Implementation Strategy for a WCRP Polar Climate Predictability Initiative (PCPI)

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Scientific Context

Over the last few decades, the polar regions have exhibited some of the most striking manifestations of climate change. Due to the polar amplification of the greenhouse-gas effect, the Arctic has been warming at a rate several times faster than the rest of the globe. Concurrently, Arctic sea ice extent has been retreating rapidly, more rapidly than predicted by most climate models, reaching a new record minimum in late summer (September) 2012. At the same time, while the rate of reduction in sea ice extent in the Bellingshausen Sea rivals that of the Arctic, the overall average Antarctic sea ice extent is observed to be slightly increasing, contrary to the model predictions (and with very high regional and temporal variability), and a record late-winter *maximum* was seen in September 2012. The largest observed changes in Antarctic climate over the past few decades have occurred during the summer season and have been primarily attributed to the development of the ozone hole. On shorter time scales, modern seasonal prediction systems mostly rely on teleconnections originating from the tropical regions such as those associated with ENSO. However, recent studies have shown the existence of seasonal predictability associated with interactions in the climate system that involve aspects of mid- and polar latitudes such as soil moisture, snow cover, sea surface temperature, sea ice, solar variability, and stratospheric sudden warmings. Theoretical studies also suggest the possibility of having a predictable climate signal on the decadal time scale with maximal signal-to-noise ratio in subpolar ocean areas. However on such timescales the forced component of climate predictability is likely to be very significant, especially in the Arctic, which suggests that in polar regions the initial-value problem and the forced problem should be considered together.

The strong coupling between polar and subpolar oceans, sea ice, land surface, troposphere and stratosphere calls for an interdisciplinary approach to research on these regional climate systems and their interaction with global climate processes. **The main goal of this research initiative is to advance our understanding of the sources of polar climate predictability on a range of timescales ranging from seasonal to multi-decadal.** Here "predictability" is understood to mean not just initial-value predictability but also predictability of the extent of variability (which especially in the Arctic can be expected to change as climate changes) and of the response to both natural and anthropogenic forcings. In addition, a prerequisite for predictability is high-quality observations for validation and initialization. Therefore, all these issues need to be considered together in order to make progress.

Programmatic Context

Polar climate predictability is a subject that cuts across all areas of WCRP, including all four core projects and the major modelling working groups (WGNE, WGSIP, and WGCM). Polar climate science is also a central focus of two international organizations, the International Arctic Science Committee (IASC) for the Arctic, and the Scientific Committee on Antarctic Research (SCAR) for the Antarctic. Therefore, good working relationships need to be established with those bodies, to avoid duplication of effort or the perception of competition. WCRP has a unique role to play through its focus on global connections within climate and its strong global modelling capability.

A sister Polar Prediction Project (PPP) focusing on time scales from hourly to seasonal has been developed by the WMO World Weather Research Programme (WWRP) as a legacy of the International Polar Year 2007-2008 (IPY) polar weather prediction research. There are many potential synergies between PPP and PCPI, including sharing knowledge on aspects of polar-ocean, atmosphere, snow and sea-ice modelling, observations, and data assimilation. Early cooperation between the groups focusing on interaction of time scales will also be useful for exploiting "seamless" aspects of polar prediction.

The WMO Executive Council Panel of Experts on Polar Observations, Research and Services (EC-PORS) is promoting a Global Integrated Polar Prediction System (GIPPS). It is expected to address three time scales: from weather time scales to a season, from years to decades, and centuries. EC-PORS sees the WWRP PPP and the WCRP PCPI as GIPPS building blocks, the former addressing the shorter time scale and the latter addressing the longer time scales. At its third meeting in Finland in February 2012, EC-PORS recommended to WWRP and WCRP to have a single polar project and a single project office for PPP and PCPI.

There is a growing demand for climate information at the regional scale, which will be met by activities of a more operational nature including the WMO system of Global Producing Centres for Long-range Forecasts, and, more generally, the emerging Global Framework for Climate Services. The WCRP provides the research component to support these WMO-led operational activities, for example through the Coordinated Regional Downscaling Experiment (CORDEX); the PCPI will fill this role for polar regions, working through the appropriate WCRP Working Groups.

Key Scientific Questions

How predictable is polar climate? What are the physical mechanisms for polar climate predictability on seasonal to multi-decadal timescales? Is there a potential for improving the actual skill of climate predictions for polar regions? How can we use seasonal prediction to deepen our understanding of longer timescales and validate and/or improve models for all timescales?

Why are the climates at the two poles changing differently to each other (with the Arctic changing rapidly, and the Antarctic unevenly), and differently to global climate? The Antarctic is exhibiting warming in some regions, and cooling in others; whilst on average Antarctic sea ice extent is not decreasing, there are regions of marked increase and decrease. The rate of warming and of sea-ice retreat in the Arctic has increased in the past decade while the rate of global temperature increase has weakened. The last five years in the Arctic shattered records, while global mean metrics of climate have not been so unusual in the context of the last decade. Meanwhile the Antarctic saw a record late-winter sea-ice *maximum* in September 2012.

