Workshop Report: Simulation of the Canadian Cryosphere

Paul J. Kushner[1], Karen L. Smith[1], Ross D. Brown[2], Chris Derksen[2], Claude R. Duguay[3], Richard Fernandes[4] and W. Richard Peltier[1]

1. Department of Physics, University of Toronto. 2. Environment Canada. 3. Department of Geography, University of Waterloo. 4. Natural Resources Canada.

Introduction

We report here on a kick-off workshop for a project entitled "Simulation of the Canadian Cryosphere" that was recently funded by the Natural Science and Engineering Research Council of Canada's (NSERC) Strategic Project Grants program. The project is motivated by 1) the need to improve our understanding of and ability to realistically simulate high latitude cryospheric processes in light of rapid changes in the Arctic, 2) new observational data and research questions stemming from International Polar Year (IPY) activities, and 3) new large-scale computing resources at the SciNet computational facility hosted at the University of Toronto. The project partners scientists with modelling and observational expertise from the University of Toronto (Kushner and Peltier), the University of Waterloo (Duguay), Environment Canada (EC – Derksen and Brown) and Natural Resources Canada (NRCan – Fernandes). Through this project we are making an effort, as IPY projects such as the Canadian Federal IPY Cryosphere Network wind down, to maintain a strong connection between the observational and modelling side of cryosphere-climate process research. Besides the standard outlets for dissemination of scientific research, the output from this research team is intended to be transferred to EC and NRCan to be employed in policy development for the Canadian North.

The workshop, which took place January 19 in the Department of Physics at the University of Toronto, was organized along the three main themes of the project: land ice, seasonal snow cover, and sea ice. It was intended to highlight directions where rapid research progress can be made that involves a close connection between simulation and observation. The expertise within the project resides primarily in the area of land-ice and snow processes, and for these processes the project is intended to capitalize upon newly available observational products and computational resources. During the workshop, a key discussion question involved how these new resources can best be used to make progress on land-ice and snow issues. The sea-ice component required further fleshing out, and discussion in the workshop was directed towards this aim. We also discussed the issue of mixing dynamics in Arctic lakes and long-term plans to carry out research in this area. We rounded out the day with a discussion of our science from the perspective of policy needs and how we might seek longer-term support for this research that extends outside the current project. A list of workshop participants is shown in Table 1, and selected papers from the workshop are available at http://pjk.atmosp.physics.utoronto.ca/workshop-presentations

We will summarize the main results of the workshop in the next section and conclude with a discussion of next steps for the three year term of the project.

Table 1: Workshop Participants

Heather Andres	University of Toronto
Ross Brown	EC
Chris Derksen	EC
Claude Duguay	University of Waterloo
Richard Fernandes	NRCan
David Fisher	NRCan

Chris Fletcher	University of Toronto
Stephen Howell	EC
Ashleigh Ingle	University of Toronto
Paul Kushner	University of Toronto
Fredéric Laliberté	New York University
Sally Macintyre	University of California at Santa Barbara (telecon)
Lawrence Mudryk	University of Toronto
Richard Peltier	University of Toronto
Karen Smith	University of Toronto
Gordan Stuhne	University of Toronto
Anne Walker	EC
Libo Wang	EC
Mathew Wells	University of Toronto
Nick Xenos	Indian and Northern Affairs Canada (telecon)
Christian Zdanowicz	NRCan
Hongxu Zhao	EC/NRCan

Workshop summary

Land Ice Theme

David Fisher (NRCan) opened by presenting recent developments in ice core research, specifically Holocene temperature reconstructions. New cores from the Greenland Agassi and Renland ice sheets, which are less sensitive to elevation effects than the central Greenland cores from the Greenland Ice-core Project (GRIP), provide high quality temperature records that can be used to adjust the records from central Greenland cores and to quantify the extent of elevation changes in this region (Vinther et al., 2008; Vinther et al., 2009). Cores from the North Atlantic sector stand in contrast to a new core from Mt. Logan in Alaska in depicting Holocene variability: North Atlantic cores show one large climate cooling event, 8,200 years ago (8.2 ky); however, the Mt. Logan record is marked by numerous large, abrupt temperature changes, many larger than the 8.2 ky event. Analysis of paleo El Nino-Southern Oscillation (ENSO) records indicate that the large shifts in δ^{18}O are associated with the state of ENSO (Fisher et al., 2008). The direction of the change in fluctuations associated with the ENSO events suggests that the core is recording a change in source water rather than a change in temperature. This paleo perspective was of great interest to workshop participants who are involved in understanding the long-time variability of the high-latitude system and new ideas for simulation tests were put forward.

