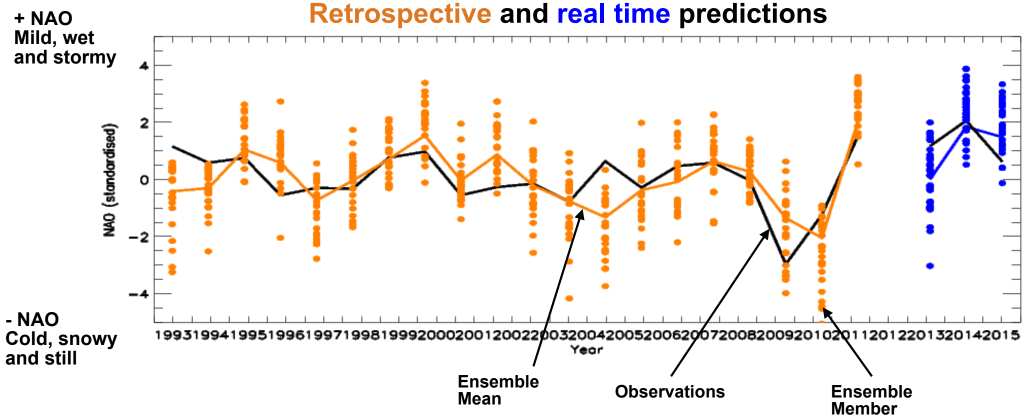
Met Office
Hadley Centre

Teleconnections to the winter North Atlantic Oscillation

Prof Adam A. Scaife
Head of Monthly to Decadal Prediction
Met Office Hadley Centre

North Atlantic predictions are skilful



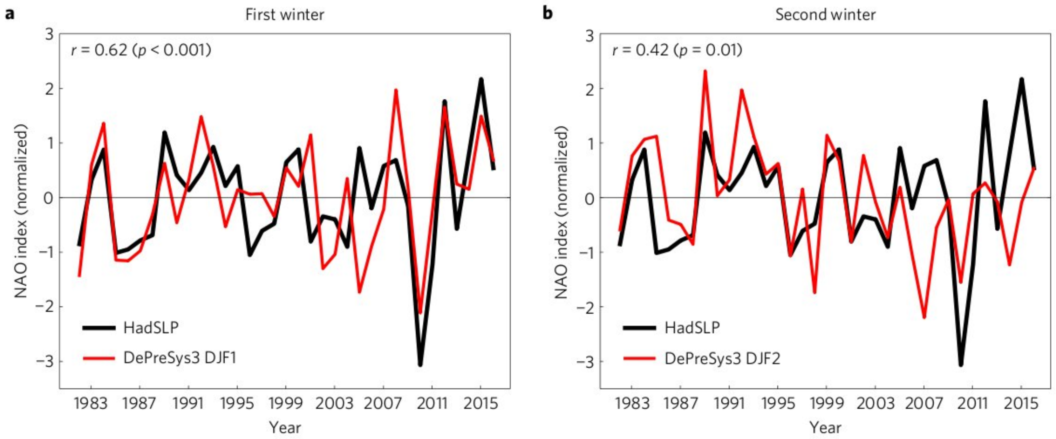
Our original tests are shown in orange and indicate a correlation skill of 62%

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

So far so good with real time forecasts...

Scaife et al, GRL, 2014

Is there multiyear predictability?



New hindcasts out to 2 years

NAO predictability in the second winter!

Dunstone et al, Nat Geosci, 2016

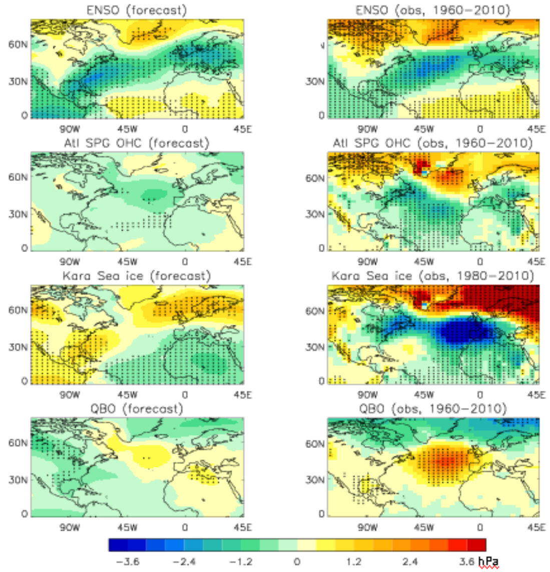
Sources of predictability

El Nino – La Nina

Warm – Cold N Atlantic

Low – High Kara Sea Ice

Wly – Ely QBO

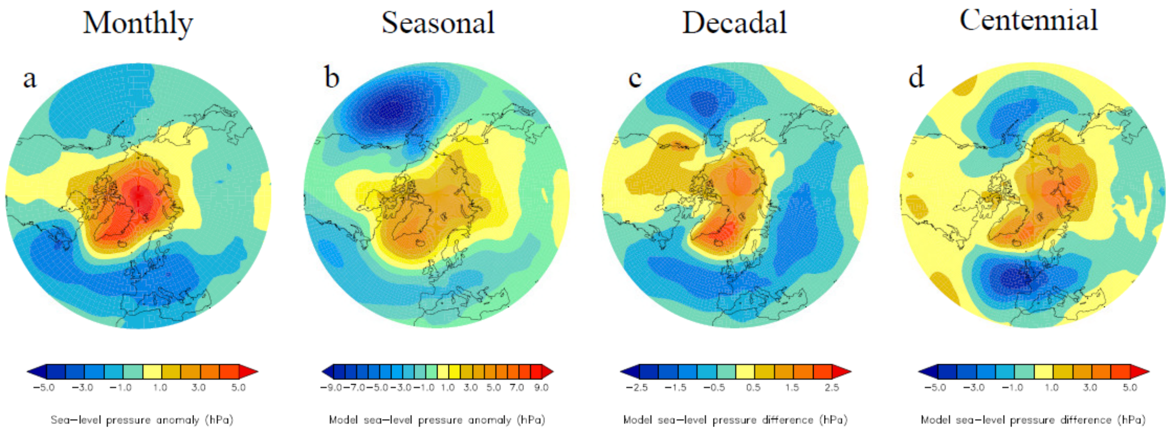


Some from El Niño Southern Oscillation (Toniazzo and Scaife 2006, Bell et al 2009, Ineson and Scaife 2009)
Some from Atlantic (Rodwell and Folland 1999, Folland et al 2002, Scaife et al 2011)
Some from Sea Ice (Pethoukov and Semenov 2011, Mori et al 2014)
Some from Quasi Biennial Oscillation (Boer and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



