State of the art of Seasonal to Decadal Prediction

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Thanks to the organisers: especially Adrian Thompkins and Susanne Henningsen

Seasonal to Decadal Prediction

Why?

How does it work?

Current Capability

Future

Why seasonal to decadal prediction?

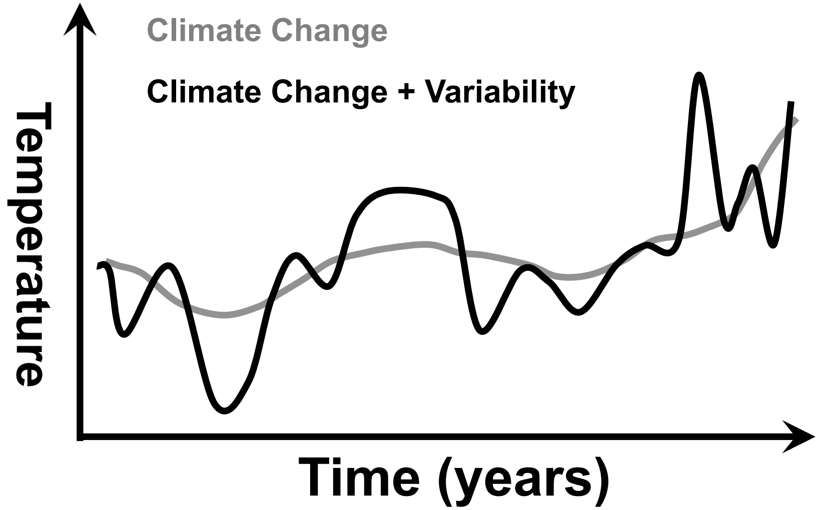
Climate varies <u>a lot</u> from year to year and decade to decade and this can greatly amplify or oppose any trend:

Tropical Floods during 2010/11

Russian heatwave 2010

African Drought 2011

Recent Cold European and US winters 2009/10…



Dry Water Pan, Kenya, 2011

Flooding at Toowoomba, Australia, 2011

Barcelona, Spain, March 2010

How does it work?

Can we forecast the coming season?

or

Does chaos (the “butterfly effect”) make it impossible?

and

Is the climate model good enough?

Long Range Forecast Drivers

Q. If weather forecasts are unreliable after a week or so, how can we hope to predict a season ahead?

A. Because slow variations in the ocean, land, sea-ice, greenhouse gases, solar radiation, stratosphere and volcanic forcing influence surface climate

Note that we are not predicting individual weather events seasons ahead (this is probably impossible), only the chances of different types

Climate Models based on laws of physics

Newton's second law

$$\frac{D_r u}{Dt} - \frac{uv\tan\phi}{r} - 2\Omega\sin\phi v + \frac{c_{pd}\theta}{r\cos\phi}\frac{\partial\Pi}{\partial\lambda} = -\left(\frac{uw}{r} + 2\Omega\cos\phi w\right) + S^u$$

$$\frac{D_r v}{Dt} + \frac{u^2\tan\phi}{r} + 2\Omega\sin\phi u + \frac{c_{pd}\theta}{r}\frac{\partial\Pi}{\partial\phi} = -\left(\frac{vw}{r}\right) + S^v$$

$$\frac{D_r w}{Dt} + c_{pd}\theta\frac{\partial\Pi}{\partial r} + \frac{\partial\Pi}{\partial r} = \left(\frac{u^2 + v^2}{r}\right) + 2\Omega\cos\phi u + S^w$$

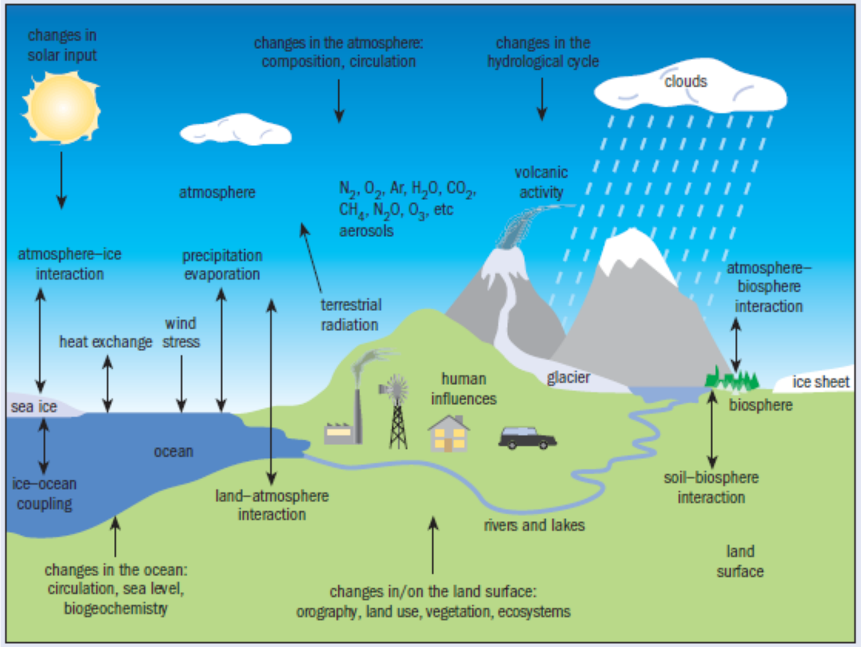
mass continuity

$$\frac{D_r}{Dt}\left(\rho_d r^2\cos\phi\right) + \rho_d r^2\cos\phi\left[\frac{\partial}{\partial\lambda}\left(\frac{u}{r\cos\phi}\right) + \frac{\partial}{\partial\phi}\left(\frac{v}{r}\right) + \frac{\partial w}{\partial r}\right] = 0$$

thermodynamics

$$\frac{D_r\theta}{Dt} = S^\theta$$

The Navier–Stokes equations for fluid flow are at the heart of climate models. The first three equations represent Newton's second law and give the acceleration of the winds in the east–west (u), north–south (v) and vertical directions (w). The mass-continuity equation ensures that although the density, speed and direction of the air change as it flows around the Earth, its mass is conserved, while the thermodynamic equation allows heat-transfer processes such as heating by the Sun to be included as a parametrized source term (S). We use the same equations to model the dynamics of the ocean, but usually make further simplifying approximations. In the equations, r is the distance from the Earth's centre, Ω is the angular velocity of the Earth's rotation, ϕ is latitude, λ is longitude and t is time. c_p is the specific heat capacity of air at constant pressure, θ is potential virtual temperature, Π is the "Exner function" of pressure and ρ is air density. The subscript "d" refers to dry air.



The Earth's climate system comprises the atmosphere, ocean, biosphere, cryosphere and geosphere. Interactions between these components lead to a large natural variability in the climate, while human influences such as the burning of fossil fuels add further complexity. Some of these processes, such as the circulation of the ocean, can be resolved explicitly in climate models, while others, such as the effects of clouds, must be "parametrized".

5 governing equations + ideal gas law

Discretized on a 3D grid of points

Unresolved processes parametrized (e.g. radiation, buoyancy waves) in 'S'

Initial Values and Boundary Values

Initial Values e.g. current state of the atmosphere, ocean, land

Boundary values e.g. greenhouse gas concentration, solar forcing

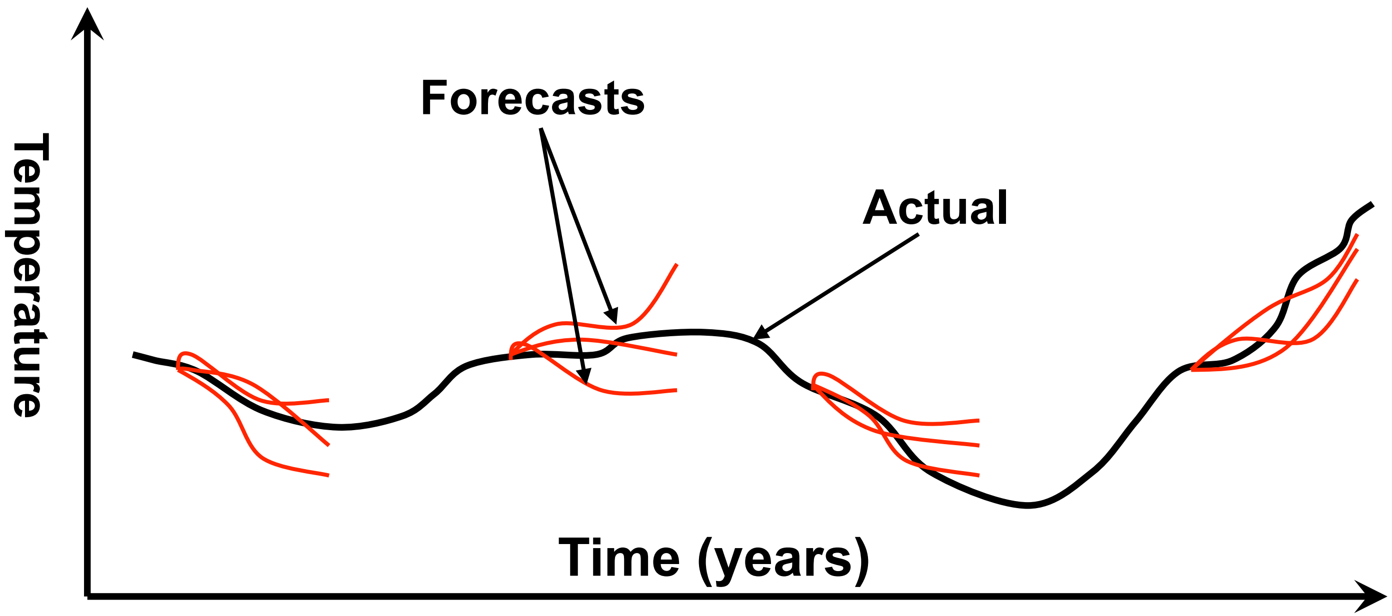
OPTIONS:

- **Unconstrained:** long control simulations of the climate model with neither initial conditions nor variation in boundary conditions
- **Initial values only:** weather forecasts: an accurate measure of the weather today is enough to predict the weather tomorrow
- **Boundary values only:** climate predictions for the coming century: knowing the future level of greenhouse gases is enough to predict changes in the statistics of the weather
- ❖ **Initial AND Boundary values:** climate predictions for the coming years: climate variability and weather statistics can both be predicted for months to years ahead

Allowing for chaos
(the butterfly effect)

Ensembles of forecasts – to represent uncertainty

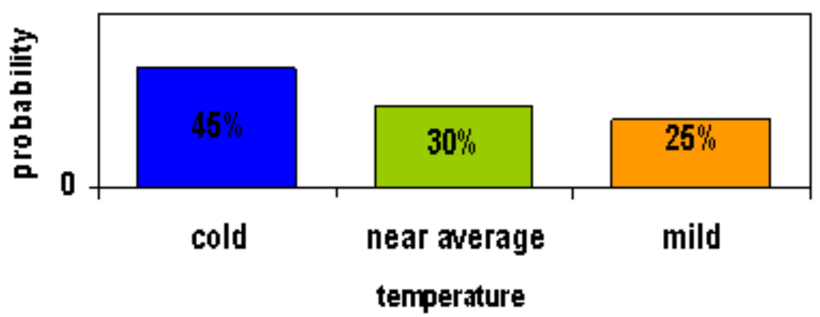
Outcome is a shift in likelihood



Predictions of Risk

Forecast is for *RISK* of e.g. a cold season

Compare with: health risk, sports events



Example on the left:

Does not mean "We are forecasting cold"

Does mean:

"Cold is more likely than either average or mild but average or mild is more likely than cold"

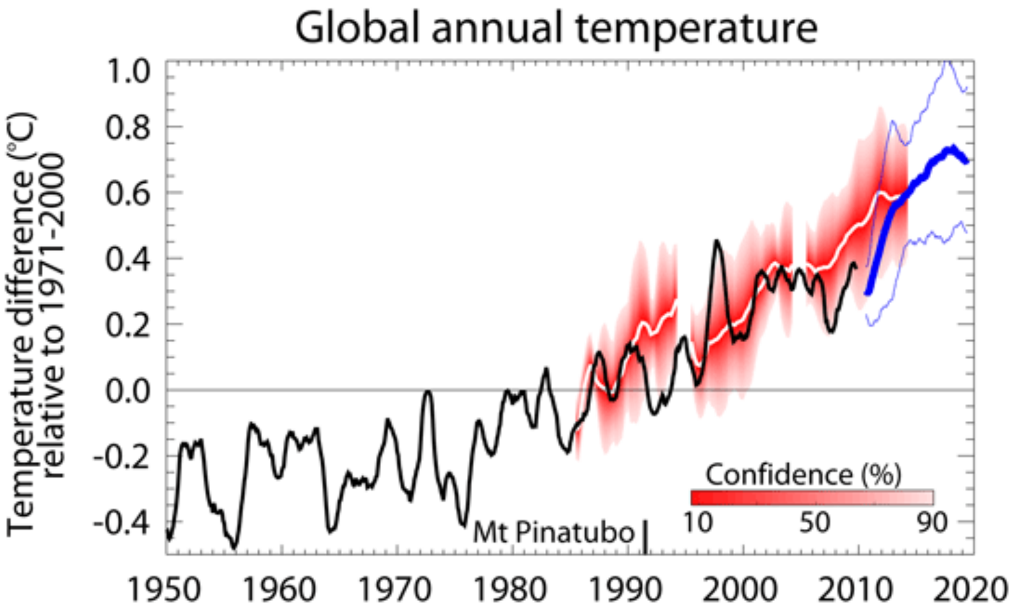
Capability

Globe

Regional

Extremes

Temperature of the Globe from Year to Year



1 yr lead time: correlation ~0.7

Forecast for 2011: "unlikely to be a record year… very likely to be between 0.28 °C and 0.62 °C. The middle of this range would place 2011 among the top-10 warmest years on the record."

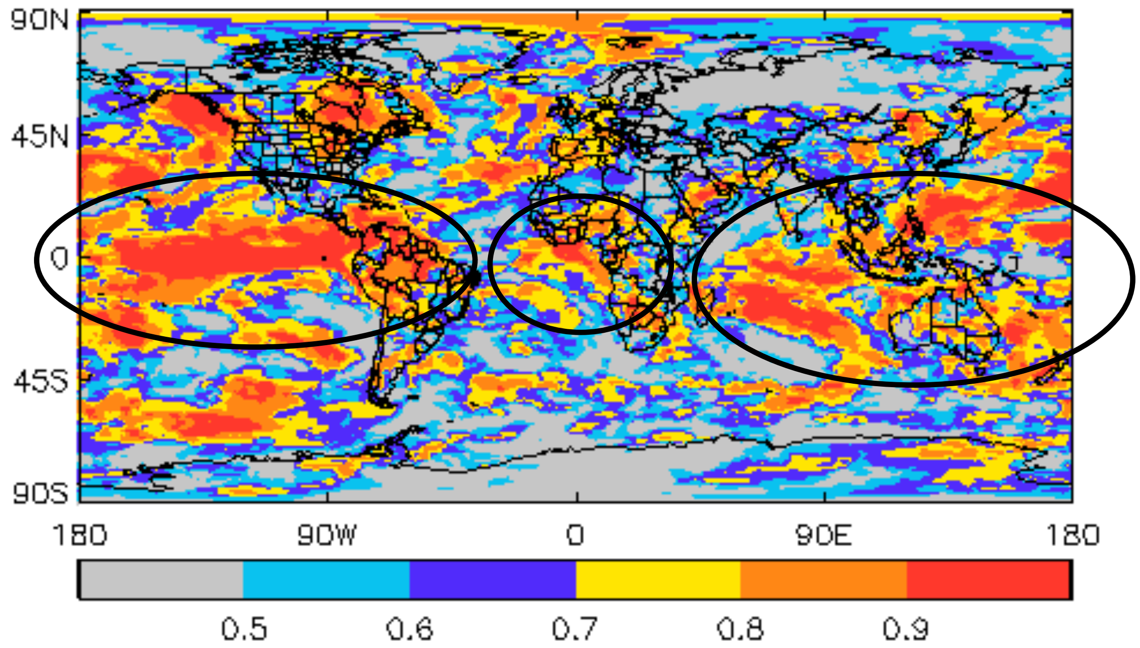
Issued Dec 2010

Forecast for 2010: "it is more likely than not that 2010 will be the warmest year in the instrumental record"

Issued Dec 2009

Rank	HadCRUT3		NOAA NCDC		NASA GISS	
	Year	Anomaly *	Year	Anomaly *	Year	Anomaly *
1	1998	0.52	2010	0.52	2010	0.56
2	2010	0.50	2005	0.52	2005	0.55
3	2005	0.47	1998	0.50	2007	0.51
4	2003	0.46	2003	0.49	2009	0.50
5	2002	0.46	2002	0.48	2002	0.49
6	2009	0.44	2006	0.46	1998	0.49

