Formalizing Uncertainty About Climate Feedbacks

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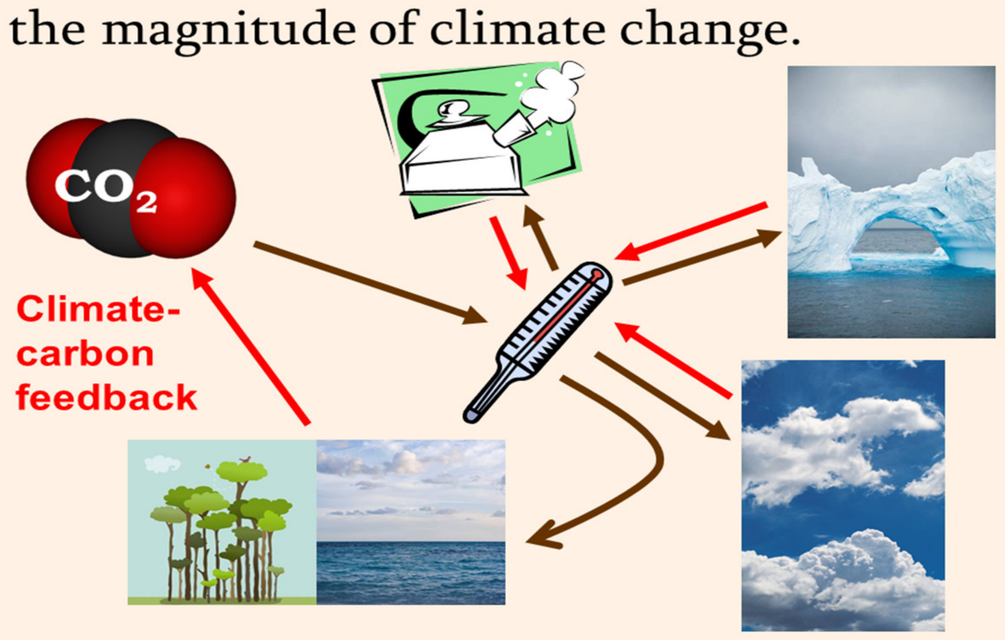
"Climate sensitivity distributions depend on the possibility that models share biases" (J. of Climate, 2010)

Several types of feedbacks determine the magnitude of climate change.



Temperature change is a nonlinear function of non-dimensional feedback factors.

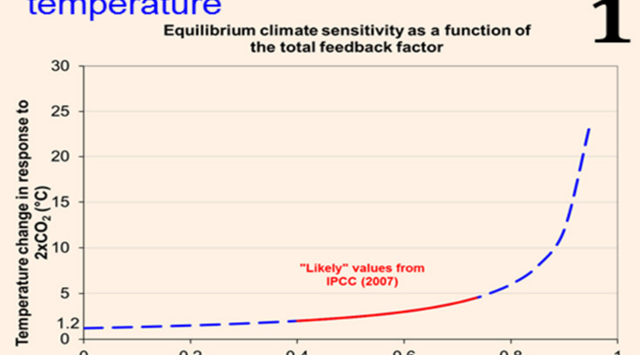
$$\Delta T = \lambda \frac{\Delta R}{1 - \sum f_i}$$

