Uncertainties in climate change projections

An overview borrowing from recent literature and some personal work

Claudia Tebaldi
ctebaldi@climatecentral.org

PUMA Workshop
San Francisco, December 2010

Outline:

sources of uncertainty
relative importance as a function of ‘forecast’ time and spatial scale

a little more about global vs. regional uncertainties
- common established features of change vs. non-robust projections

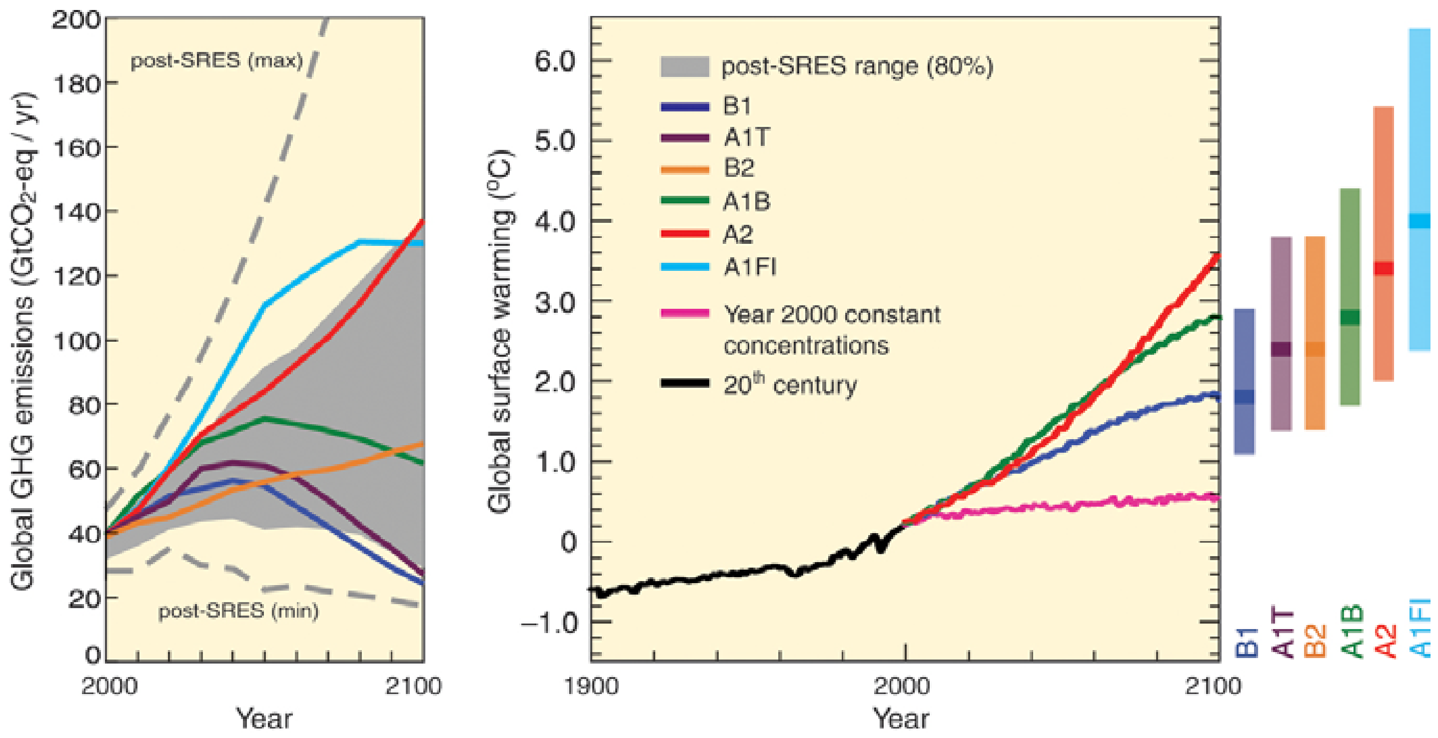
a few words about downscaling

a few words about approaches at quantifying uncertainty
- probabilistic vs. scenario projections
- truth + error vs. exchangeable view of ensembles

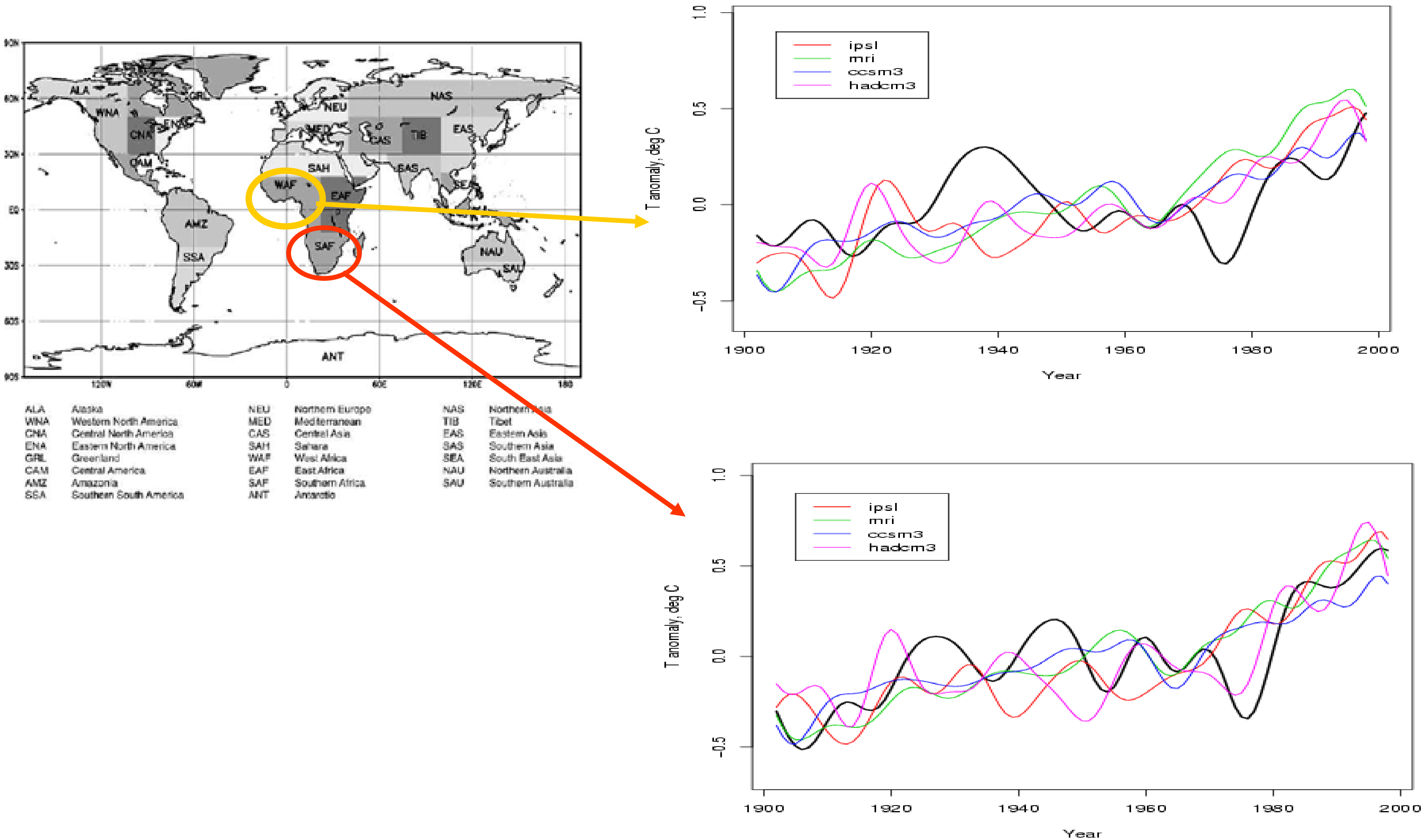
Goal:

just setting the stage for the panel discussion,
hopefully stating the agreed-upon state of affairs.

Some uncertainties are just unavoidable:
Scenarios of future emissions are one of those



Some uncertainties are just unavoidable: Natural variability is another



Slide courtesy of Lisa Goddard, IRI, Columbia

Some uncertainties are just unavoidable:
Modeling approximations cause others,
even if models were as good as they could possibly be

PNAS PNAS PNAS

Irreducible imprecision in atmospheric and oceanic simulations

James C. McWilliams*

Department of Atmospheric and Oceanic Sciences and Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1565

Contributed by James C. McWilliams, April 4, 2007 (sent for review March 1, 2007)

Atmospheric and oceanic computational simulation models often successfully depict chaotic space–time patterns, flow phenomena, dynamical balances, and equilibrium distributions that mimic nature. This success is accomplished through necessary but non-unique choices for discrete algorithms, parameterizations, and coupled contributing processes that introduce structural instability into the model. Therefore, we should expect a degree of irreducible imprecision in quantitative correspondences with nature, even with plausibly formulated models and careful calibration (tuning) to several empirical measures. Where precision is an issue (e.g., in a climate forecast), only simulation ensembles made across systematically designed model families allow an estimate of the level of relevant irreducible imprecision.

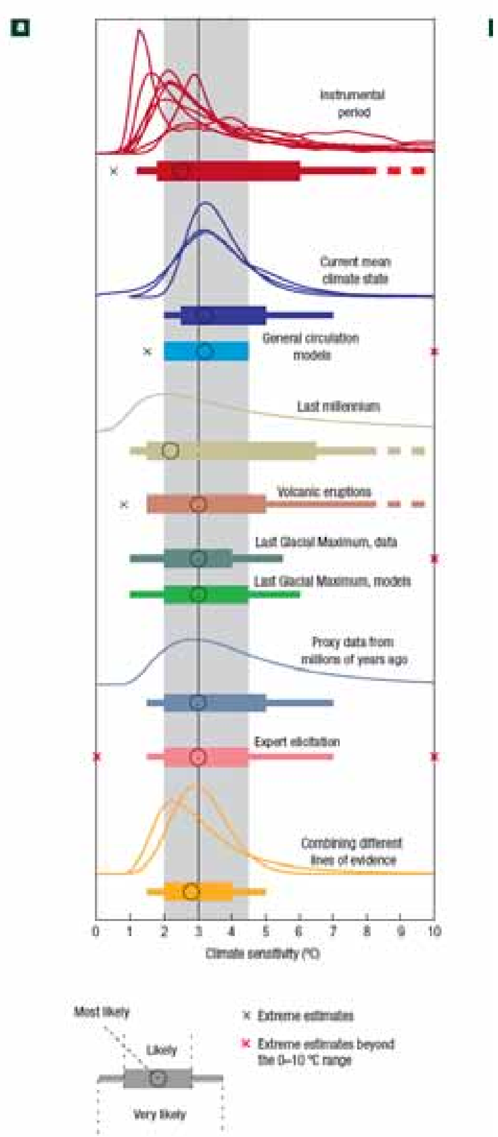
ocean | atmosphere | climate | simulation | global change

Extensive experience over several decades shows that computational atmospheric and oceanic simulation (AOS) models can be devised to plausibly mimic the space–time patterns and components are included as appropriate to the target problem. Global, equilibrium target problems include the influences of Earth's rotation, gravity, fluid compositions, and solid-surface configuration, as well as forcings by solar radiation, gravitational tides, and air–sea–land interface fluxes of momentum, heat, and materials. Local and limited-time target problems include boundary and initial conditions extracted or abstracted from the equilibrium global air–sea dynamical system.

