U.S. CLIVAR: Climate Variability and Predictability

Climate Process Modeling & Science Teams (CPTs)

Implementation and Initial Foci

Recommendations by the U.S. CLIVAR Scientific Steering Committee

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Implementation of CPTs

A new paradigm for linking process-oriented research and coupled climate model development has been proposed by the U.S. CLIVAR program. It recommends formation of teams of process-oriented observationalists, researchers and individual process and parameterization modelers working collaboratively with climate model developers. By organizing around an issue, model deficiency, and/or parameterization(s), these Climate Process modeling and science Teams (CPTs) will transcend boundaries between process-oriented research and climate model development, thereby encouraging the team to collectively focus and demonstrably improve the fidelity of coupled climate model systems through evaluations against diverse data sets, as well as development and testing of improved model physical parameterizations. Such teams would in essence provide a responsive two-way link between process-oriented research (such as short duration observation campaigns, process parameterizations, etc.) and climate modeling development. Such a linkage has not been previously been effectively demonstrated in climate modeling research.

As described in a separate “Concept” document, the overall objectives of CPTs are to a) speed the transfer of theoretical and practical process-model understanding into improved treatment of processes in climate model systems (e.g. coupled models and their component models, assimilation and prediction systems), and demonstrate, through testing and diagnostics, the impact of these improvements; b) identify process study activities necessary to further refine climate model fidelity; and c) develop sustained observational requirements for climate model systems.

Implementation of this concept is dependent on the maturity of climate research, readiness of the scientific community to utilize new data sets and tools to address fundamentally limiting issues, and the commitment of the scientists and institutions to form effective and productive teams. More practically, their implementation requires the commitment and interest of the climate modeling centers and the process-research community.

The U.S. CLIVAR program (more specifically, its Scientific Steering Committee), which developed the CPT concept, has assessed these dependencies. It has solicited and received feedback from several scientific groups representing a wide breadth of process-research and model development expertise. This positive and encouraging feedback for the CPT concept indicated the communities are ready to proceed with CPTs. Moreover, two major climate modeling centers, GFDL and NCAR-CCSM have indicated great interest in participating in a CPT program. Finally, the U.S. CLIVAR program has developed, in consultation with these groups, a recommended short-list of high-priority issues, processes, and/or model deficiencies where it is believed CPTs could demonstrate their effectiveness.

In summary, the U.S. CLIVAR SSC believes the community is ready to proceed with implementation of CPTs as a pilot-phase activity. This pilot-phase activity will allow the community to target problems that are fairly limited and where progress can be expected using current models, datasets already in-hand, and existing capabilities. Furthermore, this approach will allow the scientific research community to demonstrate the effectiveness of CPTs, generate additional community interest, and continue to refine the CPT framework concept with regards to planning and execution of process studies. This document provides the scientific motivation for specific CPTs to organize in response to this recommended pilot-phase implementation.

The U.S. CLIVAR Scientific Organizing Committee (SSC) has identified two candidate issues/processes the climate modeling and process-study research communities agree are the highest priority and where research is sufficiently mature as to have high probability CPTs would likely produce demonstrable results in 2-4 years. This document describes the specific scientific motivation, as well as some thoughts on required expertise, readiness, and strategies for CPTs that focus on these issues/processes; a) ocean mixing and b) climate model sensitivity with a focus on deep atmospheric convection and boundary-layer clouds. A more detailed motivation and strategy for an ocean mixing CPT is available in a separate document (Schopf et. al., 2002).

CPTs for Ocean Mixing

Scientific Motivation

While research continues on reducing the errors associated with modeling the relevant equations of motion to consider features of finer and finer resolution, it is clear relatively larger uncertainties of modern ocean models are traceable to the relatively poor treatment of small, i.e. sub-grid-scale, processes – most notably ocean mixing and fluxes that represent the role of unresolved mesoscale ocean eddies (e.g. Agulhas eddies). Of particular importance is diapycnal (i.e. cross-isopycnal surface) mixing which affects the heat transport, the stability and hence the distribution variability of heat. Thus ocean mixing plays a governing role in global climate change. Until the recent advent of higher-resolution ocean models for climate modeling purposes, numerically convenient parameterizations for diapycnal mixing were sufficient. However, more physically-motivated parameterizations are now required to reduce the large uncertainties associated with these sub-grid scale processes.

