Quantifying and Reducing Uncertainty in Global-Scale Climate Projections

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Barry Saltzman's Dynamical Paleoclimatology: Generalized Theory of Global Climate Change

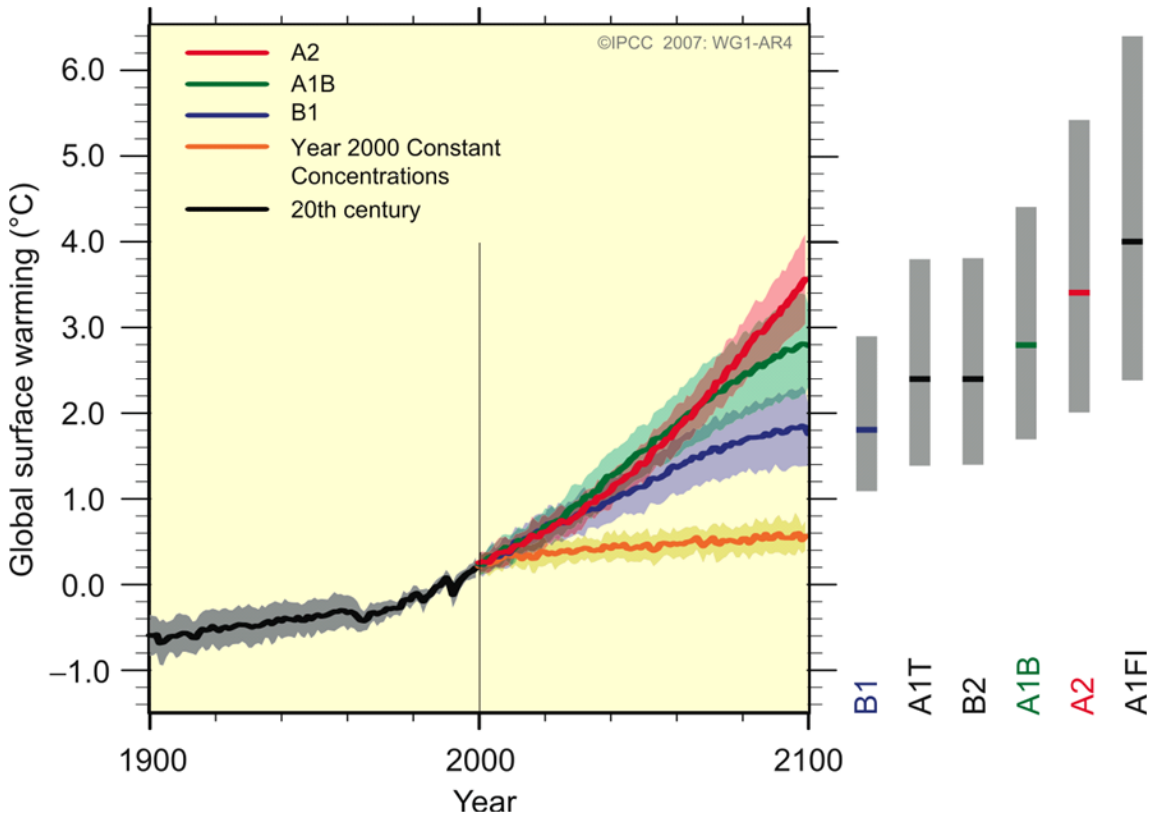
Prologue

… we recall a perceptive observation by my former colleague at Yale, Richard Foster Flint (1974), that , whereas we now have good basic paradigms for the history of the Earth's surface (global tectonics) and the history of life on Earth (Darwinian evolution), a … paradigm for the history of climatic evolution still remains to be established. In this book we shall suggest a candidate for such a paradigm centered on the role of carbon dioxide and the potential for instability in the full slow-response climate system….

It may in fact be easier to predict future climate than to understand past climate change.

