Understanding the
Arctic Climate System

The Arctic is a pivotal region in mapping global climate change. **Professor Wieslaw Maslowski** explains how he and his collaborators seek to understand both its processes and large-scale operation more fully

Firstly, could you explain the formation of the Regional Arctic System Model (RASM) project?

This project and several complementary projects grew out of regional Arctic climate modelling work at the Naval Postgraduate School, the University of Colorado, Iowa State University and the University of Washington. Currently, our team involves 30 researchers, including students, from 10 institutions, and this number is growing. Members from each institution have worked with stand-alone model components, such as ocean, ice, atmosphere and land models, and identified the need for a fully-coupled regional climate model that thoroughly explores the interactions between components.

Why is RASM an improvement on previous models?

Although our approach is similar to the one used in Global Climate and Earth System Models (GC/ESMs), RASM provides two critical advantages. Firstly, given its regional focus, it permits significantly higher spatial resolution to explicitly represent and evaluate the role of important fine-scale Arctic processes and feedbacks, such as sea ice deformations, ocean eddies and associated ice-ocean boundary layer mixing, multiphase clouds as well as land-atmosphere-ice-ocean interactions. Secondly, it allows for the simulation of a larger number of ensemble members, using different initial conditions and space-dependant sub-grid

parameterisations, to generate probabilistic predictions that would be more useful to national and local decision makers than global model forecasts alone.

The project's objectives are broad in scope, what are your long-term goals?

Our long-term goal is to advance knowledge, reduce uncertainty and improve prediction of Arctic climate through continuous expansion of RASM involving a larger climate community and including ice-sheet/ocean interaction in fjords, terrestrial and marine biogeochemistry, ecology and the associated carbon cycle integral to human dimension components.

As we develop our model and analyse its results, we gain a greater insight into the basic working of the climate system. Given that the Arctic is warming faster than the rest of the globe, understanding the processes and feedbacks of this polar amplification is a top priority. Additionally, Arctic glaciers and the Greenland Ice Sheet are expected to change significantly and contribute to sea level rise in the coming decades; the aforementioned high spatial resolution allows for detailed study of the regional response of these land ice masses to long-term warming and interannual variability.

Land ice is also an important reservoir of freshwater in the Arctic, and any loss thereof results in increased freshwater discharge to the ocean, which can impact the Arctic and global ocean circulation. We are currently working to include realistic models of the Greenland Ice Sheet and glaciers. Knowledge gained from such studies will allow for a more comprehensive picture of the Arctic System, and its improved representation in GC/ESMs.

Finally, thawing permafrost and release of land and sub-sea trapped methane is an increasingly urgent issue that is not fully accounted for in climate models. We believe that through collaboration with other programmes, such as the Department of Energy (DOE) supported Next Generation Ecosystem Experiments (NGEE) project, regional aspects of potential release of greenhouse gasses from natural sources can and will be addressed.

What value does collaboration bring to your research?

It brings expertise that no single partner could possess and huge benefits from the openness among team members to collaborate. This supportive environment allows for constructive criticism of the ongoing progress of RASM.

Collaboration is also valuable to individual team members, allowing us to work beyond our field of specialty and learn more about the Arctic System, which transcends disciplinary boundaries. It is also valuable for graduate students and postdocs, exposing them to a wider range of fields. The future of climate research will be dominated by interdisciplinary teamwork, so gaining this experience early is a significant advantage in understanding Earth's environment as a complex adaptive system.

Could you offer some thoughts on the potential reasons behind the record sea ice melt of 2012?

In my opinion, increasing heat content in the subsurface western Arctic Ocean, together with the snow-ice/albedo effect, advection of warm summer Pacific and Atlantic water, and stronger air-sea coupling due to thinner or no sea ice is one of the main reasons why the summer sea ice cover has been declining in the Arctic. This extra energy and its storage in the upper ocean can help explain the long-term negative sea ice trend and especially its acceleration since the late 1990s. The entrainment of this heat into the surface mixed layer (where it can affect the growth or melt of sea ice or be released to the atmosphere) is controlled by small scale processes, such as eddies, upwelling, coastal currents, mixed layer depth and vertical stratification.

The western Arctic Ocean, where sea ice retreat has been most extreme, combines many of these interactions, pointing to their importance to larger-scale changes. A new programme, sponsored by the Office of Naval Research to understand the dynamics of marginal ice zone (MIZ) in the western Arctic, is expected to help constrain climate models with new critical data.

