Sources of predictability beyond the deterministic limit

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(with thanks to Franco Molteni)
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Outline

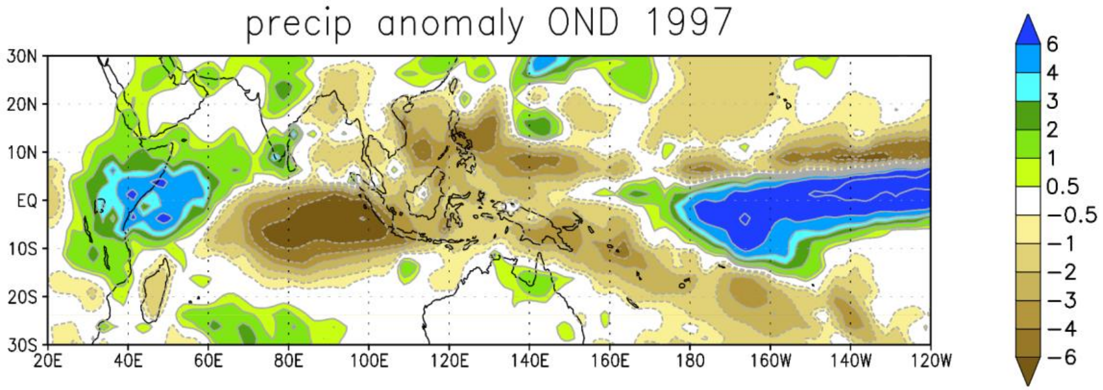
Persistent anomalies in the tropics and extra-tropics: examples from the last two decades

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

Coupled ocean-atmosphere variability - 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



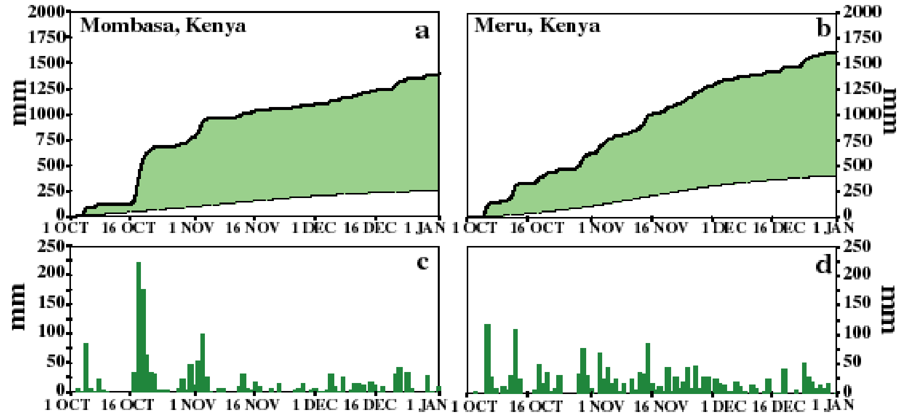
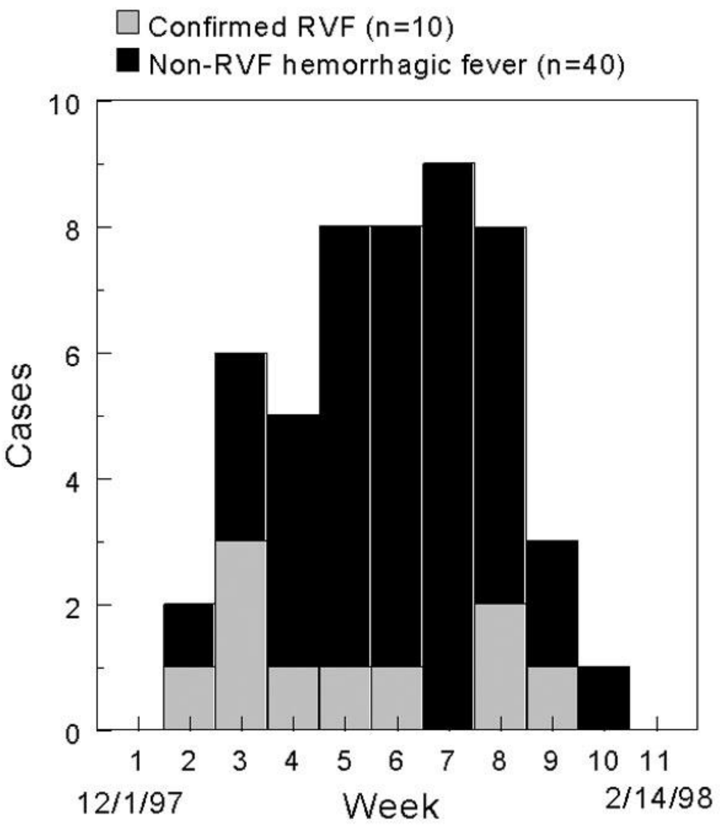
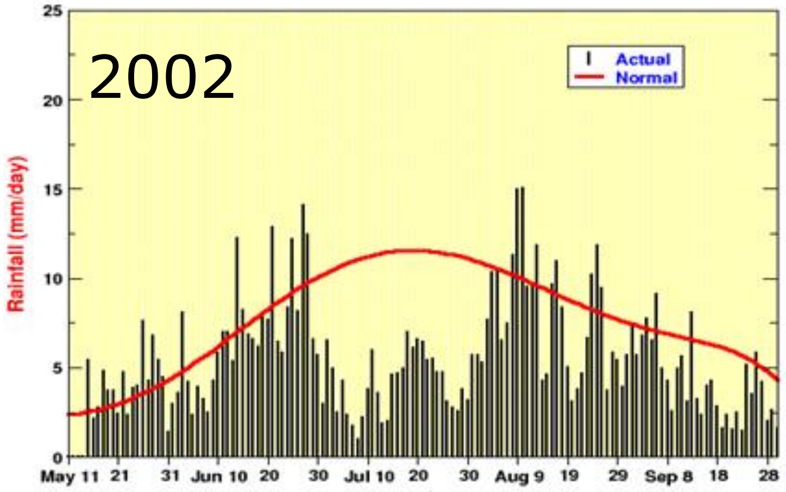


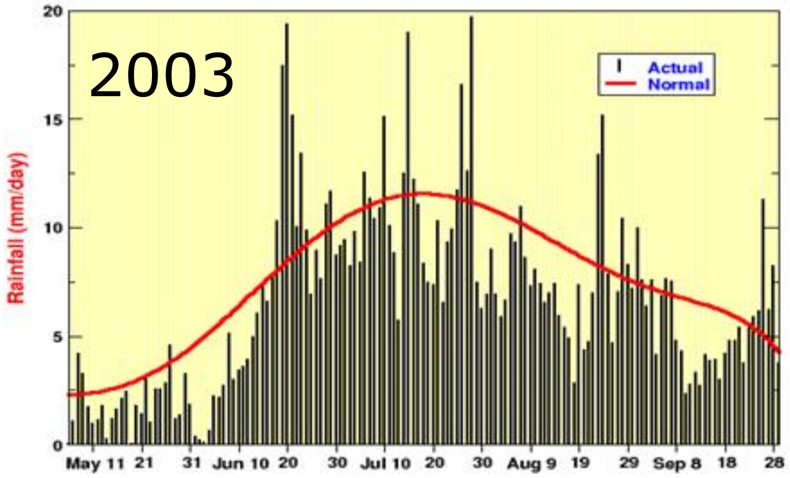
FIG. 45. (a, b) Accumulated observed precipitation (solid curve) and accumulated climatological precipitation (1961–90 base period) (dashed curve) beginning 1 October 1997 and ending 1 January 1998 at (a) Mombasa, Kenya and (b) Meru, Kenya. (c, d) Daily precipitation totals during October 1997–1 January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



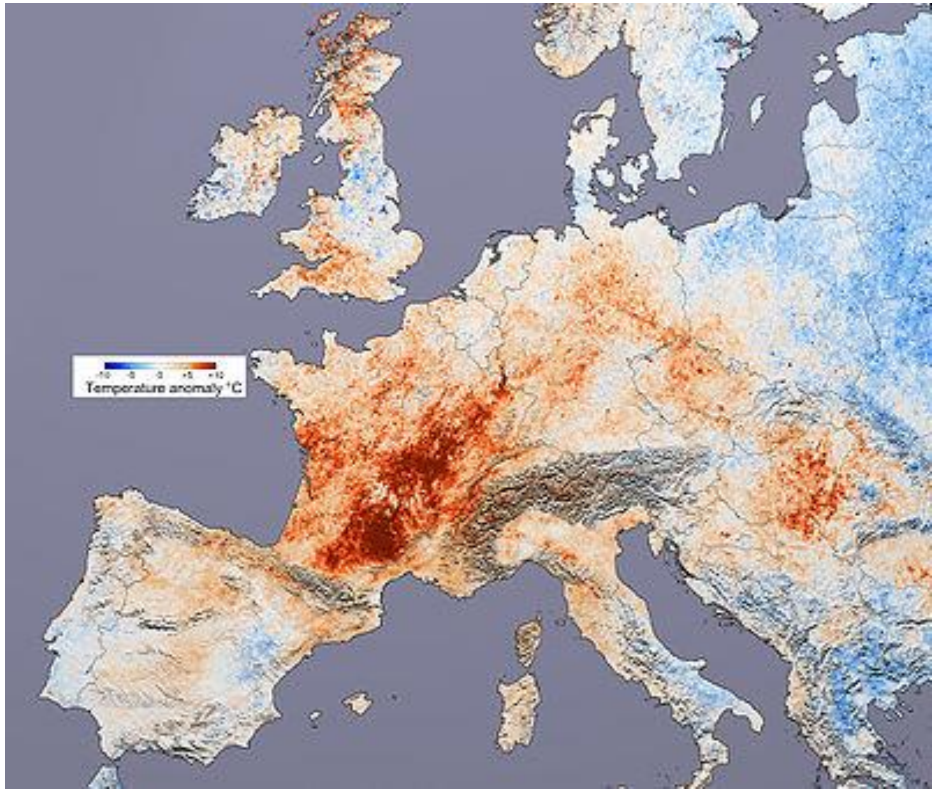
July 2002: drought in India

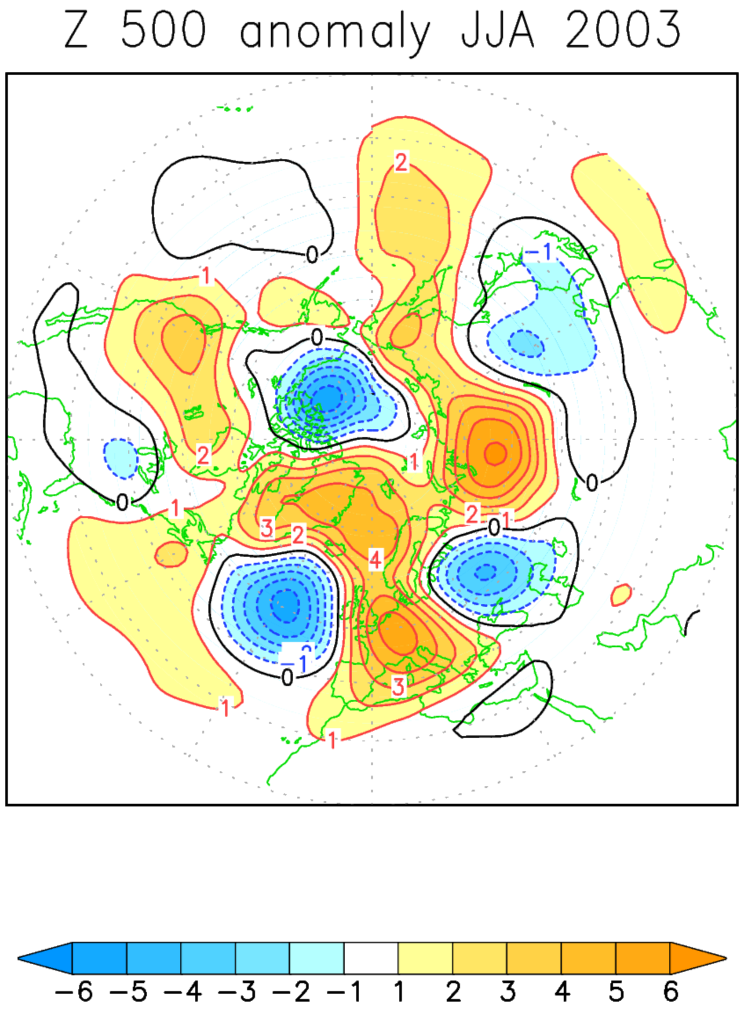




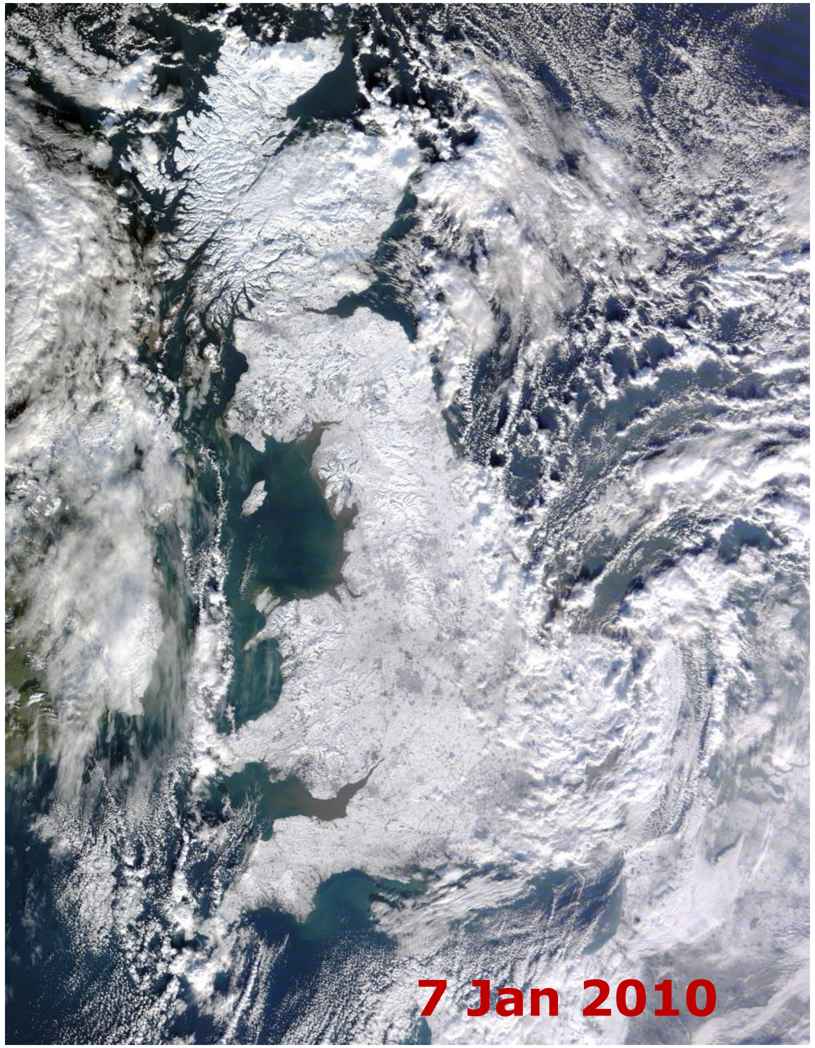
All-India Rainfall time series
May - October

