Working with climate model ensembles

PRECIS workshop, MMD, KL, November 2012

Working with climate model ensembles

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Aims of this session

- Explain how different types of climate models ensembles are used to explore different types of uncertainty
- Demonstrate how the ‘QUMP’ ensemble can be used with PRECIS to generate an ensemble of downscaled projections
  - Demonstrate sub-selection of ensemble members

What is an ‘Ensemble’

Ensemble = “all the parts of a thing taken together, so that each part is considered only in relation to the whole.”

Or, (in climate-modeling context)…

> “ the results from several models, so that each single model is considered only in context of the results of all of the models”

3 main types:

- Initial conditions ensemble

- Multi-model ensemble
- Perturbed-physics ensemble

Revisiting the sources of uncertainties

Source of Uncertainty	Represented in Climate Scenarios?	Ways to address it
Alternative emission scenarios	Yes	Scale GCM patterns by the ratio of the radiative forcing
Emissions to concentrations	Beginning	Use GCMs that include interactive chemistry
Modelling the climate response		
• Different responses by different GCMs for the same forcing.	Yes	Use an ensemble of different GCMs
• Signal (response)/noise (internal climate variability)	Not normally	Use initial conditions ensemble simulations
Providing regional climate scenarios		
• Baseline and future climates	Yes	Use observed or model baseline and different methods for changes
• Adding high resolution detail	Yes	Use of a range of dynamical and statistical techniques

What types of (downscaled) ensemble can we **currently** generate with PRECIS?

- **Initial conditions ensemble**
  - 3 - member HadAM3P ensemble
  - Useful for capturing climate change signal in regions/variables with variability on inter-annual or decadal timescales (‘noisy’ variables)
    - E.g. precipitation extremes.

- **Perturbed-Physics ensemble**
  - 17-member ensemble of HadCM3 (HadCM3 Q0-16)

  ‘QUMP’
  - We can select a sub-set of the 17 models in order to run a computationally ‘affordable’ experiment.

What types of (downscaled) ensemble can we generate with PRECIS?

- **Coming soon….**
  - Capability to downscale CMIP5 multi-model ensemble GCMs with PRECIS 2.0.

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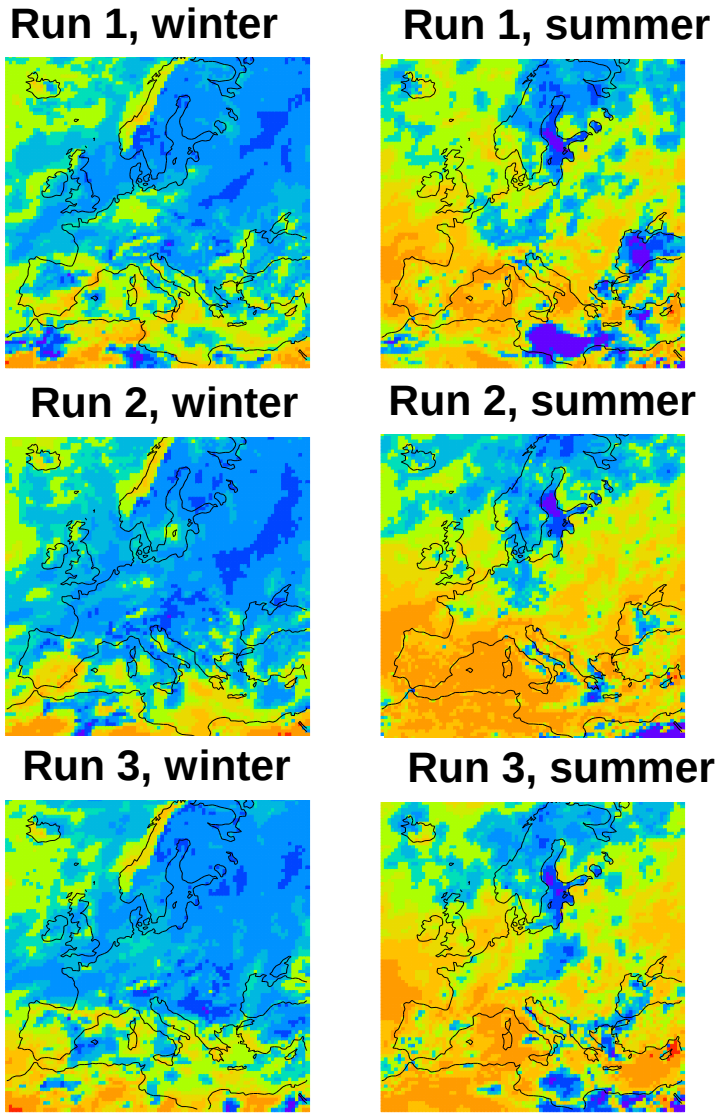
3 types of ensemble

1.) Initial Conditions ensembles

- Internal or natural variability
  - 1 model run more than once gives slightly different responses
  - Which changes are ‘signal’, and which changes are ‘noise’..?
  - I.e. which changes are *reliable?*
  - Internal variability greatest issue when we are looking for:
    - (a) Spatial or temporal details (e.g. extremes)
    - (b) Variables with strong multi-decadal variability



2.) Multi-model ensembles

- IPCC CMIP3/5 ensembles: modelling centres submitted results from equivalent simulations to allow inter-model comparisons for fourth /fifth assessment reports