Arctic climate research: **a focused approach**

A novel set of studies, headed by the **Naval Postgraduate School** in Monterey, California hopes to gain better understanding of the Arctic climate by studying small-scale processes of relevance to climate change

THE PAN-ARCTIC REGION (see figure 1) is an important area for global climate and Northern Hemisphere weather systems, both in terms of its effect on sea levels, ocean/atmosphere circulation and sensitivity as an indicator of warming trends. There is conclusive evidence to demonstrate that, since the late 1990s, melting of the perennial ice-cover in the Arctic has accelerated significantly, yet the exact mechanisms, causes and rates of this melt are still poorly understood. Interdisciplinary and multi-institutional studies led by Professor Wieslaw Maslowski at the Naval Postgraduate School (NPS) in Monterey, California, aim to advance understanding of the Arctic Climate System through rigorous, detailed and regional methodology.

A HIGH-RESOLUTION APPROACH

The research team is committed to novel technologies which increase the resolution and improve the representation of fine-scale processes and land-atmosphere-ice-ocean interactions to advance understanding and prediction of Arctic climate change. The core effort involves the development and use of a Regional Arctic System Model (RASM), consisting of atmosphere, land, ocean and sea ice, as well as vegetation, Greenland Ice Sheet and glaciers. Aside from presenting a detailed picture of the climate patterns which are emerging in the region (figure 1), the team hopes that their studies will provide future Global Climate and Earth System Models (GC/ESMs) greater insight into what they should be looking for. "Many processes of relevance to Arctic climate occur at small spatial scales, requiring models with small grid spacing to explicitly resolve them," explains Maslowski. "Part of the problem is that it is not clear which of these and other processes must be represented in GC/ESMs and which are lower priority for improved climate prediction." Although the number of processes is vast and diverse in nature, each is being carefully scrutinised by the scientists. There is much to be done to determine which are the most important to Arctic climate studies, but Maslowski is confident in his group's ability to make positive headway. Indeed, their work to date has already produced some interesting and illuminating results, which in some cases help identify important areas to obtain new or additional observations.

THE PROGRESS SO FAR

The first set of results indicates that ice-ocean interactions combined with diminishing sea ice cover plays an important role in the western Arctic Ocean. Over the last decade, there has been a significant depletion of ice pack leading to a rise in subsurface heat content as more of the ocean surface becomes exposed to the Sun's rays. Some of this solar energy becomes trapped below the surface layer after freeze-up and can reduce the growth of sea ice in winter, leading to earlier melting/retreat in spring and a further reduction of the Arctic sea ice cover. Such a positive feedback would act in addition to ice-albedo feedback and further contribute to polar amplification.

On the Atlantic side of the Arctic, in the Barents Sea, oceanic heat transport and air-sea fluxes may help explain some of the GC/ESMs biases related to the regional atmospheric circulation and excessive sea ice melting in the eastern Arctic. The former appears to be caused by insufficient mixing and cooling of Atlantic water over the Barents Sea. This could help explain the large, positive sea level pressure bias centred over the Barents Sea experienced in many of the GC/ESMs of the World Climate Research Programme's (WCRP) Third Coupled Model Intercomparison Project (CMIP3). Maslowski and his team believe that a more accurate model simulation of water vertical mixing and cooling in the Barents Sea will require improved representation of oceanic currents, eddies, tides, marginal ice zones and of overall bottom bathymetry.

Further, a depletion of sea ice may have a knock-on effect on summer weather forecasting because larger areas of direct ocean-atmosphere interaction increase oceanic regulation of the atmosphere (areas such as Alaska have shown an increase in warm extremes and a decrease in cold extremes). Maslowski's team believes the warmer weather is due to a change in atmospheric circulation influenced by an increase in open ocean. The team's Regional Arctic System Model (RASM) has also indicated an increase in precipitation in Alaska and Canada, suggesting that in future RASM could be used for exploring precipitation extremes, as well as its many other applications.

Overall, RASM is in good agreement with satellite observations for sea ice variability (figure 2), which is especially encouraging given the large model domain and forcing with reanalysed atmospheric data from the European Centre for Medium-Range Weather ForecastsInterim Reanalysis (ERA-Interim) project along the lateral boundaries (figure 1). More importantly, RASM can realistically represent extreme sea ice events, such as the September 2007 minimum (figure 3), when forced with realistic atmospheric data from the Common Ocean Reference Experiment version 2 (CORE-2). Since the Arctic sea ice is highly sensitive to and dependent on combined forcing from the atmosphere and ocean, such results bring confidence in the model's ability to simulate processes and interactions affecting the region's surface climate.