Change in equilibrium temperature

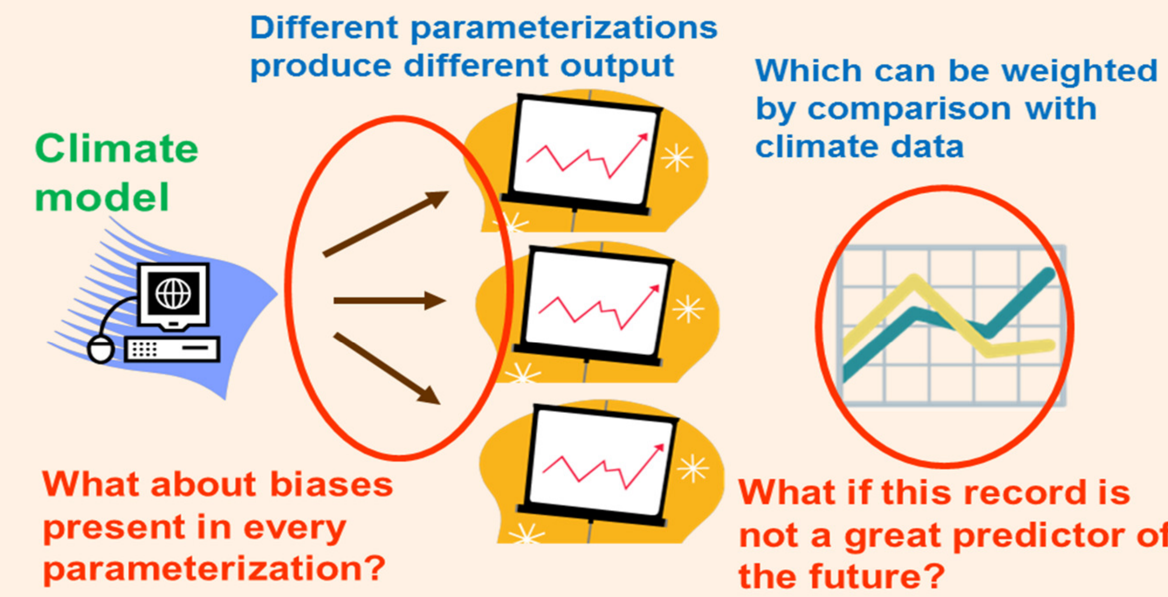
Sensitivity in radiative forcing in absence of feedbacks: 0.32 K/(W/m^2)

Change in radiative forcing due to doubling CO_2: 4 W/m^2

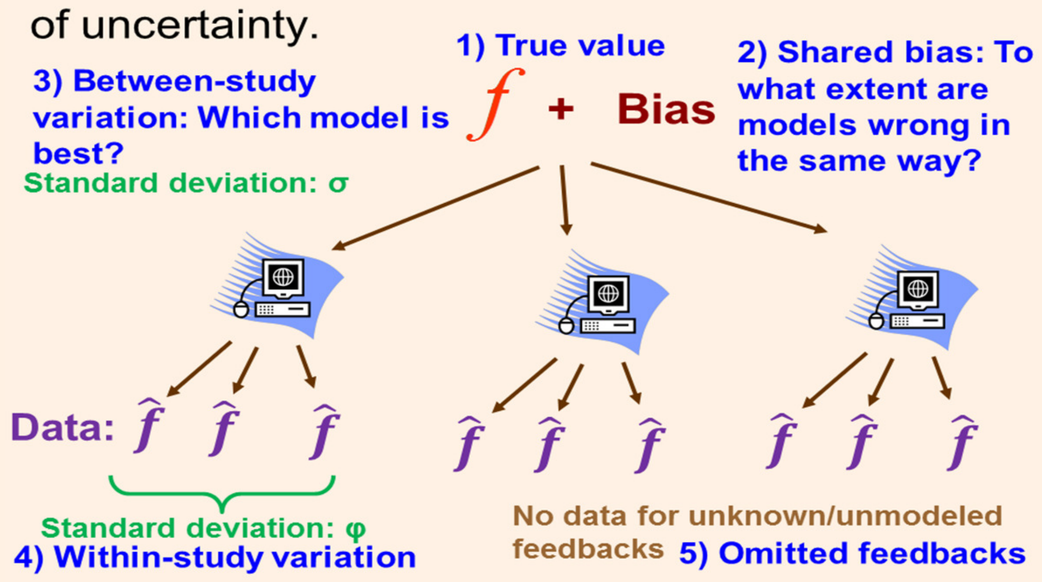
When positive, fraction of ultimate temperature change due to feedback process i