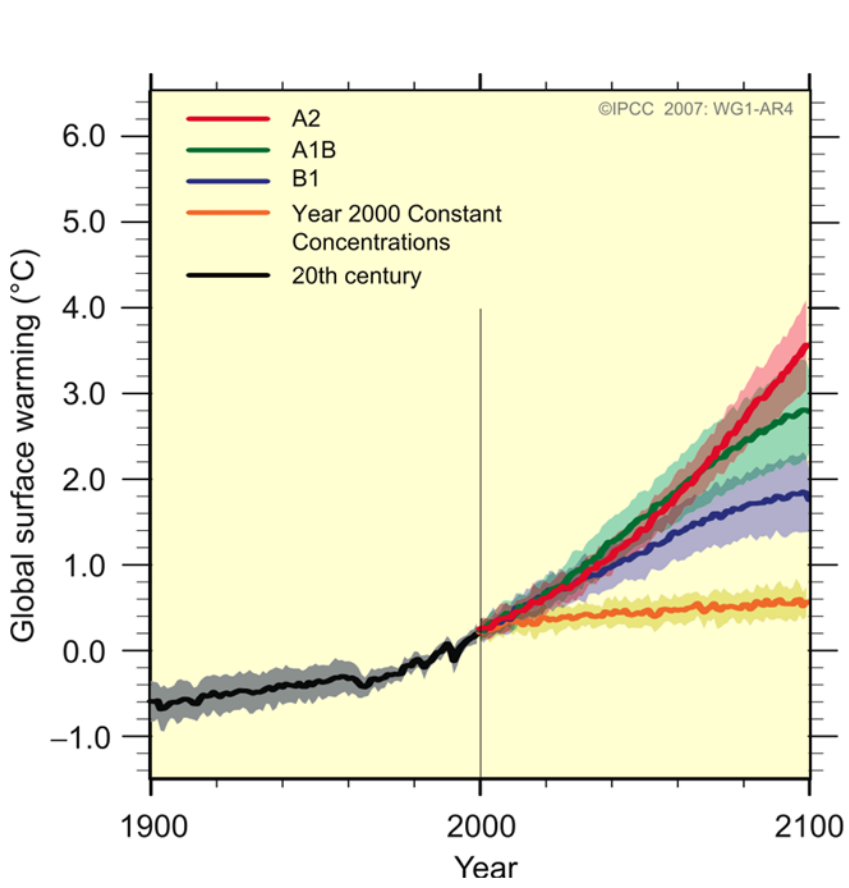
Why? Because we know that CO_2 concentration will increase as fossil fuels continue to be burned.

Range of model projections remains large, implying considerable uncertainty.



IPCC (2007)

The range of estimates of "climate sensitivity" have not decreased since Barry Saltzman's first years at Yale!



5.2 C

2.0 C

Note: 90% of models lie in the range of 2.5 to 4.1 K

IPCC (2007)

What is responsible for the range of climate sensitivities?

- Focus on the global, annual mean energy budget

(perturbation from initial equilibrium):

$$\frac{\partial E}{\partial t} = F_{\text{TOA}}$$

- Why?
  - → To zeroth order, climate is determined by energy flow across TOA
  - → Processes that strongly affect TOA flux have strong influences on climate
  - → Perturbations to the net TOA flux largely determine thermosteric changes in sea level.
  - → From TOA flux, we can estimate surface temperature changes (if we also monitor uptake of heat by the oceans).

"Radiative response" can be used to gauge the relative importance of various changes to the climate system.

(perturbation from initial equilibrium):

$$\frac{\partial E}{\partial t} = F_{\text{TOA}}$$

- Define "radiative response"
  - → Any change in the system that ***directly*** affects F_{TOA}
    - e.g., clouds, water vapor, surface albedo, [CO_2]
  - → Definition excludes changes that only ***indirectly*** impact F_{TOA}
    - e.g., changes in atmos. transport or evaporation (even though these affect water vapor and clouds)

Distinguish between radiative responses that occur on different time-scales:

- "Fast" (shorter than a few months; commonly called "forcing")
  - → e.g., direct radiative impact of [CO_2] changes; stratospheric adjustment
  - → Evident before "climate" has changed
- "Slow" (commonly called "feedbacks")
  - → e.g., "Planck response", water vapor, surface albedo
  - → Traditionally assumed proportional to global mean temperature change:

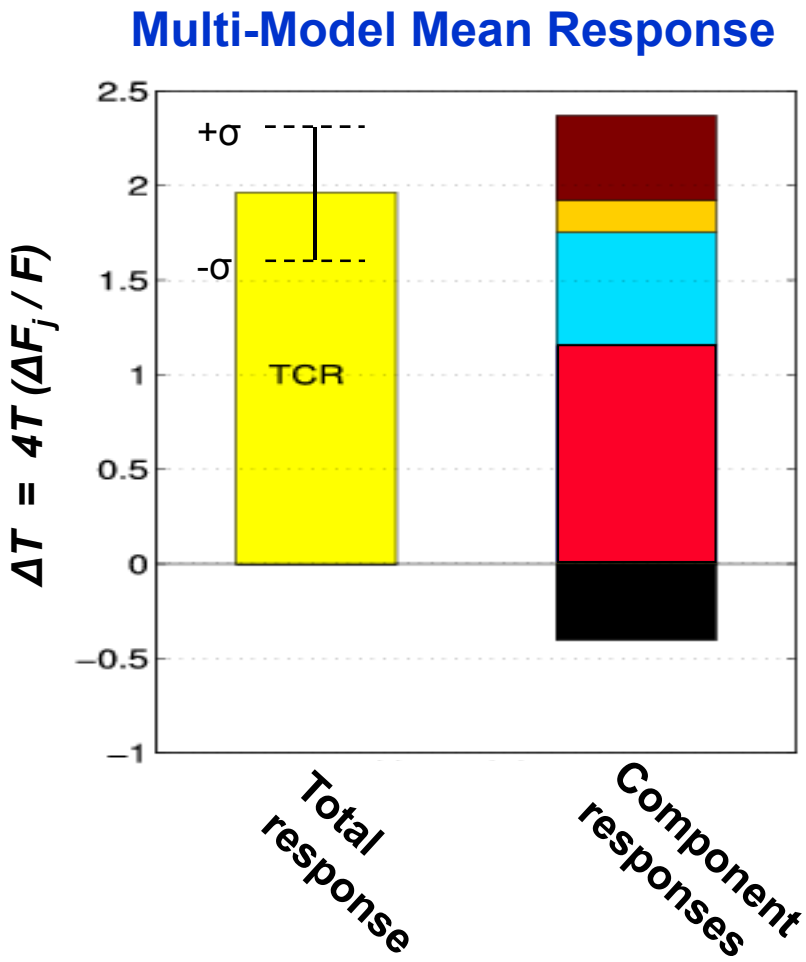
$$S \approx -\lambda \Delta T$$

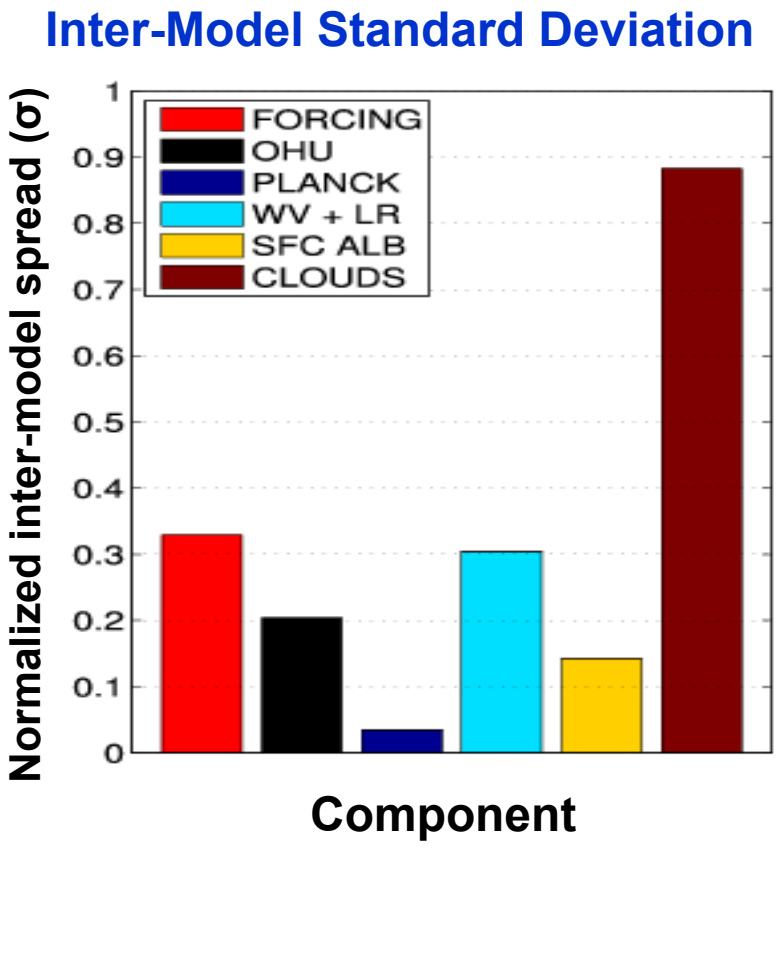
- "ultra-slow" (longer than a few decades)
  - → e.g., ice sheets, some carbon/climate responses
  - → poorly represented in current models

Where do models agree/disagree?

- "Fast responses"
  - → Agreement for major greenhouse gases
  - → Disagreement for aerosols (and their impacts on clouds)
- "Slow responses"
  - → Agreement for water vapor + lapse rate feedback and surface albedo
  - → Disagreement for clouds
- "Ultra-slow responses"

Contributions to transient temperature increase (at time of CO_2 doubling) in 1%/yr CMIP3 experiments



