Melting Ice – Global Consequences

Initial implementation plan for the WCRP Grand Challenge on the Cryosphere in a Changing Climate

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Introduction

The cryosphere is comprised of ice in the climate system: ice sheets and glaciers, snow, permafrost and sea-ice. As the climate warms, the response of the cryosphere is inevitably enhanced melt. This has had, and will continue to have, profound, societally relevant global **consequences**. The most pressing of these involve: thawing permafrost and the potential for enhanced natural emissions of carbon dioxide and methane to the atmosphere; shrinking of mountain glaciers and large ice sheets with consequent sea-level rise and impacts on water resources; declining coverage of sea ice and snow, which will affect marine and ground transportation across the Arctic. In order to make scientifically credible, quantitative projections of these critical changes, we need to better understand the underlying processes and improve our capability to represent them in global earth system models.

The overarching question: ***How will melting ice respond to, and feedback on, the climate response to increasing greenhouse gases, and what will the impacts be?***

To address this question we will consolidate historical observations from a range of sources, and focus effort on better representing the shrinking cryosphere in climate models used to make quantitative projections that underpin the IPCC Assessment Reports. We will target our activities in three areas:

1) Quantifying the amount of carbon available in permafrost areas, evaluating the potential for release of this carbon, and improving our capability to simulate the response of permafrost, and its connection to the global carbon cycle, under a warming climate. This is a pressing and timely issue given the potential for significant, positive feedback in the climate system, in addition to the direct ramifications of permafrost thaw on human activities throughout the high latitudes.

2) Assembling glacier and ice sheet models for use in projecting melt rates and corresponding sea-level rise – in both cases these represent scientific communities that have not been strongly engaged in climate projection activities, and we will take advantage of the WCRP's leadership in both climate modelling and cryospheric science. In addition to sea-level rise, shrinking glaciers will have profound and direct impacts on millions of people whose water resources depend on the summertime storage provided by mountain glaciers.

3) Assembling the most reliable observational data on sea-ice and snow and using these data to evaluate and improve climate model simulations of the remarkable changes that have already been observed and to enhance confidence in future projections. Many activities in the Arctic, from marine transportation to seasonal roads and traditional hunting are profoundly affected by the amount and timing of sea-ice and snow cover. In addition, changes in snow and ice have direct consequences for fragile high-latitude ecosystems (terrestrial and marine), and, some have suggested, impacts on global circulation and weather patterns.

All three are topics for which past IPCC Assessments have noted large uncertainty, and the WCRP has taken on the challenge of pushing progress forward in advance of the next IPCC report.

Background

The white paper "Cryosphere in a Changing Climate: A Grand Challenge of Climate Science" (Kattsov et al. 2012) provides the motivation for range of targeted efforts aimed at improving our understanding of the role of the cryosphere in the climate system and our ability to make quantitative predictions and projections of future change. A workshop, held in Tromsø, Norway (16-18 October, 2013 – meeting report by A. Pope and J. Baeseman in EOS, 95(15), 2014) further discussed this Grand Challenge and helped sharpen the focus on specific activities to be pursued. Subsequently, the WCRP leadership requested a targeted implementation plan (this document) and after some discussion, a change in name to more clearly communicate the central theme of the Grand Challenge and distinguish it from the Climate and Cryosphere core project. The result was: *Melting Ice – Global Consequences*. This title reflects the primary response of the cryosphere to a warming climate, and the focus on better understanding and quantifying the implications.

In the following workplan, we lay out specific activities that address the much more focused topics identified in the Introduction – these having been chosen as particularly compelling in terms of societally and globally important consequences of melting ice on the planet. It should be noted that these activities are closely coordinated with, and complementary to, activities underway as part of the CliC core project, and activities underway in other Grand Challenges.

Initial Implementation

As noted in the Introduction, three themes have been chosen for initial implementation. These themes were chosen largely because of the global consequences these aspects of the changing cryosphere will have. Urgent progress is needed in these areas to enable more confident projections of future change, and the implications of these changes for ecosystems and society. Because of its existing infrastructure, and ability to mobilize the international climate science community, the WCRP can lead targeted effort in these areas with modest financial investment.