Seasonal Forecast Skill



Forecast skill for mild DJF

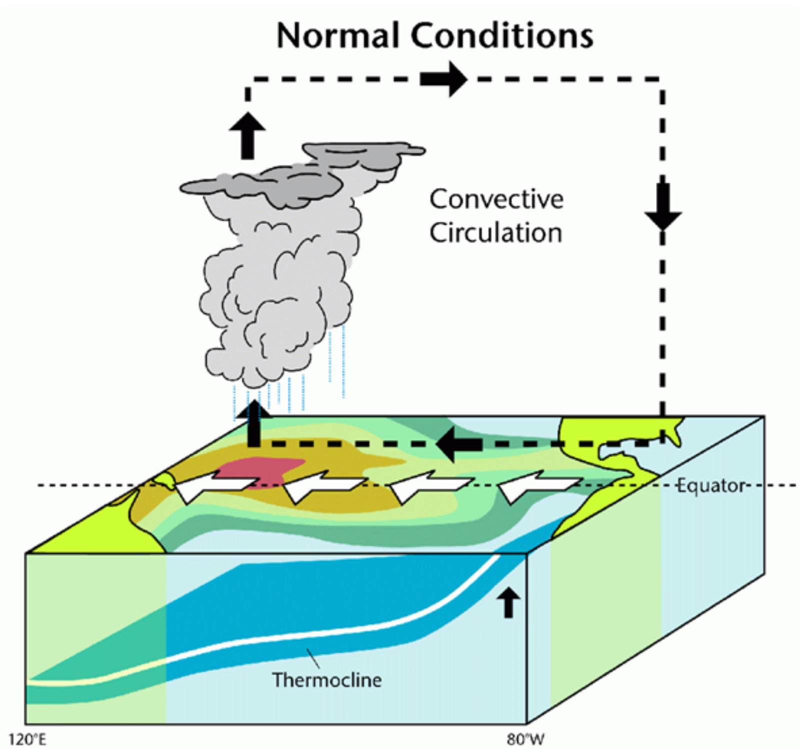
Largest in tropics

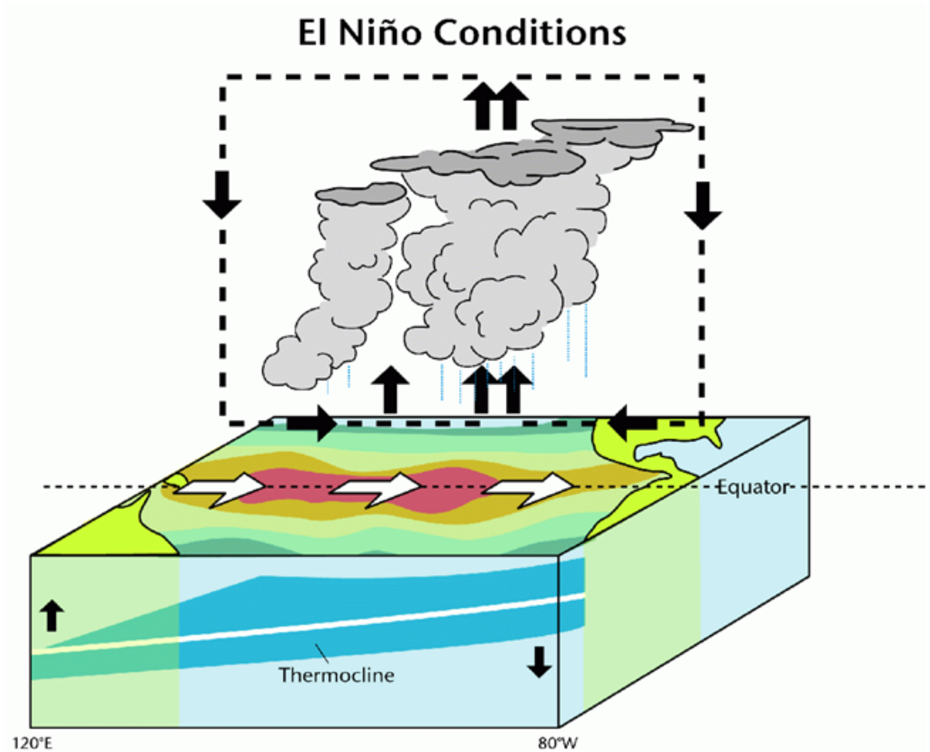
Largest over ocean

"Prognostics are also in general less uncertain on the ocean, and especially in the equinoctial parts of it…"

Alexander Von Humboldt on forecasting (C18th!)

El Nino Southern Oscillation





Warming in mid and E Pacific, convection moves E,

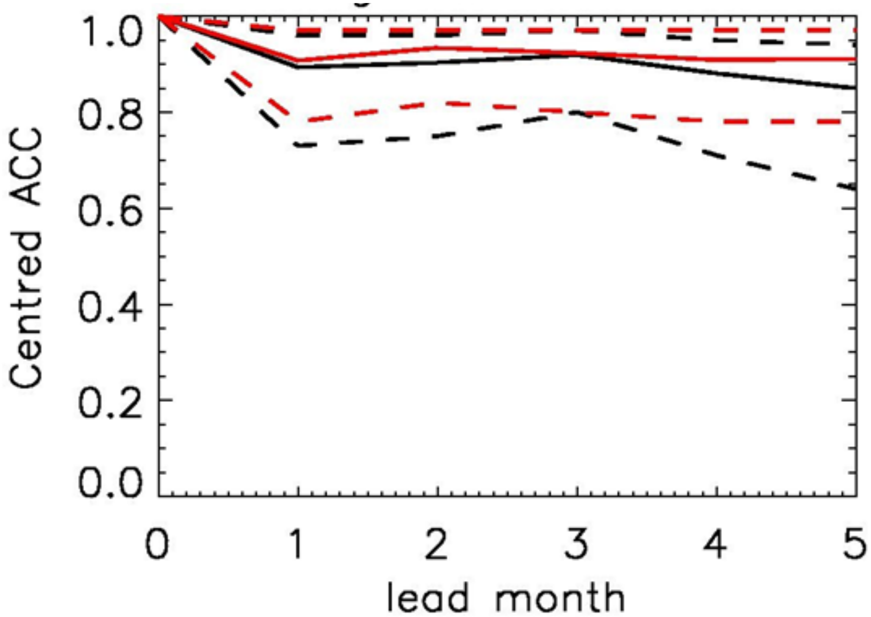
Atmospheric circulation weakens,

Upwelling in E Pacific reduces, thermocline relaxes

Biggest source of natural climate variability

ENSO forecast skill

Seasonal Forecast Skill



Arribas et al., MWR, 2011

Interannual Forecast Skill

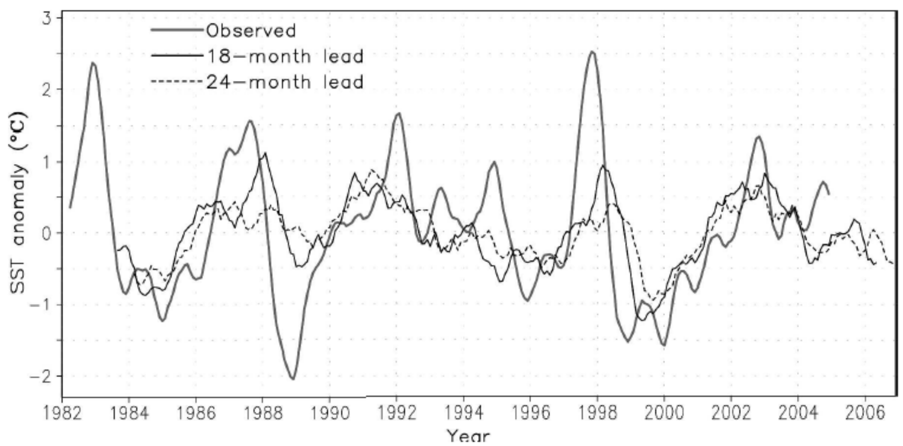


FIG. 3. SST anomalies averaged in the Niño-3.4 region (5°S–5°N, 120°–170°W). The thick gray curve is observations and black curves are nine-member ensemble-mean retrospective forecasts at 18- and 24-month leads. Results have been smoothed with a 5-month running mean. For the time series predicted up to a 12-month lead, readers are referred to Luo et al. (2005b).