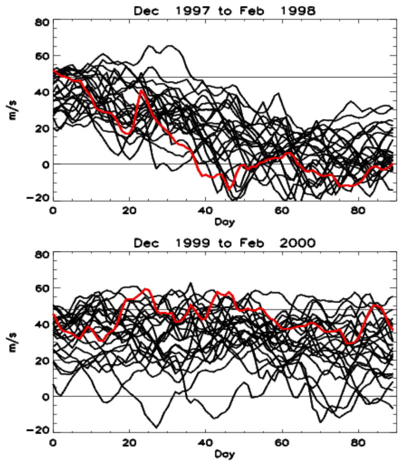
SSW **ENSO** **Solar** **Climate Change**

All stratospheric – all show same NAO response in troposphere

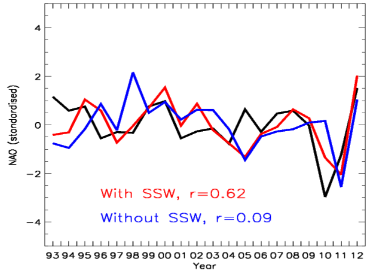
Kidston et al, Nat. Geosci., 2015.

The stratosphere is involved

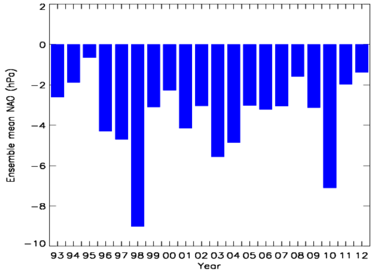
Sudden stratospheric warming risk



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

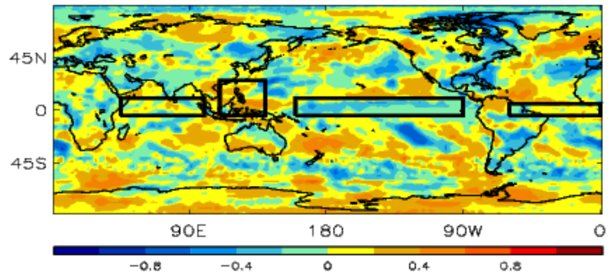
NAO skill is conditional on inclusion of these events

Scaife et al ASL, 2016

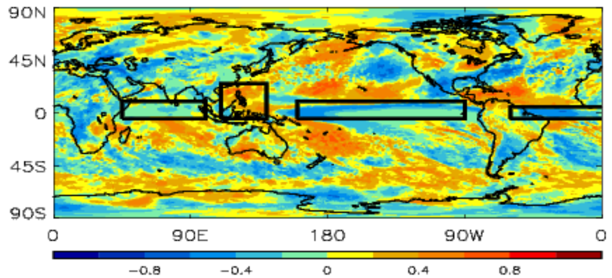
Where else could predictability come from?

Tropical rainfall....

Observed NAO versus Precipitation correlation



Modelled NAO versus Precipitation correlation



Similar connections in model and obs!

El Niño => -ve NAO

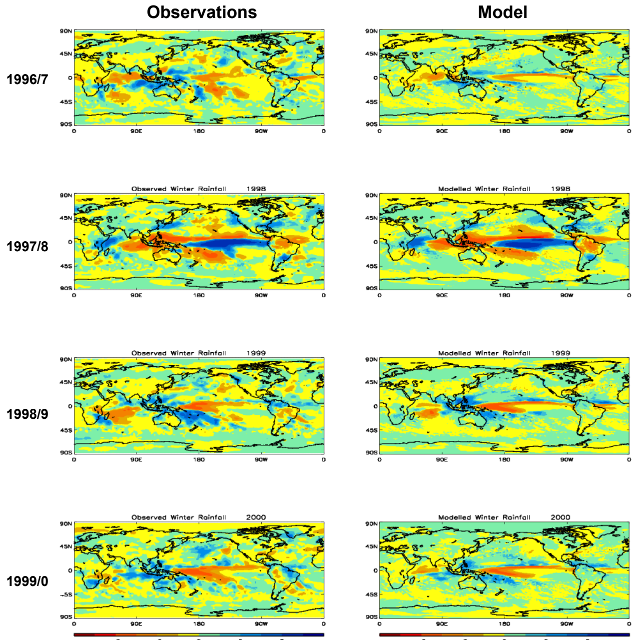
West Pacific rain => +ve NAO

Interesting tropical Atlantic signals

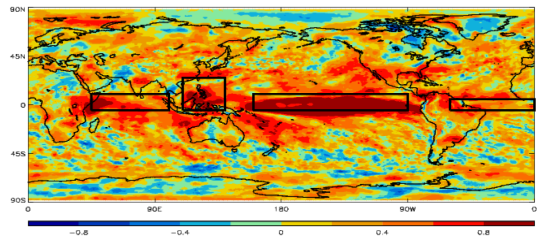
Scaife et al, QJRMS, 2016

Tropical rainfall – some good news

Individual winter rainfall



Interannual correlation skill



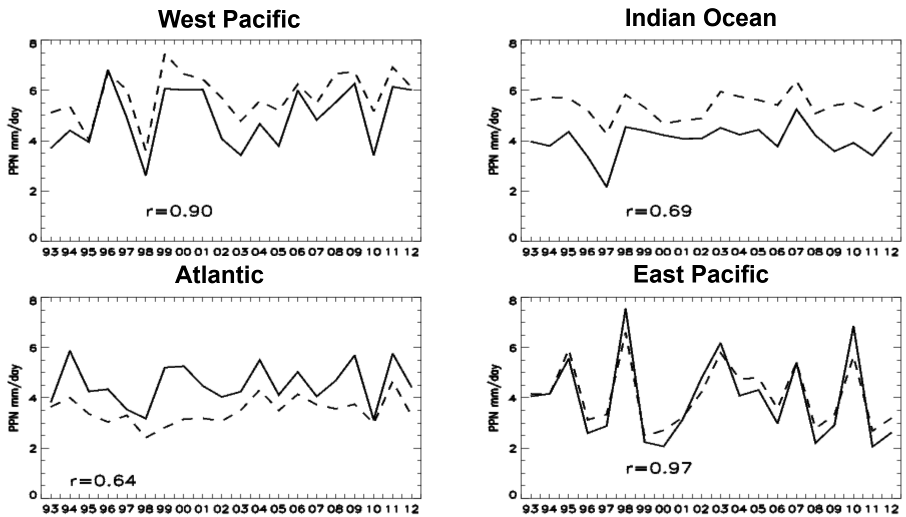
Tropical rainfall shows good prediction skill

Able to predict year to year changes

Encouraging correlations in all basins

Scaife et al, QJRMS, 2016

Tropical rainfall – some good news



Tropical rainfall variations are well predicted months in advance!

