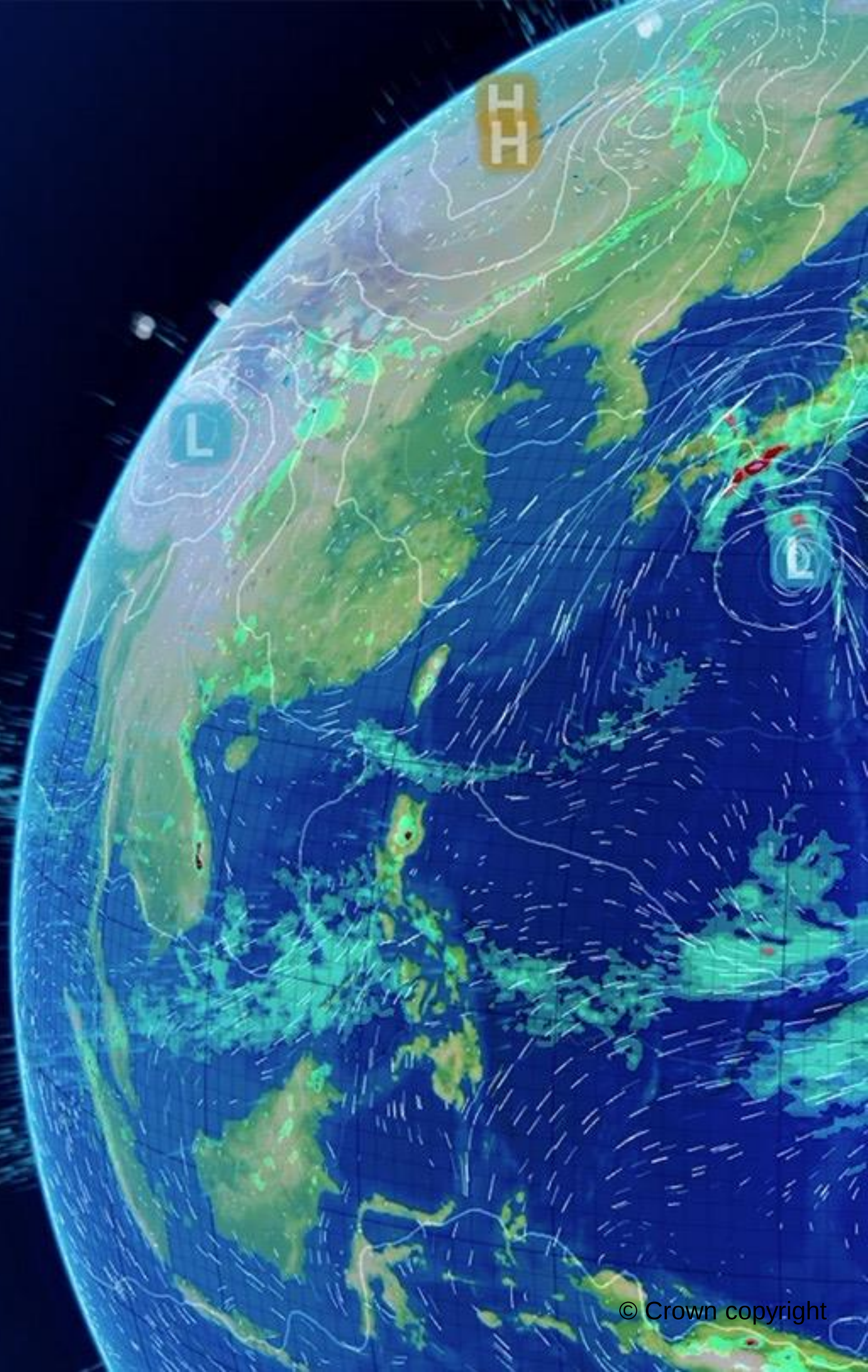
Winter Forecast Skill

Part 2: A case study and some applications

Prof. Adam Scaife

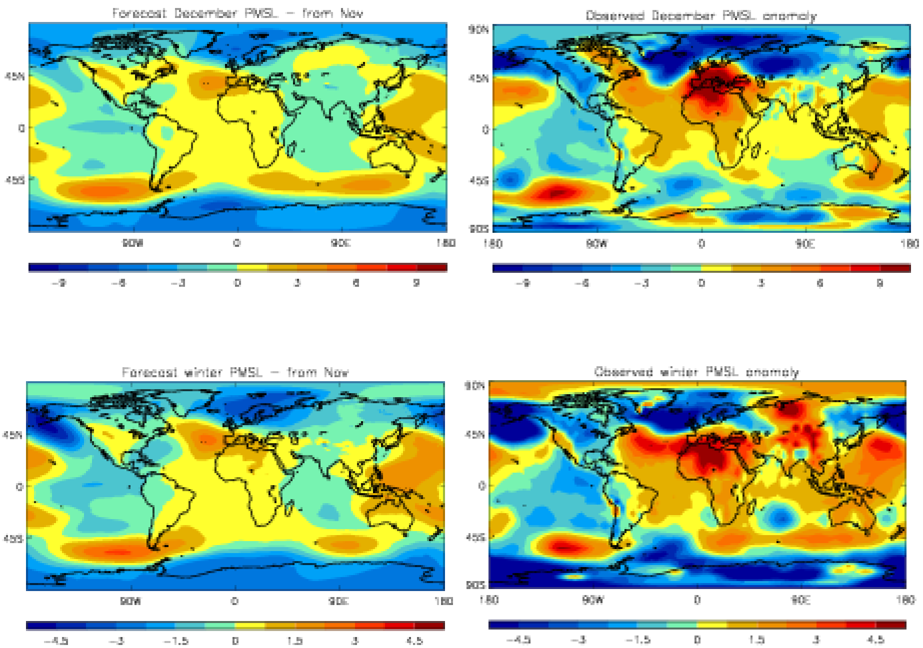
Head of Monthly to Decadal Prediction

Met Office Hadley Centre

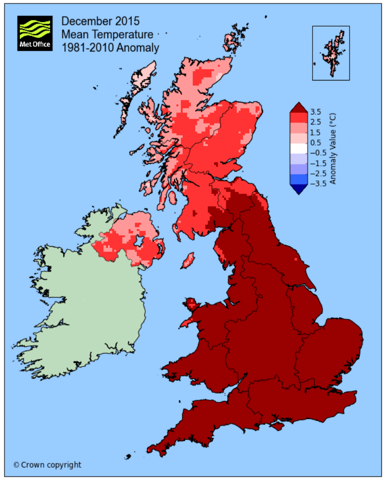


