Model error and seasonal forecasting

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with thanks to Paco Doblas-Reyes and Tim Palmer

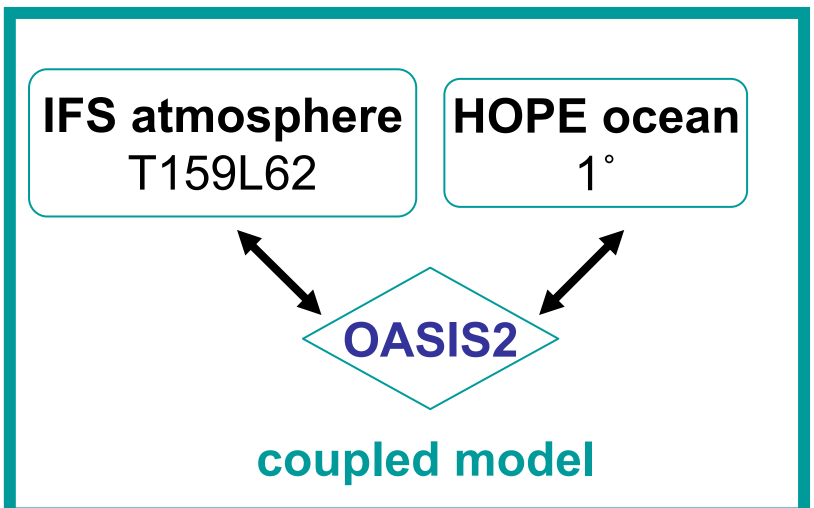
- **Model error and model uncertainty in seasonal forecasts**
  - How big are typical errors?
  - linear statistical approach to model error
  - pragmatic approach to model uncertainty
  - physical approach to model error
  - stochastic physical parameterisation approach
- **Model error on decadal and longer time scales**

Seasonal forecasts are extended-range probabilistic forecasts with atmosphere-ocean climate models initialised from analysed states

DEMETER: European multi-model ensemble for seasonal predictions; 7 GCMs each with a 9-member IC ensemble, hindcast period 1959/1980-2001

ENSEMBLES: next-generation European multi-model ensemble for seasonal-to-decadal predictions, 5 GCMs à 9 IC members, hindcast period 1960-2005

Seasonal forecasting at ECMWF:



Initialisation each month:
- **ERA-40/oper.analysis**
- **ocean re-analysis ORA-3**

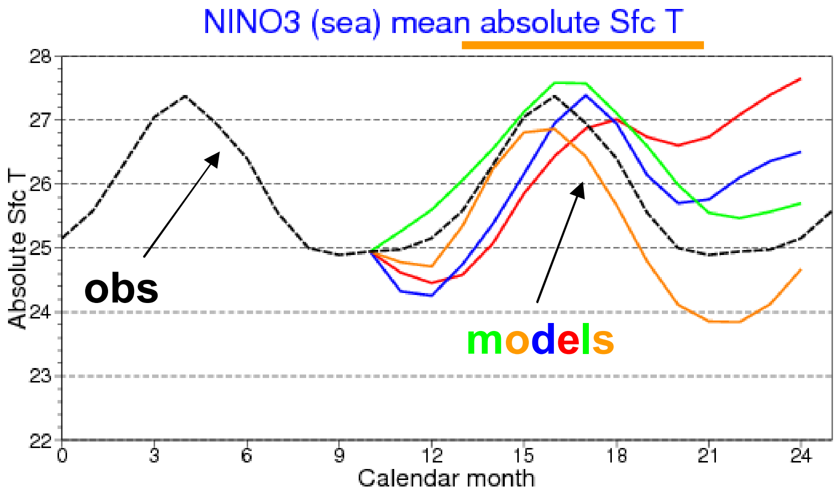
ensemble members by sampling:
- **ocean analysis**
- **singular vectors**
- **stochastic physics**

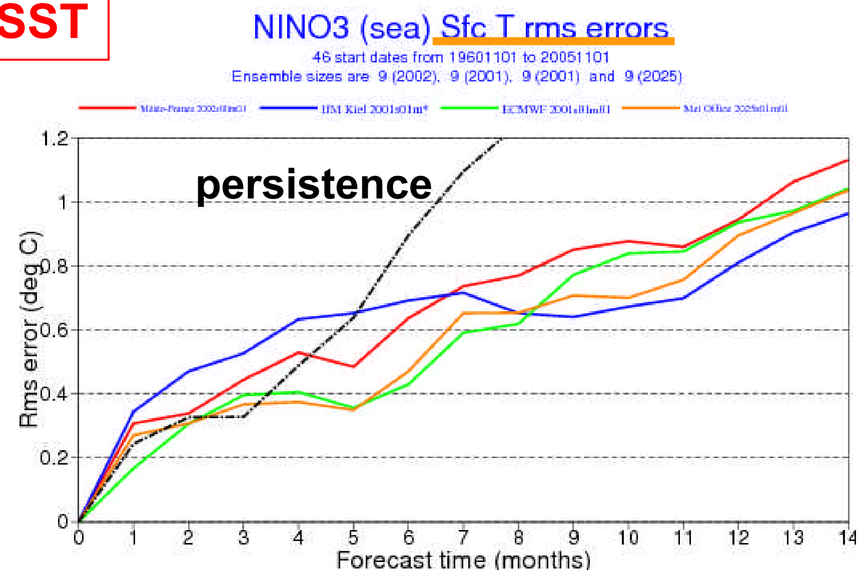
Seasonal hindcasts and forecasts

lead times: up to 14 months

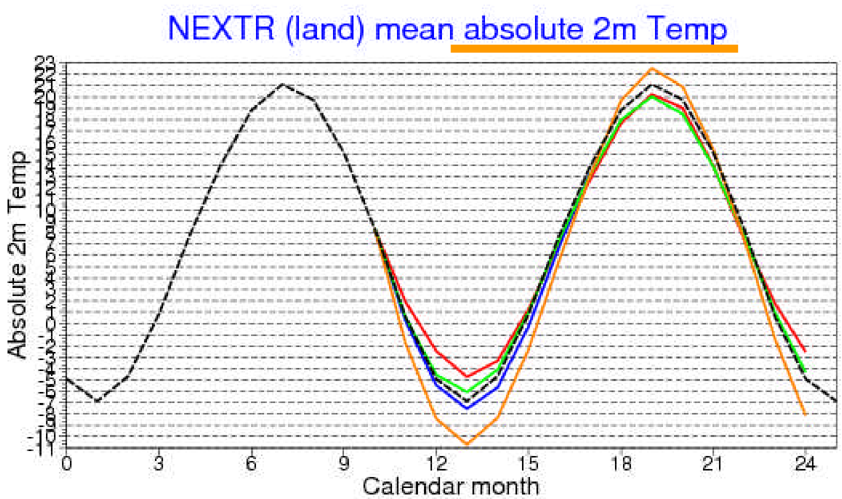
How big are biases and forecast errors in seasonal forecasts?