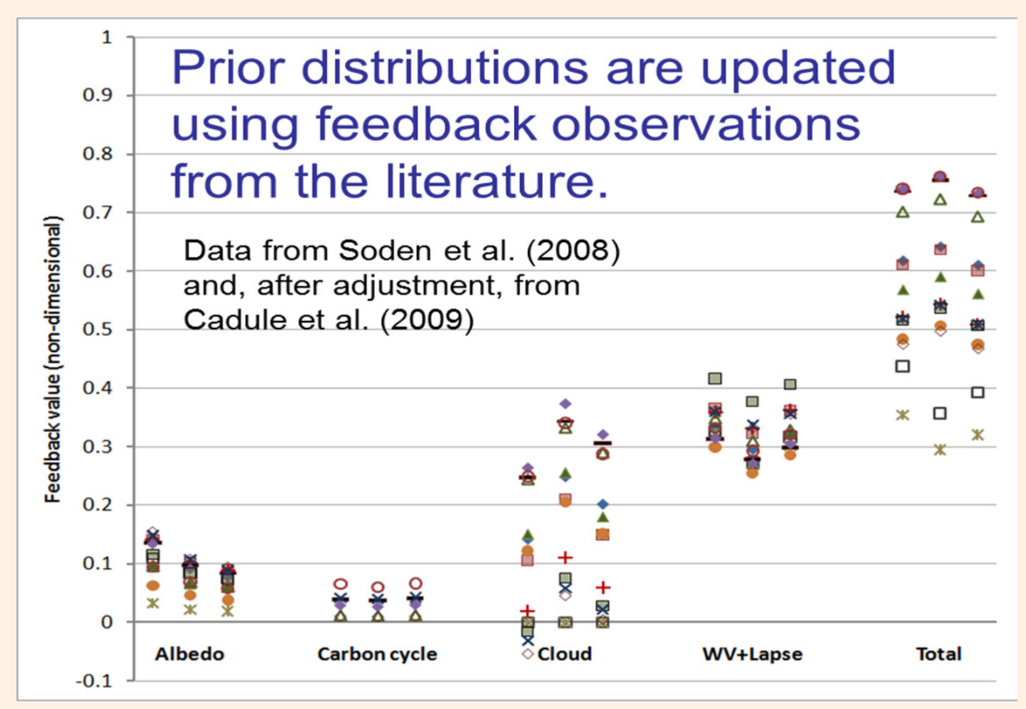


The methods used to produce a best guess are not necessarily the methods that best estimate the probability of less likely outcomes.

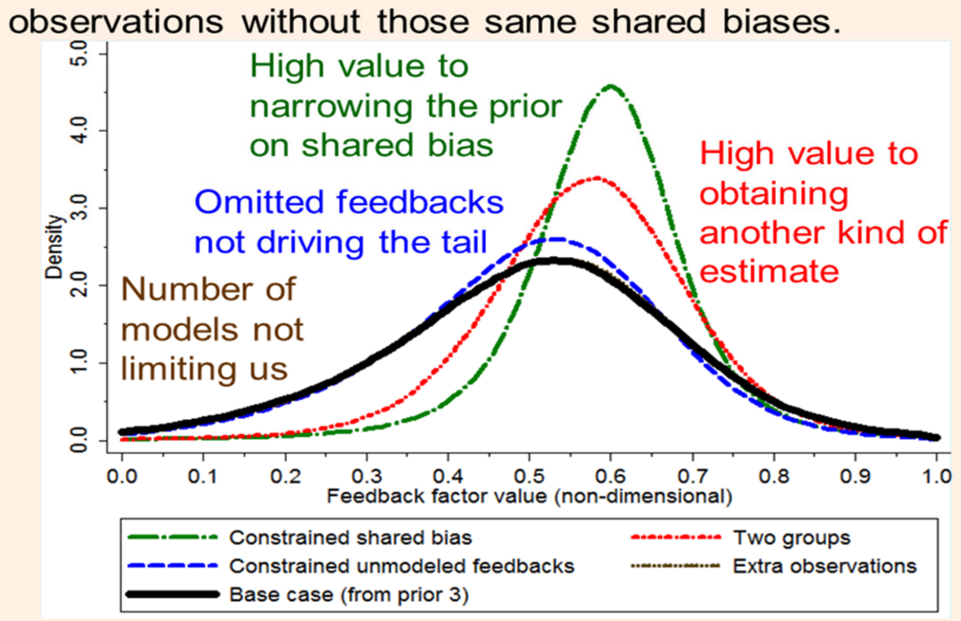


Hierarchical methods have different levels of parameters, which separates several sources of uncertainty.



