Ensembles for climate projections

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Contents

- Background
- Key sources of uncertainty
- Some examples of using ensembles in climate projections
- The next set of UK Climate Projections
    - an example in making some projections
    - Link between daily and multiyear time scales

Background

- Climate projections provide information for adaptation planning to help guide decision making
- There are several national climate projections (notably Australia, The Netherlands, Switzerland and UK).
- The different countries present their projections in different ways reflecting differences in user priorities and statutory requirements, values held by the scientists making the projections, and the diversity of climate over that region.
- The 2009 UK Climate Projections (UKCP09) was used in 80% of the studies that fed in to the 1st Climate Change Risk Assessment (CCRA) so projections have impact.

Two main ways to present climate projections

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To cover a wide spectrum of users, different types of information is needed.

- **Non-probabilistic e.g.**
  - A few examples of what future climate might look like
  - Based on model output from one or more simulations so spatially, temporally coherent across several variables
- **Probabilistic** and corresponding sampled realisations:
  - Comprehensive sampling of uncertainties used for risk assessment
  - Requires statistical post-processing which typically places limits on degree of spatial, physical, temporal coherence
- They both have one important thing in common…

Uncertainty and ensembles

Projections need to explore key uncertainties that are consistent with current knowledge and that affect future climate and so are based on ensembles of climate simulations.

- Internal variability
  - Initial condition uncertainty (ICs come from spinups or controls)
  - Stochastic uncertainty (varying random seed of stochastic physics scheme)
- Modelling uncertainty
  - Structural uncertainty
  - Parametric uncertainty
- Emissions scenario uncertainty

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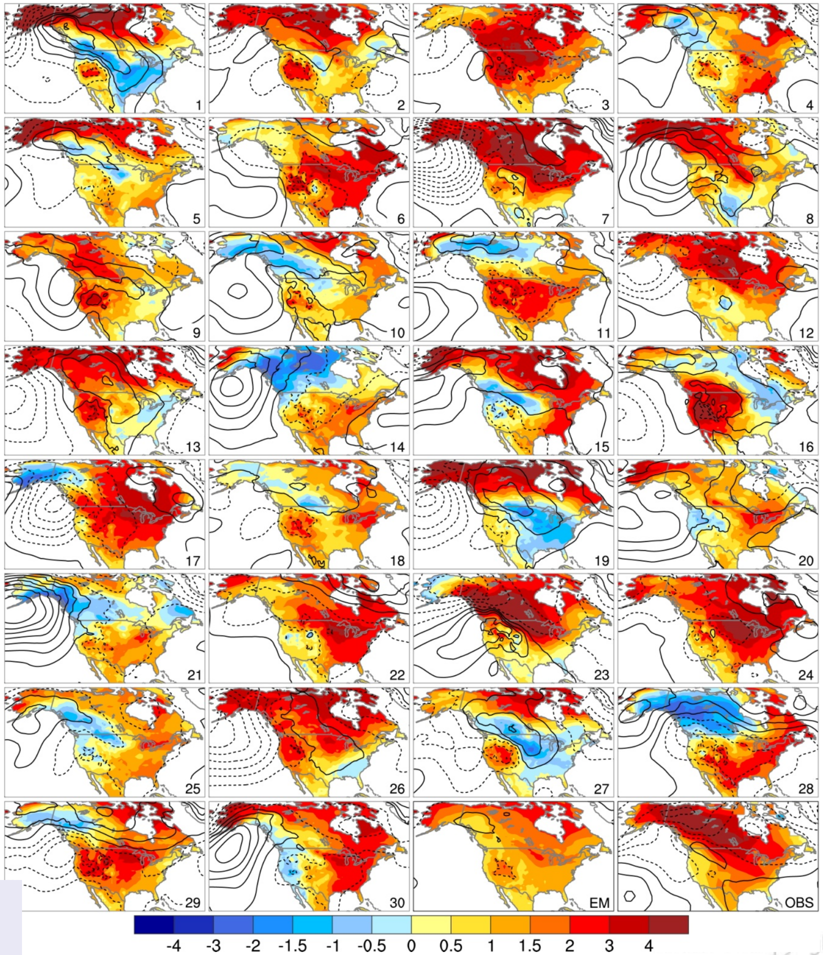
Internal climate variability

Variability that is unforced by natural or man-made forcings and generated internally to the climate system. Beyond a few years, this is unpredictable.

- 1963-2012 temperature (colours) and MSLP (contours) trends for 30 members of CESM1 (CAM5) model by Kay et al (2015)
- Members differ only in their initial conditions of temperature by $O(10^{-14}K)$ perturbation!
- Figure from shows range of possible trend outcomes resulting from the superposition of internal climate variability and anthropogenic climate change

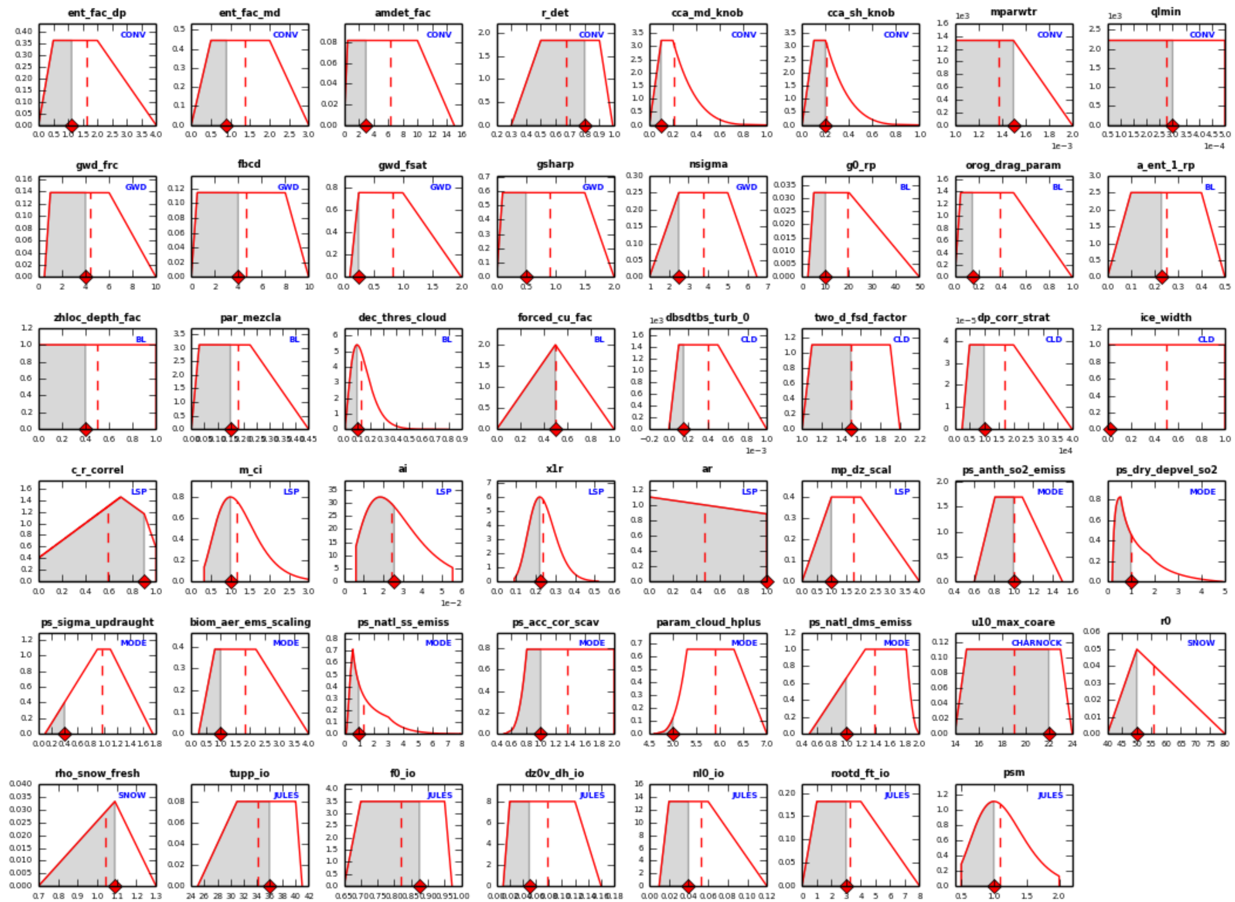


Deser et al 2016

Parametric modelling uncertainty

Model parameters that control unresolved processes can take a range of plausible values.Ensemble members differ in terms of the values assigned to key parameters.

Typically all parameters perturbed for each ensemble member. Resulting ensemble called a Perturbed Parameter Ensemble (PPE).



