Early Student Support to Investigate the Role of Sea Ice-Albedo Feedback in Sea Ice Predictions

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LONG-TERM GOALS

The overarching goals of this project are to understand the role of sea ice-albedo feedback on sea ice predictability, to improve how sea-ice albedo is modeled and how sea ice predictions are initialized, and then to evaluate how these improvements influence inherent sea ice predictability.

OBJECTIVES

The sources of errors in a model forecast are from initial conditions and the model itself. Both can be evaluated with observations and potentially improved. We will use observations and field studies to improve how sea-ice albedo is modeled. We will use methods to quantify feedback in models, and thereby directly relate feedback to predictability.

We will use initial conditions from the model itself in idealized, perfect model studies, and from other models with data assimilation. Soon the modeling system we use will have its own sea ice data assimilation scheme (it has data assimilation in the atmosphere and ocean already) and we can investigate how model improvements influence the initialization procedure as well.

APPROACH

This project supports Brandon Ray, who is at the end of his first-year of graduate studies and served in the Navy for the past seven years. Cecilia Bitz, the PI, manages the project and supervises the graduate student. Brandon took a full load of classes during the first year of the grant. Whenever possible, he read papers about this project and he taught himself about scientific computing. He spent the summer focused entirely on research, and will have considerably more time in the upcoming year for research.

An important paper published this year by Schröder et al. (2014) showed the importance of melt ponds as a predictor of pan-Arctic sea ice extent (SIE). The area of melt pond in the Arctic in early summer was found to be an even better predictor of pan-Arctic SIE than the thickness. This exciting result is consistent with our project hypothesis of the important role of ice albedo feedback in sea ice prediction. The Schröder et al. work leaves many questions unanswered, among them is why is their method so successful and yet a nonlocal relationship exists between sea ice meltponds and the location of sea ice loss? Further, will simulations with more comprehensive melt pond lead to improved local-scale forecasts? We also want to understand why the particular melt pond scheme used by Schröder et al. was so beneficial, and why the scheme used in our previous work with the Community Earth System Model Version 1 (CESM1) gave lower predictability. The work of Schröder et al. used an ice-ocean only model with atmospheric reanalysis specified at the surface. They only simulated the system through spring, and then built a regression model from the melt-pond depth in spring in their model and the observed September sea ice extent. We hypothesize that if melt ponds are indeed such a good predictor, they should also be benefit in a fully-coupled model run in forecast mode, like CESM1.

For our project, we are using CESM1, which can be run in various configurations – fully coupled and ice-ocean only. We are investigating predictability in the most advanced version of the model, known as CESM1-CAM5 because it uses the Community Atmosphere Model Version 5 (CAM5). However, at this time we are focused on testing the model so we can use it with the newer version of the Los Alamos sea ice model, known as CICE5, which has the new melt pond scheme used in Schröder et al. All previous integrations with CESM1-CAM5 were done with CICE4, which has a simpler melt-pond scheme. The new CICE5 model also has more sophisticated sea ice thermodynamics, which treats the sea ice as a mushy-layer.

CESM1 in all its versions employs the Los Alamos National Laboratory (LANL) sea ice model, known as CICE. The sea ice in CESM1 has been documented in a series of papers (e.g., Jahn et al, 2012; Kay et al, 2012; Holland et al, 2011). We shall work closely with our collaborator Dr. Elizabeth Hunke from LANL, who is the chief developer of CICE. Dr. Hunke is a partner with the sea ice prediction network and has a postdoc working with her to improve CICE specifically for the purpose of sea ice prediction. We propose to also work closely with colleagues at NCAR to evaluate model developments in other components and identify aspects of the model that need improvement for sea ice prediction.

We anticipate that stakeholders will value sea ice predictions of the summer season most, especially if they are skillful for lead times at least a season in advance (i.e., a forecast initialized in spring or earlier). This means models must be initialized prior to the melt season and must forecast through the time of strongest ice-albedo feedback, when sea ice anomalies grow most rapidly. Therefore, we propose to scrutinize the model behavior precisely at this time by examining the model physics and parameters that control the sea-ice albedo.

The melt-pond parameterization in the present CICE4 was quite simplistic. It keeps an account of all the snow meltwater starting each spring and assumes some fraction is captured at the surface. A fixed volume to depth ratio is assumed based on SHEBA data. Upon freeze-up, the meltwater account is depleted with an assumed decay rate. This parameterization has also been replaced by a detailed physics scheme described in Hunke et al. (2013) that is in CICE5 and is now coupled to CESM1.3. The new scheme has ponds develop on level-sea ice. Ponds drain through permeable ice or through cracks and leads, and refreezing eliminates ponds.

The sea ice-albedo scheme in CICE in CESM1 is part of a sophisticated, multi-scattering radiative transfer treatment that uses a Delta-Eddington approach (Briegleb and Light, 2007; Holland et al, 2012). The scheme considers inherent optical properties of the sea ice. While this scheme is very flexible, it is also complicated to tune, which is necessary in any model to make up for unavoidable small biases in clouds. The snow albedo in CESM1 was tuned to be too high, which caused the snow melt to be delayed or nonexistent in spring. This caused the snow on sea ice to be too deep in CESM1 (Hezel et al, 2012; Blazey et al 2012). We believe this made the sea ice albedo feedback too small, so the sea ice retreats more slowly than in the model's predecessor, CCSM3. We shall retune this scheme with the goal of achieving a better snow-melt onset date based on satellite observations and field data. We will consult our colleagues in the sea ice prediction network to identify the best observations for this purpose.

