Proposal for CMIP Diagnostic Subproject

Project Title: Diagnosing Oceanic Origins of Future Regional Climate Change

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Note: The work described below depends critically on access to CMIP data. However, it extends beyond an analysis of only those data. We are aware of other related CMIP subprojects and will communicate directly with the leaders of those efforts, in particular Dr. E. Schneider.

Proposed work and methodology

AGCM simulations of 20th Century climate support the argument that future extratropical (especially Northern Hemisphere, NH) climate change will be tied to changes of tropical SSTs, and that the dynamical feedback associated with this process may determine a regional specificity to climate change. Among the most frequent requests for information on future climate change is its regional manifestation, yet there is little consensus on such changes among coupled models, and confidence is judged to be low. It is reasonable to wonder to what degree such uncertainty originates from the divergence in projections of future ocean states alone. Our proposal seeks to understand the dynamical responses of the extratropics to various, plausible trajectories of the tropical oceans, and to quantify the sources of uncertainty.

We cast our proposed research in the form of specific questions that address several sources of uncertainty in regional climate change. Among these are purely intrinsic sources of uncertainty due to (i) chaotic coupled ocean-atmosphere variations, which produce spread in projected tropical SST changes, and (ii) chaotic atmospheric variations that yield spread in regional climate responses to specific SST states. There are also model-related sources of uncertainty. In particular, (iii) differences among the responses of different coupled models to identical external (anthropogenic) forcings, and (iv) differences among the responses of different AGCMs to identical SST forcing. And (v) there is the uncertainty of the external forcing of the climate system itself, reflected by a multitude of IPCC emission scenarios. The various AGCM experiments described below are designed specifically to quantify the contribution of each of these to NH regional climate change uncertainties, at least for the specific paradigm of the tropical oceanic influence. We refer to these five sources of uncertainty parenthetically to provide focus.

***Q1*:** *What is the maximum likelihood state of NH regional climate change associated with the most probable mean change in tropical SSTs over the next few decades?*

As a point of reference for subsequent uncertainty analysis, we will first determine the expected NH change in regional climate due to a mean projected change in tropical SSTs. The approach will be to evaluate and then aggregate a very large sample of available simulated SST changes, derived from different coupled models and forced with different emission scenarios, into a single change map for the next few decades (e.g., through 2030). We propose to conduct a large ensemble of AGCM simulations using this mean tropical SST change as a specified forcing, analogous to experiments we have previously done using the observed 20th Century SST change. The experiments will be conducted with (at least) the latest versions of the NCAR and GFDL atmospheric models (CAM and AM, respectively), and a minimum of 50-member ensembles will be completed with each. The resulting multi-model, ensemble-averaged response will offer an estimate of the maximum likelihood state of regional climate change due to the dynamical feedback from the tropical SST change alone.

We propose to analyze the data from the CMIP as one source of information for the projected SST change over the next few decades. We also propose to analyze the SST outputs from coupled models forced under the official IPCC emission scenarios of the Third Assessment Report (TAR; see also the Special Report on Emissions Scenarios, SRES, IPCC 2000), which are available through the IPCC Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk). We will include the data from both A2 and B2 scenarios (at a minimum) for the (seven) coupled models available. When combined with CMIP data, an ensemble average of SST change will be constructed from effectively 25-30 individual model projections[1]. We interpret this aggregate change to capture the reproducible, and thus arguably robust, changes in tropical SSTs that are independent of both the specific emissions scenario and the coupled GCM forced by it.

The aggregated NH atmospheric circulation anomalies averaged across the CMIP and IPCC greenhouse-forced coupled runs will also be constructed. These will then be compared to the multi-model, ensemble-mean responses to the specified mean tropical SST change discussed above. Our proposed focus on projected changes in climate over the next few decades, as opposed to those on a longer time horizon, is motivated partly by the fact that the near-future changes will receive much more emphasis in the next IPCC assessment. Moreover, climate change over the next few decades is likely of greater interest to policymakers, as well as to the general public, than are changes a century or more out.

***Q2*:** *How do sampling variations resulting from chaotic atmospheric dynamics contribute to uncertainty in projected NH regional climate change?*

We will compute the PDFs of preferred, regional modes of atmospheric circulation variability, including the NAO and PNA, as well as regionally-averaged surface temperature and precipitation based on the individual members of AGCM simulations generated under *Q1*. In those runs, each and every member will have been forced by the same, aggregated-mean tropical

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[1] Although it is difficult to determine whether or not a particular model is "good enough" to be used in our analysis, we will evaluate the simulated seasonal cycle and interannual variability of tropical SST from the coupled control integrations. We will also draw upon information from relevant, existing CMIP diagnostic subprojects and other published inter-comparisons to aide in our evaluations.

SST change (uncertainty ii). We will also compare the PDFs based on the ensemble members drawn from the NCAR and GFDL AGCMs to address the further uncertainty that is related to the unique sensitivities of a particular atmospheric model (uncertainty iv). To this end, we will attempt to leverage our strong existing ties with modeling groups at other international research facilities (in particular, NASA, NCEP, IRI, and the Hadley Centre) to encourage experiments under identical forcing with other AGCMs, in order to even better assess model dependence and to better estimate the forced climate sensitivity under *Q1*.