Structural modelling uncertainty

- Arises from different ways to approximate the climate system when building a climate model (other than choice of values of model parameters).
- Sampled by the multimodel ‘ensemble of opportunity’ e.g. the set of international climate models (CMIP5) used in the 5th IPCC assessment.

Importance of evaluating ensembles members

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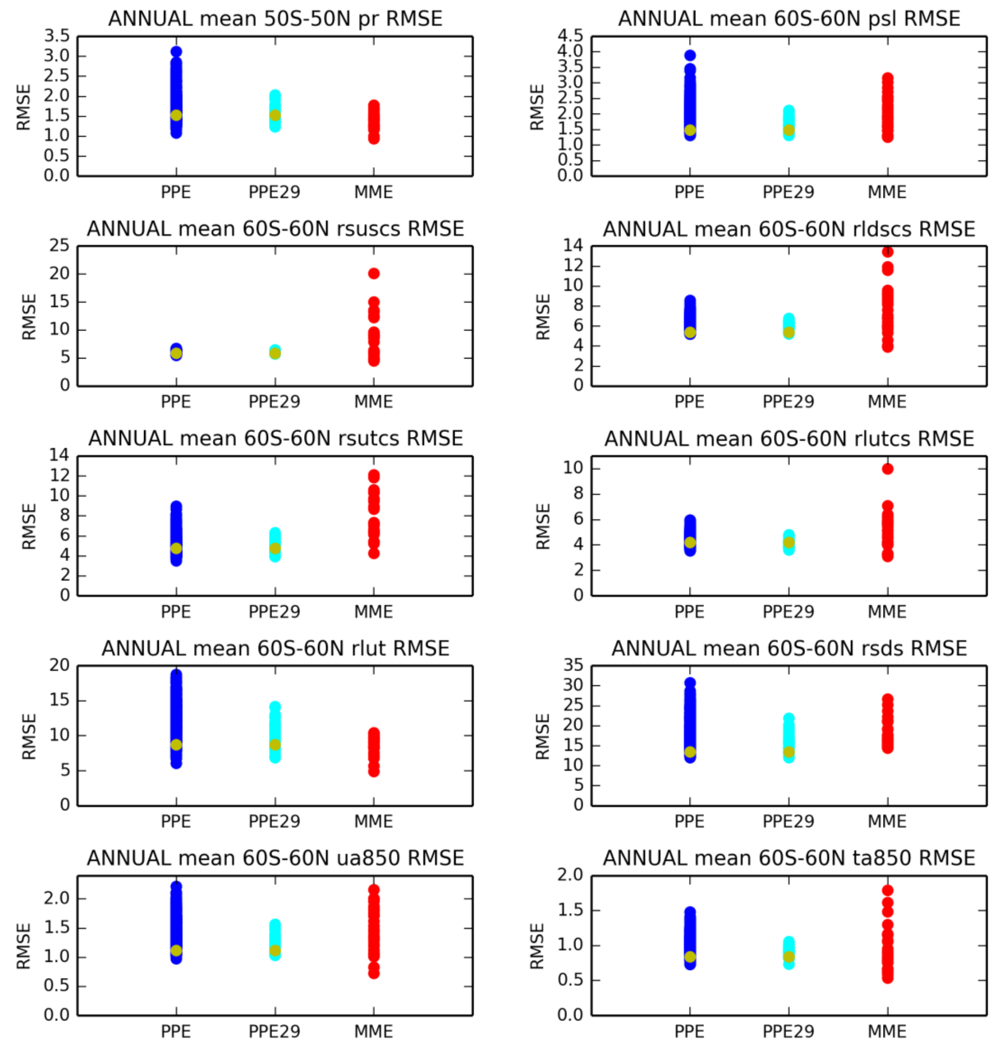
Members of both multimodel ensembles and PPEs sample a wide spectrum of model quality.

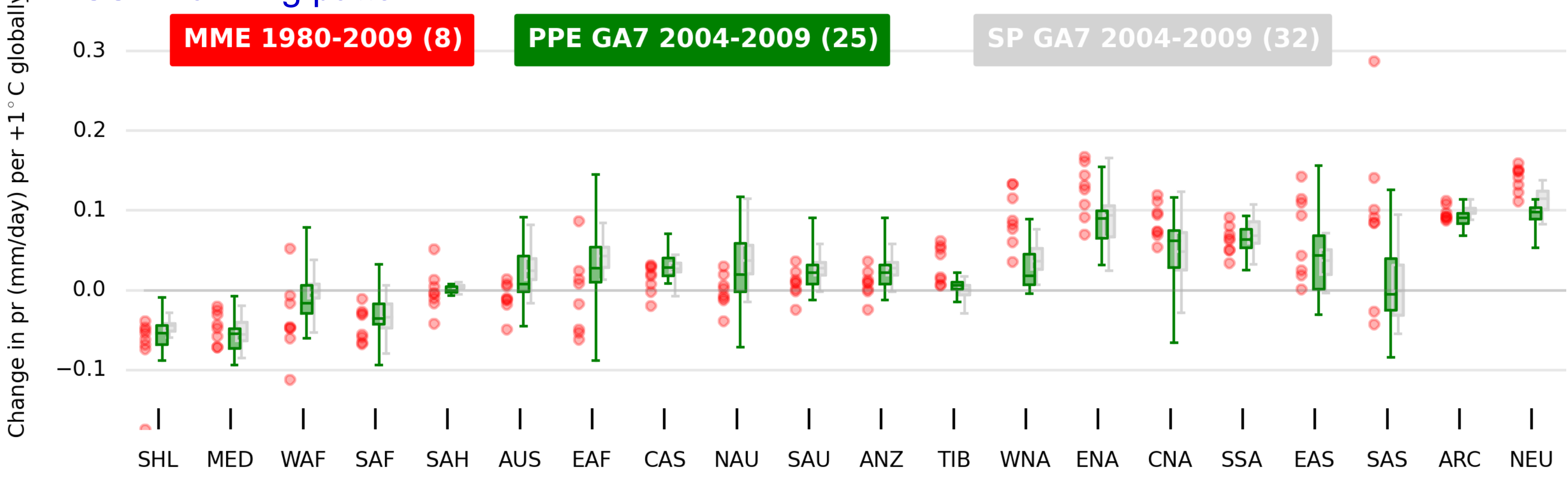
Ensemble members need to be screened or weighted based on comparison with observations.



Comparing structural, parametric and stochastic/internal variability

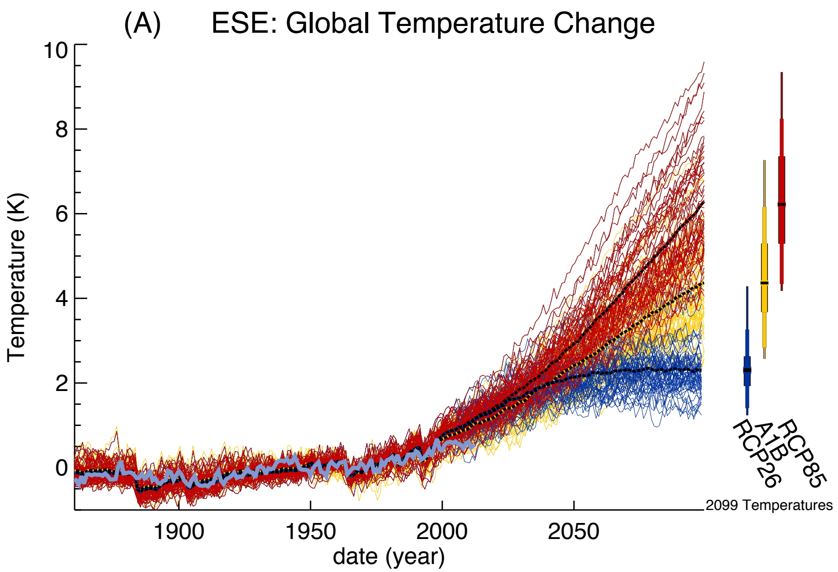
- Both PPE and multimodel ensembles sample internal variability
- PPEs and multimodel ensembles typically show a lot of overlap. Best to pool both ensembles for fuller range.

