



Ice and Climate *News*

The WCRP/SCAR Climate and Cryosphere Newsletter

In this issue:

2. *CliC Scientific Steering Group*
5. *Atmosphere-Ocean General Circulation Models*
7. *Global Prediction: Permafrost*
8. *Predicting Lake and River Ice*
10. *Operational Sea-Ice Analysis and Forecasting at met.no*
11. *Arctic Council Climate and Cryosphere Project*
12. *Seasonal Forecast of Antarctic Sea Ice*
13. *The Global Cryosphere Watch*
14. *Towards a Community Arctic System Model*
16. *Simulation of Glacier Mass and Energy Balance*
18. *The 2nd Asia CliC Symposium*
19. *First Training Workshop on Permafrost Research Methods*

"The cryosphere responds to changes in the atmosphere and ocean in highly non-linear ways that are difficult to represent in climate models and also involves many processes that are poorly understood."

Global Prediction of the Cryosphere

John Turner, British Antarctic Survey (J.Turner@bas.ac.uk)

The CliC Workshop on Global Prediction of the Cryosphere took place over 8-9 October 2007 at the headquarters of the British Antarctic Survey in Cambridge, UK and involved ten scientists from Belgium, Sweden and the UK with expertise in various aspects of the global cryosphere.

Global Prediction of the Cryosphere (GPC) is one of the four themes of the CliC project and has the goal of improving the model projections of the global cryosphere over the 21st century. The workshop goals included identifying gaps in our current understanding, and proposing research activities in the framework of CliC.

The meeting was concerned with how sea ice, the ice shelves, glaciers, snow cover, lake ice, river ice, permafrost and the large ice sheets of Greenland and Antarctica might change in the future under various greenhouse gas emission scenarios.

The ability to produce reliable predictions of how the cryosphere will change is essential because of the potential impact on sea level, land use, the atmospheric and oceanic circulations, transport, and the biosphere. However, the cryosphere responds to changes in the atmosphere and ocean in highly non-linear ways that are difficult to represent in climate models and also involves many processes that are poorly understood. One method of testing the models is to try to simulate the changes in the cryosphere that we have observed in recent decades.

With sea ice, the current generation of Atmosphere-Ocean General Circulation Models (AOGCMs) have large errors, especially in the Southern Hemisphere (see report on page 5). This is attributed to problems in simulating realistically the Southern Ocean. Errors in the sea ice are also attributed to biases in the wind forcing and to the representation of atmospheric boundary layer processes, cloudiness and oceanic mixing processes in models. The sophistication of the sea-ice models was often not a major factor. Furthermore, very few models are able to reproduce the sharp decline in arctic September sea-ice extent observed during recent decades. For the future, it was felt that sea-ice models need better formulations for the snow cover on top of sea ice, the ice-ocean interactions, and the sea-ice rheology. Over the 21st century, a large loss of sea ice is projected for both hemispheres, with about half the IPCC Fourth Assessment Report models suggesting an ice-free Arctic Ocean during summertime by the end of the century. There is, however, a considerable uncertainty between models in predicting the sea-ice concentration and thickness changes at the regional scale in both hemispheres.

The ice shelves around the Antarctic are very important since they buttress the ice streams flowing down from the interior of the continent. However, it is extremely difficult to estimate how they will change in extent or thickness over the next century. In most cases the major forcing on ice shelf evolution is the basal melt/freezing rate, which is in turn determined by the oceanographic conditions on the continental shelf. To understand how the ice shelves might respond to climate change we need to consider both the sensitivity of ice shelf melt to water temperature

Continues on page 3

CliC Scientific Steering Group (SSG)

CliC SSG-IV, Geneva, 19-21 November 2007

The CliC SSG-IV met in Geneva, Switzerland in November 2007. The attendees were Barry Goodison (Chair), Co-vice chairs Tony Worby and Koni Steffen, SSG members Gino Casassa, Thierry Fichet, Vladimir M. Kattsov, Vladimir M. Kotlyakov, Tetsuo Ohata, Terry Prowse, Qin Dahe, and John Turner as well as the CliC Project Office Director Victoria Lytle and Deputy Director Angélique Prick. The WCRP was represented by Ann Henderson-Sellers, Director, and by Vladimir Ryabinin, Valery Detemmerman, and Margaret Lennon-Smith. Other participants included Roger G. Barry and Tatiana Khromova (CliC Alpine rapporteurs), Howard Cattle (CLIVAR), Zhenlin Chen (Asia CliC office in China), Hans-W. Hubberten (International Permafrost Association), Hugues Lantuit (Permafrost Young Researchers Network and Association for Polar Early Career Scientists), Peter van Oevelen (GEWEX), Diana Verseghy (representative for Working Group on Coupled Modelling), and Daqing Yang (Rapporteur for Cold Region Precipitation).



Some of the CliC SSG-IV meeting participants.

Terms Completed

We wish to express our appreciation to two of our members whose terms expired in December 2007. Dr. Thierry Fichet served on the SSG for seven years, and Dr. Vladimir Kotlyakov for six years. Both began their terms at a time when the WCRP Arctic Climate Systems Study (ACSYS) project was ending, and CliC was in its early stage. Their expert contributions over the years helped CliC to lead, define, and prioritize research needs in the domain of climate and cryosphere. We will surely continue to consult their expertise and count on their support in future CliC activities.

New Appointments

We welcome *Vladimir Kattsov* as a new member of the CliC Scientific Steering Group. Being a Doctor of Sciences in Physics and Mathematics with a specialty in atmosphere and hydrosphere physics, Vladimir will be an asset to the CliC Steering Group. His scientific fields of expertise are in global climate 3D modelling and high-latitude climate dynamics.



Vladimir Kattsov, Russia

He is currently the director of the Voeikov Main Geophysical Observatory in St. Petersburg, Russia. Current and past scientific positions include: Officer of the International Association of Meteorology and Atmospheric Sciences of the International Union of Geodesy and Geophysics; former member the Commission on Atmospheric Sciences/Joint Scientific Committee Working Group on Numerical

Experimentation; member of the Scientific Advisory Committee, Asia-Pacific Economic Cooperation Climate Center; member of the Russian Academy of Sciences Climate Council, the Russian National Geophysical Committee, and the Russian National Council on Climate and Cryosphere.

Vladimir is the author of about 50 publications in refereed journals and books, and a lead author of the IPCC Working Group I Third and Fourth Assessment Reports (2001, 2007), with particular responsibility for evaluation of the cryospheric components of the Atmosphere-Ocean General Circulation Models. He is a member of the core writing team of the IPCC Fourth Assessment Synthesis Report and a lead author of the Arctic Climate Impact Assessment.



Annette Rinke, Germany

Annette Rinke is a meteorologist and climatologist who works as a senior scientist at the Climate Science department of the Alfred Wegener Institute for Polar and Marine Research in Germany. She heads the regional climate modelling group at their Research Department in Potsdam. Her research interests include polar climate modelling and atmosphere-

land-ice-ocean interactions. Actively involved in the Arctic Regional Climate Model Intercomparison Project, Annette is the author of 45+ refereed journal publications, many reports, book chapters and publications. She is a lead author of the AR4 IPCC report 2007 'The Physical Science Basis', for Chapter 11 "Regional Climate Projections", and a consulting author for ACIA 2005 for Chapter 4 "Future Climate Change: Modelling and Scenarios for the Arctic". She is an editorial adviser for the journal *Polar Research*.

Dr. Rinke's term on the CliC SSG began 1 January 2008.

The CliC project is fortunate to have secured two such excellent professionals as members of their Scientific Steering Group. We look forward to working with them in the years to come.

Global Prediction ... cont'd from page 1

and the sensitivity of shelf water temperatures to climate forcing. Validation of ice shelf models physics requires more data especially on basal melt rates. Parameterisations that are currently in use are based on sea-ice observations, and have been tested in one case only against sub-ice-shelf observations. We also need to better understand shelf water variability and the processes that drive it on seasonal and inter-annual timescales. Present observations are temporally and spatially sparse with a strong summertime bias. New technologies are likely to be the key to extending the observational database in regions that are perennially ice covered. We also need ocean/climate models that can resolve the key processes, especially the continental shelf edge frontal system, leads and polynyas, and the important physics of the ice-ocean boundary layer.

Glaciers are retreating in all parts of the world, but only about 300 out of approximately 200,000 glaciers across the Earth have been sampled via mass balance, which is the most common technique for estimating ice mass changes. Global mass balance sensitivity is used to estimate global glacier change in the future, but there are many uncertainties, including a knowledge of global glacier area and volume, lack of mass balance observations, basal melting and glacier calving. Regarding climate input data (mainly temperature and precipitation data), there are problems related to downscaling gridded data to local glaciers, difficulties in downscaling energy balance components, a need for data with a horizontal resolution $\sim 0.5 \times 0.5^\circ$ or higher, and problems with strong vertical gradients in mountain regions. Potential improvements could be made by mass balance observations in previously unmeasured regions, further analyses using global simplified models that include precipitation changes and ice dynamics and enhanced methods for the remote sensing of glaciers by systems such as radar altimeters.

There has been a marked decline in Northern Hemisphere snow cover over recent years, with the greatest loss during the spring and summer. The Arctic Climate Impact Assessment < www.acia.uaf.edu > produced projections for 21st century snow cover using output from five models from the IPCC Third Assessment. They estimated that relative to the 1981-2000 reference period, by 2050 the Arctic is expected to receive about 8% more precipitation, increasing to 17% and 24% by the end of the century with the B2 and A2 greenhouse gas emission scenarios respectively. There is expected to be a general decrease in snow depth because of an increase in air temperature except in the extreme north where an increase in snow depth is predicted due to substantial increase in total precipitation. Many climate and hydrologic models rely on simplistic degree-day approaches as opposed to more complex full energy balance (e.g., partitioning precipitation, rate of melt, etc.). However, a concern for future predictions is that degree-day to energy balance relationships may not hold under a changing climate (e.g., due to changes in cloud and radiation regimes). For prognosis, energy and temperature-index models need to coexist for some time, at least until more confidence is realized in downscaled energy budget components.

We have reasonable records of lake ice (see report page 8) that extend back to 1946 at 39 sites. These indicate that freeze up and break up have changed by 5.9 days over 100 years, although there are no regional trends. In the future we expect, increasing snowfall in some regions to give a delay in break-up, while less snowfall in some areas will result in earlier break-up. Many empirical relationships have been established between freeze-up and break-up dates and air temperature data that show broad-scale spatial coherence. To improve projections of change there needs to be refinement of models of lake-ice growth and ablation. The models also need to consider detailed heat storage components, including open-water heat budgets which influence freeze-up timing and ice growth.

There is a 100 year plus record of river ice (see report page 8) that shows that freeze-up has been delayed by 5.7 days, and breakup having a long-term advance of 6.3 days over this period. River ice break-up timing is linked statistically with many factors, including the date of the spring 0°C isotherm, winter accumulated freezing degree days and water and freeze-up levels/ice thickness. Spring break-up timing is expected to advance by 15-35 days by 2100. Key improvements are needed to predictive modelling in terms of changes in freshwater ice thickness and handling extreme events, such as spring floods. A major overarching need was seen as increased collaboration between terrestrial snow/ice and the atmospheric modelling communities.

In recent decades we have experienced a major loss of permafrost in parts of the high northern latitudes (see report page 7), and we expect significant further losses over the next century. To better understand and predict permafrost change we need regional high resolution downscaling from global climate models. Data at a horizontal resolution of 10 km is thought to be desirable. But forcing is strongly modulated by snow cover and we need better snow distribution modelling. For better prediction of change in permafrost we need improved knowledge of extreme events, high resolution temperature predictions, good snow cover forecasts and blowing snow included in climate models.