There are numerous types of ocean mixing with varying degrees of relevance to climate:

- Equatorial and tropical upper ocean mixing
- Double diffusion and salt fingering
- Interaction of eddies with mixed layers
- Deep gravity current entrainment
- Interior eddy flux regime geography
- Internal wave geography
- Deep convection
- Mixing within the thermocline at lateral boundaries
- Internal tides over deep topography (Abyssal mixing)
- Enhanced mixing in the Antarctic circumpolar current
- Surface boundary layer processes

Each of these types of mixing may indeed benefit from a CPT; however, the topics most amenable to CPTs will be determined based on relevance and importance of the target process to the quality of climate model simulations; the readiness and maturity of the observations, parameterization development, and testing capabilities; and finally the likelihood that a CPT effort would produce useful results as outlined in the *CPT Motivation and Concept* document.

Required Expertise/Team Composition

This activity requires a team with an optimal mix of observational and process scientists as well as model developers and analysts. The CPT should include scientists who are participating observational campaigns. Those developing and diagnosing model parameterizations should also be included. Participation by OGCM model developers that reflect the diverse approaches (e.g. sigma, isopycnal, and hybrid coordinate models) will enhance the relevance and future reliability of any developed parameterizations. The testing of new parameterizations by major climate modeling centers (e.g. NCAR-CCSM and GFDL) and the ensuing diagnosis of these tests are equally critical.

Strategy

To first order, the important measure of mixing is the diapycnal flux integrated around the globe; however, mixing is often concentrated in specific regions, and thus observational data from these regions is critical for parameterization development, but the best approach to “globalizing” these parameterizations is not certain.

The recommended strategy is to not address all mechanisms at once, but have an ongoing set of CPTs that focus on various processes over time (using relevance, readiness, and likelihood of success as indicators of where to focus efforts). A workshop would be helpful in deciding what mixing mechanisms to target initially. A Pilot Phase CPT activity would demonstrate the utility of the CPT concept and provide an initial trial of the management strategy.

The objectives of the pilot phase will be to

- Demonstrate the CPT mechanism, by implementing and verifying improved mixing parameterizations for a few processes that have a mature observational and theoretical base.
- Demonstrate how the CPT can stimulate data mining and development of observations and theory for processes whose observational or theoretical base is less than adequate.
- Demonstrate how a CPT can interact with the planning for process study initiatives, by interacting with the planning for future field programs.

CPTs for Climate Model Sensitivity with focus on deep convection & boundary-layer clouds

Scientific Motivation

The term “climate sensitivity” is used by the research community in a narrow sense to refer to the equilibrium response of global mean temperature to a doubling of carbon dioxide. Since it takes thousands of years for the full ocean-atmosphere system to closely approach equilibrium, climate sensitivity is defined operationally, even more narrowly, by computing this equilibrium response in atmospheric models coupled to “slab ocean” models with a fixed depth mixed layer that reach equilibrium in less than 50 years. Although one cannot translate a difference in climate sensitivity so defined into a difference in climates predicted in specific transient climate change scenarios, partly because the magnitude and pattern of ocean heat uptake also affects the latter, experience has shown that equilibrium and transient responses are closely linked and that the major atmospheric feedback processes that affect equilibrium sensitivity also exert control on the magnitude of transient responses.