Last Winter 2015/16

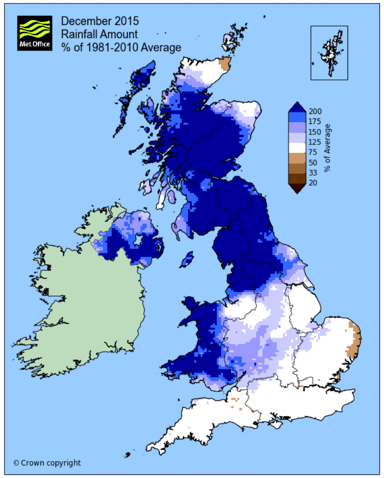
From November | **Observations**



December Temperature



December Rainfall



Very clear signals for a westerly winter

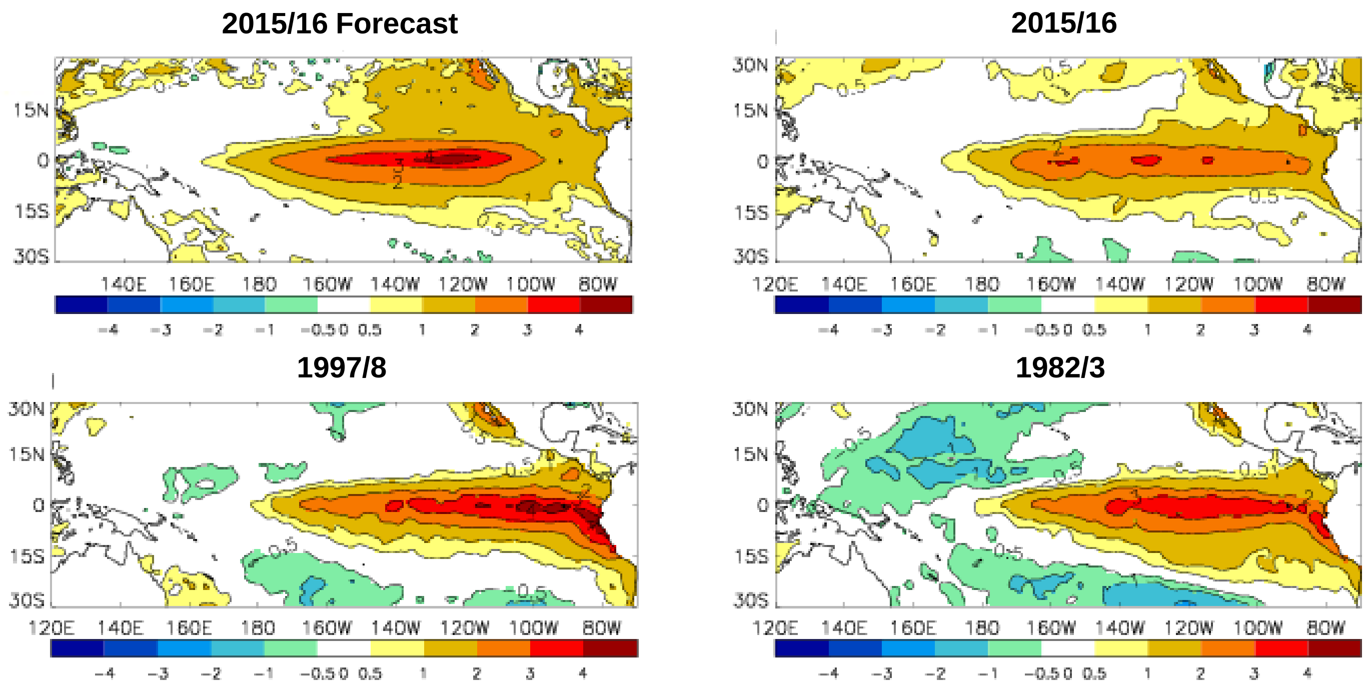
Good agreement with subsequent observations