Changes in annual mean log(precipitation) per +1K global warming due to idealised 4K SST warming pattern

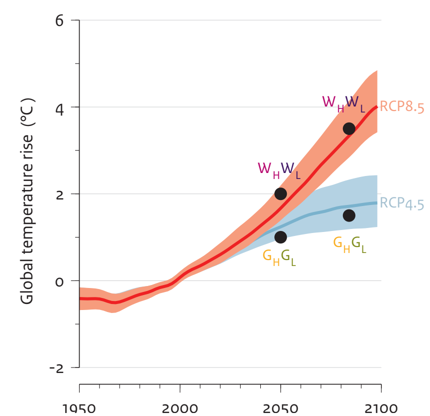


Emissions scenario uncertainty

The uncertainty in global socio-economic development and associated greenhouse gas and aerosol emissions. Typically a few ensembles, one for each emission scenario



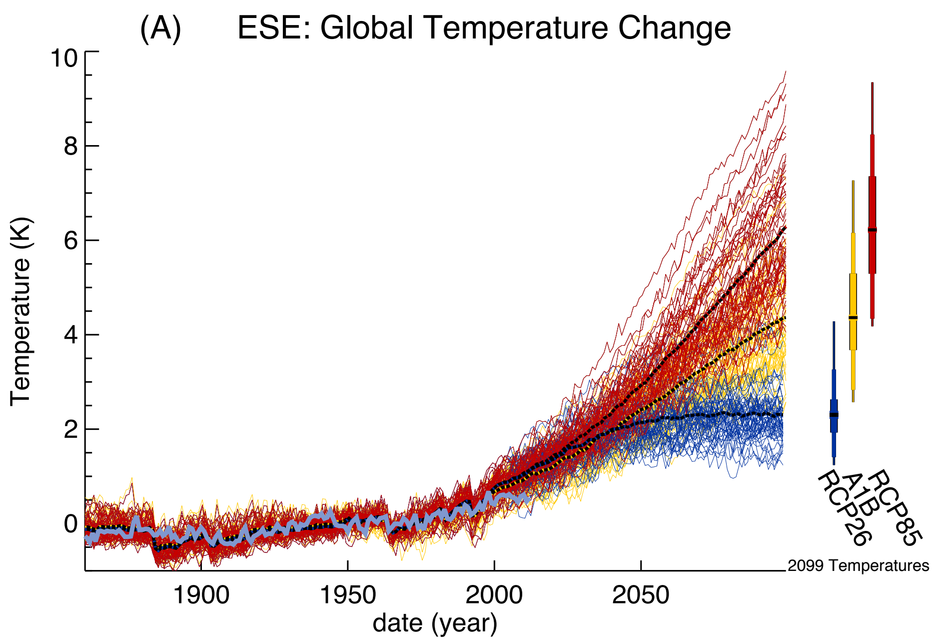
Earth System PPEs (Booth et al 2013) includes carbon cycle uncertainty

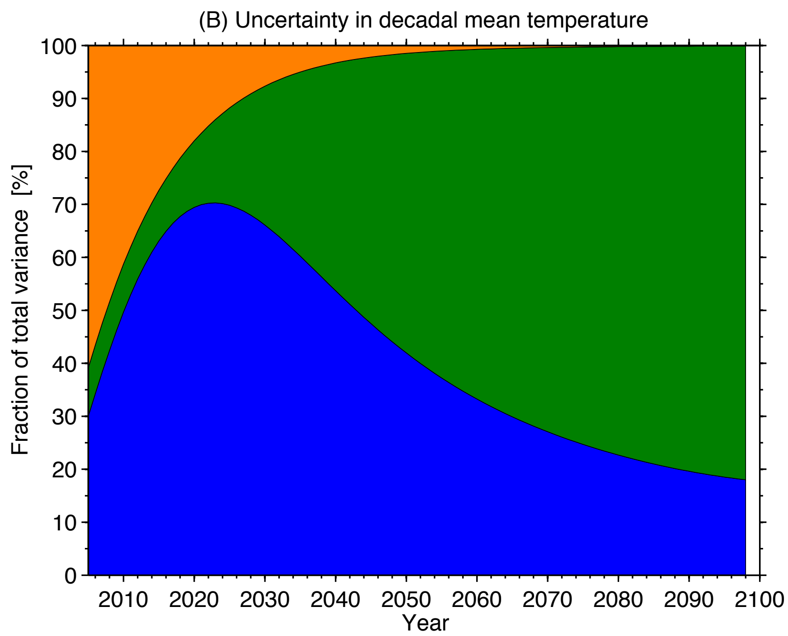


Physical atmosphere-ocean CMIP5 multimodel ensemble (KNMI14 brochure)

Changes in relative contribution of uncertainties over time

From Booth et al (2013) but right panel based on Hawkins and Sutton (2009)

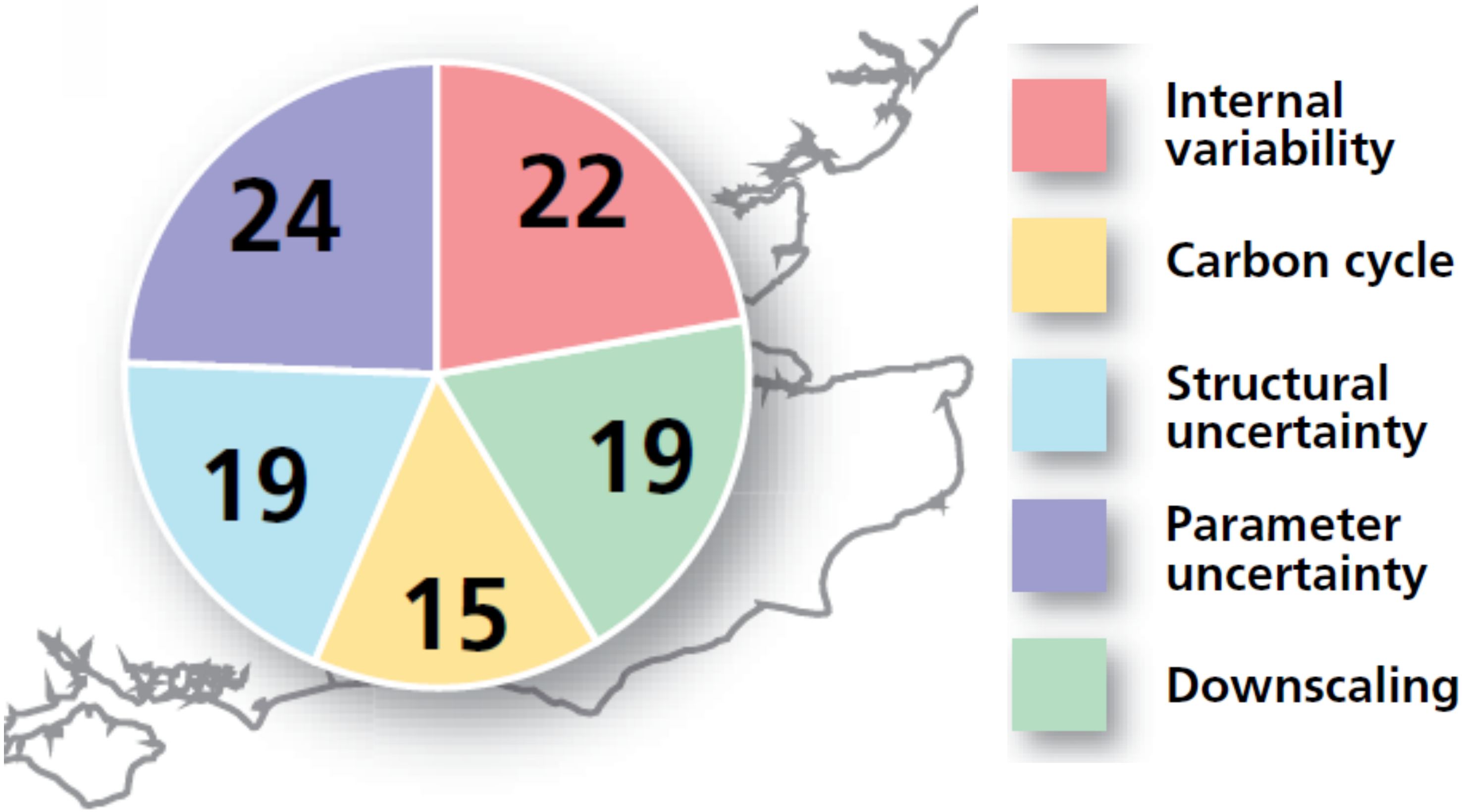




Internal variability
Model uncertainty
Emissions uncertainty

Relative contributions of uncertainty from UKCP09

Uncertainties in winter precipitation changes for the 2080s relative to 1961-90, at a 25km box in SE England



All sources of uncertainty contributing so all important to include. New information, methods, experimental design can reduce uncertainty so projections will change in future and decision makers need to consider this

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Some examples of using ensembles in climate projections

