Sources of predictability beyond the deterministic limit

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

Outline

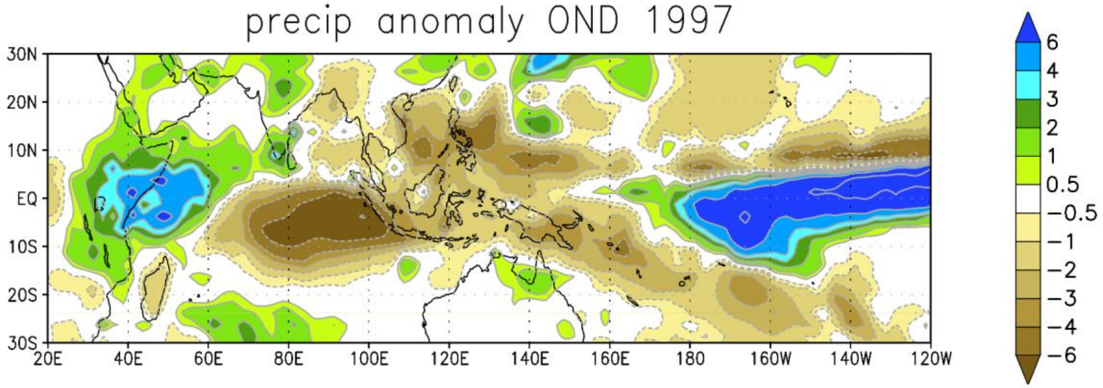
Persistent anomalies in the tropics and extra-tropics: examples from the last two decades

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



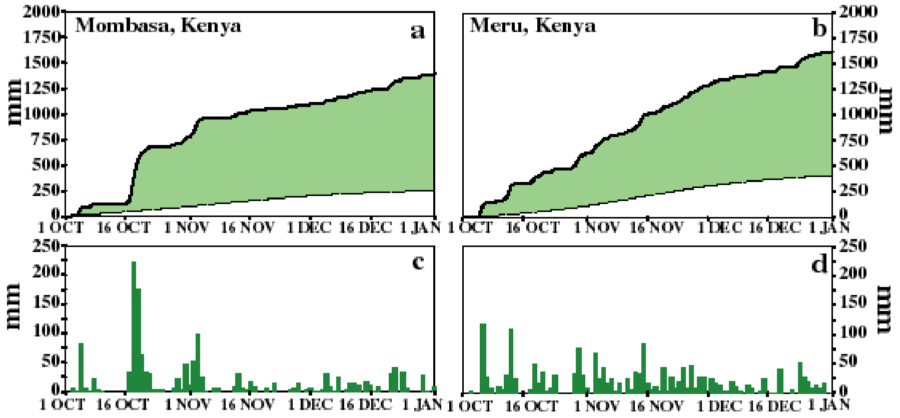
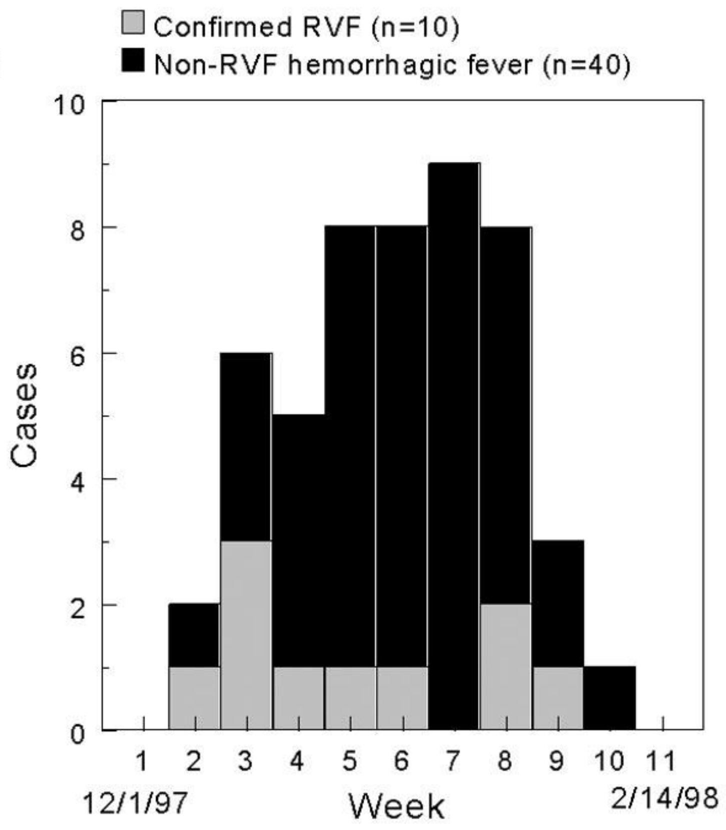
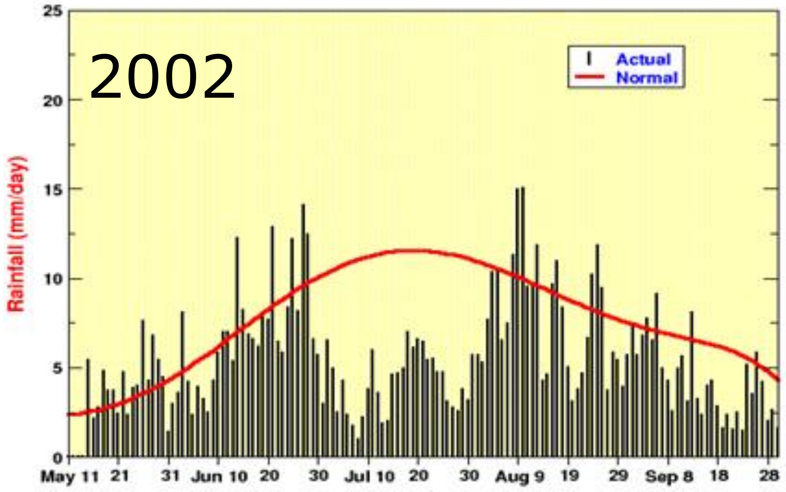


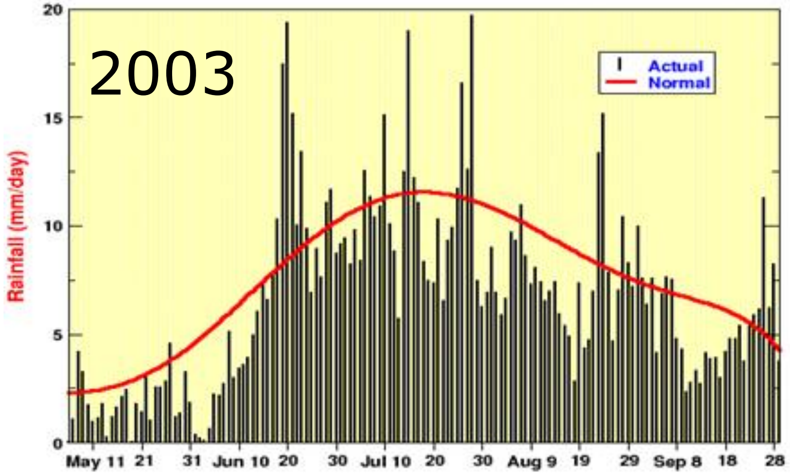
FIG. 45. (a, b) Accumulated observed precipitation (solid curve) and accumulated climatological precipitation (1961–90 base period) (dashed curve) beginning 1 October 1997 and ending 1 January 1998 at (a) Mombasa, Kenya and (b) Meru, Kenya. (c, d) Daily precipitation totals during October 1997–1 January 1998 at (c) Mombasa, Kenya and (d) Meru, Kenya. Green shading in (a)–(b) indicates the difference between the observed and normal accumulated rainfall.

Rift Valley Fever outbreak



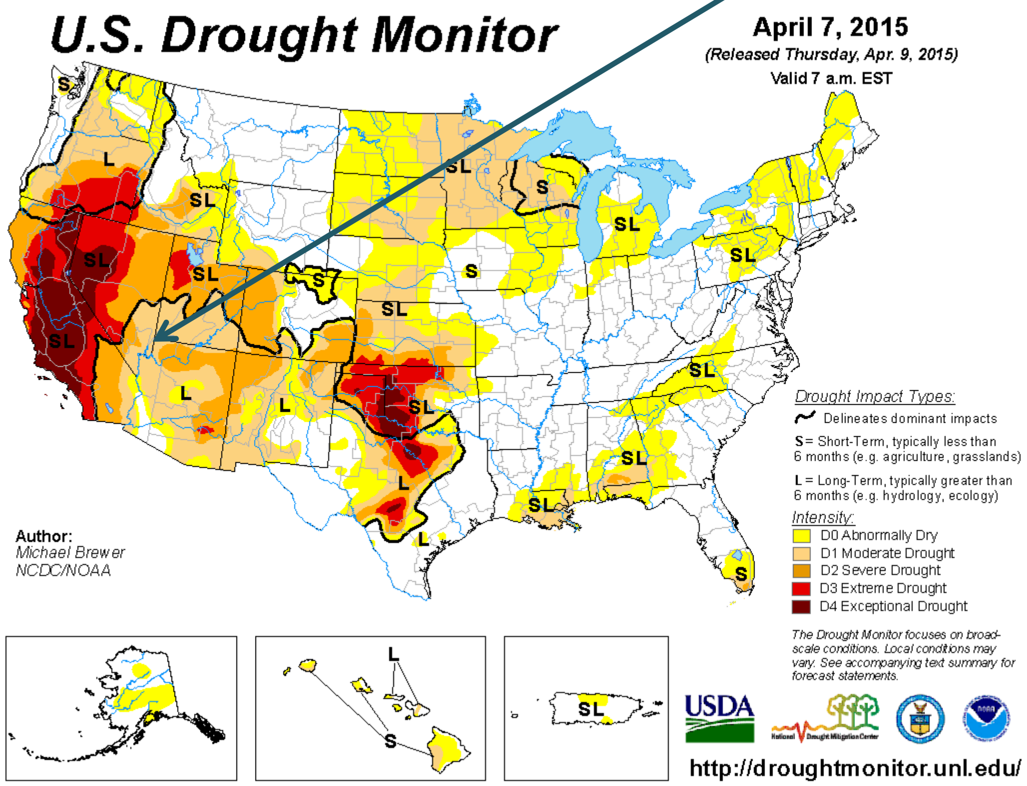
July 2002: drought in India





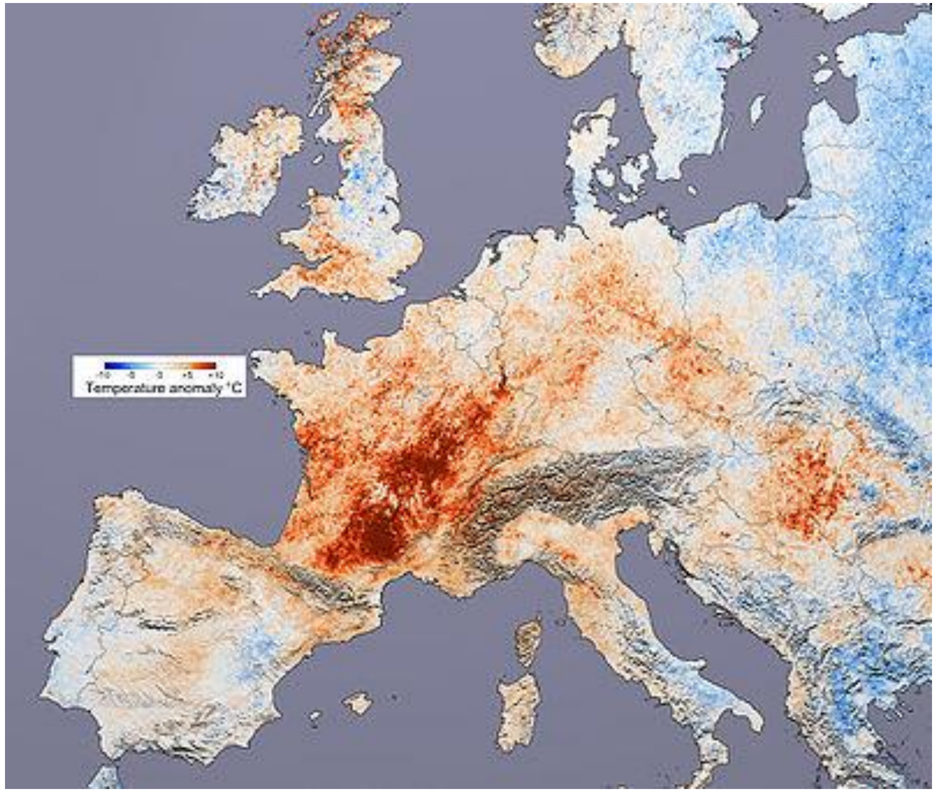
All-India Rainfall time series
May - October

