Uncertainty in future climate:
What you need to know about what we don't know

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More about my favorite subject (me)

- Climate research since 1990
- Mostly computer modeling
- My mission: use climate models to understand societal impacts of climate change, and help people make better decisions.

Outline

- Basics:
  - Climate vs. weather
  - How we express uncertainty
- Why is future climate uncertain? Imperfect knowledge of
  - Initial conditions
  - Drivers of climate change ("forcings")
  - Climate system response to drivers

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Outline…

- How do we estimate climate uncertainty?
  - Expert elicitation
  - Ensembles of opportunity
  - Perturbed physics ensemble
  - Why none of these is perfect
- Guidance for decision-makers
  - Avoid excessive risk

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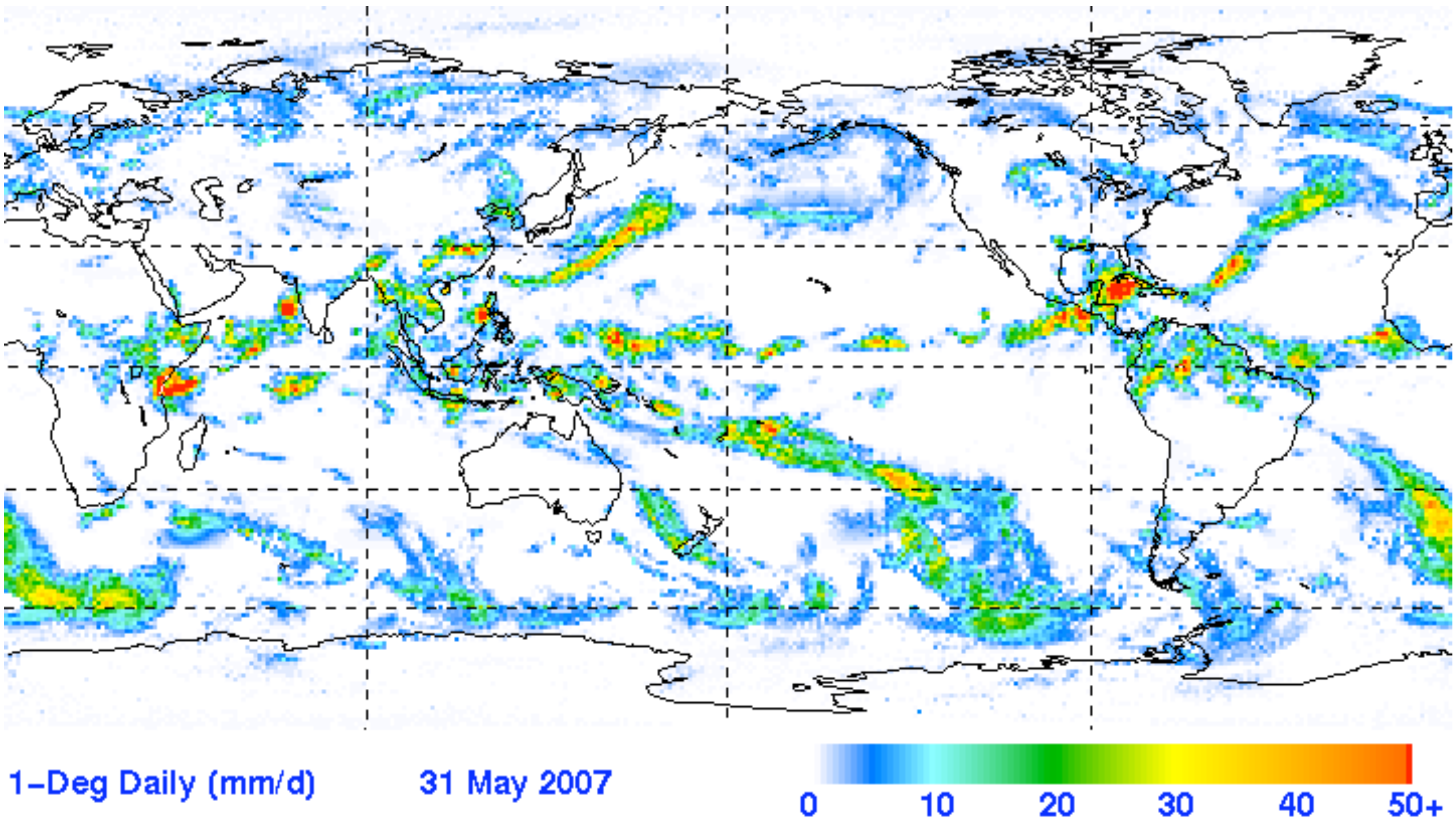
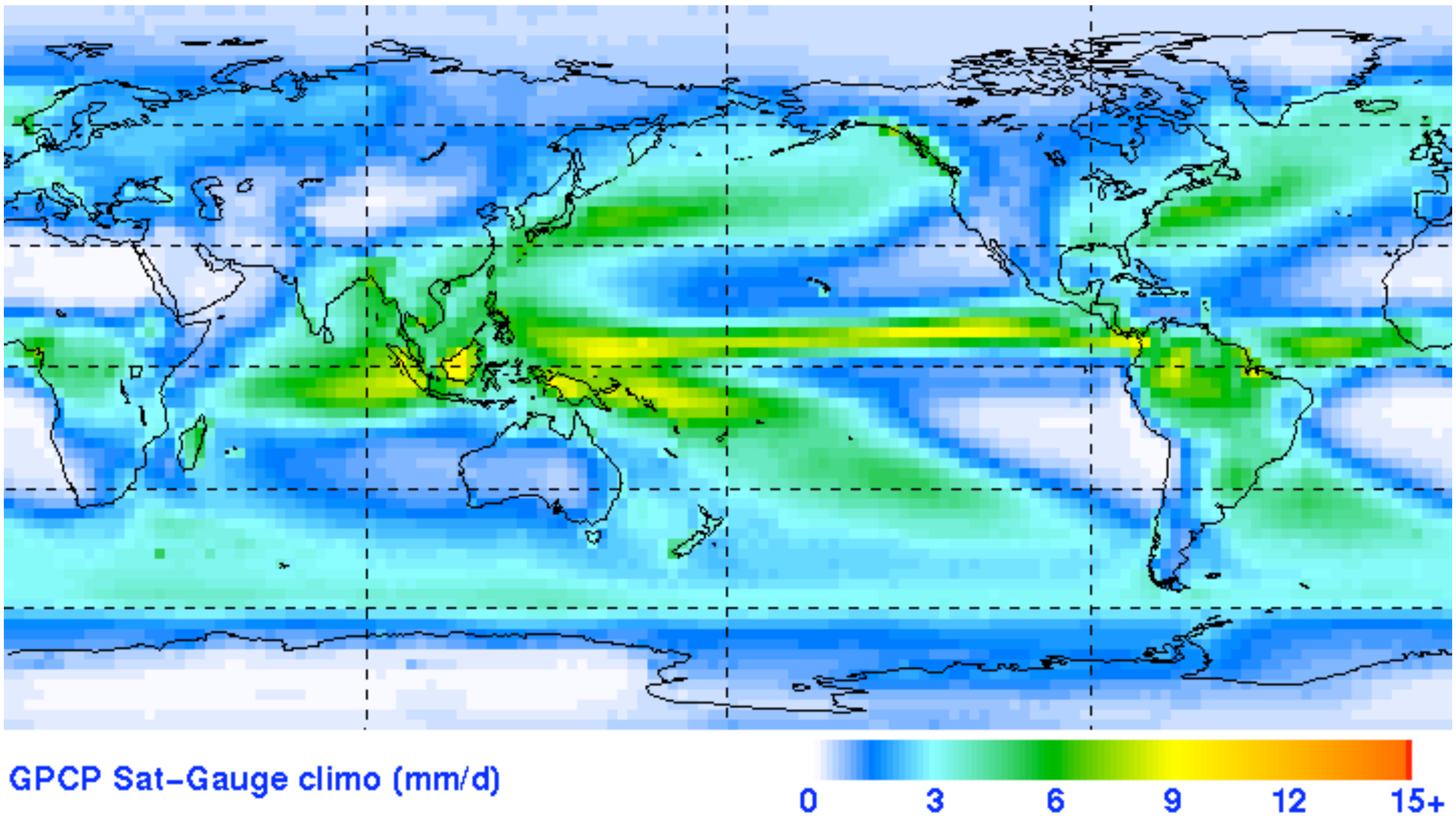
Weather: Conditions at specific time(s) and location(s)



