Progress in RT1: Development of Ensemble Prediction System

Aim

Build and test ensemble prediction systems based on global Earth System models developed in Europe, for use in generation of multi-model simulations of future climate

Coordinators James Murphy, Tim Palmer

Version 1 of Ensemble Prediction System

- Separate systems for seasonal to decadal (s2d) and multi-decadal prediction

- Preliminary assessments achieved in reports delivered in March 06:

- s2d: Recommend further assessment and development of the multi-model, stochastic parameterisation and perturbed parameter approaches to the representation of modelling uncertainties.

- multi-decadal: recommend further development of the perturbed parameter approach, looking at how to combine the results with information from multi-model ensembles and observational constraints to produce probabilistic predictions.

- Major milestone due in August 06, describing "specified system" by month 24.

Version 2 of Ensemble Prediction System

- Specifed system at month 60
- Will seek to extend the range of uncertainties sampled
- Improved methods of constructing probabilistic predictions
- Towards a single, generalised system for seasonal to centennial prediction ?

RT1 Workpackages

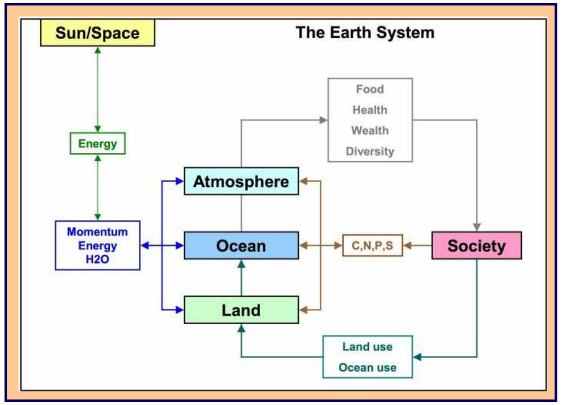
- 1.0: Management
- 1.1 Construction of Earth System Models
- 1.2 Methods of representing uncertainty
- 1.3 Initialising the ocean
- 1.4 Assembling the multi-model system
- 1.5 “pre-production” seasonal to decadal predictions
- 1.6 “pre-production” centennial predictions

RT1 Progress

- New earth system models constructed: testing (preliminary simulations, tuning experiments) in progress
- Further developments in methods for sampling model uncertainty and constructing probabilistic predictions.
- Initialisation procedures for "stream 1" seasonal-decadal integrations defined and used. Upgrading of ocean data assimilation systems for "stream 2" experiments continues.
- Ensembles of seasonal-decadal hindcasts produced, using the multi-model, stochastic physics and perturbed parameter approaches. Results saved in a common archive at ECMWF, and preliminary assessment of results conducted.
- Multi-decadal perturbed parameter ensembles using coupled models produced (Hadley) and in progress (Oxford). FUB have also performed short perturbed parameter runs.
- All deliverables and milestones met to date.

Status: New earth system models constructed:
testing (preliminary simulations, tuning experiments) in progress

Potentially an Earth system model can be arbitrarily complex ⟷



ENSEMBLES needs ensembles of "ESMs" of reasonable size

Issues:

- Intended use (seasonal, decadal, centennial) vs. complexity
  Example: carbon cycle not relevant for seasonal predictions
- Available models: many “simple” models vs. a few complex ESMs
- Time and computer limits:
  expensive models → small ensemble of integrations

Possible solution: build ensembles of different model classes, e.g.:
physical system, carbon cycle system, aerosol system

Seasonal to decadal stream 1 experiments

Three different forecast systems to estimate model uncertainty

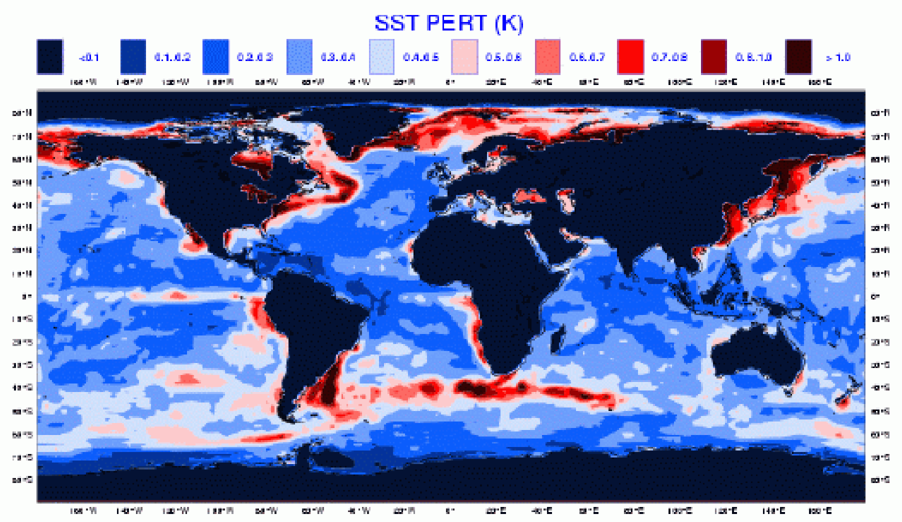
- Multi-model, built from ECMWF, Met Office, Météo-France operational activities and DEMETER experience.
- Perturbed parameter approach, built from the decadal prediction system (DePreSys) at the Met Office.
- Stochastic physics, built from the stochastic physics systems developed for medium-range forecasting at ECMWF.
- 9 member ensembles: 22 seasonal or annual hindcasts from 1May and 1 Nov 1991-2001.
- Two decadal cases (1 Nov 1965, 1994) for multi-model, stochastic systems
- Decadal simulations for all start dates from DePreSys

Advanced ocean data assimilations systems
WP1.3, D1.3 (1/2)

- **Update of the Metoffice Data Base:**
  - **Data available 1957-2004**
  - **Improved Quality control**
  - **Final data set including latest WOD05 data; available August 06**

- **New set of perturbations for Wind Stress and SST made available by ECMWF**

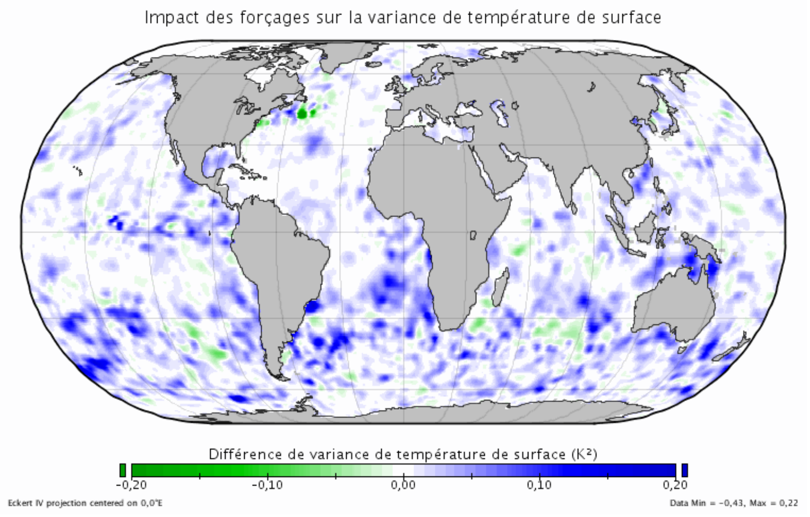
Standard deviation of the SST perturbations based on uncertainties in the ocean analysis (NCEP ERSSTv2 and Hadley SST) before 1980 (from ECMWF)



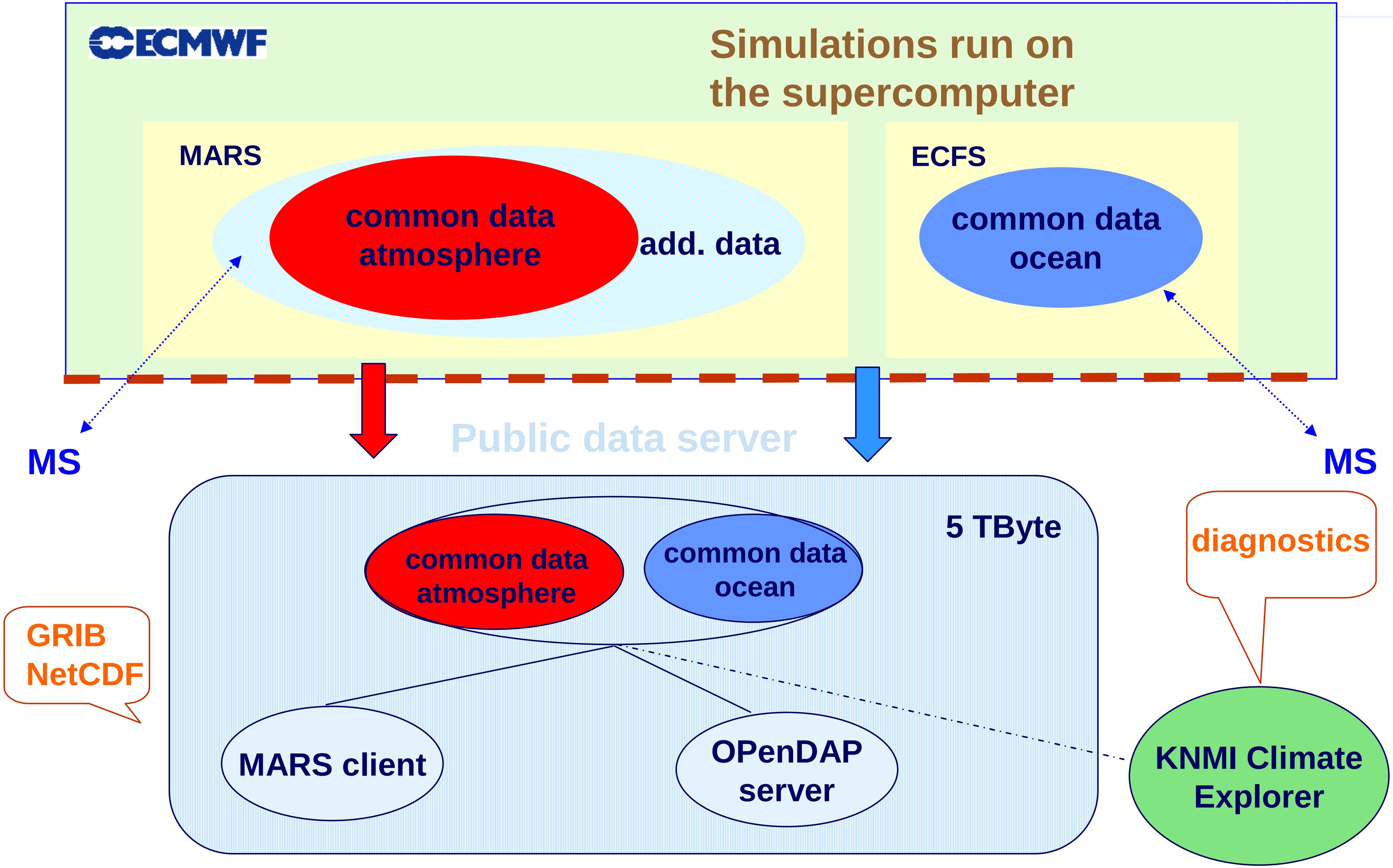
Advanced ocean data assimilations systems
WP1.3, D1.3 (2/2)

