

Quantifying uncertainty in climate model projections: Challenges and opportunities

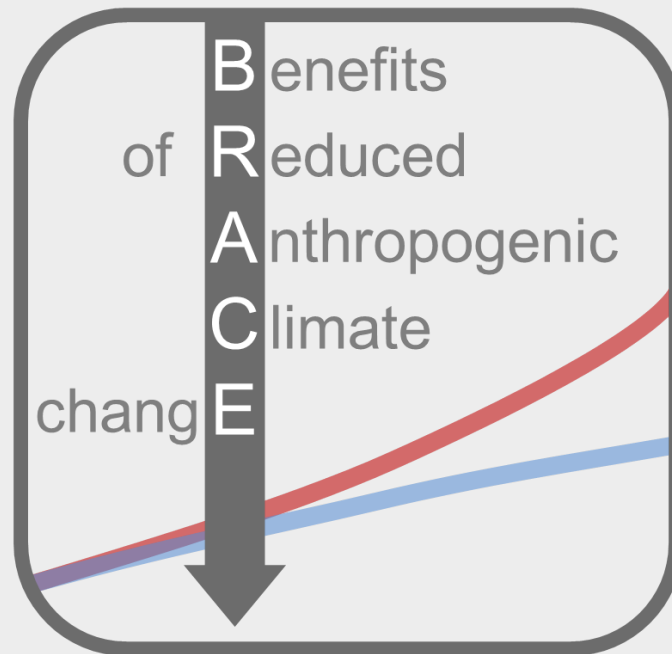
Claudia Tebaldi

**AGCI Session on Impact Relevance and Usability
of High-Res Climate Modeling and Datasets**

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A climate application question

What are the benefits of reducing anthropogenic forcings from RCP8.5 down to RCP4.5 in terms of agricultural impacts?



The recipe

Characterize a comprehensive range of possible outcomes in temperature and precipitation trends over several time frames (10 or 20 years, and longer horizons) from climate model output, using the different realizations of initial condition ensembles as “exchangeable with reality”.

Translate those projections into changes in crop yields. Use empirical frequencies as probabilistic measures.

Assess the risk of significant reduction in yields, short-term slowdowns.

Compare the results between scenarios and quantify reduced impacts/benefits of mitigation.

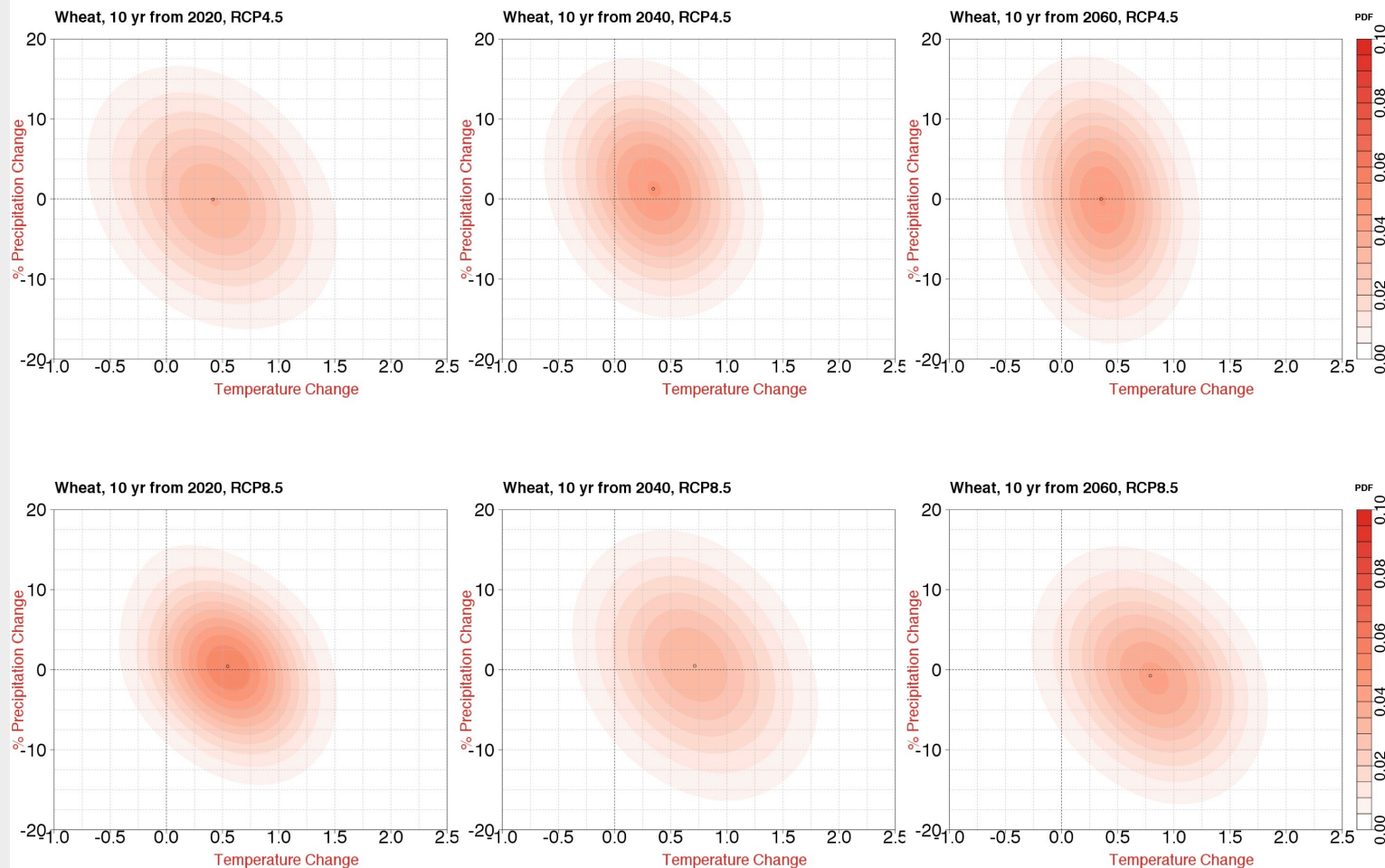
**Characterizing possible outcomes in
temperature and precipitation over the
next 10 to 20 years with or without
climate change**

