Is CESM
the best Earth System Model?

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Is CESM
the best Earth System Model?

Yes

Is CESM
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Yes

No

Is CESM
the best Earth System Model?

Yes

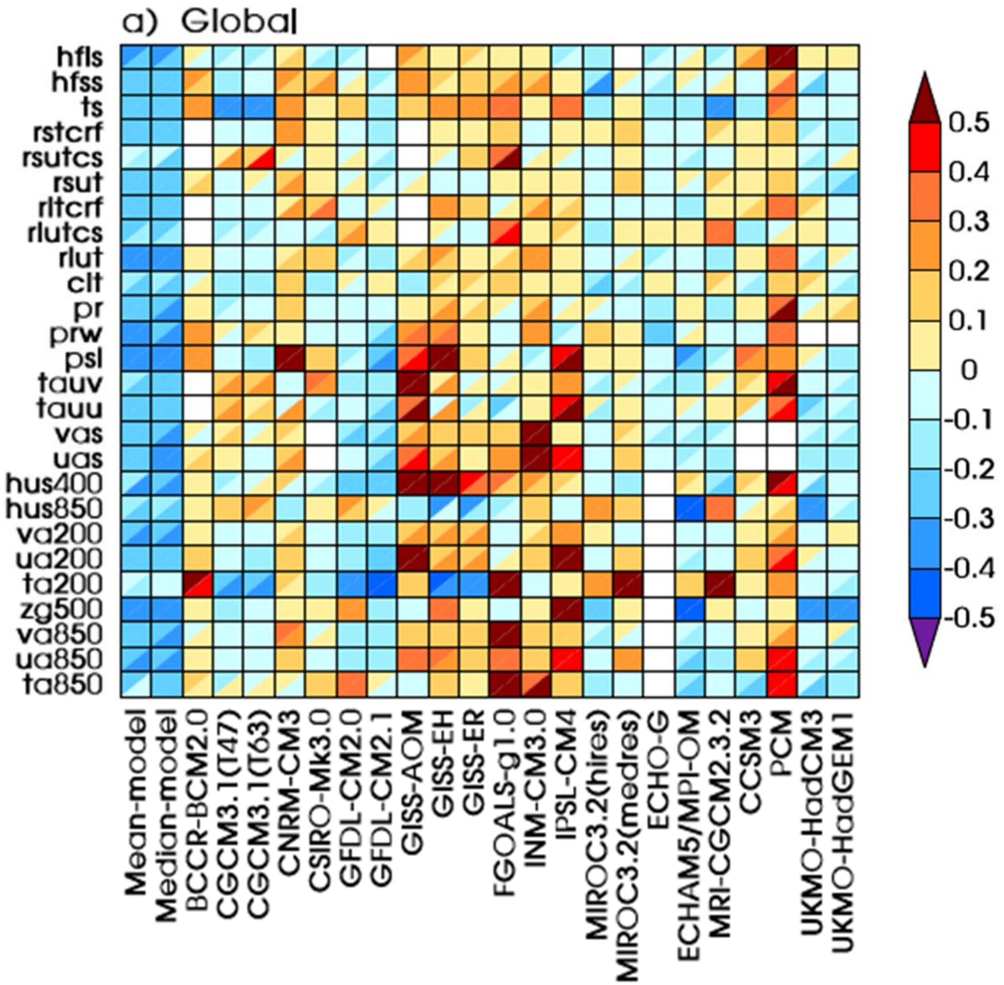
No

Stupid question

Is CESM
the best Earth System Model?

- What is the purpose, and is the model adequate for that purpose?
- What means “best” anyway?
- What is the evidence that a model is doing the right thing?
- Why are predictions uncertain?
- How well can we quantify uncertainty?
- How do we combine evidence from different models and observations?
- Why is it so hard, and are we making progress?

How do we measure
model performance?



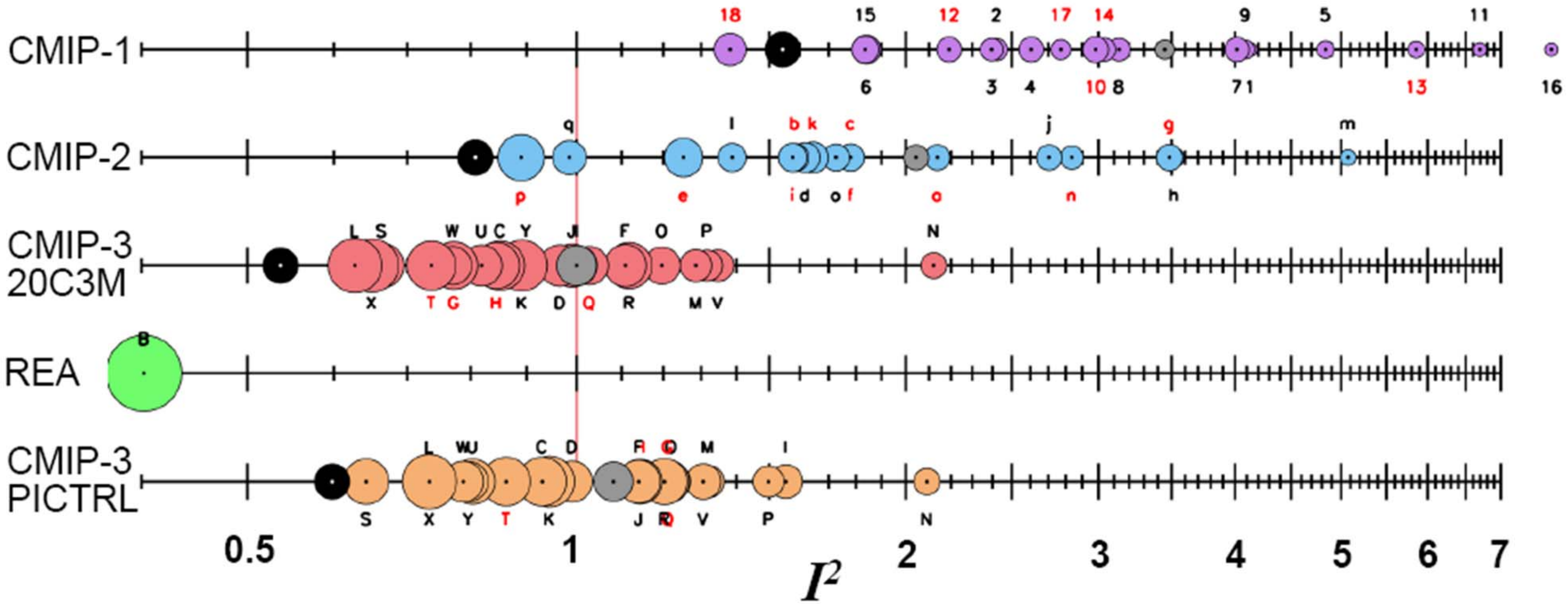
Performance metric
Measure of agreement between model and observation

Model quality metric
Measure designed to infer the skill of a model for a specific purpose

Gleckler et al., JGR 2008

My model is better

than your model



Model performance

Better

Worse

Reichler and Kim, BAMS 2008

Confidence in climate models

What is the evidence?

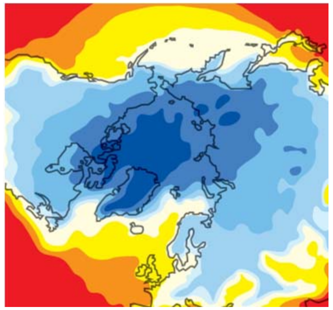
$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho u v)}{\partial y} + \frac{\partial(\rho u w)}{\partial z}$$

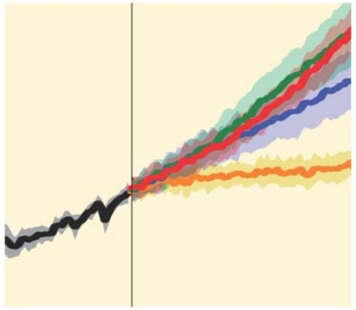
$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho u v)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho v w)}{\partial z}$$

$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho u w)}{\partial x} + \frac{\partial(\rho v w)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z}$$

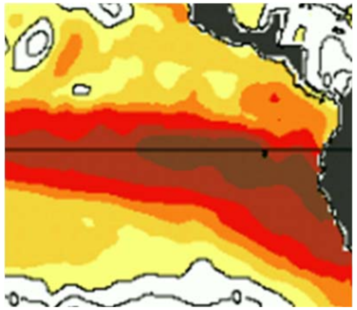
Physical principles



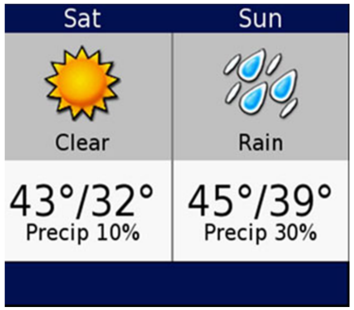
Reproduce climate



Reproduce trends

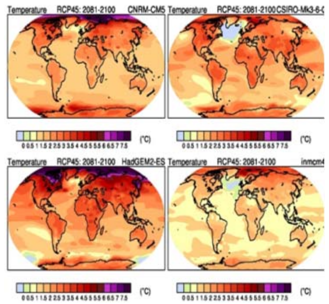


Processes



Weather

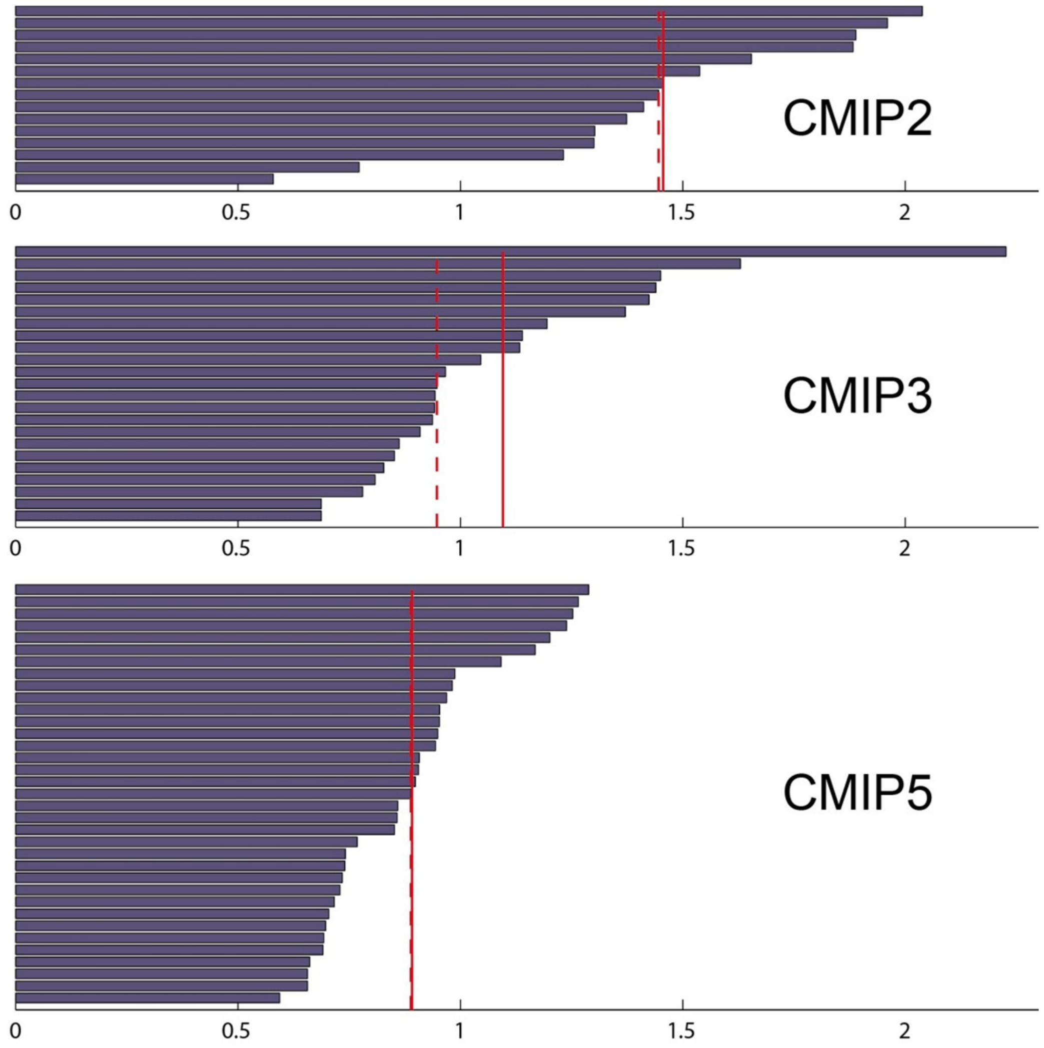
Past climate



Robustness

Distance to observations (tas/pr)

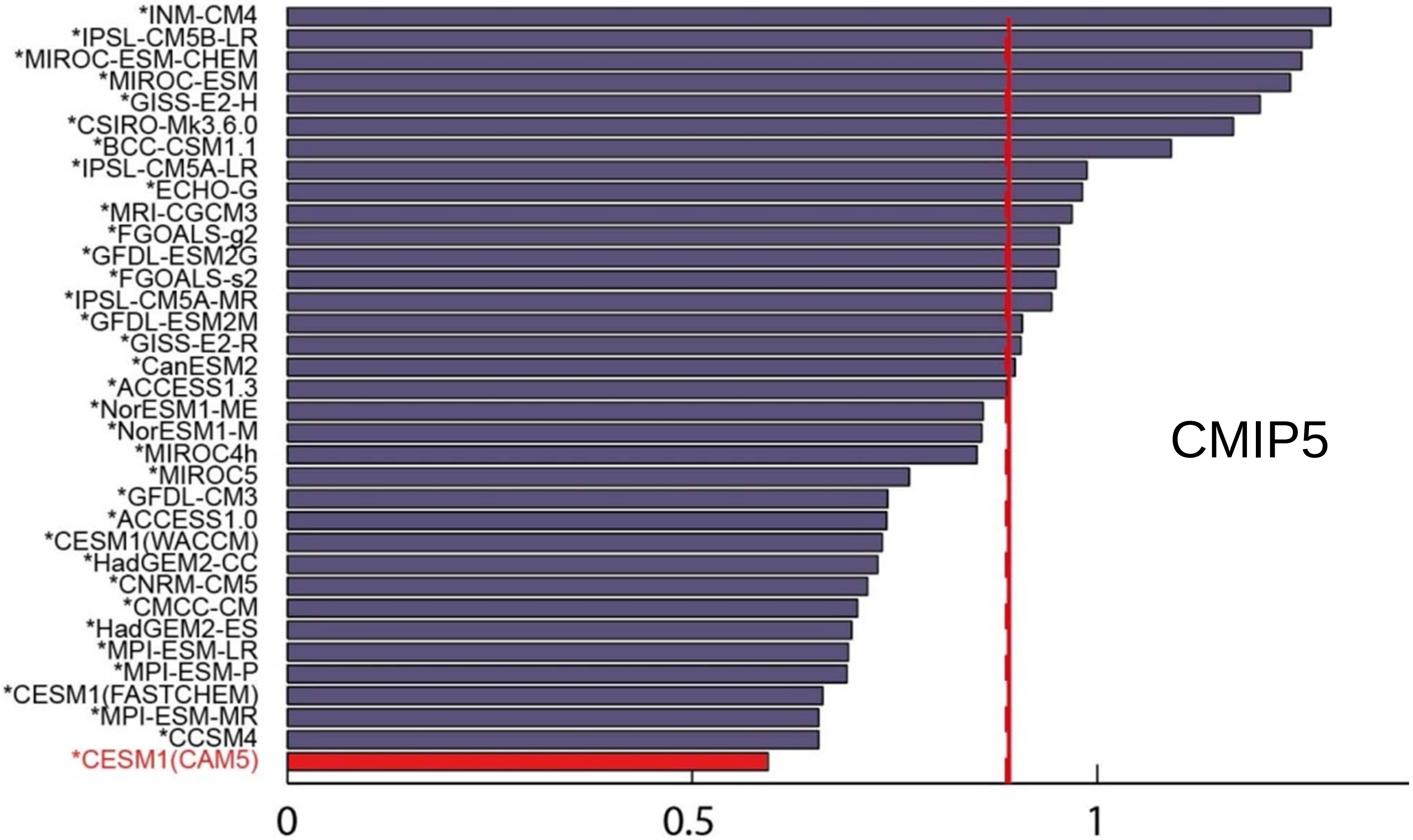
Is CESM the best model?