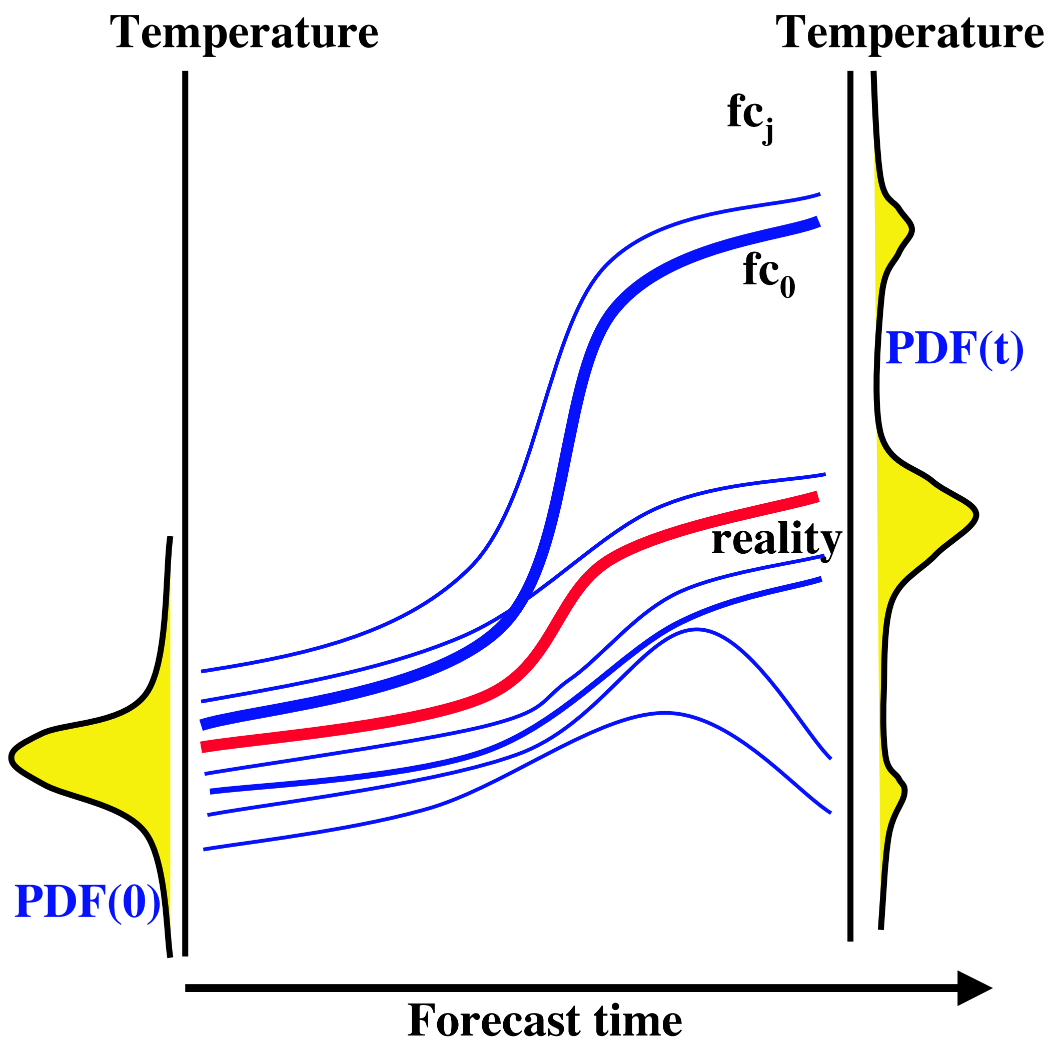
An example of weather:
Precipitation on 31 May 2007.

Climate: a statistical description of weather (averages and variability)



An example of climate:
Multi-year mean precipitation

Weather prediction skill is sensitive to uncertainty in initial conditions



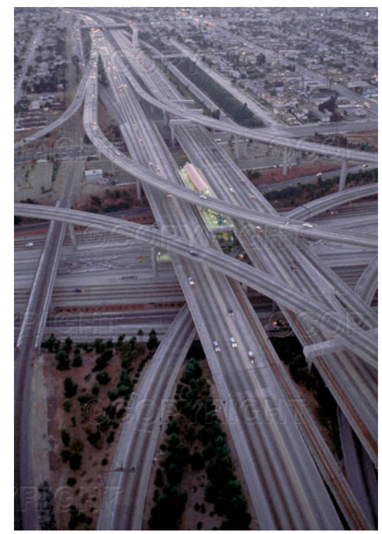
Source: Roberto Buizza, European Centre for Medium-Range Weather Forecasting

Climate prediction skill depends on knowledge of external drivers

Greenhouse gases

Particulate pollution

Surface properties



Surface properties

Weather vs. climate prediction: summary

Weather prediction

- Uses models that are very similar to climate models.
- Predict conditions at specific times and locations.
- Skill of predictions depends on very accurate initialization of model.
- Time horizon is at most a week or so.
- Skill is constantly evaluated (and constantly improves).

Climate prediction

- Climate models also predict weather! We analyze the statistics of the predicted weather, but not the weather itself.
- Skill depends on knowing future perturbing influences.
- Time horizon is typically decades, but can be even longer.
- Skill of predictions cannot be directly evaluated.
- We think models are improving.