The fruits of AOS are the many forms of intrinsic variability that spontaneously arise through instability of directly forced circulations and have important feedbacks on large-scale, low-frequency fields. Their varieties include coherent atmospheric storms and oceanic eddies, gravitational and rotational waves emitted in internal adjustments, turbulent transports between different locations, and cascades of variance and energy across the space–time spectrum that effect the mixing and dissipation essential for evolution toward balance with the forcing. An AOS can provide reliable realizations for idealized processes. AOS solutions expose structural and dynamical relations among dif-

May 2007, vol. 104, n.21

Some uncertainties will likely be narrowed with better modeling, more and better observations, or, more likely, a mix of the two…



Estimates of climate sensitivity from different sources of evidence

From Knutti and Hegerl, 2008, vol.1 Nature Geoscience

…but not for a while!

So, what in the meantime?

We are subject to a mix of uncertainty sources which varies depending on the scale of the answer we are seeking.

Regional vs. Global Projections
Short-Term vs Long Term

also:
Temperature vs. Precipitation vs…
Average Behavior vs. Extreme Behavior
Monthly vs. Daily Quantities

Characterizing this mix for temperature and precipitation

The questions that we are trying to answer are:

What are **the relative fractions of the total variance** in future projections explained by natural variability, inter-model variability and inter-scenario variability, and how does the relative importance of the three sources of uncertainty varies with "forecast lead time", with regional scale of prediction, and with specific location?

What is the **signal to noise ratio** of the projected change and how does that vary according to the same factors?

How are these analyses different when we **consider temperature vs. precipitation.**

The following discussion and maps are taken from
Hawkins & Sutton (2009), BAMS, and
Hawkins & Sutton (2010) Climate Dynamics
for temperature and precipitation respectively.

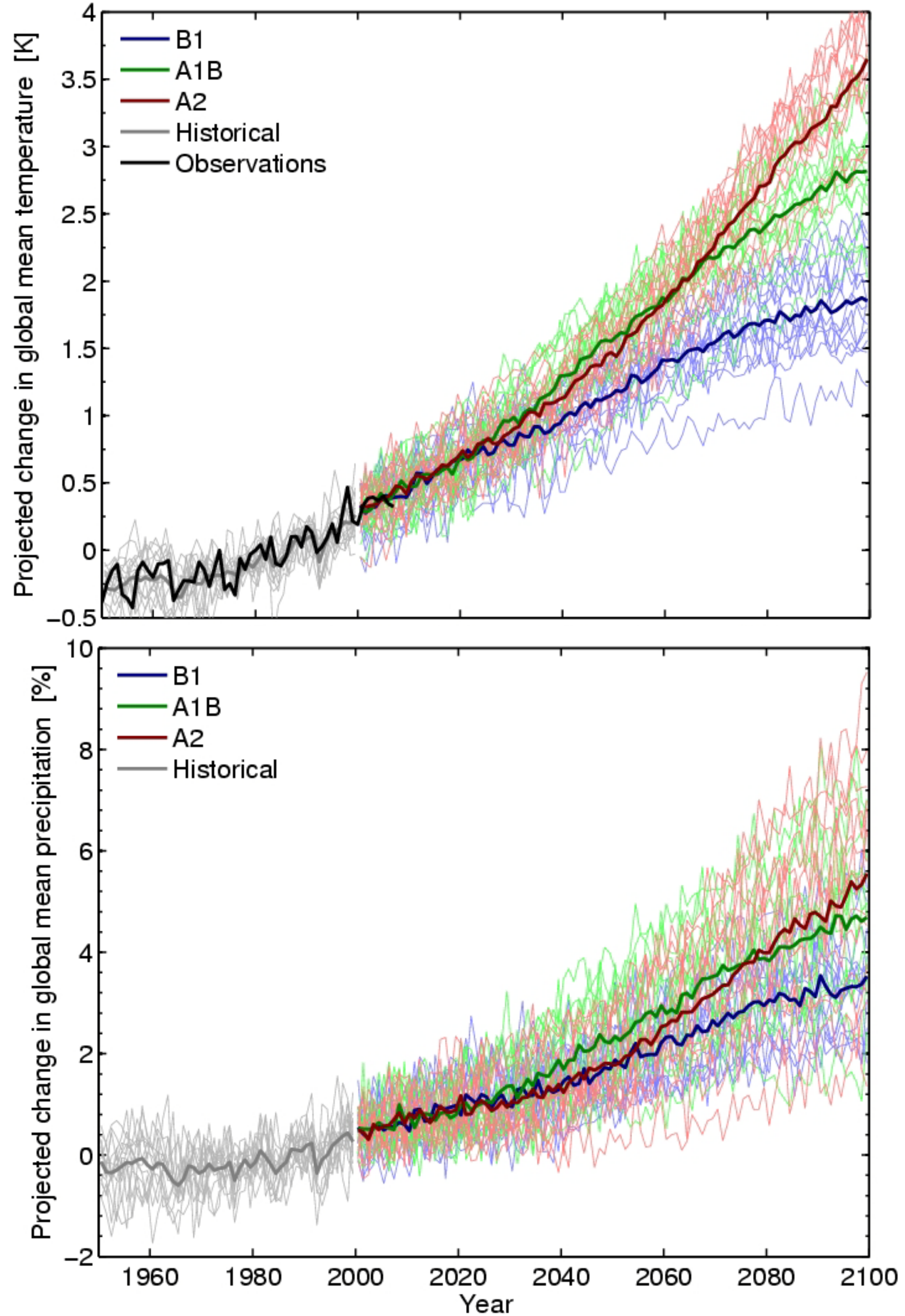
Smooth out each of the lines first.

The variance of the residuals from those smooth lines, computed across each of the trajectories is what determines the estimate of natural variability.

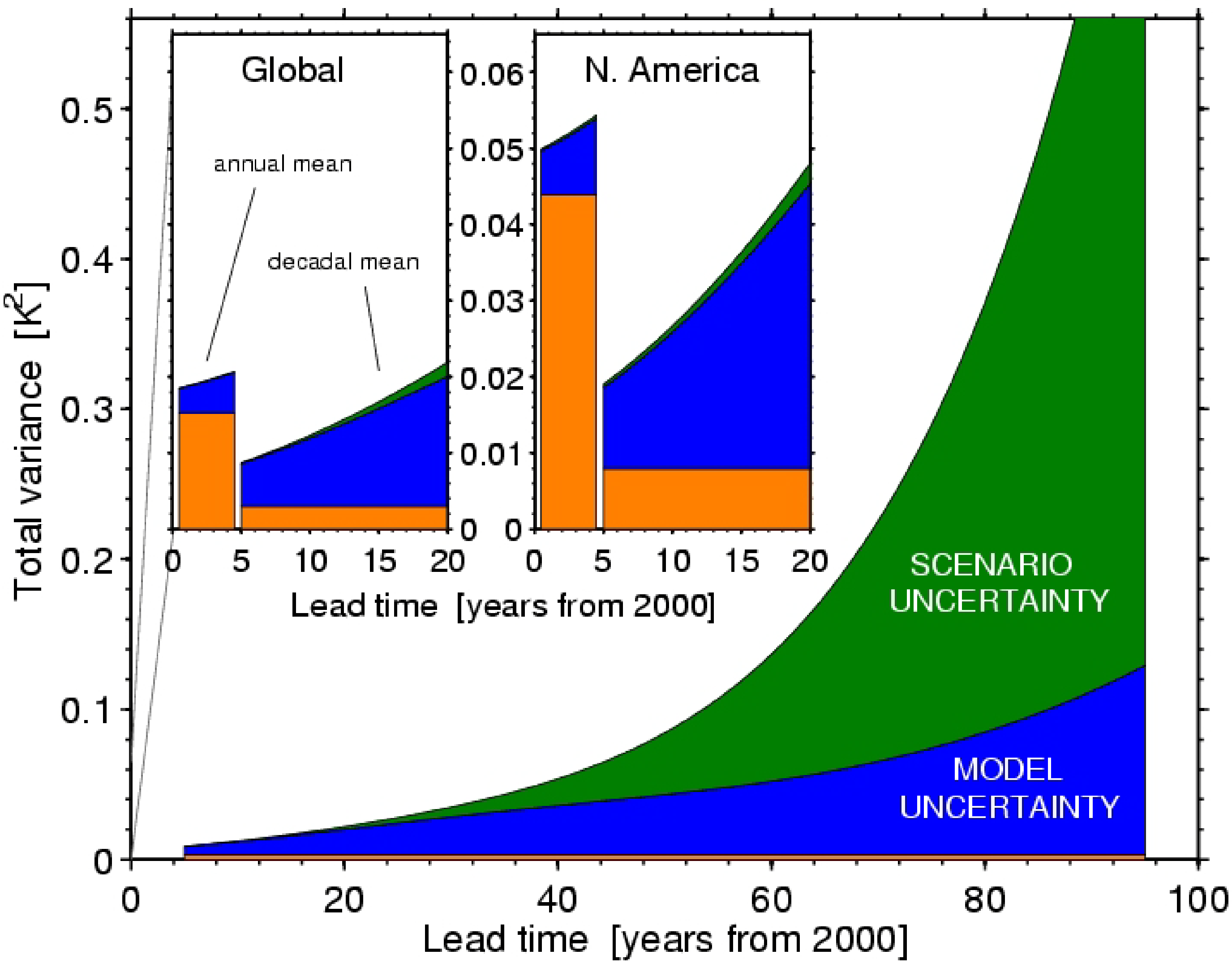
The variance of each model's smooth line from the scenario-specific multimodel mean, averaged across scenarios is what determines the model variability.