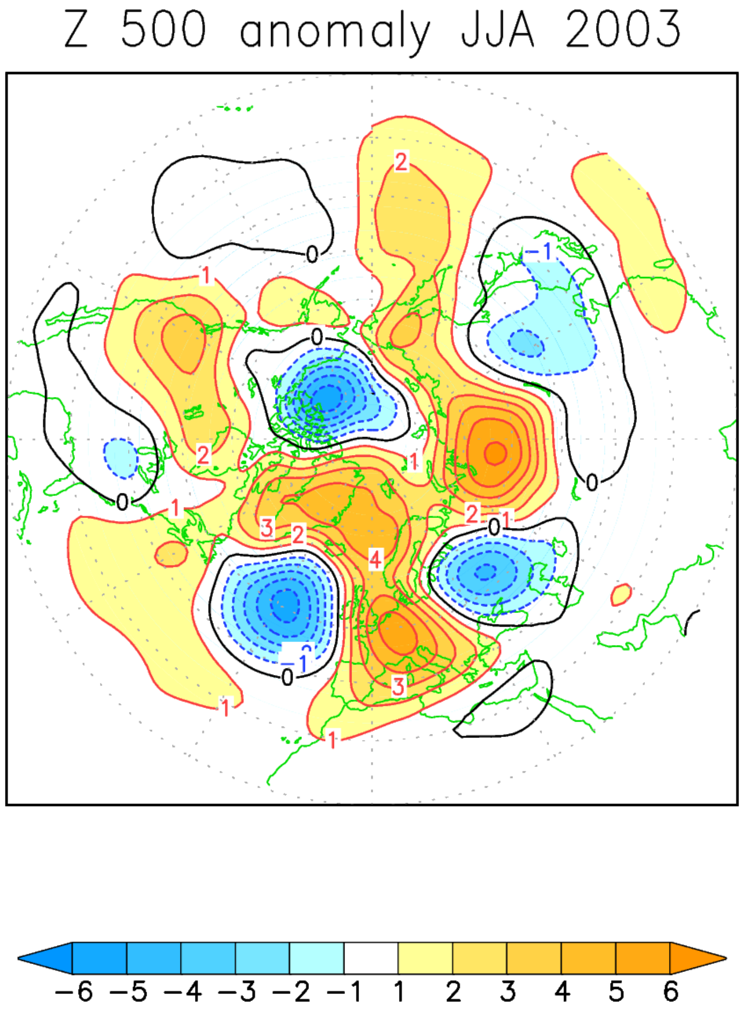
Drought in South-western USA



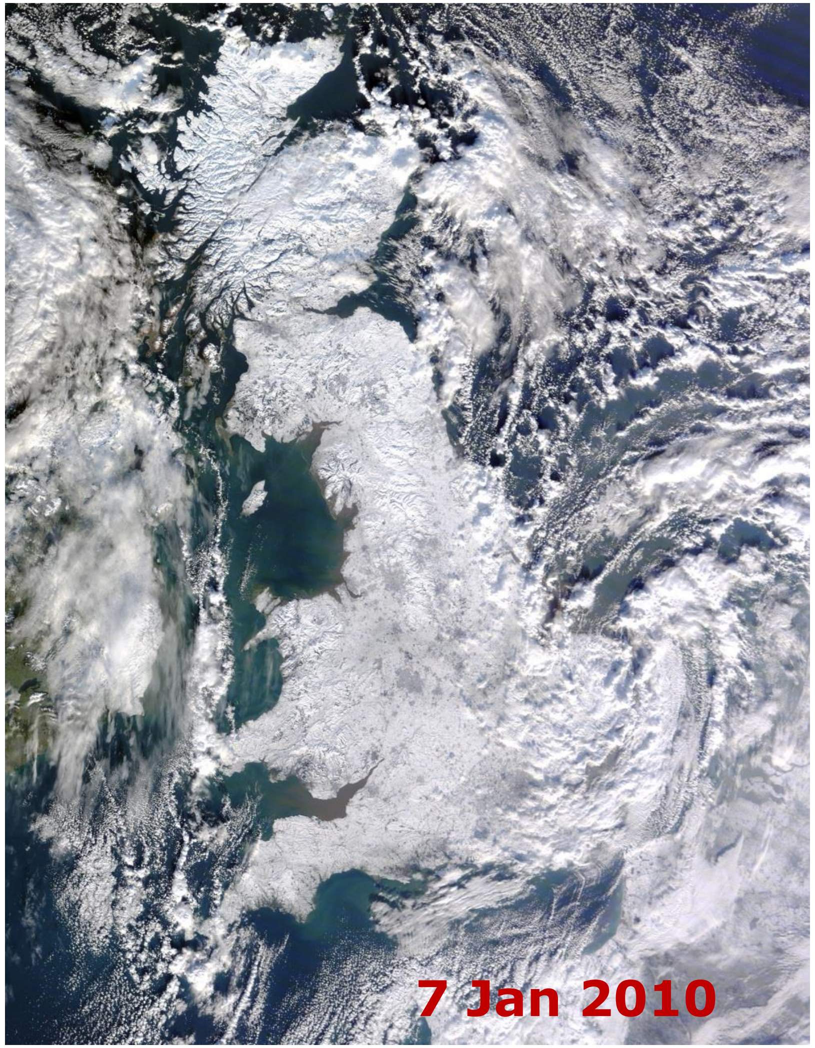
Lake Mead
(Arizona / Nevada)
15-year drought