Multiple realisations for impacts studies

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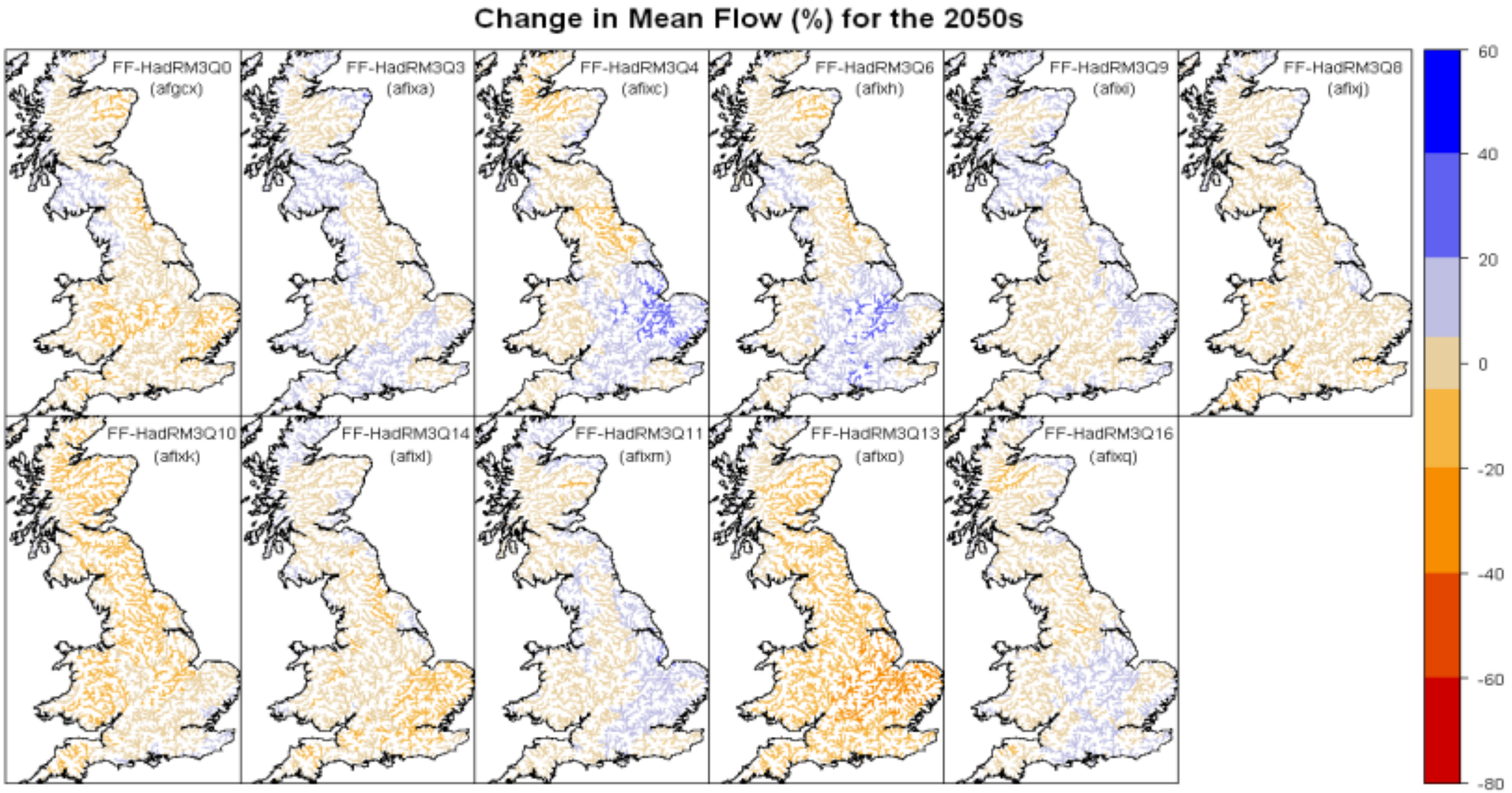
Future changes in river flow, obtained by using results from the 11 UKCP09 regional climate model simulations to drive a hydrology model

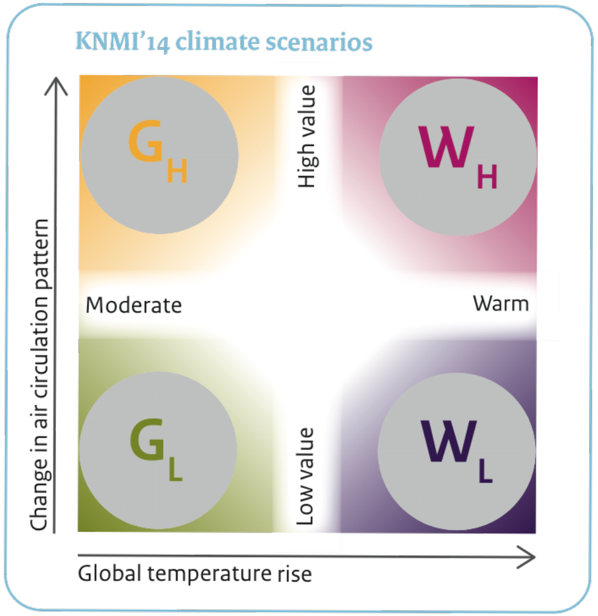


Prudhomme et al (2012), Future Flows and Groundwater Levels, CEH

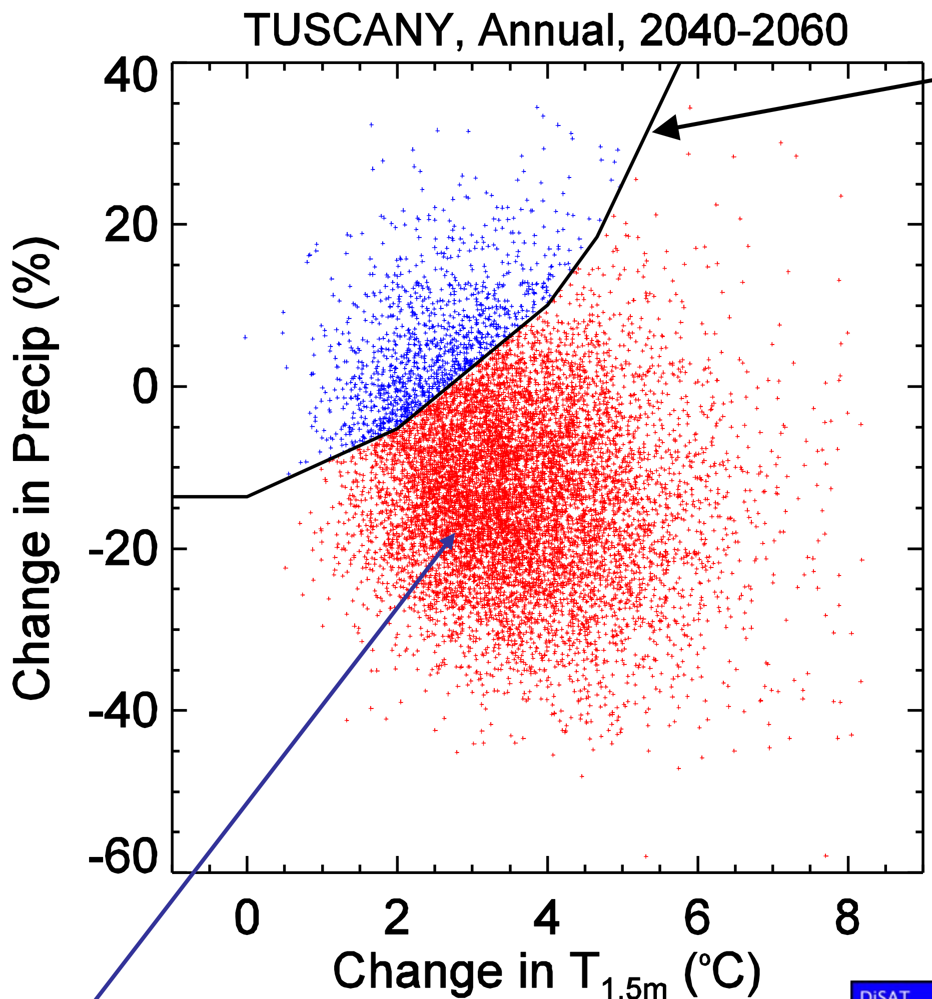
Examples of Storylines

Climate futures tool **Whetton et al (2012)**	**Pictures of the future** **KNMI (2015)**
Representative models	Clustering by drivers