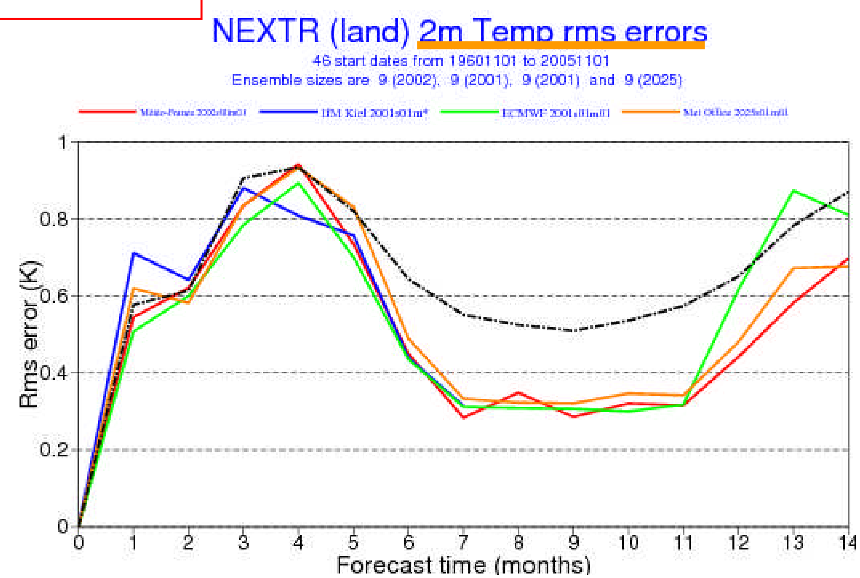
Niño3 SST





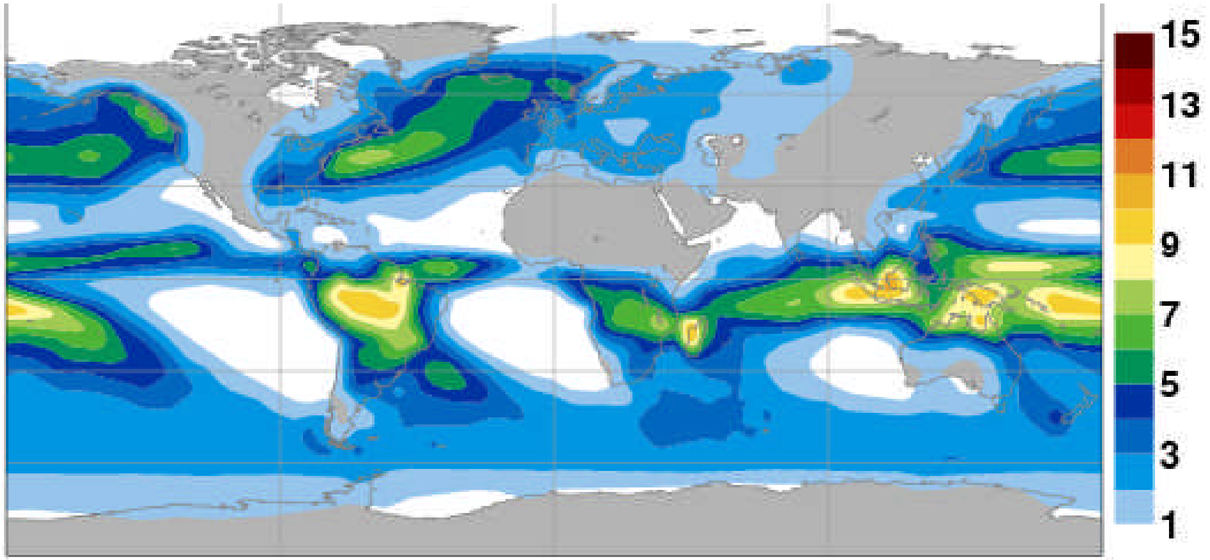
NH extratropics T2m





precipitation

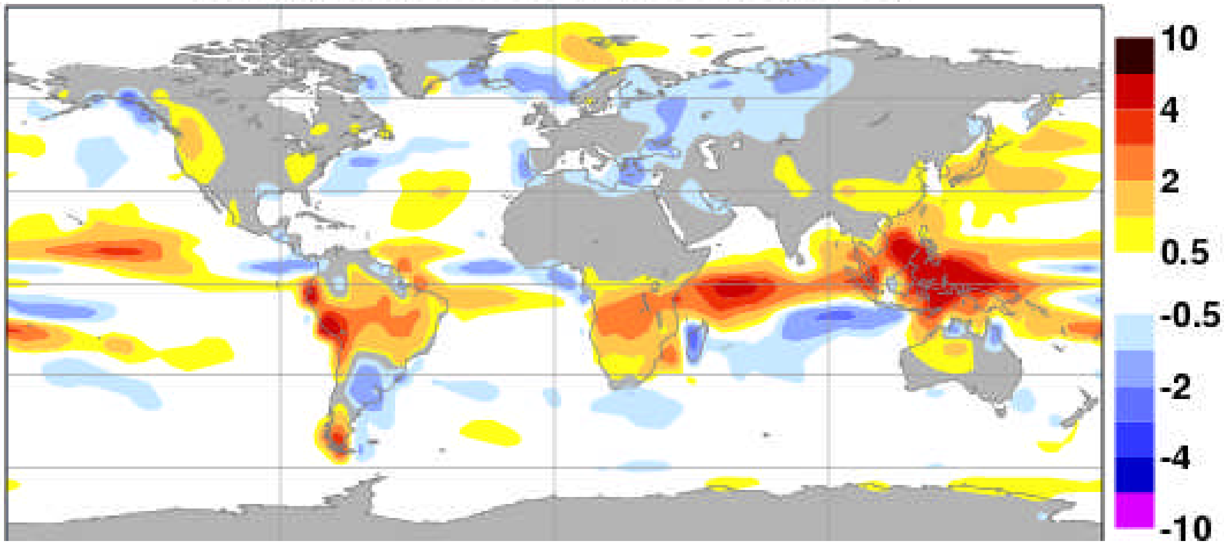
GPCP



mm/day

Precipitation f5us-GPCP (12-2 1991-2005)

model
-
GPCP



Linear statistical approach to model error

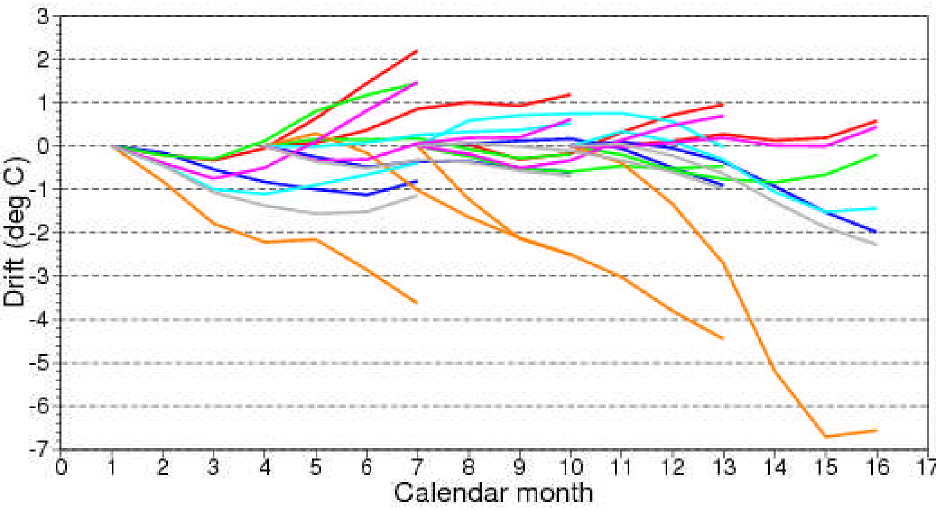
- estimate mean bias/drift from a set of hindcasts
- linearly remove bias from forecasts
- problematic assumptions:

  stationarity

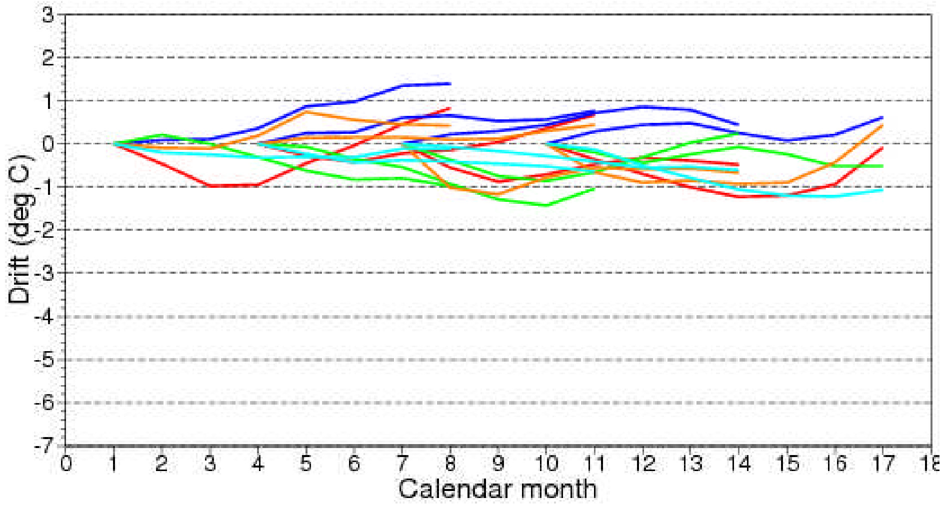
  linearity

model drift in Niño3 SST

DEMETER 7 models



ENSEMBLES 5 models

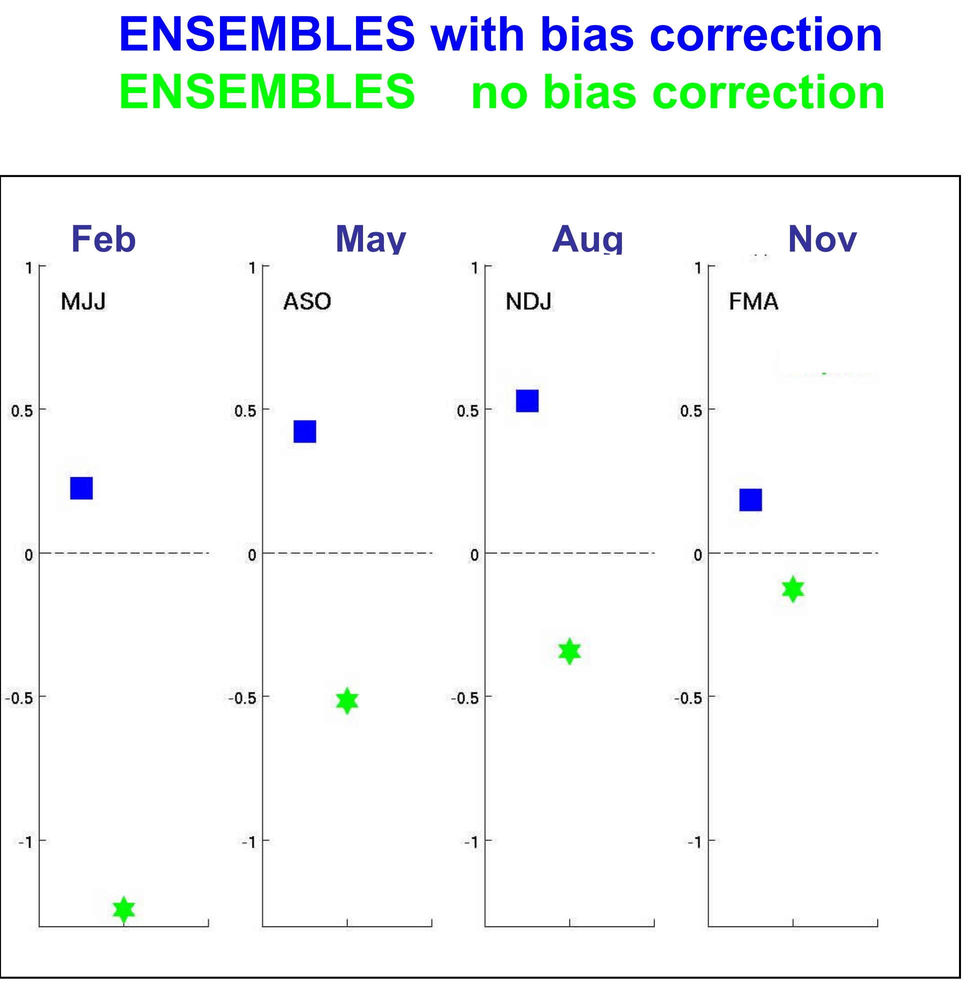


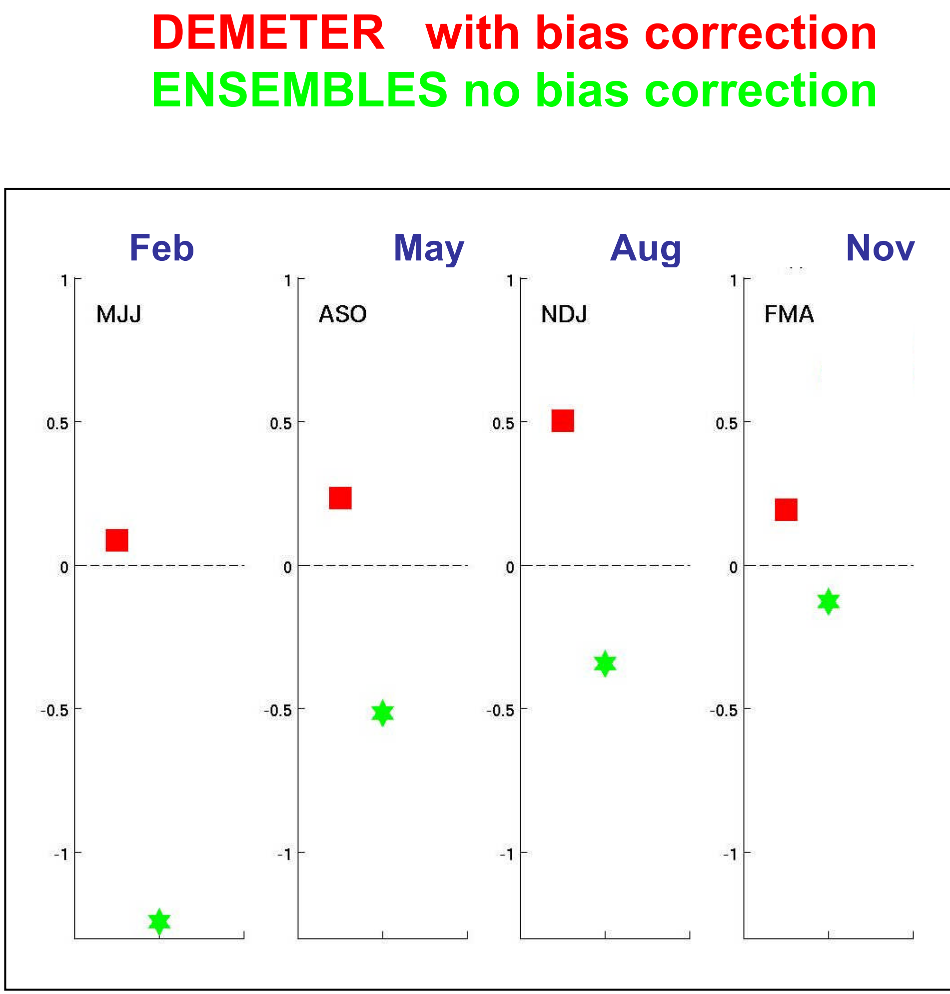
Météo France
ECMWF
Met Office
IFM Kiel
INGV

