Toward Construction of an Efficient, Lead-Resolving PIPS Model

Jinlun Zhang
Polar Science Center, Applied Physics Laboratory
University of Washington
Seattle, WA 98105-6698
Phone: (206) 543-5569 Fax: (206) 616-3142 email: zhang@apl.washington.edu

Drew Rothrock
Polar Science Center, Applied Physics Laboratory
University of Washington
Seattle, WA 98105-6698
Phone: (206) 685-2262 Fax: (206) 616-3142 email: rothrock@apl.washington.edu

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LONG-TERM GOALS

Our long-term goals are to develop and implement lead-based sea ice rheologies into a high-resolution anisotropic sea ice model that is able to efficiently simulate and predict the initialization and propagation of oriented leads and ridges of sea ice. Our particular interest is to provide such a lead-resolving sea ice model for the Navy's Polar Ice Prediction System (PIPS) for high-resolution, large-scale sea ice forecasting. We are also interested in using the model to understand the dynamic and thermodynamic sea ice processes that trigger leads and ridges to form and propagate in time and space in relation to atmospheric and oceanic forcing, and to study the air-sea exchange through leads in relation to their geometry and thickness.

OBJECTIVES

The Navy's next-generation sea ice model, PIPS 3.0, aims at high-resolution (9-10 km), lead-resolving forecasts of sea ice and ambient noise in most ice-covered regions in the northern hemisphere. To help to meet such a goal, we develop mathematical formulations and numerical schemes for lead-based rheologies that may be introduced in an isotropic sea ice model, rather than an anisotropic model, to efficiently and realistically predict the formation and propagation of oriented leads and ridges of sea ice. We will also incorporate the related rheologies in a high-resolution sea ice model, driven by realistic atmospheric forcing, to examine how they behave in actually simulating and predicting leads and ridges. The modeled leads will be compared with satellite observed leads or cracks.

APPROACH

Sea ice is characterized by oriented leads, cracks, and ridges, which determine the anisotropic properties of sea ice flow. To completely capture the anisotropic properties of sea ice requires a fully anisotropic model with a memory of past oriented leads. This, at present, would be difficult for large-scale sea ice models to accomplish because of the lack of theoretical and numerical readiness. Our approach is based on the work of Hibler and Schulson (1997). They considered sea ice to be a composite system that consists of relatively strong thick ice embedded with weak thin-ice leads. Both

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the thick ice and the thin-ice leads are allowed to follow a viscous plastic ice rheology. Hibler and Schulson were then able to achieve “isotropic realizations” in “dynamically treating” the oriented leads, in which lead or ridge formation could be captured using isotropic but lead-based ice rheologies. They suggested two rheologies, related to two different conditions of anisotropic ice composite, potentially useful in estimating the occurrence and orientation of leads. One that is represented by a teardrop-like plastic yield curve, the other a lens-like plastic yield curve. An important question is: can these lead-based but isotropic viscous plastic rheologies, if implemented in large-scale isotropic sea ice models, capture the anisotropic properties of sea ice. To answer this question, we wish to implement the above-mentioned rheologies, in addition to the widely used elliptical yield curve (Hibler, 1979), in a high-resolution isotropic sea ice model, and to examine the effectiveness of these rheologies in predicting the formation and propagation of leads and ridges under realistic conditions of surface atmospheric forcing. If they are effective, then they can be directly incorporated into PIPS 3.0 for lead-resolving sea ice forecasts.

WORK COMPLETED

We have developed mathematical formulations for the viscous plastic rheologies with teardrop and lens yield curves. These two rheologies have been numerically implemented in a high-resolution (10 km, close to the PIPS 3.0 resolution) 12-category thickness and enthalpy distribution sea ice model (Zhang and Rothrock, 2000) for the Arctic. Two model runs, driven by atmospheric forcing from 1987 to 1999, have been carried out. One uses the elliptical yield curve and the other the teardrop yield curve.