		Annual Surface Temperature (°C)			
		Slightly Warmer < +0.5	Warmer +0.5 to +1.5	Hotter +1.5 to +3.0	Much Hotter > +3.0
Annual Rainfall (%)	Much Wetter > +15.0				
	Wetter +5.0 to +15.0		2 of 30 GCMs +	9 of 30 GCMs 1 of 6 DS +	2 of 30 GCMs +
	Little Change −5.0 to +5.0			12 of 30 GCMs 4 of 6 DS +	3 of 30 GCMs +
	Drier −15.0 to −5.0			2 of 30 GCMs +	
	Much Drier < −15.0				



Example of probabilistic assessment: durum wheat (pasta) yield in Tuscany 2040-2060



Response surface for current yield, including CO_2 fertilization

⇒ 86% risk of a reduction in yield

Sampled data

Thanks to:

Roberto Ferrise, Marco Moriondo, Marco Bindi
Department of Agronomy and Land Management
University of Florence

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UKCP18 - An example of making an ensemble for climate projections

UK Climate Projections 2018 - the UKCP18 land projections

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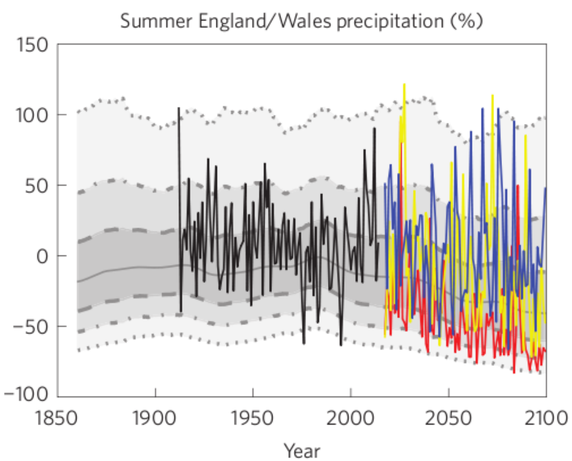
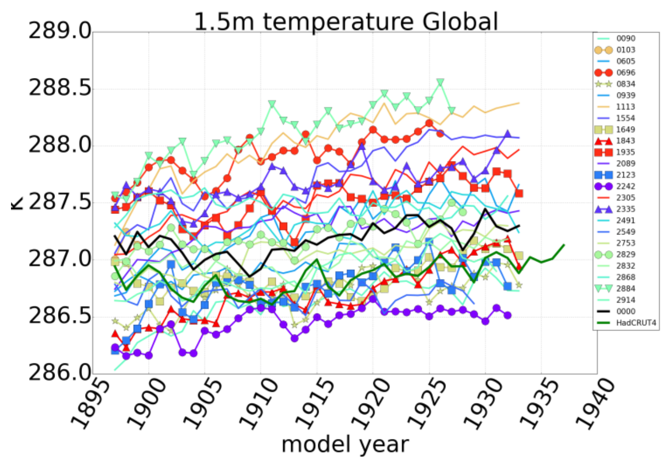
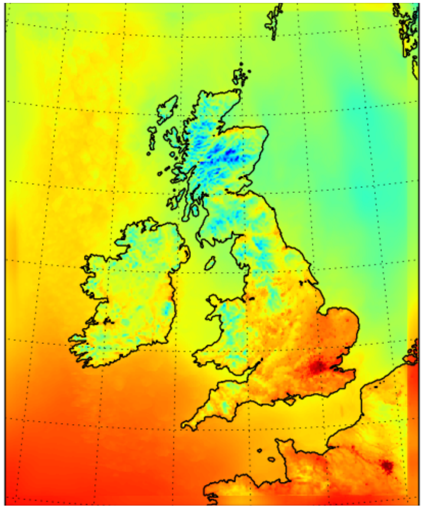
Samples plausible RCP8.5 CO2 pathways

GCM drives convection permitting model







Strand 1
PDFs evolving in time (HadCM3 and CMIP5)

Strand 2
Plausible GCM realisations

Strand 3
12km downscaled runs (2.2km later)

Aims of the three strands

Product	Key aims
PDFs	• Used for risk assessment • Comprehensive sampling of the key uncertainties
20 plausible and diverse GCM realisations	• Understanding climate variability and extremes under a warming climate • Flexible dataset for impacts, storylines • Global and historical context • Connecting the regional scale to global drivers
15 downscaled simulations (12km)	• Flexible data set for impacts, storylines • Finer scale information focused on UK • Additional or improved local processes (orography, coastlines) • Drive 10 convection permitting UK models at 2.2km

Common elements to all three strands

- Sample parameter uncertainty (not 2.2km)
- Multiple lines of evidence
  - Perturbed parameter ensembles
  - Observations
  - Multimodel ensembles (12km run users can analyse EuroCordex)
- Global CO_2 uncertainty sampled

Ensemble size and choice of model

- PDFs require very large ensembles to allow statistical methods called emulators to predict model output at untried parameter combinations. Only affordable with a cheap (old) climate model.
- Plausible realisations with the latest, best climate model are expensive to run. Only ~20 simulations affordable.
- So a compromise between ensemble size and choice of model is made to balance the thoroughness of sampling the uncertainty versus the credibility of representing the climate system.
- This affects the range of applications associated with each product.

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Strand 2 – an example of experimental design strategy

The set of perturbed parameters for atmosphere and land schemes

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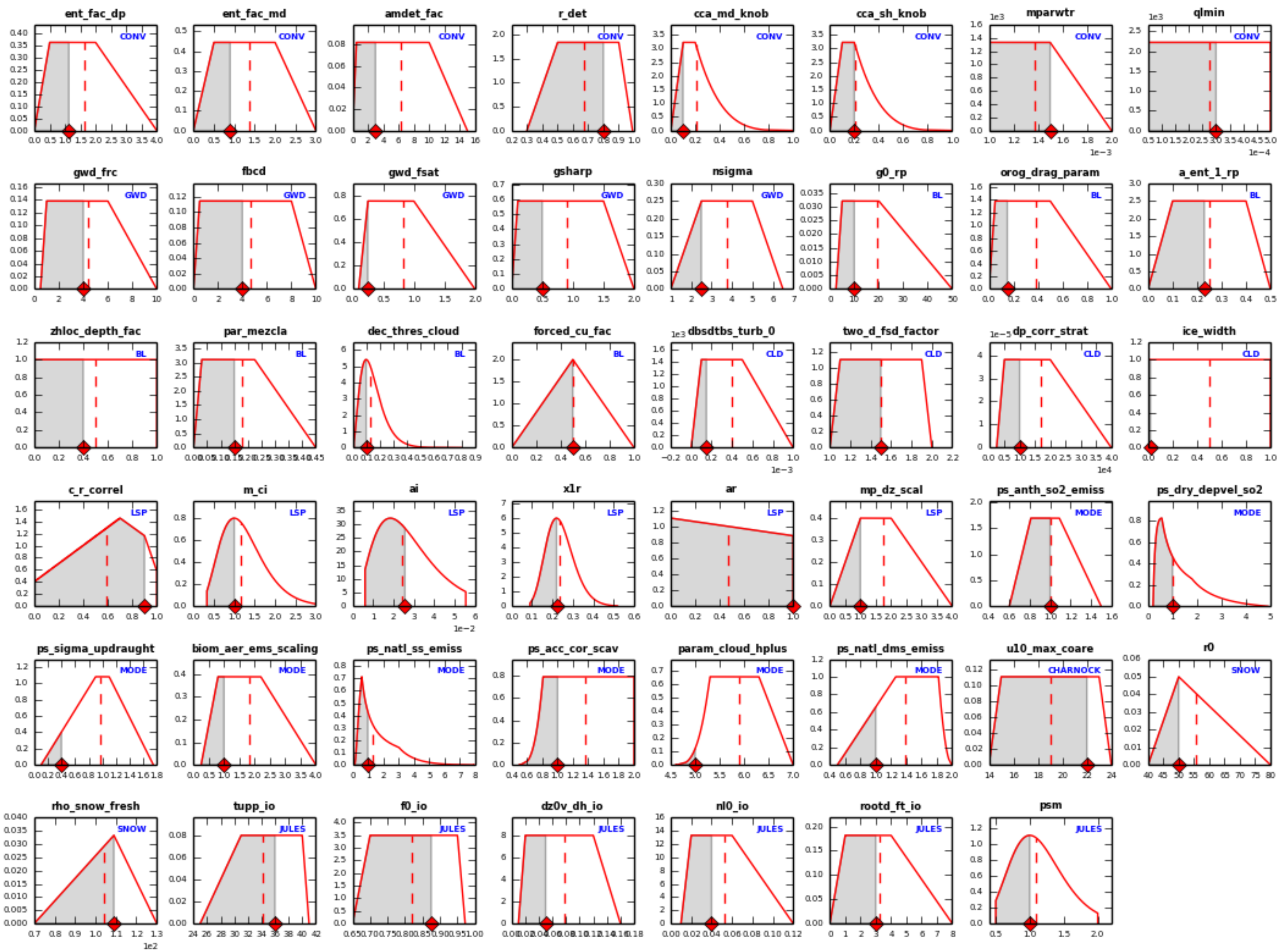
7 schemes for GA7.05:

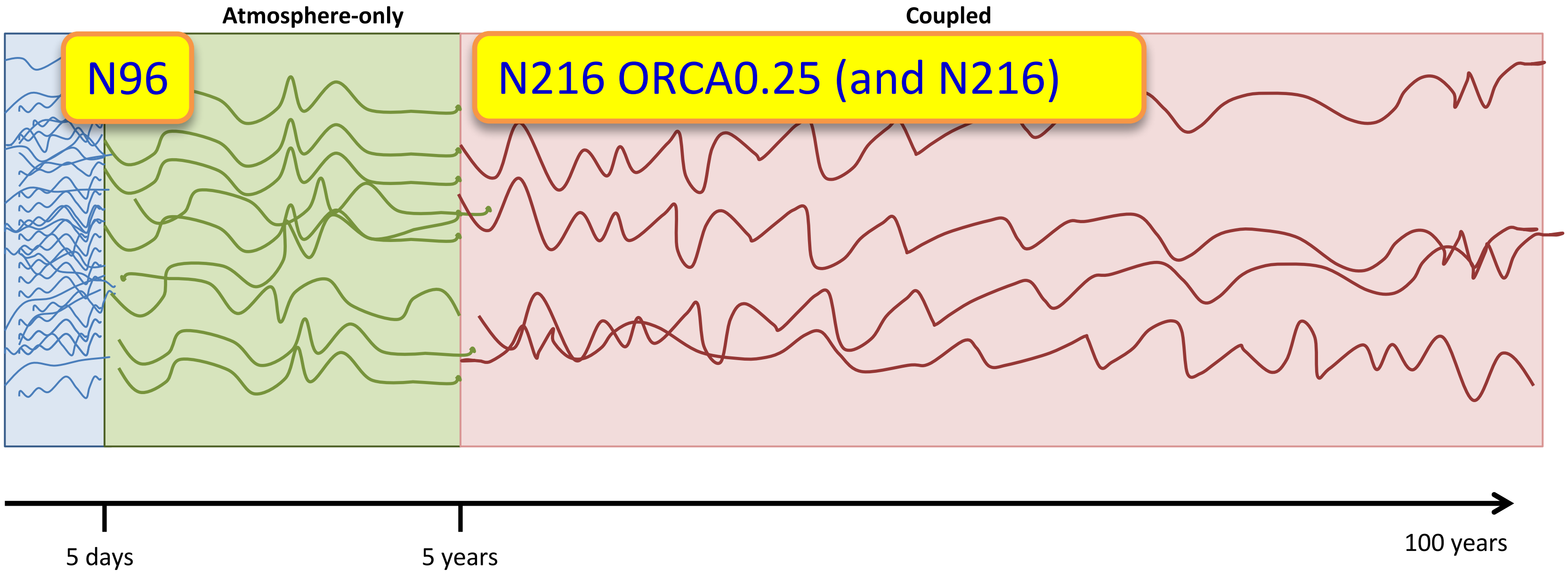
- convection
- microphysics
- GWD
- boundary layer
- land surface
- aerosols
- cloud and cloud radiation

Atmosphere, land, aerosol only. No ocean, carbon cycle in this PPE.



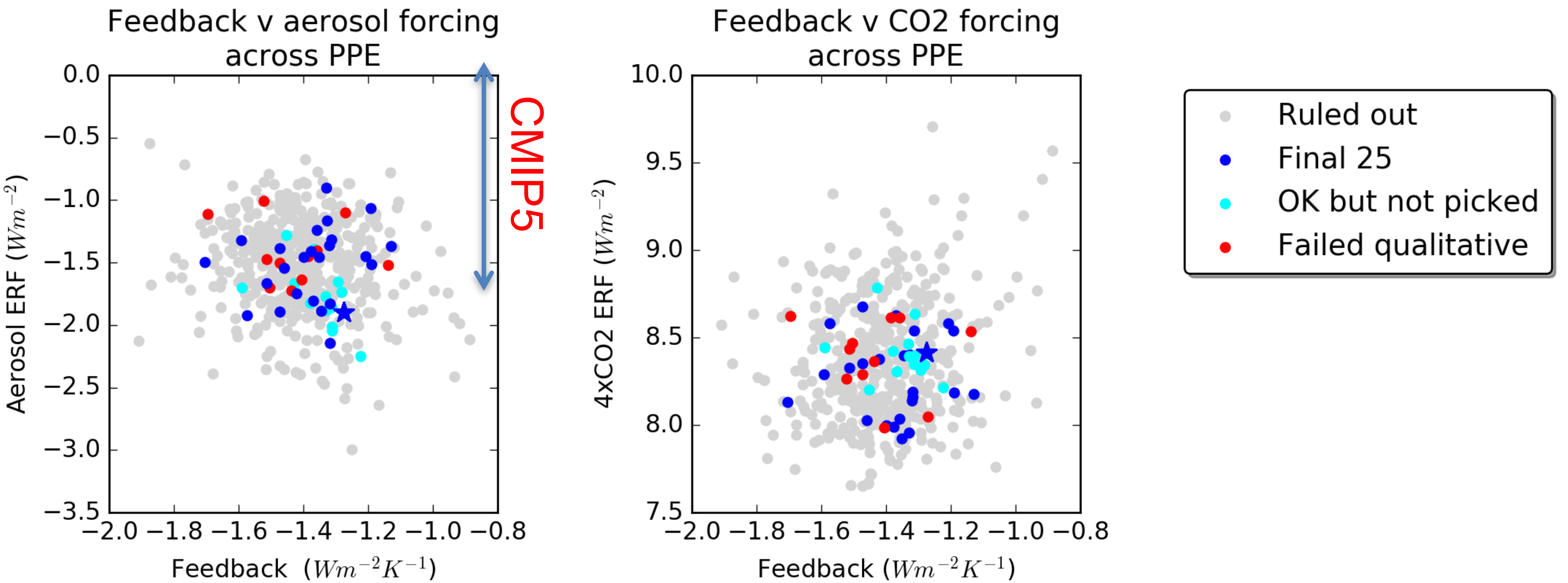
Cheap experiments to filter parameter space (following on from Rodwell and Palmer (2007))

- 49 out of 2914 parameter combinations passed quantitative acceptability criteria.
- That is a low hit rate and despite using some techniques based on history matching. Due to number of metrics and parameters.