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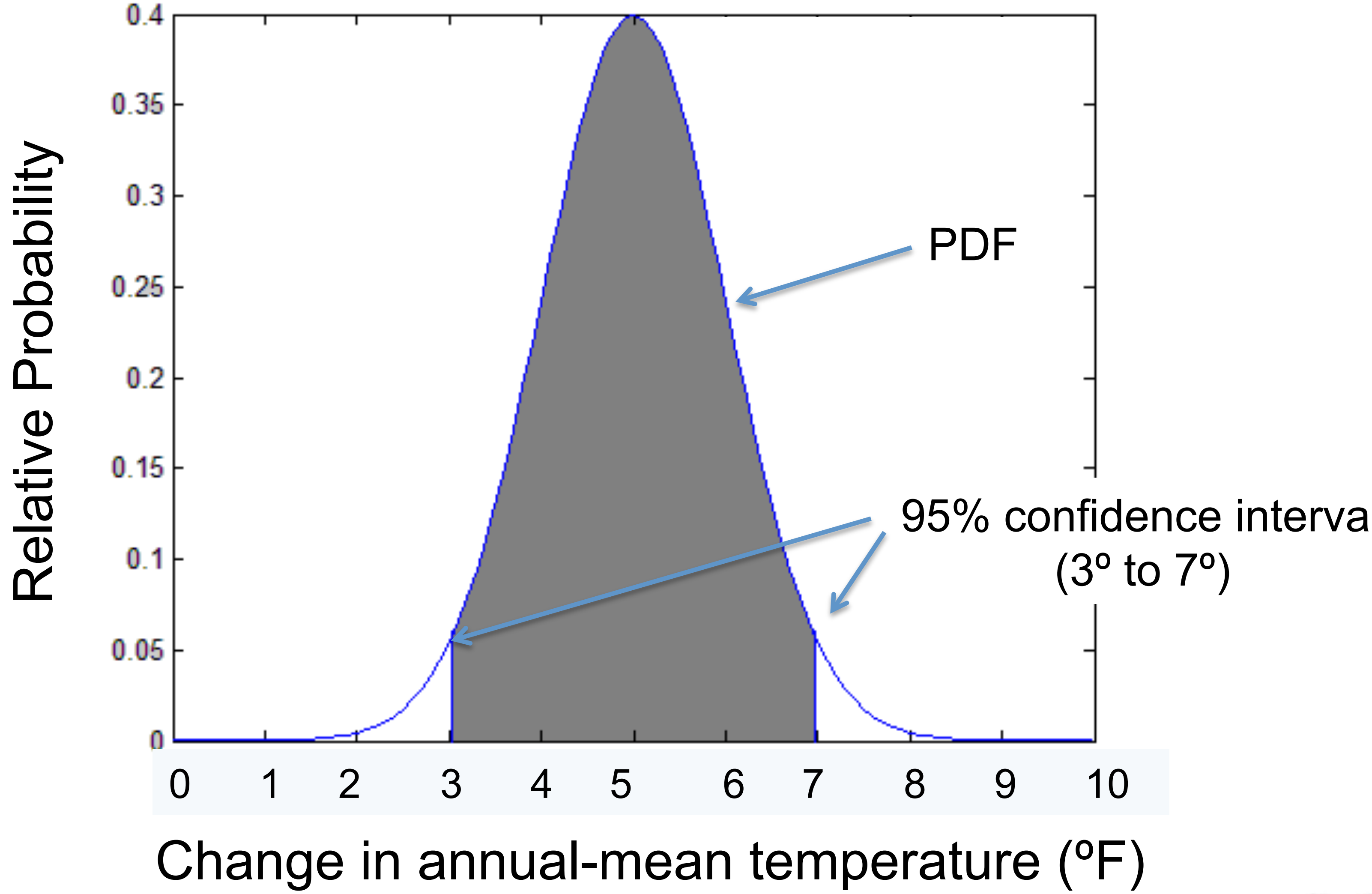
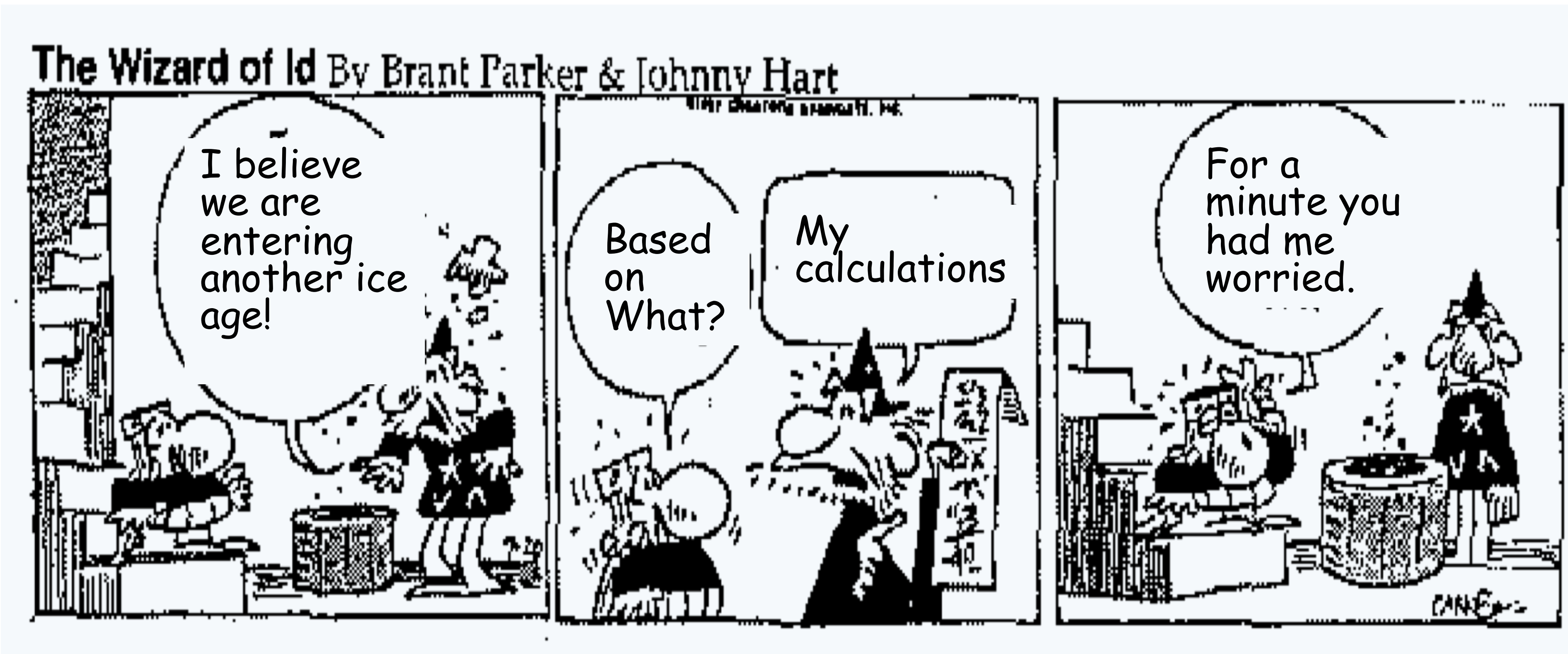
Probability Density Function (PDF) and Confidence Interval



Why is future climate uncertain?

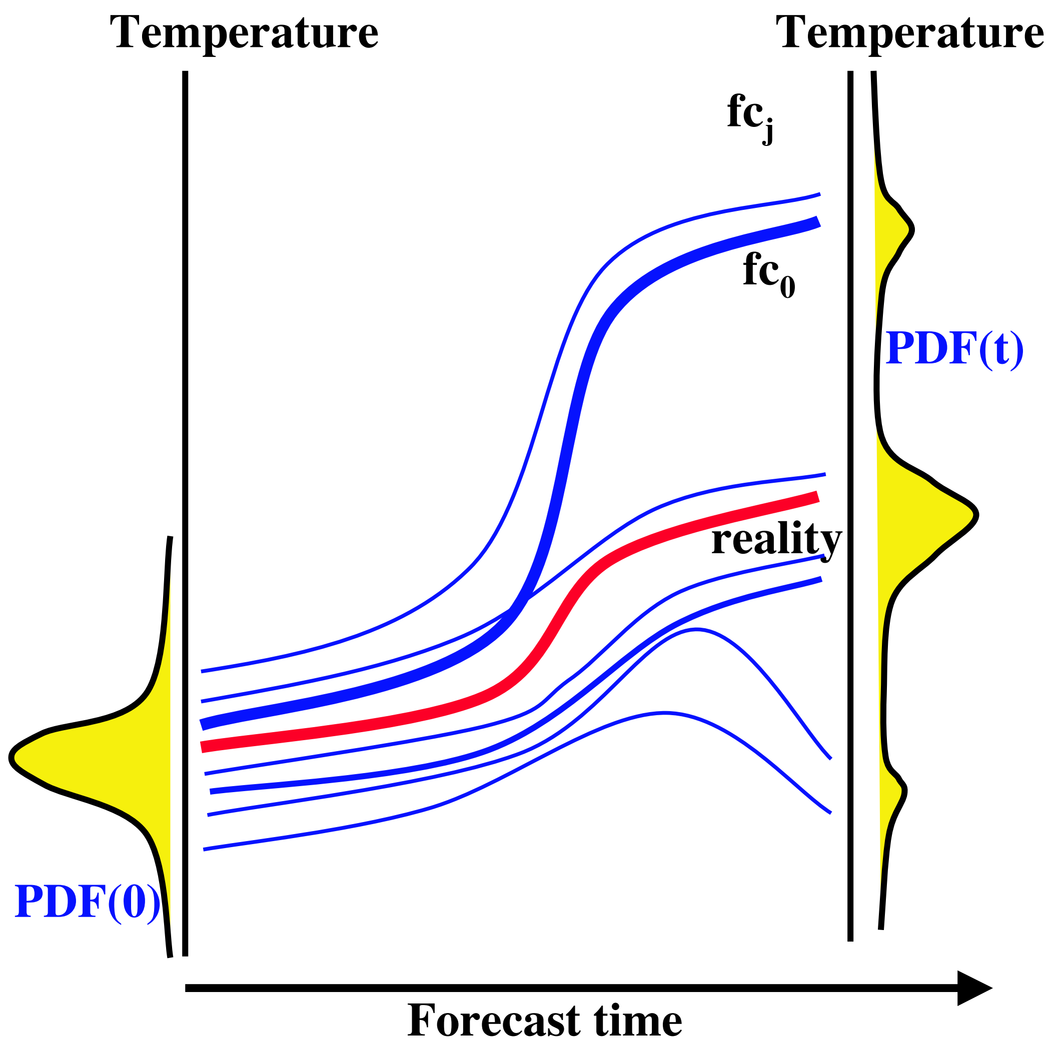


Sources of uncertainty: imperfect knowledge of

- initial conditions in the atmosphere, etc.;
- Future climate "forcings," e.g. greenhouse gas concentrations;
- how the system responds to forcings.