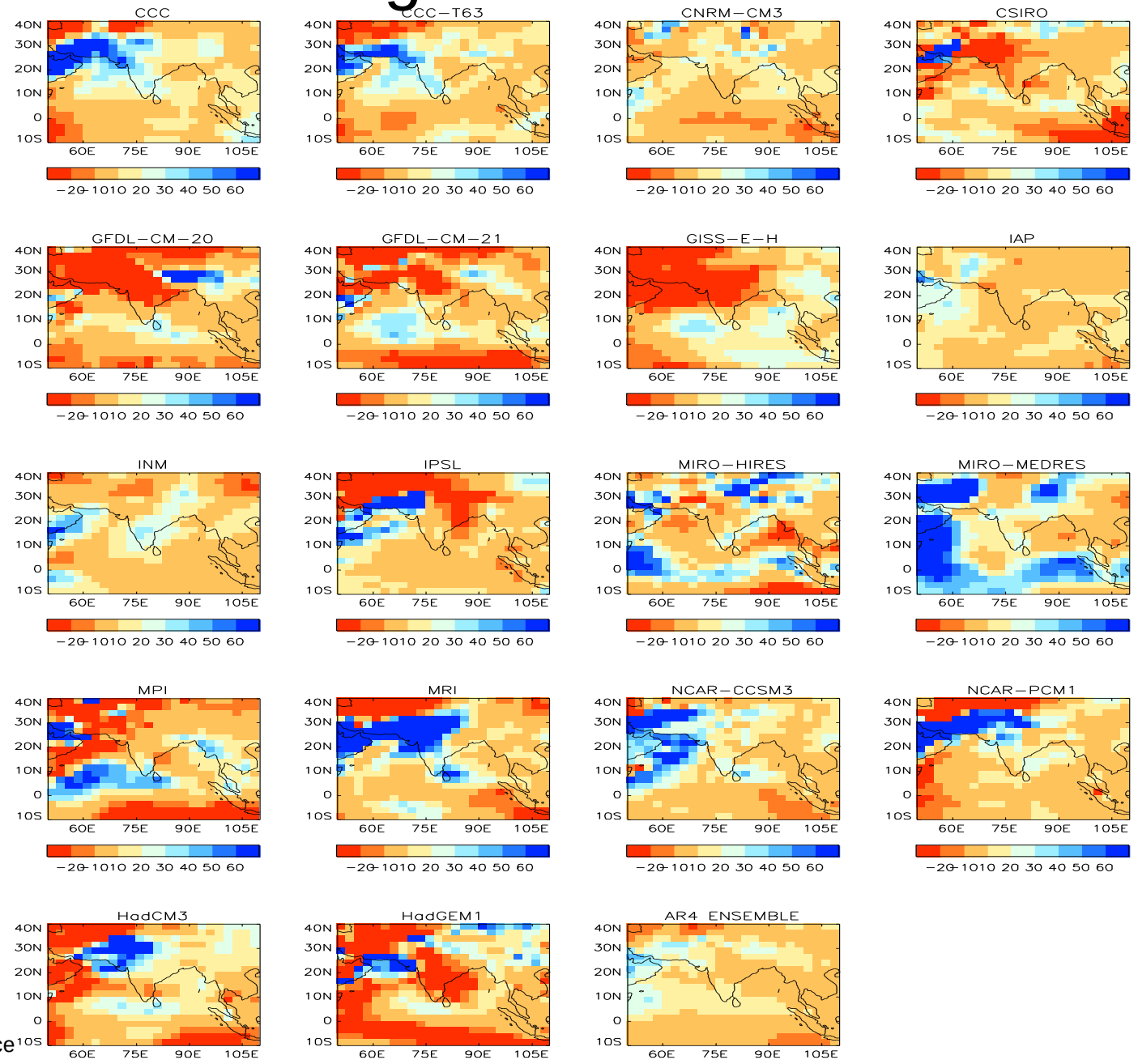
- Models from different modelling centres around the world use different structural choices in model formulation → different future climate projections:
  - 'Structural uncertainties'

- 'Disagreements' between models can be large

  i.e. between an overall increase or decrease in rainfall in a region

Rainfall change: IPCC CMIP3

- Combination of pattern and some sign differences lead to lack of consensus



Progress for CMIP5?

- Larger ensemble (x2 models)
  - ~45 models compared with 24
- Inclusion of new processes
  - earth system models (ESMs) e.g. Have interactive carbon cycle allowing representation of carbon cycle feedbacks.
- Many models higher resolution
  - around half of the CMIP5 models have atmospheric horizontal resolution finer than 1.3 degrees, while only one model in CMIP3 has resolution this high (Taylor et al, 2012).
- Availability of 6hrly inst. prognostic fields
  - Allows co-ordinated downscaling experiments

CMIP3 and CMIP5 – change in range?