The Greenland and Antarctic ice sheets are two of the most important elements of the global cryosphere because of the potential impact on sea level of even a small amount of melting. Yet predicting changes in these huge masses of ice is extremely difficult. There are three types of uncertainty in producing predictions for the ice sheets: ice sheet response (surface mass balance and ice dynamics), climate response to greenhouse gas forcing and the greenhouse gas forcing scenario. At the moment, there is no ice-sheet model that predicts both the retreat of the Antarctic ice-sheet since the end of the ice-age and correctly represents current variability. Although there have been recent advances in our knowledge, such as in grounding line dynamics, much further work is needed. Missing physics in ice sheet models consists of the interaction between ocean circulation in coastal waters and floating ice shelves, the coupling between this floating ice and the main grounded ice mass, the controls on ice stream

flow and the role of fracture and shear margins in the ice shelves. It is anticipated that there will be major advances over the next 2-3 years, including the production of the first forecasts for Antarctica. Significant questions regarding the ice sheet were thought to include; what was the past variability in dynamics, are recent dynamic changes due to ocean or atmosphere and how far can the precipitation degree day approach be used to extrapolate beyond present climate? The need was stressed for a high resolution ice sheet model to resolve all the outlet glaciers – perhaps 2 or 3 km resolution, although 10-20 km resolution would suffice in the interior. Finite element methods may be of value here.

General points that emerged from the discussions and recommendations were:

- For prediction of many aspects of the cryosphere, we need higher resolution atmospheric forcing data with which to drive cryospheric models.
- The reanalysis data were thought to be too coarse for many applications.
- Getting the ocean right in coupled models is essential, since this affects projections of many aspects of the cryosphere, such as sea ice.
- Although there have been many model intercomparison projects, further such initiatives are needed. For example, a comparison of ice-ocean models to determine why the sea-ice projections are so variable. One option would be to use the same ice-ocean model driven by different forcing fields.
- Iceberg calving is handled badly by current models, yet is very important in the freshwater balance of the Southern Ocean. Further investigation of the calving laws is needed.
- An intercomparison of permafrost models would be valuable.
- In models, we need better coupling between the ice sheet, the ice shelves, the sea ice and the ocean.

There was extensive discussion on how CliC could contribute to producing improved predictions of the cryosphere. A common theme in many of the talks was a need for high resolution atmospheric and oceanic fields with which to drive cryospheric models. The best solution would be to have a high resolution, coupled atmosphere-ice-ocean model, but this would be extremely expensive. Other possible means of obtaining such data, and also gaining insight into the role of different types of forcing on the cryosphere would be to force various high resolution, regional atmosphere-only models with sea surface temperatures, sea ice and snow data, plus reanalysis fields. Such models would be run over the last couple of decades and would generate the boundary conditions for the cryospheric models. A resolution of 10-20 km would be needed. The output from those regional models would then be used to assess the performance of the atmospheric component of AOGCMs in polar regions, which are typically run at much coarser resolution. This would enable us to carry out a comprehensive comparison of AGCMs in polar regions driven by the best available cryospheric data. The output from both the regional and global models would finally be used to drive intercomparisons of models of ice sheets, permafrost, snow cover and ice-ocean.

There are clearly many challenges in producing reliable projections of how the cryosphere will evolve over the 21st century and beyond. For elements such as sea ice, snow cover and permafrost it is currently possible to produce estimates using models, but there are large or very large discrepancies between models. This is particularly the case with sea ice, especially in the Southern Hemisphere where the ocean forcing is very important. For the ice shelves and the ice sheets, it is currently very difficult to use models to estimate their change in the future.

More data on recent changes in the cryosphere are needed for validation of models and to understand the pattern of change and the processes involved.

Many processes important in cryospheric change are not understood or included in models. For examples, few models are able to reproduce the recent loss of sea ice in the Arctic.

Failure to simulate many recent changes in the cryosphere correctly, is often found to be a result of poor atmospheric or oceanic forcing. We therefore recommend the production of high resolution forcing fields using regional climate models.



On the Ability of Current Atmosphere-Ocean General Circulation Models to Predict the Evolution of Sea Ice

Thierry Fichefet¹ (thierry.fichefet@uclouvain.be)
Olivier Arzel^{1,2} and Hugues Goosse¹

¹Institute d'Astronomie et de Géophysique Georges Lemaître, Université Catholique de Louvain, Louvain-la-Neuve, Belgium

²Climate Change Research Centre, School of Mathematics and Statistics, University of New South Wales, Sydney, Australia

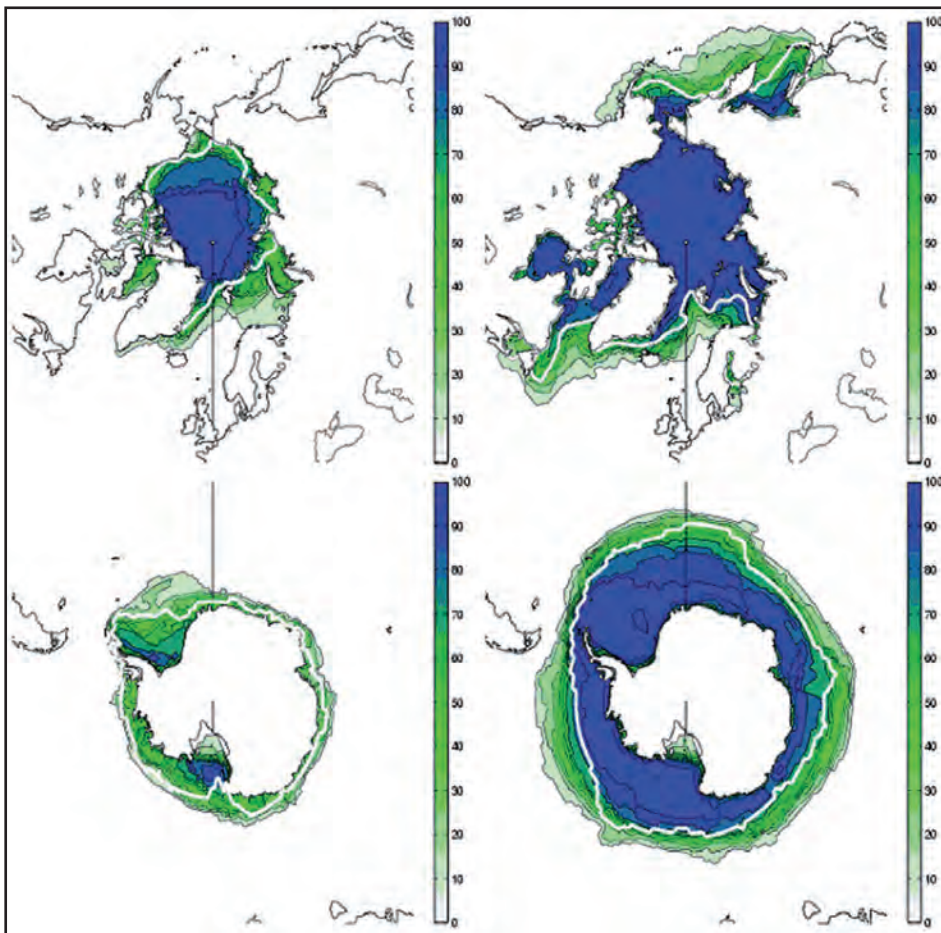
The aim of this report is to assess the ability of current Atmosphere-Ocean General Circulation Models (AOGCMs) to reproduce the sea-ice changes observed during the last decades, and to compare the sea-ice projections conducted with those models over the 21st century, for both hemispheres. This assessment is based on outputs from the *Climate of the 20th Century Experiment* and SRES A1B projection carried out for the *Intergovernmental Panel of Climate Change Fourth Assessment Report (IPCC, 2007)*. The former includes most of the observed forcings for the 20th century, encompassing greenhouse gases, sulphate aerosols, ozone, volcanic aerosols and solar variability. The latter uses a business-as-usual forcing scenario, which assumes little in the way of policy intervention to mitigate greenhouse gas and sulphate aerosol emissions in the 21st century. Overall, there is a large uncertainty about the simulation of the

present-day sea-ice coverage and thickness and the prediction of sea-ice changes in both hemispheres (e.g., Arzel *et al.*, 2006; Parkinson *et al.*, 2006; Zhang and Walsh, 2006; Gerdes and Köberle, 2007; Lefebvre and Goosse, 2008; Stroeve *et al.*, 2007).

Despite the wide differences among models, the multi-model mean winter and summer sea-ice extents averaged over the period 1981-2000 agree reasonably well with observations in both hemispheres (Arzel *et al.*, 2006; Parkinson *et al.*, 2006). For both hemispheres, the agreement between models is generally better in the winter than in summer, and it is better in the Northern Hemisphere than in the Southern Hemisphere. In the Northern Hemisphere, the multi-model mean change in annual mean sea-ice extent during 1981-2000 is very close to the observational estimate. Moreover, nearly all AOGCMs produce a statistically significant negative trend over this time

period. However, very few models are able to reproduce the sharp decline in Arctic September sea-ice extent observed during the last decades (Stroeve *et al.*, 2007). In the Southern Hemisphere, a couple of AOGCMs show an increase in annual mean sea-ice extent, while the others exhibit a decrease (Arzel *et al.*, 2006). Although the observations indicate a slight increase in the Southern Hemisphere, it is difficult to assess the agreement between models and observations, since the standard deviation of sea-ice extent is larger than the long-term change in both models and observations over the 1981-2000 period.

The figure shows (for both hemispheres) the percentage of models which have sea ice, on average, over the period 1981-2000, in summer and winter at a given location. The 50% contour corresponds to the multi-model median sea-ice edge. In the Northern Hemisphere, the multi-model median sea-ice edge agrees well with the observed one in both winter and summer. Nevertheless, between 10% and 50% of the models have their Labrador



Percentage of models (in %) having sea ice in average during 1981-2000 at the end of the summer (left) and winter (right) seasons at a given location in the Northern Hemisphere (top) and Southern Hemisphere (bottom). The thick, white line represents the observed mean location of the sea-ice front. Adapted from Arzel *et al.* (2006).

Sea and the Greenland-, Iceland- and Norwegian Seas partly covered with ice during the winter, and more than 50% of the models overestimate the sea-ice extent in the southern part of the Barents Sea. In the SH, the multi-model median sea-ice edge is slightly south of the observed one in summer, especially in the Weddell-, Bellingshausen- and Amundsen Seas. In winter, the agreement with observations is reasonable, but the simulated median sea-ice edge appears slightly too far north in the Bellingshausen- and Amundsen Seas. The spread between the 10% and 90% contours provides an indication of the disagreement in the modelled sea-ice-edge location. In the Northern Hemisphere, this spread is large throughout the year in both the North Atlantic and North Pacific sectors. In the Southern Hemisphere, the spread among the simulated sea-ice edges is large at all longitudes in the winter and in the Weddell Sea in the summer. The simulated spatial distributions of the ice thickness are also very diverse (Gerdes and Köberle, 2007). For instance, in the Northern Hemisphere, many models tend to accumulate ice near the Bering Strait and along the Siberian coast. Another recurring pattern shows the thickest ice in the interior of the Arctic Ocean, away from all coasts. Finally, very few models have an ice-thickness pattern that resembles the observed one.