Despite its limitations, this concept has proven its usefulness for several reasons. From the research perspective, it focuses attention on the 1) global energy balance at the top of the atmosphere, 2) the connections between that energy balance and mean surface temperature, and 3) the feedback processes by which an increase in greenhouse gases modifies that balance. It has been recognized for a number of years that the top of atmosphere perspective has its limitations and is, by itself, incomplete. For example, perturbations (e.g. presence of absorbing aerosols) that result in decreased surface radiative energy can partially decouple the surface from the atmosphere. The surface energy budget, and the closely related strength of the hydrological cycle, must also be a part of global climate sensitivity analysis. The paramount feedbacks that affect the energy balance include water vapor, clouds, sea-ice and snow cover, as well as the changes in the 3-dimensional

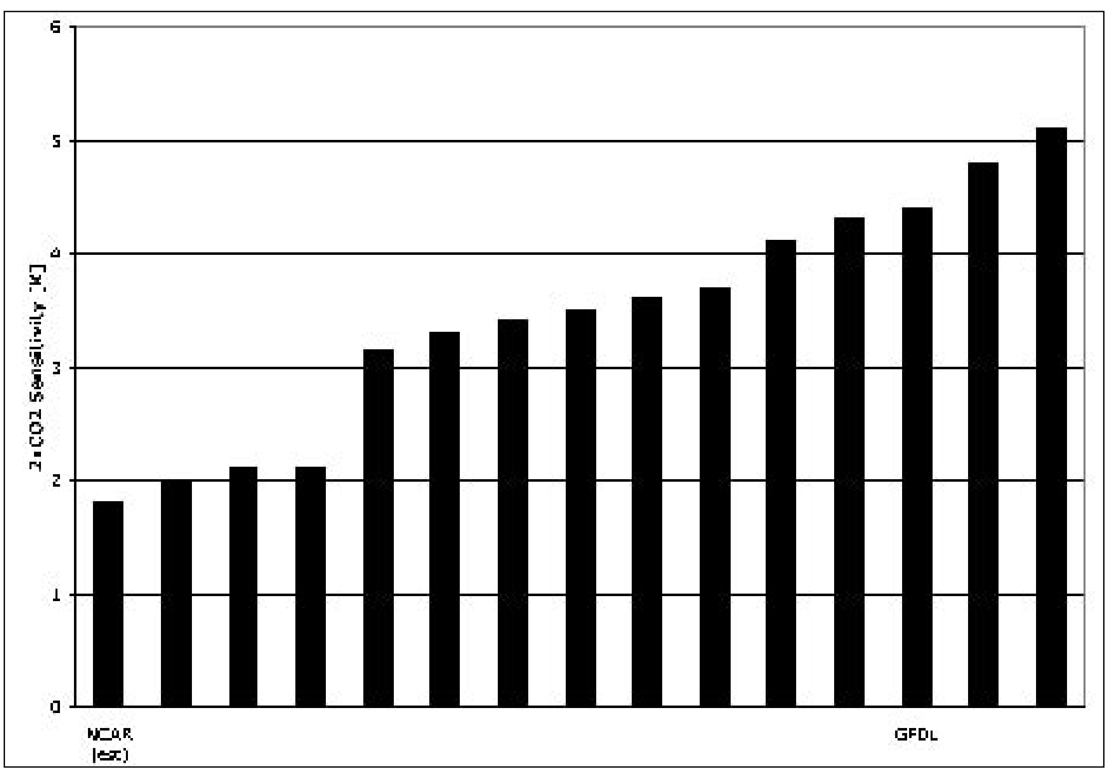

Figure 1. Climate model sensitivity (change of global mean temperature) for a range of climate models for a prescribed doubling of CO_2. Note the especially large spread between the GFDL and NCAR-CCSM models.

temperature structure referred to as “lapse-rate” feedback. Cloud feedback is generally recognized as being the largest source of uncertainty.

From the perspective of policy makers and the public, who are ultimately interested in regional climate change, “climate sensitivity” provides a useful measure of the magnitude of the expected climate changes following from different emission scenarios. Even without agreement on the predictions of detailed regional changes, temperatures in different regions are strongly enough coupled that it is a reasonable starting point to assume, for example, that the warming in any particular region in a model with a “climate sensitivity” of 4K will be larger than in a model with a sensitivity of 2K.