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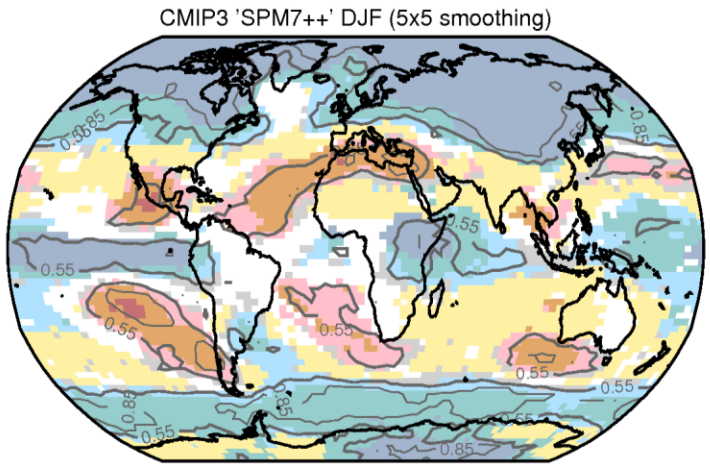
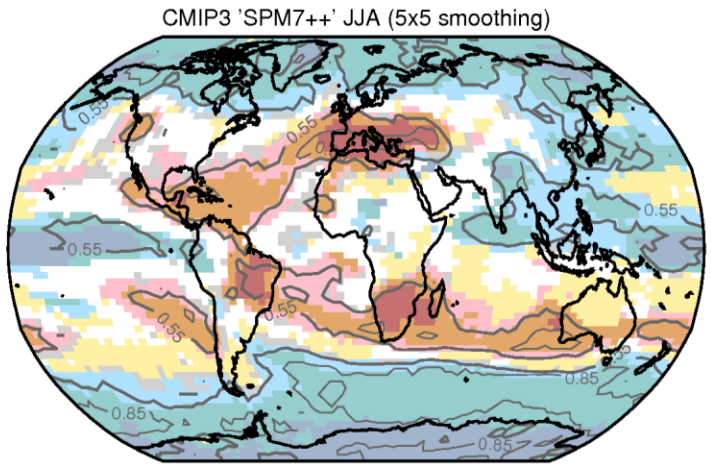
DJF