Luo et al., J. Clim., 2008

ENSO peaks in winter

Remarkable predictability 6 months ahead, some skill further ahead

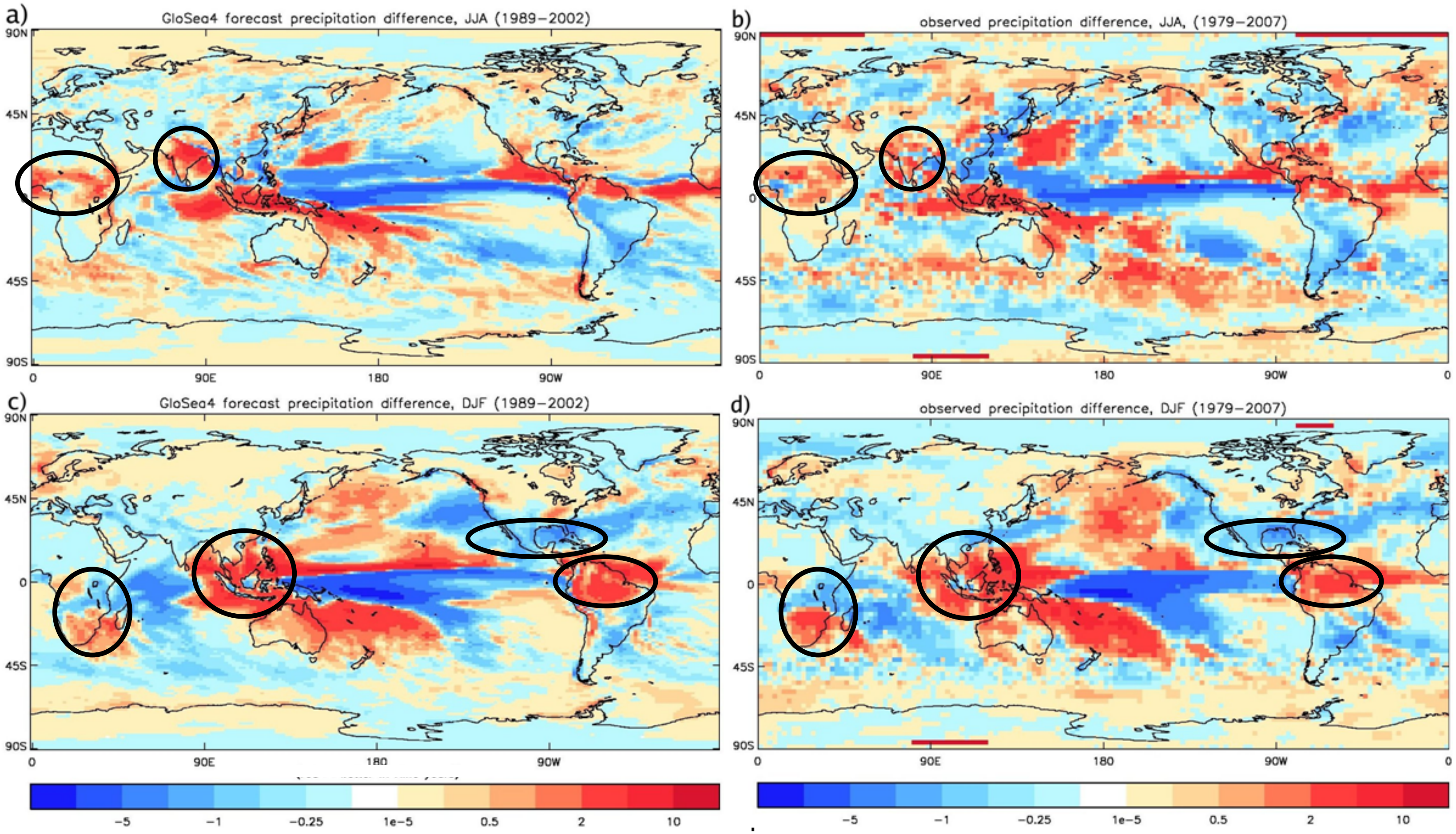
Remote effects?

ENSO effects: rainfall

Forecast | Observed

JJA

DJF

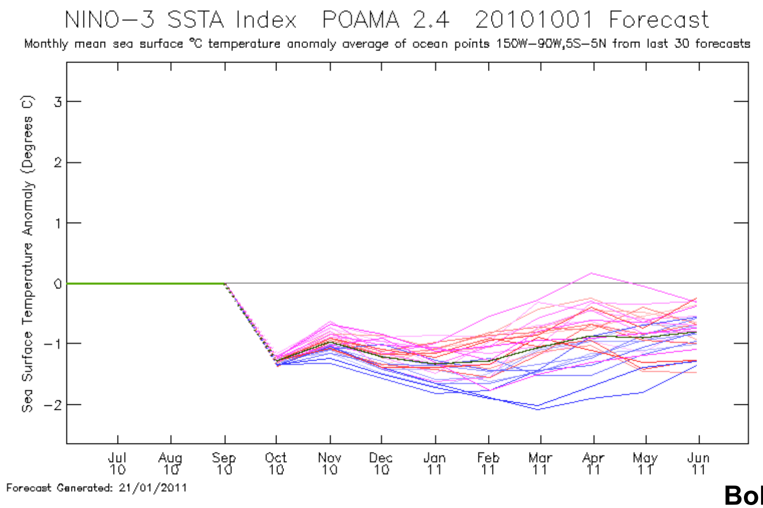


Arribas et al., 2011

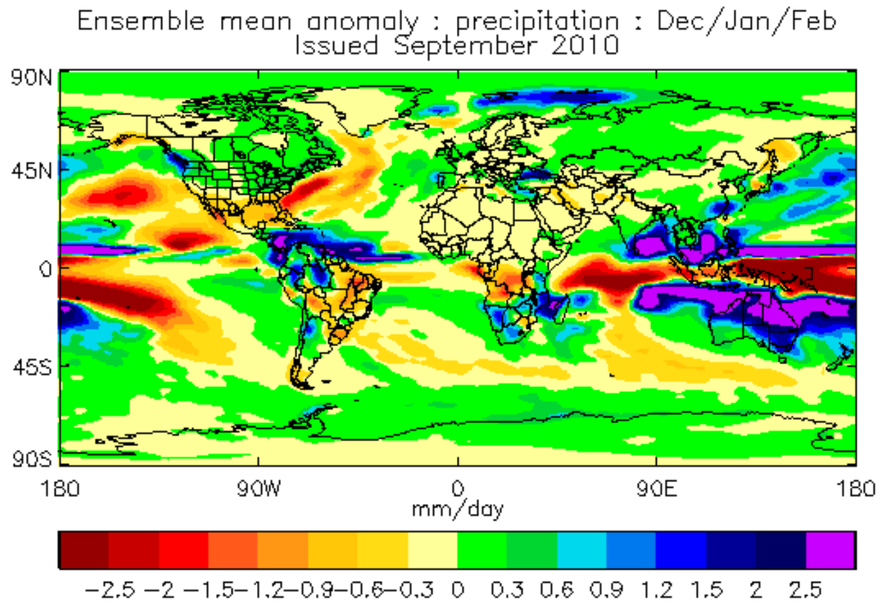
Skilful forecast signals in the tropics – even for rainfall

e.g. Australia…

ENSO effects: e.g. Australian Floods



BoM, 2010



Met Office, 2010

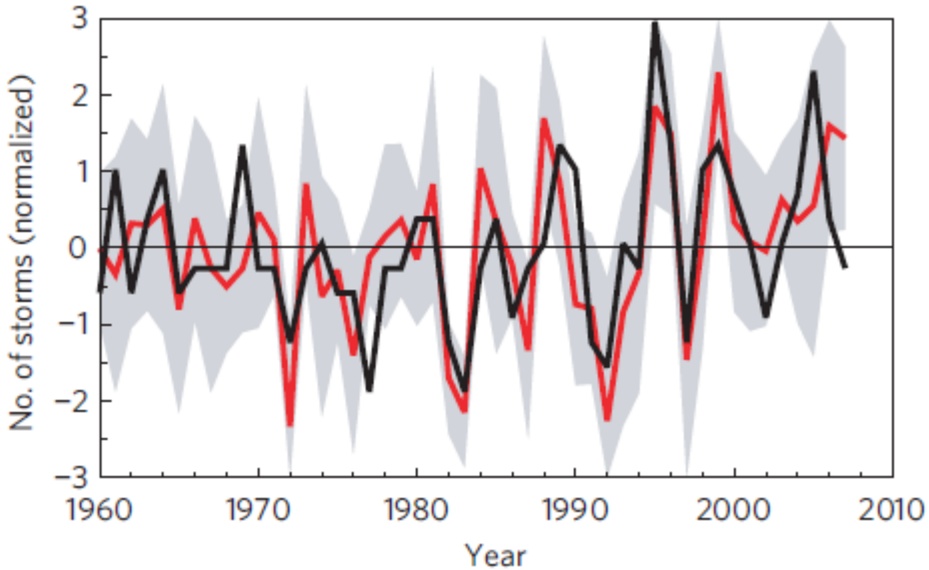
Very wet signals for NE Australia due to La Niña

Predicted increased risk from several months before!

Also Sri Lanka, S Africa

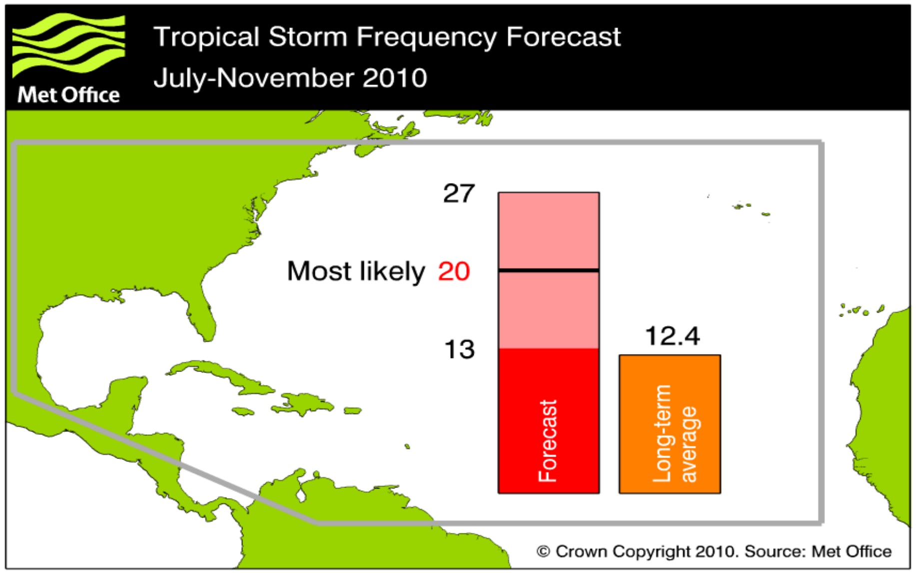
Potential for international adaptation, aid etc