Richard Peltier (Toronto) highlighted the value of the Gravity Recovery and Climate Experiment (GRACE) satellite's measurements of Earth’s gravitational field in understanding cryospheric contributions to recent sea level rise. Once the effects of glacial isostatic adjustment (GIA) and of hydrological processes are accounted for, the GRACE data indicate regions of ice sheet mass loss due to recent climate change over Greenland, Alaska, and the Amundsen Sea and Peninsula regions of Antarctica (see Fig. 1). The Alaskan glacial ice sheet loss is accounting for 0.15 mm/y of sea level rise, and the Greenland ice sheet loss is accounting for 0.62 mm/y of sea level rise, both of which contribute significantly to the global total of 1.95 mm/y (Peltier, 2009). The potential utility of the GRACE data will only improve in the future; the longer it flies, the greater spatial resolution will be obtained. Prof. Peltier's group will focus within our project on how to better understand the dynamics and climate controls of these ice sheets. **Gordon Stuhne** (Toronto) discussed how most ice sheet models can reproduce the general features of ice sheets but poorly represent details that appear to be key in determining the mass balance of an ice sheet. He has developed a model that employs an unstructured grid to better model the ice sheet margins of Greenland and has found much better agreement with the observations. **Heather Andres** (Toronto) will be using the National Center for Atmospheric Research (NCAR) climate model, CCSM4, to investigate the role local climate (e.g., cloud cover, sea-ice, etc.) on the mass balance of the Greenland Ice Sheet over the past 150 years.

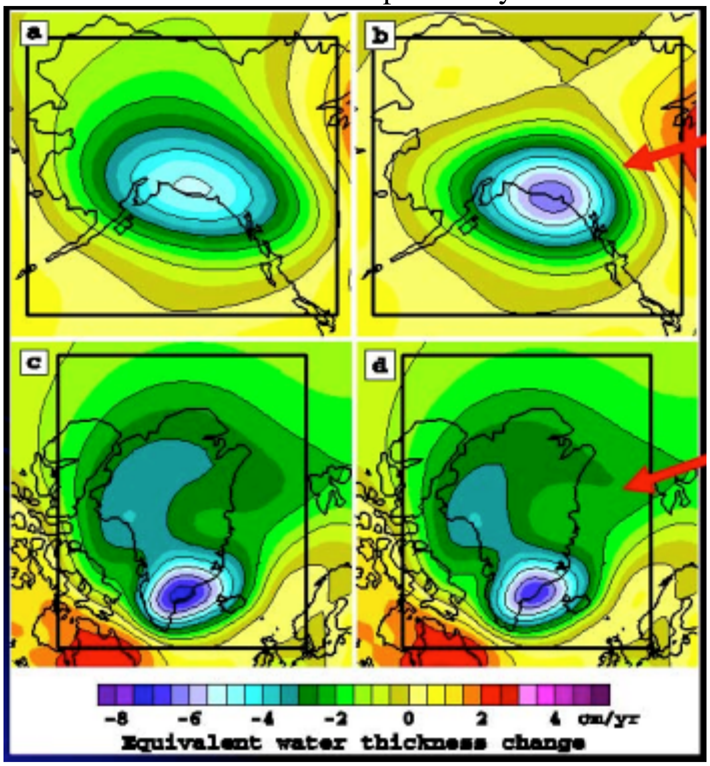

Figure 1: (a) Surface mass-rate field over Alaska from GIA corrected GRACE data. (b) Alaska mass-rate field corrected for the influence of surface hydrology using GLDAS and glacial isostasy using the predictions of the ICE-5G (VM2). The box drawn around the anomaly defines the region within which the negative anomaly is considered to be due to land ice melting. (c) Surface mass-rate field for Greenland based upon the glacial history for this region in the original ICE-5G model that contained a neoglacial re-advance of ice that continued until the present day (denoted ‘‘no stop at 2 ka’’). (d) The mass-rate field for Greenland assuming that the neoglacial re-advance in the original ICE-5G model is eliminated from 2 ka onwards (Peltier, 2009).