Masson and Knutti, GRL 2011, Knutti, Masson and Gettelman, in preparation

Distance to observations (tas/pr)

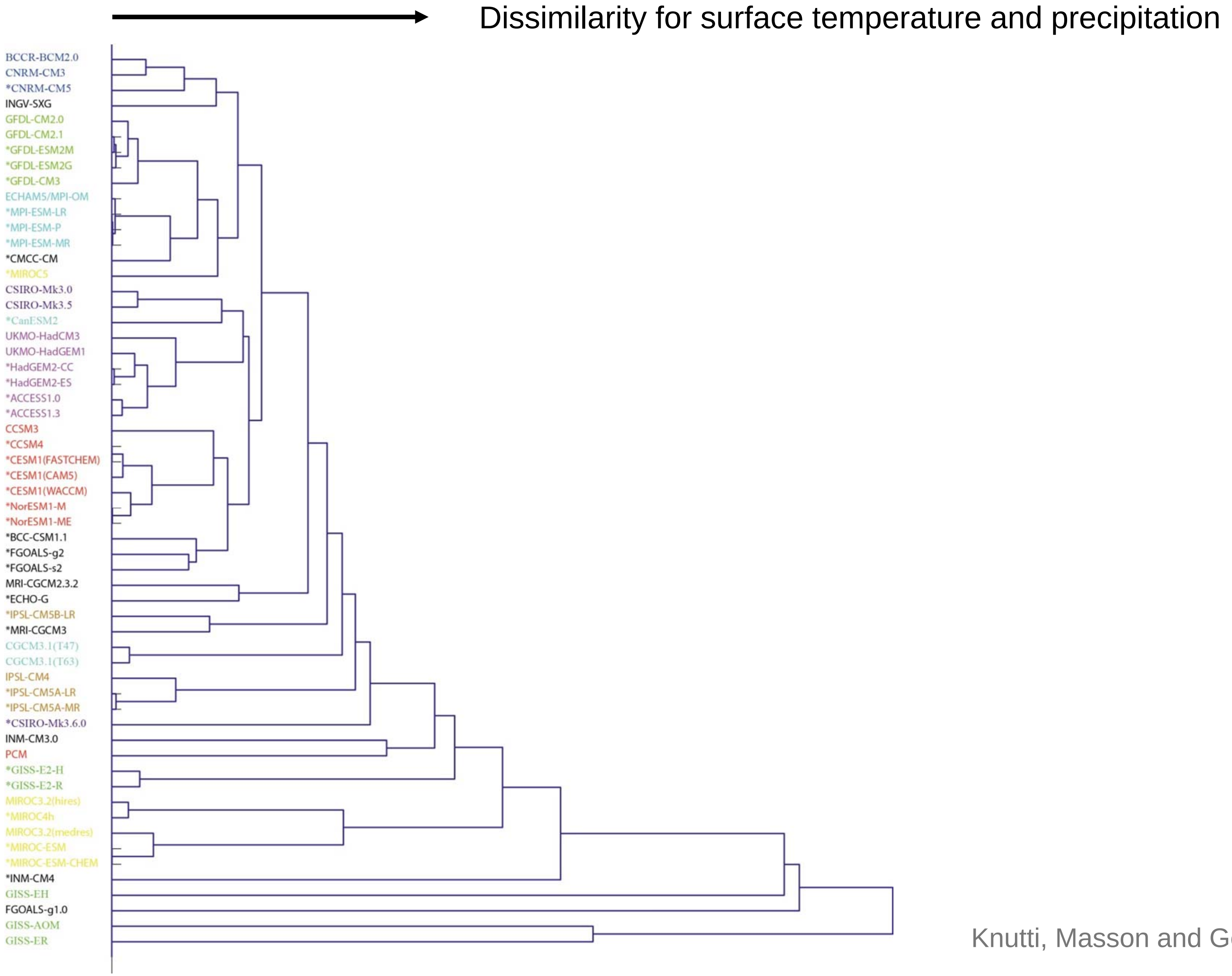
Is CESM the best model?



Knutti, Masson and Gettelman, in preparation

Climate model genealogy

Models are not independent



Knutti, Masson and Gettelman, in preparation

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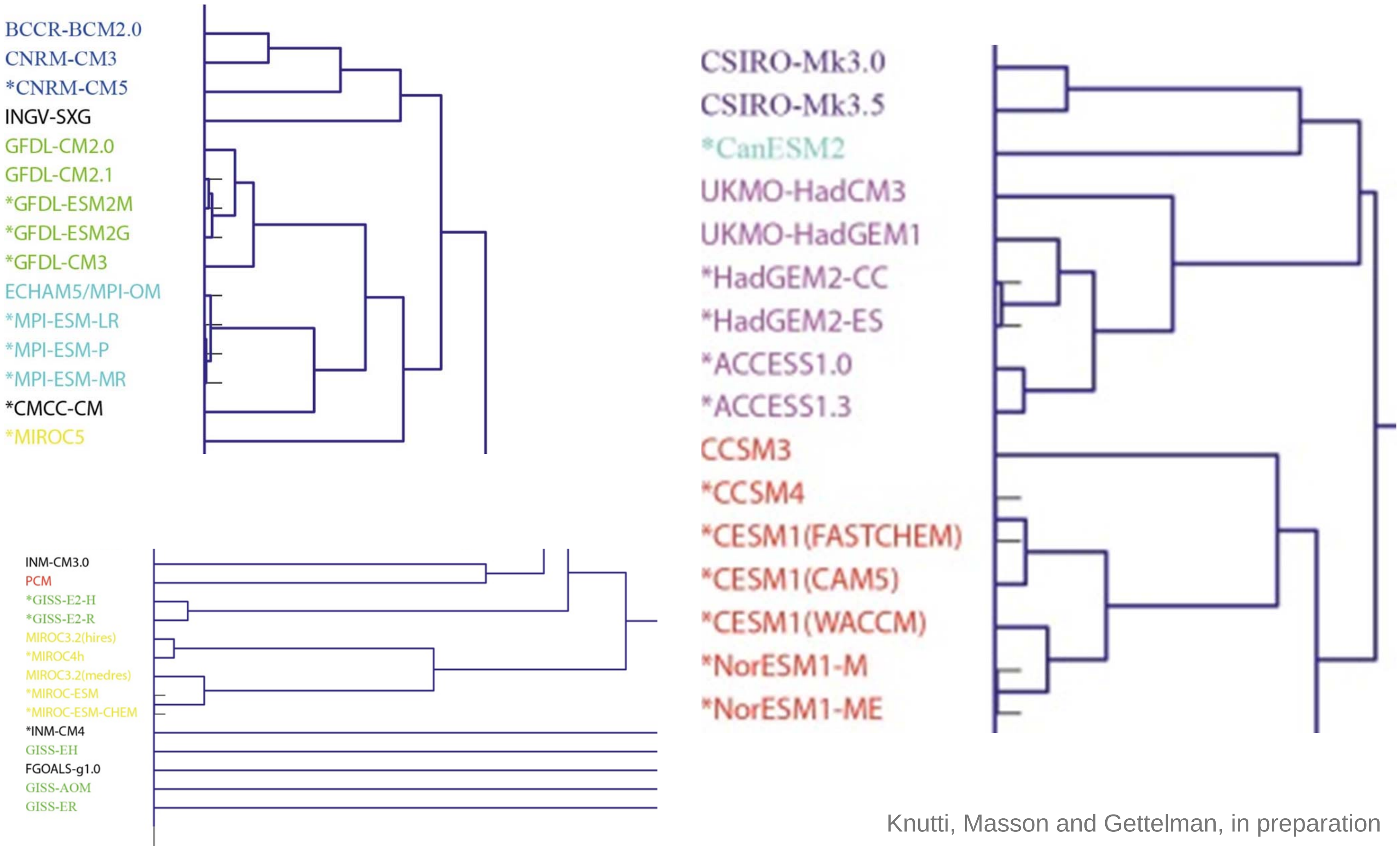

Knutti, Masson and Gettelman, in preparation

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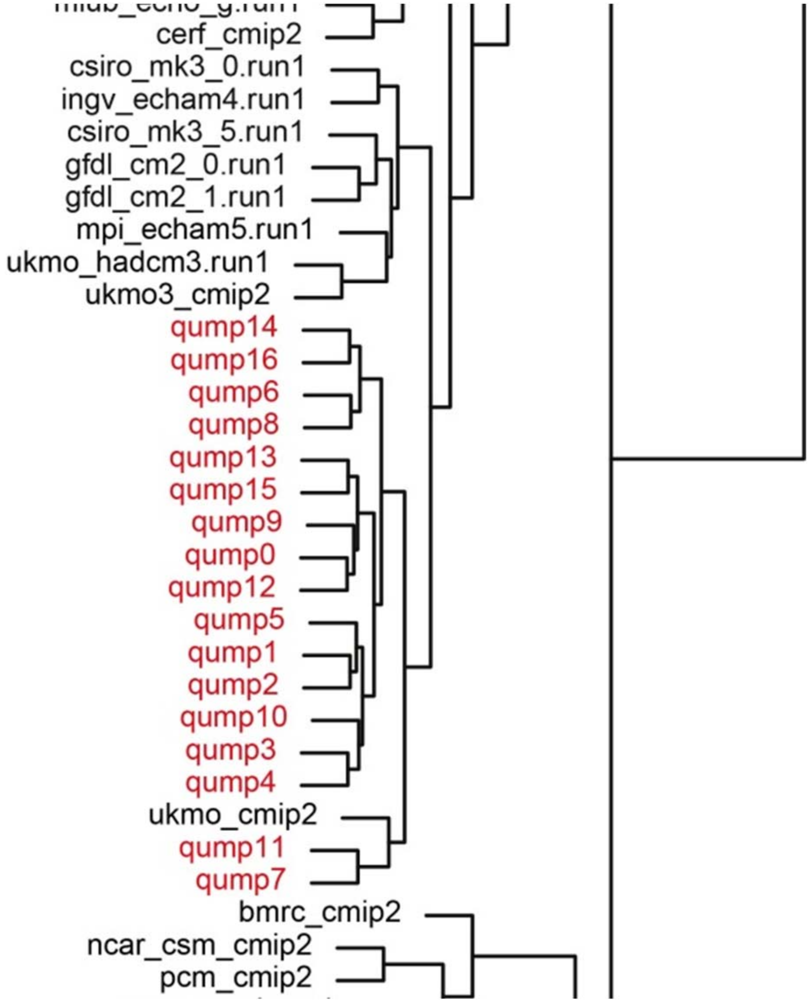
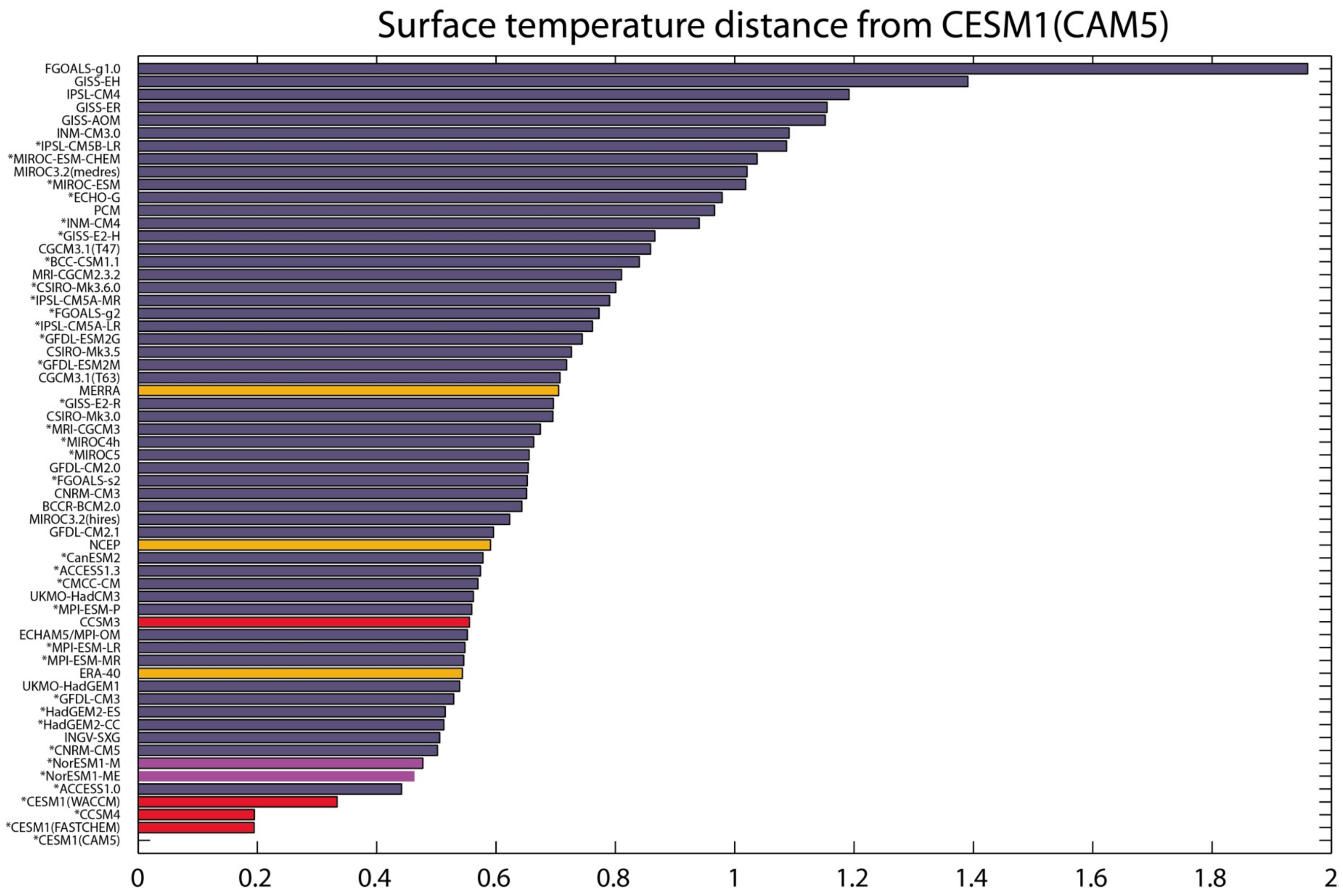


