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WCRP and ICTP Interpreting Climate Change Simulations: Capacity Building for Developing Nations Seminar

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Probabilistic projections of climate change.

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Probabilistic projections of climate change

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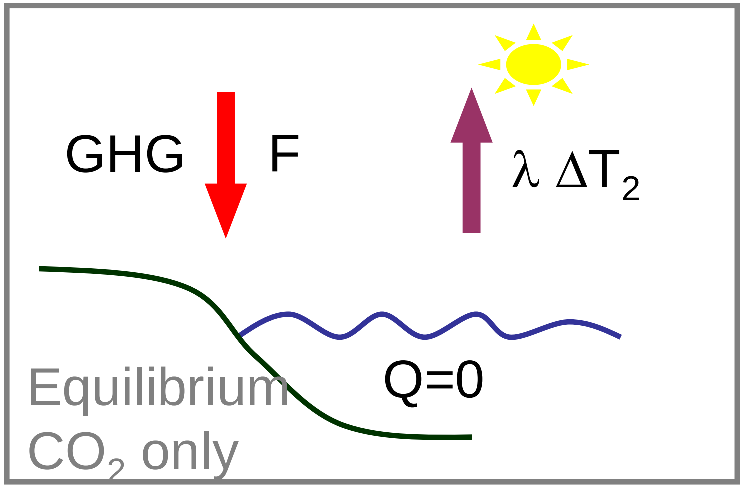
Overview

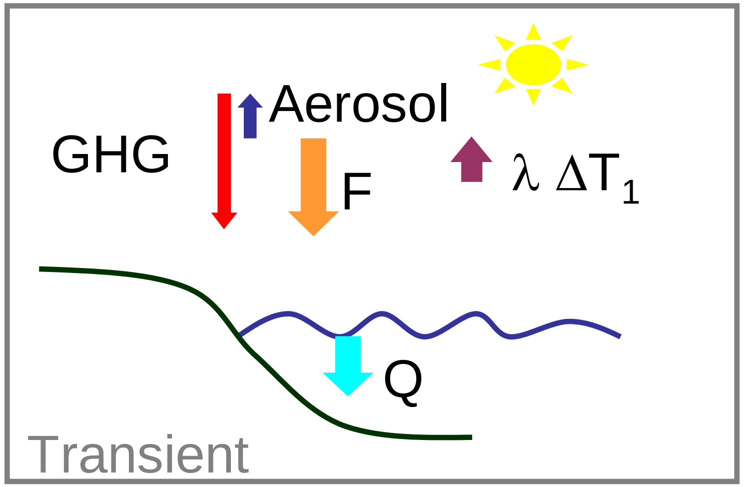
- An example: what is climate sensitivity
- Fundamental ideas in probabilistic projections
- Prior distributions
- Structural uncertainty
- Transient probabilistic projections
- The CMIP3 multi model ensemble
- What is a good model, and what do we learn from more models?

A seemingly simple question…

- By how much would the Earth warm if we doubled atmospheric CO_2 and kept it there for a long time?
- Or equivalent, what is equilibrium climate sensitivity?

The perturbation of the energy budget





$$Q = F - \lambda \Delta T$$

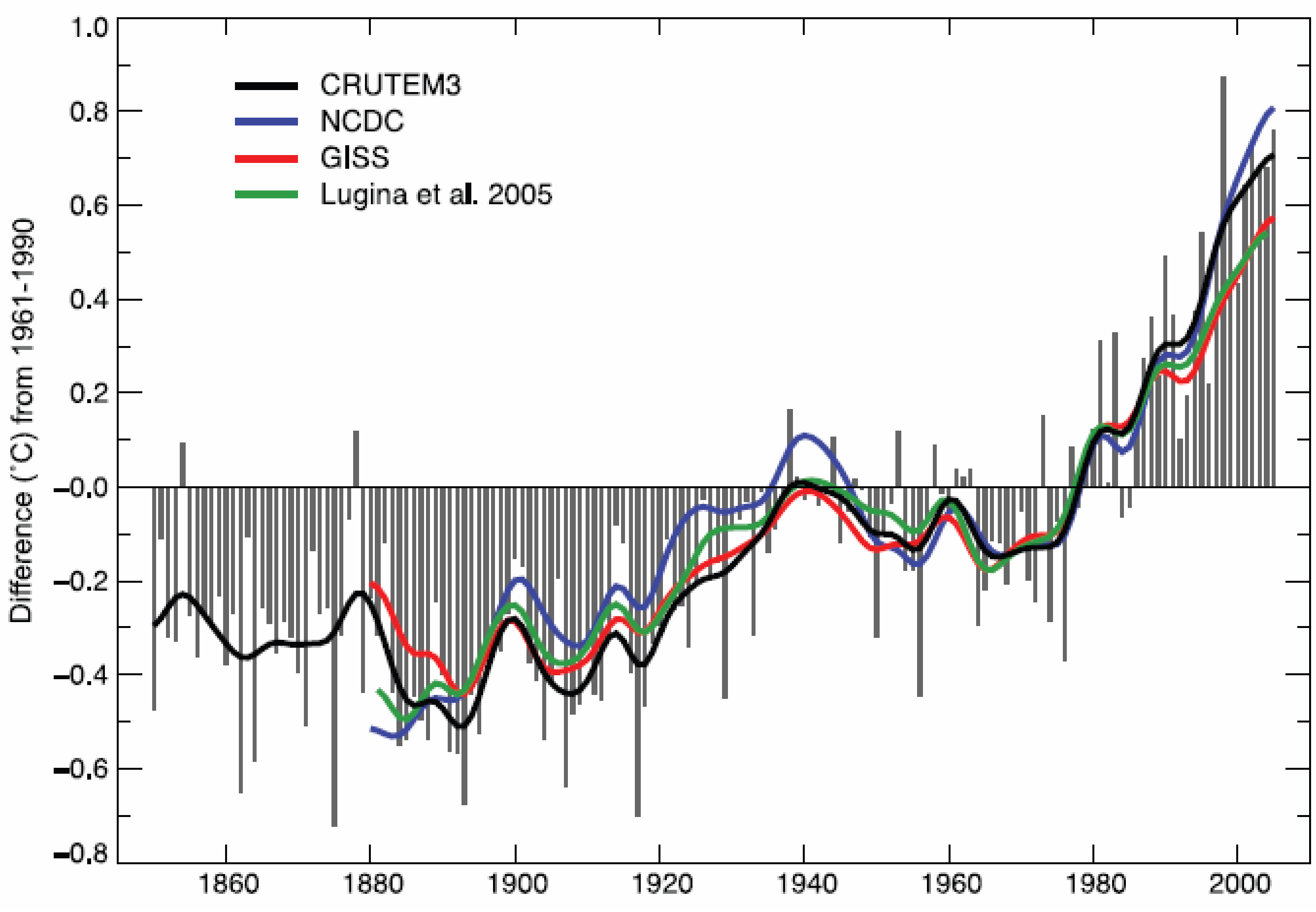
Equilibrium: Q = 0

$\Rightarrow F = \lambda \Delta T_2$

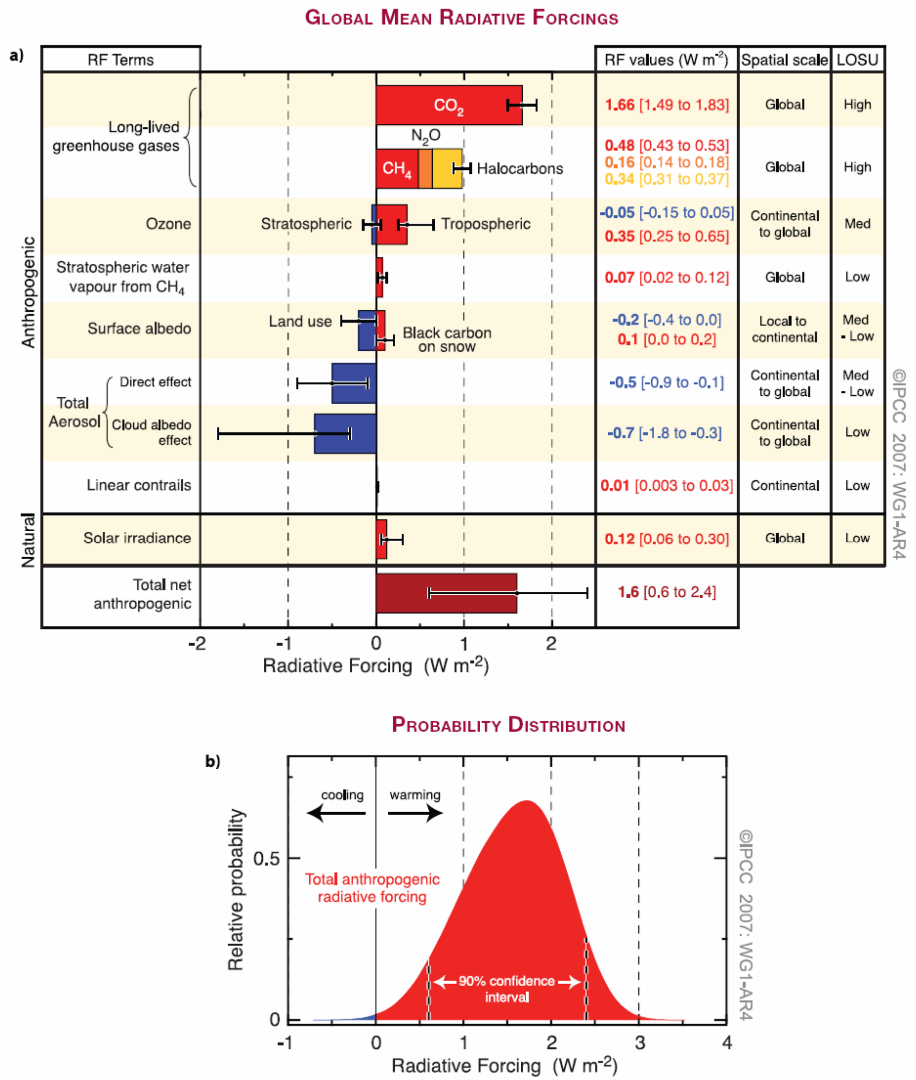
Climate sensitivity: equilibrium global mean surface warming for a given forcing:

$S = 1 / \lambda = \Delta T_2 / F$

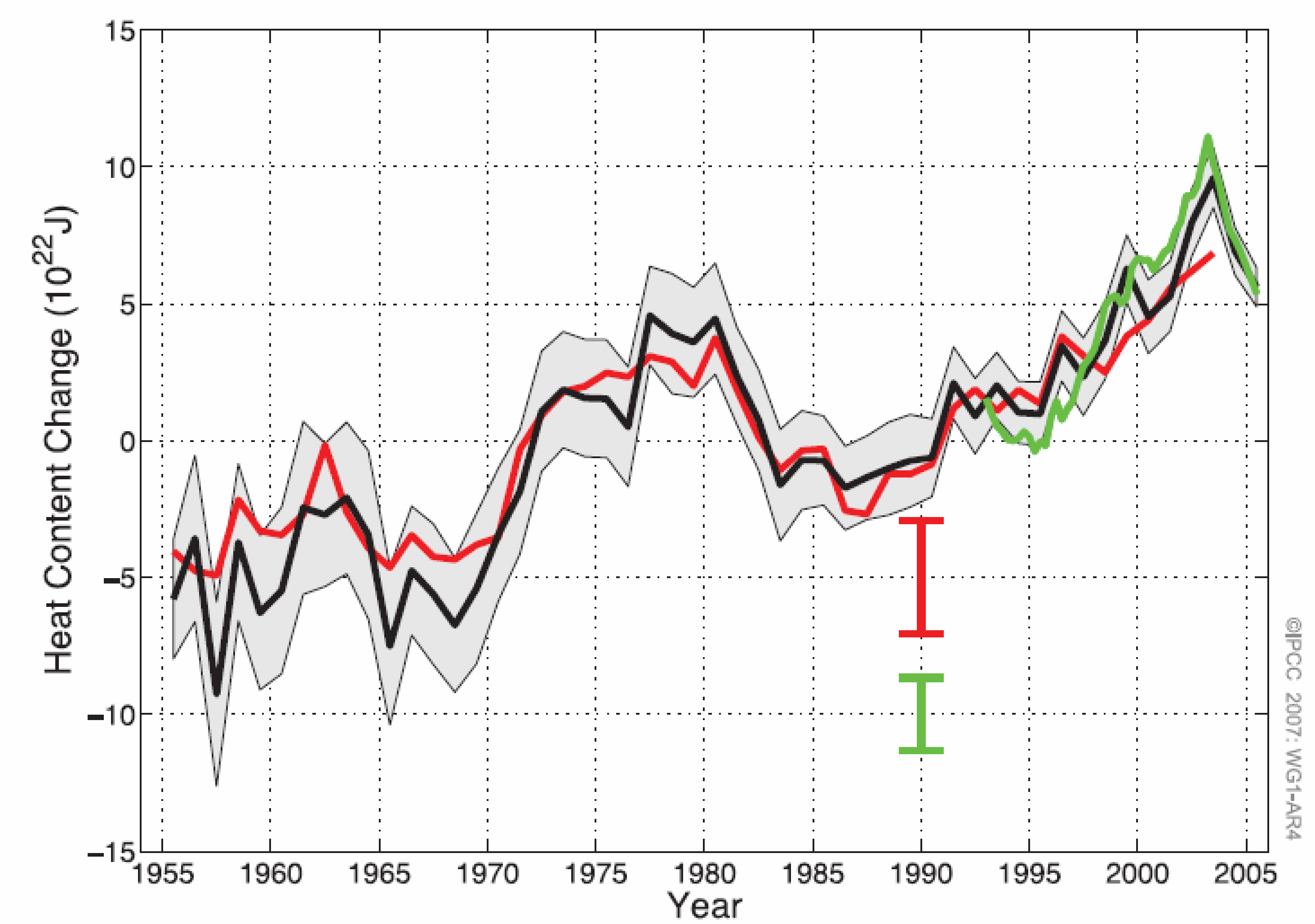
Observed surface warming



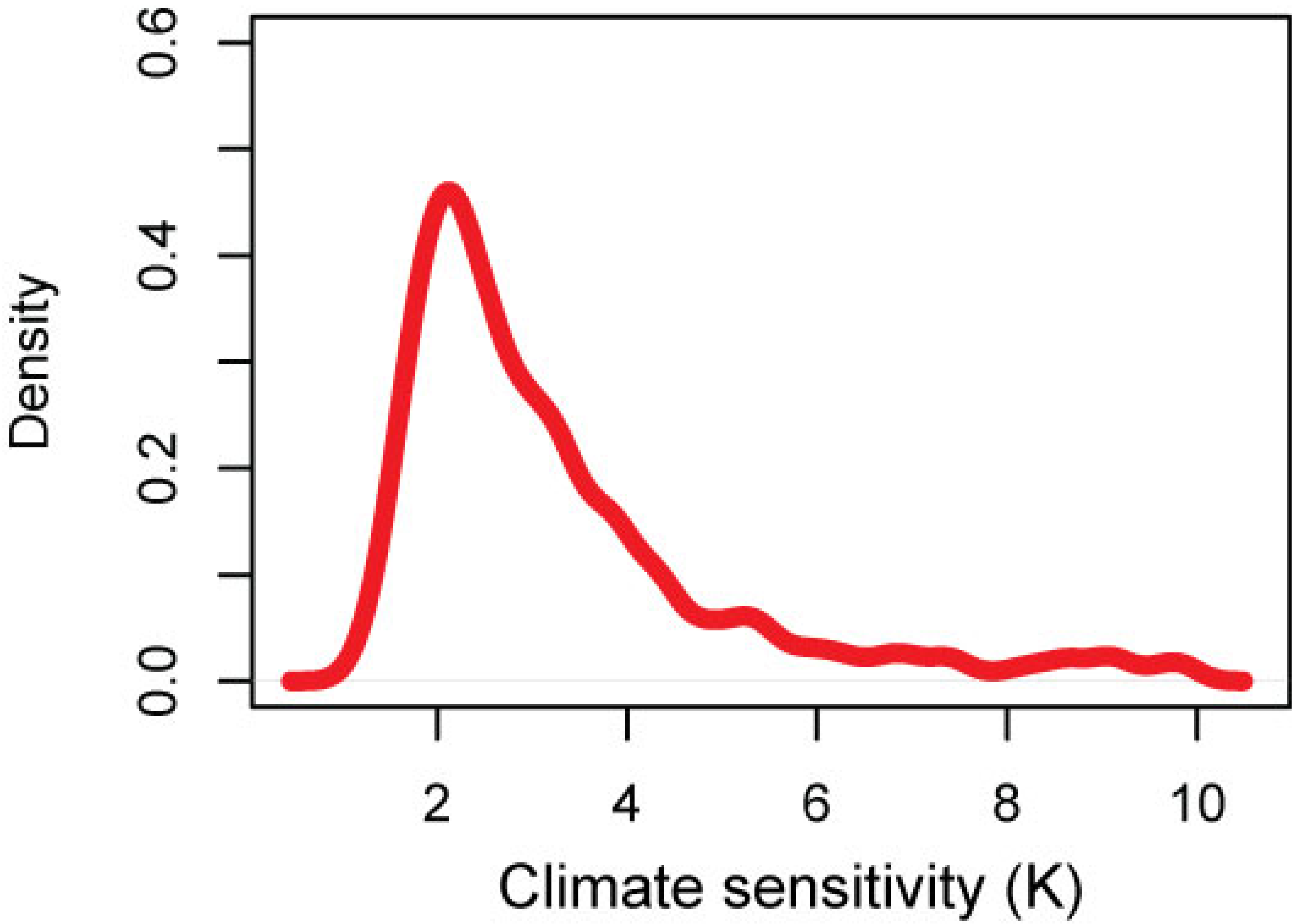
Radiative forcing



Observed ocean heat uptake

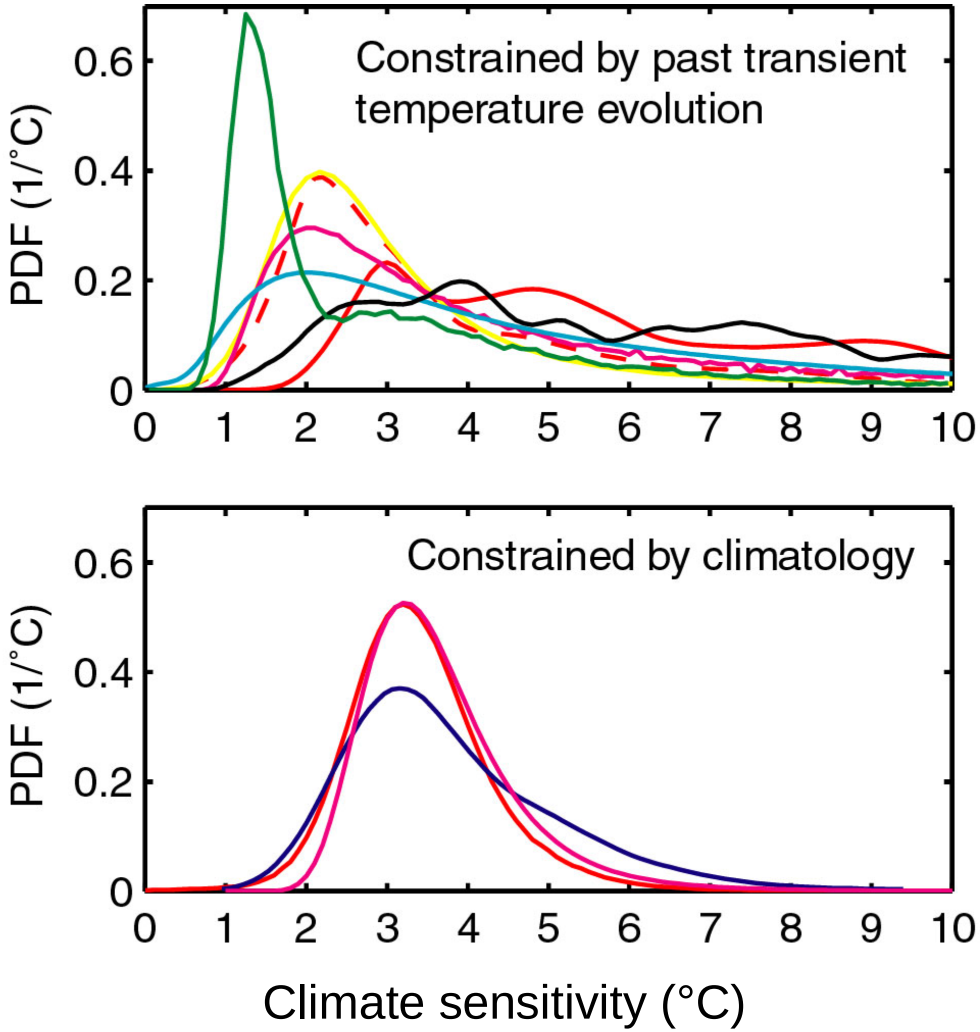


… one resulting distribution for sensitivity



(Tomassini et al. 2007)

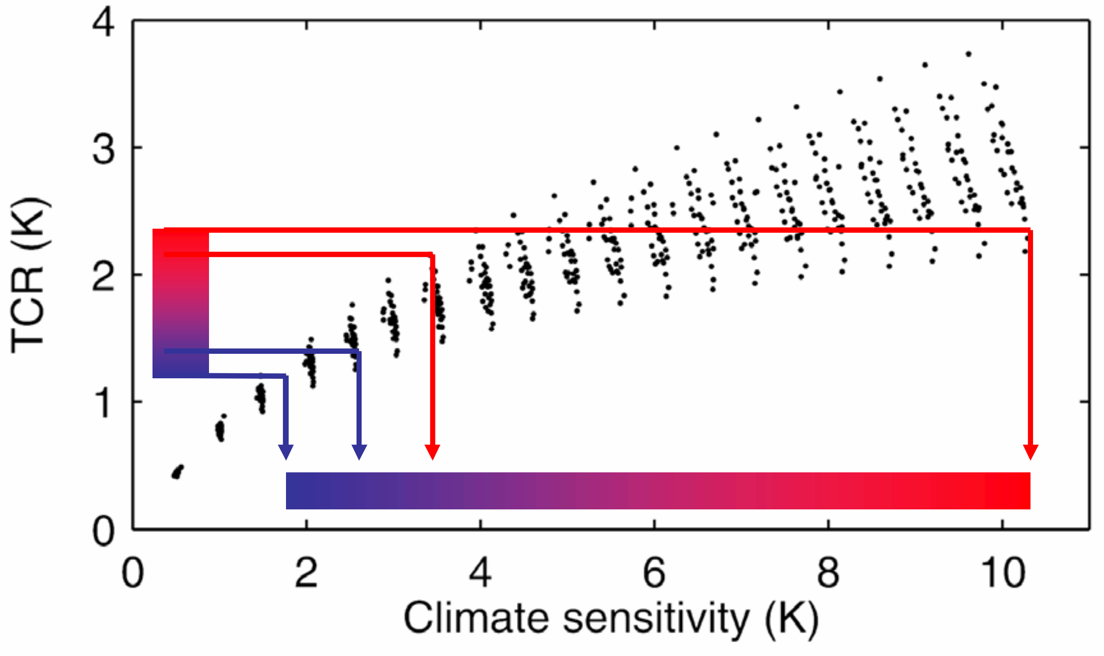
… and many other distributions for sensitivity



IPCC AR4:

- Most likely around 3°C
- Very likely >1.5°C
- Likely 2-4.5°C
- Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values.
- No IPCC PDF.

Transient response and climate sensitivity



(Knutti et al. 2005)

- Equilibrium climate sensitivity is not well constrained from the transient climate response.
- ‘Values substantially higher than 4.5°C cannot be excluded’… …is not a very quantitative statement, but it reflects the fact that there is no consensus on a very likely upper bound.

Pros and cons for probability

- A distribution (probability density function, PDF) contains the full information on the likelihood of all possible outcomes. It can be used as input into other models (e.g. impact).
- PDFs usually require a very large number of model simulations, or an assumption of what a very large ensemble would do if we had it.
- PDFs usually reflect a degree of belief and are subjective. They depend on many assumptions in the statistical scheme, the observations used as constraints, the model, etc. No prior knowledge is impossible.
- It is misleading to speak about 'the PDF'. 'My PDF' would be better…
- Structural uncertainty is hard to account for. The synthesis of PDFs is problematic.

Bayes' theorem

Thomas Bayes (1702-1761, Tunbridge Wells, Kent)

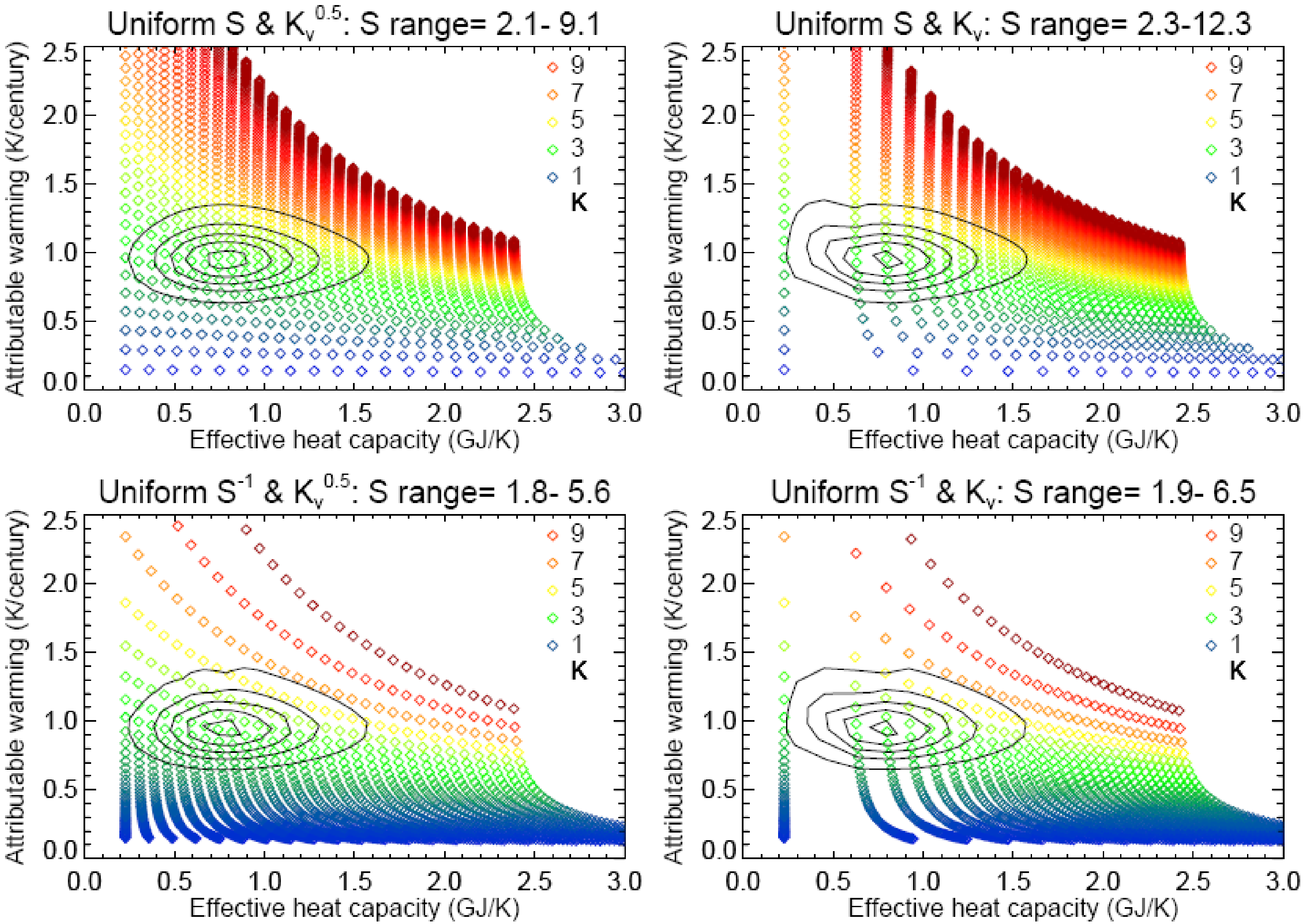
$$P(A,B) = P(A) \cdot P(B|A) = P(B) \cdot P(A|B)$$

$$P(B|A) = \frac{P(B) \cdot P(A|B)}{P(A)}$$

P(S | obs)= P(obs | S) · P(S) / P(obs)

P(S | obs)	what we want to know
P(obs | S)	what the model simulates for parameter S
P(S)	prior distribution on parameters
P(obs)	probability of observations, normalizing constant

The problem of prior distributions

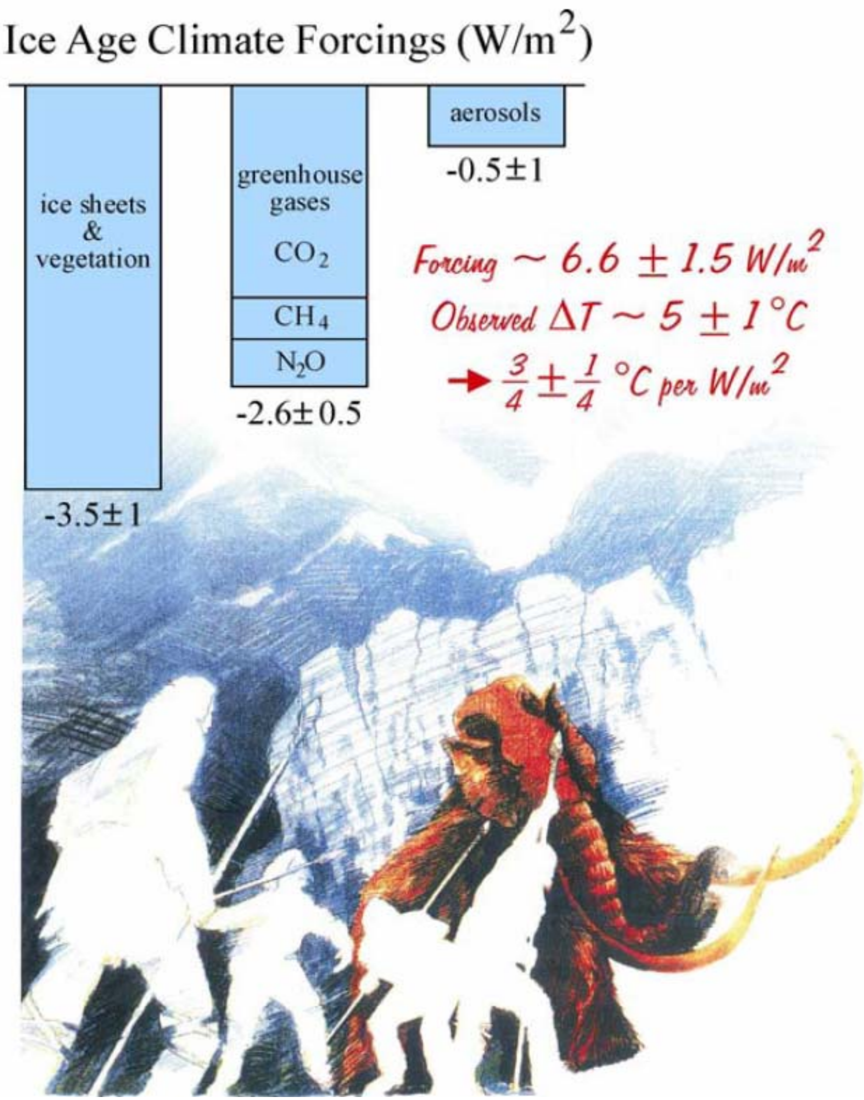


Courtesy: Myles Allen, Dave Frame

Open issues

- Every PDF of climate sensitivity is conditional on the model used.
- Laziness brings success... Simplifying the problem by neglecting sources of uncertainty leads to overly tight results.
- Back of the envelope calculations oversimplify the problem, and likely underestimate uncertainties.