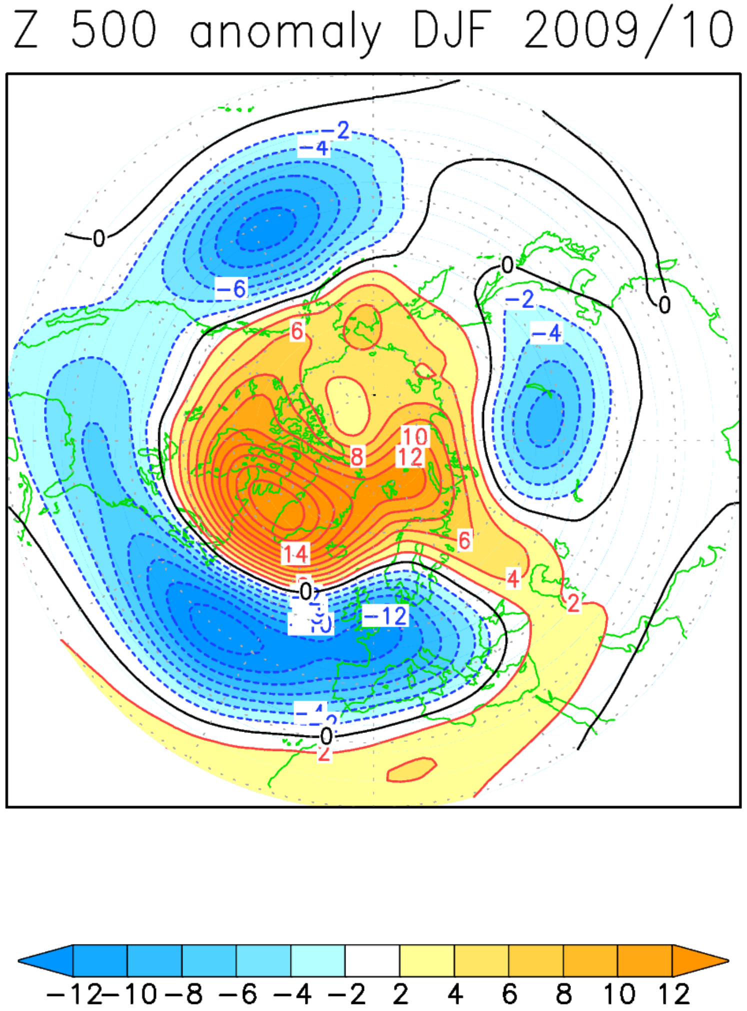
Summer 2003: European heat-wave





Winter 2009-2010: cold anomaly over N. Europe



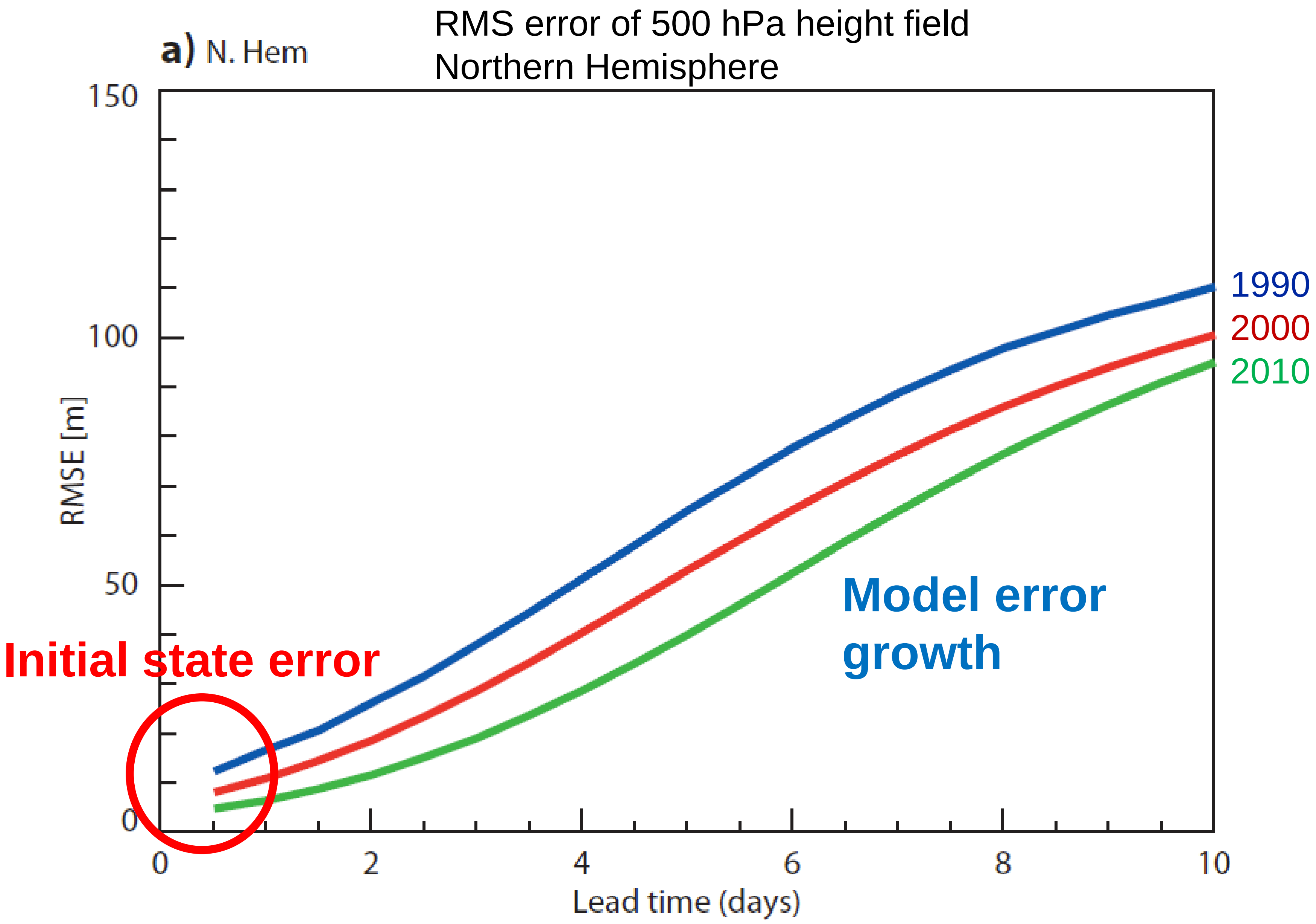


What limits deterministic prediction?

1. Size of the initial condition error
2. Error growth rate
3. Saturation value of the error

- Explains the seasonal, regional and hemispheric variations in NWP skill.
  - Winter more predictable than summer
  - Mid-latitudes more predictable than tropics

Limits of predictability



How can we forecast on long timescales?

Ocean – Magdalena

Sea ice

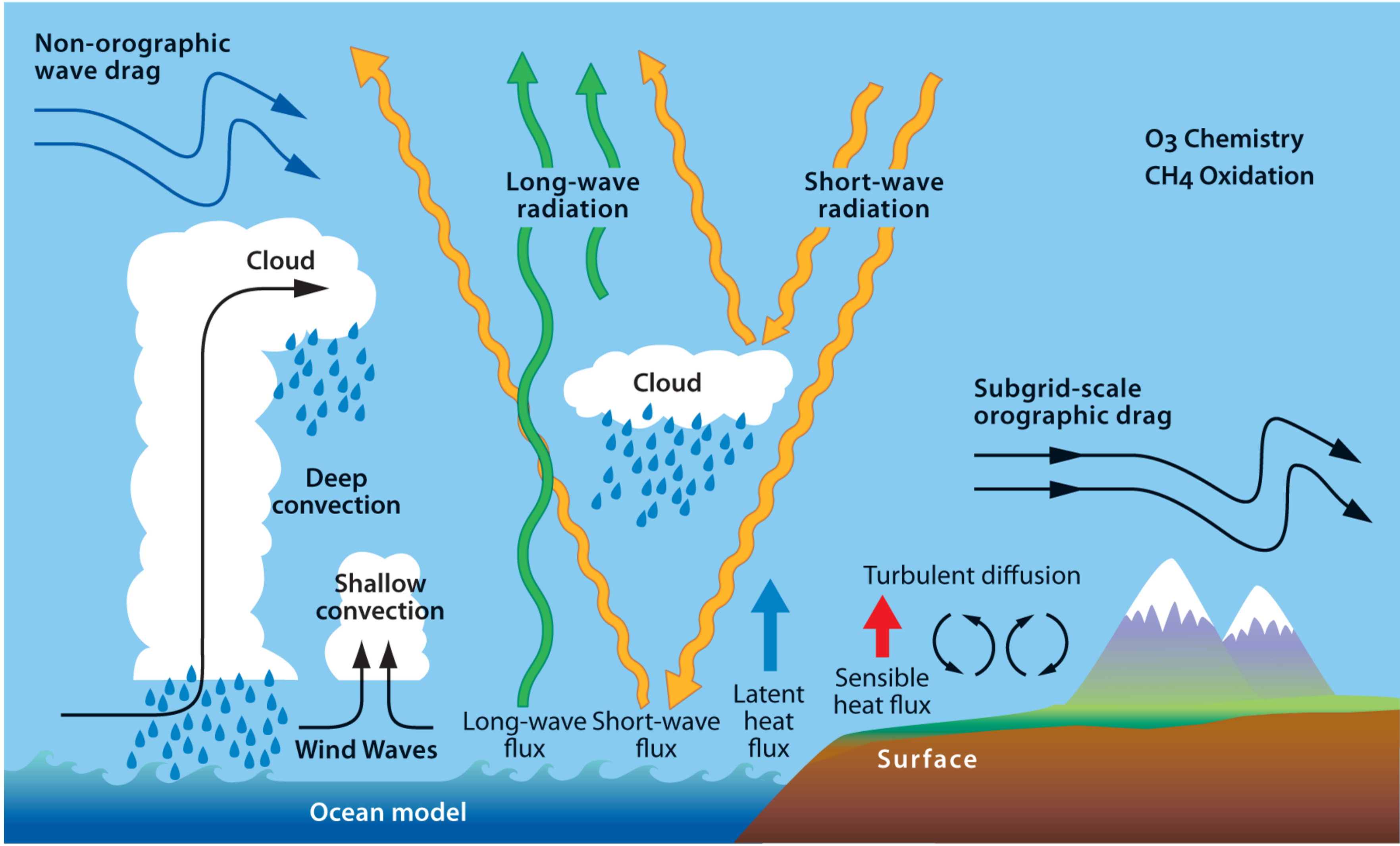
Land Surface - Bart

- Soil moisture
- Vegetation
- Snow

Stratosphere – Andrew

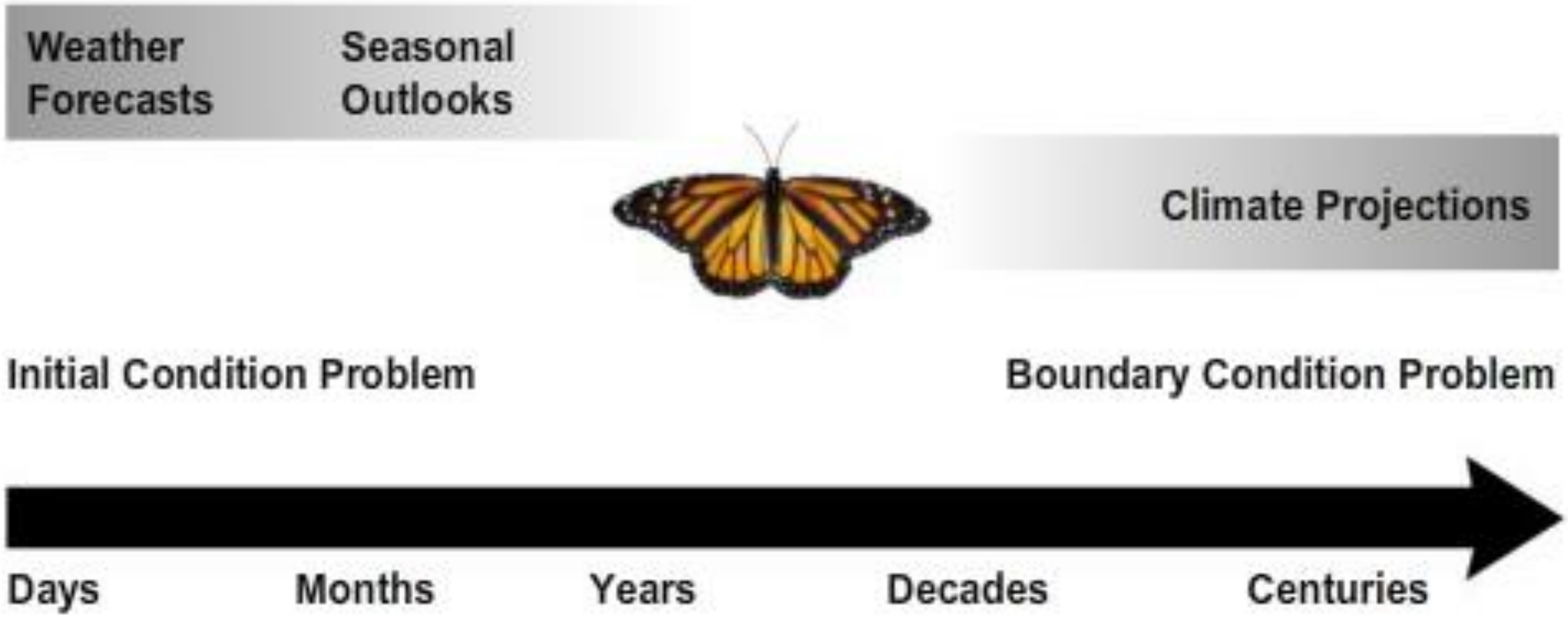
Atmospheric composition

Solar



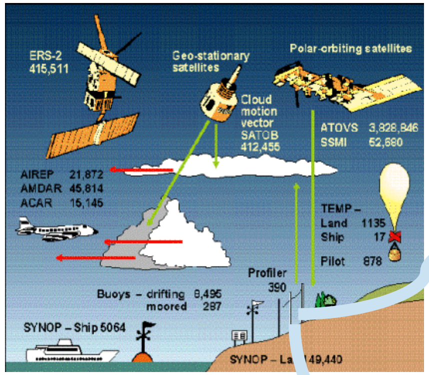
ECMWF

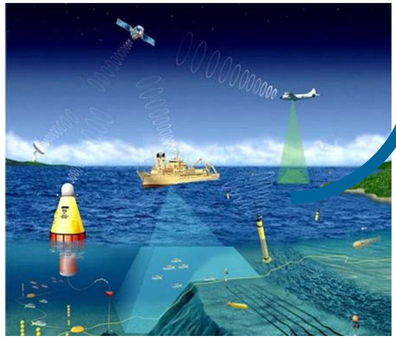
Climate forecasts are not crucially sensitive to the initial conditions. They are a mixed initial-boundary condition (forcing) problem in a chaotic system.