Early warning of December flooding

Driven by ENSO + few others

Scaife et al, ASL, accepted

Winter 2015/16: a near record El Niño



Very clear signals for a near record event

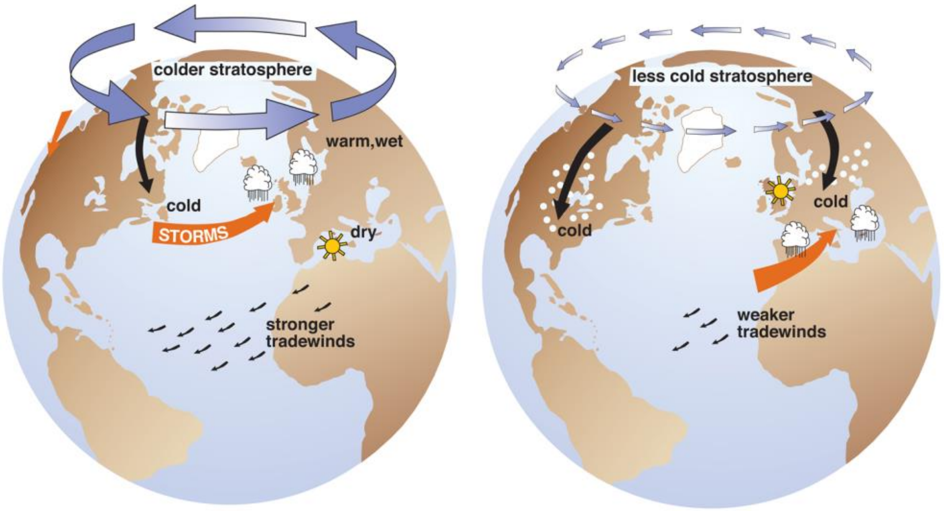
Remote but not irrelevant

Similar to 1982/3

Scaife et al, ASL, submitted

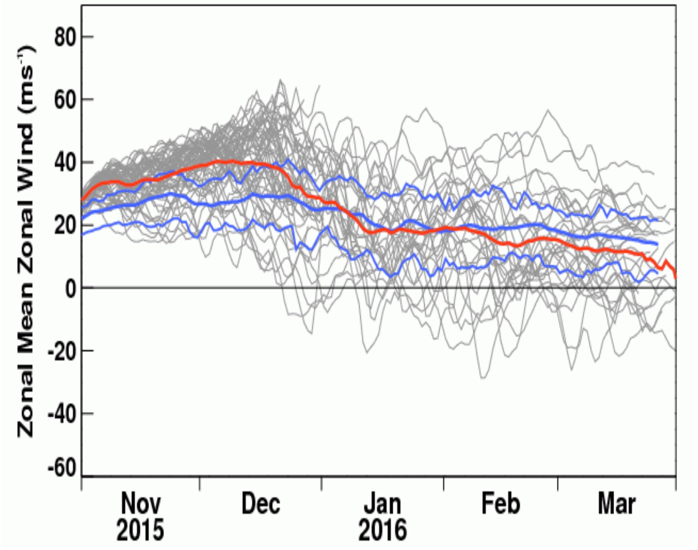
Last Winter 2015/16

Strong polar vortex | **Weak polar vortex**



NSIDC

Forecasts of the polar vortex

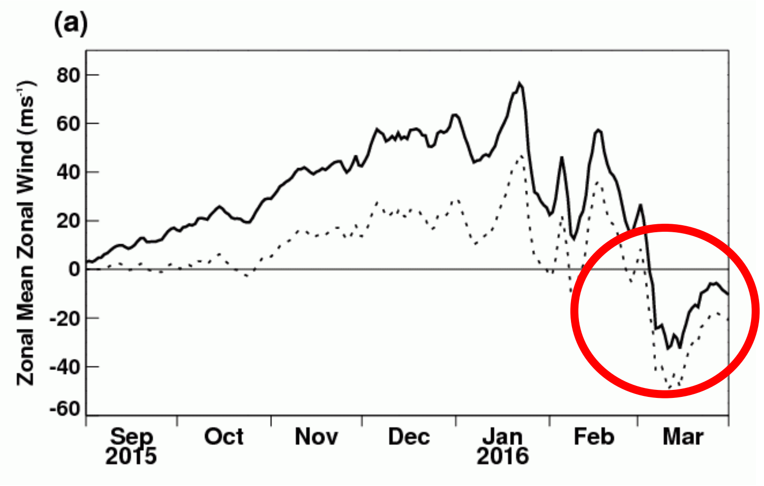


Very strong in December, weak towards late winter

=> low pressure and a mild, wet and stormy start to winter

Scaife et al, ASL, submitted

Stratospheric conditions: winter 2015/16

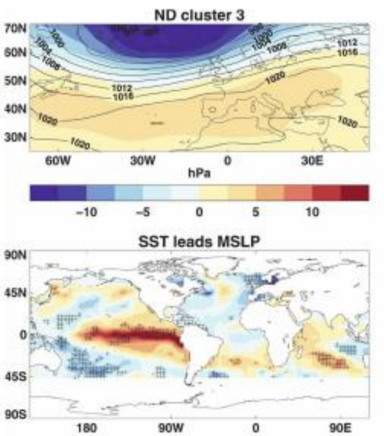


A sudden warming finally happened in early March (consistent with the cold dry start to spring)

Later than the most likely time in the forecasts but within the spread of forecasts from Autumn

Scaife et al, ASL, submitted

Early vs late winter and an analogue...



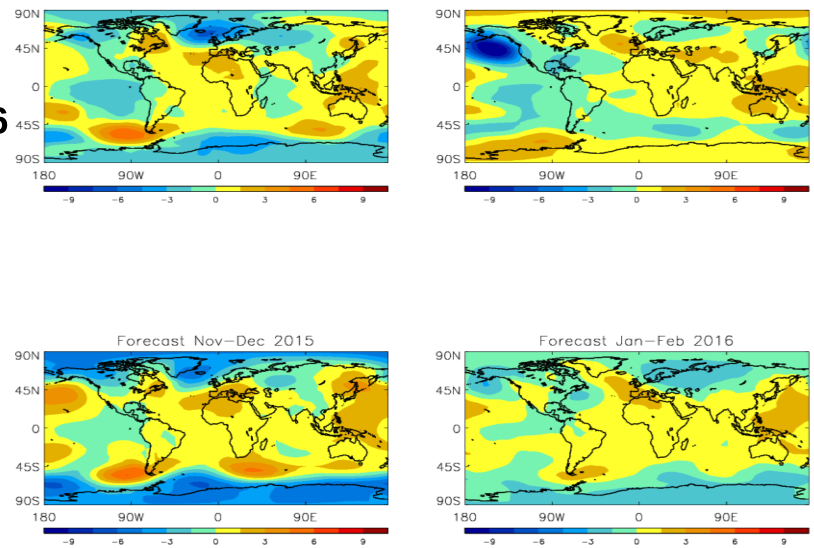
Fereday et al,
Clim. Dyn., 2008

Early winter
Nov-Dec

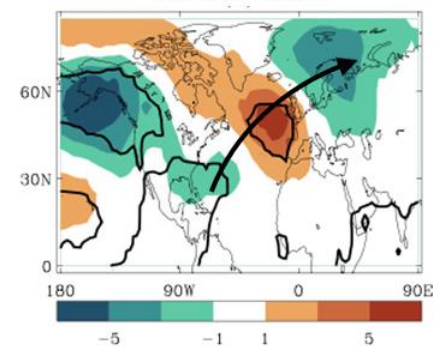
Late winter
Jan-Feb

2015/16

1982/83



Strong El Niño



Toniazzo and Scaife,
GRL, 2006

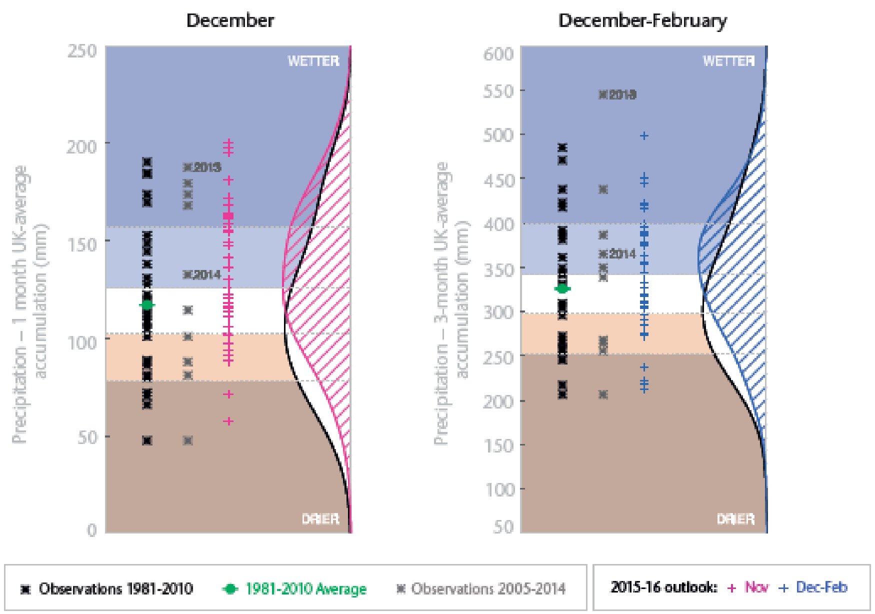
Remarkable similarity with 1982/3 case

Remarkable similarity in late and early winter to other strong El Nino events

Scaife et al, ASL, submitted

Winter 2015/16: November Forecast

1-month and 3-month UK outlook for precipitation in the context of observed climatology



December showed a very clear signal for wet

Circulation implied increased storm risk

Dec-Feb showed similar signal overall but a switch to colder in late winter

Allowed real time *warnings* to:

DEFRA, Cabinet Office and DfT

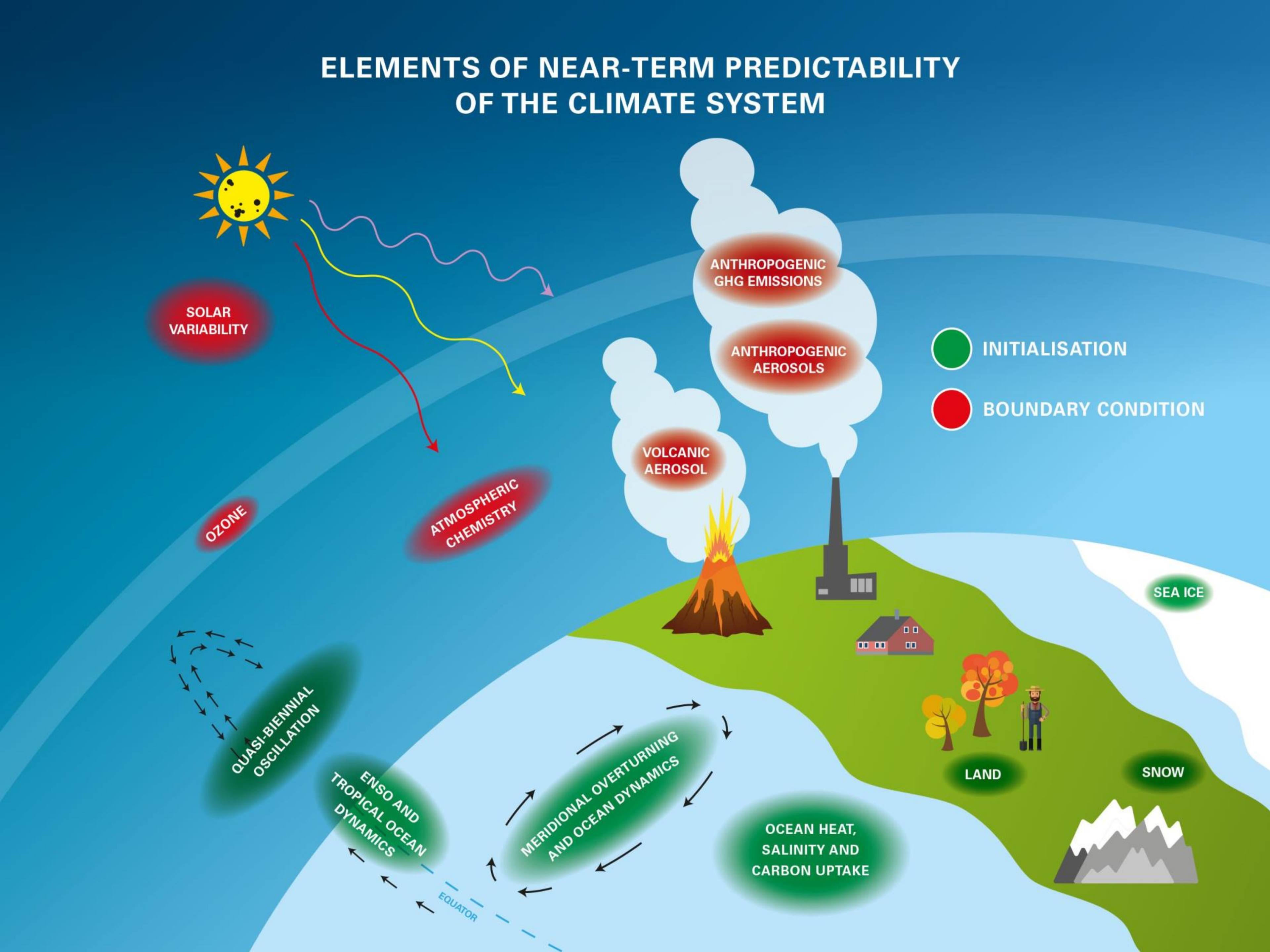
SUMMARY - TEMPERATURE:

During December above-average temperatures are more likely than below-average temperatures. The likelihood of a prolonged spell of cold weather is relatively low compared to normal.

Predictions for UK-mean temperature for the whole of the winter season (December-January-February) show only a slight shift from the normal range of expected conditions. In this instance, however, there are reasons to believe that this unremarkable outlook conceals the likelihood of a switch from a mild start to winter towards colder conditions later on. These different phases balance the probability of above- and below-average conditions in the overall 3-month average, but that does not imply normal chances of weather impacts this winter. Specifically, we consider there to be an increased risk of storms and very wet conditions in the early part of the winter, and a greater risk of cold weather impacts in late winter.

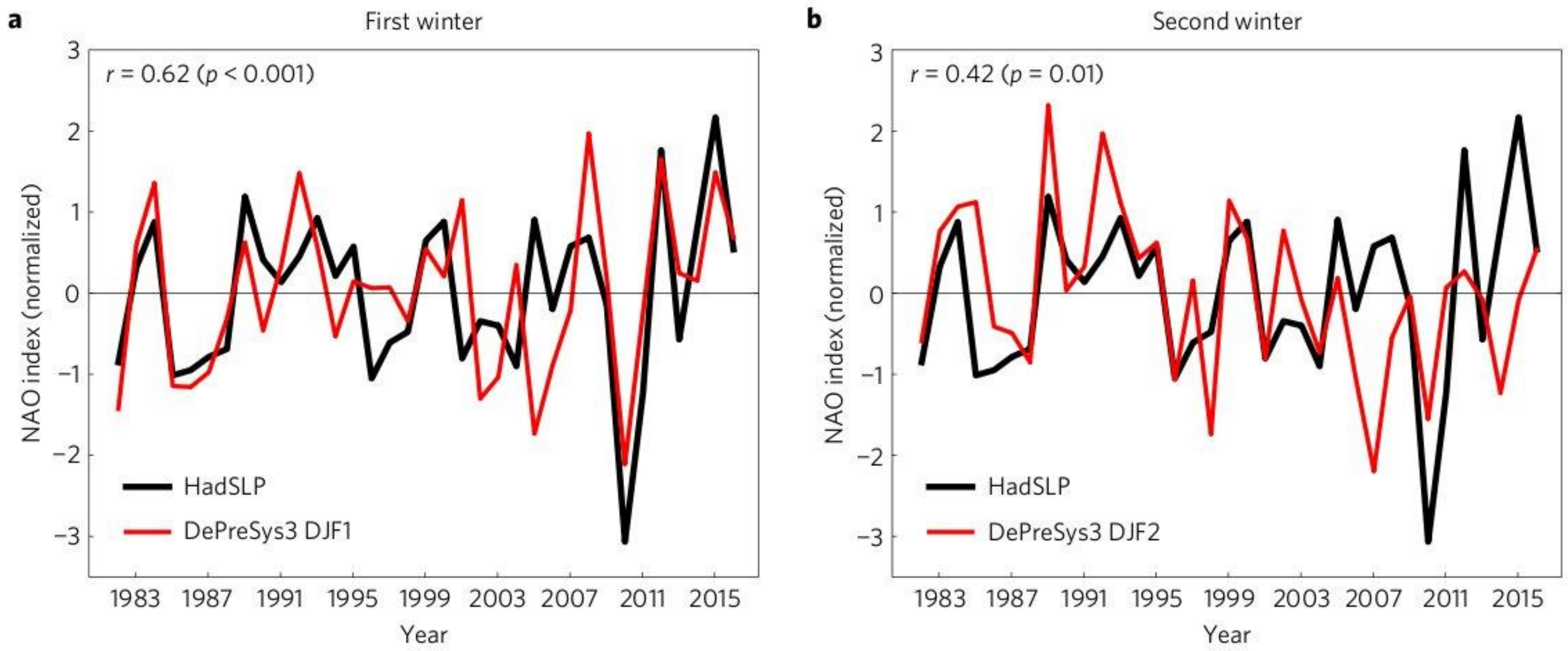
Overall, the probability that the UK-average temperature for December-January-February will fall into the coldest of our five categories is 15% and the probability that it will fall into the warmest of our five categories is between 20% and 25% (the 1981-2010 probability for each of these categories is 20%). As stated above, however, these overall statistics disguise a shift in probabilities as winter progresses.