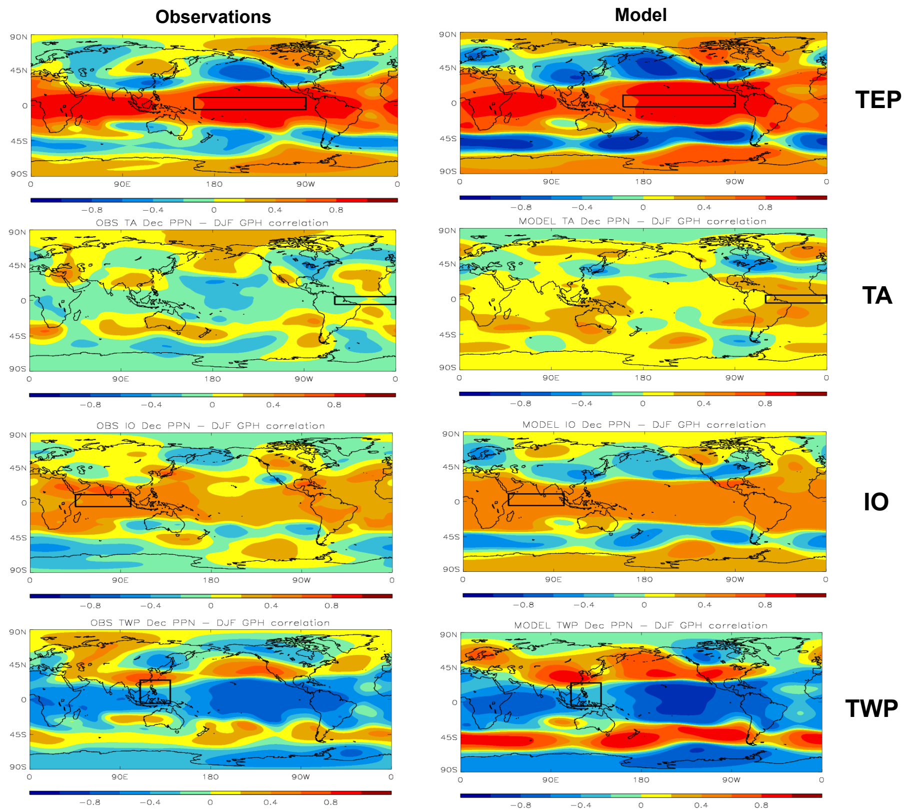
Respectable *correlations* which are all statistically significant

Ensemble mean and observations agree on *amplitude*

=> tropical precipitation is highly predictable out to months ahead

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

Global teleconnections to tropical rainfall



Symmetrical about the equator as expected

Correlations ~0.4

Similar in model and obs

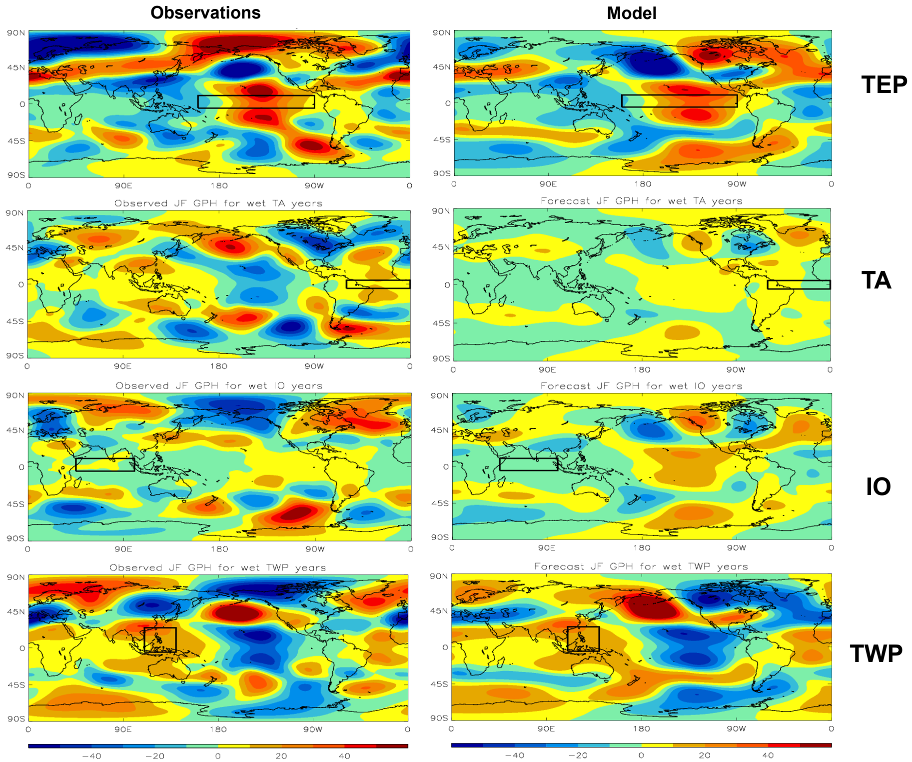
Regional detail different

Tropical Atlantic?

Largest signals not always local

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

Barotropic Rossby Waves

$$\frac{D(\zeta+f)}{Dt} = 0$$ constant absolute vorticity, no forcing

$$\left\{\frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y}\right\}\zeta + \beta v = 0$$

Perturbation to zonal mean flow: $u = \bar{u} + u'$ $v = v'$ $\zeta = \bar{\zeta} + \zeta'$

Perturbation streamfunction: $u' = -\frac{\partial \Psi'}{\partial y}$ $v' = \frac{\partial \Psi'}{\partial x}$ $\zeta' = \nabla^2 \Psi'$

$$\left\{\frac{\partial}{\partial t} + \bar{u}\frac{\partial}{\partial x}\right\}\nabla^2\Psi' + (\beta - \bar{u}_{yy})\frac{\partial \Psi'}{\partial x} = 0$$

