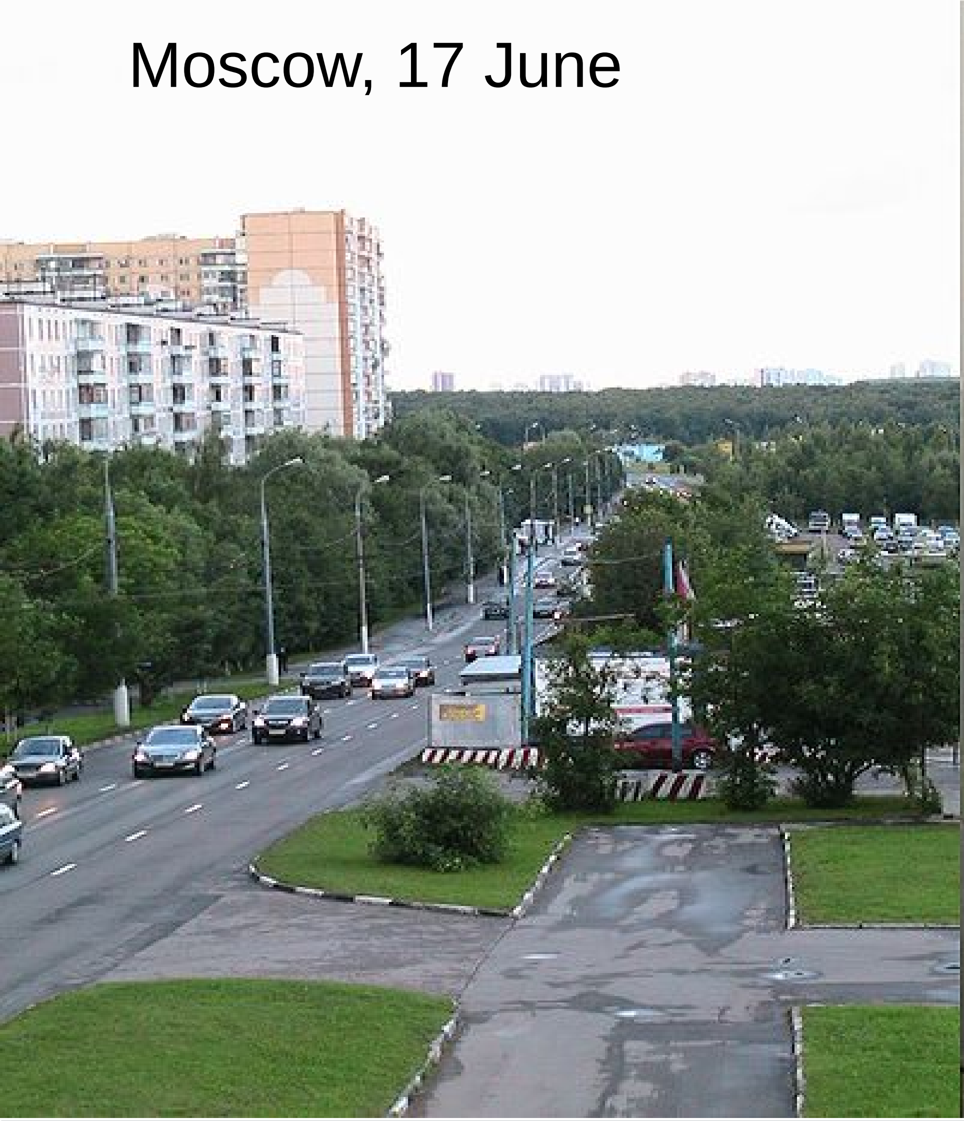
WAGENINGEN UR
For quality of life

Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Verkeer en Waterstaat

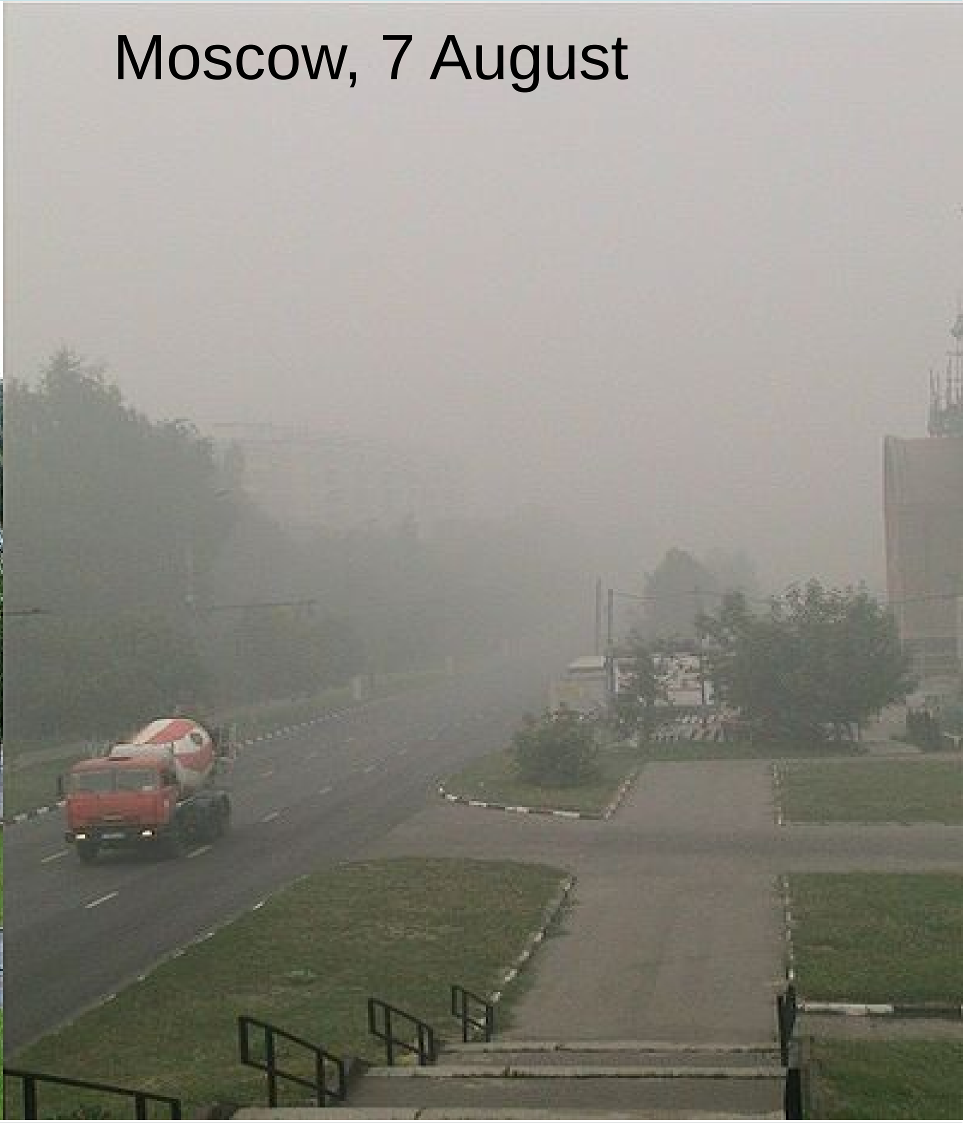
Beyond the seasonal time scale…

Wilco Hazeleger

Geert Jan van Oldenborgh, Bert Wouters, Camiel Severijns, Torben Koenigk (SMHI), Paco Doblas Reyes (IC3), Simona Stefanescu (ECMWF) and many others



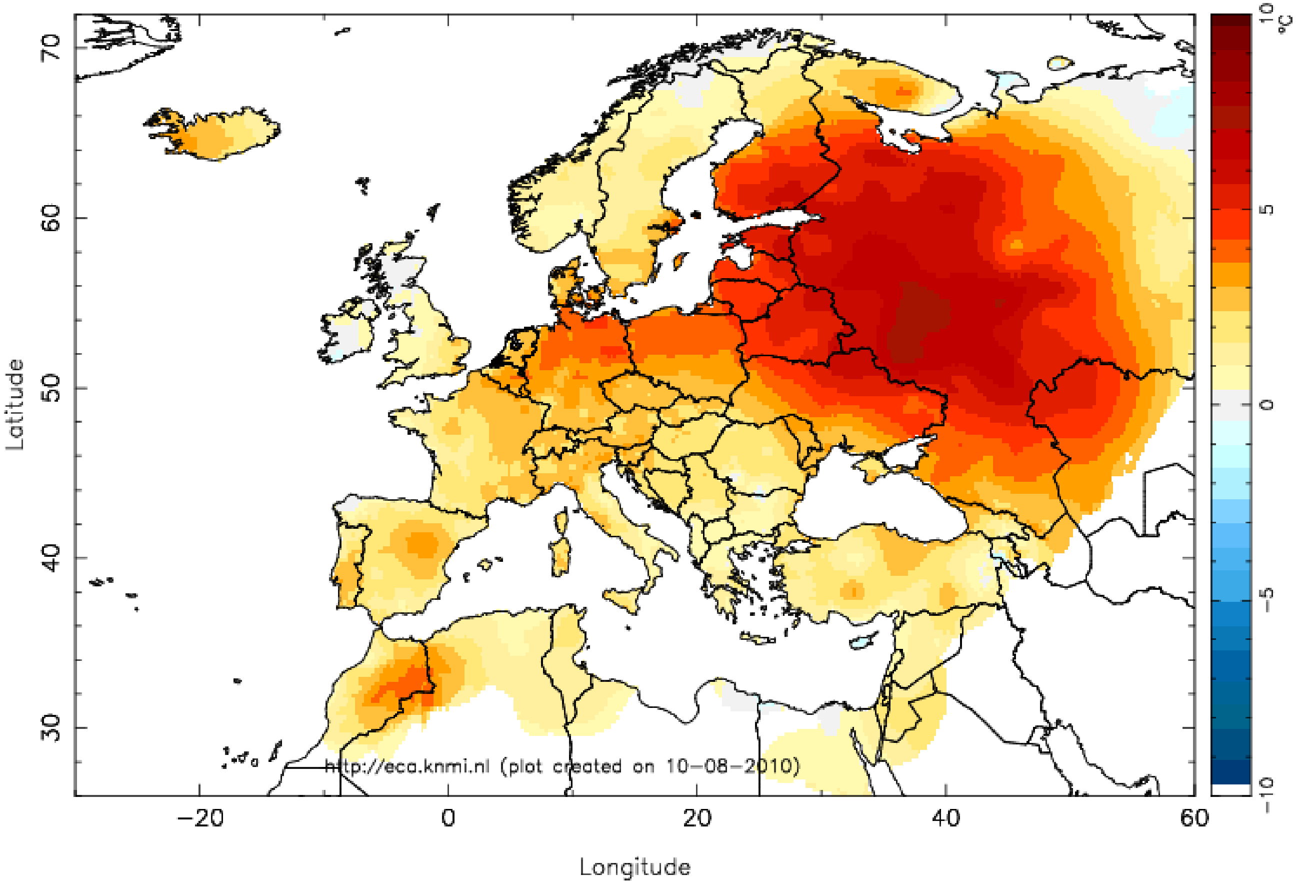
Moscow, 17 June



Moscow, 7 August

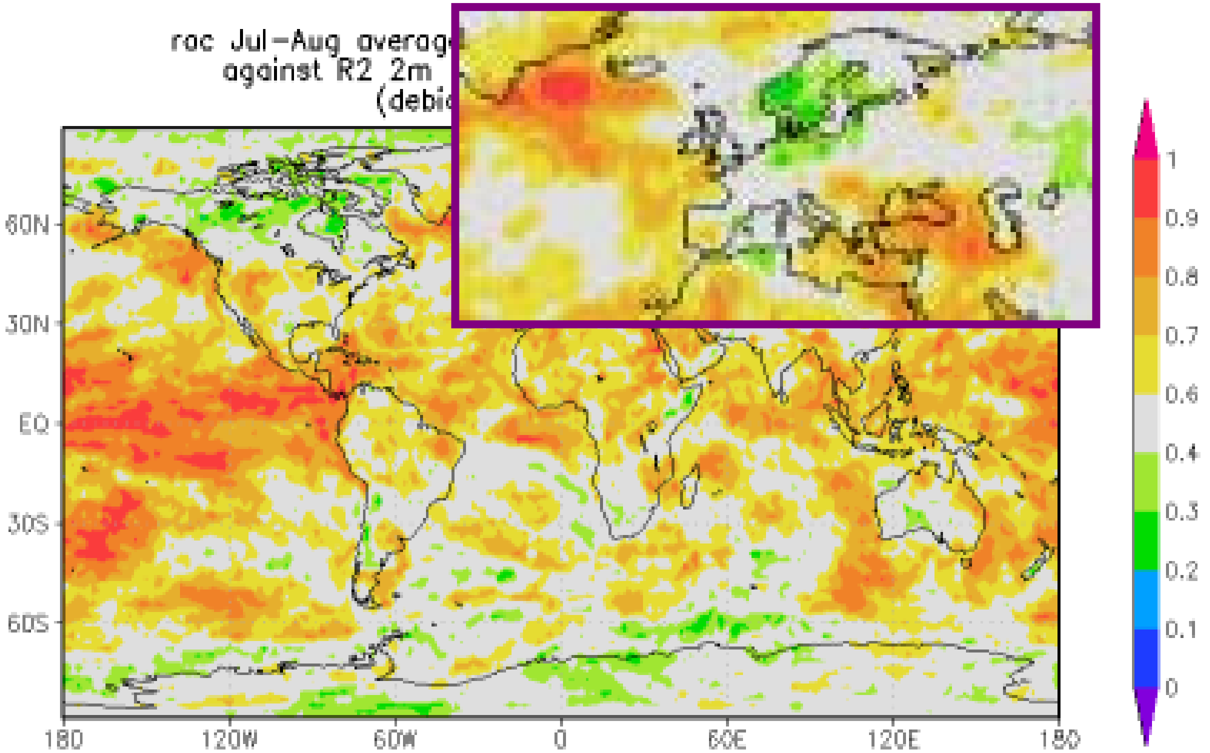
2-meter temperature anomaly in July

E–OBS tg Anomaly 07–2010 w.r.t. 1971–2000



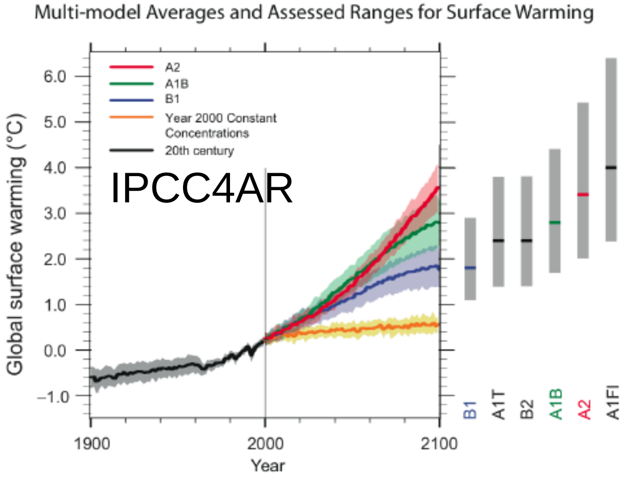
http://eca.knmi.nl (plot created on 10–08–2010)

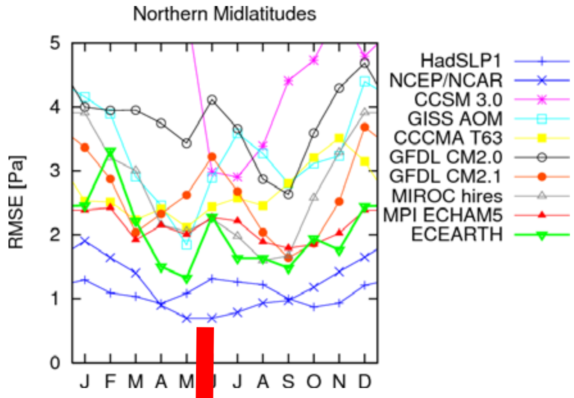
Verification of seasonal prediction T2m

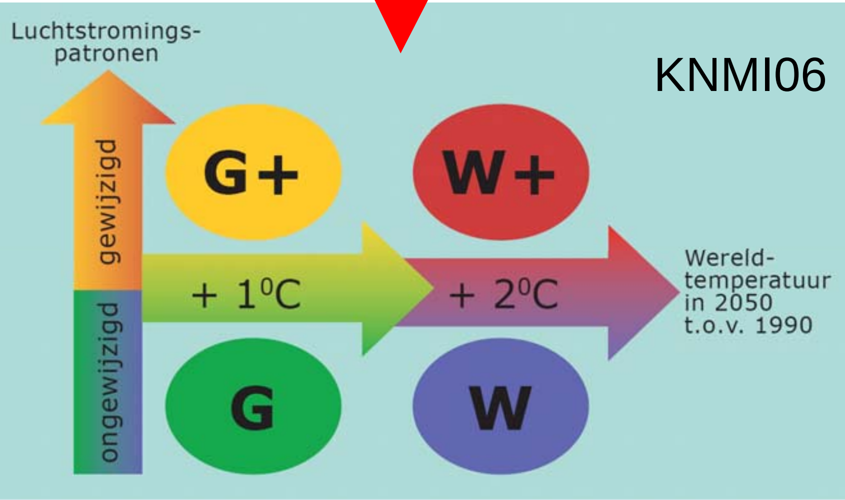


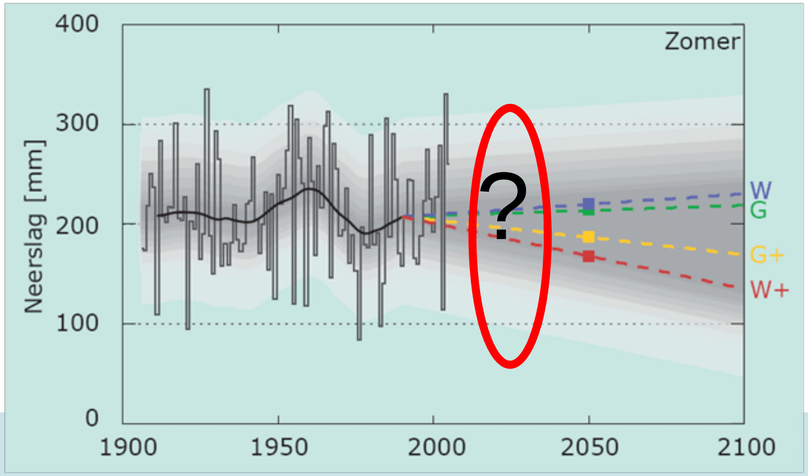
ROC score - hit rate vs false alarm rate using a set of increasing probability thresholds. The area under the ROC curve is plotted (1 perfect, 0.5 no skill)