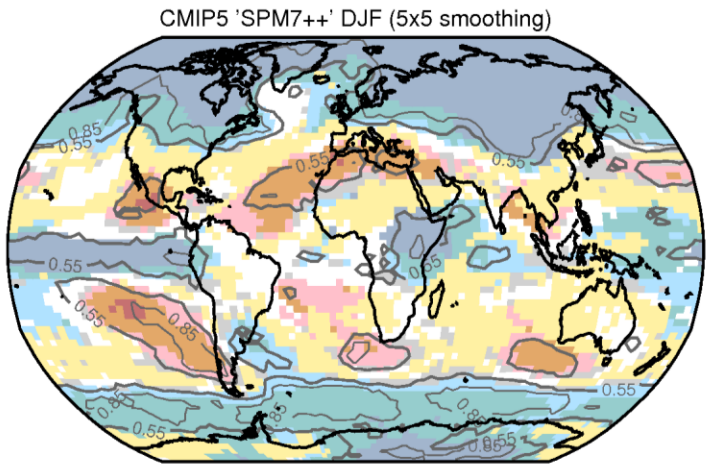
JJA

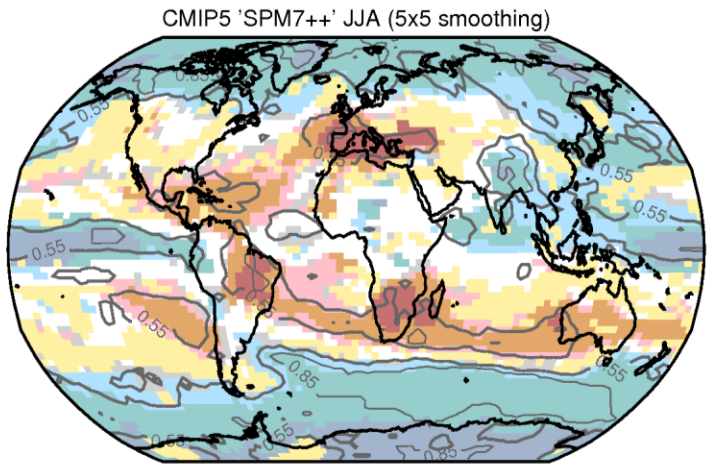
CMIP3

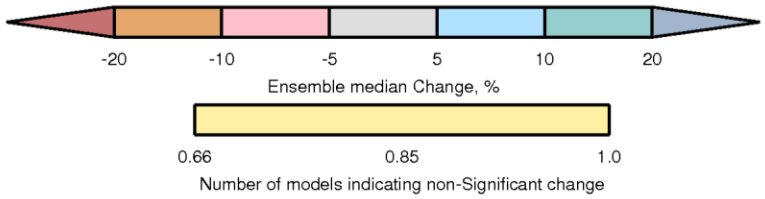
CMIP5





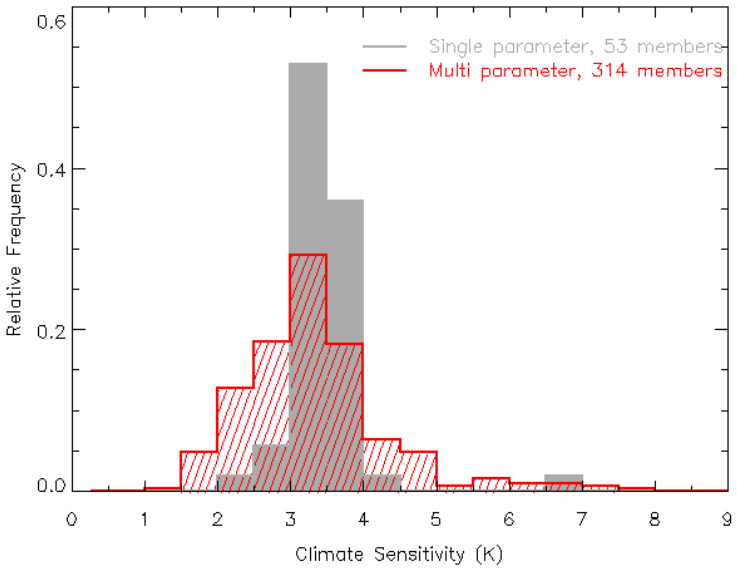






McSweeney and Jones, Submitted to Climatic Change

3.) Perturbed-Physics Ensembles

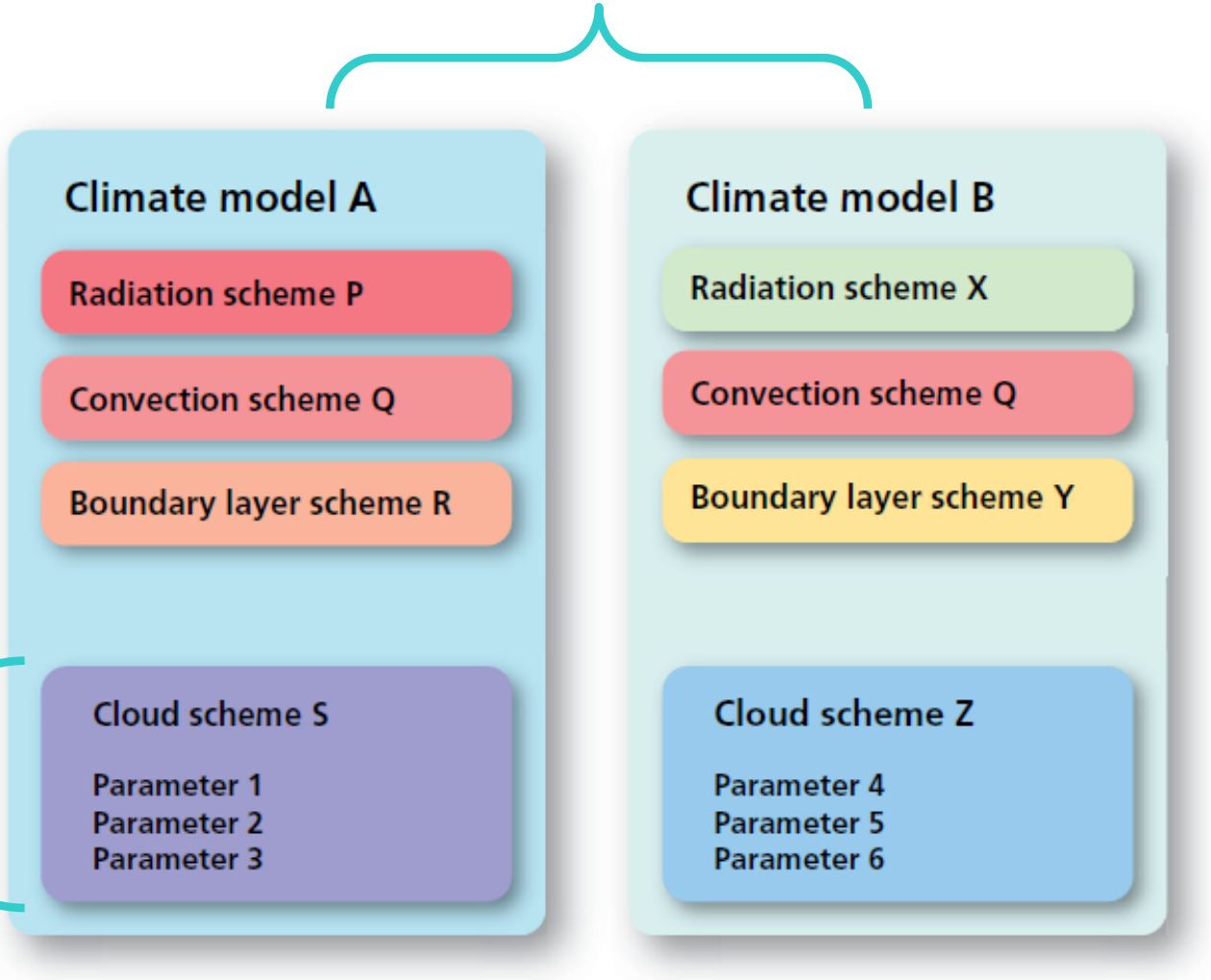


- An alternative route to exploring GCM uncertainty
- Many processes in GCMs are ‘parameterised’
  - Parameterisations represent sub-gridscale processes
  - Values of parameters are unobservable and uncertain
  - Explore model uncertainty by varying the values of the parameters in one model
- **HadCM3Q0-16**

Climate Model Uncertainties

Structural Uncertainty

(IPCC CMIP3 multi-model ensemble)

