Uncertainties in climate change projections

An overview borrowing from recent literature and some personal work

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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.
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?
What about signal-to-noise ratio?

Temperature change. Fourth decade illustrated in right panel.
Signal-to-noise ratio for precipitation change

[Map showing signal-to-noise ratio for 1st, 3rd, and 9th decades of DJF and JJA precipitation]
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?
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:

- High latitudes warm more than mid-to-low latitudes.
- Land warms more than oceans.
- Global mean precipitation increases in a warmer world.
- Wet regions become wetter, dry regions drier.
- 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.
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
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:

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*. 

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.