Over the 21st century, the multi-model, average annual mean sea-ice extent decreases at similar rates in both hemispheres (Arzel *et al.*, 2006). In the Northern Hemisphere, the reduction in annual mean sea-ice volume is about twice the decrease in annual mean sea-ice extent. By contrast, in the Southern Hemisphere, the reduction in annual mean ice volume only slightly exceeds the decrease in annual mean ice extent. Interestingly enough, the amplitude of the seasonal cycle of sea-ice extent increases in response to enhanced greenhouse gas concentrations, and this increase is larger in the Northern- than in the Southern Hemisphere. It is also worth mentioning that about half of the models predict an ice-free Arctic Ocean during summertime at the end of the 21st century. A detailed analysis of the individual model results indicates that the simulated changes in annual mean sea-ice volume at the end of the 21st century are in better agreement in the Northern- than in the Southern Hemisphere (Arzel *et al.*, 2006). Actually, the greatest model uncertainty occurs in the summer in the Southern Hemisphere, and the smallest one in the winter in the Northern Hemisphere. By contrast, the model uncertainty is somewhat lower in the Southern- than in the Northern Hemisphere regarding the response of the annual mean sea-ice extent. This analysis also shows that the model predictions of regional changes in sea-ice concentration and thickness remain highly uncertain.

References

- Arzel, O., T. Fichefet, and H. Goosse. 2006. Sea ice evolutions over the 20th and 21st centuries as simulated by current AOGCMs. *Ocean Modell.*, 12, 401-415, doi:10.1016/j.ocemod.2005.08.002.
- Gerdes, R., and C. and Köberle. 2007. Comparison of Arctic sea ice thickness variability in IPCC Climate of the 20th Century Experiments and in oceansea ice hindcasts. *J. Geophys. Res.*, 112, C04S13, doi:10.1029/2006JC003616.
- IPCC. 2007. *Climate Change 2007: The Physical Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., and Miller H.L. (Eds.), Cambridge Univ. Press, Cambridge, U.K. and New York, U.S.A., 996 pp.
- Lefebvre, W., and H. Goosse. 2008. Analysis of the projected regional sea-ice changes in the Southern Ocean during the twenty-first century. *Clim. Dyn.*, 30 (1), 59-76.
- Parkinson, C.L., K. Y. Vinnikov and D.J. Cavalieri. 2006: Evaluation of the simulation of the annual cycle of Arctic and Antarctic sea ice coverages by 11 major global climate models. *J. Geophys. Res.*, 111, C07012, doi:10.1029/2005JC003408.
- Stroeve, J., M.A. Holland, W. Meier, T. Scambos and M. Serreze. 2007. Arctic sea ice decline: Faster than forecast. *Geophys. Res. Lett.*, 34, L09501, doi:10.1029/2007GL029703.
- Zhang, X., and J.E. and Walsh. 2006. Toward a seasonally ice-covered Arctic Ocean: Scenarios from the IPCC AR4 model simulations. *J. Clim.*, 19, 1730-1747.

Geocryological Map of Russia and Neighbouring Republics — English Language Version

Permafrost data collected over many decades in the former Soviet Union and the successor republics are available with English translations, but in a limited number. The 16-sheet, detailed map provides and impressive depth of information on the regions permafrost and permafrost conditions.

This second edition enhances a number of technical translation points and includes color legends. The publication is accompanied by translations and detailed explanations of the terminology used. For further information and to view samples, please visit <www.freezingground.org> or contact <map@freezingground.org>.

Global Prediction of the Cryosphere: Permafrost

Charles Harris (harrisc@cardiff.ac.uk)

School of Earth, Ocean and Planetary Sciences, Cardiff University, UK

Permafrost is a major component of the global cryosphere, and it is particularly sensitive to climate change. Since heat advection is minimal in permanently frozen ground, conductive heat flux dominates ground thermal responses. Surface temperature cycles are attenuated with depth, with the annual cycle generally penetrating to between 15 and 20 m. Short-term warming due to extreme seasonal or annual air-temperature anomalies are associated with a rapid response in both near-surface permafrost temperatures and active-layer thickness (Gruber *et al.*, 2004). Larger-scale thermal cycles over decades or centuries are reflected in perturbation of the permafrost thermal profile, but it may take millennia for these to propagate through thick permafrost. However, where permafrost is thin, and its temperature is close to 0°C, thaw may be much more rapid.

Warming Evidence

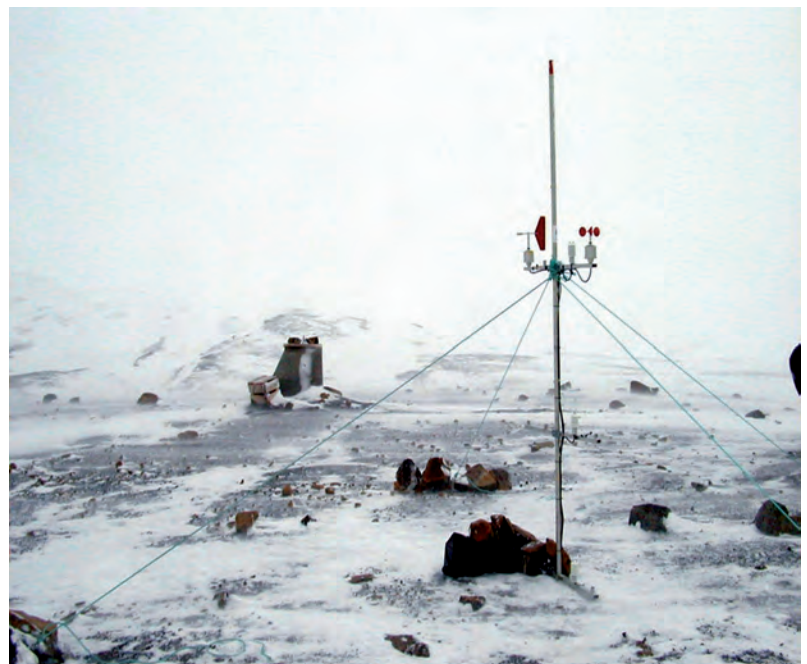
Ground temperatures are currently rising in most permafrost areas, though warming rates vary considerably (Romanovsky *et al.*, 2002). For instance, Osterkamp (2003) reported warming of up to 1.3°C per decade at 20 m depth (just below the depth of seasonal temperature fluctuation) since the 1980s in the continuous permafrost zone of northern Alaska, but less than half this rate further south in the discontinuous permafrost zone. In the European Alps, annual fluctuation in near-surface temperatures are often more strongly influenced by snow cover than air temperatures (Harris *et al.*, 2003). But at the Janssonhaugen bore hole in Svalbard (78° 11'N), snow cover is thin, and temperatures have risen by around 0.4°C/decade at 20 m depth since 1998, and by 0.6°–0.7°C/decade at the permafrost table (Isaksen *et al.*, 2007).

Modelling Permafrost Response to Climate Change

The interaction between climate and ground temperatures at a local scale is complex due to variation in topography, ground cover (including snow), and substrate characteristics. Modelling permafrost response at a local scale therefore demands high resolution Regional Scale Climate Models (RCMs). Such an approach has been described by Stendel *et al* (2007) to downscale surface climate characteristics in Eastern Siberia and to apply these to detailed permafrost thermal modelling. Improving such regional downscaling, and the coupling of resulting Regional Climate Models to spatially distributed data sets on permafrost and terrain characteristics, remains a major challenge in improving our capacity to model permafrost responses at a scale appropriate for mapping resulting geo-hazards.

References

- Gruber, S., M. Hoelzle and W. Haeberli. 2004. Permafrost thaw and destabilization of Alpine rock walls in the hot summer of 2003. *Geophysical Research Letters*, 31, L13504, doi:10.1029/2004GL020051.
- Harris, C., D. Vonder Mühl, K. Isaksen, W. Haeberli, J.L. Sollid, L. King, P. Holmlund, F. Dramis, M. Guglielmin and D. Palacios. 2003. Warming permafrost in European mountains. *Global and Planetary Change*, 39, 215-225.
- Isaksen, K., J.L. Sollid, P. Holmlund, C. Harris. 2007. Recent warming of mountain permafrost in Svalbard and Scandinavia. *Journal of Geophysical Research*, 112, F02S04, doi:10.1029/2006JF000522.
- Osterkamp, T.E. 2003. A thermal history of permafrost in Alaska. In: *Permafrost—Proceedings of the 8th International Conference on Permafrost, Zürich, Switzerland, 21–25 July 2003* (M. Phillips, S.M. Springman, and L.U. Arenson, eds.) 863-868.
- Romanovsky, V., M. Burgess, S. Smith, K. Yoshikawa, and J. Brown. 2002. Permafrost Temperature Records: Indicators of Climate Change. *Eos Trans. AGU*, 83(50), 589, 10.1029/2002EO000402.
- Stendel, M., V. Romanovsky, J.H. Christensen and T. Sazonova. 2007. Using dynamical downscaling to close the gap between global change scenarios and local permafrost dynamics. *Global and Planetary Change*, 56 (1-2), 203–214.



Winter conditions at the Janssonhaugen permafrost borehole, Svalbard (Photograph Ketil Isaksen, met.no).

Predicting Lake and River Ice: Modelling of Historical and Future Conditions

T.D. Prowse (Terry.Prowse@ec.gc.ca), L. de Rham and Y. Dibike
Water & Climate Impacts Research Centre, Environment Canada, University of Victoria, Canada

Lake-and river-ice are major components of the cryosphere and affect an extensive portion of the global hydrologic system. Since the various forms and processes of freshwater ice are directly controlled by atmospheric fluxes, their spatial and temporal trends can be used as indicators of climate variability and change. Recognizing the broad ecological and economic significance of freshwater ice, scientific concern has been expressed about how future changes in climate might affect lake and river-ice regimes (e.g., Anisimov *et al.*, 2007).

Historical Analyses

Attempts to predict freshwater ice-conditions have focused on a number of ice-related characteristics. In the simplest cases—driven primarily by an interest in lake- and river ice as indicators of climatic trends—the focus has been on ice phenology, specifically freeze-up and break-up dates.

Many empirical relationships have been established between lake-ice dates and various monthly air-temperature indices. As noted by Bonsal and Prowse (2003); however, such empirical relationships may not be reliable under future climatic conditions because of changes in the composition of the major heat fluxes on which the temperature relationships are founded. Broad regional analyses of lake-ice phenologies have also been undertaken based on the timing of 0°C-isotherms (Duguay *et al.*, 2006), linkages with broad-scale atmospheric teleconnections (Bonsal *et al.*, 2006), or temperature regimes and basic lake physical characteristics such as depth, latitude and elevation (Walsh *et al.*, 1998; Williams and Stefan, 2006; Williams *et al.*, 2004).

More detailed—although primarily site-specific—analyses of lake-ice conditions that include additional ice characteristics such as thickness and composition, have been conducted using physically based models. These have, to varying degrees, incorporated an energy balance of the entire lake system (Duguay *et al.*, 2003; Fang and Stefan, 1996; Saloranta and Anderson, 2007; Vavrus *et al.*, 1996).

For river ice, as for lake ice, a number of attempts have also been made to link the broad-scale timing of freeze-up and break-up events with air temperature, 0°C-isotherms, and atmospheric teleconnections (Bonsal *et al.*, 2006; review by Prowse *et al.*, 2007). Given the special importance of river-ice break up in producing extreme floods, considerable research effort has been expended in attempting to predict site-specific timing and severity of such events. Common methods of predicting river-ice break-up initiation (Beltaos, 1990) rely on establishing a relationship between the rise in stage above the preceding freeze-up level and the total pre-break-up heat input to the ice cover. Thermal and less severe break ups are represented by high heat inputs and low stage increases and vice versa for the more dynamic break ups (see illustration). Unfortunately, relationships between these two terms remain empirical and site-specific.

