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Estimation of optimal perturbations for decadal climate predictions

Ed Hawkins

Thanks to: Rowan Sutton

DSWC09 workshop

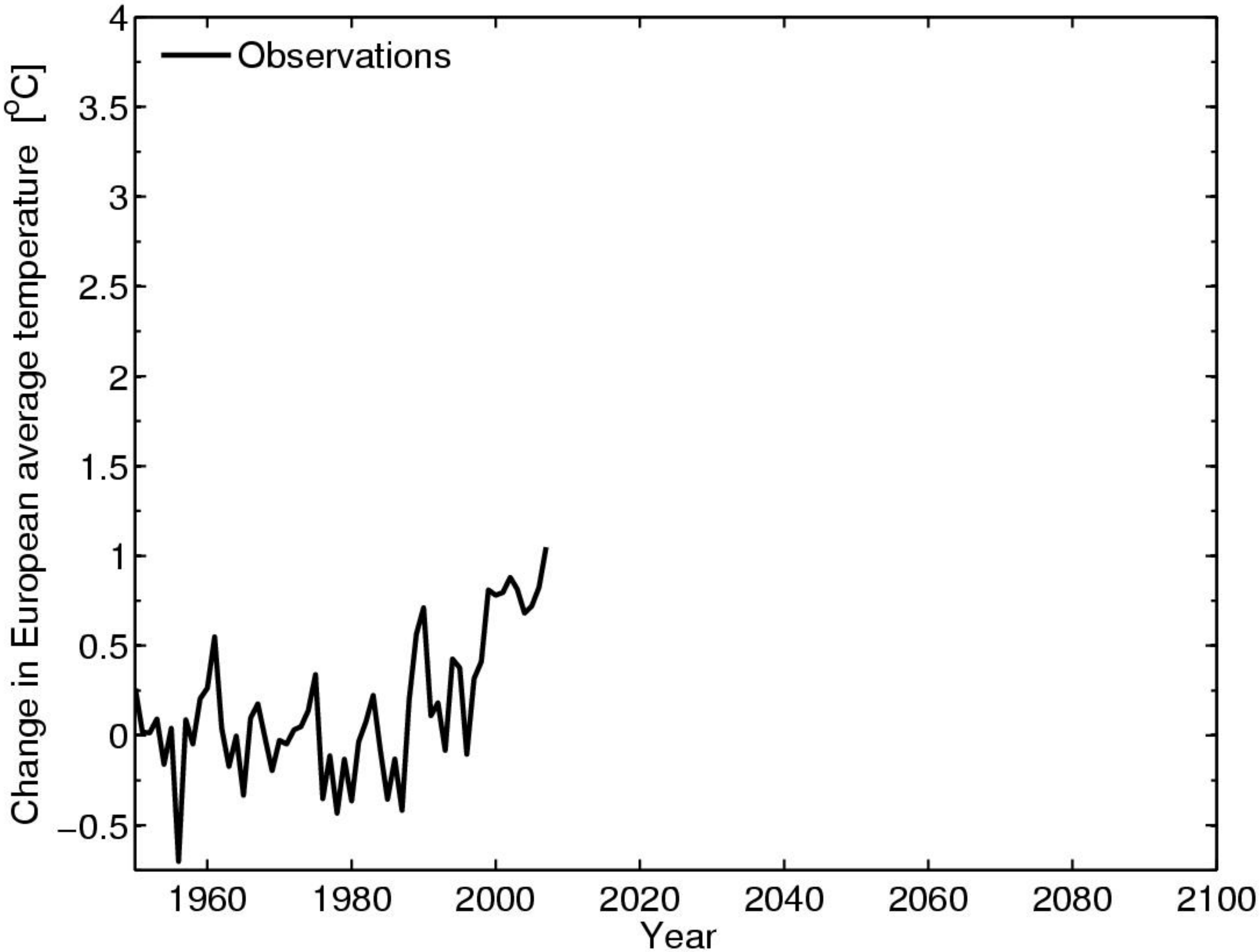
University of Reading

THOR

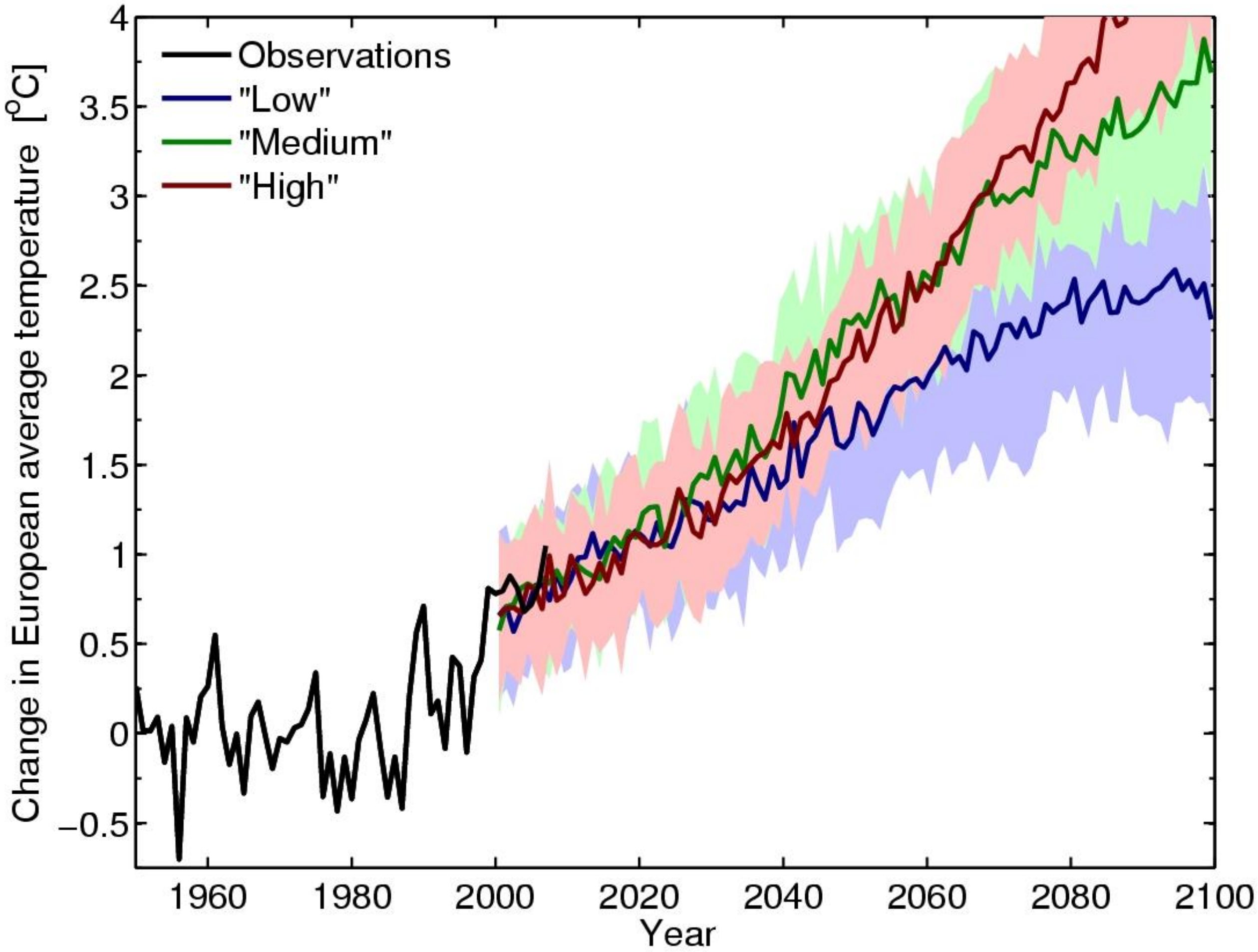
Rapid Climate Change

Walker Institute