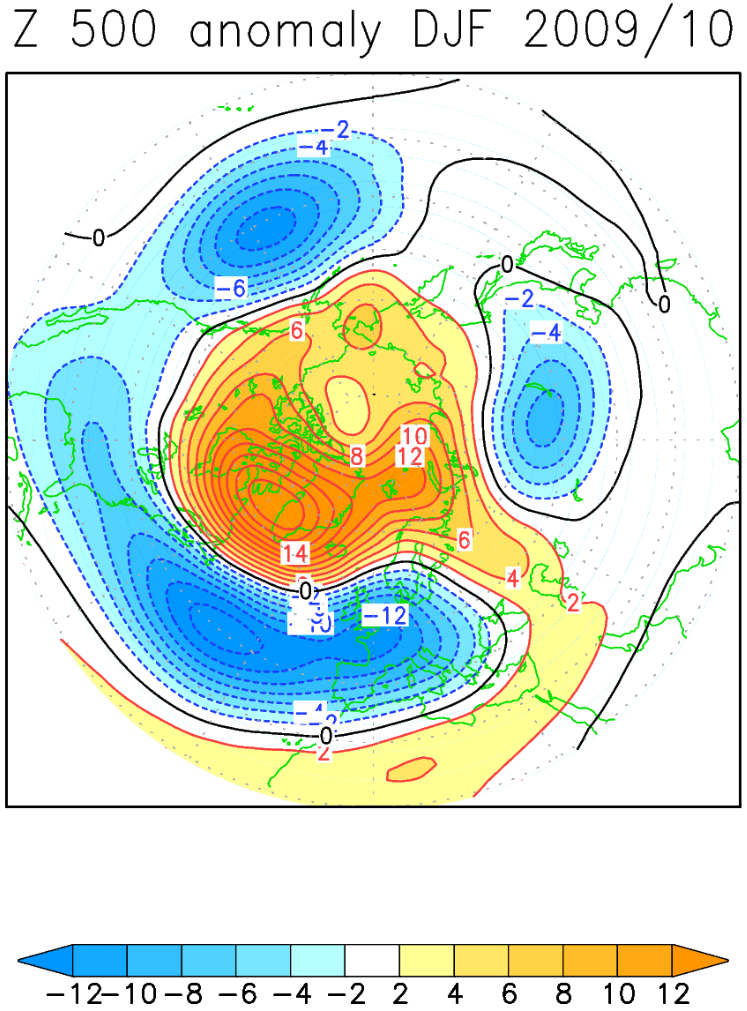
Summer 2003: European heat-wave



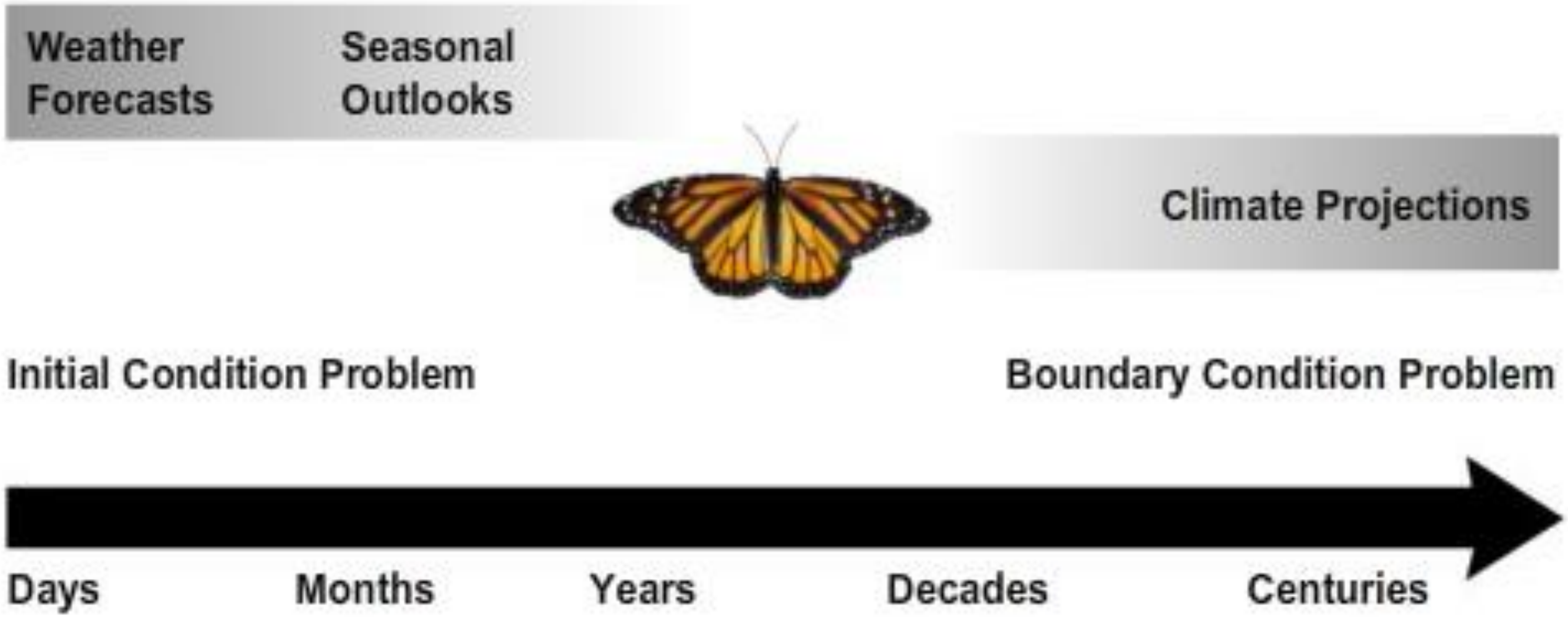


Winter 2009-2010: cold anomaly over N. Europe





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

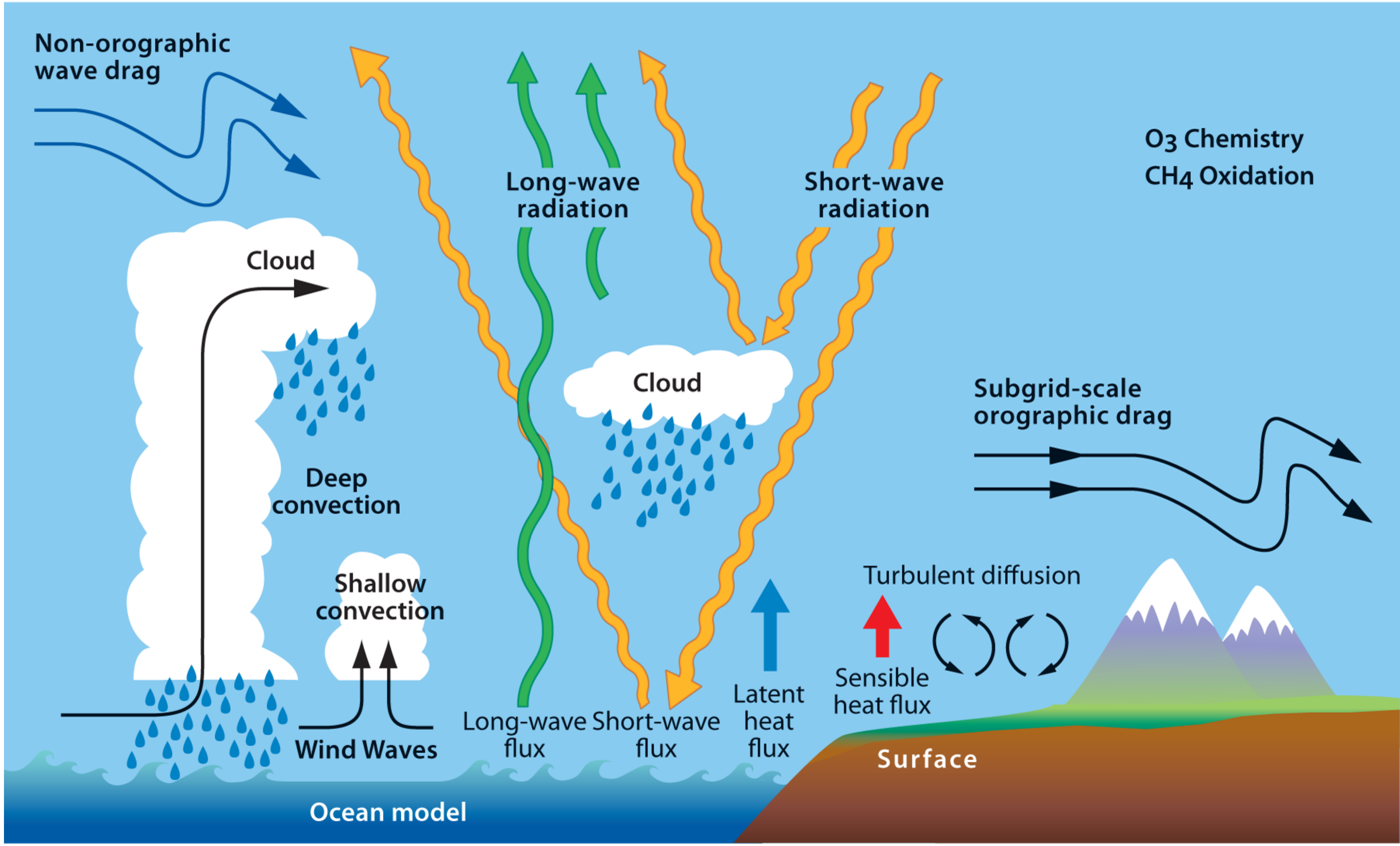
Land Surface

- Soil moisture
- Vegetation
- Snow

Stratosphere

Atmospheric composition

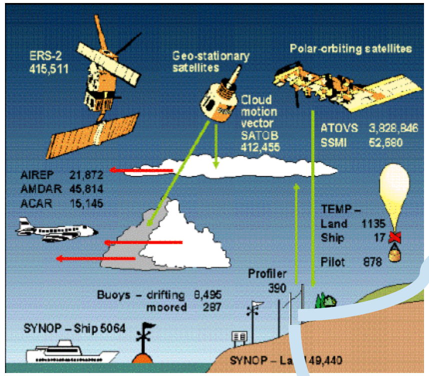
Incoming solar radiation

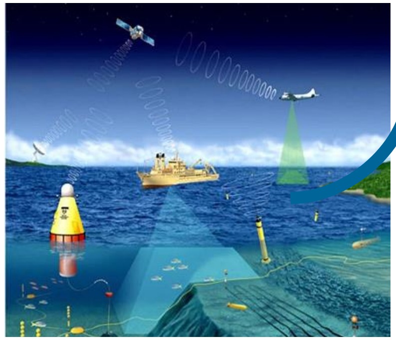


ECMWF

Forecast models extended range predictions
(All ensemble forecasts at ECMWF)

Observations





Data Assimilation

current state of the atmosphere

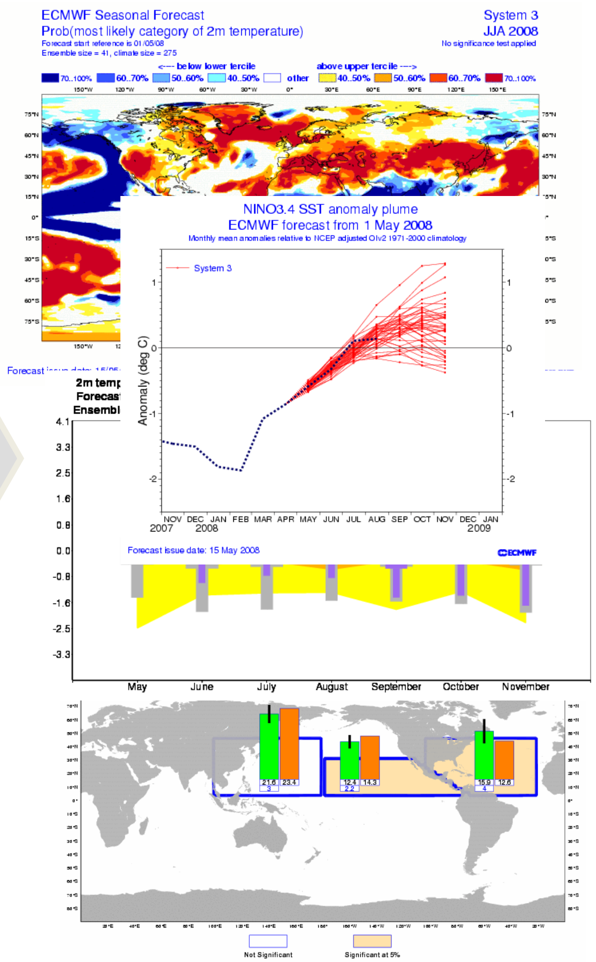
current state of the ocean

Coupled model

atmospheric model

ocean model

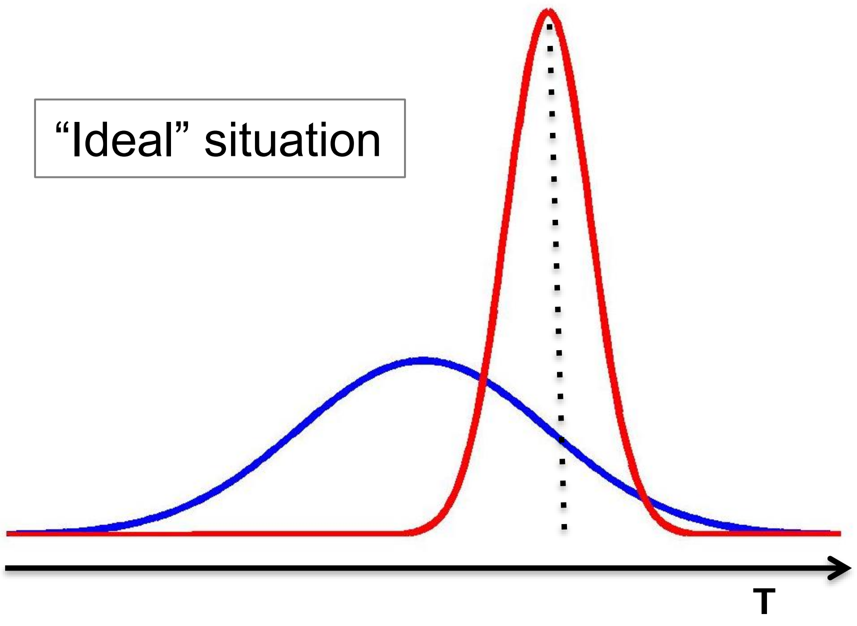
Forecast Products

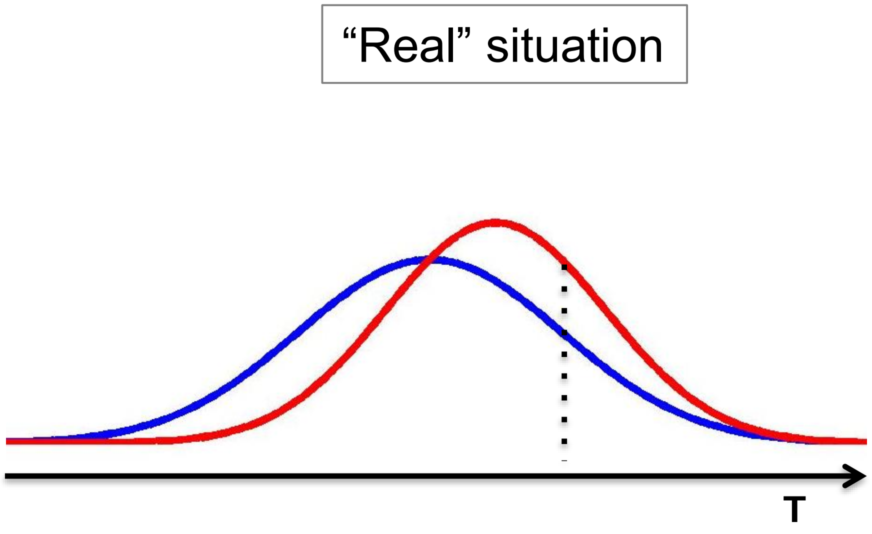


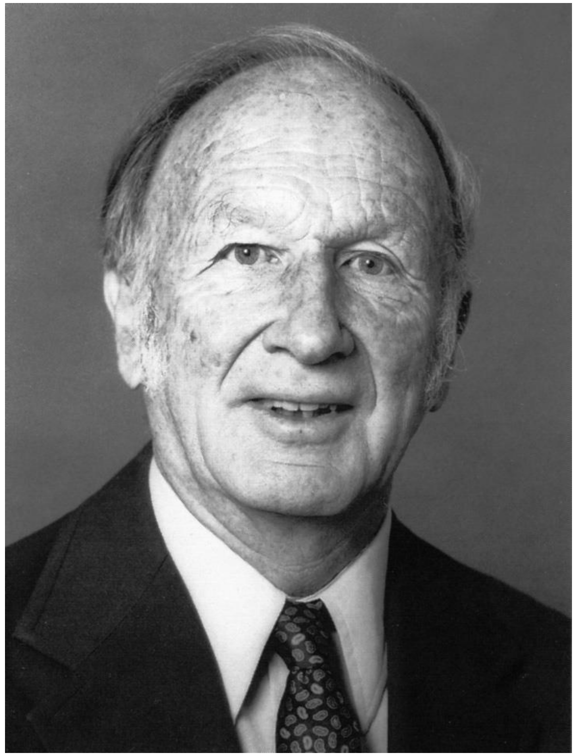
Forecasting probability distributions

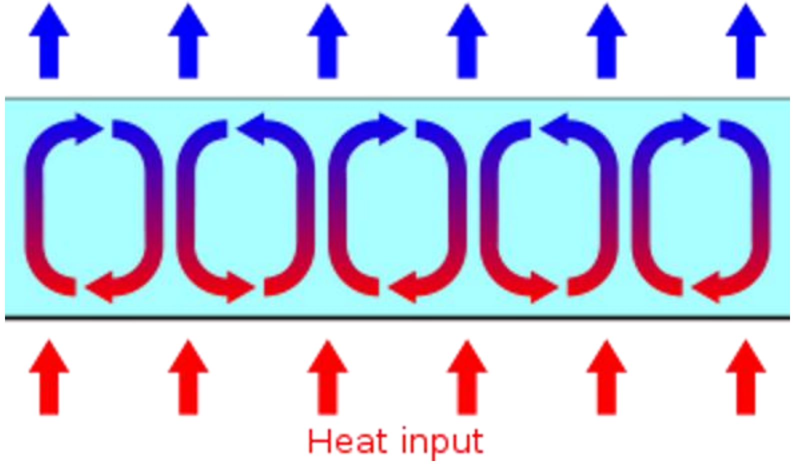
Seasonal forecasts aim to predict an anomaly from the default climatological probability.