Future Conditions

Predicting the state and fate of freshwater ice over the next century will require a number of significant advances, the most difficult being for river ice. For the simpler case of lake ice, improvements will need to be made in the physical modelling of the full-season lake thermal regime. This is especially important in determining freeze-up timing and in considering the increasing role of precipitation (e.g., snow accumulation) that affects ice-growth rates, ice-cover composition, ablation rates, and break-up timing. As for most other surface variables, refinements will be made to properly downscale (statistically or dynamically) the requisite variables that control surface energy exchanges, including appropriate atmospheric coupling to account for feedback in the case of large lakes. Site-specific- to broad-scale predictions of changes in most lake-ice characteristics would be possible with the advancements noted above. Some of this work is now under way by the authors of this summary.

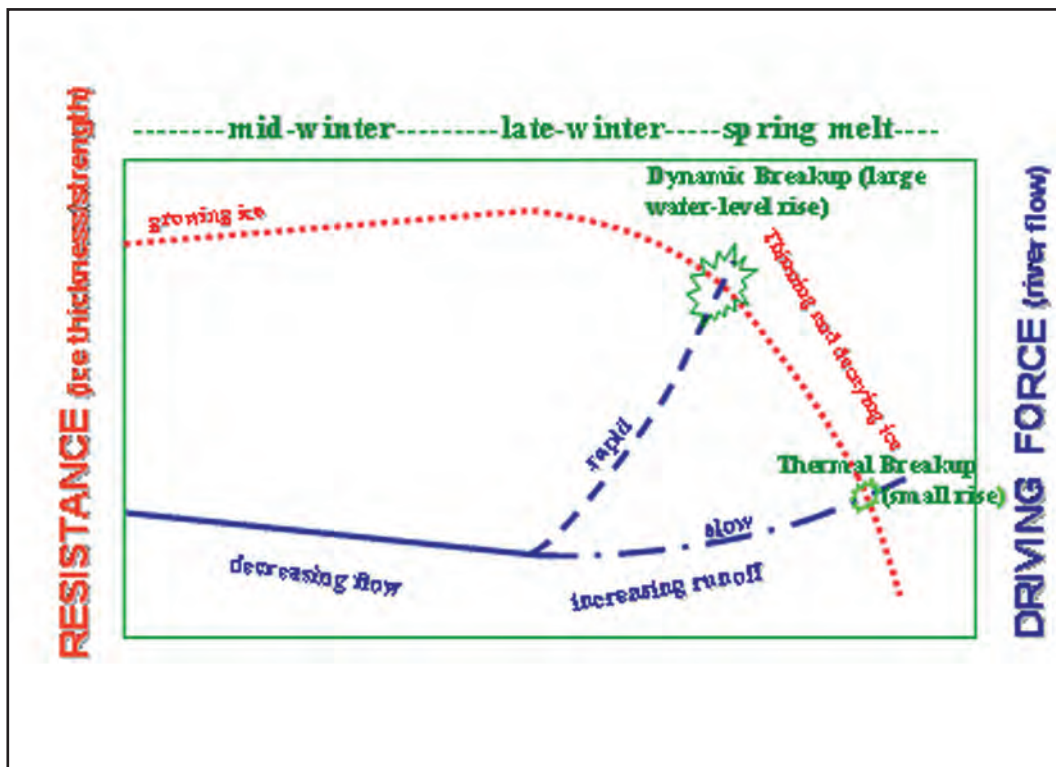
Some preliminary estimates of changes in river-ice phenology have been made (Prowse *et al.*, 2002) relying on simple historical rates of change by degree-day of warming (Magnuson *et al.*, 2000). Predicting future changes in timing of events using previously established relationships with 0°C-isotherm has also been proposed. However, as cautioned earlier for lake ice, the accuracy of any such predictions are questionable because the future reliability of such temperature-index approaches remains unknown. Since large-scale teleconnections have been shown to influence river-ice characteristics, knowledge about their future intensity and frequency might also provide insight into future river-ice regimes. Unfortunately, the effects of climate change on large-scale teleconnection patterns remain uncertain; hence, so would any such related predictions of river-ice regimes (Prowse *et al.*, 2007).

Whether any projected temporal shifts will produce more or less severe break-up events (i.e., floods) remains unknown, largely because of the complicating role of precipitation which has the potential to control both the driving (snowmelt runoff) and resisting forces (ice thickness/strength/composition) that affect break-up severity (see Prowse and Beltaos, 2002; Figure 1). Although some very limited, site-specific predictions of changes in these two cryospheric components (snow and river ice) have been made to estimate the effect on river-ice break-up severity (Beltaos *et al.*, 2006), broad-scale analyses have never been undertaken. This is especially important on large river basins where changes in climatic gradients (e.g., south-to-north temperature patterns) can influence break-up severity (Prowse *et al.*, 2006).

To predict changes in river-ice regimes effectively, more research needs to be directed towards developing physically based river-ice models that effectively couple with hydrologic runoff and atmospheric flux models. Such development would also permit the employment of Global Circulation Model/Regional Climate Model output for prediction of river-ice regimes.

References

- Anisimov, O.A., D.G. Vaughan, T.V. Callaghan, C. Furgal, H. Marchant, T.D. Prowse, H. Viljalmarsson and J.E. Walsh. 2007. Polar regions (Arctic and Antarctic). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 653-685.
- Beltaos, S. 1990. Fracture and breakup of river ice cover. *Canadian Journal of Civil Engineering*, 17: 173-183.
- Beltaos, S., T. Prowse, B. Bonsal, R. MacKay, L. Romolo, A. Pietroniro and B. Toth. 2006. Climatic effects on ice-jam flooding of the Peace-Athabasca Delta. *Hydrological Processes*, 20(19): 4031-4050.
- Bonsal, B.R., and T.D. Prowse. 2003. Trends and variability in spring and autumn 0°C-isotherm dates over Canada. *Climatic Change*, 57:341-358.
- Bonsal, B.R., T.D. Prowse, C.R. Duguay and M.P. Lacroix. 2006. Impacts of large-scale teleconnections on freshwater-ice duration over Canada. *Journal of Hydrology*, 330: 340-353.
- Duguay, C.R., G.M. Flato, M.O. Jeffries, P. Ménard, K. Morris, W.R. Rouse. 2003. Ice-cover variability on shallow lakes at high latitudes: Model simulations and observations. *Hydrological Processes*, 17: 3456-3483.
- Duguay, C.R., T.D. Prowse, B. Bonsal, R.D. Brown, M. Lacroix and P. Ménard. 2006. Recent trends in Canadian lake ice covers. *Hydrological Processes*, 20(4): 781-801.
- Fang, X. and H. Stefan. 1996. Development and validation of the water quality model MINLAKE 96 with winter data. *Project Rep. No. 390*, St. Anthony Falls Laboratory, Univ. of Minnesota, Minneapolis, USA.
- Prowse, T.D. and S. Beltaos. 2002. Climatic control of river-ice hydrology: a review. *Hydrological Processes*, 16(4): 805-822.
- Prowse, T.D., B.R. Bonsal and M.P. Lacroix. 2002. Trends in river-ice breakup and related temperature controls. In: *Ice in the Environment. Proc. 16th IAHR International Symposium on Ice, Dunedin, New Zealand, December 2-6, 2002*, Vol. 3: 64-71.
- Prowse, T.D., F.J. Wrona, J. Reist, J.J. Gibson, J.E. Hobbie, L.M.J. Lévesque, and W. Vincent. 2006. Climate change effects on hydroecology of arctic freshwater ecosystems. *Ambio*, 35(7): 347-358.
- Prowse, T.D., B.R. Bonsal, C.R. Duguay and M.P. Lacroix. 2007. River-ice break-up/freeze-up: a review of climatic drivers, historical trends and future predictions. *Annals of Glaciology*, 46: 443-451.
- Saloranta, T.M. T. and Anderson. 2007. MyLake – A multi-year lake simulation model code suitable for uncertainty and sensity analysis simulations. *Ecological Modelling*, 207: 45-60.
- Vavrus, S.J., R.H. Wynne, J.A. and Foley. 1996. Measuring the sensitivity of southern Wisconsin lake ice to climatic variations and lake depth using a numerical model. *Limnology and Oceanography*, 41: 822-831.
- Walsh, S.E., S.J. Vavrus, J.A. Foley, V.A. Fisher, R.H. Wynne, and J.D. Lenters. 1998. Global patterns of lake ice phenology and climate: Model simulation and observations. *Journal of Geophysical Research*, 103(D22): 28,825-28,837.
- Williams, S.G. and H.G. Stefan. 2006. Modelling of lake ice characteristics in North America using climate, geography and lake bathymetry. *Journal of Cold Regions Engineering*, 20(4): 140-167.
- Williams, G., K.L. Layman and H.G. Stefan. 2004. Dependence of lake ice covers on climatic, geographical and bathymetric variables. *Cold Regions Science and Technology*, 40: 145-164.



Resisting and driving forces that control the severity of river-ice breakup. For example, large and rapid increases in snowmelt and associated river runoff that occurs while the ice cover has had minimal time to decrease in thickness and strength produces a dynamic breakup with the greatest probability of a flood. Slow and limited increases in spring flow permits the ice cover to weaken and become thin, resulting in minimal increase in water levels. Predicting such river-ice break-up conditions requires coupled atmospheric-snowmelt runoff models, as well as atmospheric ice decay and river-hydraulic models.

Operational Sea-Ice Analysis and Forecasting at met.no

Lars-Anders Breivik (lars.anders.breivik@met.no) and Jens Debernard
Norwegian Meteorological Institute (met.no)

At the Norwegian Meteorological Institute (met.no), a coupled ice-ocean model system was developed primarily to study the Arctic climate. With high demands for accurate sea-ice forecast in polar regions, the model was adjusted to run in an operational mode in order to produce ice and ocean forecasts for the Arctic. The ice ocean model system is composed of a locally developed sea-ice model coupled to an ocean model over the Arctic Ocean. The model produces daily 120-hour forecasts at 20 km resolution, with atmospheric input from the European Centre for Medium Range Forecasting (ECMWF). To find out more about the oceanographic models, please go to: http://met.no/english/r_and_d_activities/rd_oceanography.html. Daily forecasts are available from: http://met.no/kyst_og_hav/northern_anim.html.

To initialize daily runs of the ice-ocean model system, an accurate sea-ice analysis is needed. For this, the model assimilates the Ocean and Sea Ice Satellite Application Facility (OSI SAF) ice concentration and Sea Surface Temperature (SST) products <http://saf.met.no>. The OSI SAF which is produced by EUMETSAT provides daily global sea surface temperature and sea-ice information based on satellite data. Microwave data from the Special Sensor Microwave Imager (SSM/I) corrected for atmospheric humidity are used for the ice products, while Advanced Very High Resolution Radiometer (AVHRR) data are used as input to the SST analysis. The OSI SAF products are regularly validated against ice charts from the Danish and Norwegian operational ice services.