- **Update of the data assimilation systems:**
  - **Further scheme development and better tuning of system parameters (CERFACS, Meto-HC, INGV, IfM, KNMI)**
  - **More experimentations of the systems (ECMWF, CERFACS, METO-HC,KNMI)**
  - **Test of the impact of the new perturbations in most systems**

Variance in ensembles of analyses produced when perturbing wind stress, SST and ocean observations, relative to the variance produced by perturbing ocean observations alone. The differences are largest in poorly observed regions (from Cerfacs)



Archiving and dissemination strategy



ENSEMBLES stream 1 seasonal simulations 1991-2000

May & Nov start dates

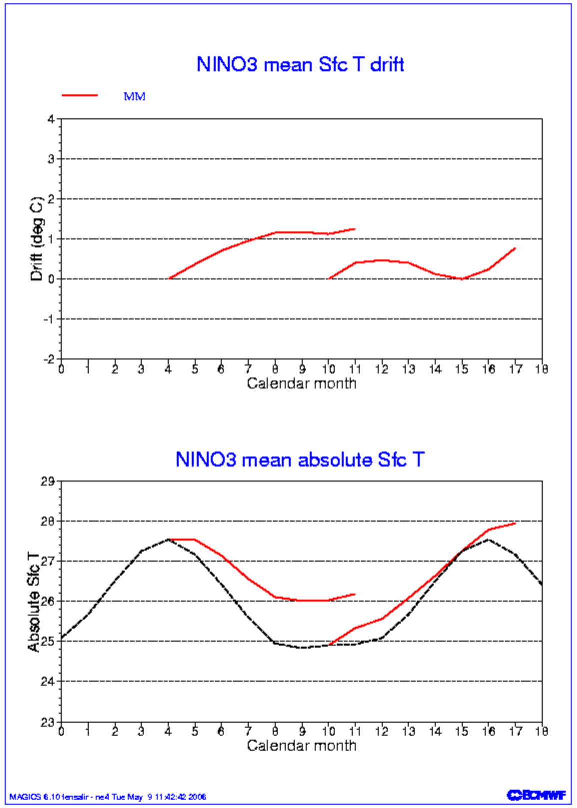
near-surface temperature and precipitation

multi-model vs perturbed physics vs CASBS

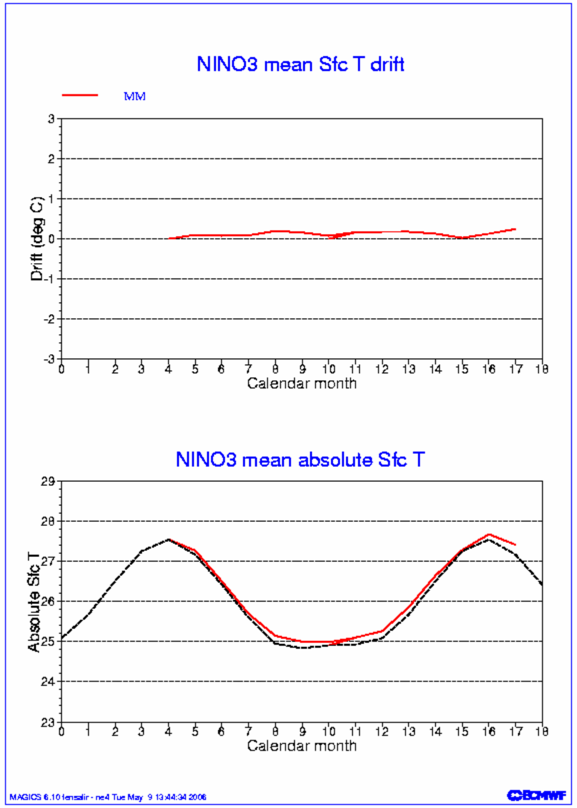
seasonal forecasts 1991-2001 May & Nov start dates: mean drift

near-surface temperature Nino3

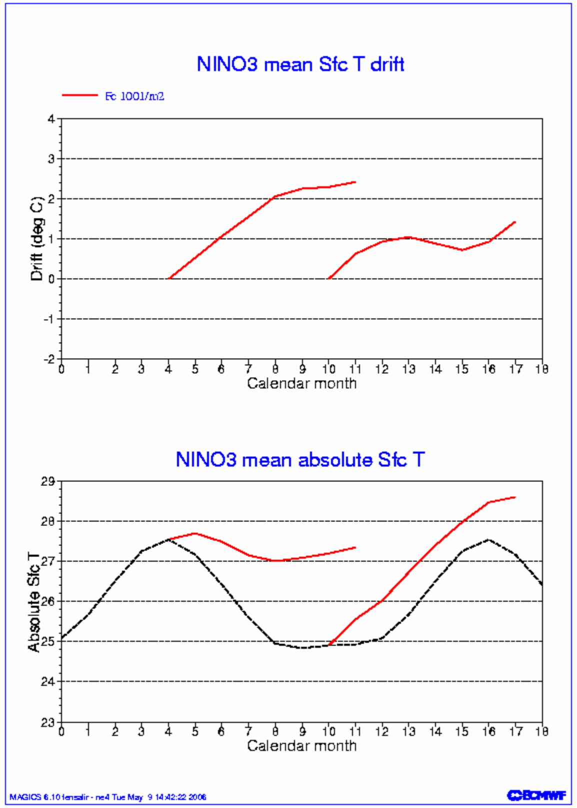
multi-model	perturbed physics	stochastic physics



3 models à 9 members
= 27 members



9 models à 1 members
= 9 members



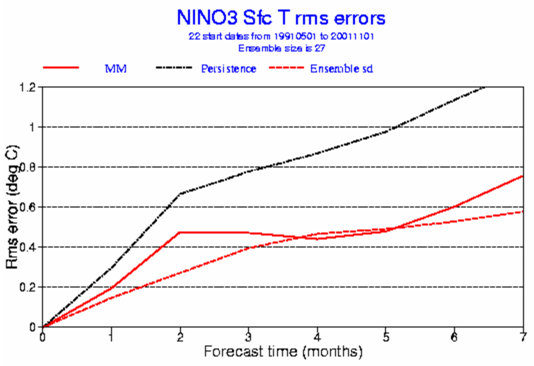
1 model à 9 members
= 9 members

seasonal forecasts 1991-2001 May & Nov start dates: RMSE and spread

near-surface temperature Nino3

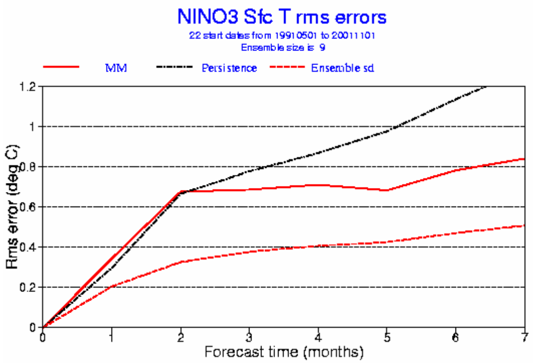
RMSE | stdev | RMSE persistence

multi-model



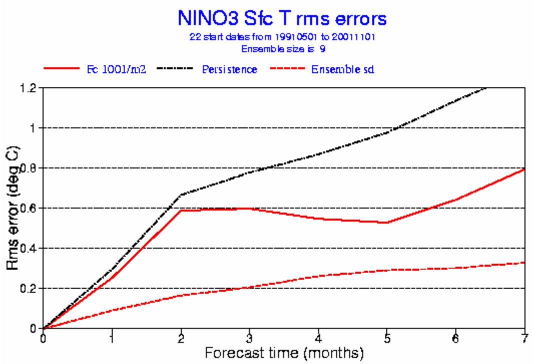
3 models à 9 members
= 27 members

perturbed physics



9 models à 1 members
= 9 members

stochastic physics

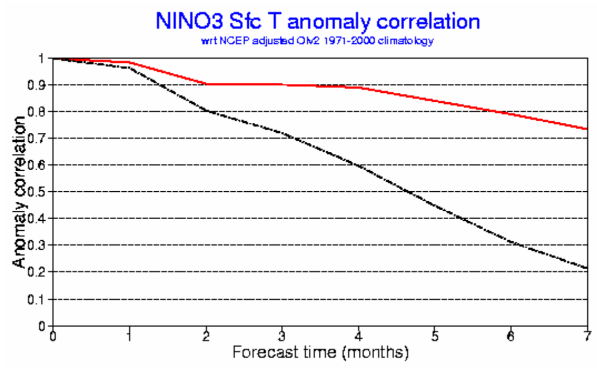


1 model à 9 members
= 9 members

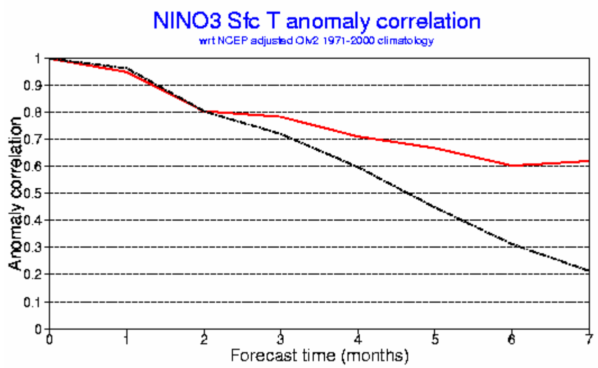
seasonal forecasts 1991-2001 May & Nov start dates:
Anomaly correlation