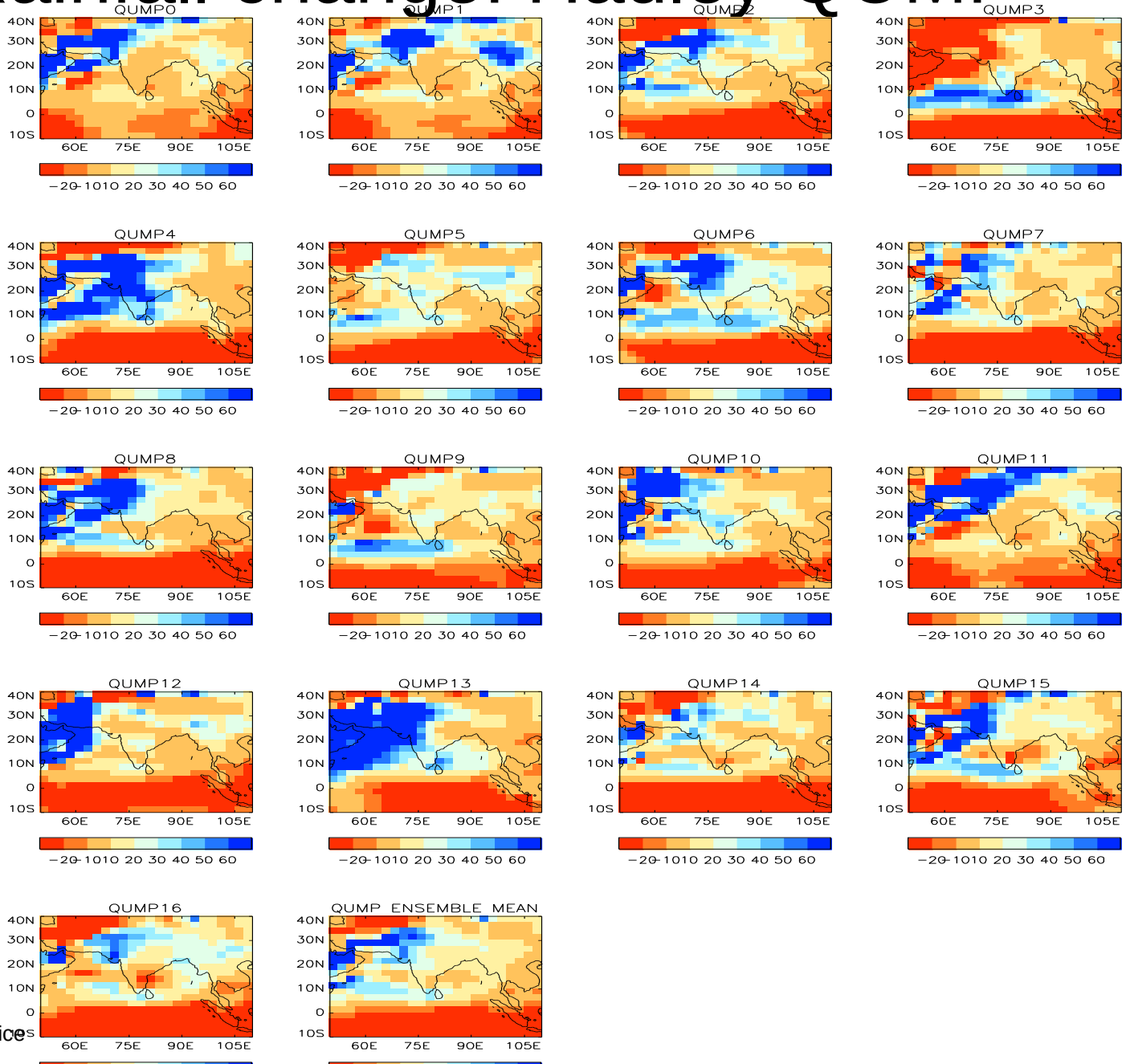


Parameter Uncertainty

(QUMP perturbed physics ensemble)

Rainfall change: Hadley QUMP

- Again significant range of different projected changes
- Similar range and behaviour to IPCC models?



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Generating ensembles of high-resolution simulations with PRECIS

Issues in ensemble downscaling…

- Need to include a range of driving GCMS
  - The major uncertainties in the simulated broad-scale climate changes come from GCMs
- Need to generate projections at ‘high resolution’
  - Global climate models provide information which is often too coarse for applications thus downscaling is required

However:

High res’ +multiple models = large resources required!

Why sub-select?

- If we can represent the range of outcomes from the full ensemble with a subset of 4-6…
  - Save on computing resources required to run RCMs
  - Save on boundary data required
  - More feasible to apply outputs from fewer RCMs to impacts models

- Why take the time to sub-select carefully?
  - The uncertainty range spanned by an ‘ad-hoc’ subset is meaningless
  - A carefully sample subset can span represent the range of uncertainties in a large ensemble efficiently.

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Approaching Model Sub-Selection

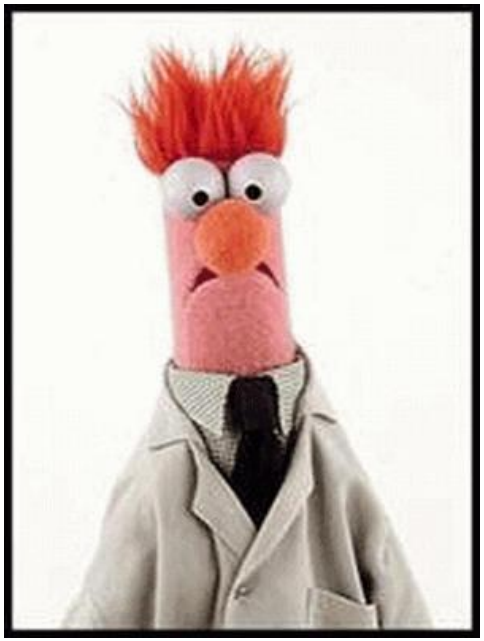
Case Study #1

- Jack is considering the impacts of climate change on international terrorism.
- He decides to use the PRECIS regional modelling system and some members of the QUMP ensemble to explore model uncertainty.

