Sources of predictability beyond the deterministic limit

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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 in the tropics and its teleconnections with the extra-tropical flow

Ensemble predictions in the “extended” range: estimates of predictability and actual skill

Predictability on the weekly/monthly time scale arising from sub-seasonal tropical variability and teleconnections
FIG. 45. (a, b) Accumulated observed precipitation (solid curve) and accumulated climatological precipitation (1961–90 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 (a)–(b) indicates the difference between the observed and normal accumulated rainfall.
July 2002: drought in India

All-India Rainfall time series
May - October
Summer 2003: European heat-wave

Temperature anomaly °C

Z 500 anomaly JJA 2003
Winter 2009-2010: cold anomaly over N. Europe

7 Jan 2010
Drought in South-western USA

Lake Mead, Colorado River

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

Lake Mead
(Arizona / Nevada)
15-year drought

U.S. Drought Monitor

Intensity:
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

Drought Impact Types:
- D0: Abnormally dry impacts
- D1: Short-Term, typically less than 6 months (e.g., agriculture, grassland)
- D2: Long-Term, typically greater than 6 months (e.g., hydrology, ecology)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for detailed statements.

http://droughtmonitor.unl.edu/
Chaotic behaviour in non-linear systems

3-variable model of Rayleigh-Benard convection *(Lorenz 1963)*

\[
\begin{align*}
\frac{dX}{dt} &= \sigma (Y - X) \\
\frac{dY}{dt} &= -XZ + rX - Y \\
\frac{dZ}{dt} &= XY - bZ
\end{align*}
\]

*Unstable stationary states*

\[
X = Y = Z = 0 \\
X = Y = \pm \sqrt{b (r-1)} , Z = r - 1
\]
The global energy cycle (2000-2004)

from Trenberth et al. 2009
Sea ice: Interaction of climate change and natural variability

Record minimum in Arctic sea-ice extent: 16/9/2012 (from NSIDC)
El Niño and the Southern Oscillation

Walker and Bliss (1932); Bjerknes (1969)
ENSO impacts: rainfall and temperature
The Indian Ocean Dipole (or I.O. Zonal Mode)

Saji et al. (1999)
Webster et al. (1999)
The North Atlantic Oscillation

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

Positive NAO phase

Negative NAO phase
The Pacific / North American (PNA) pattern

500-hPa height composites from Wallace and Gutzler 1981
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
Multiple flow regimes in non-linear models

Charney and DeVore 1979: multiple steady states of a low-order barotropic model with sinusoidal bottom topography

Fig. 4. Streamfunction fields of the stable first mode equilibria of a topographically forced flow for $k = 10^{-3}$, $L/a = \frac{1}{4}$, $n = 2$, $h_b/H = 0.2$ and $\psi^* = 0.2$: for the spectral model above resonance (a) and slightly below resonance (b); and for the grid-point model above resonance (c) and slightly below resonance (d). The nondimensional topographic heights are shown with light lines; the contour spacing is 0.05 units, with negative regions shaded.
The ECMWF Seasonal fc. system (Sys-4)

- IFS 36R4
  - 0.7 deg (T255)
  - 91 levels

- NEMO
  - 1/1-0.3 d. lon/lat
  - 42 levels

- H-TESSEL

- 4-D variational d.a.

- 3-D v.d.a. (NEMOVAR)

- Gen. of Perturb.

- Initial Con.

- Ens. Forecasts

- System-4 CGCM
ECMWF System 4: main features

Operational forecasts

51-member ensemble from 1\textsuperscript{st} day of the month
released on the 8\textsuperscript{th}
7-month integration

Experimental ENSO outlook

13-month extension from 1\textsuperscript{st} Feb/May/Aug/Nov
15-member ensemble

Re-forecast set

30 years, start dates from 1 Jan 1981 to 1 Dec 2010
Variability in an ensemble of time-evolving fields

\[ F(t, m) = F(t', j, m) \]

\( t' = \text{time within year} \)
\( j = 1, N \) (no. of years) \( m = 1, M \) (no. of ens. members)

Climatology:
\[ F_{cl}(t') = \{ F(t', j, m) \}_{j, m} \]

Anomaly:
\[ A(t', j, m) = F(t', j, m) - F_{cl}(t') \]

Seasonal mean anomaly:
\[ A_s(j, m) = \{ A(t', j, m) \}_{t'} \]

Ens./seas. mean anomaly:
\[ A_{es}(j) = \{ A(t', j, m) \}_{t', m} \]

• for an observation/analysis dataset, \( M = 1 \)!
• in a “perfect” model environment, the average correlation between \( A_{es} \) and \( A_s \) is equal to the ratio of their standard deviations.
Variability of Z 200hPa in DJF from seasonal ensembles

Standard deviation from 11-member ensembles, DJF 1981/2005
Prediction of tropical SST anomalies in Sys4

Nino3.4 DJF

IOD SON
Prediction of tropical rainfall in Sys4: East Africa (SON)

eaf mon=10(3)  GPCP(red), SYS4(g/b)  ac=0.491

cov (eaf, prec)
Prediction of 2-m temperature in Sys4: Europe (DJF, JJA)
Prediction of 2-m temperature in Sys4: Europe (MAM)
Sub-seasonal variability: the Madden-Julian Oscillation

OLR Anomalies: Daily-averaged; Base period 1979–2001
8-Oct-2007 to 7-Apr-2008

(RMM1, RMM2) phase space for 1-Dec-2007 to 31-Mar-2008
MJO teleconnections in October-March

500 hPa height, MJO phase 3 + 10 days

2002 MOFC hindcasts

2011 MOFC hindcasts

ERA Interim

from Vitart 2014
Z 500 hPa anomaly
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.

In the extratropics, persistent anomalies can be generated by (linear) teleconnections with tropical variability (eg 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