AN INCREASE IN STORMS

Another predicted result of the changing global climate is an increase in the incidence of cyclonic storms. Maslowski and his colleagues fear that this, too, may cause a decrease in the Arctic sea ice cover: "Storms can contribute to sea ice melt during the summer through increased mixing and wave-ice interaction, as was the possible case in early August 2012," he notes. "A loss of sea ice abutting land could increase coastal erosions during storms and more intense rainfall could increase land erosion." Yet, whilst it is expected that storms will increase in both incidence and severity, their effects are as yet not fully understood within the wider picture of global climate change.

FIGURE 1. RASM domain in the fully coupled model (rendered bathymetry). The Arctic System (black contour) is as defined in Roberts *et al.* (2010). The extended ocean domain (magenta) indicates where observations are used to generate atmospheric surface fluxes beyond the ice/ocean model domain.
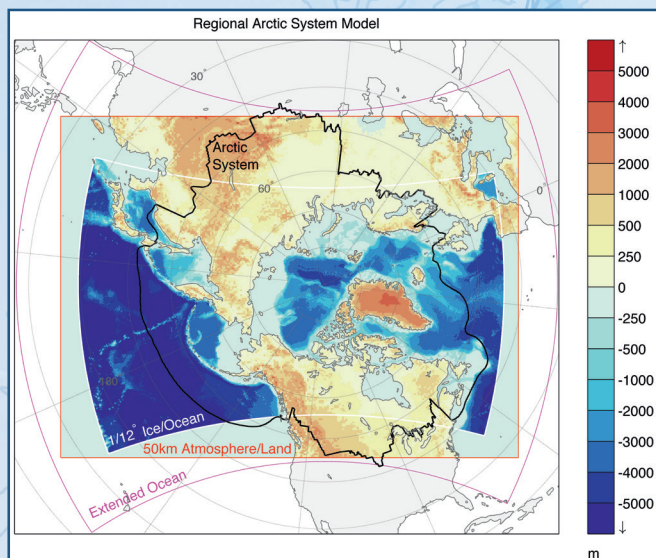
Regional Arctic System Model

REGIONAL ARCTIC SYSTEM MODEL (RASM)

OBJECTIVES

• To develop and apply a regional Arctic System model to resolve small-scale processes and feedbacks as well as to realistically represent large-scale climate variability and trends

• To advance understanding of past and present states of Arctic climate and to improve seasonal to decadal predictions

RASM will soon include ice sheets, ice caps, mountain glaciers, and dynamic vegetation. RASM allows high spatial resolution to represent critical processes and determine the need for their explicit representation in GC/ESMs.

KEY COLLABORATORS

A Roberts; **J Clement Kinney**, Naval Postgraduate School • **J Cassano**; **E Cassano**; **A DuVivier**; **M Hughes**; **S Knuth**, University of Colorado in Boulder • **W Gutowski; B Fisel; J Glisan**, Iowa State University • **D Lettenmaier**; **B Nijssen**; **J Hamman**, University of Washington • **W Lipscomb; J Fyke; M Hecht; M Maltrud, E Hunke**, Los Alamos National Laboratory • **X Zeng**; **M Brunke**, University of Arizona in Tucson • **S Tulaczyk**; **S Hossainzadeh**, University of California Santa Cruz • **W Robertson, A-C Ayers Pereira Barbosa**, University of Texas at El Paso • **J Hutchings**, University of Alaska Fairbanks • **R Osinski**, Institute of Oceanology, Polish Academy of Sciences • **A Craig**, consultant, Naval Postgraduate School • **J Renteria**; **K Lind**, DoD High Performance Computing Modernization Program