1. Permafrost and the Global Carbon Cycle

The potential for enhanced release of carbon from thawing permafrost (in the form of either methane or carbon dioxide -- both greenhouse gases), is a worrisome source of uncertainty in future climate projections owing to the possibility of a strong, positive warming feedback.

The permafrost carbon project, co-funded by CliC, has pulled together a large modeling community aware of this challenge. It recently carried out an informal model intercomparison project to diagnose key model weaknesses, and to identify some of their major causes. As part of this new Grand Challenge initiative, we will establish a *Permafrost Modeling Forum* to provide a basis for this community to accelerate progress in this important area. It is anticipated that fluid knowledge exchange through the Forum will foster rapid and coordinated progress over the next five years. The aim is to implement essential physical and biogeochemical processes related to permafrost in a large range of global climate models, and to eliminate sources of major biases in the existing models, such as incorrect representation of snow.

In order to improve physical understanding and to facilitate quantitative evaluation of model performance, there is a need for a global synthesis of permafrost carbon observations obtained from existing networks of permafrost physical parameters. Such a global synthesis, linked directly to established permanent observational networks, will provide the basis for quantifying the amount of carbon currently stored in permafrost areas, and the potential rate at which it could be released

2. Ice Sheets, Glaciers and Rising Sea Level

The large ice sheets of Greenland and Antarctica are responding to climate change and contain vast stores of freshwater that, when delivered to the ocean, can raise sea level by many meters. This constitutes a long-term, essentially irreversible consequence of anthropogenic climate change and, as a result, this topic has received considerable attention in both the scientific and popular literature. Projections of future melt and potential dynamic instability of these large ice sheets is hampered by our limited understanding of the complex, non-linear physical processes (both within the ice sheet and at the bedrock interface) that control the rate at which ice can be discharged to the ocean. In addition, the atmospheric and oceanic forcing must be inferred from global climate model projections, which are themselves highly uncertain over the ice sheets. Although there have been intercomparisons of ice sheet models, these activities have, in the past, been completely disconnected from coordinated global climate modelling initiatives like CMIP. As a result, the implications of uncertainty in atmospheric and oceanic forcing have not been well explored. A further development is the prospect for implementation of ice sheet model components *within* global Earth System Models, allowing for direct feedbacks between the ice sheet and climate system. Some coupled models of this type will be available for use in CMIP6, and so in preparation for this, CliC has begun organization of a new Ice Sheet Model Intercomparison for CMIP6 (ISMIP6). This initiative, which will be pursued under the Grand Challenge, will provide the impetus to bring the ice sheet modelling community in closer contact with the global climate modelling community. This coordinated effort will significantly enhance our ability to make scientifically sound quantitative projections of future contributions of ice sheets to sea-level rise, and will feed directly into the upcoming IPCC Assessment, and the WCRP's grand challenge on regional sea-level rise.

But large ice sheets are not the only concern. Over the 20th century, one of the largest contributors to sea-level rise was from mountain glaciers. An important issue is the future fate of these mountain glaciers, both in terms of ongoing contributions to sea-level, and also as a source of freshwater storage important to many drought-prone regions of the planet. Simulating the global mass balance of mountain glaciers is a daunting challenge owing to their sheer number and spatial distribution. The coarse resolution of global (and even regional) climate models precludes explicit simulation of individual mountain glaciers as their existence depends on very fine topographic detail. There are however global models of glacier mass balance that can be run ‘off line’ with historical forcing from global atmospheric reanalyses and future forcing from global climate model projections. At this point, there has been no coordinated effort to compare the different models using the same forcing, and so inherent model uncertainties are not quantified. Further, there has been no attempt to comprehensively apply such models to a wide range of projected future forcings so as to estimate the range of potential changes in this important contributor to sea-level rise and freshwater availability. CliC has begun to organize the developers of global glacier mass balance models under an initiative to carefully compare the different approaches, to quantify their differences, to assess their ability to reproduce historical changes, and to provide more comprehensive projections of future change. This work will be an important contribution to both the sea-level and fresh water availability grand challenges of the WCRP, and will provide much-needed information on the regional impacts of climate change on this challenging and widely-distributed aspect of the global cryosphere.