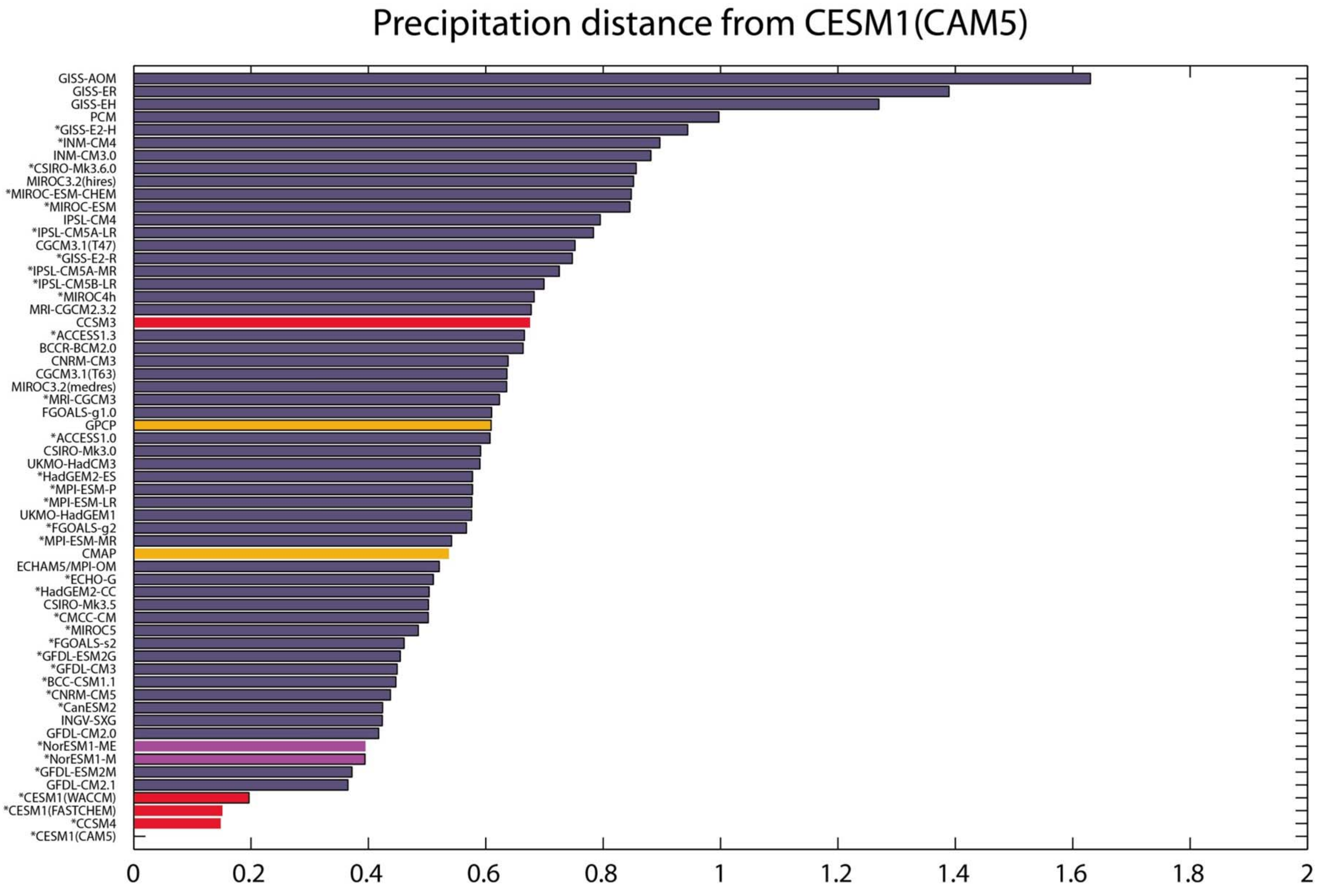
Masson and Knutti, GRL 2011

Climate model genealogy

Distance from CESM1(CAM5)

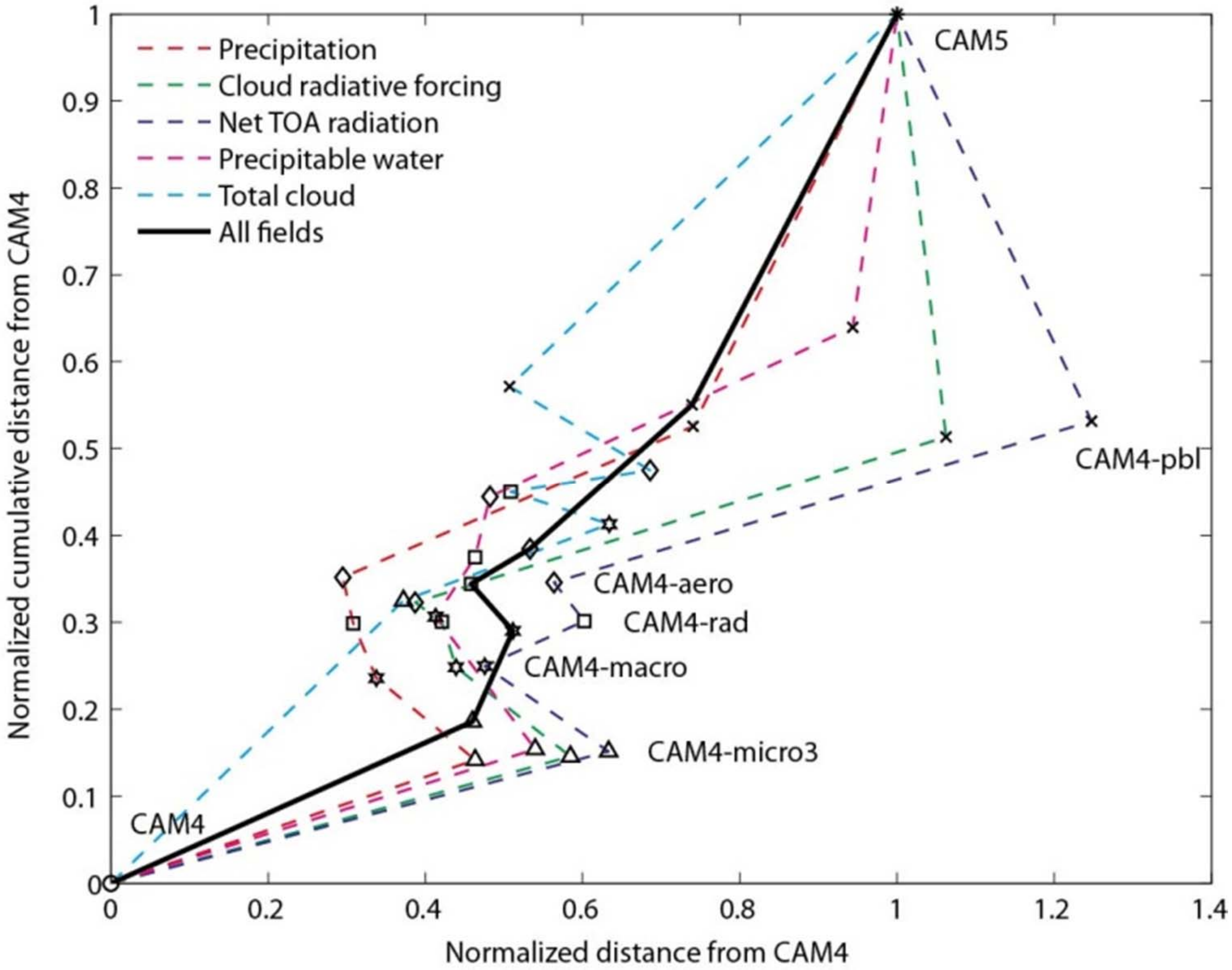


Climate model genealogy
Distance from CESM1(CAM5)



CCSM4 to CESM1(CAM5)

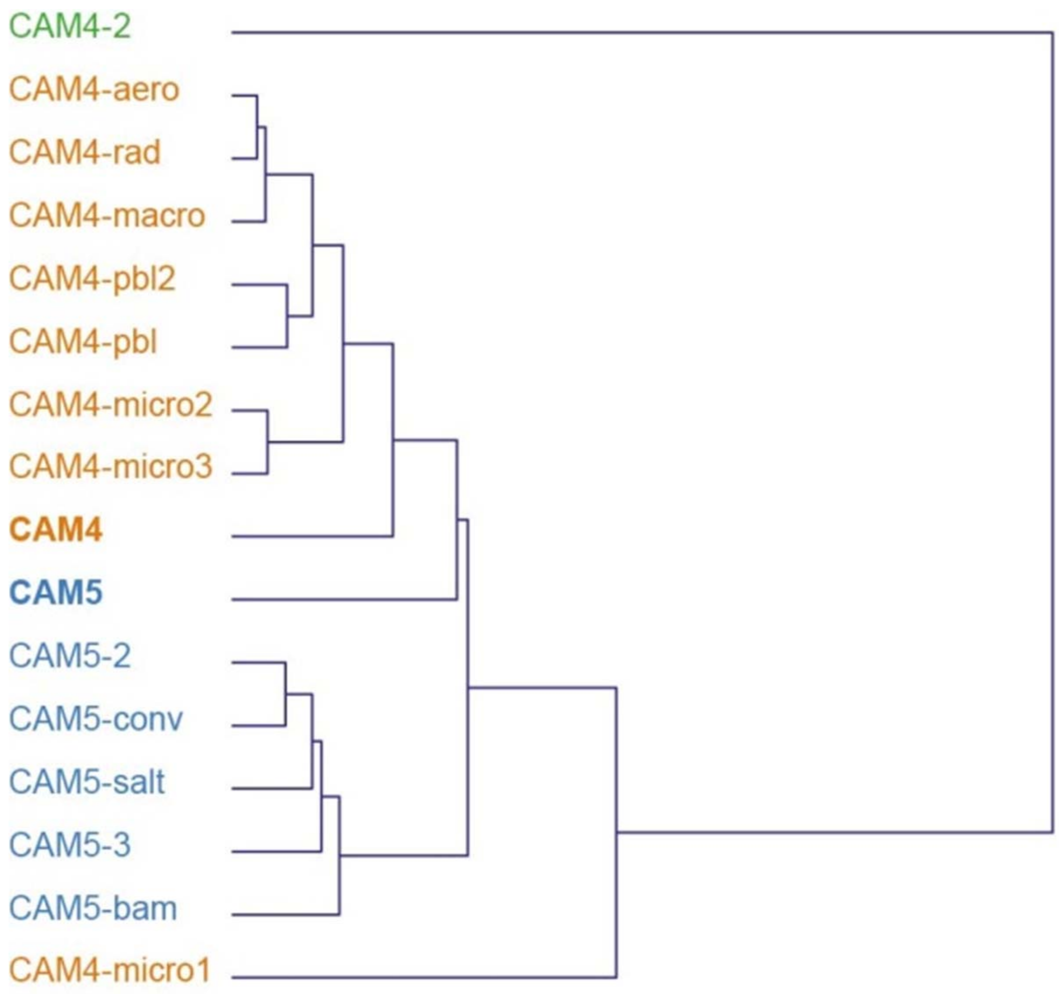
Tracing model development



Knutti, Masson and Gettelman, in preparation

CCSM4 to CESM1(CAM5)