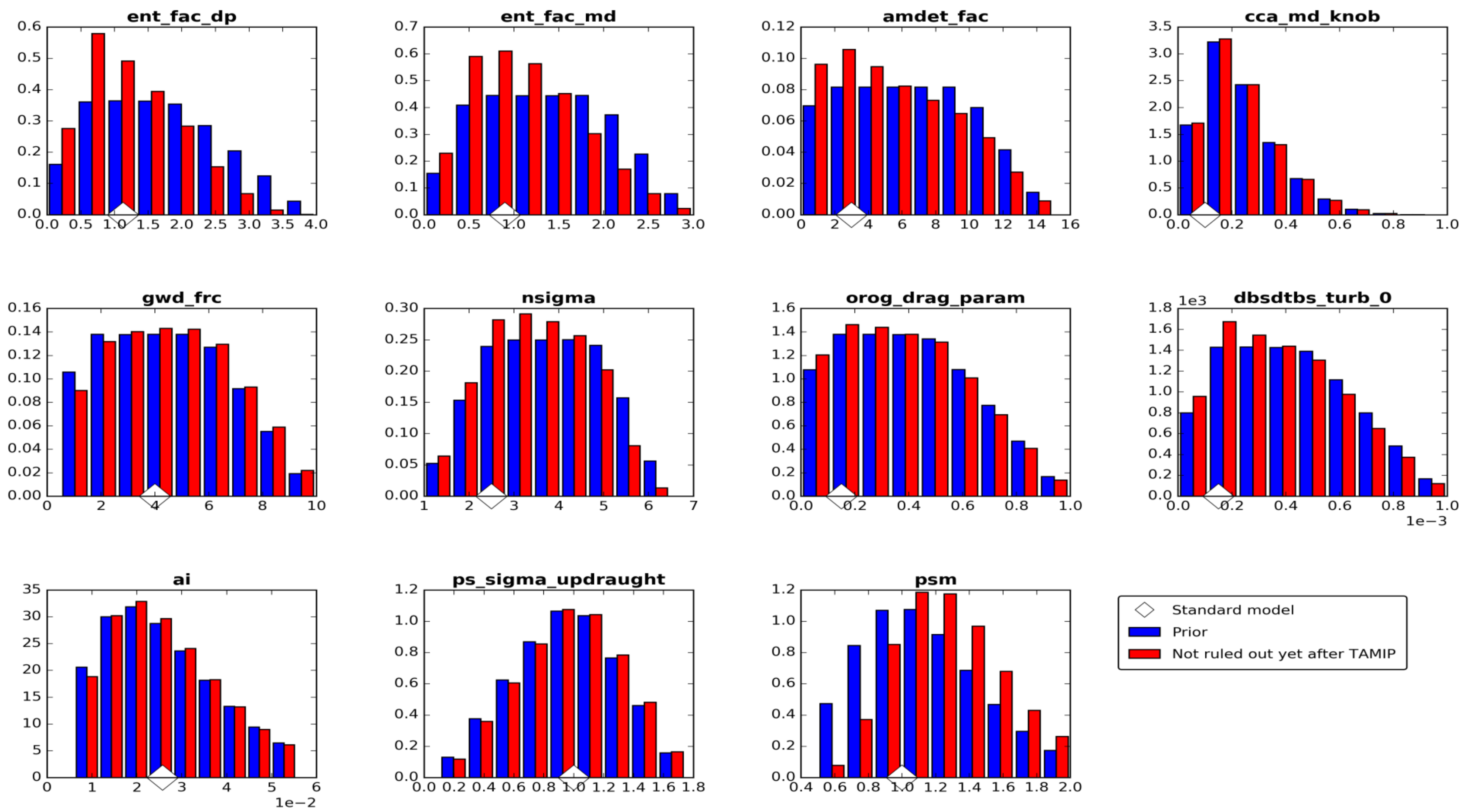


Selecting 20 PPE members for coupled simulations

The forcing and feedback estimates come from extra experiments like AMIPfuture, AMIP4CO2, AMIP-PIAERO.



The parameters constrained by 5-day forecast errors



5-year mean MSE versus 5-day forecast error MSE

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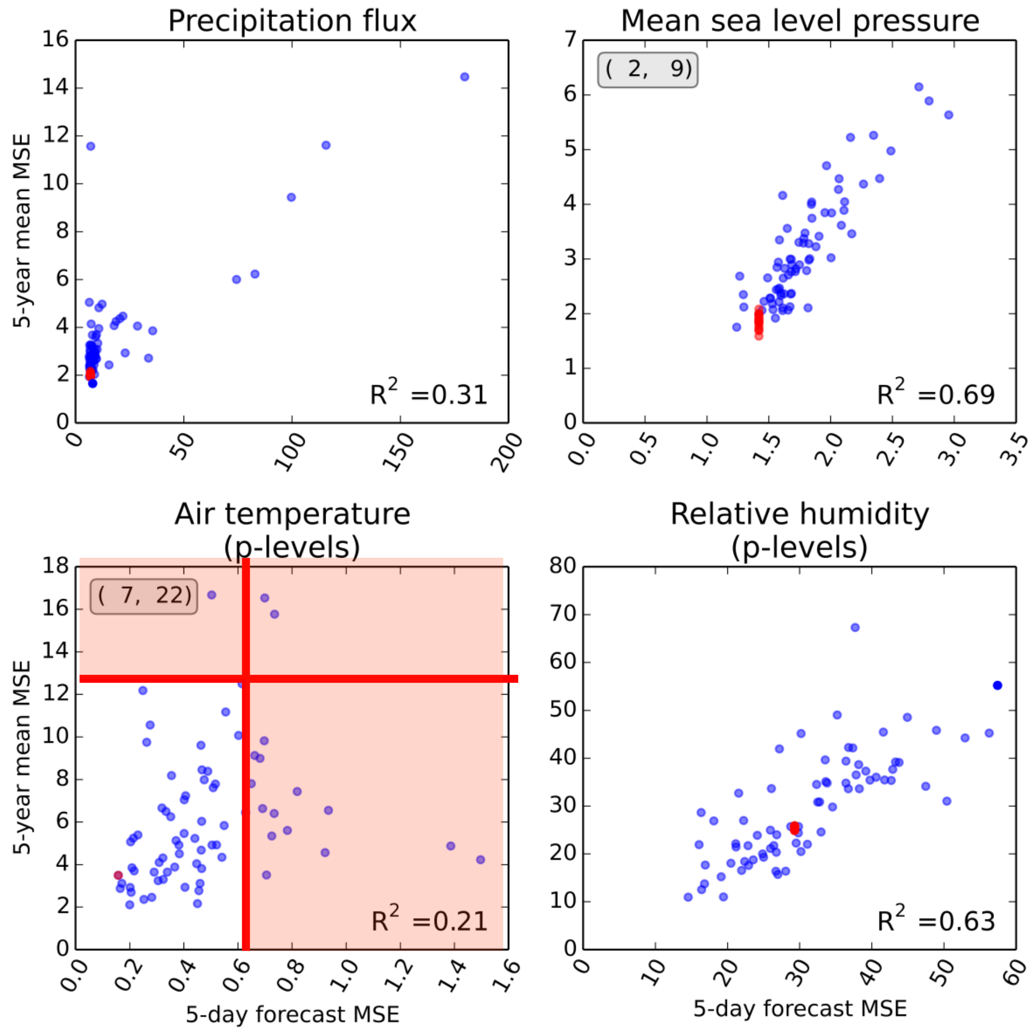
Sexton et al (in preparation) based on parallel PPEs of 5-day and 5-year means using an earlier HadGEM3 configuration (GA4)

Basic idea is to rule out members where MSEs are beyond a multiple of the standard model's MSE



Comparison of ensemble means for 5-day forecast error and 5-year mean

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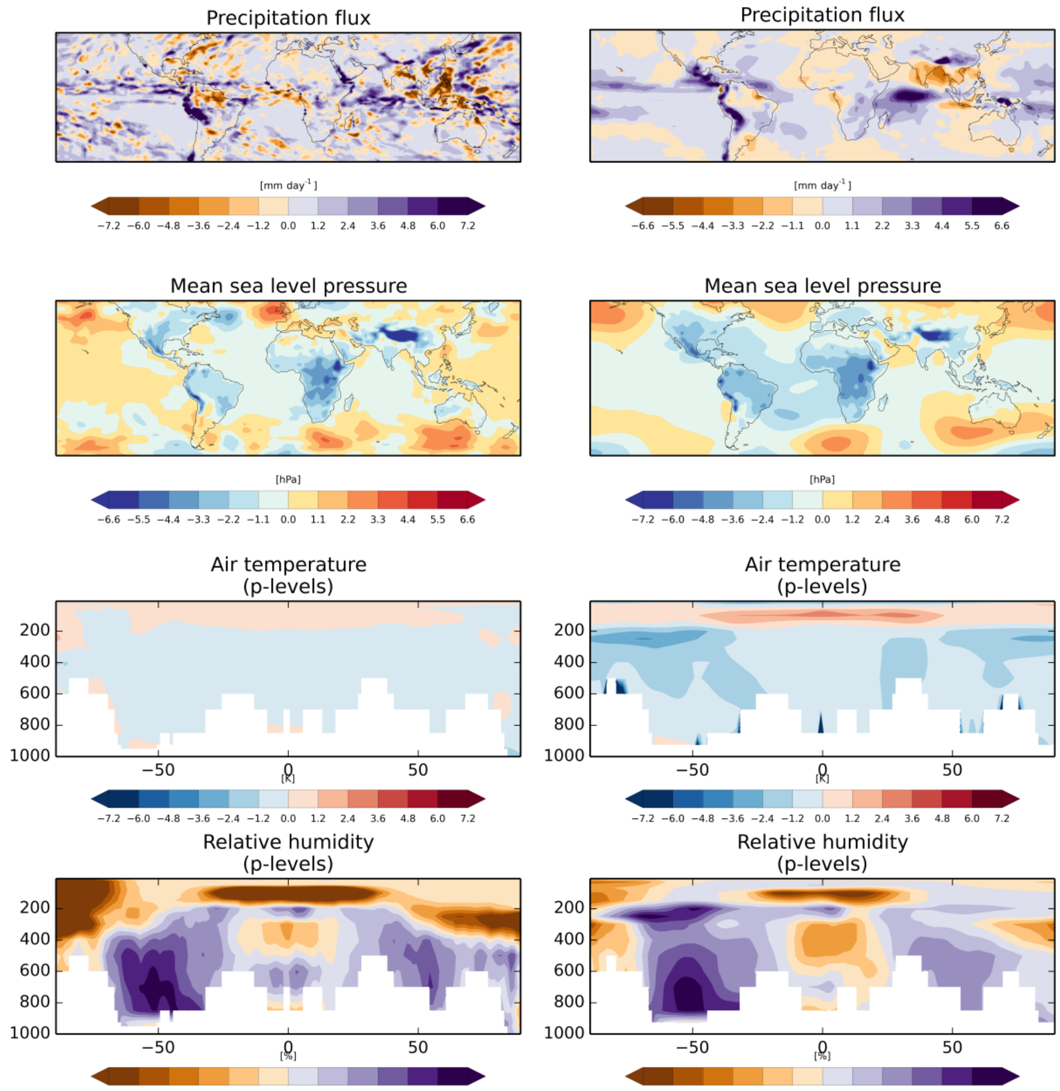
5-day forecast errors

