### Some Thoughts on Uncertainty:

# Applying Lessons to the CCSP Synthesis and Assessment Products

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CCSP emphasizes "reducing uncertainty"

"Reducing uncertainty" is probably not the appropriate goal; we should instead focus on "increasing credibility"

#### FUNDAMENTAL QUESTION:

Is the assessment process and "science for policy" (as interpreted by climate scientists) torquing climate science in a direction that is fundamentally less useful for both science and policy?

The answer to this question is probably "yes", and both the root of the problem and its eventual solution lies in how scientists and decision makers deal with the issue of uncertainty.

Why have scientists making observations and evaluating trends of atmospheric temperature not conducted a rigorous error analysis?

Scientists and funding agencies are better rewarded for proposing and funding large new observational systems, rather than for careful analysis of existing data sets, and "preferred" data sets become a political issue as the stakes for publicity and funding is accelerated.

Two proposals are on the table at NOAA to reduce errors in T profiles:

- 1) spend \$1B/yr to have UAVs drop reference radiosondes
- 2) use COSMIC plus ground based reference radiosondes (+\$5M/yr)

A rigorous uncertainty analysis will help NOAA assess these proposals:

- How much uncertainty is due to instrument accuracy and precision, T calculations/retrievals from measurements, and errors in sampling?
- Is there any value in reanalyzing the current data sets with improved methods for calculating temperature from the measurements?

Climate modelers (and the agencies that fund climate modelers) infer pressure from policy makers to reduce uncertainties in climate models implied by the spread among predictions made by different models.

This "pressure" may be torquing climate science in the wrong direction:

- By adding new degrees of freedom to individual climate models (e.g. increasing the number of prognostic variables, model resolution, etc.), disagreement among model projections is likely to increase. Such disagreement is a sign that progress is being made in understanding the importance of previously neglected processes.
- Given that climate models cannot presently be evaluated using out-of-sample observations, focusing solely on reducing the range of model projections will mislead and there will be no motivation to uncover common flaws among the models.

Evaluation of model errors and prediction uncertainty is essential to establish the credibility of climate projections for decisionmaking

#### Model errors:

- Errors in functional relationships
- Numerical errors (coding, model resolution)
- Errors in treatment of unresolved degrees of freedom (subgridscale)
- Neglect of important processes (e.g aerosol processes)

#### Prediction uncertainty:

- Imperfect models
- Chaotic behavior of system
- Imperfect initial, boundary conditions

Ensemble simulations are a MUST, and frequentist distributions must be generated for each model, otherwise we are faced with a single unequivocal prediction from each model that may be very far from reality and no understanding of prediction uncertainty using that model.

"Science for policy must be recognized as a different enterprise than science itself, since science for policy must be responsive to policymakers' need for expert judgment" (Moss and Schneider)

#### "Science for science":

Publication of a paper in a scientific journal may or may not "require" a rigorous analysis of errors and uncertainty (but perhaps it should!)

#### "Science for policy"

Credibility in the science for policy enterprise requires rigorous science with a rigorous analysis of uncertainty combined with expert judgment

Assessing/learning what the current uncertainties really are is even more relevant/valuable for policy than in the basic science.

"a Bayesian or subjective characterization of probability will be the most appropriate" (Moss and Schneider)

Simply because it is difficult to evaluate climate model predictions using observations does not imply that we cannot conduct rigorous error analysis on climate models and conduct a rigorous uncertainty analysis on climate model projections.

Basic statistical good practice requires that we do the error analysis and Monte Carlo runs, before we revert to the use of subjective probabilities to combine the conflicting model distributions.

By introducing subjectivity too early, "the hard stuff" is avoided but we significantly reduce the value of the uncertainty analysis to policy makers.

#### Issues in communicating uncertainty:

- 1) Assuming that a rigorous uncertainty analysis **has** been done, how best to communicate this uncertainty to decision makers, who may have unsophisticated understanding of probabilistic information, difficulties in assessing small-probability high-consequence events, framing issues, etc.?
- 2) If a rigorous uncertainty analysis **has not** been done, what should be communicated to decision makers regarding uncertainty (other than that a rigorous uncertainty analysis has not been done)?

#### FUNDAMENTAL QUESTION #2:

Is a projection useful for policy applications if the model is so complex that we "can't" understand the model errors and the uncertainty of its predictions?

Communication of uncertainty in Assessment and Synthesis Reports:

<u>Category 1</u> (audience: scientists and funding agencies)

- sources of uncertainty
- magnitudes of uncertainties if they have been determined
- actions required to conduct a rigorous uncertainty analysis

<u>Category 2</u> (audience: adaptive managers)

- how to exploit the uncertainty in ensemble forecasts of decisionrelevant variables in their decision making process, focusing first on weather and seasonal/interannual variability.
- how new policies (e.g. emission reductions) will impact them

<u>Category 3</u> (audience: policy makers)

Policy makers need "credible" observations and projections.

Credibility =

rigorous analysis of observation/model errors

- + uncertainty in projections from monte carlo simulations
- + expert judgment + common sense

#### Recommendations:

- Form an Uncertainty Oversight Committee to assist in preparing the Synthesis and Assessment Reports.
- National agencies funding climate research should explicitly require proposals to include strategies for evaluation of uncertainty and presentation of uncertainty

#### Science Reports to Inform Evolution of the Science Research Agenda

- Temperature trends in the lower atmosphere—steps for understanding and reconciling differences
- Past climate variability and change in the Arctic and at high latitudes
- Updating scenarios of greenhouse gas emissions and concentrations, in collaboration with the Climate Change Technology Program (CCTP); review of integrated scenario development and application
- North American carbon budget and implications for the global carbon cycle
- Climate models and their uses and limitations, including sensitivity, feedbacks, and uncertainty analysis
- Climate projections for research and assessment based on emissions scenarios developed through the CCTP
- Climate extremes including documentation of current extremes; prospects for improving projections
- Relationship between observed ecosystem changes and climate change
- State of the science of socioeconomic and environmental impacts of climate variability

## Synthesis and Assessment Products to Inform Adaptive Management Decisions

- Risks of abrupt changes in global climate
- Coastal elevation and sensitivity to sea-level rise
- Within the transportation sector, a summary of climate change and variability sensitivities, potential impacts, and response options
- Preliminary review of adaptation options for climate-sensitive ecosystems and resources
- Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions
- Best practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decisionmaking
- Decision support experiments and evaluations using seasonal-to-interannual forecasts and observational data

#### Synthesis and Assessment Products to Inform Policy Decisions

- Re-analyses of historical climate data for key atmospheric features; implications for attribution of causes of observed change
- Aerosol properties and their impacts on climate
- Trends in emissions of ozone-depleting substances, ozone layer recovery, and implications for ultraviolet radiation exposure and climate change
- State-of-knowledge of thresholds of change that could lead to discontinuities (sudden changes) in some ecosystems and climate-sensitive resources
- Scenario-based analysis of the climatological, environmental, resource, technological, and economic implications of different atmospheric concentrations of greenhouse gases