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

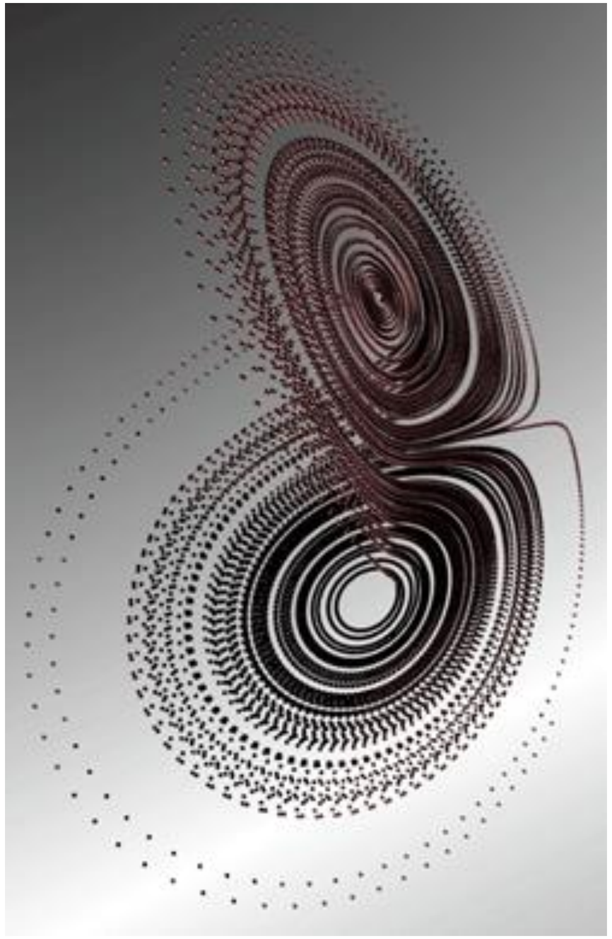




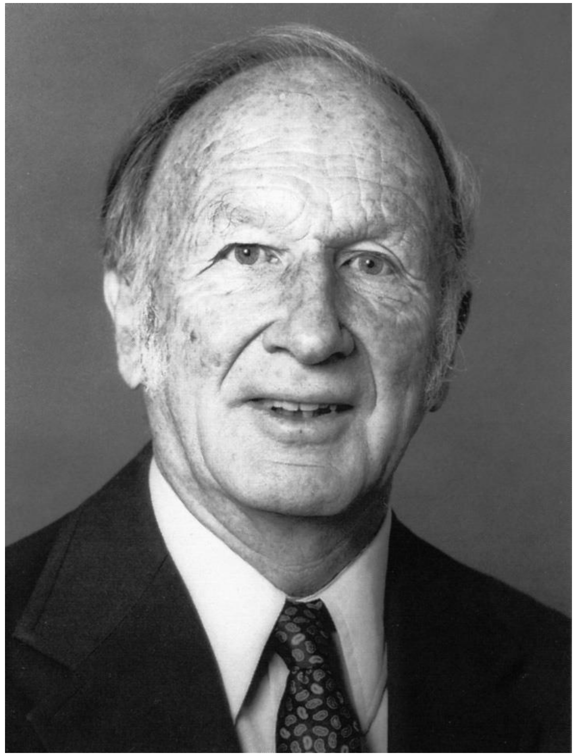




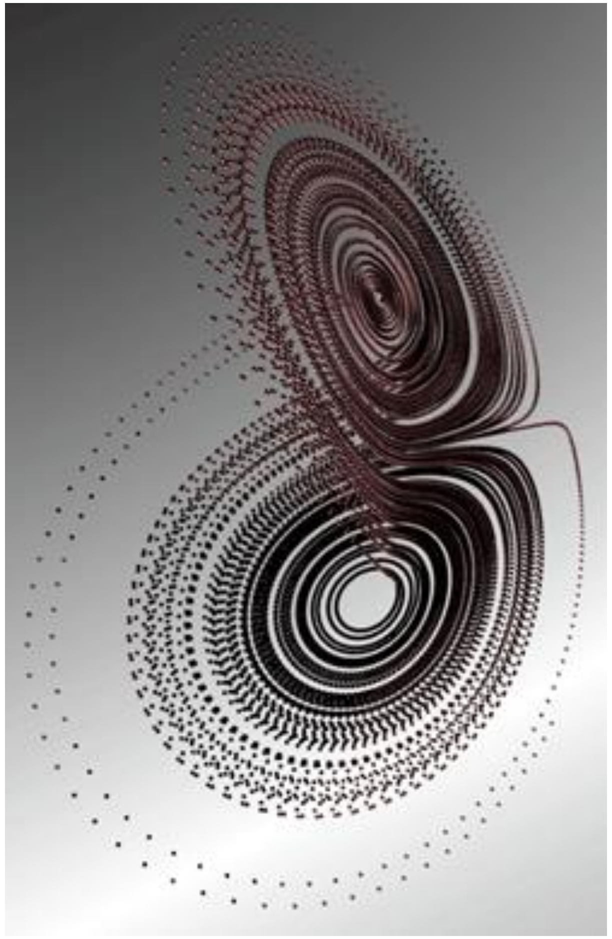
$$\dot{X} = -\sigma X + \sigma Y$$
$$\dot{Y} = -XZ + rX - Y$$
$$\dot{Z} = XY - bZ$$



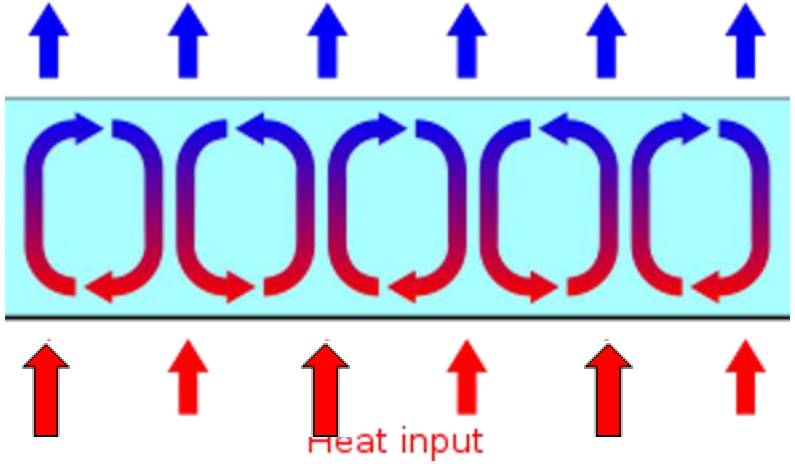
Lorenz E., 1963: Deterministic non-periodic flow



$$\dot{X} = -\sigma X + \sigma Y$$
$$\dot{Y} = -XZ + rX - Y + f$$
$$\dot{Z} = XY - bZ$$

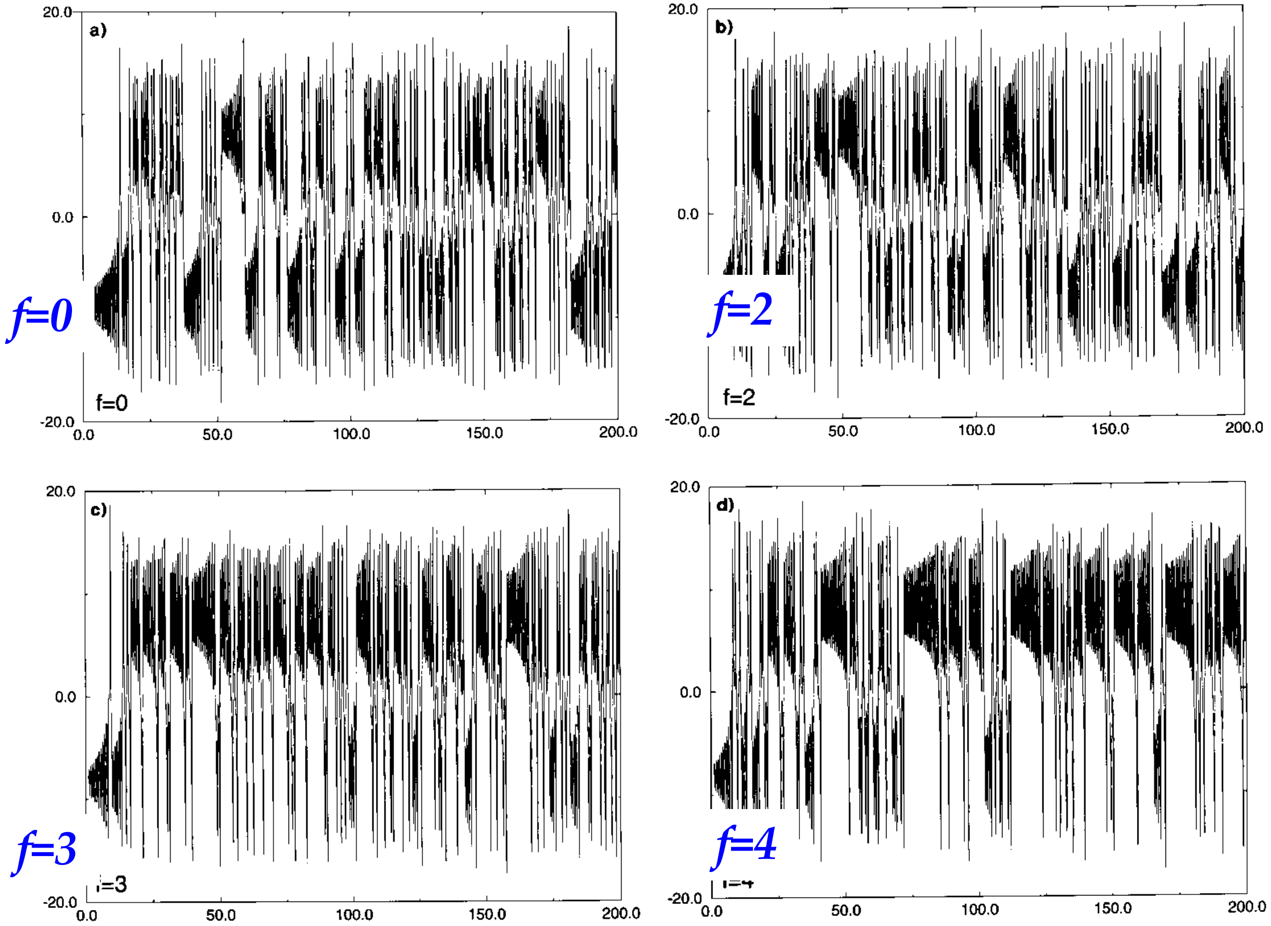


What is the impact of ***f*** on the attractor?