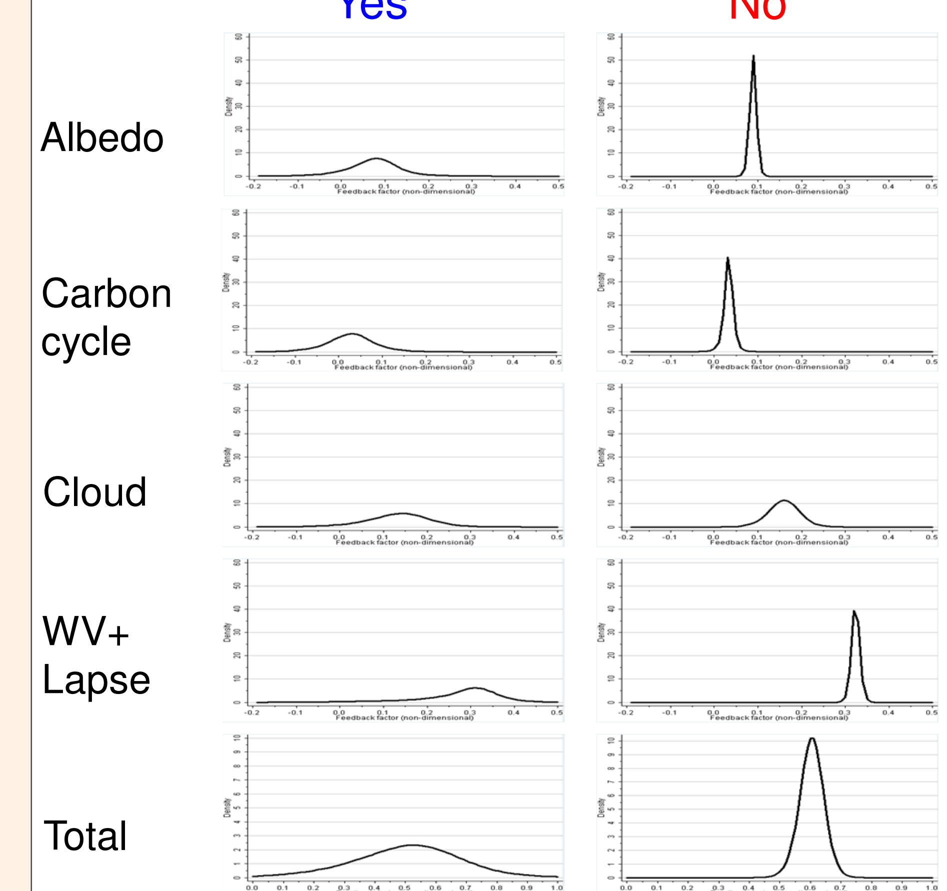


Learning experiments:
We can most effectively constrain the distributions by reducing the possibility of shared bias or by obtaining a set of observations without those same shared biases.

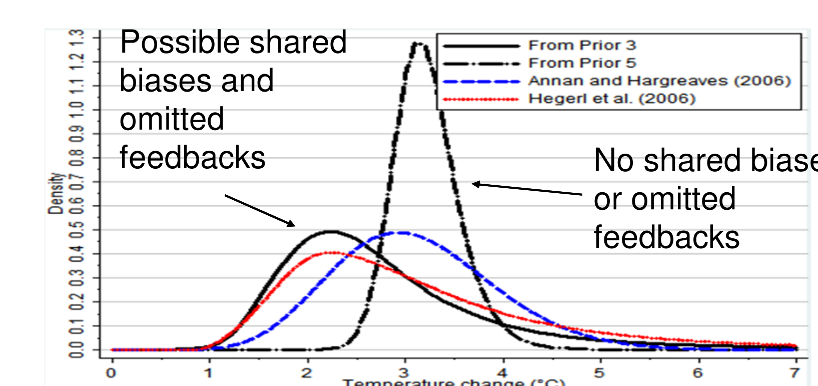


Results: Posterior distributions

Priors allow the possibility of shared biases and omitted feedbacks?



Allowing possible shared biases moves some probability mass to lower values for climate sensitivity while also thickening the positive tail.



Conclusions: Feedback probability

- Posterior distributions for feedbacks and climate sensitivity are especially sensitive to prior beliefs about models' shared structural biases.
- These posterior distributions are best constrained by narrowing prior beliefs about shared biases or by obtaining estimates with uncorrelated biases.
- The hierarchical Bayes framework provides a means of updating beliefs as new models and techniques for validating them become available.
- Possible refinements:
  a) Method for estimating how connected models may be
  b) How to use (and optimize) information that is not a model's best guess

"Paleoclimatic warming increased carbon dioxide concentrations" (J. of Geophysical Research, 2010)

How can we isolate the causal effect of warming on carbon dioxide?