Snow Theme

Ross Brown (EC/OURANOS) summarized the latest observational trends in snow cover extent and highlighted the differences between North American and Siberian snow trends. The Siberian snow onset date has not changed much over the observational record while the North American snow onset date is trending later in the season. The snow off date is earlier in both the Canadian Arctic and Northern Siberia and trends are strongest in coastal areas likely in response to decreasing sea-ice and more open water near the coastlines. Over the last half century wintertime snow depth has been increasing in Siberia but decreasing in North America. The latter is somewhat difficult to explain as precipitation has been increasing over northern Canada. One possible explanation is that the Canadian snow depth observing network, which is based on open sites areas near airports, is not responding to the trend toward increased shrubbiness and associated snow catching potential. New multidataset estimates of Arctic spring snow cover trends over the 1979-2008 period (see Fig. 2) show that snow cover, sea-ice, and temperature track each other very closely. Brown pointed out that the Intergovernmental Panel on Climate Change (IPCC) models underestimate the temperature sensitivity of snow cover over the Arctic during the spring melt period which may be related to a number of factors including overestimation of precipitation, not accounting for black carbon effects on snow albedo, and simplified representation of Arctic snow processes (Brown and Mote, 2009).

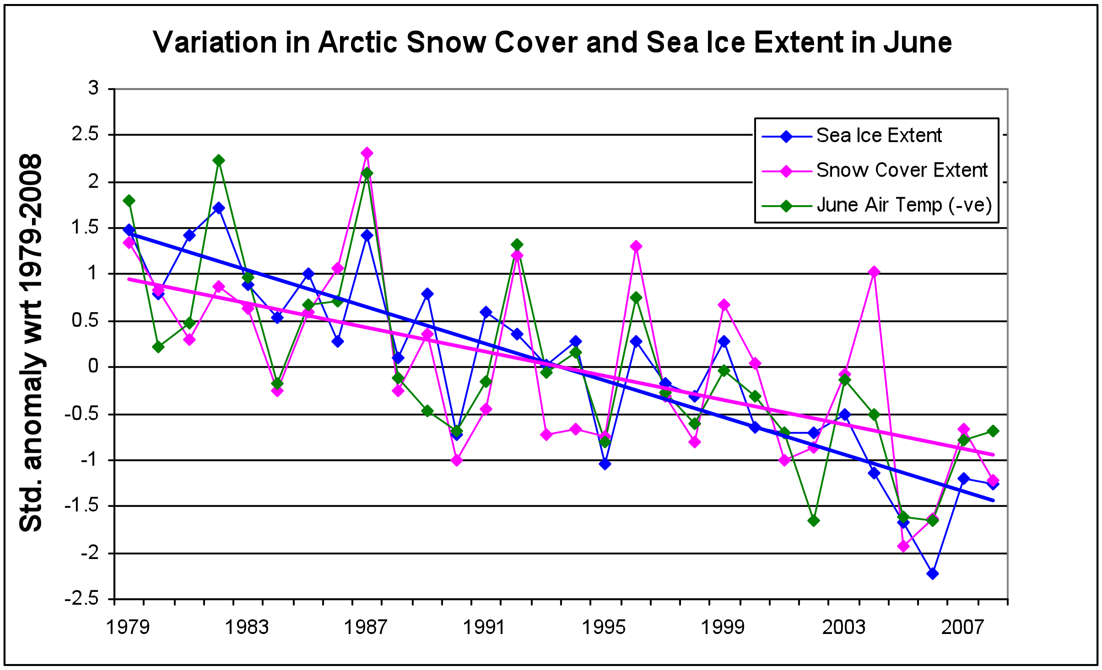

Figure 2: Variation in Arctic June snow cover extent, sea ice extent and air temperature (plotted as negative anomaly) over the 1979-2008 period. Least squares trends are shown for snow cover and sea ice extent (from Brown et al., submitted).