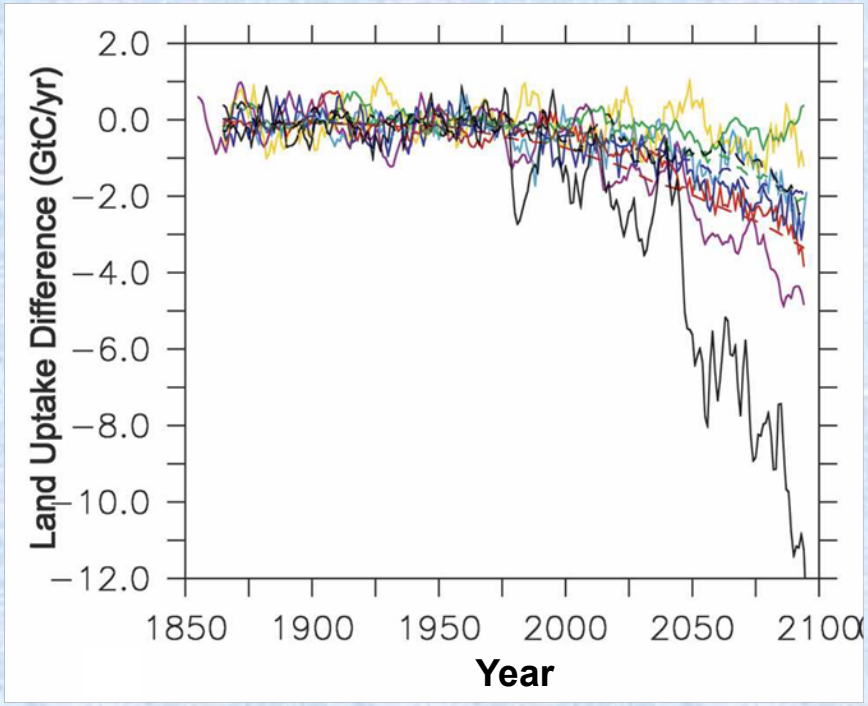


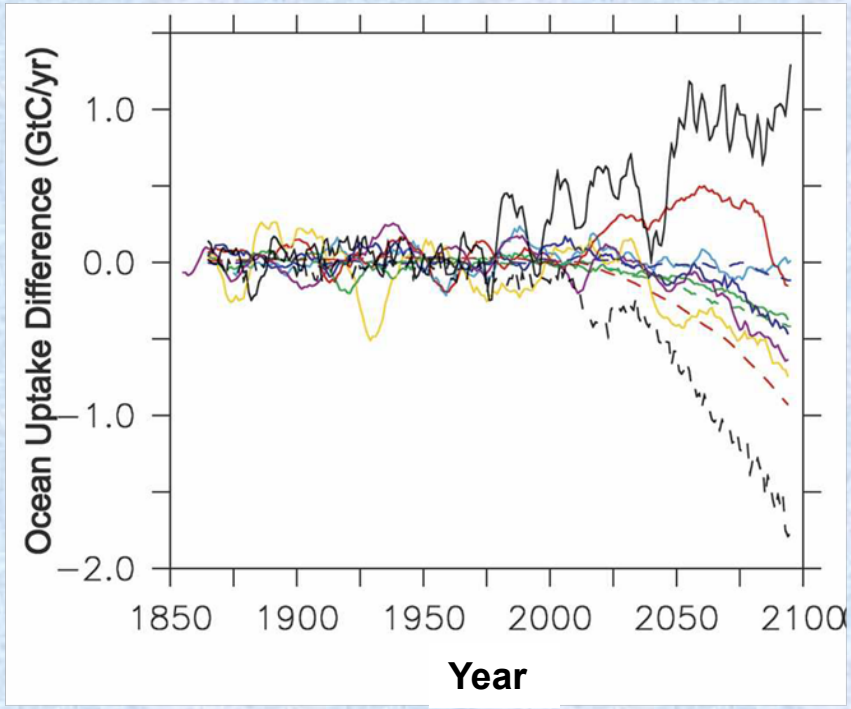
Dufresne & Bony (2008); based on Soden & Held (2006), and Forster & Taylor (2007)

Where do models agree/disagree?

- "Fast responses"
- "Slow responses"
- "Ultra-slow responses"
  - → Disagreement for climate – carbon cycle feedbacks

Carbon/climate feedback in C4MIP models is generally positive, but there is a large spread.





Friedlingstein et al., 2006

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- "Ultra-slow responses"
  - → Disagreement for climate – carbon cycle feedbacks

