A Perspective on Decadal Variability and Predictability

Mojib Latif
Leibniz Institute of Marine Sciences, Kiel University, Germany

The New York Times

...Mojib Latif...wrote a paper last year positing that cyclical shifts in the oceans were aligning in a way that could keep temperatures over the next decade or so relatively stable, even as the heat-trapping gases linked to global warming continued to increase.

By ANDREW C. REVKIN
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The AMO has a projection on Northern Hemisphere and even global SAT

Knight et al. 2005
AMO impact, SAT 1978-2007?

The last decades may contain a strong contribution from internal variability

Semenov et al., 2009
Outline

• Mechanisms of decadal variability
• History of decadal prediction
• What are the limiting factors?
• Challenges
The Pacific Decadal Oscillation/ Variability

monthly values for the PDO index: 1900-2008
A stochastic view for the Pacific

Stochastic Climate Models

- **first order model**
  - Frequency vs. scale

- **ocean-only oscillator**
  - Frequency vs. scale

- **coupled ocean-atmosphere oscillator**
  - Spectral density vs. frequency

AGCM - OCM

- **a)** ECHAM5–OZ EOF–1 (14%) timescale: 1–5 yrs
- **b)** ECHAM5–OZ EOF–1 (18%) timescale: 5–20 yrs
- **c)** ECHAM5–OZ EOF–1 (29%) timescale: >40 yrs

Hyper mode, Dommengent and Latif 2008
Interannual to decadal predictability originates from gyre adjustment

Multi-millennial control run of KCM, lag ~2-10 years

Courtesy W. Park
Atlantic Multidecadal Oscillation/Variability

Changes in hurricane activity and Sahel rain, for instance, can be traced back to variations in Atlantic sea surface temperature (SST)
Decadal predictability stems from MOC adjustment

Most evidence points towards the “ocean-only” oscillator in the Atlantic
Decadal variations in the North Atlantic Oscillation

NAO drives Labrador Sea convection
The NAO spectrum is almost white, so that a simple stochastic scenario may apply.
NAO $\rightarrow$ LS convection $\rightarrow$ “MOC”
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Potential Predictability in Surface Air Temperature

IPCC AR4 Models (8900 yrs Control) 10 yr means

Boer and Lambert (2008)

potential predictability variance fraction ($\sigma_v^2/\sigma^2$)

Higher extra-tropical SST Predictability
The history of decadal prediction: perfect predictability studies

Griffies and Bryan 1997

Grötzner et al. 1999
Current state-of-the-art models yield similar results

The MOC is predicable at a lead of one to two decades in perfect model studies
Forecasts for the next decade

(A) Global average surface temperature

- Smith et al. 2007
- Keenlyside et al. 2008
- Pohlmann et al. 2009
- Observations

3 climate model hind/forecasts

(B) Atlantic SST dipole index

„MOC“

Hurrell et al. 2009
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• Mechanisms of decadal variability
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Model biases are large

Typical bias in surface air temperature (SAT)

Errors of several degrees (°C) in some regions

St. Michaels 12 Oct 2009
The Tropical Atlantic SST bias in the Kiel Climate Model (KCM)

The zonal SST gradient along the equator is reversed in many models. Bad news for prediction in the Tropics.

Wahl et al. 2009
Gulfstream SST front

Representation of small-scale processes
Atmospheric response: resolution matters

The AGCM has T239 horizontal resolution (~50 km) and 48 levels

Compared to the smoothed SST run, rain-bearing low pressure systems tend to develop along the Gulf Stream front in the control simulation

Minobe et al. 2008

St. Michaels 12 Oct 2009
The signal-to-noise problem

Pohlmann et al. 2006
Arctic sea ice melts faster than projected by the models: why?

Stroeve et al. 2007

St. Michaels 12 Oct 2009
Do we have enough data?

Global Number of Temperature Observations (1980-2006)

A major challenge for climate analysis and prediction: uneven observational coverage in both space and time; deep ocean and ice covered regions are poorly observed.

ARGO made a big difference. Is it sufficient?

Courtesy Tony Rosati, Hurrell et al. (2009)
Strong volcanic eruptions, for instance, can cause global cooling of about 0.2°C for a few years and persist even longer in the ocean heat content. If they happen, we can exploit their long-lasting climatic effects.
Outline

• Why decadal prediction
• Mechanisms of decadal variability
• What is the decadal predictability potential
• Challenges
Challenges

• A decadal predictability potential for a number of societal relevant quantities is well established.
• The signal-to-noise ratio is a problem. How can we best use decadal forecasts?
• We need a better understanding of the mechanisms of decadal variability (atmospheric response to extra-tropical SST).
• We need a suitable climate observing system (ocean, land surface, sea ice...). Is the current one sufficient?
• We need „good“ models! We know from NWP that reduction of systematic bias helps. Biases in climate models are still large.
• Higher resolution helps. Yet we still need improved parameterizations.
• The models are not complete. More physics must be incorporated (e. g., ice, stratosphere, chemistry,...).
• Much increase in computing power is necessary.
To realize the full decadal predictability potential we need a coordinated scientific programme under the auspices of the World Climate Research Programme (WCRP)
Decadal variability in sea level

Topex/Poseidon 1993-2005
Decadal variations in Sahel rainfall
Decadal variations in Atlantic hurricane activity
Decadal variability in sea level

Linear trend 1993-2003

Kwajalein (8°44'N, 167°44'E)
Changes in the AMO are felt on a hemispheric and even global scale

How much did internal decadal variability contribute to the warming during the recent decades?
The NAO as a driver of the MOC

![Diagram showing time series of Wintertime North Atlantic Oscillation index, Labrador Sea Water thickness, and Atlantic SST dipole index over the years from 1880 to 2000.]
NAO leads “MOC“ (SST dipole)

Cross correlation implies predictability

Cross correlation function NAO/“MOC“

～10 years
Shifts in PDFs of European SAT in response to MOC changes

coupled model simulation

weak THC

strong THC
The natural variability can fool us
Global change prediction is a joint initial/boundary value problem

Projections were not initialized in IPCC-AR4
The basis for climate prediction

Griffies and Bryan 1997

SST predict ~5 years
SSS predict ~10 years

Dynamic topography predict ~10 to 20 years
Mid-depth ocean

1100 m

Abyssal ocean
NAO leads SST Dipole ("MOC")

Labrador Sea convection

"MOC"

NAO

Latif et al. 2006
Northern Hemisphere SAT zonal means
SAT in different zonal bands

60-NP
40-60N
20-40N
EQ-20N
Definition of the „MOC“ - index, SST (NA) – SST(SA)

SST trend 1980-2004, global mean removed

Latif et al. 2006
The uncertainty in climate projections for the 21st century

- Internal variability
- Unpredictable external influences
- Model bias

Hawkins and Sutton 2009
The scenario uncertainty becomes important in the long run

**CO₂ emissions and equilibrium temperature increases for a range of stabilisation levels**

- Historical emissions
- Stabilisation level

- I: 445–490 ppm CO₂-eq
- II: 490–535 ppm CO₂-eq
- III: 535–590 ppm CO₂-eq
- IV: 590–710 ppm CO₂-eq
- V: 710–855 ppm CO₂-eq
- VI: 855–1130 ppm CO₂-eq

- Equilibrium global average temperature increase above pre-industrial (°C)

**IPCC 2007**
Climate observing system

Example: ocean observing system

We need climate observations to initialize the models to forecast variations up to decadal time scales.