EU temperature projections



EU temperature projections



EU temperature projections

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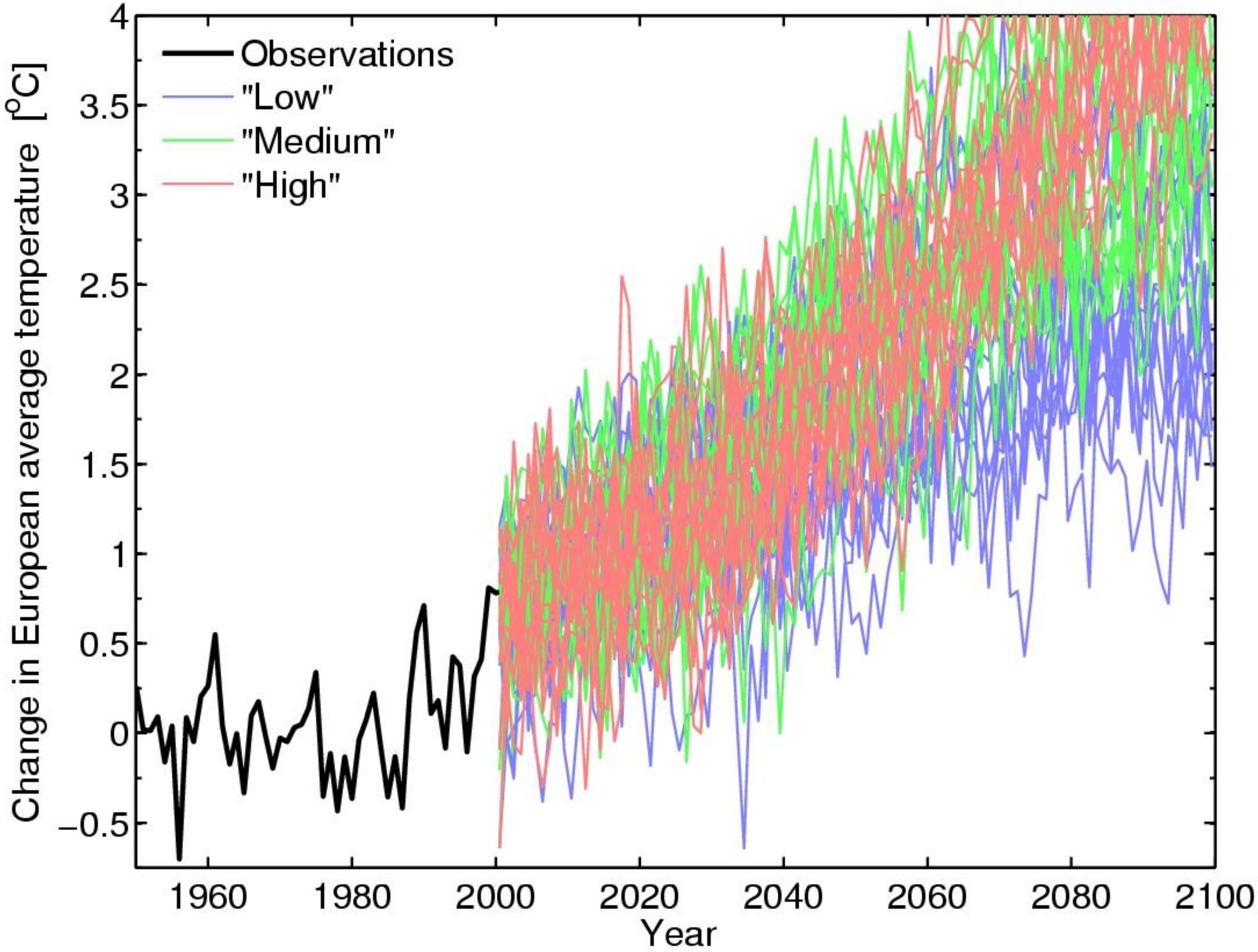

“Ensembles contain information”

EU temperature projections

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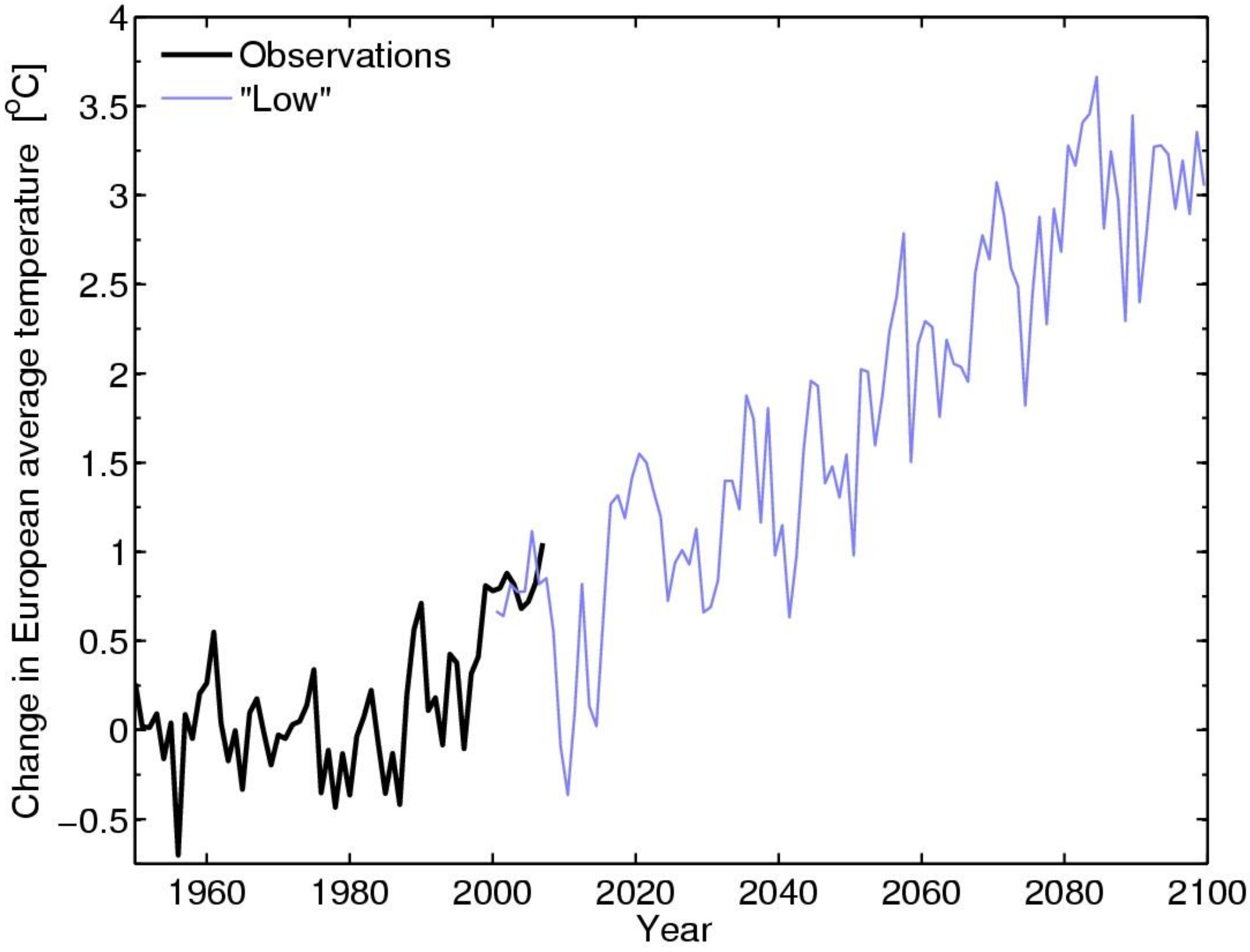