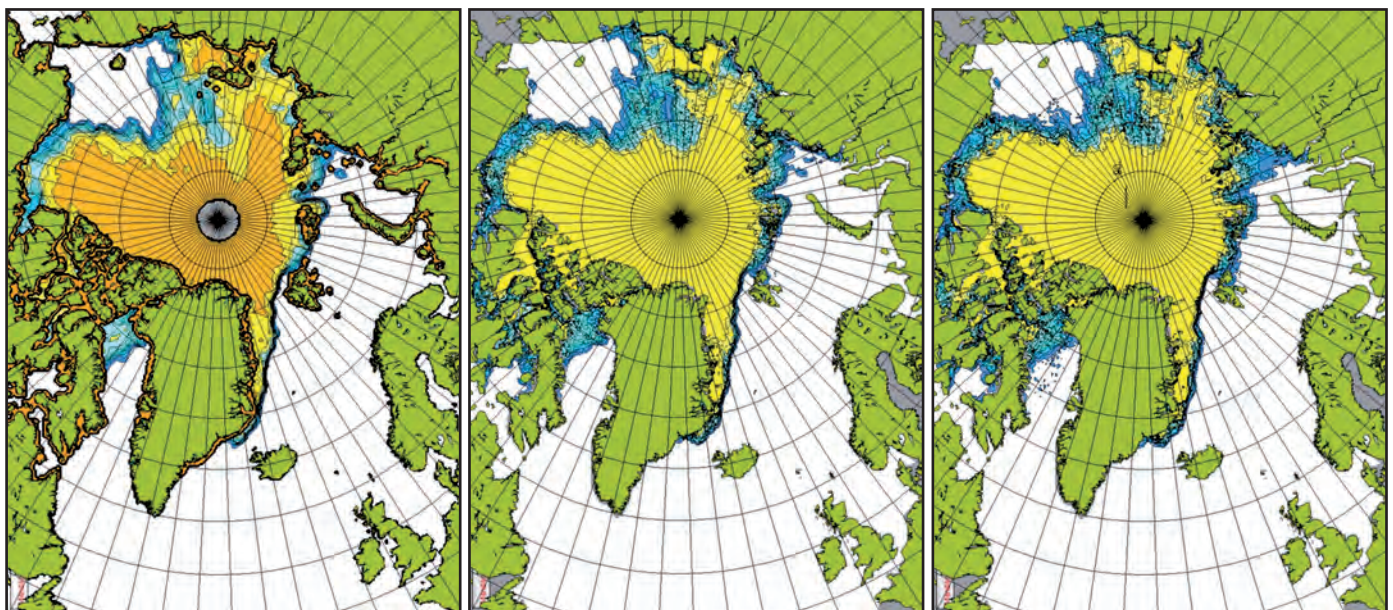
Users operating in the Arctic often need more precise sea-ice information, and there is a demand for higher resolution ice analysis and forecast. This is provided by the operational Sea Ice Services. The met.no Sea Ice Service produce daily ice charts where high-resolution SAR¹ data and image data (AVHRR and MODIS data^{2,3}) are used in addition to the OSI SAF products. A test version of the ice-ocean model system set up at 2 km horizontal resolution for the Svalbard area, is providing five-day forecasts daily. Products, analyses and forecasts are found on <http://polarview.met.no>.

The examples described here are the first versions of the operational ice forecasting at met.no. There is a large potential for improvement of both the ice-ocean models and the assimilation system. The model system complexity required for the ice forecasts depends on the type of forecast and its duration, and on what kind of physical processes are the most important for particular cases. For data assimilation, the specifications of the model error covariances are crucial. These specifications determine how the information contained in the observations are assimilated in the full model field, as well as the ability to correct unobserved variables such as ice thickness and under-ice ocean variables. Ignoring important spatial and multivariate covariances can lead to imbalances or artificial spatial discontinuity in the analyzed model state. International research and development in this field are ongoing at several institutions.

¹SAR: Synthetic Aperture Radar

²AVHRR: Advanced Very High Resolution Radiometer

³MODIS: Moderate Resolution Imaging Spectrometer



OSI SAF ice concentration 2007.10.29
assimilated in the Arctic model.

Model analysis.

Model results: Forecast mean for period
+36 → +60 h, valid 2007.10.31.

Arctic Council Project on Climate Change and the Cryosphere: Snow, Water, Ice, and Permafrost in the Arctic (SWIPA)

John Calder (John.Calder@noaa.gov), Chair, Arctic Monitoring and Assessment Programme (AMAP)

The 2006 Arctic Council ministerial meeting approved the Norwegian proposal for priority areas for their lead period, which included further studies on the reduction of snow and ice in the Arctic. Norway—on behalf of Denmark, Norway, and Sweden—presented a sketch for a project on Climate Change and the Cryosphere to the Senior Arctic Official (SAO) meeting in April 2007. Experts from the eight Member States of the Arctic Council and some international organizations—including CliC and the International Arctic Science Committee—have evaluated and discussed the content of the project. The full proposal has been presented to Arctic Council SAO meeting in late November 2007 for final approval. The final reports from this project are planned for delivery to the Arctic Council in spring of 2011.

The objectives of the cryosphere project are to provide the Arctic Council with updated and synthesized scientific knowledge about the present status, processes, trends, and future regional and global consequences of rapid changes in: 1) sea ice, 2) melting of the Greenland ice sheet, and 3) snow cover, permafrost, small glaciers, and the hydrological situation in the Arctic. Future scenarios will be developed to determine the consequences of these changes on physical processes, biological systems, as well as on human societies and lifestyles on local, regional, and global scales.

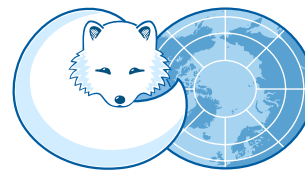
The cryosphere project is organized around national leads and international work and cooperation. Each sub-projects will be managed by a lead country: 1) Arctic sea ice in a changing climate (lead-Norway); 2) the Greenland Ice Sheet in a changing climate (lead-Denmark); and 3) Impact of Changes in the Terrestrial Cryosphere. The latter consists of four modules; snow conditions; and permafrost (lead-Sweden); glaciers and small ice caps; and hydrology: rivers and lakes (lead-Russia and co-lead country to be decided).

The Project on Climate Change and the Cryosphere does not intend to initiate any new research, but will be based on recent or current projects, including International Polar Year research. The resulting reports will highlight the status and trends, effects on local, regional and global scale, gaps in knowledge, and recommend actions for future research and

monitoring. The first delivery is a report to COP XV (15th Session of the Conference of the Parties) regarding the situation for the Greenland Ice Sheet. Based on the outcome of this project, the Arctic Monitoring and Assessment Programme Working Group (AMAP) will prepare a report covering recommendations for the improvement of observing platforms and networks (SAON input), adaptation strategies, and mitigation action where possible.

This new Arctic Council project is still in its preliminary stage, and the information released here is subject to change as required by future development.

<<http://arctic-council.org>>



ARCTIC COUNCIL
NORWEGIAN CHAIRMANSHIP
2006-2008



Arctic Monitoring and
Assessment Programme

Seasonal Forecast of Antarctic Sea Ice and Beyond

Xiaojun Yuan (xyuan@ldeo.columbia.edu) and Dake Chen

Lamont-Doherty Earth Observatory of Columbia University, U.S.A.

The variability of Antarctic sea ice is controlled by both remote and local processes in the atmosphere and ocean. The atmospheric anomalies from low latitudes could excite certain modes of the Antarctic climate system, which then could be amplified and sustained by the local air-sea-ice interaction. Specifically, Antarctic sea ice has exhibited large anomalies in response to El Niño/Southern Oscillation (ENSO) forcing in the tropical Pacific. These anomalies, called Antarctic Dipole (ADP), could grow, amplify and persist up to a year in the polar seas of the western hemisphere long after the ENSO signal diminished in the tropics. Because of its broad spatial scale, long persistence, and large magnitude, ADP is the dominant short-term climate variability in the Antarctic sea ice field (Yuan, 2004). This characteristic of Antarctic sea ice provides a potential of enhancing atmospheric seasonal predictions, although such potential has not yet been explored.

It has been shown that Antarctic sea ice itself can be predicted empirically in the regions dominated by the ENSO influences. A recent study (Chen and Yuan, 2004) explored the possibility of forecasting Antarctic sea ice anomalies using a technique combining multivariate empirical orthogonal function (MEOF) analysis and linear Markov prediction. The model results indicate that the dominant modes of the Antarctic climate variability are indeed predictable up to one year in advance. Particularly in the Antarctic Dipole action centers, the sea ice prediction skill evaluated by a cross-validation scheme (Barnston and Ropelewski, 1992) beats the persistent prediction significantly in terms of both anomaly correlation and rms error (see figure). Among the four model experiments with different numbers of MEOF modes included, the one with seven modes had the highest overall score. In this case, the anomaly correlation is above 0.6 and the rms error is below 9% for almost all lead times up to almost one year. The real time seasonal forecast from this model is available on http://rainbow.ldeo.columbia.edu/forecasts/sea_ice.html.

Despite the fact that significant predictability exists in Antarctic sea ice, its feedback to atmospheric conditions at seasonal time scales is poorly understood, which hinders our understanding of the contributions from the cryosphere and polar regions to extra-polar climate variability. The workshop of WCRP Task Force on Seasonal Prediction held on July 2007 in Barcelona, Spain, inspired the research community to address such issues. The atmospheric seasonal forecast community is seeking the untapped seasonal predictability from the interactions among the elements of the climate system: atmosphere, ocean, land and cryosphere. However, current atmospheric seasonal forecast models generally use climatological sea ice as a boundary condition, or to initialize the sea ice models. Consequently, sea ice variability is poorly represented. On the other hand, because of the scale and magnitude of the ADP as well as its predictability, Antarctic sea ice has the potential to enhance atmospheric seasonal forecasts.

To explore such potential, we need a better understanding of the feedback from sea ice to the atmosphere and the feedback from polar regions to extra-polar regions. This can be achieved in several steps. First, systematically assessing the predictability of cryosphere components at seasonal time scales is needed so that we know what is predictable, and where. Second, we should foster the development and improvement of both dynamical and statistical prediction models for cryosphere elements that show some predictability. Currently, statistical models still outperform dynamical models and are practical tools for the seasonal forecast of cryosphere elements. Next, we need to assess and isolate the feedback of sea ice to the atmosphere and the feedback of the polar regions to lower latitudes. Poor understanding of these feedbacks is a limiting factor for integrating the cryosphere into the global climate system. Better understanding of such feedback will lay the foundation for tapping the potential seasonal predictability. Finally, we need to assess the contribution of cryosphere variability to seasonal prediction skill in extrapolar regions. Efforts should be made to include sea-ice variability in current seasonal prediction models. If this improves seasonal prediction skill in some locations, we should explore the feasibility of combining cryosphere statistical forecast models and atmosphere dynamic forecast models to further enhance the seasonal prediction by using predicted ice / snow variability as the boundary conditions for atmospheric forecast models.

Because polar regions amplify climate changes, and the variability of polar regions dictates the strength of the thermal gradient from the tropics to the poles, improving the forecast skill for cryosphere and understanding the feedback of the polar regions become increasingly important to climate sciences as we face a rapidly warming world. In addition, these achievements could lead to additional predictability in lower latitudes at seasonal time scales, providing additional societal benefit.