RCP4.5 Medium Ensemble: 15 initial condition ensemble members from CESM1-CAM5

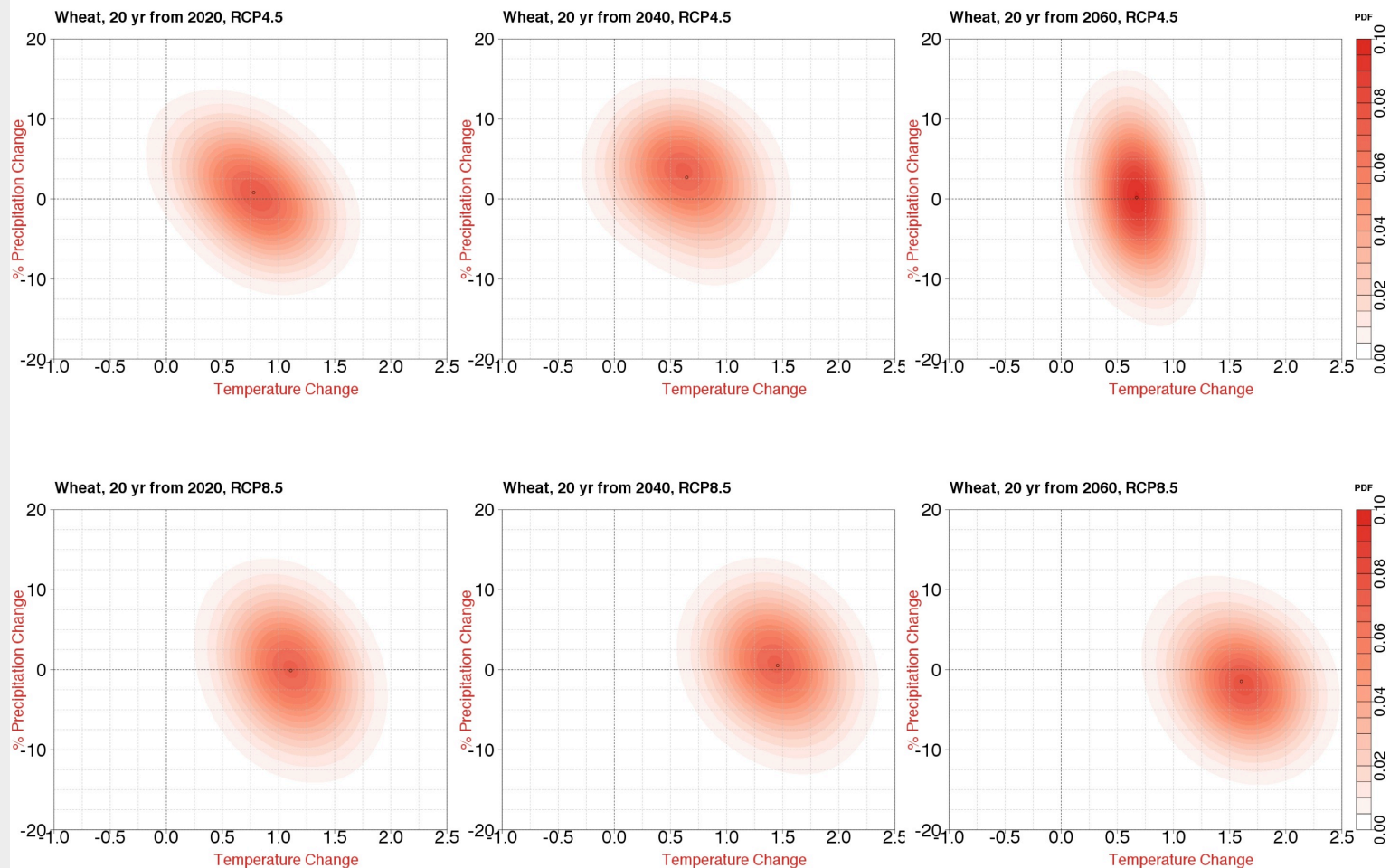
RCP8.5 Large Ensemble: 30 initial condition ensemble members from CESM1-CAM5