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

Observations





Data Assimilation

current state of the atmosphere

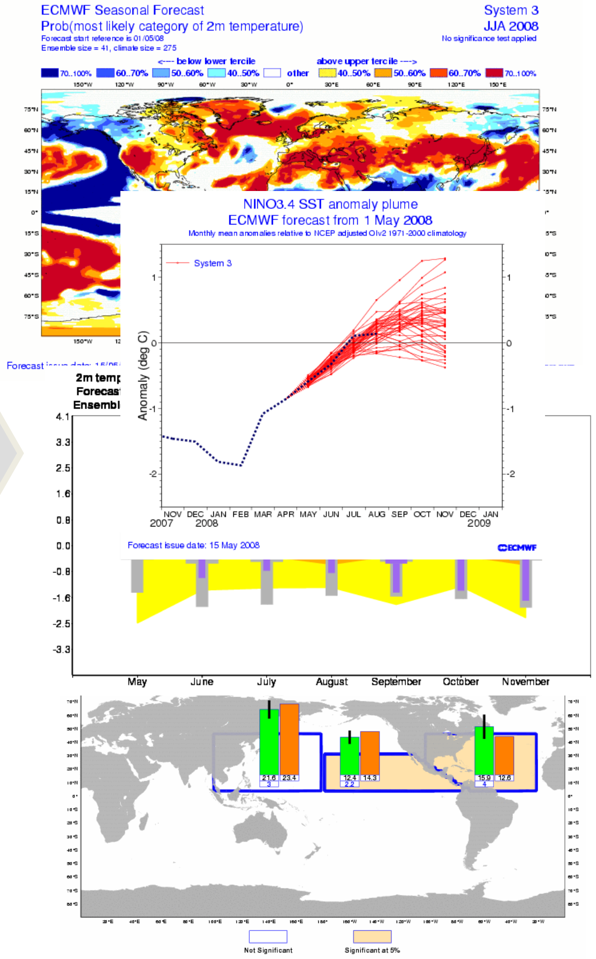
current state of the ocean

Coupled model

atmospheric model

ocean model

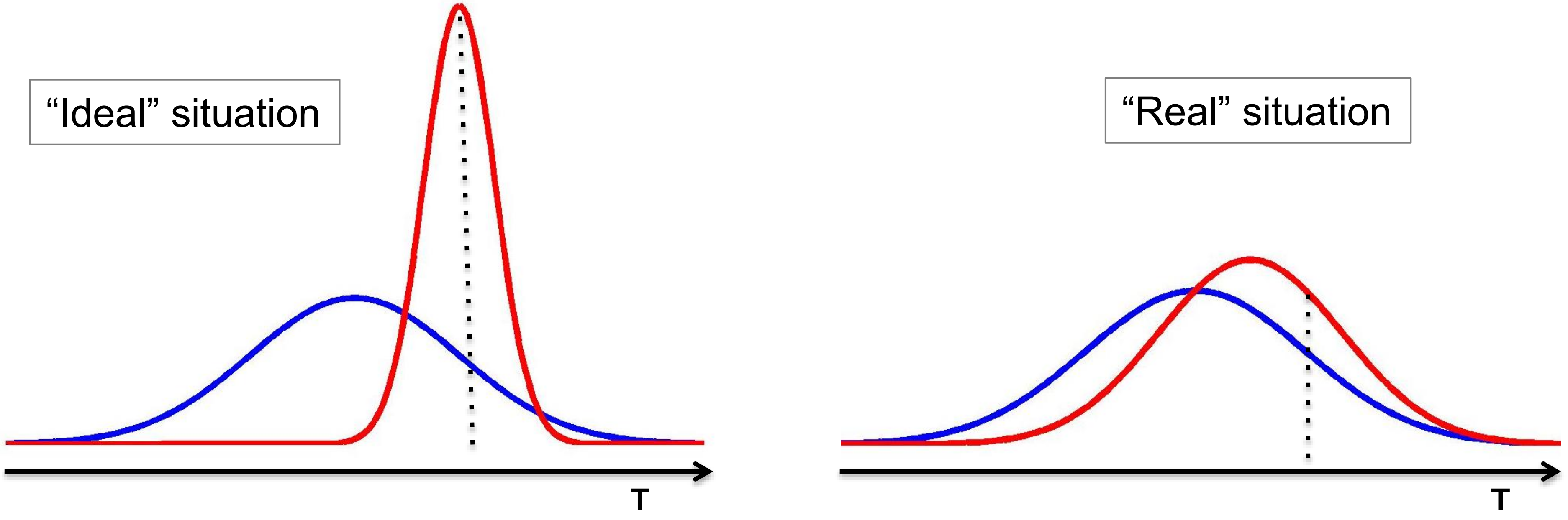
Forecast Products

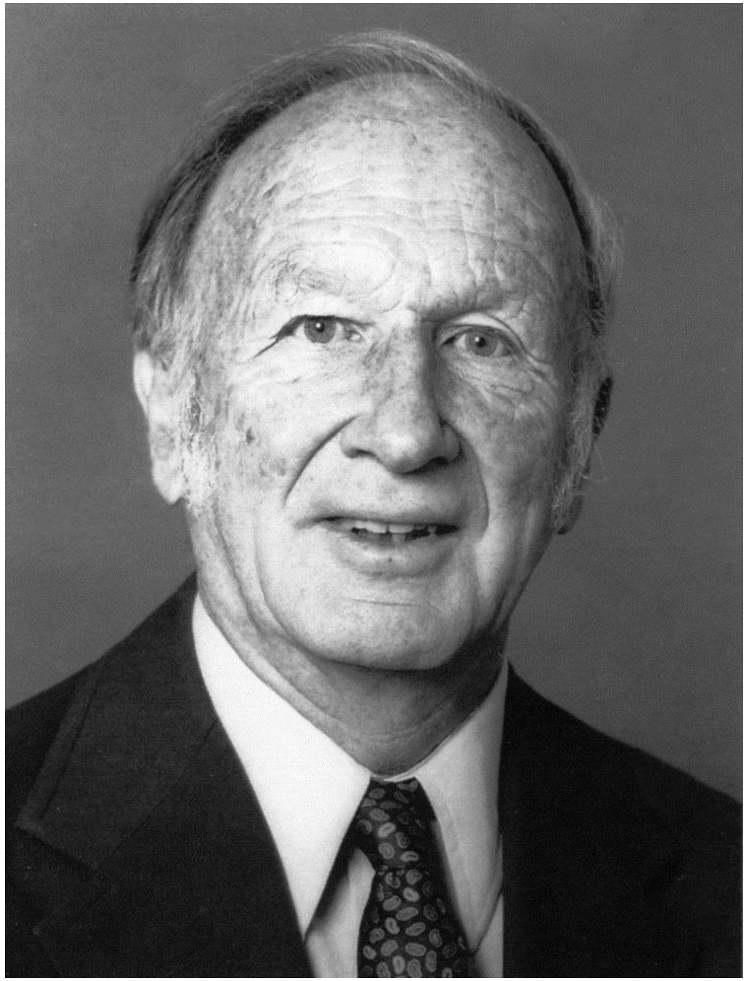


Forecasting probability distributions

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

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

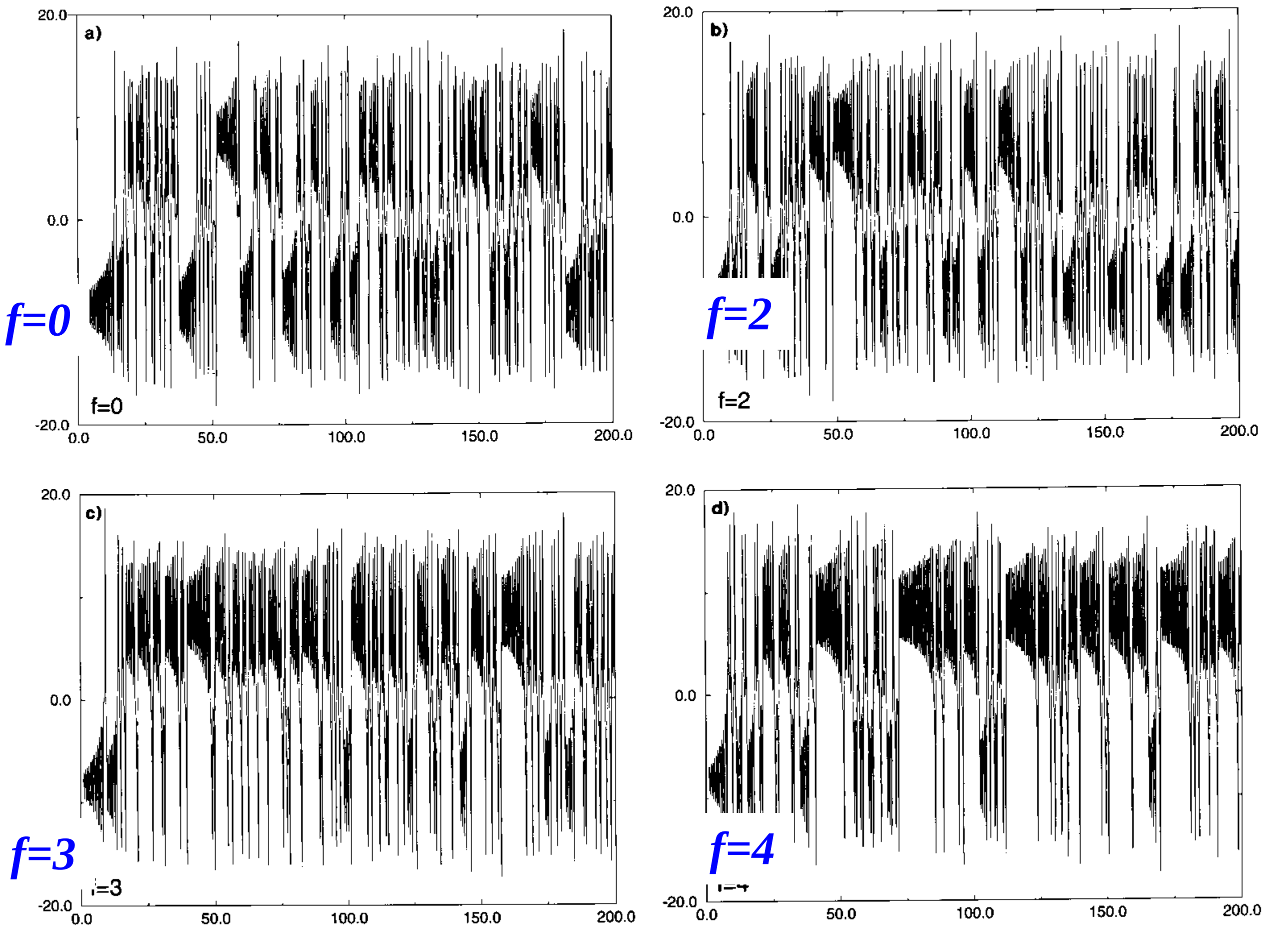




$$\dot{X} = -\sigma X + \sigma Y + f$$
$$\dot{Y} = -XZ + rX - Y + f$$
$$\dot{Z} = XY - bZ$$

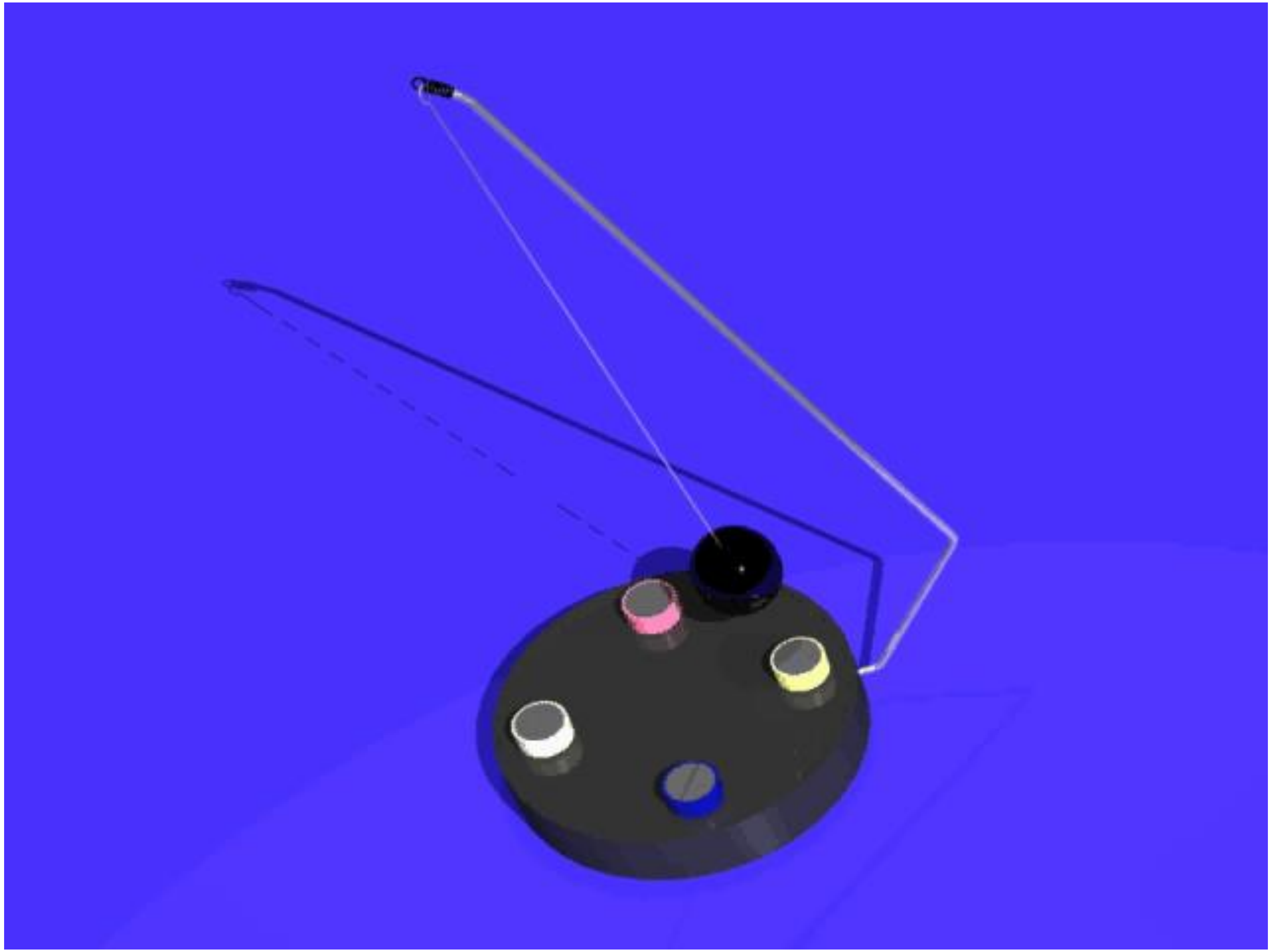
What is the impact of f on the attractor?

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

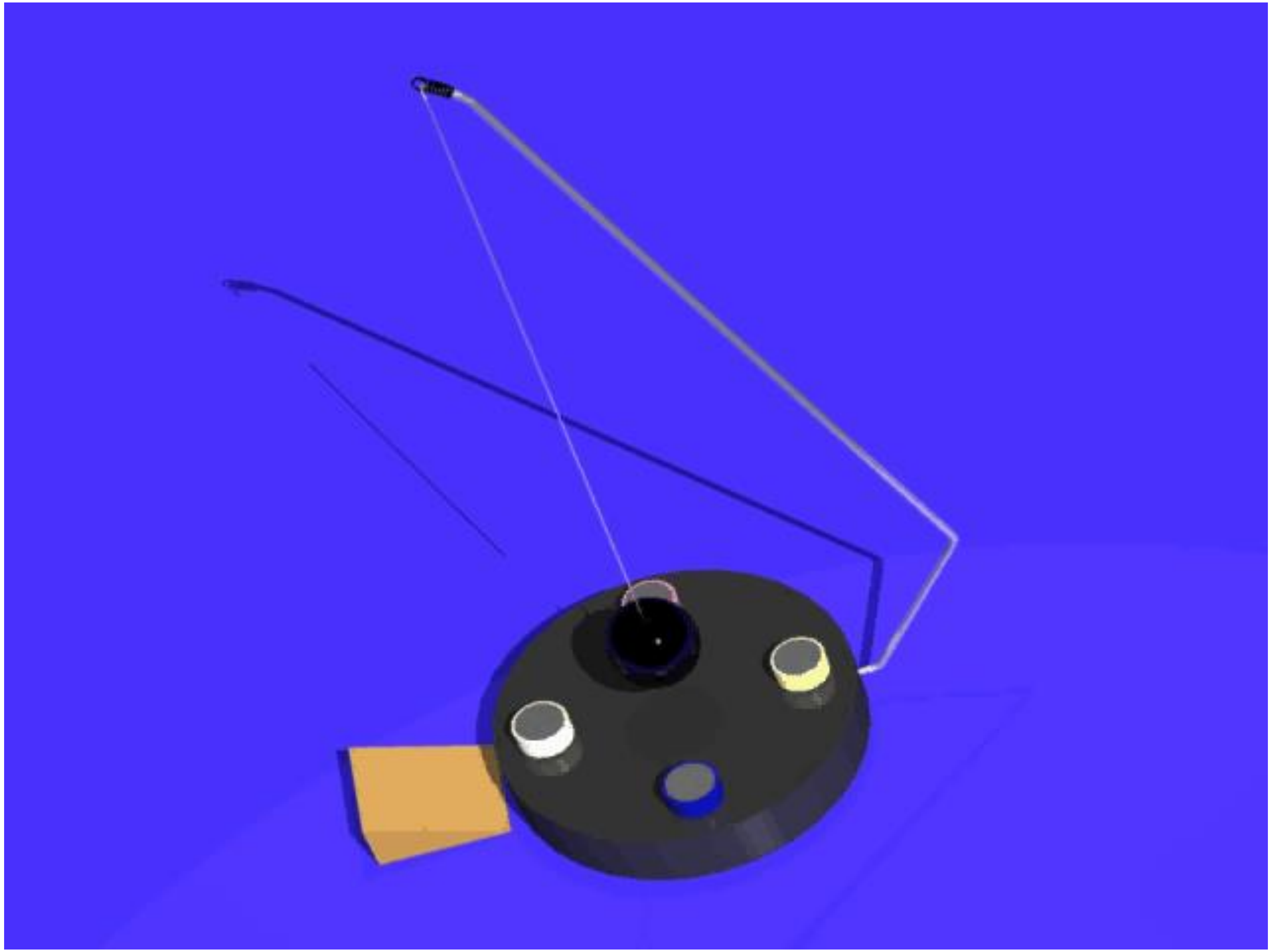


The influence of f on the state vector probability function is itself predictable.