Further ahead



ELEMENTS OF NEAR-TERM PREDICTABILITY
OF THE CLIMATE SYSTEM
SOLAR VARIABILITY
OZONE
ATMOSPHERIC CHEMISTRY
ANTHROPOGENIC GHG EMISSIONS
ANTHROPOGENIC AEROSOLS
VOLCANIC AEROSOL
INITIALISATION
BOUNDARY CONDITION
SEA ICE
QUASI-BIENNIAL OSCILLATION
ENSO AND TROPICAL OCEAN DYNAMICS
MERIDIONAL OVERTURNING AND OCEAN DYNAMICS
OCEAN HEAT, SALINITY AND CARBON UPTAKE
LAND
SNOW
EQUATOR

Is there multiyear predictability?



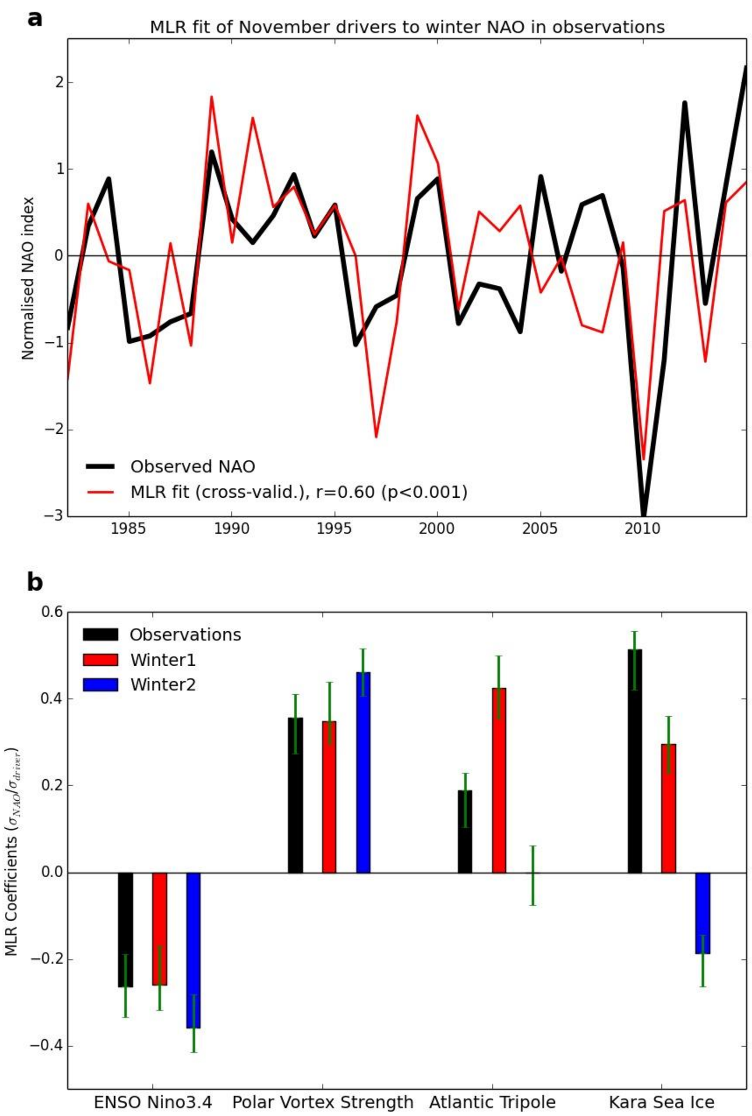
New hindcasts out to 2 years

NAO predictability in the second winter!

Potential for multiyear skill

Dunstone et al, Nat Geosci, 2016

A few drivers of predictability



Much of the skill can be explained by:

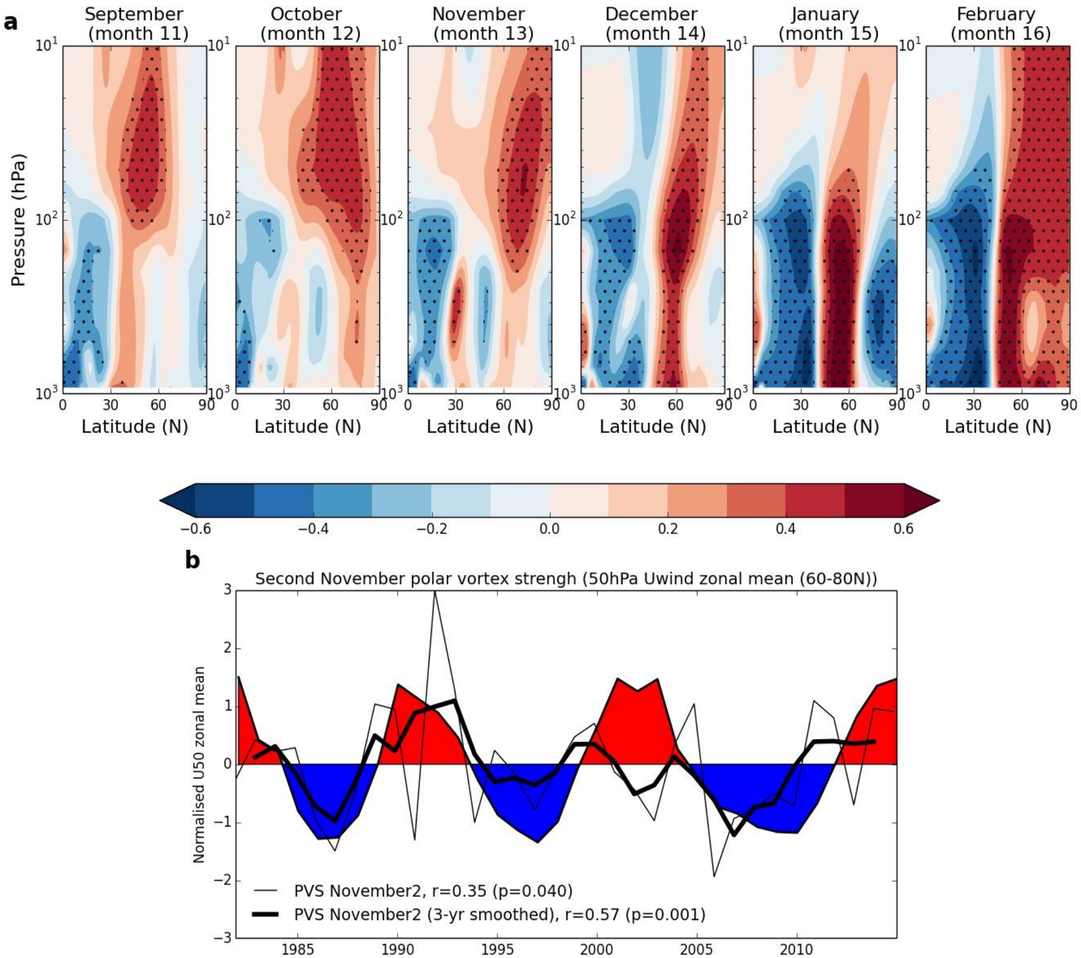
- **ENSO**
- **Polar vortex strength**
- **Atlantic Tripole**
- **Kara sea ice**

Using multiple linear regression model

This also does well with the observed NAO

Dunstone et al, Nat Geosci, 2016

Solar variability plays a role



Solar variability affects the jet

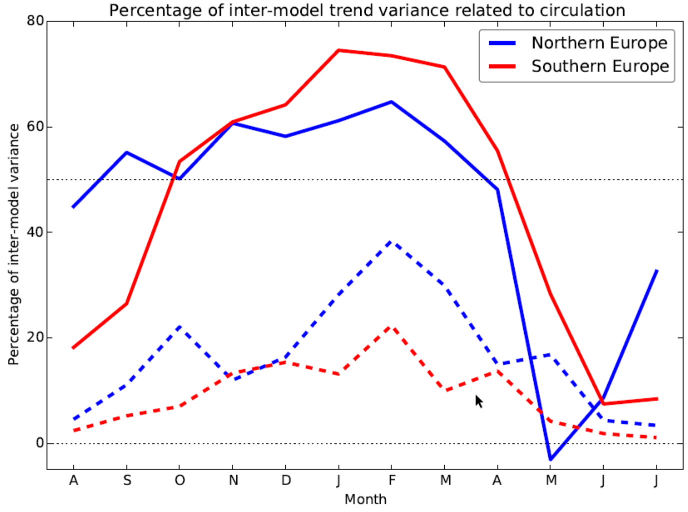
Signals burrow downwards

Ultimately change the NAO

Dunstone et al, Nat Geosci, 2016

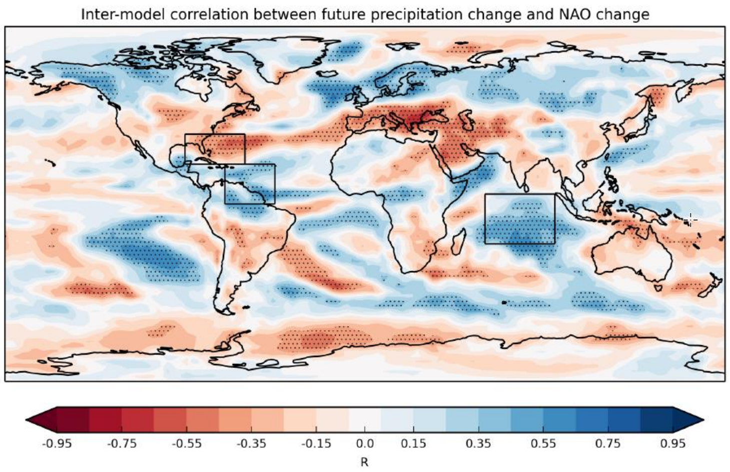
Even further ahead

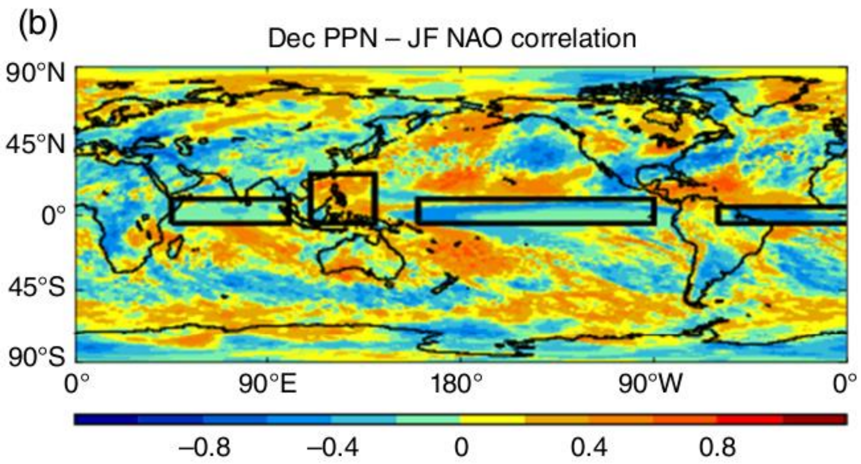
Similar processes affect climate change



Dynamics explains majority of uncertainty in future UK winter rainfall

Similar teleconnections to the Caribbean and Indian regions





Fereday et al, 2017

Scaife et al, 2016

Climate Services?