Empirical models (linear regressions) of the relation between temperature and precipitation change and yield change for two crops (wheat and maize).

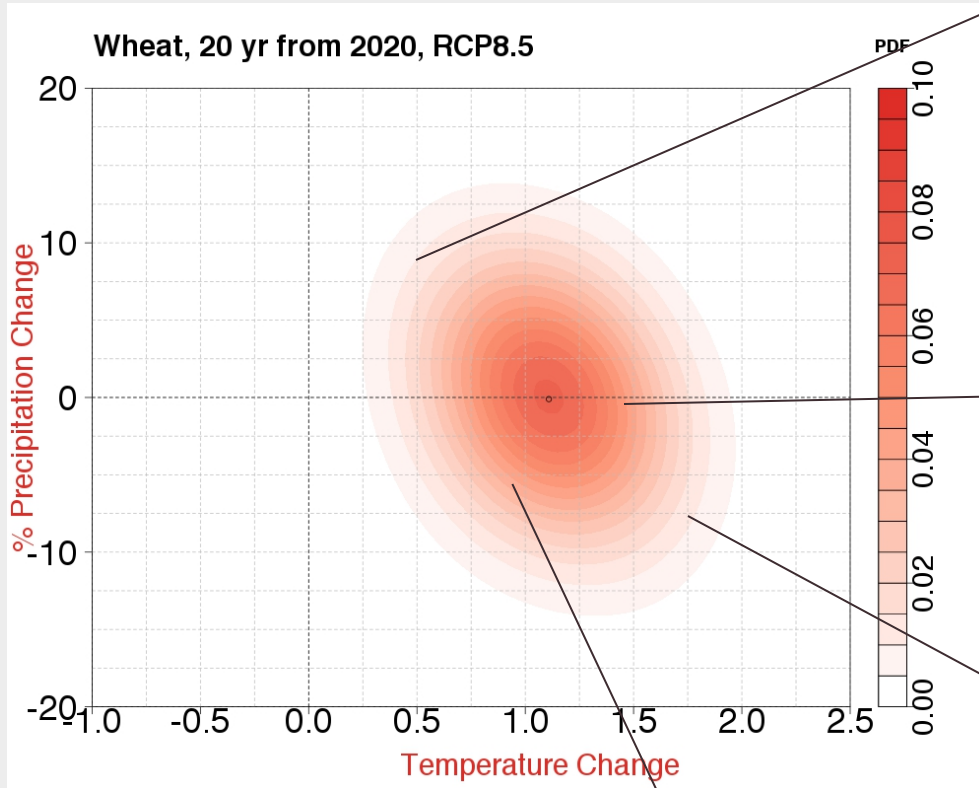
Joint changes (10-yr trends) in Temperature and Precipitation according to the two ensembles