Niño3 SST hindcasts 1960-2001 upper tercile (warm events) lead time: 4-6 months

ECMWF model

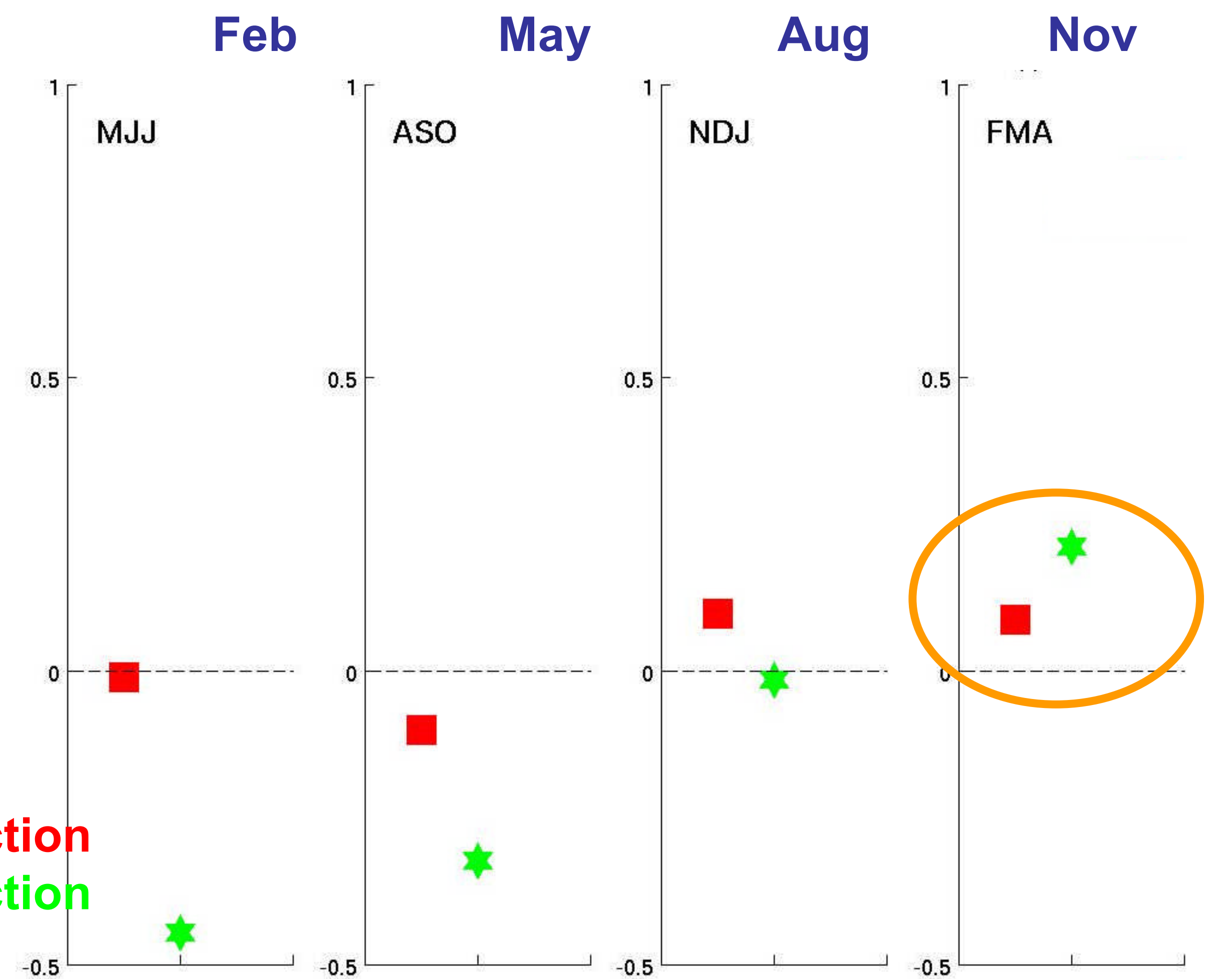
Brier skill score





Niño3 SST hindcasts 1960-2001 upper tercile (warm events) lead time: 4-6 months

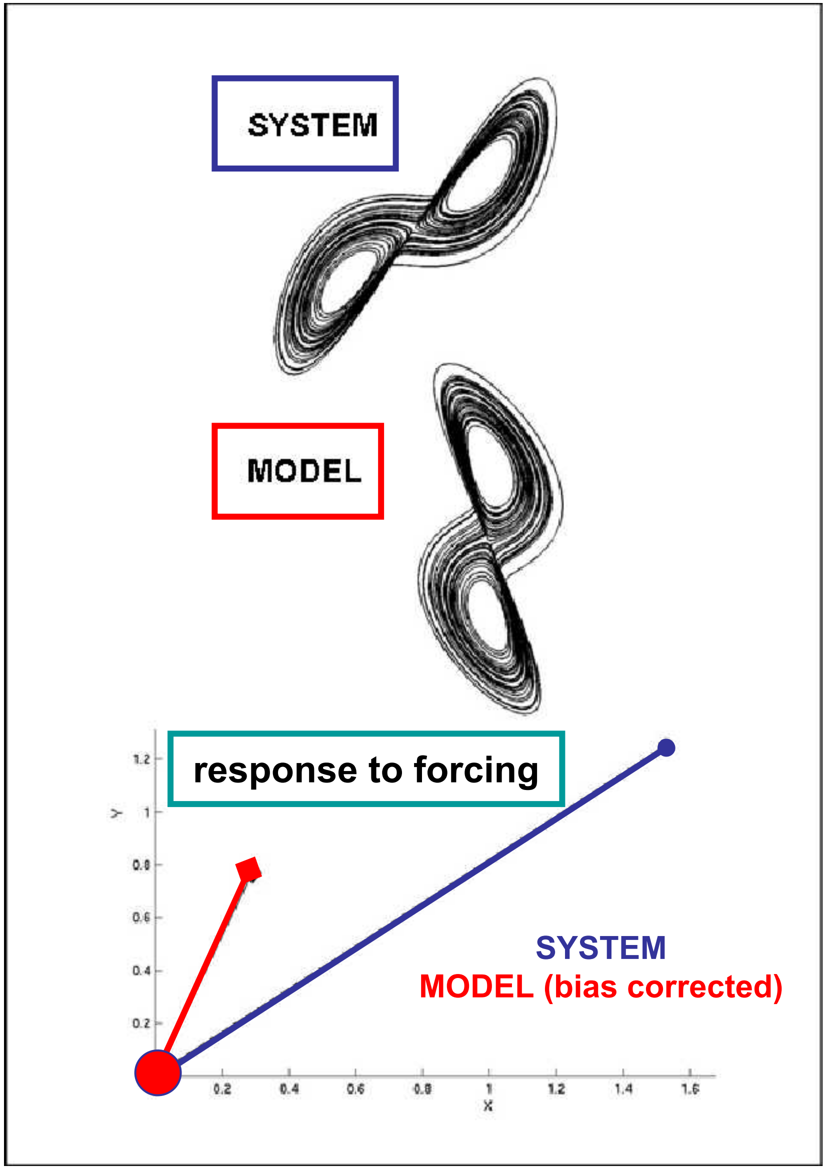
IfM Kiel model



DEMETER with bias correction

ENSEMBLES no bias correction

bias correction in "forced" systems



SYSTEM (Lorenz'63)

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

MODEL

$$\begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \quad \begin{aligned} \dot{X} &= -\sigma X + \sigma Y \\ \dot{Y} &= -XZ + rX - Y \\ \dot{Z} &= XY - bZ \end{aligned}$$

forced SYSTEM (and MODEL)

$$\dot{X} = -\sigma X + \sigma Y + f_0$$
$$\dot{Y} = -XZ + rX - Y + f_0$$
$$\dot{Z} = XY - bZ$$

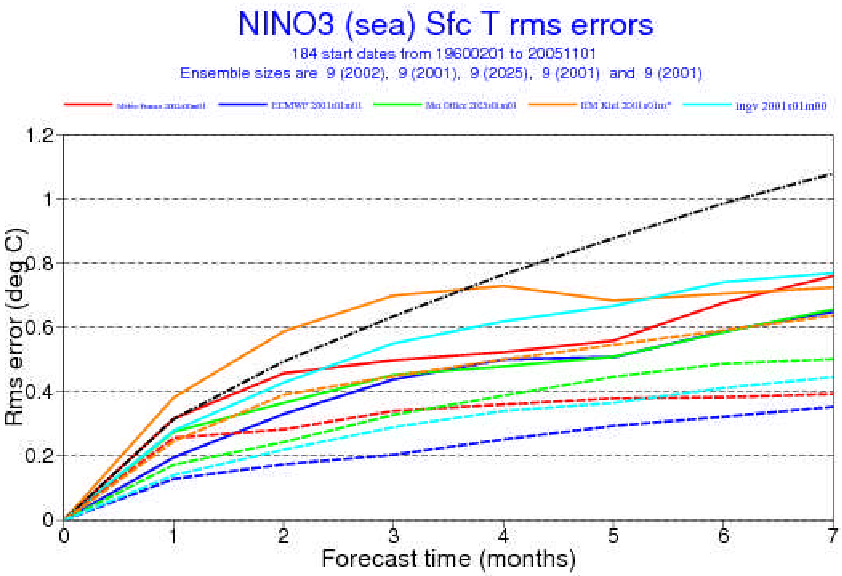
Pragmatic approach to model uncertainty

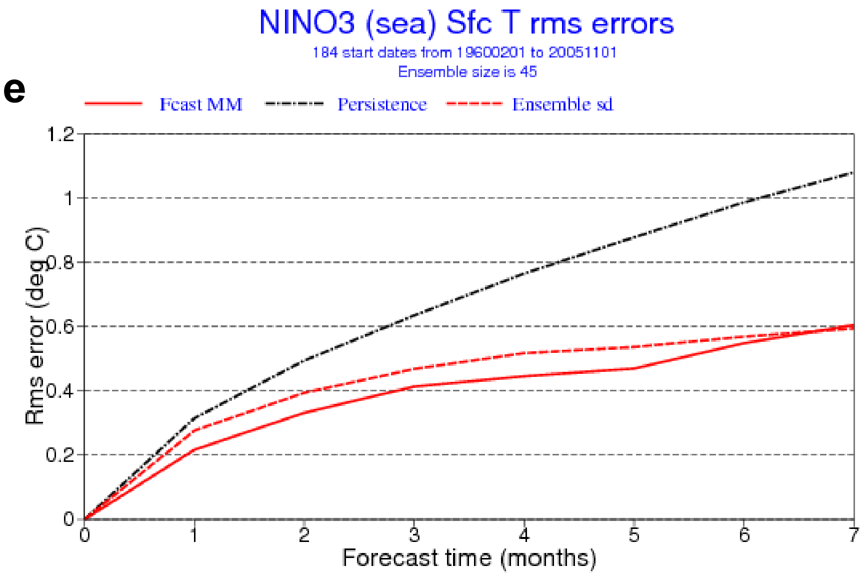
- different models have different errors
- construct a multi-model from quasi-independent forecast models to sample model uncertainty across a range of models
- inherently *ad hoc* approach ("ensemble of opportunity")