Extreme Events: e.g. Atlantic Hurricanes



Smith et al., 2010

Numbers of hurricanes can be forecast months ahead



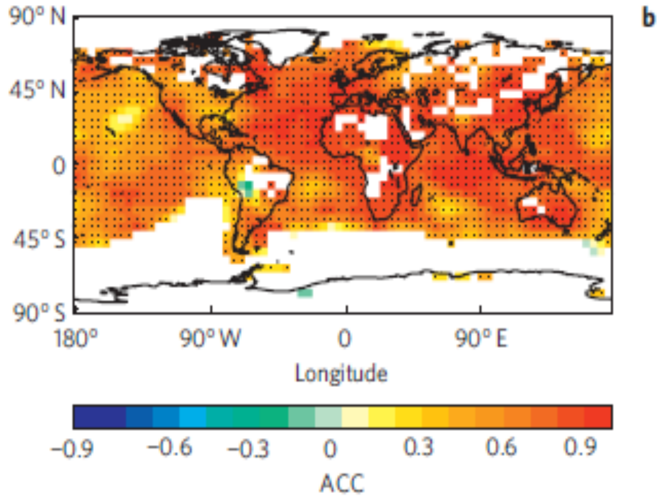
Last year's *real time* forecast:

Well above average numbers

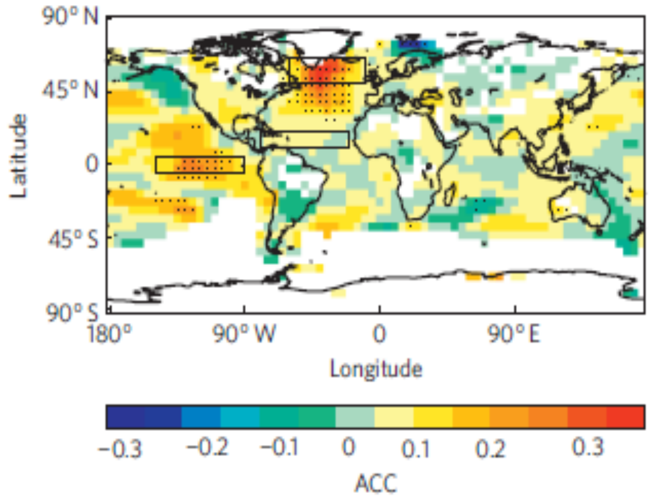
Observed 19!

Decadal forecast skill

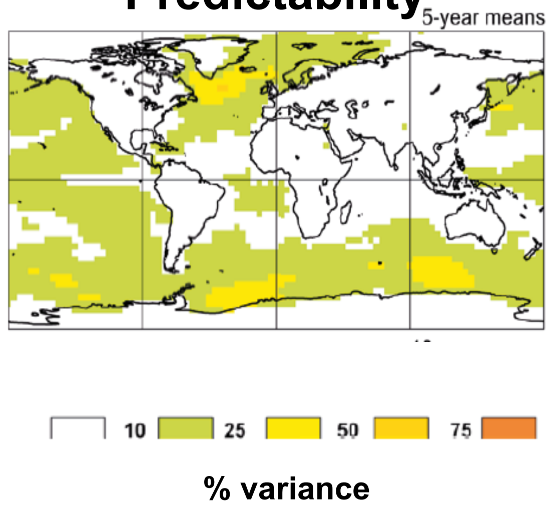
Full Prediction Skill (5yr)



From Initial Conditions



Estimated Potential Predictability



Much decadal predictability from boundary conditions (GHGs, recent volcanoes, ozone etc)

Additional decadal predictability from initial conditions (esp N Atlantic and Eq Pacific)

Smith et al., *Nat. Geosci.*, 2010 and Boer, *Clim. Dyn.*, 2004

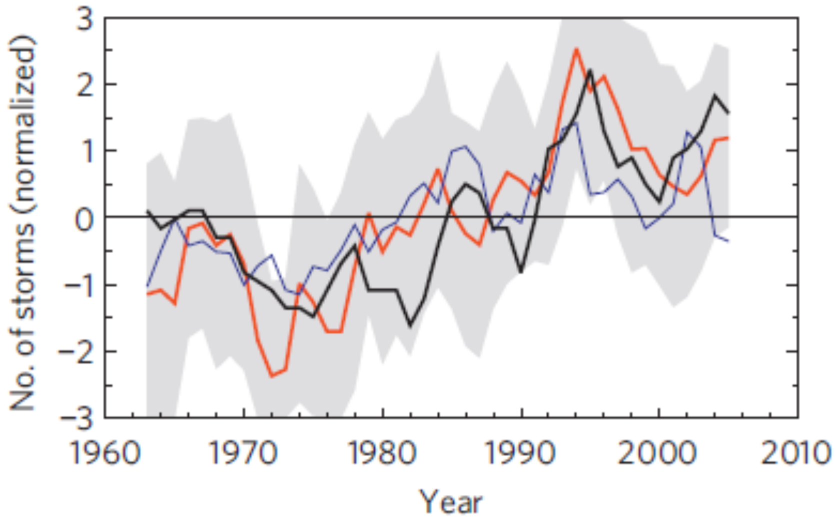
Extremes: Hurricane Predictions

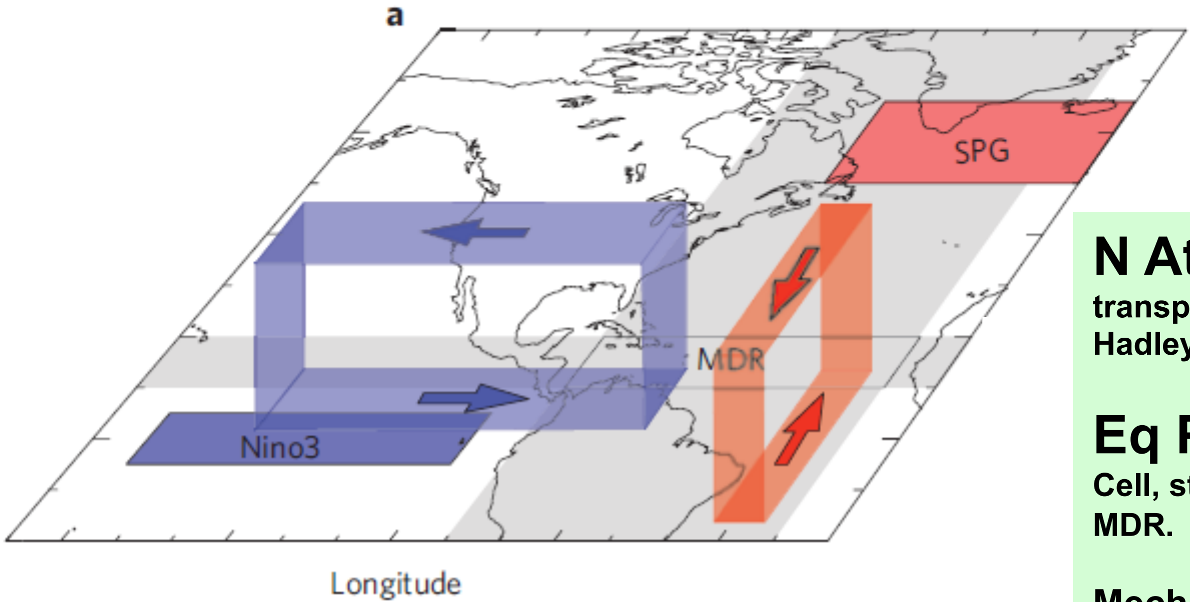
Hindcasts of hurricane no.s:

5 year rolling means

Skilful

Forced component





N Atlantic: **warm SPG, weakened heat transport, warm subtropical SST, anomalous Hadley Cell => less shear in MDR.**

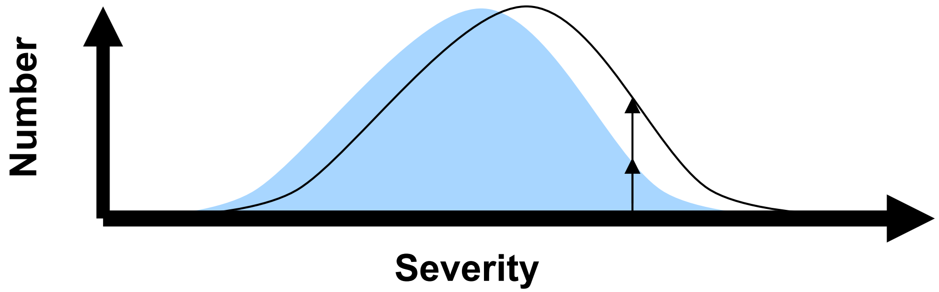
Eq Pacific: **cool SST, stronger Walker Cell, stretches over Atlantic => less shear in MDR.**

