

AICS

ARCTIC ICE COVER SENSITIVITY

a project proposal to the Norwegian Research Council

OBJECTIVE

The overall goal of AICS is to *increase the understanding and quantify the sensitivity of the Arctic sea ice to changes in the atmospheric and oceanic energy budget and how uncertainties in these changes are related to representation of small scale processes.*

BACKGROUND

Scenario simulations of future climate changes due to increased levels of greenhouse gasses, predict the worldwide strongest warming in the Arctic, but also the area with the largest spread among the model results (Cubash et al., 2001, Raisanen, 2001, Sorteberg et al., 2005a). This highlight the difficult task of simulating the Arctic climate, both due to difficulties in modelling sea ice behaviour and the many atmosphere-ice-ocean feedbacks, which tend to make the climate variability of the Arctic highly non-linear (eg, Dethloff et al., 1998, Holland and Bitz, 2003). Despite the climatic significance of the Arctic, many physical processes occurring in this region are still not well understood and depending on the choice of climate model and physical parameterizations (eg. Rinke et. al., 2000; Dethloff et al., 2001).

In addition to the problems of simulating the local processes within the Arctic, the atmospheric meridional heat and moisture transport into the arctic region constitutes a major part of the total arctic heat budget. On average around 100W/m^2 (Nakamura and Oort, 1988; Overland and Turet, 1994) is transported into the region (at 70N) with an interannual variability of 10W/m^2 (Overland and Turet, 1994), making the arctic much warmer than the radiation budget suggests. The energy transport is divided into transport by transient eddies, quasi stationary eddies and the mean meridional circulation, with the eddy transport constituting the largest term (Overland et al., 1996). The main pathways of both the mean energy transport and the interannual variability is identified to be the northward heat transport by transient eddies over the Greenland and Barents Sea, and the southward anomalies in transport east of the Siberian High by quasi stationary waves.

This large energy source which is mainly transported into the Arctic between 900 and 500hPa, has been shown to be strongly coupled to the near surface temperatures and the ice thickness (eg. Overland and Guest, 1991). The sensitivity of the ice thickness was investigated by Thorndike (1992), which reported that the ice disappeared when the northward energy flux was increased by 30W/m^2 and reached 12m when the energy flux was increased by 20W/m^2 from the current value. Recent studies of Björk and Söderkvist (2002) confirms the large sensitivity with an increase in energy transport by 9W/m^2 giving a 2m (more than 50%) reduction in ice thickness and a large open-water fraction in summer. An increased heat transport of 30W/m^2 gave an ice-free Arctic. In addition they reported a transition in the sensitivity of the ice to the changes in the meridional heat transport through an additional albedo feedback. The transition appeared when the

melting was strong enough for all first year ice to melt within a year. The disappearance of first year ice had a strong impact on the ice albedo which induced a positive feedback on the sea ice melting. The sensitivity of sea ice to changes in heat transport has been shown to be sensitive to the inclusion of feedbacks related to the cloud cover (which was ignored in the two previous cited studies). Beesley (2000) suggested that feedbacks between the meridional heat transport and Arctic cloud cover may strongly affect the sensitivity of the Arctic sea ice to changes in the Arctic cloud cover. A recent study investigating the surface heat budget (Sorteberg et al., 2005b) using simulations from 18 coupled models show a wide range of estimates for both the current state and future changes in the Arctic heat budget. Confirming that the Arctic climate still is a challenging task for state-of-the-art coupled climate models.

The Arctic sea ice cover sensitivity towards its lower boundary was demonstrated in the 1990's when the cold halocline disappeared over the Eurasian basin (Steele et al. 1998). The cold halocline is a layer of water close to the freezing point gradually increasing in salinity with depth. This layer at the freezing point insulates the Arctic ice cover from the warm Atlantic water below, and is mainly created by river water being cooled mixed with cold shelf waters of varying salinity. It is still unclear how large the effect of the missing cold halocline was to the close to 40 % thinning of the central Arctic ice cover reported by Rothrock et al.(1999), but most researchers in the field finds it to be an important effect. An increase in the oceanic heat flux from below over the 30 years in question of only 2-4 W/m² would lead to the observed mean thinning/melting of 1.4 m of sea ice. At the end of the 1990's unusual large amounts of fresh water was found in the upper layers of the Canada basin during drift station SHEBA (McPhee et al.1998). This layer was equivalent to a freshwater input of 2 m, and was much larger than changes in river input may have caused. This period in the 1990's thus provide an example of the variability in the Arctic ice cover, and is also similar to the changes predicted by the Global models. Yet, the Arctic halocline is not represented in these models, as their vertical resolution is too coarse.