We are testing the influence of these new schemes for melt-ponds and retuned radiative transfer with regard to sea ice prediction. We will begin by first evaluating the influence of these schemes on sea ice-albedo feedback strength. We will compute shortwave radiative feedback and climate response in two ways: (1) from the kernel feedback method (e.g., Soden et al, 2008; Shell et al, 2008; Bitz et al, 2012) and (2) from the top of atmosphere absorbed shortwave radiation sensitivity to a climate forcing (e.g., Kay et al, 2012). In both cases, the quantification will be accomplished by abruptly doubling carbon dioxide in the CESM1 and integrating the model for 30 yrs. We shall quantify the feedback strength for the baseline CESM1-CAM5 model and then with the new melt-pond, snow, and retuned radiative-transfer schemes implemented sequentially.

Once we have quantified the feedback strength, we shall first run a perfect-model ensemble study to identify how predictability depends on feedback strength in an idealized experimental framework. A perfect-model method is used first because it requires a more limited number of integrations compared to a hindcast, which is otherwise needed to test predictability. We can use the perfect-model technique to test a range of sea ice model formulations and link feedback to predictability. Our past experience indicates that a perfect-model ensemble requires about 40 members of a few years length each. We anticipate running six ensembles, for a total of 240 runs. This is computationally feasible but will require us to automate using workflow scripts. We have written such scripts in the past and will refine them to streamline the large number of integrations needed for this study.

Eventually we will make a forecast for the Sea Ice Outlook, using our best model formulation possible, identified from our earlier work. This is only an exercise to build experience because the forecast would not include an estimate of uncertainty yet. The initial conditions would also need to be taken from another model with sea ice data assimilation.

WORK COMPLETED

Brandon completed an academic year of intensive coursework in atmospheric sciences and oceanography. He also took an optional Arctic policy class titled "Re-Imagining Area/International Studies in the 21st Century: The Arctic as an Emerging Global Region", in his winter term. In spring, he took an independent study with the policy course organizers that culminated in a paper submitted to a peer reviewed journal (Sojka et al, see publications list). Brandon also wrote an extensive literature survey about his predictability research project for a term paper in another class.

Brandon downloaded the latest version of the Los Alamos Sea Ice model, known as CICE5. He learned how to compile and run it on our department cluster. He also learned how to run CESM1.3 in ice-ocean only mode using CORE forcing. His plan was to run the ice-ocean CESM1.3 model with the most up to date physics and then revert the model to older, more well-tested, schemes for the melt ponds and thermodynamics. While he was becoming familiar with the code, the developers discovered some bugs that prevented us from making further progress. The bugs were fixed and our colleagues at NCAR, NPS, and LANL all agree that the model is ready for further testing.

While waiting for the bug fixes, Brandon explored empirical relationships between the North Atlantic Oscillation and sea ice extent by basin in the Arctic. He investigated relationships on daily, monthly, and seasonal timescales. He pesented an oral summary of his first-year of research to his class and the faculty in Sep 2014.

RESULTS

Brandon found the strongest relationship between NAO and sea ice extent in certain Arctic basins occur on daily timescales, with the NAO leading by a few days. The relationship is significant but modest for winter month and winter means. These monthly and seasonal relationships are nonetheless important to establish so we can subsequently make the first winter sea ice predictions in regions such as the Barents Sea and Baffin Bay, which has high winter sea ice variability and high sensitivity to the NAO. The opportunity has just arisen because forecasts of the winter NAO have been found to have usable skill with lead times of 1 to 3 months in recent studies by Scaife et al. (2014) and Riddle et al. (2013).

IMPACT/APPLICATIONS

Loss of sea ice in recent decades has opened the Arctic Ocean to increasing access of wide-ranging vessels and activities. The Navy is concerned about the potential for conflict and need for search and rescue on the Arctic Ocean. Each year the sea ice cover is different owing to natural variability and forced change. Forecasts of Arctic sea ice and atmospheric conditions have high societal value if they predict when ship transit lanes will be open and where low ice cover might lead to dangerous coastal erosion or ice shelf break-up. Sea ice forecasts have scientific value as they could inform scientists of locations that should be instrumented to monitor large anomalies. This project aims to improve Arctic sea ice prediction of the natural variability and forced change, which is a benefit to society, scientists, and Naval operations. We also seek to improve the simulation of sea ice-albedo feedback in models in general.

RELATED PROJECTS

ONR Project N00014-13-1-0793 An Innovative Network to Improve Sea Ice Prediction in a Changing Arctic is also about investigating sea ice predictability. The project website http://www.arcus.org/sipn

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HONORS/AWARDS/PRIZES

Cecilia Bitz of University of Washington was a Fulbright Fellow at University of Otago, New Zealand from Nov. 2014-Feb. 2015.

Cecilia Bitz of University of Washington was the Sears lecturer of the 2014 Geophysical Fluid Dynamics Summer School at the Woods Hole Institute.

Cecilia Bitz of University of Washington in 2014 was elected a fellow of the American Meteorological Society.