Mechanism => Increased confidence

Smith et al., *Nat. Geosci.*, 2010

Extremes: Hot Summer Days

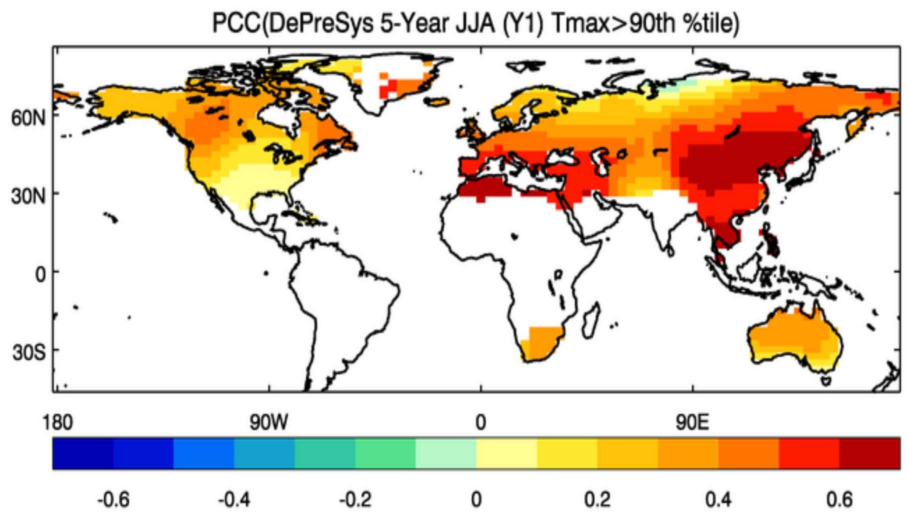
If we can predict the mean climate shift maybe we can predict extremes?



Predicting number of hot summer days for the coming 5 summers

Skilful over continental scales using 1960-2003 data

<u>Same skill as shifting distribution</u>



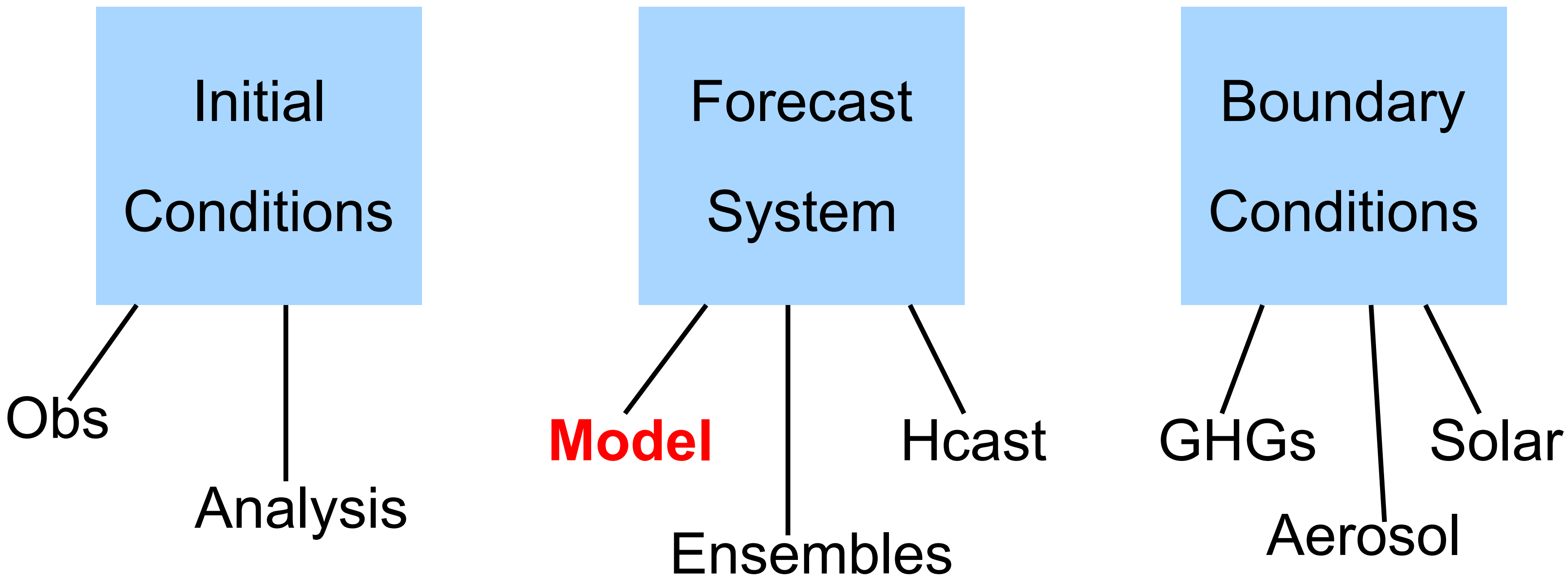
Rosie Eade

Future

Improved Models

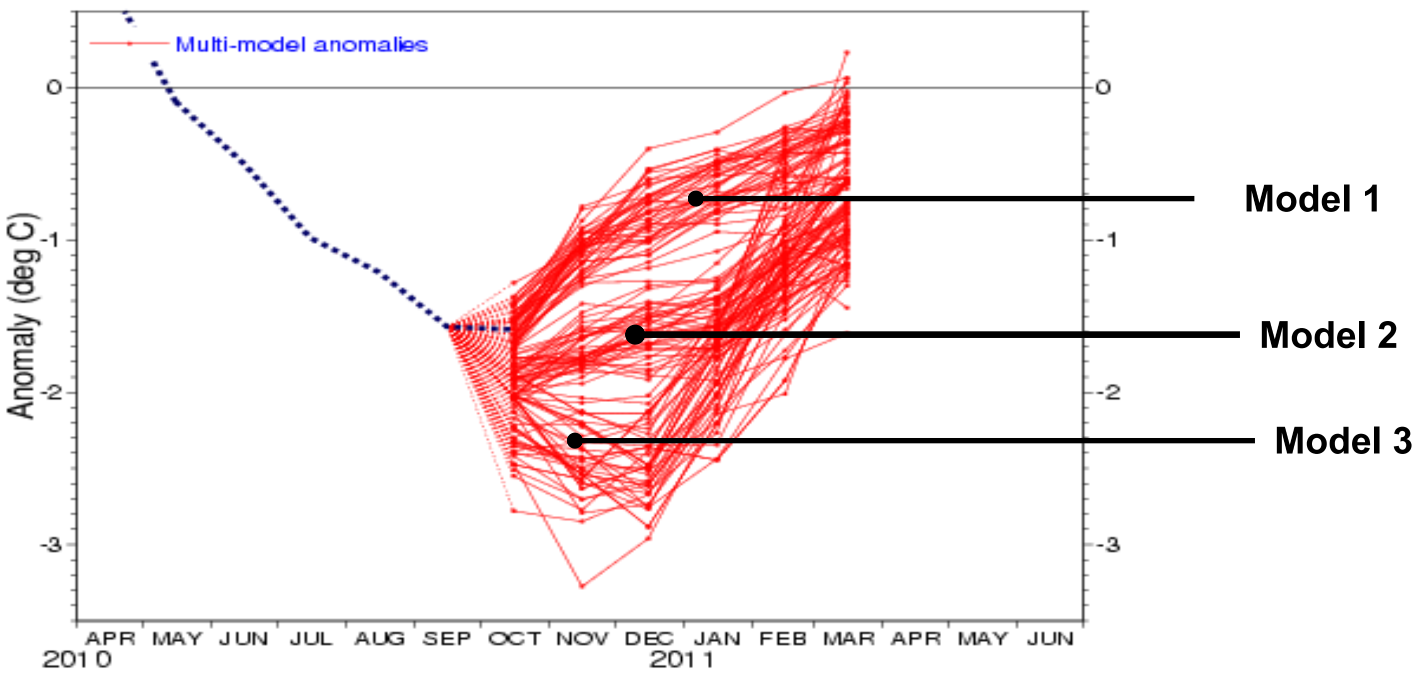
Improved teleconnections

Sources of Error



Model errors and overconfidence

Multimodel prediction of the recent La Nina



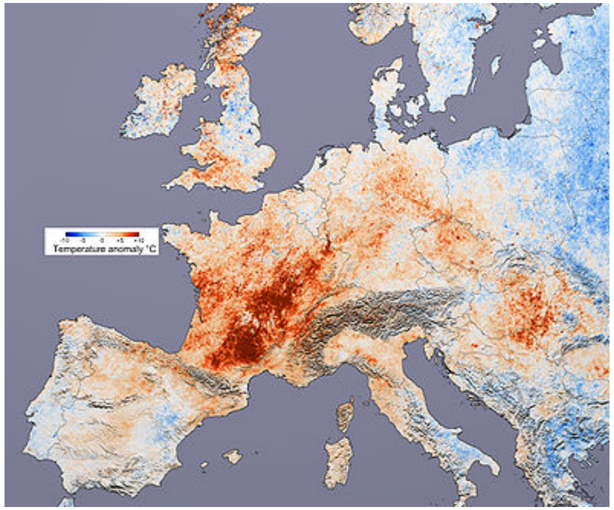
Ensembles with the same model are too confident

This can be seen in individual forecast cases!