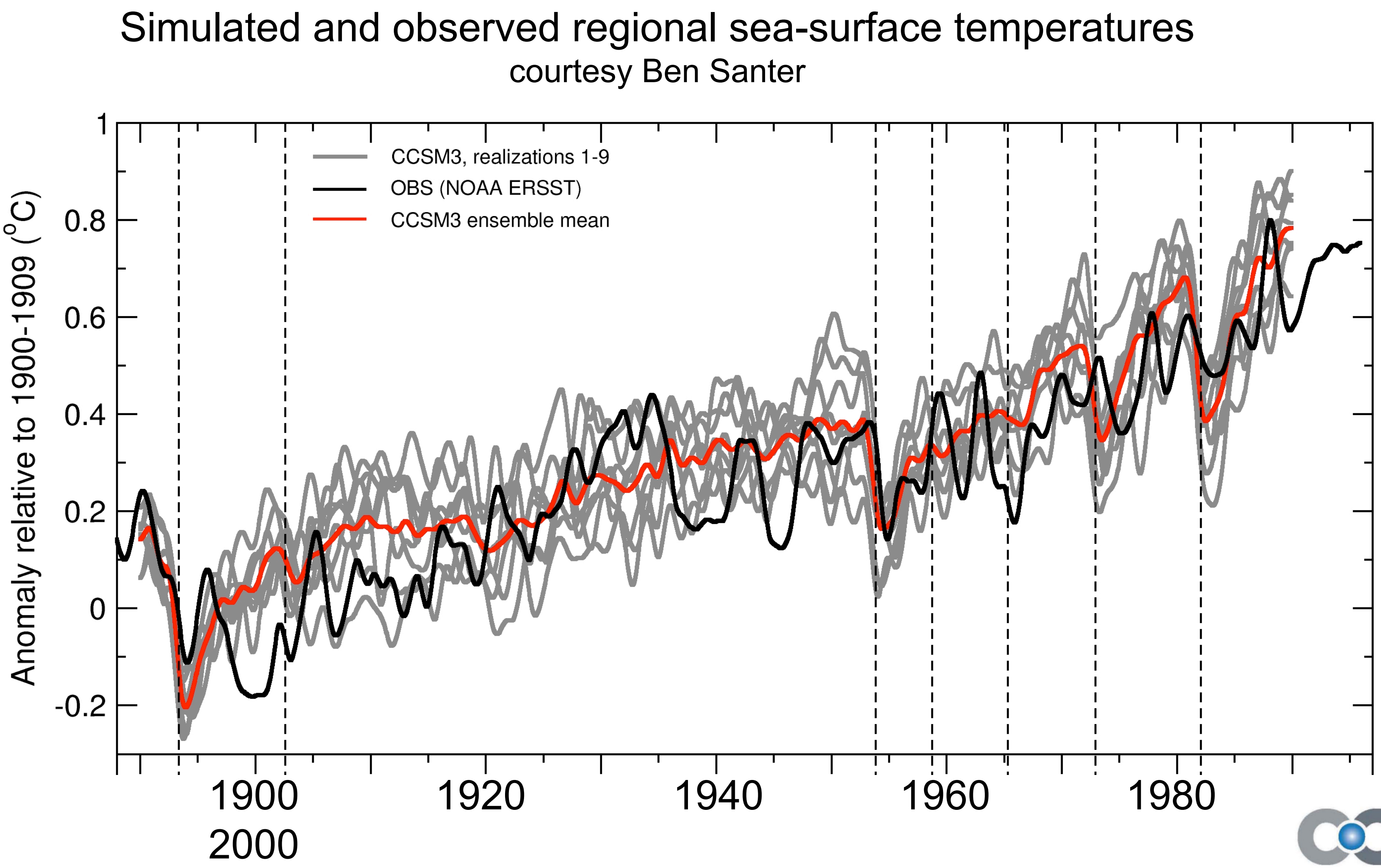
  These errors arise from:
  - numerical discretization
  - Imperfect representation of unresolved phenomena
  - relevant processes that are omitted (including "unkown unknowns").

Uncertainty about initial conditions results in larger uncertainty in future climate