Try wave solution: $\Psi' = A\, e^{i(kx + ly + \omega t)}$

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

Wave Propagation

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*

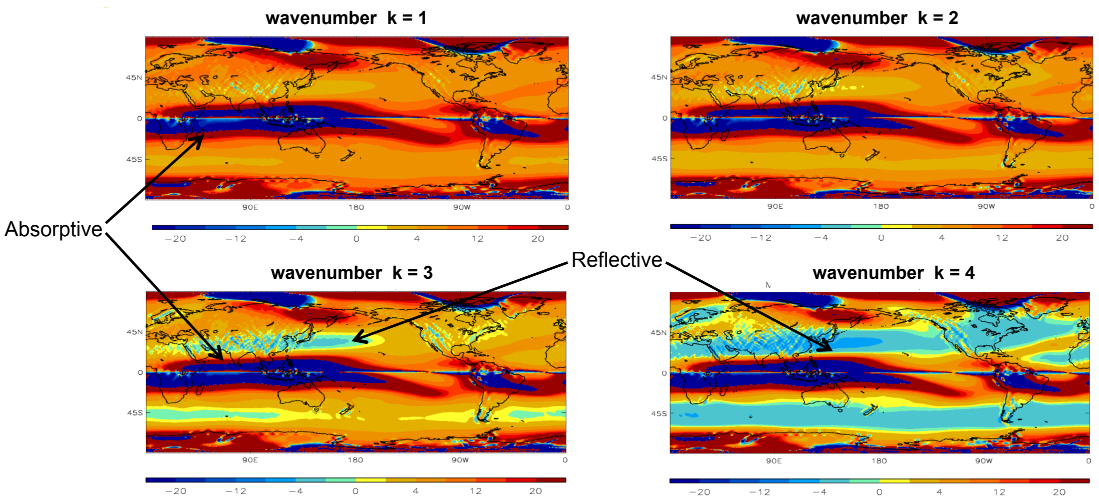
Meridional propagation stops in strong winds - *reflections*

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

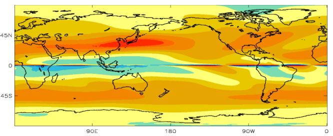
Dark blue regions are easterly winds – absorption of all waves

Light blue regions – reflection of short waves

Scaife et al, QJRMS, 2016

Ray Tracing (see Hoskins and Karoly, 1981)

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

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

Calculate local group velocity C_g

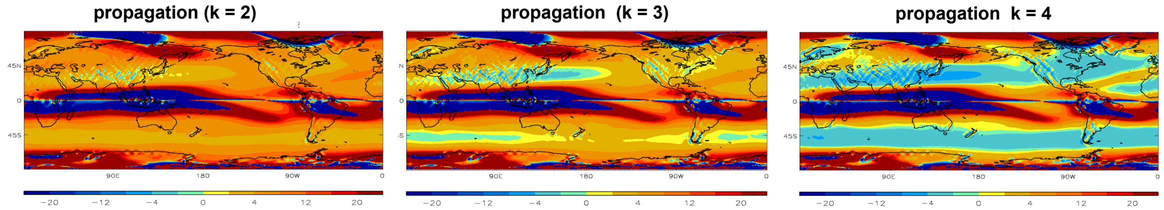
Discretise with a timestep of 2h

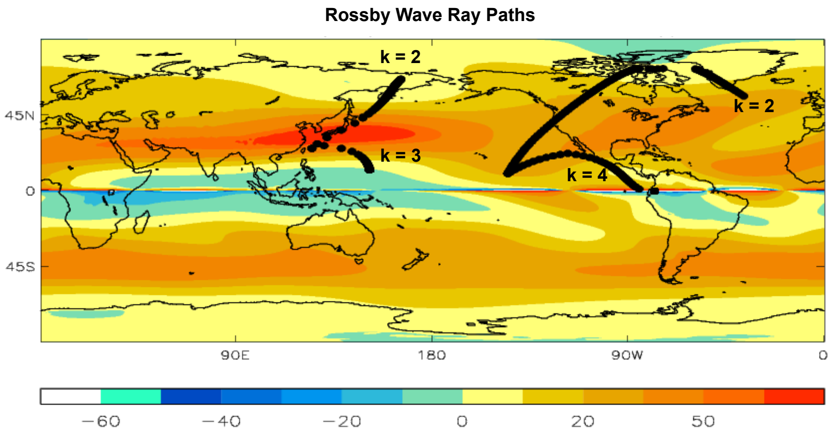
Calculate new ray position in spherical coordinates

Recalculate C_g

And so on.....

Rossby Wave Rays





From the W Pacific:

Wave2 propagates

Wave3 reflects

From the E Pacific:

Wave2 propagates

Wave4 reflects

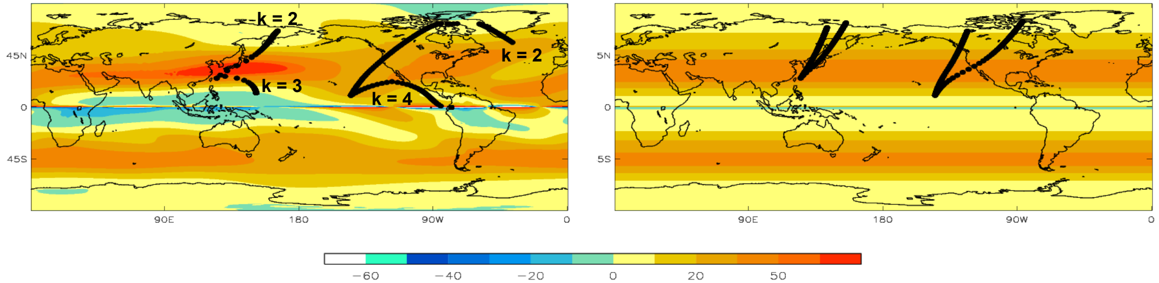
Seems to be working...