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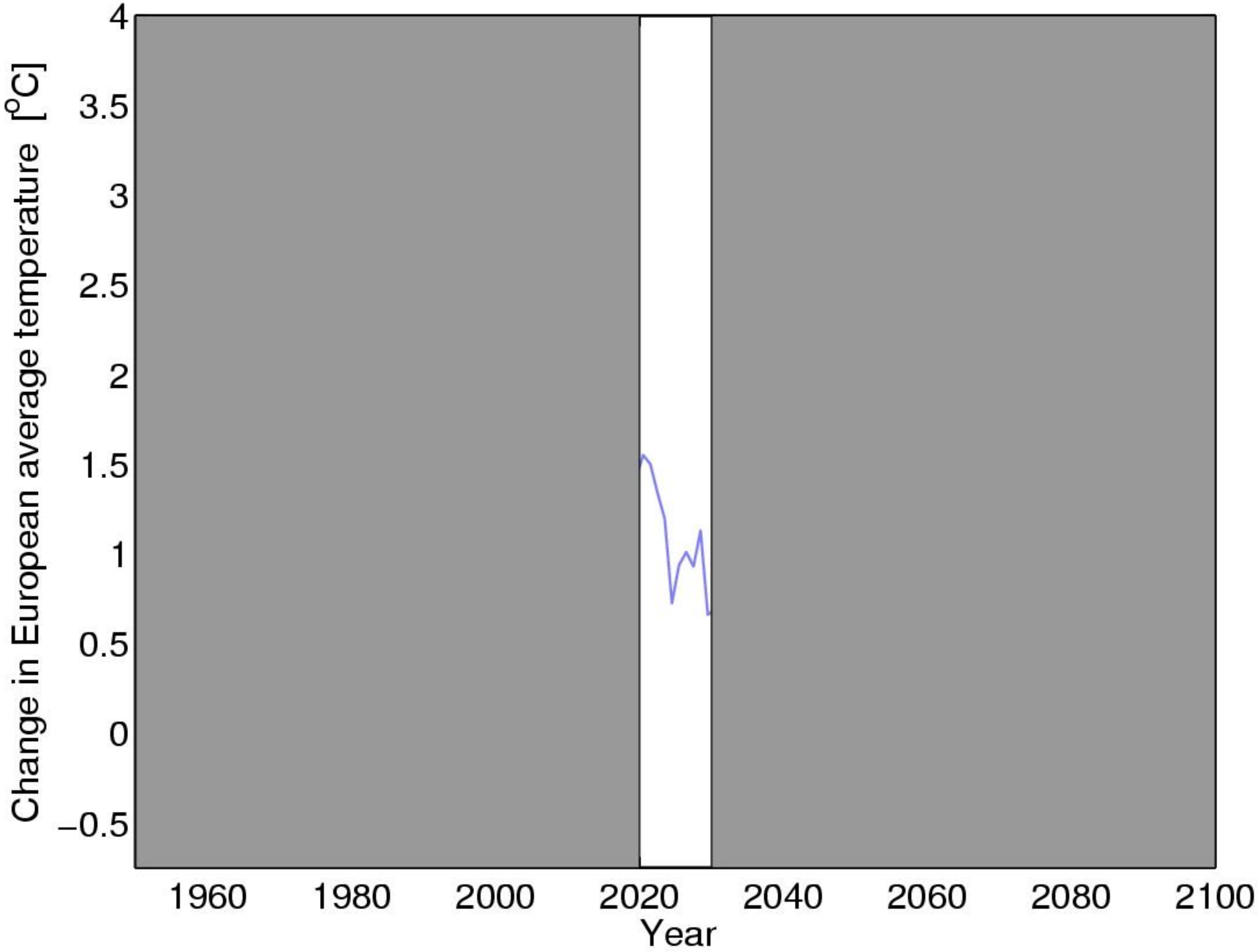

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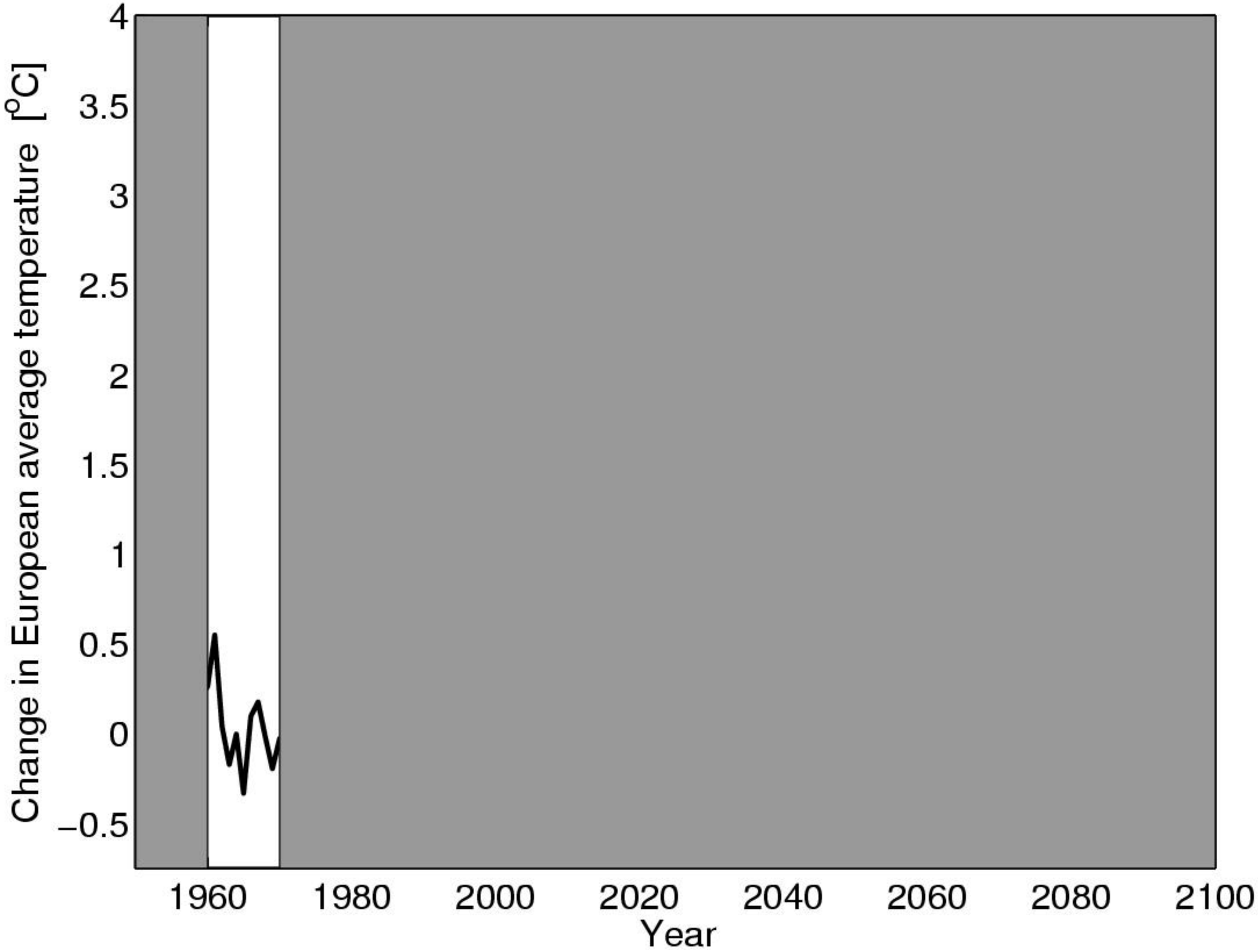