Mechanical analogue of preferred atmospheric circulation states



Preferred atmospheric circulation states: role of the forcing



Which regions are most predictable?

Use models to estimate predictable signal by comparing ensemble spread and ensemble mean

Variability of Z 200hPa in DJF from seasonal ensembles

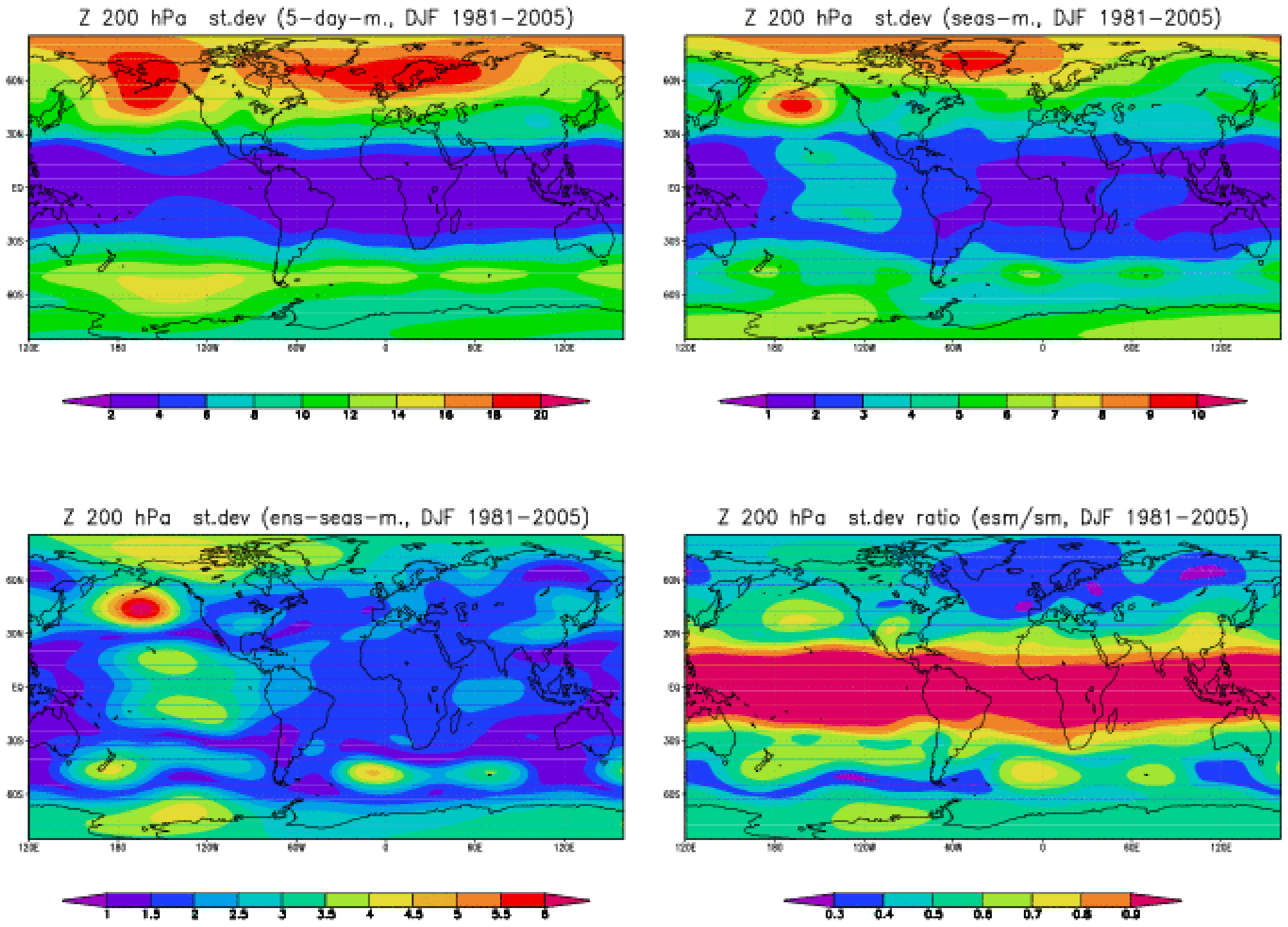
Standard deviation from 11-member ensembles, DJF 1981/2005

5-day means

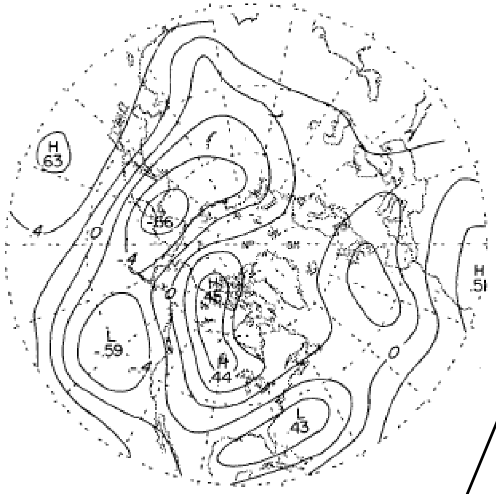
Seasonal means

Seasonal - ensemble means

St.dev. ratio



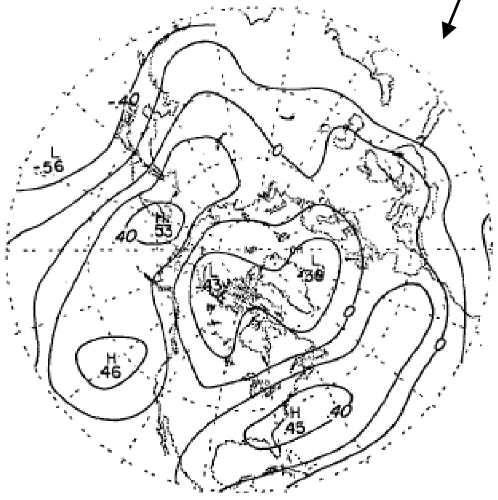
Teleconnections with ENSO



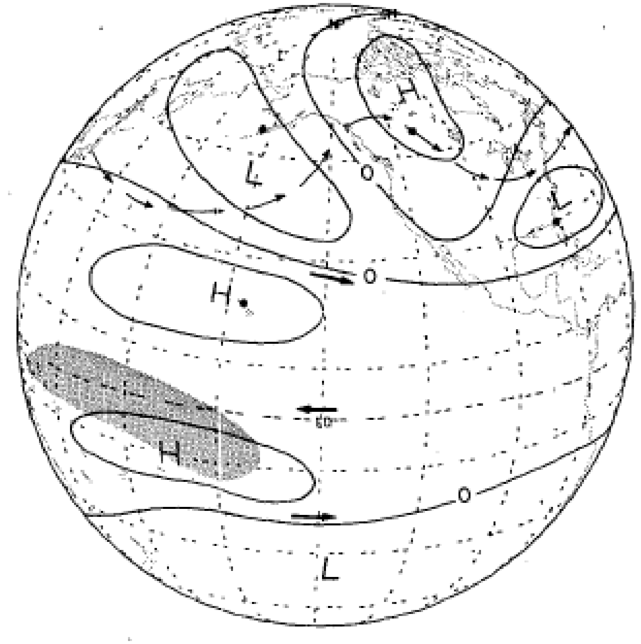
a

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

Schematic diagram of tropical-extratropical
teleconnections during El Niño



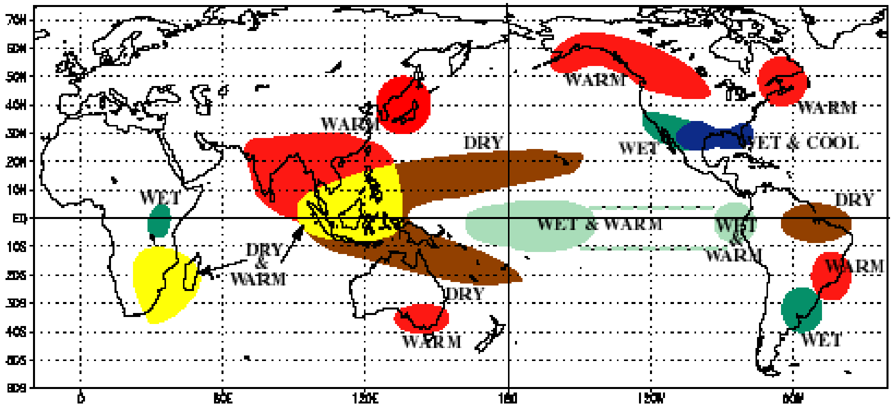
c



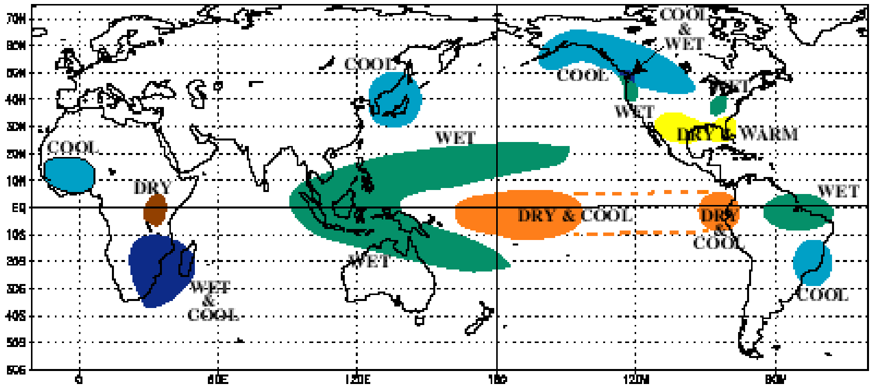
Horel and
Wallace 1981

ENSO impacts: rainfall and temperature

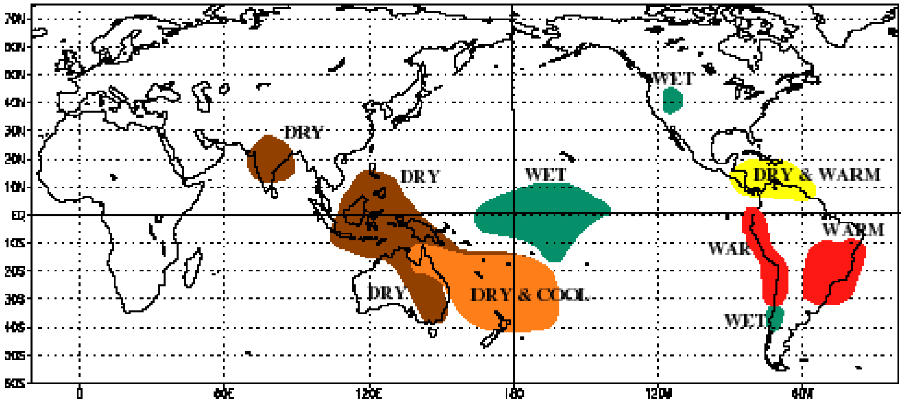
WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



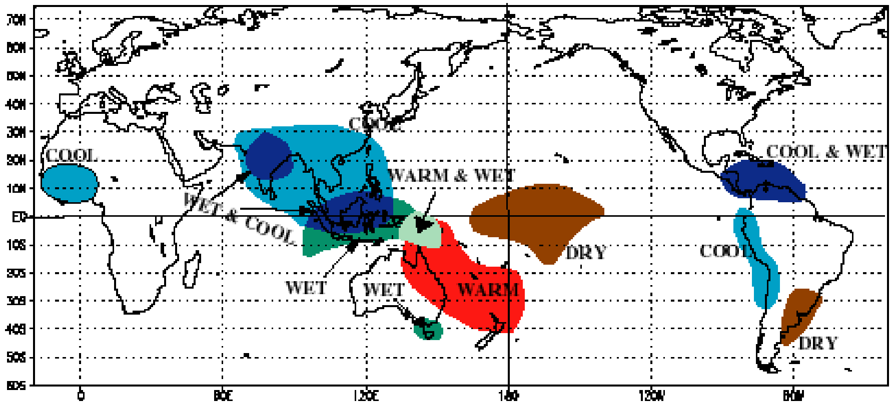
COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



WARM EPISODE RELATIONSHIPS JUNE - AUGUST



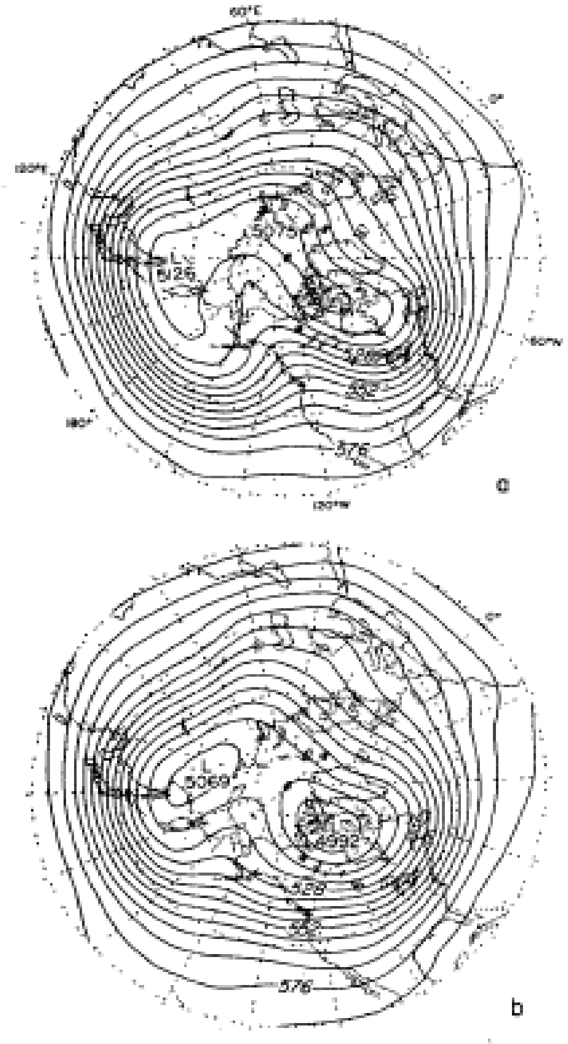
COLD EPISODE RELATIONSHIPS JUNE - AUGUST