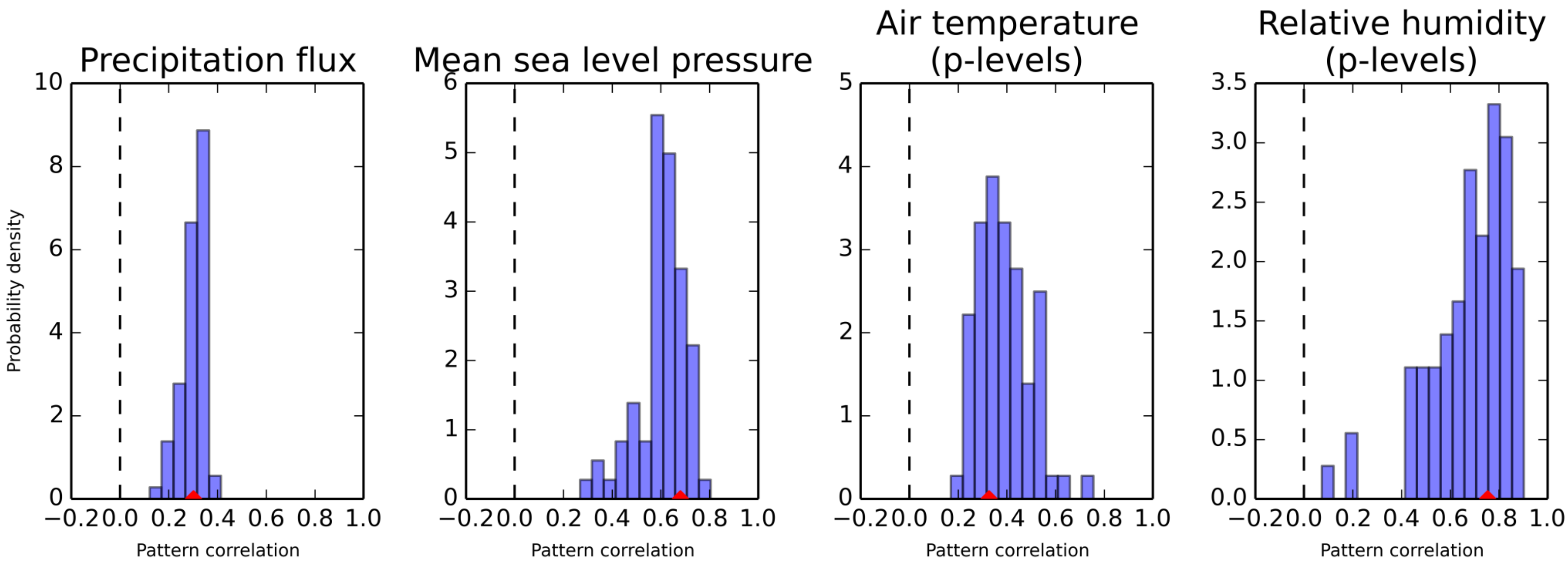


5-year means

Sexton et al (to be submitted)

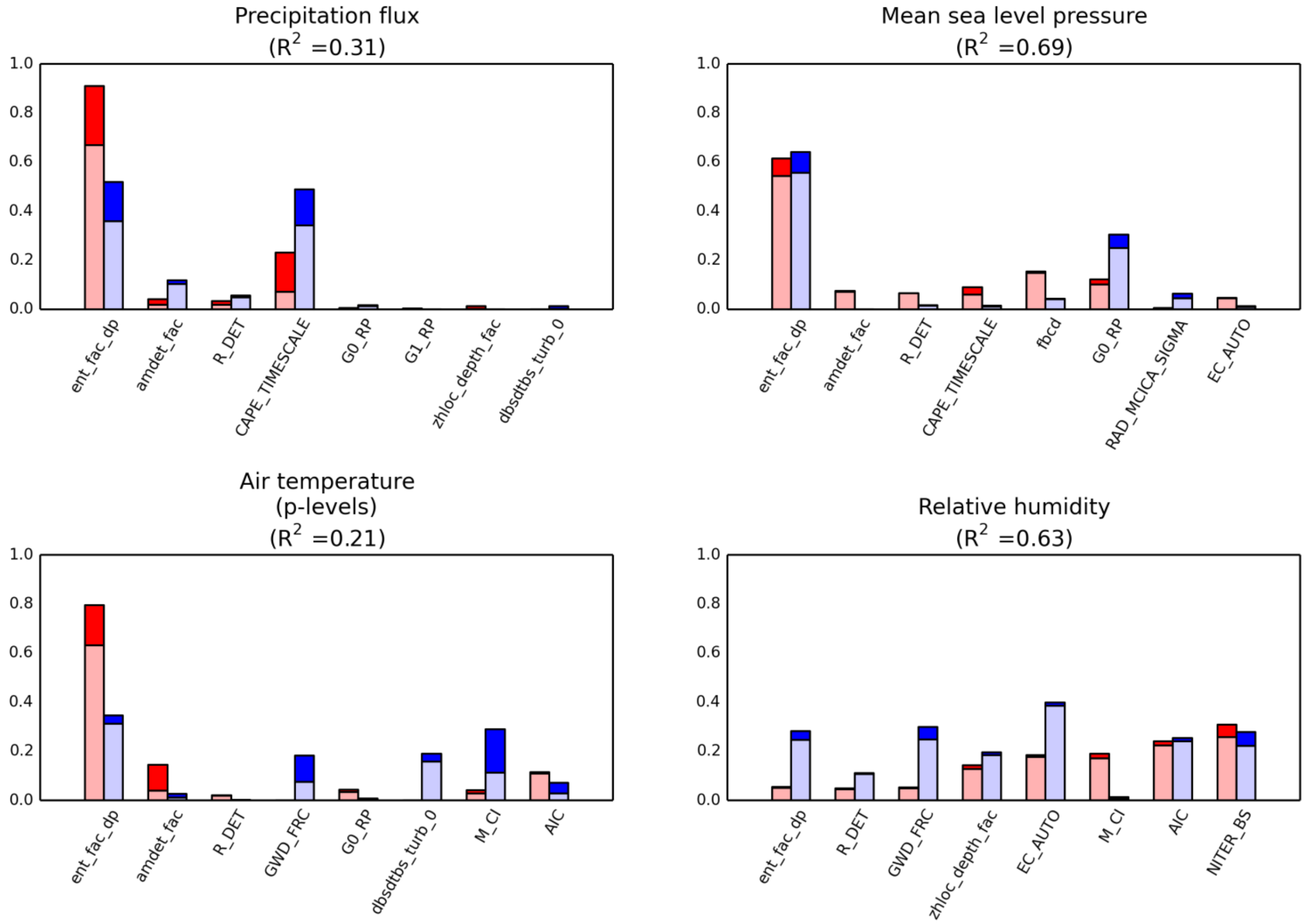
Pattern similarity of errors across time scales

Histogram of pattern correlations between 5-day forecast errors and 5-year biases for each member



Parameter sensitivity across the two time scales

Fraction of variance of the MSE across parameter space explained by top 8 parameters (internal variability not included)



Time scale:
5-day
5-year

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Summary

- Ensembles that sample key uncertainties underpin the different types of climate projection.
- Evaluation of the ensemble using a wide range of metrics is essential
- Although the projections are the main product, the analysis of the ensembles themselves offers a rich source of information about modelling the climate system. Can be used to understand limitations in models, time scales of processes, emergent relationships between observables and future climate etc.