Chris Derksen (EC) reported on the latest in satellite-derived snow observations developed during the IPY. The observing network in the Canadian Arctic is sparse and EC's satellite derived products are designed to fill in these spatial gaps. A new tundra specific snow water equivalent (SWE) algorithm was developed and validated for satellite passive microwave data through a series of sub-Arctic field campaign in 2008 (Derksen et al., in press). The passive microwave time series (1979-2008) indicates that peak SWE is increasing over the Canadian Arctic (see Fig. 3). This finding is not consistent with observed trends in maximum snow depth from station observations, but agrees with observations of increasing winter season precipitation over northern Canada. The discrepancy between the satellite-derived and conventional observations is likely due to differences between single point surface observations which are influenced by local conditions at observing stations, and the spatially integrated satellite measurements. These time series will be investigated further to clarify these differences. Because Arctic spring snow cover duration is decreasing, an increase in winter season snow depth or SWE would suggest an intensification of the high latitude water cycle in spring. Time series analysis of terrestrial snow and sea ice extent datasets identified linkages between the terrestrial and marine cryosphere, with the timing of pan-Arctic terrestrial snow melt onset significantly correlated with summer sea ice extent anomalies. The strength of this terrestrial melt versus sea ice extent relationship peaks in July, which suggests early melt onset on land during spring reinforces large scale warming in the Arctic.

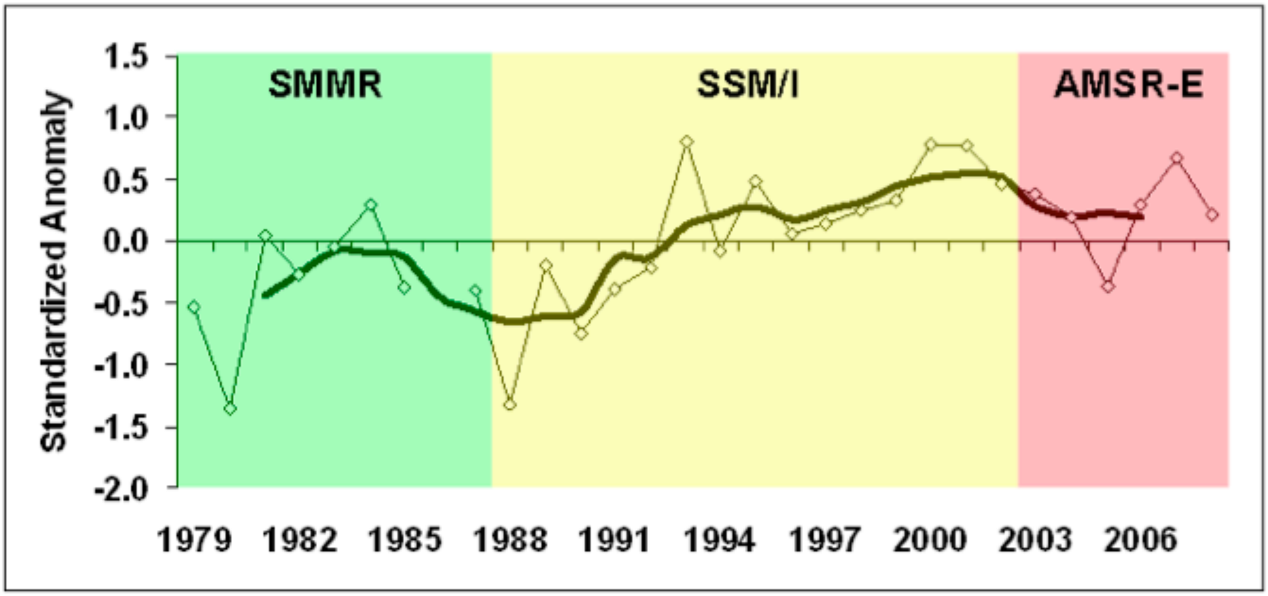

Figure 3: Standardized SWE anomalies for the Canadian sub-Arctic tundra derived from the satellite passive microwave data record (Derksen et al., in preparation).