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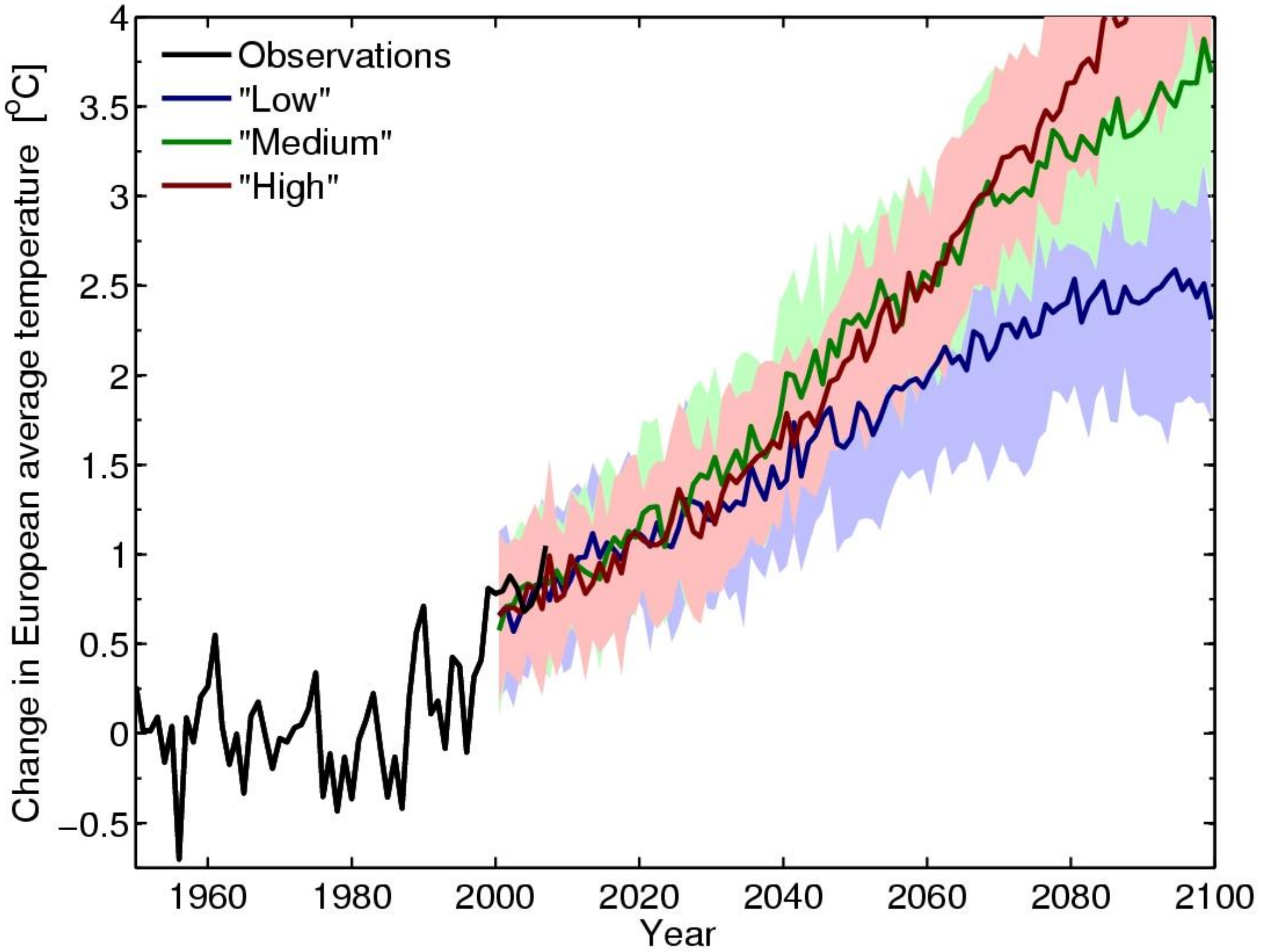
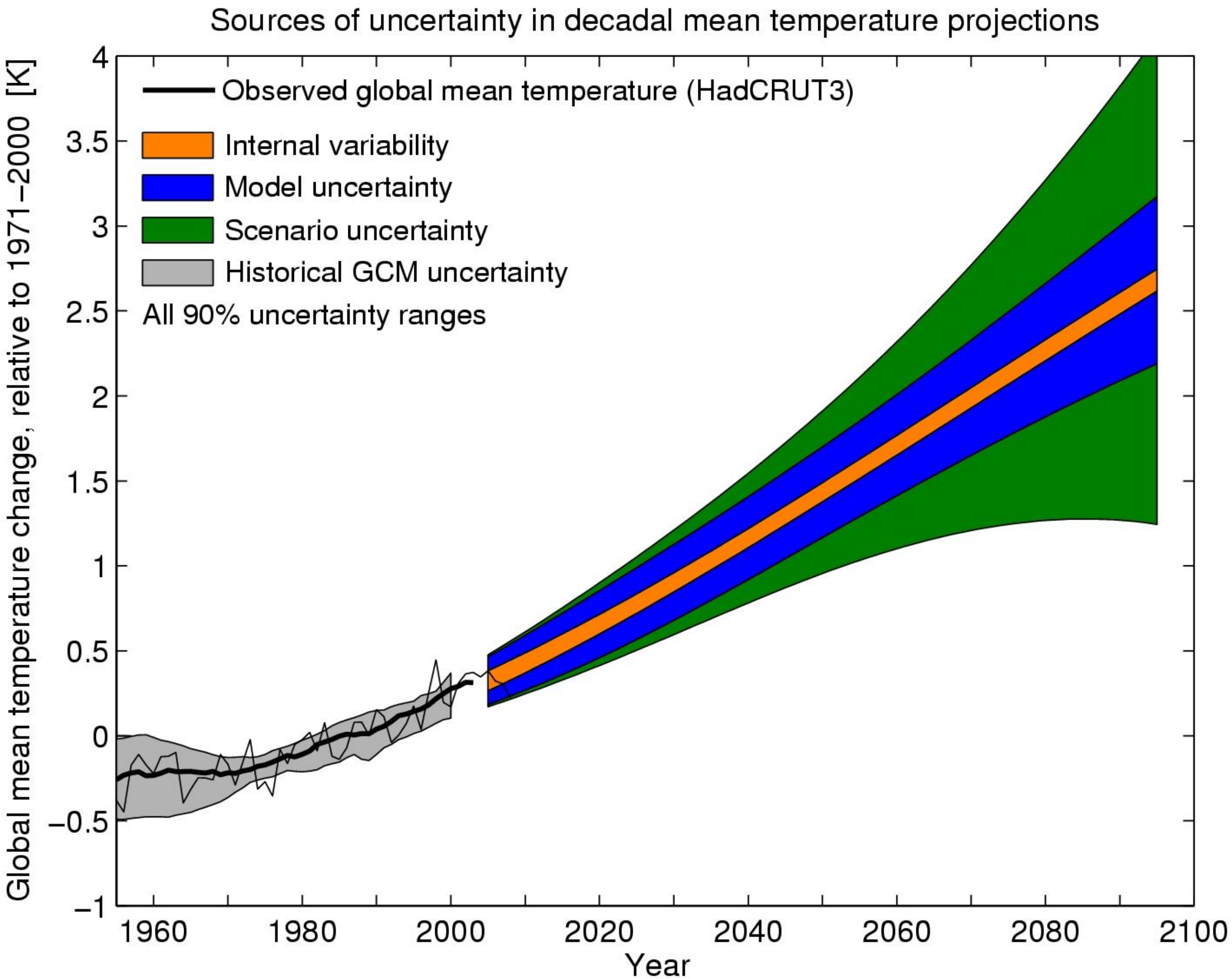


“Ensembles contain information”