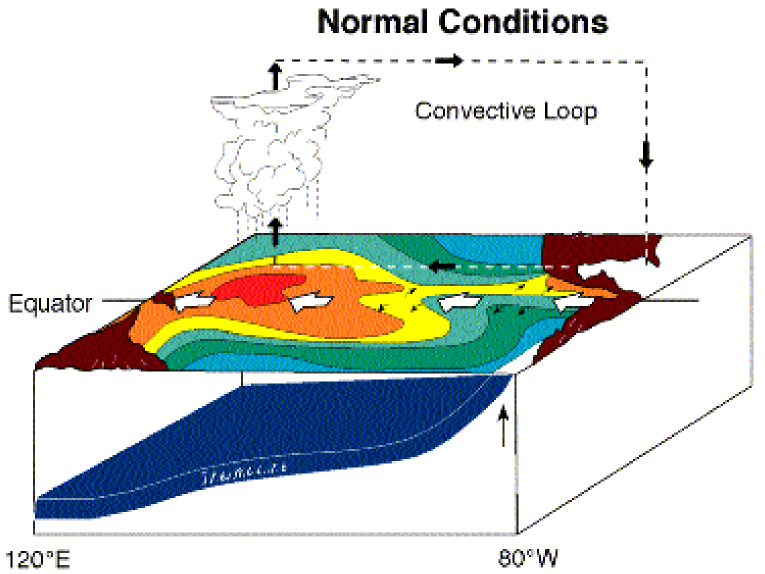
Lorenz E., 1963: Deterministic non-periodic flow

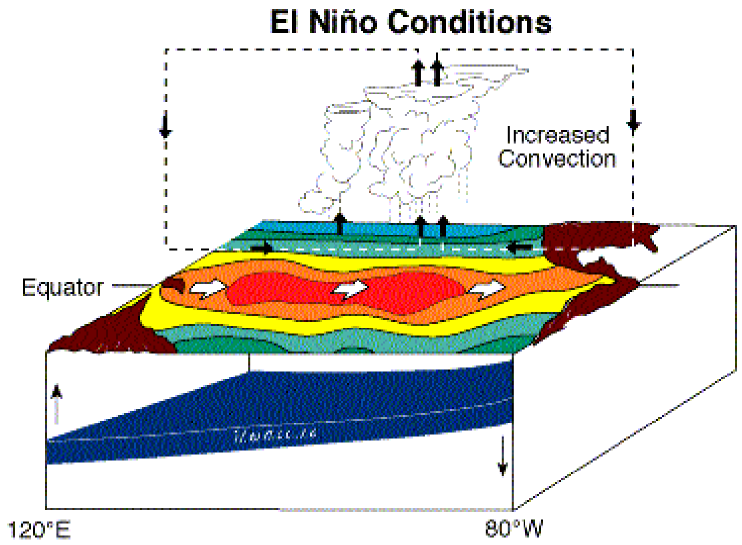
Add external steady forcing *f* to the Lorenz (1963) equations

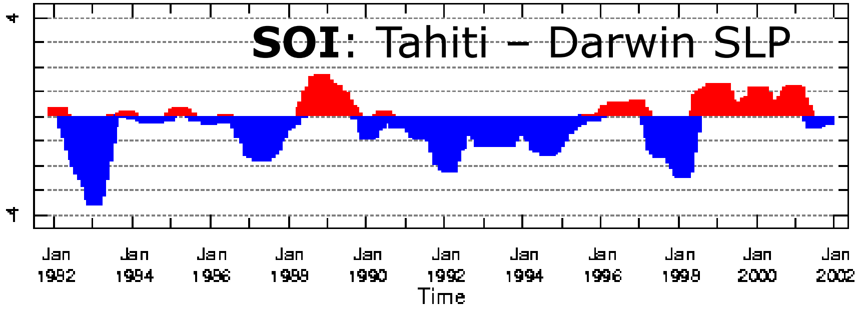


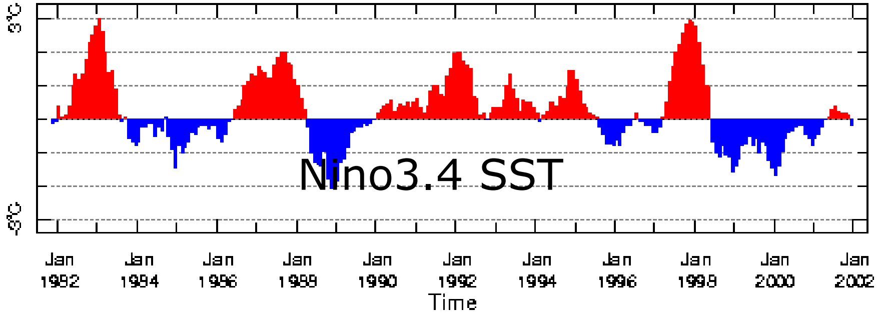
The influence of *f* on the state vector probability function is itself predictable.

El Niño and the Southern Oscillation





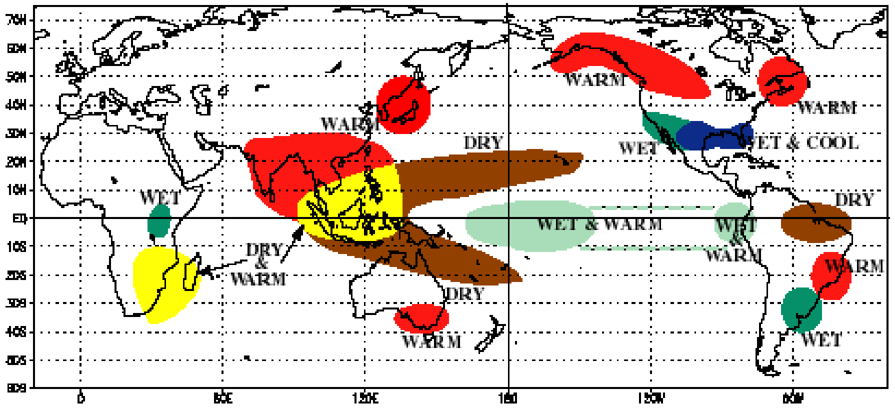




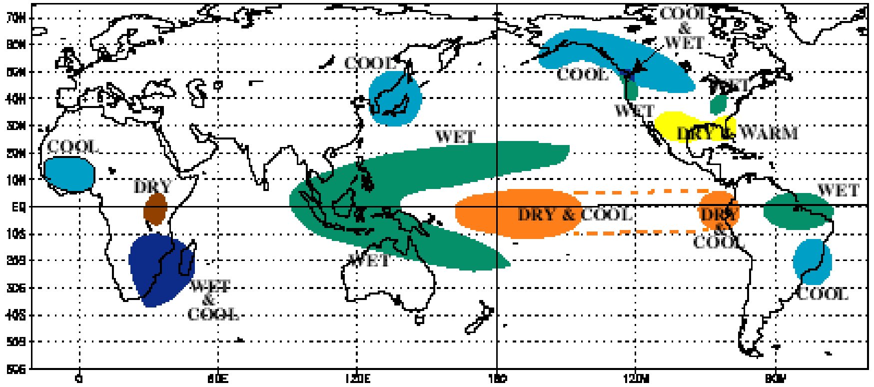
ECMWF

ENSO impacts: rainfall and temperature

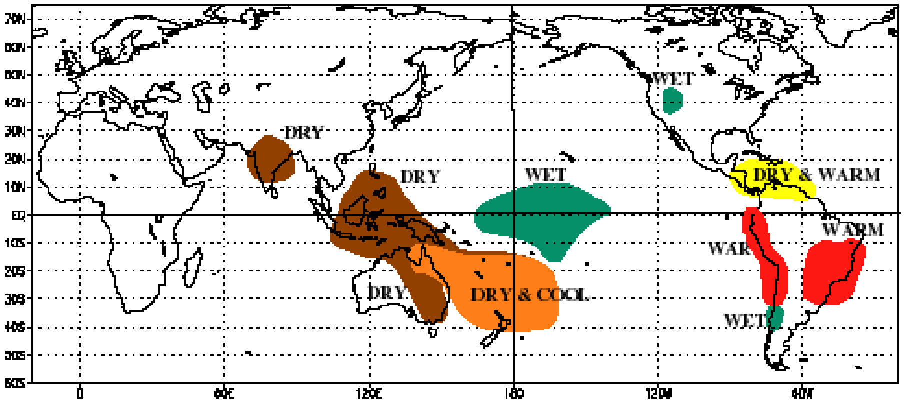
WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



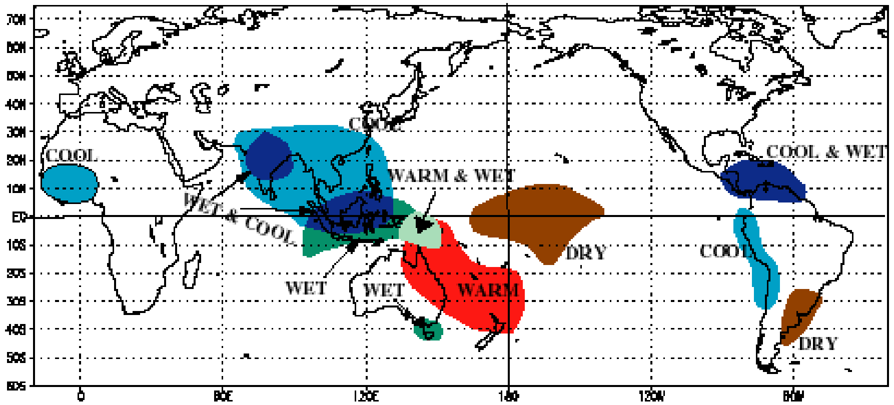
COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