Claude Duguay from the University of Waterloo discussed an important limitation of conventional passive microwave algorithms for SWE. Over regions with large lake fraction, standard algorithms yield very low or even negative SWE values for snow cover on frozen lakes. This artifact arises because conventional algorithms retrieve SWE by taking the difference between the 19 GHz band and the 37 GHz band which are differentially influenced by lake ice due to different penetration depths. The new EC tundra-specific algorithm avoids this issue by utilizing the temporal change of single frequency measurements (37 GHz) which are uncorrelated with lake fraction. This highlights the need to develop algorithms using field data and models specific to lake-dominated landscapes.

Chris Fletcher (Toronto) continued the discussion of snow processes by presenting his analysis of snow-albedo feedback (SAF) using the new NRCan/CCRS snow cover and albedo data product (Zhao and Fernandes, 2009). SAF contributes approximately 10-20% to global climate sensitivity. Previous work has indicated that there is a three-fold spread in the IPCC-AR4 models' SAF (Qu and Hall, 2006) and that this spread contributes up to 20-30% of the spread in the surface temperature response to climate change over North America (Fletcher et al., 2008). The SAF due to climate change roughly corresponds with the SAF due to seasonal winter-to-spring melt within each model, implying that accurate observations of what the true winter-to-spring SAF should be could allow models to be better constrained (Fernandes et al., 2009). Dr. Fletcher and collaborators have used the new snow cover and albedo product to better quantify the seasonal SAF in the climate system (see Fig. 4). On average, the models reproduce the observed regional patterns of SAF factors but the spread among models is quite large, particularly in the snow metamorphosis contribution to the SAF that is inferred from this analysis.