The departure of each scenario-specific, smooth multimodel mean from the overall smooth mean is what determines the scenario variability.

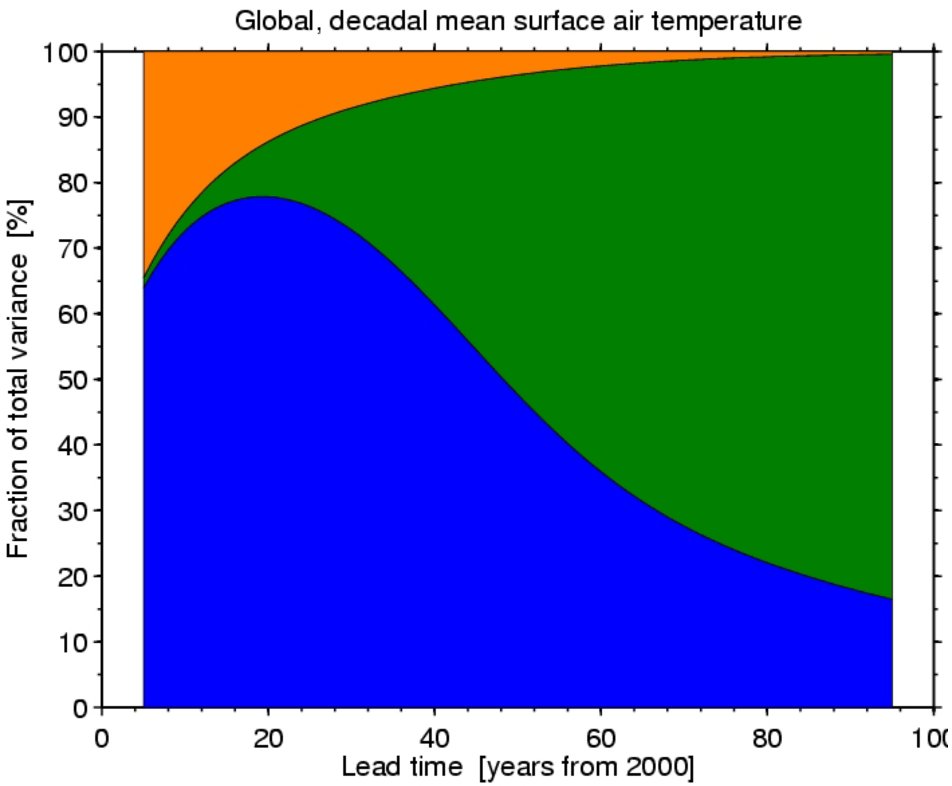
The total variance is made up of the sum of the three. The fractional variance is computed by dividing the total variance by the overall mean change.

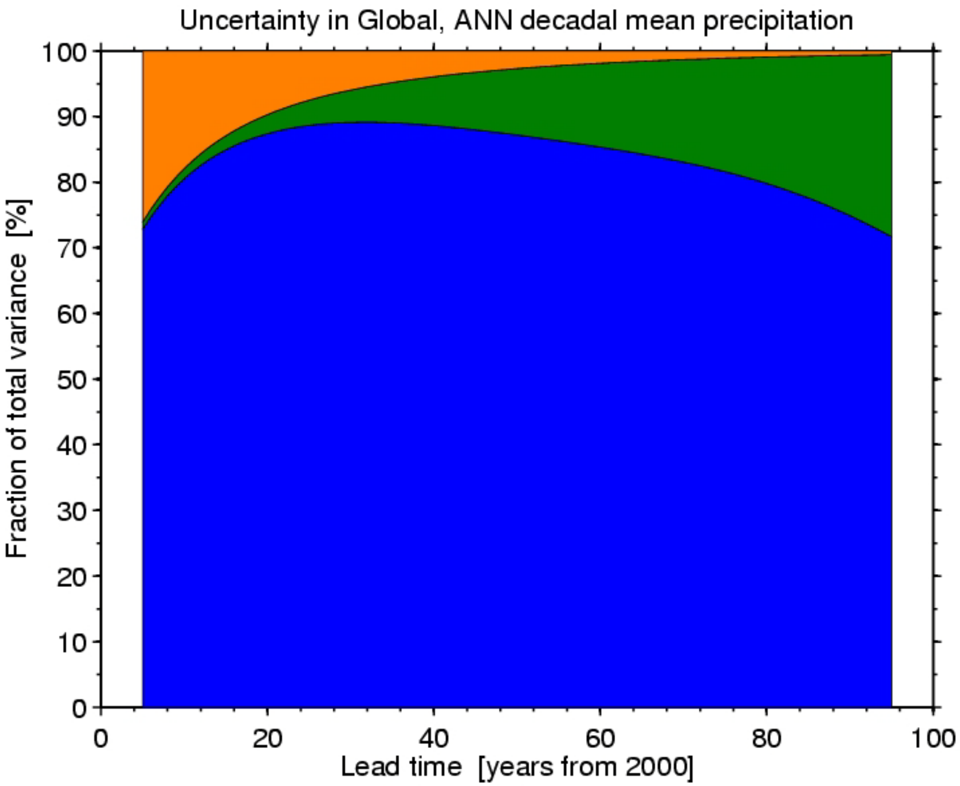


Total variance – a measure of the “cone” getting wider with time

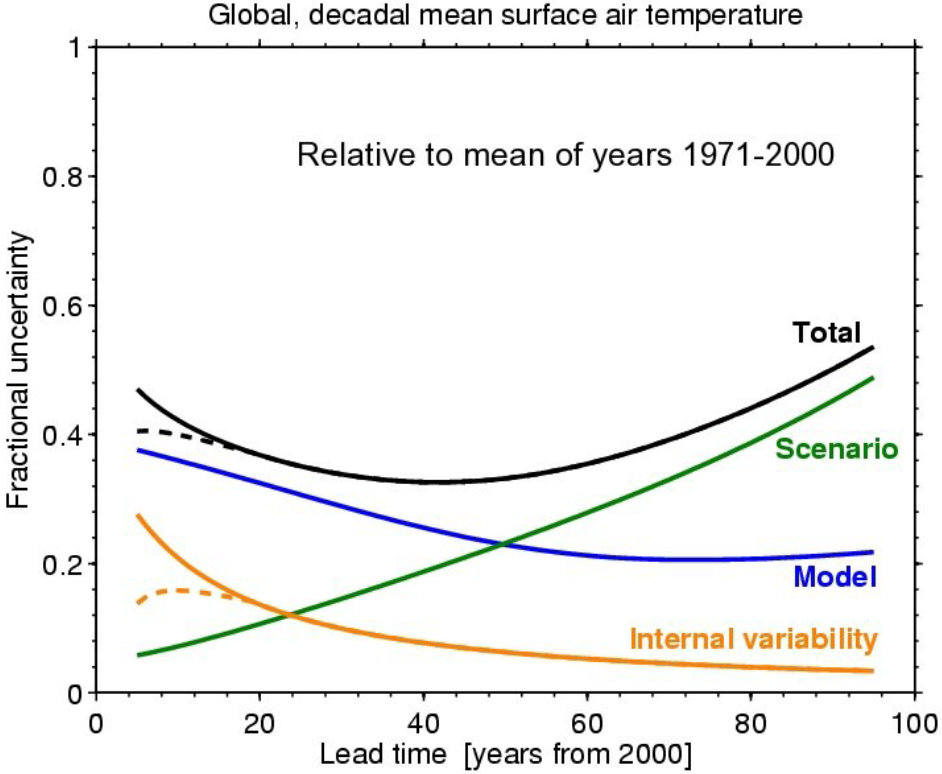


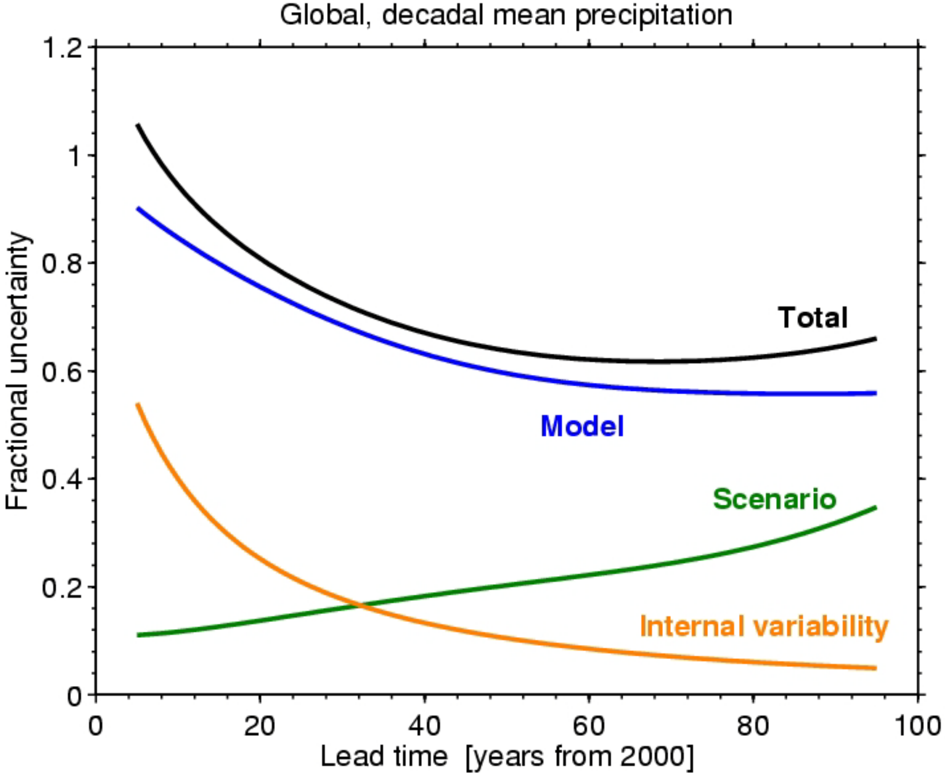
Fraction of total variance:
conditional on the total variance, what is the relative importance of the three sources?