However, climate sensitivity in the narrow sense has been found to vary by more than a factor of two among existing models, e.g. Figure 1. Even with identical climate forcing inter-model differences will lead to significant differences in predicted transient climate responses. This uncertainty has existed for decades, with only a very modest concerted effort to understand the source of these inter-model differences. The major US modeling centers can no longer present, to the policy community and to the public at large, climate change scenarios with dramatically differing climate sensitivities without, at a minimum, a coordinated definitive study of the causes of these differences and an evaluation of the ability of each model to simulate key observational data sets that test the fidelity of the most relevant feedback processes.

The most quantitative analyses indicate that cloud processes are the largest source of uncertainty. But little has been accomplished in actually identifying the root causes within the cloud prediction (or boundary layer and convection) components of the models. Of greater importance is understanding which models, if any, are simulating feedbacks most accurately. This can only be accomplished through the use of observations. The CPT concept will help provide the link between observational experts, process scientists, and climate modelers.

We view CPTs as focusing not just on the classical and narrow definition of “climate sensitivity” but also more generally on “the magnitude of planetary-scale climate change, and the atmospheric feedbacks that control this magnitude”. As outlined below, neither would it focus exclusively on model experiments with slab ocean models, but rather on a variety of ways of experimenting with climate models that allows the most useful confrontation with observations for the purpose of evaluating the fidelity of the relevant feedbacks within the models.

Required Expertise/Team Composition

This activity requires a team with an optimal mix of observational and process scientists as well as model developers and analysts. The CPT should include scientists who are familiar with critical observational data sets such as satellite retrieved cloud properties. In particular, the MODIS and CERES science teams are creating invaluable datasets that provide a new opportunity to evaluate cloud feedback processes. Representation from participating modeling centers is critical, but also needed are university and national laboratory scientists who can provide expertise in model diagnosis as well as in understanding, diagnostics, and modeling of specific physical processes. Coordination with the Atmospheric Radiation Measurement (ARM) program science teams should also be taken into account when establishing this Climate Process Team.

Readiness

There has been significant progress in the past decade or so, in particular, in our understanding of moist boundary layers and associated clouds. If these low-level clouds are indeed the primary source of spread in climate sensitivities then we can hope for some reduction in this spread, on the time scale of this CPT, as the models incorporate the recognized needed improvements in their boundary layer parameterizations. The CPT can play a vital role in expediting and helping to evaluate these model developments, as it will bring together relevant expertise in boundary layer observations and modeling.

The extension of existing satellite data sets to several ENSO events, and the development of new data streams from satellites, field programs, and the ARM stations, combined with the ability to manipulate massive data sets with relative ease with ever-increasing computer power, allows us to perform a larger variety and more ambitious comparisons of models and observations than ever before. The literature from the past several years has a number of examples of analyses that are likely to be insightful with regard to the fidelity of the model's cloud feedbacks. The CPT can facilitate and energize this kind of work in a coordinated way, greatly increasing the likelihood that this diagnostic work will impact the model development process in the participating centers.

Strategy

Climate sensitivity in the narrow sense has been found to vary by more than a factor of two among existing models. Even with identical climate forcing inter-model differences will lead to significant differences in predicted transient climate responses. This uncertainty has existed for decades, with only a very modest concerted effort to understand the source of these inter-model differences. The most quantitative analyses indicate that cloud processes are the largest source of uncertainty. But little has been accomplished in actually identifying the root causes within the cloud prediction (or boundary layer and convection) components of the models. Of greater importance is understanding which models, if any, are simulating feedbacks most accurately. This can only be accomplished through the use of observations. A climate process team on climate sensitivity must work along two paths simultaneously

1. *Understanding causal mechanisms for model differences in climate sensitivity*