SST **Nino3**

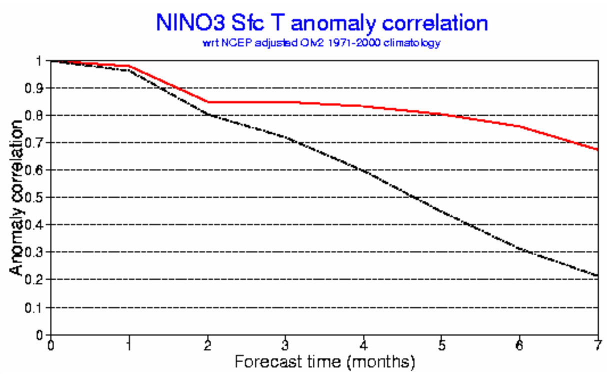
multi-model



perturbed physics



stochastic physics



ACC

persistence forecast

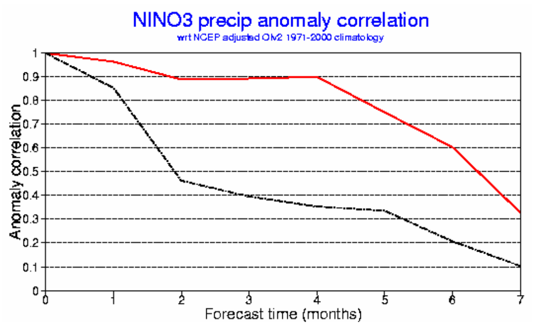
seasonal forecasts 1991-2001 May & Nov start dates: Skill and spread

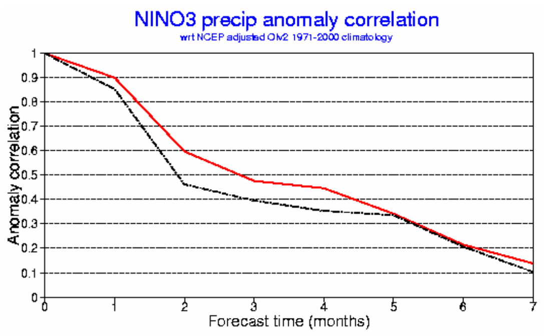
precipitation Nino3

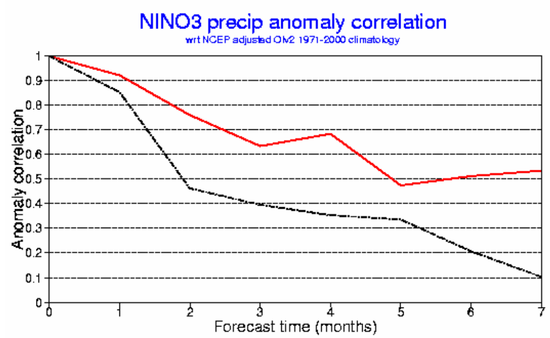
multi-model

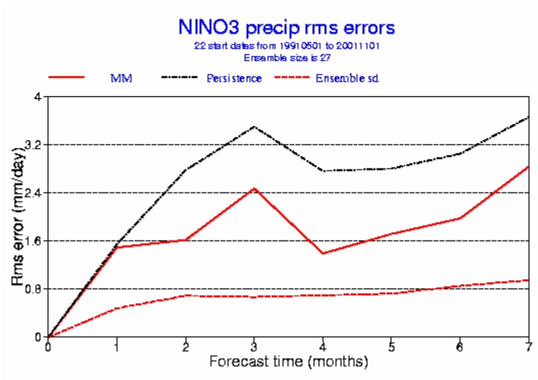
perturbed physics

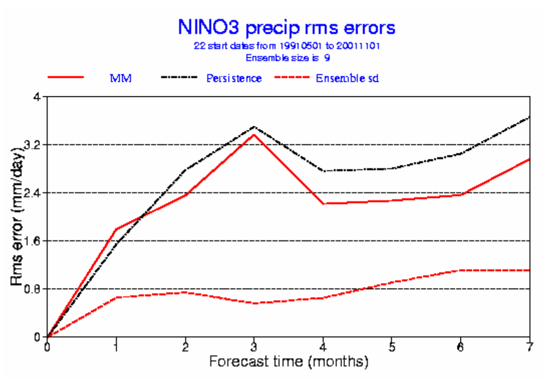
stochastic physics

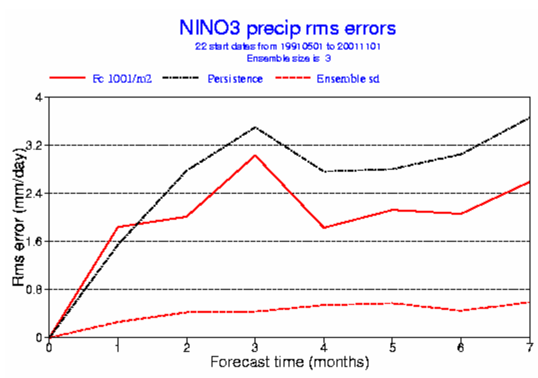












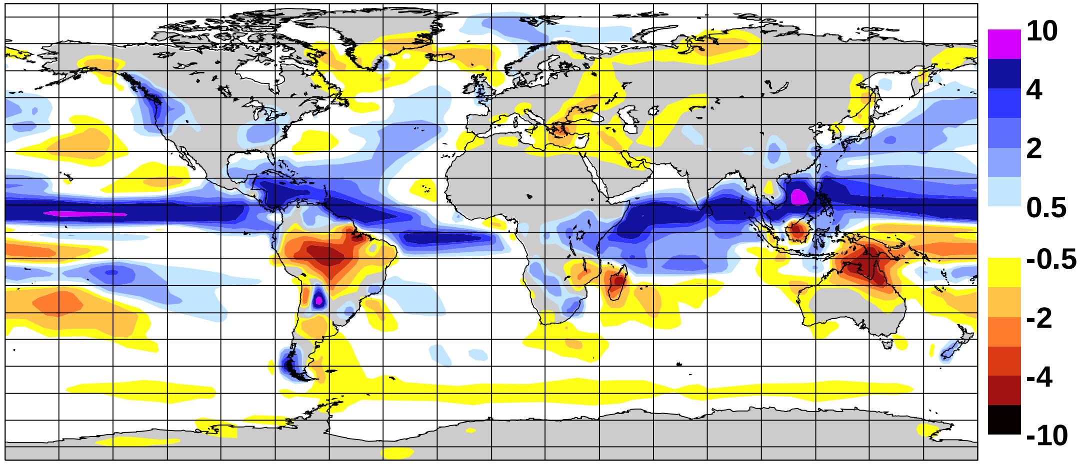
3 models à 9 members
= 27 members

9 models à 1 members
= 9 members

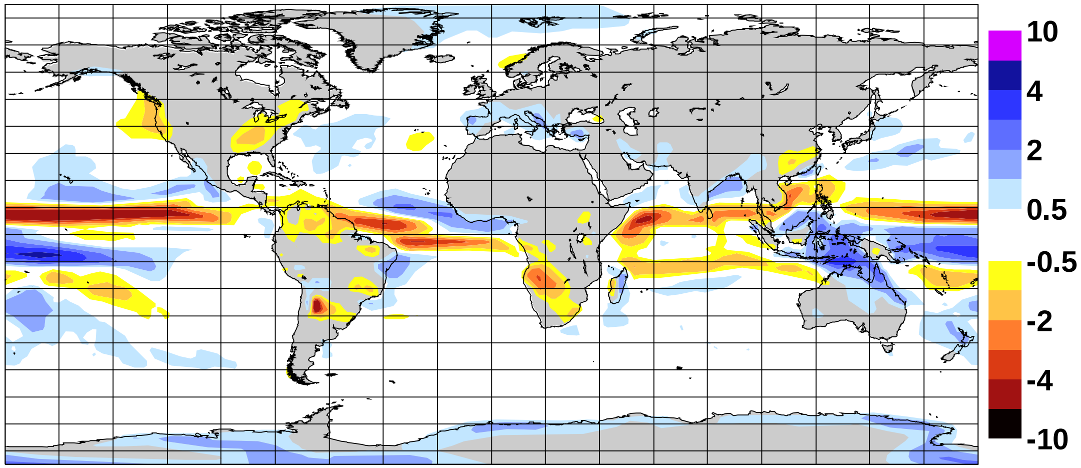
1 model à 9 members
= 9 members

December-February Precipitation bias (mm/day)