Source: Roberto Buizza, European Centre for Medium-Range Weather Forecasting

Example of initial condition uncertainty

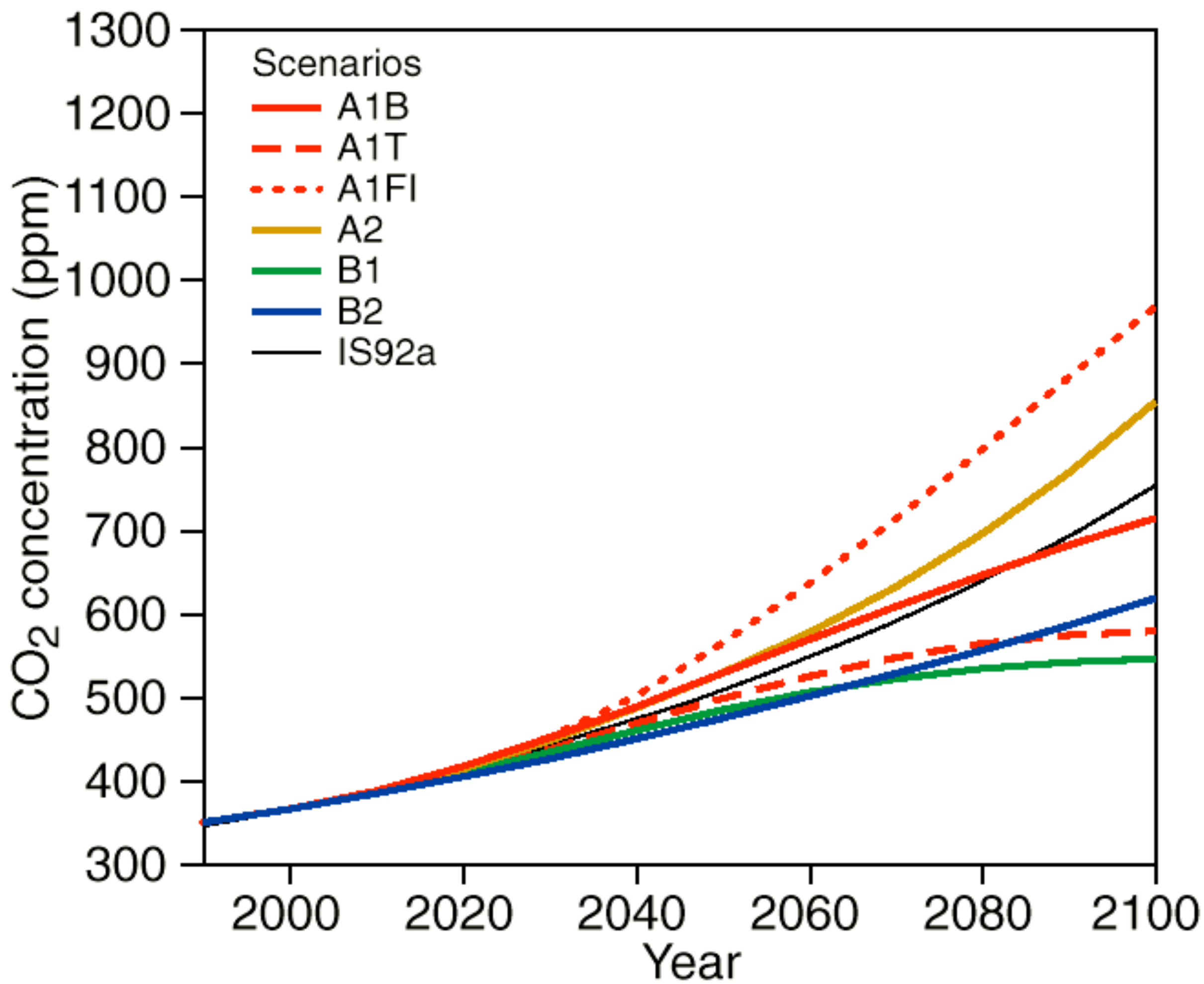


Sources of uncertainty: imperfect knowledge of

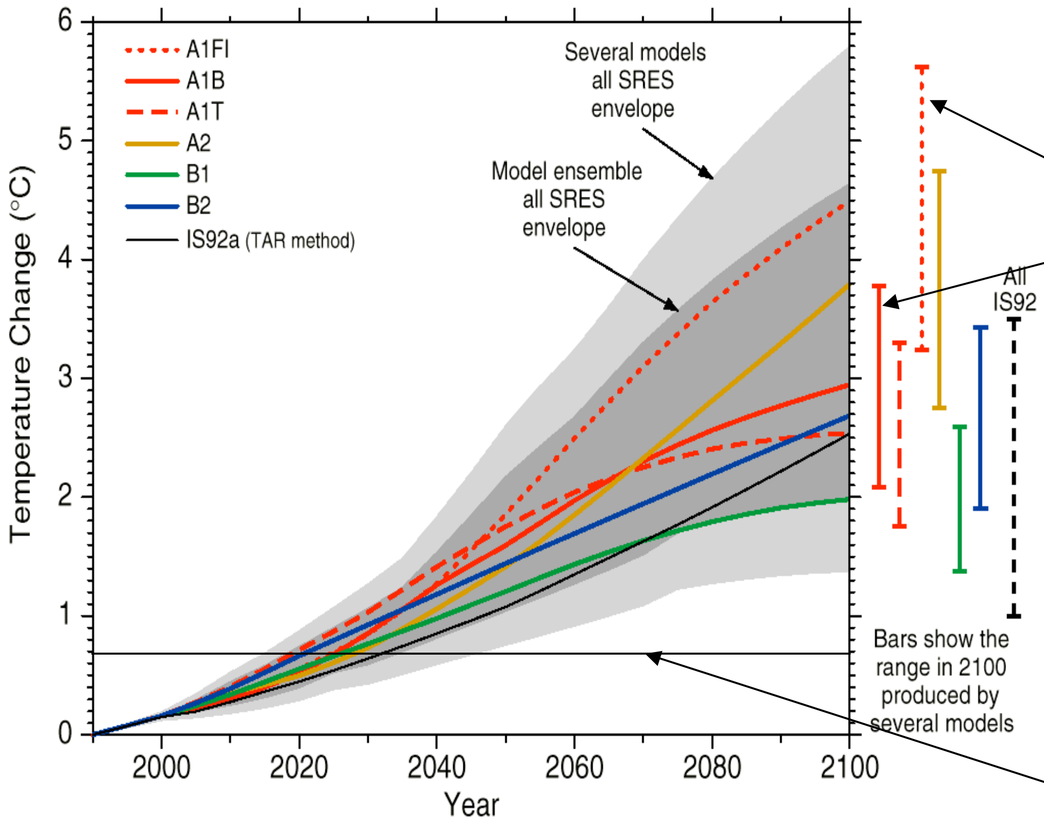
- initial conditions in the atmosphere, ocean, etc.;
- future behavior of climate “forcings,” e.g. greenhouse gas concentrations;
- how the system responds to forcings.

  These errors arise from:
  - numerical discretization
  - unresolved phenomena
  - relevant processes that are omitted.

Future CO_2 concentrations are *unknowable;* this is true of other influences also



About half of future uncertainty in temperature comes from uncertainty in future CO_2 emissions.



Each vertical bar shows the range of results obtained for one greenhouse gas emissions scenario

0.6° C is the amount of warming that occurred during the 20th century.

Global T will increase by 1.4° - 5.8 °C before 2100.

Sources of uncertainty: imperfect knowledge of

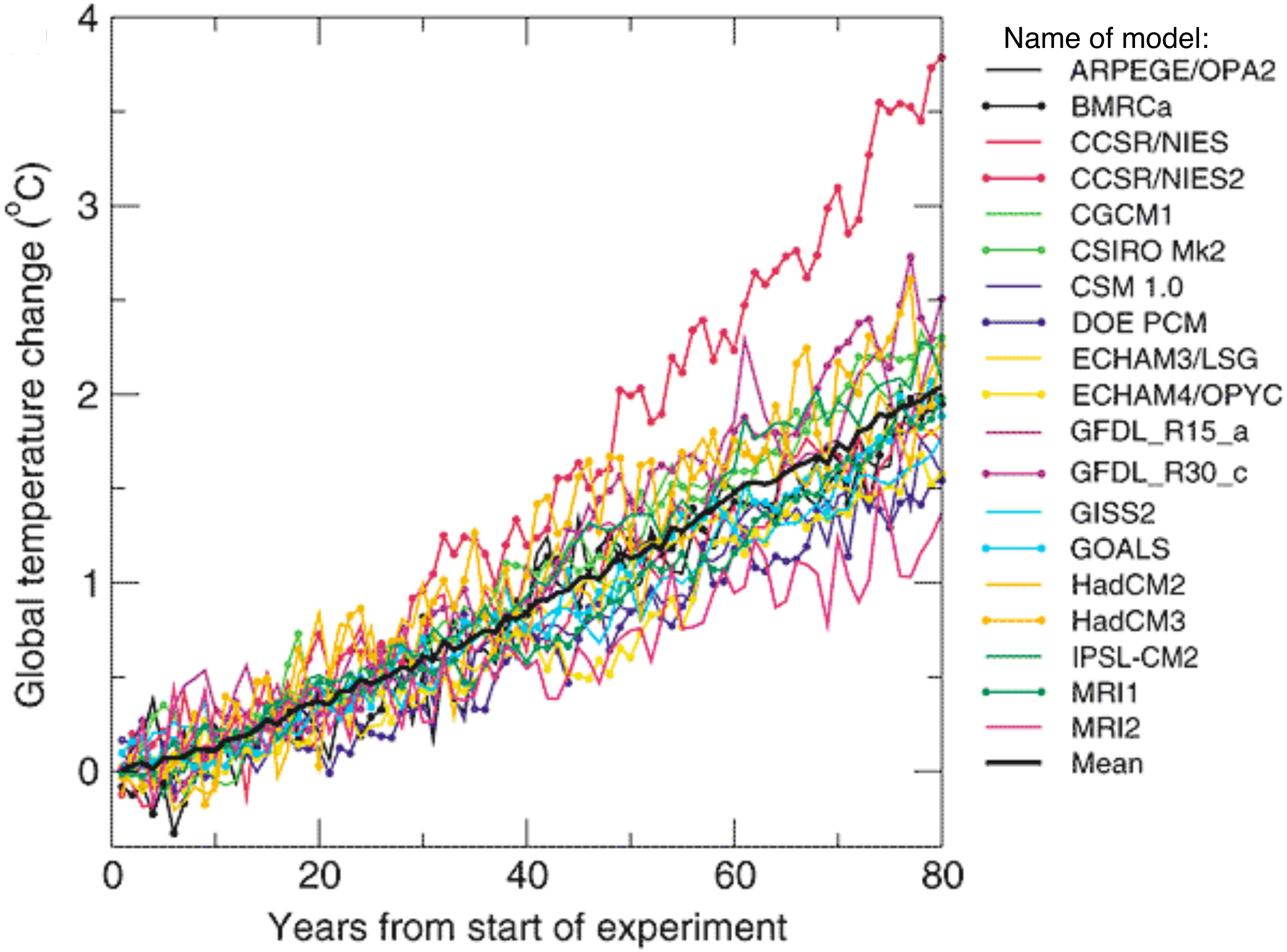
- initial conditions in the atmosphere, etc.;
- future behavior of climate "forcings," e.g. greenhouse gas concentrations;
- how the climate system behaves.

  These errors arise from:
  - Imperfect representation of unresolved phenomena (notably clouds)
  - numerical discretization
  - "unknown unknowns".

“Computers only tell you what you already know.”