Hansen et al., Natl. Geogr. Res. & Explor., 9, 141, 1993

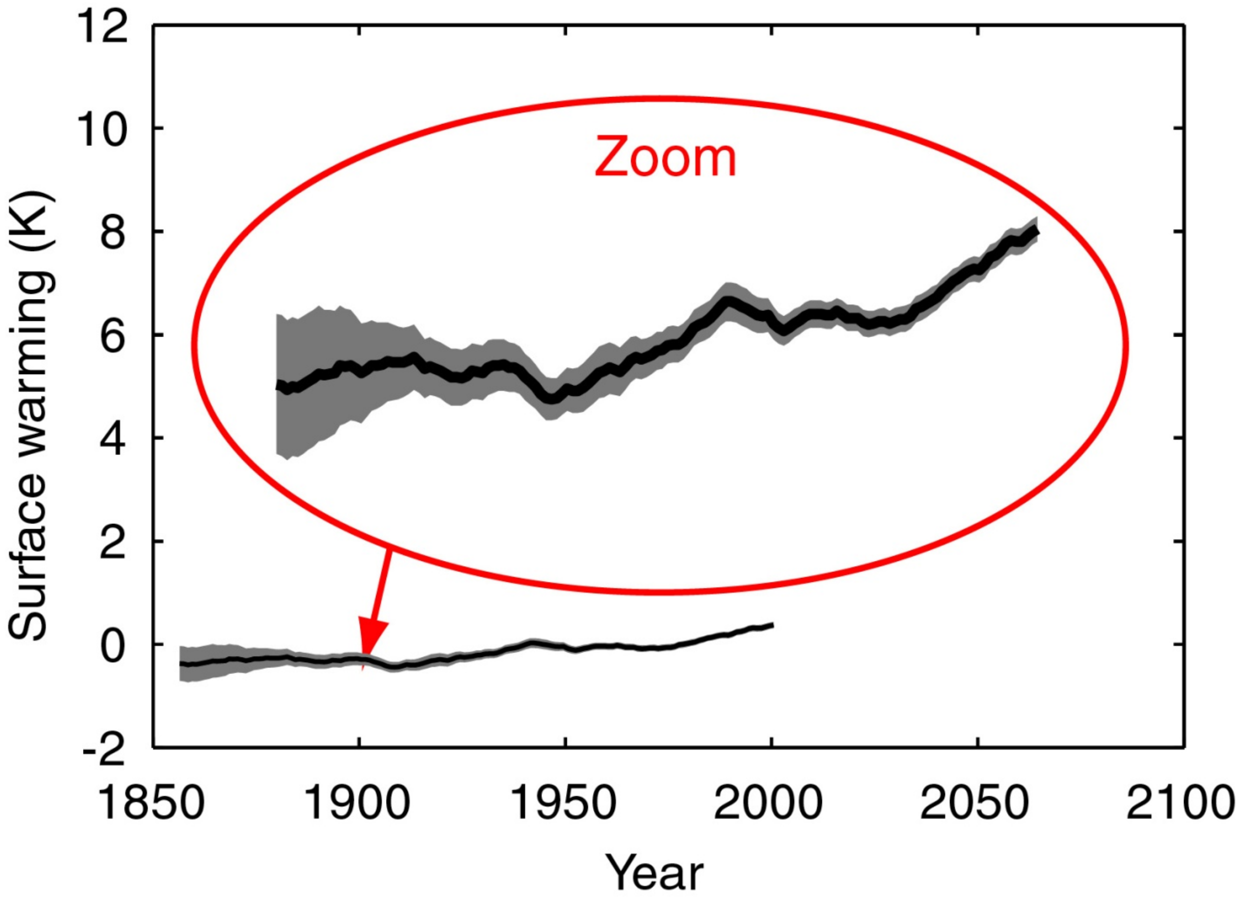


Conclusions

- Lower bound of climate sensitivity at about 1.5°C relatively robust, upper bound more uncertain. Most likely value near 3°C, supported by many lines of evidence.
- No positive evidence for high values. No inconsistent estimates.
- AOGCM climate sensitivity range almost unchanged for decades.
- Uncertainty has not really decreased, but confidence has increased.
- Arbitrariness in priors means there is no ‘true’ PDF.
- Combining multiple constraints should decrease the uncertainty.
- Structural uncertainties not considered in most studies could increase the uncertainty.