Why are climate models generally unable to capture the observed behaviour in polar regions? The observed rate of Arctic change is at the edge (or beyond) the distribution of model estimates. In the Antarctic, models uniformly predict decreasing sea extent, which is not observed. Models generally predict that the ozone hole would have decreased rather than increased sea-ice extent, which only exacerbates the discrepancy with observations.

What does high latitude climate change mean for lower latitudes? The albedo feedback at high latitudes from melting snow and ice affects the global energy balance. Dynamical changes at high latitudes can affect lower latitudes, including extremes, through teleconnections and circulation anomalies in both atmosphere and ocean. Carbon and heat uptake in the Southern Ocean affects global budgets of these quantities. Permafrost thawing in the Arctic has the potential to turn this region in a matter of decades from a carbon sink to a carbon source.

Do the ongoing amplified changes in the Arctic have an influence on extremes in the Arctic? What are the socio-economic and ecosystem impacts from extremes and climate change, especially when compounded?

Is the stability of ice sheets changing? What is the probability of catastrophic ice sheet breakdown? Could this process be much faster than the previous estimates predict? Ice sheet breakdown has major implications for sea level rise. Rapid breakdown could also significantly perturb the meridional overturning circulation of the ocean. Recent evidence suggests that coastal currents around Antarctica and Greenland could be redirected as a result of climate change, affecting ice-sheet stability.

Opportunities for Significant Progress in the Next Five Years

Recent expansion of the ocean observing system. The explosion of new subsurface ocean observations in the last decade or so from Argo floats and from the recent “seal” network has revolutionized the polar ocean observing system. This provides new opportunities for characterizing ocean variability and for model validation and initialization. SCAR has recently established a Southern Ocean Observing System to characterise the poorly observed Southern Ocean.

New measurements of sea-ice thickness and other important surface variables. New types of remote sensing from space are emerging that are capable of providing measurements of sea-ice thickness, land surface moisture, ocean surface salinity, etc. For example, ESA's recently launched CryoSat and SMOS satellite missions are providing measurements of sea-ice thickness, previously a crucial missing component of sea-ice measurements. There are other satellites in orbit and in planning with similar capabilities.

New reanalysis products. There has been an explosion of reanalysis efforts in recent years, with now multiple products available, which will allow a better understanding of the uncertainties in our knowledge of climate and climate variability. An experimental version of a regional polar reanalysis is also available. These activities have also driven data rescue efforts.

More comprehensive global models. Many studies have shown the importance of a realistic representation of stratospheric variability and change for surface climate in both the Arctic and Antarctic, and state-of-the-art coupled models are increasingly including such representation, including interactive ozone chemistry. Eddy-permitting ocean circulation models are becoming more widespread, which should greatly improve the representation of the Southern Ocean, a key link between Antarctic and global climate.

The pieces are in place. The WCRP workshop in Bergen in October 2010 showed that much progress can be achieved just by bringing together previously disparate scientific communities to work on common problems that involve a strong coupling between the different components of the climate system. The workshop demonstrated that the scientific community recognises this and is willing to work together.

***Interest of the scientific community*.** The recent rapid changes in Arctic sea ice, the growing need for climate information in the Arctic as we move towards an ice-free summertime Arctic, and the increasing awareness of the role of the polar regions *of both hemispheres* in global climate (not just "canaries in coal mines") have greatly increased the interest of the scientific community in this area. Improved funding opportunities to support that interest are expected to emerge.

Synergy with the WWRP-PPP. The recently launched WWRP-PPP will stimulate efforts on improved model processes (e.g. stable boundary layers), data assimilation, and synoptic-scale atmospheric coupling between polar regions and lower latitudes, all of which will directly benefit studies of polar climate predictability. It will include a Year of Polar Prediction in 2017-2018, providing an opportunity for a focused effort that includes a strong observational campaign with subsequent comparison and validation possibilities. By advancing efforts in polar prediction out to seasonal timescales, the

WWRP-PPP will also help provide an opportunity for exploiting the benefits of seamless prediction in polar regions.

Specific Initiatives (not in order of priority)

1. ***Improve knowledge and understanding of past polar climate variations (100+ years).*** Because of the very limited observational record in polar regions, it is imperative to consider all estimates of past behaviour — data records, reanalyses, and models — in an optimal manner, to obtain estimates of past variability and change. Models can potentially be used to enhance state reconstructions through forward data simulators. New data records have become available through the 20th century reanalysis data collection efforts, which are especially important in the pre-satellite era. These efforts can also help in the design of optimized observing systems for detecting and attributing changes, and quantifying the impact of losing certain observations.