Scaife et al, QJRMS, 2016

Sensitivity test: zonal averaging

Ray paths in 60^{o} sector winds

Ray paths in zonal mean winds



Here we plot rays using zonal mean or sector mean winds

This has a big effect on ray paths because zonal rarely reach the required strength for reflection

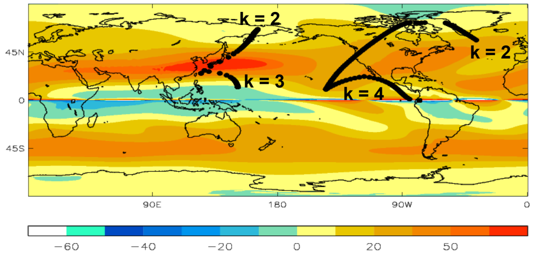
We therefore use 60 deg sector averaged winds along the path from now on

Scaife et al, QJRMS, 2016

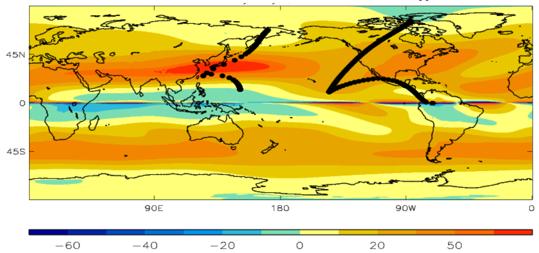
Sensitivity test: including curvature

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

Rossby Wave Ray Paths with U_{yy}



Rossby Wave Ray Paths without U_{yy}



Here we plot rays with or without the curvature of the wind (U_{yy}) included

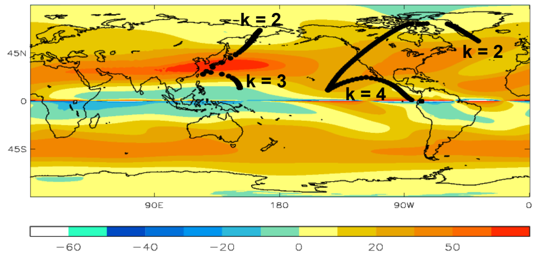
This has little effect on the ray paths

Compared to other aspects it can be ignored in all but special cases

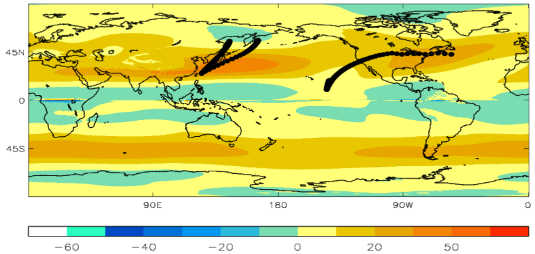
Scaife et al, QJRMS, 2016

Sensitivity test: vertical structure

Rossby Wave Ray Paths on 200hPa flow



Rossby Wave Ray Paths on 500hPa flow



Here we used zonal winds from different levels from mid and upper troposphere

This changes which wavenumbers propagate out of the tropics

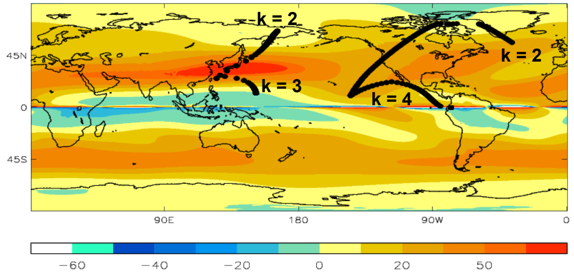
This is clearly an important uncertainty and requires more investigation

For now we continue with 200hPa.............and will justify this choice

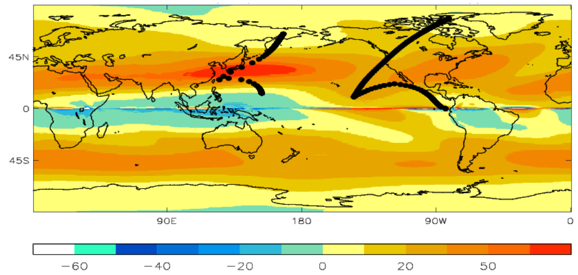
Scaife et al, QJRMS, 2016

Sensitivity test: model U error

Ray paths in modelled winds



Ray paths in observed winds



Ray paths are quite similar

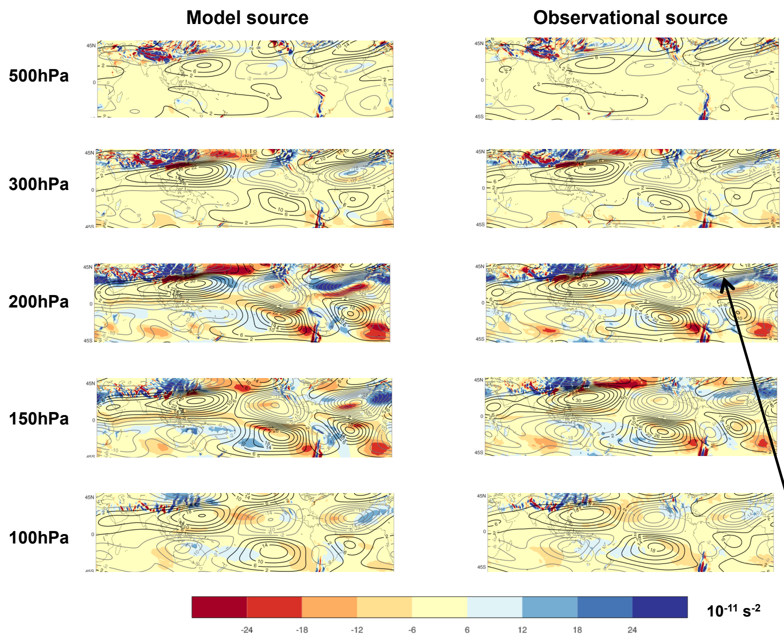
Model error in mean winds here is relatively unimportant for propagation!

Would be good to look at longer lead times and other models

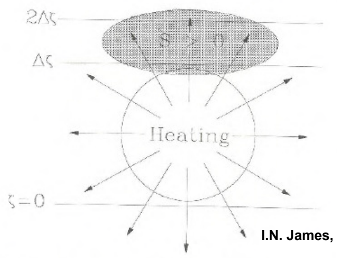
Scaife et al, QJRMS, 2016

Rossby Wave Sources

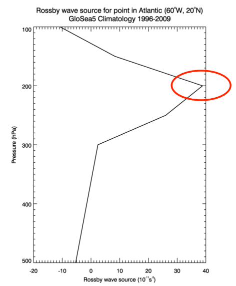
Rossby wave generation requires divergent flow *and* a gradient of absolute vorticity