Joint changes (20-yr trends) in Temperature and Precipitation according to the two ensembles



From an ensemble of climate projections to an ensemble of Yield change projections



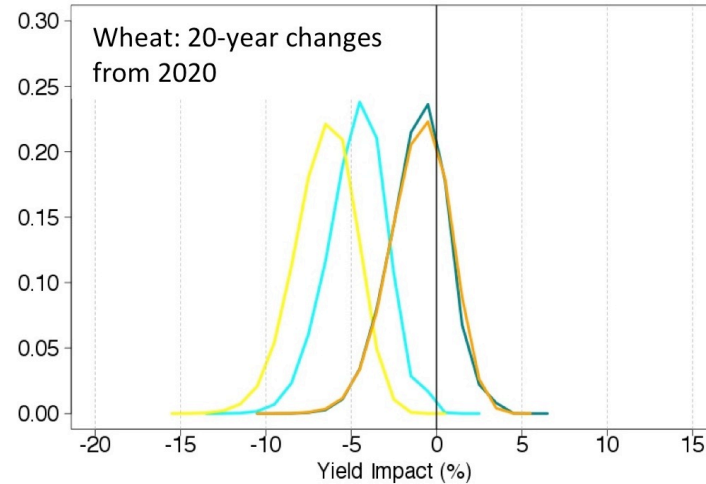
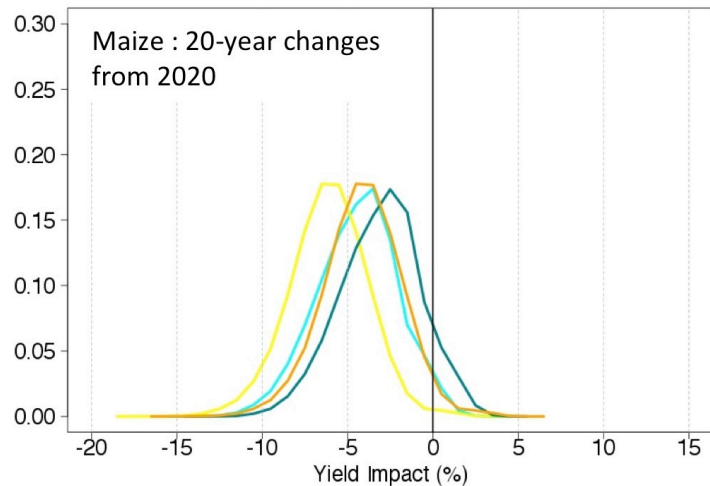
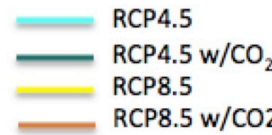
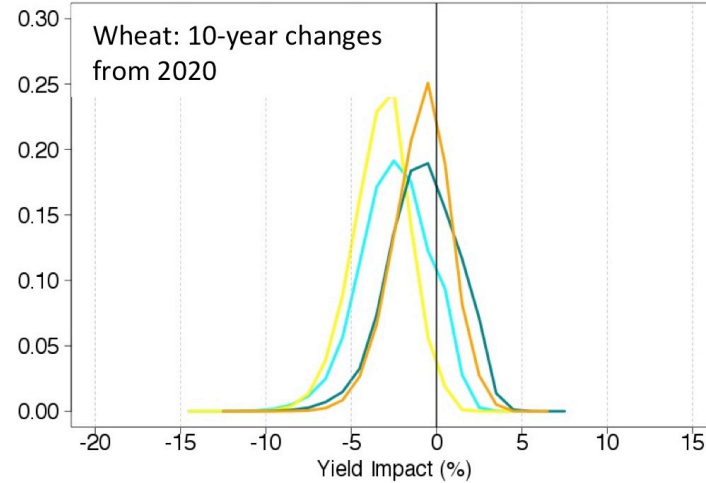
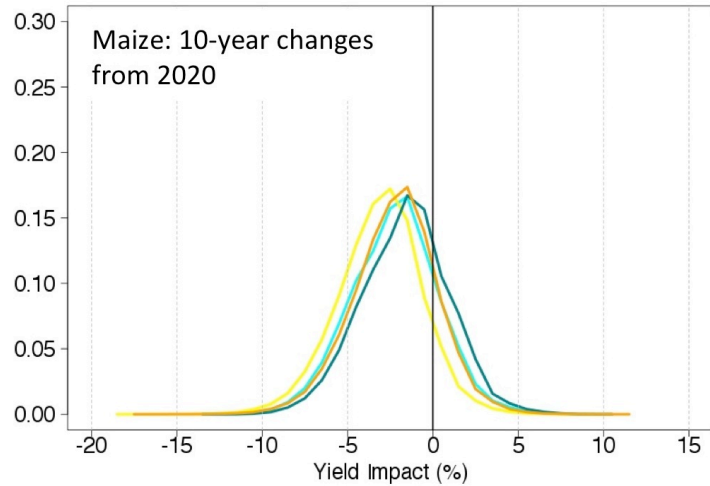
$$\Delta Y_1 = \hat{\beta} \Delta T_1 + \hat{\gamma} \Delta P_1$$