IFS-HOPE
control



IFS-HOPE
with
CASBS
stochastic
physics



ENSEMBLES stream 1 decadal simulations

1965 & 1994
1991-1994

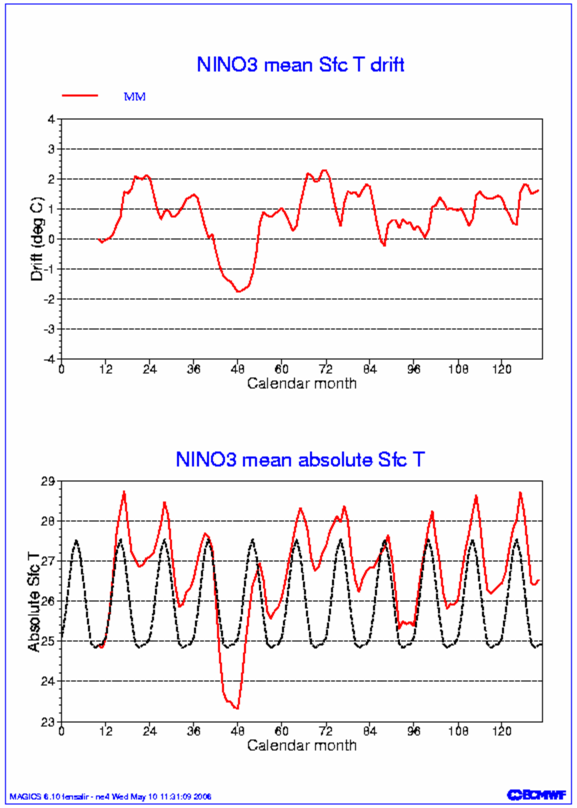
SST

multi-model vs perturbed physics vs CASBS

decadal forecasts: mean drift

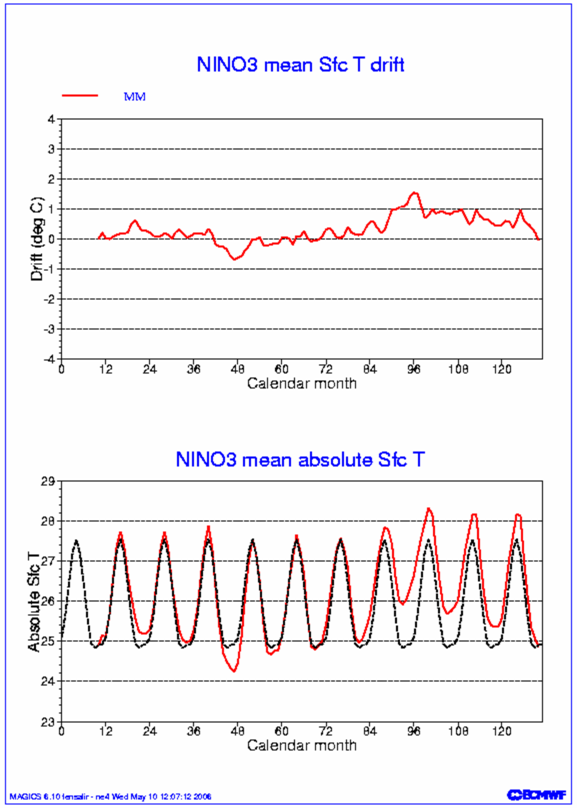
SST Nino3

multi-model



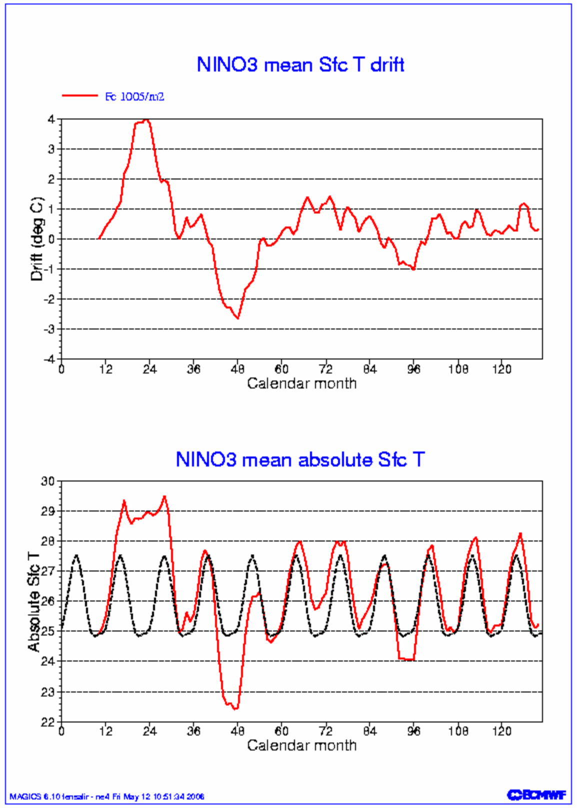
start dates:
1965 and 1994

perturbed physics



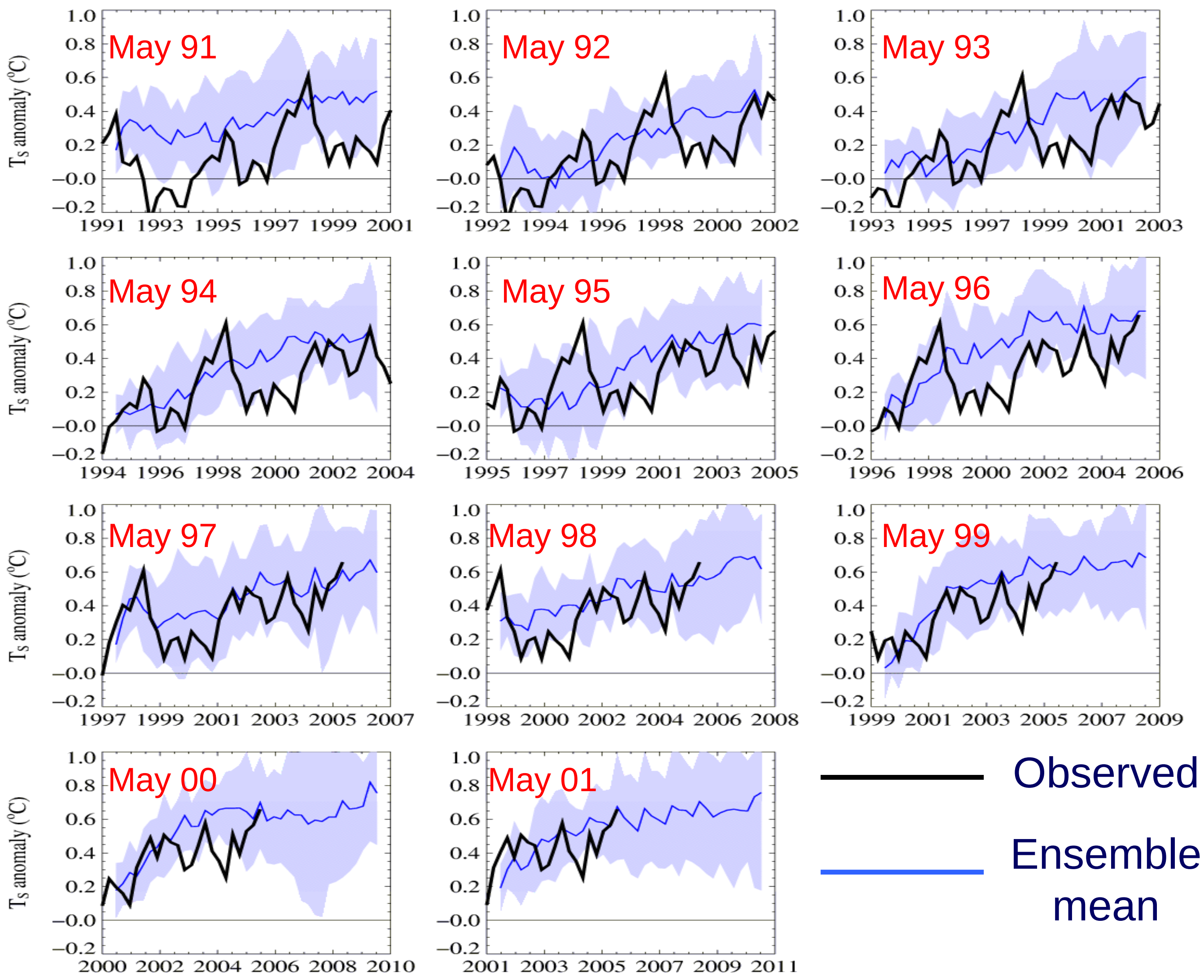
start dates:
1991 - 1994

stochastic physics

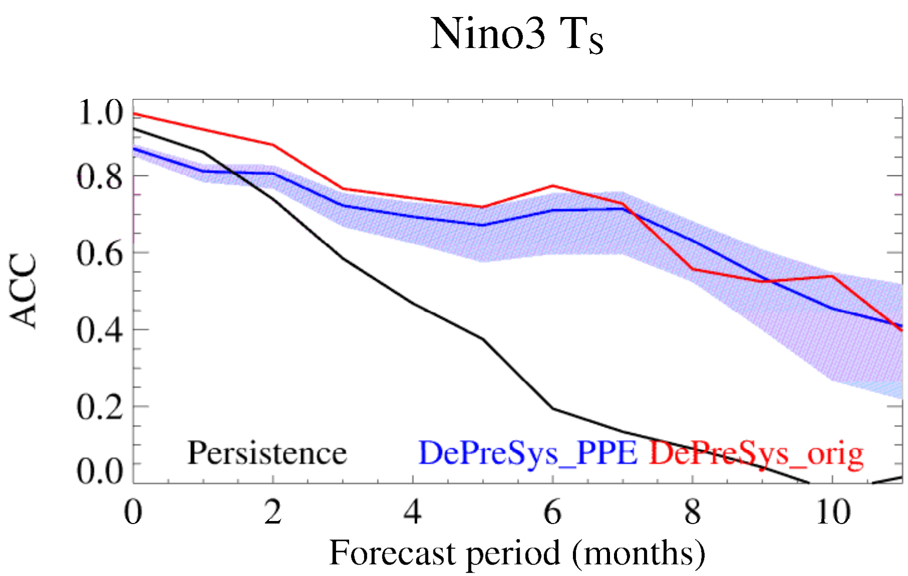


start dates:
1965 and 1994

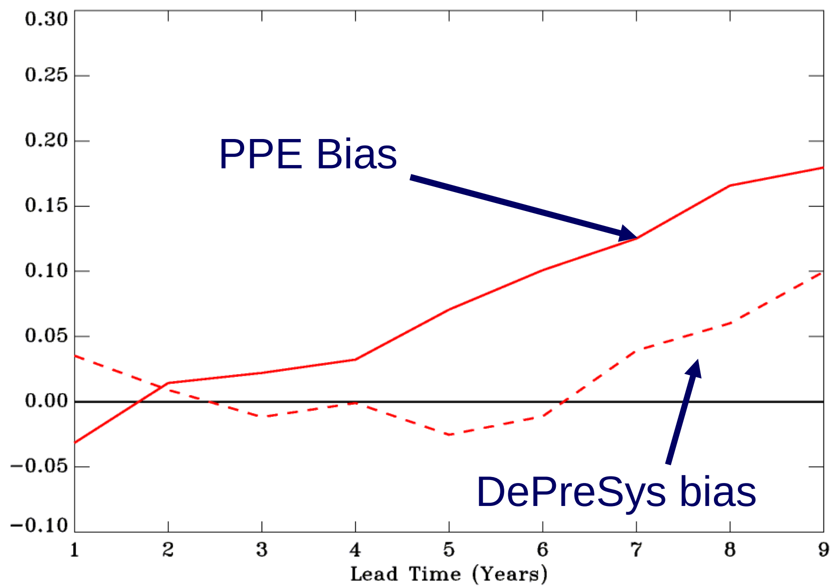
Global annual mean temperature in perturbed physics ensemble hindcasts



Skill in perturbed ensemble hindcasts vs earlier hindcasts using standard HadCM3 with perturbed initial conditions



Global mean T_s