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



I.N. James, 1994

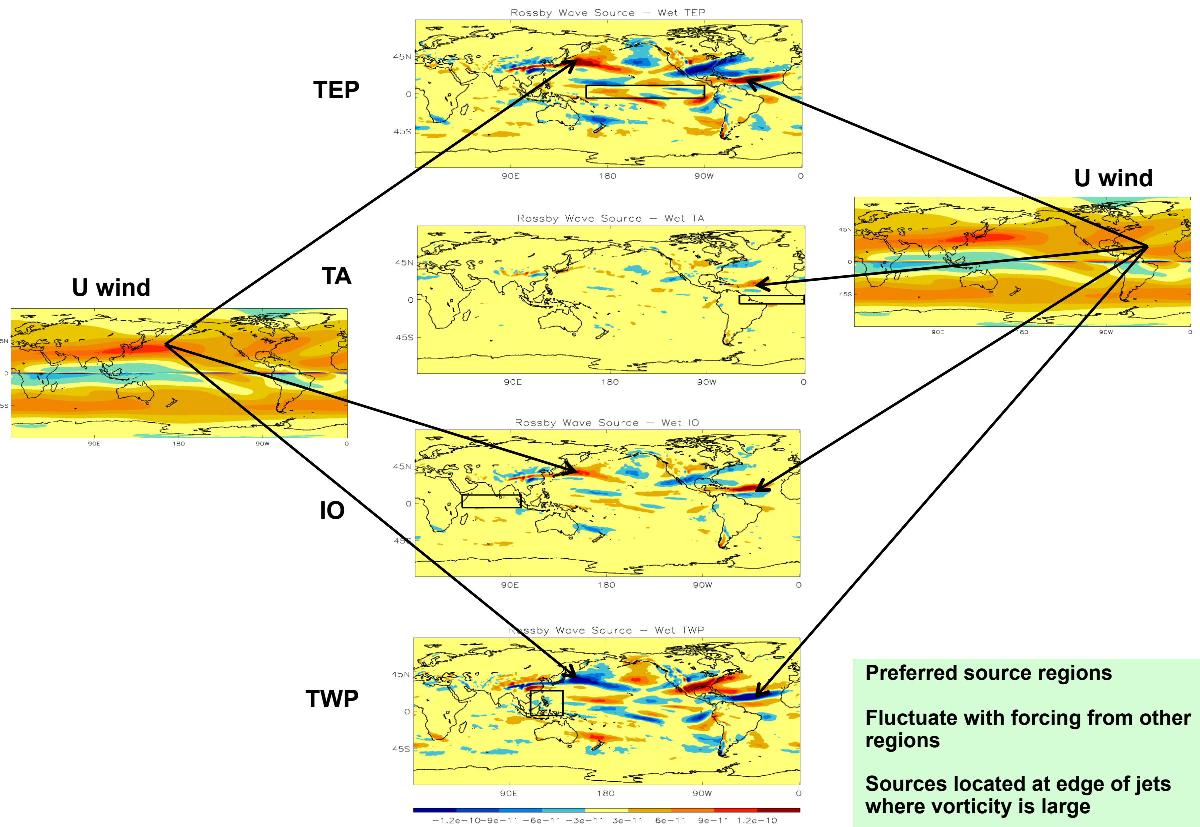


Increases with height

Maximum at 200hPa

Justifies earlier approach

Rossby Wave sources



Preferred source regions

Fluctuate with forcing from other regions

Sources located at edge of jets where vorticity is large

Scaife et al, QJRMS, 2016

Interbasin Rainfall Connections

Inter-basin rainfall correlations

Obs

Ens Mean

	IO	TA	TWP	TEP
IO	1	0.12, 0.44	-0.3, **-0.62**	0.4, **0.62**
TA	-0.28 to **0.64**	1	0.12, -0.14	-0.02, 0.1
TWP	**-0.60** to 0.09	-0.41 to **0.58**	1	**-0.73, -0.91**
TEP	0.23 to **0.74**	**-0.53** to 0.24	**-0.90** to **-0.70**	1

Ens Members

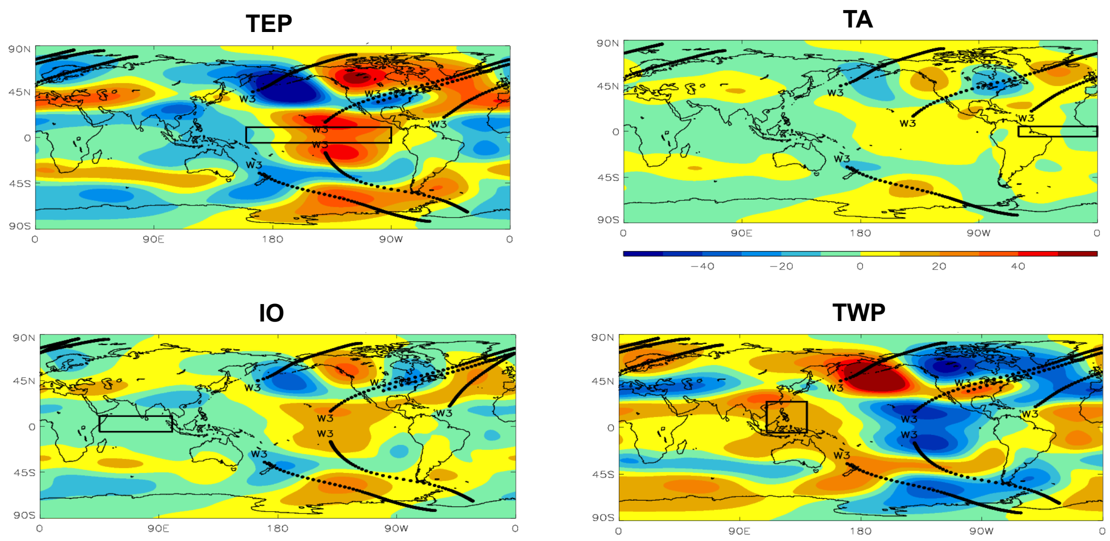
Some basins are significantly connected, especially with the East Pacific due to ENSO

Also help to ensure similar Rossby wave sources are associated with different rainfall regions

Ensemble member correlations span observed value in all cases

Scaife et al, QJRMS, 2016

Teleconnections as Rossby Waves



Rays intersect main centres *from a few common sources*

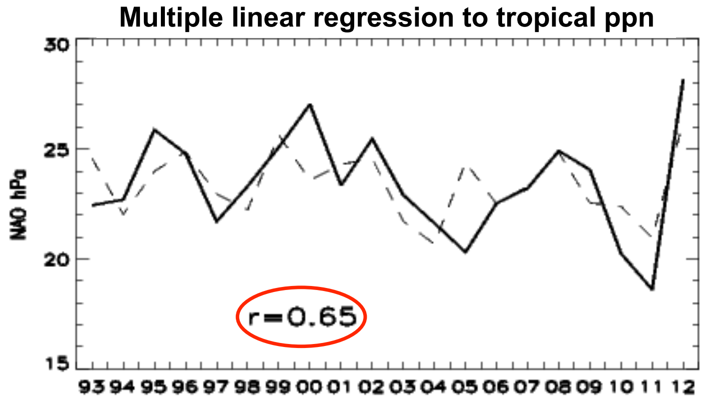
Wave 2, 3 mainly responsible as wave 4 rarely propagates