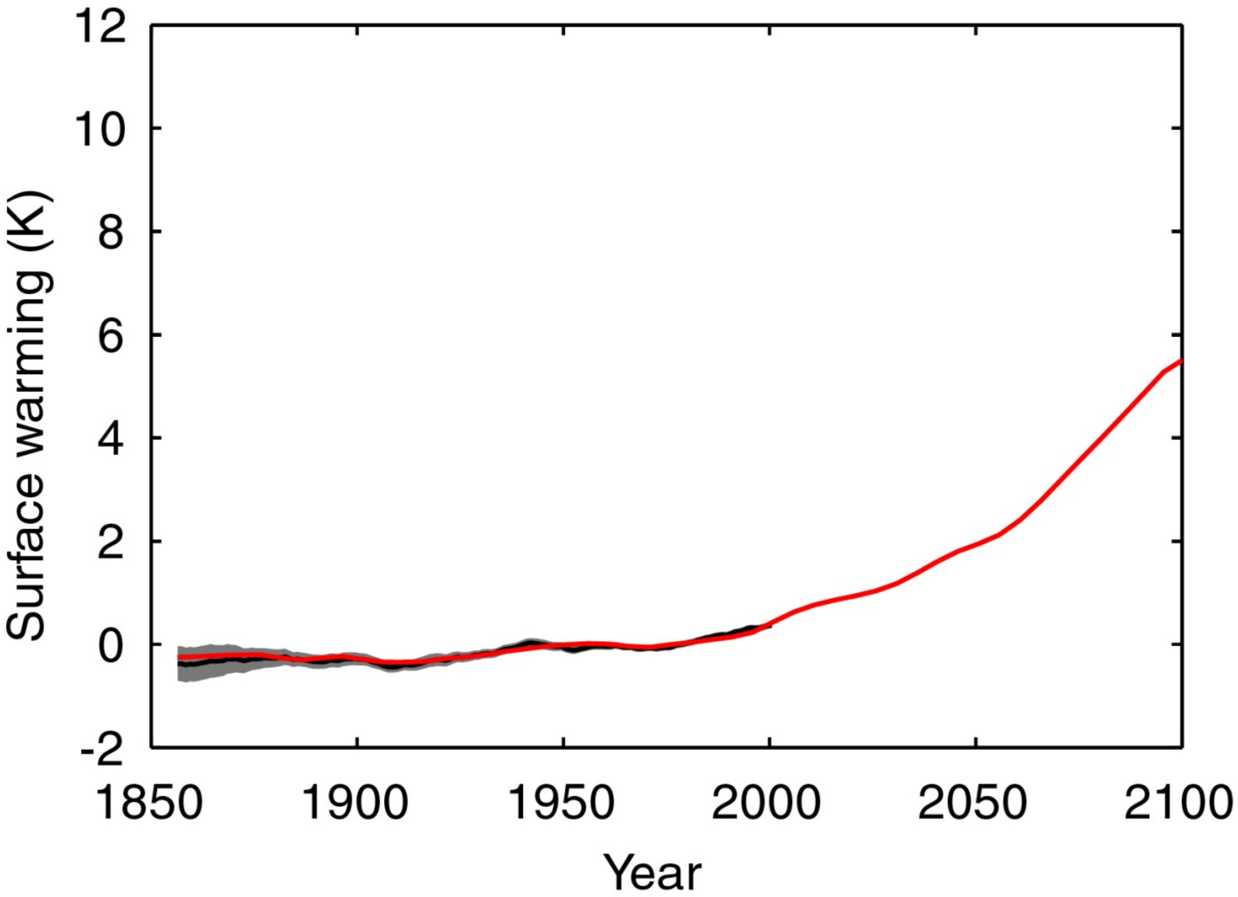
Uncertainty in transient projections

Observed warming



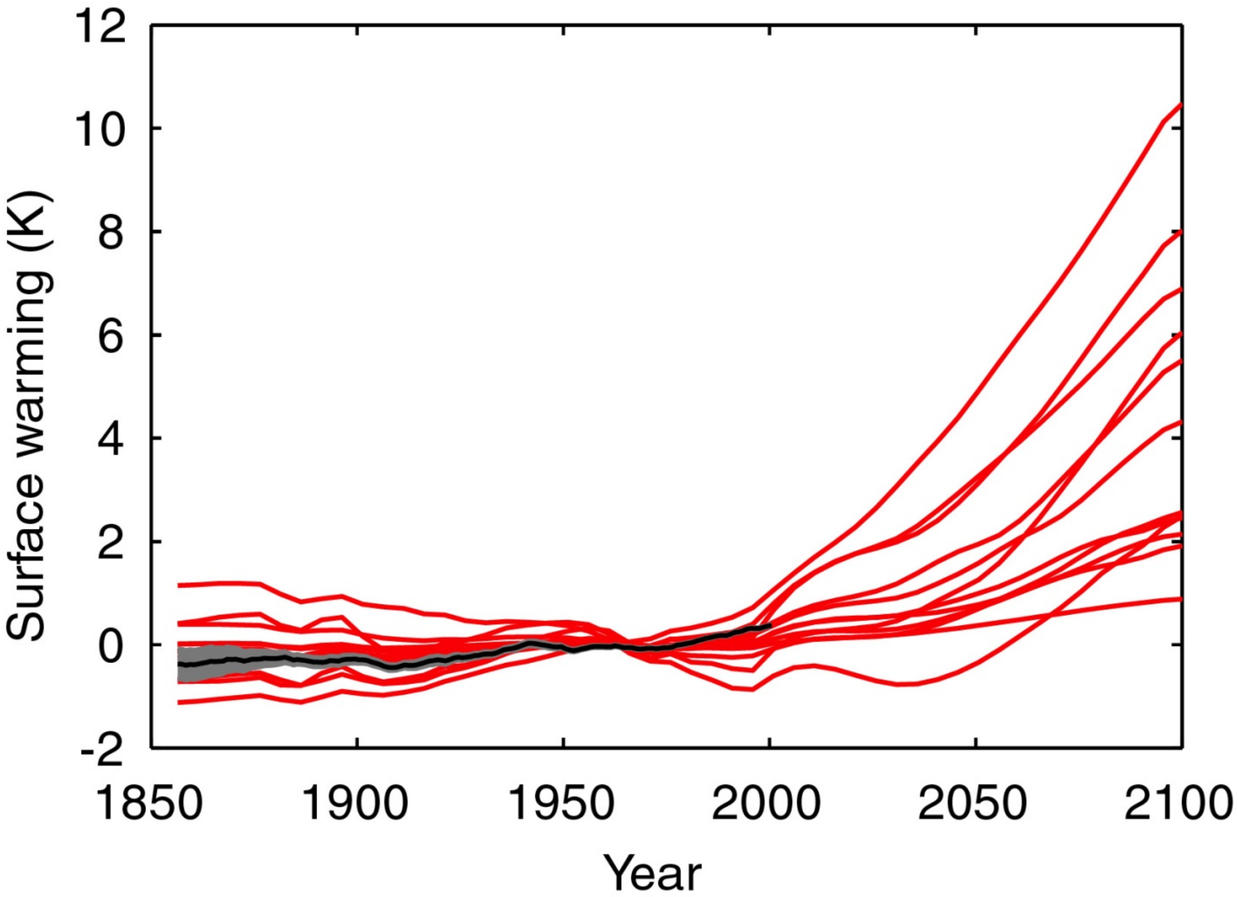
Uncertainty in transient projections

A single model…



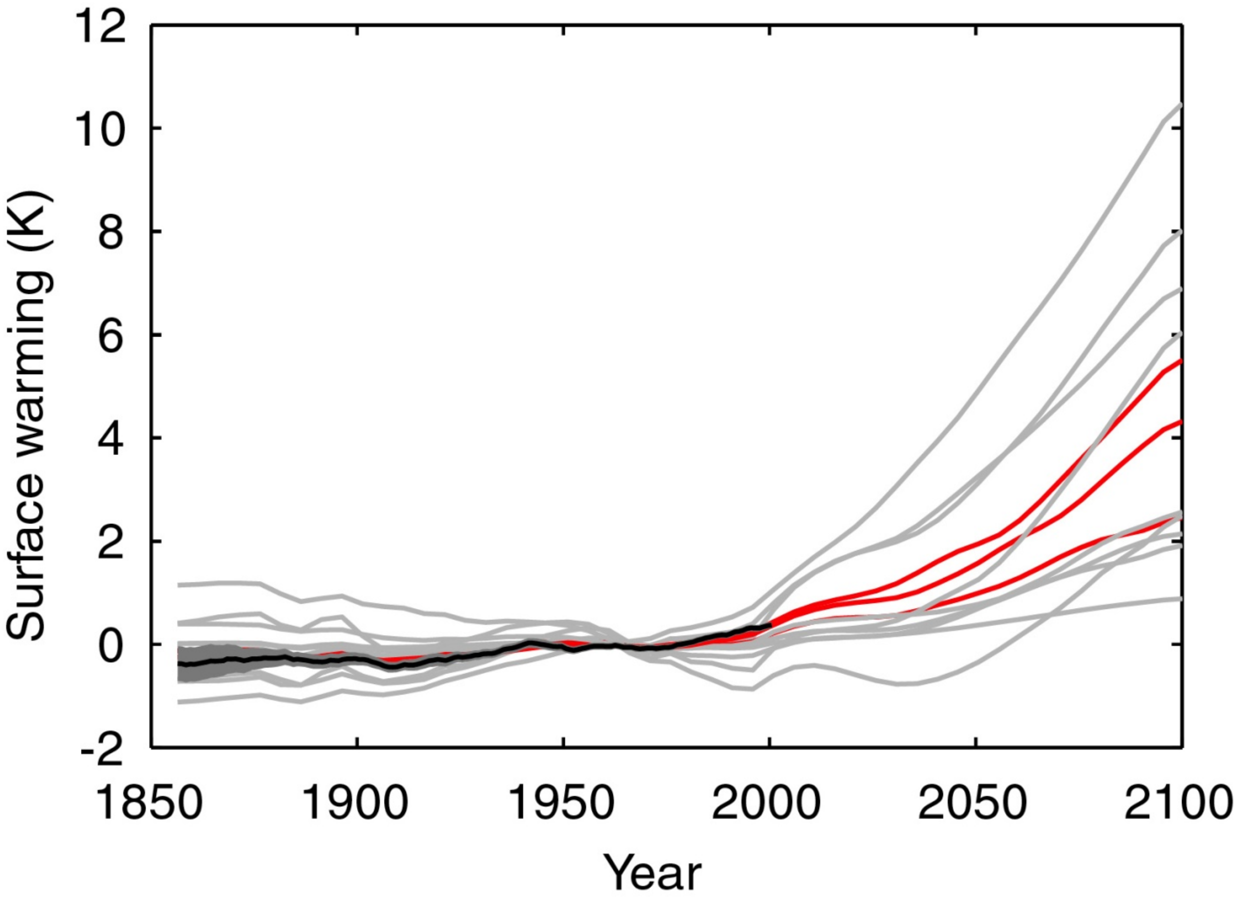
Uncertainty in transient projections

Many models…

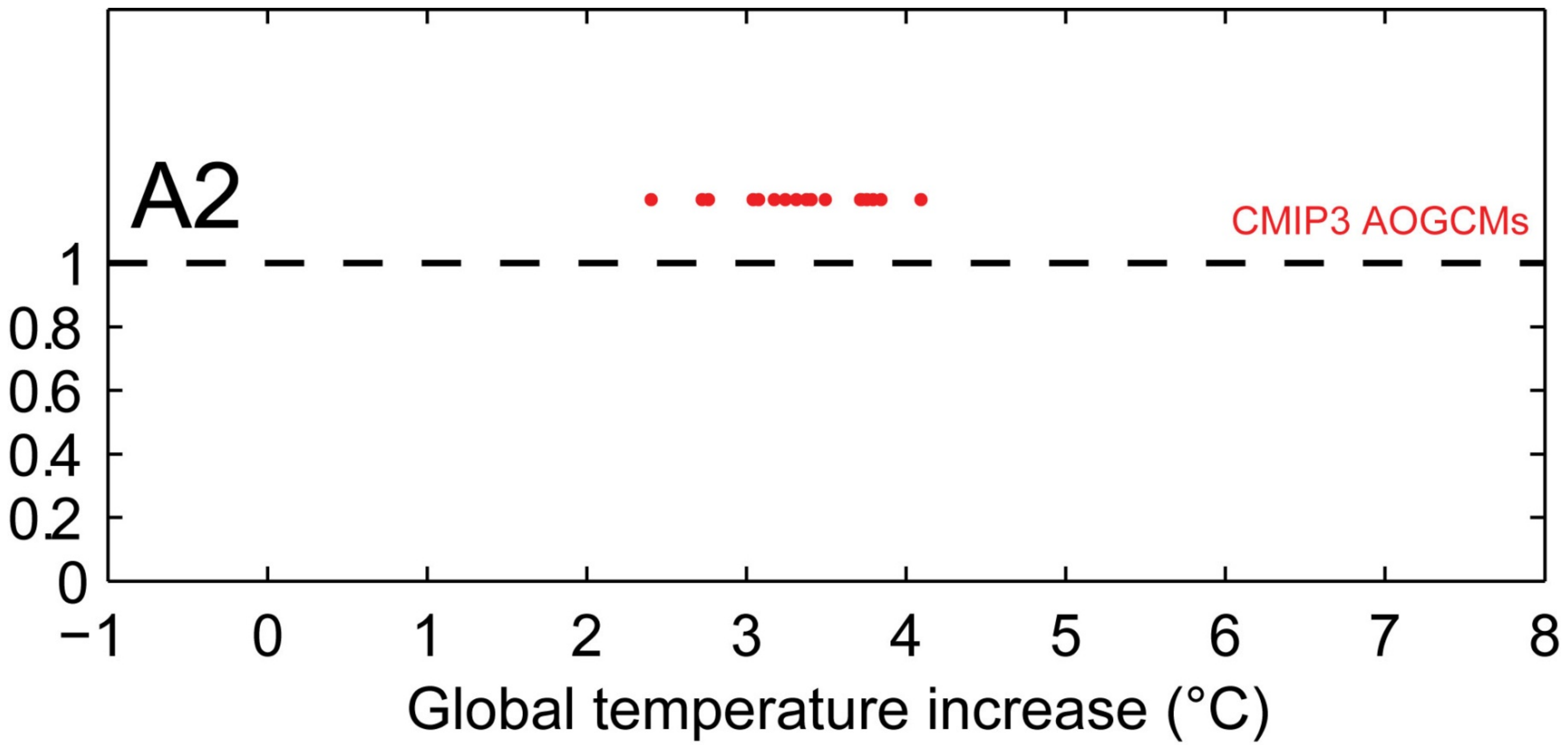


Uncertainty in transient projections

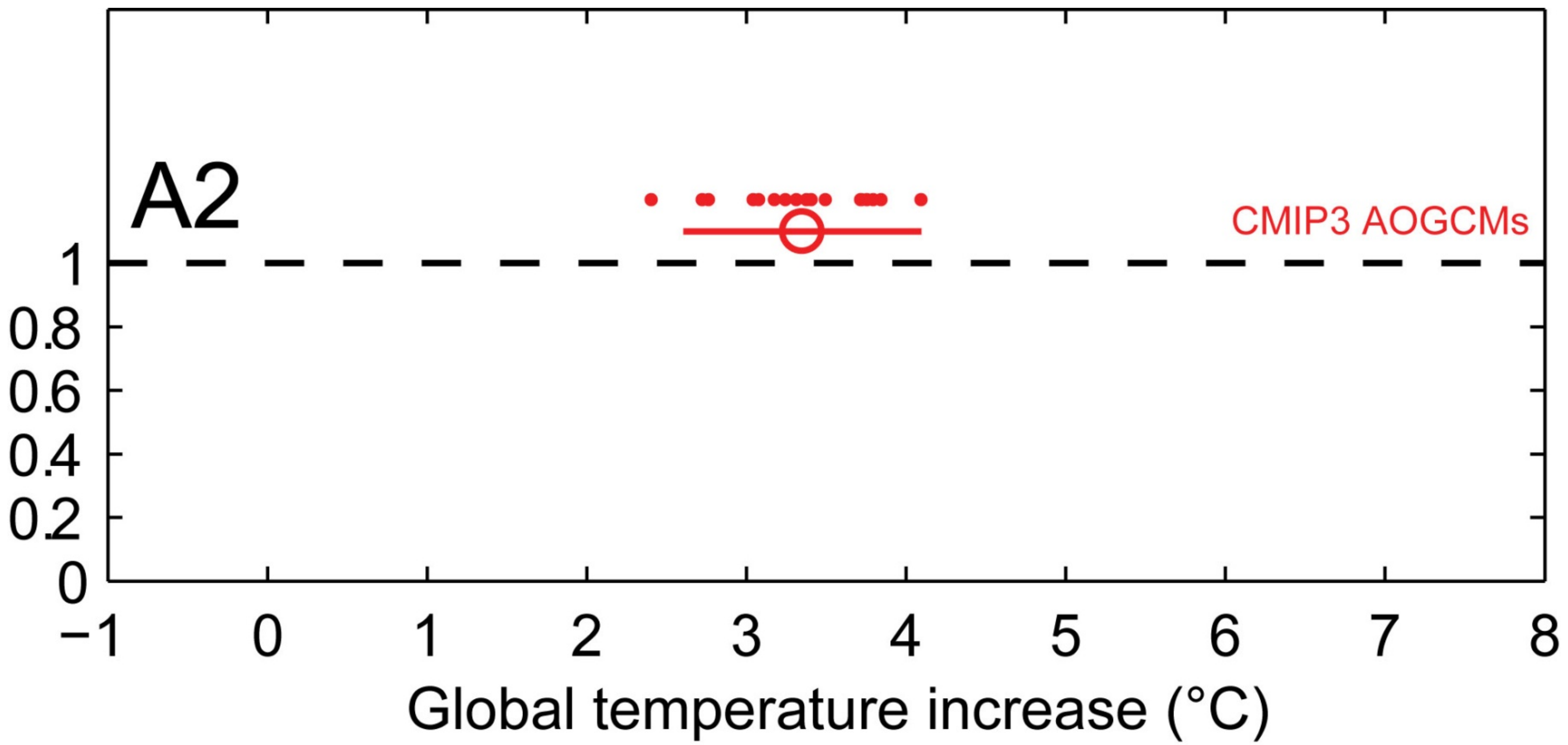
Select models which perform ‘well‘ on the past



SRES A2 2100 temperature uncertainty



SRES A2 2100 temperature uncertainty



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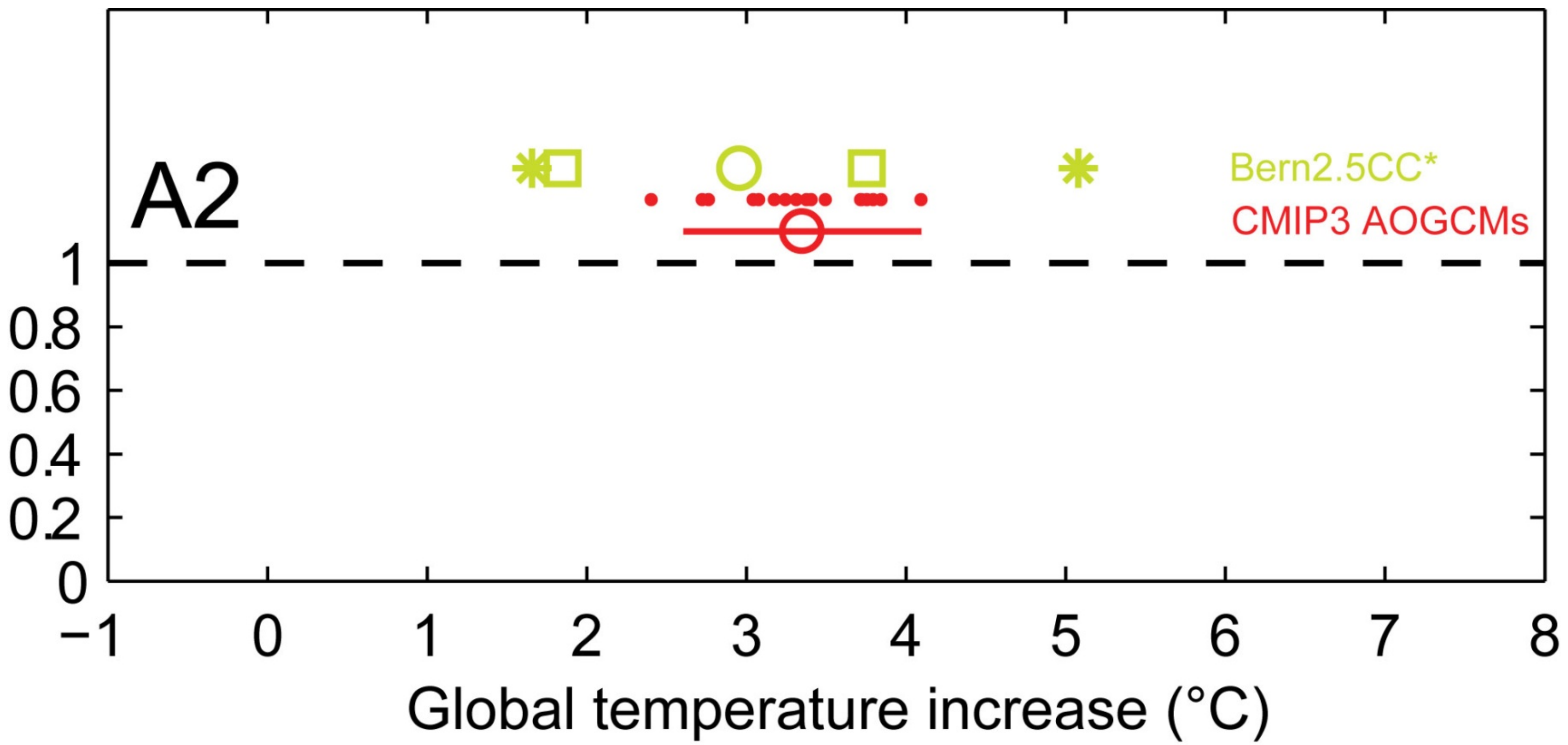

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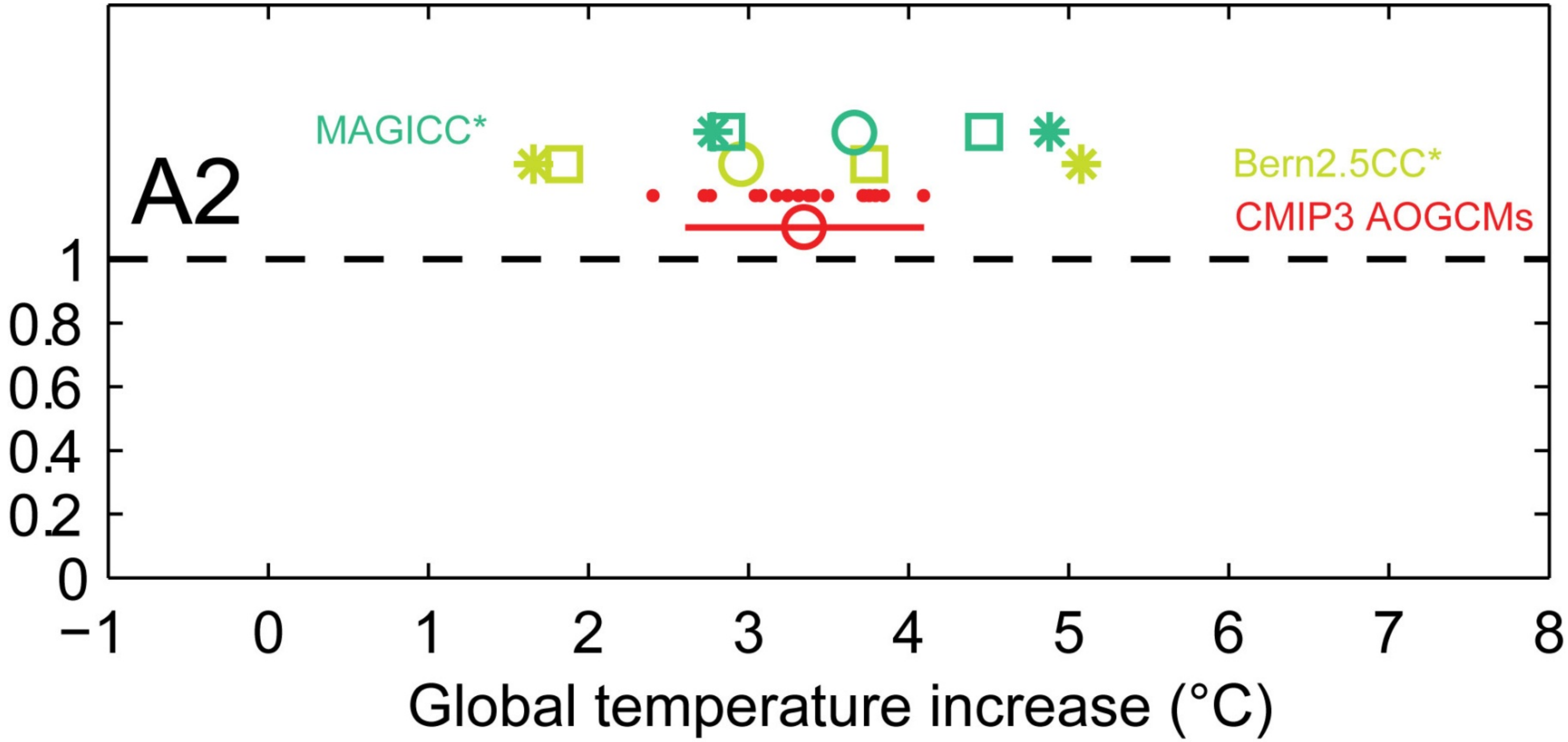