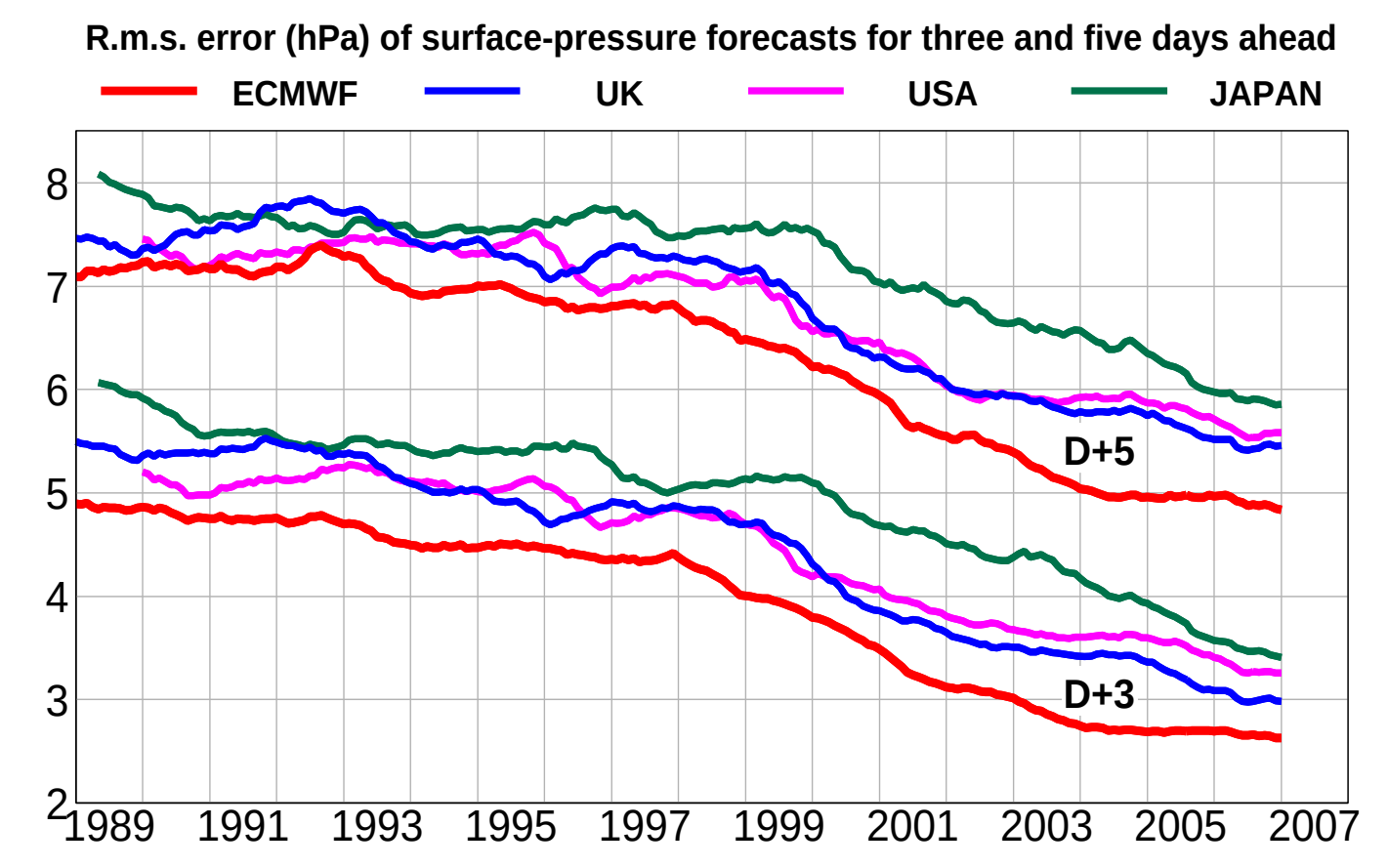
Research is focused on the responses that are both large and where disagreement is greatest.

What are the options for assessing the reliability of climate projections?

- Limited by the relatively short observational record
  - → Unlike weather prediction where we have daily opportunities to assess forecast skill.
  - → Much longer "proxy" records are of some use in constraining projections, but mainly provide only rough bounds (M. Mann)

Unlike numerical weather prediction systems, climate model skill cannot be routinely monitored.

