Developing the skill of seasonal - multi-annual climate prediction

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Swedish Meteorological and Hydrological Institute (SMHI)

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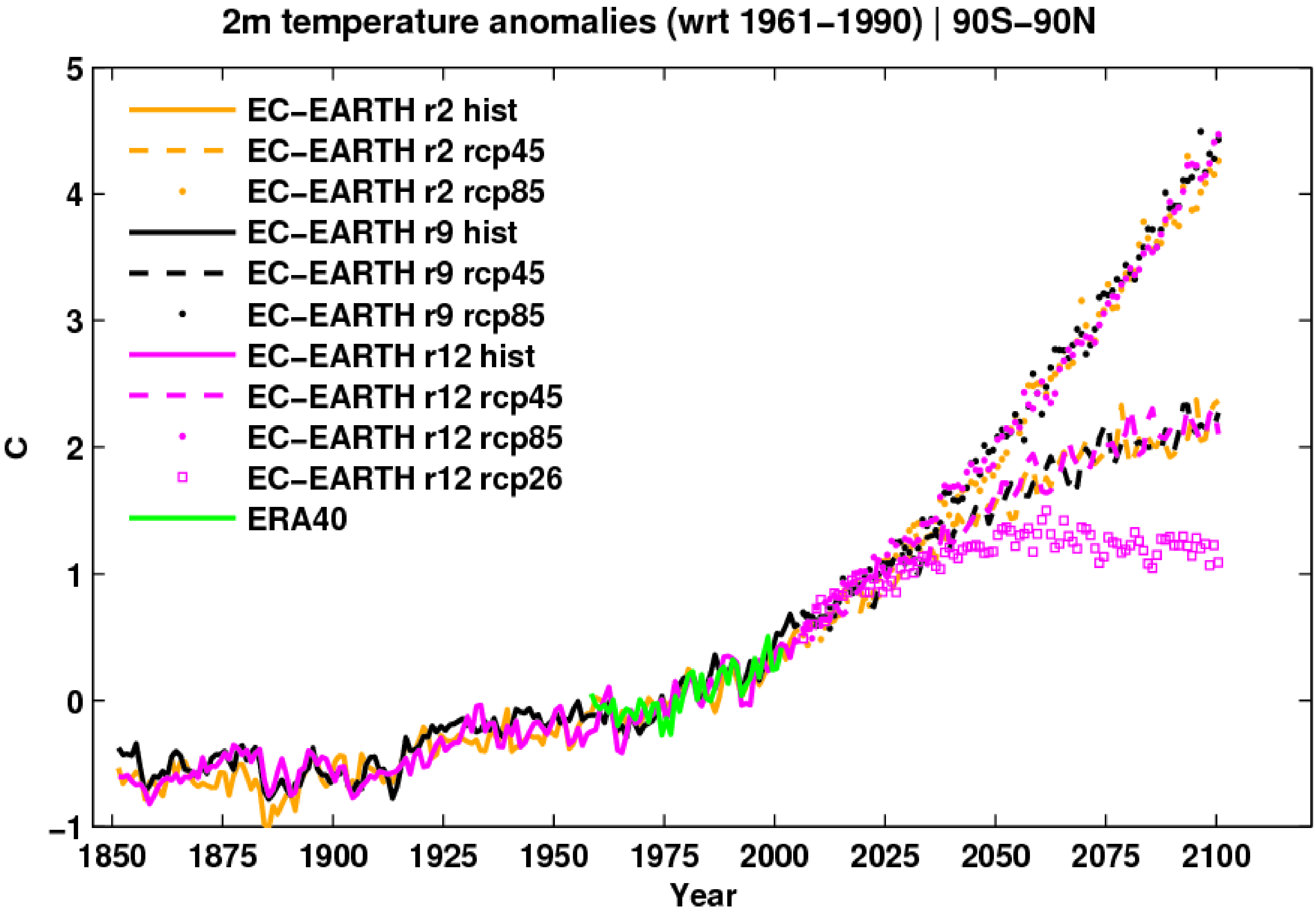
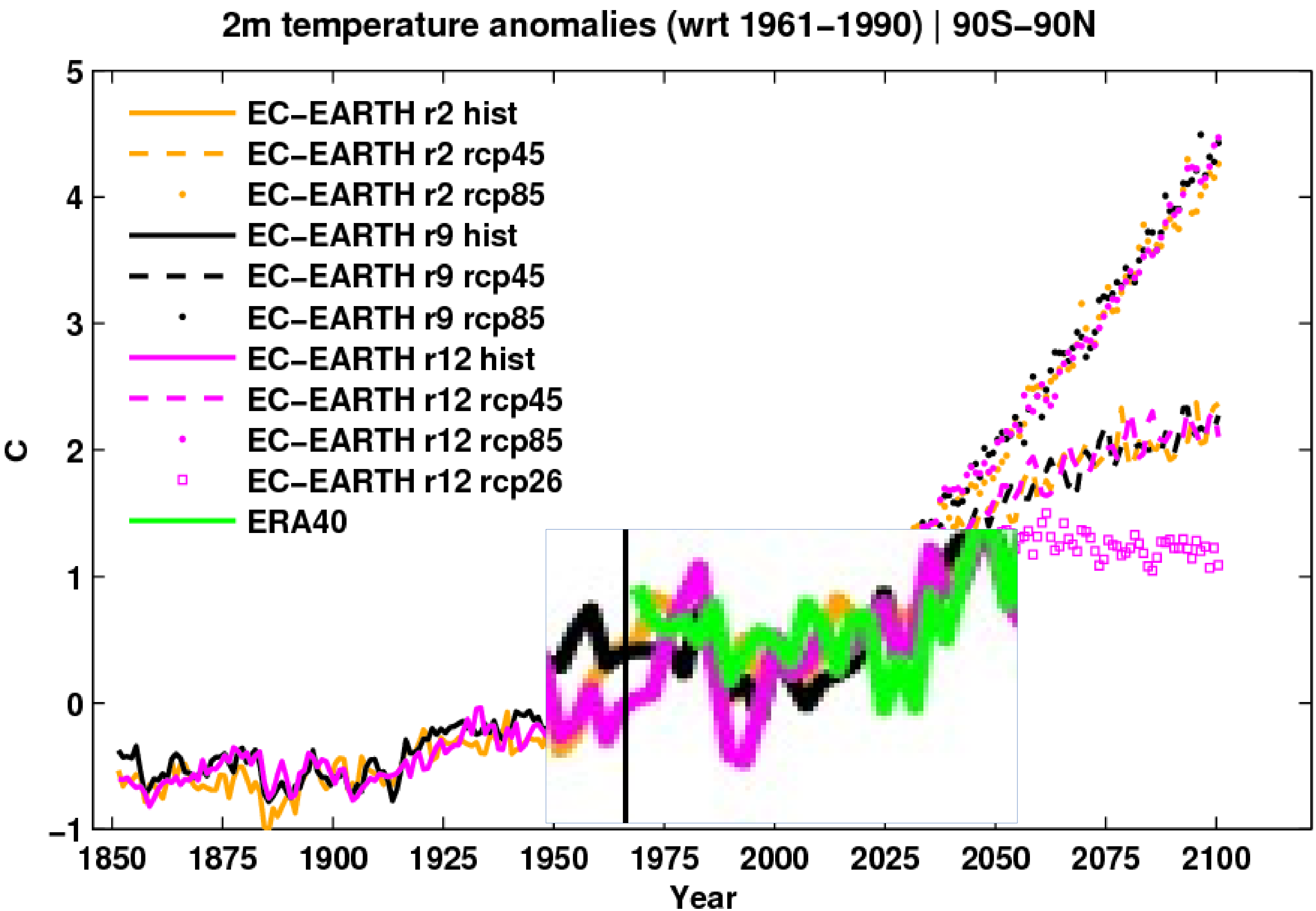
What is climate prediction?

- Forecast based on climate models, starting from observed conditions
- Often targeting average climate conditions and extremes
  - of the coming 10 years
  - of the coming season
- Goal:
  - to provide probabilities in addition to persistence and observed trends, suitable for actionable information and services for public and private stakeholders

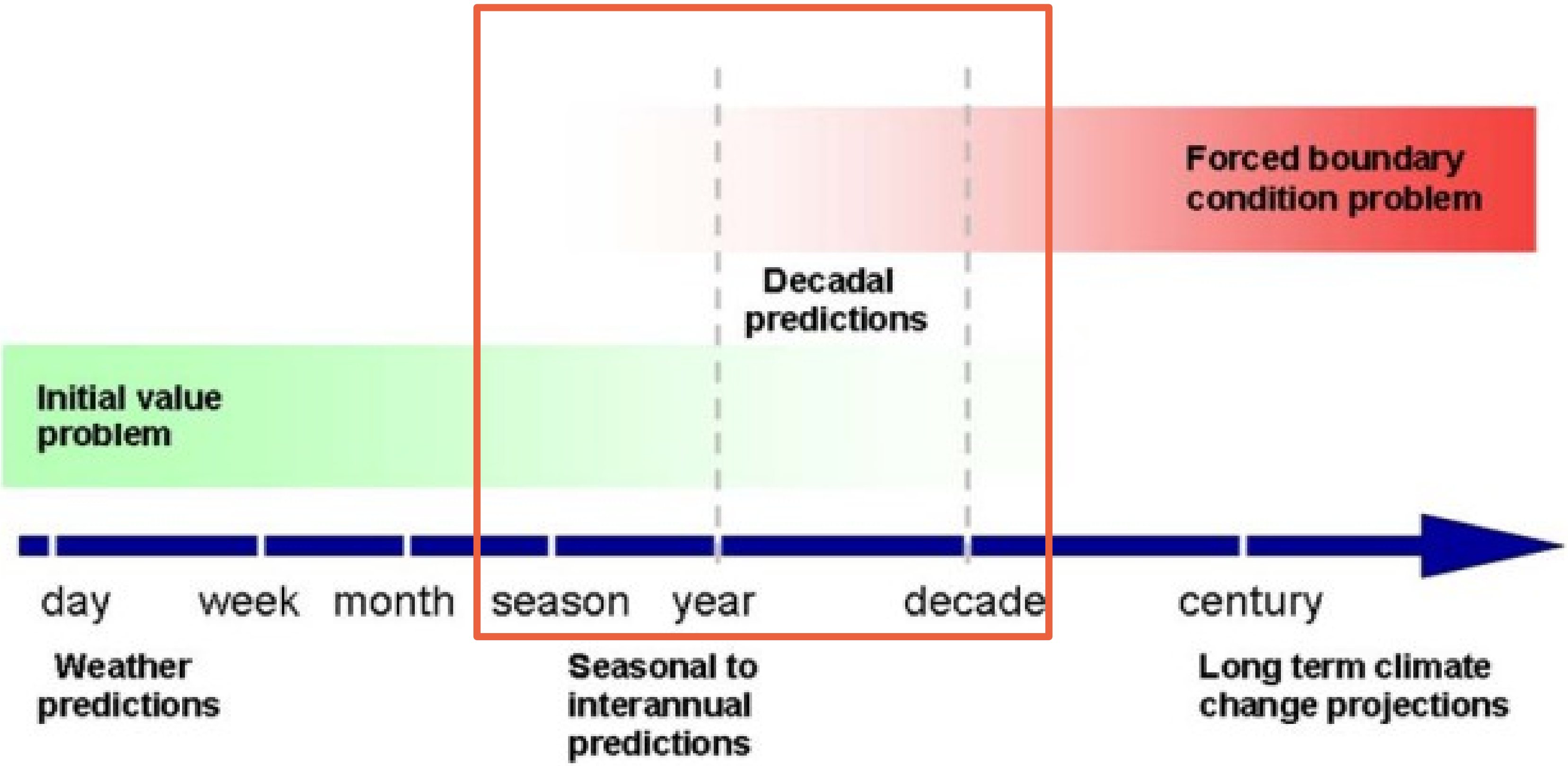
The problem: Long term climate prediction and internal variability



The problem: Long term climate prediction and internal variability



Climate prediction



Box 11.1, Figure 2: A schematic illustrating the progression from an initial-value based prediction at short timescales to the forced boundary-value problem of climate projection at long timescales. Decadal prediction occupies the middle ground between the two (based on Meehl et al. (2009b)).

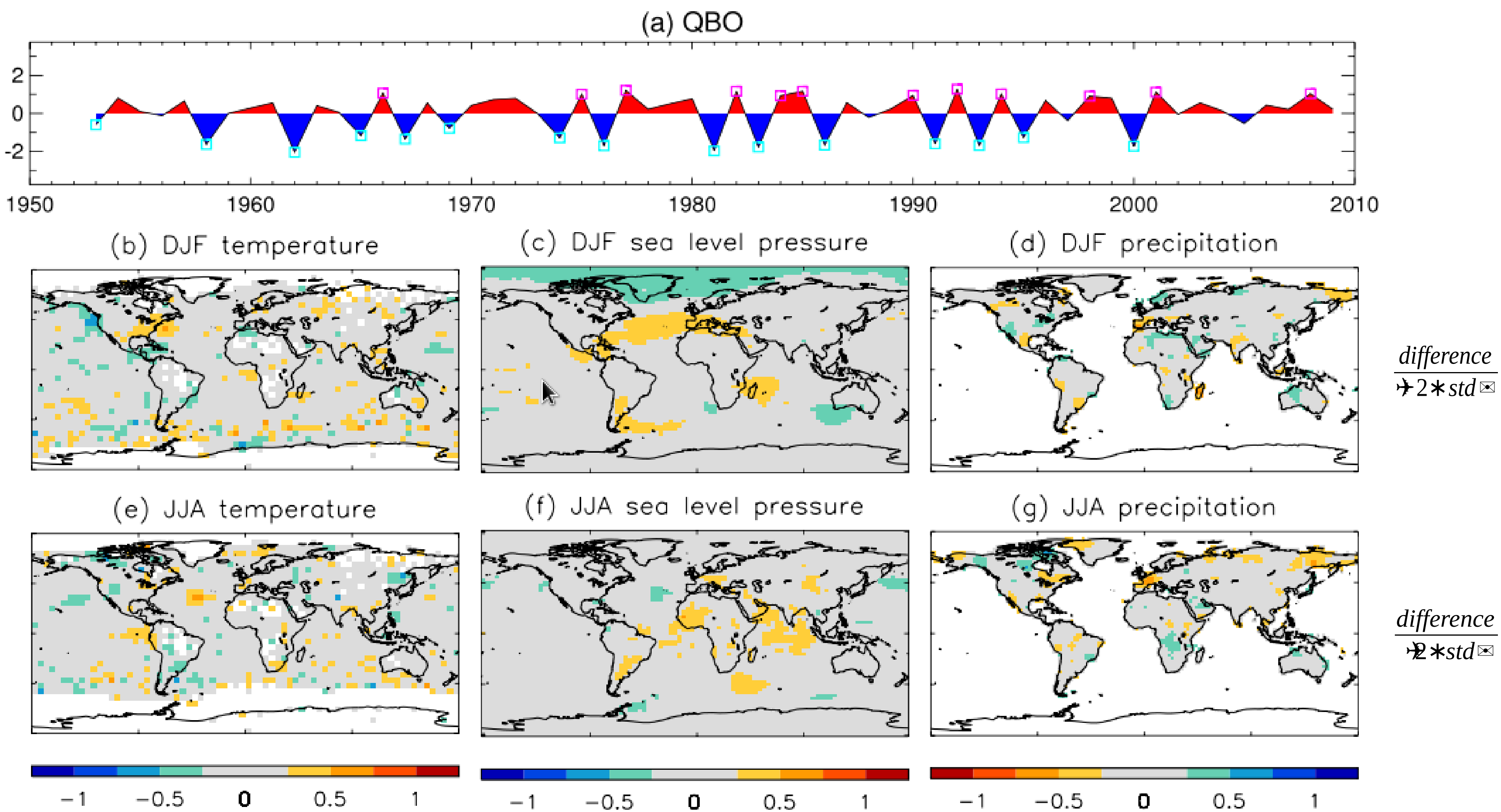
Sources of predictability

- **Signal storage capacity**
- **Observable phenomena (oscillations, forcing, events) which can serve as predictor (i.e,. relate to a quantity to be predicted).**
- **Physical mechanisms linking predictors to predicted quantity (e.g. temperature over Europe or the Arctic)**
- Need to
  - understand physical mechanisms representation in models to gain confidence in forecasts
  - optimize
    - initialization methods
    - ensemble building methods
    - climate models

Example for a source of predictability:

Quasi-biennial oscillation (**QBO**) of the zonal wind in the tropical stratosphere

Environ. Res. Lett. **7** (2012) 015602 D M Smith *et al*



QBO is predictable years ahead, provides moderate predictability of European winter climate.
QBO affects polar vortex and winter NAO → forecast skill for cold spells in Europe
QBO is typically simulated by climate models.

Example for a source of predictability:

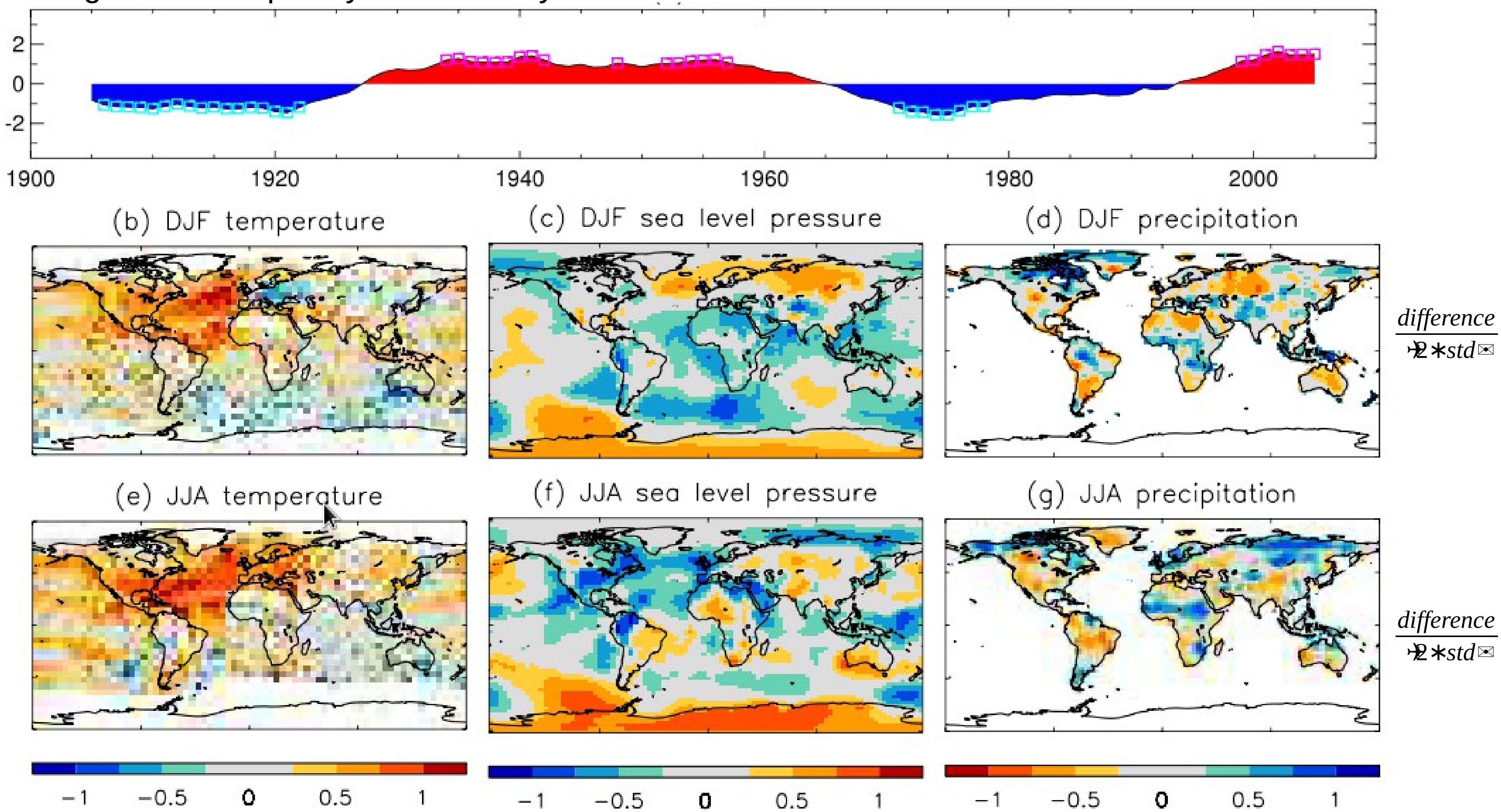
Atlantic multi-decadal oscillation (AMO)

is characterized by a sharp rise and fall of the North Atlantic basin-wide sea surface temperatures (SST) on multi-decadal time scales.

AMO can be related to
- Air temperatures and rainfall anomalies of Northern Hemisphere,
- North American and European summer climate.
- frequency changes of droughts in North America
- Drying of Sahel in the 1960–70s
- change in the frequency and intensity of Atlantic hurricanes

AMO is predictable "a few years" ahead.

Smith et al, 2012

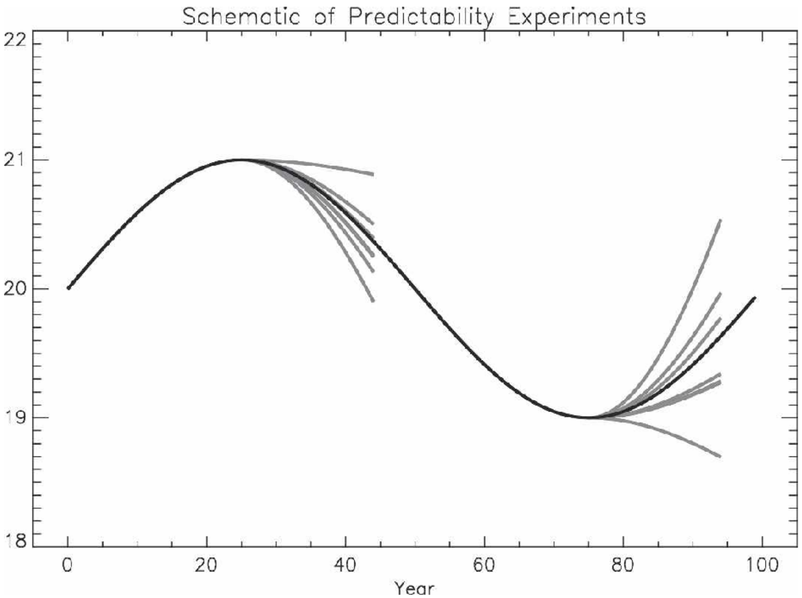


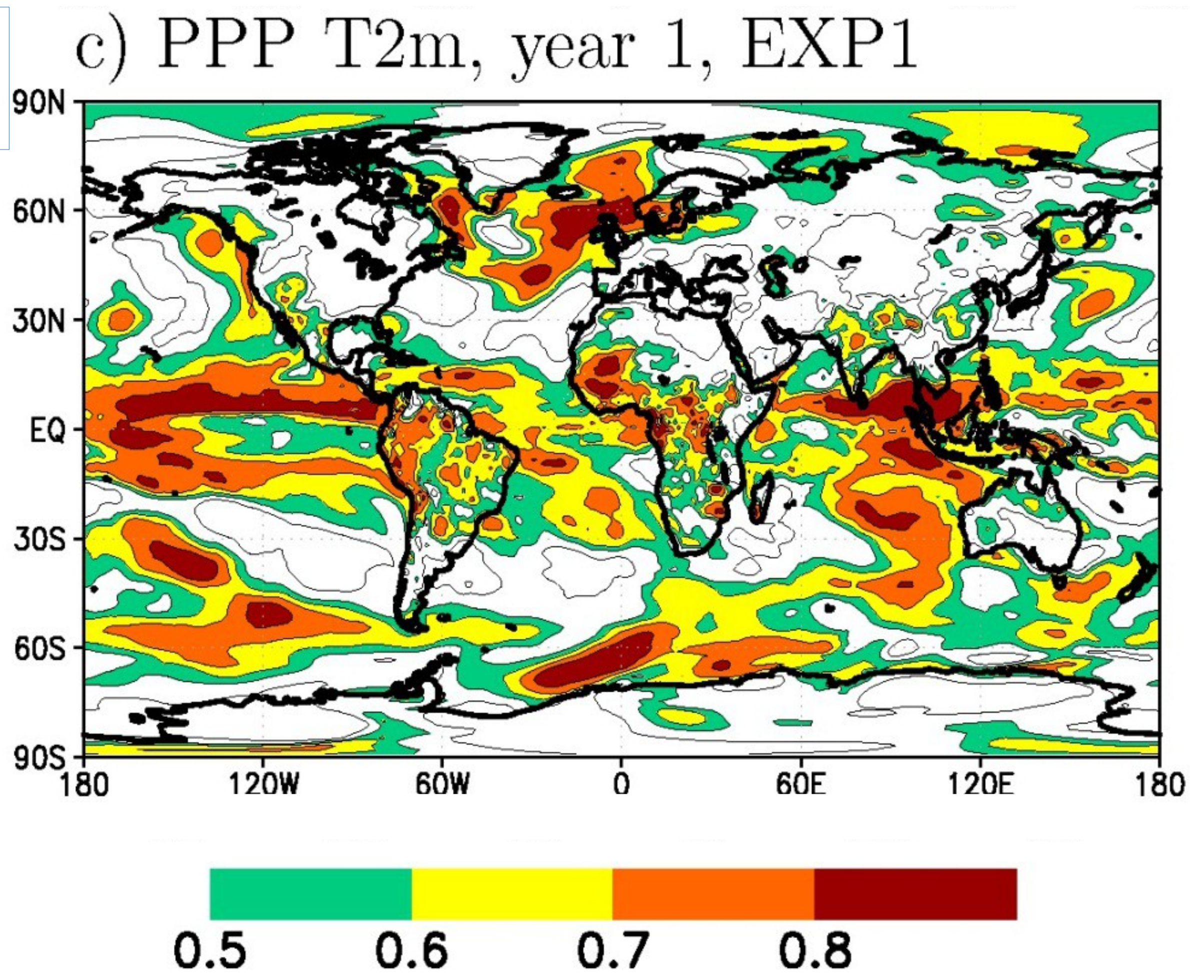
More sources of predictability

- **Solar cycle** (Ineson et al. 2011)
- **North Atlantic Oscillation** (NAO)
- Arctic **sea ice** extent (SIE)
- **El Nino** (Ineson and Scaife, 2009) and La Nina variability (Fereday et al, 2008)
- **Snow cover** (e.g. Cohen and Jones 2011)
- **Vegetation** (Weiss et al. 2012)
- Sea surface temperature (SST) variability in the North Atlantic (Rodwell and Folland 2002)
- Quasi-biennial oscillation (**QBO**) in the tropical stratosphere (e.g. Marshall and Scaife 2009)
- Major tropical **volcanic eruptions** that cause warming of the Nordic regions sometimes for more than one winter (Jones et al. 2003; Marshall et al 2009). Remote influences on Atlantic hurricanes and sahel precipitation.
- Madden-Julian Oscillation (**MJO**)
- The role of resolution and ensemble technique
- Pacific decadal variability (**PDV**)
- Atlantic multi-decadal variability (**AMV**)
- North Atlantic ocean currents are potentially predictable on decadal timescales. “Some skill” in initialised (real live) predictions
- Increased **aerosols** => cool N. Atlantic => anomalous Hadley circulation => ITCZ shifts south => fewer storms
- Aggressive aerosol mitigation in RCP2.6 => reduced cooling (more warming) in N. Atlantic) => stronger anomalous Hadley circulation => ITCZ shifts north => more storms
- skill from the climate change signal
- Emerging importance of external factors: aerosols, volcanoes, solar, greenhouse gases via sea ice?

Interannual potential predictability

PPP= prognostic potential predictability





Koenigk et al. 2012, SMHI

- Potential predictability = Approximation of **upper limit** predictability, under the assumption that the climate model represents the real world.
- That upper limit **can be further enhanced** by improving the model (more realistic descriptions of the sources of predictability)

Decadal Prognostic potential predictability for surface air temperature

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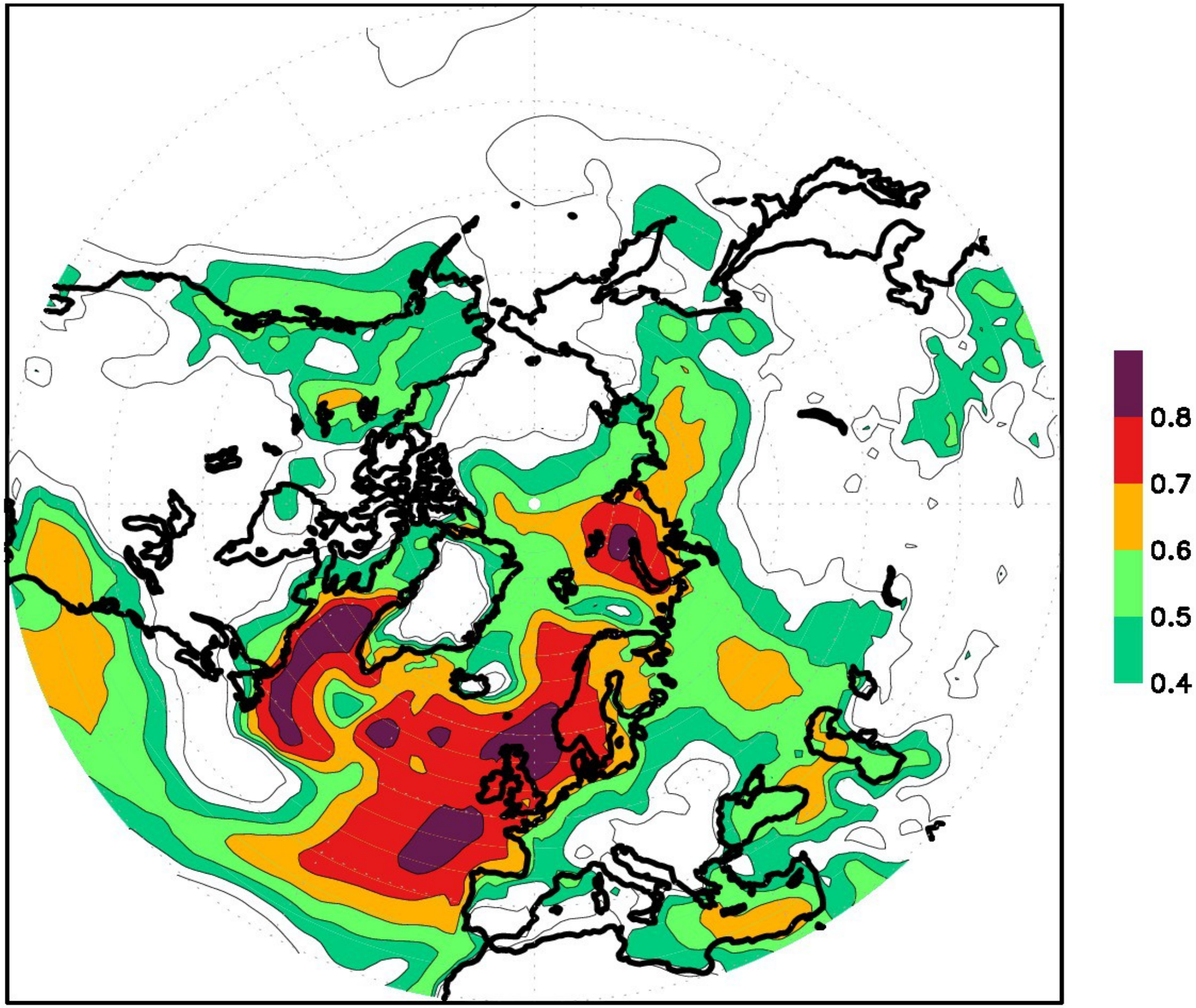
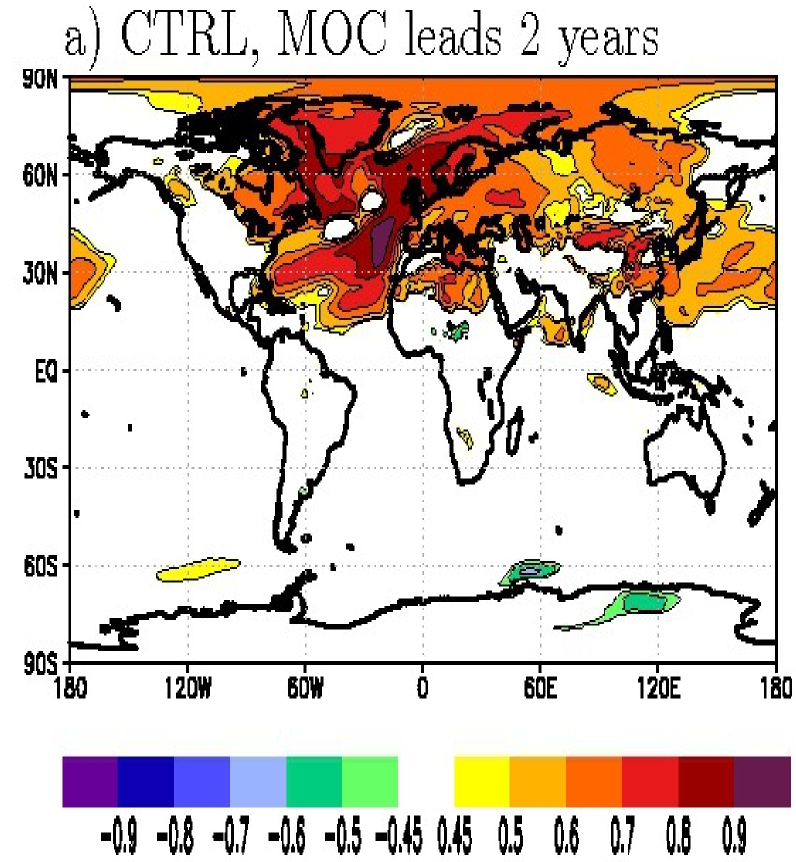


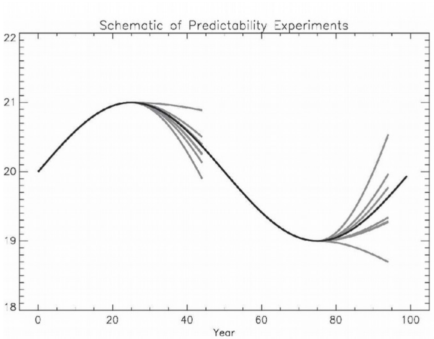
Prognostic potential predictability for surface air temperature in perfect ensemble experiments with EC-Earth 2.1 using present day climate conditions. Values between 0.4 and 0.9 display the scale from low to high predictability. Shown is the potential predictability of the mean of the first 10 years after initialization. The figure is based on Koenigk et al. 2012 (their Fig. 11). Note that all values have been detrended before calculating the predictability. The potential predictability of local decadal mean surface air temperature is significant over entire Europe with exception of the South and South-west.

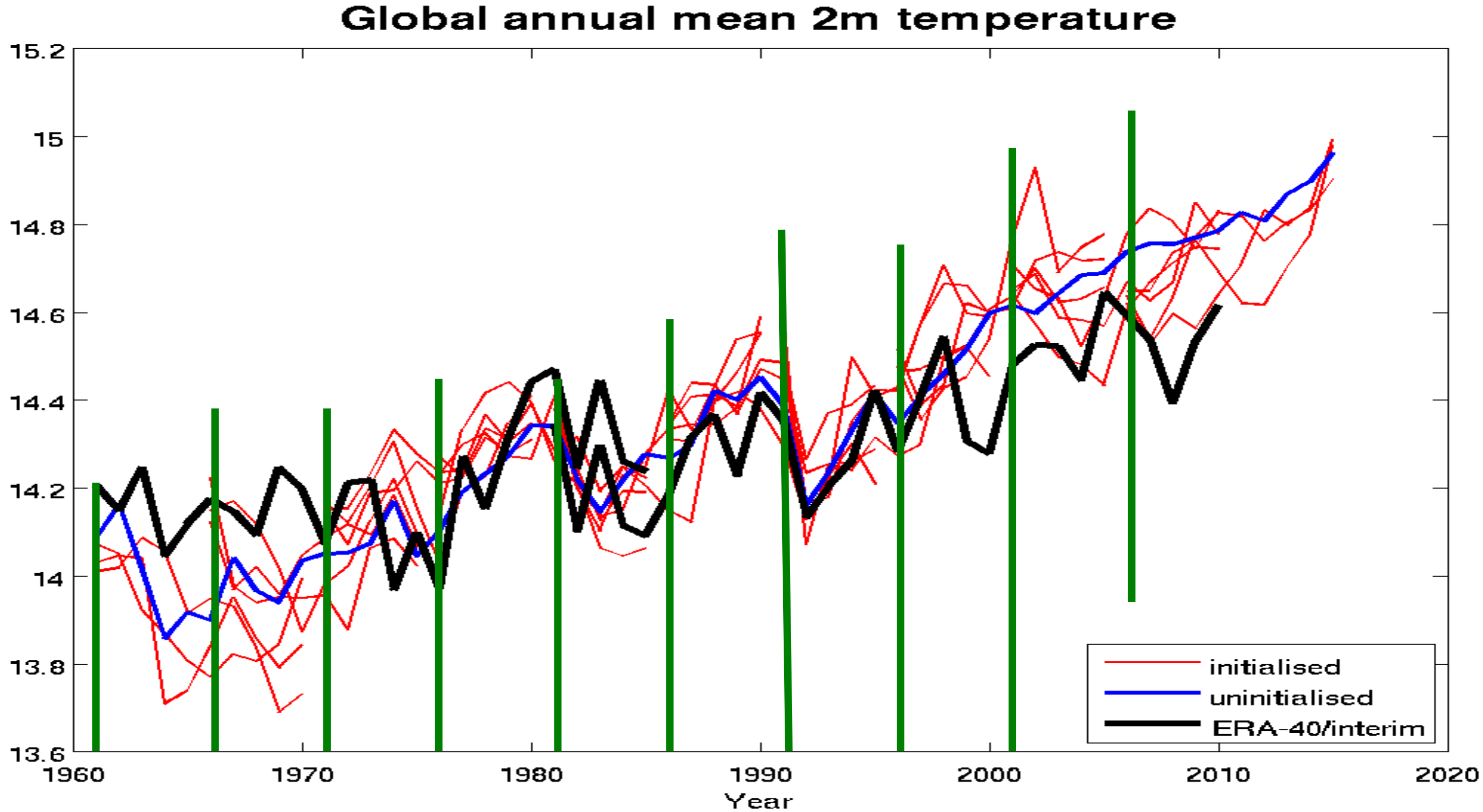
Reason for high predictability over Europe:



Decadal correlation between the ocean overturning circulation (MOC) and surface air temperature

Experiments from the real world





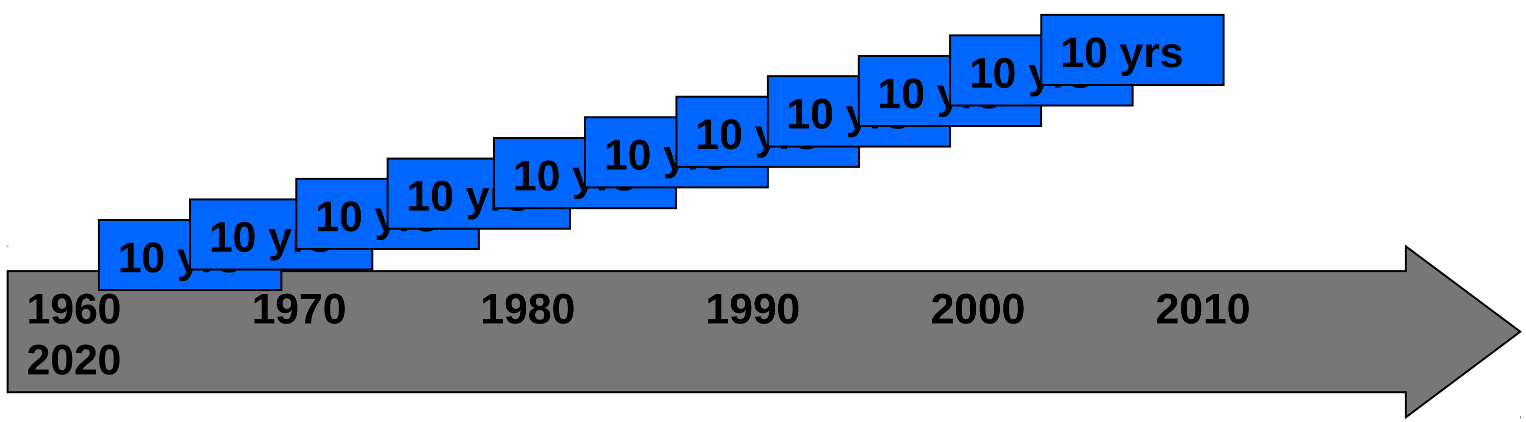
Different initialization methods

- full field (FFI)
- Anomaly (AI)

Examples:

AI better for the first year sea ice prediction

FFI performs the best in the Tropical Pacific



Impact of initialization in CMIP5

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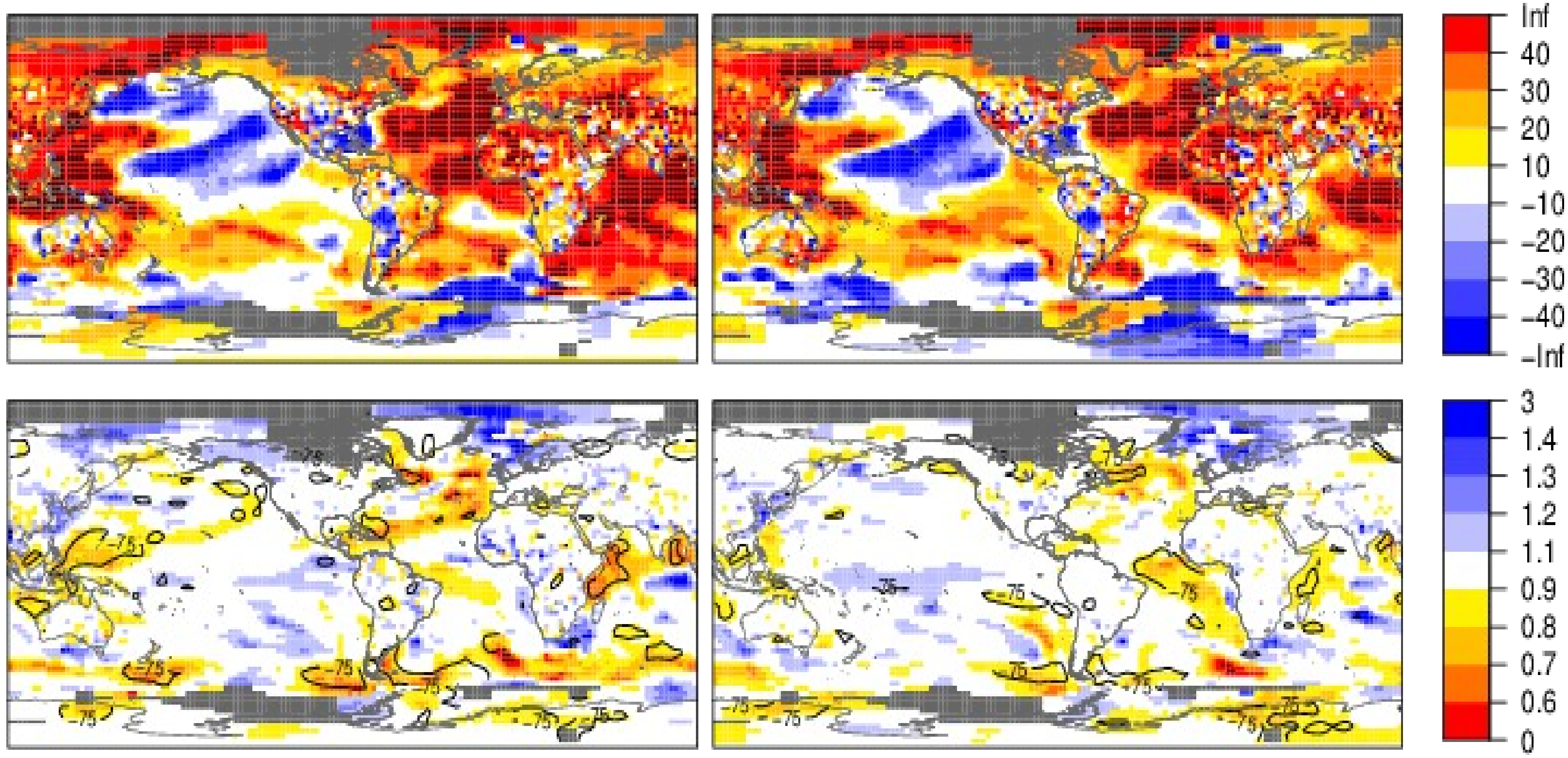
Retrospective Prediction skill for the near-surface temperature from the multi-model CMIP5 experiment (1960-2005)

Forecast year 2-5 | Forecast year 6-9

Initialized RMSSS of ensemble mean

Ratio RMSE Init/NoInit



Doblas-Reyes et al. (2013)

(Top row) Root mean square skill score (RMSSS) of the ensemble mean of the initialised predictions and (bottom row) ratio of the root mean square error (RMSE) of the initialised and uninitialised predictions for the near-surface temperature from the multi-model CMIP5 experiment (1960-2005) for (left) 2-5 and (right) 6-9 forecast years. Five-year start date interval.

Prediction of regional extremes

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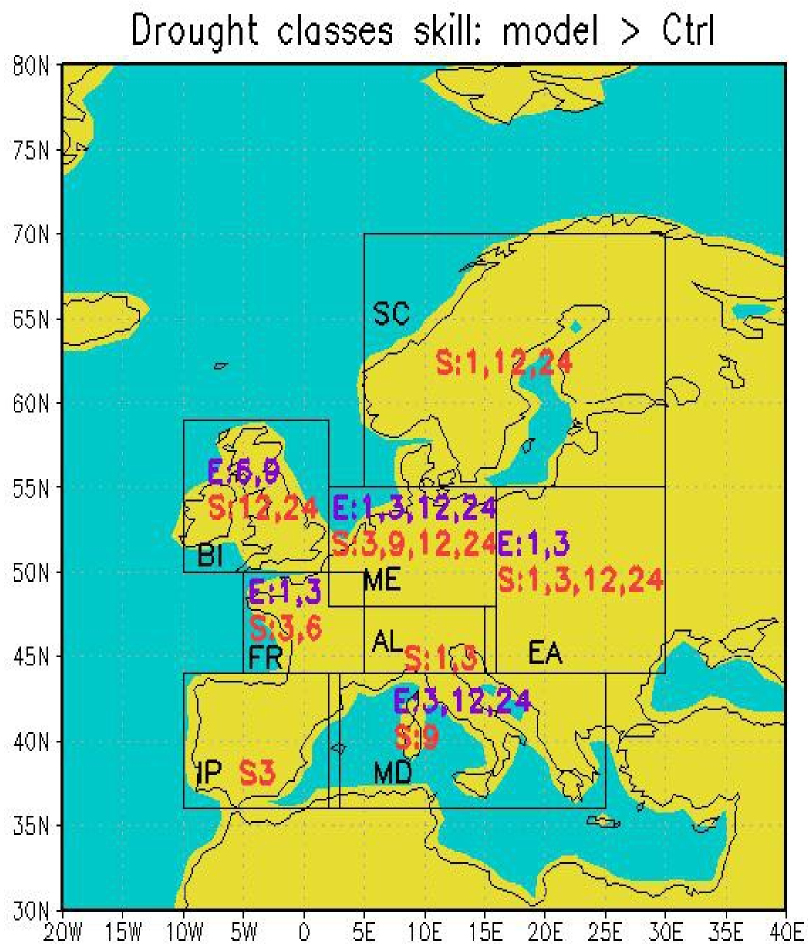
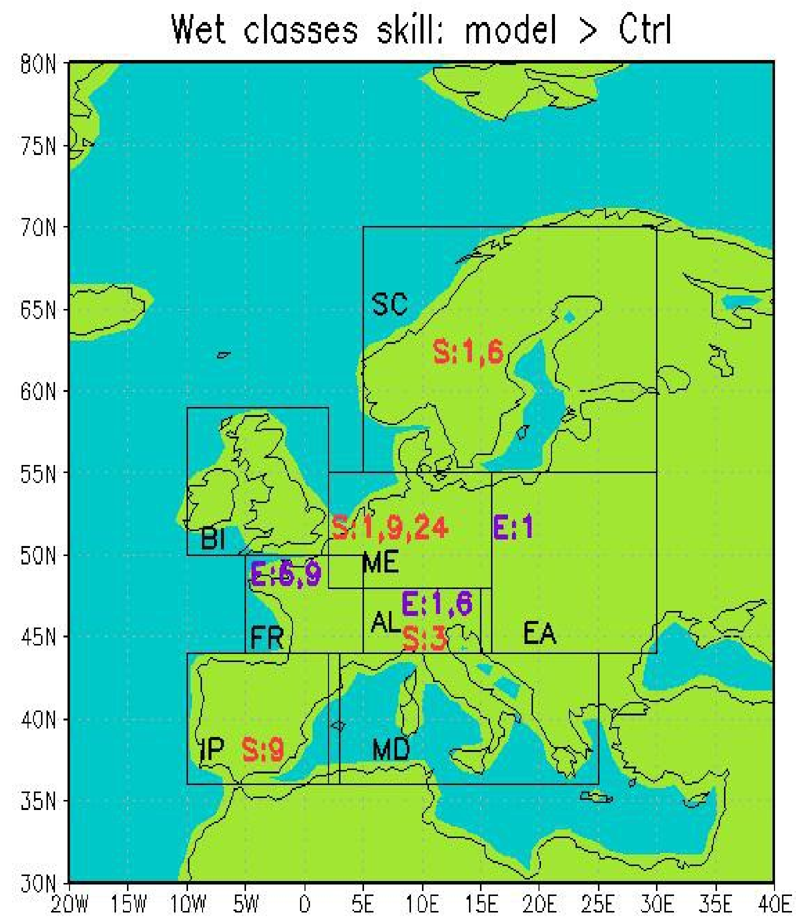




Regions and their forecast skill for extreme (E) or severe (S) events. The numbers in the figure indicate the length of periods with extremes (in months) with skill. (blue for extreme events, red for severe events)

The model is able to give the probability of extreme or severe events for specific regions

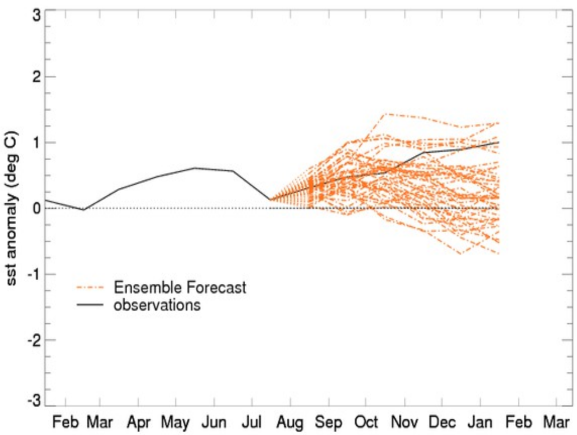
(Skill is measured by means of the Standardized Precipitation Index (SPEI, Edwards and McKee, 1997). The forecast was an initialized climate prediction run with EC-Earth v2. Skill is shown in the figure only if it outperforms the non-initialized model and if the skill has statistically significant values.)

SPECS

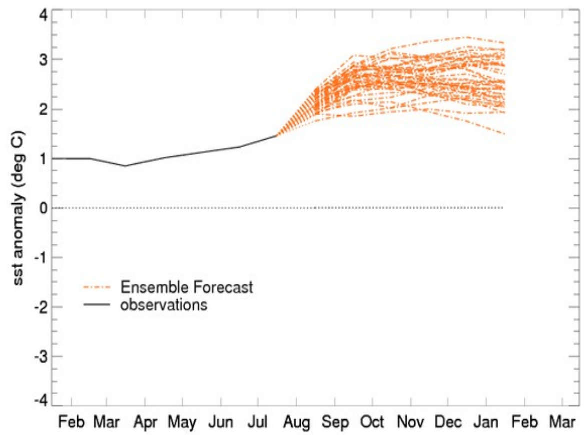
Caian, Rossby Centre, SMHI

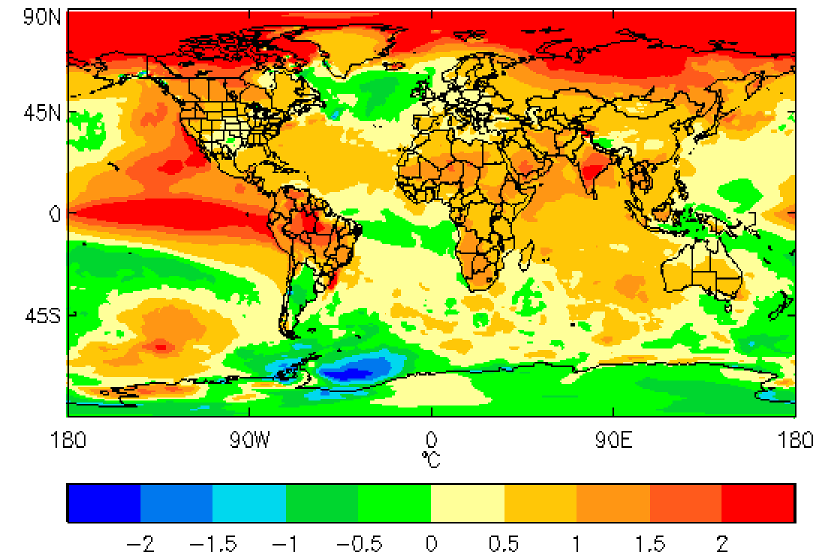
Seasonal Forecast: ENSO 2014 vs 2015

From Aug 2014



From Aug 2015





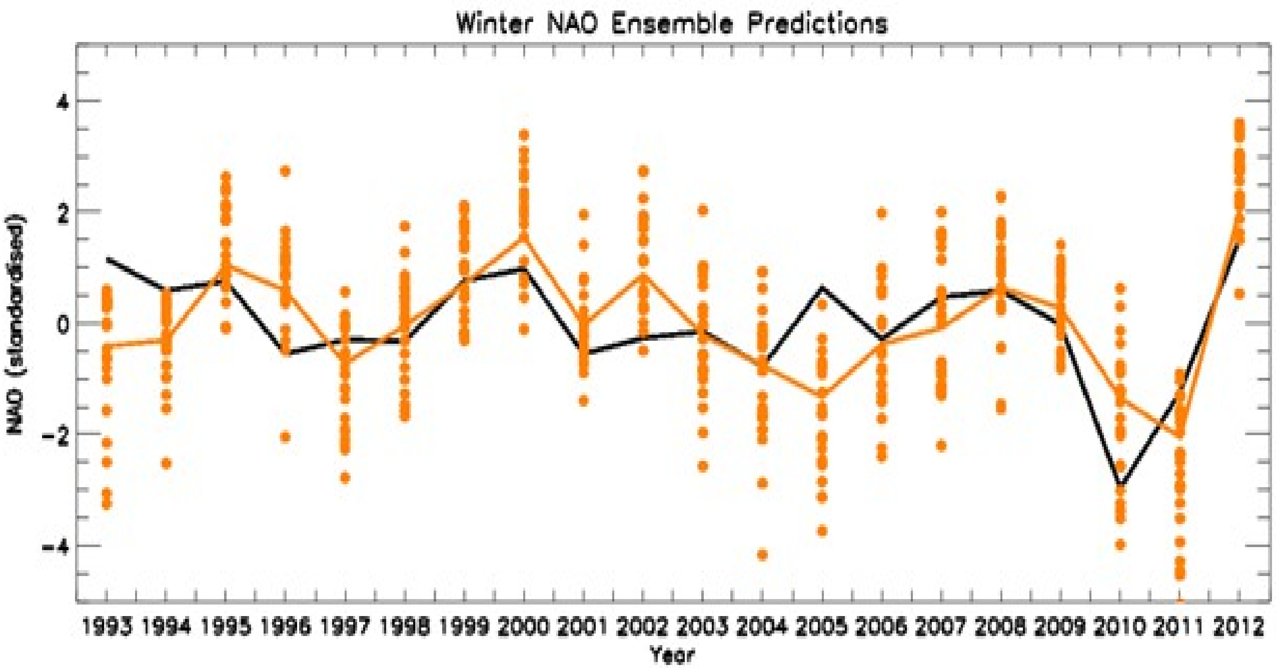
Metoffice forecasts

Very clear signals for strong ENSO event this year

Met Office forecasts did NOT predict a significant event in 2014

Figures by courtesy of A. Scaife, UK Metoffice

Seasonal Forecast: NAO



Winter ensemble forecasts of the NAO

Correlation score = 0.62, highly significant and potentially useful for winter European seasonal forecasting....

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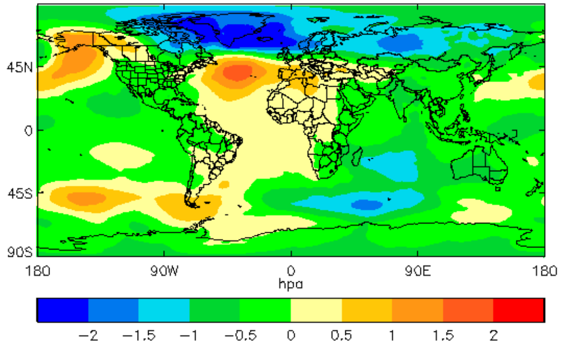
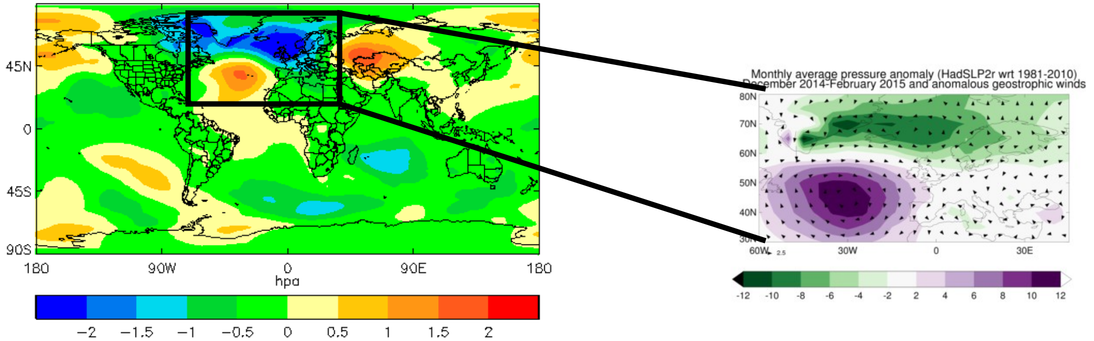
Last Winter 2014/2015

From October



From November **Observations**



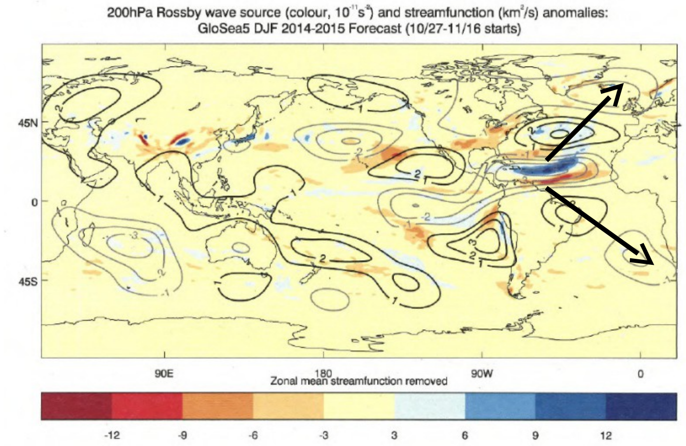
Very clear signals for a westerly winter

Present at least 2 months before winter this time

Good agreement with observations

Snow cover statistical forecasts suggested -3 sigma!

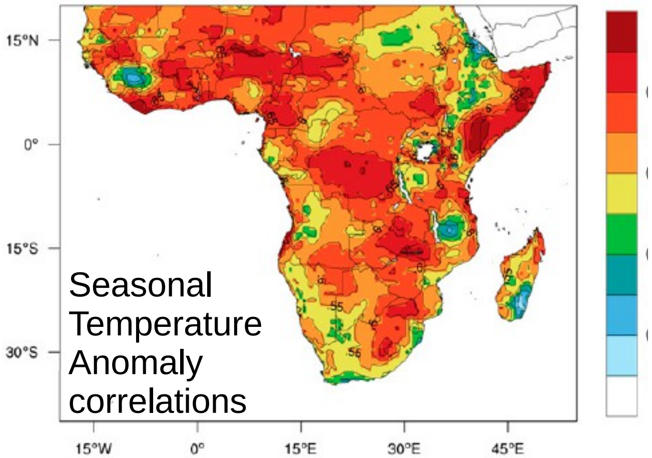
Rossby wave emanating from the tropical Atlantic



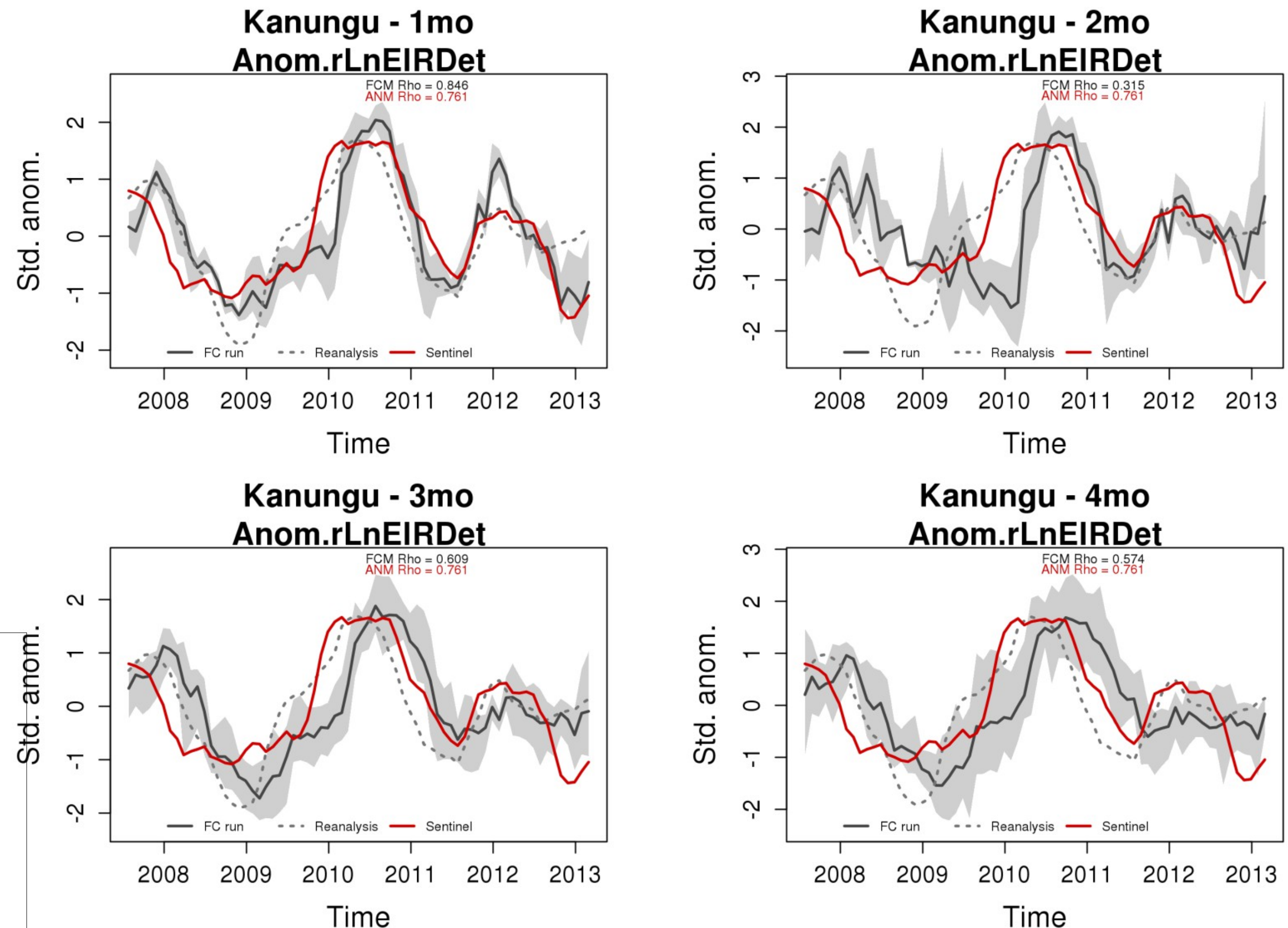
Figures by courtesy of A. Scaife, UK Metoffice

Use of ECMWF monthly and seasonal forecasts to predict malaria in Africa and Uganda

Adrian M Tompkins, ICTP



Rainfall predictability still limited in most areas that do not have strong ENSO connections.



Uganda:

The forecast for 5/6 sites is potentially statistically skillful four months in advance

First ever demonstration of a potentially skillful malaria forecasting system based on a coupled dynamical system, and at the sub-national scale

Red line: normalized **confirmed** cases
Black Line: normalized malaria forecast
Grey shading: **range** of the 5 forecasts
Dash lined: the malaria initial conditions
Four panels: the four levels of advance warning

Tompkins and Di Giuseppe, J. Appl. Met. Clim, 2015

What can we expect from climate prediction ?

SMHI

- Provision of **probability information**, better than persistence and observed trends
- There is **potential decadal predictability for Northern Europe and parts of the Arctic**, and other regions, sources of predictability exist
  - Skill exists today **for specific regions, seasons and variables**
- Real-world multi-annual forecasts exist in an experimental state (SPECS, ...)
  - **Different skills in average conditions and extreme events**
- Specific applications (e.g. hurricane prediction) has good prospects in the future
- **Improvements** expected from
  - Better models / more complete process description / signal storage / atmospheric composition / higher resolution
  - More sophisticated initialization / assimilation methods / coupled initialization / ensemble building / Arctic: sea ice thickness
- The demand of action-relevant climate information on multi-annual time scales is growing. Forecaster and users need to learn how to make use of probability information.

What is ongoing in seasonal prediction ?

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- New WGSIP activities on seasonal prediction
  - **Teleconnections** (Focus on tropical rainfall and connections to extratropics)
  - Drift (Focus on transient **drift after initialisation** with observations)
  - **Snowcover** (Focus on effects of snow cover initialisation)
    - Presence of thick snowpack over Eurasia maintains the initial negative NAO pattern
    - Upward coupling into the stratosphere
    - Rapid tropospheric adjustment to stratospheric vortex weakening, focused over the N. Atlantic
    - Only high-horizontal resolution models capture snow-NAO coupling (via stratosphere)
    - Resolving background circulation (Siberian High) over Eurasia might be key
- **Volcanoes**
  - There is an increased chance of NAO+ in the winter following a large tropical eruption
  - Models disagree on strength and sometimes even sign of impact & this varies with volcano
- **Vegetation**:
  - Realistic representation of vegetation cover leads to enhancements of climate predictions across time scales (seasonal - decadal)
    - enhanced seasonal predictions over boreal forests in winter and hot spot regions in Summer
    - 3-days weather forecasts in spring 2015 showed consistent improvement over north-eastern Europe.
- Arctic sea ice
  - Trend bias correction methods
  - Atlantic sector of the Arctic is more predictable than Pacific sector
- Other activities
  - **Attribution of skill**: Separation of skill from local processes and teleconnections

End