3. Sea Ice and Snow Interacting with a Changing Climate

The WCRP’s Working Group on Coupled Modelling (WGCM) has a very successful track record in organizing Coupled Model Intercomparison Projects, and the one being planned now is CMIP6. In the past, the cryospheric research community has not been as actively involved in CMIP planning or the analysis of CMIP results as it could have been, and therefore our ability to understand model biases attributable to the representation of cryospheric processes has been hampered. Two particular issues have emerged in past IPCC Assessments as topics of considerable uncertainty: namely the ability of models to simulate recent declines and future changes in sea ice and snow. Recent studies linking changes in snow and ice to circulation changes, weather extremes, and the obvious impacts on terrestrial and marine ecosystems in the Arctic create and even greater sense of urgency.

As part of the Grand Challenge, we will make a concerted effort to link the snow and sea-ice observational communities to the modelling realm so as to deliver quantitative assessments of model performance and therefore improved confidence in our understanding of the causes of historical change, and projections of the future. We will address this through two closely aligned efforts:

a. Evaluation of the sea-ice component of CMIP6 models. Large biases in historical simulation of sea ice in both the Arctic and Antarctic have been noted in previous CMIP multi-model analyses, along with large differences in the projected future changes in sea-ice extent and thickness. As one example, the historical trend in Arctic sea-ice extent has tended to be underestimated by CMIP3 models (and to a lesser extent by CMIP5 models), whereas the simulated downward trend in Antarctic sea-ice extent is at odds with the small observed positive trend. Careful analysis of the sea-ice simulations, and detailed comparison to observations, has been done on an ad hoc basis by different investigators, using different methodologies, different observational data, and different performance metrics. In most cases, the source of model errors has remained elusive, and the role of natural (internal) climate variability has not been dealt with very well. In an attempt to foster a more revealing analysis of CMIP6 model output, and in particular to try to quantify the roles of low-frequency variability versus forced trend, the *CliC Sea Ice and Climate Modelling Forum* has begun coordinating a CMIP6 intercomparison activity, starting with a model output data request that was submitted to the CMIP6 organizers in fall of 2014. The forum will organize meetings to bring modellers, analysts and observationalists together to develop model performance metrics (quantitative measures of model performance), and then to apply these metrics to the evaluation of CMIP6 model results as they become available. The goal is to have detailed analyses of CMIP6 model results published in time to feed into the next Assessment of the Intergovernmental Panel on Climate Change (IPCC) whose publication is anticipated in 2020. *Tentative timeline:* 2015 – continue to develop CMIP6 data request and identify suitable datasets and metrics for model evaluation; 2016 – begin initial analysis using available CMIP5 output to test evaluation methods; 2017-2018 – begin in-depth analysis and evaluation of CMIP6 model output as results become available; 2018-2019 – multi-author overview papers summarizing results serving as input to IPCC AR6.

b. In direct analogy to the sea-ice activity described above, the evaluation of simulated snow cover and the fidelity with which snow processes are represented in global Earth System models has not been systematically addressed in past CMIP planning. As a result, large biases continue to be noted in CMIP model results, but understanding of the source of these biases, and their role in affecting large-scale climate feedbacks, is lacking. In order to address this, the ESM-SnowMIP effort will specifically target evaluation and improvement of the representation of snow in Earth System models, through evaluation of CMIP6 model results and the specification of novel experiments aimed at isolating climate feedbacks related to snow cover and snow albedo. It should be noted that, for efficiency, this activity is being jointly coordinated with GEWEX under the umbrella of a broader intercomparison of land surface components in CMIP6 – the overall effort is termed LS3MIP. Planning of this activity is well underway and has entrained researchers involved in global climate modelling, snow process simulation, in-situ observations, and global remote sensing of snow. It is important to maintain this momentum, with the goal of having detailed analysis and published papers available in time to feed into the IPCC 6th Assessment which is anticipated around 2020.