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



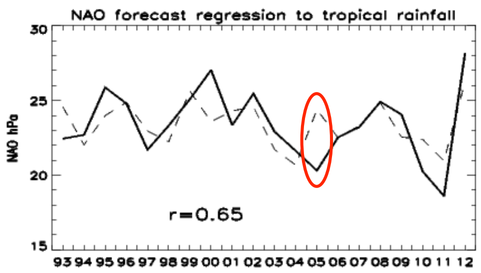
Our four regional rainfall series explain a sizeable fraction (~40%) of forecast variance

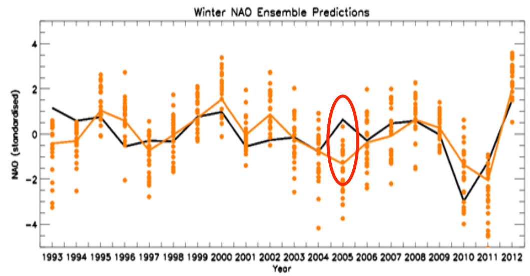
The Atlantic is most important (but may indirectly represent other regions)

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

Scaife et al, QJRMS, 2016

...and a forecast ‘bust’





The tropical rainfall signals do not explain the 2004/5 winter forecast

Interestingly, 2004/5 was the worst year in the original experiments!

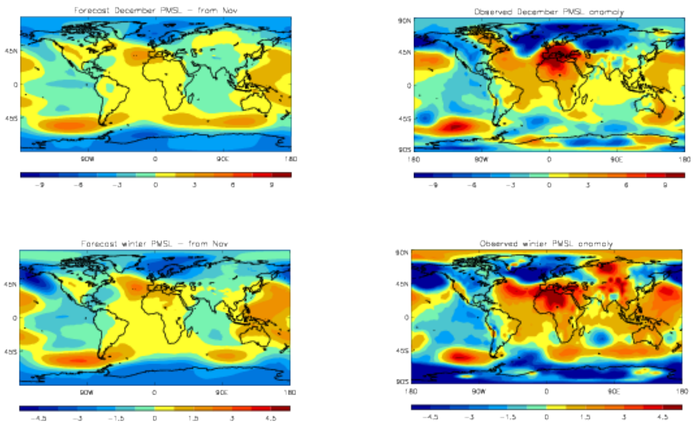
Was that because the tropical rainfall signal was ‘ignored’

More evidence for a tropical rainfall effect

Scaife et al, QJRMS, 2016

Winter 2015/16

From November | Observations



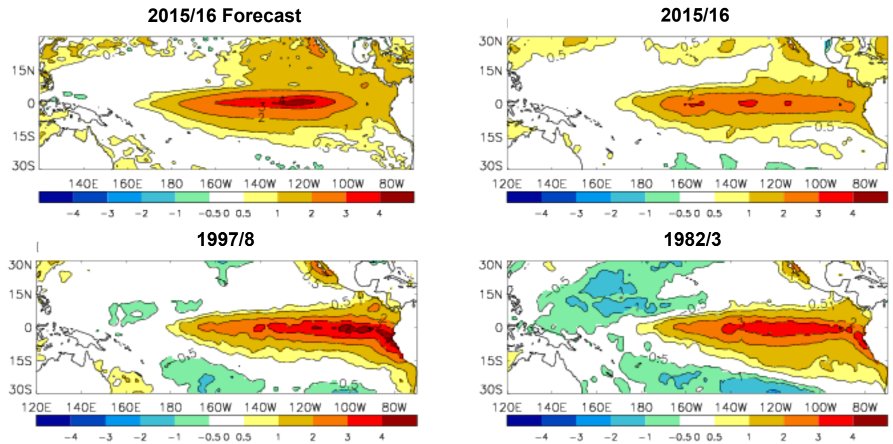
Very clear signals for a westerly winter

Good agreement with subsequent observations

Early warning of December flooding

Scaife et al, ASL, submitted

Winter 2015/16: a near record El Niño



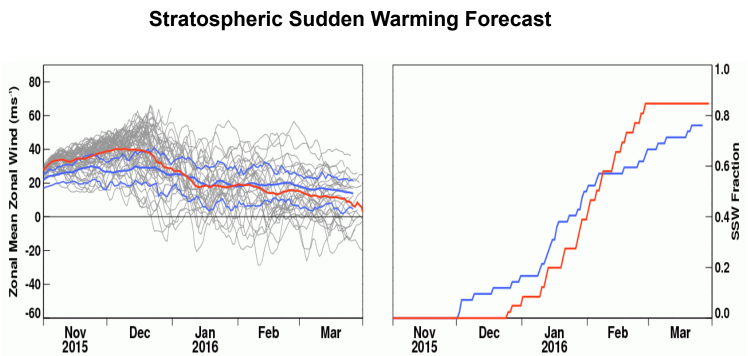
Very clear signals for a near record event

Remote but not irrelevant

Similar to 1982/3

Scaife et al, ASL, submitted

Winter 2015/16: a high risk of sudden stratospheric warming



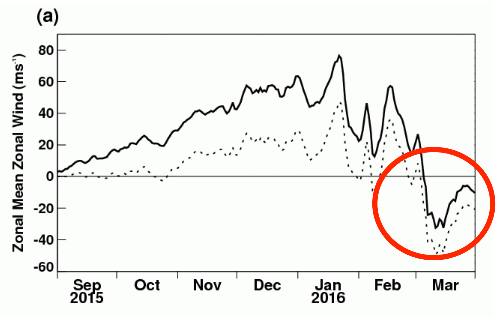
Very strong jet and low probability of a sudden warming predicted for December

A high probability (80-90%) of a sudden stratospheric warming predicted for late winter

Consistent with forecasts for other El Niño winters

Scaife et al, ASL, submitted

Stratospheric conditions: winter 2015/16

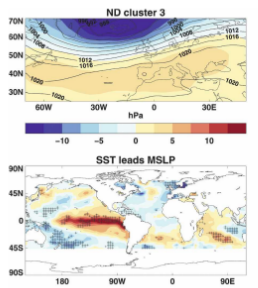


A sudden warming finally happened in early March (consistent with the cold dry start to spring)

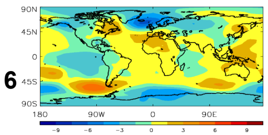
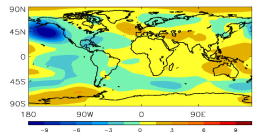
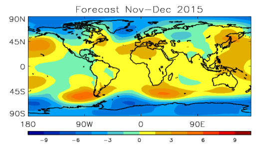
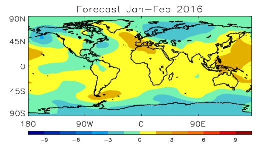
Later than the most likely time in the forecasts but within the spread of forecasts from Autumn

Scaife et al, ASL, submitted

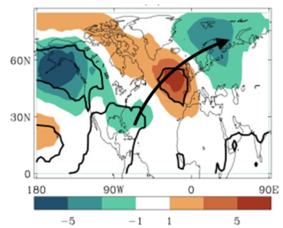
Early vs late winter and an analogue...