Weather Prediction Skill



Courtesy of M. Miller

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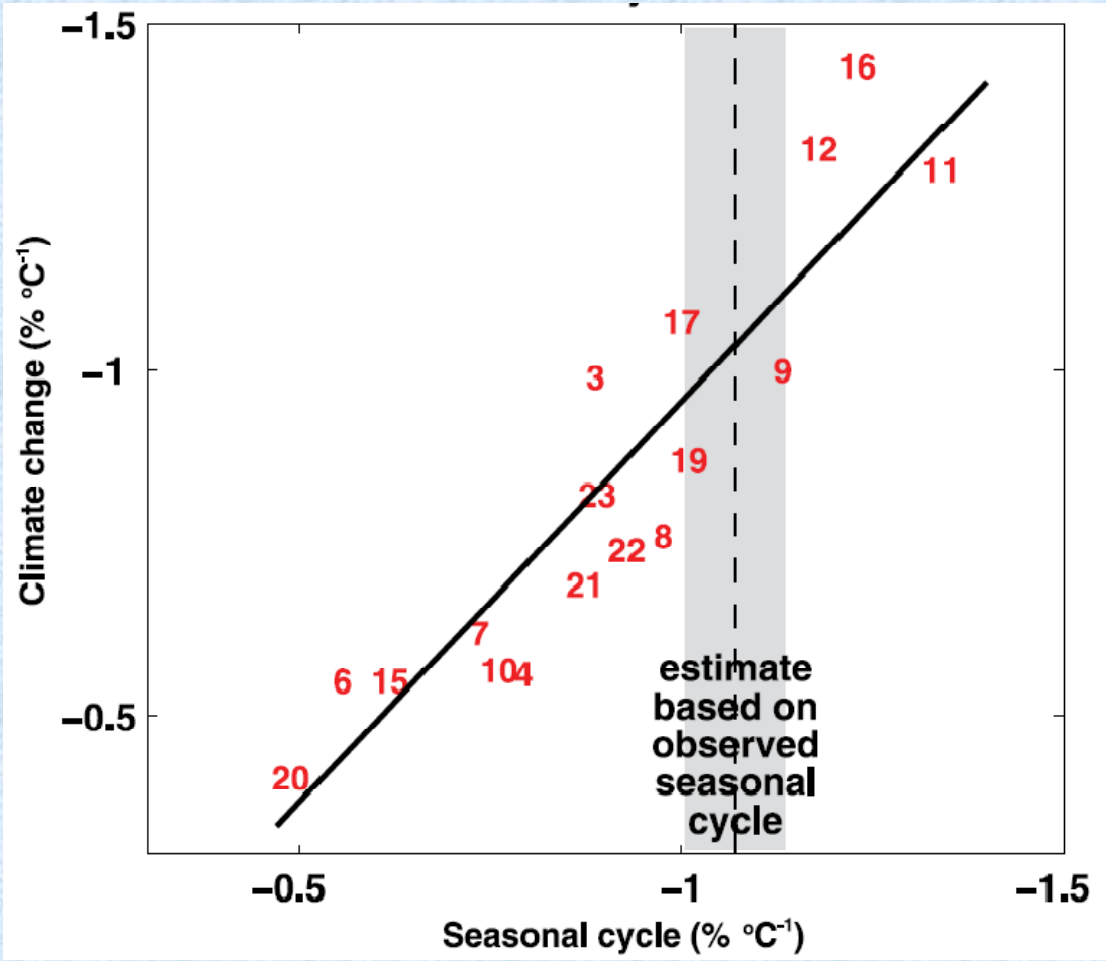
  - → Unlike weather prediction where we have daily opportunities to assess forecast skill.
  - → Much longer "proxy" records are of some use in constraining projections, but mainly provide only rough bounds (M. Mann)
- Are there robust relationships between model skill in simulating processes on time scales that are well observed and skill in simulating climate change on longer time scales?

Can we make use of results from a diversity of climate models to gain insights?

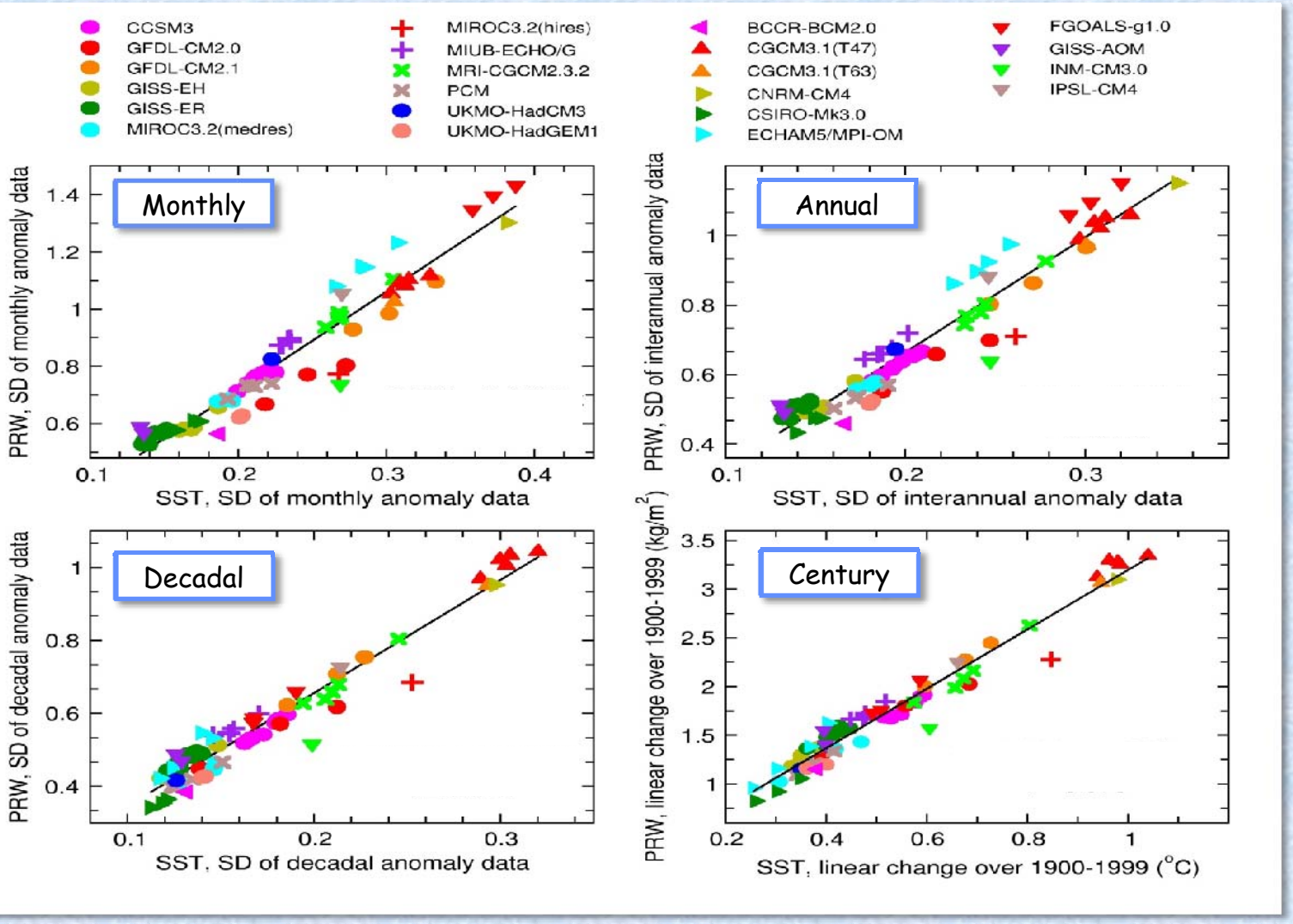
Use the multi-model ensemble to uncover relationships between observables and future changes