Ernesto Colnago

Different models respond differently to same inputs



Simulated temperature responses to 1%/yr CO_2 increase

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  - Perturbed physics ensemble
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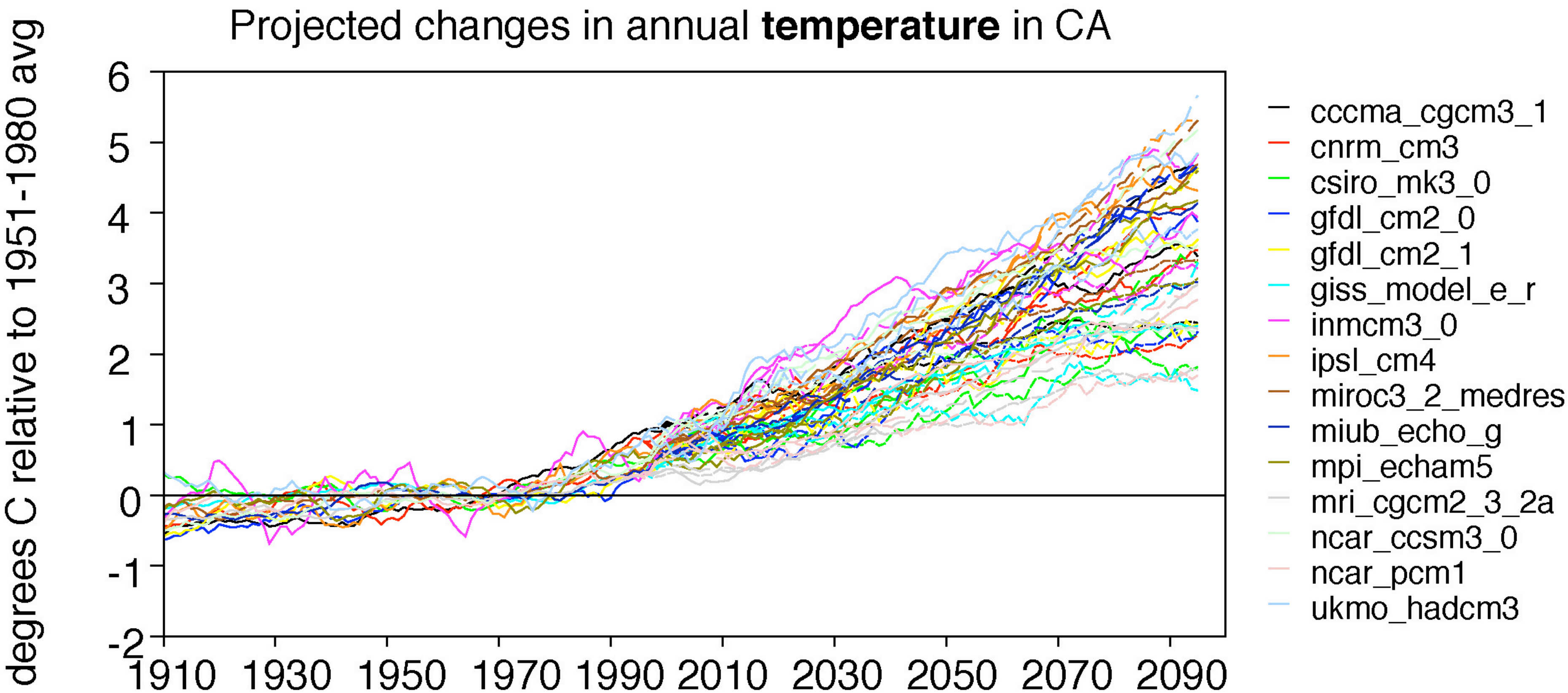
- Guidance for decision-makers

"Expert Elicitation"

- Fancy term for asking a bunch of so-called experts.
- Why I don't like this approach:
  - It's completely subjective
  - (but often made to look quantitative)
  - Groupthink creates false consensus

"Ensemble of opportunity:"

a collection of results from a number of available models



Results from 15 models, each simulating 3 CO_2 scenarios

What's **good** about quantifying uncertainty in this way?

1. It's a start

What's **good** about quantifying uncertainty in this way?

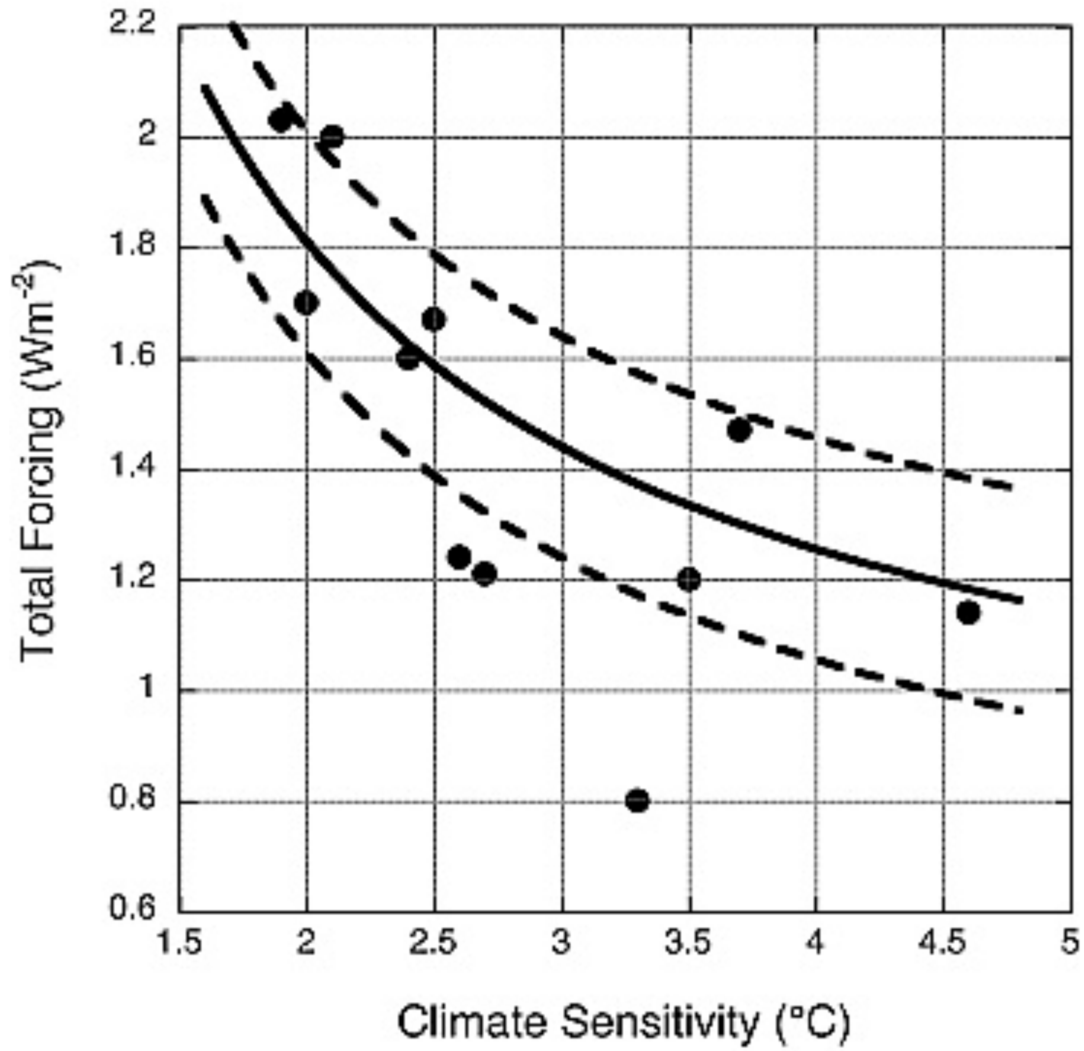
1. It's a start
2. The mean of a large number of models consistently performs better than any single model
   - This is true in climate simulation and in seasonal weather prediction
   - So having results form multiple models seems to give a better estimate of the most likely outcome.

What's **bad** about quantifying uncertainty in this way?

1. Results can be influenced by selection of models, which can be haphazard.
2. Can be misleading because errors common to many models may be important. I.e., even if models agree with each other, they could all be wrong.
    - Superiority of mean model *suggests* that this is not important
    - Hence this approach measure consensus more than uncertainty