Early results from experimental new systems: need to identify and correct problems for stream II simulations.

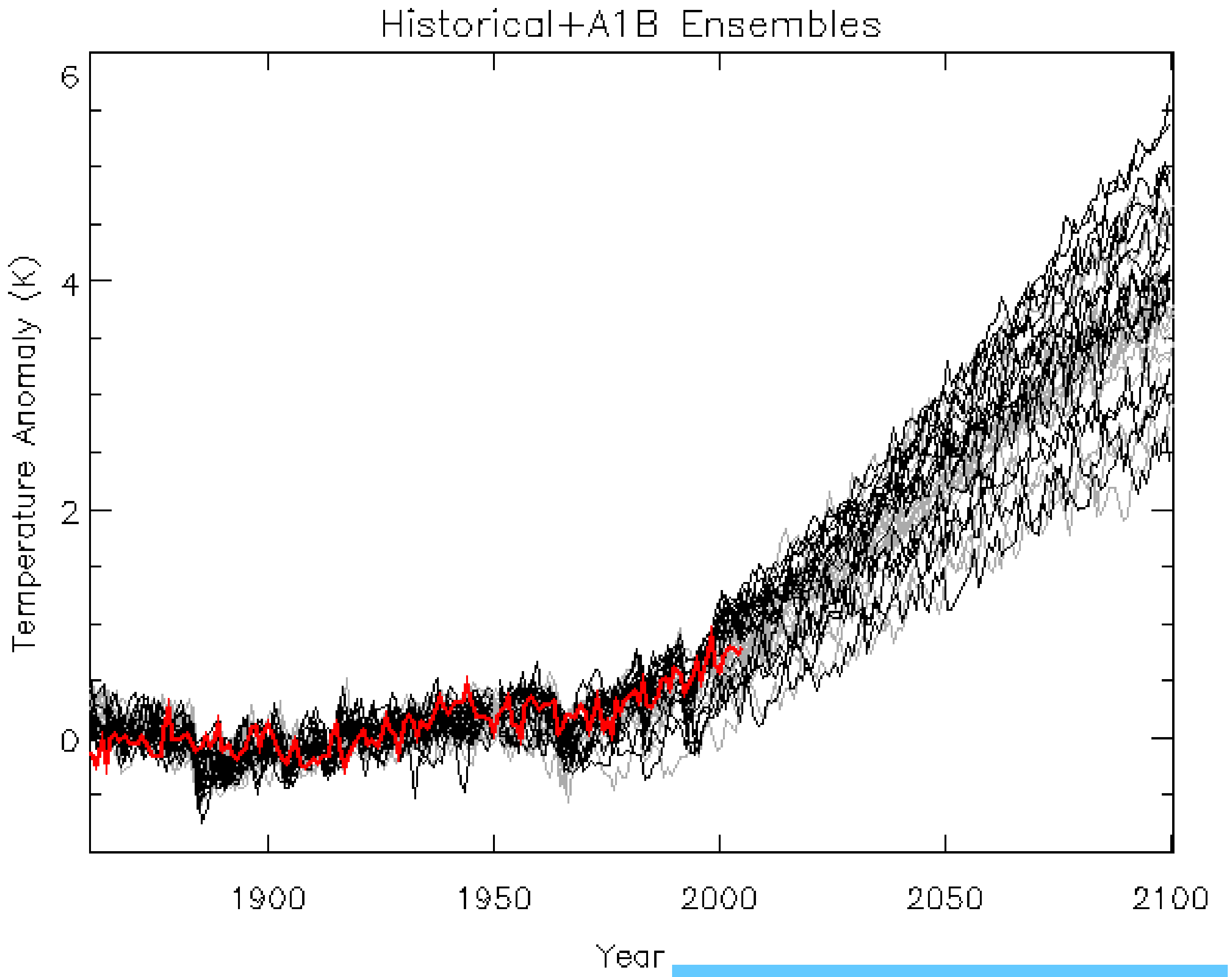
Centennial climate predictions

RT1 is focusing mainly on the development of perturbed physics approaches, assessed alongside multi-model approaches (RT2A, IPCC AR4, etc)

New HadCM3 perturbed parameter ensemble

- Old ensemble (grey)
- New ensemble (black)
- HadCRUT observed series (red)

- Slightly wider range of feedbacks explored in new ensemble

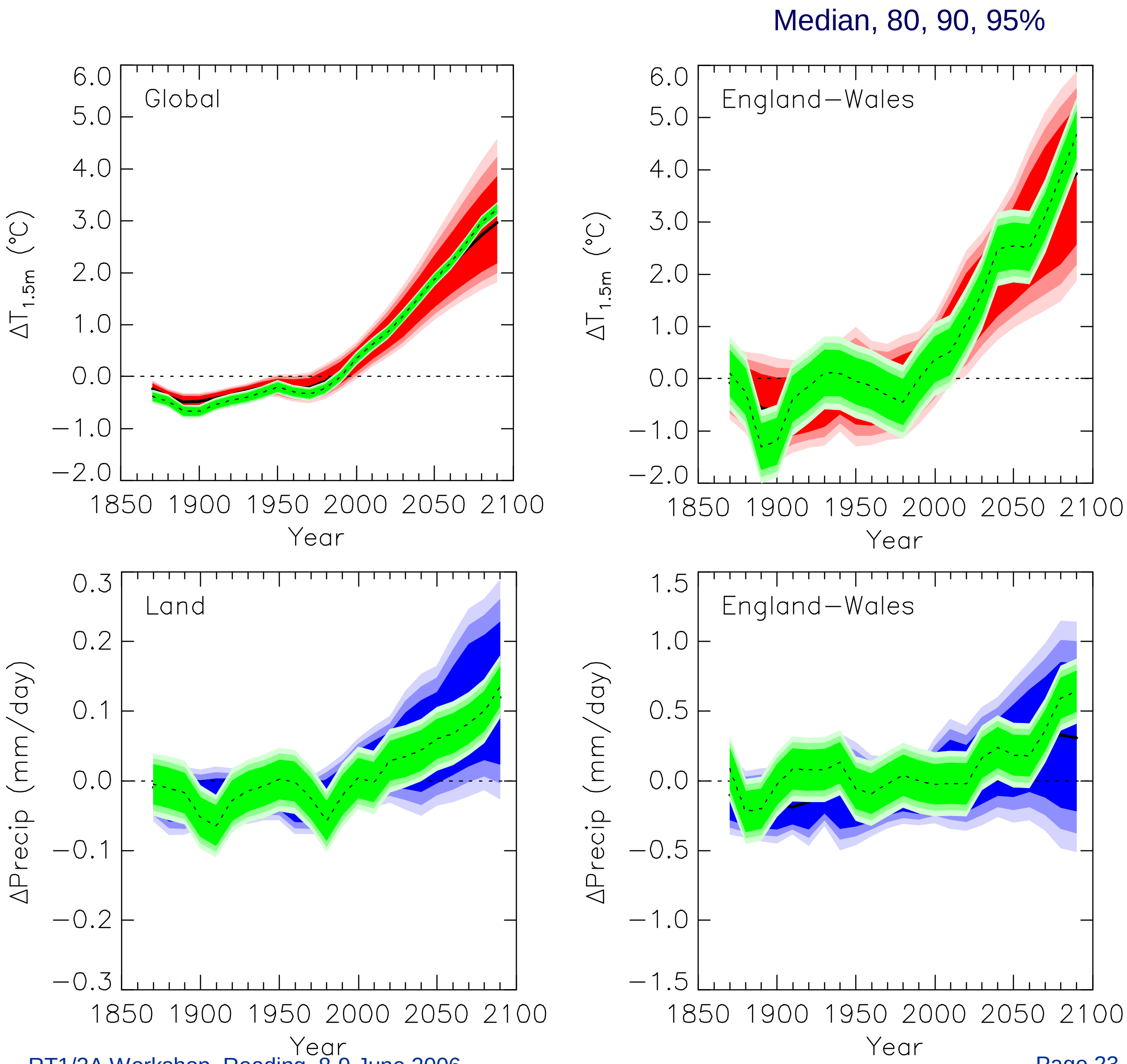


Glen Harris, Ben Booth

Pattern Scaling for Time-Dependent Change

- Distributions based on scaling the equilibrium pattern of climate change from 209 equilibrium experiments
- Uses an EBM
- Relationships trained using 17 coupled model experiments with same parameter perturbations
- Uncertainties propagated