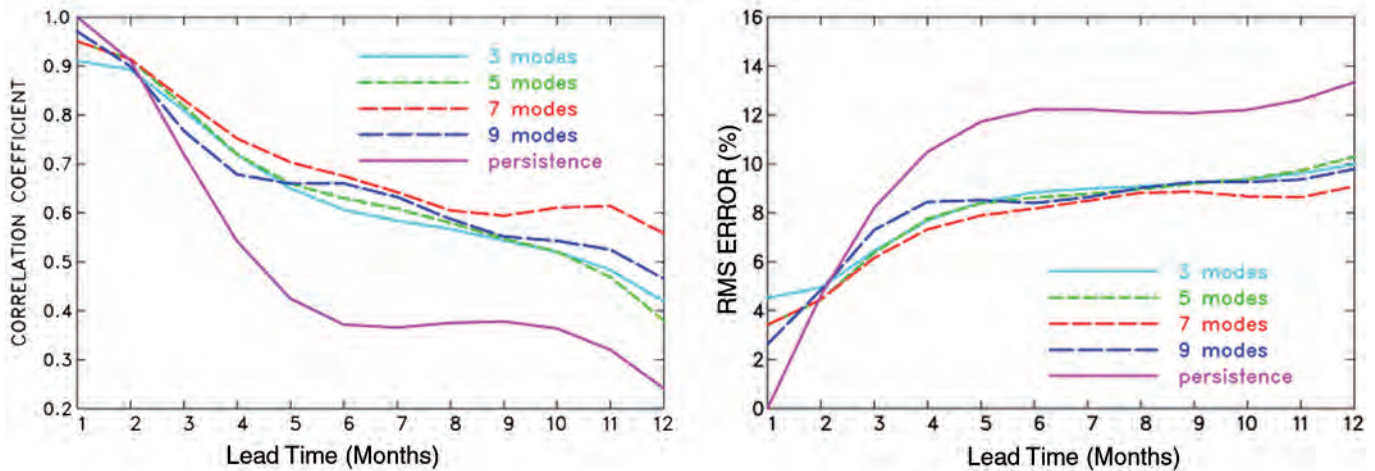
Acknowledgements

This research is supported by the National Science Foundation through grant OPP 02-30284.

References

- Barnston, A.G., and C. F. Ropelewski. 1992. Prediction of ENSO episodes using canonical correlation analysis. *J. Clim.*, 5, 1316-1345.
- Chen, D. and X. Yuan. 2004. A Markov model for seasonal forecast of Antarctic sea ice. *Journal of Climate*, 17(16), 3156-3168.
- Yuan, X. 2004. ENSO-related impacts on Antarctic sea ice: Synthesis of phenomenon and mechanisms. *Antarctic Science*, 16(4), 415-425.

Cross-Validated Skill for DP1 Sea-Ice Anomaly (1980-2000)



Cross-validated correlation (left) and rms error (right) between hindcast and observed sea-ice concentration anomalies averaged in the region (130-150°W, 60-70°S) from 1980-2000. Compared are four model hindcast experiments with different numbers of MEOF modes included. The skill of persistence prediction is also shown for reference (Chen and Yuan, 2004).

Global Cryosphere Watch – a World Meteorological Organization (WMO) Initiative

Contact: Barry Goodison, Chair, CliC SSG <Barry.Goodison@ec.gc.ca>

The cryosphere exists at all latitudes and in nearly one hundred countries of the world; yet, it may be the most under-sampled domain in the climate system. The International Polar Year 2007-2008 (IPY) provides a unique opportunity to help close this gap in global observations by developing our polar observing systems further. CliC led the development of the conceptual framework for the Cryosphere Observing System <<http://igos-cryosphere.org>>, a sustained, robust observing system for the cryosphere and a crucial element of the future multi-disciplinary observing system. But, we need to ensure a legacy for cryosphere observing and monitoring, not only in polar regions, but also globally.

At the 15th WMO Congress, Canada proposed to create a Global Cryosphere Watch (GCW) as a component of the IPY legacy. Congress welcomed the proposal and requested the WMO Inter-Commission Task Group on IPY to explore the possibility of creating such a global system as an important contribution to the IPY legacy and prepare recommendations for its development. This work will be initiated at the January meeting of the Task Group. An *ad hoc* expert group on GCW will ensure widespread consultation, reaching across all WMO Programmes and Technical Commissions, while engaging other organizations and agencies, and the cryosphere scientific community. The proposal is an exciting new WMO initiative largely resulting from CliC activities, and CliC now has to continue its efforts to turn the GCW vision into reality.

GCW will contribute to WMO's integrated observing and information systems and to the Global Climate Observing System network (like the Global Atmosphere Watch does). It will cover all aspects of the cryosphere and be an intergov-

ernmental mechanism for supporting key cryospheric *in-situ* and remote-sensing observations - while implementing the recommendations of the IGOS Cryosphere Theme. In collaboration with other international programmes and agencies, the proposed GCW will provide reliable, comprehensive observations of the elements of the cryosphere through an integrated observing approach on global and regional scales. It will work with, and build on, existing programmes such as the Global Terrestrial Network for Glaciers / Global Terrestrial Network for Permafrost and work with external partners such as space agencies and World Data Centers for Glaciology.

A GCW goal would be to establish a one-stop portal for authoritative cryosphere data and products/information, helping existing elements to be better integrated and contributing to a global data system. If approved, GCW will provide the integrating mechanism needed to ensure better quality of data and metadata, and ensure comparison of algorithms and the evaluation of products. It will also ensure the means to provide the scientific community with good-quality data to predict the future state of the cryosphere, resulting in improved prediction of the earth system over a wide range of time and space scales, and while facilitating assessment of changes in the cryosphere and their impact on climate. GCW will use this information to aid the detection of climate change and organize assessments of changes in regional and global components of the cryosphere to support decision-making and policy development.

The proposed Global Cryosphere Watch will help the IPY cryospheric projects to develop elements of a lasting observing system that will benefit science in the future.

Towards a Community Arctic System Model

Andrew Roberts^{1,2}, John Walsh², Larry Hinzman², Ralf Döscher³, Akimasa Sumi⁴, Marika Holland⁵, John Cassano⁶,
Wieslaw Maslowski⁷, William Gutowski⁸, Juanxiong He^{1,2}

¹Arctic Region Supercomputing Center, U. of Alaska Fairbanks, USA; ²International Arctic Research Center, U. of Alaska, USA;

³Swedish Meteorological and Hydrological Institute, Sweden; ⁴Center for Climate System Research, University of Tokyo, Japan;

⁵National Center for Atmospheric Research, USA; ⁶Cooperative Institute for Research in Environmental Sciences and Department of Atmospheric and Oceanic Sciences, U. of Colorado, USA; ⁷Naval Postgraduate School, USA; ⁸Department of Geological and Atmospheric Sciences, Iowa State University, USA

Coupled regional Arctic System Models comprising ocean, atmosphere, sea-ice and terrestrial-models are of growing importance in understanding the northern cryosphere and in analyzing the Arctic as an integrated system. The stage has been set for increased activity in coupling arctic component models by activities such as the *Arctic Regional Climate Model Intercomparison Project* and the *Arctic Ocean Model Intercomparison Project*. Several regional coupled arctic models have evolved during the past decade, including the *Arctic Regional Climate System*, and the *HIRHAM* (Rinke *et al.*, 2000). More recent developments include the Rossby Center *Regional Atmosphere-Ocean* model (Räisänen *et al.*, 2004) and the *HIRHAM-NAOSIM* (Dorn *et al.*, 2007). In the USA, recently initiated projects are coupling the *Polar Weather Research and Forecast* model with ice-ocean and terrestrial models for climate simulations, data assimilation and observing system experiments. Each of these efforts highlights a growing need to downscale information from global models toward the temporal and spatial resolution of *in-situ* and satellite measurements. This helps to facilitate better understanding and validation of modelled cryospheric processes and perpetuates model improvements with the aim of reducing the large uncertainties in current Arctic climate projections reported by the Intergovernmental Panel on Climate Change (2007).

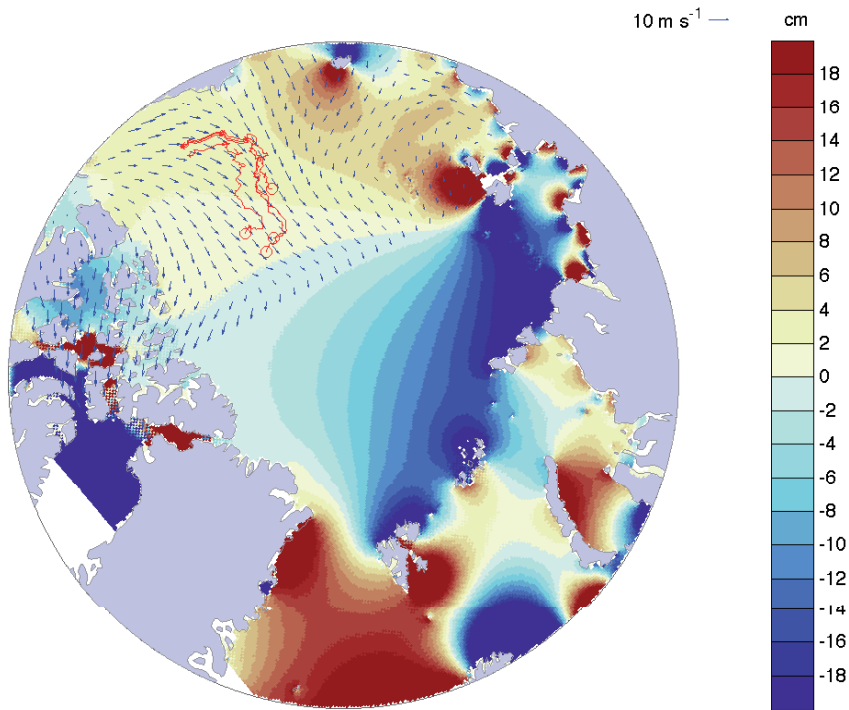
There are many questions about the Arctic that are best addressed using a high resolution, regional coupled model. Additionally, there are still process studies that must be completed before we can quantifiably characterize the links among and within system components. For the Arctic Ocean, uncertainty remains about the impact of decreasing sea-ice cover on arctic weather systems annually. The potential impact of ice-tide interaction on the oceanic boundary layers is under investigation (e.g., Hibler *et al.*, 2006) and would benefit from coupled high-resolution simulations. The role of clouds remains critically important but is, as yet, not completely understood in the arctic system (Francis *et al.*, 2006). Terrestrial models are at the cusp of interfacing hydrology and ecosystem dynamics with permafrost and atmospheric dynamics (Baldocchi *et al.*, 2006), and the resolution available in a regional coupled model is better suited to this task than that of global models. These examples, and many more, are providing the impetus to create numerical tools for researchers capable of resolving small-scale variability in ice, ocean, atmosphere and terrestrial processes with high resolution topography and bathymetry to match.

An international workshop designed to work on plans to develop an international coupled *Community Arctic System Model*, will be held in Boulder, Colorado from 19 to 21 May 2008. The workshop will bring together participants from the atmosphere, ocean, sea ice, terrestrial, ecosystem, and glacier arctic-modelling communities. It is anticipated that a *Community Arctic System Model* will capitalize on recent software development for interfacing component models (e.g., Hill *et al.*, 2004), enabling different modelling groups to apply their own component models to the project. This will broaden the meaning of a 'community model' to a network of component models—potentially providing multiple ice, ocean, atmosphere and terrestrial modules as an arctic system-modelling package. Thus, considerable flexibility would be introduced to Arctic system modelling, creating an excellent tool for understanding regional change, studying the arctic as an integrated system, and refining model intercomparison. Ultimately, it is hoped that this effort will help to reduce uncertainty in climate projections for this data-poor region of Earth.

For information about the workshop, please contact Andrew Roberts at: aroberts@arsc.edu.