Several other processes that might be of fundamental importance are not included, or not validated, in Global models. The Atlantic layer inflow is one such process, that in principal should be included, but will have limited realism in a coarse resolution Global model. The Atlantic inflow is of vital importance for the Arctic ice cover in cases where the insulating cold halocline has disappeared. The Atlantic layer inflow seemed to be warming when comparing the 1990's towards the earlier climatology (Grotefendt et. al.1998), and validation of the present Global models towards the deeper water masses of the Arctic basins in general seems to be lacking. One other potentially fundamental process that needs to be addressed is new ice formation in leads and polynyas (Morales Maqueda 2004). Such openings in the Arctic sea ice have heat fluxes two orders of magnitude above the the heat flux through the ice, and how fast these openings refreeze determine the overall heat loss from the ocean to the atmosphere during winter. Detailed numerical modelling of polynyas, including grease/frazil ice (the surface slurry of ice) indicate that they typically freeze over during 1-2 days (Smedsrud 2003). Recent field studies during winter in fjords on Svalbard indicate that the grease ice may be thicker than earlier anticipated (Smedsrud and Skogseth 2005), and such processes are yet to be included in sea ice models .

SCIENTIFIC RATIONALE

As emphasised above, simulations of natural variability and future climate change in the Arctic is dependent on correctly accounting for the local arctic processes related to the formation and melting of the ice. State of the art dynamical climate change scenarios for the arctic is at present done by global coupled ocean-atmosphere-ice models which are computational expensive to run, and the possibility of performing sensitivity experiments are few. The continued development and refinement of computational models that can simulate the past and future conditions of the Earth system is crucial for developing capabilities to provide more accurate understanding of the climate system and projections of future change. However, the high computational cost of running 3-D atmosphere-ice-ocean models makes them not very suitable tools to investigate the sensitivity of the results to details of the arctic atmospheric, oceanic or ice parameterisations. In addition to the difficulties of doing extensive sensitivity testing with 3-D models, the global models have relative simple parameterisations of the physical processes in both the atmosphere, ocean and sea ice, which might influence the result. By using 1-D and 2-D models, which has an added complexity in both the formulation of the ocean mixed layer physics and the physics and thermodynamics of the ice cover, there are possibilities to investigate how the simplifications within the 3-D model system are affecting the results.

Thus, we propose to conduct 1-D and 2-D simulations to assess the sensitivity of the Arctic sea ice changes to changes in the local Arctic heat budget and poleward energy and moisture budget. This work will build upon the work of Björk and co-workers by coupling their 1-D arctic ocean-ice model to a 1-D version of the Bergen Climate Model (BCM; Furevik et al., 2004) atmospheric component. The coupling will provide the possibility of conducting a wide range of sensitivity studies to assess the importance of different physical processes related to the interaction between moisture/clouds and changes in the Arctic sea ice that is not possible with the simplified treatment of the arctic atmosphere in the current version of the 1-D ice model. In addition, it will provide a test-bed for new physical parameterisations of processes both in the Arctic atmosphere, ocean and sea ice providing a useful link between climate modellers and researcher working with smaller scale Arctic processes.

Simplifying to the extreme one could state that the future global changes is likely to have to main effects; a mean warming, and possibly a more dynamic state of the atmosphere (Johannessen et al. 2004). For the Arctic ice cover these effects will partly be contradictory. The ice will melt more efficient, or grow less efficient, but it will also be ridged more violently, and we may expect a thicker multiyear ice cover due to thicker pressure ridges. To understand the sensitivities of such processes a sea ice model with an advanced rheology will be needed, and this is the main reason to include the 2-D model as well (Tremblay et al. 1997). This model was successful in reproducing sea ice anomaly exports out of the Fram strait in the 1958-1998 period, and related the export anomalies to changes in circulation patterns within the Arctic Ocean (Arfeuille et al. 2000). This model will be forced with idealized fields that are investigated in the 1-D model, and we will thus be able to validate the integration done within the 1-D model in an efficient way, and study some of the ridging and ice class parameterizations applied. The 2-D model is much more efficient to apply than normal the sea ice models coupled to a 3-D

ocean, and is an ideal bridge between the 1-D simplified approach and the coupled global coarse resolution model.