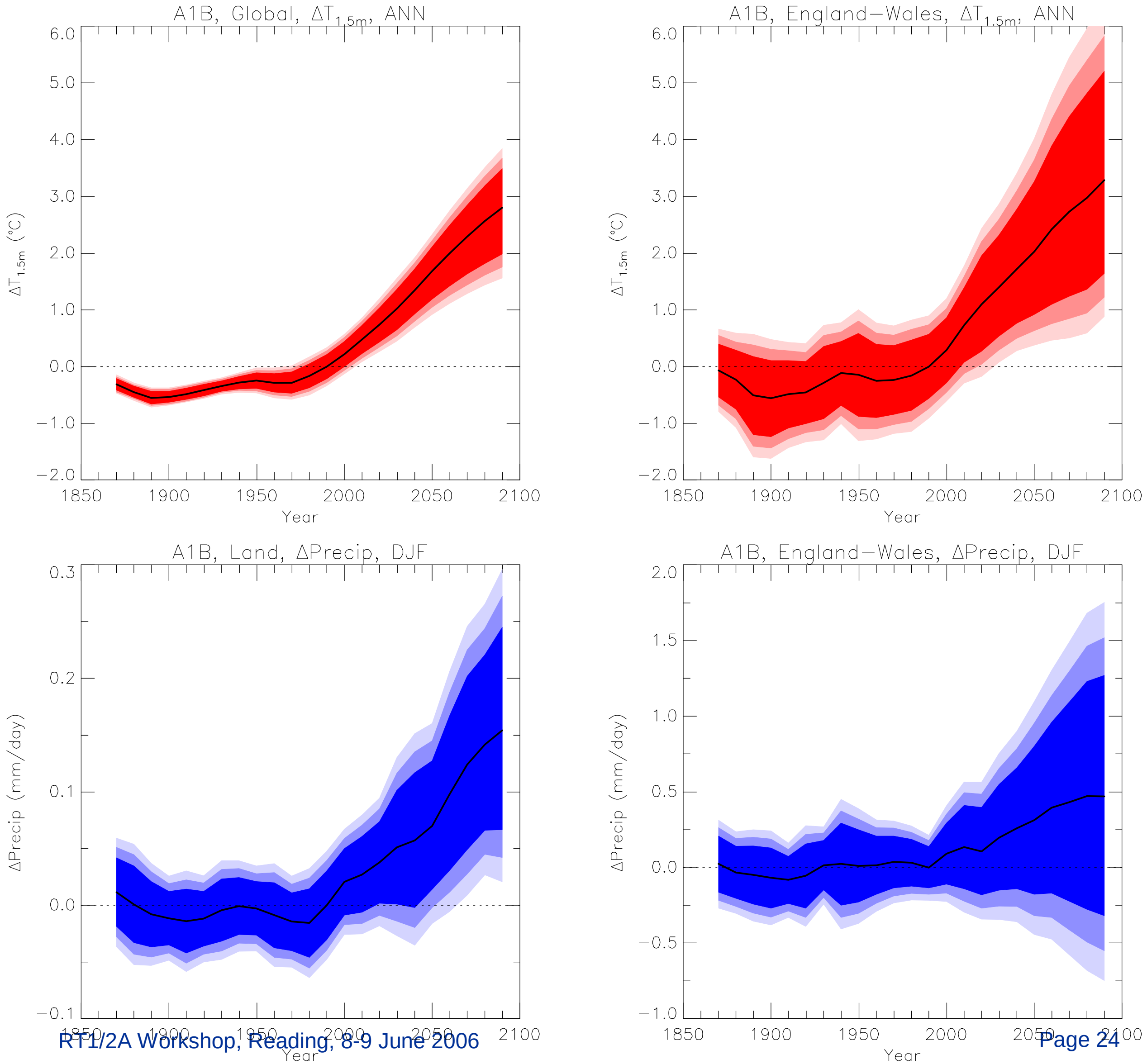
Based on Harris, et al., 2006, Clim Dyn, in press



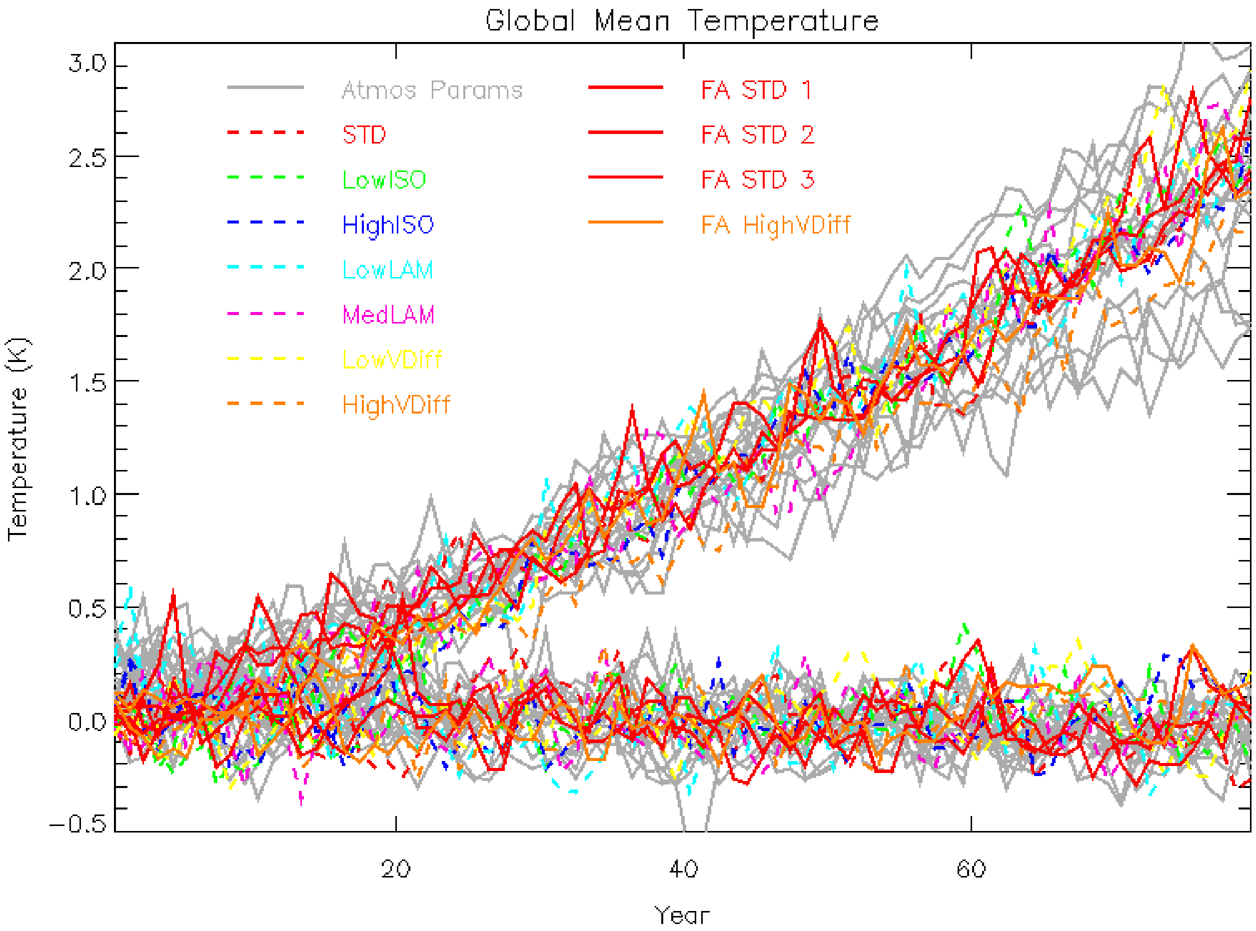
Towards Time-Dependent PDFs

- Including emulation at un-tried parameter values
- Assumes triangular distributions for most parameters

Based on Harris, et al., 2006, Clim Dyn, in press and Rougier et al. in prep.