Deliverables and Outcomes

The activities outlined above are laid out, from the start, with very specific objectives. These include the active involvement of the relevant observational communities to establish benchmark data sets, and the corresponding modelling communities to undertake detailed evaluations and analyses. The outcomes will be peer-reviewed, community-led papers that summarize the state of knowledge, and clearly articulate both areas in which confident statements can be made and those for which major uncertainties remain. By engaging the international community, and building upon the scientific network the WCRP has long established, efficient and effective progress can be made with only modest investment (primarily funds to bring people together and to sustain ongoing communication and collaboration). The community papers that arise from this work will serve two distinct purposes: one is to draw attention to knowledge gaps that require further attention and would serve as foci for national and international funding opportunities; the second is to consolidate current understanding and develop improved modelling capabilities that will be brought to bear in climate change projections that underpin the IPCC and other assessment reports, and thereby the global policy-development arena.

Timeline and Funding

The activities outlined above will take full advantage of the coordination and logistical support available through the CliC Project and its International Project Office. The specific activities that have been elaborated here, arise directly from the Cryosphere Grand Challenge white paper that was presented to and endorsed by the WCRP Joint Scientific Committee and the initial Cryosphere Grand Challenge workshop held in Tromsø, Norway in October 2013. The activities have been chosen in response to the need for Grand Challenge initiatives to be timely and of broad interest, as well as being able to deliver substantive results within a 5-year period. This has naturally led to a focus on connection to the WGCM's CMIP6 planning which ensures wide connectivity to the global Earth System modelling community and the foundational contribution CMIP has always made to the IPCC's Assessment Reports. These in turn constitute the primary, science-based information upon which regional, national and international climate policy is built. Therefore focusing initially on CMIP6 related activities allows CliC to make rapid progress on some of the key issues identified in the white paper, taking advantage of the large international investment that will be made in CMIP6, and ensuring that key cryospheric issues are addressed in ways that have been lacking in the past.

A key milestone is therefore the publication of the IPCC 6th Assessment report which is anticipated in 2020. Leading up to that, coordinated experiments must be conducted, careful analysis undertaken, and results published in peer-reviewed literature (a requirement for inclusion in IPCC reports). By focusing on a few key topics, and by taking advantage of the connections inherent in the CliC core project, initial groundwork has already been laid and dedicated groups of scientists have been engaged. Moving forward, modest WCRP funds are required to co-sponsor targeted meetings and workshops to strengthen ongoing electronic communication and collaboration. Face-to-face meetings are vital to maintain momentum in international projects of this kind, and funds will be used exclusively in support of such meetings.

Activities and Future Milestones

Funding in support of this Grand Challenge for 2014 and 2015 has been at the level of roughly CHF 20,000 per year. More detailed progress reports are available in the CliC Annual reports for these years, but in short, meetings have been sponsored to coordinate the ISMIP6, ESM-SnowMIP/LS3MIP, and SIMIP activities, allowing detailed plans to be formulated, submitted and approved by the CMIP6 Panel. Meetings for the GlacierMIP and Permafrost Carbon Network have also been supported, with an active group of glacier modellers now fully engaged in preparing specific experiments to allow careful comparison, and permafrost modellers continuing progress toward improved permafrost/carbon simulation.

2016

Data requests for the CMIP6-endorsed MIPS will be finalized and distributed to modelling centres. Plans for analysis of CMIP6 model output will be further developed in anticipation of model output availability. Meetings of individual MIP groups will permit refinement of plans, and in some cases allow new analysis or offline modelling approaches to be tested using CMIP5 data already available.

2017

Initial steps taken toward organizing observational synthesis/review papers, particularly related to sea-ice thickness, glacier and ice sheet mass balance, and Arctic river and lake ice. Lead authors identified and preliminary outlines created. These observational syntheses will contribute directly to assessment of historical variability and change, and to subsequent evaluation of CMIP6 model results. Connections between observational synthesis and MIP participants will be fostered.

2018-2019

As CMIP6 model results become available, in depth analysis of cryospheric aspects will begin in earnest. Offline simulations using global glacier mass balance, Greenland Ice Sheet, detailed snow process, and Arctic permafrost carbon models will be undertaken. Analysis of results will be published in time for citation in IPCC AR6 report, with cut-off date anticipated in 2020 (though IPCC timeline is still to be determined).