2. ***Assess reanalyses in polar regions.*** There are comparatively limited observational constraints on reanalyses in polar regions, hence it is especially critical to assess their reliability and self-consistency. This includes both atmospheric and ocean reanalyses. Metrics should be developed that reflect the coupling processes between the different components of the climate system, which can then inform the development of coupled reanalyses. Uncertainties in reanalyses should be investigated (e.g. by looking at increments) to determine whether they reflect biases in modelled processes.

3. ***Improve understanding of polar climate predictability on seasonal to decadal timescales.*** WGSIP/CHFP and WGCM/CMIP have the infrastructure and connection to modelling centres to perform prediction studies on seasonal and decadal timescales, respectively, but need the expertise of polar climate scientists to interpret the results of those studies in polar regions (e.g. the CHFP Sea Ice Historical Forecast Project) and design new experiments. Close liaison would be expected here with the WWRP-PPP, e.g. for coupled data assimilation, especially of sea ice for which initialization is a key issue in polar predictability. An important focus would be the impacts of polar variability on lower latitudes, for which there is growing evidence. The sensitivity of polar predictability on decadal timescales to initial-state error in the ocean should be better understood, to guide ocean observational network design.

4. ***Assess performance of CMIP5 models in polar regions.*** Process-oriented metrics specific to polar regions should be developed to assess the models, including extreme events. These would need to be chosen bearing in mind where useful observational constraints exist. Where suitable observational constraints for key processes do not exist, this should be identified. Optimal use of “ensembles of opportunity” such as those produced by CMIP5 should be explored. CMIP5 model behaviour should be analysed in the context of simpler models, to identify traceable

physical phenomena and feedbacks so as to develop confidence in the representation of physical processes in the CMIP5 models. A question of particular importance (for oceanic carbon and heat uptake, and heat transport to the sea-ice margin) is the role of eddies in the Southern Ocean and how their representation affects the response of the Southern Ocean to atmospheric forcing. More generally, do the CMIP5 models represent an improvement over the CMIP3 models with respect to important polar processes, and if not, why not? Can these models be used at all to assess the corresponding extremes?

5. ***Develop methods to calibrate long-term predictions of polar climate change.*** Models exhibit significant biases in polar regions and generally fail to reproduce past trends, so it is essential to calibrate the long-term predictions if they are to be useful. Since in the Arctic the forced response may be relevant on time horizons of less than a decade, this folds into the decadal prediction problem. There have been several examples published for the Arctic showing how past behaviour can be used to calibrate predictions, grounded in solid physical understanding. Can this approach be used in a more widespread manner? Useful decadal predictability may be possible using just the forced response together with estimates of natural variability.

6. ***Improve understanding of how jets and non-zonal circulation couple to the rest of the system in the Southern Hemisphere.*** Compared to the Arctic, where the scientific community is fairly large, the number of scientists working on Antarctic climate and predictability is small and there is a need to take deliberate steps to form a cohesive scientific community. Many of the current pressing scientific questions involve the response of the atmospheric circulation to ozone depletion/recovery and greenhouse-gas increases, and how this impacts surface climate, ocean circulation, sea ice, and ice shelves. These interactions have implications for carbon and heat uptake and the stability of ice sheets. We need to understand the observed relationships and how they are represented in models, in order to improve decadal prediction and longer term projections of Antarctic climate.

Implementation

The PCPI will be a **sub-initiative** within the “Cryosphere in a Changing Climate” WCRP Grand Challenge. Overall responsibility for the latter will lie with CliC, but SPARC will initially have responsibility for the development of PCPI. PCPI will also represent the WCRP component of EC-PORS GIPPS.

A dedicated ***PCPI Steering Committee*** should be formed. Because new activities will need to be initiated, it should not be a “committee of representatives”, but should consist of champions who are committed to take an active role in helping to move things forward.

Activities should be focused and have clear timelines and expected outcomes, and be targeted on issues where the WCRP can play a unique role and where the complementarity with activities of other bodies (especially IASC and SCAR) is clear. Activities could range from focused workshops to coordinated efforts of up to 2-3 years' duration, e.g. coordinated model experiments, development of recommended operational protocols for seasonal prediction, assessment of data sets, or synthesis analysis. As a first step, small workshops or meetings of opportunity should be held as soon as possible focused on the initiatives listed above, to define such activities.

There must be **close cooperation** with the WWRP-PPP, with existing WCRP core projects and working groups, with the WCRP Grand Challenges, and with IASC and SCAR. The PCPI can be an 'incubator' to generate community research efforts that could be adopted, in the longer term, by more permanent components of the WCRP or of partner organizations.

Secretariat support should be provided through a joint WWRP-PPP/WCRP-PCPI coordination office, as suggested by EC-PORS. It would nevertheless be very important that the current support for the PCPI at the University of Toronto (Dr. Diane Pendlebury, SPARC Project Scientist) from the Canadian Space Agency be maintained.

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