What's **bad** …

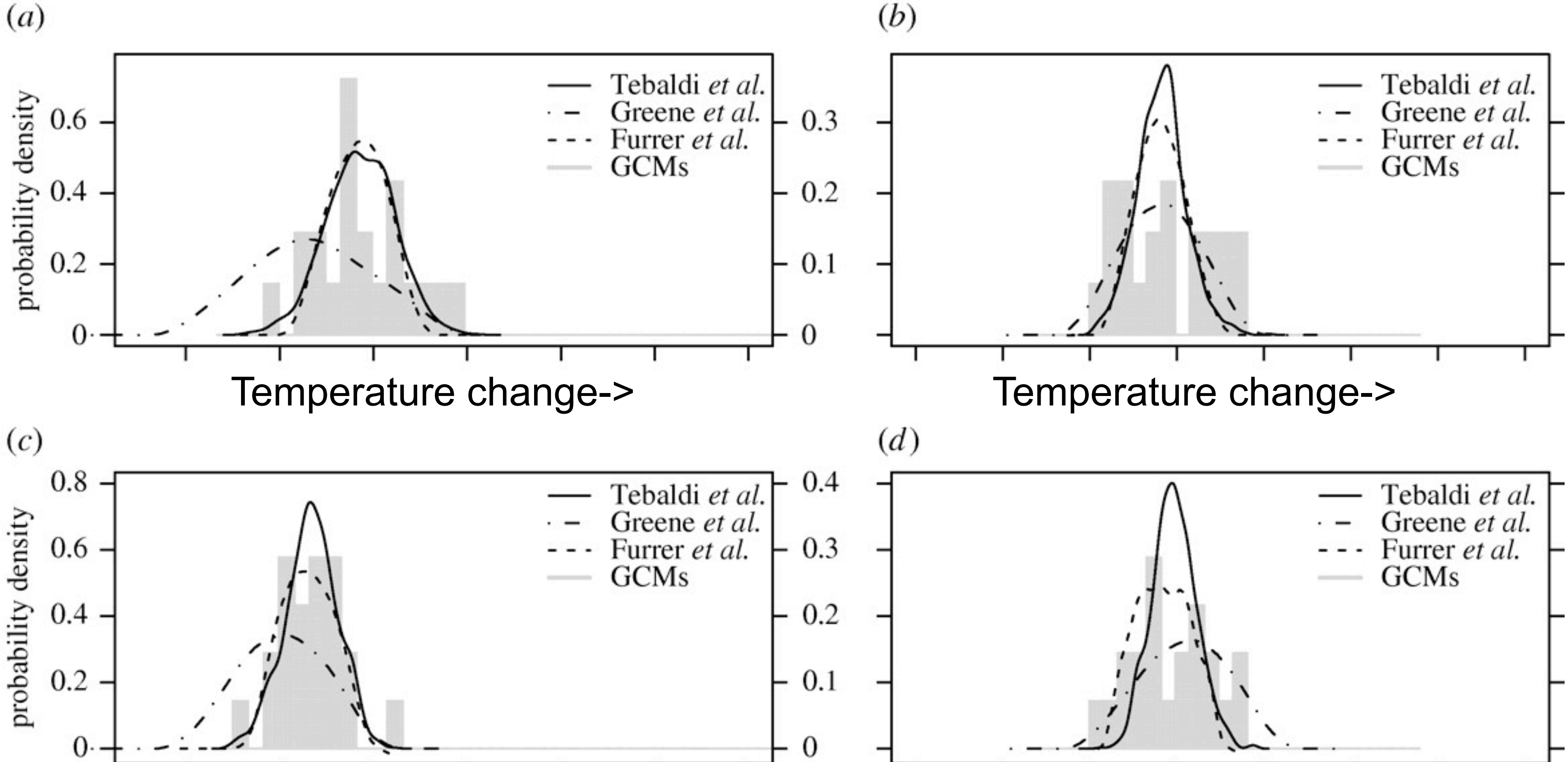
3. Some evidence that GCMs have been unconsciously "tuned"



Source: Kiehl, GRL (2007)

What's **bad** …

4. Often values all models equally, which *can't* be optimal
   - But we can't agree on best way to combine models



Tebaldi C., Knutti R. *Phil. Trans. R. Soc. A*;2007;365:2053-2075

What's **bad** ...

5. Does not include outcomes that all agree have low (but non-zero) likelihood.

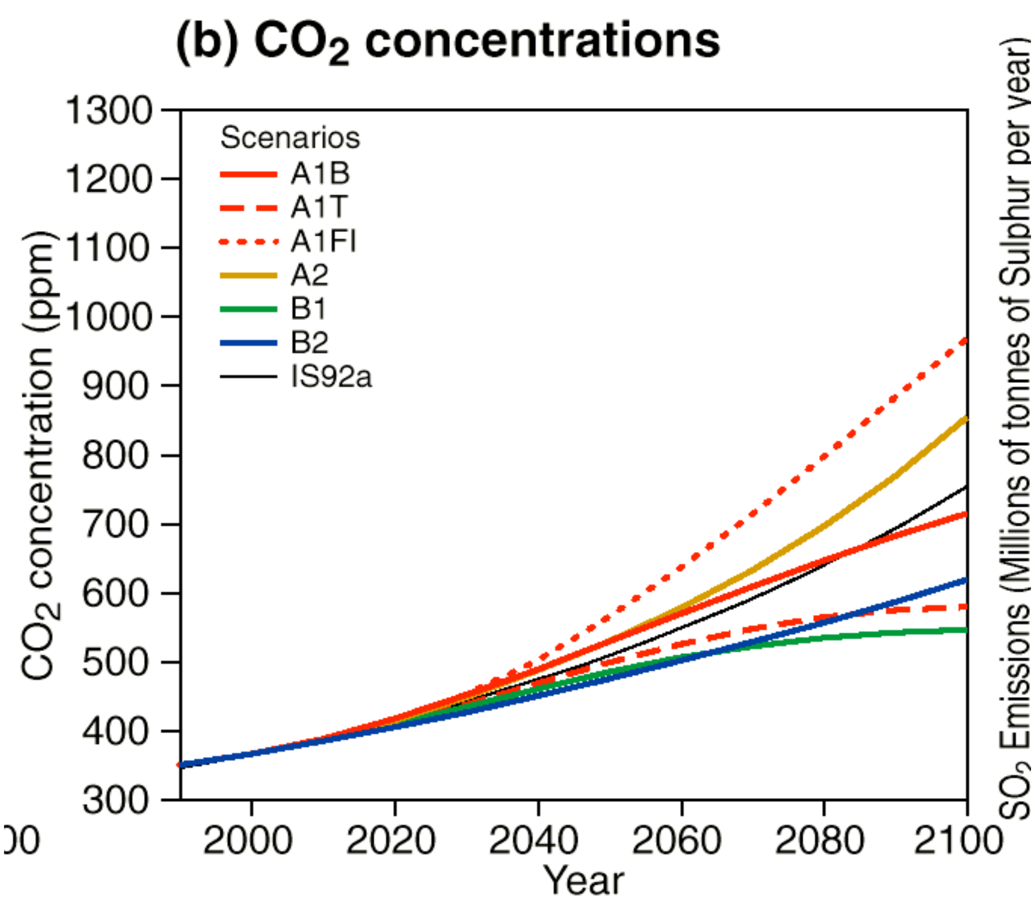
Temperature response to 2 x CO_2 (ºC)

A range of model results estimates the uncertainty in the most likely outcome, not the full range of possible values.