Climate services: hydrology

UK winter river flows

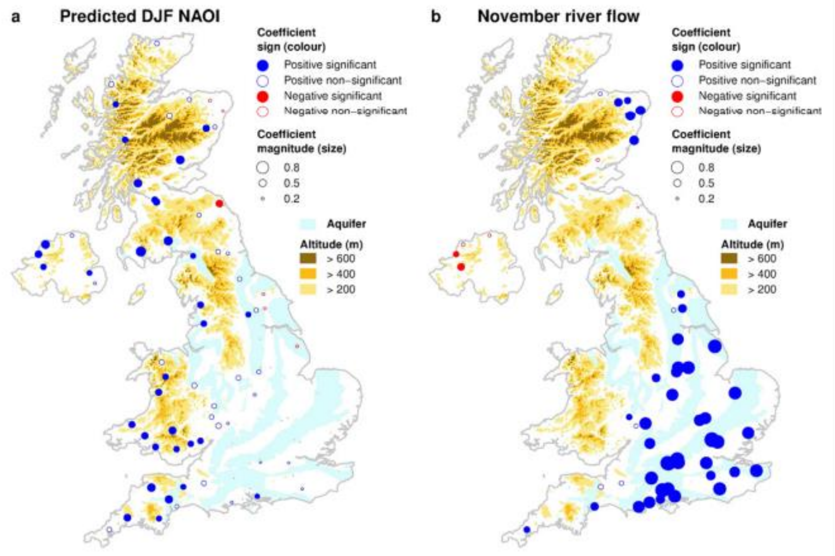


Figure 2. Sources of predictability of winter river flows as reflected by the coefficients for a regression model of winter river flow on either or both of two predictors: long-range forecasts of atmospheric circulation over the North Atlantic as characterized by the NAO index (a), and observed monthly mean river flow for November (b). The aquifer outcrop areas (light blue shading) show where groundwater makes an important contribution to river flows.

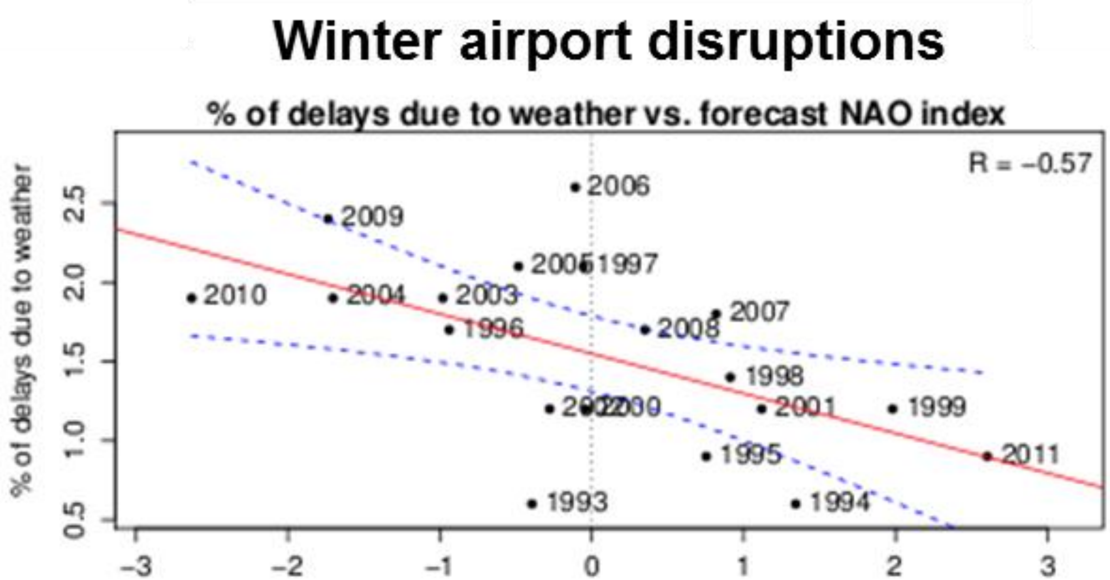
Application of seasonal forecasts is now feasible