Maybe I will choose members Q1, Q7 and Q16 to span the range of global sensitivities?

Case Study #2

- Beeker is exploring climate impacts on frog and pig populations. He will apply outputs from regional models to his species models.
- Beeker wants to use a range of projections to help him understand the uncertainty in the future projections climate variables that are predictors in his model.



I will choose the '**best**' 5 models according to their validation. I could use the models with the lowest RMSE for temperature and precipitation.

Case study #3

- Inspector Lewis is considering the impact of climate change on flood frequency at some popular riverside crime scenes in Oxford.
- Lewis will use the PRECIS outputs to drive a catchment model of the River Cherwell and estimate peak flows.

I might choose 4 members that span the widest possible range of mean precipitation change for the GCM gridbox that Oxford lies in.

Case study #4

- Uncle Bulgaria is interested in the impacts of climate change on burrow habitats on Wimbledon Common.
- He needs regional climate model data to explore the possible changes in soil moisture and temperature in the future.
- Uncle Bulgaria has very limited resources and can only run one simulation.

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Can we select the models that validate the best in our region, or eliminate/downweight those that don't?

Some advice from Reto Knutti about combining information from multiple model projections

1.Metrics and criteria for evaluation must be demonstrated to relate to projection

2.It may be less controversial to downweight or eliminate specific projections that are clearly unable to mimic important processes than to agree on the best model.

3. Process understanding must complement ‘broad brush metrics’.

For more see Knutti, 2010, Climatic Change 102.

Basis for selection:

1.) Exclude models which we have good reason to think give unrealistic projections of the future

- Avoid cherry picking best models (might be right for wrong reasons)
- But we should reject models that really don't represent the key large-scale processes

2.) Span the range of future outcomes in the region

- *Span range of magnitudes of change (i.e. global sensitivity, and regional sensitivity)*
- *Span multiple variables/characteristics of change*
  - *E.g models that are wetter or drier in different regions*
  - *Different spatial patterns of change*
  - *Change in key large-scale processes*

Sub-selecting ensemble members for downscaling with PRECIS – an example from Vietnam (McSweeney et al, 2012, J. Clim)

Example of Model sub-selection: Vietnam

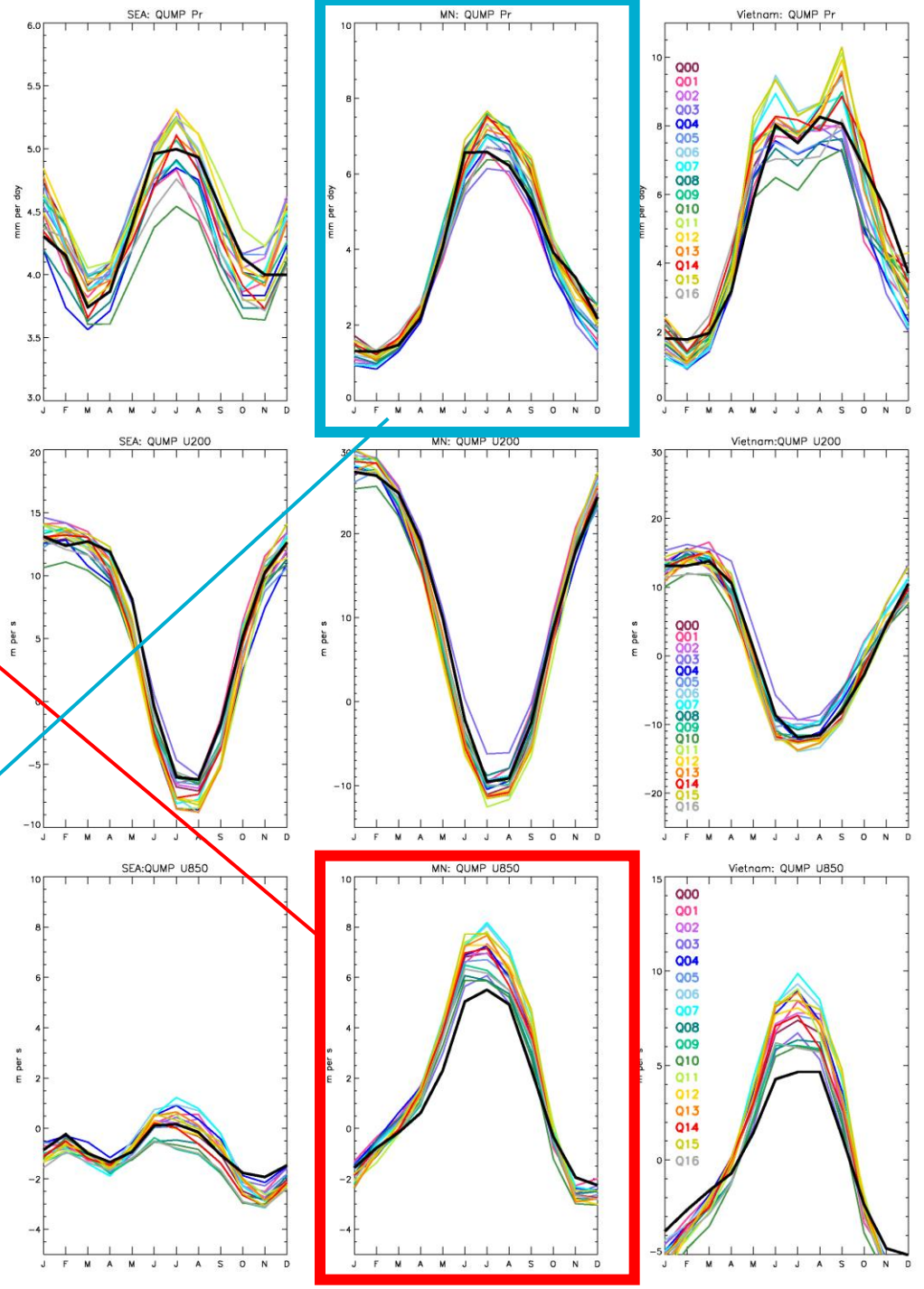
Examine GCMS fields…

- Avoid ‘implausible’ projections
  - Selected models should represent Asian summer monsoon (position, timing, magnitude), and associated rainfall well, as this is key process