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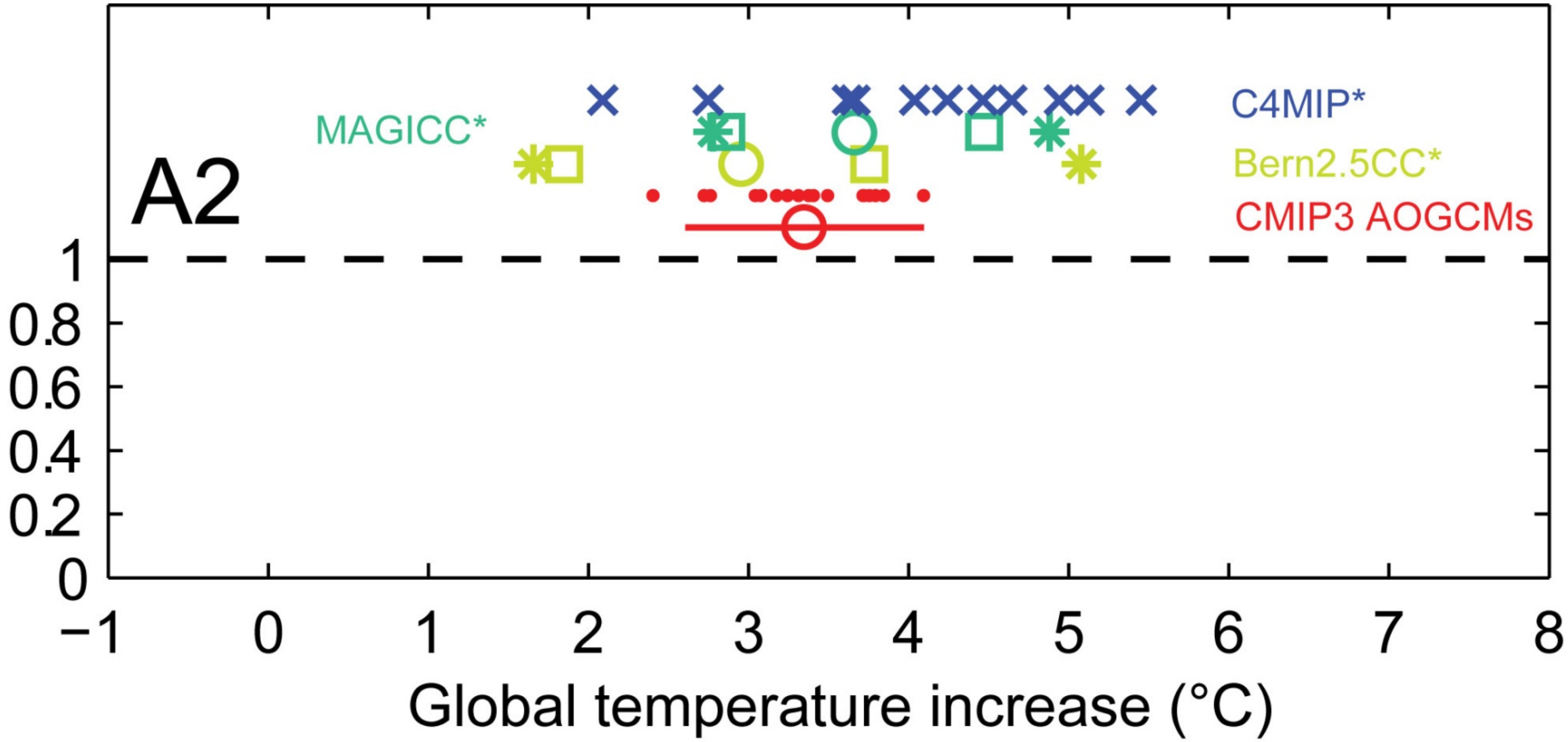

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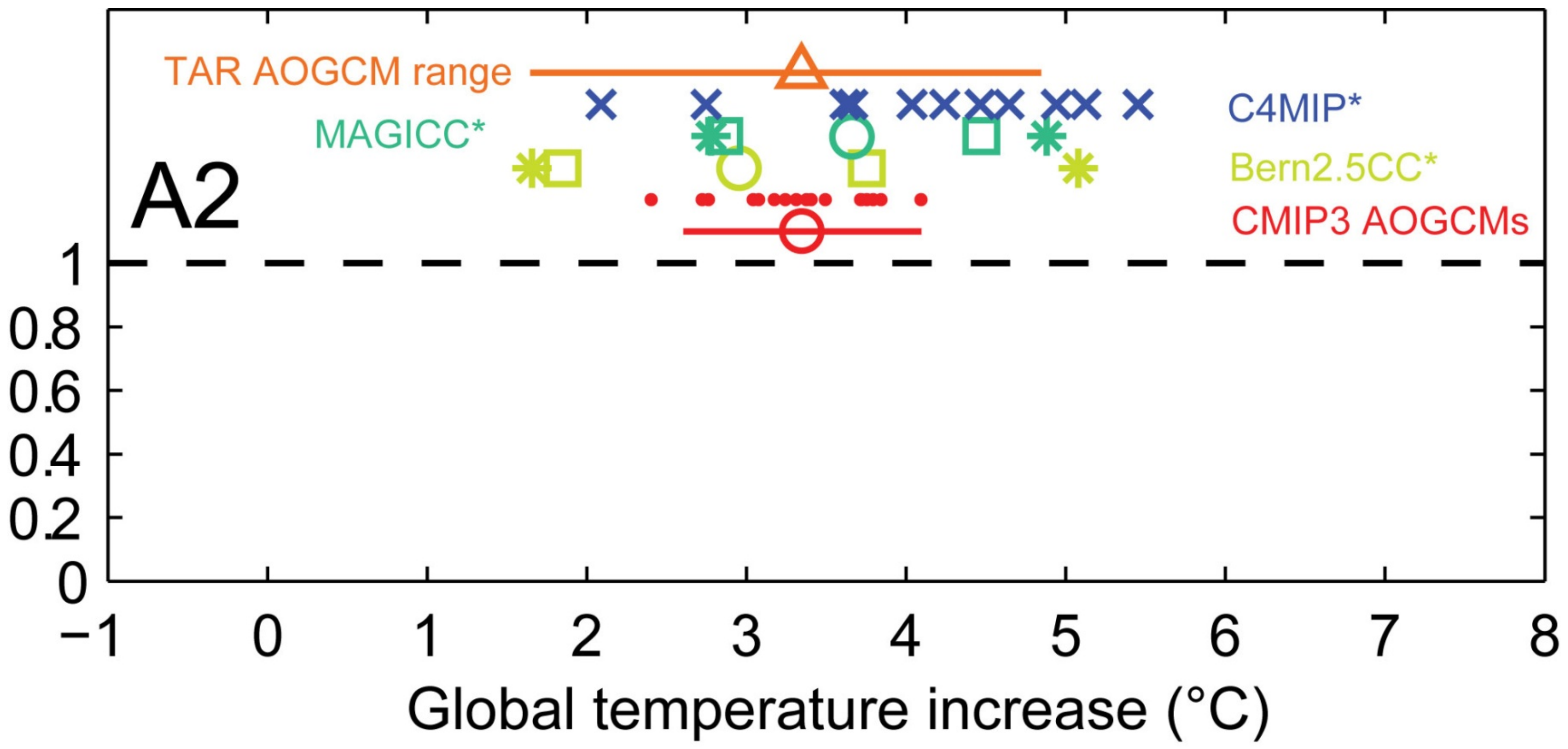

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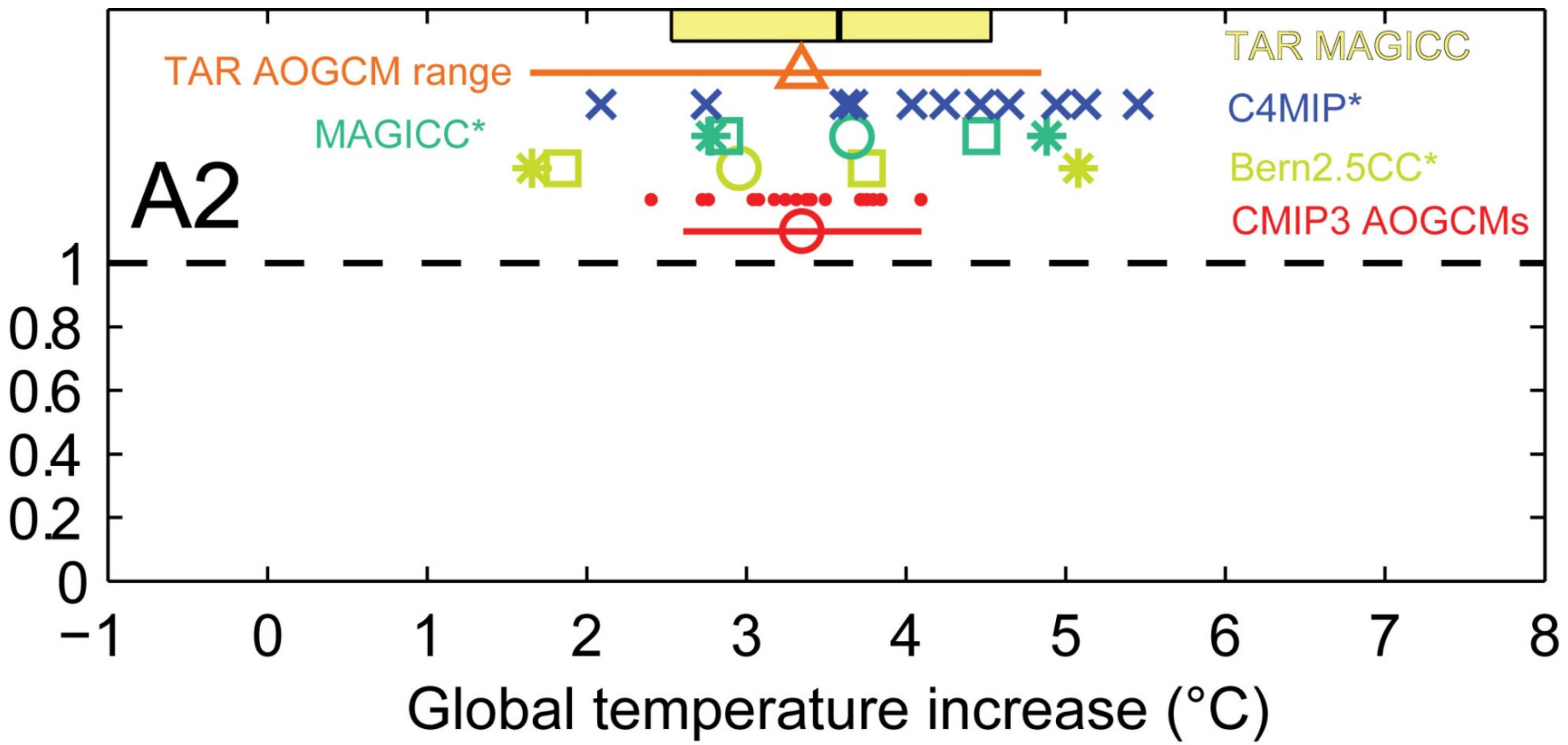

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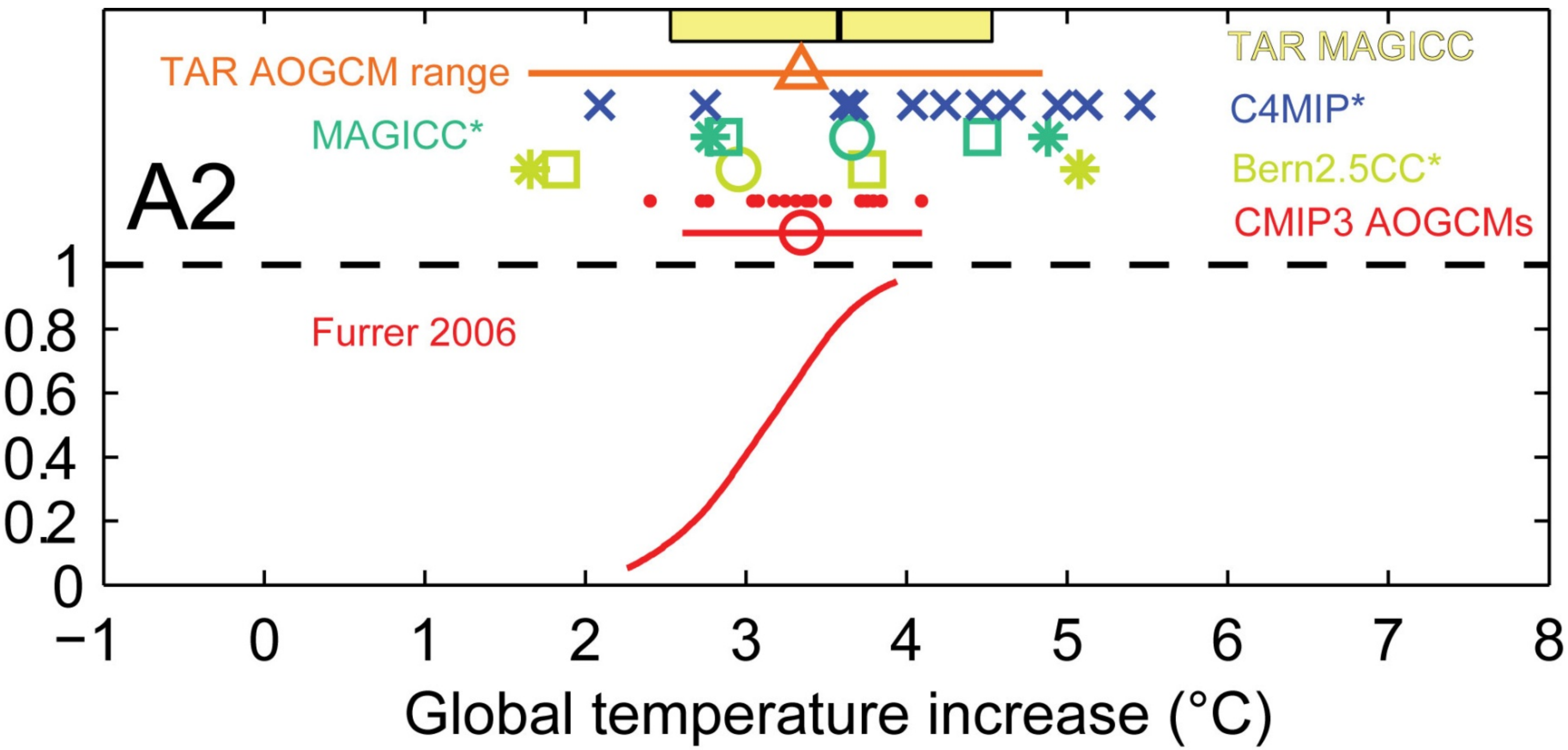