Uncertainty in climate projections



Also see poster 9

Uncertainty in climate projections

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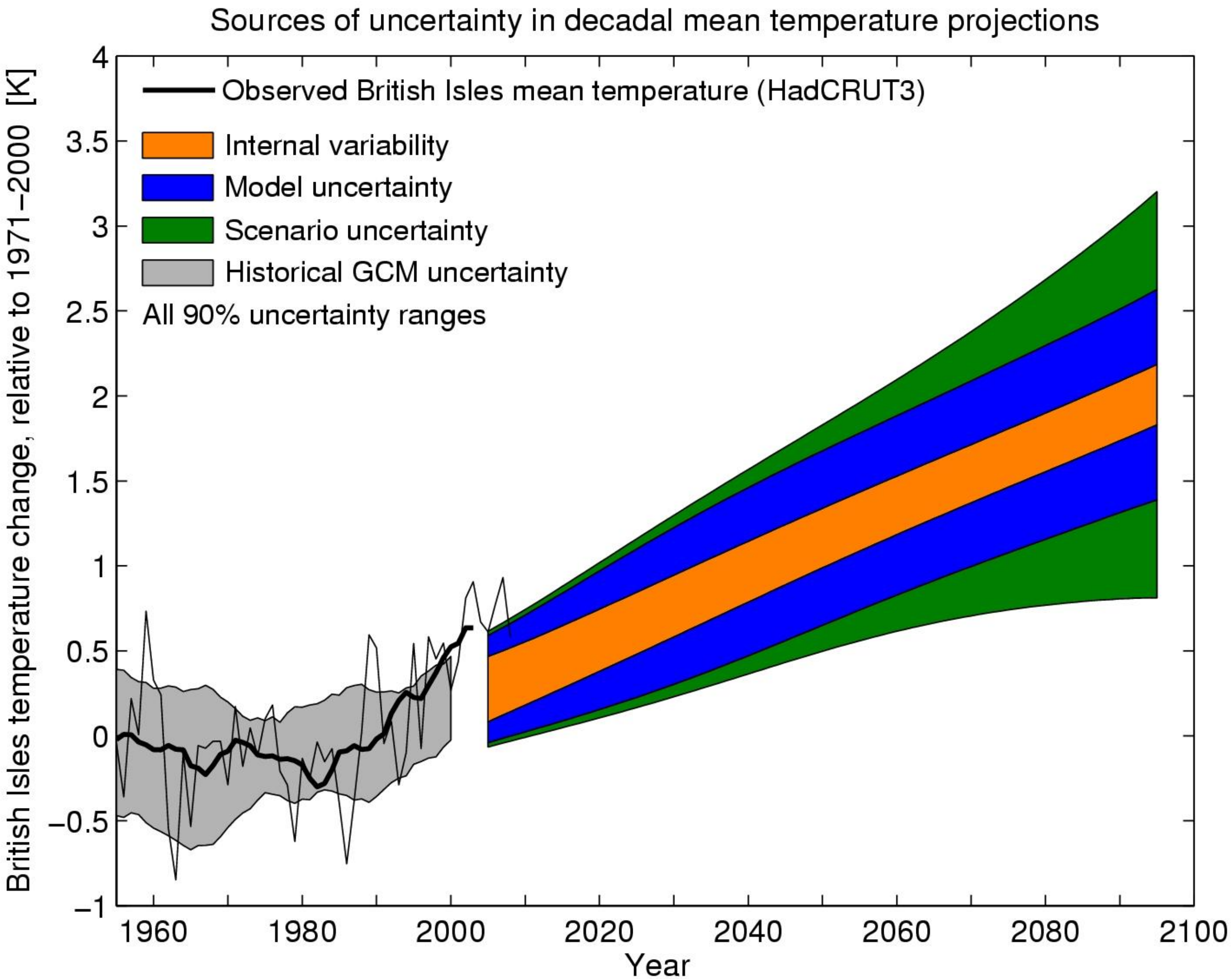
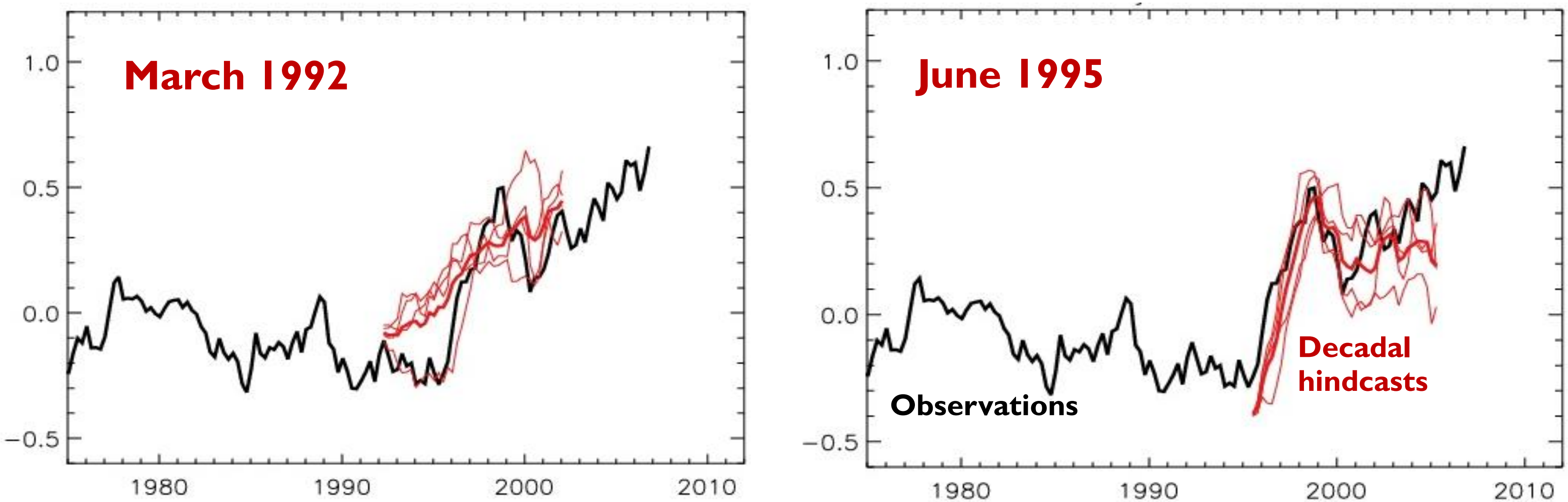


Also see poster 9

Decadal prediction case study

From: Jon Robson, Rowan Sutton, Doug Smith

North Atlantic upper ocean heat content



Can potentially use decadal predictions to:

- validate (or not) GCMs on climate timescales,
- learn about model errors at a process level
- reduce uncertainty in predictions

Motivation

- Long 'memory' in the ocean provides potential predictability on decadal timescales
- Decadal climate predictions are now being made (for IPCC AR5)

  — initialised from ocean state to try and predict both the response to radiative forcings *and* the internal variability component of climate

- But, large uncertainties in our knowledge of current ocean state

  — need to efficiently sample this initial condition uncertainty

- Methods developed for numerical weather prediction can be extended and adapted for decadal climate predictions

  — requires identifying perturbations relevant for climate timescales

Optimal perturbations (or 'singular vectors')

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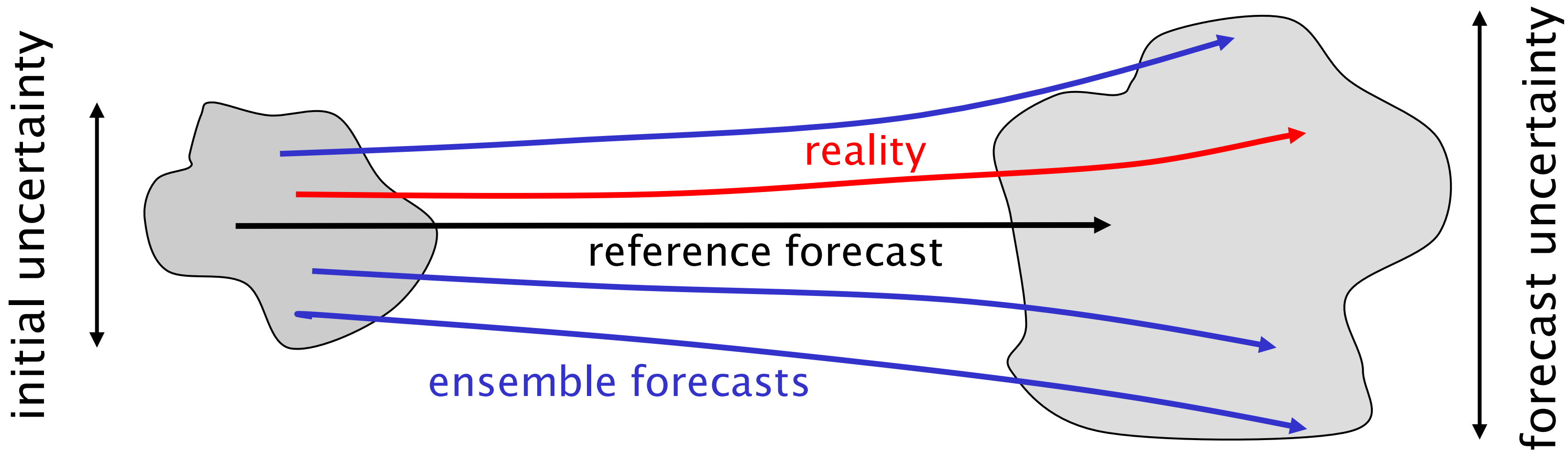

Optimal perturbations for decadal predictions are:

- perturbations which grow most rapidly
- consistent with the observational uncertainties
- average over weather 'noise'
- useful for:
  - efficient perturbations in ensemble forecasts
  - identifying regions where *additional* observations would be most valuable to improve predictions

Optimal perturbations

Using two different methods for the Atlantic Ocean in the HadCM3 GCM:

1. Linear Inverse Modelling (LIM) — e.g. Penland & Sardeshmukh (1995)

(computationally inexpensive, initial condition independent)

2. Climatic Singular Vectors (CSVs) — e.g. Kleeman et al. (2003)

(expensive, estimated for each initial condition separately)

LIM optimal perturbations

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Reduce dimensionality by representing ocean variability in HadCM3 control run (1100 years) with leading 3d EOFs:

GCM: $$\frac{d\mathbf{y}}{dt} = \mathrm{F}(\mathbf{y})$$

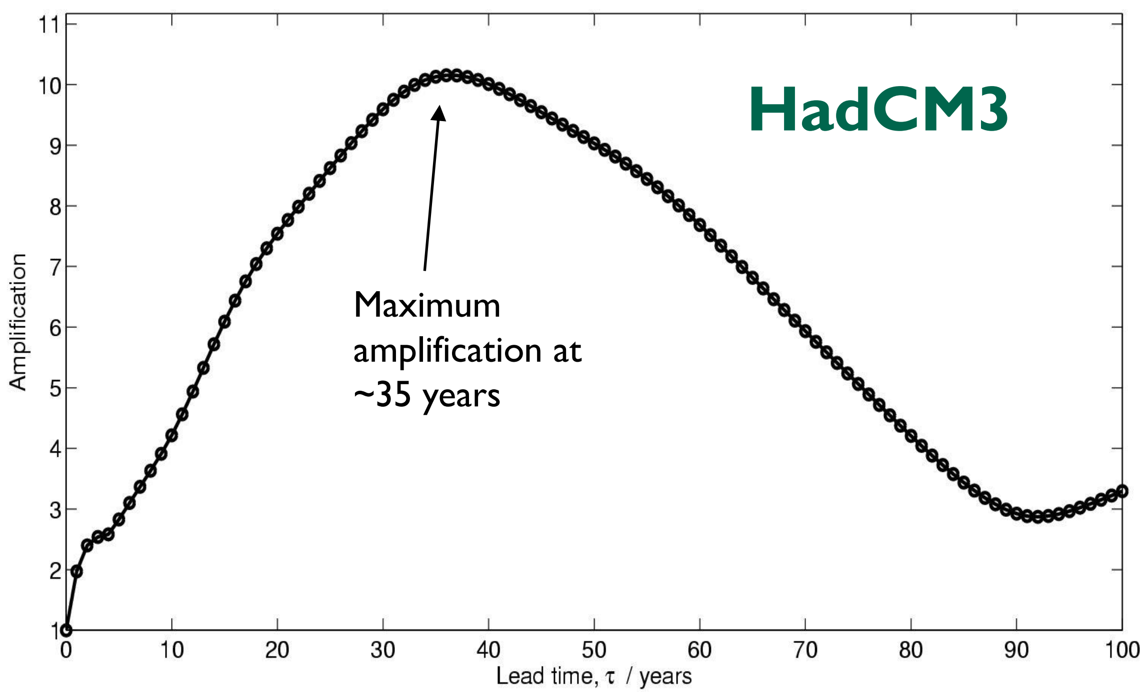
LIM: $$\frac{d\mathbf{x}}{dt} = \mathbf{B}\mathbf{x} + \xi$$

$\mathbf{y}$ represents ocean data

$\mathbf{x}$ represents leading PCs

LIM forecast model:

$$\mathbf{x}(t+\tau) = \mathbf{P}_\tau \mathbf{x}(t)$$



Hawkins & Sutton, 2009

Growth of optimal perturbations

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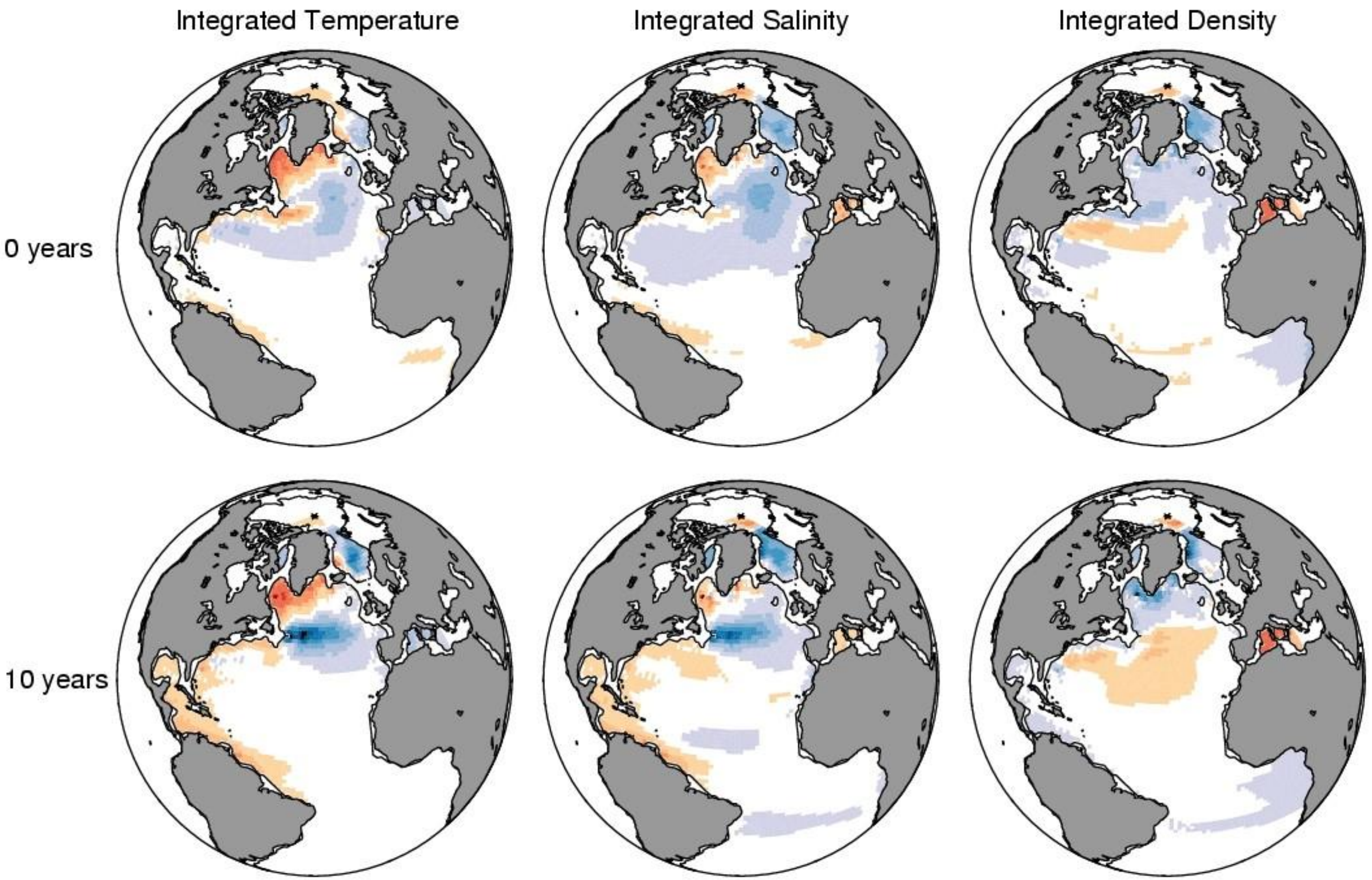
Ocean variables integrated to 1500m depth