individual model ensembles

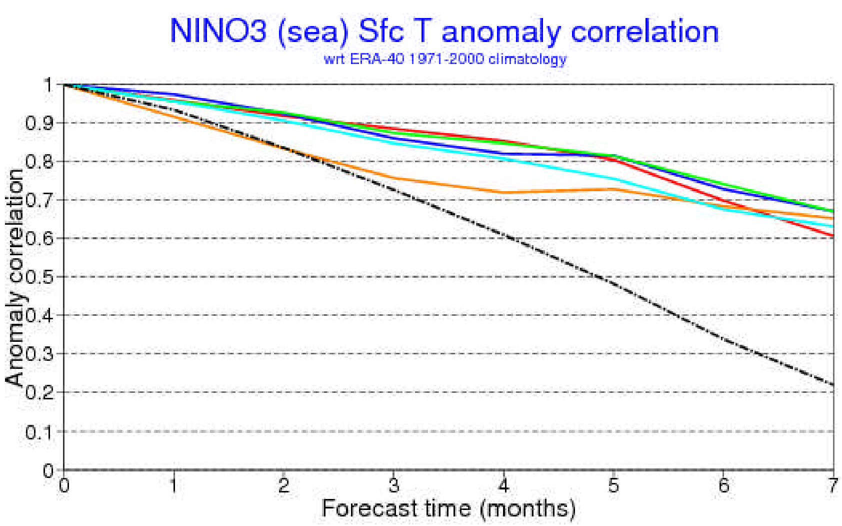
multi-model ensembles

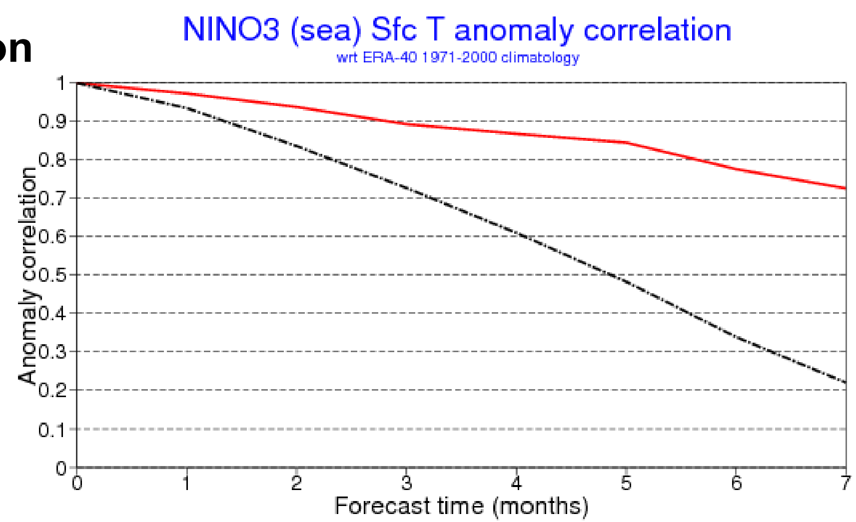
RMSE and ensemble spread





correlation





Multi-model seasonal forecast ensembles are, on average, more skilful than any individual model ensembles due to

- error cancellation
- a reduction of overconfidence/ under-dispersiveness, that is the ensemble spread is widened while the average ensemble mean error is reduced (increased reliability)

  → net gain in prediction skill because probabilistic skill scores penelise overconfidence
- even the addition of an objectively poor model can improve the multi-model skill

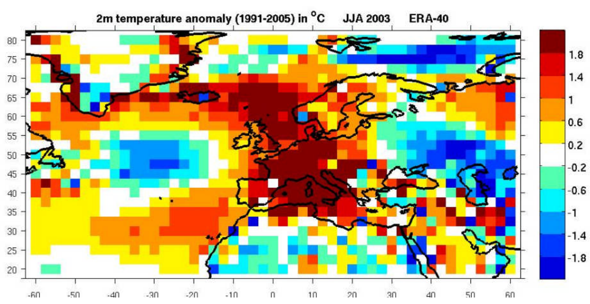
Physical approach to model error

- improve model physics
- critical testing of physical parameterisation schemes
- example: European heat summer 2003

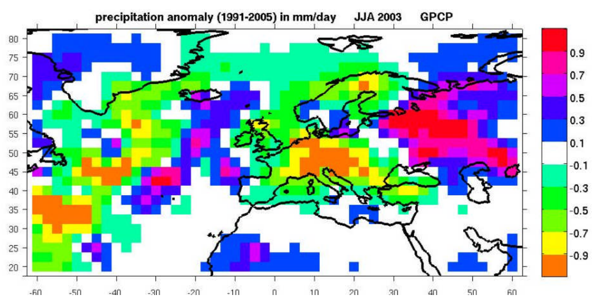
- The summer (JJA) 2003 was the hottest summer on record over Central and Southern Europe
- Conditions were very dry over land
- The atmospheric anomaly had a quasi-barotropic structure with a positive pressure anomaly in the middle troposphere

Was the extremeness of these conditions predictable a few months ahead using a state-of-the-art dynamical seasonal forecasting system?

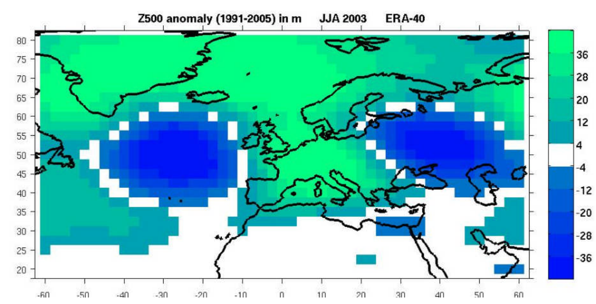
2m temp (ERA-40/oper.anal)



precipitation (GPCP)

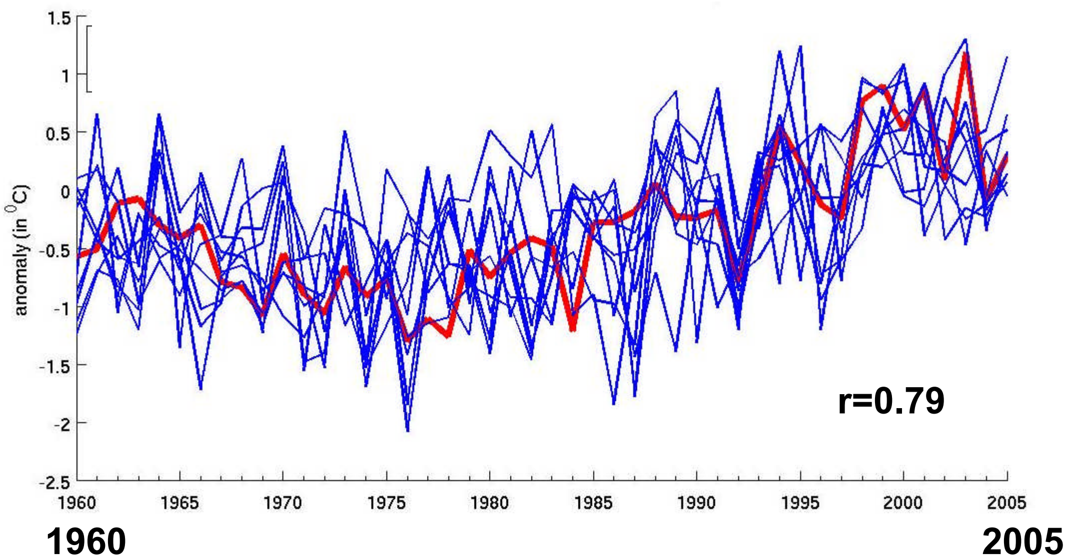


Z500 (ERA-40/oper.anal)



anomalies wrt 1991-2005 climate

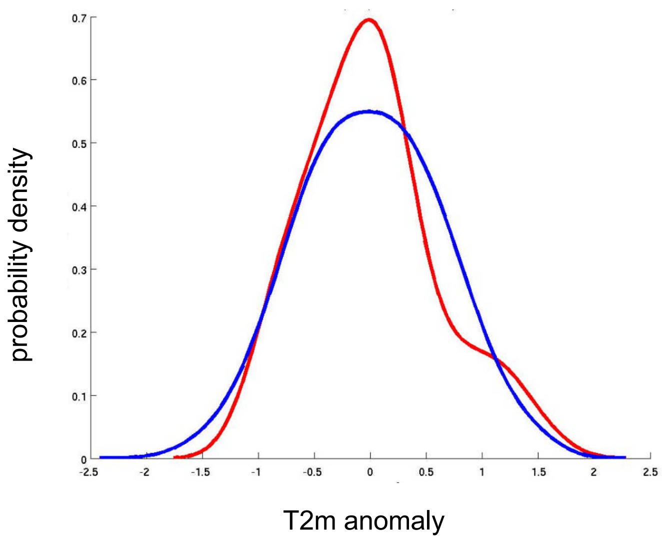
ENSEMBLES seasonal hindcasts for JJA T2m over Southern Europe (land)