- Coupled climate-carbon cycle models
  - Friedlingstein et al. (2003,2006), Cadule et al. (2009)
  - Because models share biases, it is important to obtain a different type of estimate.
- Paleoclimatic data
  - Scheffer et al. (2006), Torn and Harte (2006), Cox and Jones (2008), Frank et al. (2010)
  - Assumptions underlying univariate Ordinary Least Squares probably bias previous results upwards.

If we can estimate the effect of temperature on CO_2, we can calculate the strength of climate-carbon feedbacks.

$$f_{cc} = \lambda \left[\frac{\partial R}{\partial \ln CO2} \boxed{\frac{d \ln CO2}{d\, T}} \right]$$

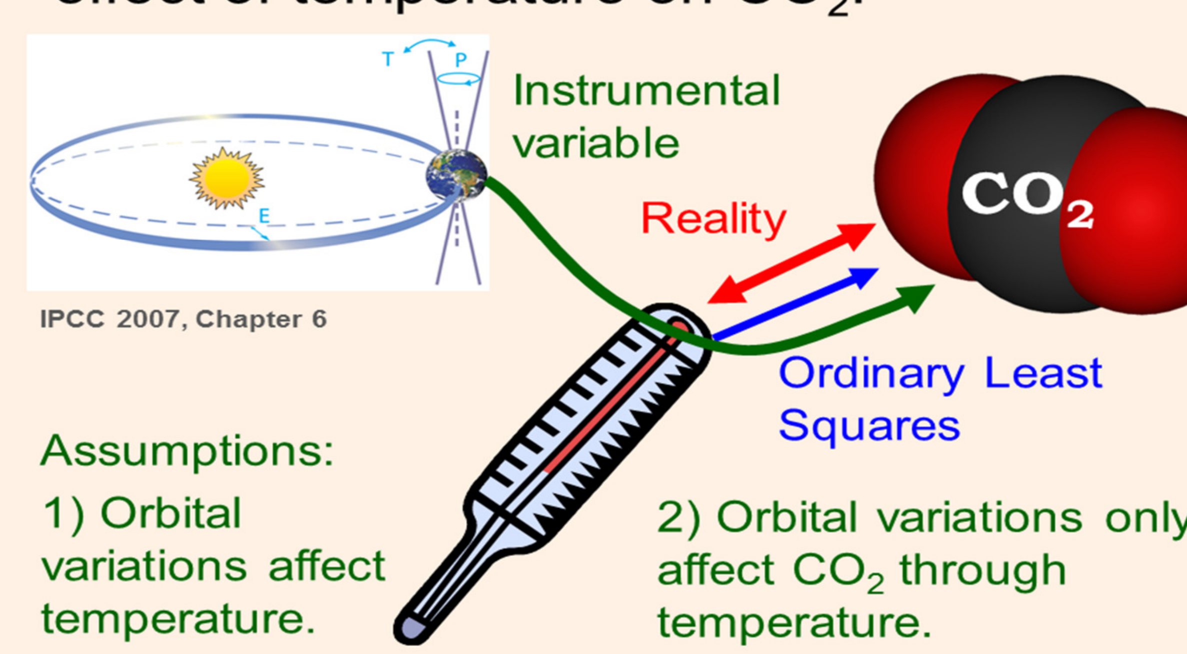
Climate-carbon feedback factor

Increase in radiative forcing due to unit increase in log CO_2: 5.35 (W/m^2) (ln ppm)$^{-1}$