WARM EPISODE RELATIONSHIPS JUNE - AUGUST

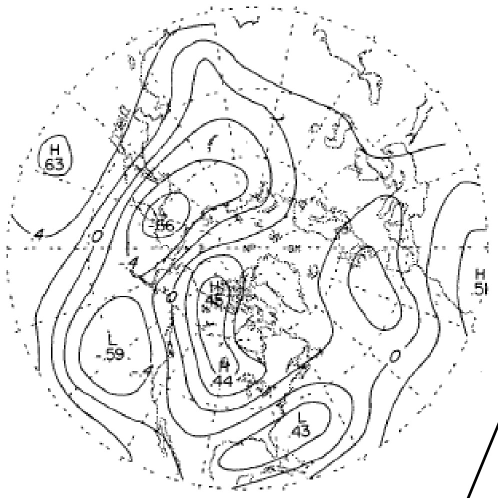


COLD EPISODE RELATIONSHIPS JUNE - AUGUST

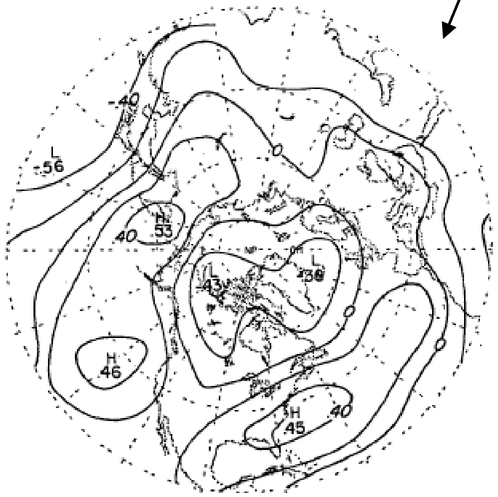


ECMWF

Teleconnections with ENSO



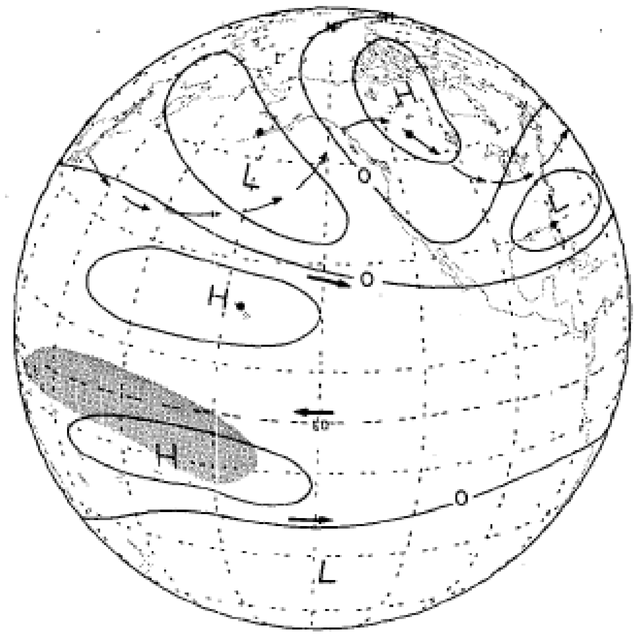
a



c

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

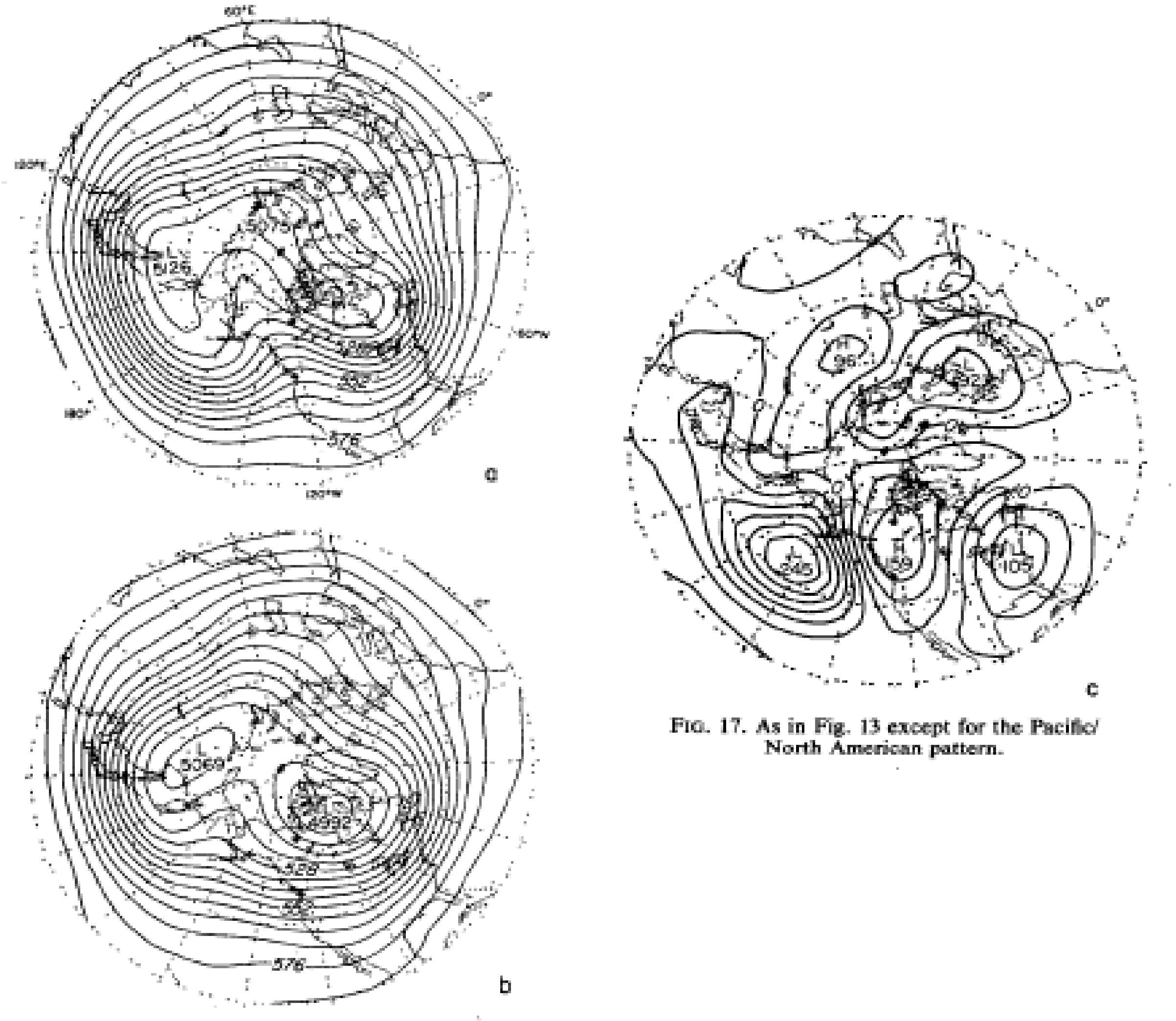


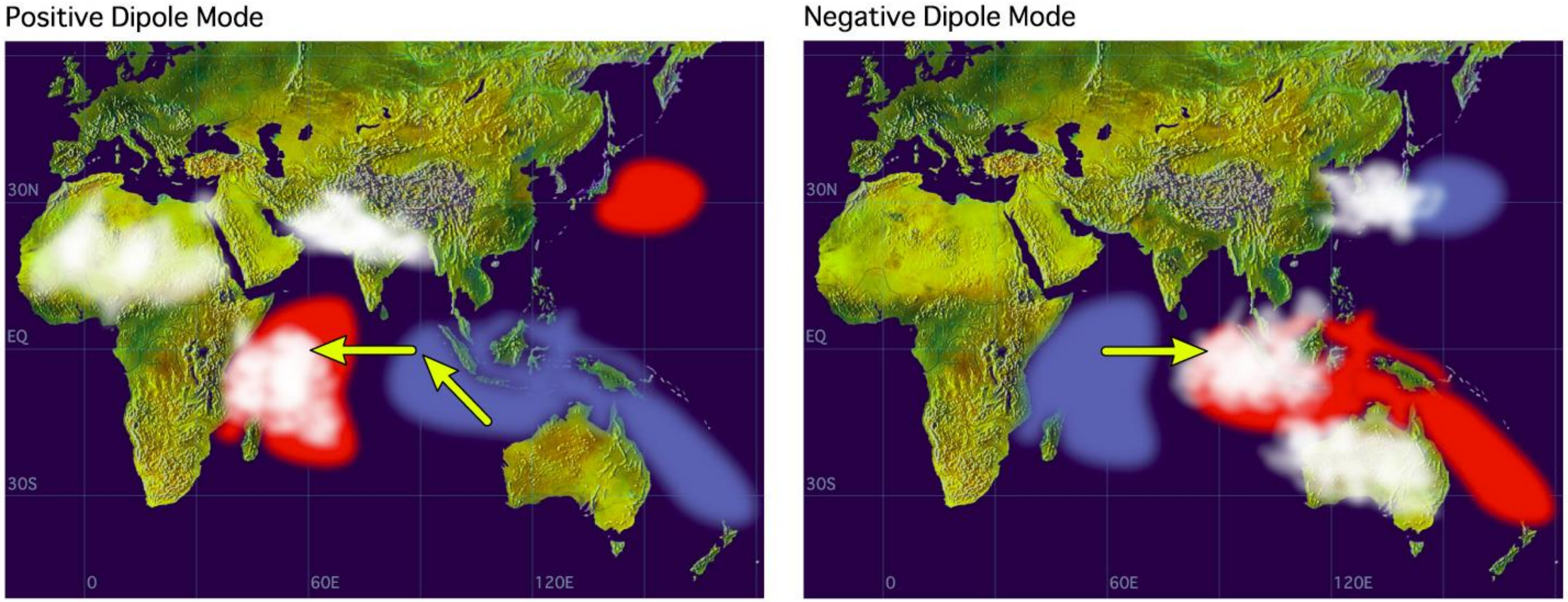
Fig. 17. As in Fig. 13 except for the Pacific/North American pattern.

ECMWF

The Indian Ocean Dipole (or I.O. Zonal Mode)

Saji et al. (1999)

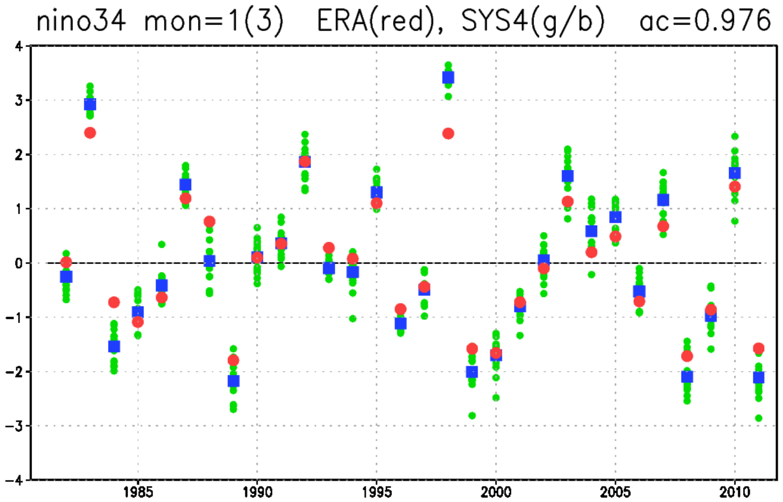
Webster et al. (1999)

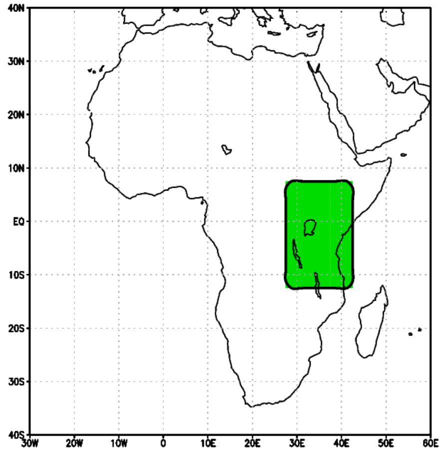


ECMWF

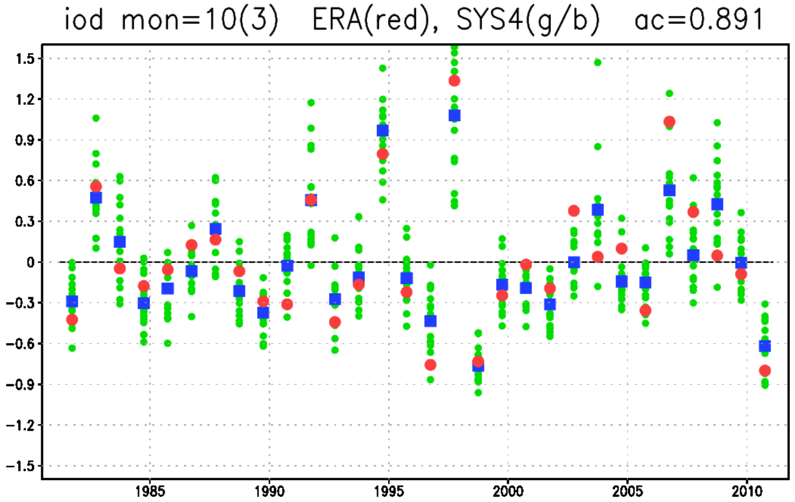
Prediction of tropical SST and rainfall anomalies in Sys4

