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 as much as possible. 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 will be undertaken by Brandon Ray, a first-year graduate student who served in the Navy for the past seven years. Cecilia Bitz, the PI, will manage the project and supervise the graduate student. We will use the Community Earth System Model Version 1 (CESM1), which is managed by the National Center for Atmospheric Research (NCAR). This model can be run in various configurations. We intend to investigate predictability in the most advanced version of the model, known as CESM1-CAM5 because it uses the Community Atmosphere Model Version 5 (CAM5). Our University of Washington group has substantial experience developing and running simulations in CESM1-CAM4 (e.g., Blanchard-Wrigglesworth et al, 2011a,b). However, the CAM5 version has been shown to have a superior simulation in the Arctic over previous versions (Kay et al, 2012).

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 sea ice model has an ice-thickness distribution (ITD) with a heritage stemming from work by Thorndike et al (1975), Bitz et al (2001), and Lipscomb (2001). The sea ice thermodynamics is from Bitz and Lipscomb (1999), which is a modified version of the Maykut and Untersteiner (1971) model that takes into account internal, brine-pocket melt in the mass balance. The ITD and thermodynamics are the best-known methods for treating thin sea ice physics, but with three significant wildcards in the sea ice-albedo scheme, melt-pond parameterization, and treatment of snow for a given sea ice thickness category.

Presently the snow is treated thermodynamically as a uniform depth for each sea ice category (thin sea ice categories tend to have smaller snow depth). Snow is not allowed be blown in the wind, it does not compact, and it does not hold liquid water or permit refreezing of snow melt (hence no superimposed ice). Snow loading can depress the snow-ice interface below sea level, permitting a basic estimate of snow-ice conversion. These oversimplifications are being replaced by more sophisticated treatments in a developmental version of CICE (Hunke pers. com.), not yet in CESM1.

The melt-pond parameterization in the present CESM1 is similarly 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 CICE but has not yet migrated to CESM1. 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 propose to test the influence of these new schemes for snow, melt-ponds and retuned radiative transfer with regard to sea ice prediction. We shall begin by first evaluating the influence of these schemes on sea ice-albedo feedback strength. We shall 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

The graduate student began work on this project less than two weeks ago. He has begun reading background materials on this topic beginning with the project proposal, a PhD dissertation (Blanchrard-Wrigglesworth, 2013) and a National Academy of Sciences study report (National Research Council, 2011)

RESULTS

Work on our project began less than two weeks ago. We have no results yet.

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 the University of Washington is the recipient of the Rosenstiel Award in Oceanographic Sciences 2013 from the Rosenstiel School of Marine and Atmospheric Science at the University of Miami.

Cecilia Bitz of the University of Washington was awarded the American Geophysical Union Ascent Award in Atmospheric Science 2013.

Cecilia Bitz of the University of Washington gave the Aggasiz Visiting Lecturer at Harvard University in 2013.