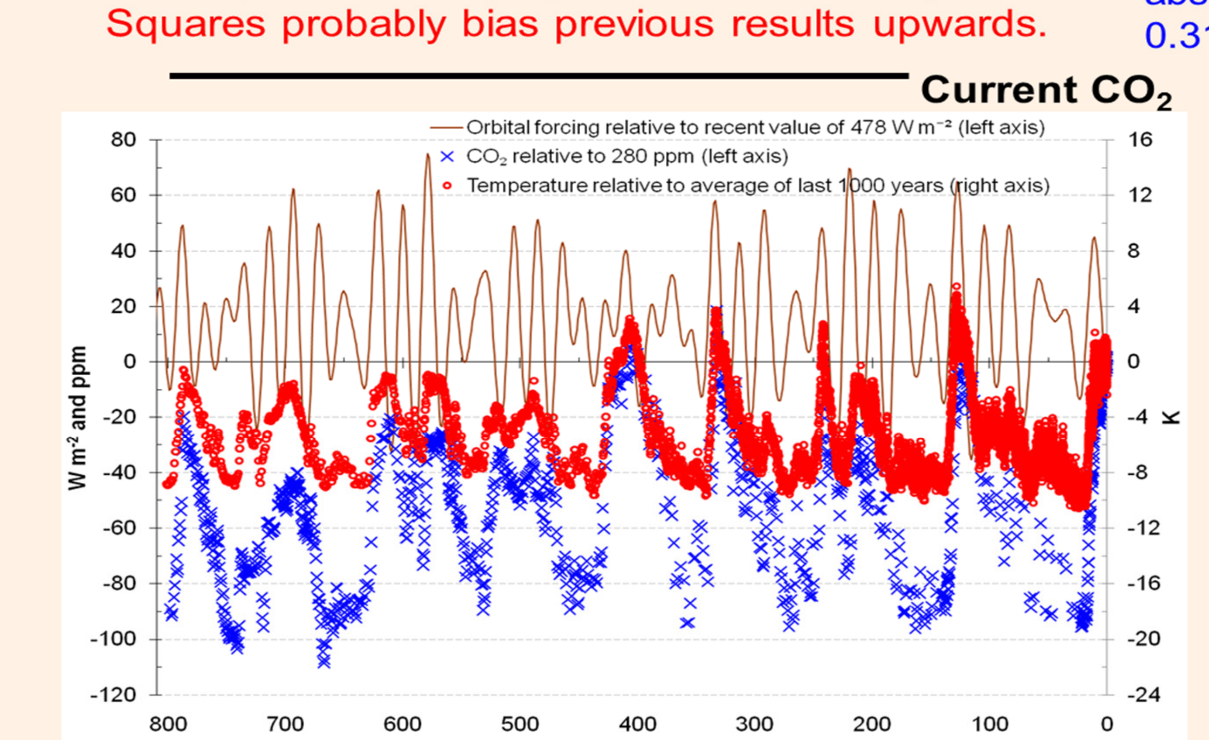
Sensitivity of temperature to change in radiative forcing in absence of feedbacks: 0.315 K (W/m^2)$^{-1}$

Response of CO_2 to unit increase in temperature: ??? (ln ppm) K^{-1}

We can use orbital forcing to isolate the effect of CO_2 on temperature from the effect of temperature on CO_2.