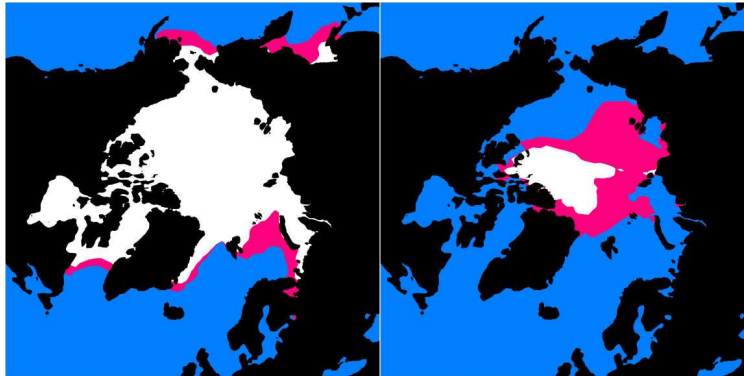


Figure: September (left) and March (right) sea ice extent during present day (purple) and doubling of CO₂ (white) from the global coupled Bergen Climate Model (BCM).

OBJECTIVES

The over-all objectives of the project are to:

Validation of state of the art coupled climate models ability to simulate the Arctic climate and its variability

Understand and quantify the sensitivity of Arctic sea ice to changes in the different parts of the Arctic heat budget and in the poleward meridional heat and moisture transport.

Investigate the sensitivity of future Arctic climate change scenarios to details in the parameterisation of sea ice processes and atmosphere-ice interactions.

WORKPLAN

The over-all goals will be implemented by dividing the objectives into different tasks. Each task constitutes an entity of work that aims to increase the level of understanding of the present day and future variability in the Arctic sea ice and the sensitivity of sea ice to changes in the heat budget and physical parameterizations. We envisaged that each task will merit at least one written publication. The publications will be a technical report in the case of a technical task or a manuscript for submission to a peer-reviewed scientific journal for more scientific tasks. There will also be room for production of popular articles in some of the tasks.

Task 1: Validation of state-of the art coupled climate models

We will utilise a set of new simulations of present and future climate that has been performed for the next Intergovernmental Panel of Climate Change (IPCC) Assessment

Report (AR4). The work will expand on the study of Sorteberg et al. (2005b) of the surface heat budget. Special emphasis will be placed on the validation of the poleward heat and moisture transport. Results of the Bergen Climate Model (BCM), which is one of the coupled global climate model participating in the IPCC effort will be given special attention. BCM has been developed over the last 7 years within the Bjerknes Collaboration and later the Bjerknes Centre for Climate Research (BCCR). The model consist of the joint ECMWF-METEO France climate model (ARPEGE-IFS, Deque et al.,1994) including the soil and snow model ISBA (Noilhan and Mahfouf 1996), a modified version of the Miami Isopycnal Coordinate Ocean Model (MICOM, Bleck et al.(1992)) and the Nansen Center for Environmental and Remote Sensing (NERSC) sea ice model (Harder, 1996; Drange and Simonsen, 1996). The models are coupled using the OASIS coupler (Terry and Thual, 1995). A detailed description and evaluation of the model is given in Furevik et al. (2004).

Task 2: Coupling and testing of the Arctic 1-D atmosphere-ice-ocean model

The main goal is to implement a specific model test-bed for Arctic processes. This will be an ocean-ice-atmosphere column model based on a coupled ocean-ice model (Björk and Söderkvist, 2002; Söderkvist and Björk, 2004) and a 1-D version of the BCM atmospheric component. The ice-ocean part includes much more detailed descriptions of the mixed layer physics and ice cover than possible in the global model. The ice cover is described in terms of a thickness distribution where each ice category evolves independently according to the thermodynamic forcing. The coupling to the BCM atmospheric component to the 1-D ice-ocean model will provide added possibilities to include the effects of changes and feedbacks related to clouds, moisture and precipitation. The column model will be forced by moisture and heat fluxes at the boundary that can be either from reanalyse data (gives real time forcing) or from the BCM. The column model will be evaluated against available observations of surface radiation, surface temperature, cloudiness and ice thickness distribution, as well as against Arctic Ocean CTD data and small scale field based estimates of turbulent mixing (Fer, et al. 2004) and polynya processes (Smetsrud and Skogseth 2005). Different parameter values and types of parameterizations (e.g. surface albedo, cloud formation, and grease ice properties) will be tested in order to find a best case. This will also provide a possibility to investigate the sensitivity of different parameterizations.

Task 3: Explore the linkages and sensitivity of the the poleward meridional heat and moisture transport, Arctic cloud formation and changes in sea ice

The coupling gives the possibility to extend the work by Björk and co-workers to include the effect of changes of energy and moisture transport on Arctic clouds and thereby including cloud-heat/moisture transport feedbacks that has not been taken into account in previous studies. Thus the main aim of this task is to investigate the sensitivity of the simulated Arctic climate change to changes in the poleward heat and moisture transport linkages to cloud formation and the sea ice changes. By imposing the changes in heat and moisture transport from the 3-D climate change simulation, the influences of

and sensitivity to details in the treatment of local Arctic cloud formation and the parameterization of sea ice processes may be studied. This may reveal to what extent the climate change simulation is robust to details in the physical parameterisations and indicate main areas which need improvement in 3-D model climate models.