Scenarios for Climate Services (climate adaptation, KNMI06)

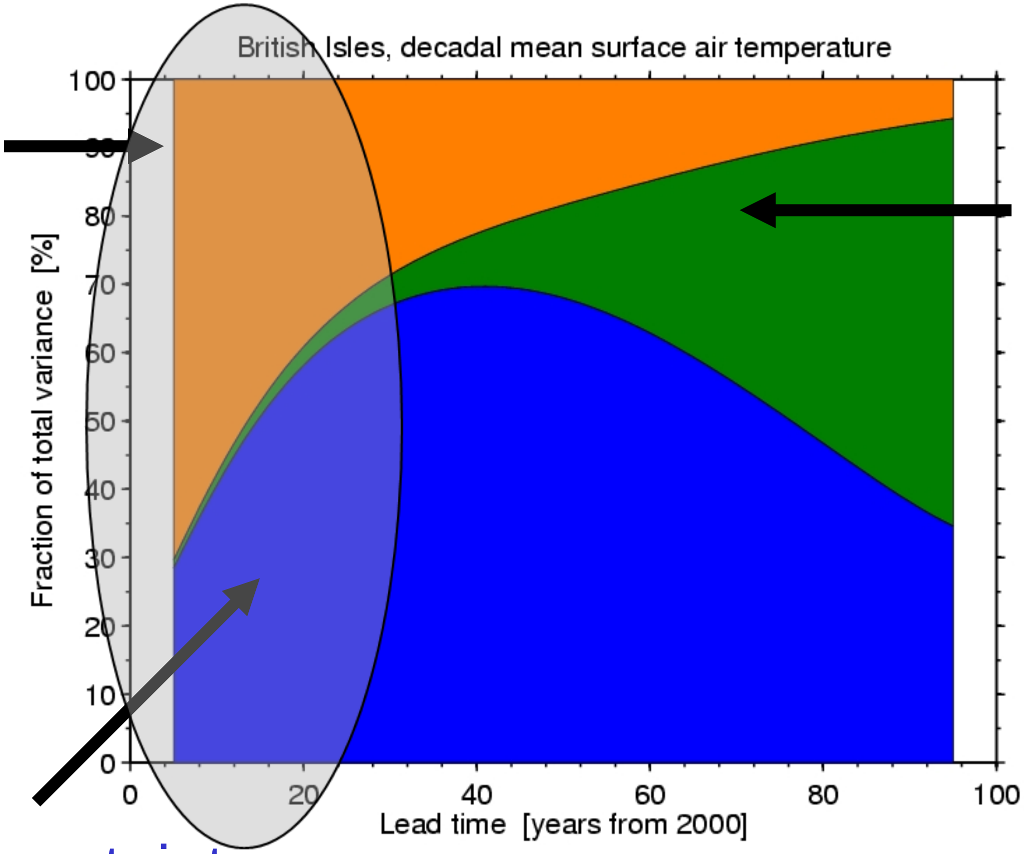








Modelling climate changes: uncertainties



Natural fluctuations

GHG emission uncertainty

Model uncertainty

Hawkins and Sutton, 2009

Predicting natural variability: more than noise?

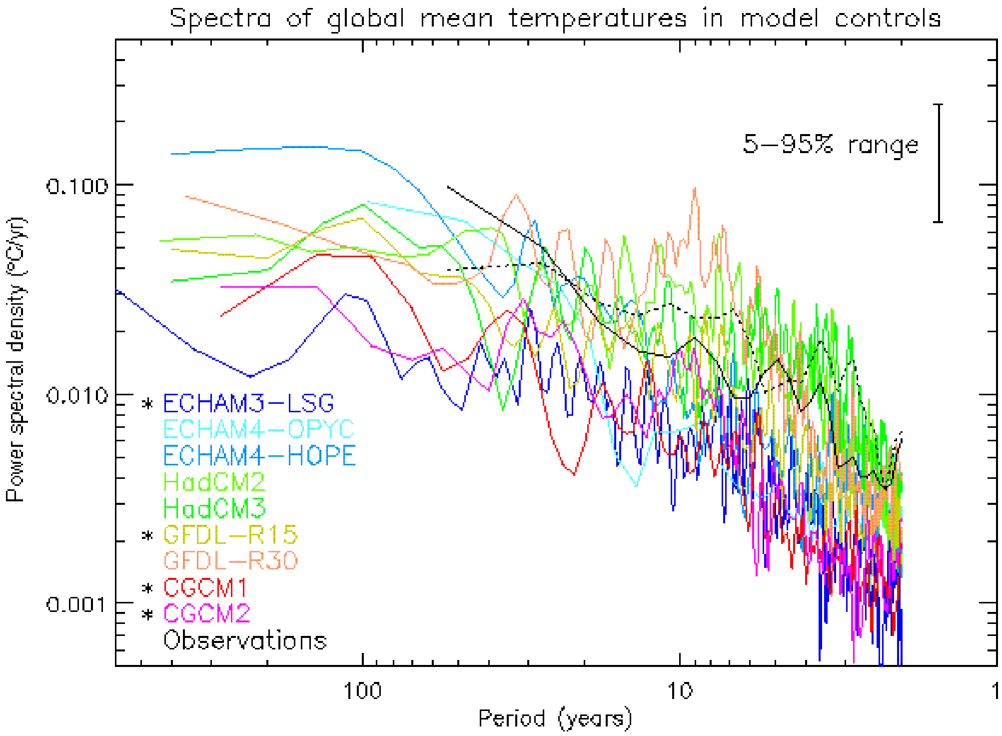
- 0-hypothesis: ocean integrates white noise (weather) (Hasselmann 1976)

$$\frac{dX(t)}{dt} = -\alpha X(t) + \zeta(t)$$

With ɑ damping coefficent and ζ(t) random variable (AR1 process → red noise)

- When variability stands out of red noise, e.g. oscillations due to internal dynamics, dynamical predictions may be possible

Spectra of global mean temperature: peaks?



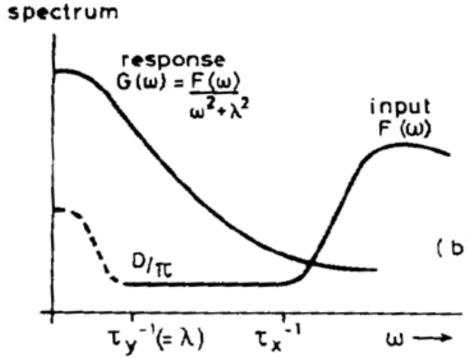
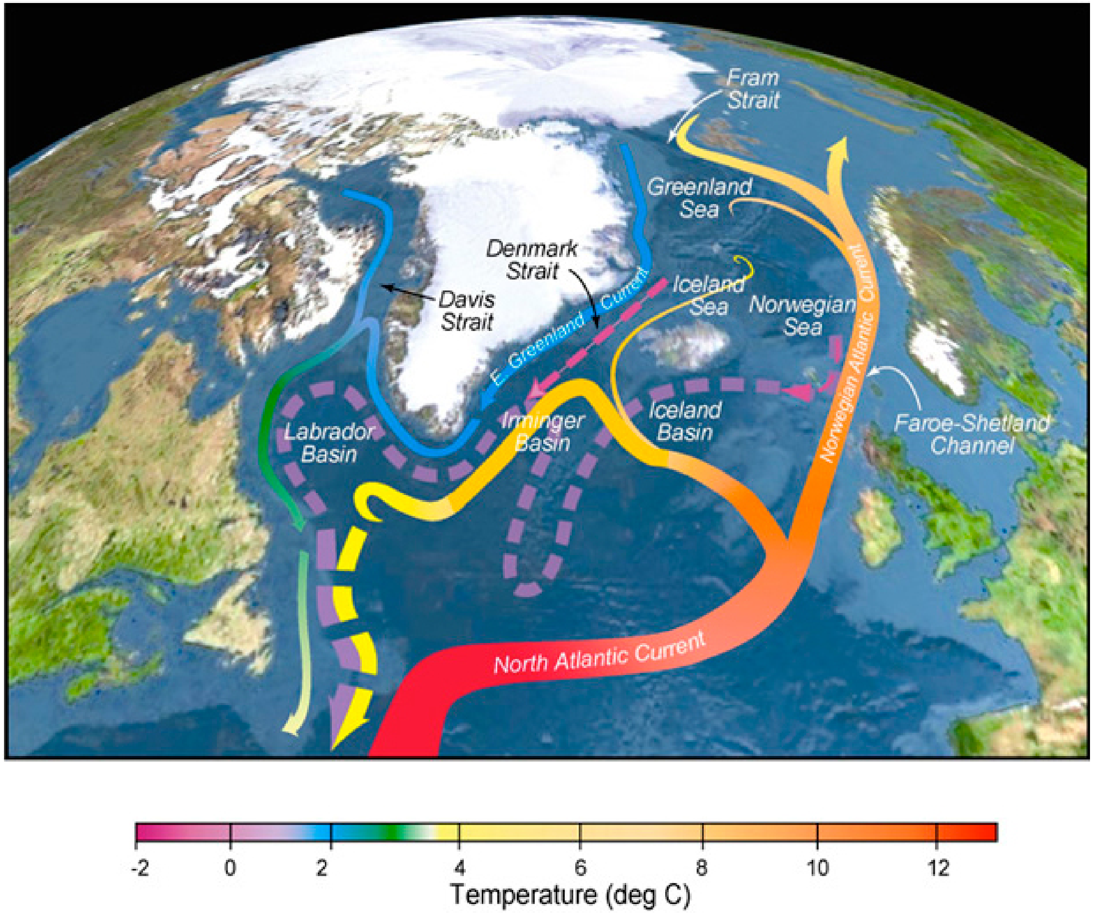


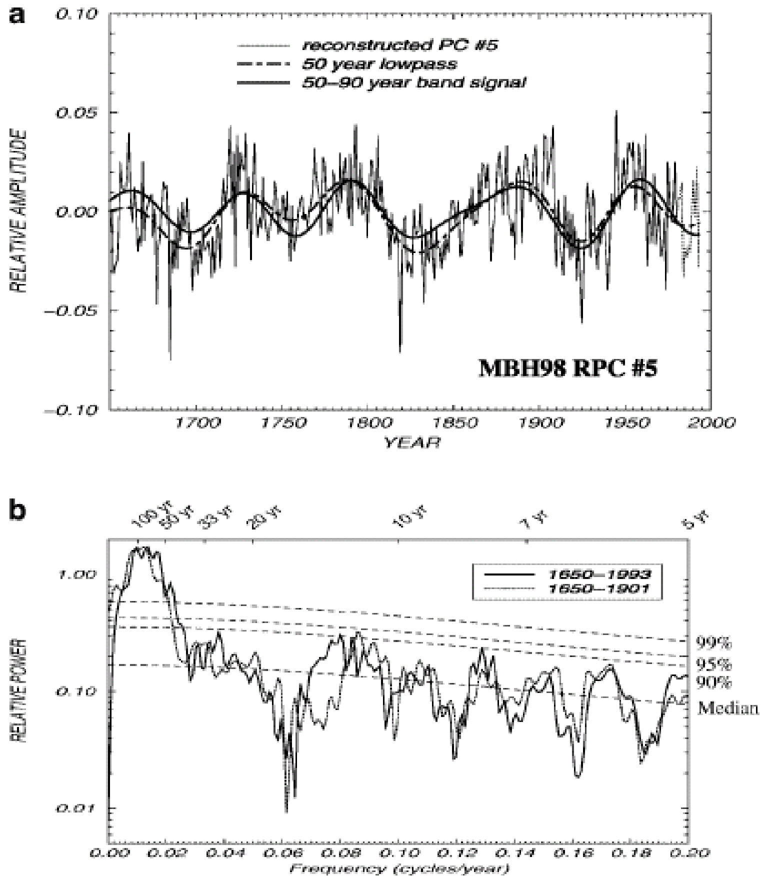
Fig. 2. Input and response of stochastically forced (single component) climate model with linear feedback; (*a*) covariances, (*b*) spectra. In the ranges $\tau_x \ll \tau \ll \tau_y$ and $\tau_y^{-1} \ll \omega \ll \tau_x^{-1}$ the models with and without feedback are identical. In the range $\omega \lesssim \tau_y^{-1}$ the spectrum $F(\omega)$ cannot be regarded as part of the "weather input", but is coupled to the climate response.

Perhaps …patterns of variability: e.g. Atlantic Multidecadal Oscillation

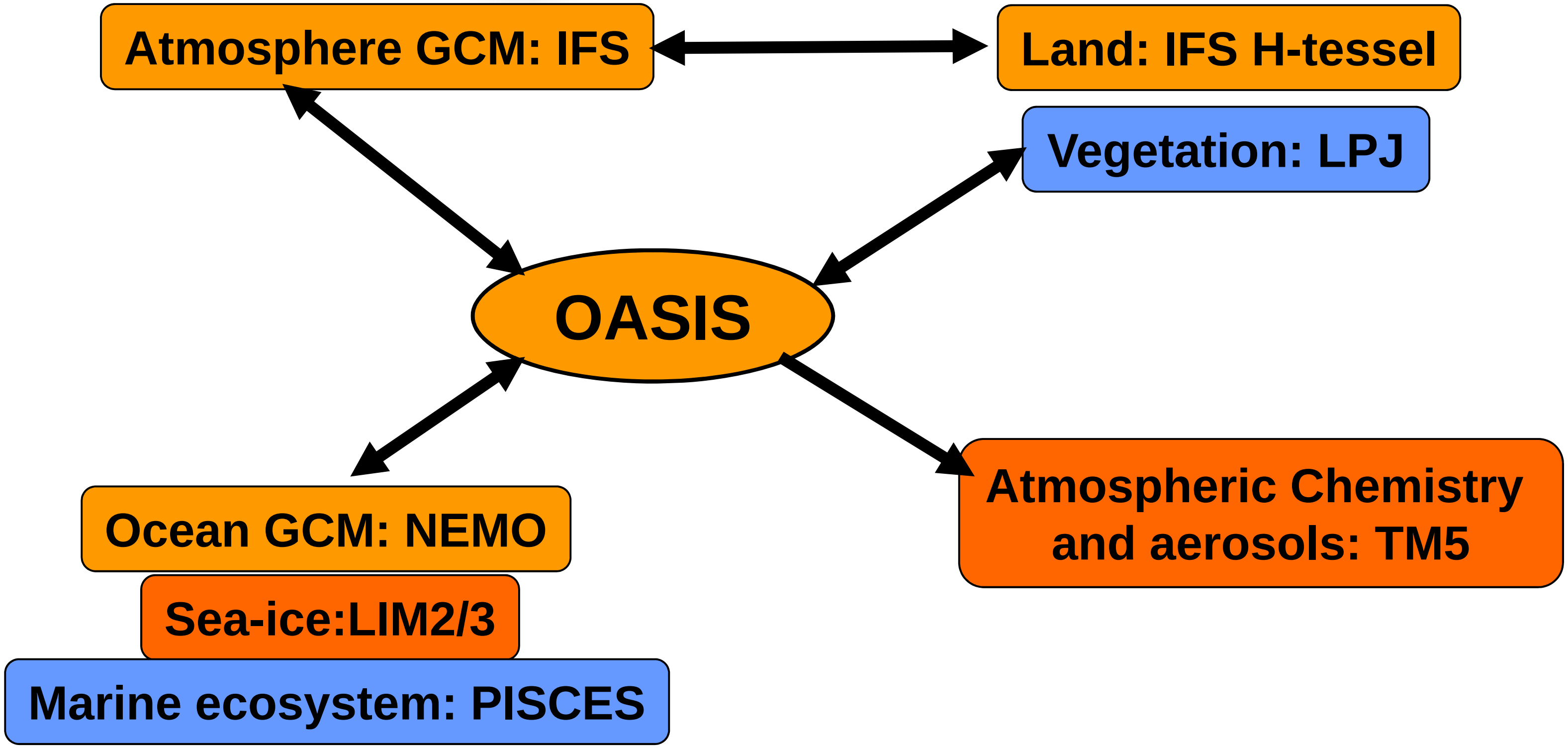


Knight et al. 2005

Perhaps …spectra from reconstructions of climate



- Reconstructed principal component from eigenvector describing long term variations in dominant multidecadal SST variability in the North Atlantic (Mann et al 1998; nb heavily disputed)



Atmosphere GCM: IFS

Land: IFS H-tessel

Vegetation: LPJ

OASIS

Ocean GCM: NEMO

Sea-ice:LIM2/3

Marine ecosystem: PISCES

Atmospheric Chemistry and aerosols: TM5

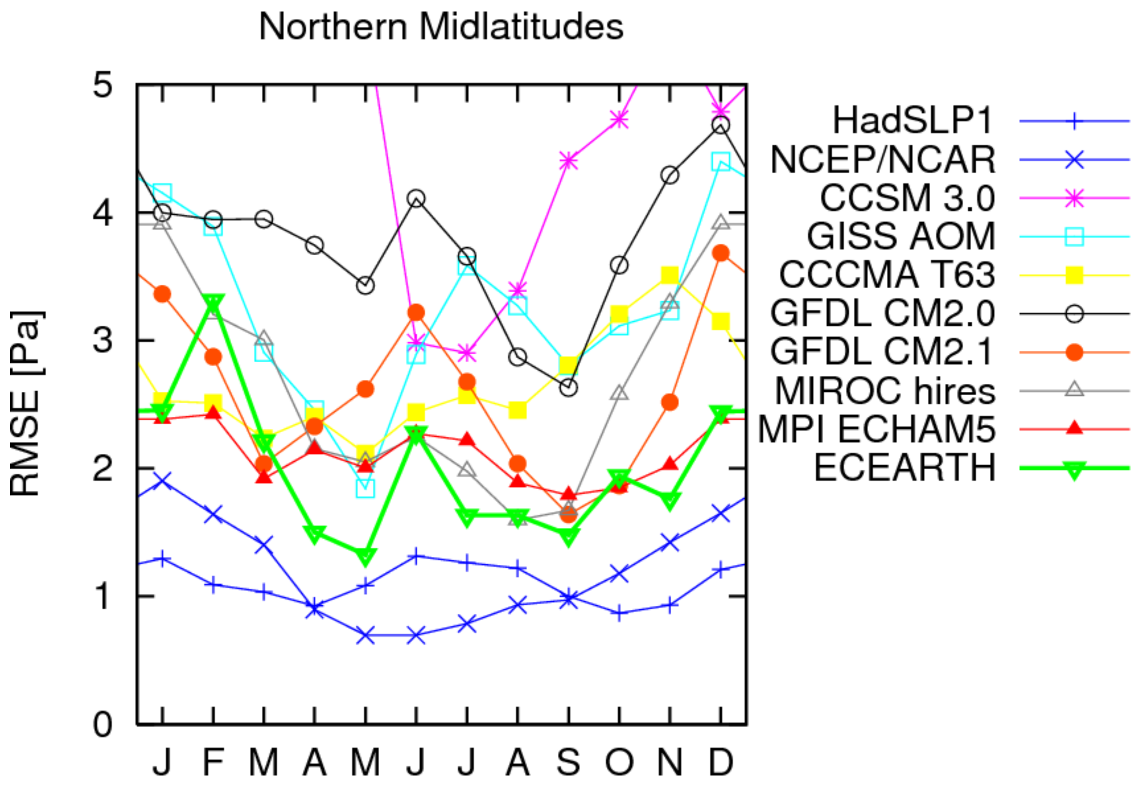
T159L62, 1 deg Ocean, based on Seasonal Forecast System 3 of ECMWF
Consortium of 20 institutes from 10 European Countries (Hazeleger et al, BAMS 2010)

New EC-Earth components

Joint EC-Earth and ECMWF seasonal forecast components

Planned EC-Earth components

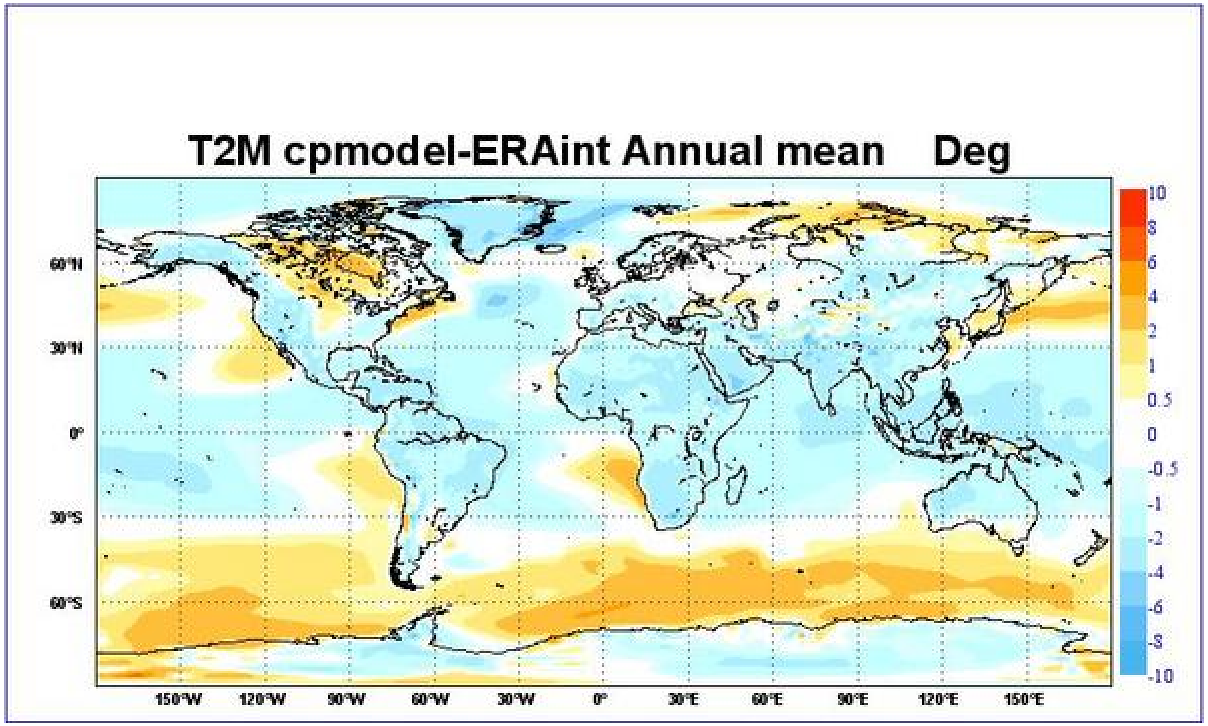
Validation of EC-Earth



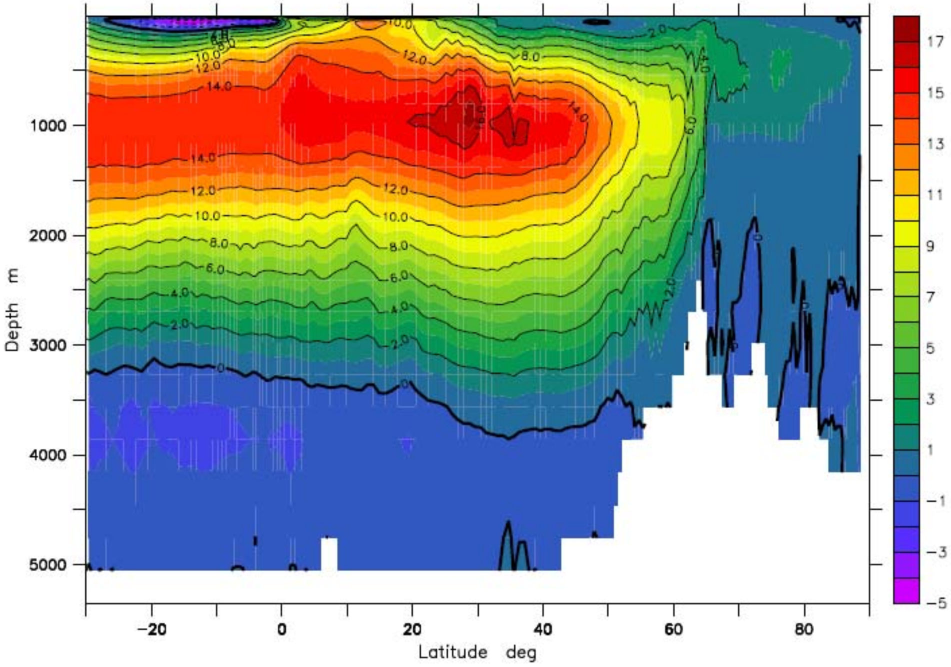
RMS monthly mean seal level pressure in 20cm3 runs wrt ADVICE data

Hazeleger et al, BAMS, 2010

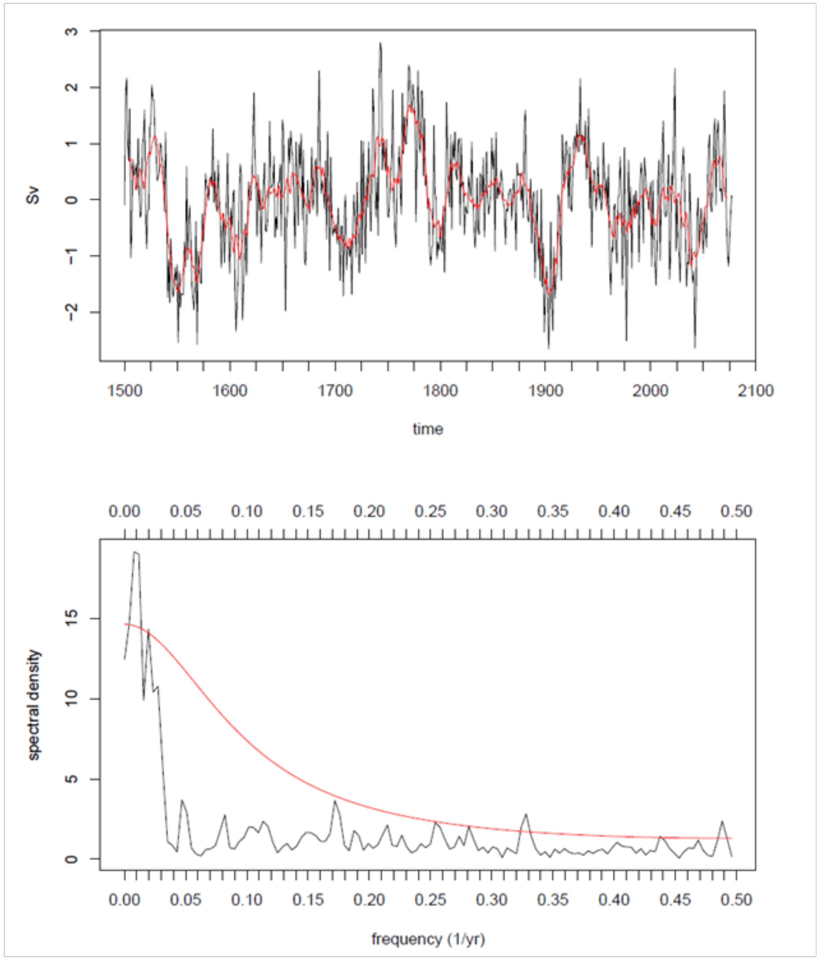
Systematic error



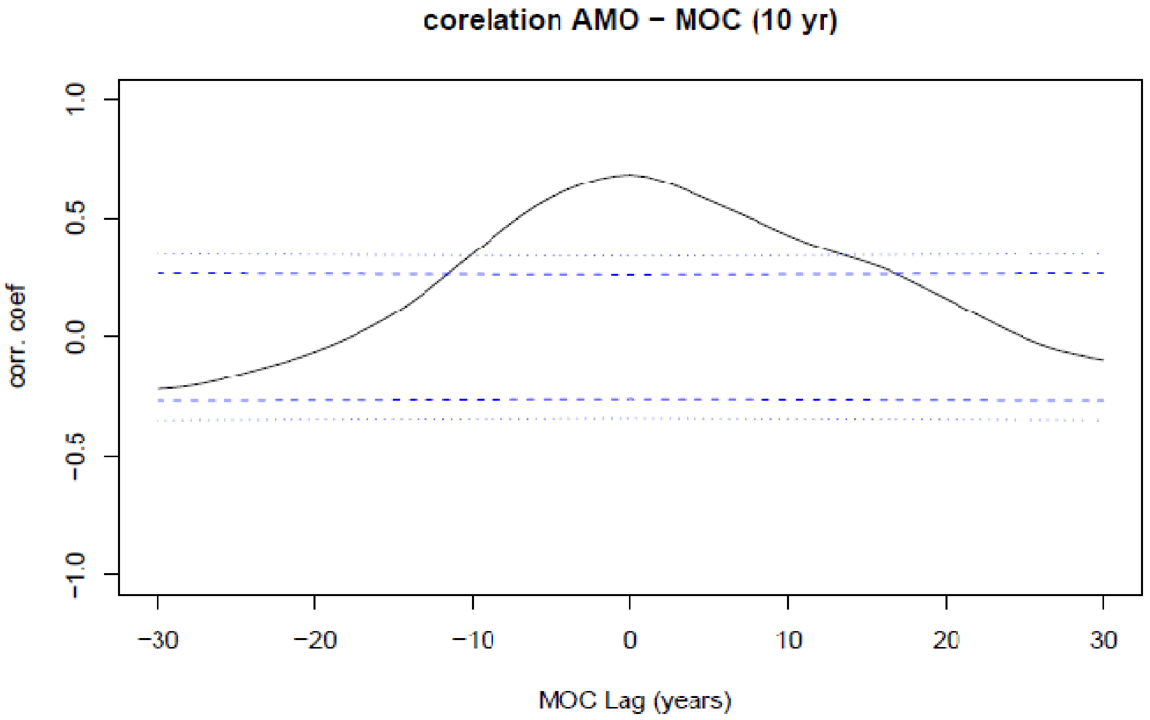
Simulated low frequency variability: AMOC in pre-industrial run EC-Earth



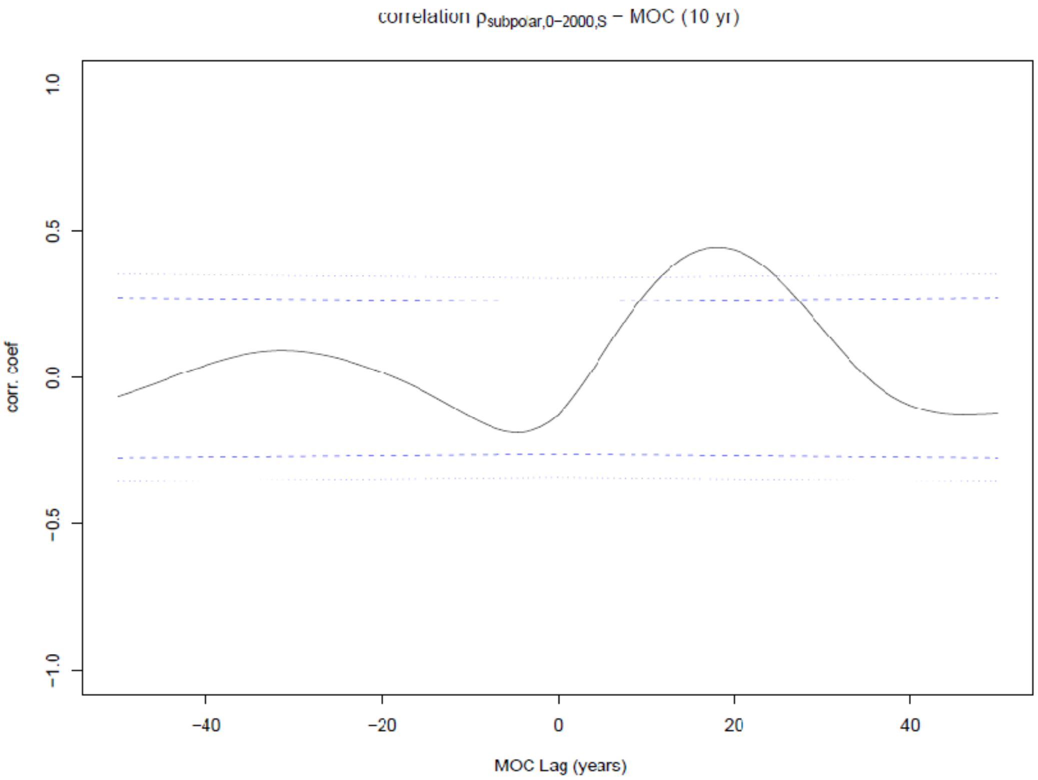
Similar variability in other models

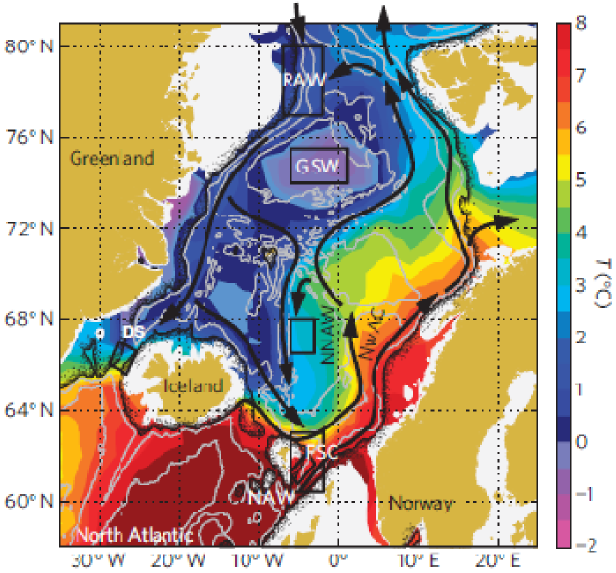


Atlantic MOC- North Atlantic SST (AMO) relation



Fresh water changes drive AMOC variability

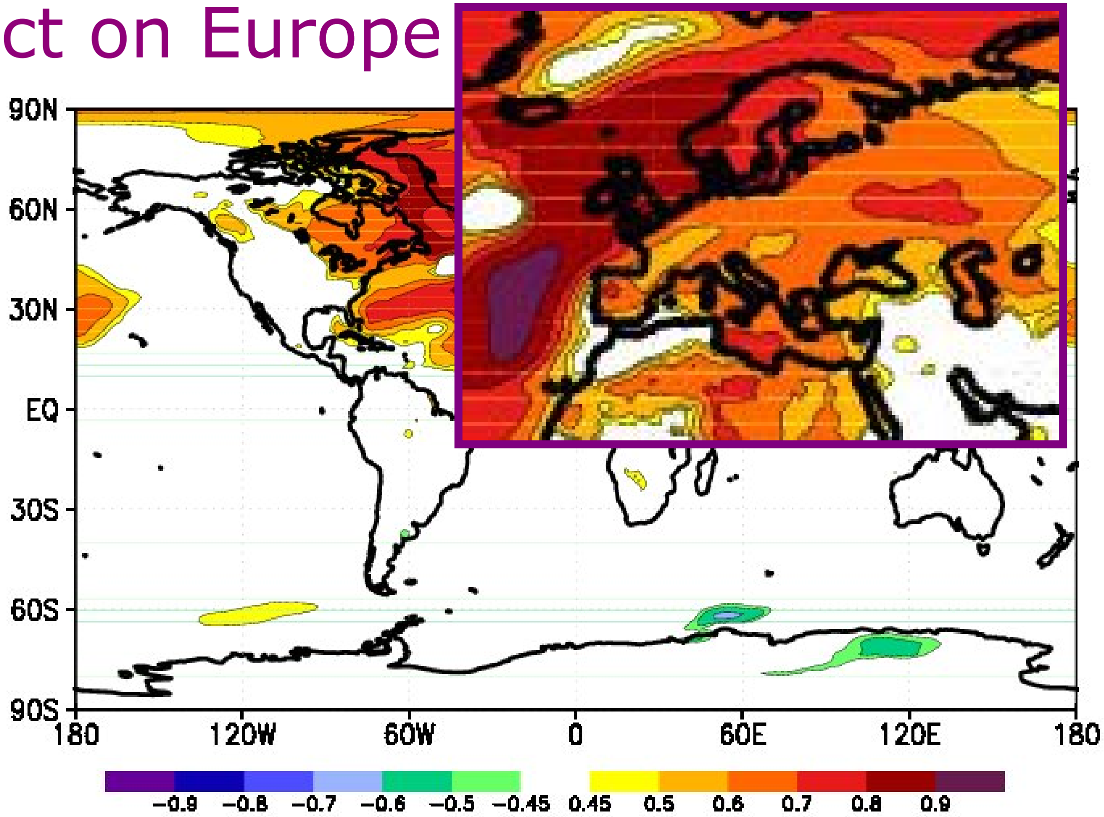




Eldevik et al 2009

Nb time scales and mechanisms are very model dependent!
Here it comes from the North….

MOC impact on Europe



EC-Earth, correlation between air temperature and AMOC (lag 2 years).
Other correlations: rainfall over Sahel, possibly hurricanes

Remarks

Seasonal predictions over the European region are not very skillful; perspective for longer time scales seem to be slim

But…

- Any information on climate *variability* can be helpful for sectors vulnerable to climate *change*
- Gridpoint verification gives a negative picture
- Decadal patterns of variability are observed associated with ocean variability
- Models reproduce some of that variability, but suffer from large systematic error and differ between each other

It is a scientific challenge!

What to expect from decadal predictions?

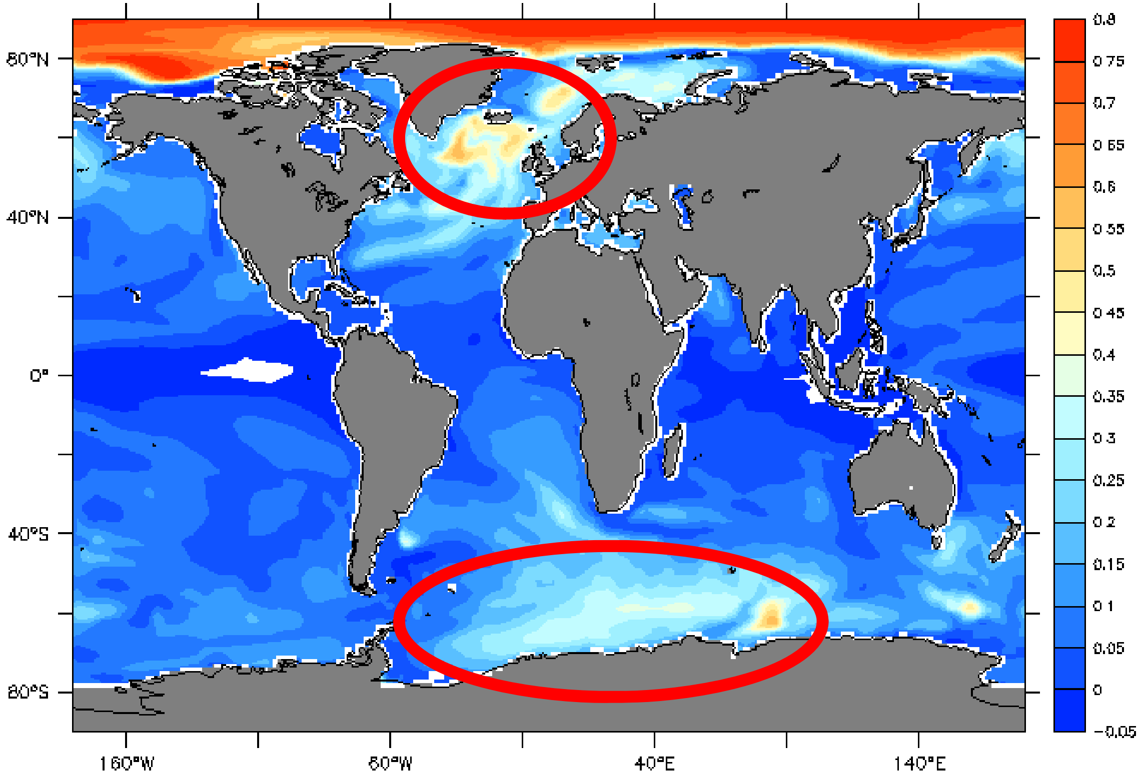
- Diagnostic potential predictability: ratio of variances in a long control simulation

$$DPP = \frac{\sigma_v^2 - \frac{1}{m}\sigma^2}{\sigma^2}$$

With σ_v^2 variance of m-year means

(e.g. Boer et al, Pohlmann et al)

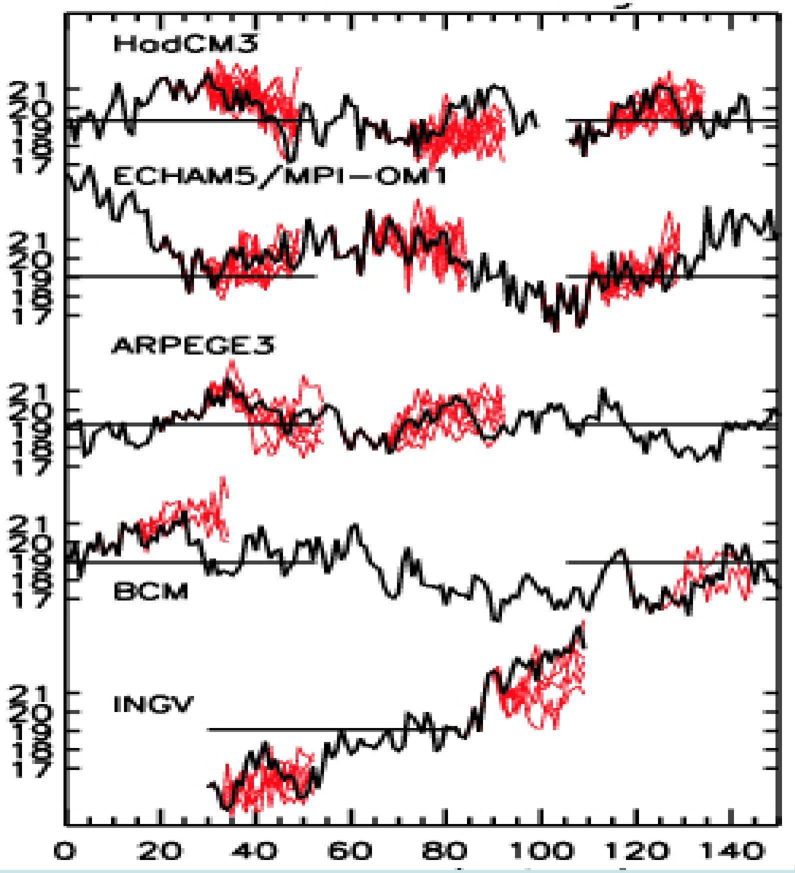
Diagnostic potential predictability in EC-Earth



10 yr

What to expect?

Atlantic MOC (30N)



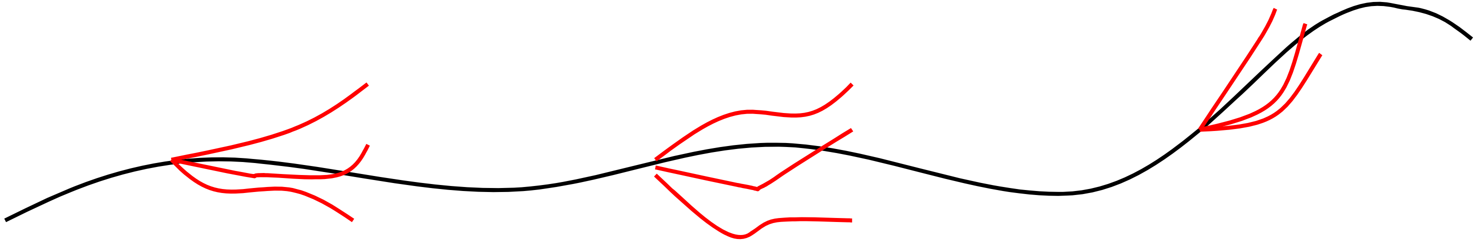
Collins et al 2006

What to expect from decadal predictions?

- Prognostic potential predictability: ensemble spread in relation to total variance

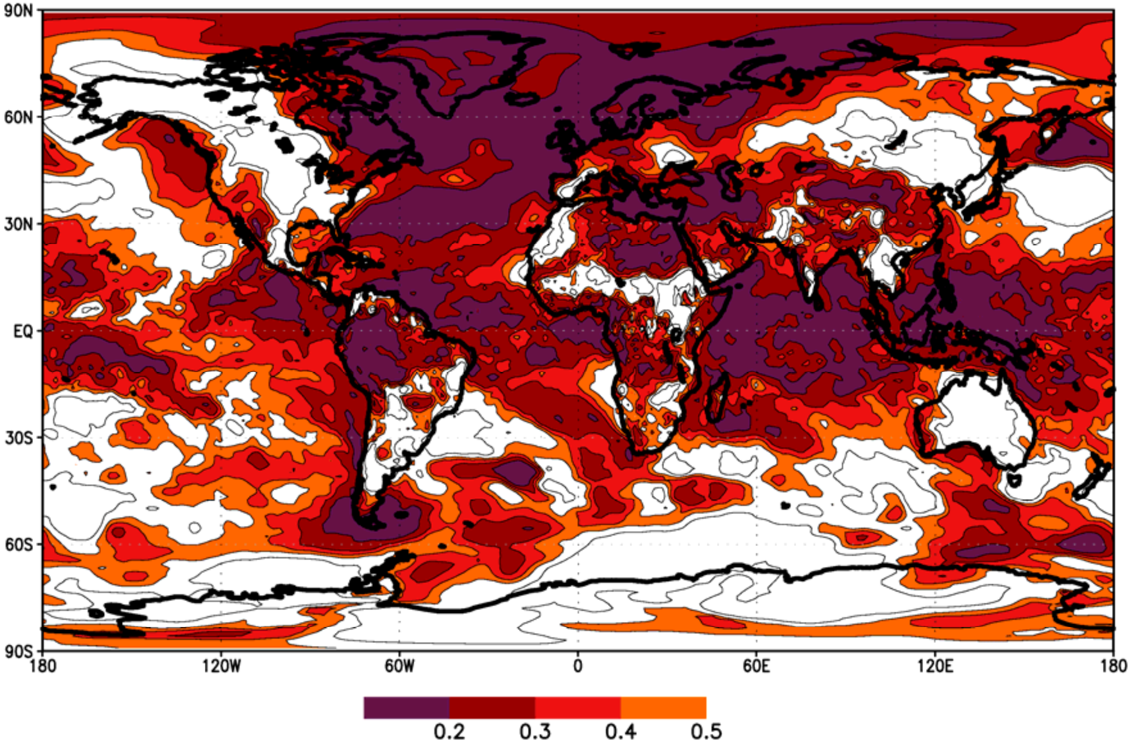
$$PPP = 1 - \frac{\frac{1}{N(M-1)} \sum_{j=1}^{N} \sum_{i=1}^{M} [X_{ij}(t) - \overline{X}_j(t)]^2}{\sigma^2}$$

With X_{ij} is the i^{th} member of j^{th} ensemble, N is number ensembles, M number of ensemble members



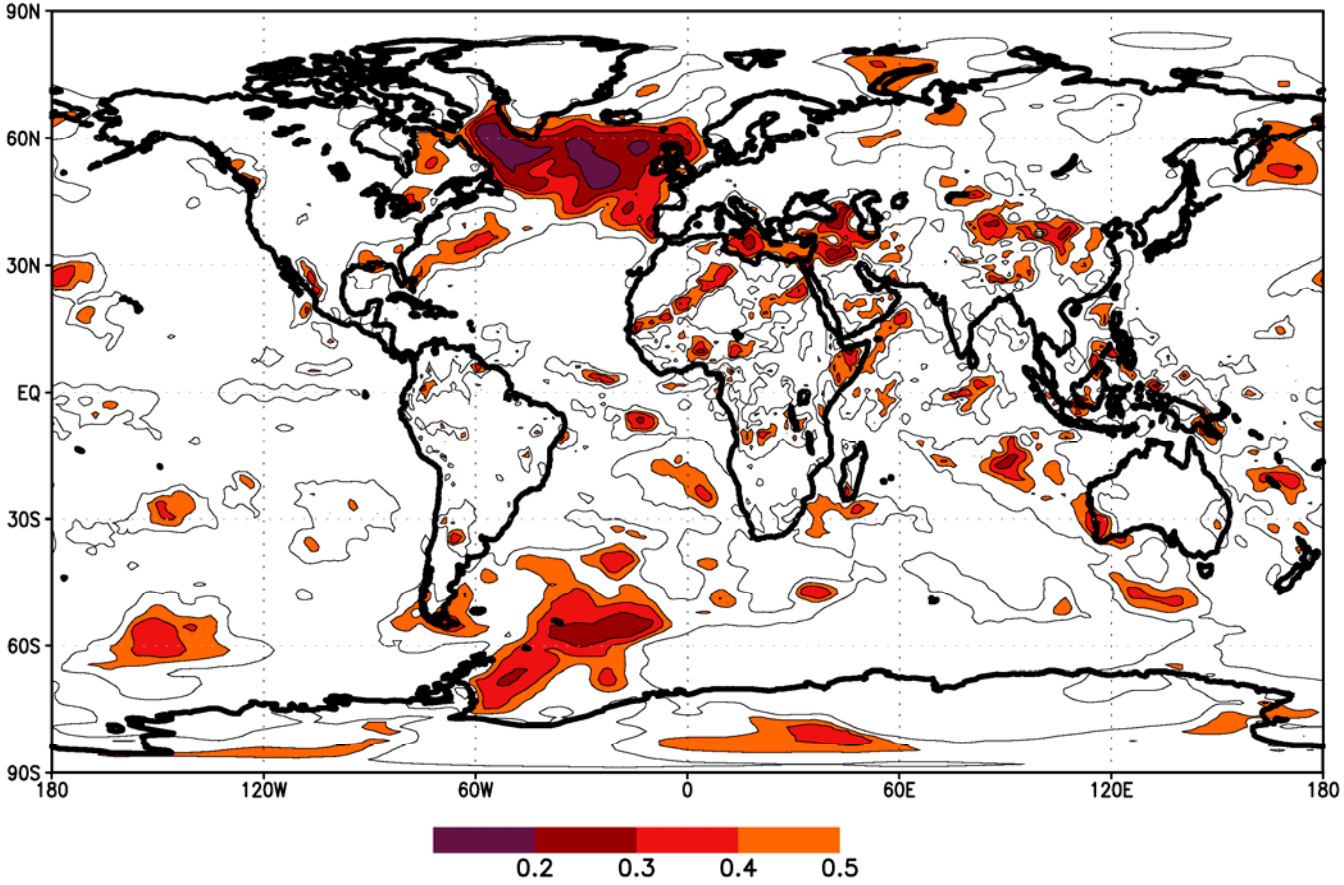
Griffies and Bryan 1997, Collins et al, Pohlmann et al

Prognostic Potential predictability in EC-Earth (T2m, yr 1-10)



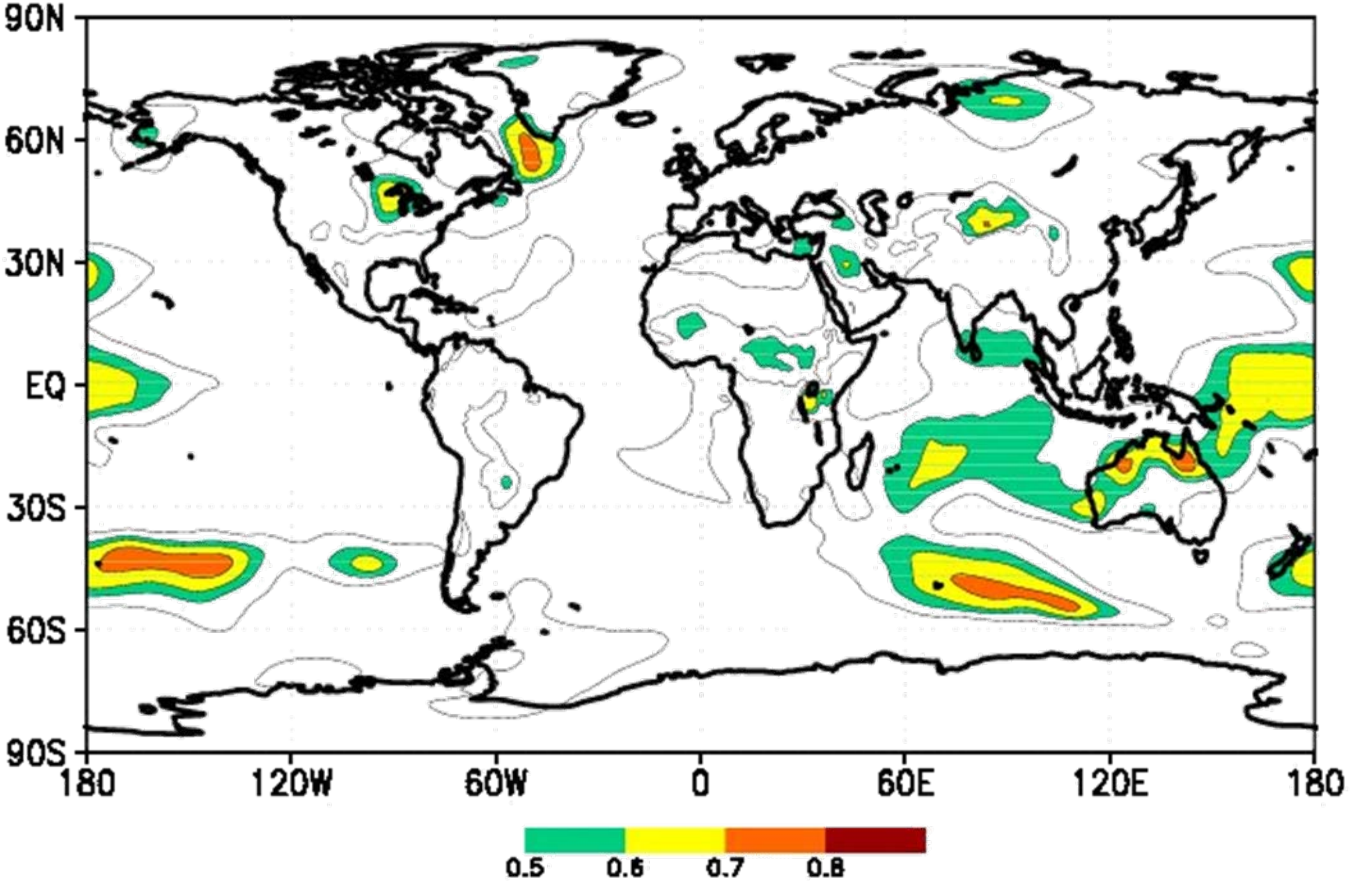
T. Koenigk, SMHI, pers. comm.

Prognostic potential predictability in EC-Earth (T2m, yr 1-10; without trend)



T. Koenigk, SMHI, pers. comm.

Prognostic potential predictability EC-earth (SLP, yr 1-10)



T. Koenigk, SMHI, pers. comm.

Remarks

Potential predictability associated with patterns of variability in the North Atlantic

The trend is predictable!

Most models show variability associated with MOC variability, but mechanisms differ

→ Let's try to make predictions!

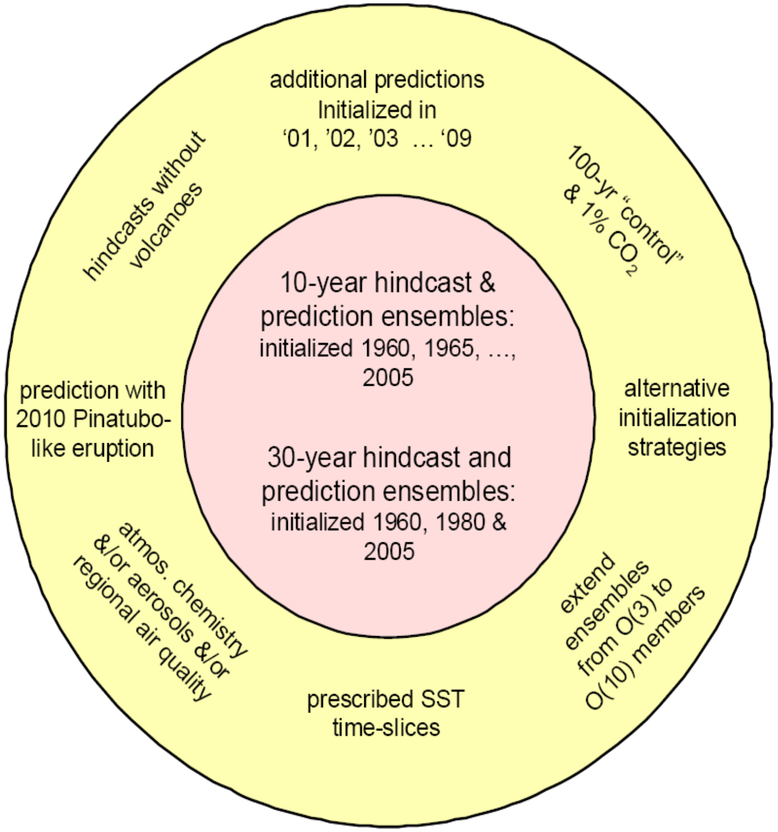
Prototype ‘Real’ decadal predictions

Initialize atmosphere-ocean-sea ice-land models from observed/analyzed ocean and sea ice state

Perturb initialized models to generate ensembles

Verify the results against own analyses and independent observations

CMIP5 (contribution to IPCC AR5) decadal prediction experiments



10-year hindcast & prediction ensembles:
initialized 1960, 1965, …, 2005

30-year hindcast and prediction ensembles:
initialized 1960, 1980 & 2005

additional predictions
Initialized in
‘01, ’02, ’03 … ‘09

100-yr “control”
& 1% CO_2

alternative
initialization
strategies

extend
ensembles
from O(3) to
O(10) members

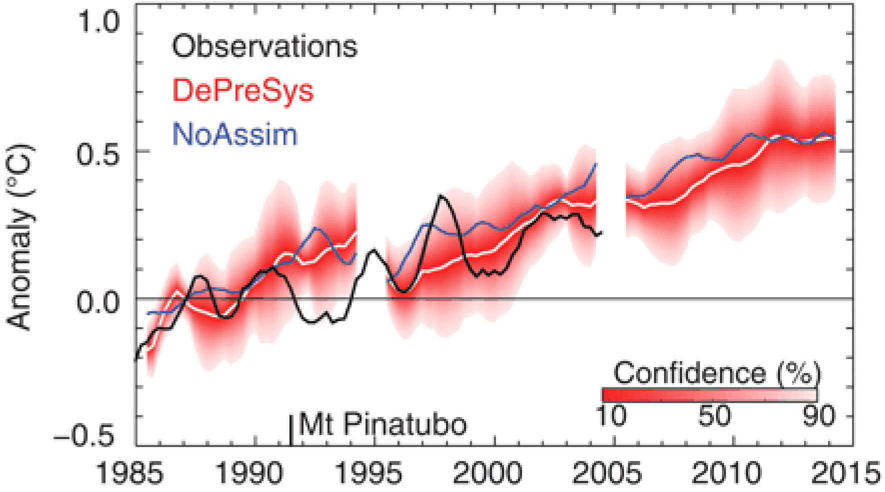
prescribed SST
time-slices

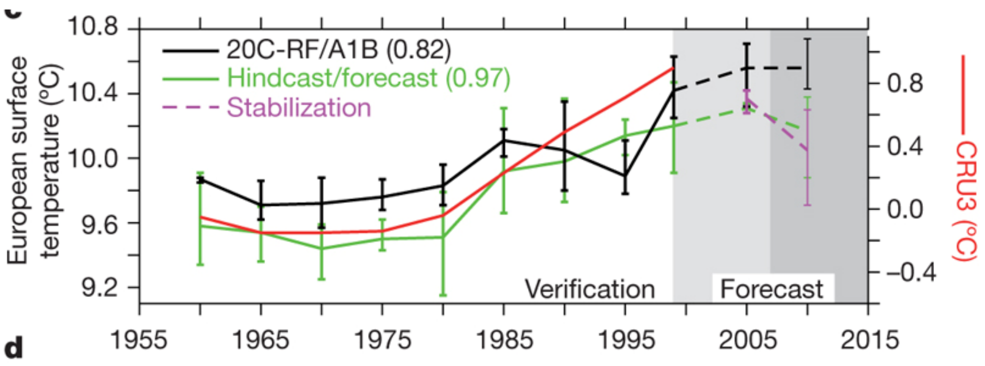
atmos. chemistry
&/or aerosols &/or
regional air quality

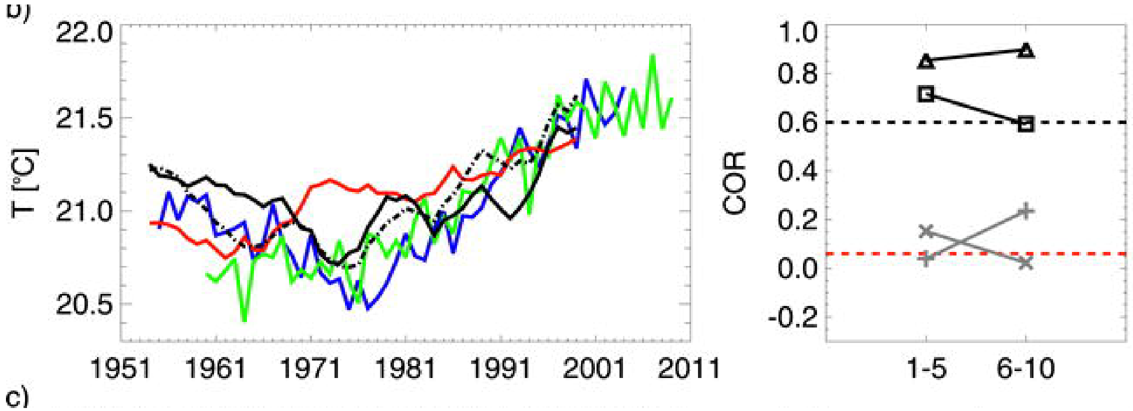
prediction with
2010 Pinatubo-
like eruption

hindcasts without
volcanoes

Published decadal predictions, e.g.:



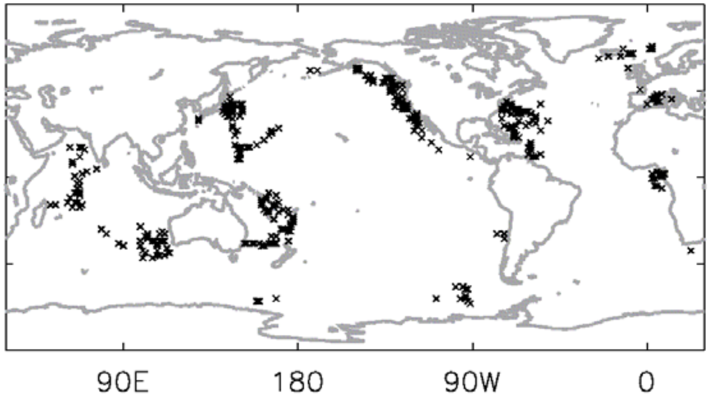




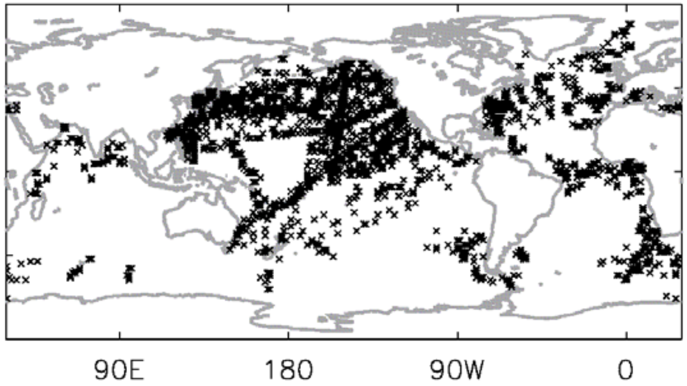
Smith et al 2007
Keenlyside et al 2008
Pohlmann et al 2009

Initialization, in particular the ocean:
Limited subsurface ocean observations

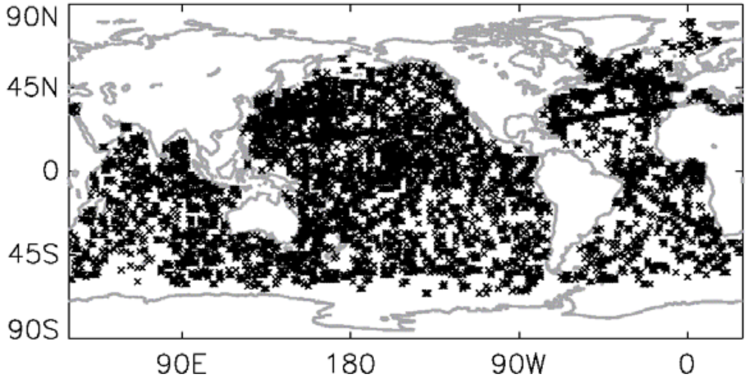
1960

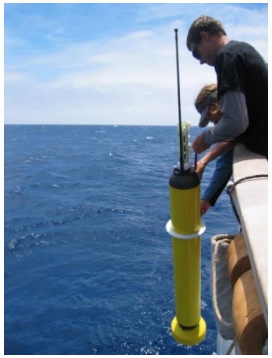


1980

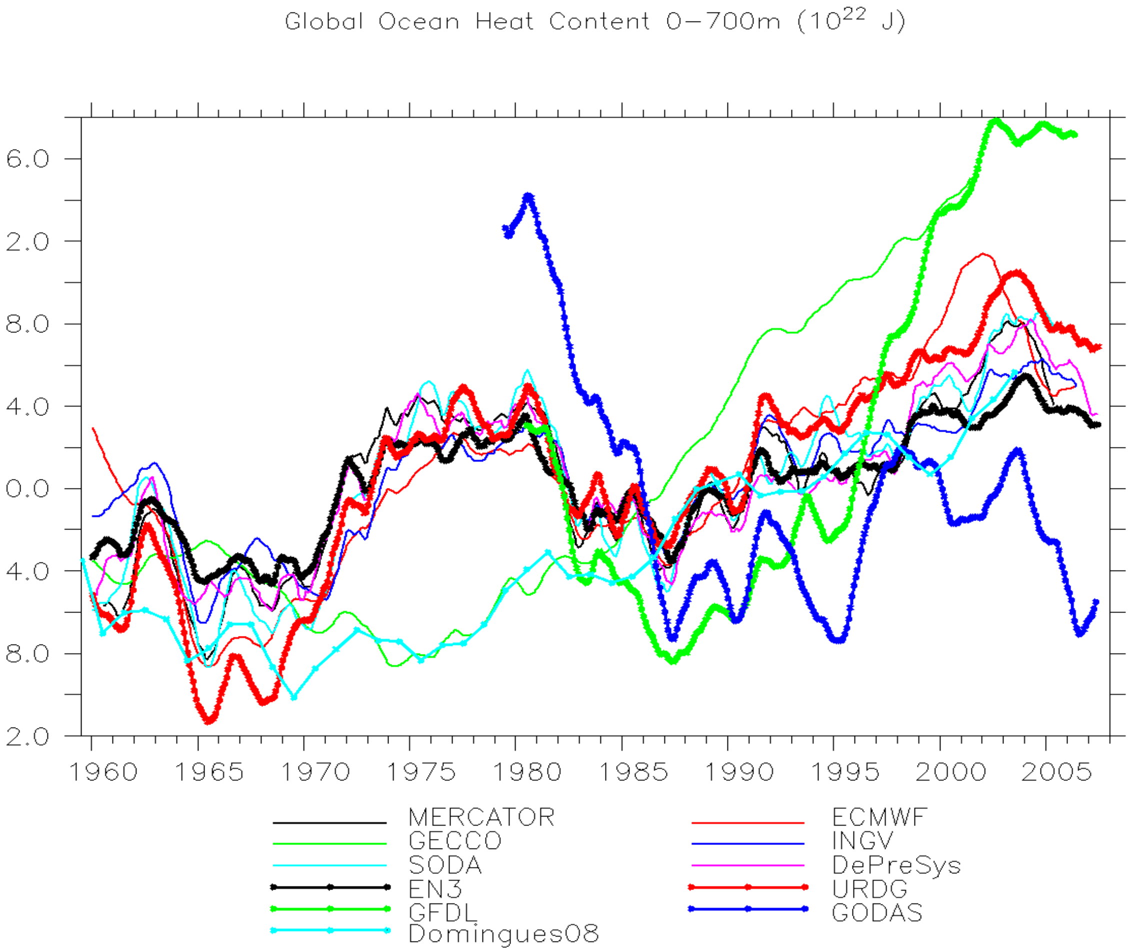


2007





Initialisation ocean: ocean analyses



A. Koehl, pers. comm.

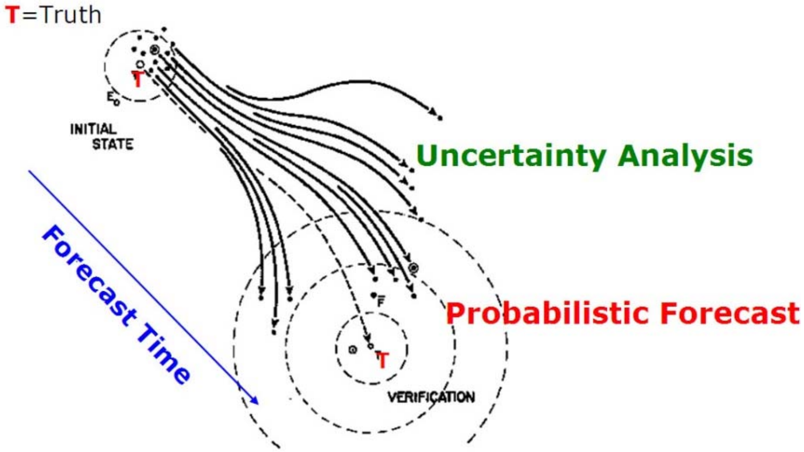
Ocean Initialization: methods

- Initialization with estimate of climate state
  - Drift
  - No spinup needed
  - Systematic error

- Initialization with estimate of anomaly of climate state on top of model’s mean state (stay on attractor)
  - Need spinup to get mean state model
  - Choice for nudging (how strong, long, which variables?)
  - Still drift….systematic error (apply flux correction?)

Perturbing the ensemble

- Perturbations which grow most rapidly in slow component (e.g. in ocean, for instance Kleeman et al. for ENSO, Hawkins and Sutton for 3D ocean, bred vectors B. Kirtman etc.)
- Consistent with the observational uncertainties
- Can be useful for identifying regions where additional observations would be most valuable to improve predictions



Perturbing ocean

- E.g. linear Inverse Modelling (Penland & Sardeshmukh 1995, Hawkins & Sutton 2009)

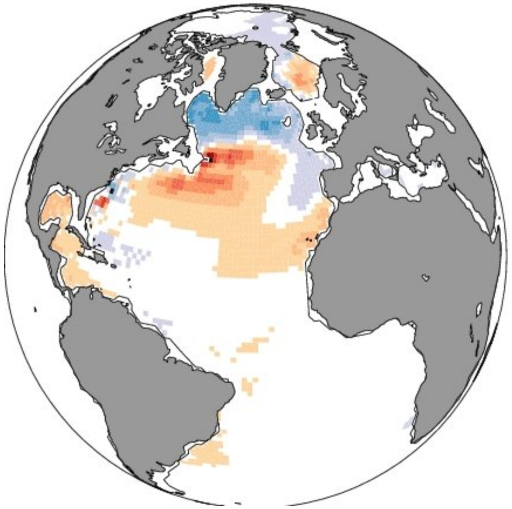
$$\frac{dx}{dt} = Bx + \zeta$$

x represents leading EOFs

$$x(t+\tau) = P_\tau x(t)$$

$$P^T P x_0 = \lambda x_0$$

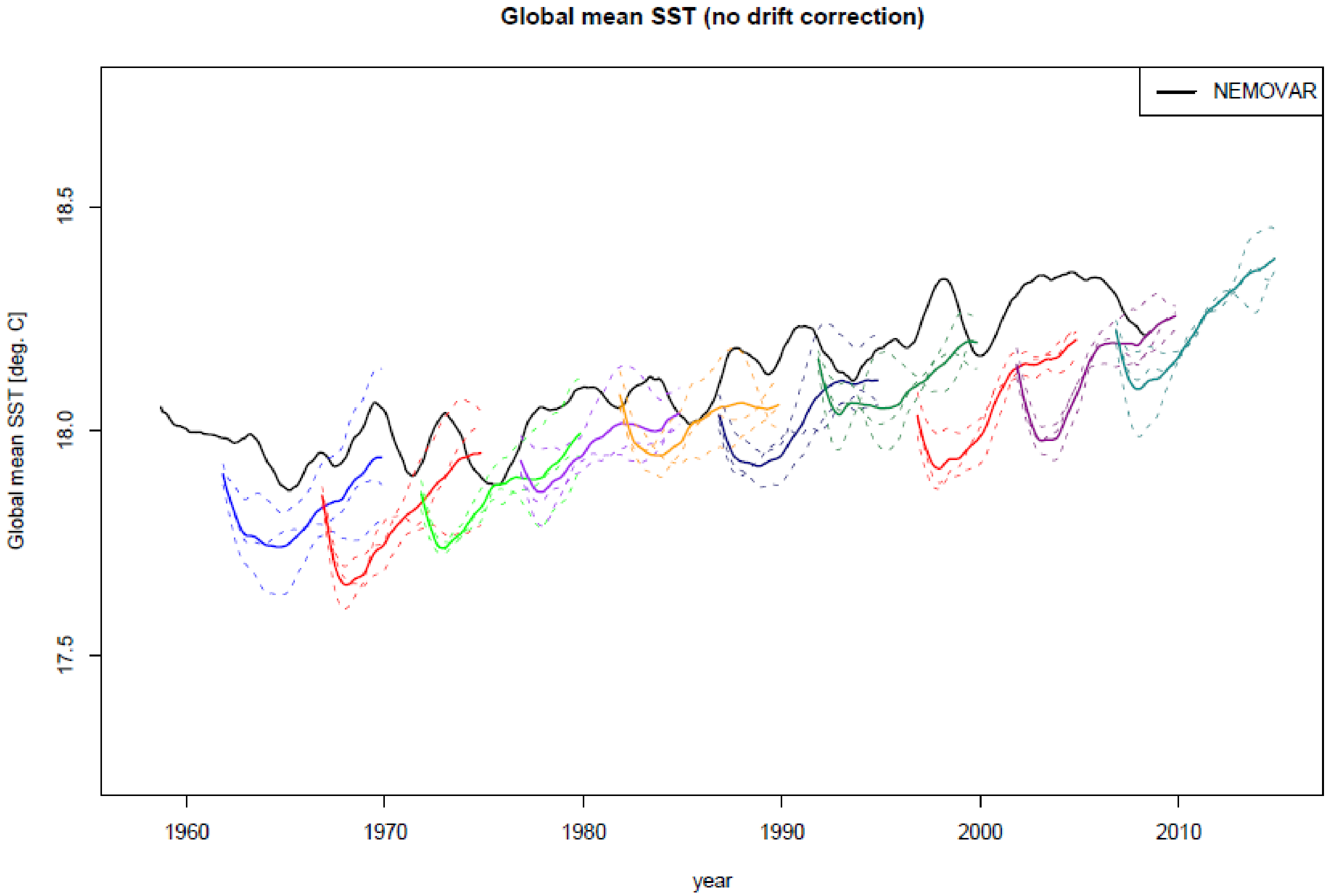
Eigenvectors are optimal growing perturbations



In practice, pragmatic approaches (perturbing atmosphere, different ocean states, perturbing ocean diffusivity)

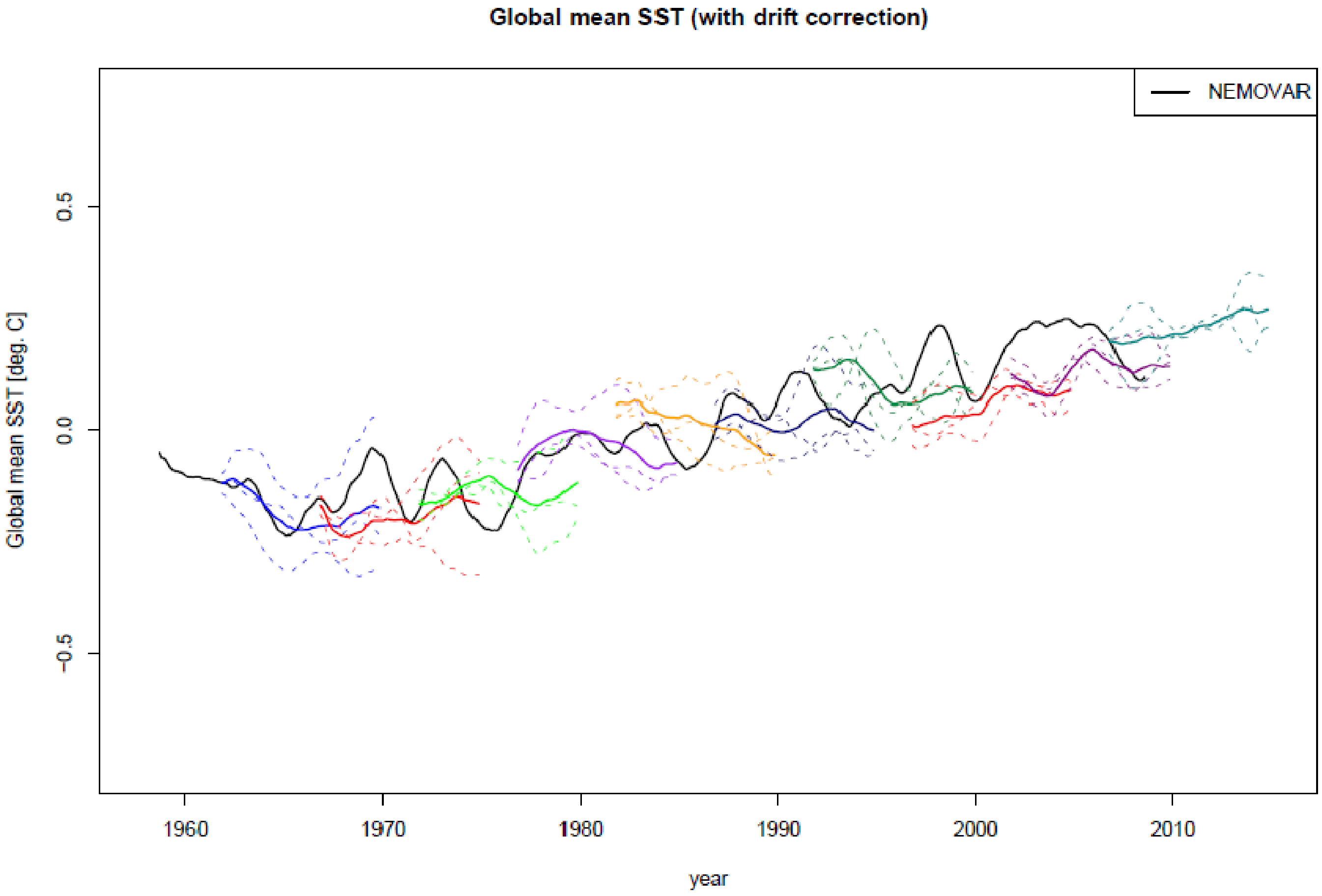
Hawkins & Sutton 2009

The real thing: CMIP5 decadal predictions in EC-Earth



Wouters et al, in prep

CMIP5 decadal predictions in EC-Earth, drift corrected



Wouters et al, in prep

Verification of decadal forecast

- Against simplest statistical model (AR1, damped persistence, or climatology)

$$X(t+\tau) = A(\tau)X(t)$$

$$A(\tau) = 0$$ (climatology)

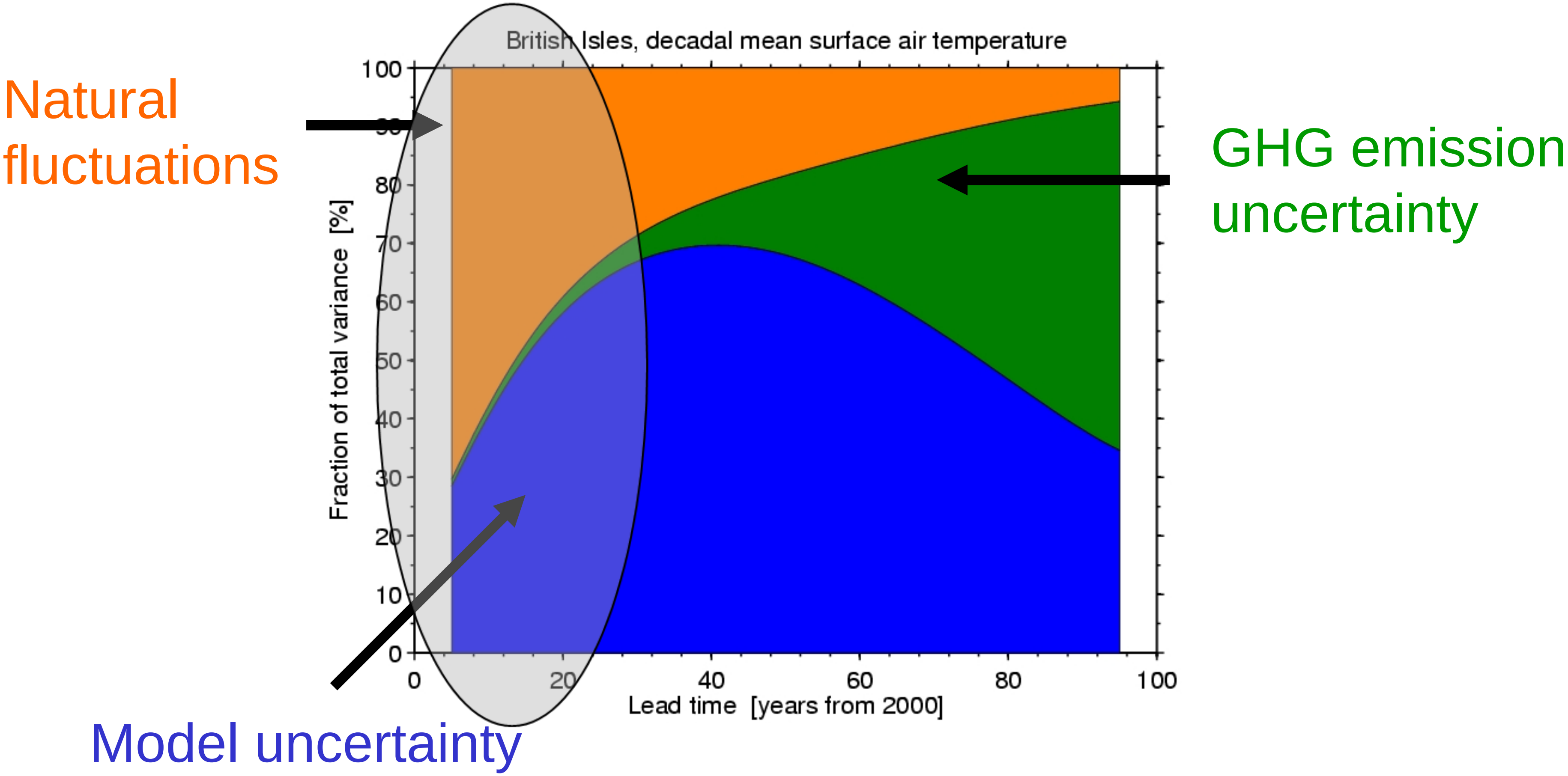
$$A(\tau) = 1$$ (persistence)

- Correlation coefficient of the ensemble mean has the best signal/noise ratio – we only have 9 or 10 data points

  → probabilistic scores are nearly impossible

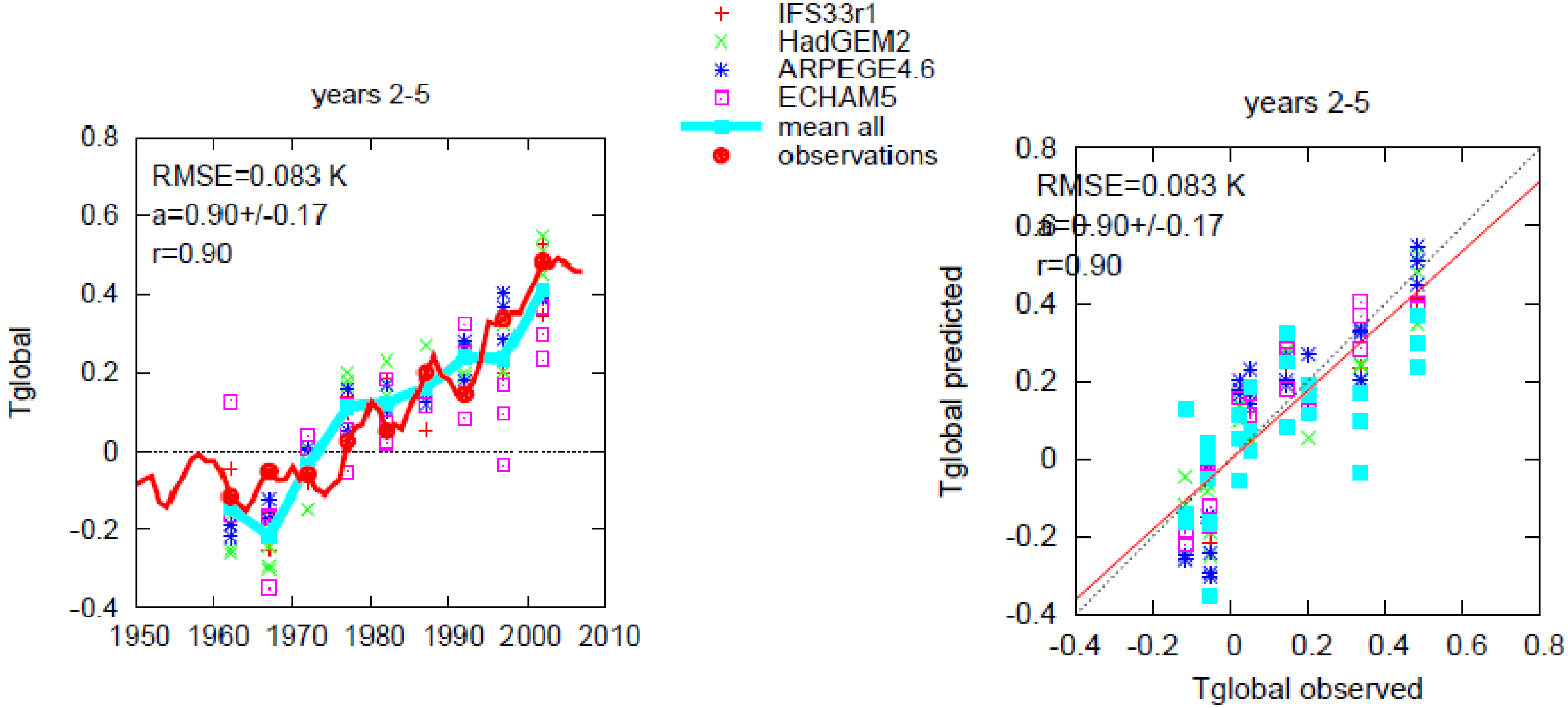
  → avoids the (constant) bias correction

Verification: deal with model uncertainty



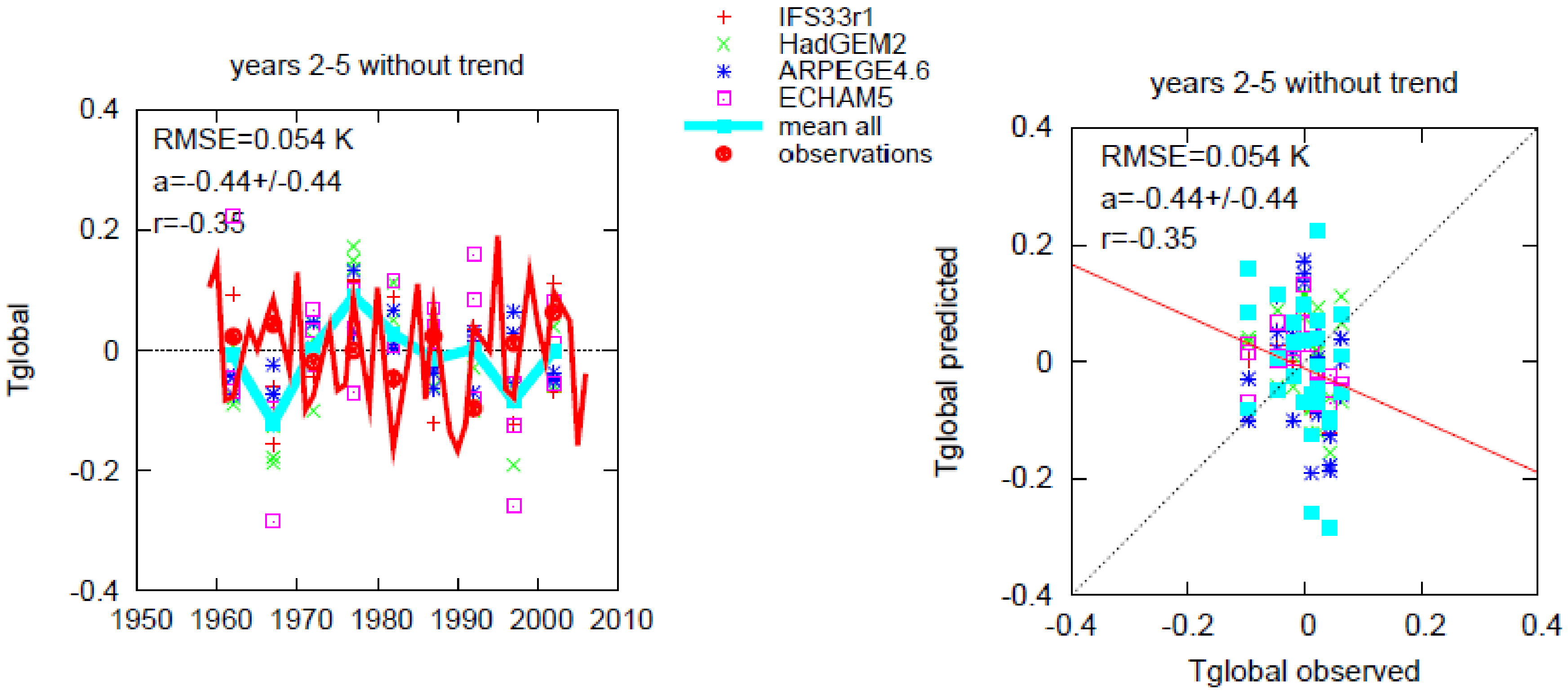
Hawkins and Sutton, 2009

Verification multi-model EU-ENSEMBLES decadal predictions



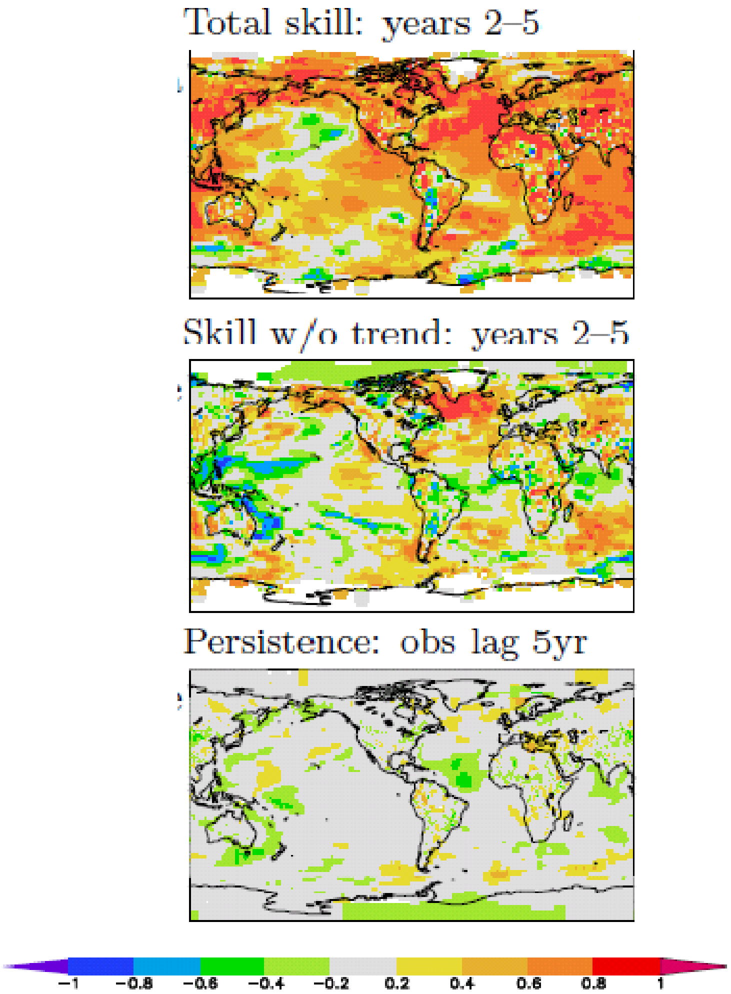
van Oldenborgh, Doblas-Reyes, Wouters and Hazeleger, subm

Verification multi-model decadal predictions



van Oldenborgh, Doblas-Reyes, Wouters and Hazeleger, subm

Verification of skill in multi-model ENSEMBLES data

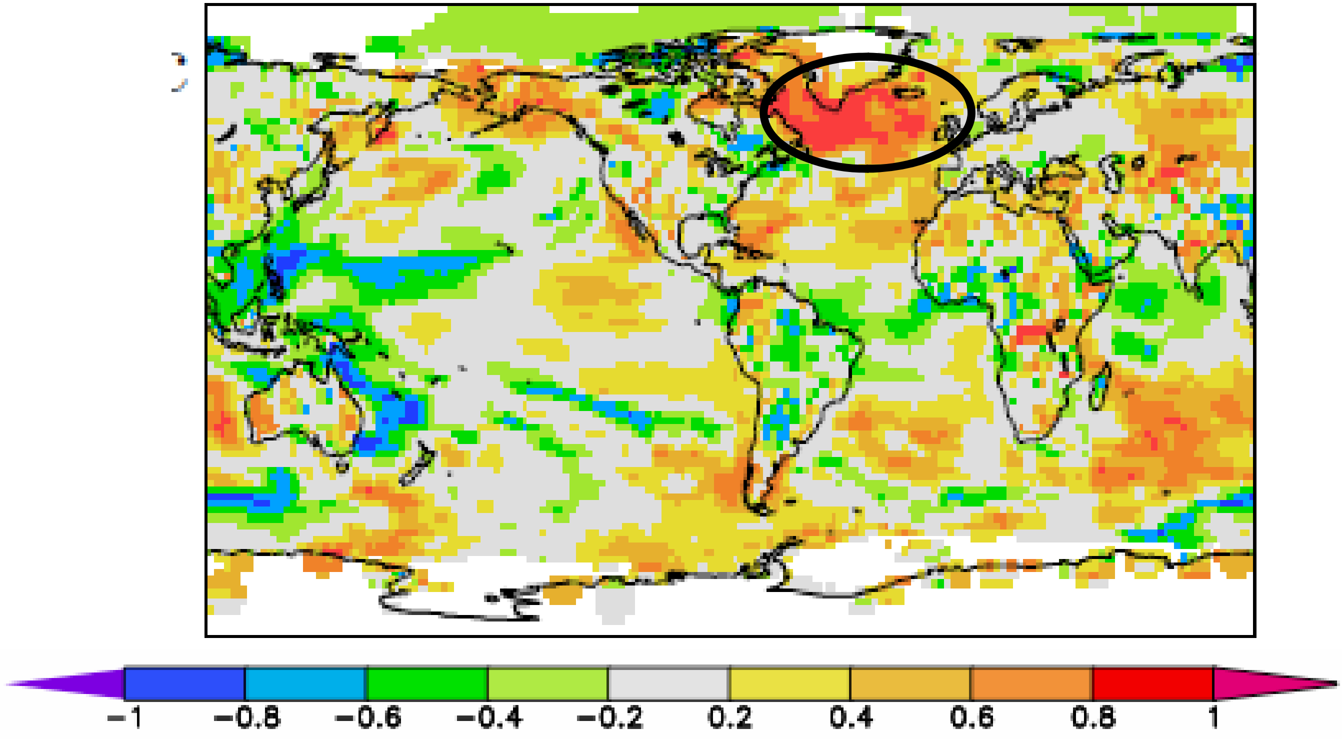

Total skill: years 2–5

Skill w/o trend: years 2–5

Persistence: obs lag 5yr

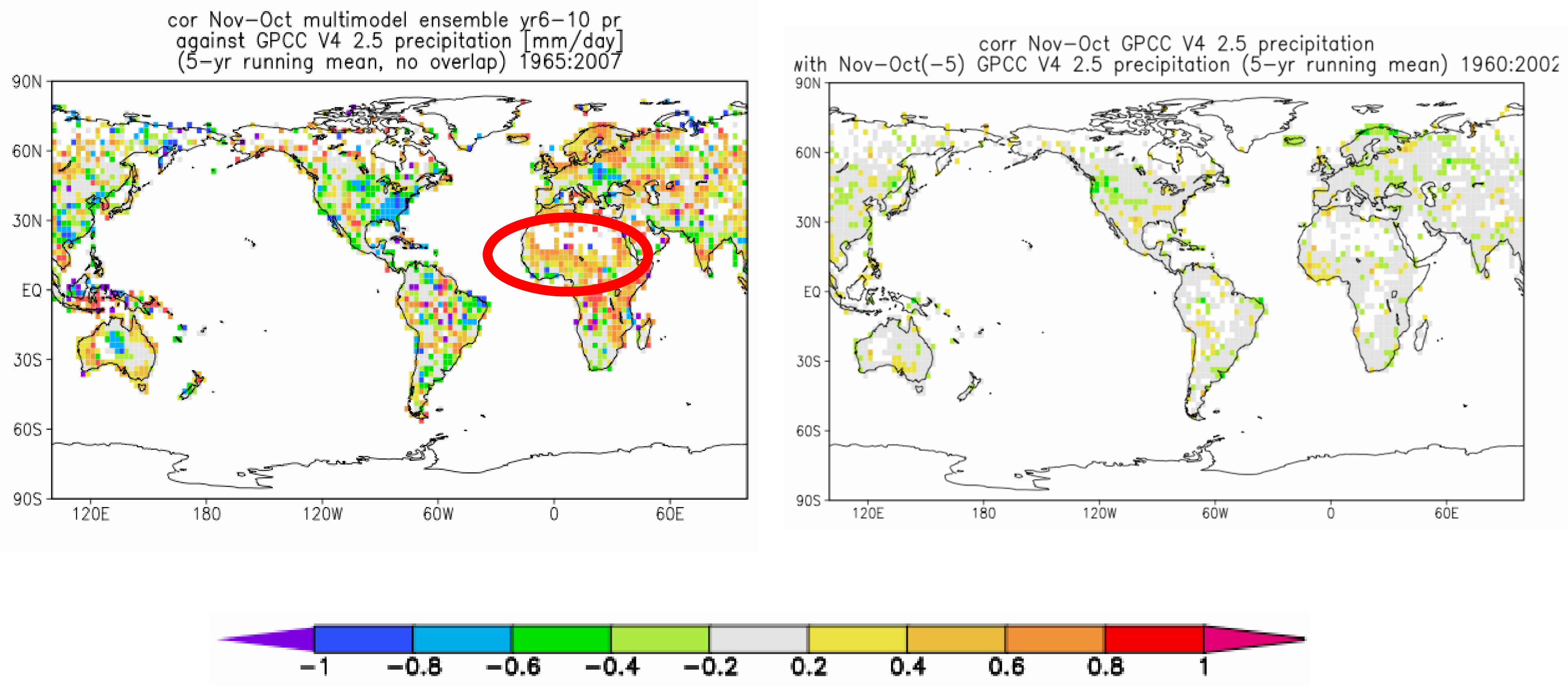
Van Oldenborgh et al subm.

Verification multi-model decadal predictions



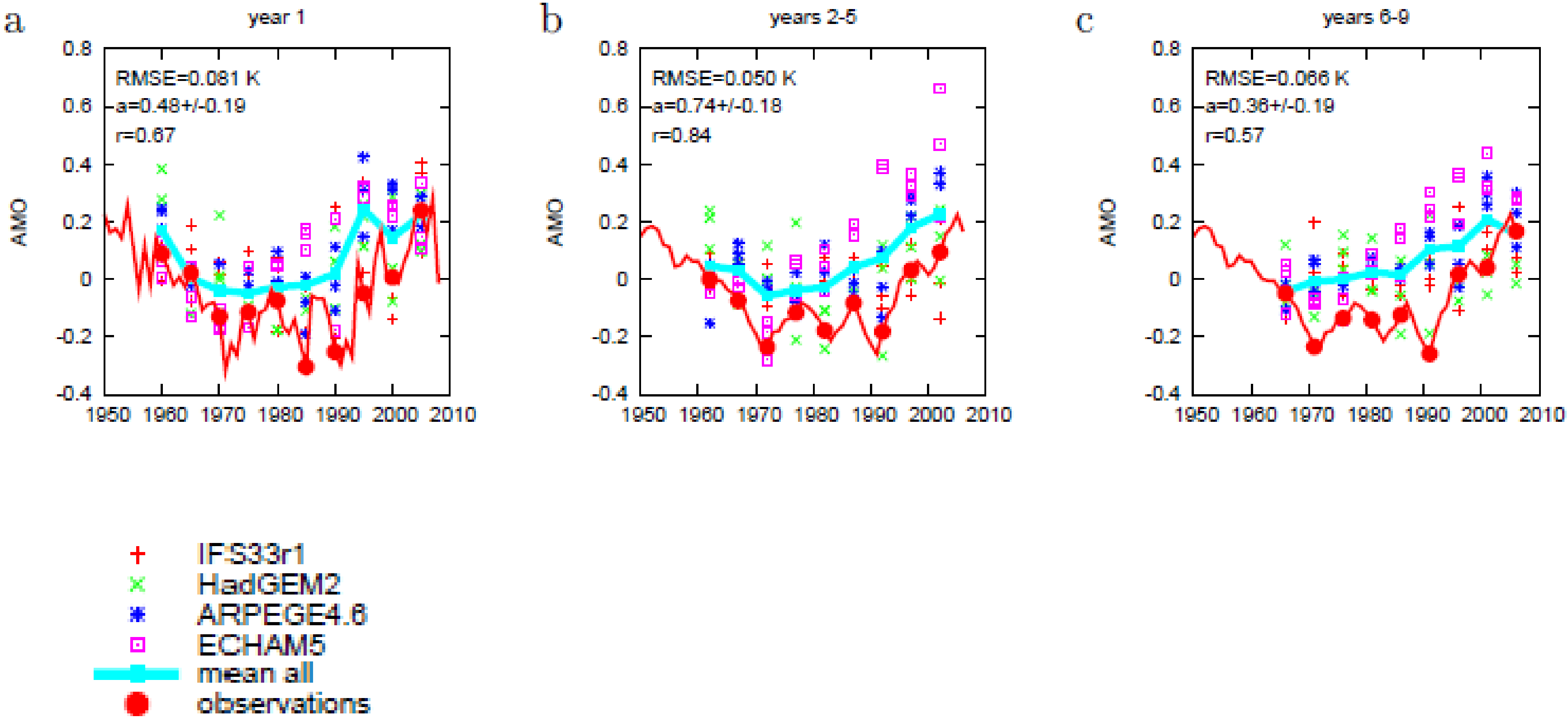
2 meter temperature multi-model anomaly correlation
2-5 year lead time averaged, without trend.

Verification multi-model EU-ENSMEBLES decadal predicition: 6-10 yr mean precipitation


cor Nov–Oct multimodel ensemble yr6–10 pr
against GPCC V4 2.5 precipitation [mm/day]
(5–yr running mean, no overlap) 1965:2007

corr Nov–Oct GPCC V4 2.5 precipitation
with Nov–Oct(–5) GPCC V4 2.5 precipitation (5–yr running mean) 1960:2002

AMO multimodel predictability



Final remarks

Decadal predictions are still at its infancy:

- Systematic model error is large & sparse observations
- There are indications for skill in predictions in the North Atlantic. Impact on land is limited, but there is scope (e.g. Sahel, perhaps Europe given impact of MOC in models).
- Trend is predictable (climate change)! Scientifically, from a predictability point of view, of less interest, but of practical use.
- Skill on natural variability is the icing on the cake (it is small and the amplitude is small)
- CMIP5 ensemble opportunity of studying different methodologies

Final remarks

Most advances needed for oceanic part of the problem

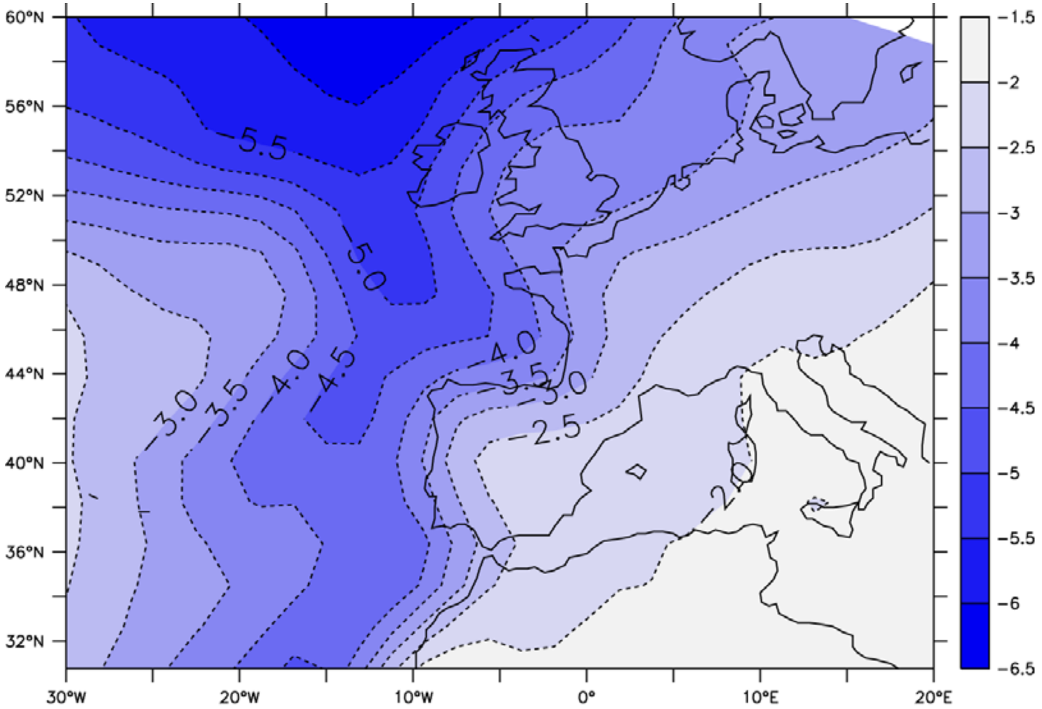
- Models: low resolution limits realistic ocean circulation characteristics (overflows, western boundary currents, upwelling zones)
- Observing system: look for places that need to be observed well (seems to be deep ocean, sea ice)
- Initialization: trial and error with full and anomaly initialization. Systematic assessment needed.
- Perturbation: how to perturb the slow component, in particular deep ocean, sea ice?
- Verification: simple methods are useful (rmse, correlations). In addition we can learn from ‘windows of opportunity’ (e.g. mid 90s warming in the Atlantic)

CLIVAR Earth System Initialisation for Decadal Predictions

http://www.knmi.nl/samenw/easyinit/

Thank You

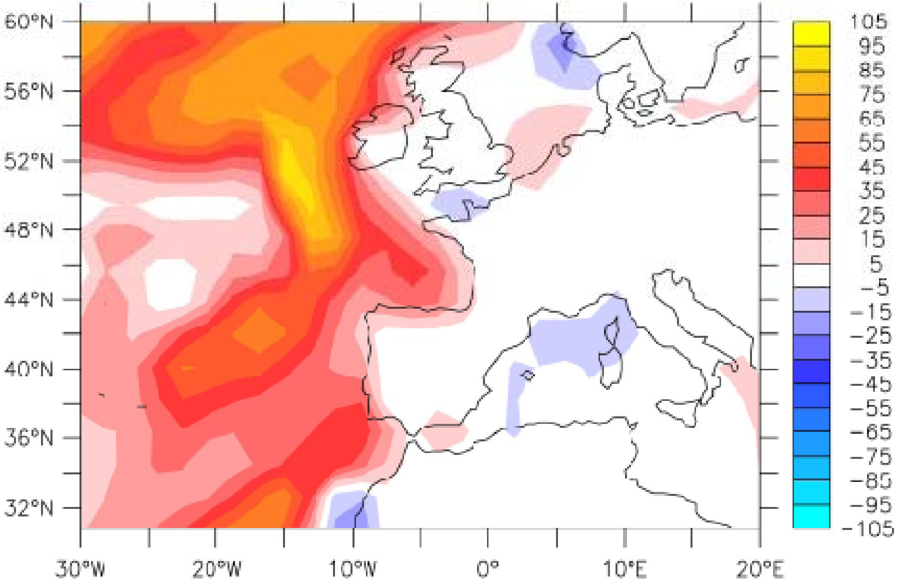
Why is impact of AMOC on Europe relatively small?



Temperature response in a coupled GCM in response to a (forced) collapse of the AMOC

Laurian et al Clim Dyn 2010

Anomalous net surface fluxes



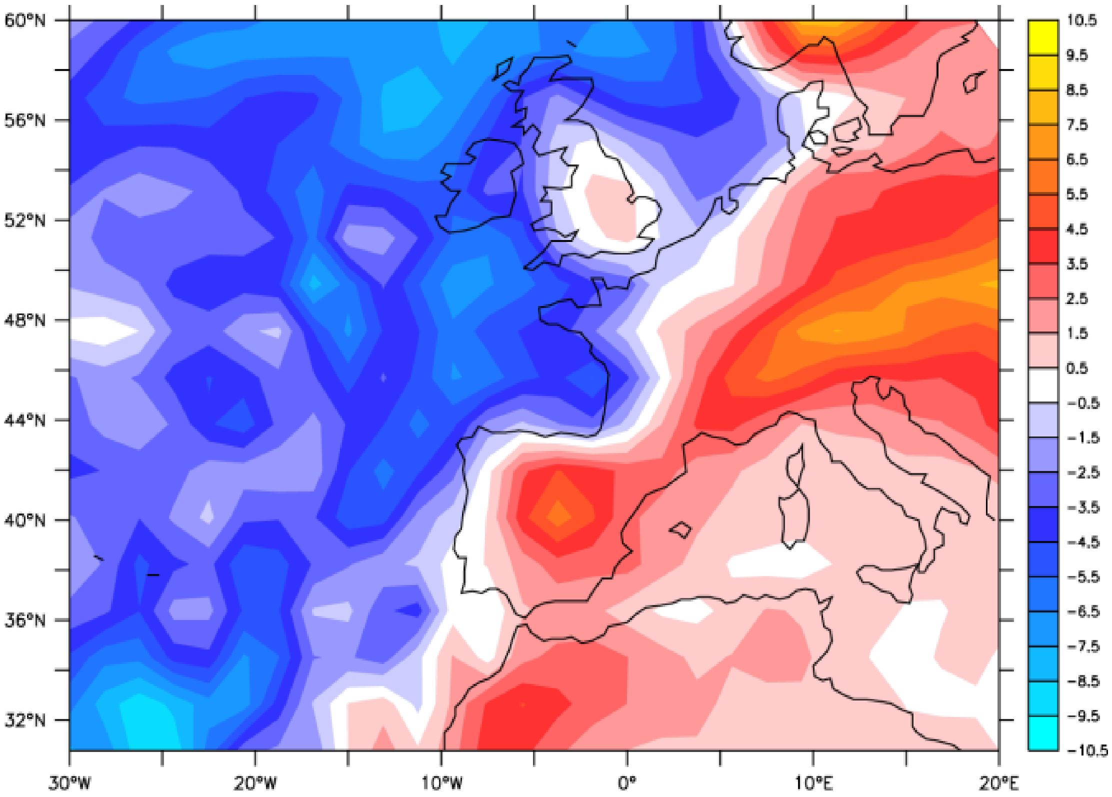
Atmosphere 'warms' the ocean to compensate for reduction in oceanic heat transport divergence

Divergence of moist static energy (MSE=c_pT+L_q+gz) over ocean strongly decreases → less transport of MSE from ocean to continent

Laurian et al Clim Dyn 2010

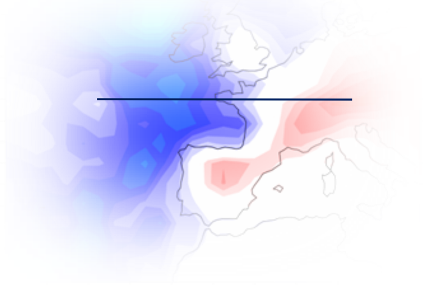
Anomalous radiative fluxes at the suface → cloud response

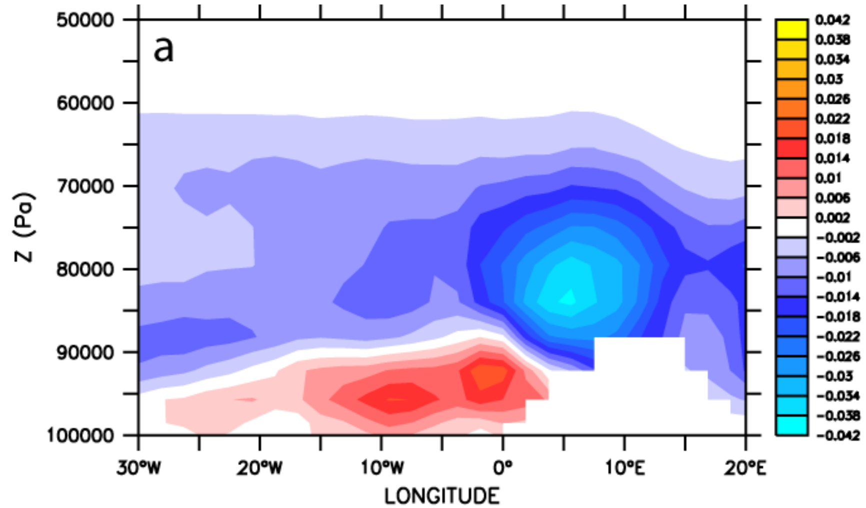
SW at surface



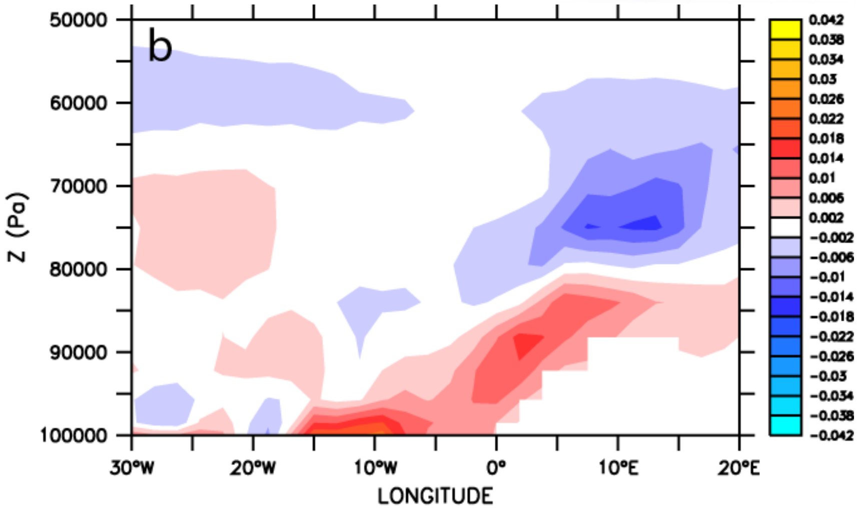
Laurian et al Clim Dyn 2010

Change in cloud water





Cloud water, 48N (g/kg) H−E DJF

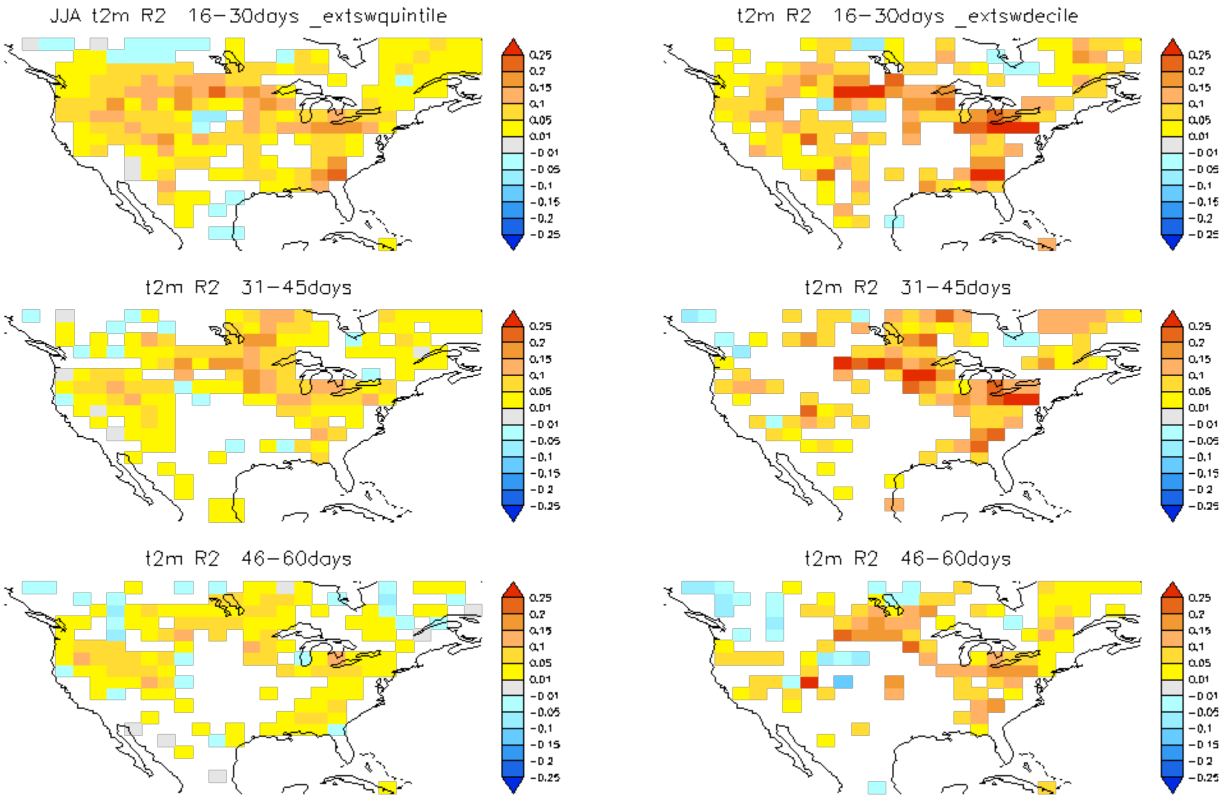


Cloud water, 48N (g/kg) H−E JJA

- Over sea: Increase of low clouds in both seasons (more stable planetary boundary layer & increase RH)
- Over land: Decrease of clouds in DJF (less MSE divergence)

Laurian et al Clim Dyn 2010

Andere ontwikkelingen: initialiseren bodemvocht



Verandering in skill van extremen van temperatuur wanneer bodemvocht geinitialiseerd wordt (GLACE-2, vd Hurk pers. comm.)