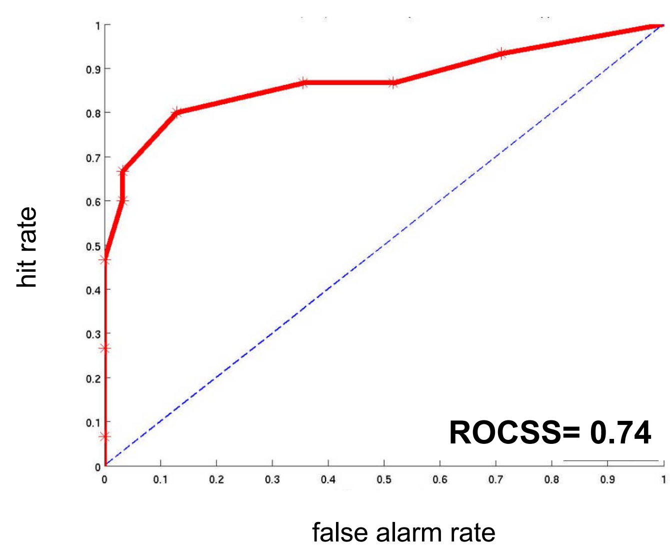


analysis

model

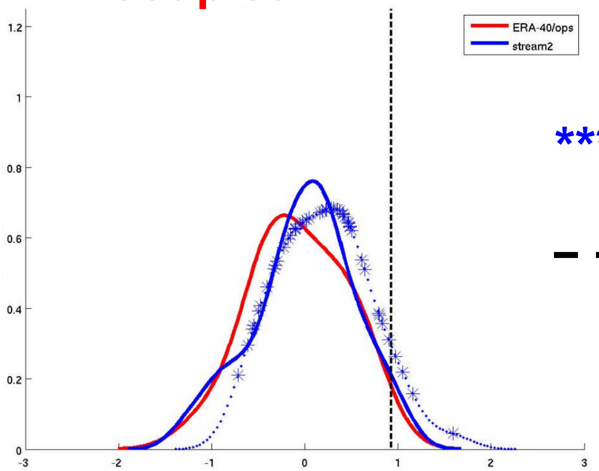
ROC diagrams upper tercile



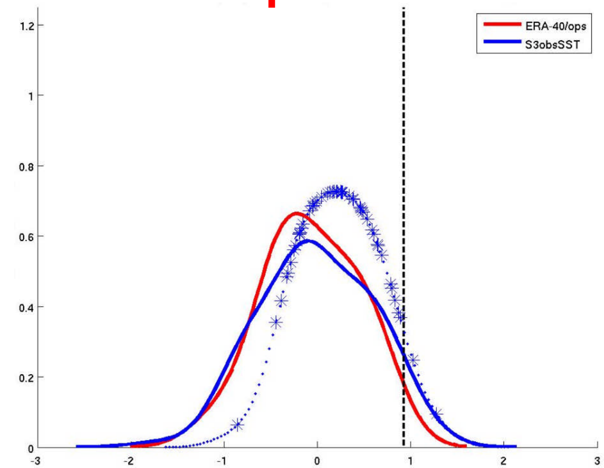


ENSEMBLES hindcasts for JJA 2003

coupled



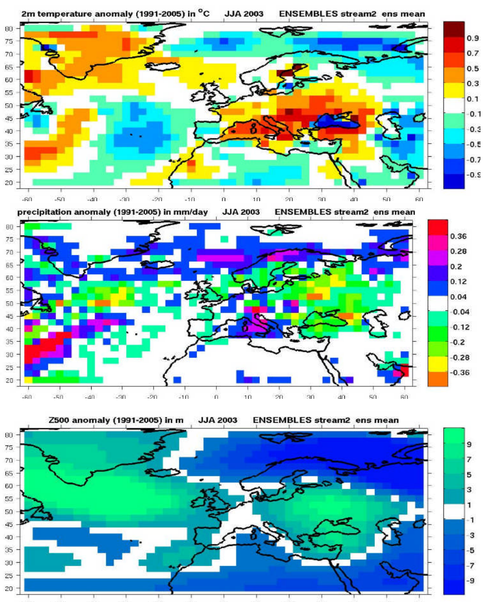
uncoupled



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

- - - - observed anomaly

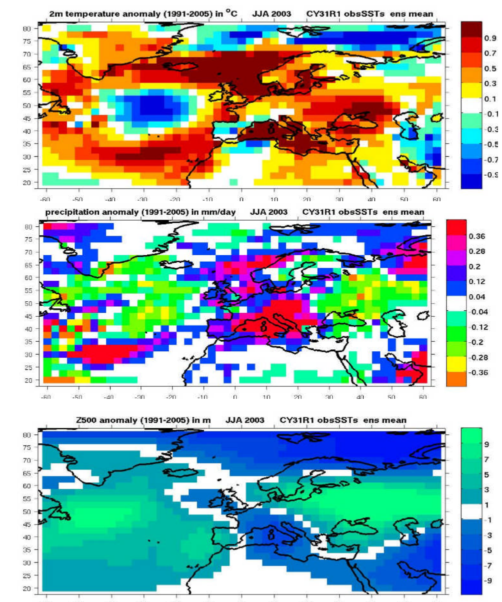
Ensemble mean anomalies



2m temperature

precipitation

Z500



wrong signal!