Our first goal can be achieved through the close collaboration of the participating modeling groups and the assistance of other experts on the Team. The modeling groups will need to carry out both equilibrium and transient simulations of climatic responses to provide the model data for a quantitative assessment of differences in model response. In addition to the slab ocean simulations, coupled model simulations with a 1%/year compounded increase in carbon dioxide have a become a standard for inter-model comparison and will be needed to asses the robustness of the feedbacks present in the equilibrium integrations. Coordinated atmosphere-only simulations in which observed sea surface temperatures are used as a lower boundary condition will also be analyzed, as these provide important information, particularly with regard to the responses of tropical cloudiness to SST anomalies, that can further guide exploration of specific physical parameterizations in the models.

Other model frameworks will likely be useful in this process. "Cess" simulations, in which atmosphere-only models are integrated with globally uniform increases or decreases is SST can potentially provide information very quickly on how changes in model configuration affect the sensitivity of the top of the atmosphere fluxes. Coordinated simulations of the climate of the Last Glacial Maximum with atmosphere+slab ocean models, in which the climate is perturbed by imposing land glaciers, atmospheric CO2 and changes in sea level, provide a test of climate sensitivity towards cooler climates that can help clarify model differences (and brings into play paleoclimatic data for model evaluation). And comparison of simulation of the climatic response to the Pinatubo aerosol, or absorbing aerosol, could possibly bring out model differences in alternative settings. Without committing ourselves to this large an array of configurations, the participating model centers need to be open to coordinated experimentation along various such lines.

Agreed upon model diagnostics will need to be created so that the models can be evaluated and compared in a self-consistent manner. We need to go beyond standard approaches. For example, a detailed analysis of changes in regional cloud properties will be required, which includes, not only cloud radiative properties, but cloud fraction, condensate amount and phase, particle size, and cloud overlap statistics. For extratropical clouds, we need to characterize not just mean cloud parameters, but each model's cloud fields in the very different meteorological backgrounds provided by different phases of the cyclones, anticyclones, and fronts that dominate midlatitude weather. More generally, regional analysis of the simulations will be an important part of the diagnostic process. For the atmosphere only simulations, responses of both deep convective and boundary layer clouds in the tropics can be analyzed by compositing El Niño and La Niña conditions. For the slab ocean and transient simulations, there will need to be a focus not only on globally averaged fields, but on identifying the regional climate changes that are most responsible for the inter-model differences or that best isolate the behavior of model components (for example, cold coastal upwelling regions that highlight the behavior of low cloud cover).

A more rigorous diagnosis of the model differences will generate hypotheses as to the cause of these differences. Experiments to test these hypotheses will be an essential next step in the process. This process may involve simulations with not only the three dimensional atmosphere and/or coupled models, but also single column models that can be forced with model or observational boundary conditions. Specific physical parameterizations can be exchanged between the two models to better define sources of inter-model difference. The goal is a definitive and quantitative isolation of the sources of the differences in sensitivity between the models.

2. *Evaluation of model sensitivity processes against observations*

We believe that it is unrealistic to expect to obtain quantitative estimates of climate sensitivity directly from observations. Observations provide signatures of modes of variability and trends within the climate system. To the extent that climate models can quantitatively reproduce this rich range of observed variability, specific feedback mechanisms are most likely accurately represented in these models and the overall magnitude and global shape of climate change simulated by these models become more credible.

What is currently required is a more systematic evaluation of climate models against a diverse range of observations, targeted in such a way that this evaluation provides information on the feedbacks and processes, particularly cloud feedbacks, that are incorrectly or insufficiently represented in the models, thus contributing to the relatively large range of estimates of climate sensitivity in different models. Such an evaluation, initially requiring development of a common diagnostic strategy, will quantitatively evaluate, on appropriate time and space scales, the relevant performance of the participating climate models as related to sensitivity, in order to motivate the introduction and testing of revised parameterizations aimed at increasing the fidelity of model processes, particularly those that contribute to model sensitivity.

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