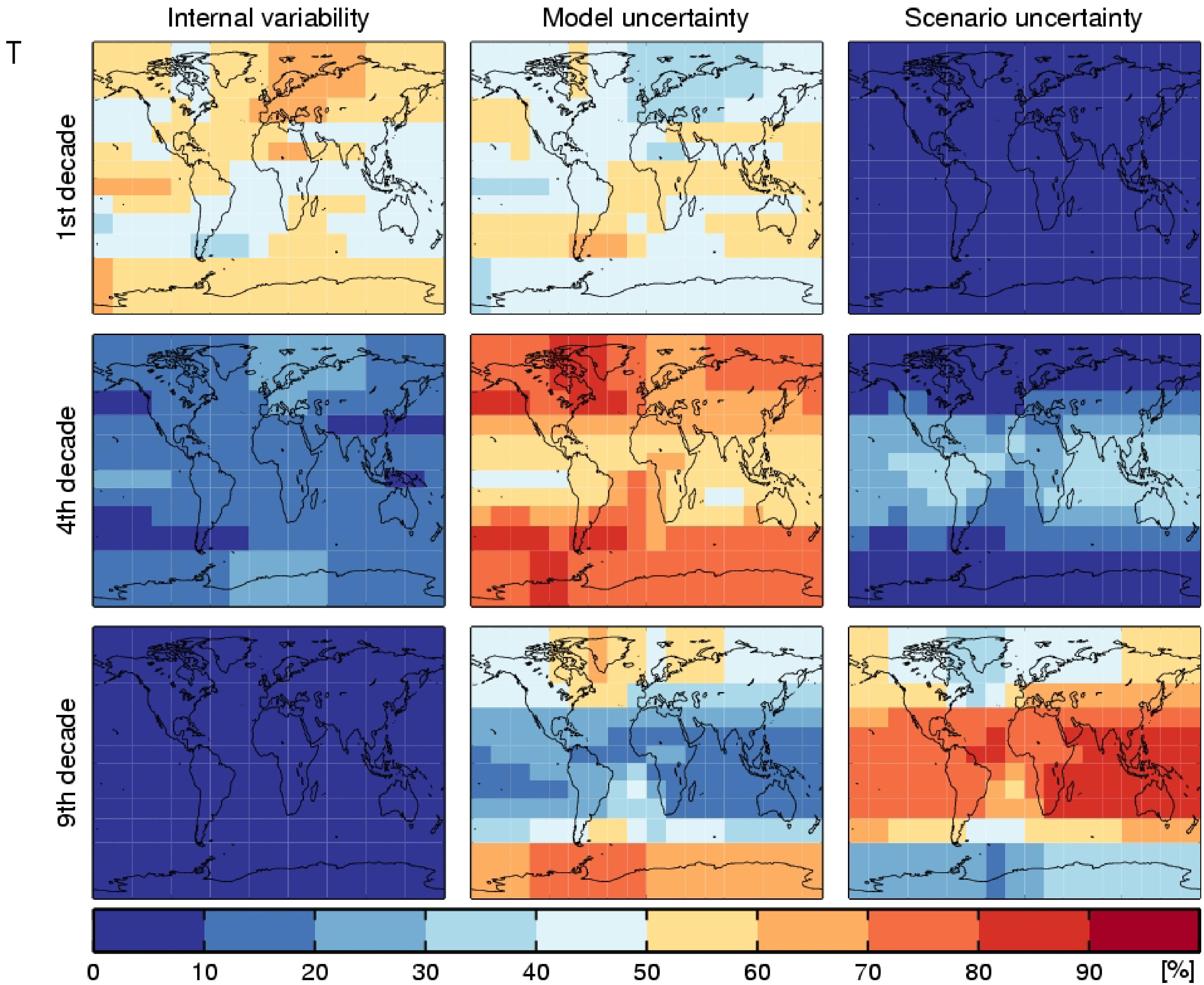
Fractional variance
total variance, divided by the mean change
You can also think of it as the inverse of S/N

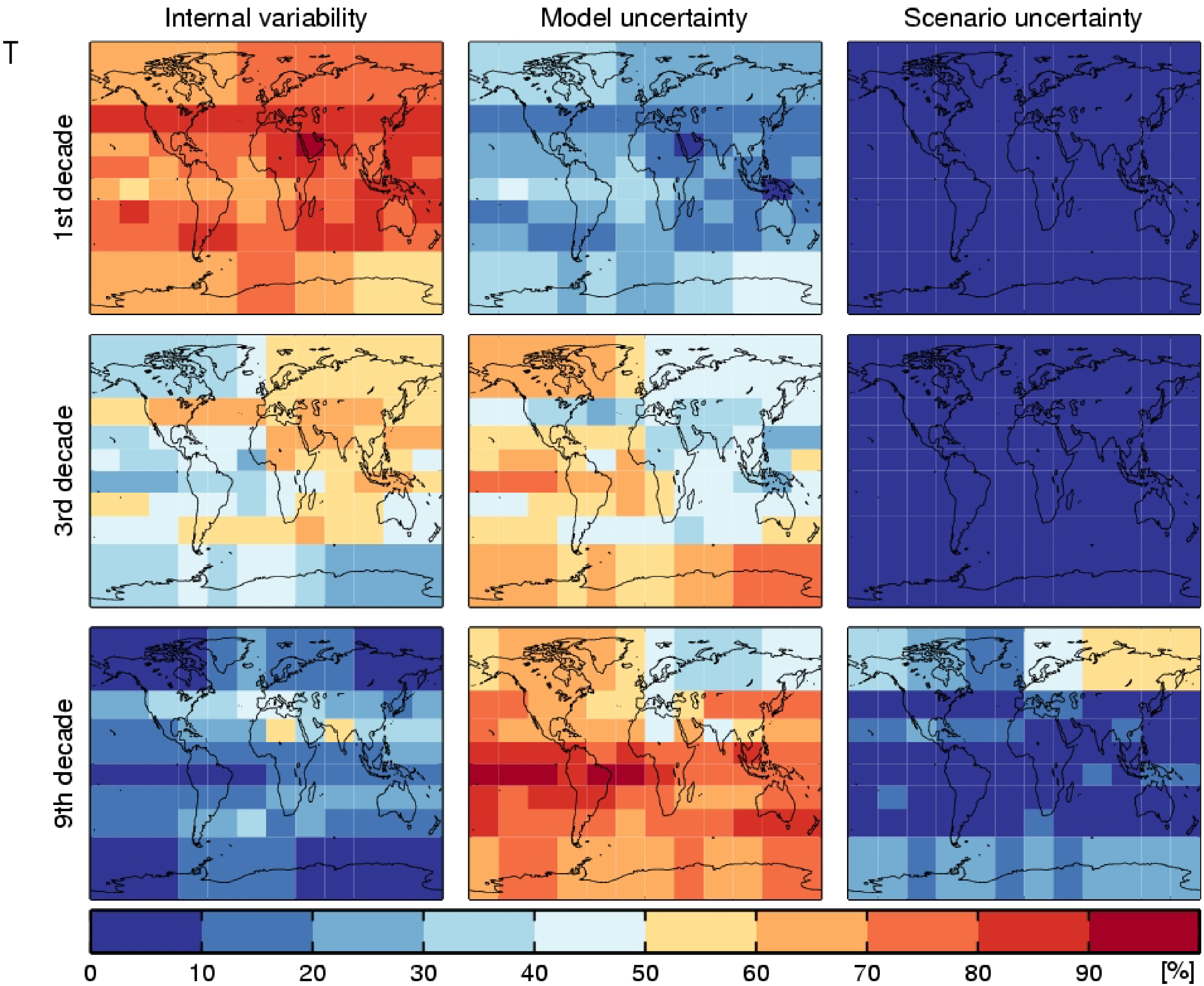




H&S point out the existence of a *sweet spot* for T around year 40

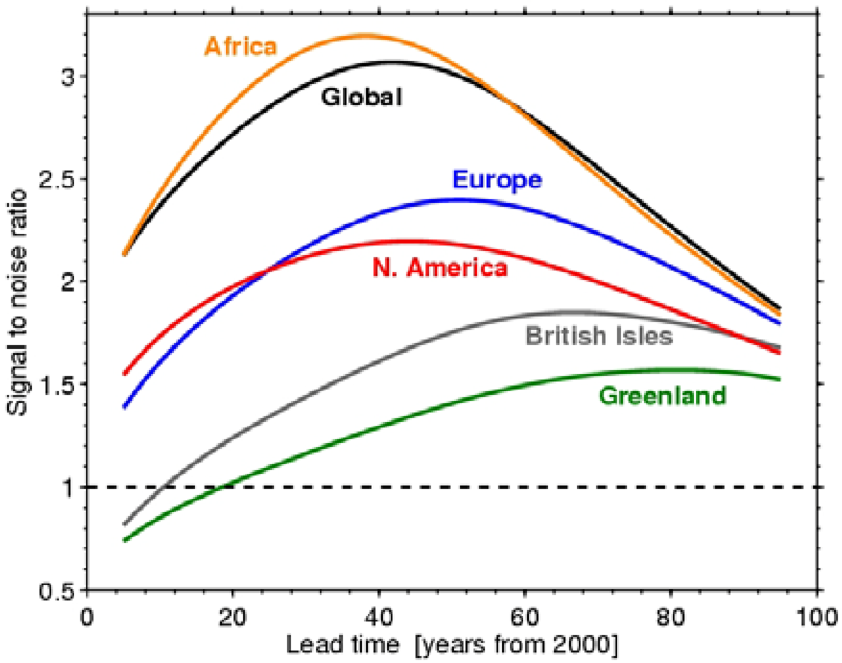
How does this all change when focusing on **regional rather than global** means?