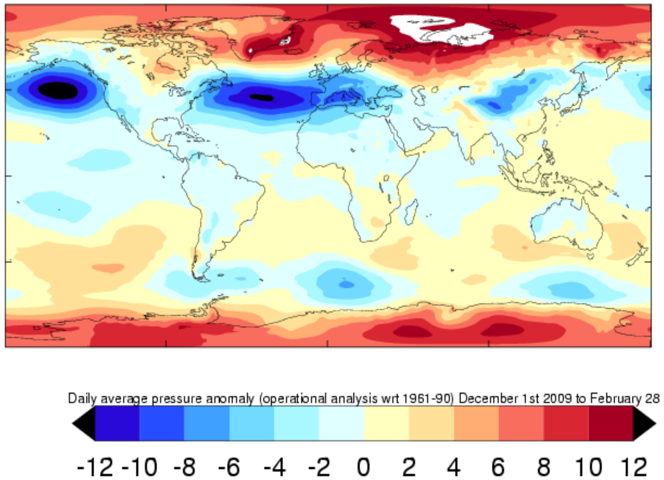
We need improved models: **components, resolution, teleconnections**

e.g.1 Blocking => extreme weather

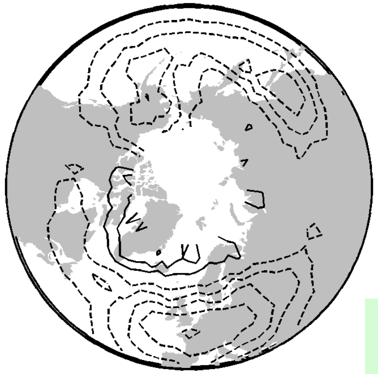
Summer 2003 temperature anomaly



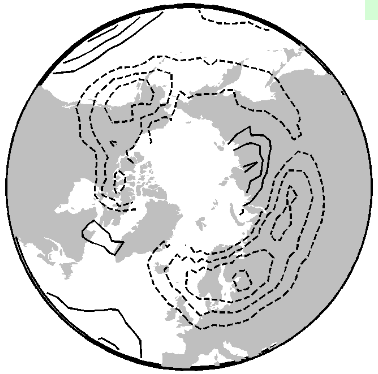
Winter 2009/10 sea-level pressure anomaly



Winter



Summer



Blocking deficit

>50% of observed value!

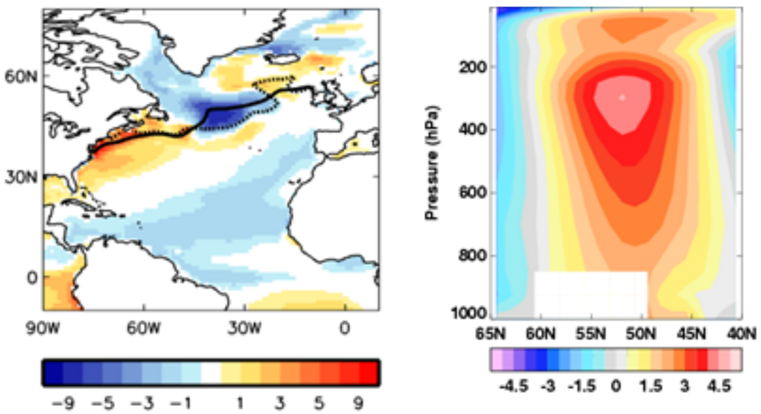
"recent studies have found that GCMs tend to simulate the location of NH blocking more accurately than frequency or duration"

(IPCC, AR4, WG1 Chapter 8)

e.g.1 Blocking

Here's the cause of the error:

Current Model

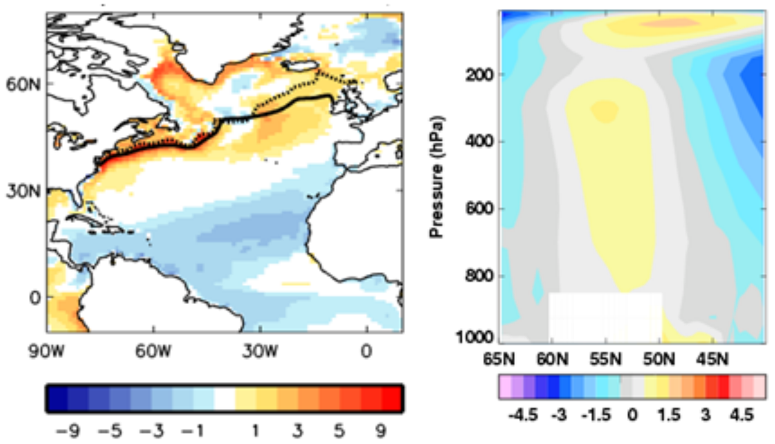


Gulf Stream Bias

Wly wind bias

=> Blocking Deficit

New Model

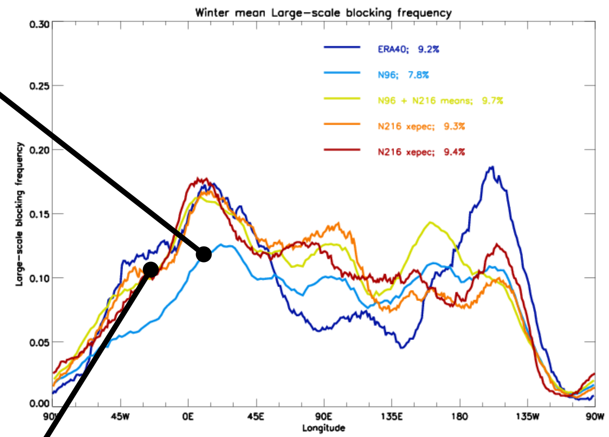


No Gulf Stream Bias

No Wly wind bias

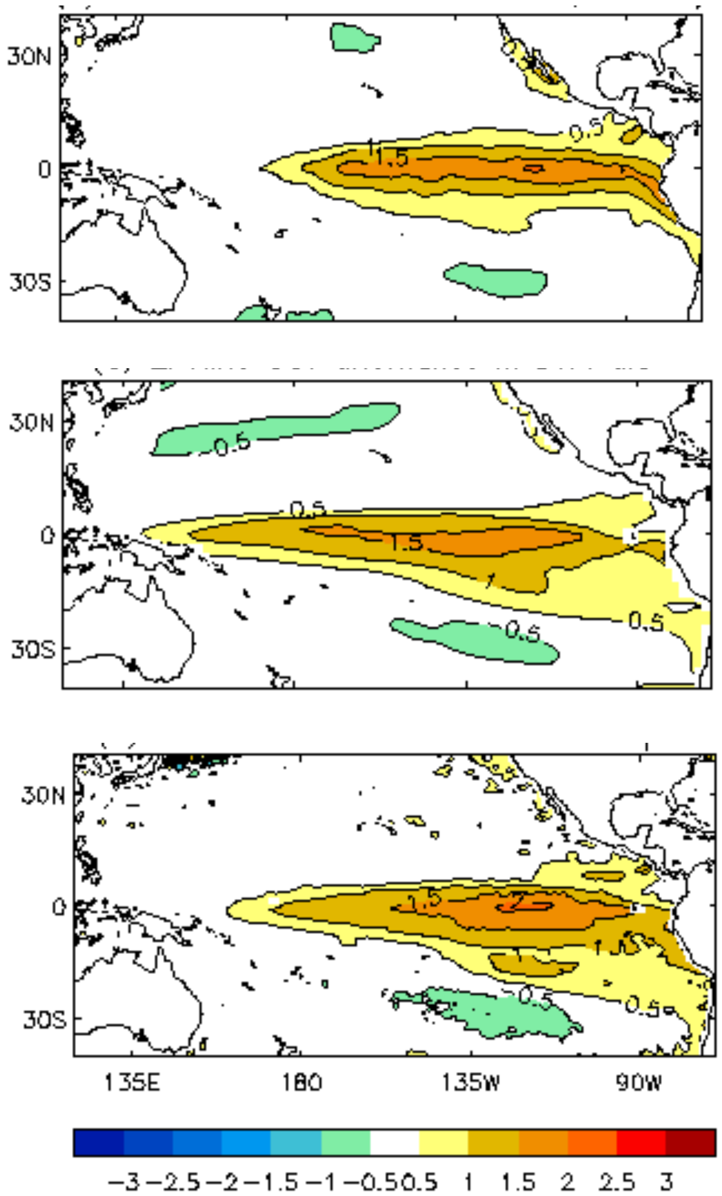
=> Good Blocking

Blocking Frequency



Scaife et al., *Geophys. Res. Lett.*, submitted.