$$\Delta Y_2 = \hat{\beta} \Delta T_2 + \hat{\gamma} \Delta P_2$$

$$\Delta Y_3 = \hat{\beta} \Delta T_3 + \hat{\gamma} \Delta P_3$$

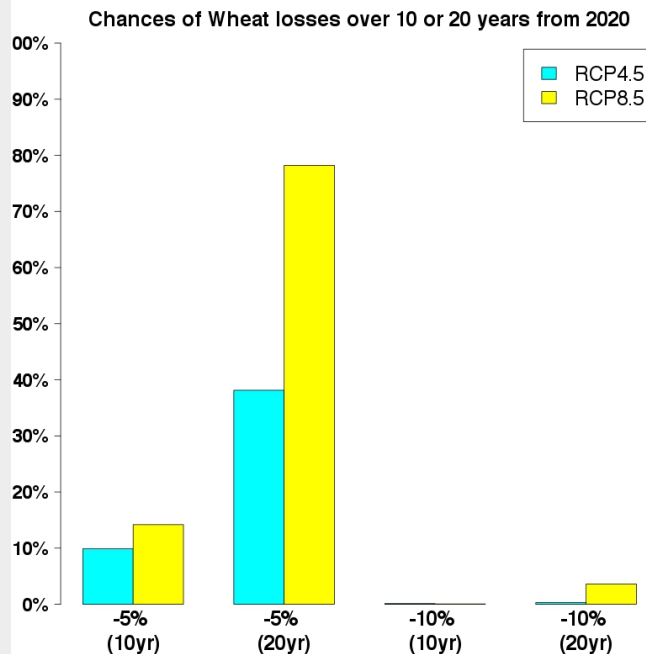
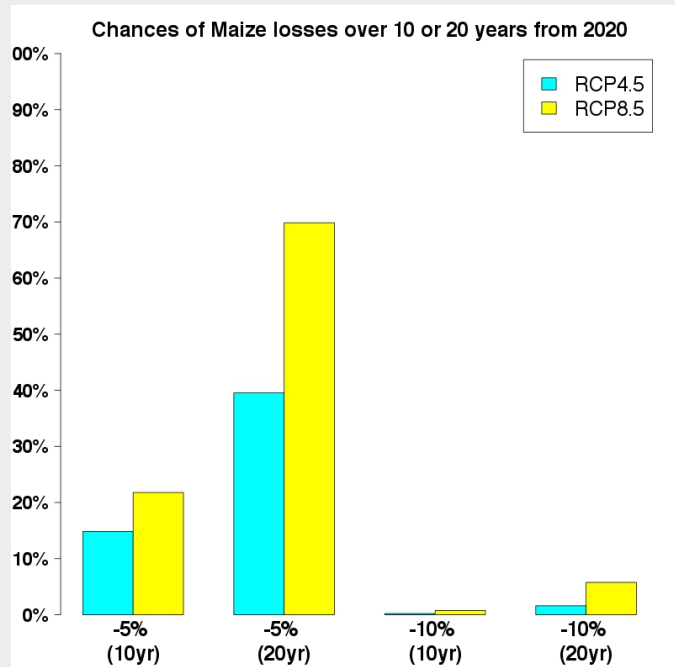
$$\Delta Y_{1000} = \hat{\beta} \Delta T_{1000} + \hat{\gamma} \Delta P_{1000}$$

Probability distributions of yield changes obtained through ensemble of climate projections