Tracing model development



Knutti, Masson and Gettelman, in preparation

Conclusions
Metrics and model quality

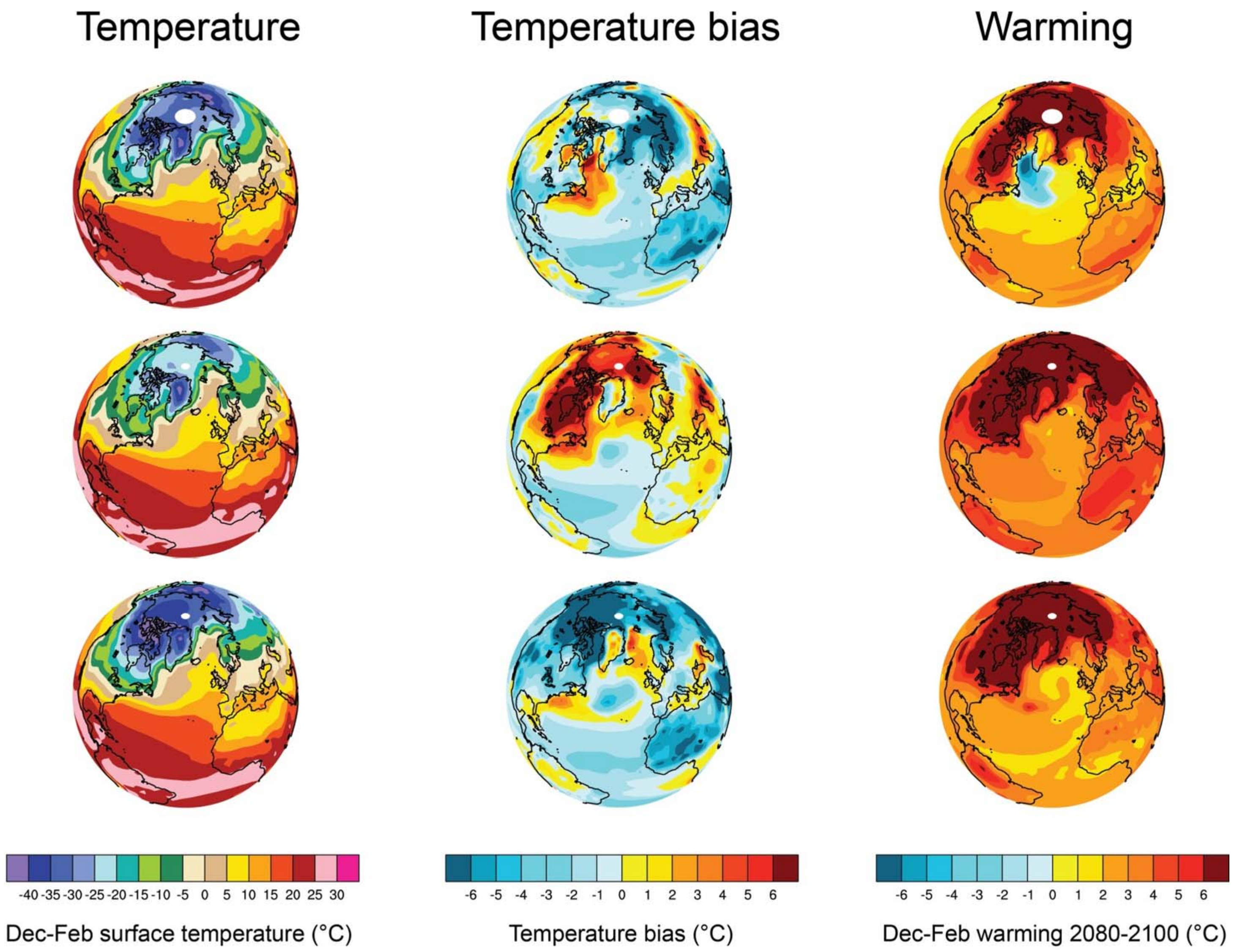
- An infinite number of metrics can be defined.
- Many metrics are dependent.
- Observation datasets and uncertainty matters.
- The concept of a “best model” is ill-defined.
- There may be a best model for a particular purpose, where “best” measured in a specific way. But determining that is hard.

Conclusions

Where CESM certainly stands out

- Free availability
- Documentation
- Portability
- Support
- Community involvement
- Tutorials

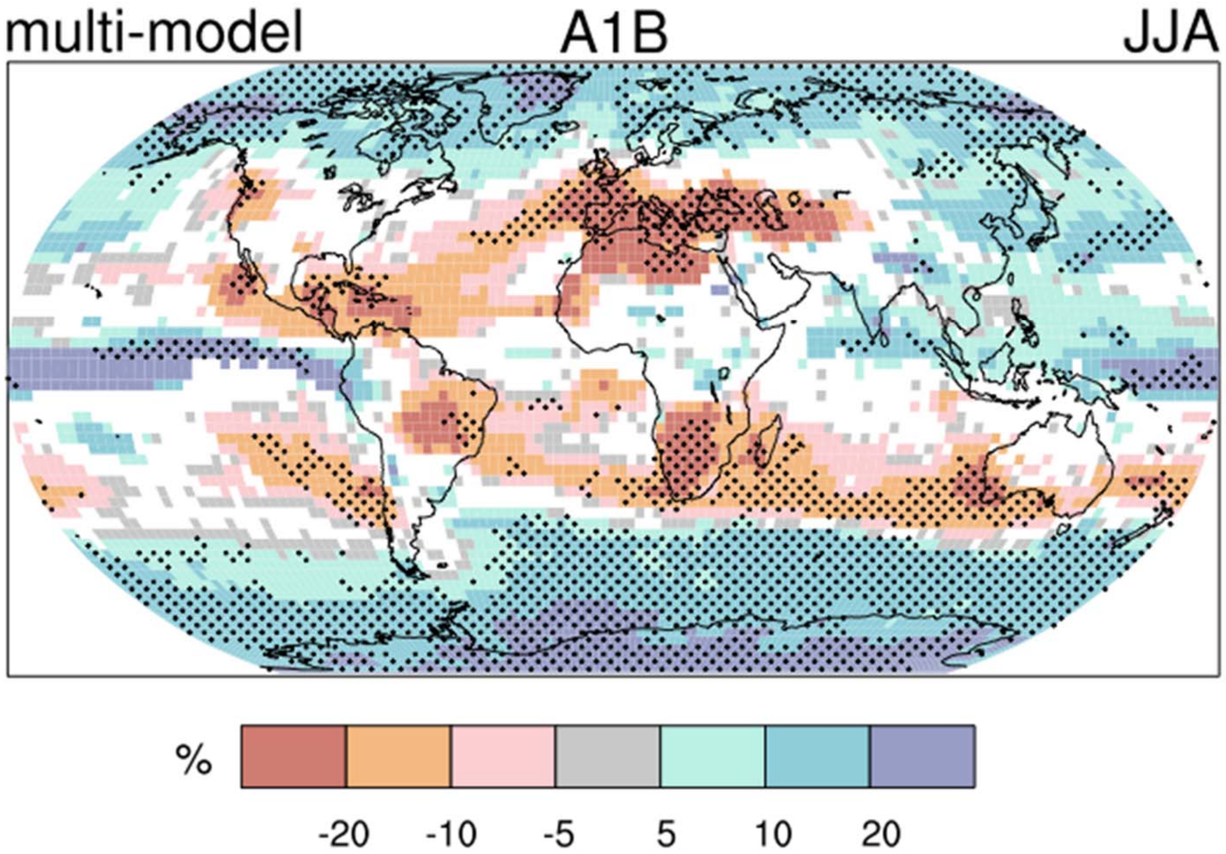
Relating model performance to projections



Knutti, Phil Trans Roy Soc 2008

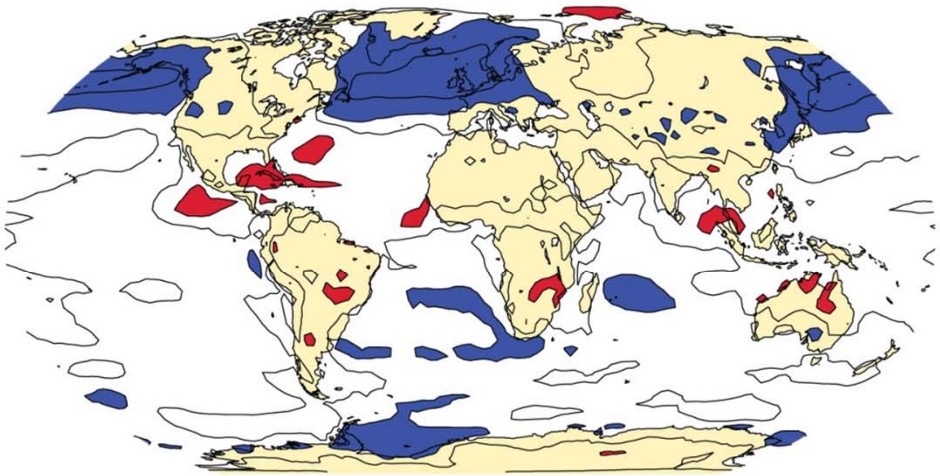
How do we relate
model performance to projections?

We don't.