An improved cycle of the atmospheric model

land-surface

new soil hydrology
H-TESSEL

above PBL

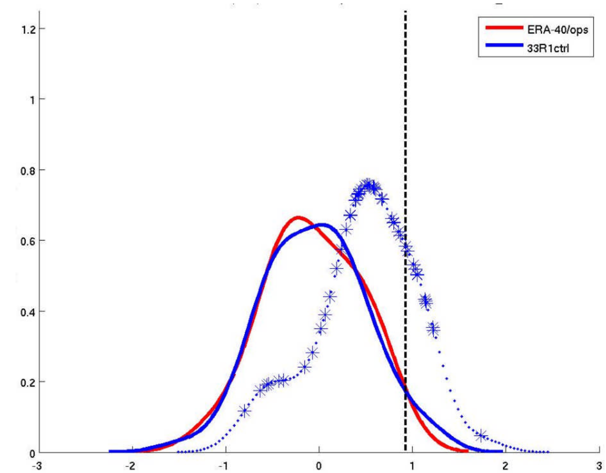
vertical diffusion

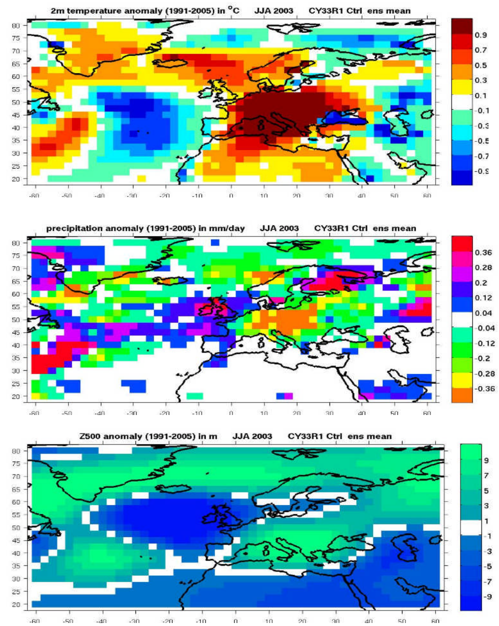
radiation

new SW scheme,
McICA cloud-radiation interaction,
MODIS albedo

convective entrainment
→ more active scheme

convection

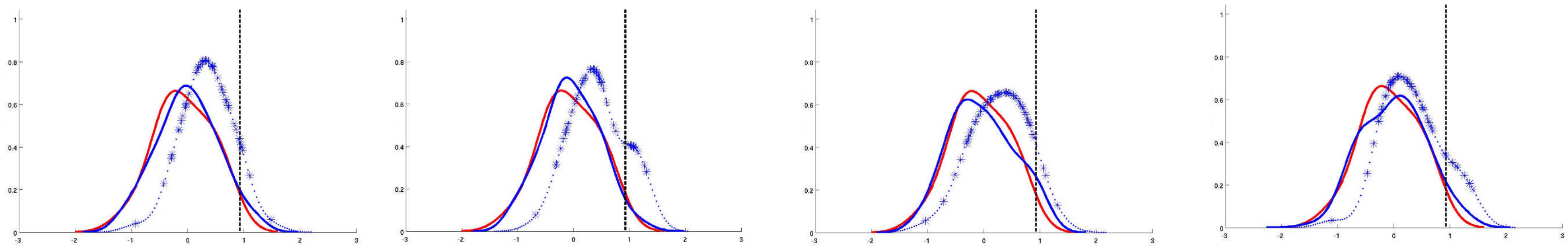


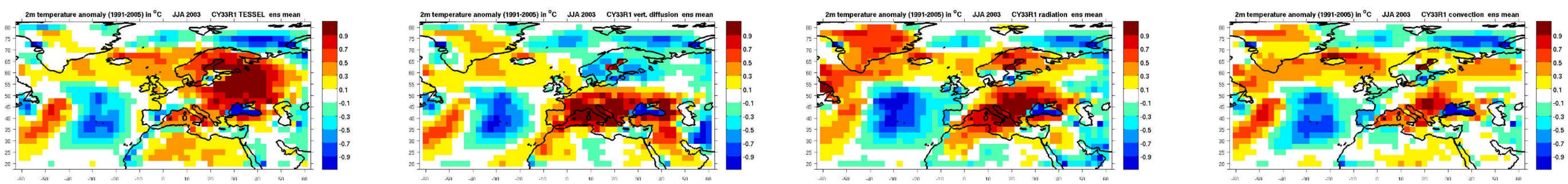


Impact of physical parameterization schemes

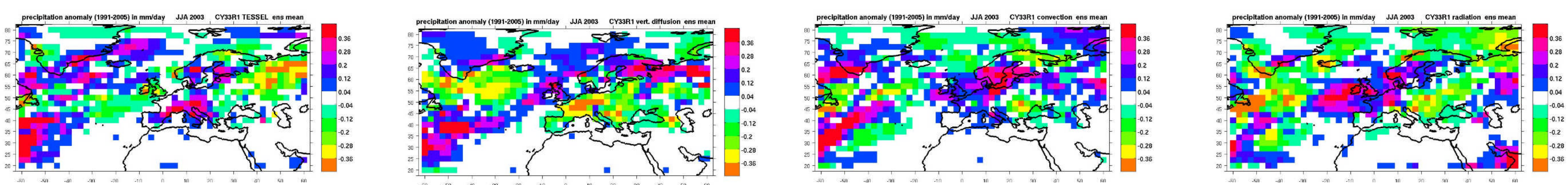
land-surface | vertical diffusion | radiation | convection

T2m





precip



Stochastic parameterisations

- quasi-equilibrium assumption in deterministic bulk-formulation parameterisation schemes
- model uncertainty in physical parameterisation schemes → stochastic physical tendency perturbation
- impact of sub-grid scales on resolved scale dynamics by stochastic backscatter of energy

3.1 Revision of the stochastic tendency (STPH) scheme

Operational scheme $dX_p = (1 + r_X)\, dX_c$	Revised scheme $dX_p = (1 + \mu r)\, dX_c$
Random numbers r_X constant in 10° by 10° lat/lon boxes, and for 6 model time steps (4.5h in T399)	Random pattern r varies smoothly in space and time, with de-correlation scales 500 km and 6 h
Uniform distribution between −0.5 and +0.5	Gaussian distribution with stdev 0.5 (limited to ±3stdev)
Independent random numbers r_X for $X=T, q, u, v$	Same random number r for $X=T, q, u, v$
Perturbations in entire column	No perturbations in lowest 300 m and above 50 hPa ($0 \le \mu \le 1$)

two-scale version in seasonal forecasting with de-correlation scales of 2500 km and 30 d

Buizza, Palmer and Miller (1999)

Leutbecher et al. (2009)

3.1 Stochastic back-scatter spectral (BS) scheme

- Rationale: a fraction of the dissipated energy is backscattered upscale and acts as streamfunction forcing for the resolved-scale flow (*Shutts & Palmer* 2004, *Shutts* 2005, *Berner et al* 2009)

- Stream-function forcing is given by:

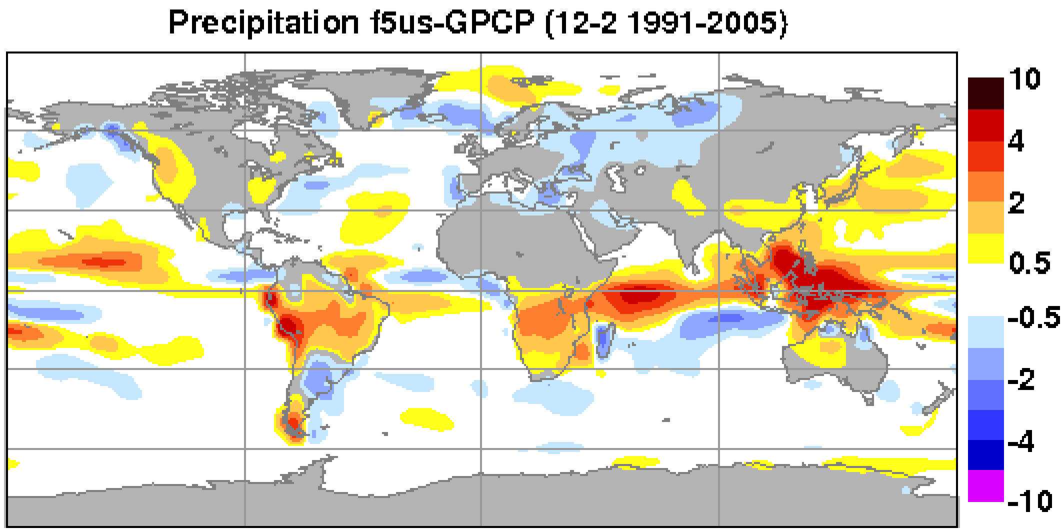
$$\hat{F}_{\psi} = b_R \sqrt{D_{*tot}}\, F_{\psi}$$

Streamfunction forcing	Backscatter ratio	Total dissipation rate	Pattern generator

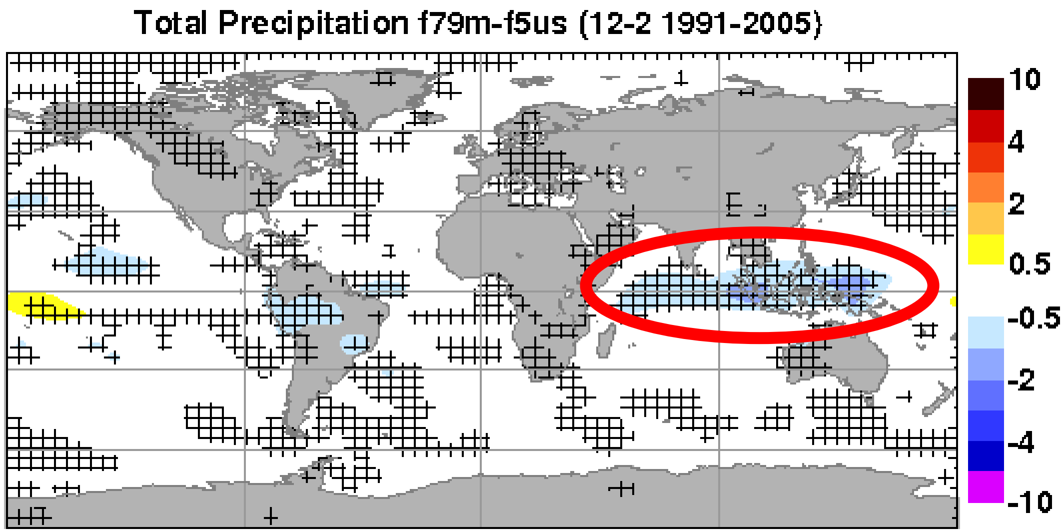
- The pattern is generated in spectral space, with spatial and temporal correlations defined using cloud-resolving model data