Hawkins & Sutton, 2009

HadCM3

Growth of optimal perturbations

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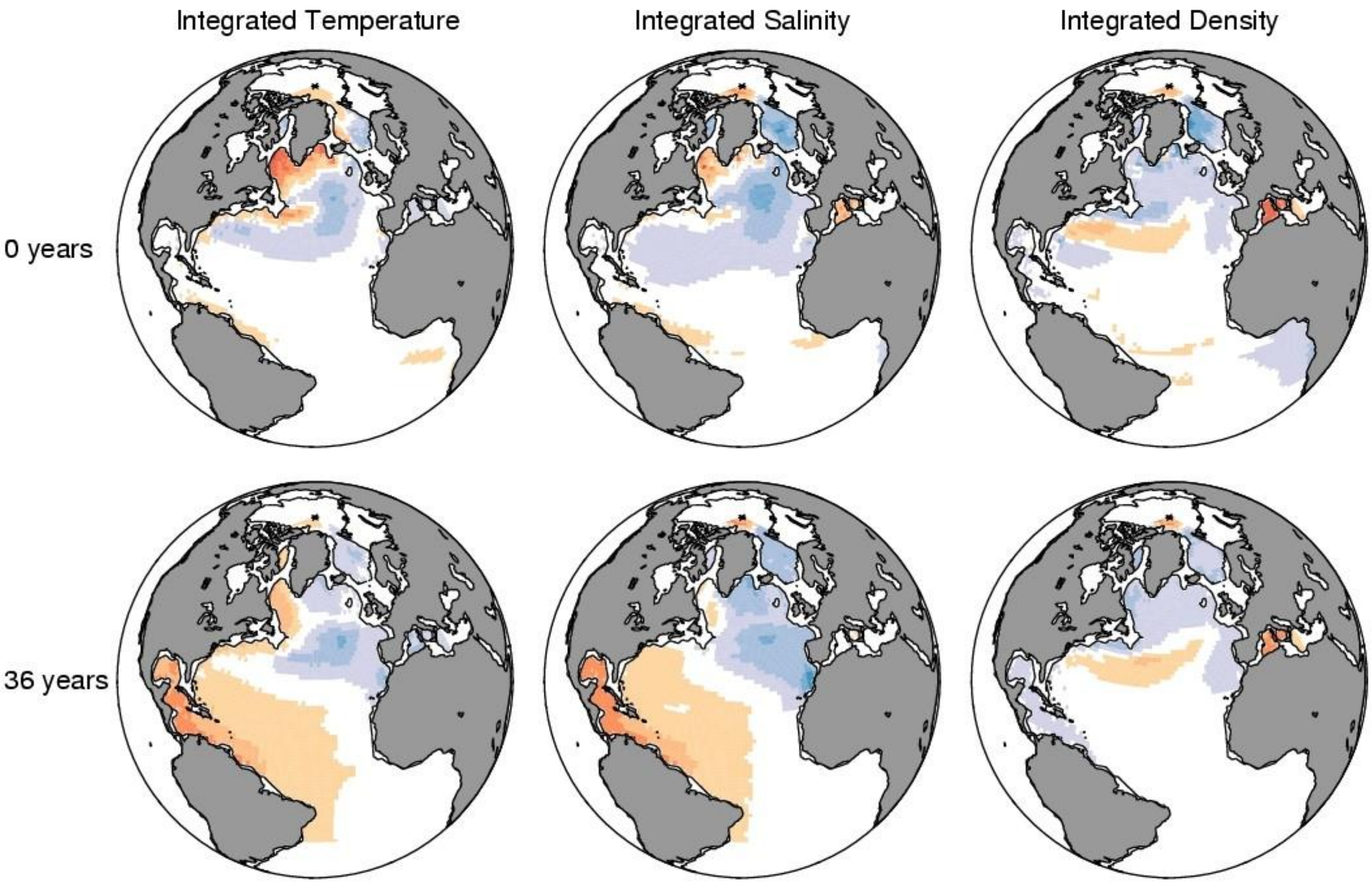
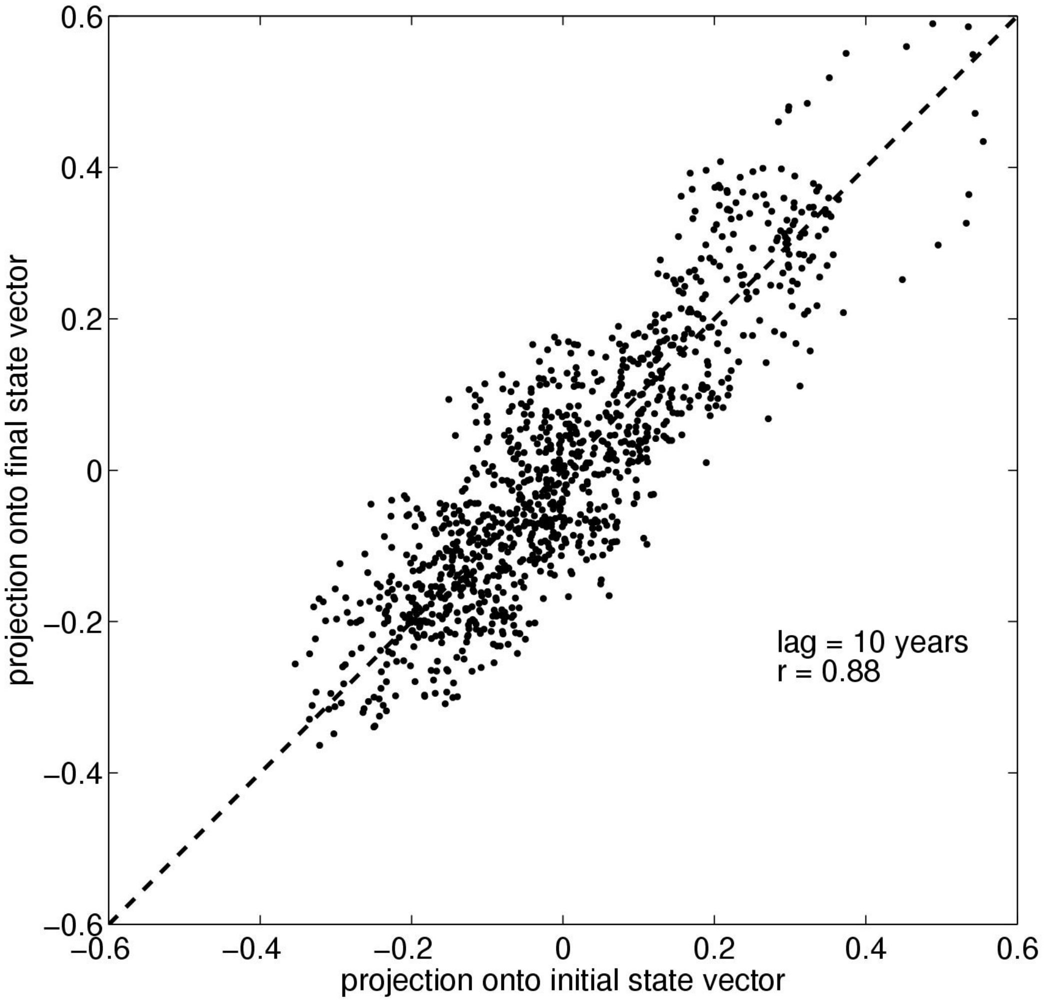
Ocean variables integrated to 1500m depth



Hawkins & Sutton, 2009

HadCM3

Does the linear model work?



Hawkins & Sutton, 2009

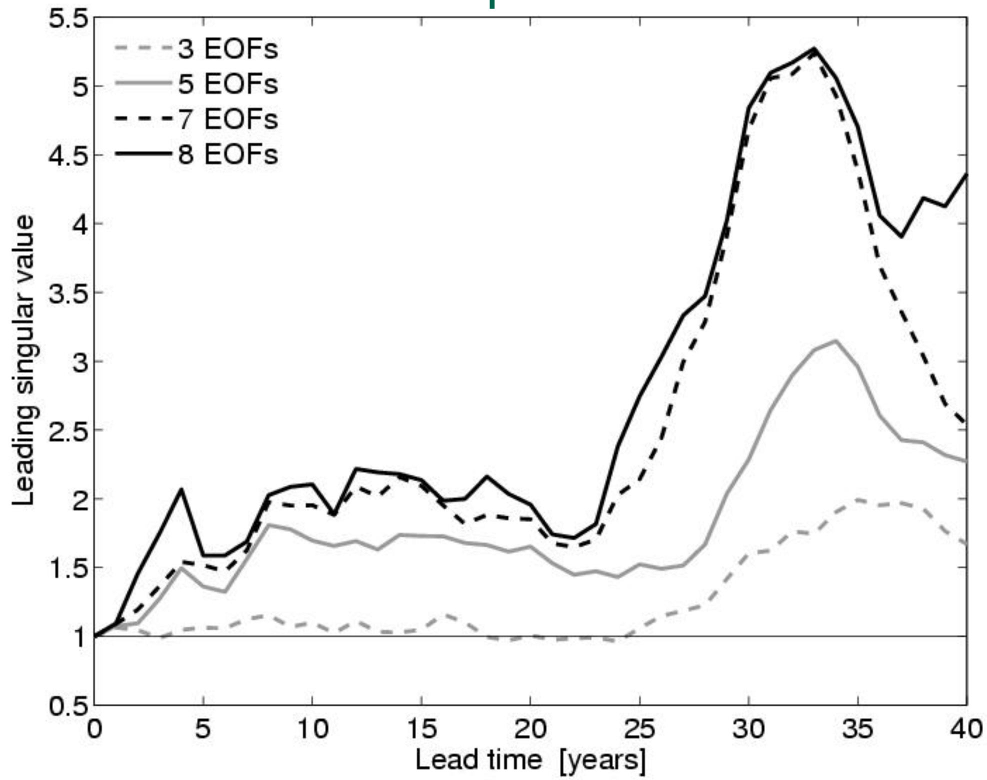
Climatic Singular Vectors (CSVs)

Build a tangent linear propagator matrix (**P**) using an "ensemble of ensembles" run from a single initial condition

- control ensemble
- 8 EOF perturbed ensembles
- 16 members each
- run for 40 years
- further ensembles to test optimal perturbations