Task 4: Understand the sensitivity of Arctic sea ice changes to parametrisation of small-scale ice processes in different regions.

The experiences from task 2 and 3 will be applied in the 2-D granular sea ice model to estimate the different contribution of the processes on a regional basis. A process that is important on the Siberian shelves might not be important in the middle of the Beaufort Gyre. We thus propose to use the 2-D approach both to validate the horizontal integration of the 1-D model, and quantify the different processes in the different regions. In addition we will be able to run sensitivity studies towards increased atmospheric and oceanic heat fluxes, as well as stronger and weaker wind forcing on regional basis, and compare with the integrated estimates.

Task 5: Explore the Arctic sea ice thinning during the 1990's and related observations, and validate our range of models on this decadal event.

The thinning of the 1990's could in many ways be tracked back to an increase in the westerly wind field, or the NAO/AO/NAM index. These increased winds probably transported more heat into the Arctic through the Fram Strait and Barents Sea, and the number of cyclones in the Barents Sea sector increased as well. The disappearing of the cold halocline is also mostly thought to be caused by a shift in the wind field guiding the river outflow in the Siberian Arctic along the coast to a larger degree. Thus if global anthropogenic warming leads to a higher NAO/AO/NAM index it is likely that the thinning of the 1990's is a good example of the future state of the Arctic Ocean as well. By applying the range in sea ice models (1-D, 2-D, 3-D) we will be able to quantify the observed changes in the 1990's and thus be able to address the skill of the present global climate models in predicting the future state of the Arctic sea ice.

LINKS TO OTHER NATIONAL PROJECTS

The project is directly linked to the continued development of the Norwegian coupled climate model initiative at the Bjerknes Centre for Climate Research (BCCR). The project will constitute an important link between the climate modeling group of the BCCR and more process oriented groups by providing a test-bed for testing the importance of different physical processes and the sensitivity of the Arctic climate to the representation of this smaller scale processes.

More specific, the project will provide opportunities to test the new developments within several ongoing Norwegian Research Council (NFR) projects:

- The parameterisations of the Arctic stable boundary layer within the *Marine Climate and Ecosystems in the Seasonal Ice (MACEIZE)* project (WP3: Numerical model improvement).

- ❑ *Improved Parameterisation of Microphysical and Optical Properties of Clouds in Global Climate Model* which aims to improve the parameterizations of microphysical processes in mixed-phase clouds.
- ❑ *Parameterization of snow and ice albedo in the ECHAM5 General Circulation Model* which will provide new information on parameterization of snow and ice albedo.
- ❑ *Polar Climate Research Programme 2003-2006 (PROCLIM) Studies brine ejection, deep convection, slope currents, and circulation on the Svalbard shelves and in the Greenland Sea.*

RELATION TO INTERNATIONAL PROJECTS

We propose the work to be a national component of the International Study of Environmental Arctic Change (SEARCH) programme.

(<http://psc.apl.washington.edu/search/>)The project addresses two of the SEARCH activity: *Detecting and Quantifying Unaami* (Inuit word for change) and close cooperation with other International SEARCH initiatives will be provided.

The Arctic Ocean Model Intercomparison Project (AOMIP) is an international effort to identify systematic errors in Arctic Ocean models under realistic forcing (http://fish.cims.nyu.edu/project_aomip/overview.html). The main goals of the research are to examine the ability of Arctic Ocean models to simulate variability on seasonal to interannual scales, and to qualitatively and quantitatively understand the behaviour of different Arctic Ocean models. As we will not run a 3-D regional ocean model we will not participate in AOMIP, but our simplified approaches (1-D and 2-D) should be able to reproduce the main features of the AOMIP models, and BCM results will be compared to the AOMIP results as well. We will also attend the AOMIP meetings to exchange results and ideas.

INTERNATIONAL COLLABORATION

There will be a tight cooperation with Prof. Göran Björk at the Earth Sciences Centre, Göteborg University and Dr. Bruno Tremblay at the Lamont-Doherty Earth Observatory. Through the AOMIP community we will also keep in touch with the leading Arctic Ocean modellers from the US, Canada, Russia, Belgium and Germany (http://fish.cims.nyu.edu/project_aomip/participants.html) .

PUBLICATIONS AND PUBLIC OUTREACH

The results of the project will be published in international peer reviewed journals (1 publication for each scientific task) and produce technical reports for more technical tasks. We will attend relevant international meetings and workshops (including AOMIP meetings). The key findings will also be as published in national popular and semi-popular journals such as *CICERONE*.

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