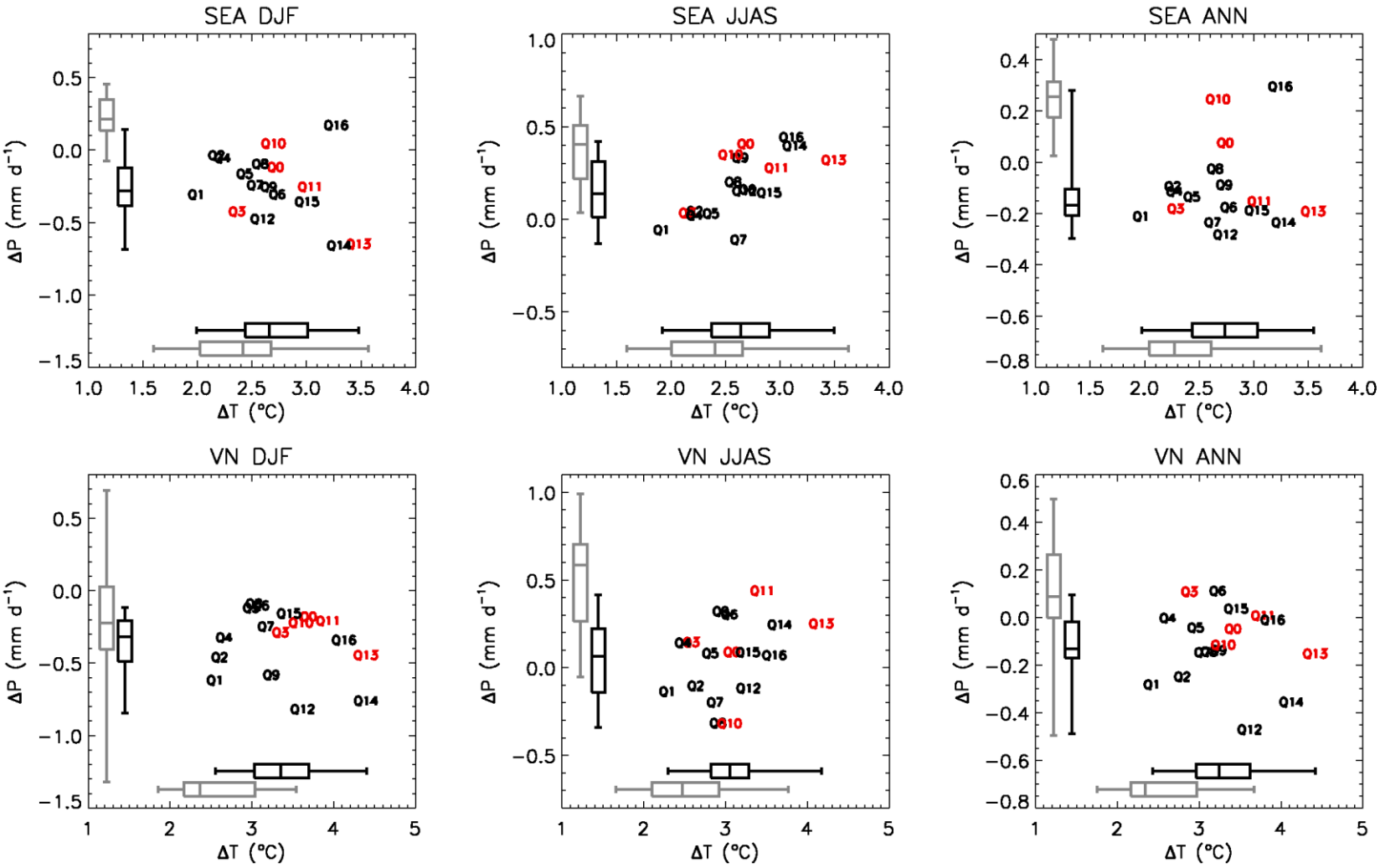
- Sample the range of future outcomes
  - *Magnitude* of response: greatest/least regional/local warming, greatest/least magnitude of change in precipitation
  - *Characteristics* of response
    - Direction of change in wet-season precipitation (increases and decreases)
    - Spatial patterns of precipitation response over south-east Asia
    - Response of the monsoon circulation