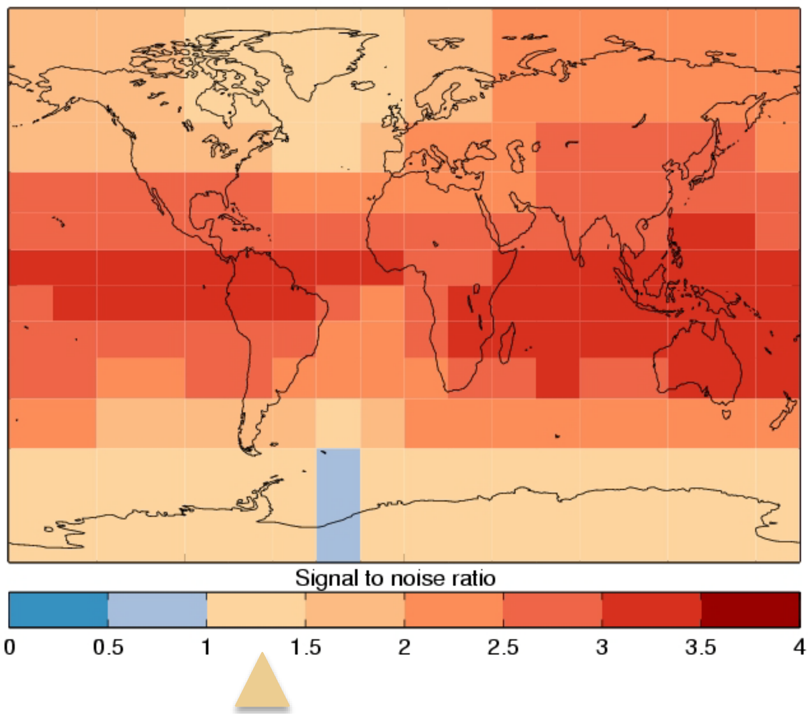

T
Internal variability
Model uncertainty
Scenario uncertainty
1st decade
4th decade
9th decade
0
10
20
30
40
50
60
70
80
90
[%]



T
Internal variability
Model uncertainty
Scenario uncertainty
1st decade
3rd decade
9th decade
0
10
20
30
40
50
60
70
80
90
[%]

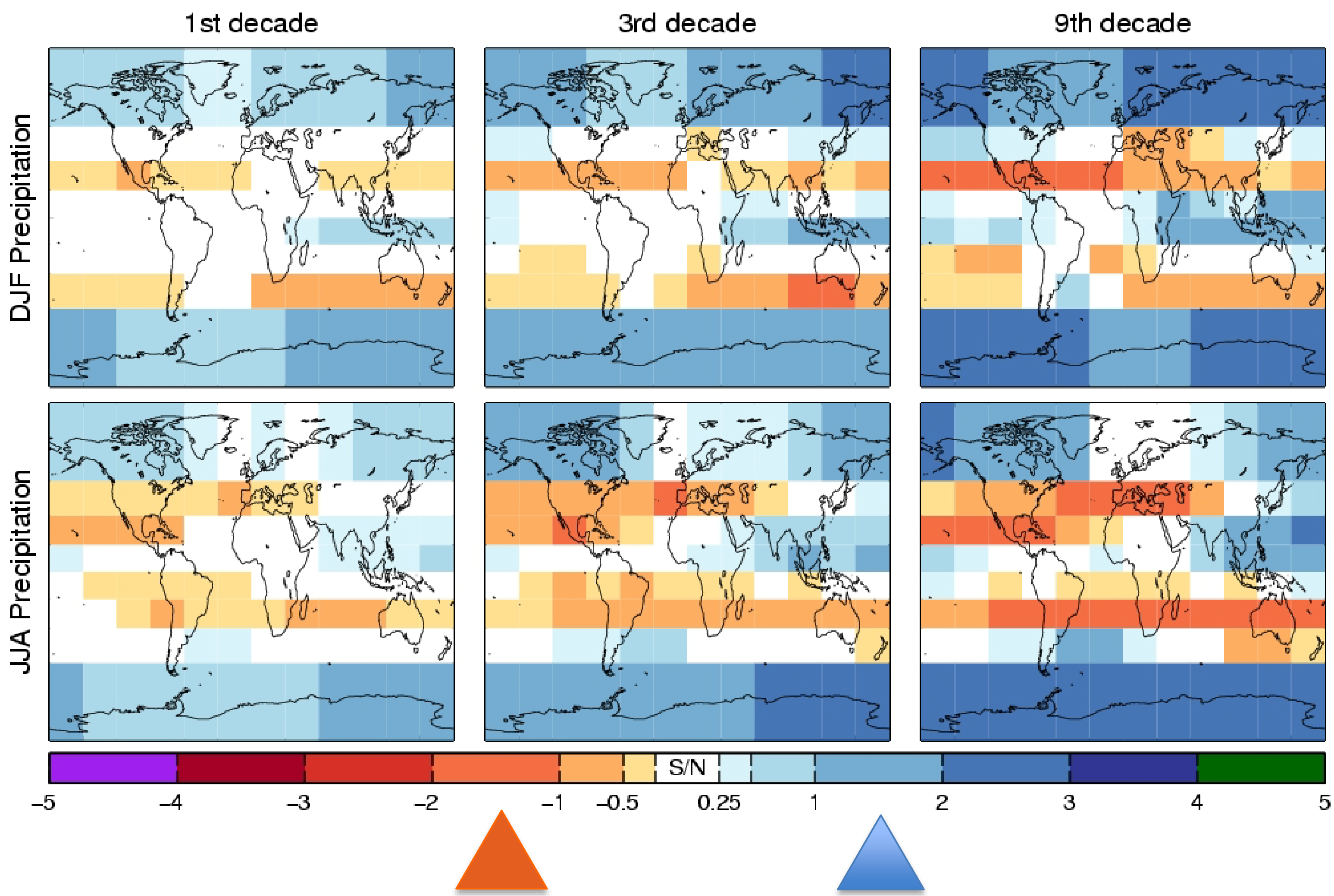
What about signal-to-noise ratio?





Temperature change. Fourth decade illustrated in right panel

Signal-to-noise ratio for precipitation change



So it seems as **if model uncertainty** and **natural variability** play the major role, with **scenarios** kicking in only after 30 years or so of lead time.

What are the **robust findings** across models for temperature and precipitation and what remains uncertain beyond that?

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

C. R. Geoscience 340 (2008) 584–590

COMPTES RENDUS GEOSCIENCE

http://france.elsevier.com/direct/CRAS2A/

External Geophysics, Climate and Environment

Uncertainties attached to global or local climate changes

Hervé Le Treut *, Guillaume Gastineau, Laurent Li

Laboratoire de météorologie dynamique/IPSL (université Pierre-et-Marie-Curie, École normale supérieure, École polytechnique, CNRS), 24, rue Lhomond, 75231 Paris cedex, France

Received 7 April 2008; accepted after revision 16 June 2008
Available online 15 August 2008

There are **robust changes** in temperature and precipitation, that have been noted across many generations of GCMs and start to also surface in observations.

They are **mostly qualitative rather than quantitative**:

ü High latitudes warm more than mid-to-low latitudes.

ü Land warms more than oceans.

ü Global mean precipitation increases in a warmer world.

ü Wet regions become wetter, dry regions drier.

ü Precipitation intensity will tend to increase.

What we cannot say with precision is **how much** and **where** exactly.

What the paper contributes is an explanation of why:

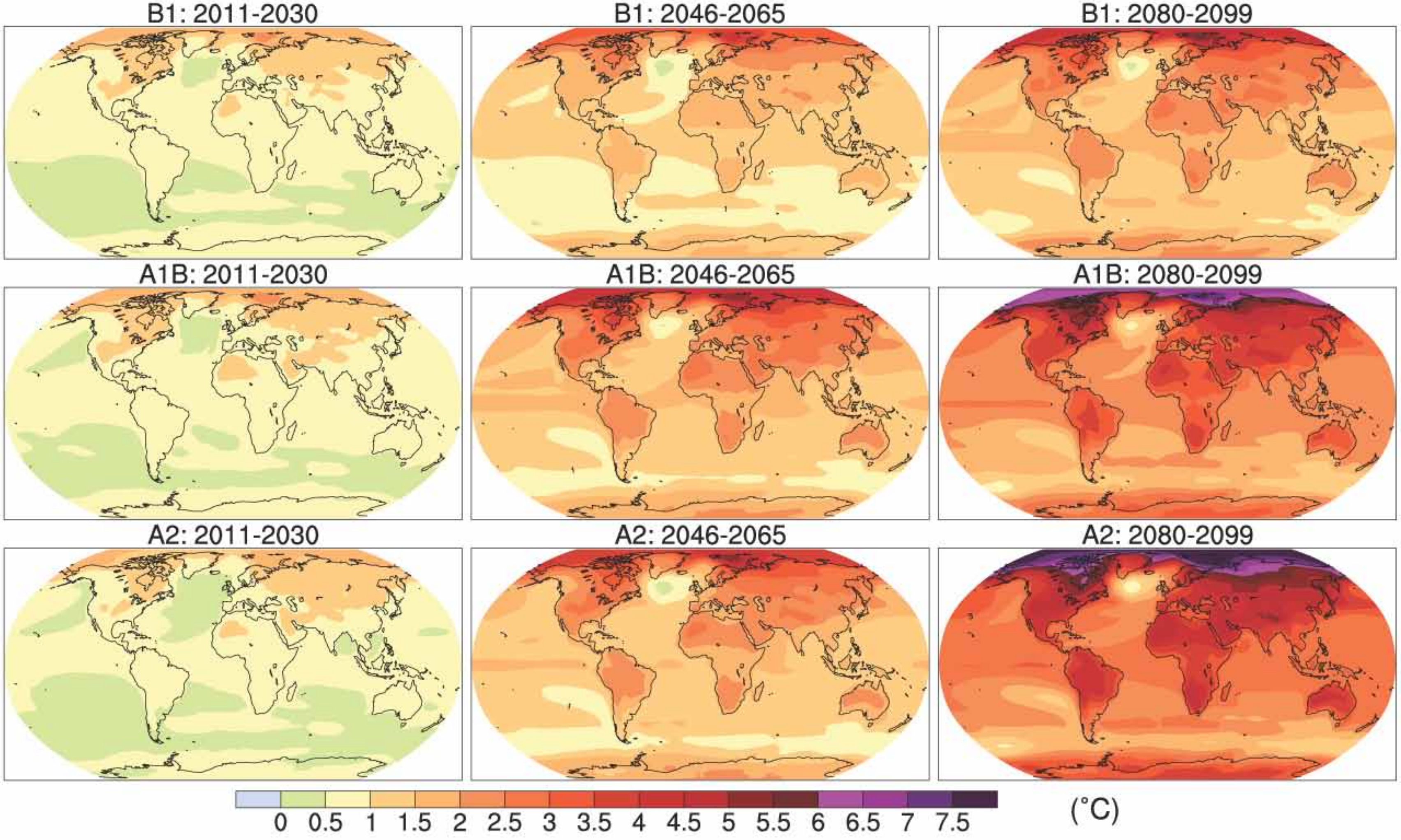
Those qualitative changes have to do with the **thermodynamic** response to increased GHGs, whose basic features are common to models.