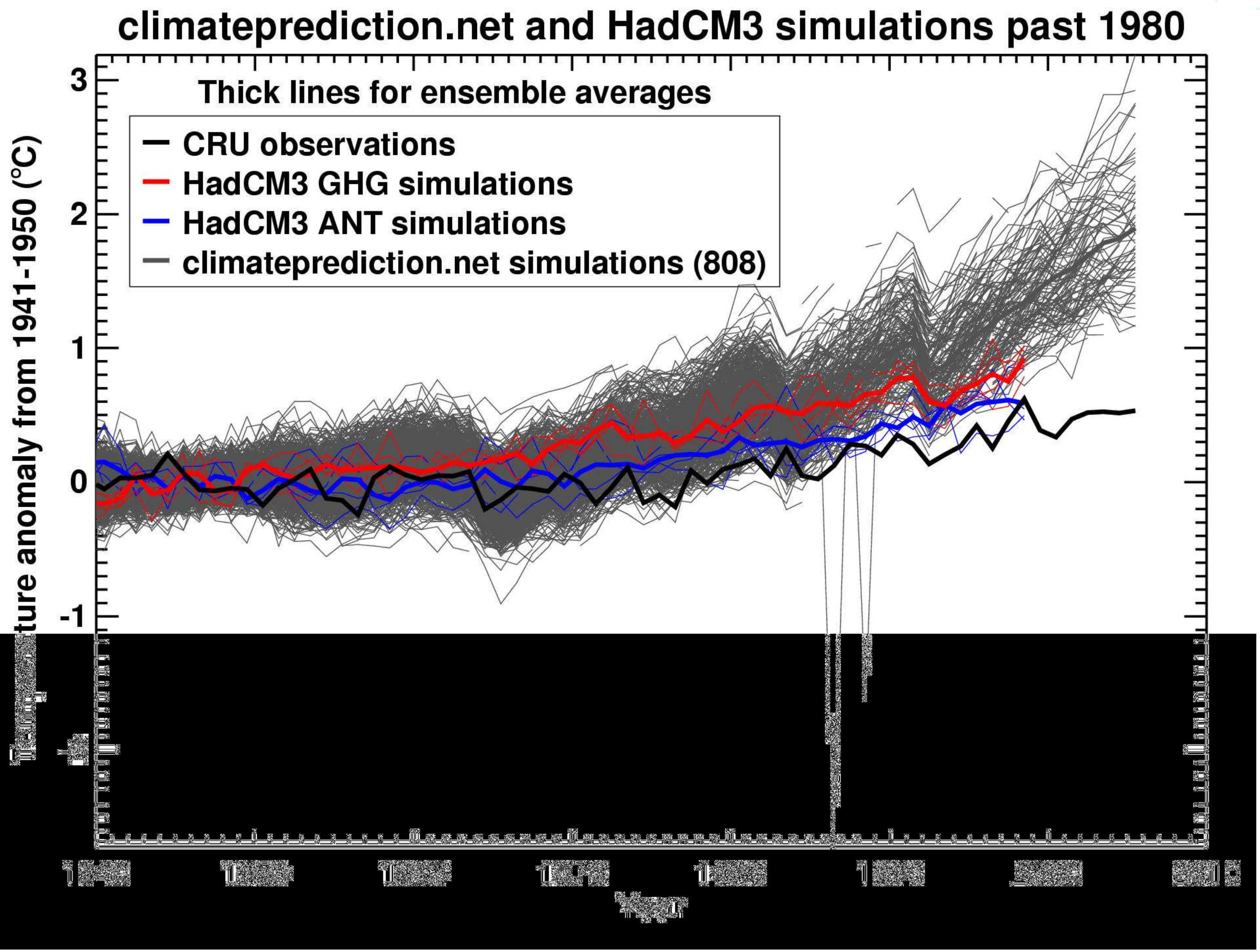
Ocean Parameter Perturbation Experiments



Changing these ocean parameters has little effect on the rate of time-dependent climate change

Collins, Brierley, MacVean, Booth and Harris, submitted to J. Clim.

HadCM3L ‘Attribution’ Project (courtesy Daithi Stone)



Perturbed Physics Approach at the FUB

A 30 member perturbed physics ensemble was generated by varying 5 cloud parameters.
(Sampling of the underlying uncertainties imperfect)

Parameters for the perturbations: (Comparable to studies with different models)
1) Conversion rate from cloud water to rain
2) Entrainment rate for shallow convection
3) Overshooting of cumuli above the level of non-buoyance
4) Sedimentation rate of ice crystals in cold clouds
5) Efficiency of rain formation

Aim: A probabilistic estimate of the Climate Sensitivity with the perturbed physics approach.
A model comparison with other perturbed physics approaches.

1st phase: Integrations under 10yrs of present day conditions (finished)
2nd phase: Integrations under a doubling of CO_2 (planned)

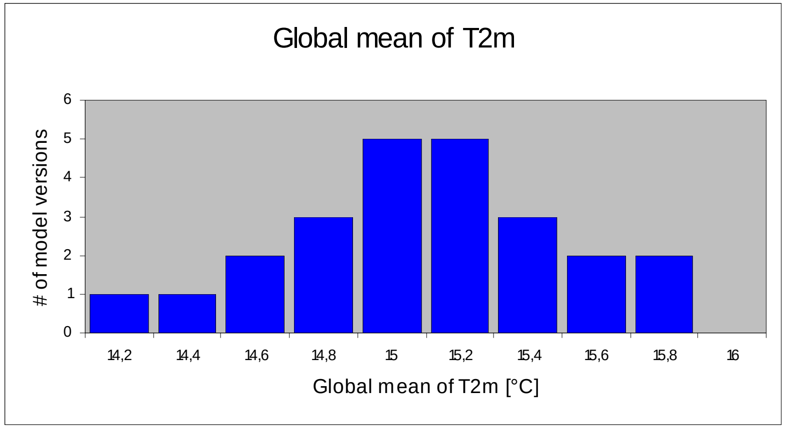


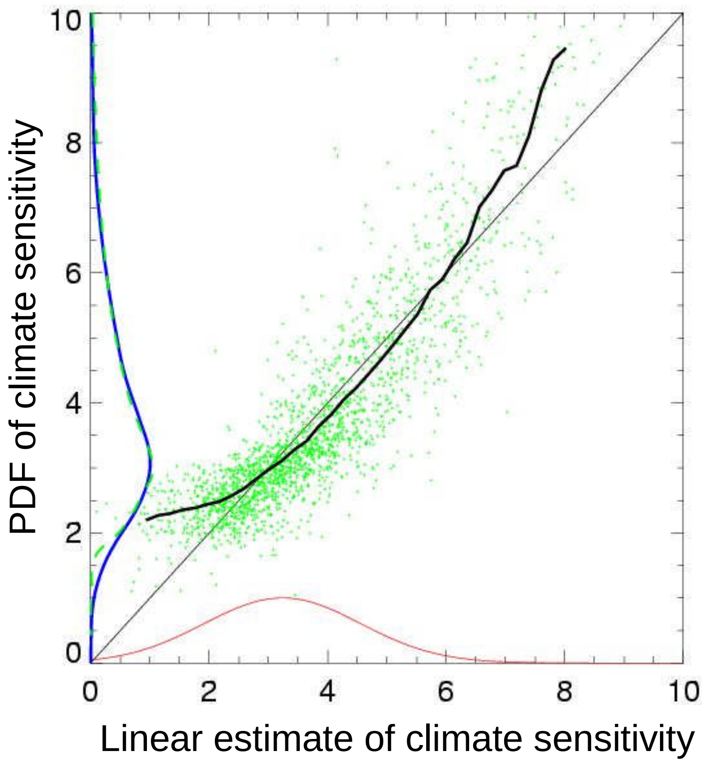
Fig.1: Global mean temperature in the last 5 years of the integrations in the ensemble of the perturbed EGMAM versions

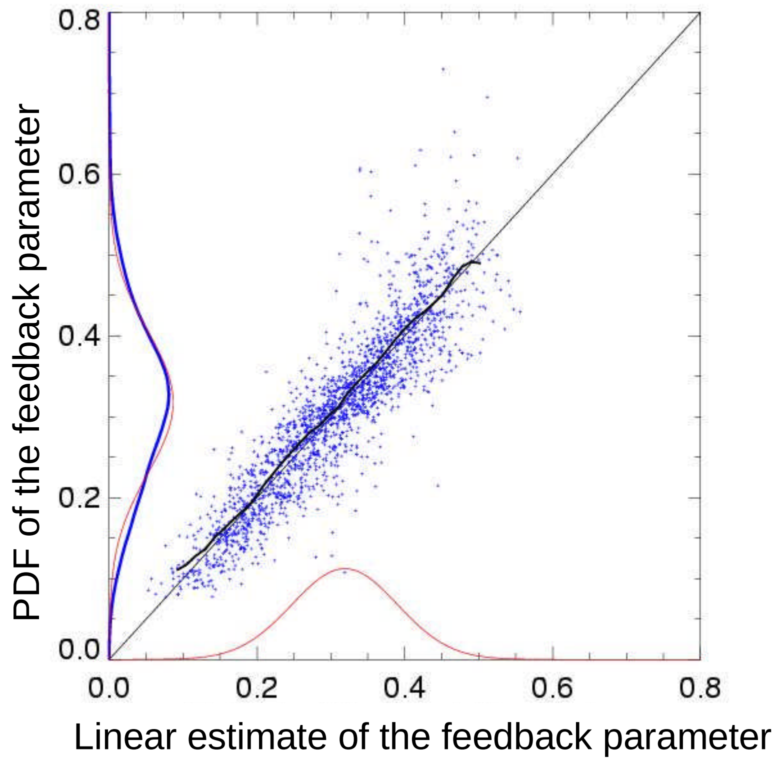
First results:

Strong linear behaviour of the global mean temperature to variations of the sedimentation rate

Non-linear behaviour in radiative quantities for multi parameter variations, especially with involved entrainment rate

A methodology for observationally constrained probabilistic predictions (WP 1.2)





Constrains future climate variables using transfer functions between future variables and present day climate observables. Transfer functions developed from the cp.net perturbed parameter ensemble, but results are minimally sensitive to expert choices in the design of the ensemble.