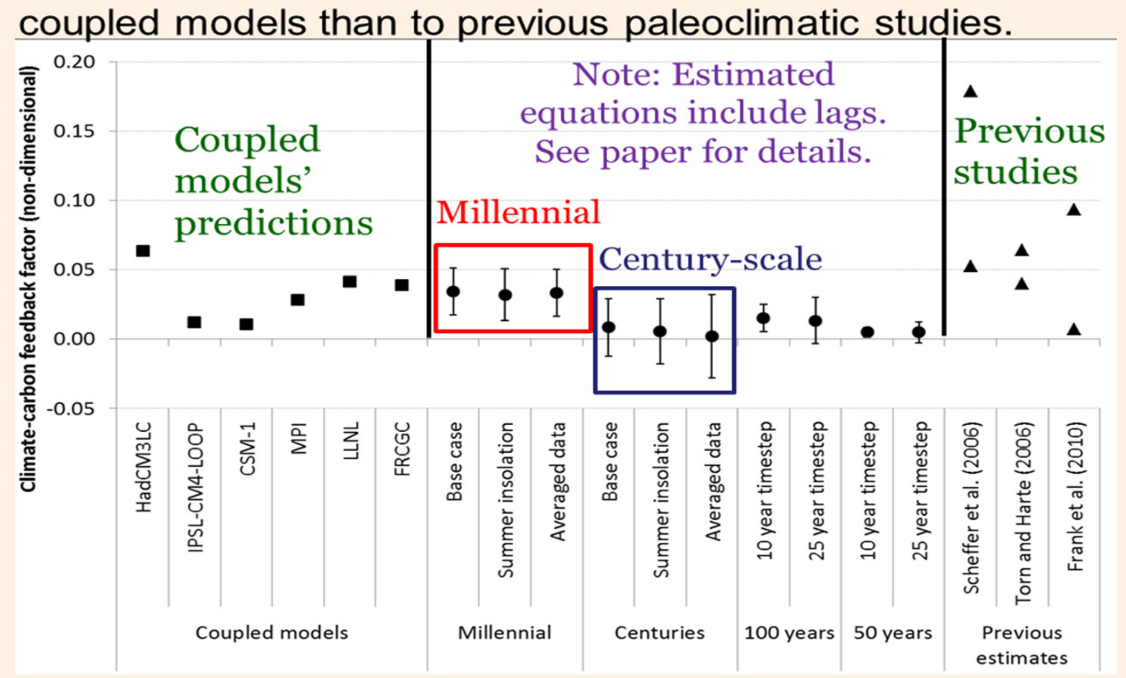


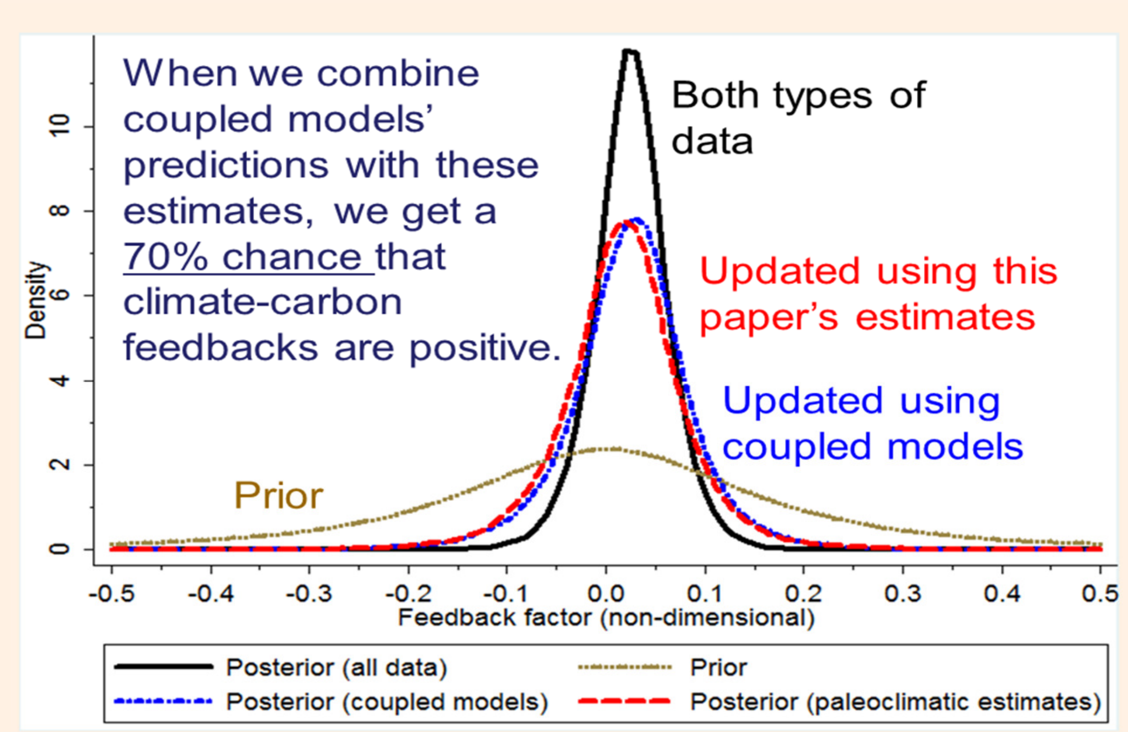
Assumptions:
1) Orbital variations affect temperature.
2) Orbital variations only affect CO_2 through temperature.



Berger, 1978; Jouzel et al., 2007; Lüthi et al., 2008

Estimated feedback strength is closer to that predicted by coupled models than to previous paleoclimatic studies.





Conclusions: Climate-carbon feedback

- Orbital forcing provides a strong instrument. It produces positive feedback estimates in line with those of coupled climate-carbon cycle models.
- Climate-carbon feedback is not significantly different from 0 on sub-millennial timescales.
- Estimation at sub-century timescales is limited by the density and extent of paleoclimatic data.
- Climate-carbon feedback is not a dominant source of uncertainty about future temperature change, but it does increase the probability of extreme outcomes.
- Possible refinement: Nonlinear relation between temperature and orbital forcing