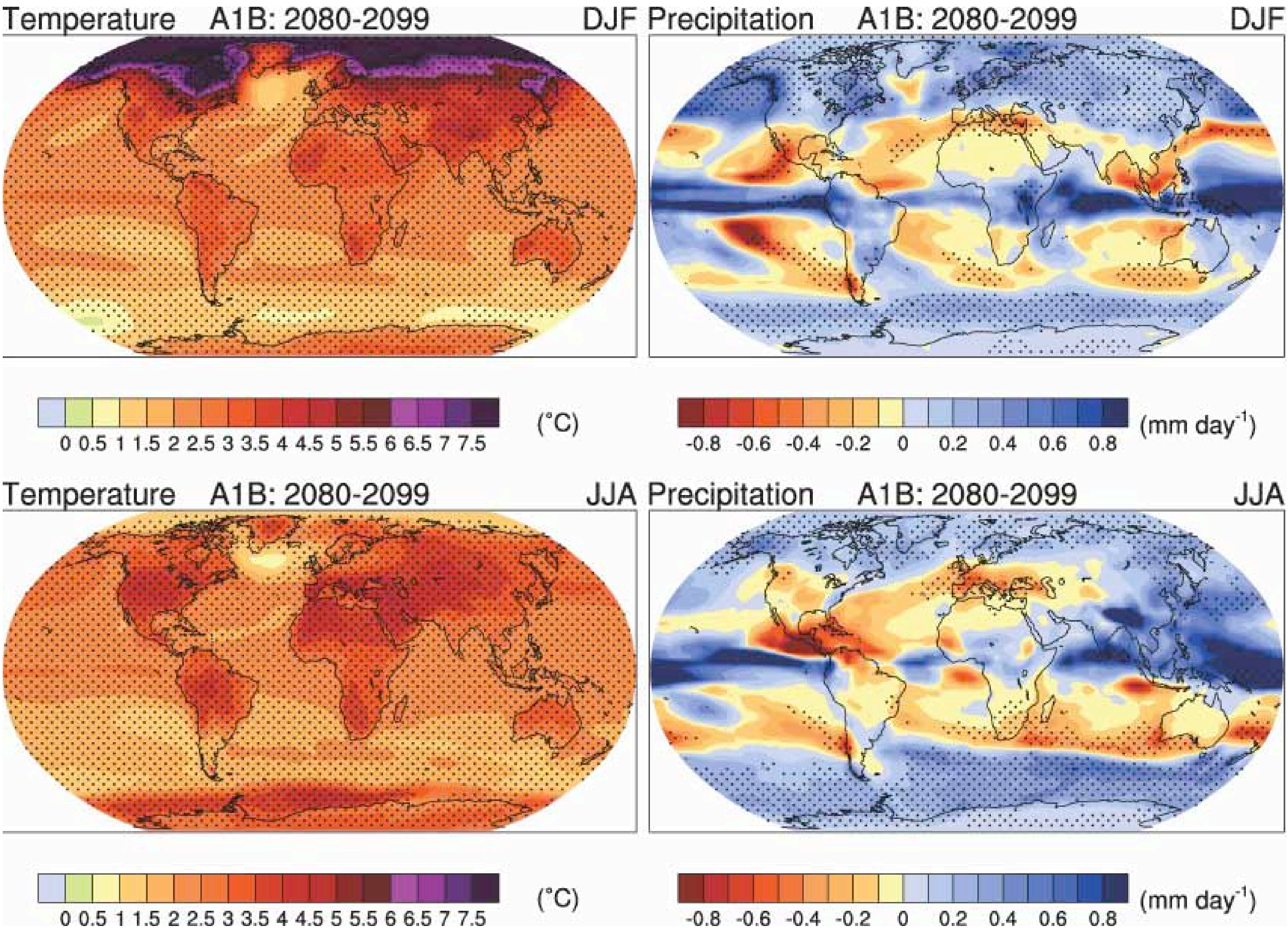
The regional changes and the quantitative changes depend on the **feedbacks** mechanisms and the **atmospheric dynamic** changes (expansion of the Hadley cell) that are not robust across models.

The paper concludes by calling for the need of increased resolution, better physics parameter exploration (which was also mentioned in McWilliams' paper)

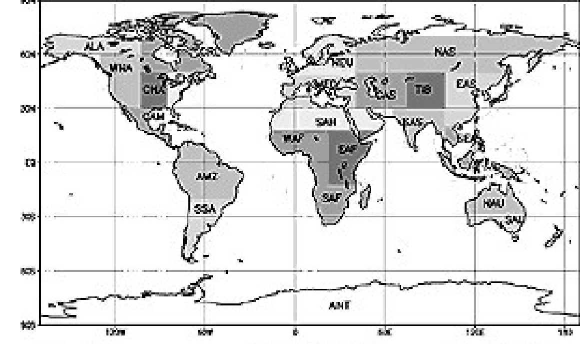
That is where Multi-Model Ensembles and Perturbed Physics Ensembles need to come in.

MMEs and PPEs are to help in characterizing model uncertainty, as it can described by parameter or structural uncertainty.

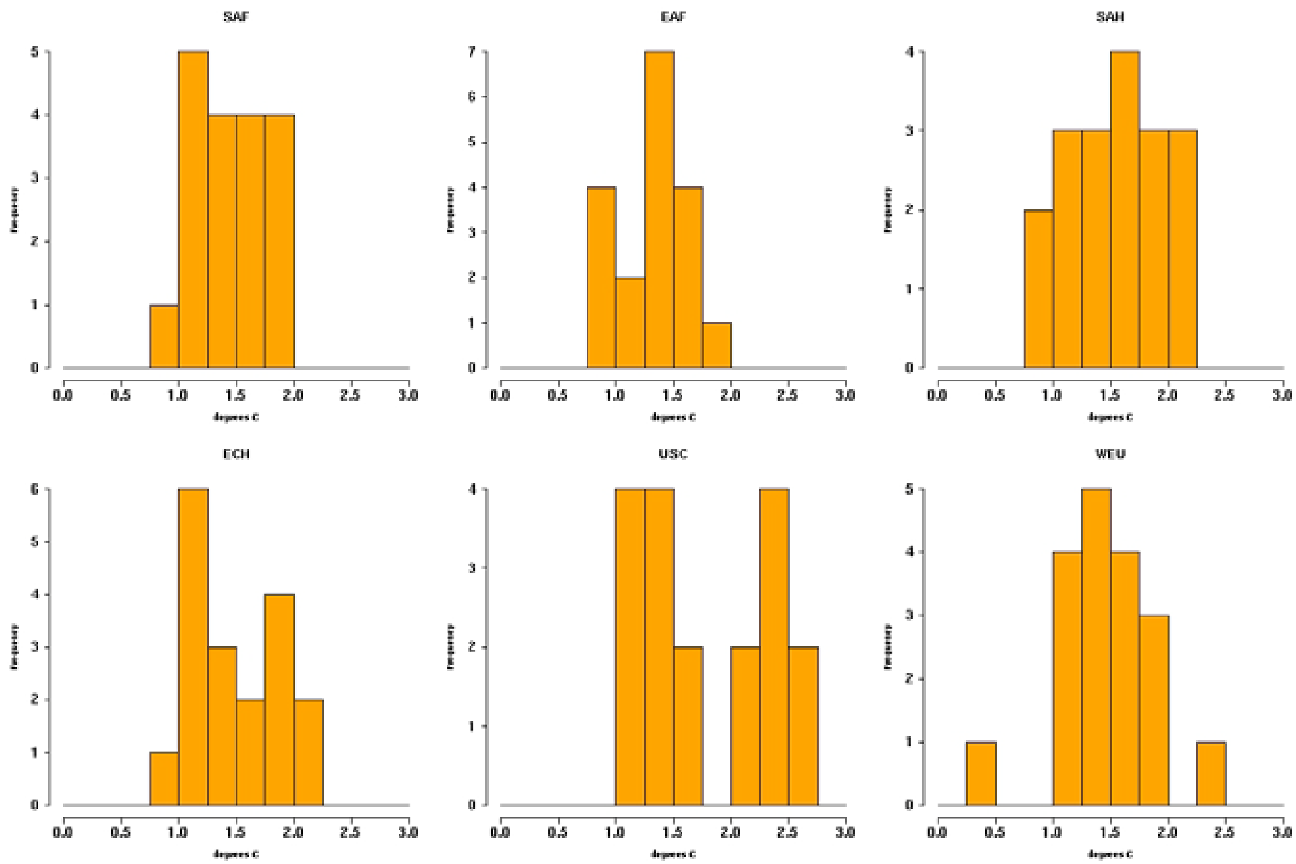

B1: 2011-2030
B1: 2046-2065
B1: 2080-2099
A1B: 2011-2030
A1B: 2046-2065
A1B: 2080-2099
A2: 2011-2030
A2: 2046-2065
A2: 2080-2099
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5
(°C)


Temperature A1B: 2080-2099 DJF
Precipitation A1B: 2080-2099 DJF
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5
(°C)
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
(mm day^{-1})
Temperature A1B: 2080-2099 JJA
Precipitation A1B: 2080-2099 JJA
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5
(°C)
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
(mm day^{-1})

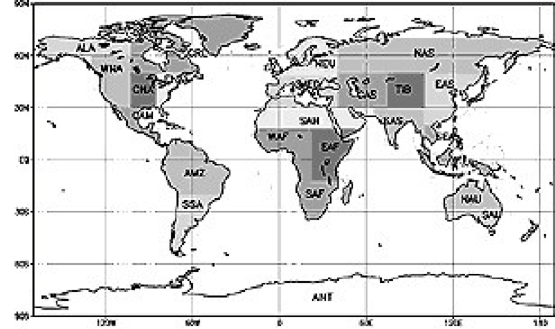
What is behind agreement/disagreement:
A distribution of projected changes