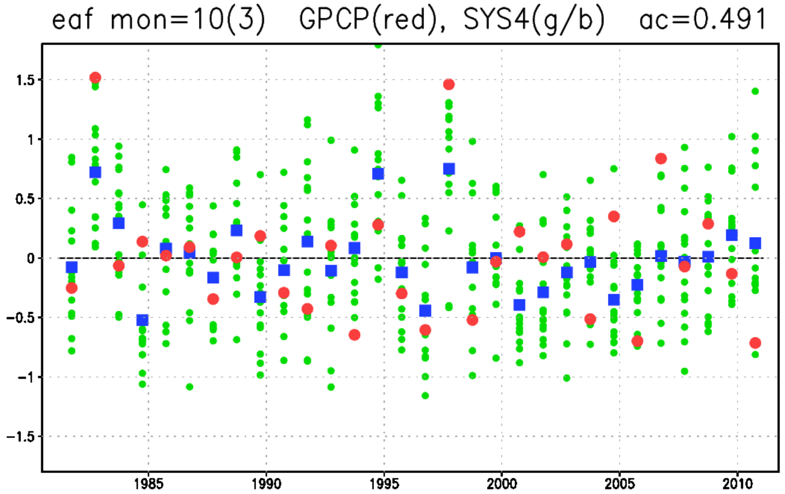
Nino3.4
DJF





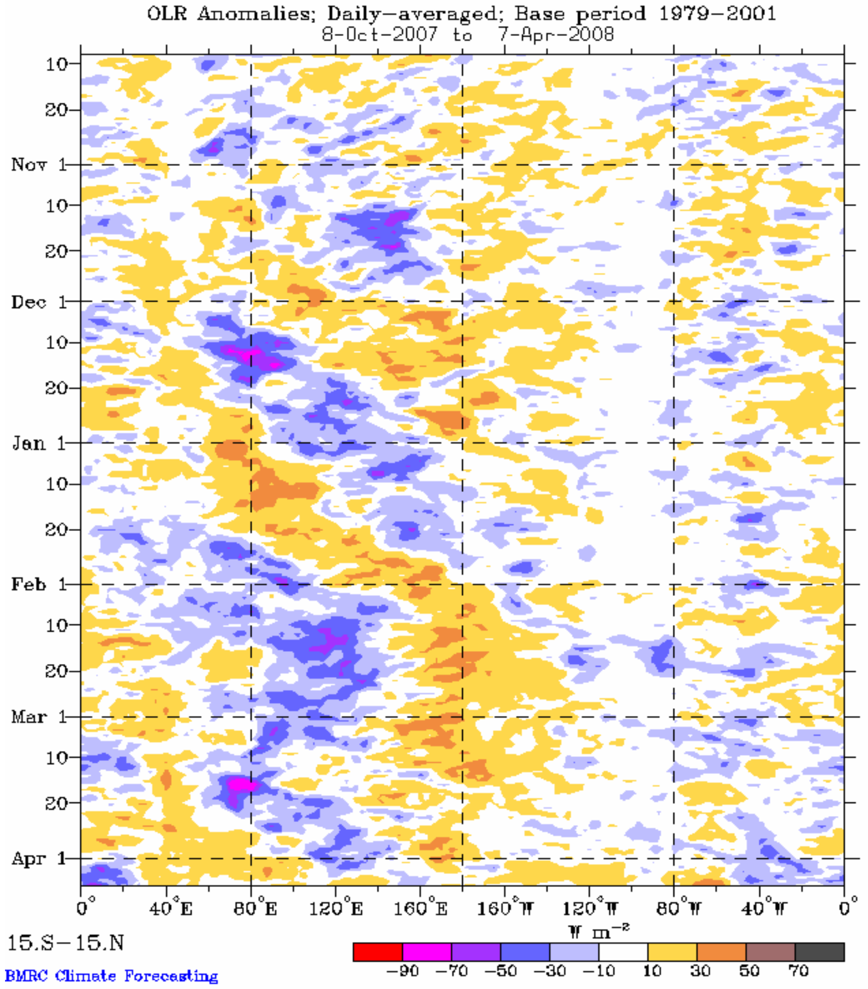
IOD
SON

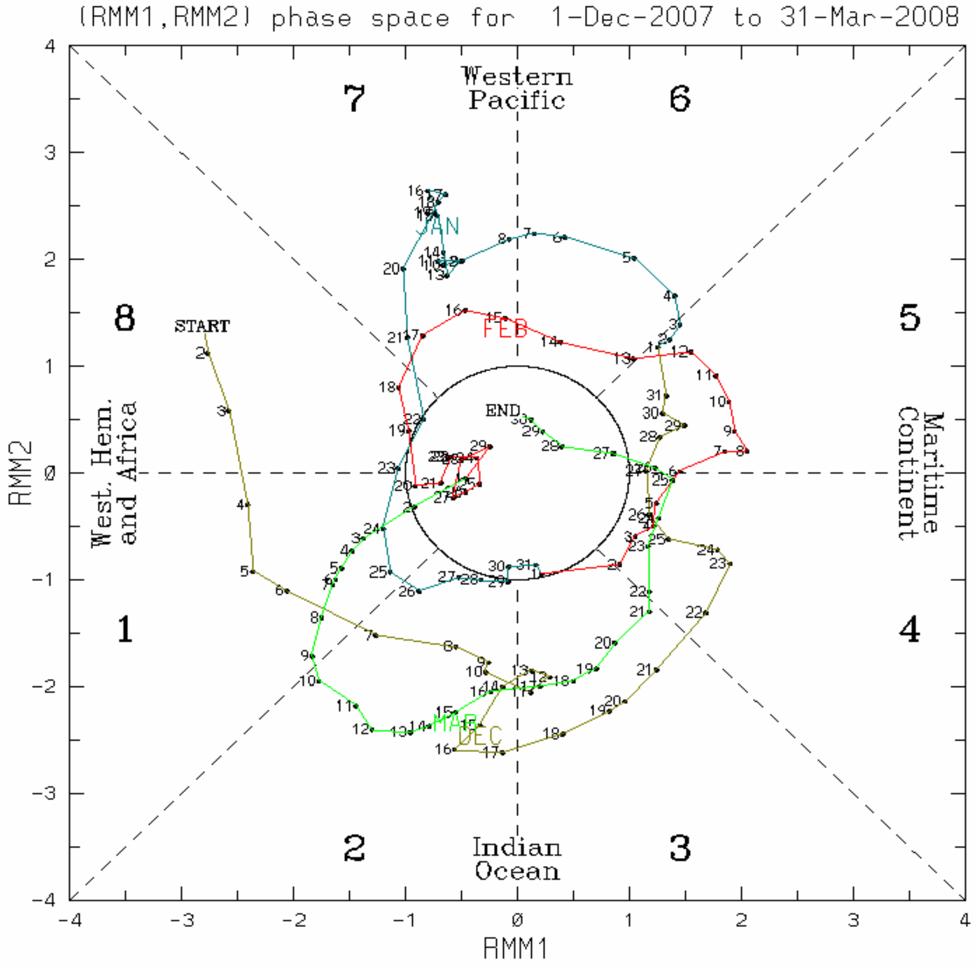




ECMWF

Sub-seasonal variability: the Madden-Julian Oscillation



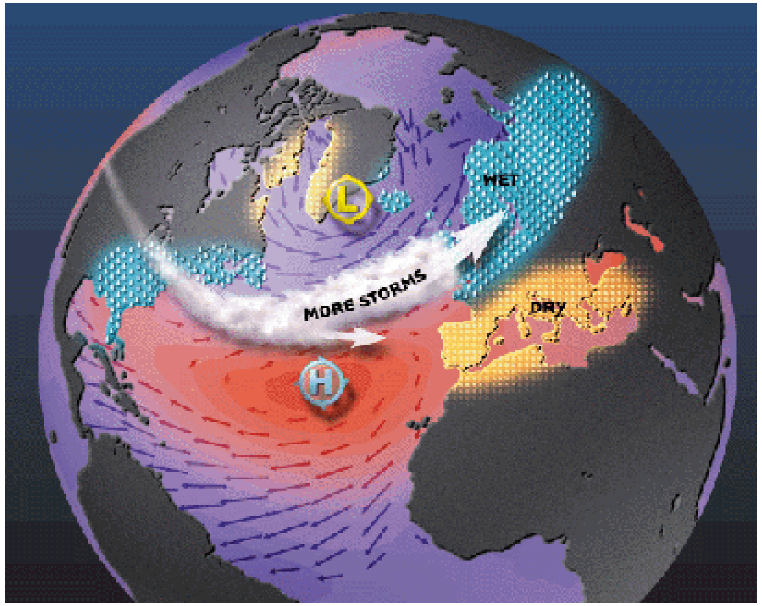


ECMWF

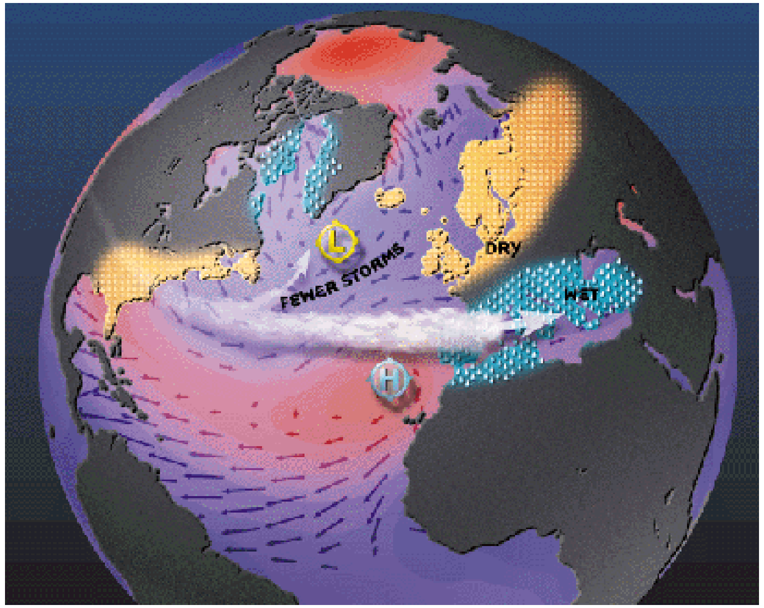
The North Atlantic Oscillation

Walker and Bliss (1932)

Van Loon and Rogers (1978)