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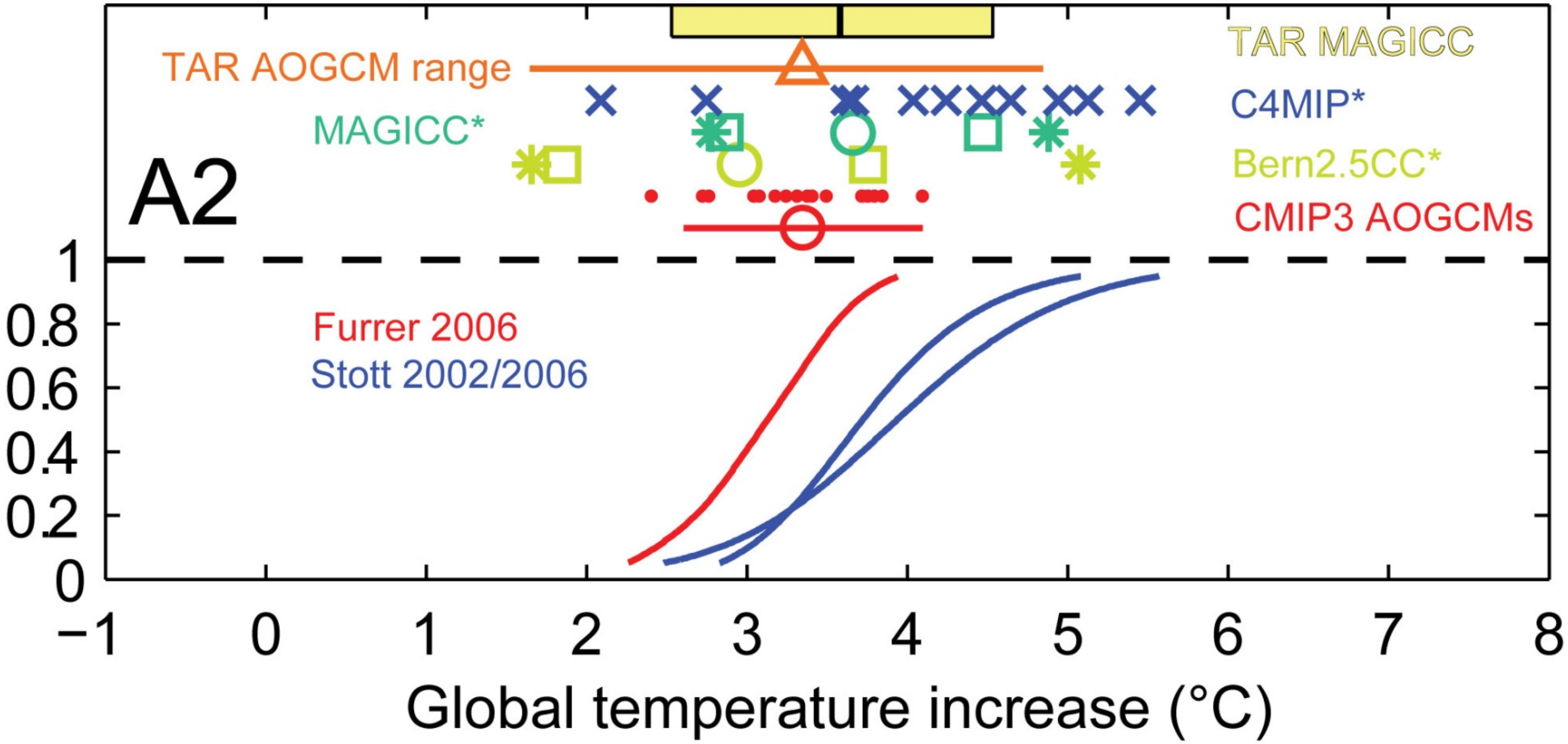

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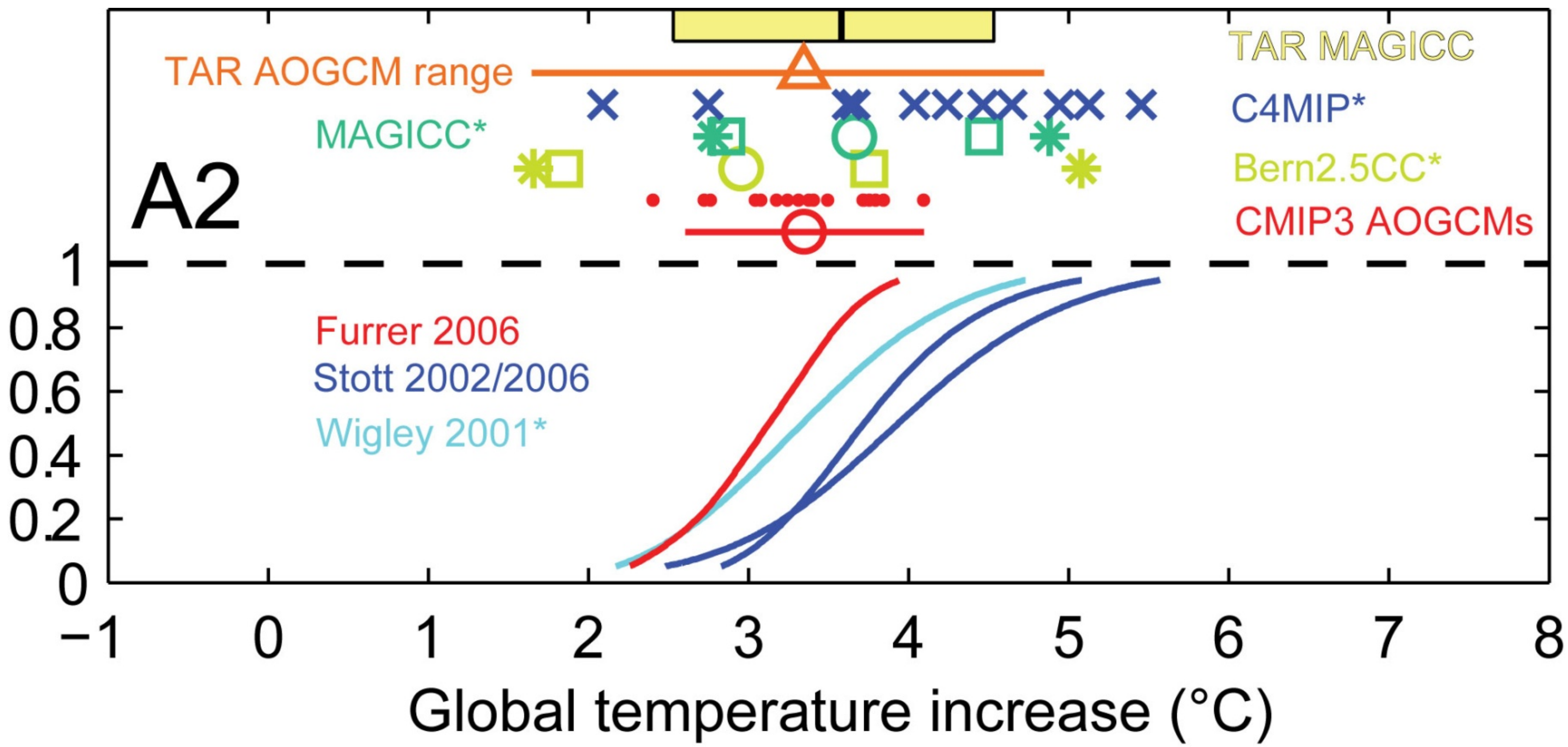
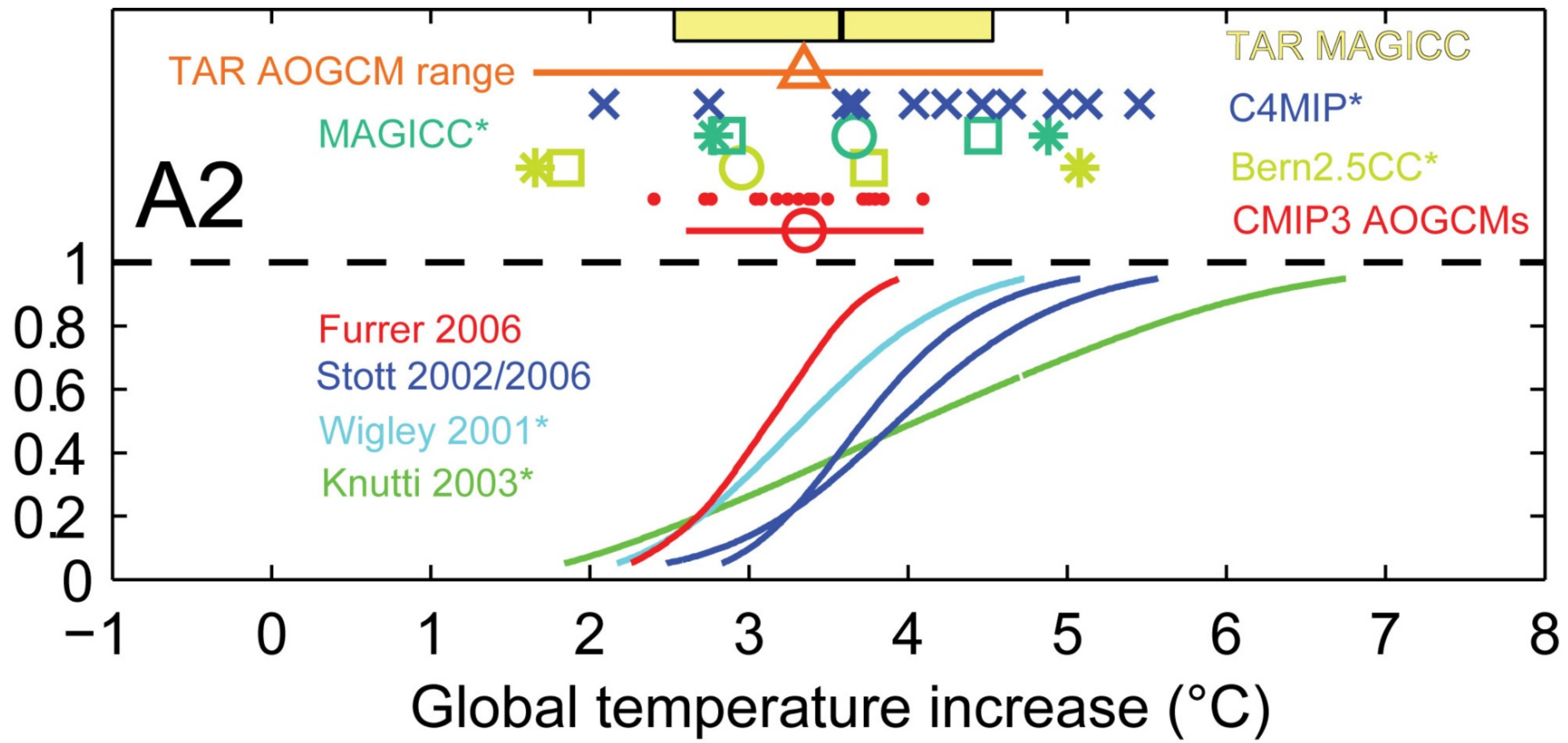