Impact of the new stochastic physics: reduction of systematic errors through nonlinear noise-induced rectification

model - obs



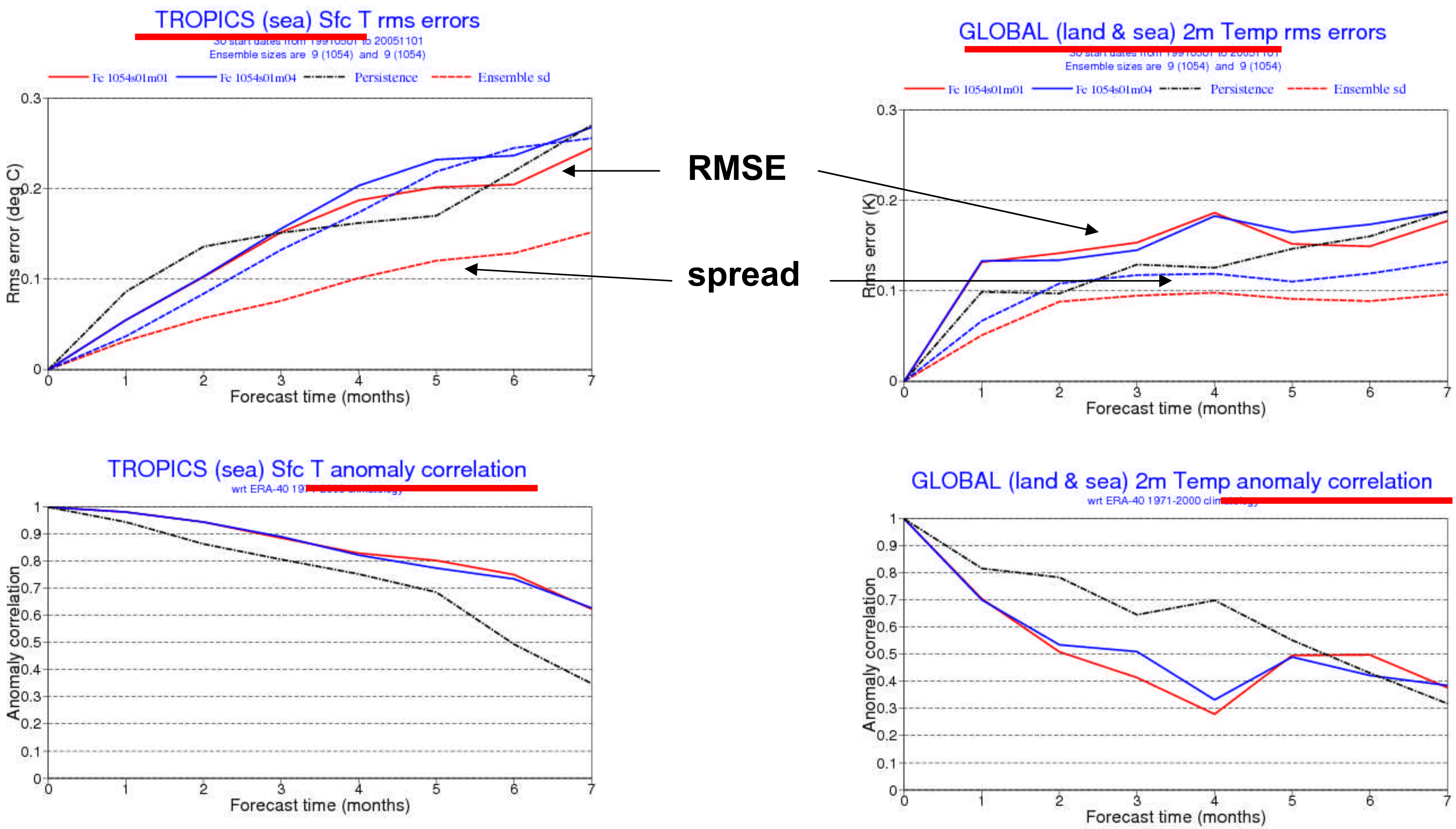
stoch. phys - control



significant reduction of excessive tropical precipitation

Impact of the new stochastic physics

control **stoch. physics**

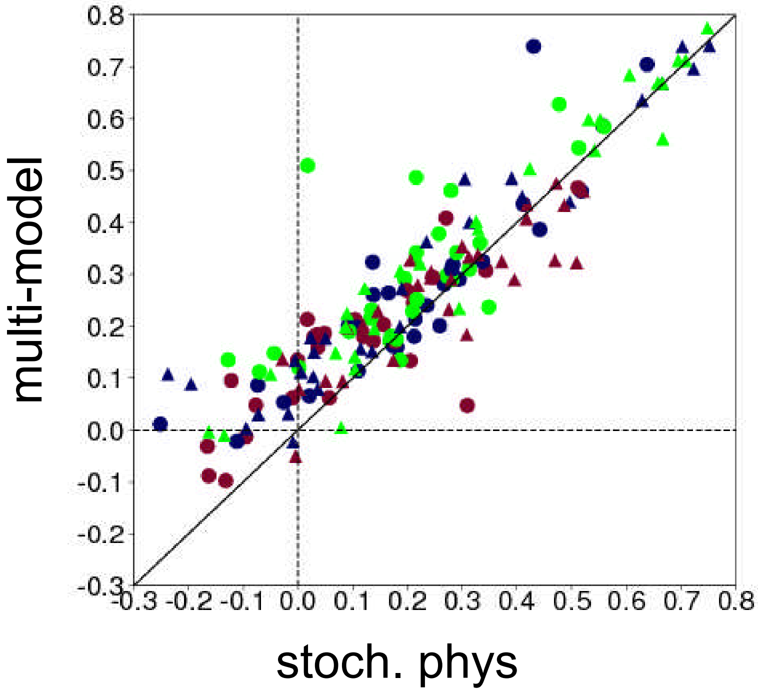


New stochastic physics vs ENSEMBLES multi-model

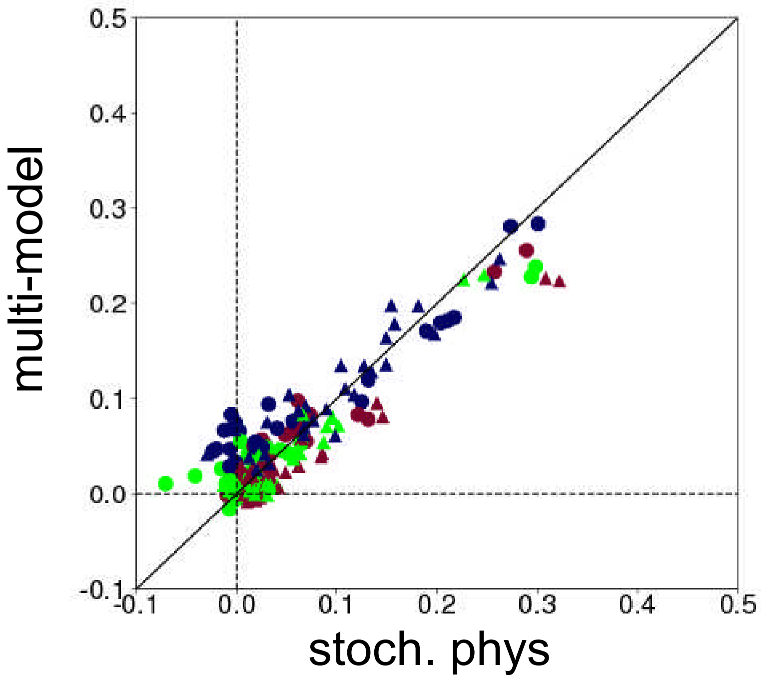
- T2m and precip
- all lead times
- May and Nov starts
- lower and upper terciles

debiased BSS

Tropical Pacific
Niño3, 3.4 and 4



Tropics, NH/SH extratropics
(land and sea)



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