Response of snow cover to global warming in models is related to their snow response to spring warming



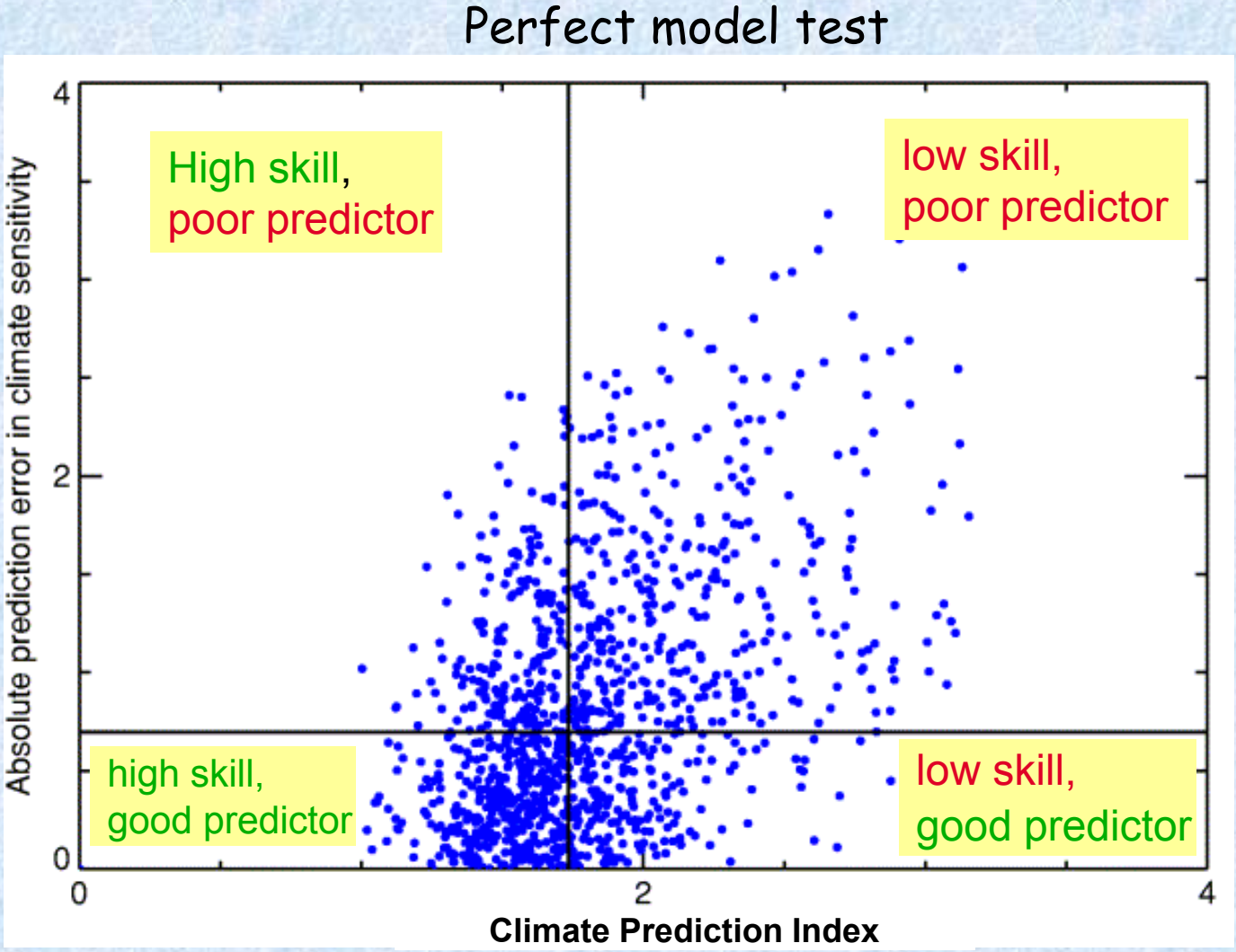
Hall & Xu, (2006)