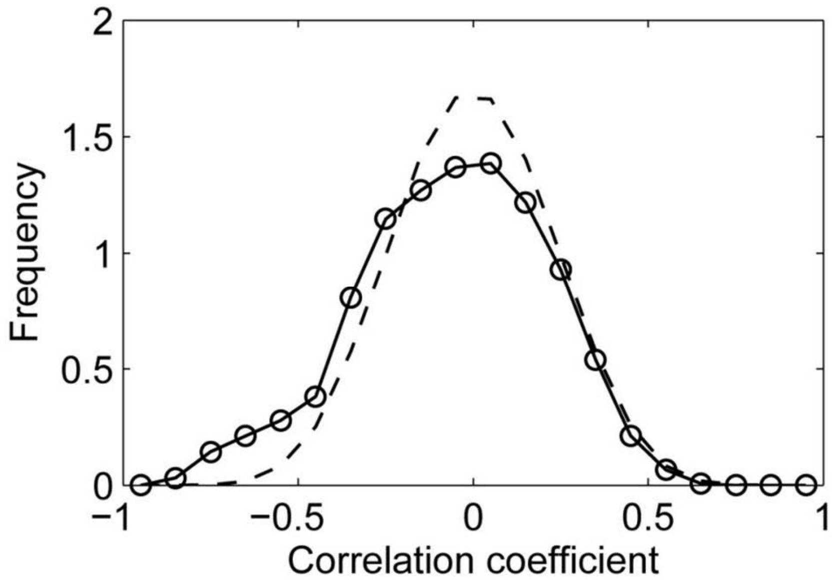


IPCC AR4, Fig. SPM7

Present day temperature and warming
do not correlate across models



Correlation of Dec-Feb temperature
to projected warming
R<-0.4
R> 0.4



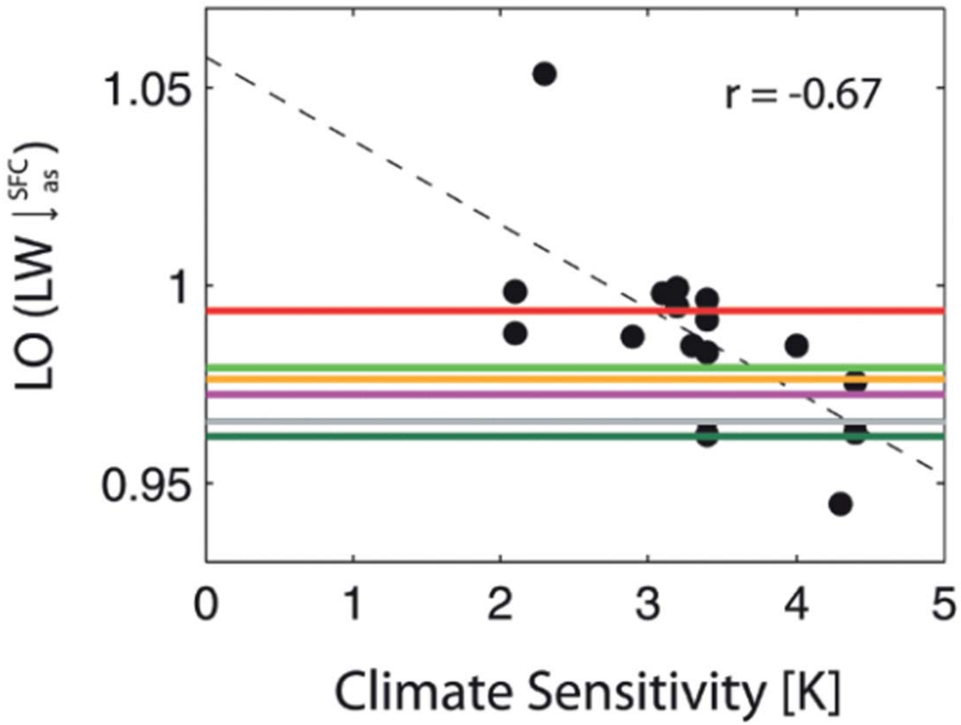
o-o-o Model
- - - - Random

Knutti et al., J. Climate 2010

Some observable climate indices

do correlate with future warming

Land ocean contrast
in surface longwave
downward all sky radiation



Huber et al., J. Climate 2011

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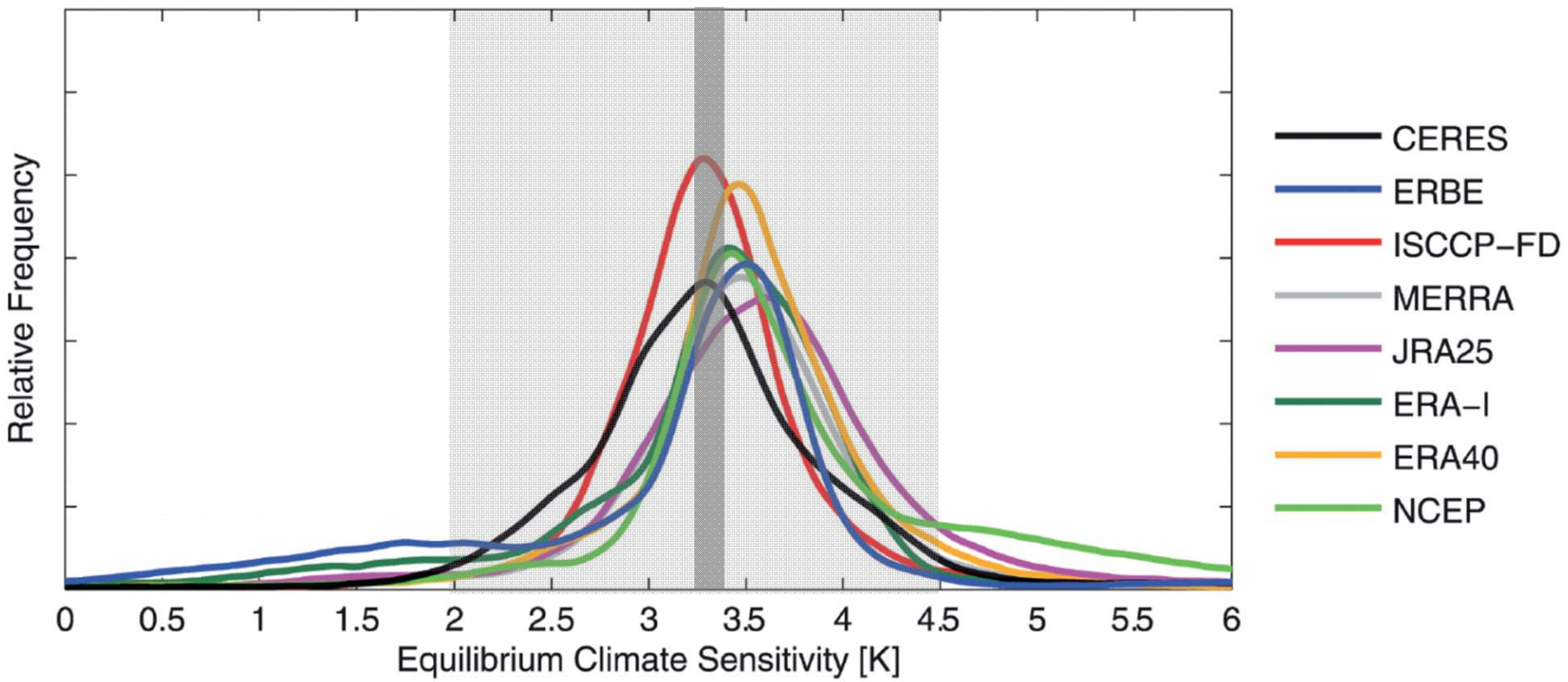
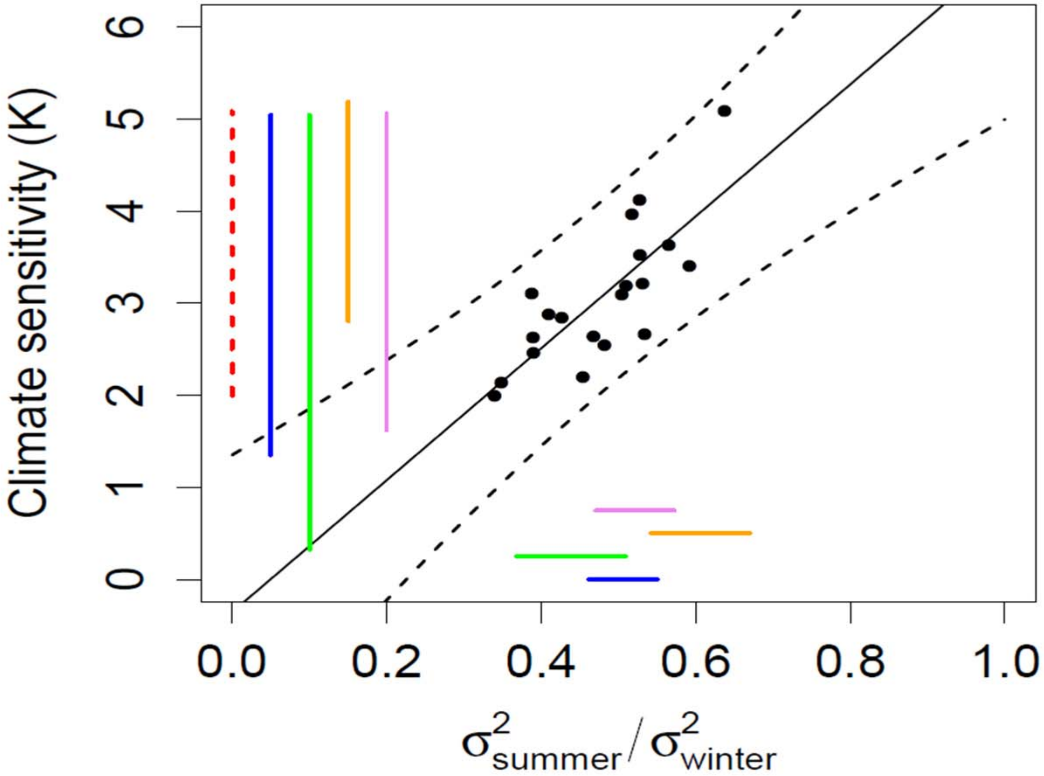


Huber et al., J. Climate 2011

Some relationships
are not stable in different ensembles



Summer to winter interannual variability

Masson and Knutti, J. Climate, submitted

Some relationships
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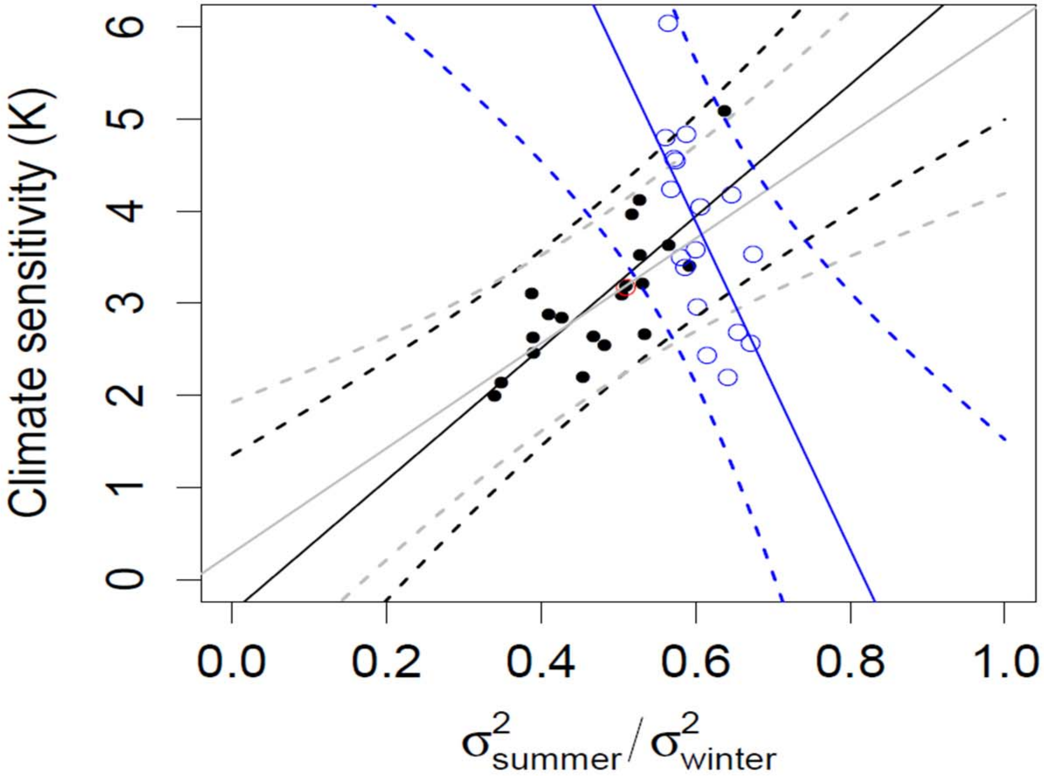
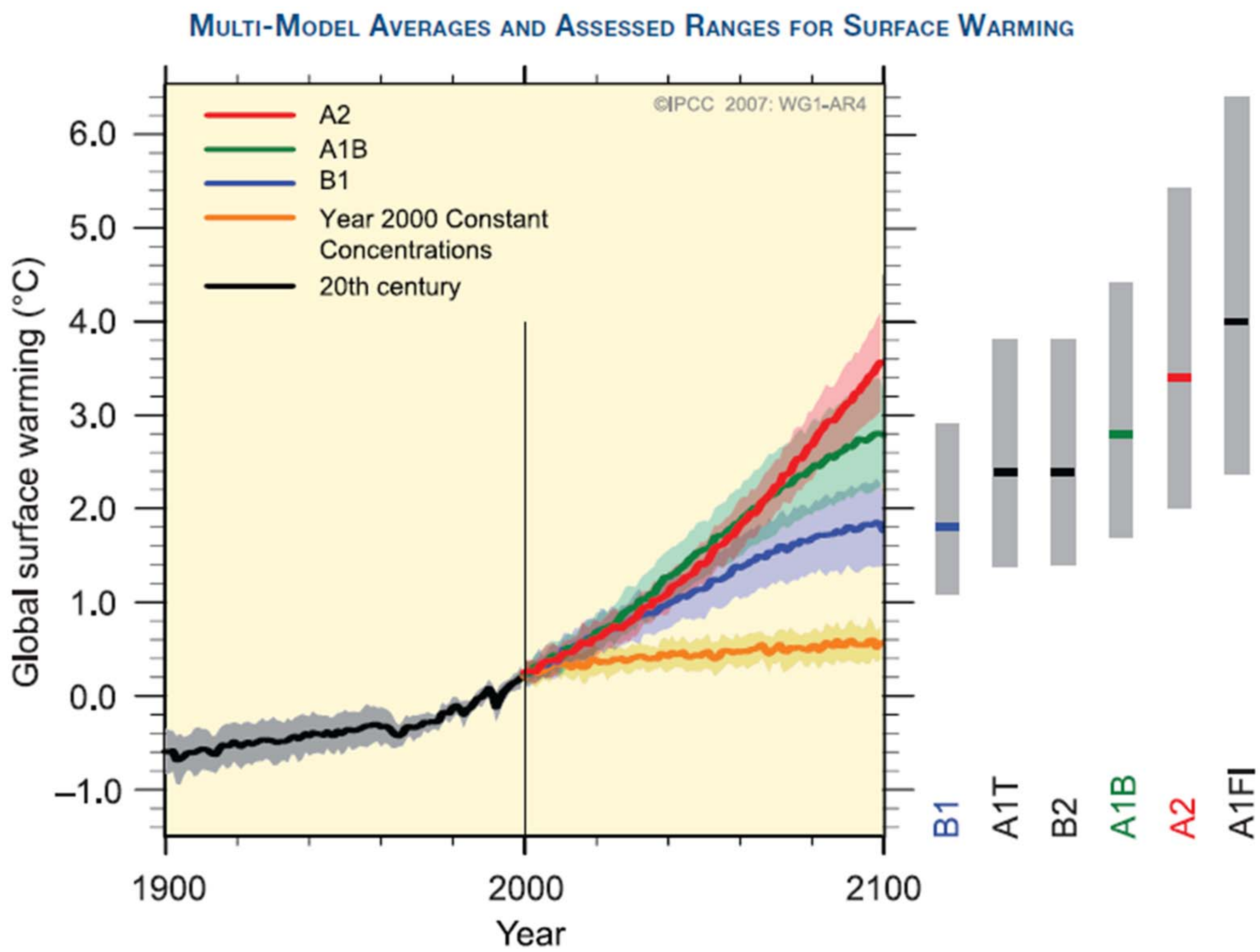


Summer to winter interannual variability

Masson and Knutti, J. Climate, submitted

Model spread in an ensemble of opportunity

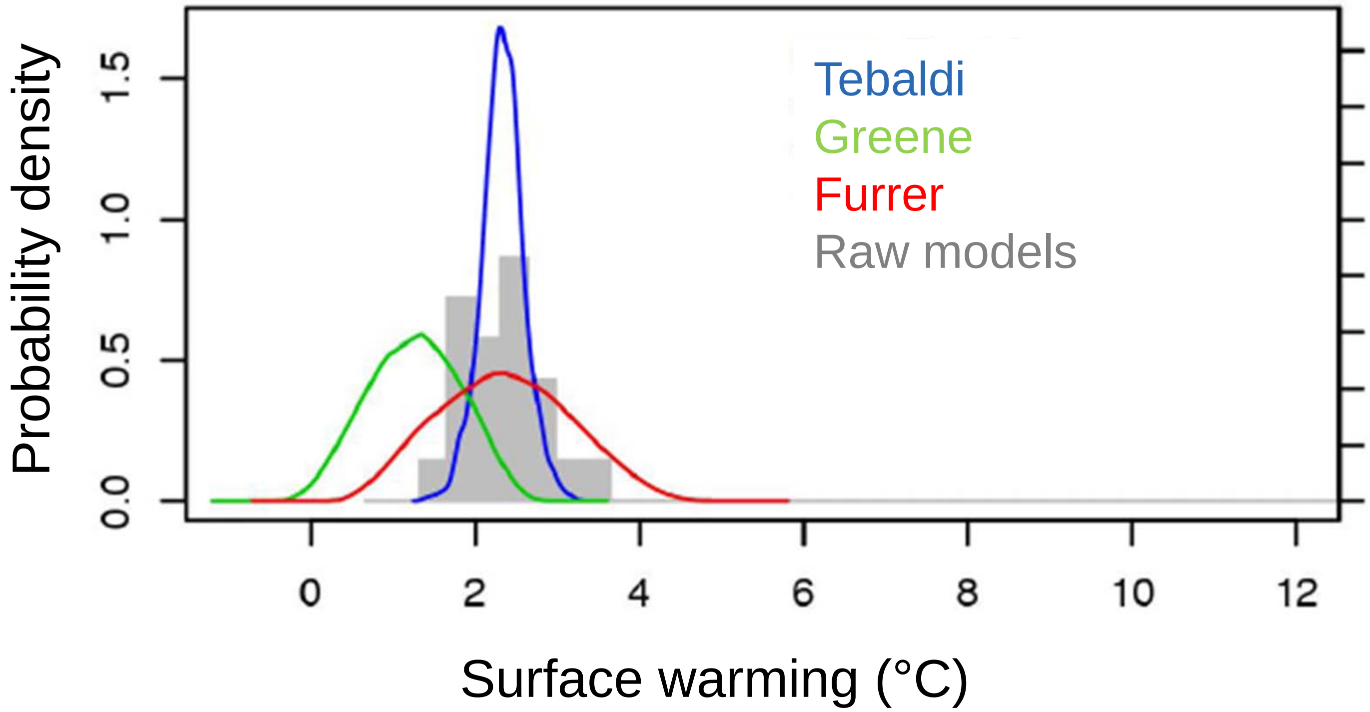
not always useful as a measure of uncertainty