Source: Roe and Baker, UW

What's **bad** …

7. Uncertainty in future forcings (e.g. greenhouse gases) is difficult to quantify.



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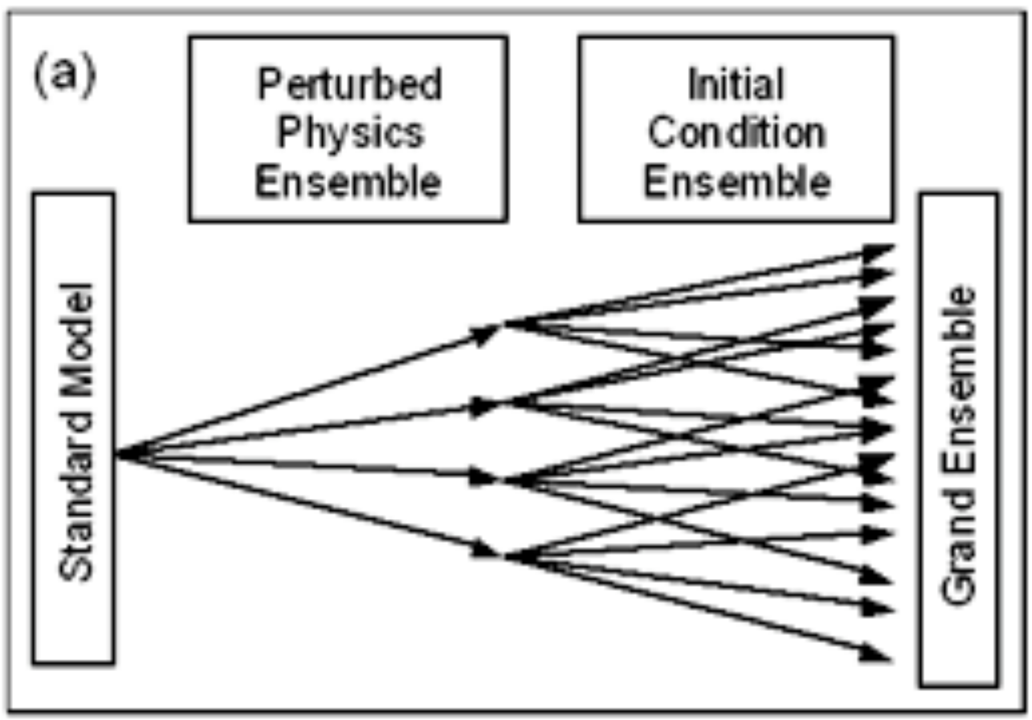
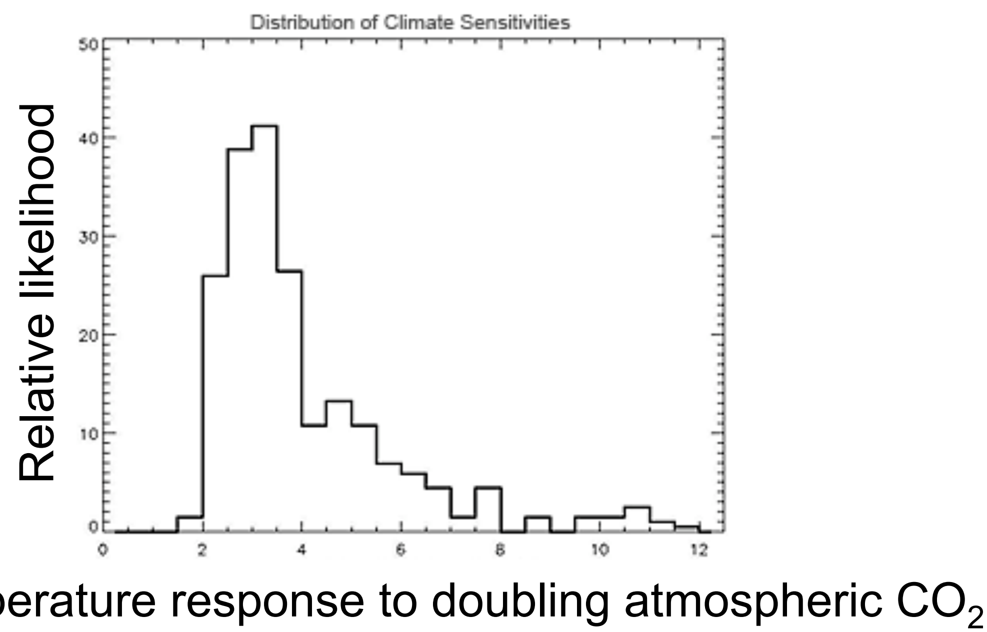
“Perturbed Physics Ensemble”

- Many simulations performed with one model, varying values of parameters that are uncertain.
- E.g. Climateprediction.net



Perturbed Physics Ensemble

- Good: A better way to estimate the full range of possible outcomes.
- Bad: Based on only one model (but does not have to be).
- Bad: highly demanding computationally.



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Two quasi-fundamental barriers to good estimates of climate uncertainty:

- Future climate “forcings,” e.g. greenhouse gas concentrations, may be unknowable.
- It is very difficult to know if climate models share important errors.

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- Why is future climate uncertain? Imperfect knowledge of
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  - Why is this inadequate?
- Guidance for decision-makers

Things to keep in mind

- All decisions involve uncertainty
- A common approach is to avoid excessive risk

(also known as CYA)

Risk = probability x badness of outcome

- Postponing a decision *may* be OK; but don't expect climate science to improve markedly from year to year.

Ask yourself 5 questions:

1. Is there consensus among models?
2. Does what the models predict seem sensible?
3. Is the predicted change seen already in observations?

If "yes" to these, then no reason to doubt the models.

4. What would happen if the models are right and you ignore them? (How much trouble would you be in???)

If you don't like the answer to this, then ask the 5th question:

5. “Do you feel lucky?”

Parting Thoughts (1):

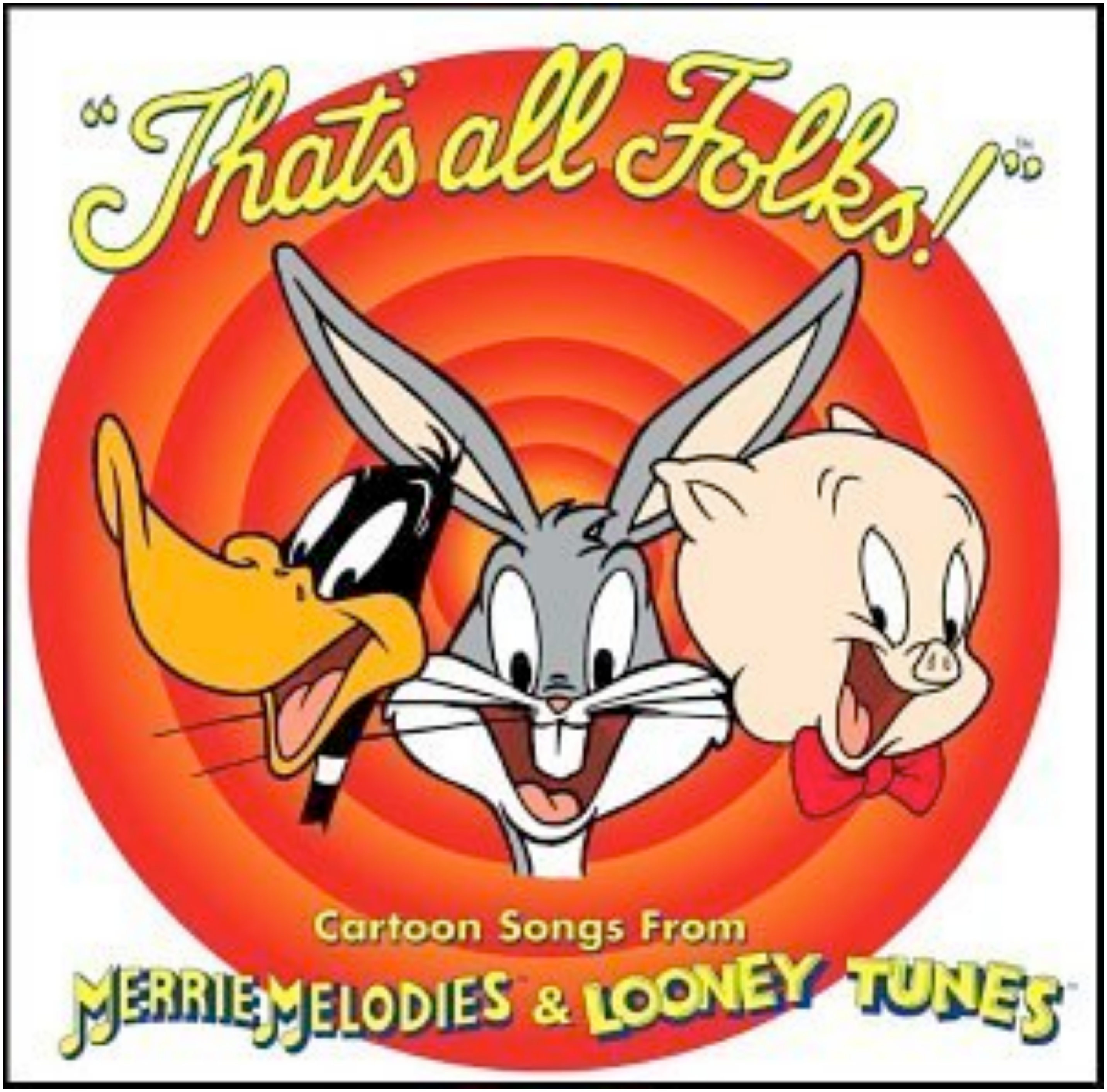
- We are only starting to think seriously about climate uncertainty.
- We are learning how to estimate uncertainty, but need to do better.
- There are some major barriers to good uncertainty quantification.
- It is important to work with decision-makers to
- find better ways to make good climate-related choices
- do the best we can with today's knowledge

Parting Thoughts (2):

Given all the limitations, what can we learn using today's climate projections?

We can:

1. develop methodologies for making well-informed decisions;
2. assess what aspects of climate decisions are sensitive to;
3. determine if future climate is too uncertain to allow us to draw reliable conclusions;
4. improve our understanding of how natural and human systems respond to climate change.


"That's all Folks!"
Cartoon Songs From
MERRIE MELODIES & LOONEY TUNES