Relationship between water vapor variability and SST variability is consistent across time scales



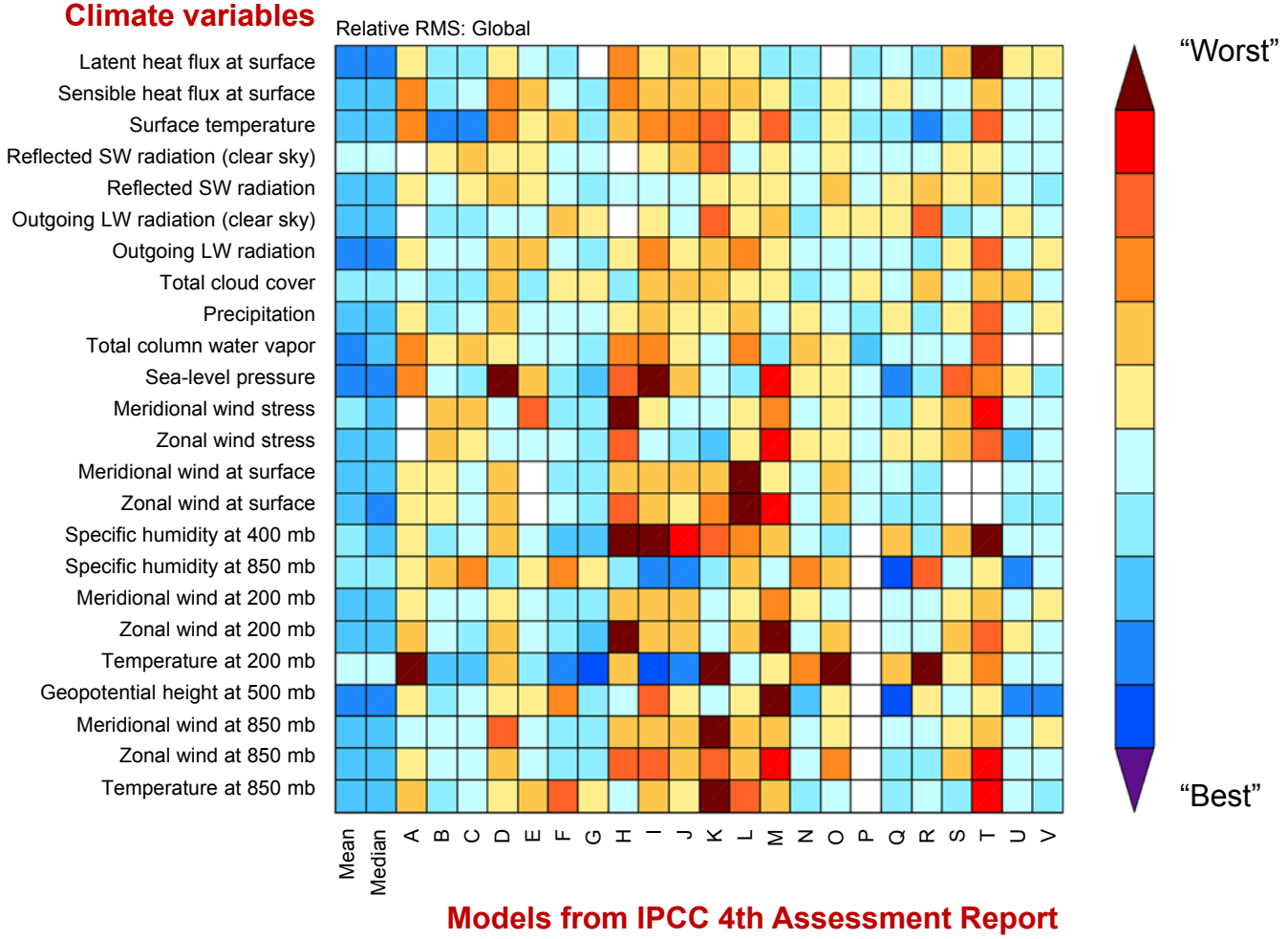
Santer et al., 2009

One study found only a weak relationship between one measure of climatological skill and skill of projections.



Courtesy of J. Murphy & D. Sexton

Some hints that the multi-model mean simulation is superior to even the best individual model



Gleckler, Taylor, and Doutriaux, *JGR* (2008)

Summary of challenges in measuring and reducing uncertainty in model projections

- How can we determine model forecast skill in the absence of opportunities to make forecasts?

  Verify that the physics of climate is adequately represented in models.

- What observed physical phenomena must models simulate particularly accurately if we are to have confidence in their projections?

  We don't know, but presumably we should focus on processes that strongly affect radiative fluxes at the TOA (either directly or indirectly).

- Can we weight model projections in a scientifically defensible way to improve accuracy of the consensus projection and reduce uncertainty?

  We don't know, but we should start by determining how skill in simulating observed (past and present) climate relates to credibility of projections?