Seasonal to decadal climate prediction: filling the gap between weather forecasts and climate projections

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Walter Orr Roberts memorial lecture, 9th June 2015
Contents

• Motivation
• Practical issues
• What can we predict?
• What is the forecast?
Improved weather forecasts

- Weather forecasts much improved over last 30 years
- 4 days ahead now as accurate as 1 day ahead in 1980
- BUT fundamental limits (weeks) due to chaotic atmosphere
You can’t predict the weather in a couple of weeks time, so how can you say anything about the winter/summer/decade?
More extreme weather events

Can only forecast probabilities
Greenhouse gases
The diagrams illustrate the changes in temperature anomaly due to natural and combined natural and human forcing over time. The top graph shows the natural forcing, while the bottom graph combines natural and human forcing. Both graphs display temperature anomalies in °C and are marked with observations, CMIP3, and CMIP5 models. The maps on the right provide a spatial representation of the observed trend from 1951-2010, indicating temperature changes across different regions of the world. The source of the data is credited to the IPCC.
Want to predict variations and trend

- **External forcing**: greenhouse gases, aerosols, volcanoes, solar
- **Natural internal variability** – need to start predictions from the current state of the climate system
- Climate varies a lot around the trend!

**UK 9-year mean temperature**

- Observations
- IPCC AR4
- “Global warming” trend
- Natural internal variability, or errors in simulation of external forcing
Sahel drought 1980s

Climate model forced by observed SST simulates Sahel rainfall variations.

Giannini et al., Science, 2003

Observed rainfall trend, 1950-2000

Held et al., PNAS, 2005
US dust bowl
1930s

Climate model forced by observed SST simulates US great plains rainfall variations.
Schubert et al., Science, 2004

Dust Storm, Oklahoma, 1936
Indian monsoon rainfall

Year-to-year changes difficult to simulate.

Modeled (black) and Observed (red) mm/day

But decade-to-decade potentially predictable
GIVEN ACCURATE OCEAN PREDICTIONS
Kucharski et al., Climate Dynamics, 2008
Model simulations of hurricane frequency

- 50 km resolution (GFDL model)
- Forced by observed SST

(Zhao et al. 2009)
North Atlantic variability

North Atlantic SST

Sahel rainfall

India rainfall

Hurricanes

Warm – cold Atlantic: summer composite

Temperature

Pressure

Rainfall

(Zhang and Delworth 2006; also Knight et al 2006; Hermanson et al 2014)
Many idealised experiments suggest that North Atlantic ocean currents are potentially predictable on decadal timescales.
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An optimistic view:

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

Perform historical tests (“retrospective forecasts” or “hindcasts”) to assess likely skill and correct biases
Models are imperfect!

(Kharin et al. 2012)
Sub-surface ocean observations

- Need historical tests to assess likely skill of forecasts
- Far fewer sub-surface ocean observations in the past
- Could forecasts be more accurate than hindcasts?
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Seasonal forecast skill
Dec-Feb (DJF, months 2-4)

• High skill in tropics
• Much lower for mid-latitude land (Europe and USA!)
• Limited skill for precipitation

Kim et al., 2012
Tropical Rains - seasonal

El Niño minus La Niña composite

**Forecast**

**Observed**

**Jun-Aug**

**Dec-Feb**

Arribas et al., MWR, 2011
The Polar Vortex

• Winter in USA and Europe depends on the wind direction
• Influenced by the Polar Vortex
• Sometimes breaks down → wavy
• Cold northerly winds e.g. 2014
Atlantic winter climate: the North Atlantic Oscillation (NAO)

POSITIVE PHASE: Winds coming in off the Atlantic send warm and damp air into Britain
2012: capability for predicting NAO is very low

Skill (correlation) for predicting DJF sea level pressure starting on 1st November

Time series of observed (circles) and seasonal forecast (solid line) of the NAO
2014: capability for predicting NAO is high!

Skill (correlation) for predicting DJF sea level pressure starting on 1\textsuperscript{st} November

Time series of observed (black) and seasonal forecasts (orange) of the NAO

New model is 10 times more expensive
But now very skilful for European winters!

Observations

Forecasts

Correlation > 0.6

• Scaife \textit{et al}, 2014
• Split the world into boxes
• For each box, ensure fundamental laws of physics are satisfied:
  - Conservation of mass, momentum and energy
• Small scale processes (e.g. Clouds) must be parameterised
• The smaller the boxes the higher the accuracy
• ...but more expensive (need large supercomputers)
Higher resolution

ORCA $\frac{1}{4}^°$

ORCA $1^°$

2 years of monthly mean temperature at 370m depth
The next 5 years

Skill of initialised predictions

Initialised - Uninitialised

- 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)
Case study: sub-polar gyre

Predictions of sub-polar 1990s gyre warming

- Low skill in general, but some impacts captured over land for specific events

(Robson et al. 2012, 2013, Smith et al 2013)
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El Niño forecast

Mid-May 2015 Plume of Model ENSO Predictions

(d) DJF precipitation

(g) JJA precipitation

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What next?

Observed Atlantic overturning circulation

- Atlantic predicted to cool…
- …in response to weakening of Atlantic overturning
- Not a reversal (yet), but impacts associated with warm Atlantic less likely:
  - cold winters and wet summers in Europe less likely
  - fewer hurricanes than recent peaks
  - reduced Sahel rainfall
  - reduced risk of drought in SW USA

Decadal forecasts of Atlantic temperature

- Smeed et al, 2013; Hermanson et al 2014
North Atlantic variability

North Atlantic SST

Sahel rainfall

India rainfall

Hurricanes

Warm – cold Atlantic: summer composite

Temperature

Pressure

Rainfall

(Zhang and Delworth 2006; also Knight et al 2006; also Hermanson et al 2014)
Summary

• Many people are vulnerable to changes in climate over the coming seasons to decades

• There are good physical reasons why we may be able to predict some aspects of climate on these timescales

• ...though there will be uncertainties that need to be carefully communicated!

• This is a new and rapidly developing area

• Much recent progress...

• ...but also many issues still to overcome