ECMWF

The Pacific /North American (PNA) pattern

500-hPa height composites from Wallace and Gutzler 1981



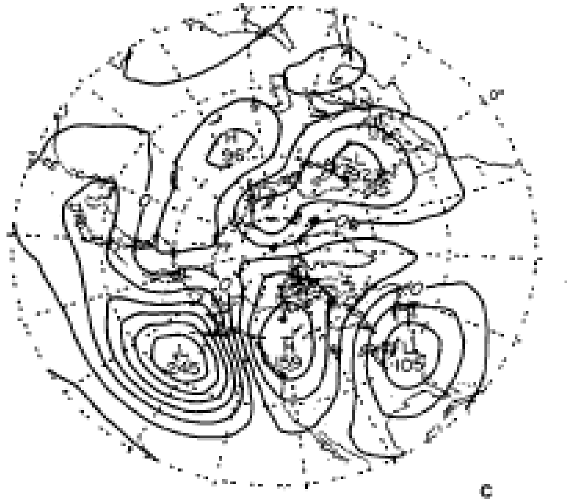
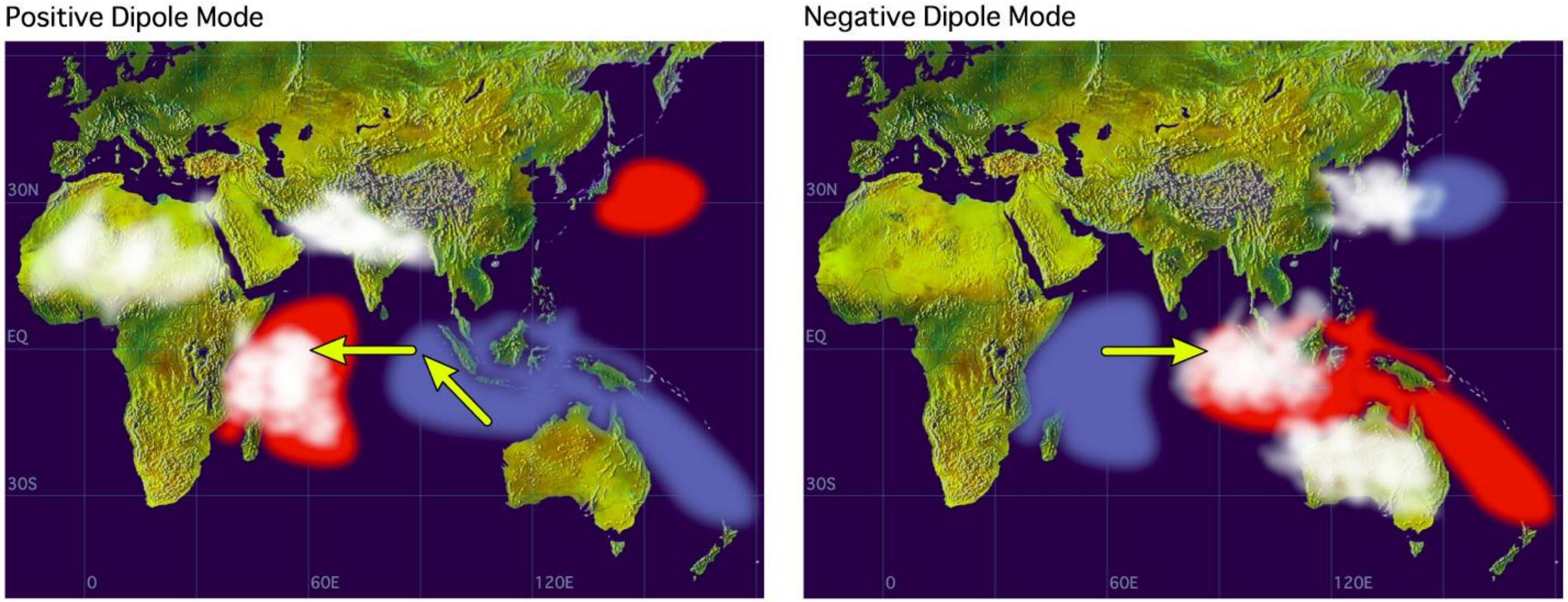


FIG. 17. As in Fig. 13 except for the Pacific/ North American pattern.

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

Saji et al. (1999)

Webster et al. (1999)

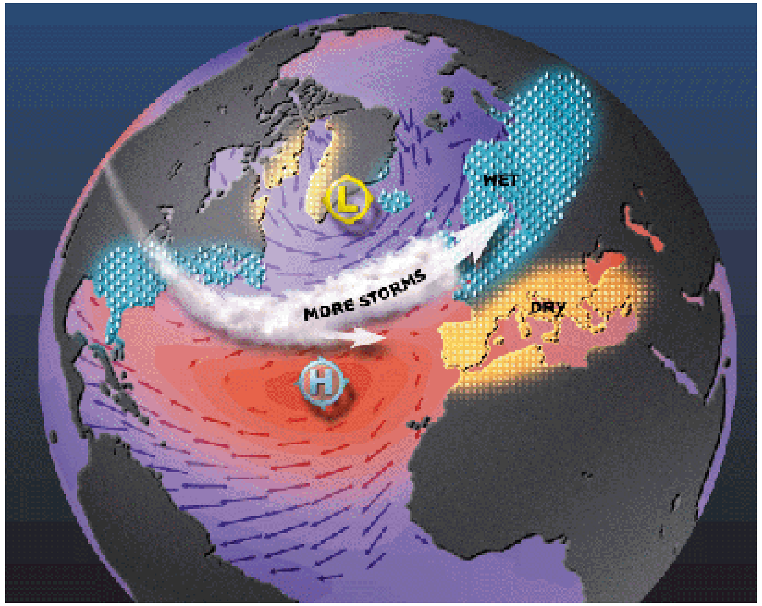


ECMWF

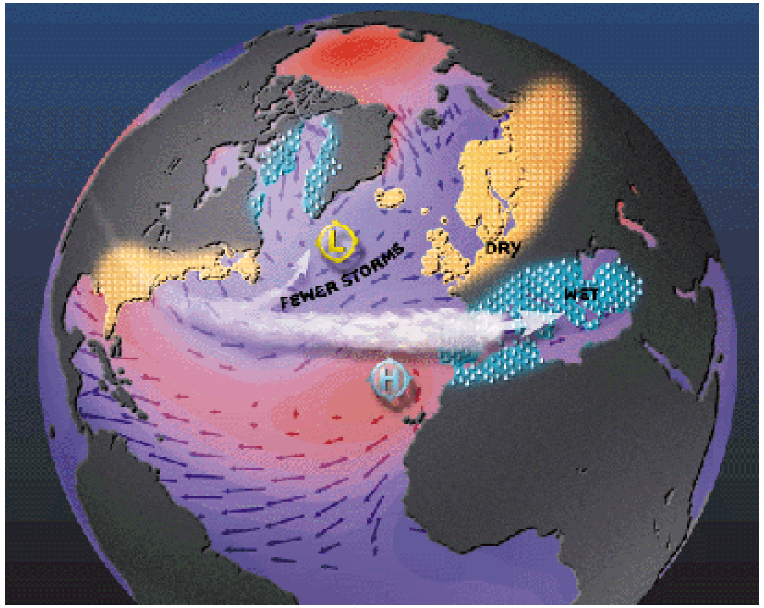
The North Atlantic Oscillation

Walker and Bliss (1932)

Van Loon and Rogers (1978)



Positive NAO phase

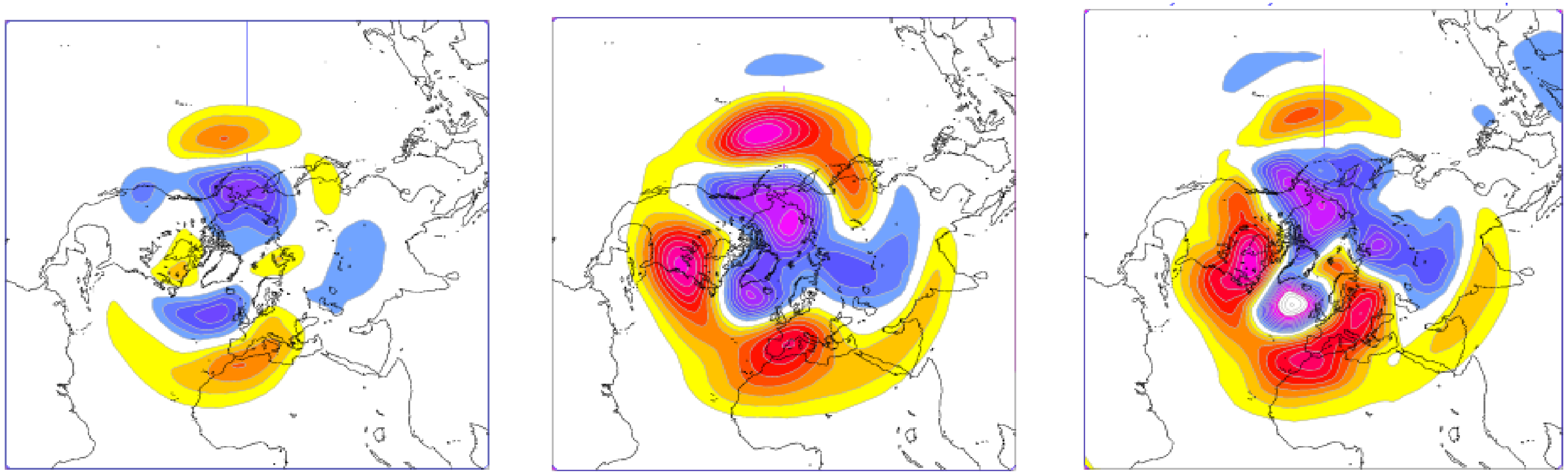


Negative NAO phase

MJO teleconnections in October-March

500 hPa height, MJO phase 3 + 10 days

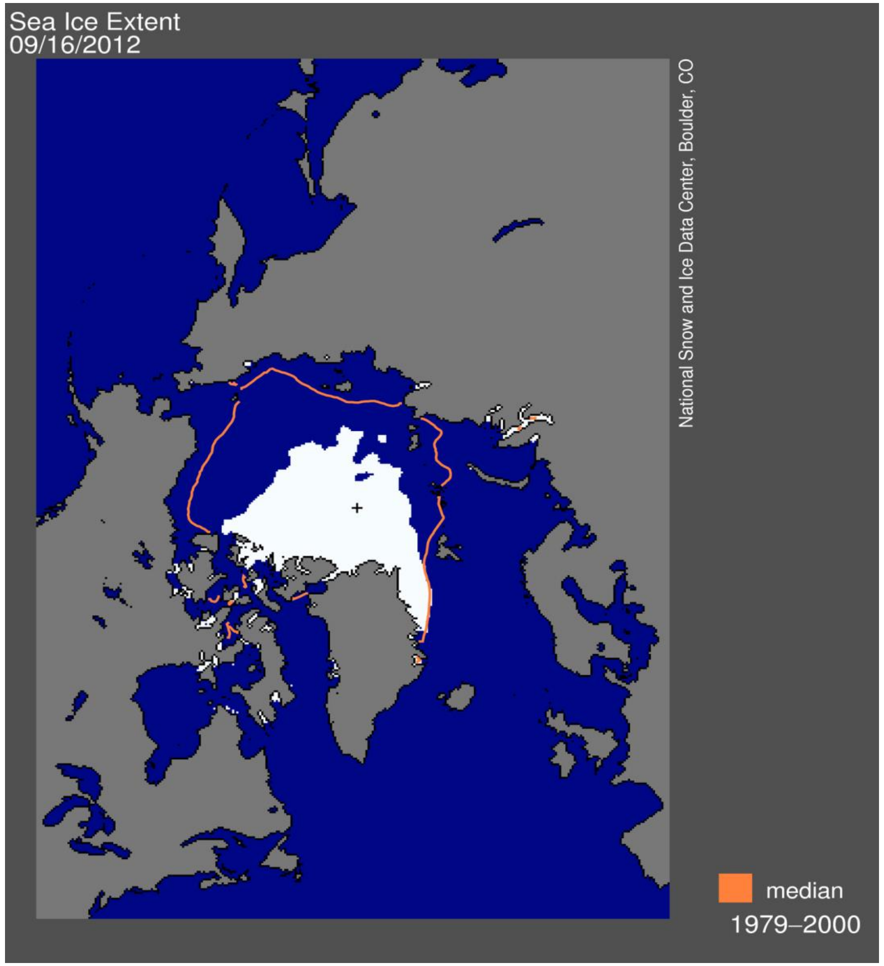
2002 MOFC hindcasts | 2011 MOFC hindcasts | ERA Interim



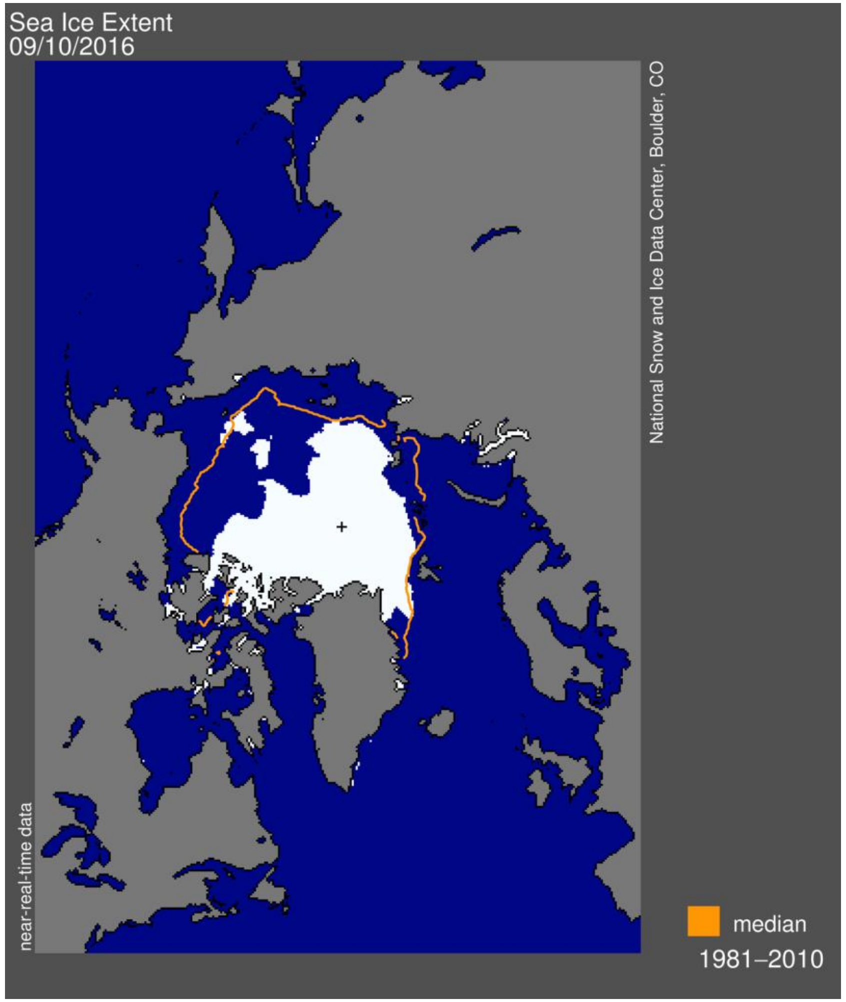
from Vitart 2014

ECMWF

Sea ice: Interaction of climate change and natural variability



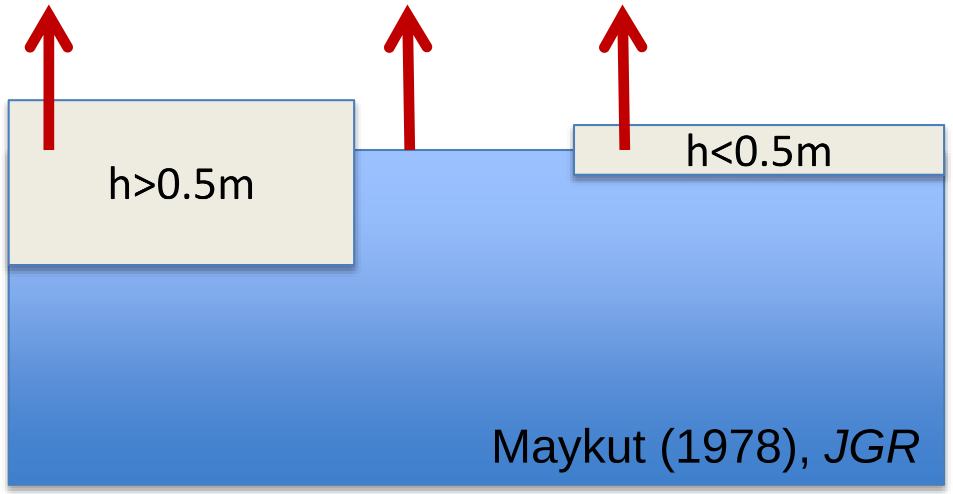
Record minimum in Arctic sea-ice extent: 16/9/2012
(from NSIDC)



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)