***Q3*:** *What is the uncertainty in expected NH regional climate change from chaotic coupled ocean- atmosphere dynamics?*

As part of the U.S. contribution to the upcoming Fourth Assessment Report (AR4) of the IPCC, ensembles of coupled climate change simulations will be performed with new versions of both the NCAR and GFDL climate models. The precise emissions scenarios and ensemble sizes to be produced are not yet determined, but it is expected that ~5 member ensembles will be generated for a single scenario (J. Meehl, personal communication). The spread among the individual SST realizations under a single scenario will, then, be entirely due to intrinsic ocean-atmosphere coupled variations (uncertainty i). We propose to analyze these data, focusing on the spread of mean tropical SST change among the individual members of the coupled ensembles under a given emission scenario.

We further propose to conduct ensemble sets of AGCM experiments, using the atmospheric components of both the NCAR and GFDL climate models. Each ensemble set will be forced with identical changes of tropical SST, corresponding to each of the SST change patterns realized from the coupled ensembles. We expect a 25-member ensemble average of AGCM simulations to be adequate for extracting the signal of atmospheric sensitivity to each SST change map. Differences among these various signals, for a given emission scenario, then quantify the uncertainty in regional climate change due to chaotic fluctuations in tropical SSTs (uncertainty i), and this uncertainty will then be compared to the uncertainty related to chaotic atmospheric variations alone (uncertainty ii). The latter will be diagnosed from the PDF spreads of the 25-member ensembles, and compared to the alternative estimate of this same uncertainty obtained under *Q2*.

***Q4*:** *What is the uncertainty in expected NH regional climate change due to different change patterns of tropical SSTs arising from the use of different emission scenarios?*

For a given emission scenario, we will also compute the ~5 member ensemble-mean change over the next few decades in tropical SSTs from the NCAR and GFDL IPCC simulations. Differences in these SST change maps will reflect different mean responses among coupled models to identical external forcings (uncertainty iii). Each of these mean SST change patterns will then be used as a specified lower boundary forcing for large, AGCM ensembles. The differences among the regional climate change signals among the AGCM ensembles will help quantify the uncertainty in regional climate change that arises from the different tropical SST trajectories forced under different emission scenarios (uncertainty v). Also, by forcing the NCAR AGCM with the projected SST fields from the GFDL model, and vice versa, will we further establish the robustness of emission scenario-dependent responses across models.

***Q5*:** *What is the importance of the time history of SST variations for the mean NH regional climate change?*

The steady SST anomaly forcing experiments exclude the possibility that nonlinearities associated with changes in the statistics of higher-frequency SST anomalies could be an important factor in determining regional climate change, as we (Fig. 5) and others have argued to explain observed changes in the climate of the North Pacific sector in recent decades. We thus propose to construct ensembles of integrations with the NCAR and GFDL atmospheric models forced with the time-evolving tropical ocean states (e.g., through 2030) extracted from the IPCC scenario runs of their coupled configurations. We shall compare the atmospheric circulation statistics from these runs with those from the mean SST change simulations of *Q4* to evaluate the impact of higher-frequency (e.g., interannual) variability on projected changes in extratropical circulation states.

Because of the increased computational demands of these integrations, relative to the steady state experiments of *Q1-4*, we will limit our efforts to 10-member TOGA-type experiments with both the AGCMs. In addition, we will also force the NCAR AGCM with the time history of mean tropical SSTs from a GFDL coupled IPCC scenario integration, and vice versa. For such moderately sized ensembles, it is important to remember that internal variability might make an important contribution to the variability of the ensemble mean. We will employ statistical techniques that lead to less biased estimates of the true forced response as well as continue our approach of examining the statistical behavior within an ensemble through the PDFs of the leading atmospheric circulation states.

We are aware of some caveats to the prescribed SST approaches outlined above. We have chosen to focus on the role of tropical SST forcing, based largely on the results of our earlier research. Yet specifying projected SST change patterns over the extratropics could be important, as anthropogenic changes in extratropical SSTs may play an increasingly important role in future regional climate change. Doing so, however, may be problematic since the SST anomalies are not allowed to respond to the atmospheric circulation anomalies they create, an aspect that is unrealistic. We will conduct, therefore, some additional sensitivity experiments in which the SST change patterns are specified globally, as well as over the extratropics only. In addition, we also have the capability to prescribe the tropical SST changes, but with an upper-ocean mixed layer model operating outside of the Tropics. The atmospheric responses in the prescribed versus the mixed-layer model ensembles would be compared to assess the role of SST anomalies in the extratropics, and the extent to which the extratropical SST anomalies in the IPCC scenario simulations can be interpreted as passive responses to atmospheric circulations anomalies driven from the tropics.

We believe that the large AGCM ensemble approach discussed above will allow for a much stronger statistical assessment of regional climate changes, as well as insight into inter-model sensitivities and other sources of uncertainty. These are all perspectives that cannot be gained from the relatively small IPCC scenario ensembles to be performed with the fully coupled NCAR and GFDL models as U.S. contributions to the AR4.