References

- Baldocchi, D. D., F. S. Chapin III, W. Eugster, S. E. Hobbie, E. S. Kasischke, A. D. McGuire, R. Pielke Sr., J. R. Randerson, E. B. Rastetter, N. Roulet, S. W. Running, S. A. Zimov, R. Fielke Sr., and W. Eugester. 2000. Arctic and boreal ecosystems of western North America as components of the climate system. *Global Change Biology*, 6, Suppl.1, 211-223.
- Dorn, W., K. Dethloff, A. Rinke, S. Frickenhaus, R. Gerdes, M. Karcher, and F. Kauker. 2007. Sensitivities and uncertainties in a coupled regional atmosphere-ocean-ice model with respect to the simulation of Arctic sea ice. *J. Geophys. Res.*, 112, D10118, doi:10.1029/2006JD007814.
- Francis, J. A., J. R. Miller, F. Aires. 2006. Observed Relationships between Arctic Longwave Cloud Forcing and Cloud Parameters Using a Neural Network. *J. Climate*, 19, 16, 4087-4104.
- Hibler, W. D., III, A. Roberts, P. Heil, A. Y. Proshutinsky, H. L. Simmons, and J. Lovick. 2006. Modelling M2 tidal variability in Arctic sea-ice drift and deformation. *Ann. Glaciol.*, 44, 418-428.
- Hill, C., C. DeLuca, V. Balaji, M. Suarez, and A. de Silva. 2004. Architecture of the Earth System Modelling Framework. *Computing in Science and Engineering*, 6, 1, 18-28.
- Räisänen, J., and Coauthors. 2004. European climate in the late twenty-first century: regional simulations with two driving global models and two forcing scenarios. *Clim. Dynam.*, 22, 13-31.
- Rinke, A., A. H. Lynch, and K. Dethloff, 2000: Intercomparison of Arctic regional climate simulations. Case studies of January and June 1990. *J. Geophys. Res.*, 105, D24, 29669-29683.
- IPCC, 2007. Climate Change 2007: The Physical Science Basis. *Intergovernmental Panel on Climate Change*, Solomon, S. and Coeditors, Cambridge University Press, 996pp.



An example of regional models as downscaling tools: A 50 km resolution version of the Weather Research and Forecast (WRF) model (10 m winds shown here) and a 14 km resolution barotropic ice-tide model of Hibler *et al.* (2006) (shaded sea surface height) are being used to downscale information from global models to help understand sea-ice deformation measured by buoy arrays (red traces), deployed during 2007 in the Beaufort Sea. (WRF output courtesy of Mark Seefeldt, University of Colorado and buoy locations courtesy of Jenny Hutchings, University of Alaska Fairbanks.)

The Norwegian Polar Institute's Journal Sports a New Look



Starting last year, *Polar Research* boasts a fresh, new look and a new online submission/peer-review website. The journal is the international, peer-reviewed journal of the Norwegian Polar Institute—Norway's central institution for research, environmental monitoring and mapping of the polar regions. Aiming to promote the exchange of scientific knowledge about the Arctic and Antarctic across disciplinary boundaries, *Polar Research* serves an international community of researchers.

Original primary research papers comprise the mainstay of *Polar Research*. Review articles, brief research notes and book reviews are also included. Special issues, typically conference proceedings, are published from time to time.

The scope of *Polar Research* encompasses research in all scientific disciplines relevant to the polar regions. These include, but are not limited to, the subfields of biology, ecology, geology, oceanography, glaciology, and atmospheric science. Submissions from the human and social sciences and those focusing on polar management and policy issues are welcome.

Contributions about Antarctica are particularly encouraged. Please see guidelines at <www.blackwellpublishing.com/por>. -- H. Goldman

Simulation of Glacier Mass and Energy Balance within a Regional Climate Model

Sven Kotlarski¹, Daniela Jacob¹, Frank Paul²

¹Max Planck Institute for Meteorology, Hamburg, Germany

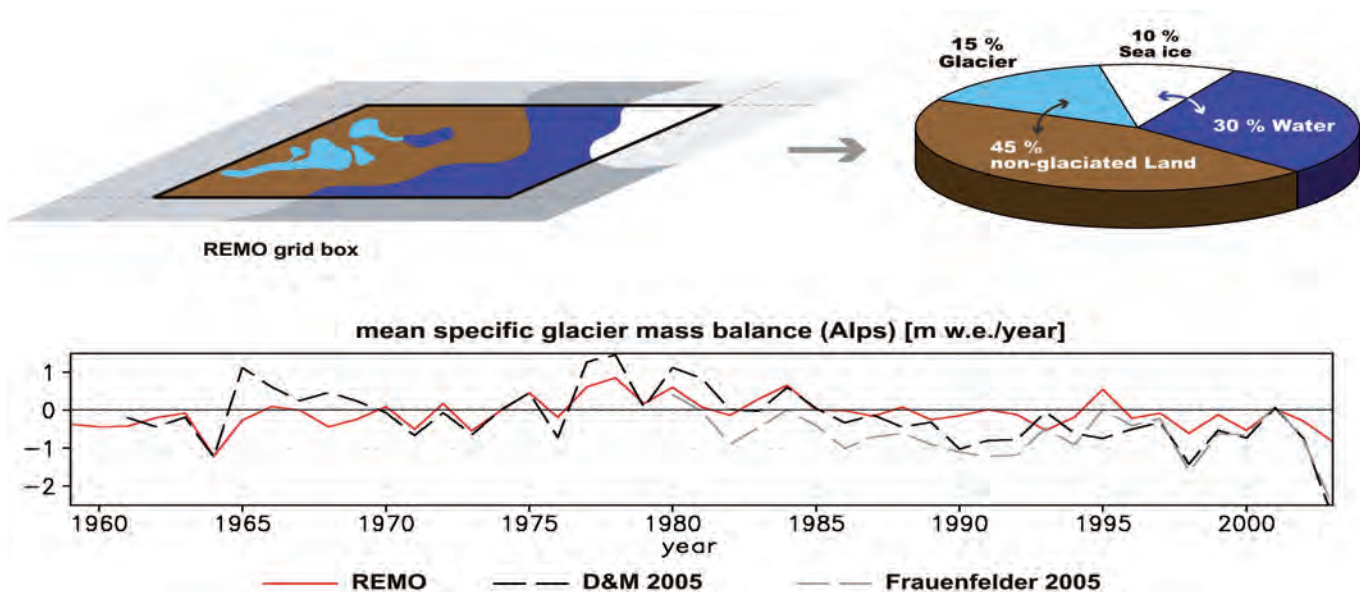
²Department of Geography, University of Zurich, Switzerland

Due to their unique surface characteristics and their function as hydrological reservoirs, glaciers play an important role for water and energy budgets in many alpine areas. Regional climate models (RCMs) are an important tool in the analysis of the corresponding water and energy cycles and for the prediction of future changes in the individual components. In contrast to general circulation models (GCMs) the model domain of an RCM does not cover the entire globe but is typically restricted to some hundred to some thousand kilometres in x- and y-direction. This allows for the long-term simulation of regional climatic processes with a high horizontal resolution at comparatively low computational costs (current resolutions range from about 10 to 50 km). At the lateral domain boundaries, RCMs are driven by the output of a GCM or by global re-analysis products.

In mountainous terrain high resolution is especially important to resolve small-scale atmospheric processes, for instance those affected by orography or by details of the land surface. In many alpine areas the latter includes the presence of glaciers. However, mountain glaciers are only represented in an extremely simplified way—or even totally neglected—in state-of-the-art RCMs. Their size is usually far smaller than grid box resolution and only the largest glaciers are treated as fixed surface boundary conditions with runoff generation on glaciated surfaces being highly simplified. The simulation of a possible feedback of changes in ice cover extent to the

atmosphere and of the influence of enhanced glacier melt on runoff conditions is therefore not possible.

To overcome these deficiencies and to represent processes related to mountain glaciers in an appropriate way, a glacier parameterization on the subgrid level has been developed and implemented into the RCM REMO (Jacob, 2001). The new scheme is embedded in the land surface model of the RCM and replaces the static glacier mask used previously. It bi-directionally couples the atmospheric model component to glaciated surfaces and allows for an explicit simulation of glacier mass and energy balance in each RCM grid box. Given the size of typical RCM domains, the new parameterization must be applicable on the scale of entire mountain ranges (e.g., the European Alps) and, hence, should only require a minimum amount of glacier-specific input data. At the same time it should be based on physical principles in order to ensure its predictive capability and its validity under future climatic conditions. Following these requirements a rather simplistic approach has been chosen in which the total ice mass within a climate model grid box is represented by a two-layer ice body covering a certain fraction of the total grid box area (see Figure, upper panel). Surface fluxes are derived separately for glaciated and non-glaciated parts. The glaciated fraction of an individual grid box is adjusting dynamically depending on accumulation and ablation conditions. Surface runoff and drainage originating from the glacier fraction are



Upper panel: Simplified treatment of glacier surfaces in REMO's land surface model based on a dynamic tile approach. Example for a grid box covered by non-glaciated land (45%), glacier ice (15%), water (30%) and sea ice (10%).

Lower panel: Mean specific mass balance for the entire European Alps for the period 1958 to 2003 as simulated by REMO and as compiled by Dyurgerov & Meier (2005) and Frauenfelder *et al.* (2005).

added to total grid box runoff which finally closes the grid box water balance. The subgrid variability of precipitation and of global radiation within each RCM grid box is explicitly accounted for. In order to assess the effect of changing ice volumes on river discharge in glaciated catchments, a hydrological routing scheme is coupled to REMO in an offline mode.

The new parameterization scheme has been developed and validated in the area of the European Alps applying a horizontal RCM resolution of approximately 18 km x 18 km. The illustration shows a comparison between the simulated alpine-wide glacier mass balances for the period 1958-2003 (REMO) with recent estimates by Dyurgerov & Meier (2005) and Frauenfelder *et al.* (2005), both based on mean values of measured mass balances at individual glaciers. In a number of years, the simulated values almost match the observation-based estimates and the observed inter-annual variability of glacier mass balance is, in general, very well reproduced by the model. The strong glacier mass loss towards the end of the century is, however, clearly underestimated. We believe that this deficiency is mainly related to a) an overestimation of precipitation in the 1970s and 1980s as simulated by the atmospheric component of the RCM and b) the simplifying assumption of a uniform glacier surface in each REMO grid box which is either totally snow-free or totally covered by a snow layer. The simulated glacier area loss in the Alps between 1958 and 2003 is 23.6 % which is less than estimates based on glacier inventory data (about 30 %).

A further interesting point from the climate modelling perspective is to investigate the influence of glaciers on the regional climate (the full feedback loop is closed as the new parameterization scheme is coupled in a two-way mode to the RCM). In the chosen model setup the effect of the new subgrid parameterization on atmospheric parameters is generally restricted to the lower troposphere and to glaciated grid boxes and those in the direct vicinity. The large scale flow conditions are not affected significantly. In glaciated grid cells the incorporation of the glacier scheme into REMO causes a lowering of the near surface air temperature by several degrees Celsius and a less intense local recycling of water by reducing both precipitation and evapotranspiration. These effects are most pronounced in summer and autumn.

The results indicate that it is possible to approximately reproduce observed regional glacier mass balances within an RCM based on extremely simple concepts of glacier-climate interaction. However, it is also clear that realistic results can only be achieved if the subgrid variability of atmospheric parameters within a climate model grid box is explicitly accounted for (model results are very sensitive to the applied subgrid concepts). This point has to be investigated in more detail in the future, hopefully leading to improved subgrid parameterization concepts (area-altitude distribution within an RCM grid box, etc.). A further investigation will focus on the influence of glacier melt on discharge characteristics. The new model will now be applied in climate scenario simulations for the European Alps.

A full description of the new parameterization scheme as well as more details on model results can be found in Kotlarski (2007).