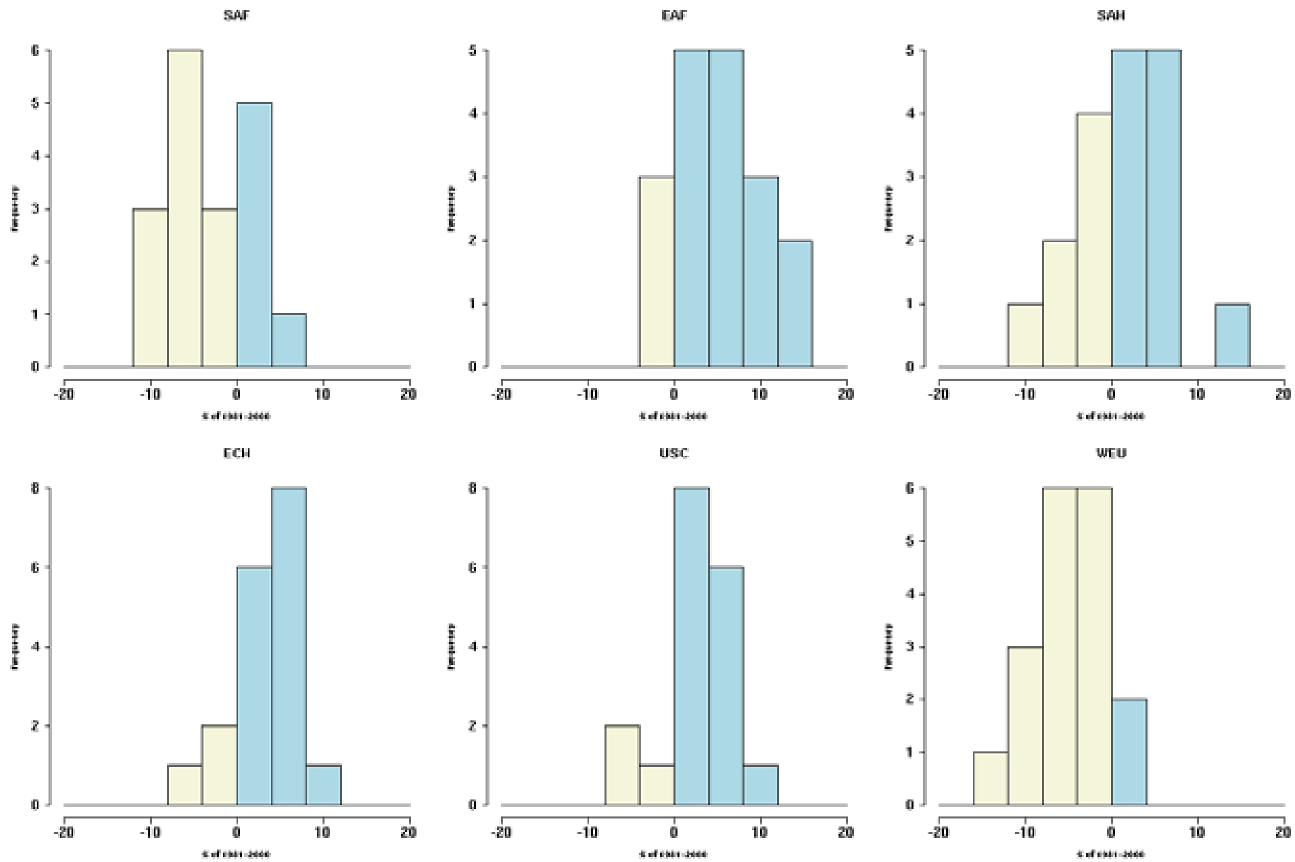
Looking at regional averages of temperature change



