Sources of predictability beyond the deterministic limit

Franco Molteni, Sarah Keeley
European Centre for Medium-Range Weather Forecasts
Outline

Persistent anomalies in the tropics and extra-tropics: examples from the last two decades

Beyond deterministic predictability in non-linear, chaotic systems: the role of variability in surface conditions and energy/water fluxes

Coupled ocean-atmosphere variability - predictability on the weekly/monthly time scale arising from sub-seasonal tropical variability and teleconnections

A look at sea ice and the impact on predictions
Oct-Dec 1997: floods in East Africa

Precip anomaly OND 1997

Rift Valley Fever outbreak

FIG. 45. (a, b) Accumulated observed precipitation (solid curve) and accumulated climatological precipitation (1981–90 base period) (dashed curve) beginning 1 October 1997 and ending 1 January 1998 at (a) Mombasa, Kenya and (b) Meru, Kenya. (c, d) Daily precipitation totals during October 1997–1 January 1998 at (c) Mombasa, Kenya and (d) Meru, Kenya. Green shading in (c)–(d) indicates the difference between the observed and normal accumulated rainfall.
July 2002: drought in India

All-India Rainfall time series
May - October
Drought in South-western USA

Lake Mead, Colorado River

Lake Mead (Arizona / Nevada)
15-year drought

U.S. Drought Monitor

April 7, 2015
(Released Thursday, Apr. 9, 2015)
Valid 7 a.m. EDT

Drought Impact Types:
- Elevated: dominant impacts
- Severe: short-term, typically less than 6 months (e.g., agriculture, business)
- Exceptional: long-term, typically greater than 12 months (e.g., hydrology, ecology)

Legend:
- DRASTIC
- DD: Drought
- DD: Depleted
- DD: Drought
- DD: Exceptional
- SD: Severe

Author: Michael G. Bars and K.C. Howell

http://droughtmonitor.unl.edu/
Summer 2003: European heat-wave

Temperature anomaly
20 July – 20 August
Winter 2009-2010: cold anomaly over N. Europe

7 Jan 2010
Short-term climate forecasts are a mixed initial-boundary condition problem in a chaotic system.
How can we forecast on long timescales?

Ocean
Sea ice
Land Surface
• Soil moisture
• Vegetation
• Snow
Stratosphere
Atmospheric composition
Incoming solar radiation
Observations

Data Assimilation

Coupled model

Forecast Products

- Current state of the atmosphere
- Current state of the ocean
- Atmospheric model
- Ocean model
- Forecast models extended range predictions (All ensemble forecasts at ECMWF)
Seasonal forecasts aim to predict an anomaly from the default climatological probability.

Probability density distributions of a hypothetical climatology and forecast given an observation.

“Ideal” situation

“Real” situation
\[
\begin{align*}
\dot{X} &= -\sigma X + \sigma Y \\
\dot{Y} &= -XZ + rX - Y \\
\dot{Z} &= XY - bZ
\end{align*}
\]

Lorenz E., 1963: Deterministic non-periodic flow
What is the impact of $f$ on the attractor?

Lorenz E., 1963: Deterministic non-periodic flow
Add external steady forcing $f$ to the Lorenz (1963) equations 

The influence of $f$ on the state vector probability function is itself predictable.
El Niño and the Southern Oscillation

SOI: Tahiti – Darwin SLP

Nino3.4 SST
ENSO impacts: rainfall and temperature
Teleconnections with ENSO

Correlation of 700hPa height with
a) PC1 of Eq. Pacific SST
c) SOI index

Schematic diagram of tropical-extratropical
teleconnections during El Niño

Horel and Wallace 1981
The Pacific /North American (PNA) pattern

500-hPa height composites from Wallace and Gutzler 1981
The Indian Ocean Dipole (or I.O. Zonal Mode)

Saji et al. (1999)
Webster et al. (1999)
Prediction of tropical SST and rainfall anomalies in Sys4

Nino3.4
DJF

IOD
SON
Sub-seasonal variability: the Madden-Julian Oscillation
The North Atlantic Oscillation

Walker and Bliss (1932)
Van Loon and Rogers (1978)

Positive NAO phase
Negative NAO phase
MJO teleconnections in October-March

500 hPa height, MJO phase 3 + 10 days

2002 MOFC hindcasts  2011 MOFC hindcasts  ERA Interim

from Vitart 2014
Sea ice: Interaction of climate change and natural variability

Record minimum in Arctic sea-ice extent: 16/9/2012 (from NSIDC)
Impacts of Sea Ice

• Energy Fluxes:
  – Changes albedo of the region – solar heating of upper ocean
  – Thickness of the sea ice alters the surface heat fluxes
    • Winter; biggest effect – no sun and air colder than ocean
    • Leads in the ice are important (Badgerley, 1966)

• Impact on waves
• Salinity fluxes:
  – Production of brine (freezing) and freshwater (melting)

Maykut (1978), JGR
Impacts on the ocean

Deep convection:

- More important on longer time scales

- Impact on the Gulf Stream and the Thermohaline circulation – part of the feedback on the Arctic system

Cold Halocline Layer:

- Layer of freshwater that insulates sea ice from warmer waters that are advected into the basin
Sea Ice predictability experiment – July 2012

Sea ice: 2012 - climatology

SST: 2012 - climatology

July MSLP anomaly
Era Interim 2012 - climatology

SST2012

SealIce2012
Conclusions

Regional anomalies in atmospheric flow and weather parameters may persist on time scales longer than the deterministic predictability limit, and have substantial societal impacts.

The possibility of performing probabilistic predictions of these events arises from the interaction of the atmospheric flow with slowly varying anomalies in surface conditions, which modify the energy and water sources for the atmosphere. We need to initialise and model the coupled phenomena important for atmospheric variability.

In the extratropics, persistent anomalies can be generated by (linear) teleconnections with tropical variability (e.g., ENSO) but also from the alternation of different (non-linear) flow regimes.

Ensemble prediction systems provide an estimate of long-range predictability based on the ratio of ensemble spread and ensemble-mean variability.

Predictability over Europe: limited by strong internal variability during winter (but with significant teleconnections on the sub-seasonal scale), higher in other seasons when internal variability is reduced.
References