References:

- Dyurgerov, M. and M. Meier. 2005. Glaciers and the changing earth system: A 2004 snapshot. *Occasional Paper 58. Institute of Arctic and Alpine Research, University of Colorado.*
- Frauenfelder, R., M. Zemp, W. Haeberli and M. Hoelzle. 2005. Worldwide glacier mass balance measurements: Trends and first results of an extraordinary year in Central Europe. *Ice and Climate News. The WCRP Climate and Cryosphere Newsletter*, (6), 9-10.
- Jacob, D. 2001. A note to the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin. *Meteorology and Atmospheric Physics*, 77, 61-73.
- Kotlarski, S. 2007. A subgrid glacier parameterization for use in regional climate modelling. PhD Thesis. *Reports on Earth System Science No. 42.* Max Planck Institute for Meteorology, Hamburg. Downloadable from: http://www.mpimet.mpg.de/fileadmin/publikationen/Reports/WEB_BzE_42.pdf.

News from Glaciers-online

"Glaciers-online" has recently added a new section to their website which may provide useful information for educational purposes. This new page shows imagery of Arctic islands with brief descriptions focusing on glaciology and other aspects of the natural history of the Canadian Arctic, Greenland, and Svalbard.
<www.glaciers-online.net/arctic-islands/>.

The site's Alpine glacier section has been developed further to include more images. For instance, repeat photography of the Stegletscher and the Triftgletscher that illustrates their dramatic recession over the last five years.
<www.glaciers-online.net/glaciers/alps/>.

Contacts: Michael Hambrey (mjh@aber.ac.uk) and Juerg Alean (jalean@stromboli.net).

The 2nd Asia CliC Symposium 'The State and Fate of Asian Cryosphere'

Dahe Qin, China Meteorological Administration, Chinese Academy of Sciences (qdh@cma.gov.cn)

The 2nd Asia CliC Symposium *The State and Fate of Asian Cryosphere* was held in Lanzhou, China, 22-26 October, 2007; involving 148 scientists from 15 countries. The main aim of the symposium was to promote international communication about the state of cryospheric studies in Asia. The 51 oral presentations were split between one plenary session and eight topical sessions. In addition, 33 posters were presented and six split sessions gave a unique opportunity for group discussions. The outstanding results presented covered a wide range of cryospheric topics including: glaciology, snow cover, hydrology and water resources, frozen ground and permafrost, land surface and atmosphere processes; as well as cold regions ecology and data issues.

The Symposium emphasized the progress accomplished since the 1st Asia CliC Symposium, and showed that amount of existing meteorological, cryospheric, and hydrological data related to the Asian region has increased. However, the collaboration among researchers and groups is not yet sufficiently developed to allow an optimal use of these data.

The Symposium stressed the unique characteristics of the Asian cryosphere as the headwater of the major rivers flowing into the Pacific, Indian and Arctic oceans. Cryospheric changes can therefore have impacts locally, but also potentially on a much larger scale. In a near future, the *International Asia Cryospheric Years* could be launched; and, dedicated to the central Asian region, build on the basis of the already existing research in China and Japan (North Hydrology Studies in the sub-Arctic). The various cryospheric components display a large diversity throughout the region. Moreover, climatic forcing influencing the Asian cryosphere varies considerably within the region, for example under the influence of

the East Asia monsoons, the Indian monsoons, or the dipole of Arctic sea ice. This diversity makes it necessary to study Asian cryosphere in a complex climate system, especially when examined in the context of global change.

Required future actions include a high-priority involvement of the Asia-CliC community in data management and archiving, the establishment of improved observational network, the pursuit of higher quality data, and the use of various models to overcome spatial/temporal shortcomings.

As an outcome of the symposium, the constitution of an Asia CliC Committee and Science Steering Group in the near future are currently examined. Asian cryosphere scientists must contribute further to the international CliC activities through submitting papers for the CliC newsletter, registering as a CliC specialist, and organizing meetings. The implementation structure was further discussed at the November 2007 CliC Scientific Steering Group meeting. Several workshop suggestions were put forward on topics such as "Mountain glaciers under a global warming" (Lhasa, China) and "Snow cover and hydrology" (Japan). It is suggested that an Association of Polar Early Career Scientists (APECS) Secretariat, helping the training and communications of young Asian cryosphere researchers, could be located in the State Key Laboratory of Cryospheric Sciences in Lanzhou.

The Symposium created a strong momentum for future activities, leading to the organization of the 3rd Asia CliC Symposium in 2009 or 2010.

The 2nd Asia CliC Symposium: the State and Fate of Asian Cryosphere Lanzhou, China (2007.10.22-26)



Symposium participants.

The First Training Workshop on Permafrost Research Methods: A Milestone for the Cryosphere Community

H. Lantuit (Hugues.Lantuit@awi.de), H. Kassens, M. Johansson, L. Timokhov, T. Haltigin, J. Baeseman, K. Volkmann-Lark



Group of young scientists participating in the first ever training workshop on permafrost research methods held in St. Petersburg, Russia.

Fifty young researchers from 14 countries met in the *Otto Schmidt Laboratory for Polar and Marine Sciences* at the *Arctic and Antarctic Research Institute* in St. Petersburg, to study the latest methods used in permafrost research and engineering and to discuss future plans to address climate-change issues in permafrost areas. This workshop (29 November - 2 December 2007) was an official International Polar Year event organized jointly by the Otto Schmidt Laboratory for Polar and Marine Sciences in St. Petersburg, the Permafrost Young Researchers Network (PYRN) and the Association of Polar Early Career Scientists (APECS).

The workshop provided insights into the latest techniques and methods used in permafrost research in fields as diverse as permafrost modelling, investigations of mountain ice segregation, bubbling from thermokarst lakes, submarine permafrost detection, etc. It brought together experts from Germany, Russia and Switzerland to provide young investigators with a multidisciplinary and cross-border perspective on permafrost research, a much-needed approach in a discipline marked by strong research history in most Arctic countries.

The workshop triggered discussions and exchange of ideas among the young scientists which guarantees capacity building for the future. The involvement of young scientists ensures a long-term perspective of scientific projects, which is crucial as changes of the state of permafrost often occurs over long time periods. It is very important that young scientists are able to participate in wider international workshops like this to gain experiences that can be used to carry the responsibility of assessing the impacts of a warming permafrost until the next International Polar Year (2032).

The workshop's success highlights the need for a "sense of belonging" among scientists beyond the traditional, nationally established borders. The new generation of permafrost scientists seeks the acknowledgement of its activities as part of the global research effort, and workshops such as this provide the platform for them to break borders, exchange information and contribute to the early elaboration of relevant scientific questions.

The workshop was sponsored by the German Federal Ministry of Education and Research, the Leibniz Institute for marine science IFM-GEOMAR, the International Arctic Research Center, Fairbanks, the International Permafrost Association, the SCAR-WCRP Climate and Cryosphere project (CliC), the Arctic and Antarctic Research Institute, St. Petersburg, and the Alfred Wegener Institute for Polar and Marine Research.

Association of Polar Early Career Scientists (APECS) Newsletter

APECS is an interdisciplinary organization of undergraduate and graduate students, postdoctoral researchers, early faculty members, and educators with interests in polar regions and the cryosphere.

The January 2008 issue of their newsletter is available online from <<http://arcticportal.org/apecs/apecs-news>>.

The *Ice and Climate* newsletter is published by the CliC International Project Office.

Editor:

Angélique Prick
Angelique@npolar.no
Tel: +47 77 75 01 47

Layout, design and contact:
Tordis Villinger
tordis@npolar.no
Tel: +47 77 75 01 46

This newsletter is distributed free of charge upon request, thanks to funding from the Norwegian Polar Institute, the Norwegian Science Council, the Scientific Committee on Antarctic Research, and the World Climate Research Programme.

Address changes and requests to be added to or removed from the mailing list should be sent to:

CliC International Project Office
The Polar Environmental Centre
Norwegian Polar Institute
NO-9296 Tromsø, Norway
Tel: +47 77 75 01 50
Fax: +47 77 75 05 01
cl ic@npolar.no
http://cl ic.npolar.no

Past issues are available from:
http://cl ic.npolar.no/disc/

Articles, letters, announcements and other contributions are welcomed.

Printed by:
Lundblad Media AS
Tromsø, Norway

ISSN: 1502-7252

Conferences and Meetings - 2008

- 28 January - 1 February: GLACIODYN Workshop - Obergurgl, Austria.
<www.universitycenter-obergurgl.at>.
- 28 January - 1 February: 3rd WCRP International Conference on Reanalysis - Tokyo, Japan <http://jra.kishou.go.jp/3rac_en.html>.
- 26 March - 2 April: Arctic Science Summit Week - Syktyvkar, Russia
<www.assw2008.org >.
- 9-11 April: 2nd IPY Workshop on Sustained Observing Networks - Edmonton, Canada <www.arcticobserving.org>.
- 6-9 May: WCRP/WWRP Modelling Summit - Reading, UK
<www.ecmwf.int/newsevents/calendar>.
- 19-21 May: Workshop - Community Arctic System Model - Boulder, Colorado.
Contact: <aroberts@arsc.edu>.
- 29 June - 3 July: Ninth International Conference on Permafrost - Fairbanks, Alaska, USA <www.nicop.org>.
- 8-11 July: SCAR/IASC IPY Open Science Conference - St.Petersburg, Russia
<www.scar-iasc-ipy2008.org>.
- 17-22 August: IGS-International Symposium on Dynamics in Glaciology - Limerick, Ireland. Contact: <igsoc@igsoc.org>.
- 20-24 September: IGS International Workshop on World Glacier Inventory - Lanzhou, China <http://www.igsoc.org/symposia>.
- 15-17 October: 3rd IPY Workshop on Sustained Observing Networks - Helsinki, Finland <www.arcticobserving.org>.
- October: CliC Scientific Steering Group - Invitation only.
- October: Asia CliC mountain cryosphere: Mountain Glaciers under the Climate Warming - Lhasa, China.
- October: Sochi Conference on IPY results and Russia CliC meeting - Sochi, Russia.
- 4-6 November: International Symposium on the Arctic Research (ISAR) - Miraikan, Tokyo, Japan.

CliC Scientific Steering Group ([//cl ic.npolar.no/org/stcom.php](http://cl ic.npolar.no/org/stcom.php))

- Barry Goodison, Canada, Chair (Barry.Goodison@ec.gc.ca)
- Tony Worby, Australia, Co-vice chair (a.worby@utas.edu.au)
- Koni Steffen, USA, Co-vice chair (konrad.steffen@colorado.edu)
- Gino Casassa, Chile (gc@cecs.cl)
- Mark R. Drinkwater, The Netherlands (mark.drinkwater@esa.int)
- Vladimir M. Kattsov, Russia (kattsov@main.mgo.rssi.ru)
- Tetsuo Ohata, Japan (ohatat@jamstec.go.jp)
- Terry Prowse, Canada (Terry.Prowse@ec.gc.ca)
- Qin Dahe, China (qdh@rays.cma.gov.cn)
- Annette Rinke, Germany (arinke@awi-potsdam.de)
- Vladimir Romanovsky, USA (ffver@uaf.edu)
- John Turner, UK (J.Turner@bas.ac.uk)

CliC Principal Goal

To assess and quantify the impacts that climate variability and change have on components of the cryosphere and its overall stability, the consequences of these impacts for the climate system.

In order to achieve this goal CliC has the supporting objectives to:

- Enhance the observation and monitoring of the cryosphere in support of process studies, model evaluation, and change detection.
- Improve understanding of the physical processes and feedbacks through which the cryosphere interacts within the climate system.
- Improve the representation of cryospheric processes in models to reduce uncertainties in simulations of climate and predictions of climate change.