Fereday et al,
Clim. Dyn., 2008

	Early winter Nov-Dec	Late winter Jan-Feb
2015/16		
1982/83		

Strong El Niño



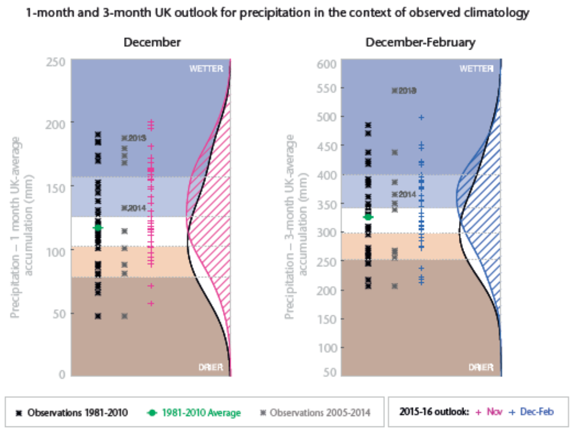
Toniazzo and Scaife,
GRL, 2006

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



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:

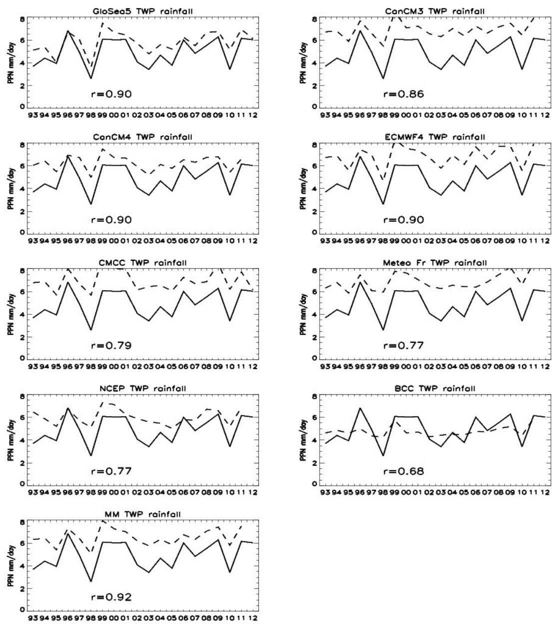
During December above-average temperatures are more likely than below-average temperatures. The likelihood of a prolonged spell of cold weather is relatively low compared to normal.

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.

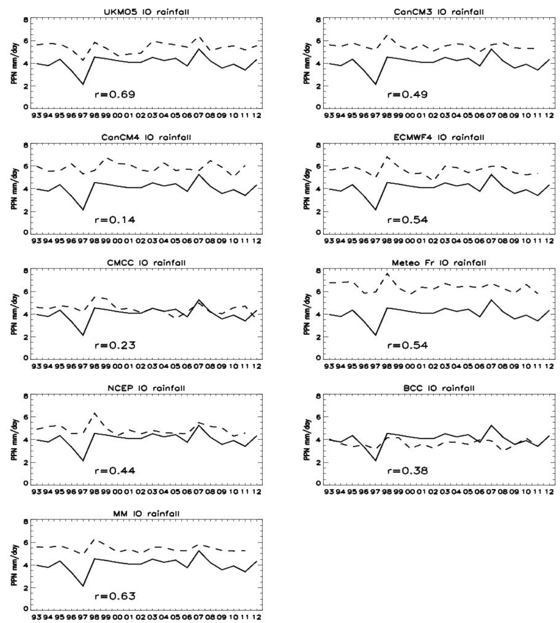
Overall, the probability that the UK-average temperature for December-January-February will fall into the coldest of our five categories is 15% and the probability that it will fall into the warmest of our five categories is between 20% and 25% (the 1981-2010 probability for each of these categories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

What about other forecast systems?

West Pacific



Indian Ocean

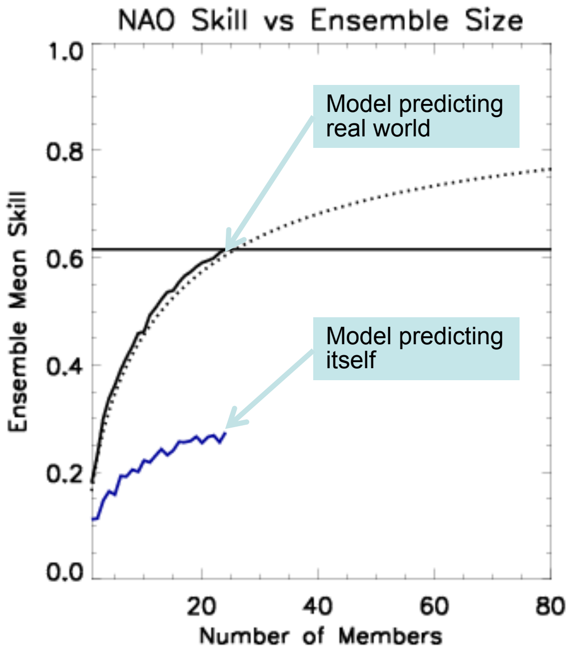


Eight systems so far – more to follow

Skill is very high in W Pacific and E Pacific (ubiquitous wet bias)

Lower in Indian and Atlantic basin **(continues with WGSIP)**

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 on seasonal timescales**
  - Potential for high seasonal and some interannual skill exists
  - 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
  - Rossby wave dynamics goes a long way to explaining these
  - Multi-model work underway with Laura Ferranti and others
- **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?
  - This winter shows a blocked signal for early winter and then more westerly...

There is a lot more to do!