What is behind agreement/disagreement:
A distribution of projected changes

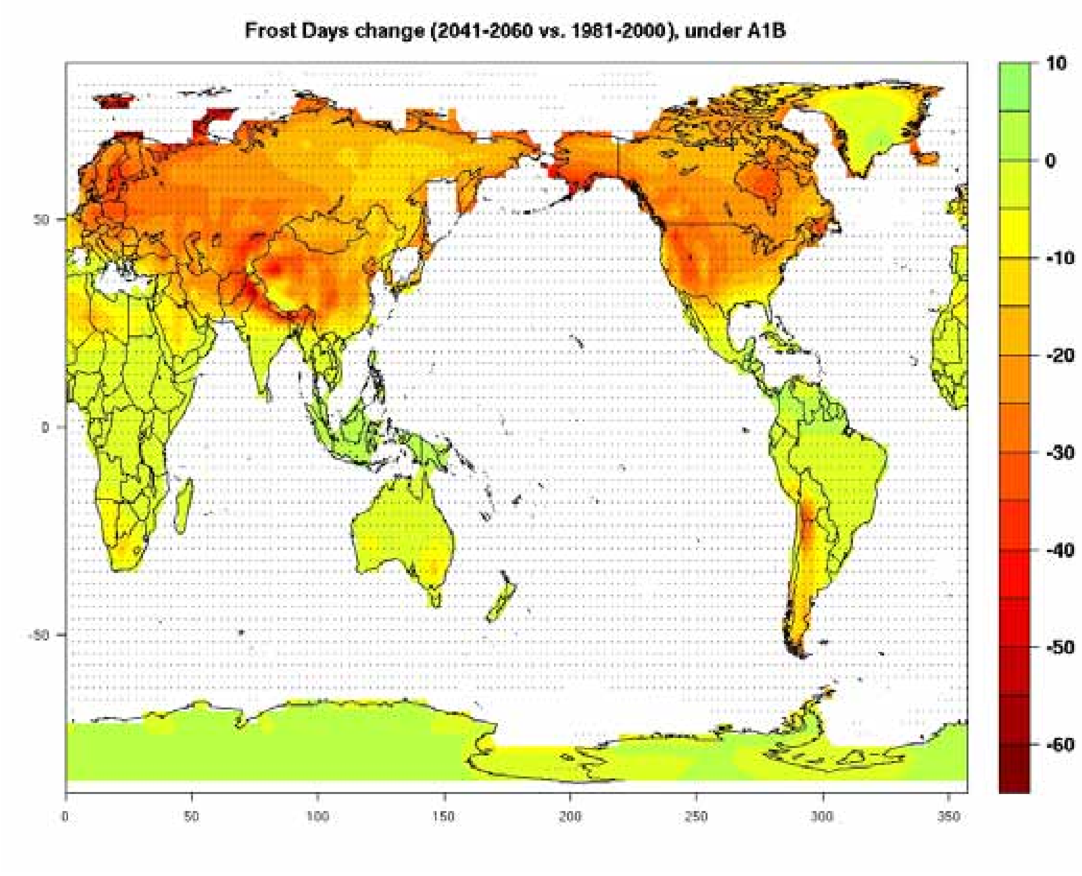


Looking at regional averages of % precipitation change

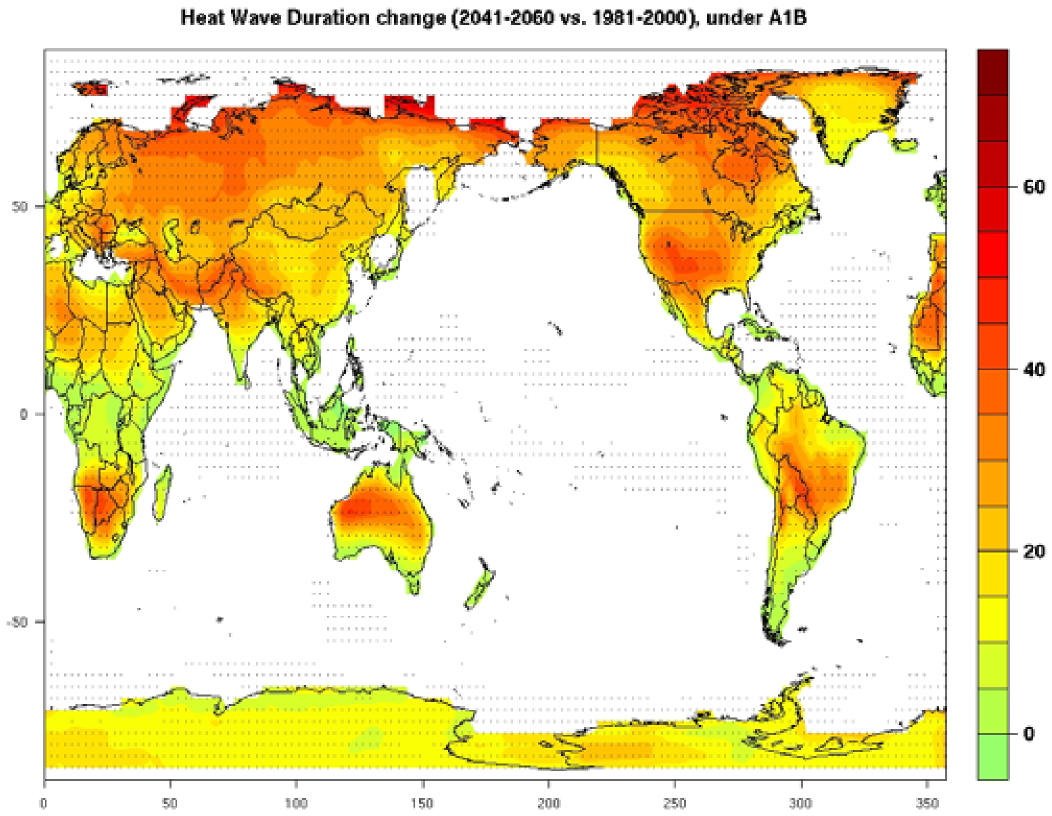


Extremes from GCMs

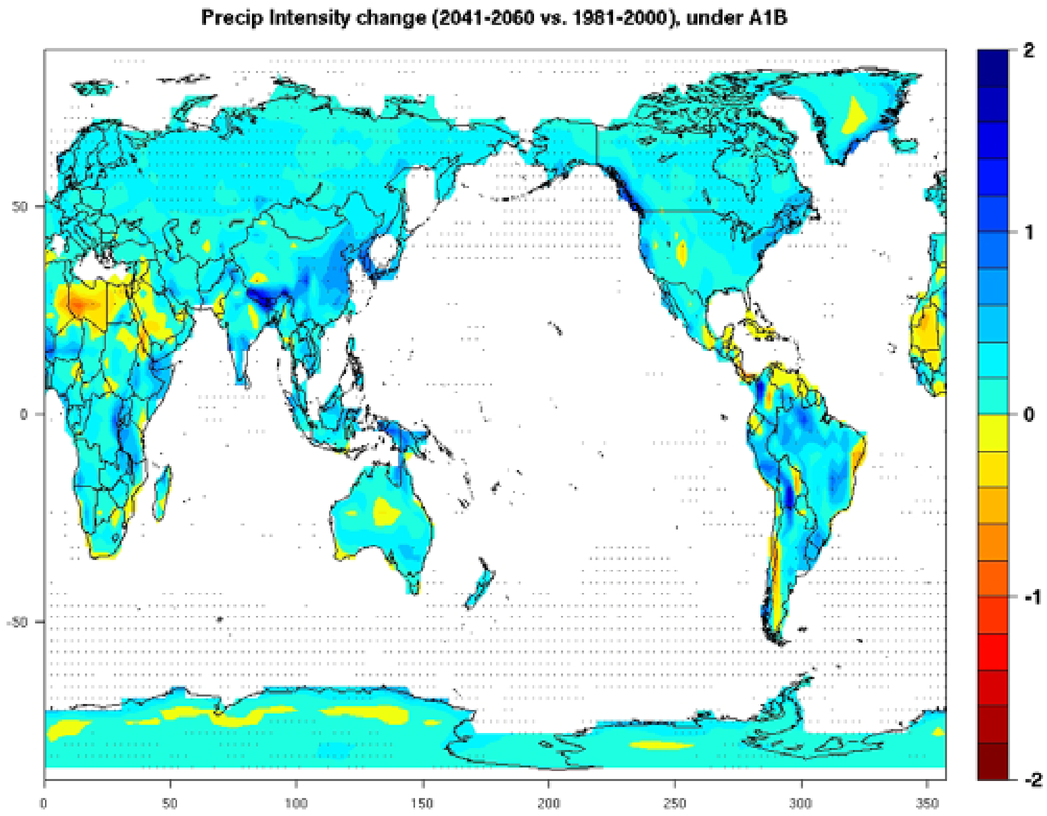
Frost Days



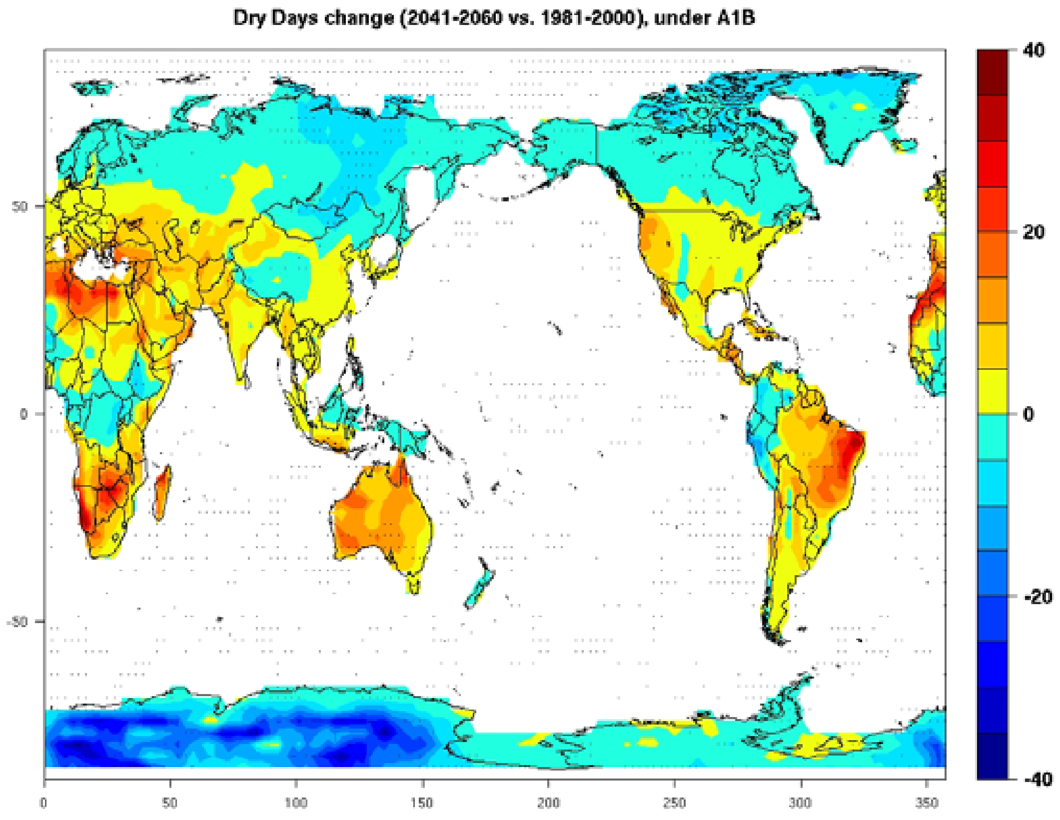
Heat Waves Duration



Precipitation Intensity

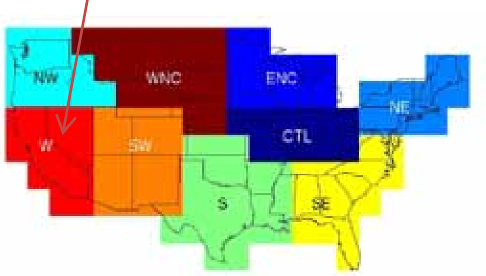


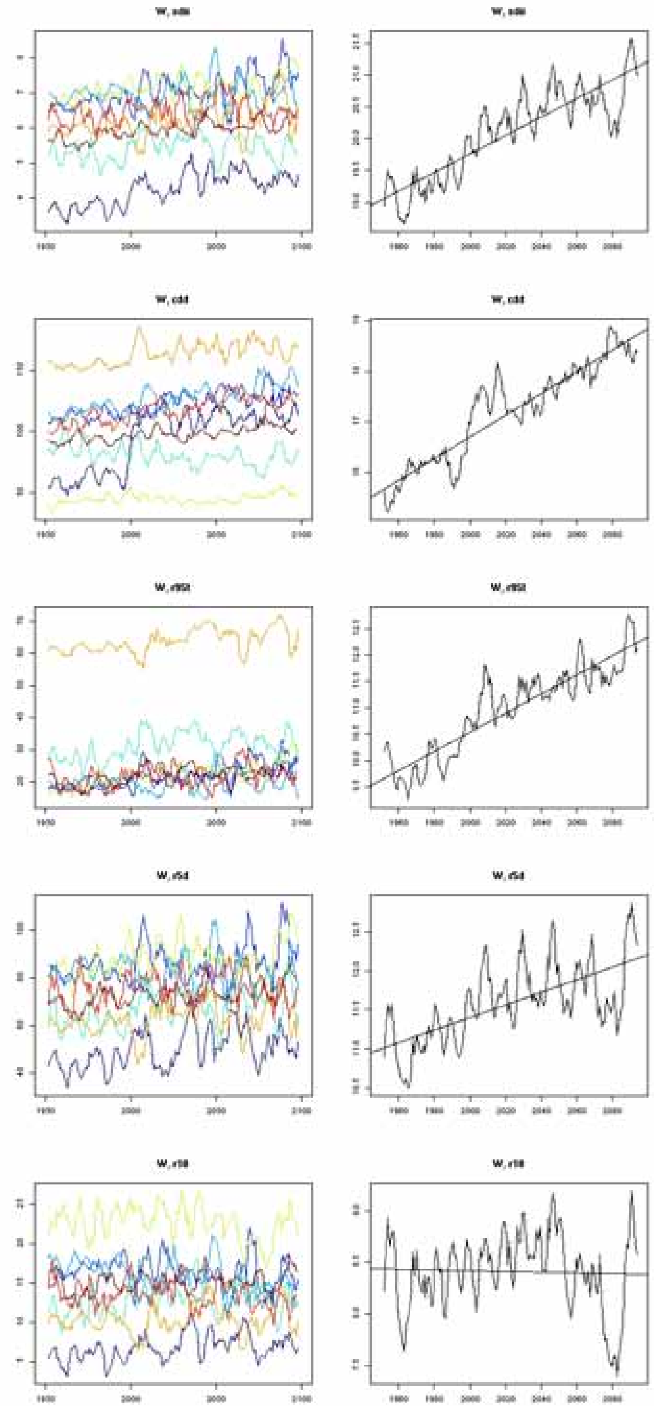
Dry Days


Dry Days change (2041-2060 vs. 1981-2000), under A1B
50
0
-50
0
50
100
150
200
250
300
350
40
20
0
-20
-40

Regionally averaged
extreme precipitation indices
9 models, 1950-2100 (A1B)

West US





Precip intensity

Consecutive dry days

Days with precip>10mm

Max 5-days total amount

Percent falling in heavy
Days (>95th percentile)

A couple of words about quantification of the uncertainty
(*more in the panel I would hope*)

There is a lot going on out there, in terms of methodological development.

Weighted vs. unweighted ensembles
Truth+error vs undistinguishable paradigm

You can consult the paper by IPCC about Good Practice/Guidance on the use of multiple models:
http://www.ipcc.ch/pdf/supporting-material/expert-meeting-assessing-multi-model-projections-2010-01.pdf

It's fair to say that there is no clear winner among the approaches, and unfortunately different approaches result in different uncertainty quantifications.

Underlying all this there is also the awareness/concern that these models may not span the range of the known unknowns, and may be missing on some of the unknown unknowns*.

Downscaling

The lion share of uncertainties resides with global modeling. *So one good rule of thumb is to use downscaling only if it provides downscaled output from a set of GCMs.*

Other people in this room have looked at different downscaling options and may have something to say about that part, but --- as Linda points out in her answers to the survey -- *we need to perform a systematic comparison of the options out there, until then any answer will be very case-specific.*

What I conclude for now – again the panel will do better than this!

Characterizing uncertainties in climate change projections requires extreme attention to the sort of question we are trying to answer: spatial scale, time horizon, variable(s) of interest, mean vs variability, natural vs. forced, on the basis of which the relative importance of the different sources of uncertainty will change.

What I conclude for now – again the panel will do better than this!

The quantification of uncertainty can be attacked through multi-model datasets, but won't be, at least for sometime, a robust quantification, and it will necessarily be dependent on some fundamental assumptions. Do we take the central tendency of these models as our best guess? Do we consider each model independent? Do we believe they are sampling enough of the parameter and structural uncertainty? Again the answers will very much depend on what variable we are interested in. These may likely have positive answers when it comes to large scale, long term projections for the forced signal.

What I conclude for now – again the panel will do better than this!

The top down approach will necessarily be limited by the overwhelming nature of what a description of future climate may consist of. Perhaps a bottom up approach, where the utilities strive to define at best what the question that is relevant to their operation is and the uncertainty quantification focuses on that, e.g. threshold characterization, could facilitate moving forward.