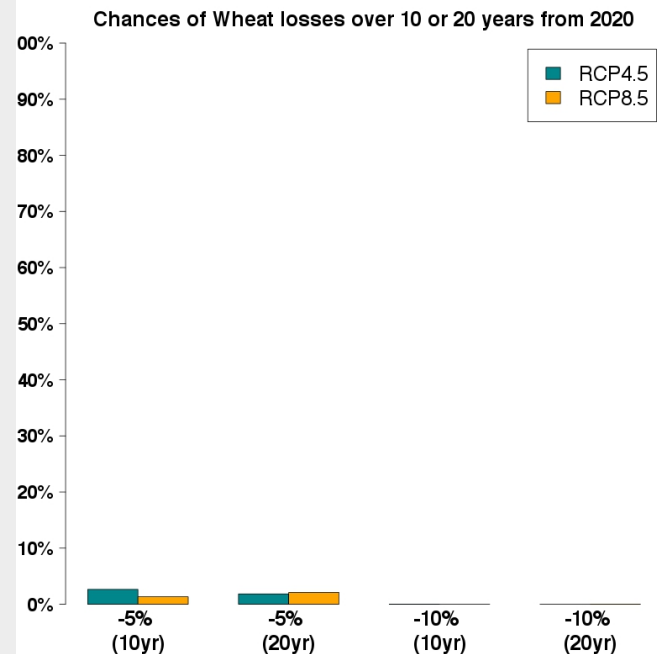
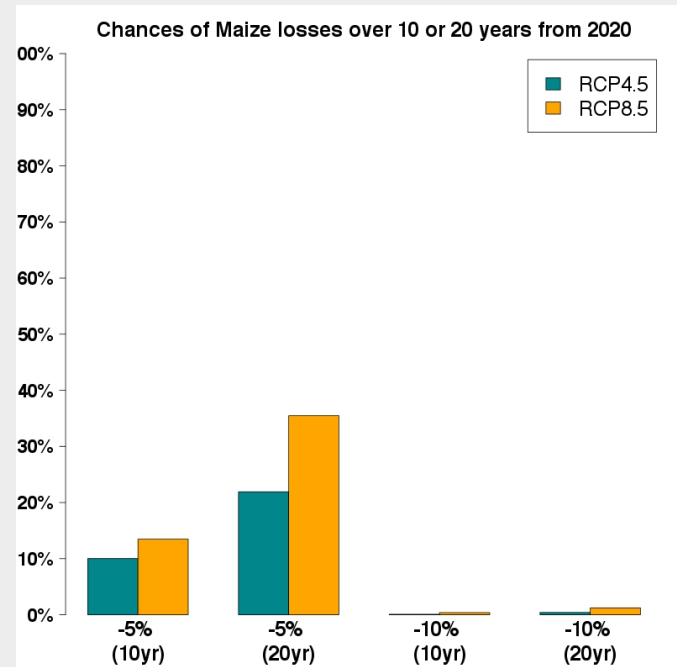


Focusing on the risk of significant slowdowns

Without
CO₂



With
CO₂



What is it about this problem that makes it manageable/quantifiable?

Output from large initial condition ensembles is aimed at characterizing the next 10-20 years **when model uncertainty does not kill us**.

We could probably as effectively use a ***multi-model ensemble as an initial condition ensemble*** for this problem and obtain the same results (and if we don't we should question the internal variability of the single model).

What makes other problems less manageable?

Longer time horizons make model uncertainty more relevant, and making sense of multi-model ensembles is a much tougher statistical problem.