IPCC 2007

Assumptions in the weighting
matter for the result

Surface warming South East Asia
Dec-Feb 2080-2099, A1B scenario



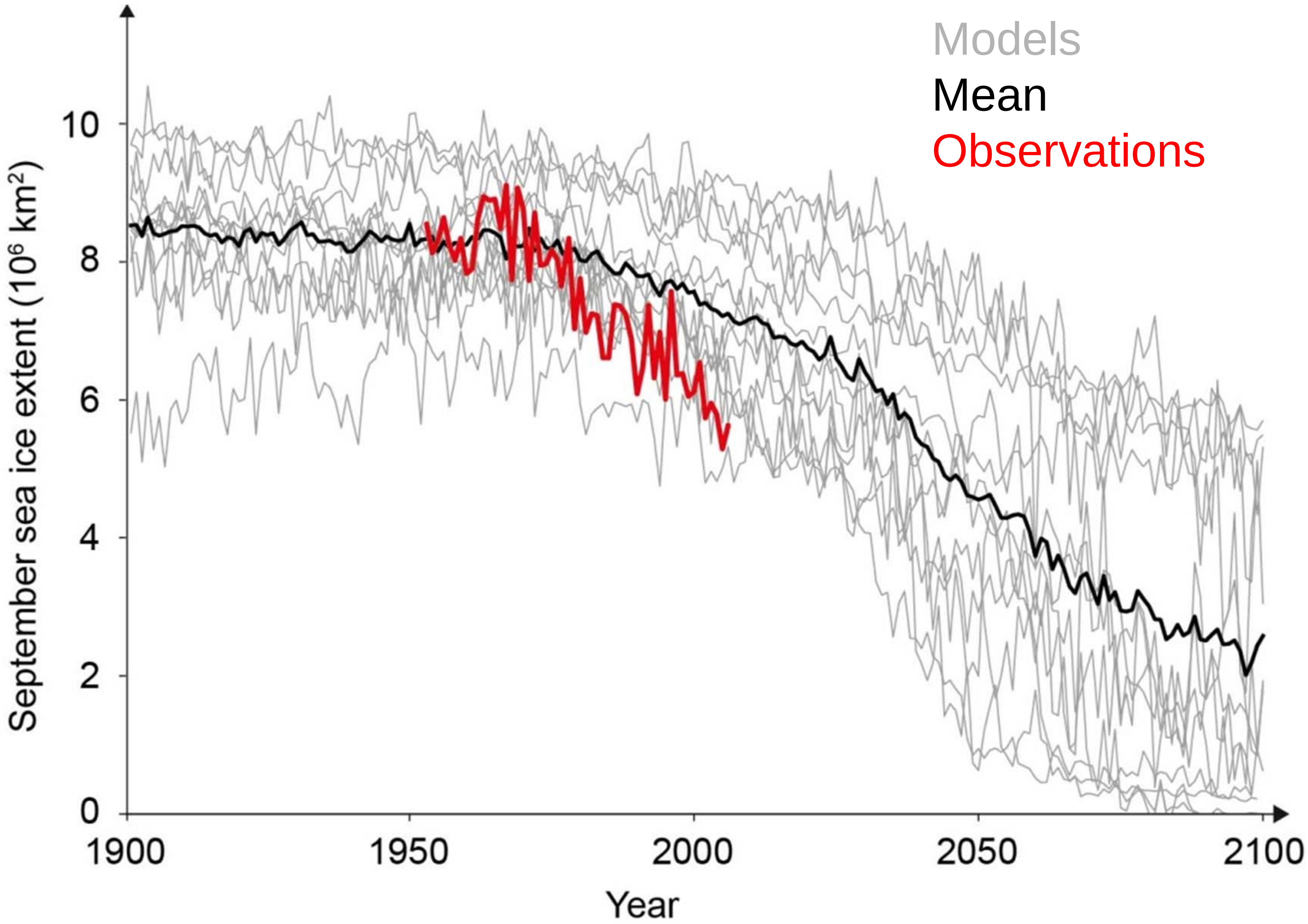
Tebaldi and Knutti, Phil Trans Roy Soc, 2007

Arctic sea ice decline

Faster than forecast?

Arctic sea ice

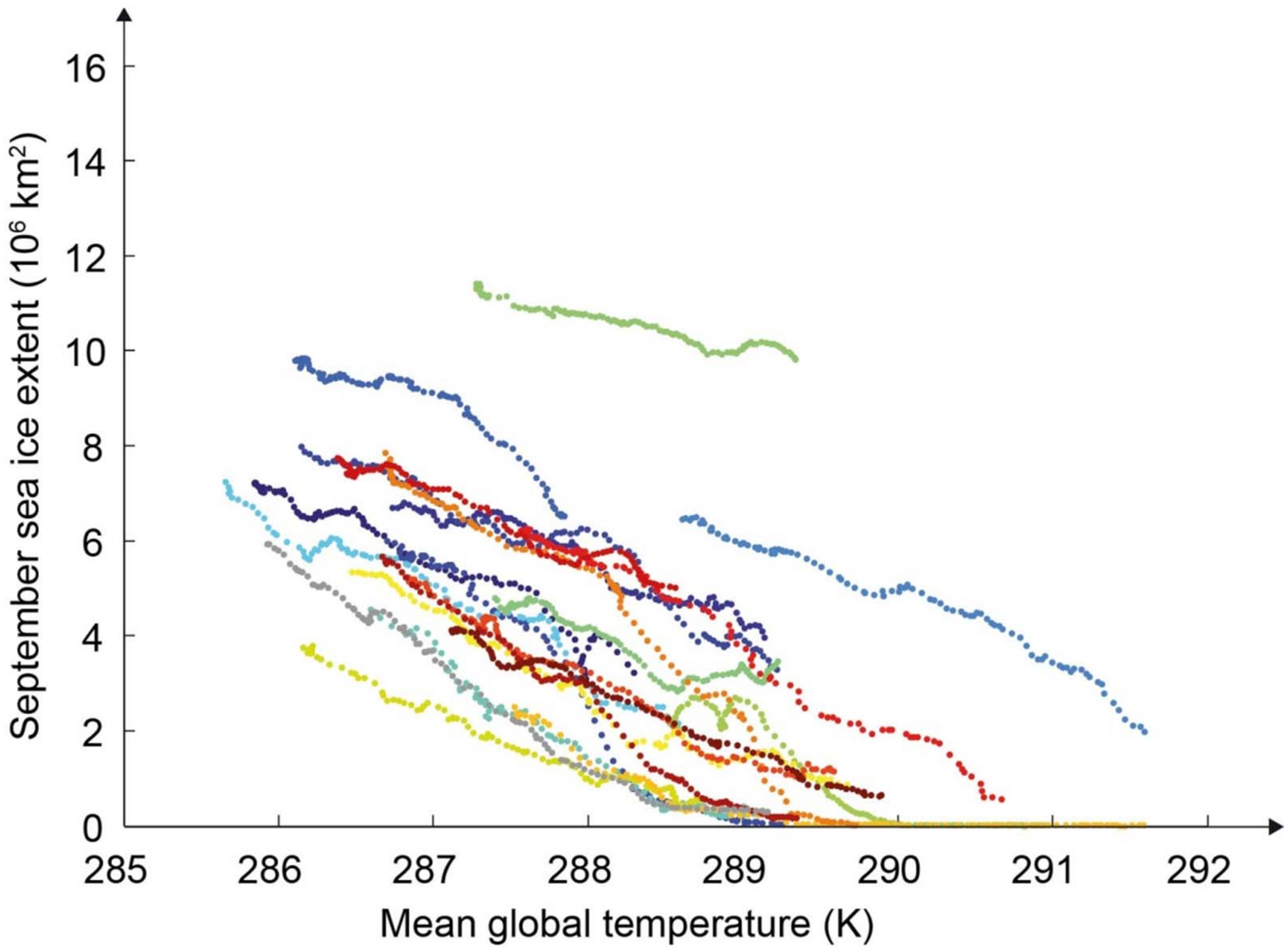
decreases in all models, but less than observed



Stroeve et al., GRL 2007, Mahlstein and Knutti, 2012, JGR

Arctic sea ice

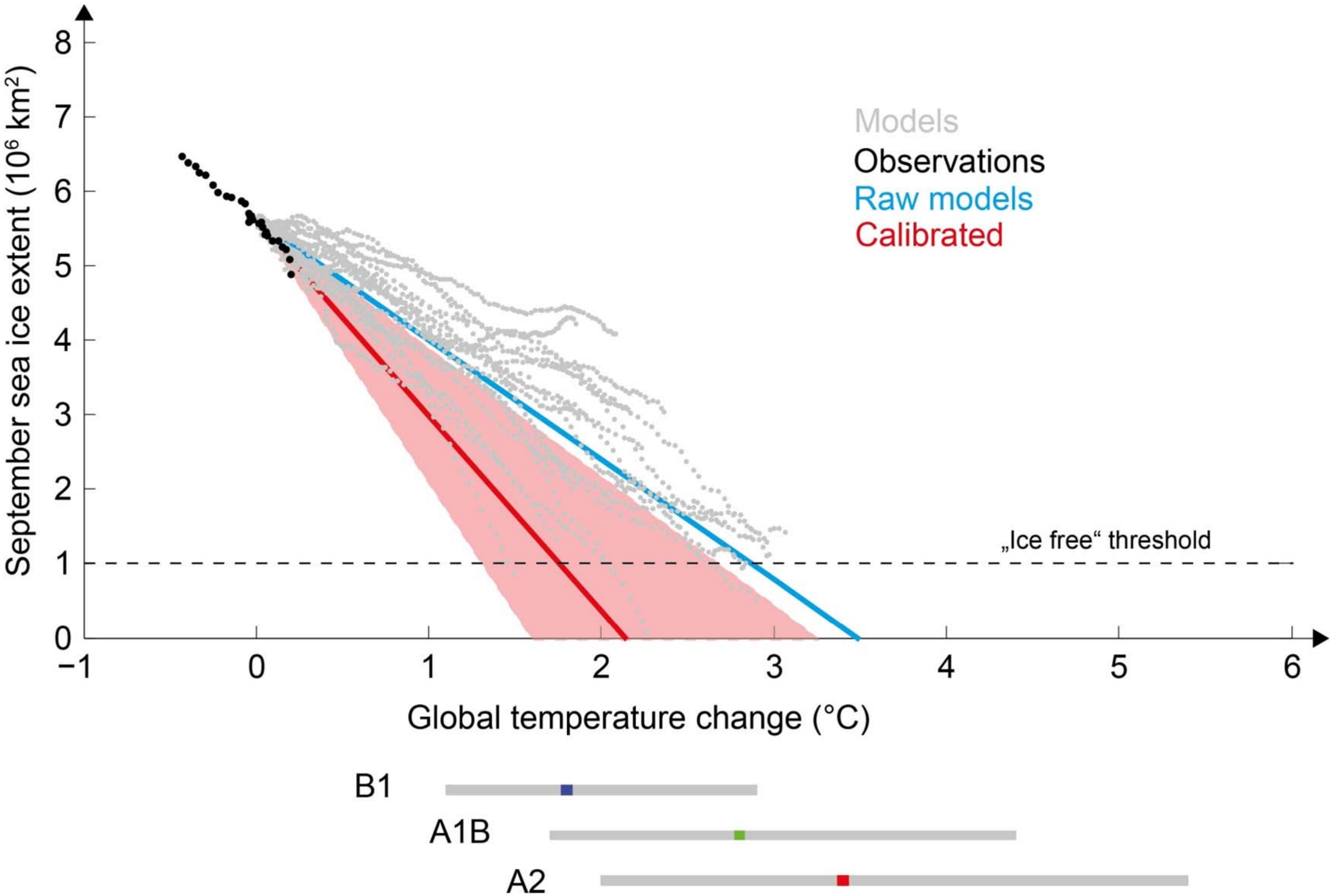
is approximately linearly related to temperature



Mahlstein and Knutti, 2012, JGR

Arctic sea ice

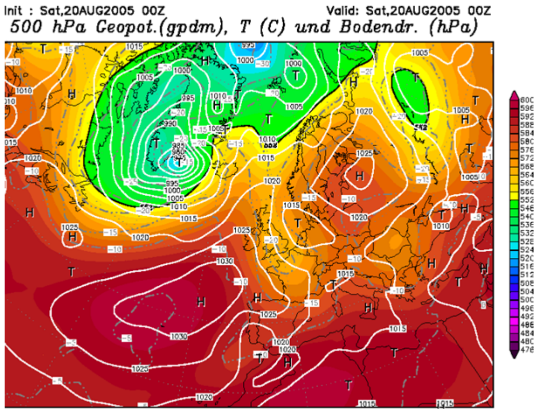
A calibrated prediction

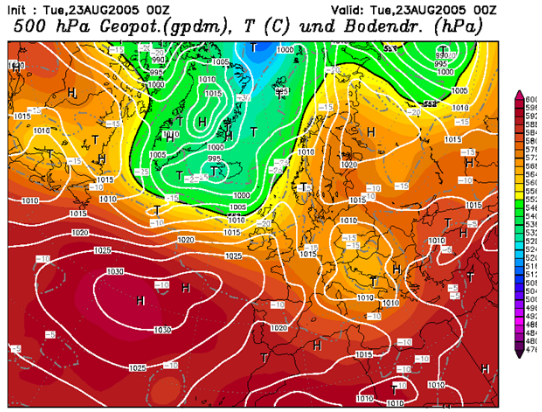


Mahlstein and Knutti, 2012, JGR

How is the weather tomorrow?