Positive NAO phase

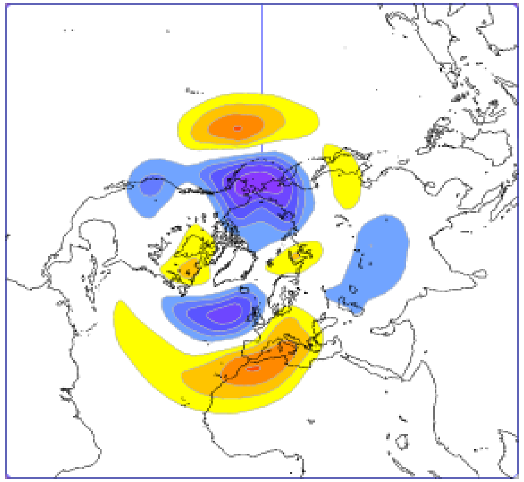


Negative NAO phase

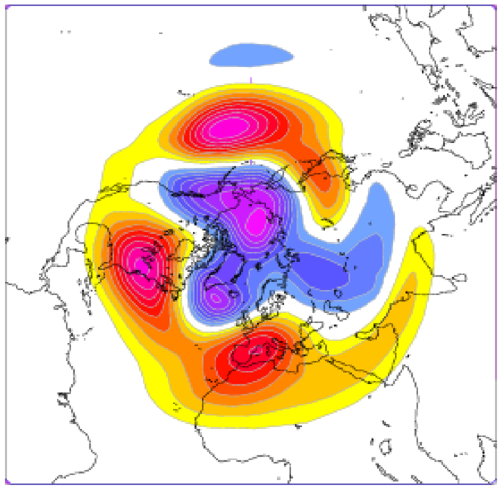
MJO teleconnections in October-March

500 hPa height, MJO phase 3 + 10 days

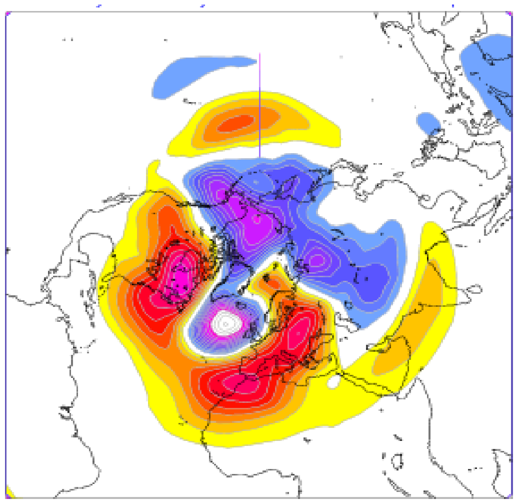
2002 MOFC hindcasts



2011 MOFC hindcasts

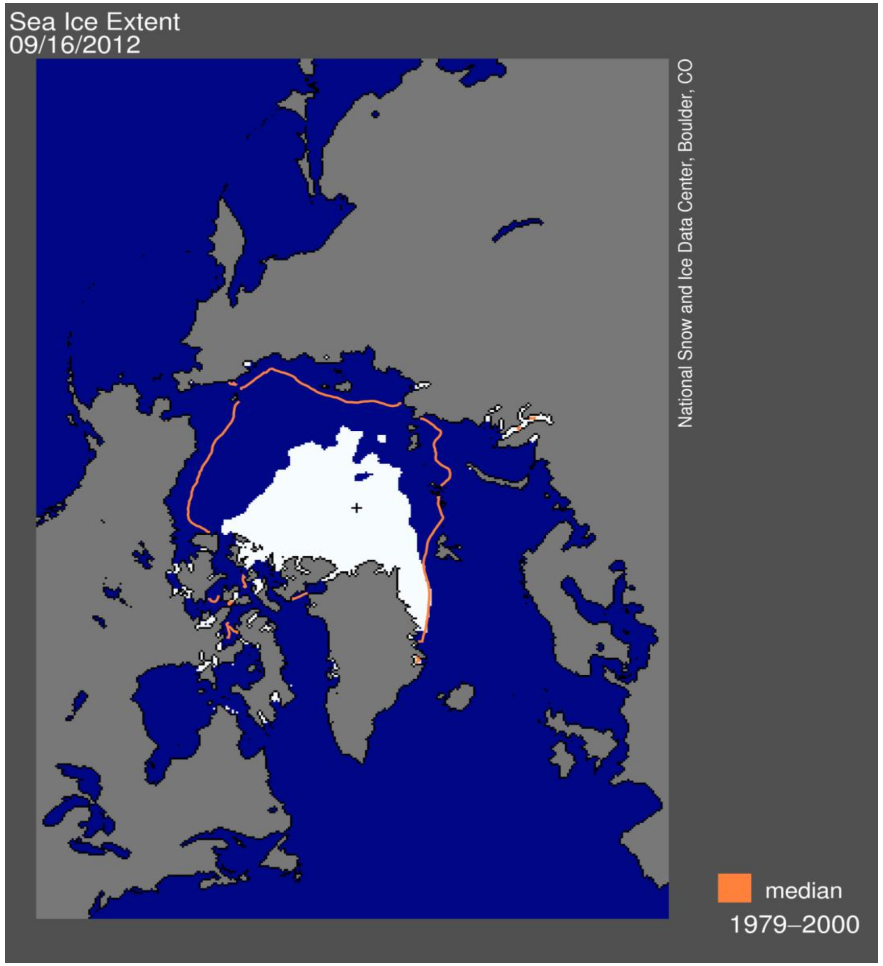


ERA Interim

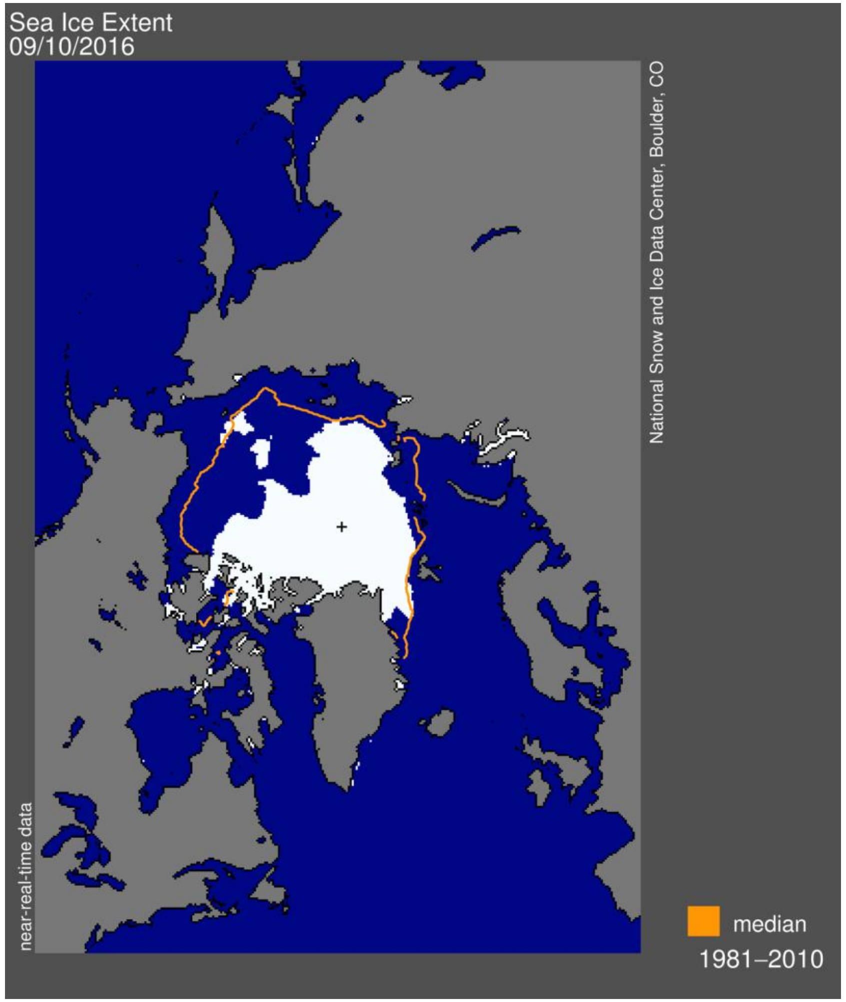


from Vitart 2014

Sea ice: Interaction of climate change and natural variability



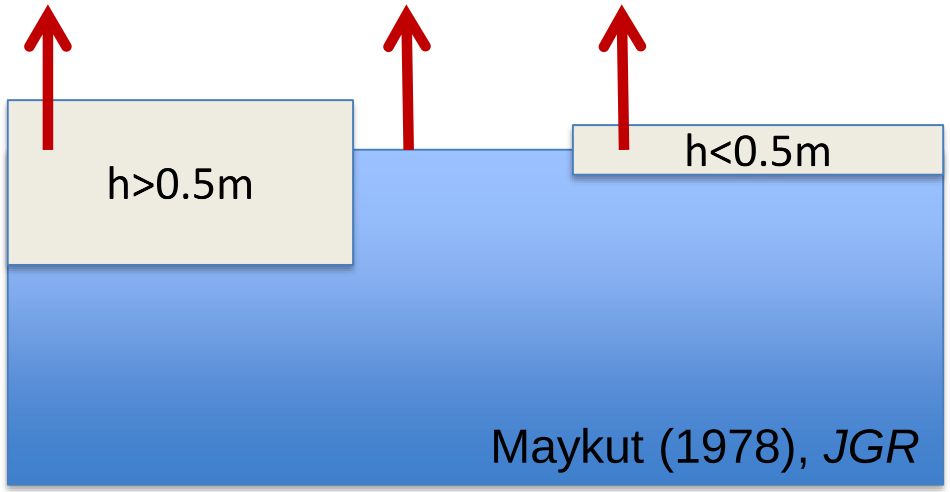
Record minimum in Arctic sea-ice extent: 16/9/2012
(from NSIDC)



ECMWF

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)

Impacts on the ocean

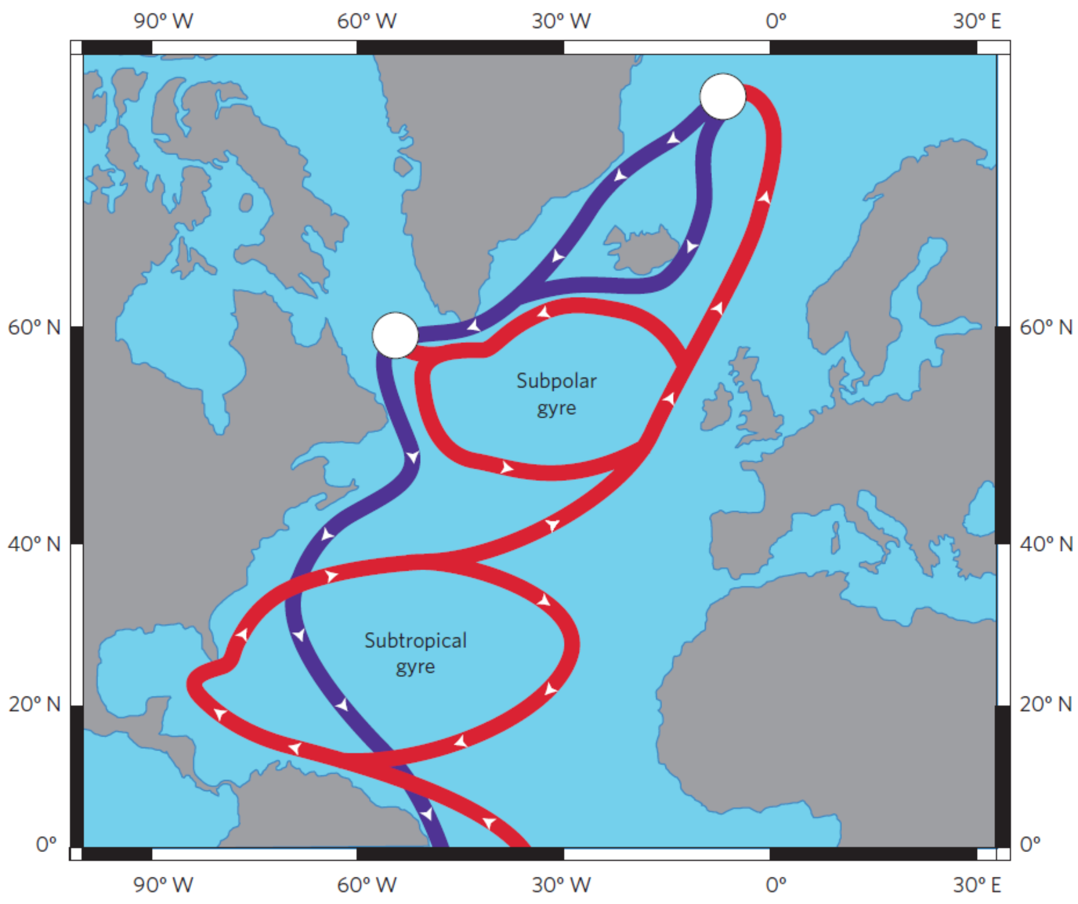
Deep convection:

- More important on longer time scales

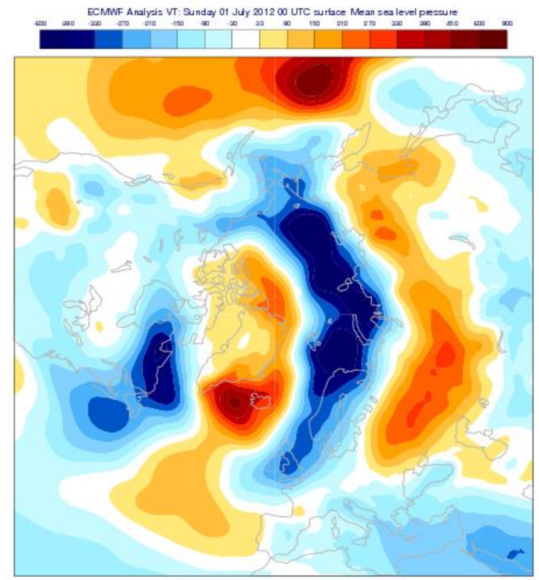
- Impact on the Gulf Stream and the Thermohaline circulation – part of the feedback on the Arctic system

Cold Halocline Layer:

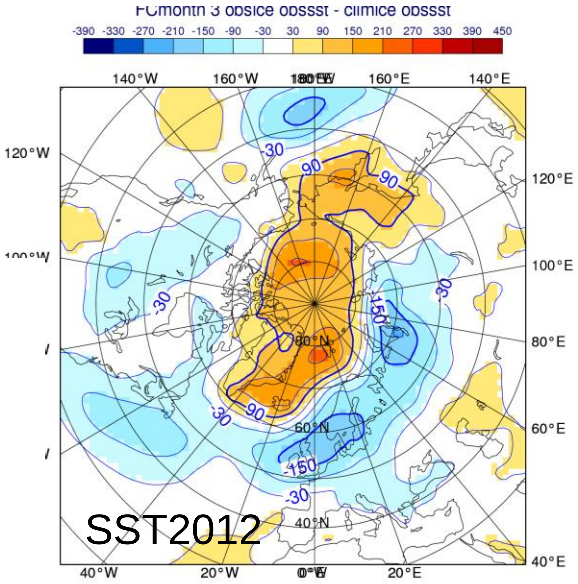
- Layer of freshwater that insulates sea ice from warmer waters that are advected into the basin



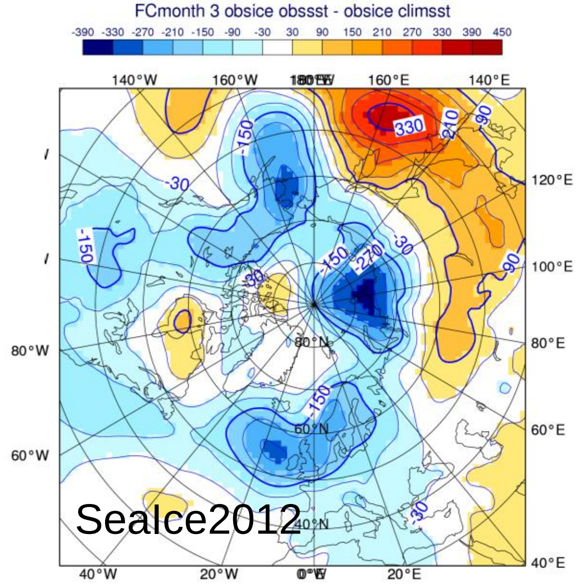
Sea Ice predictability experiment – July 2012



July MSLP anomaly
Era Interim 2012 - climatology



sea ice: 2012 - climatology



SST: 2012 - climatology

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 (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.

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ECMWF