The sampled models are **not random nor systematic**

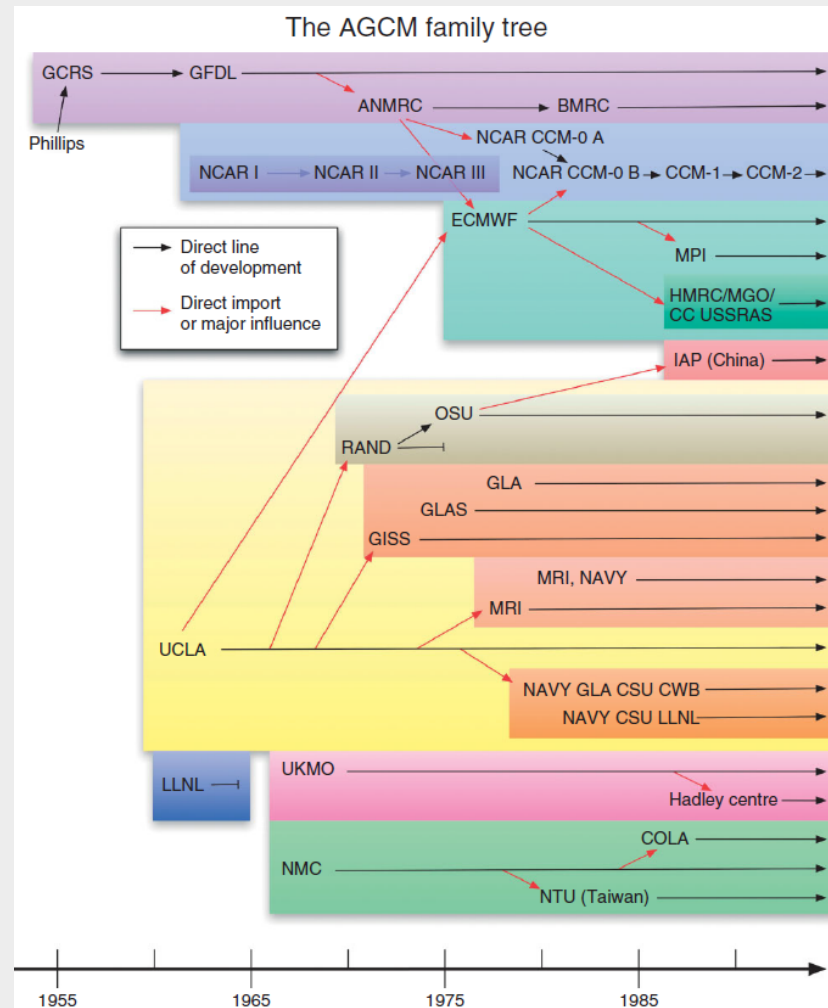
They are **not independent**

They **do not span the whole uncertainty range**

Uncertainty quantification for anything requiring Global Climate Models is complicated by these statistical oddities, even in the presence of a large ensemble.