Total: ~7000 years with HadCM3, or ~20 CPU-years

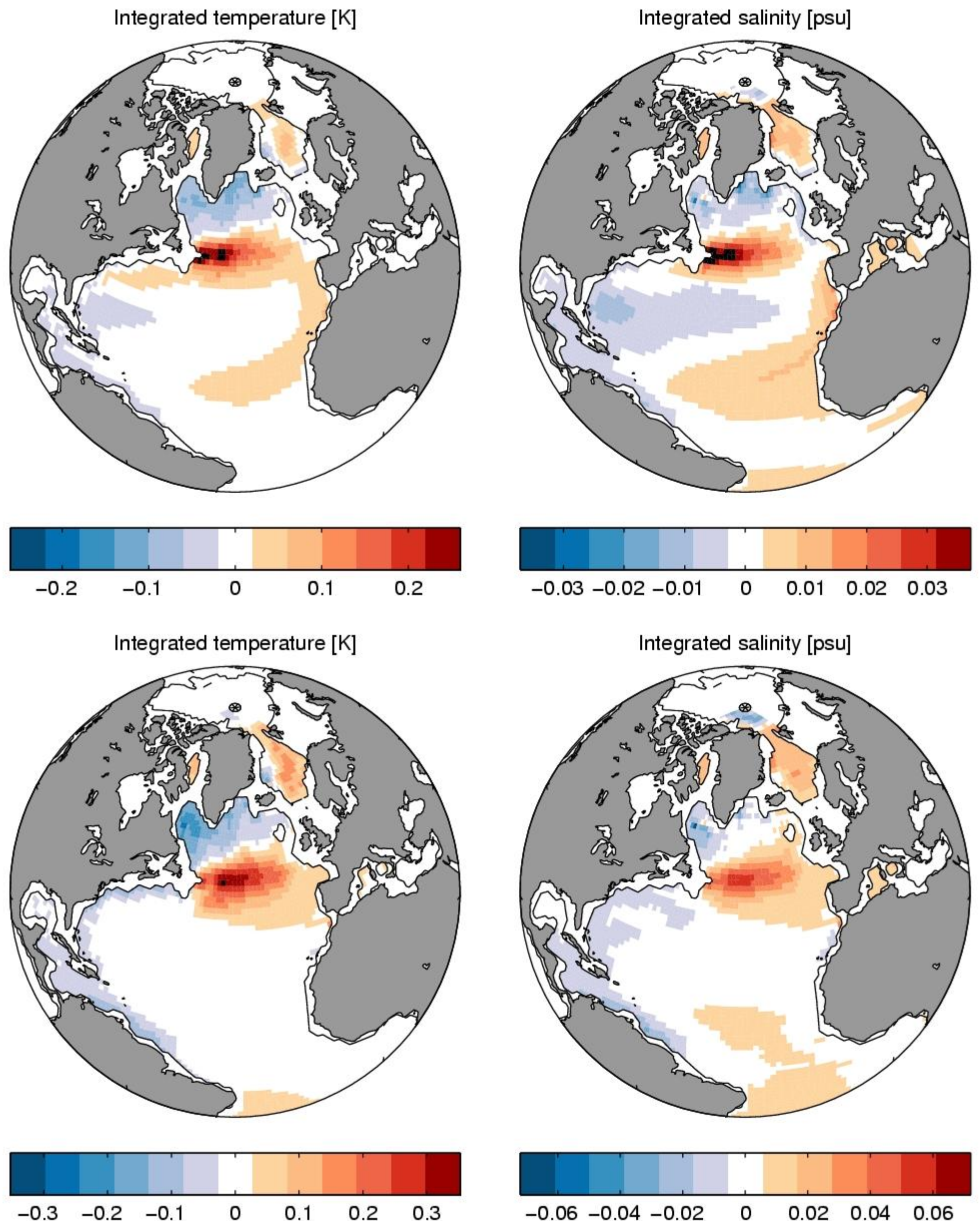
Amplification



Leading CSV in HadCM3

Optimal perturbation

Linear model prediction for 10 years later



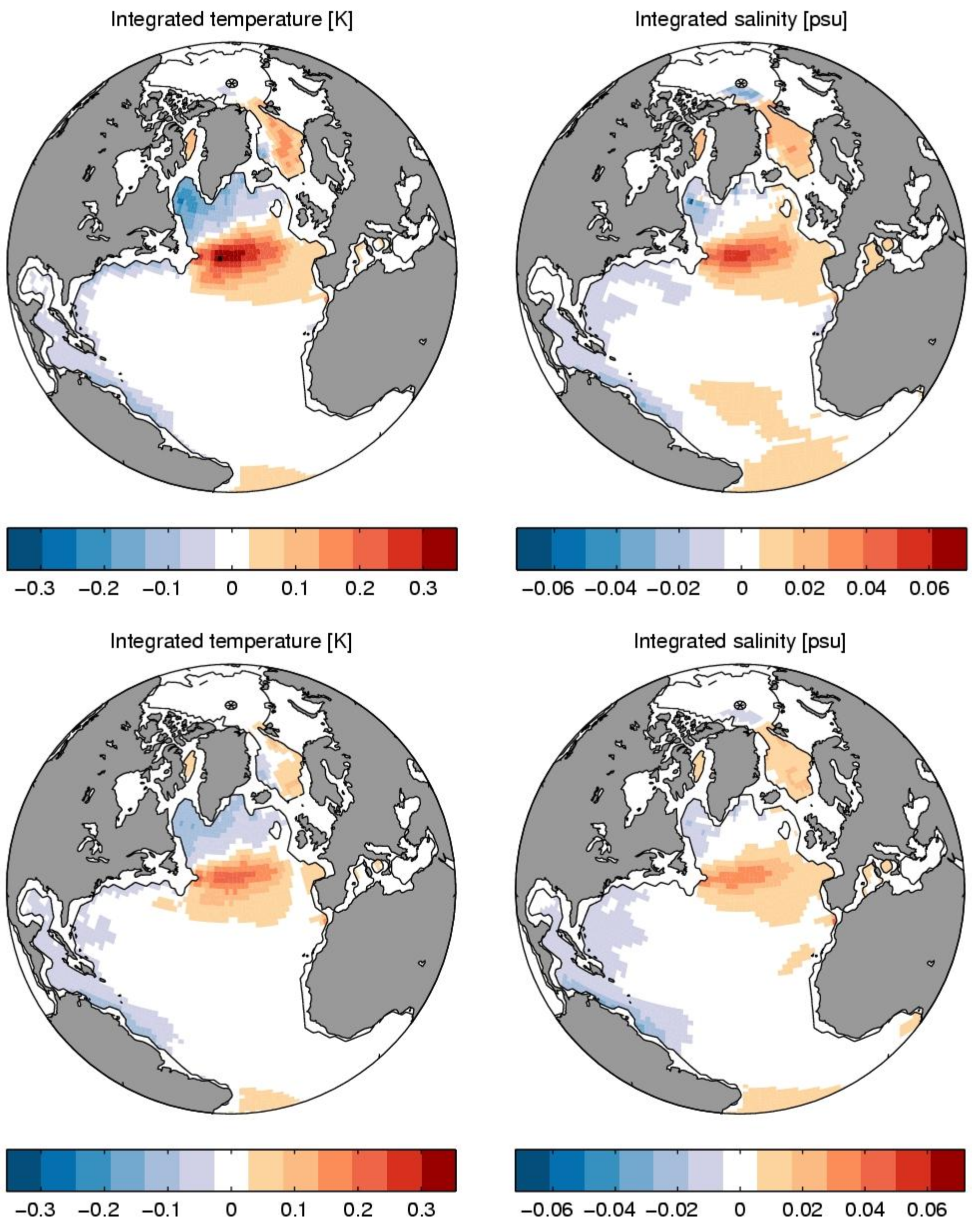
Note changed colour scales!

Does the CSV work?

Linear model prediction:

After 10 years

Actual:



Summary

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- Decadal predictions can help test climate models at a process level
- Demonstrated two methods for estimating optimal perturbations for decadal climate predictions
- In HadCM3, both methods show significant amplification
  - maximum growth after ~35 years
  - largest growing perturbations located in far North Atlantic
  - other models show similar features (e.g. Tziperman et. al. 2009)
- These approaches have great potential to guide development of both:
  - efficient decadal ensemble forecasting systems
  - optimal ocean observing systems

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