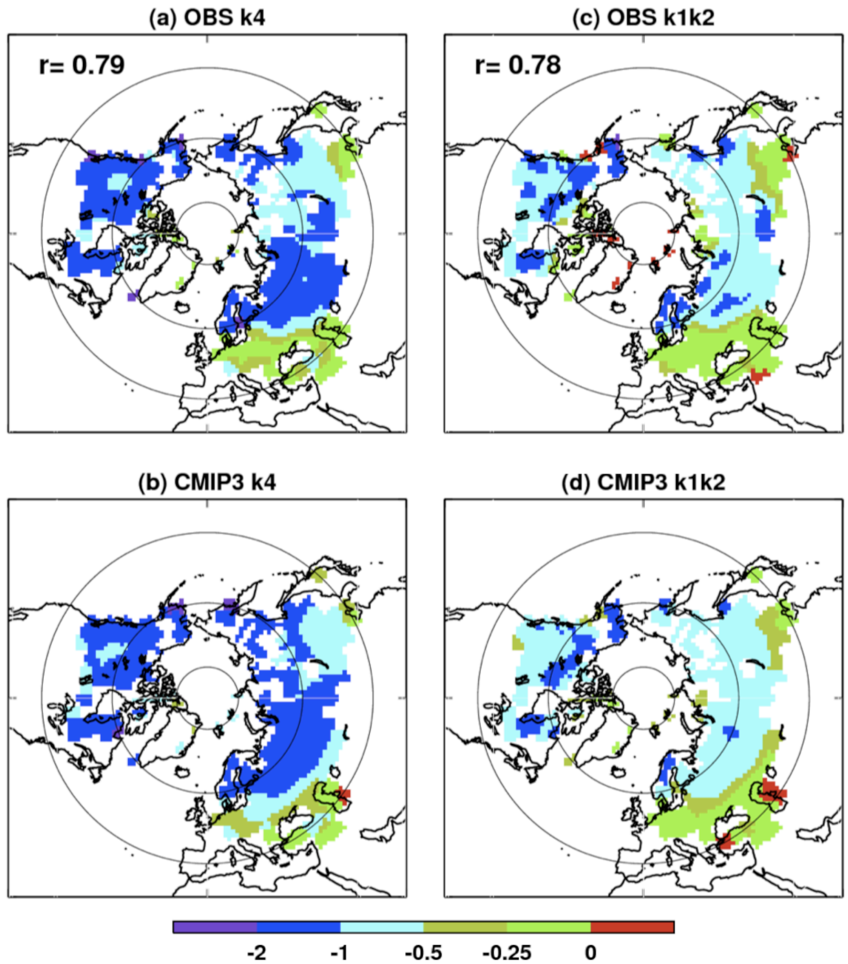

Figure 4: Maps of total snow albedo feedback (SAF) sensitivity in %/K ("k1k2"), and the contribution to the total from snow cover effects ("k4") derived from observational data (top row) and CMIP3 multi-model ensemble mean data (bottom row). All data are March-April-May averages; the observations cover the period 1982-1999, while CMIP3 covers the period 1900-99 from the 20c3m simulations. Positive values are coloured red and missing values are not shaded. The anomaly correlation between the observed and CMIP3 maps is shown in the top left corner of each observational plot (Fletcher et al., in preparation).

To conclude the snow section of the workshop, **Karen Smith** (Toronto) discussed how snow cover remotely affects the large-scale atmospheric circulation through teleconnection dynamics involving the Northern Annular Mode/Arctic Oscillation (NAM/AO). Observational data indicate that years in which there is anomalously high snow cover over Eurasia in October are correlated with negative phased-NAM wintertime climate. The lead-lag relationship between anomalous autumn snow cover and wintertime tropospheric climate points to the utility of snow cover as a seasonal forecasting tool and to connections between cryospheric processes and large-scale circulation. However, this observed connection is not simulated in climate models. Ms. Smith discussed recent insights into the underlying dynamics of the process based on GCM studies, establishing the role of linear interference in determining the nature of the NAM response to a snow forcing experiments (Smith et al., submitted to *J. Climate*). Greater understanding of snow processes and accurate simulation of snow cover extent and variability are vital to capturing this process within the natural variability of GCMs.

Sea-Ice Theme and Future Research Directions

Christian Zdanowicz (NRCan) opened the final session of the workshop with a discussion of his recent work to characterize the climatology of Canadian Arctic sea-ice. The trend from 1980-2004 indicates decreasing concentrations in Hundson Bay, to the east of Ellesmere Island and off the north shore of Yukon and Alaska, and increasing concentrations within the Archipelago. Overall, he notes a 3.6% per decade decrease in Canadian Arctic sea-ice concentration (Kinnard et al., 2006). His group conducted a principle component (PC) analysis of a multi-paleo-proxy data set from the Arctic region in order to develop a long-term reconstruction of Arctic sea-ice extent. The first PC corresponded to temperature variability while the second roughly corresponded to the sea-ice extent minimum. Detailed analysis could only be conducted for a few years as the proxy data become sparse further back in time; however, they extrapolated their analysis to reconstruct a sea-ice extent time series from 1128-2003 (Kinnard, Ph.D. thesis). The reconstruction indicates that sea-ice extent in the last decade is the lowest it has been in the past 875 years.

Stephen Howell (EC) then discussed the observed sea-ice record in the Canadian Archipelago, which lag those in the Arctic Ocean due to the protected nature of the region. The Archipelago sea-ice minimum during the observational record was in 1998, not 2007 as in the Arctic Ocean, and the minimum in multi-year ice was in 1999 (see Fig. 5; Howell et al., 2009). Over the last 30 years, the source of multi-year ice in the Archipelago has changed. In the past, first-year ice was promoted to multi-year ice but now multi-year ice is imported as first-year ice melts each season. The most important determinant of a sea-ice minimum in the Archipelago is the winds, which can act to prevent the import of multi-year ice. Dr. Howell and others have found that over the past 30 years, ENSO is positively correlated with multi-year ice and negatively correlated with first-year ice in the Archipelago. A warm temperature anomaly over the Archipelago during El Niño melts first-year ice, which allows multi-year ice to flow into its place along the currents (Tivy et al., accepted).