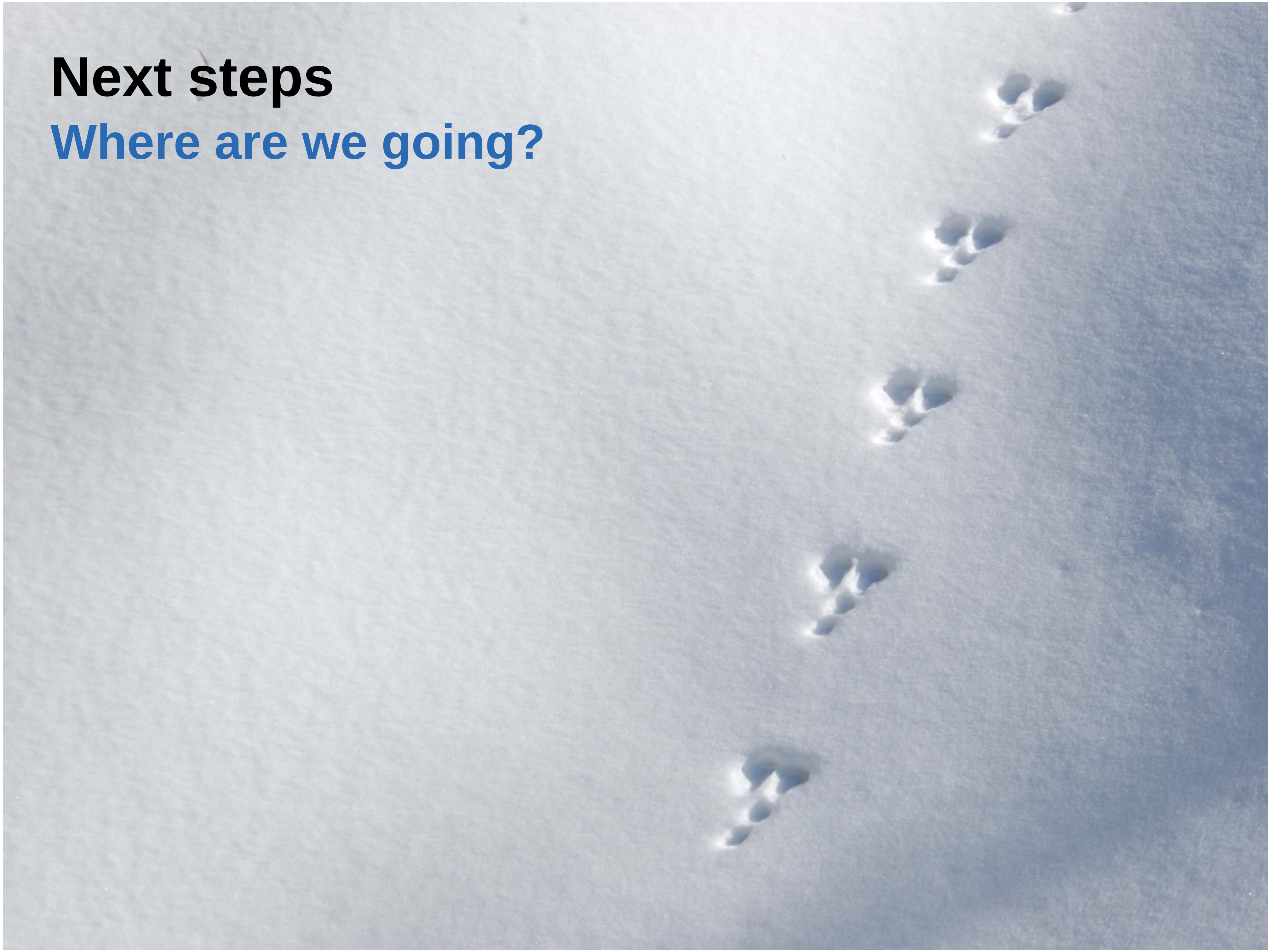
Combining lines of evidence





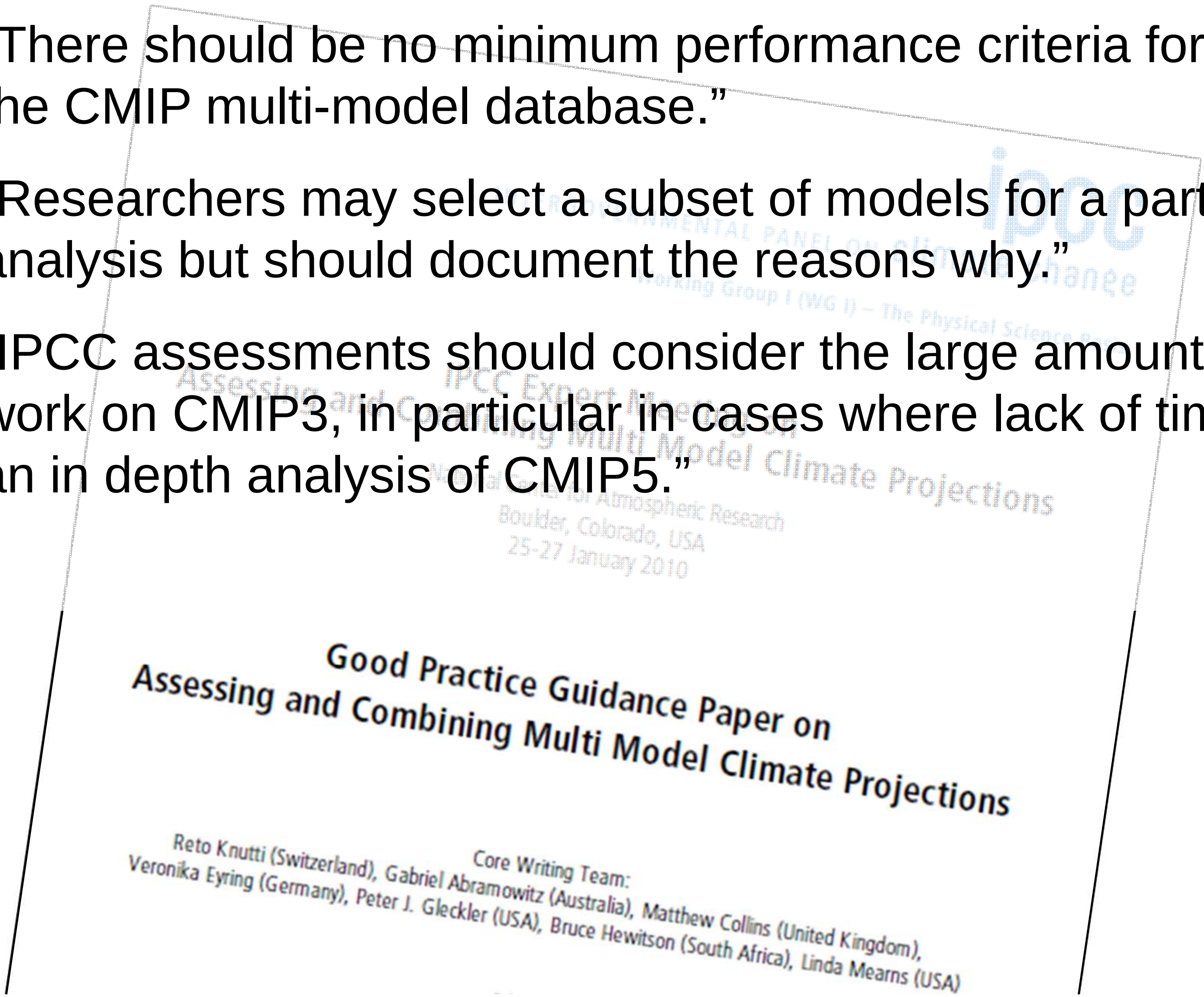
Next steps

Where are we going?



Are we making progress?
The end of model democracy?

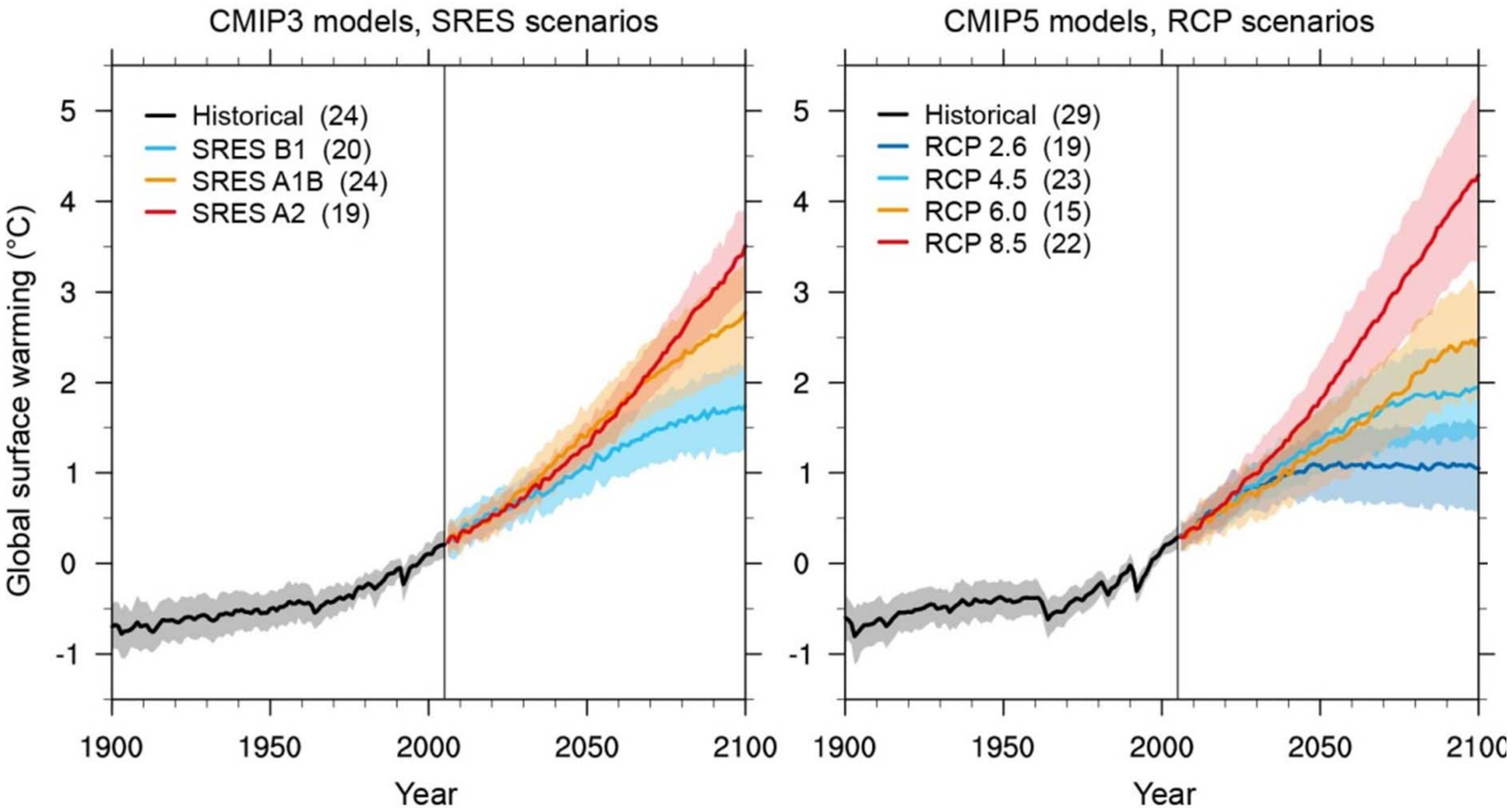
- “There should be no minimum performance criteria for entry into the CMIP multi-model database.”
- “Researchers may select a subset of models for a particular analysis but should document the reasons why.”
- “IPCC assessments should consider the large amount of scientific work on CMIP3, in particular in cases where lack of time prevents an in depth analysis of CMIP5.”



Are we making progress?

Projections are robust, uncertainties remain

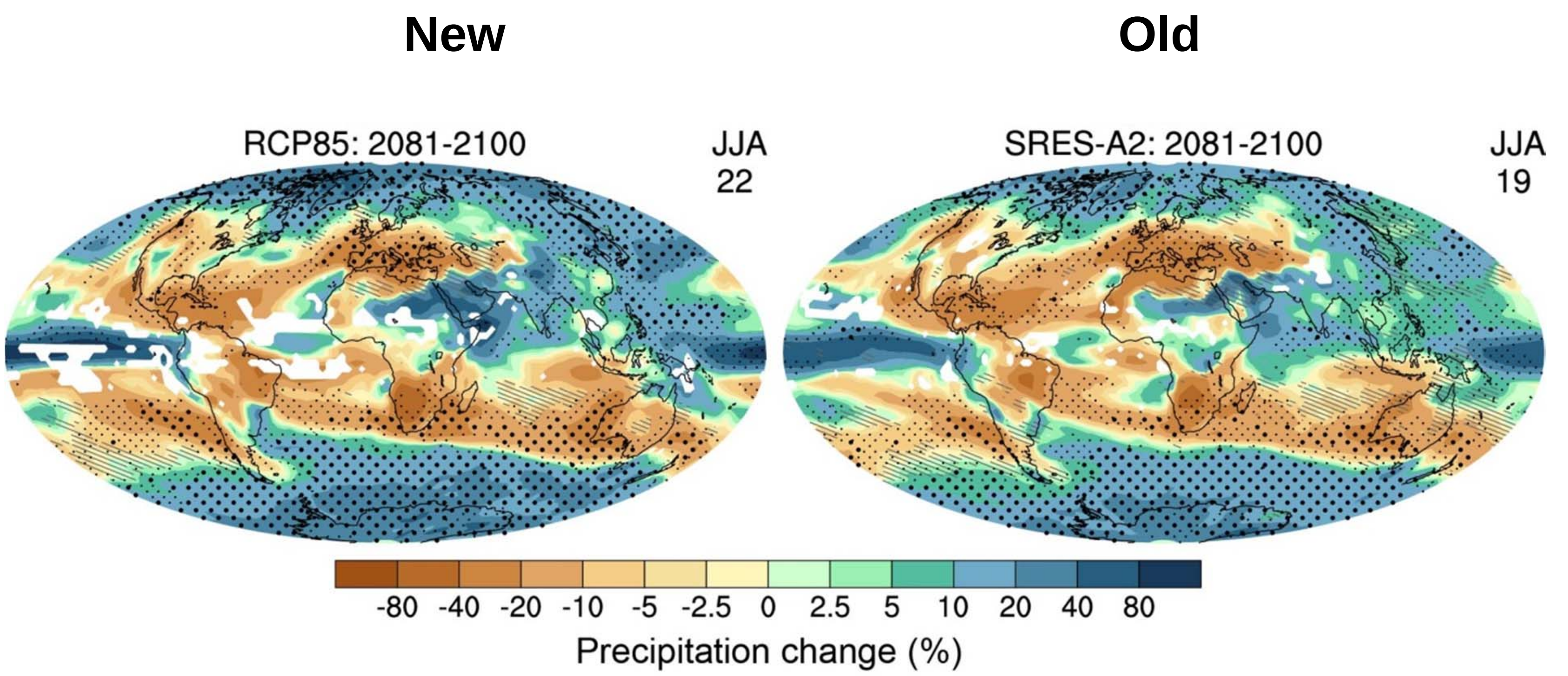
Old **New**



Knutti and Sedlacek, submitted

Are we making progress?