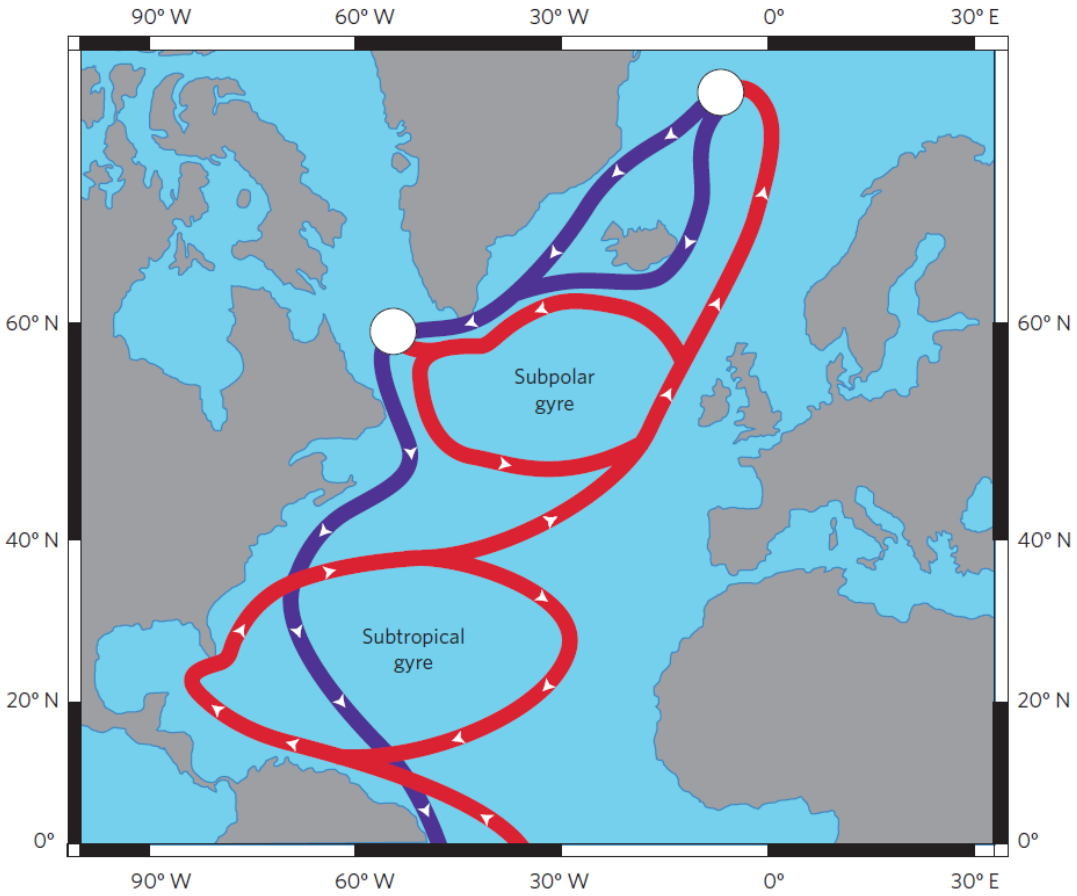
- Impact on waves
- Salinity fluxes:
  - Production of brine (freezing) and freshwater (melting)

Impacts on the ocean

Deep convection:

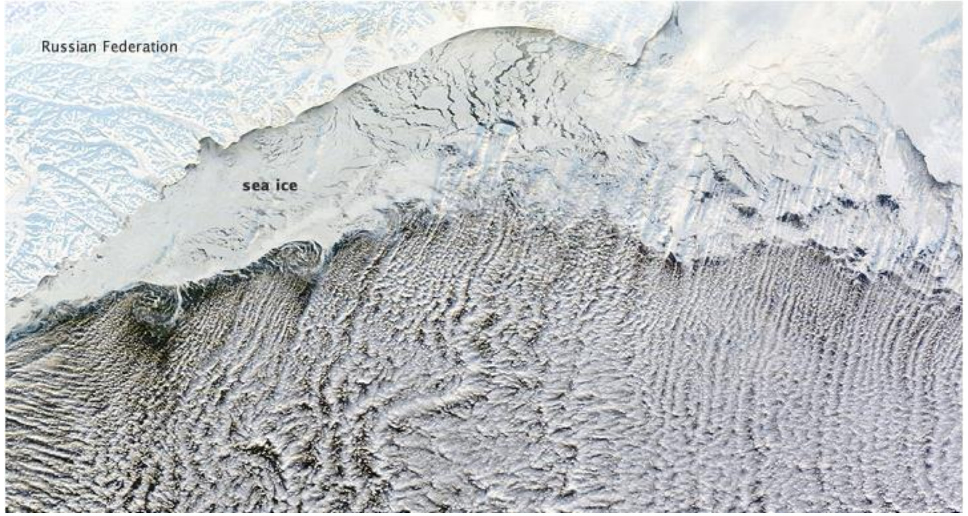
- More important on longer time scales

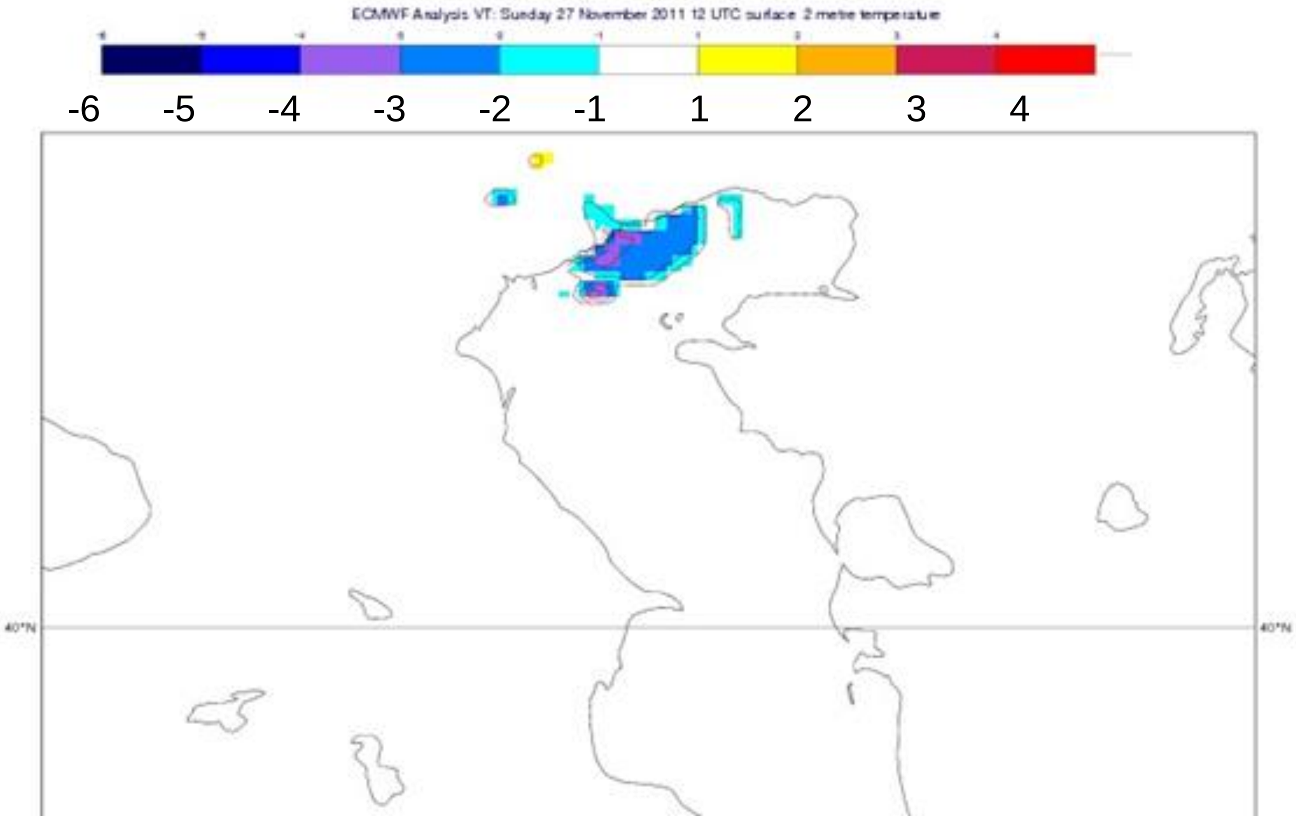
- Impact on the Gulf Stream and the Thermohaline circulation – part of the feedback on the Arctic system



Impacts on the atmosphere

- Surface air temperatures
- Cloud
- Storm tracks
- Precipitation
- Large scale variability – NAO – seasonal timescale predictions



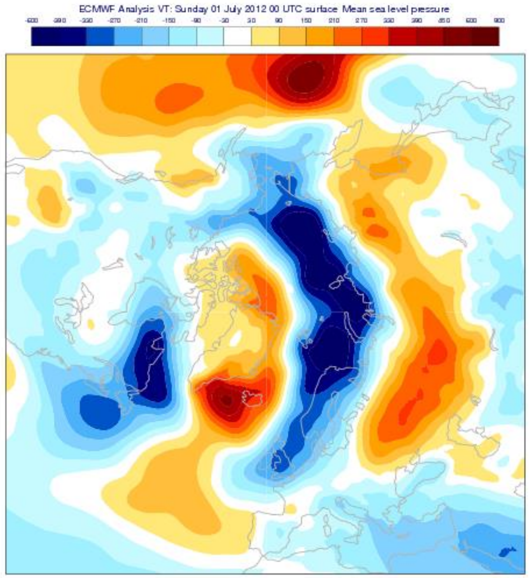


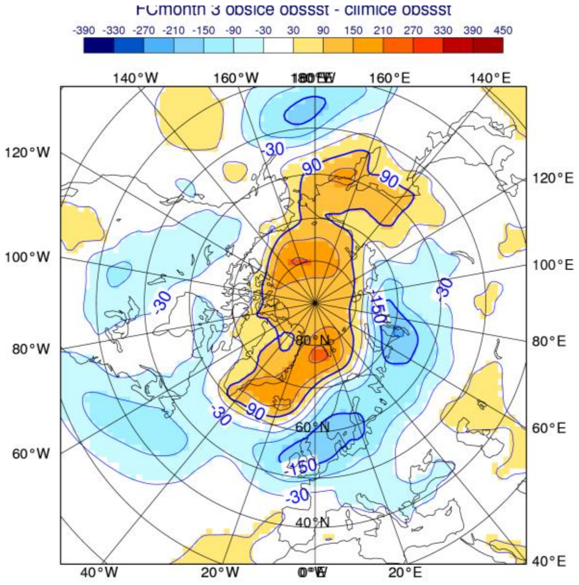
ECMWF

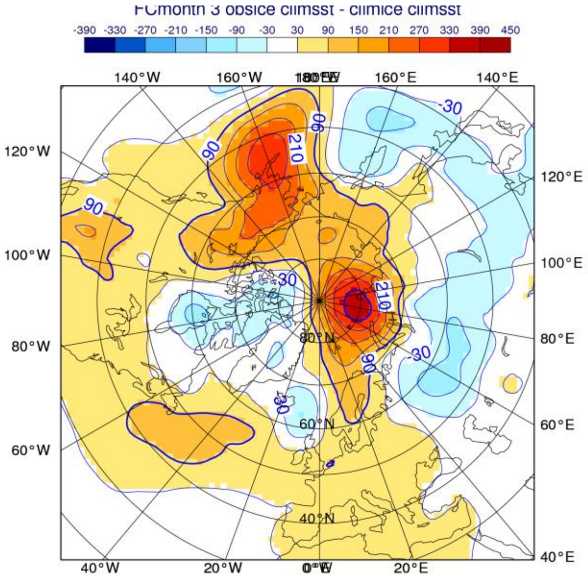
Summer sea ice impacts – Case study 2012

- Ensemble mean MSLP differences between experiments:

2012 sea ice - sea ice climatology







Reanalysis

July MSLP anomaly
Era Interim 2012 - climatology

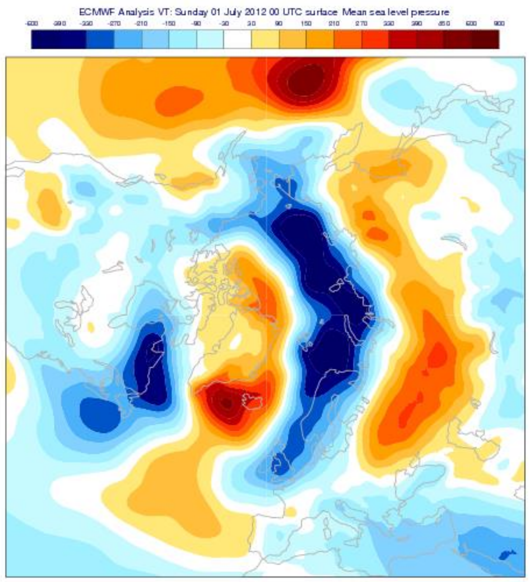
SST 2012

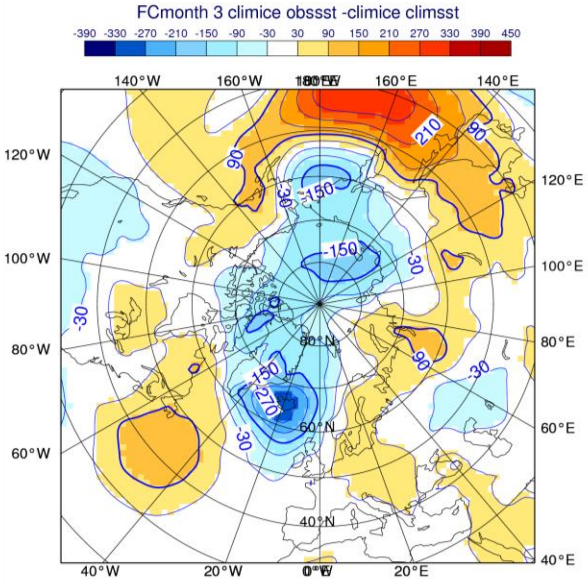
SST Clim

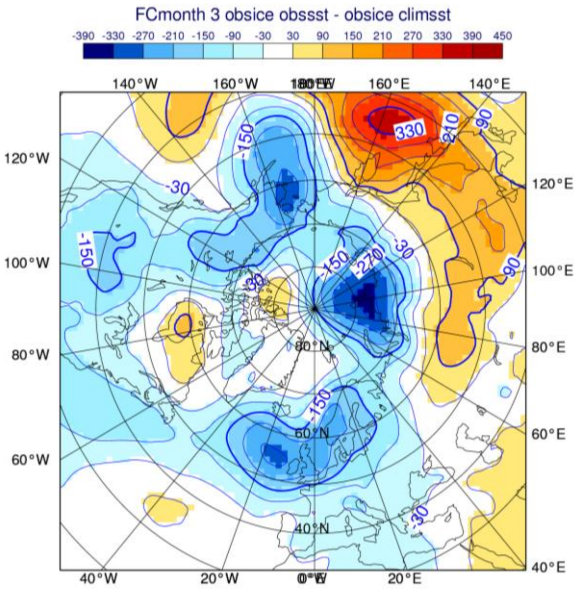
Summer SST impacts – Case study 2012

- Ensemble mean MSLP differences between experiments:

2012 SST - SST climatology







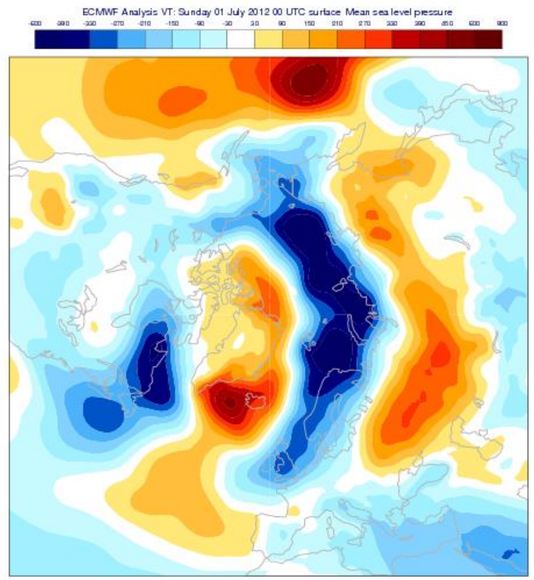
Reanalysis

Sea ice clim

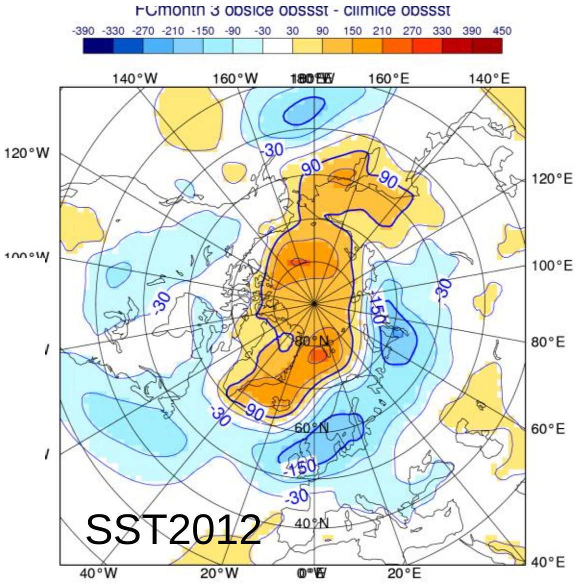
Sea ice 2012

July MSLP anomaly
Era Interim 2012 - climatology

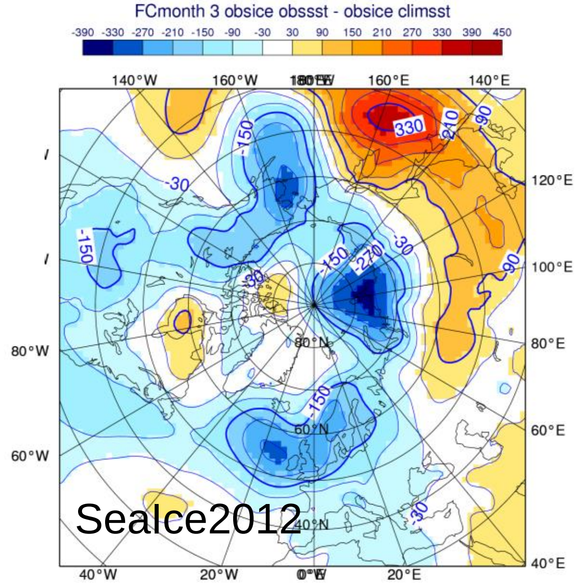
Results Sea Ice Predictability – July 2012



July MSLP anomaly
Era Interim 2012 - climatology

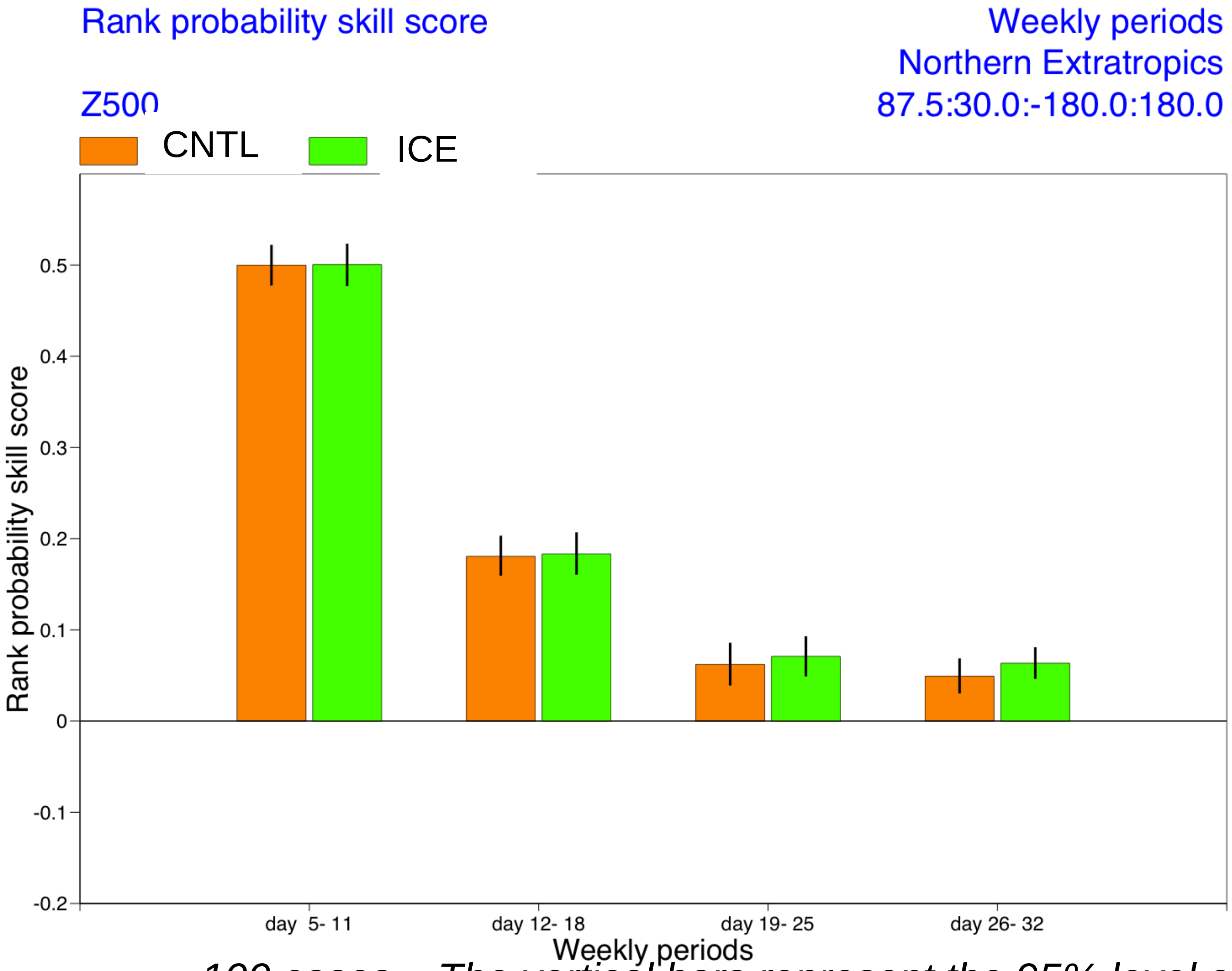


sea ice: 2012-climatology



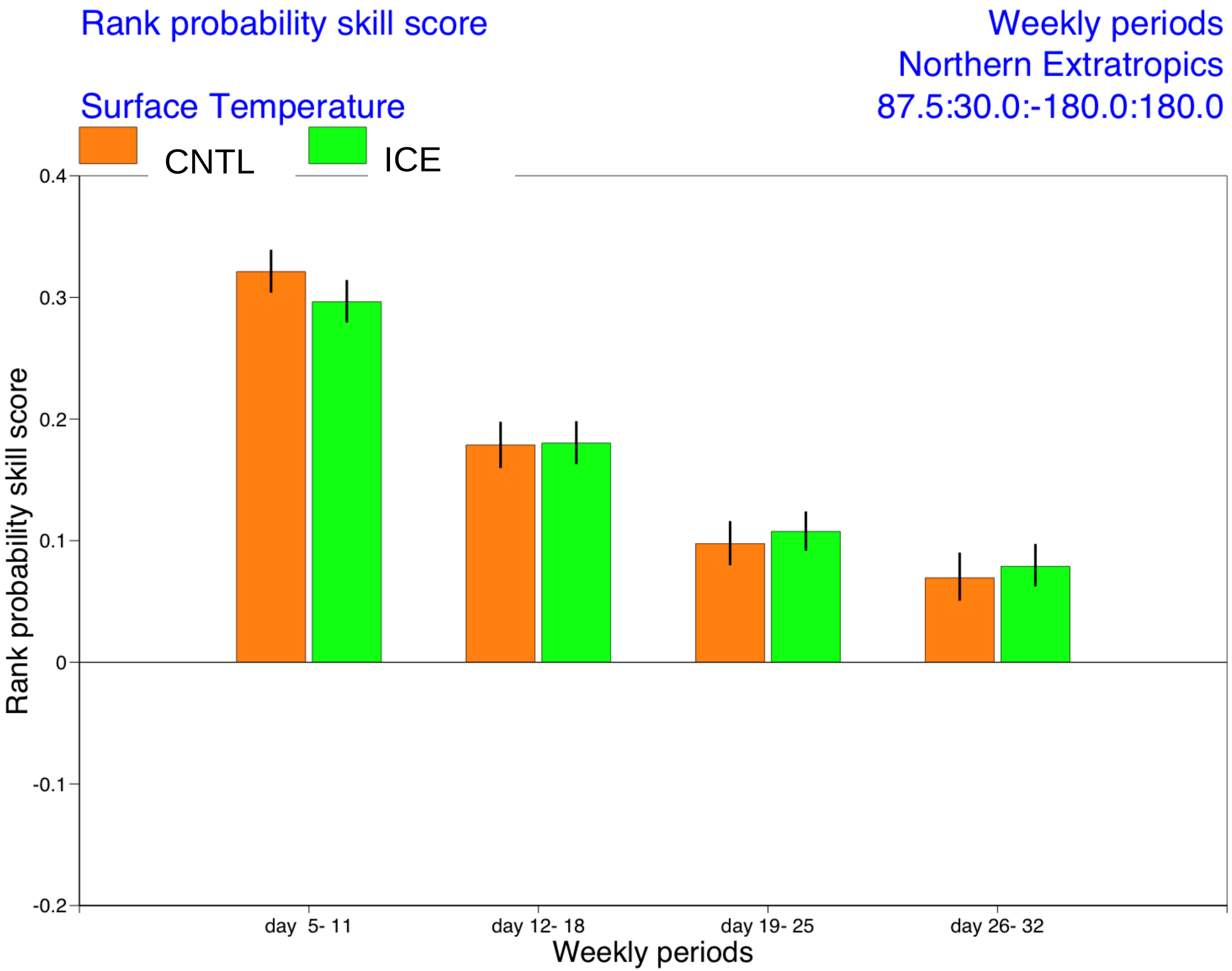
SST: 2012-climatology

Headline scores comparing ERA-I with: CNTL (persisted – climate ice) and LIM2

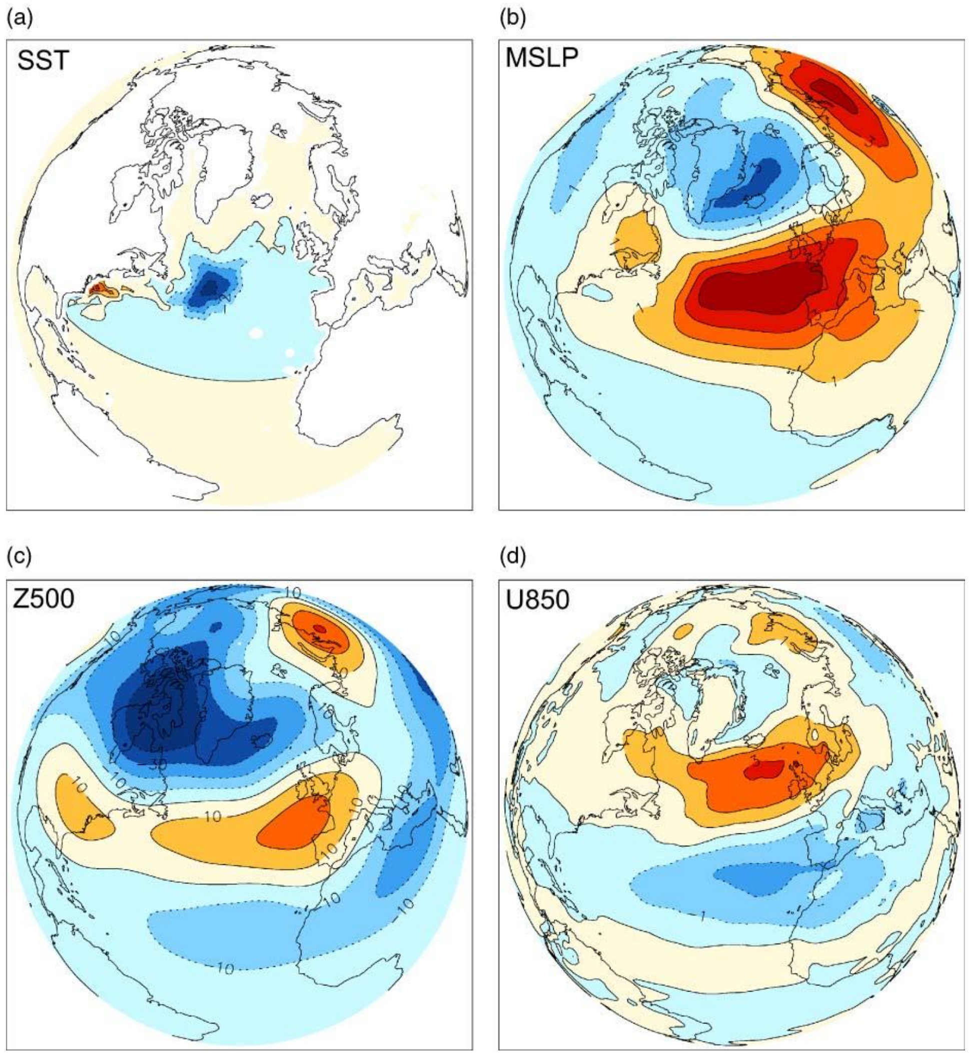


100 cases – The vertical bars represent the 95% level of confidence

Headline scores comparing ERA-I with: CNTL (persisted – climate ice) and LIM2



Note of caution about increasing complexity



Keeley et al (2012) QJRMS

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 processes important 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.

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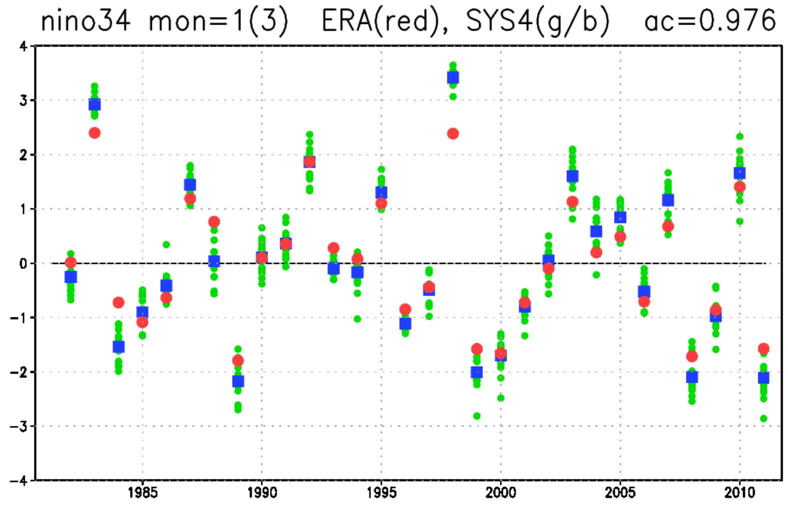
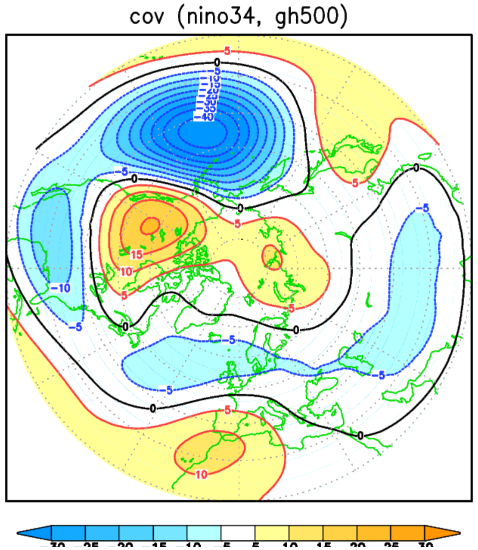
Extra slides

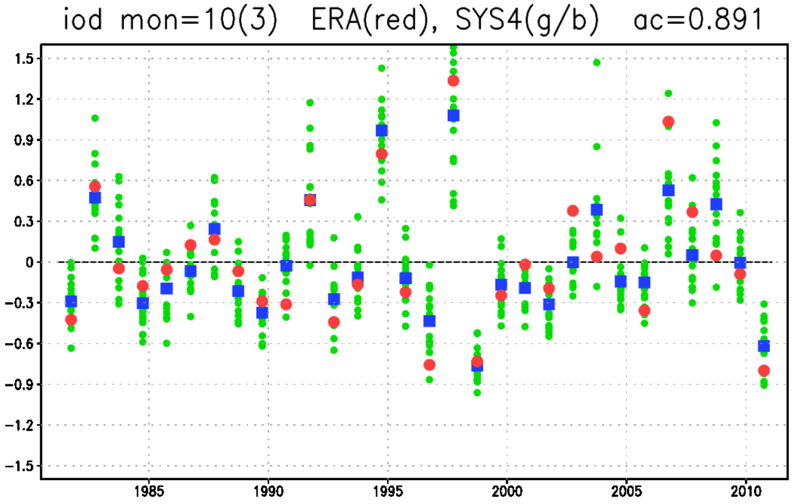
Prediction of tropical SST anomalies in Sys4

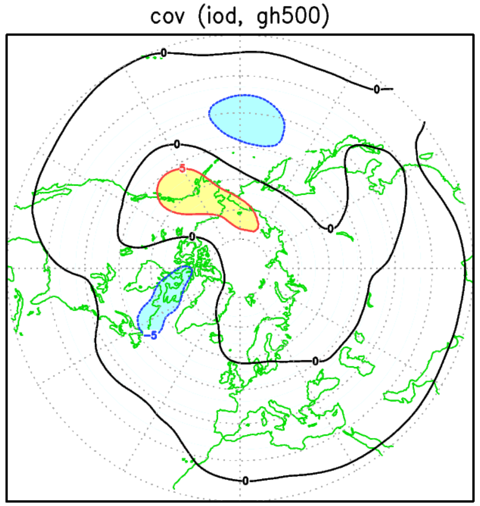
Nino3.
4
DJF





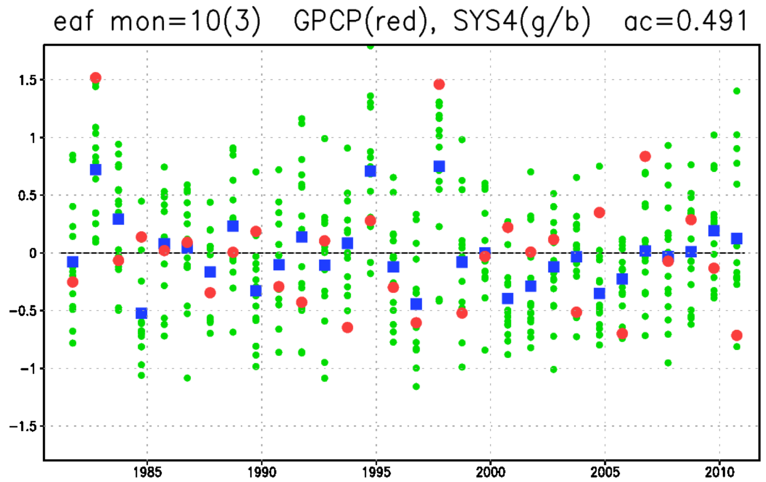
IOD
SON

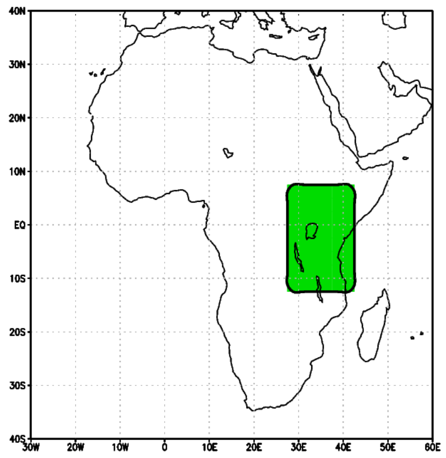


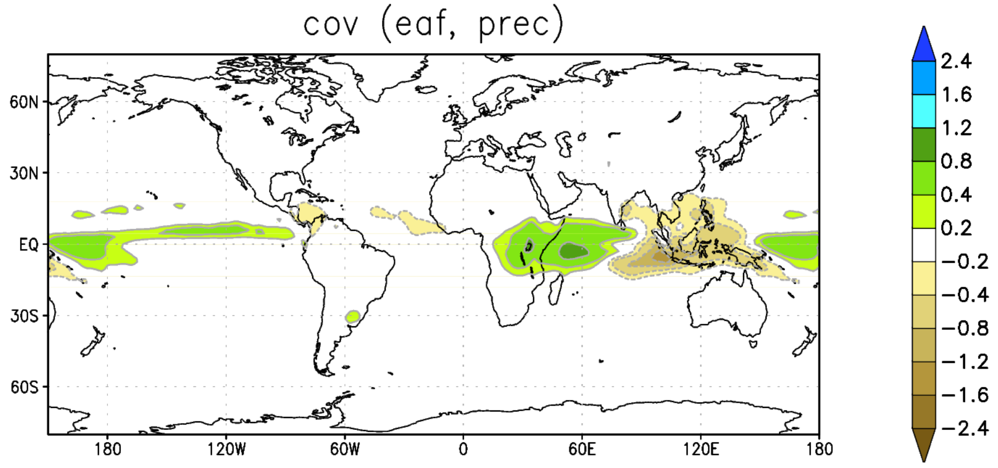


ECMWF

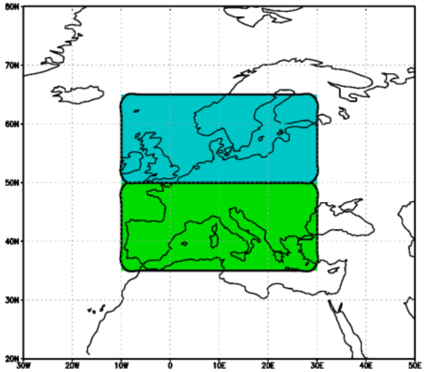
Prediction of tropical rainfall in Sys4: East Africa (SON)

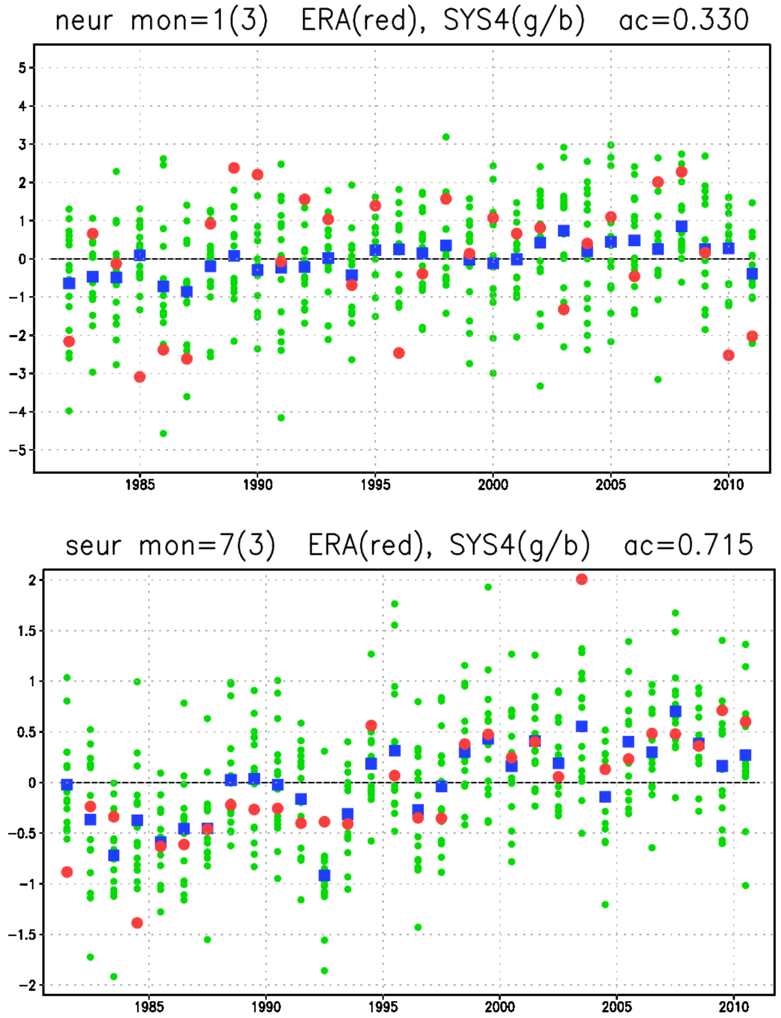


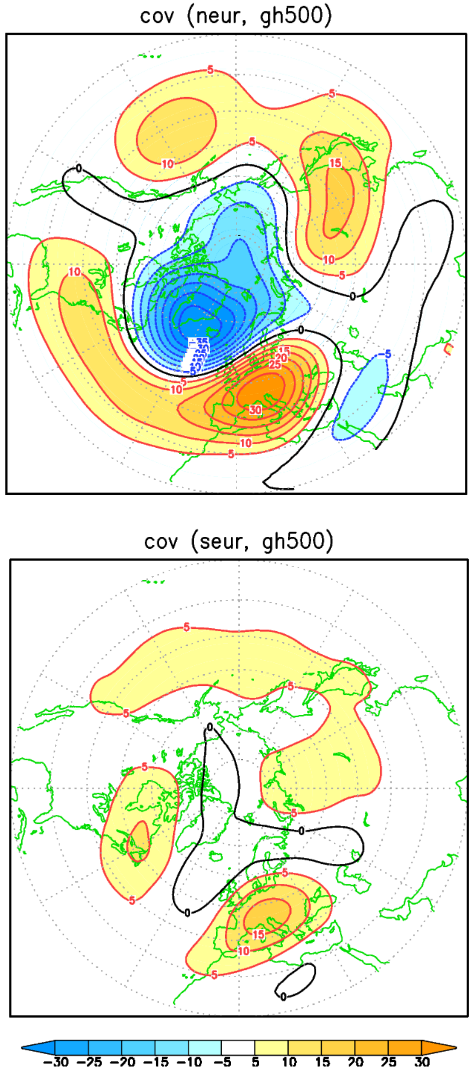




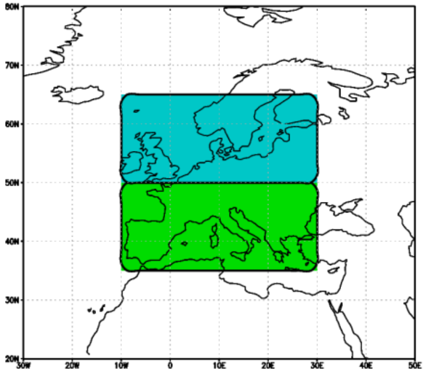
Prediction of 2-m temperature in Sys4: Europe (DJF, JJA)

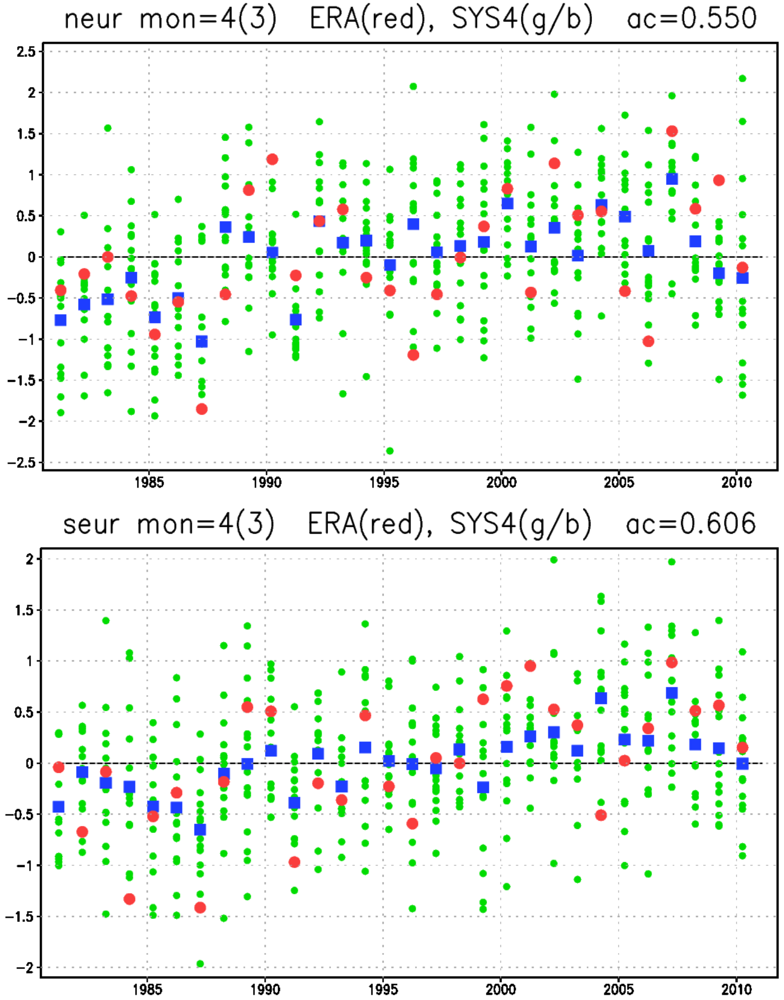


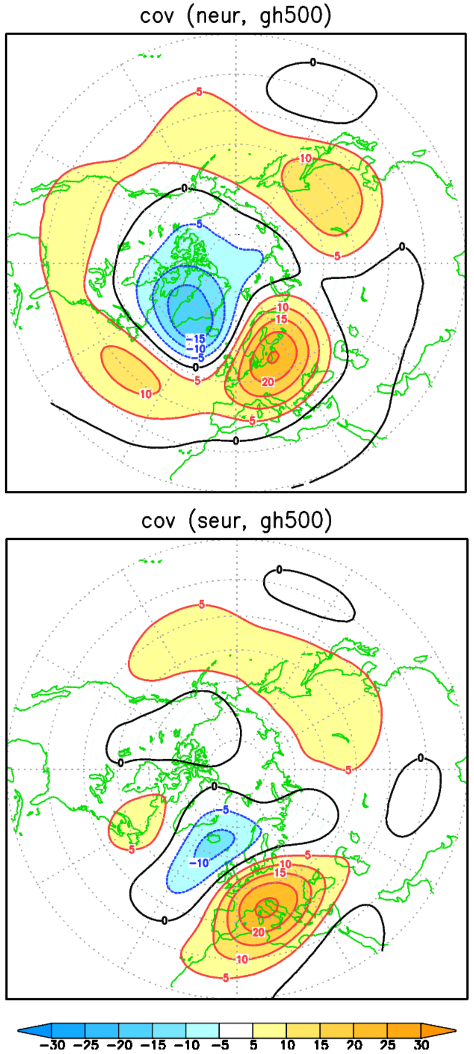




Prediction of 2-m temperature in Sys4: Europe (MAM)







Predictability varies with spatial and time scales

Temperature 850 hPa	40-minute average			2-day average			8-day average		
	NH	SH	TR	NH	SH	TR	NH	SH	TR
T120 (170 km)	23.0	16.5	22.0	25.0	18.0	26.0	> 28.0	25.0	> 28.0
T30 (680 km)	24.0	17.0	23.0	25.0	18.0	27.0	> 28.0	25.5	> 28.0
T7 (3,000 km)	> 32.0	23.0	26.5	> 31.0	23.5	28.0	> 28.0	> 28.0	> 28.0

Table 1 Forecast skill horizons for the probabilistic prediction of 850 hPa temperature over the northern hemisphere (NH), the southern hemisphere (SH) and the tropics (TR), for fields with increasingly larger spatial scales (T120, T30 and T7 spectral triangular truncation) and longer time averages (40-minute, 2-day and 8-day averages). The 'greater than' symbol (>) indicates that the forecast skill horizon is larger than the last time step that could be verified (i.e. 32 days for 40-minute average forecasts, 31 days for 2-day average forecasts and 28 days for 8-day average forecasts).

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