Piani et al., 2005

Some issues for this meeting

- New Earth System models
- Assessment of stream 1 experiments (s2d, centennial)
- Plans for stream 2 simulations
- Observational constraints for ensemble predictions (links to RT4/5).
- Regional predictions (RT2B/3)
- Emissions scenarios (RT7)

Imminent Deliverables, Milestones, Reports

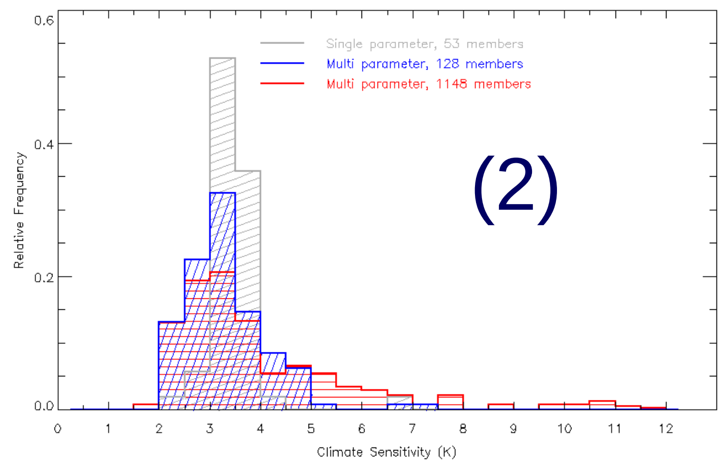
- D1.5 WP1.1 workshop (this meeting)
- D1.6 Report on developed and tested ESMs Aug 06
- D1.7 Interim probability distributions of transient climate change over Europe, for use by other RTs in testing methodologies for predicting impacts Aug 06
- M1.4 Updated quality-controlled oceanographic database (Agreed delay till Aug 06)
- MM1.1 Provision of a set of tested Earth System models Aug 06
- MM1.2 Provision of a "first generation" ensemble prediction system for use in RT2 Aug 06

Extras

Towards PDFs of regional climate change from perturbed physics ensembles of global models

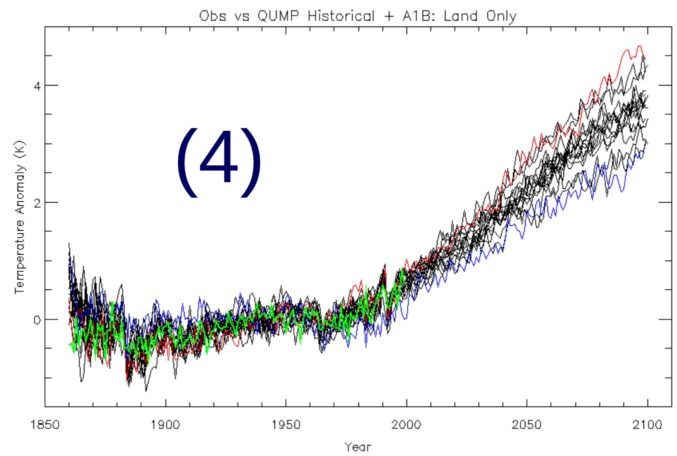
(1)

- Take one model (version 3 of the Hadley Centre Atmosphere model coupled to a mixed layer ocean – HadSM3)
- Ask the model experts for ranges on uncertain parameters
- Run an ensemble of equilibrium climate change simulations



(3)

- Run a smaller ensemble of transient simulations using a subset of perturbed atmospheres coupled to the dynamical HadCM3 ocean



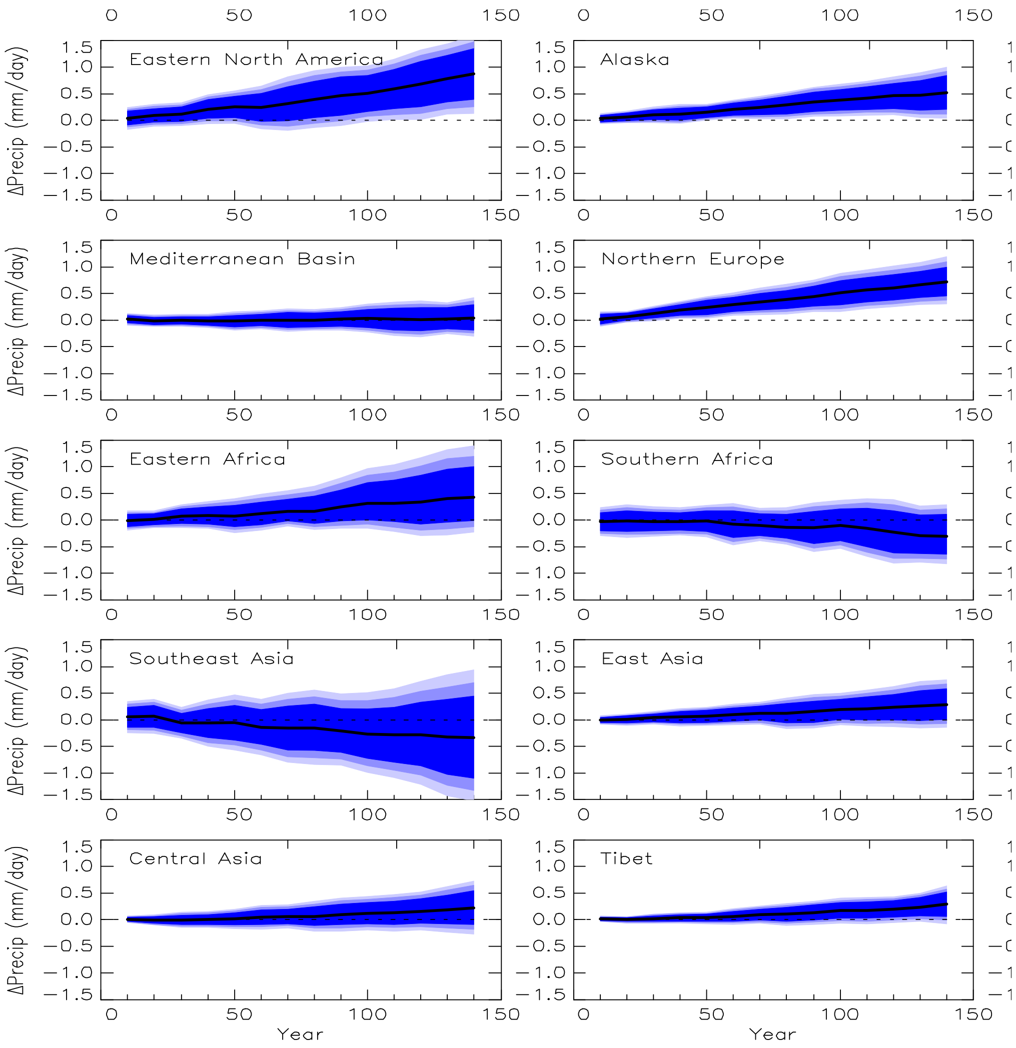
Frequency distributions of transient regional changes

(5)

- Develop scaling relationships between the equilibrium and transient responses and use to infer results of a larger ensemble of transient simulations from the equilibrium ensemble

(6)

- Gives frequency distributions of time dependent changes for regions of choice
- E.g. precip changes over Giorgi regions in DJF



Formal Bayesian framework for probabilistic prediction

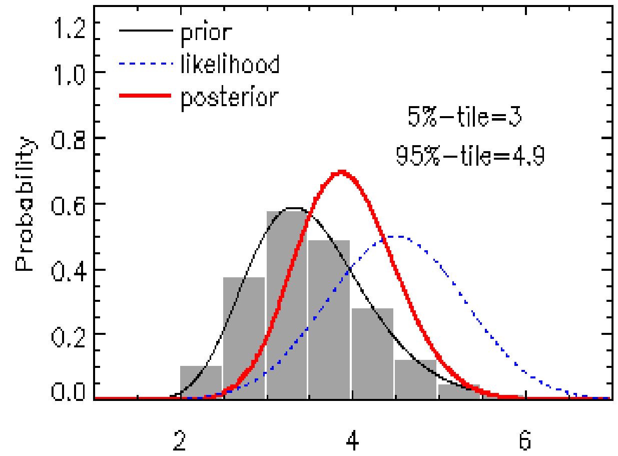
(7)

Take an expert prior for uncertain model parameters

- Construct a prior for climate change variables using a statistical *emulator* to predict GCM results for unsampled regions of parameter space
- Introduce the *discrepancy,* the difference between the observed climate and the best possible model version obtainable by varying parameters. It measures uncertainty arising from structural model deficiencies.
- Estimate (a lower bound for) *discrepancy* by using perturbed physics ensemble results to predict multi-model ensemble results
- Calculate the likelihood and hence produce posterior distributions for future climate variables

$$p(s \mid data) \propto p(s)\, p(data \mid s)$$

posterior = *prior* x *likelihood*



Summary of plans for PDFs of regional climate change from perturbed physics ensembles of global models

- RT1 will construct a methodology for producing pdfs of regional changes based on perturbed physics ensembles of global models

- We propose an interim product by month 24, consisting of distributions of changes in selected regional variables for Europe, for the A1B forcing scenario, for use by other RTs in testing methodologies for predicting impacts.

- These will account only for surface and atmospheric modelling uncertainties, and will not account for variations in likelihood between different model versions.
- Beyond month 24:

- Hope to use multi-model ensemble results in the construction of likelihood-weighted pdfs, to calibrate the effects of structural model deficiencies.

- Include modelling uncertainties arising from oceanic physical processes, and the terrestrial carbon cycle and atmospheric sulphur cycle, through further ensembles and statistical emulation.