Climate model genealogy

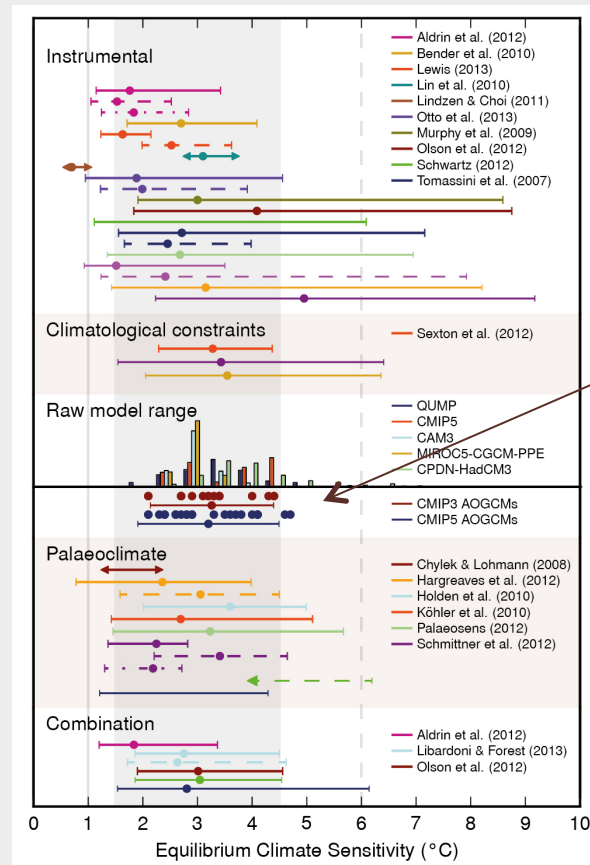
Models are not independent



Models do not span the whole range of uncertainty

Climate Sensitivity

Different estimates

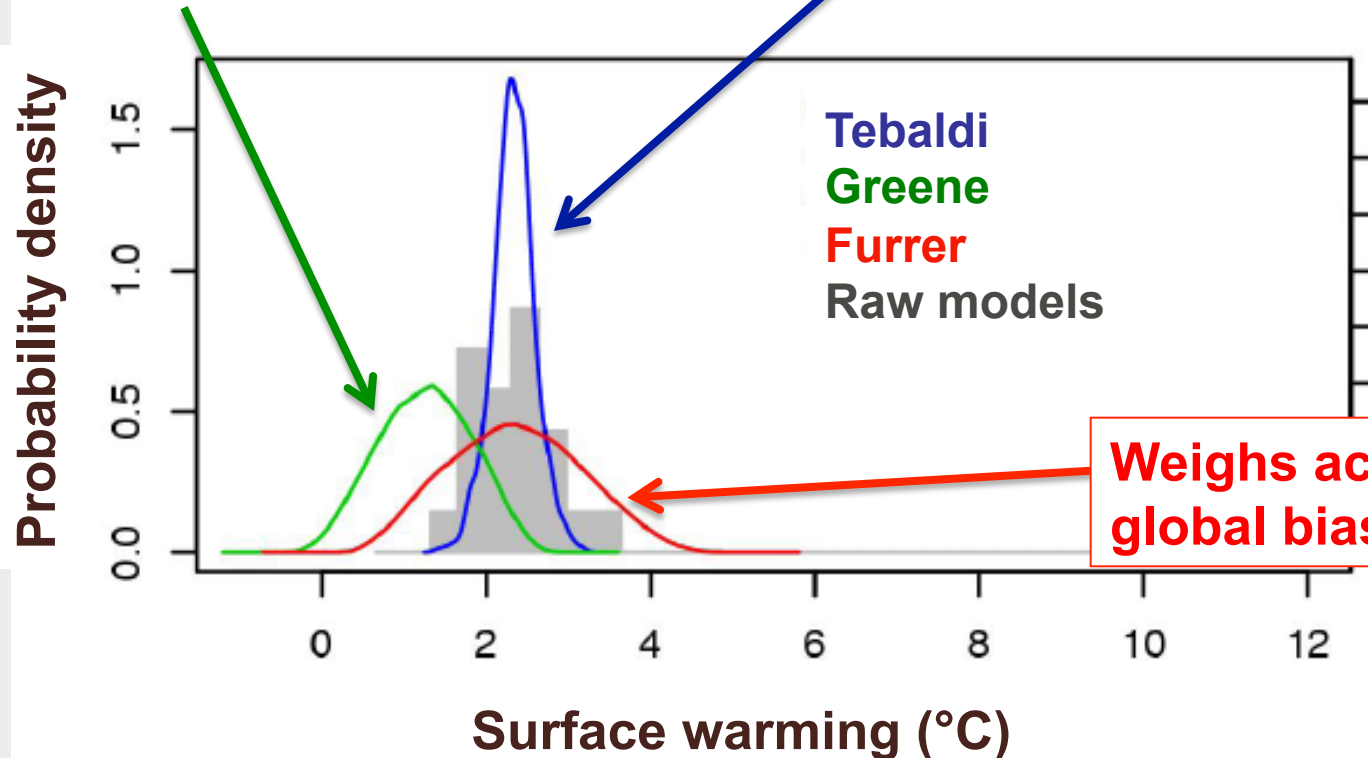


Model ranges

Assumptions, esp. in the weighting matter for the result

Weights according to past performance on regional trends

Weights according to regional bias and consensus



Weights according to global bias measures

Finding metrics that constrain future projections remains an elusive quest

- Very few examples of robust relations, scientifically justified and robust across generations of models (CMIP3, CMIP5).
- Most attempts are however aimed at constraining **global quantities** (like climate sensitivity). Maybe **regional analyses** are on better footing to perform model ranking/culling/weighting.

Conclusions

- When the problem is mostly about characterizing internal variability, uncertainty **quantification** is helped by the availability of ensembles of simulations. For short-term projections single-model or multi-model ensembles should be interchangeable. But we need a large number of realizations.
- When the problem is about forced variability and response to scenarios in the mid-to-long term, model uncertainty is paramount (unless high resolution diminishes that); in this case both single model initial condition ensembles and multi-model ensembles are necessary to **characterize** possible outcomes.
- Quantification of uncertainty in the latter case is challenged by the fact that multi-model ensembles are **odd statistical samples**.

What does this all mean for the topic of this meeting?

- High-res is usually in a tight competition with ensemble size/length of a control run. How do we characterize uncertainty then?
- A possible approach:
 - build a statistical relation between high-res and coarser-res model output;
 - Characterize uncertainty for the latter, transfer knowledge to the former.
- Does it matter given uncertainties in impact models?