Validation: Monsoon Onset

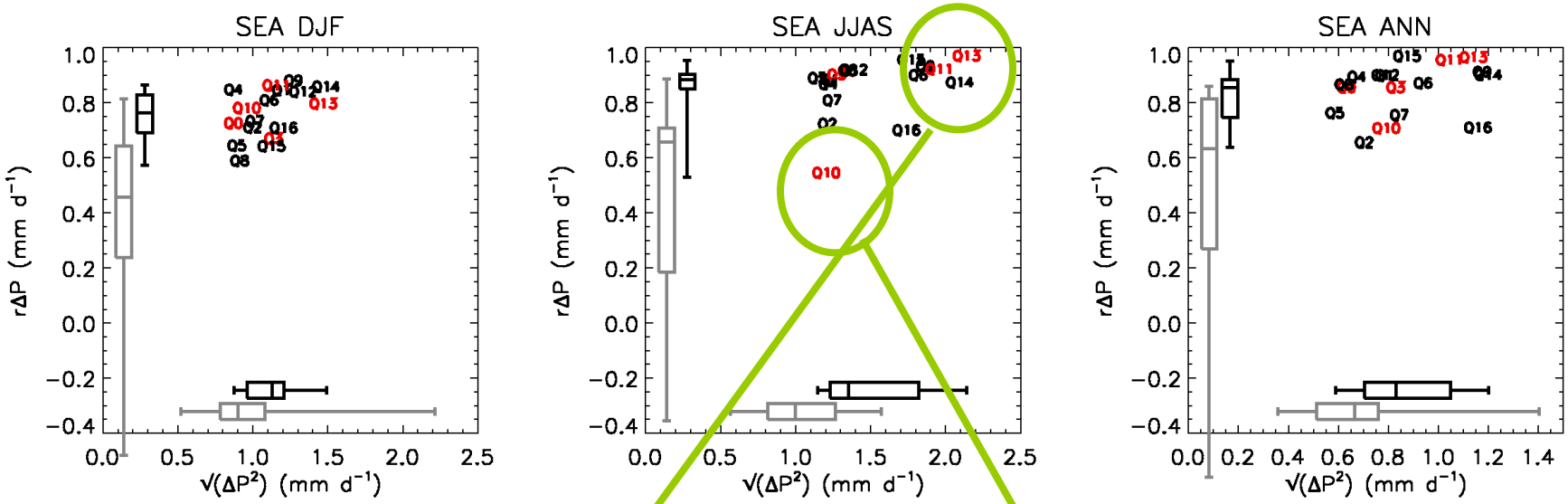
- Monsoon flow has some systematic error – a little too high, but timing (and position) of features is very good.
- All do a reasonably good job at simulating rainfall in the region
- Those that best represent the characteristics of the monsoonal flow don't necessarily also best represent the local rainfall…
- **No reason to eliminate any models on grounds of validation**

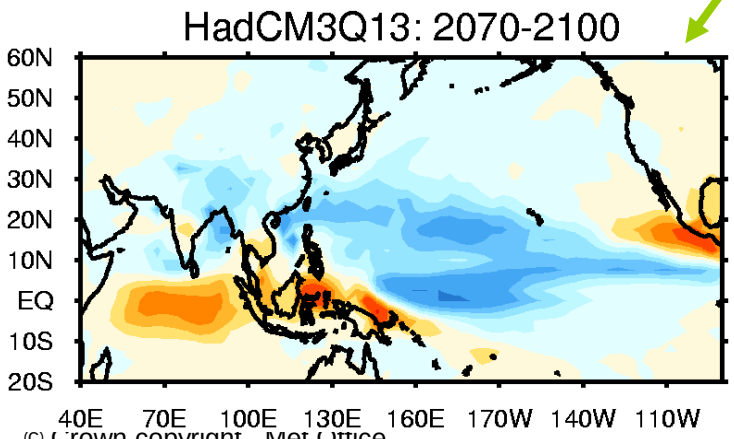


Range of Future changes



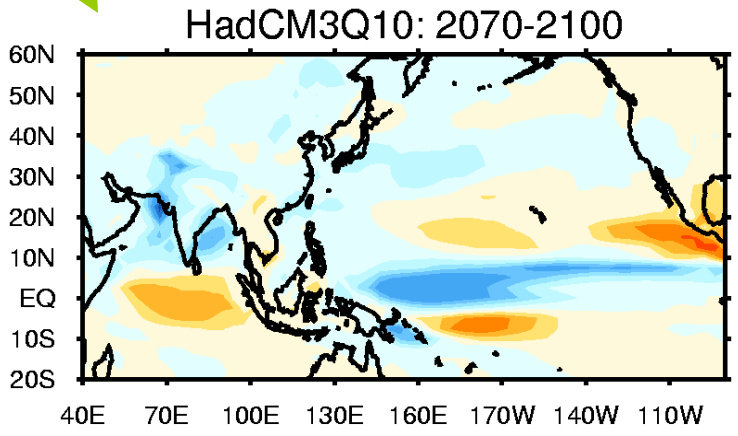
Spatial patterns of future changes (precip)





←Typical

Atypical →



Recommended QUMP members for this region

- HadCM3**Q0** – The standard model

- HadCM3**Q3** – A model with low sensitivity (smaller temperature changes)
- HadCM3**Q13** – A model with high sensitivity (larger temperature changes)

- HadCM3**Q10** – A model that gives the driest projections
- HadCM3**Q11** – A model that gives the wettest projections

- Including Q10 and Q13 means that we also cover models which characterise the different spatial patterns of rainfall change, and different monsoon responses.

Summary

- Using an ensemble of models gives us an idea of how confident we can be in modelling outcomes
- Can use ensemble(s), or sub-sets of ensembles, to try to capture as wide a range of plausible outcomes as we can.
- PRECIS users can currently downscale members of a 17-member PPE, and will soon be able to downscale CMIP5 GCMs.

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Questions and answers