e.g.2: El Nino Pattern errors



Obs

Current model

New Model

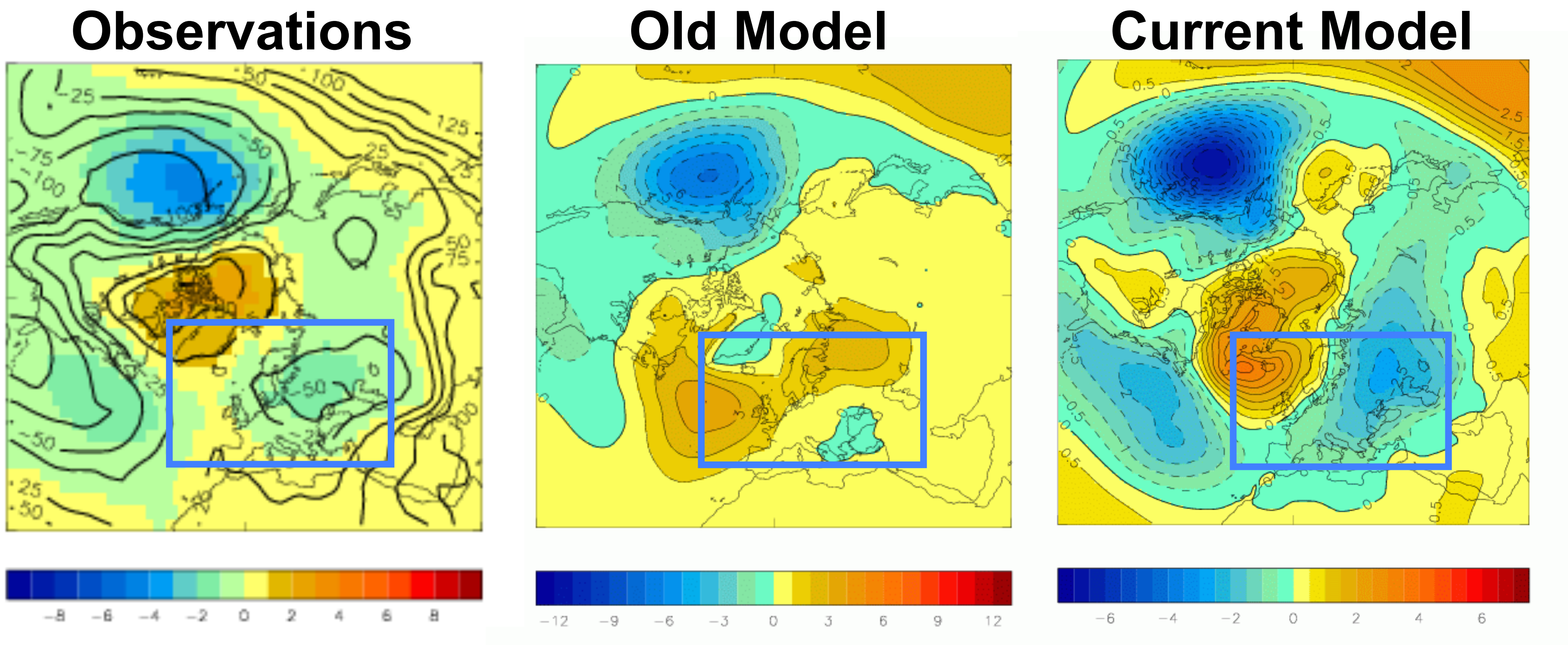
New model has better El Niño pattern

This error is common to many climate models

It affects remote regions

e.g.3: El Nino and Europe?

El Nino => negative Arctic Oscillation/NAO
Cold European Winter signal
Only works in high vert. resolution model

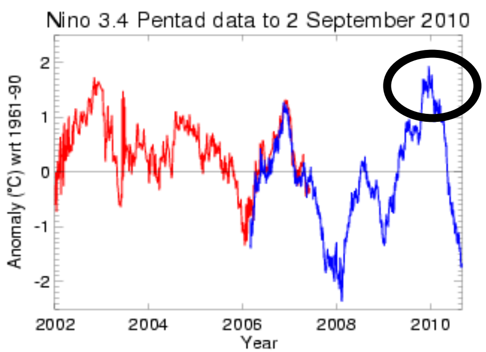


See: Ineson and Scaife, *Nat. Geosci.*, 2009

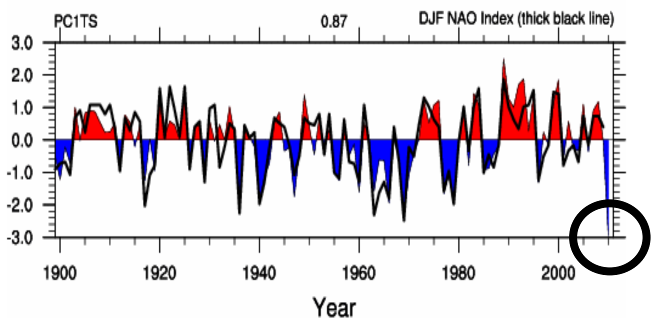
e.g.3: El Nino and Europe?

Winter 2009/10

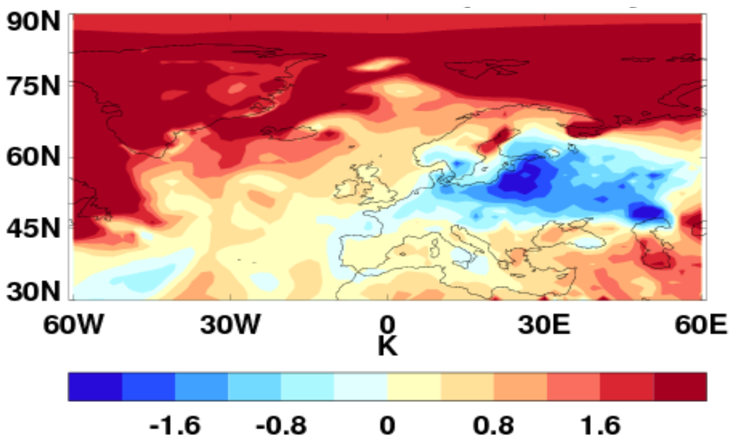
El Nino



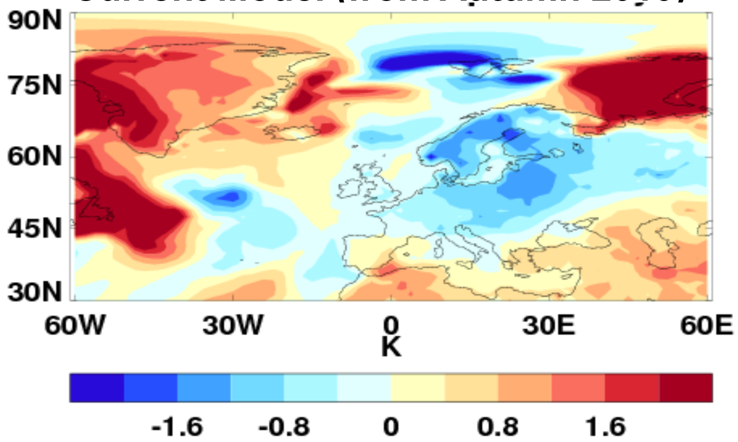
N Atlantic Oscillation



Old Model



Current Model (from Autumn 2010)



Fereday et al, submitted

CMIP5 Decadal *Hindcasts* for IPCC

- A new focus for IPCC: initialised climate predictions
- Every 5 years 1960, 1965,….2005, ensembles of 3 or more
- Groups producing first hindcasts; a research exercise
- Data being served for all to analyse alongside uninitialised climate simulations

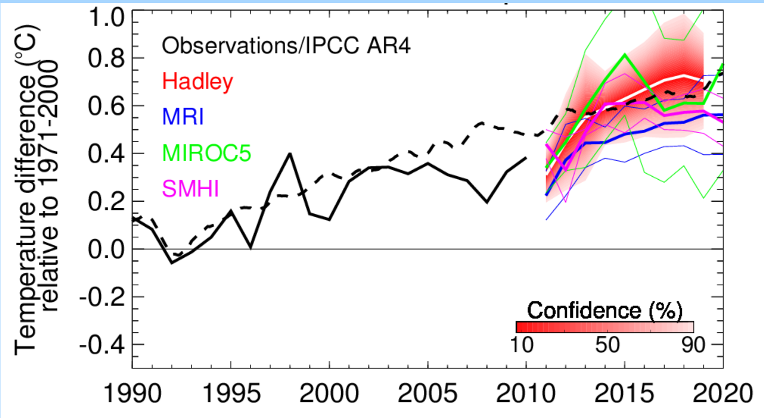
Decadal *Forecast* Exchange

Informal exchange of real time forecasts

Several prediction centres involved

First results starting to be collected together

First multimodel decadal prediction



WMO: CLIVAR, WGSIP and long range forecast provision

The World Meteorological Organization (WMO) sponsors the World Climate Research Project (WCRP)

WCRP has core projects: CLIVAR, GEWEX, SPARC, CliC

CLIVAR has a number of *research* working groups including WGSIP - Working Group on Seasonal to Interannual Prediction

WMO also provides real time long range *predictions* through designated Global Producing Centres: