Seasonal and Interannual Prediction in the ENSEMBLES Project

F. J. Doblas-Reyes

ECMWF

representing the ENSEMBLES s2d group

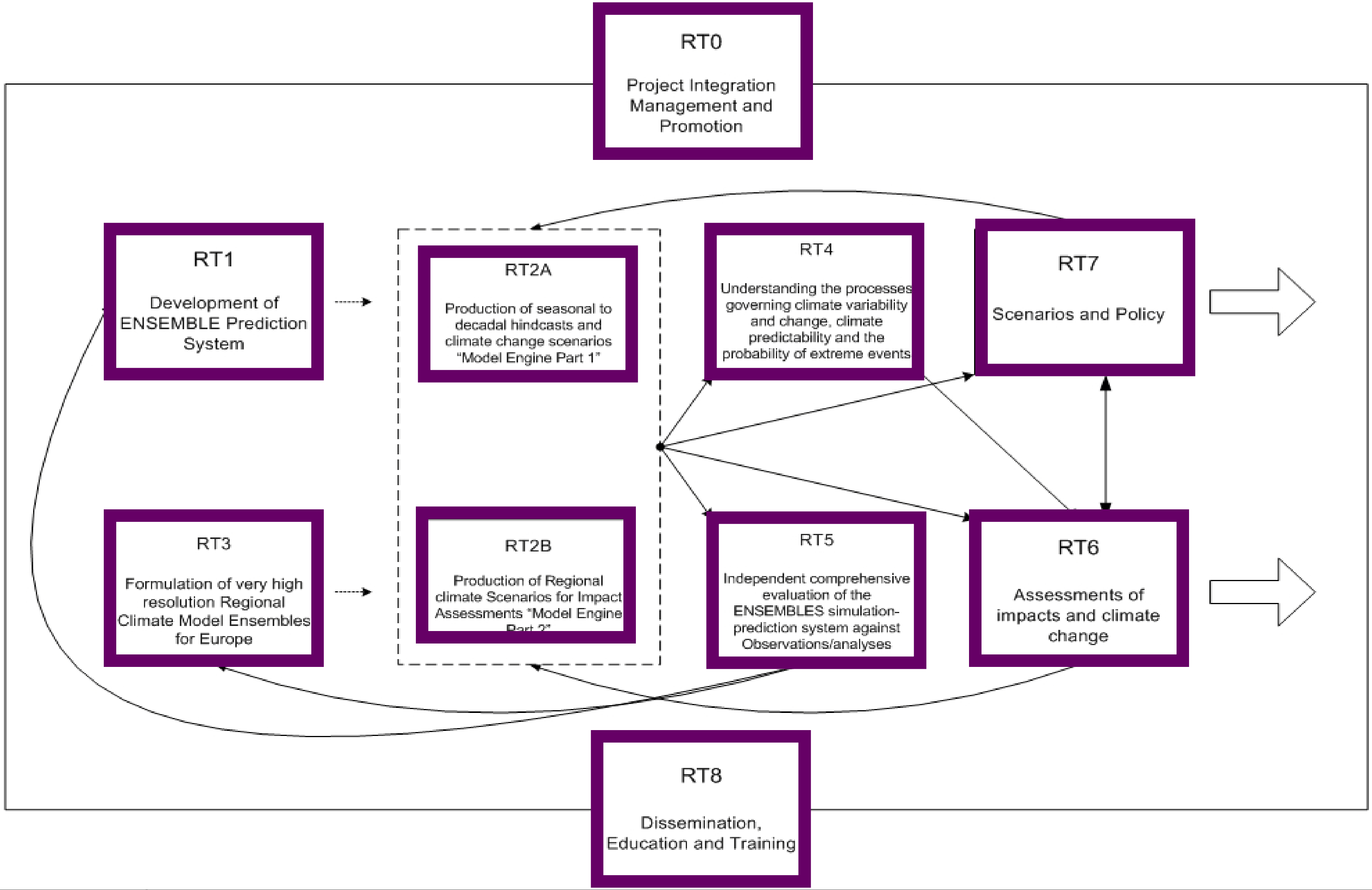
The ENSEMBLES project

- Supported by €15M of European Commission funding, coordinated by Met Office Hadley Centre, with 67 partners from across EU, Switzerland, Australia, US.
- Collaborates with other international initiatives and brings together a wide range of climate-related research communities.
- Project Goal: *To maintain and extend European pre-eminence in the provision of policy relevant information on climate and climate change and its interactions with society*

ENSEMBLES objectives

- Project Goal: *To maintain and extend European pre-eminence in the provision of policy relevant information on climate and climate change and its interactions with society*
- Three objectives:
  - ➢ Develop an ensemble prediction system based on global and regional climate models, validated against observations and analyses, to work towards a probabilistic estimate of uncertainty in future climate at the seasonal, decadal and longer timescales.
  - ➢ Quantify and reduce uncertainty in the representation of physical, chemical, biological and human-related feedbacks in the Earth System.
  - ➢ Exploit the results by linking the outputs to a range of applications, including agriculture, forestry, health, energy, water resources, insurance.

Project structure



ENSEMBLES ensembles

- Why ensembles? Predictions of natural climate variability and the human impact on climate are inherently probabilistic.
- The ensembles method tries to address uncertainties in several aspects:
  - ...ithin climate models
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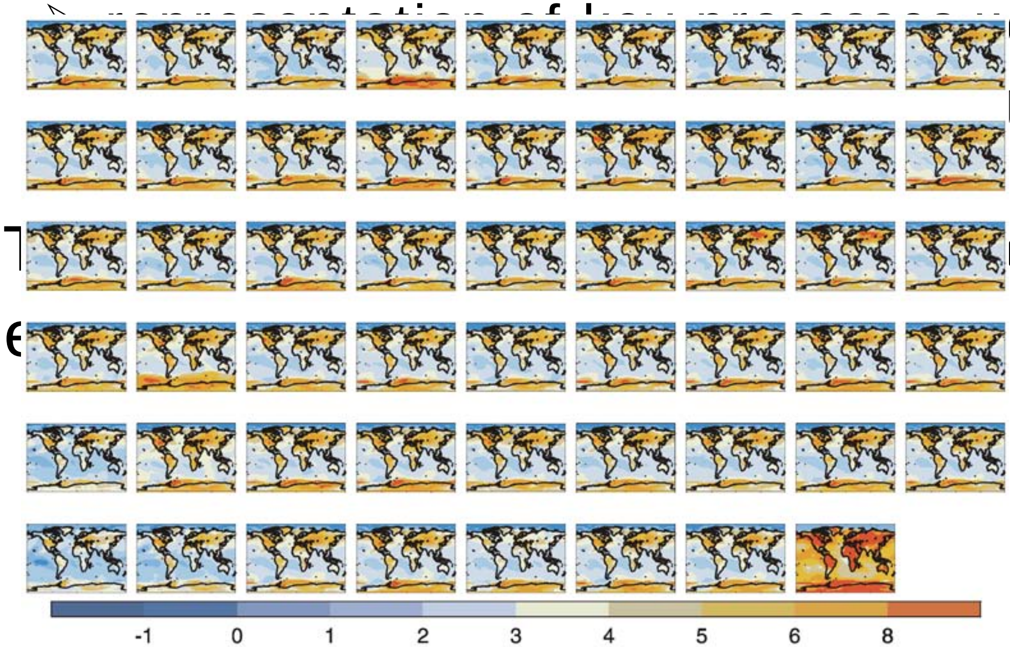
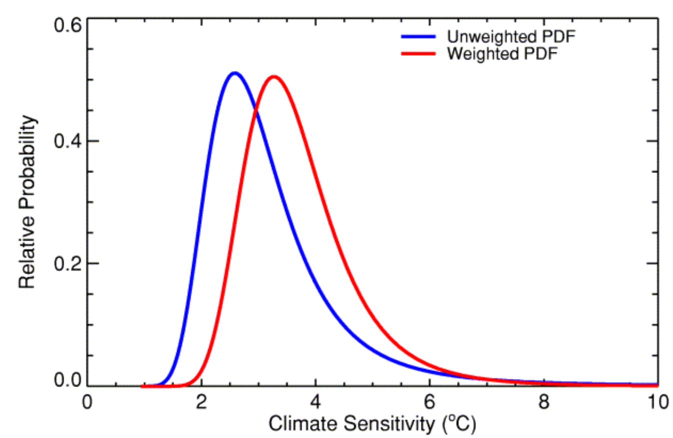
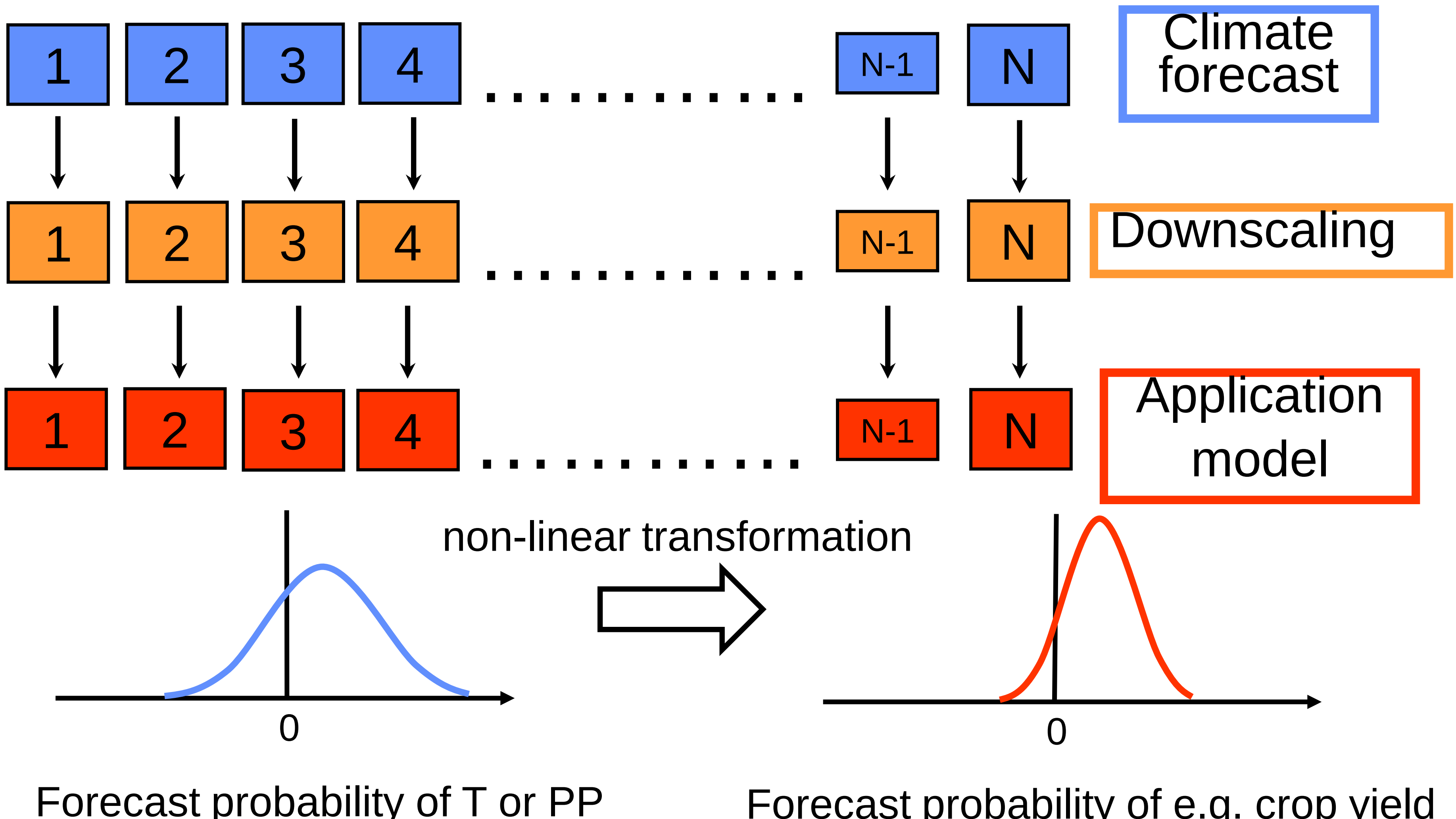
- T... o pr... d e...





Murphy *et al*, Nature 2004

Probabilistic applications: end-to-end



Climate science across time scales

- Merging information from s2d and climate change simulations might help in the assessment of the reliability of climate change projections.
- Furthermore, the possibility of adaptation to climate change via a learning process taking place at seasonal and interannual time scale is an obvious way to provide useful climate information.
- This implies
  - ➢ That similar forecast systems should be used for climate forecasting and climate change simulations.
  - ➢ Involvement of both climate scientists and end-users to consider the whole range of time scales. For instance, crop managers see the adaptation to long-term climate change as a process that takes place on a yearly basis.

Long-Term Climate Change Activities

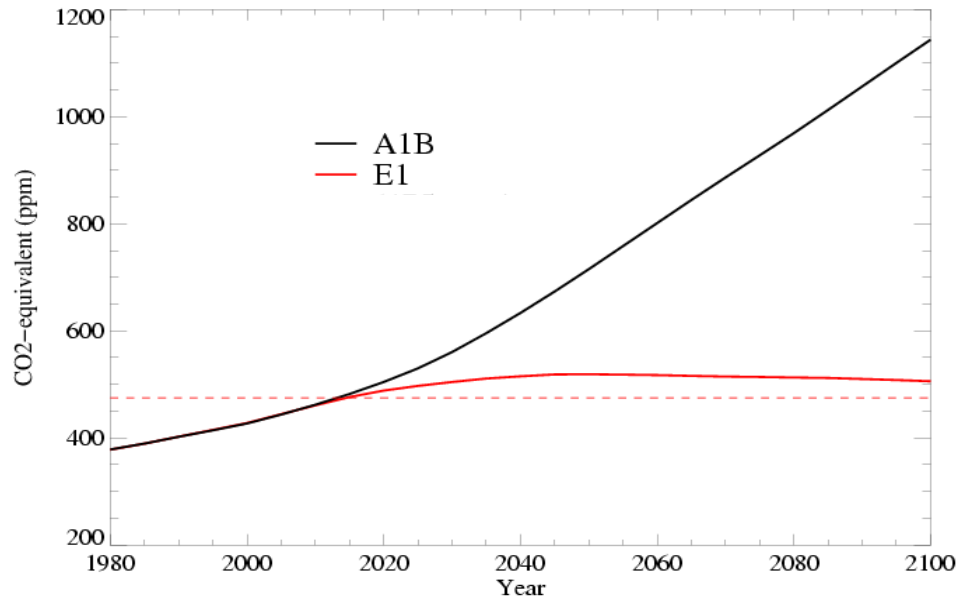
ENSEMBLES GCM-RCM Matrix

Global model Regional model	METO-HC	MPIMET	IPSL	CNRM	NERSC	CGCM3	Total number
METO-HC	1950-2100£	1950-2100					2 (4)
MPIMET		1950-2100	1950-2050*				2
CNRM				1950-2050			2
DMI		1950-2100		1950-2050*			2
ETH	1950-2050						1
KNMI		1950-2050					1
ICTP		1950-2050					1
SMHI	1950-2050				1950-2050*		2
UCLM	1950-2050						1
C4I		1950-2050					1
GKSS**			1950-2050*				1
Met.No**					1950-2050*		1
CHMI**				1950-2050*			1
OURANOS**						1950-2050*	1
Total (1950-2050)	4 (6)	6	2	3	2	1	18 (20)

ENSEMBLES mitigation scenario

New emissions scenario developed

- IPCC SRES A1B baseline, stabilise towards 450ppmv CO_{2eq}
- provides information towards EU goal of limiting warming to less than 2°C above pre-industrial levels



- Uses the proposed IPCC "AR5" design: Earth system models will be driven by GHG concentrations, rather than emissions. Carbon fluxes give implied emissions.
- Will inform details of AR5 design and how to scientifically exploit the runs.

Seasonal-to-Decadal Prediction Activities

CERFACS (France), ECMWF, KNMI (Netherlands), IfM (Germany), INGV (Italy), LMD (France), Météo-France, Meteoswiss, UK Met Office

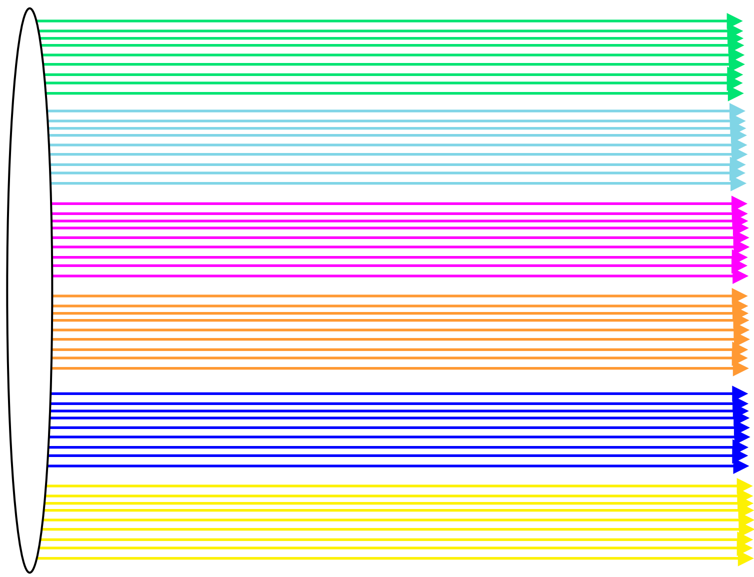
ENSEMBLES and model uncertainty

- Model uncertainty is a major source of forecast error. Three approaches to deal with model uncertainty are being investigated in ENSEMBLES: multi-model (ECMWF, GloSea, DePreSys, Météo-France, IfM-Kiel, INGV), stochastic physics (ECMWF) and perturbed parameters (DePreSys).
- Seasonal hindcasts in two streams:
  - Stream 1: Hindcast period 1991-2001, seasonal (7 months, May and November start date), annual (14 months, November start date), nine-member ensembles, ERA40 initialization in most cases.
  - Stream 2: As in Stream 1 but over 1960-2005, with 4 start dates for seasonal hindcasts, at least 1 for annual.

Ensemble climate forecast systems

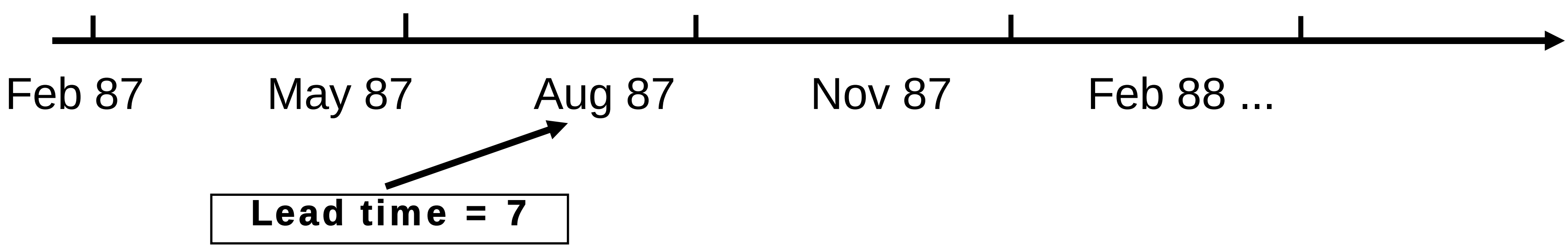
Assume a multi-model ensemble system with coupled initialized GCMs

Model 1 Model 2 Model 3 Model 4 Model 5 Model 6



K models x M ensemble members

M*K-member ensemble



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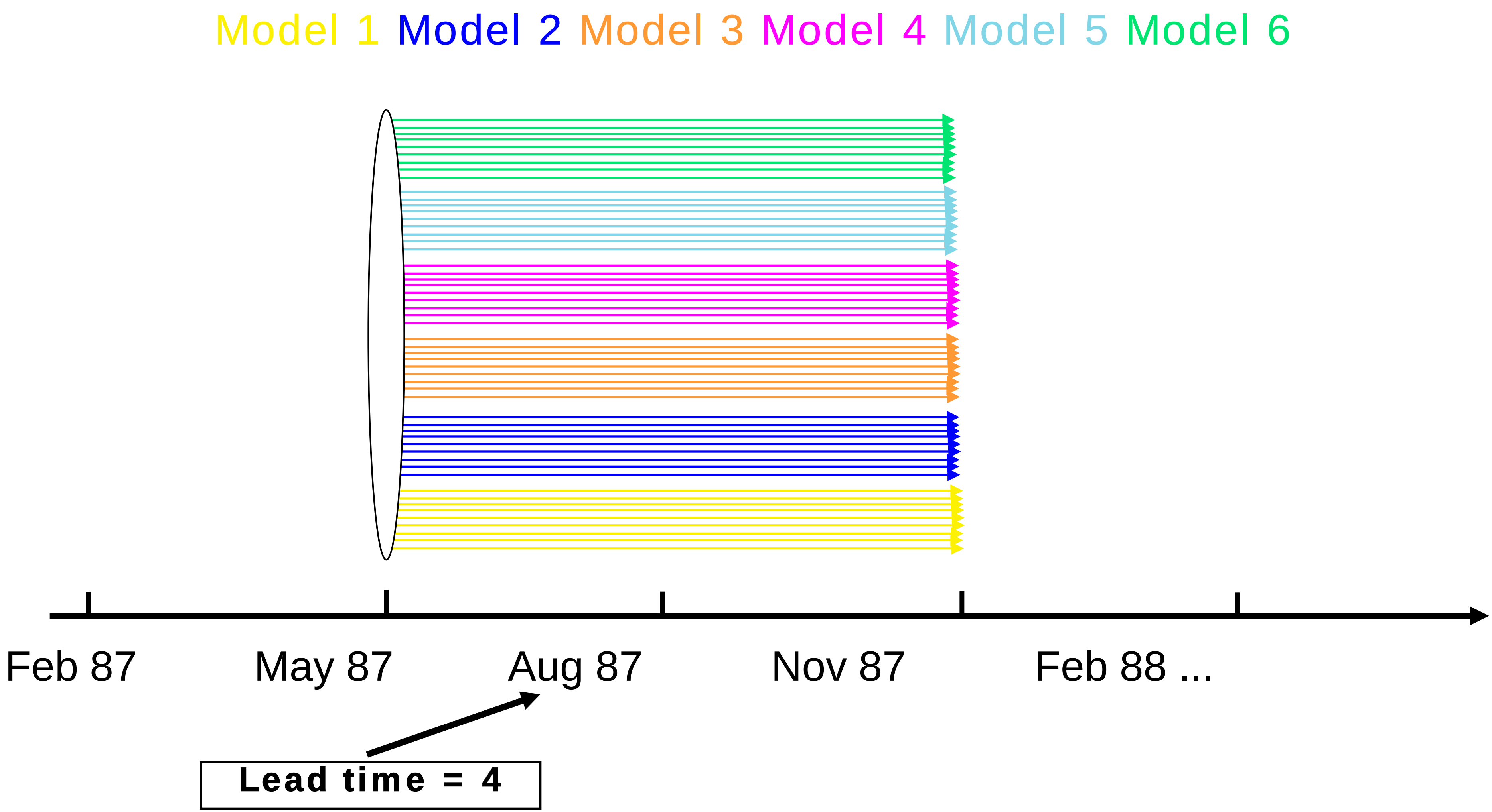
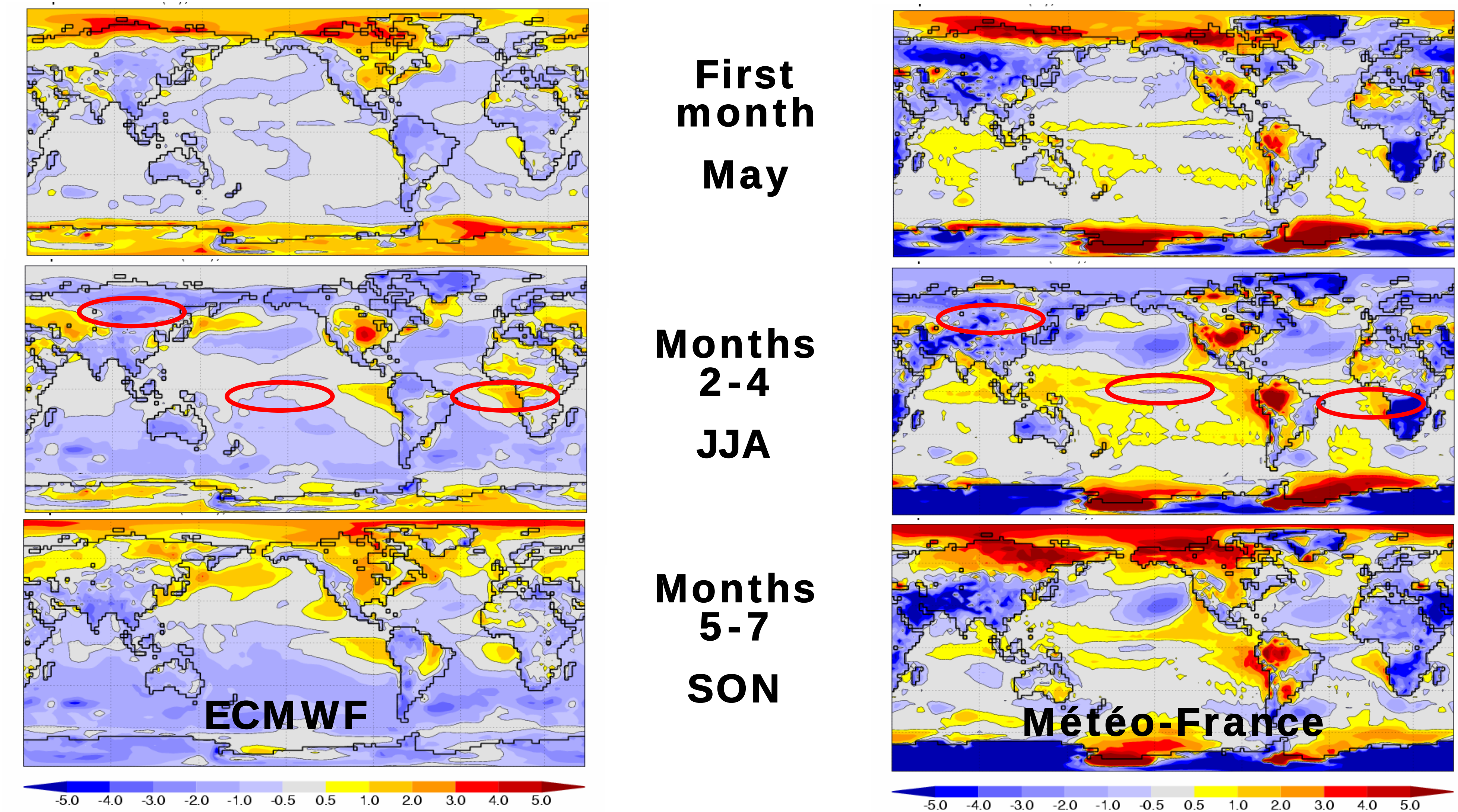


Systematic error in seasonal forecasts

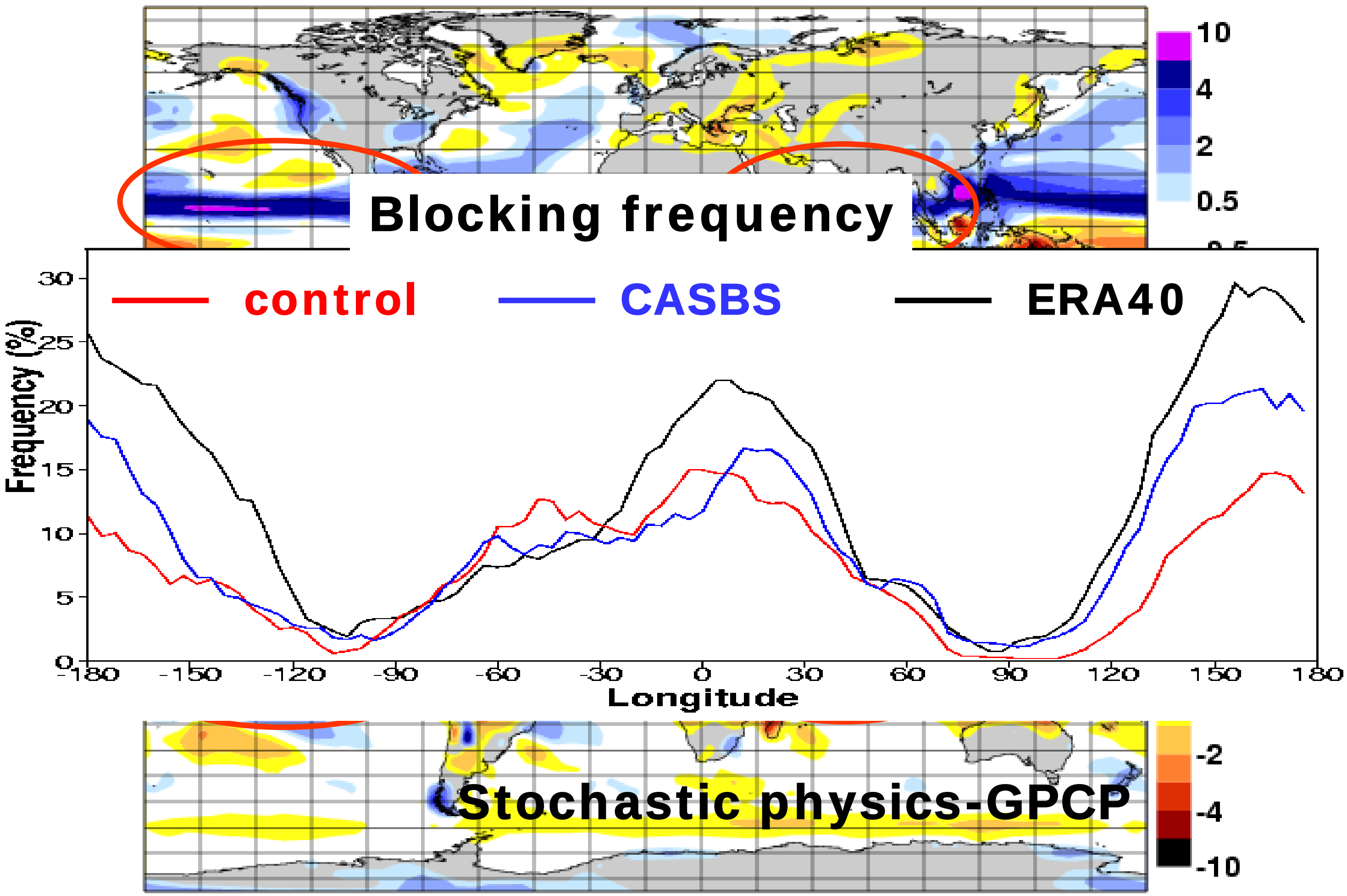
ENSEMBLES Stream 2 T2m mean bias wrt ERA40/OPS, 1960-2005



Error reduction: stochastic physics

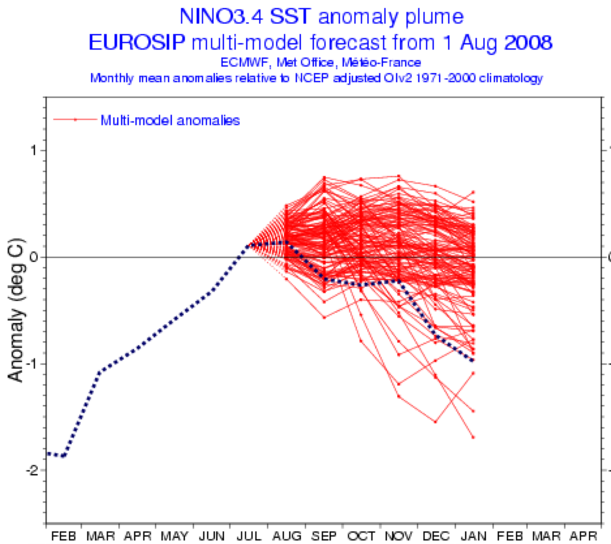
Precipitation bias (DJF, 1-month lead, 1991-2001, CY29R2)

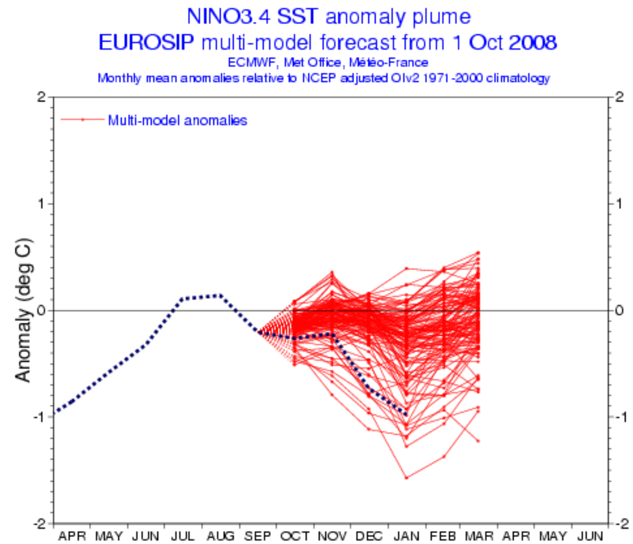
CASBS reduces the tropical and blocking frequency biases

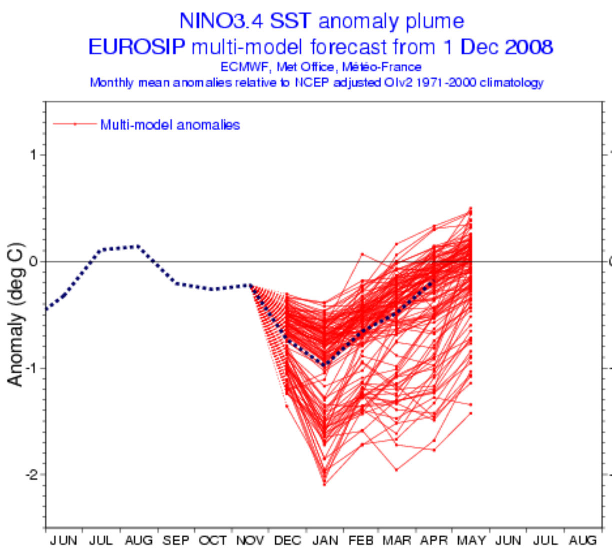


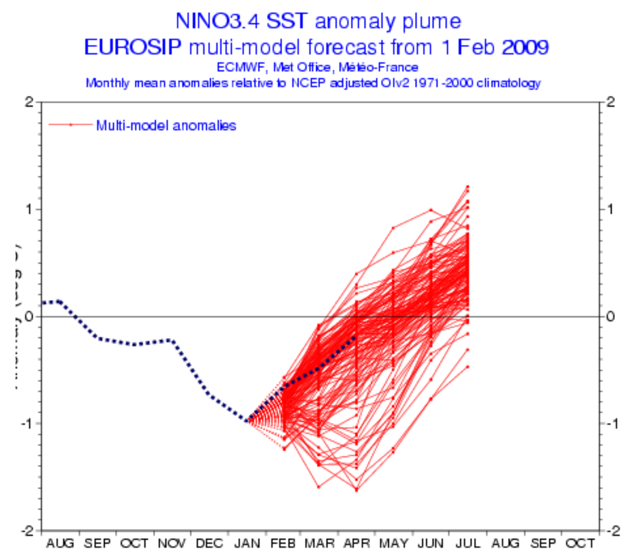
Berner et al. (2008)

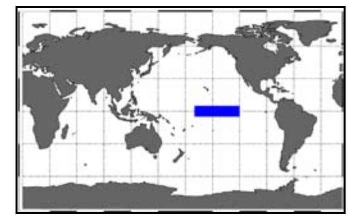
Forecast anomalies







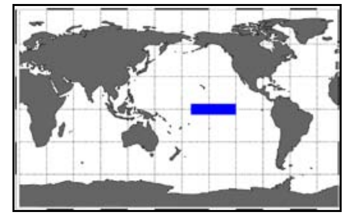




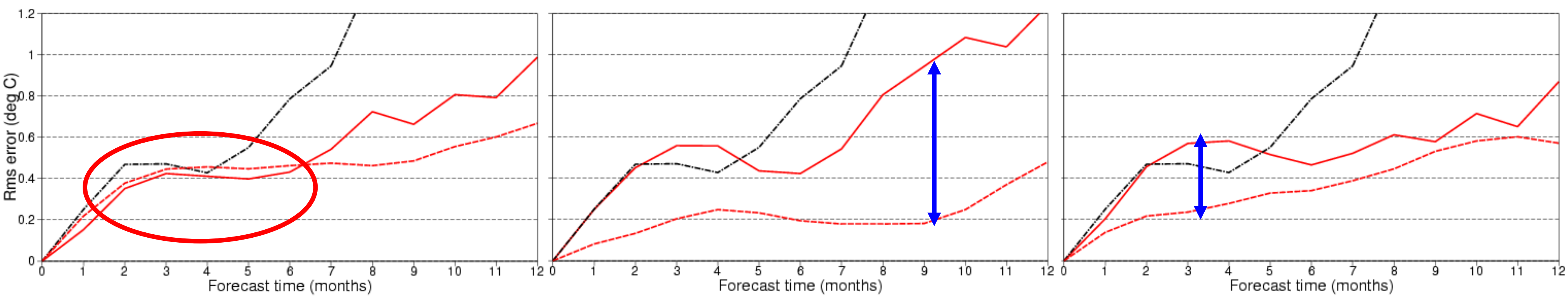
Reliability and accuracy

Sea surface temperature RMSE (solid) and spread (dashed) averaged over the Niño3.4 region for the ENSEMBLES Stream 1hindcasts of the 1st November start dates over the period 1991-2001. Persistence RMSE in dashed black.

All forecast systems beat persistence. The multi-model is the most skilful system, with highest deterministic reliability (RMSE~spread), in the first 6 months, while perturbed parameters is as good for longer lead times.

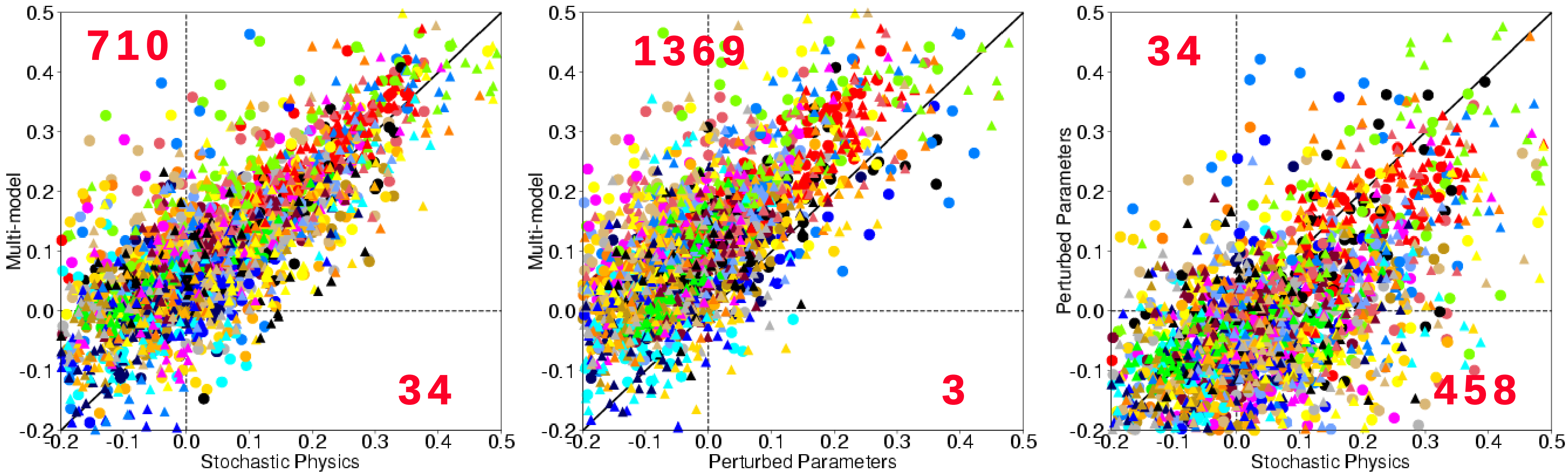


Multi-model (5 models, 45 members) | **ECMWF Stochastic Physics (9 members)** | **Perturbed Parameters (9 members)**



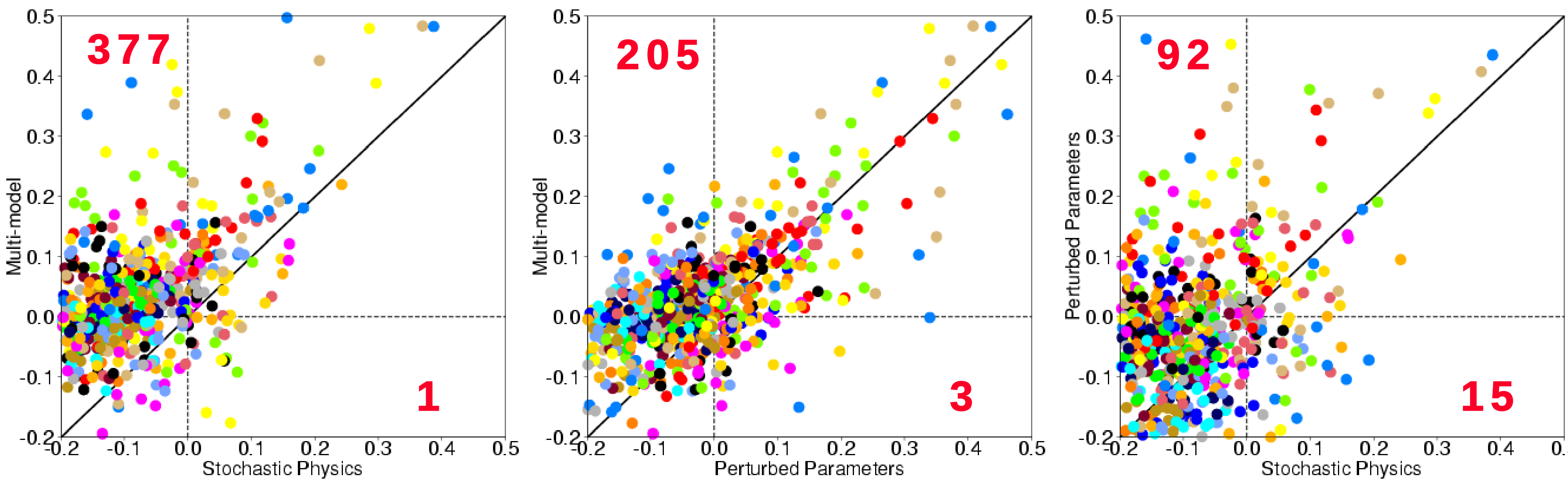
Stream 1 seasonal hindcasts

Brier skill score of the three different forecast systems for several regions, lead times (1-1, 1-3, 2-4, 3-5, 4-6 months), events (anomalies above/below the upper/lower tercile and above the median), start dates (May and November) and variables (near-surface temperature, precipitation, Z500, T850 and MSLP) computed over the period 1991-2001. The inset numbers indicate the number of cases where a system is superior with 95% confidence.



Stream 1 annual hindcasts

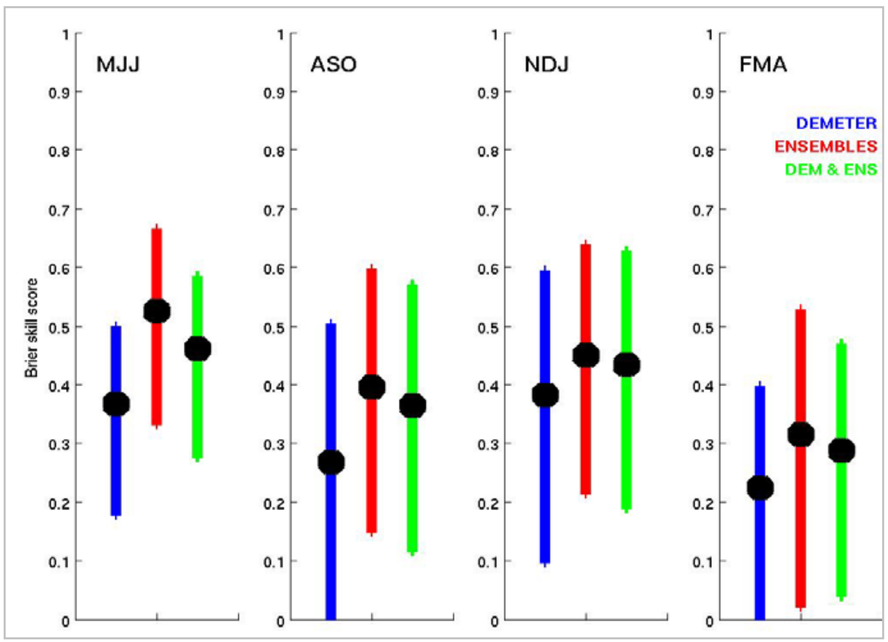
Brier skill score of the three different forecast systems for several regions, lead times (6-8, 8-10, 10-12 months), events (anomalies above/below the upper/lower tercile and above the median) and variables (T2m, precipitation, Z500, T850 and MSLP) computed over the period 1991-2001 for the November start dates. The inset numbers indicate the number of cases where a system is superior with 95% confidence.



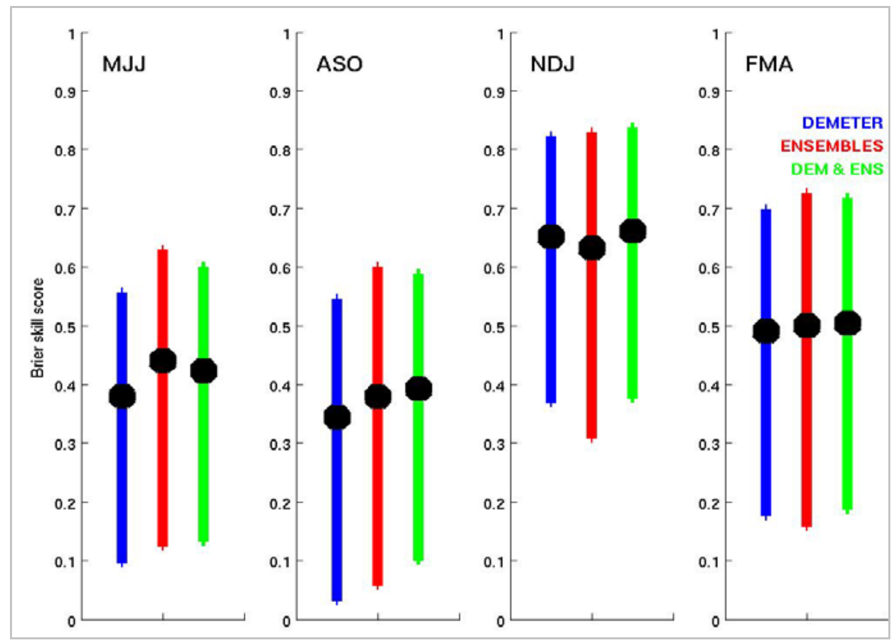
Stream 2 seasonal hindcasts

Brier skill score of 4-6 month lead time Niño3 SSTs for DEMETER, ENSEMBLES and their combination verified over 1980-2001.

SST < lower tercile

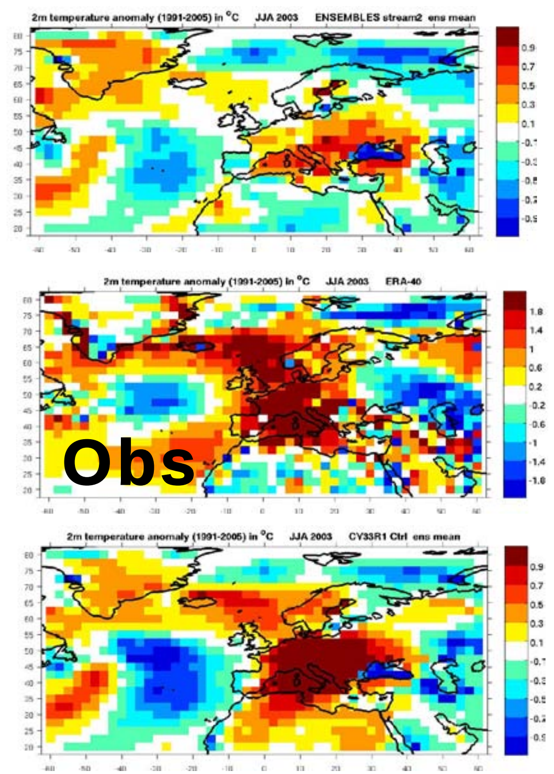


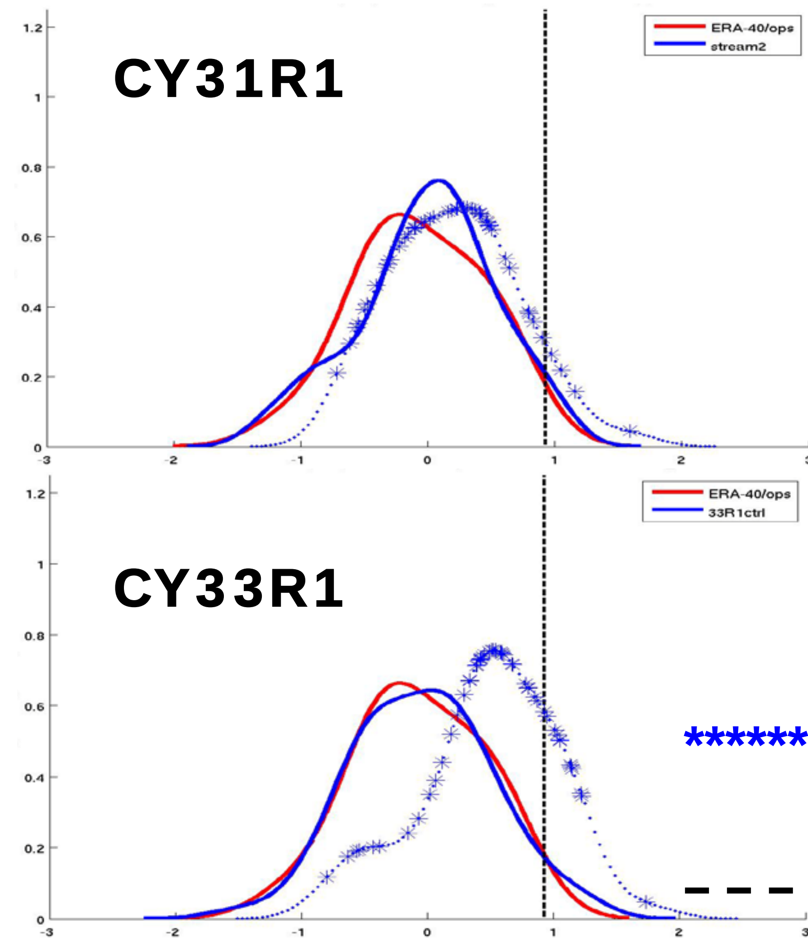
SST > upper tercile



Model improvement

T2m coupled forecasts for JJA 2003 (one-month lead time) with two different versions of ECMWF's IFS: operational (CY31R1) and CY33R1 (revised convection, land surface, PBL vertical diffusion, radiation)





******* forecast (50 ensemble members)

– – – – analysed anomaly

Summary seasonal forecasts

- Substantial systematic error, including lack of reliability, is still a fundamental problem in dynamical seasonal and interannual forecasting and forces *a posteriori* corrections to obtain useful predictions. Recalibration can alleviate the lack of reliability, but requires long samples for robustness.
- Stochastic physics schemes can reduce the systematic error without compromising the forecast quality.
- Comprehensive assessments of the forecast quality measures (including estimates of their standard error) are indispensable in forecast system comparisons.
- Perturbed-parameter ensembles are competitive with multi-model ensembles, with gains both in accuracy and reliability.

ENSEMBLES decadal re-forecasts

- Model uncertainty is a major source of forecast error. Three approaches to deal with model uncertainty are being investigated in ENSEMBLES: multi-model (ECMWF, HadGEM2, IfM-Kiel, CERFACS) and perturbed parameters (DePreSys).
- Decadal hindcasts in two streams:
  - Stream 1: hindcast period 1991-2001, DePreSys (IC and PP ensembles), two start dates per year, nine-member ensembles, 10-year runs in every instance.
  - Stream 2: hindcast period 1960-2005, one three-member decadal hindcast every 5 years; DePreSys 10-year runs once a year and 30-year runs every 5 years.

ENSEMBLES decadal: questions

- Is there climate predictability with a horizon of several years? Where? Is it useful?
- Does initialization of dynamical climate models improve forecast quality with respect to AR4-style climate-change integrations? What is the role of initial conditions versus that of the boundary forcings?
- Does an improved use of ocean observations increase forecast quality?
- What are the relevant physical processes in the ocean and the atmosphere?
- What is the impact of model error on forecast quality?
- What are the relative merits of different methods to deal with the impact of model uncertainty on forecast error?

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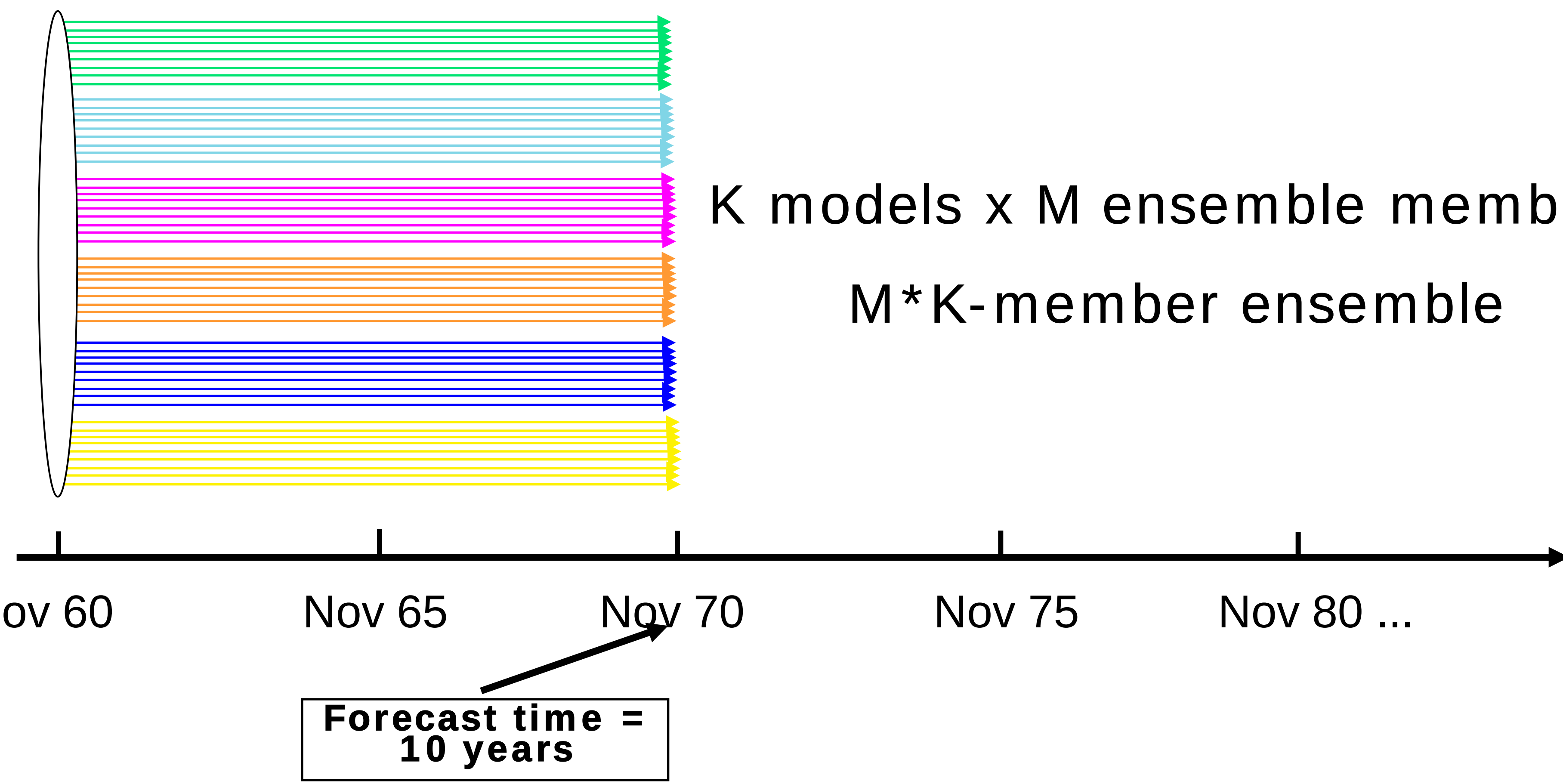

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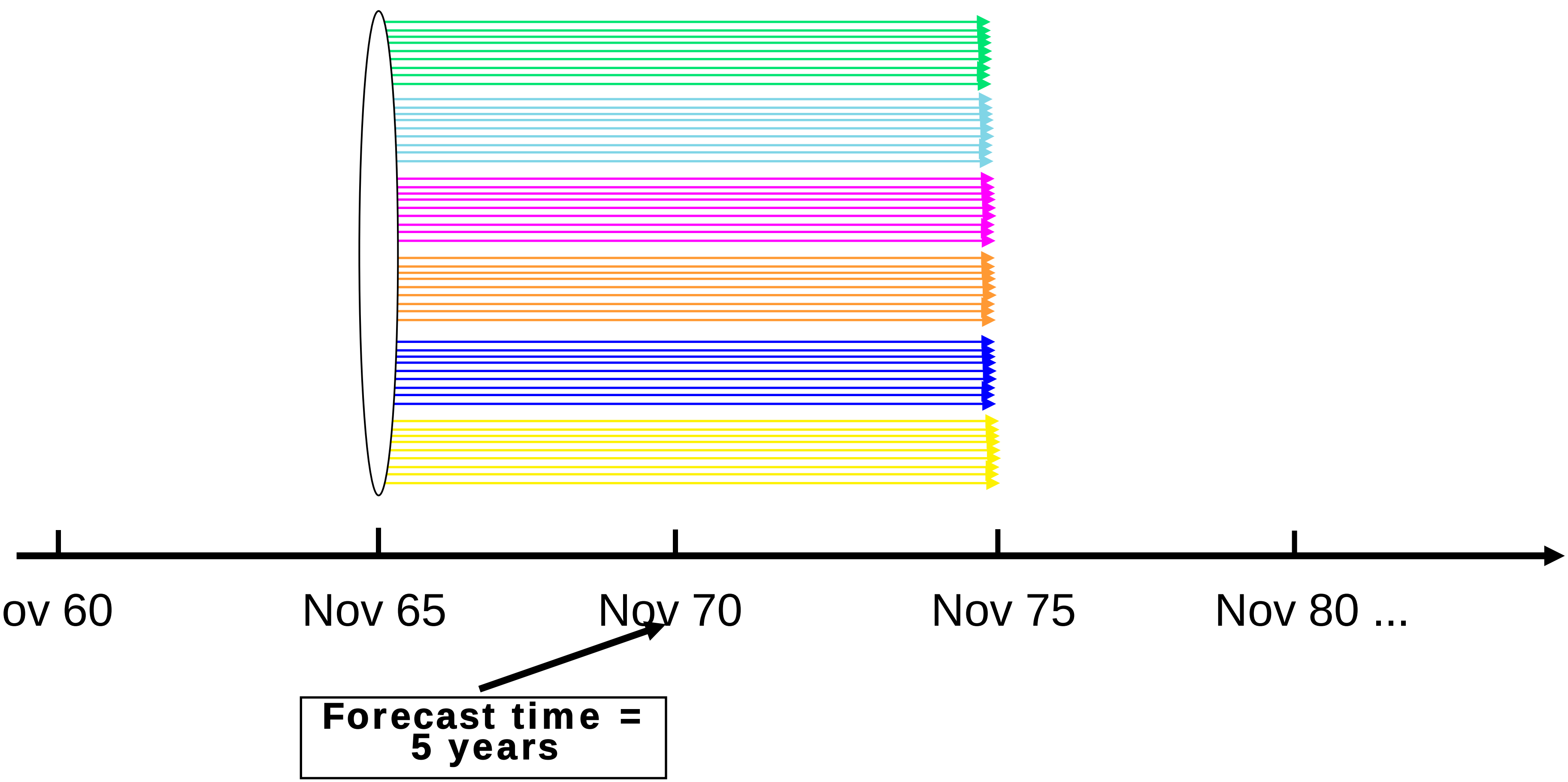
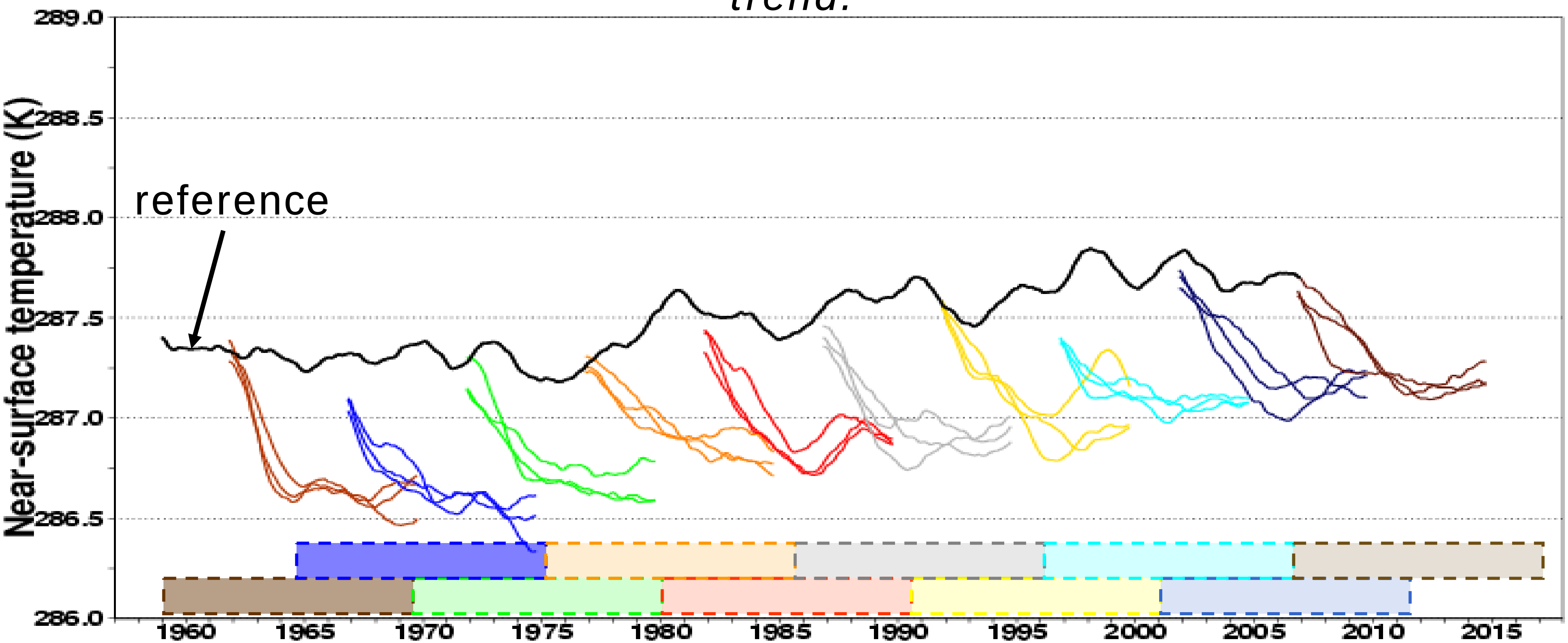


ECMWF global-mean temperature

Global mean near-surface air temperature (2-year running mean applied) from 3-member ensemble IFS/HOPE re-forecasts. Each hindcast is shown with a different colour. ERA40/OPS is used as reference.

Note the cold bias of the model and the overestimation of the long-term trend.



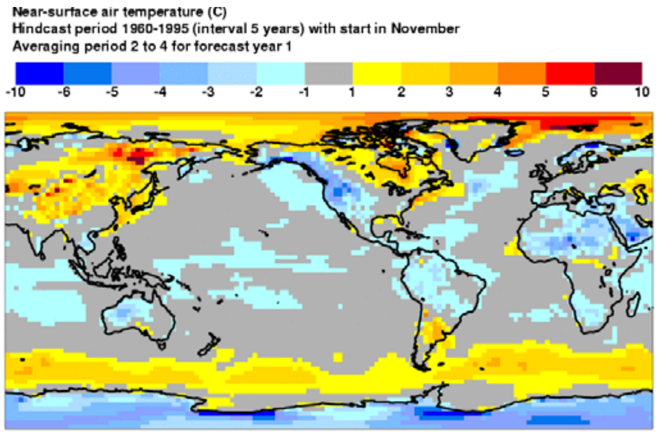
ECMWF systematic error

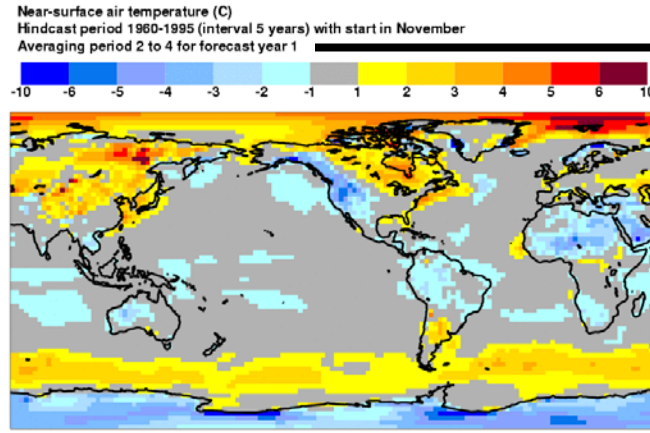
T2m systematic error with respect to ERA40/ERA-Int for 10-year 3-member ensembles started on 1st Nov over 1960 and 1995

NoObs | **Assim**

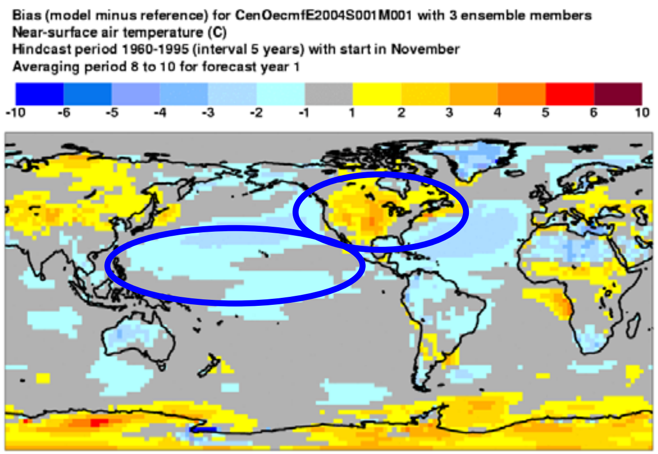
Forecast year

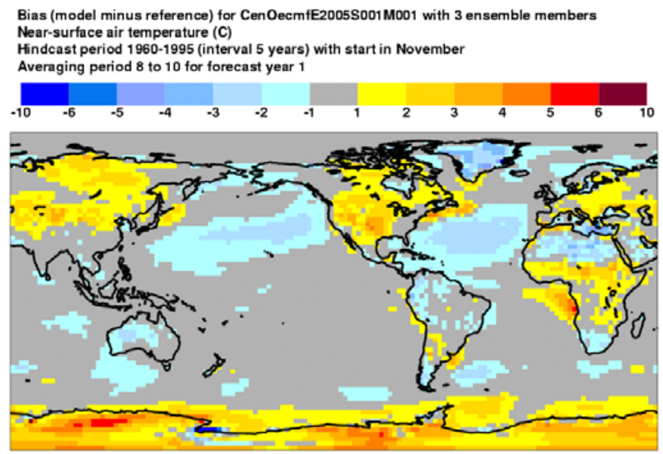
Winter





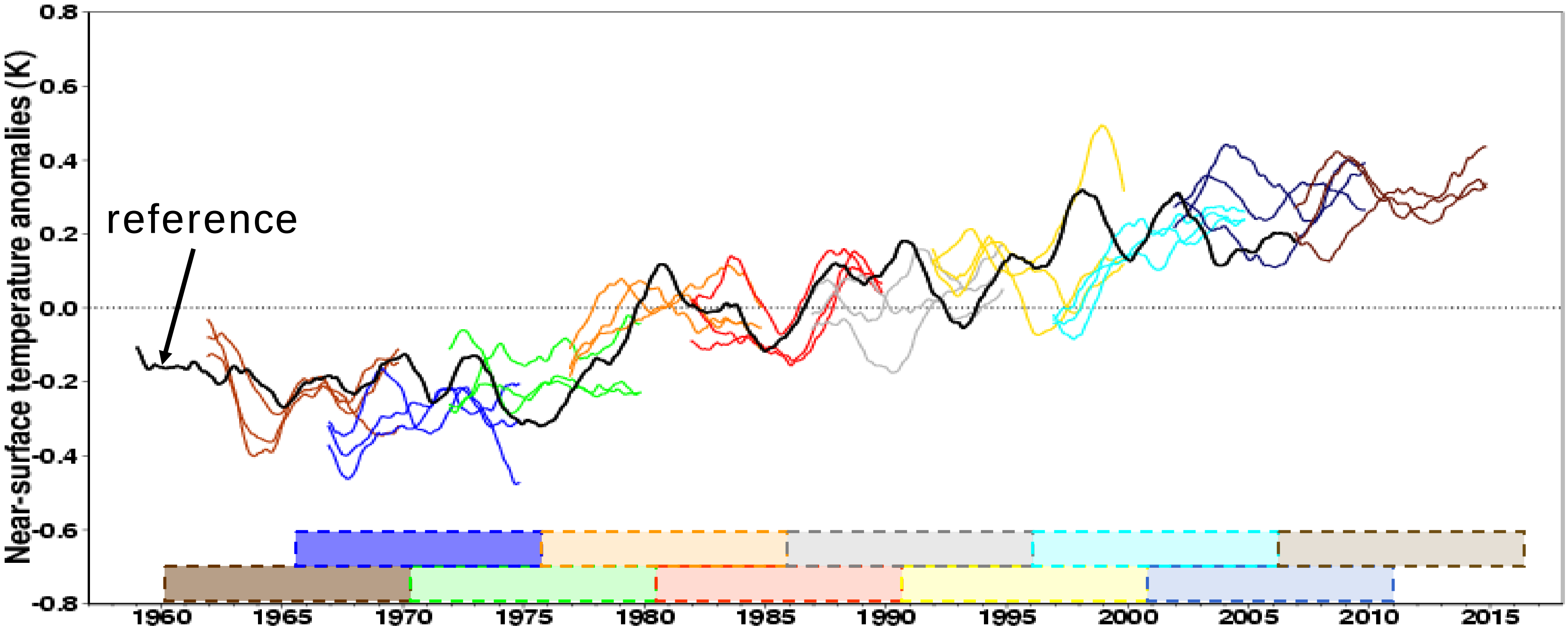
Summer





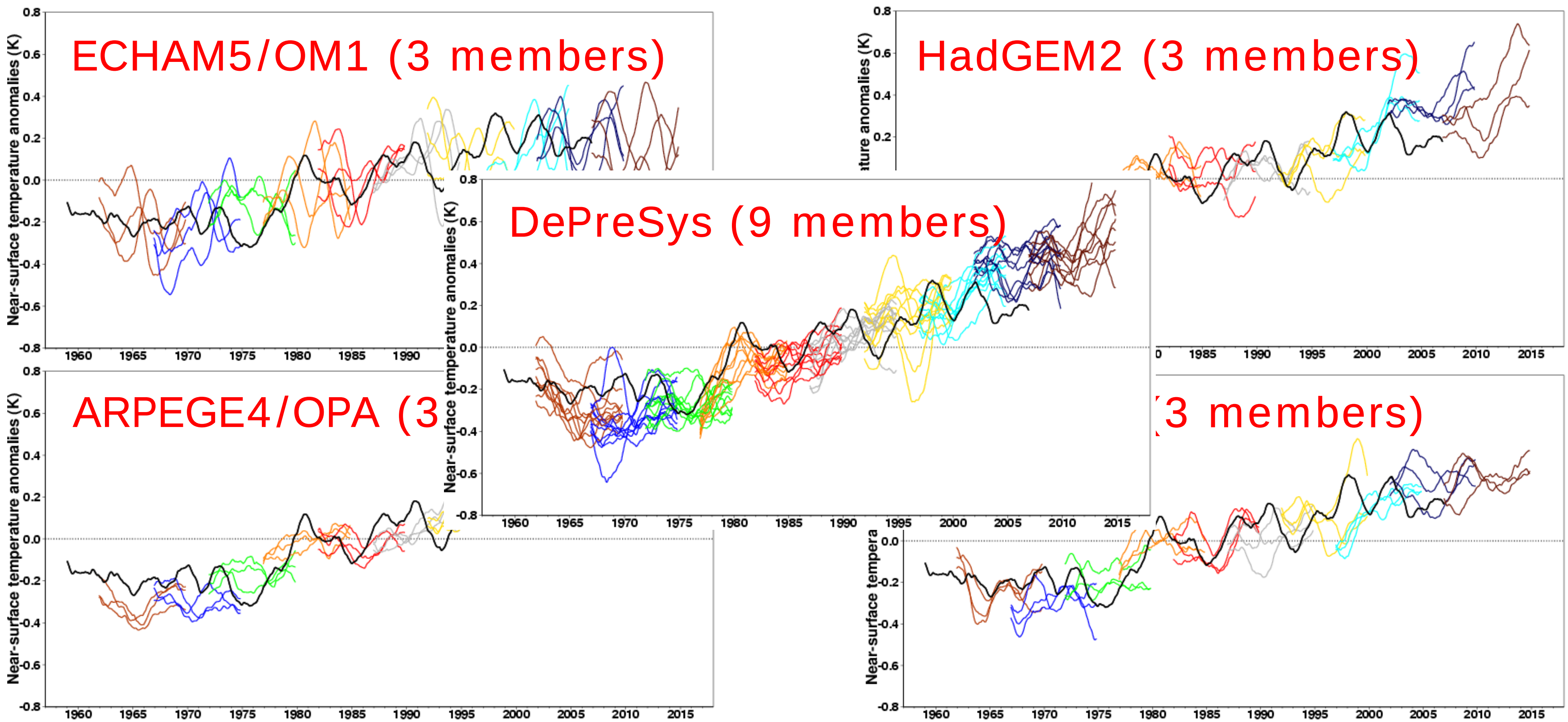
Re-forecast anomalies: global T2m

Global mean near-surface air temperature anomaly (2-year running mean applied) from 3-member ensemble IFS/HOPE re-forecasts. ERA40/OPS is used as a reference. The mean systematic error has been removed over the period 1960-2005.



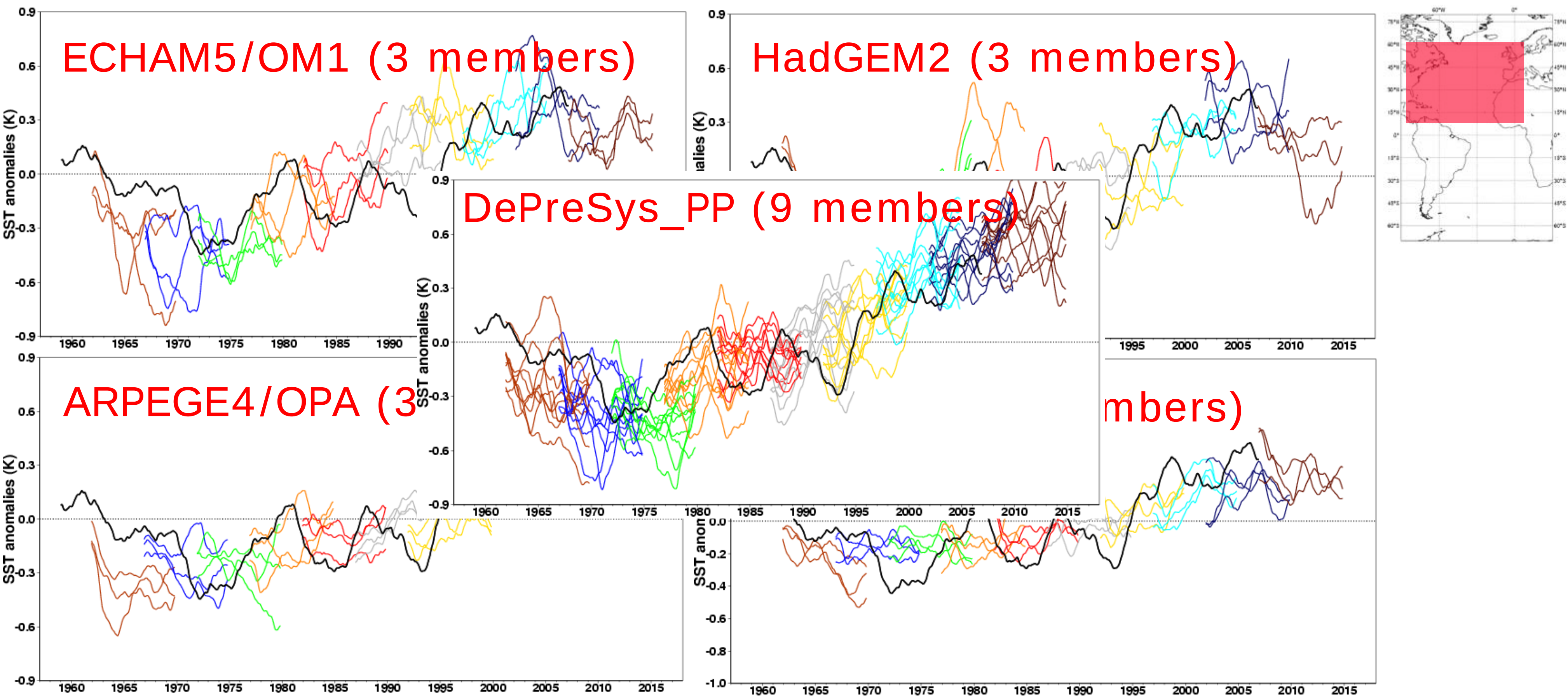
Re-forecast anomalies: global T2m

Global mean near-surface air temperature anomaly (2-year running mean applied) from the ENSEMBLES re-forecasts. ERA40/OPS is used as a reference. The mean systematic error has been removed over the period 1960-2005.



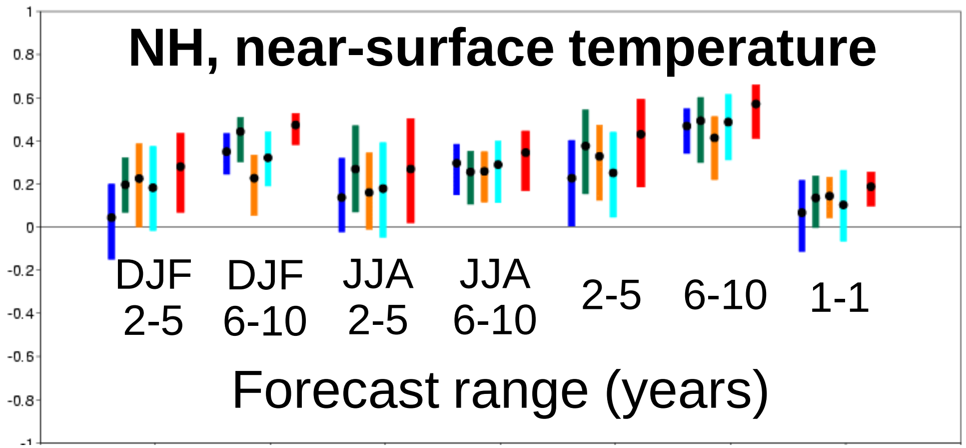
Re-forecast anomalies: ocean

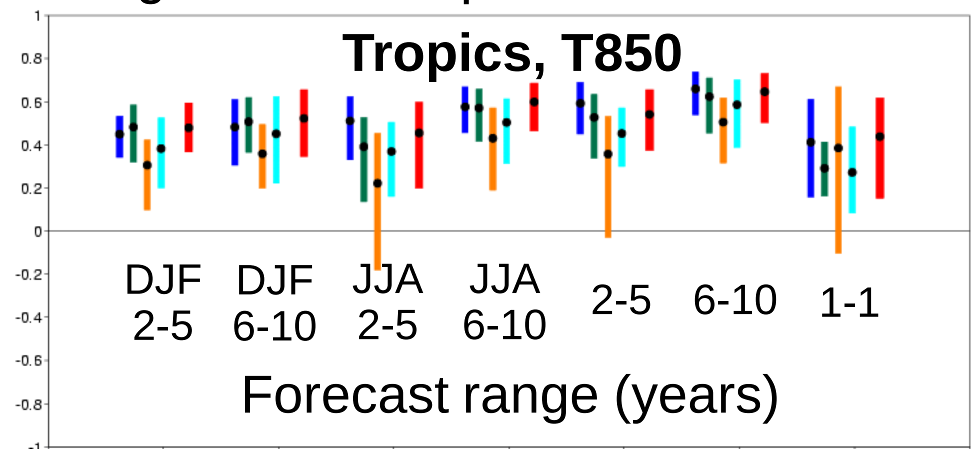
North Atlantic average SST anomalies (2-year running mean applied).
Mean systematic error removed over the period 1960-2005.

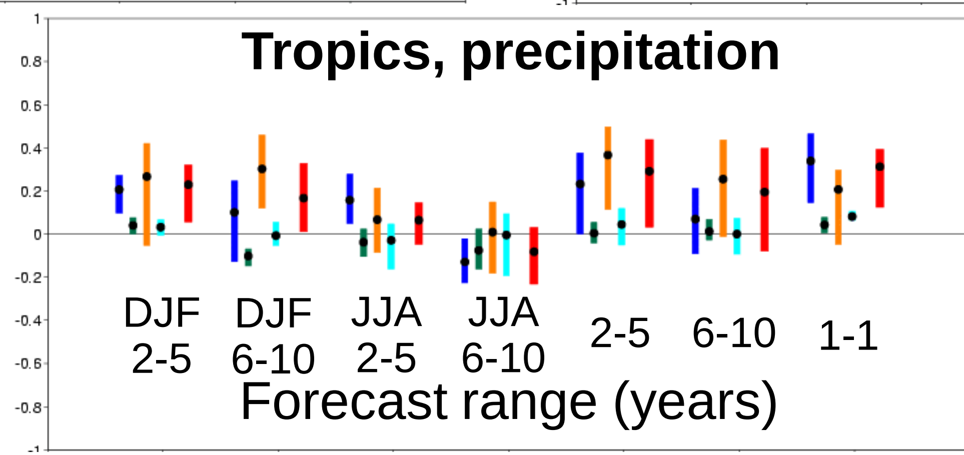


Multi-model: forecast quality

ACC for ECMWF, CERFACS, IfM, HadGEM2 and the multi-model wrt ERA40/ERA-Int of 3-member ensembles started on 1st Nov over 1960-1995. Sample values are shown with black dots along with 95% confidence intervals obtained using a bootstrap method.

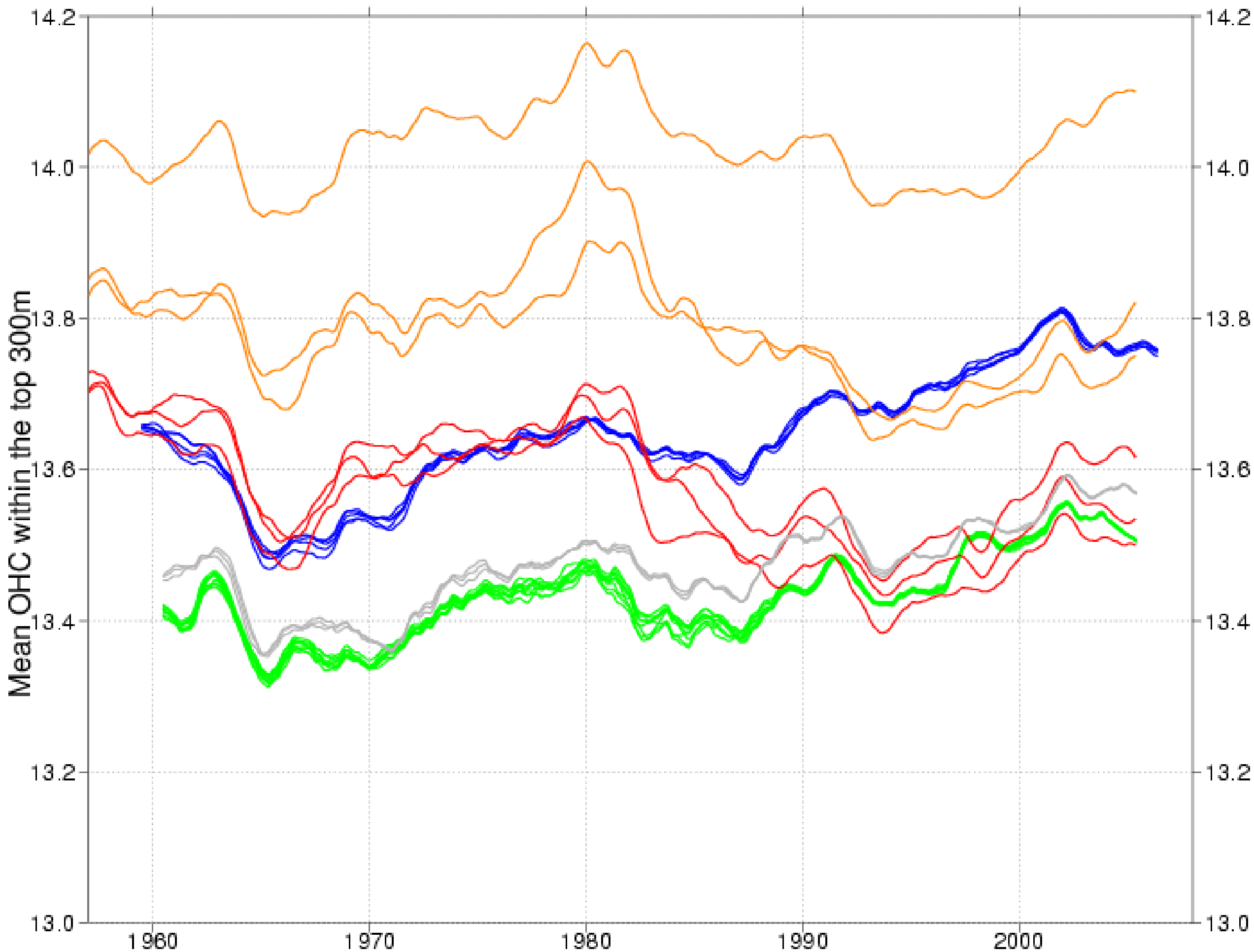






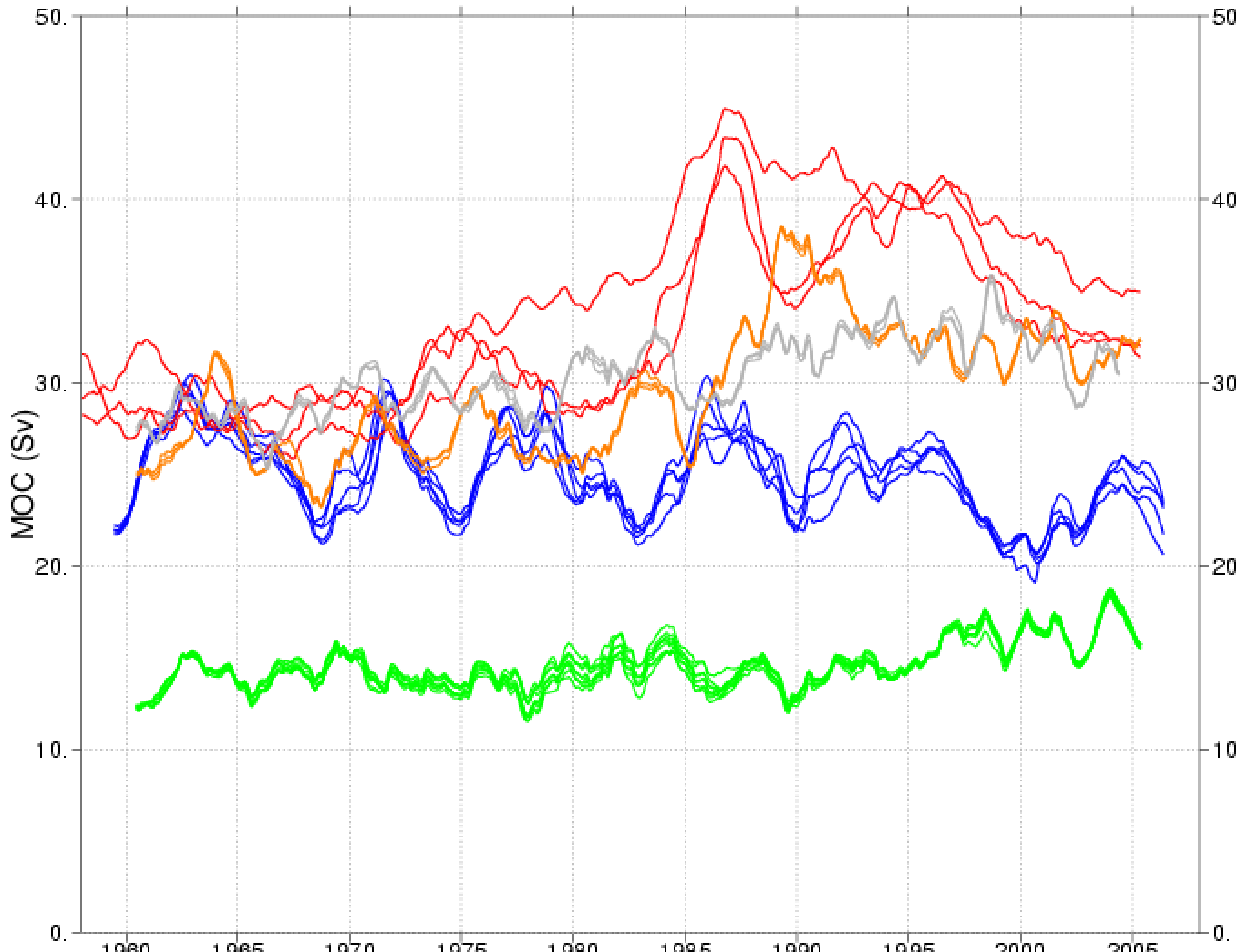
Ocean analyses: OHC

Global ocean heat content (°C) over the top 300 metres from four different ocean analyses: CERFACS (9 members), ECMWF ORA-S3 (5), IfM/anomaly SST nudged (3), IfM/SST nudged (3) and INGV (3).



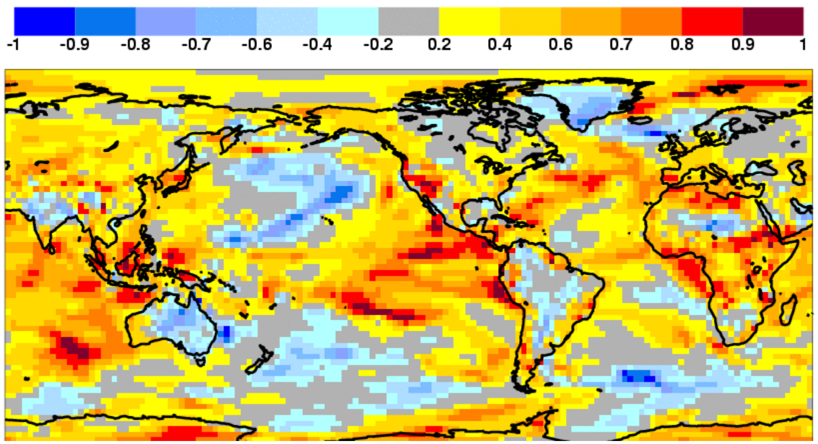
Ocean analyses: AMOC

Atlantic meridional overturning circulation intensity estimates from five different ocean analyses: CERFACS (9 members), ECMWF ORA-S3 (5), IfM (3), INGV (3) and Met Office HadGEM (3).



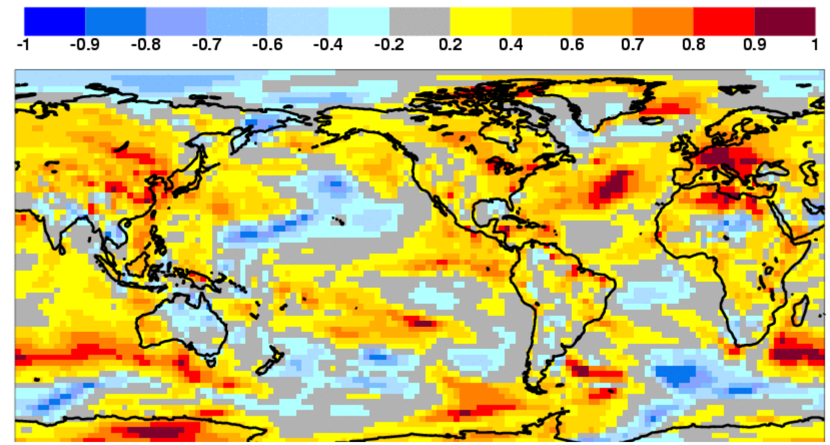
ECMWF: impact of ocean obs.

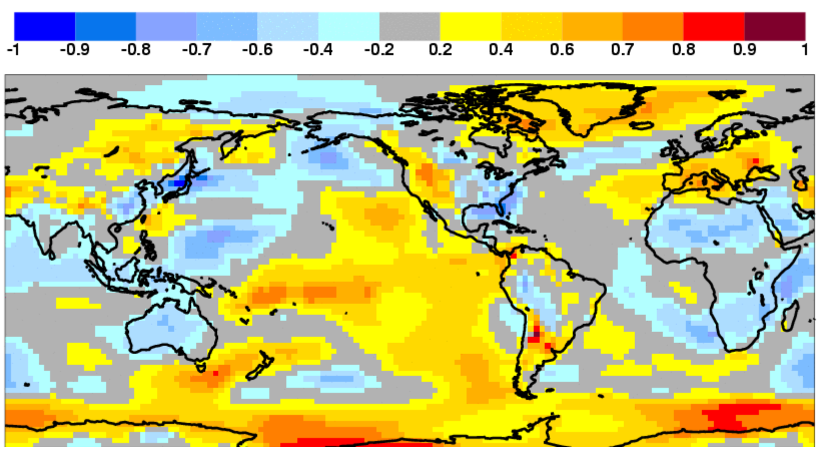
Correlation of annual mean Assim (left) and NoObs (right) wrt ERA40/ERA-Int of 3-member ensembles started on 1st Nov over 1960-1995.



Near-surface air temperature ACC

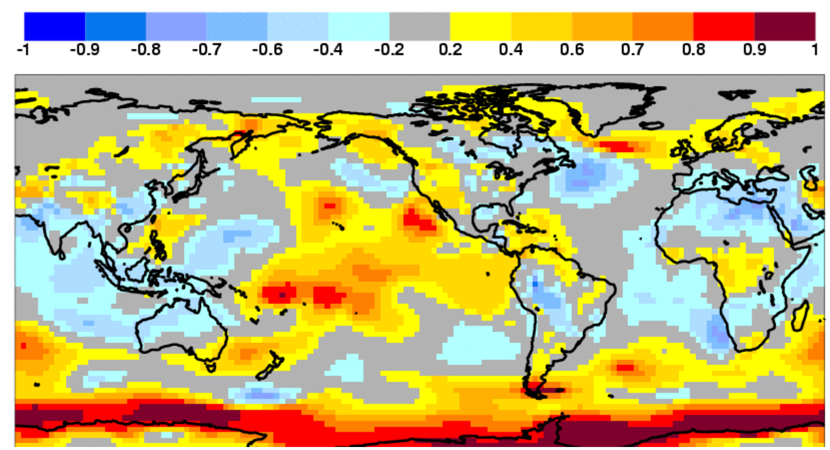
Years 2-5





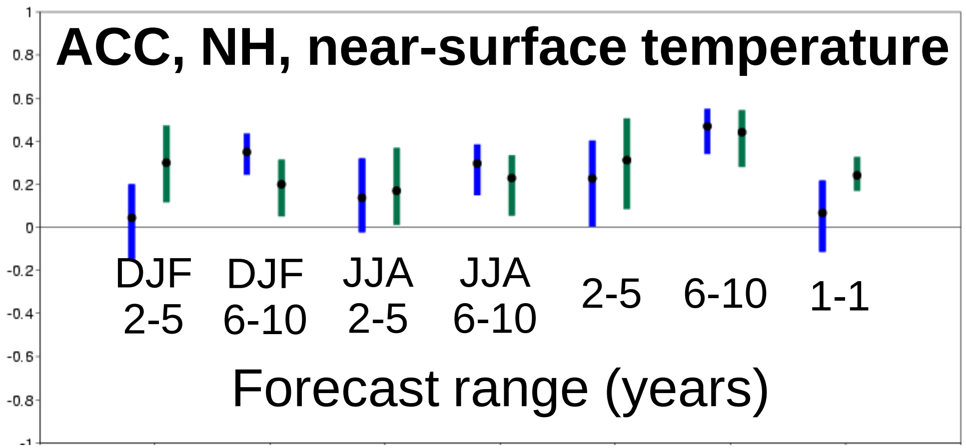
MSLP ACC

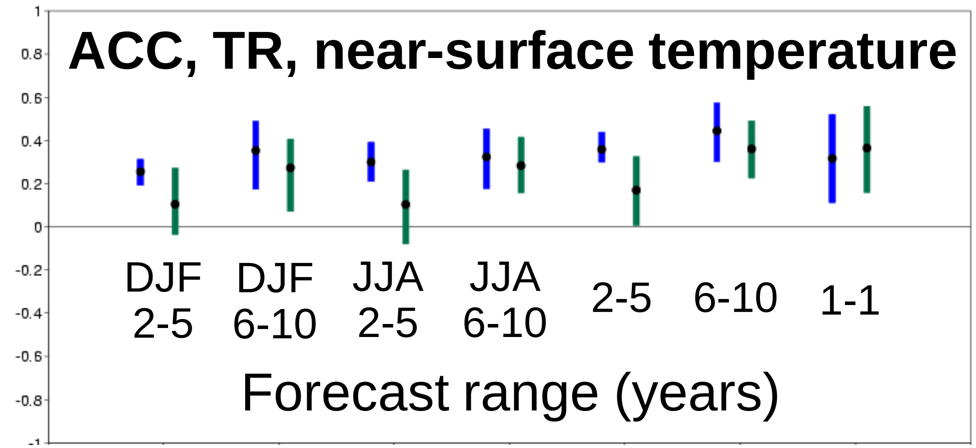
Years 2-5



ECMWF: impact of ocean obs.

T2m grid-point scores (ACC and perfect-model ACC, or ACP) for Assim and NoObs wrt ERA40/ERA-Int of 3-member ensembles started on 1st Nov over 1960-1995. Sample values are shown with black dots along with 95% confidence intervals obtained using a bootstrap method.

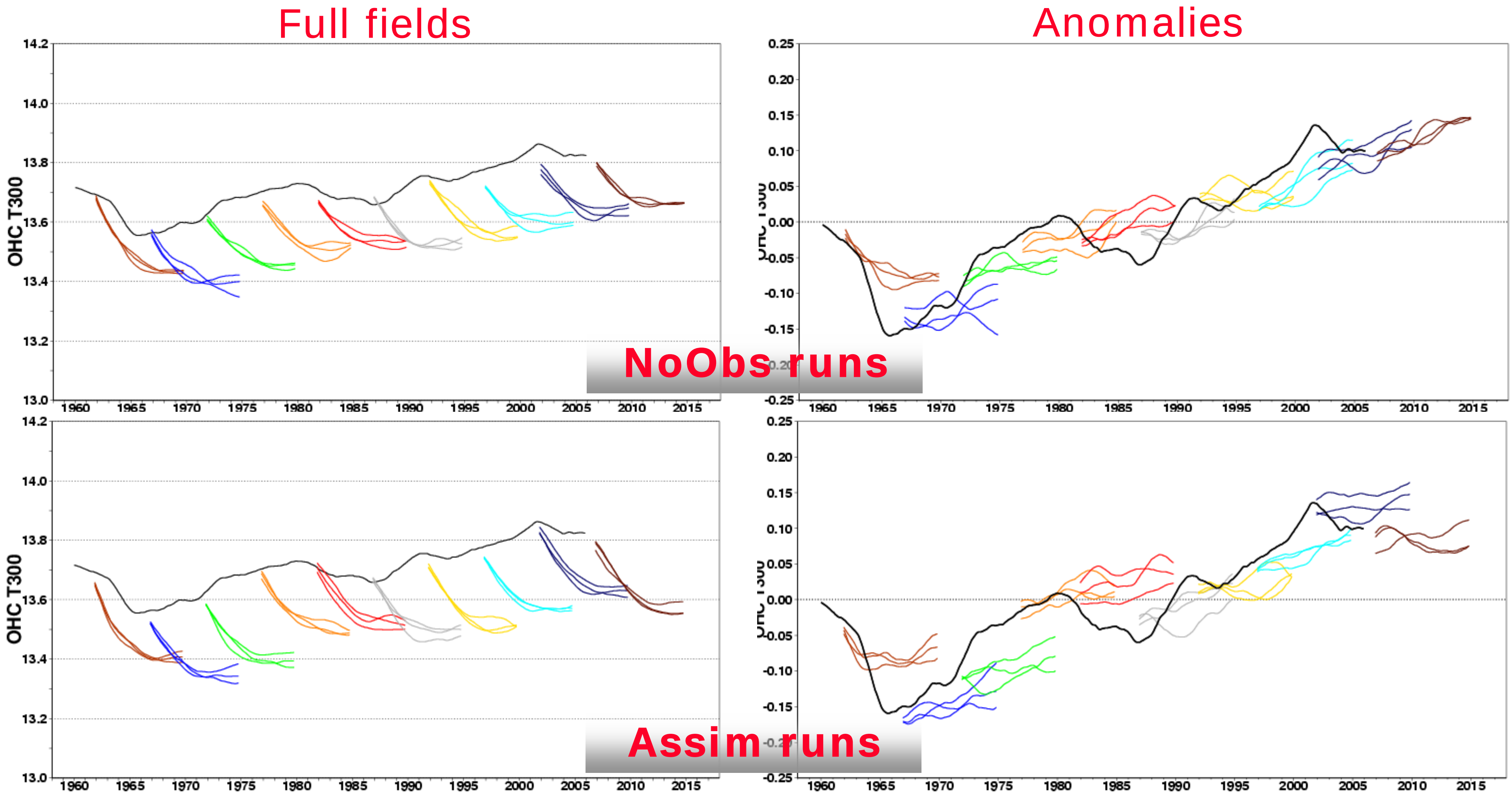




ECMWF: impact of ocean obs.

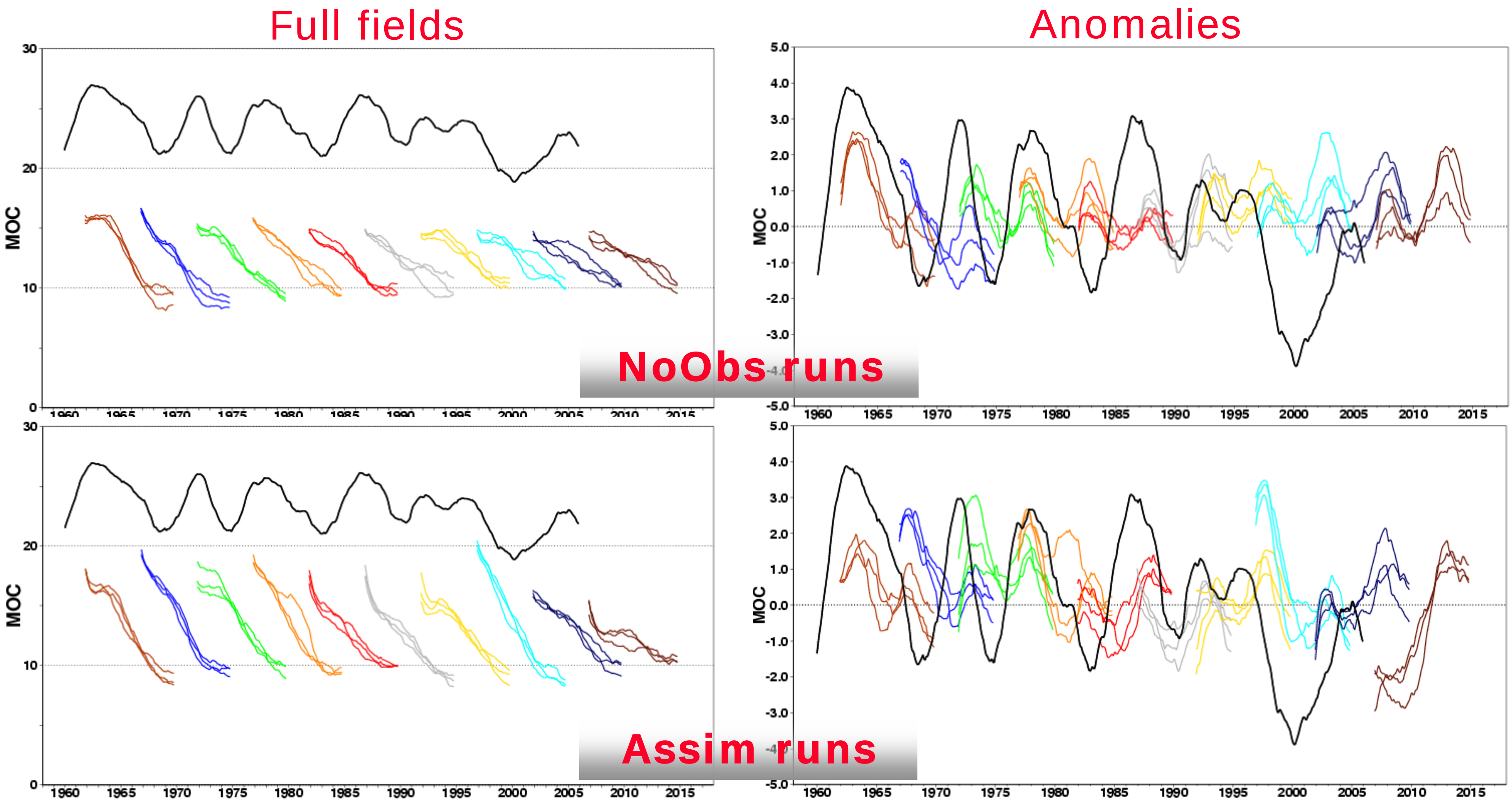
ENSEMBLES

Global ocean heat content (°C) over the top 300 m for the ECMWF decadal forecasts (2-year running mean applied) wrt ORA-S3 ensemble mean.



ECMWF: impact of ocean obs.

Atlantic meridional overturning circulation (AMOC) intensity estimates for the ECMWF decadal forecasts (2-year running mean applied).



Summary decadal forecasts

- ENSEMBLES has done a large set of multi-model and perturbed parameter decadal ensemble forecasts.
- Substantial systematic error can be found even for systems with anomaly initialization. It is not clear how much benefit can be obtained from initial conditions in the presence of large systematic error.
- Uncertainty in ocean circulation and thermal structure in re-analyses is large; this affects the build up of a useful reference dataset for validation and forecast verification.
- Global and regional mean near-surface air temperature is well predicted, though the improvement with initialization is low. Ocean decadal variability shows some skill. Other variables have very low skill beyond the first year.

S2d archiving and dissemination