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WIESLAW MASLOWSKI research interests include polar oceanography, sea ice and climate; regional climate system modelling and prediction; mesoscale processes in the ocean and sea ice, their interaction with the atmosphere, feedbacks within and impact on large-scale climate change.
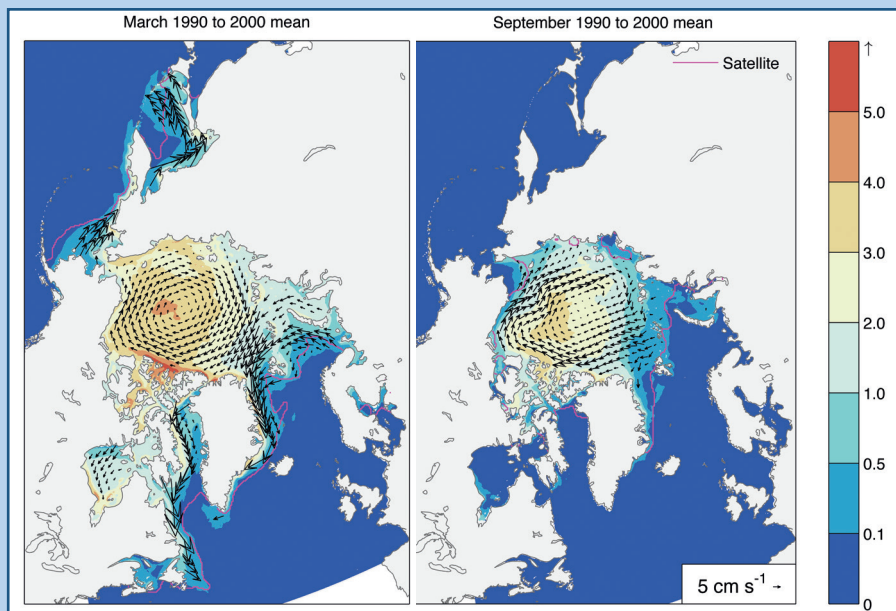

FIGURE 2. Mean March (**left**) and September (**right**) 1990-2000 sea ice thickness and velocity from an ensemble member generated with the latest RASM version. Magenta and green contours indicate SSM/I sea ice extent from Meier (2011) and RASM, respectively.

The researchers also plan to investigate the shifts in both land and marine ecosystems that accompany climate change. For example, it is thought that the observed gradual replacement of tundra grass with shrubs and forest could potentially have an alleviating effect on Arctic cyclonic storms. However, the northward shift of marine ecosystems, combined with changes over land in response to a warming climate may change the overall carbon budget in the Arctic. The RASM team believes that their expanded regional model, including ecosystem submodels, would allow advancement in such outstanding research areas.

DISSEMINATING THE FINDINGS

Key to RASM's success is the team's commitment to the wide circulation of result
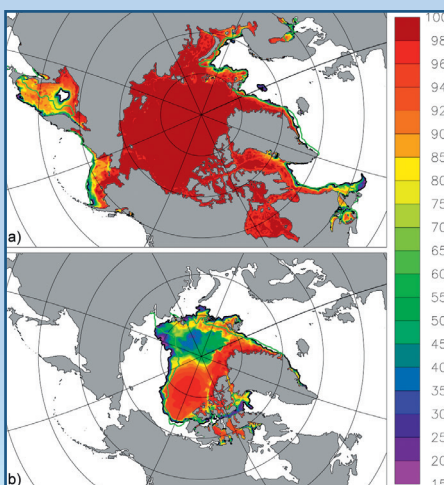
FIGURE 3. RASM sea ice concentration in March **(top)** and September **(bottom)** of 2007 as forced with the CORE2 atmospheric forcing of Large and Yeager (2008). The solid black and green lines represent the model simulated and observed (SSM/I) 15 per cent sea ice concentration contours, respectively.

to raise awareness and understanding of their methods. "We are currently preparing several papers based on the latest RASM results for publication in peer-reviewed scientific journals and we also plan to present findings at major scientific meetings, such as the Fall American Geophysical Union (AGU) conference, European Geosciences Union and World Climate Research Programme," explains Maslowski.

One of Maslowski's collaborators, Dr William Gutowski, based at Iowa State University, spoke about RASM at the 2012 Fall AGU special union session, entitled 'The Arctic System: From Critical Process Studies to Global Perspectives' which was co-convened by Maslowski himself, A Roberts, K Dethloff and L Hinzman. Other presentations at the AGU looked in particular at the sensitivity of RASM to ice-ocean state; land surface hydrology and freshwater flux to ocean; and prediction and predictability of the Arctic Climate System. Another RASM investigator, Dr William Robertson from the University of Texas at El Paso, is working to develop and implement a suite of educational and outreach efforts, including innovative RASM-based classroom materials for use by students and teachers in both high schools and universities. Already, this project has an array of potentially influential findings to report in addition to significant advances in technology.

Ultimately, it is anticipated that RASM becomes a community model, available for use by others on their own or in collaboration with the RASM team, which is the main reason it has used the established and open framework of the National Center for Atmospheric Research (NCAR) Community Earth System Model (CESM). It is hoped that with the continuation of this research and its application to other studies, a deeper, more detailed understanding of the Arctic Climate System and prediction of its future change will eventually be possible.