SRES A2 2100 temperature uncertainty

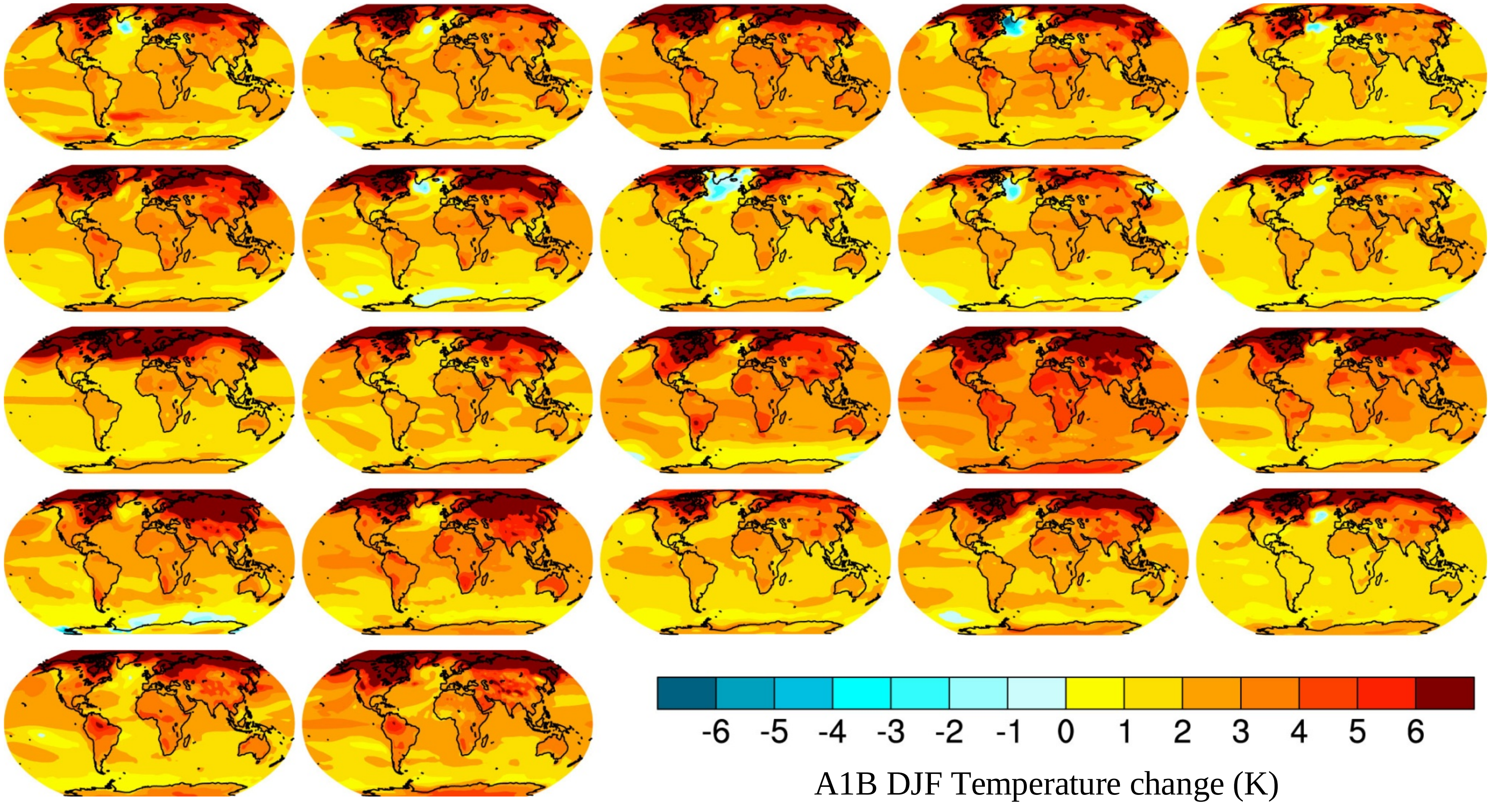


The ensemble of opportunity

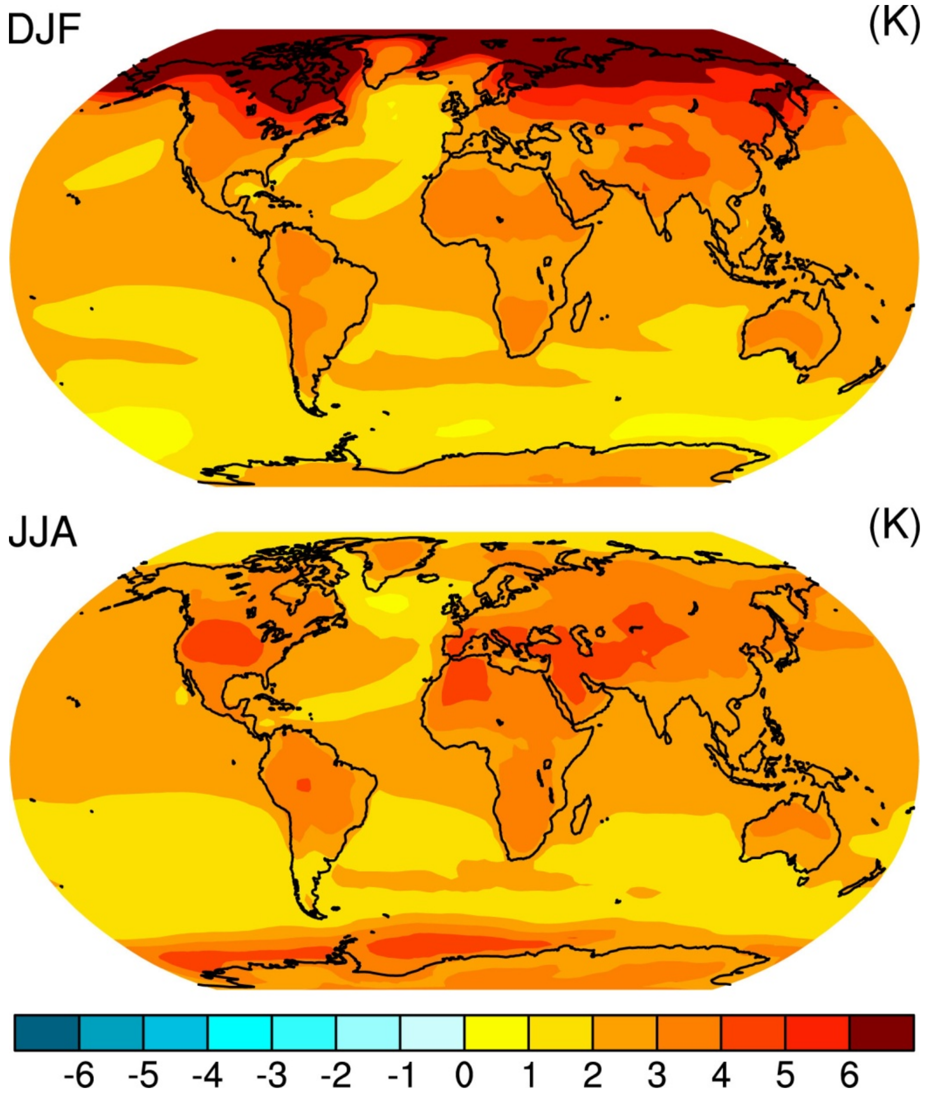
The CMIP3 archive used in IPCC AR4 is:

- An ensemble of opportunity
- Neither systematic nor random sampling, arbitrary prior.
- Not designed to span the full uncertainty range (e.g. sensitivity)
- It does sample structural uncertainty at least partly.
- The multi model mean often performs better than the individual models. But models share biases, are dependent, and not distributed around the truth.
- It is essentially a ‘collection of best guesses’ rather than a attempt to explore extremes, and therefore more likely underestimates rather than overestimates the uncertainty in projections.
- Yet, in terms of GCMs, it’s pretty much all we have…

Which is the best model?

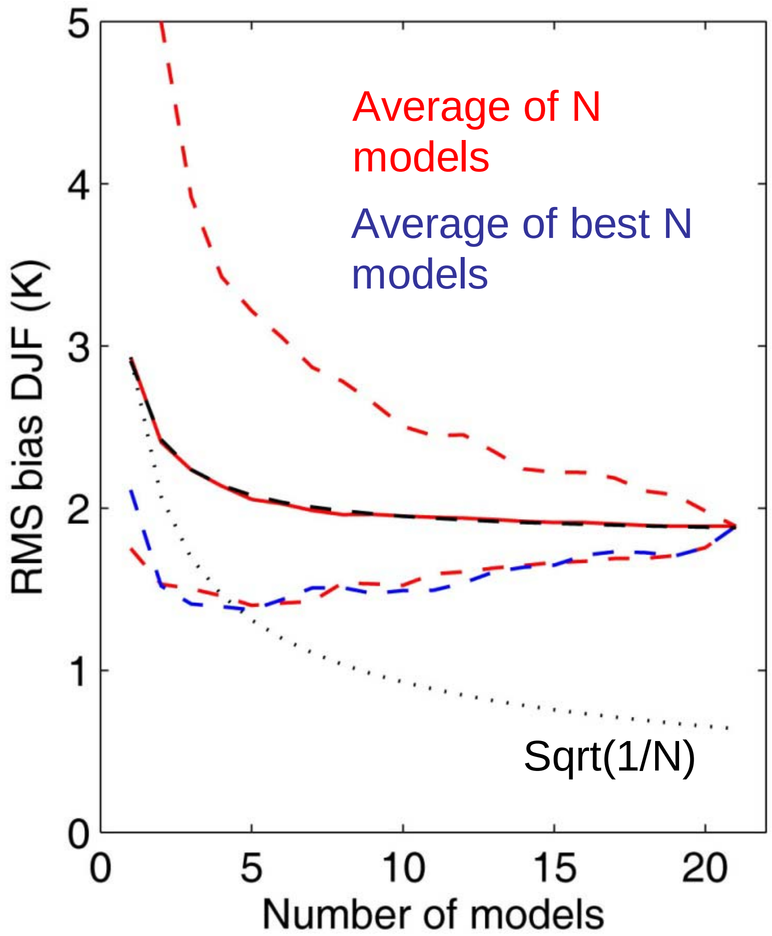


Warming in 2100 for SRES A1B



- The multimodel average is often used to summarize results, also in IPCC.
- There is an implicit or explicit assumption that errors compensate.

Error compensation for the present day climate



- The multi model mean is better than any individual model
- A large fraction of the error remains even for a large number of models of the same quality.

How does a passenger jet look like?

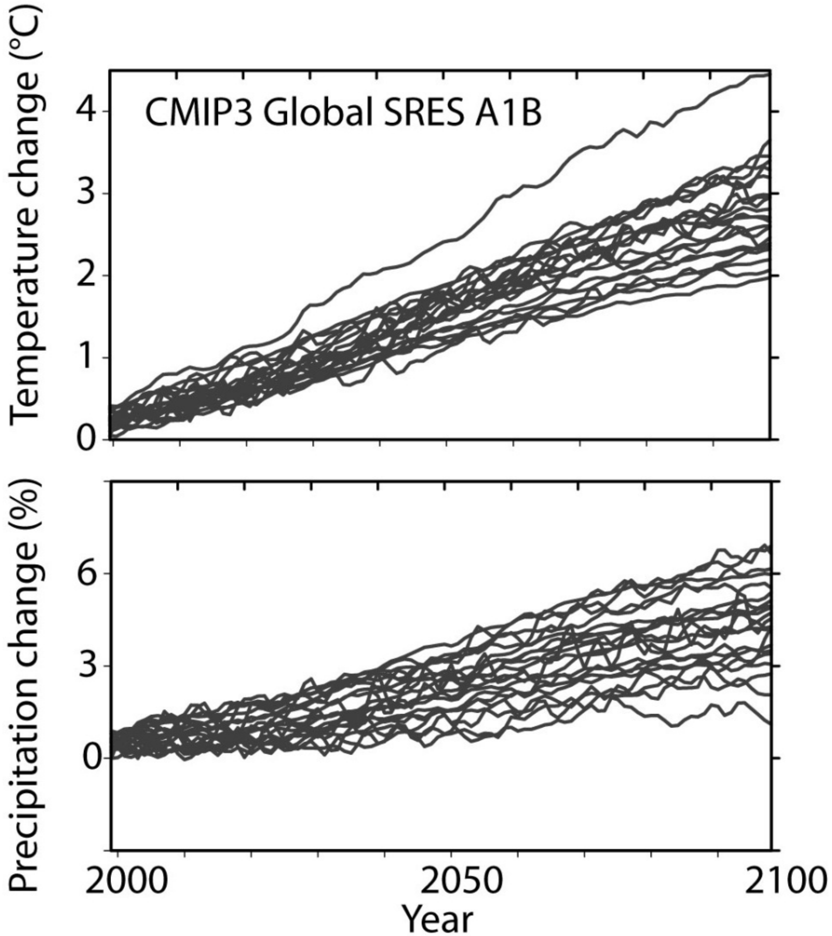
How does a passenger jet look like?

The average jet:

How does a passenger jet look like?

- Is the mean useful?
- Not independent
- Better and worse information
- Does the selection reflect the uncertainty we think exists?

Which is the best model?



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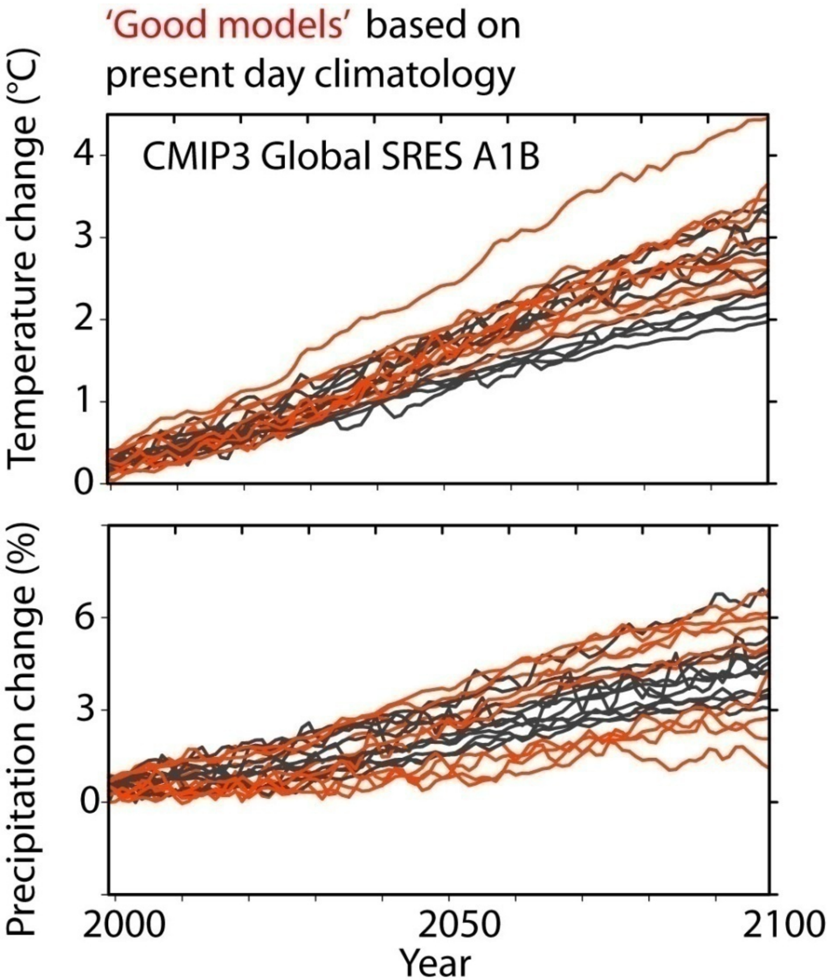
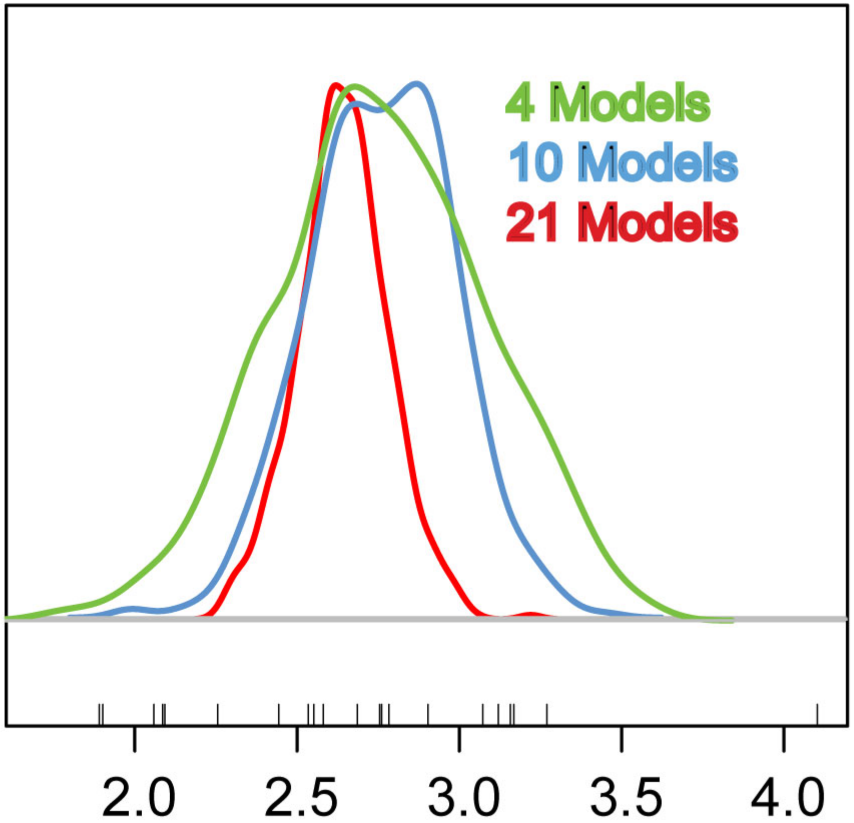


- Models agree better and better with observations, but uncertainties in projections have not decreased.
- We cannot verify the models on the projections we make, but only test them indirectly.

What do we learn from more models?