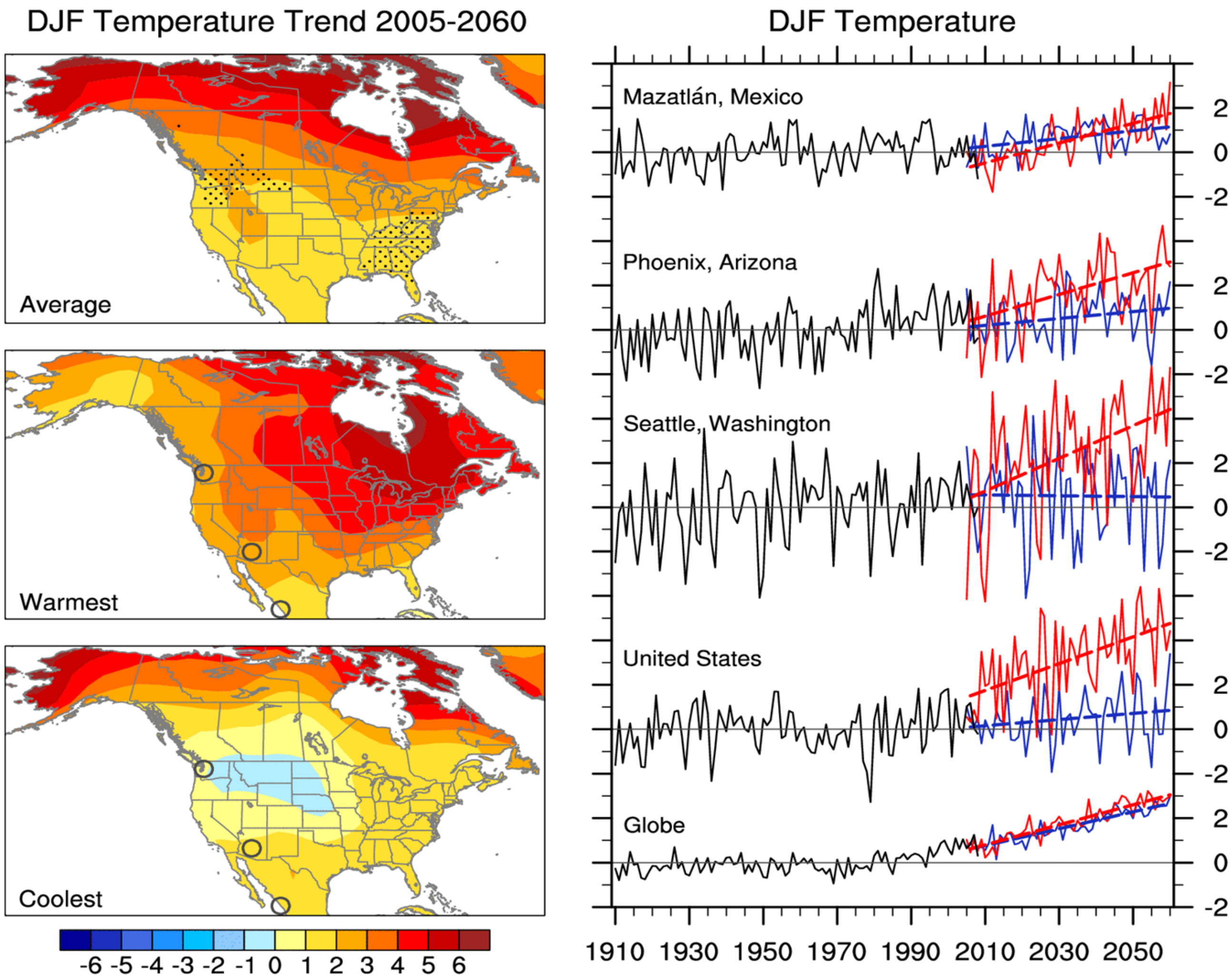
June-August precipitation projections



Knutti and Sedlacek, submitted

Limits of predictability

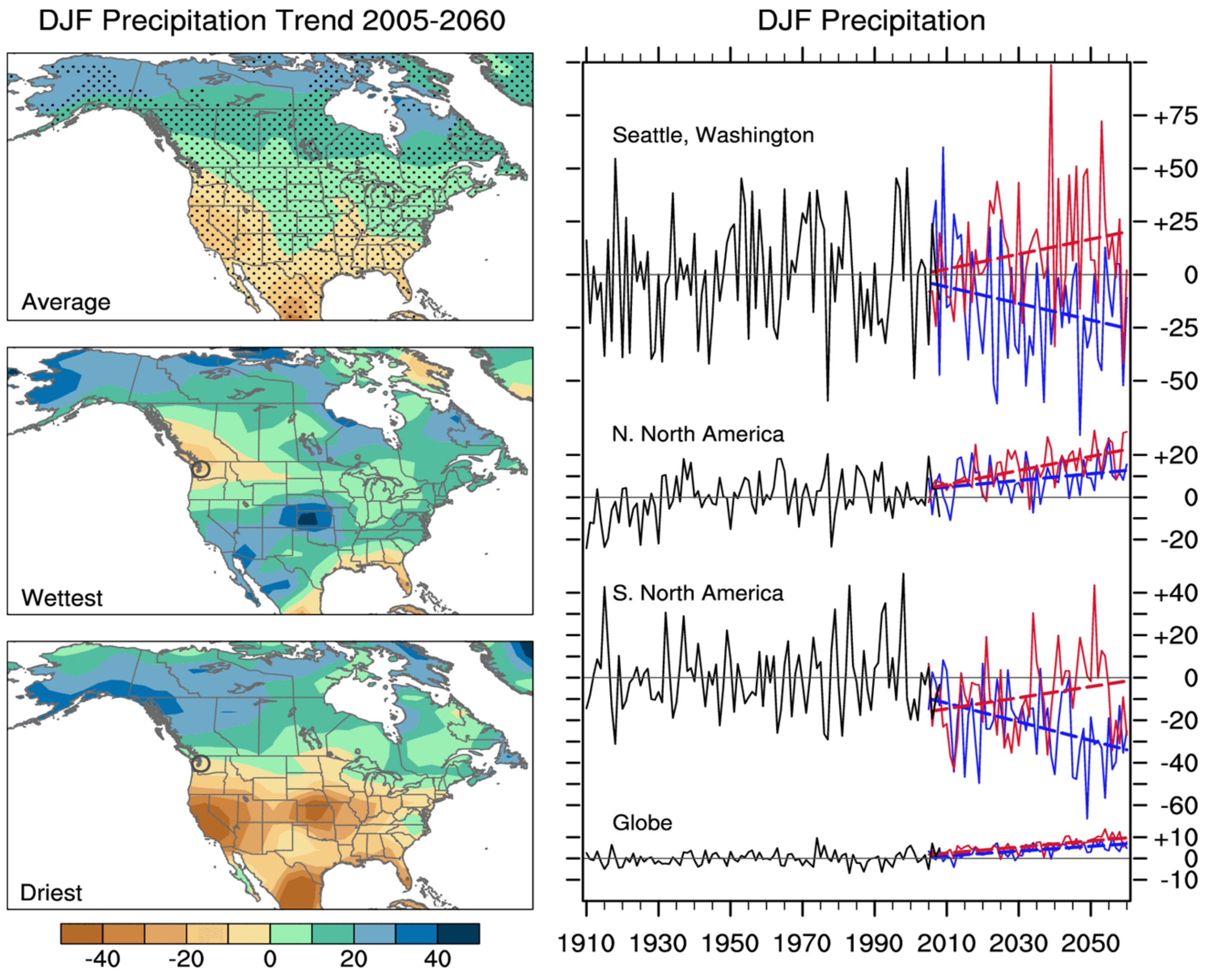
Warmest and coolest of 40 realizations



Deser, Knutti, Solomon and Phillips in press

Limits of predictability

Wettest and driest of 40 realizations



Deser, Knutti, Solomon and Phillips in press

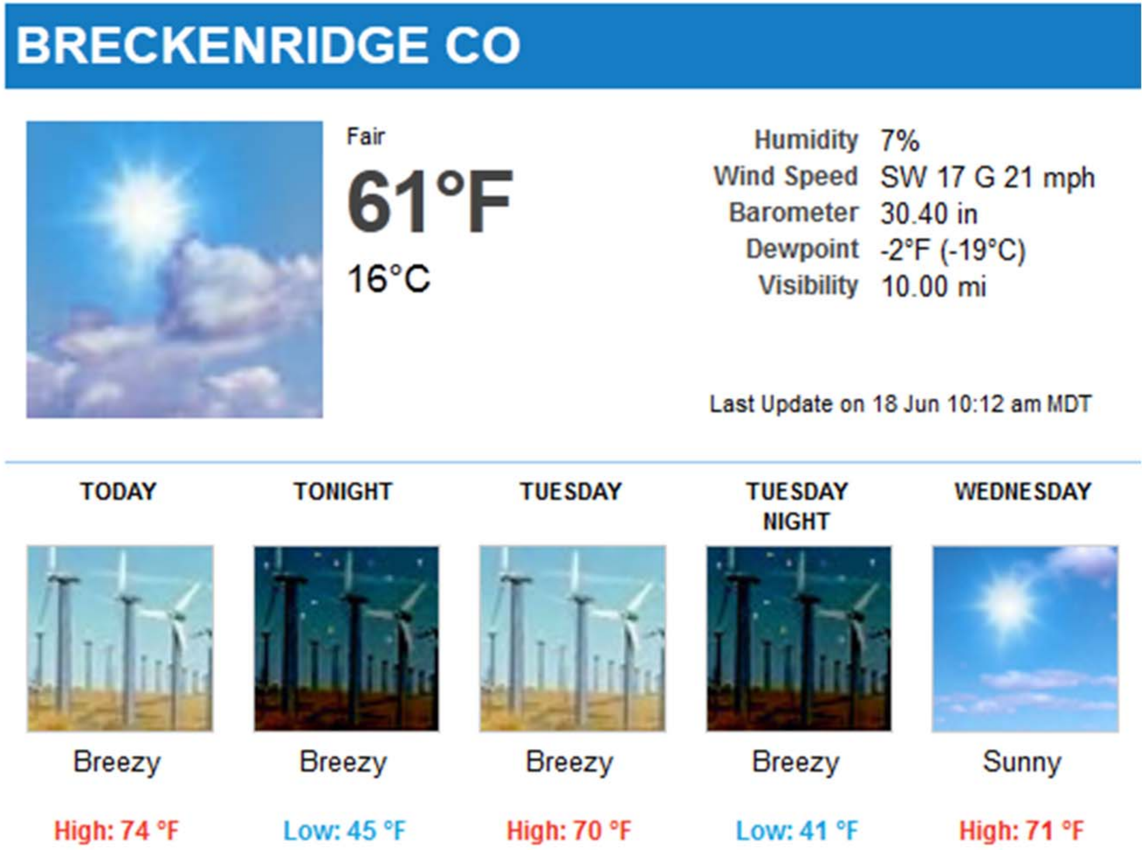
Are we making progress?

Yes and no. And why it is hard.

- Open system, complex, non-linear
- Interaction from seconds to millennia, from micrometers to thousands of kilometers
- Dimensionality
- Natural variability
- Limited and uncertain observations
- Model discrepancy
- Expensive models, petabytes of data
- Calibration problem in a high-dimensional space
- Out of sample prediction, no proper verification

Establishing confidence in a prediction

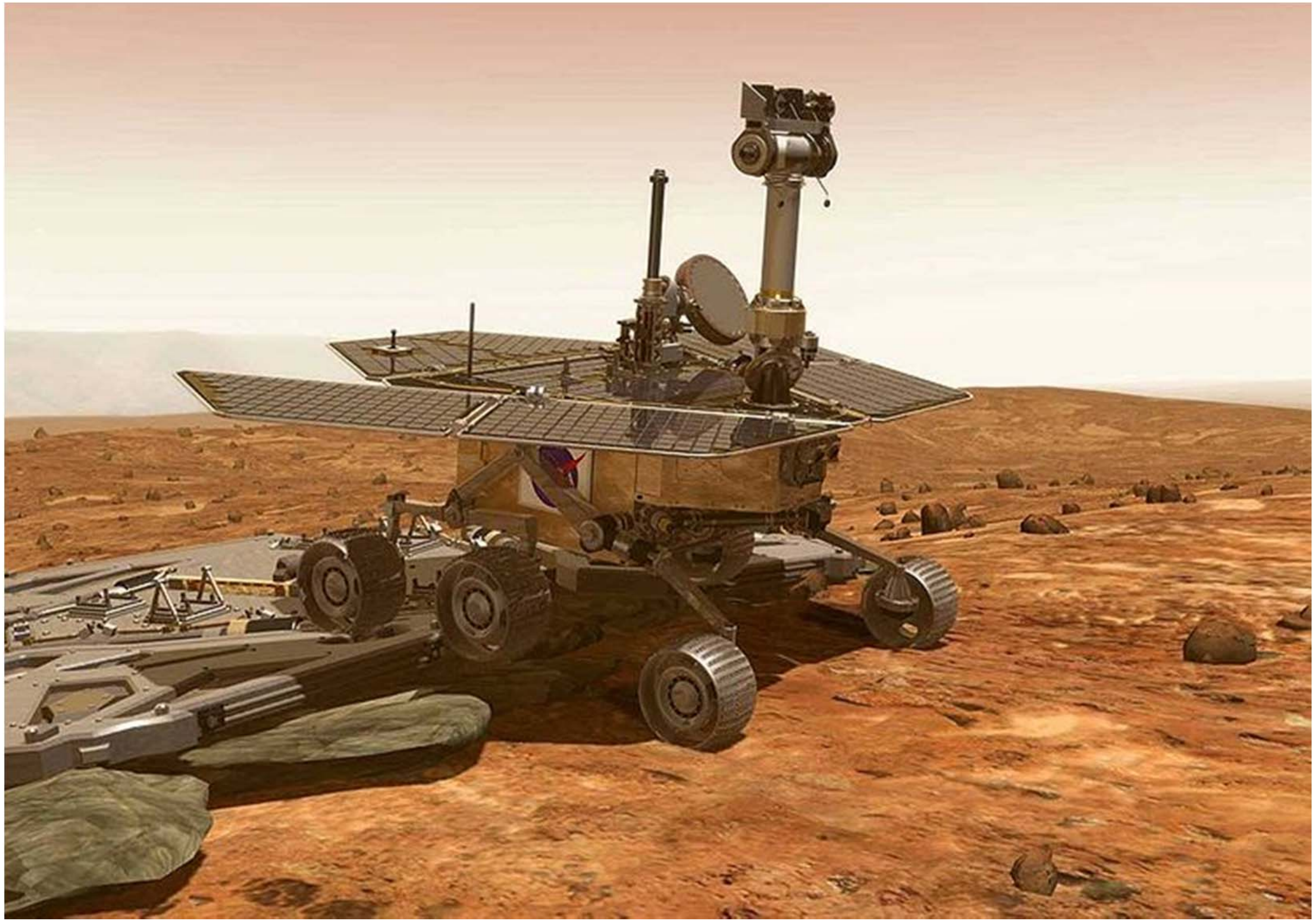
Why do you believe the weather forecast?



Tuesday: Sunny, with a high near 70. Breezy, with a west southwest wind 9 to 18 mph, with gusts as high as 29 mph

Establishing confidence in a prediction

Lack of verification



Establishing confidence in a prediction

Lack of verification

Conclusions
and challenges

Climate models have reached a remarkable level of maturity, but:

- Model sampling is neither systematic nor random.
- We use a collection of ‘best guesses’ not designed to span any uncertainty range, and not independent.
- Models are getting “better” at things we observe, but model spread is not reduced for projections.
- Model performance varies but we don’t know how to translate into weights. But we discard old models.
- Combining model may help but can create unphysical results.
- No independent verification of the prediction.
- There is no best model without defining a purpose.