Hydrology is an obvious example

Here we have skilful winter river flow predictions

Svensson et al ERL 2015

Climate services: transport impacts



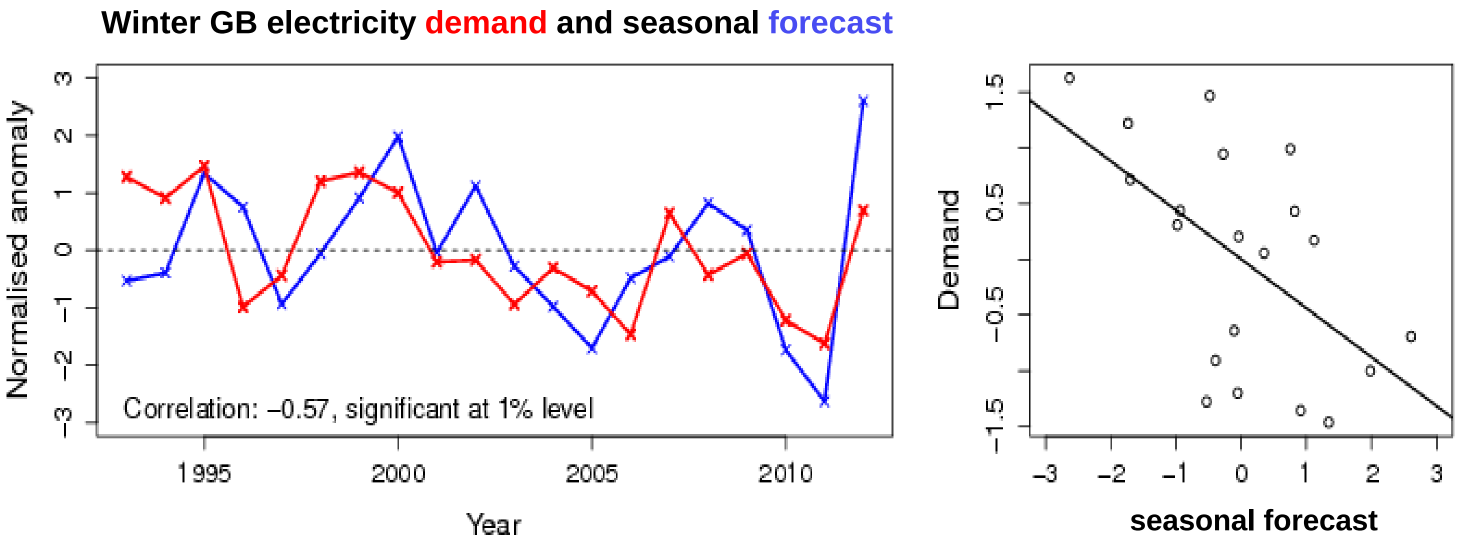
seasonal forecast

Extreme winter weather has an impact on transport

Seasonal forecast skill translates to skill in transport impacts

Palin et al, Met Apps, 2015

Climate services: energy predictions

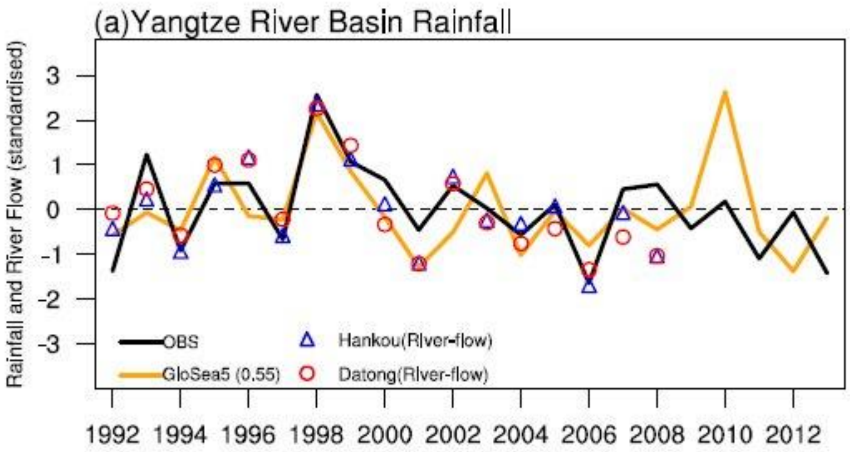


Both energy demand and supply are skilfully predicted

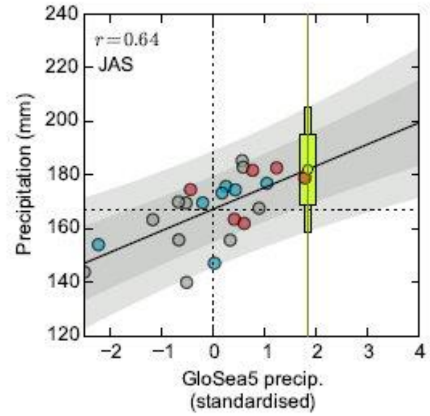
Could be used to predict likely winter demand

Clark et al, ERL, submitted

Climate Services: Yangtze rainfall and river flow



Li et al, ERL, 2016



Above-average precipitation		Observed: Yes	Observed: No
Predicted	Yes	10 Hits	4 False alarms
Predicted	No	4 Misses	5 Correct rejections
Hit Rate:		70%	
False Alarm Rate:		45%	

Useful regional average skill (r = 0.55)

Real time service tested

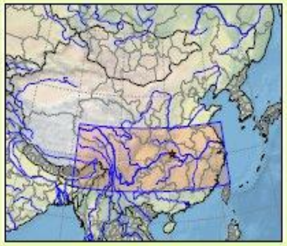
This document provides forecasts for the Yangtze river region in 2016. The region used is shown on the right. The location of the Three Gorges Dam is marked with a star. Forecasts are for area-averaged seasonal precipitation accumulations, or river flow. The current headline results are:

For the coming 3-month period (JAS):

- **There is a 90% chance of above-average *rainfall*.**
- **There is a 85% chance of above-average *river flow*.**

For the following 3-month period (ASO):

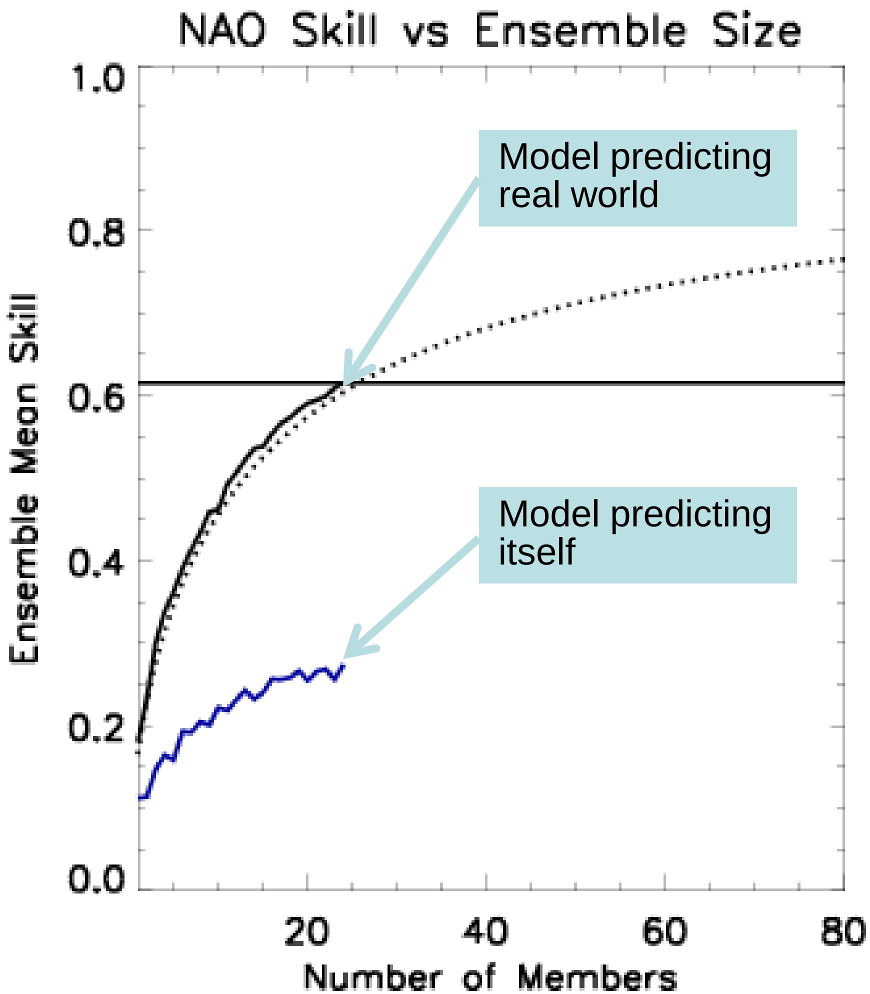
- **There is a 75% chance of above-average *rainfall*.**



Wuhan flooding, photo: Radio Free Asia

A mysterious outstanding issue

Outstanding issues: signal to noise ‘paradox’



Model ensemble mean predicts the real world better than itself!

High skill despite low signal to noise in model

“signal to noise paradox”

Eade et al, GRL, 2014

Conclusions

- **Skilful predictions of the winter NAO are possible**
  - **Predictions on seasonal and to some degree interannual lead times show skill**
  - **Large ensembles are needed**
  - **Signals are anomalously small – why?**

- **Tropical rainfall explains some of the extratropical skill**
  - **Rainfall is highly predictable despite large mean biases**
  - **Large extratropical responses, symmetric about the tropics**
  - **Linear Rossby wave dynamics goes a long way to explaining these**

- **Individual case studies can teach us a lot**
  - **Real time forecasts: so far so good**
  - **Winter 2015/16 was a predictable case with big impacts: are we using our science enough?**

- **Early climate services are now being developed**
  - **Both European and worldwide**
  - **Many sectors and applications – we are happy to collaborate – there is a lot more to do!**