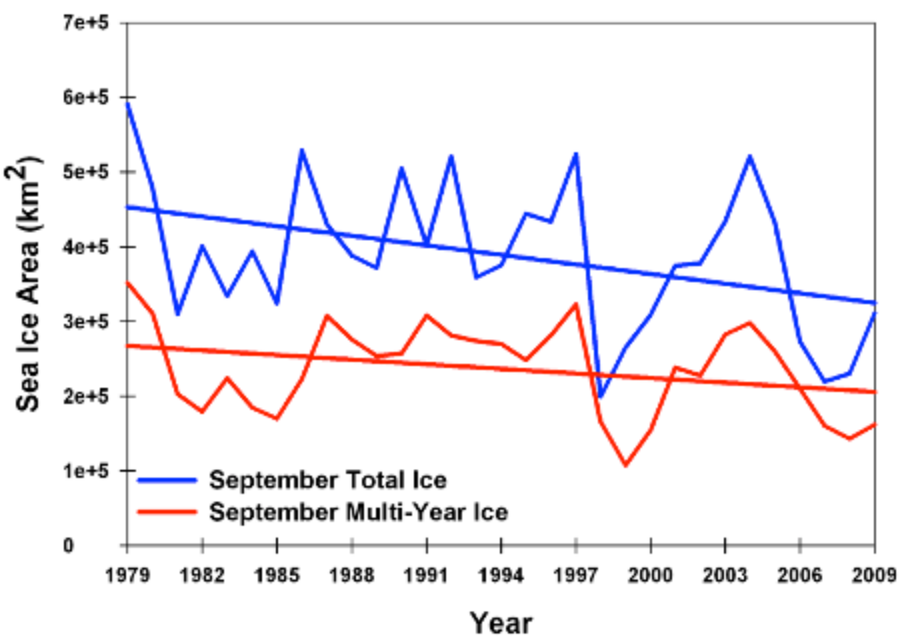

Figure 5: Time series of average monthly September total ice and multi-year ice area within the Canadian Arctic Archipelago, 1979-2009. Data is from the Canadian Ice Service Digital Ice Chart Archive.

The science portion of the workshop concluded with a discussion of lake mixing dynamics by **Mathew Wells** (Toronto) and **Sally Macintyre** (UC Santa Barbara), which is a potential new research direction of interest to several participants. The primary research question for this discussion was how increasing temperatures affect lake dynamics and, consequently, lake biology in Arctic lakes. The manner in which different climate variables such as temperature or surface wind speed influence lake mixing depends on the type of lake and its seasonal mixing properties (monomictic, dimictic or polymictic). As the climate warms, these lakes could potentially experience regime shifts which could dramatically alter the mixing properties of the lake. Studies at Toolik Lake in Alaska and Lake Opeongo in Algonquin Park suggest that Arctic and boreal lakes are already showing the effects of climate change.

Policy Theme

A general goal of our proposal to NSERC was to provide useful policy information to EC and NRCan. During his presentation on snow trends, Ross Brown presented snow parameters that are connected to societal and policy needs, such as SWE for hydrological forecasting, annual maximum snow depth for snow-loading calculations in building standards, etc.. In the final part of the workshop, we focused on larger policy questions. **Nick Xenos**, director of Arctic science policy at Indian and Northern Affairs Canada, discussed Canada's Northern Strategy and Arctic Science. Mr. Xenos discussed how federal support for Arctic research fits into larger plans for infrastructure and resource development in Canada's North. His presentation detailed the proposed High Arctic Research Station (HARS), a permanent scientific research and technology centre in an Arctic location to be decided in the coming year, and its potential benefits for high-latitude research across the country. The next steps in this process include finalizing plans for the HARS, continuing to refine the science and technology strategy for Northern research, and delivering on funded infrastructure investments.

Conclusion

This kick-off workshop helped to energize the "Simulation of the Canadian Cryosphere" project as it starts its three year term. It brought together scientists deeply involved in Arctic field campaigns, remote sensing analysis, and climate simulation for a structured but informal and friendly discussion on recent research issues. It highlighted the value of the Canadian Federal IPY Program in initiating new partnerships that will continue important activities well past the IPY period. A new research theme that emerged was to make a strong effort to link our work to the latest ice-core research. The workshop also opened possible directions for exploring the policy implications of our research, for example by improved characterization of our confidence in Arctic climate predictions for parameters critical to infrastructure and ecosystems. An ongoing challenge will be to make the broader policy community aware of these research efforts and of the value in bridging the observational and simulation sides of our science. We closed the day with a proposal to hold a second workshop in about two year's time to review the status and achievements of the project.

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