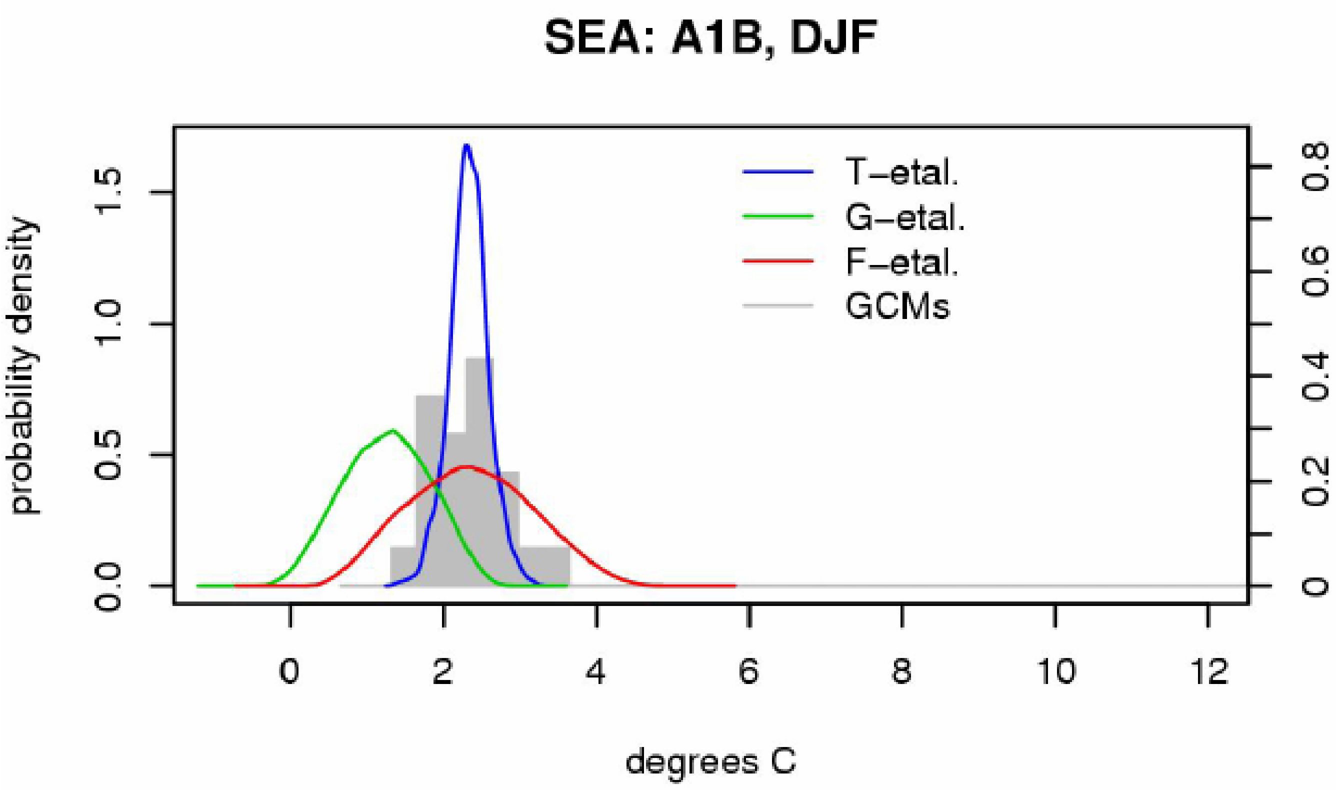
PDF of global temperature increase (°C)
2080-99 relative to 1980-99, DJF, SRES A1B
following Furrer et al. (2006)



The assumption of model independence implies that the uncertainty in our projection decreases as more models are added.

Regional probabilistic projections

- Very different results, depending on the method.
- How do we account for structural uncertainty?



Conclusions

- The IPCC AR4 multi model ensemble of opportunity is neither systematic nor random sampling, arbitrary prior.
- It is not designed to span the full uncertainty range (e.g. sensitivity)
- Model performance varies. The multi model mean often performs better than the individual models. But models share biases, are dependent, and not distributed around the truth.
- Good performance on present day climate is necessary for a model to be credible, but not sufficient to guarantee reliable projections.
- Uncertainty in temperature projections has not really decreased, but confidence has increased. Accounting for structural uncertainty is a problem.
- Uncertainty does not question climate change, nor does it justify delay.

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Using the CMIP3 archive and publishing results

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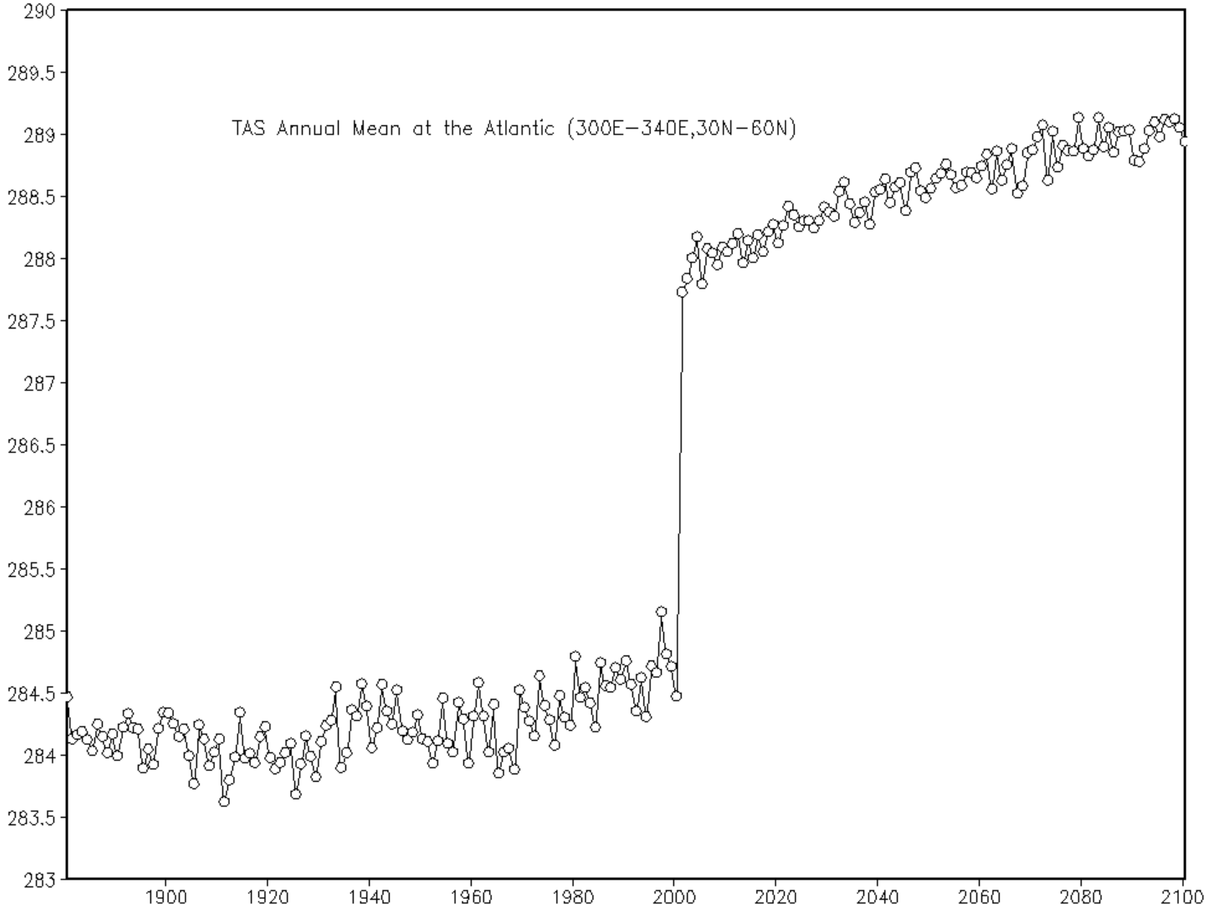
- It is essentially a ‘collection of best guesses’ rather than a attempt to explore extremes, and therefore more likely underestimates rather than overestimates the uncertainty in projections.

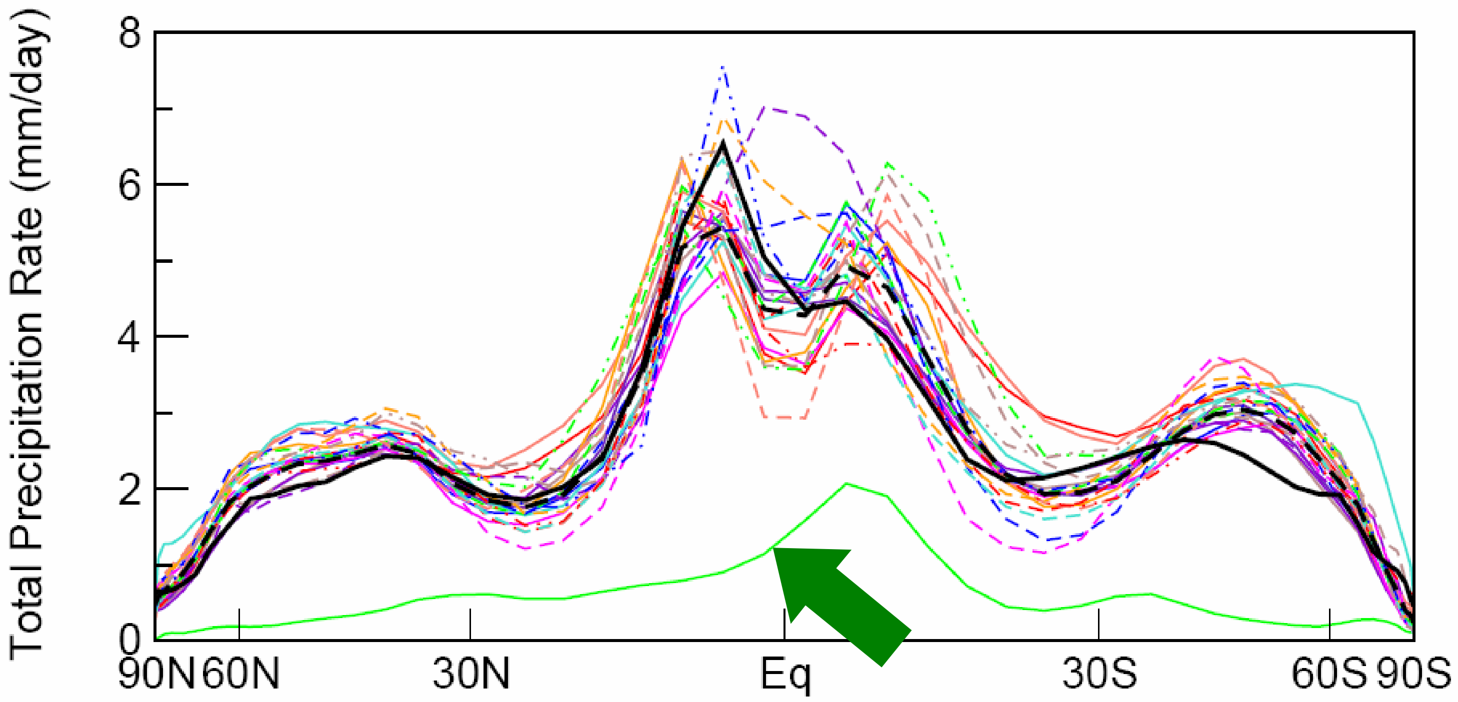
Important points when using CMIP3

- Look at the models carefully, there may be problems in the data
- Consider removing to remove control model drift (how?)
- Model branching dates can be tricky to find out
- Ensembles: use one per model, or all?
- Model resolution varies. Some interpolation schemes produce unphysical results for bounded variables (e.g. negative precipitation).
- Many models used special grids in the ocean (displaced poles, etc.). Be careful e.g. when looking at transports.
- Models are not independent, e.g. there are two CCMA (T47, T63) models, two from GFDL, three from GISS…
- Model performance varies

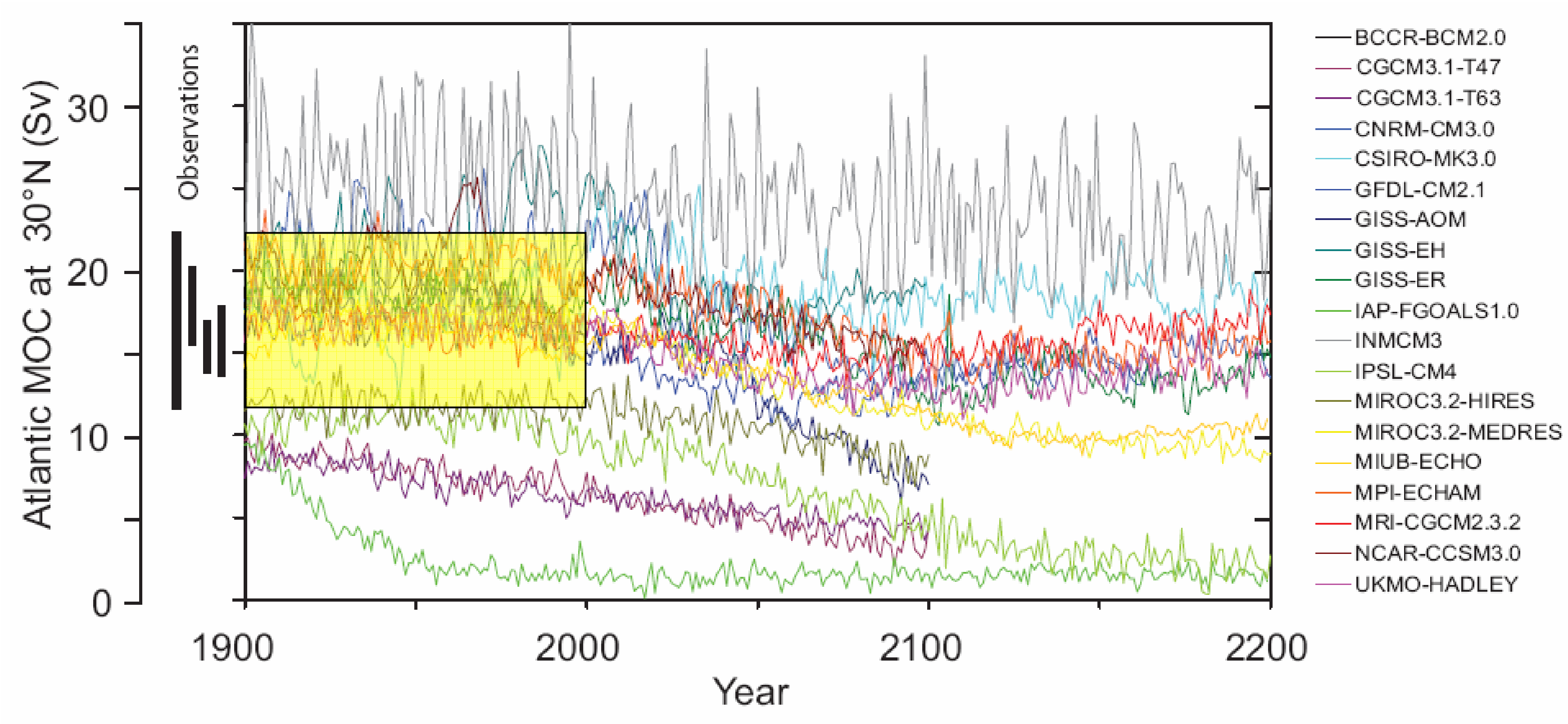
Data problems….



How to select and combine models



How to select and combine models



Important points when using CMIP3

- Eight dimensions are a problem: x,y,z,t,model,ensemble,variable,scenario
- Think about your question first. More data and more models do not necessarily help. Consider selecting a subset. All models are wrong, but some are useful…
- The fact that all that data is easily available does not mean that you don‘t have to understand what you are doing. Talk to the model developers if something looks strange. They don‘t like their model being misrepresented.
- Check what has been done before. There are hundreds of papers on CMIP3. Talk to the people who have done similar work. They may have a better feeling for the data, or may have thought further than what is published.
- Acknowledge model contributions and the efforts by PCMDI. List papers on PCMDI. Read errata pages. The archive changes.

Publish or perish…

- Publications are important, but poor papers won't get you far.
- Talk to experienced people if you are not familiar with the interpretation of model results.
- Study the literature first. What has been done? What is new?
- Select the appropriate journal.
- A good presentation of the results is as important as the results themselves. Make your case clear, create a flow of arguments that is logical and easy to understand, highlight what is new and interesting.
- There is no excuse for poor English. There are many native speakers who can help.
- Know your audience. Know your 'enemy', and discuss caveats.
- Keep it short and to the point if you can.