RESULTS

From the two model runs, we have found that, with a horizontal resolution as high as10 km, the sea ice model is still able to obtain an accurate viscous plastic solution for both the elliptical and teardrop plastic yield curves, as shown in Figure 1. The figure also indicates that the teardrop yield curve’s mathematical formulation and numerical implementation are correct. We have also found that the isotropic rheologies implemented in an isotropic sea ice model with a 10-km resolution are able to simulate the initialization and propagation of major leads and ridges, represented by strong, long shear zones, especially those initiated at coastal boundaries, as shown in Figure 2 (also see Overland and Ukita, 2000). This indicates that isotropic viscous plastic rheologies are able to capture the anisotropic properties of sea ice with sufficiently fine model resolution.

IMPACT/APPLICATION

Our model results have shown that using isotropic viscous plastic rheologies in fine-resolution (in the scale of 10 km) sea ice models are able to simulate major oriented leads and ridges in the Arctic. Lead-resolving modeling would improve the calculation of ice dynamics and therefore forecasting of sea ice. Reliable prediction of leads and ridges is also important for the Navy’s operations in the ice-covered oceans. Modeling lead formation and propagation is also useful for understanding the air-sea exchange in the polar regions, which is important for climate studies.

TRANSITIONS

The current PIPS model uses the sea ice dynamics model developed by Dr. Bill Hibler and one of us (Zhang and Hibler, 1997). We have provided the PIPS model development group at the Naval Postgraduate School with a new sea ice model using an alternating direction implicit technique to efficiently solve ice dynamics (Zhang and Rothrock, 2000). We will work with the group to implement the teardrop and lens yield curves in the high-resolution PIPS 3.0 model.

RELATED PROJECTS

Drs. Axel Achweiger and Ruth Preller and one of us (Zhang) are investigating the effects of surface atmospheric forcing on sea ice forecasting. Accurate surface atmospheric forcing is essential to the quality of sea ice forecasting.

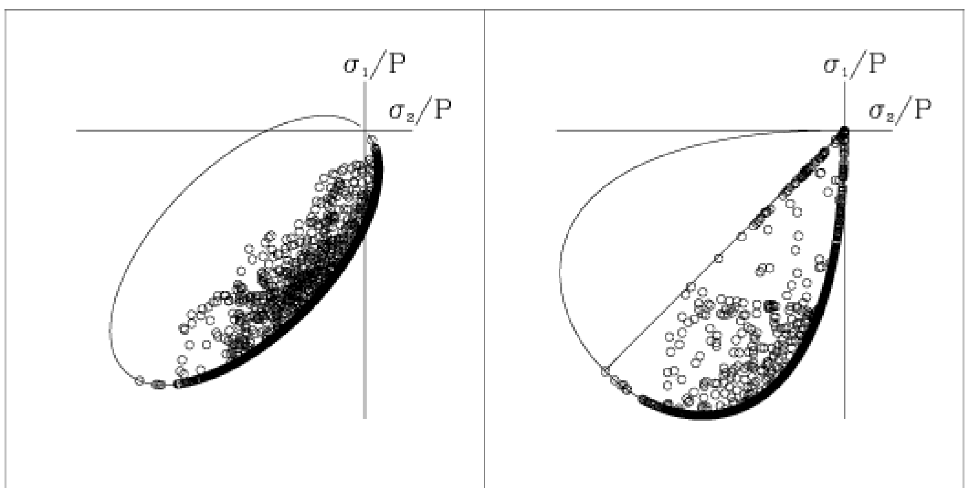

Figure 1. Principal ice internal stress states normalized by ice strength that were predicted using a 10 km-resolution, 12-category thickness and enthalpy distribution sea ice model with either an elliptical plastic yield curve or a teardrop yield curve. This figure shows that the model basically obtains an accurate viscous plastic solution in simulating sea ice of different strengths for both rheologies. Most of the stress states fall on the elliptical or teardrop plastic yield curve, indicating that the ice is in a state of plastic flow. Some of the stress states fall inside the yield curves, indicating that the ice is in a state of viscous flow.

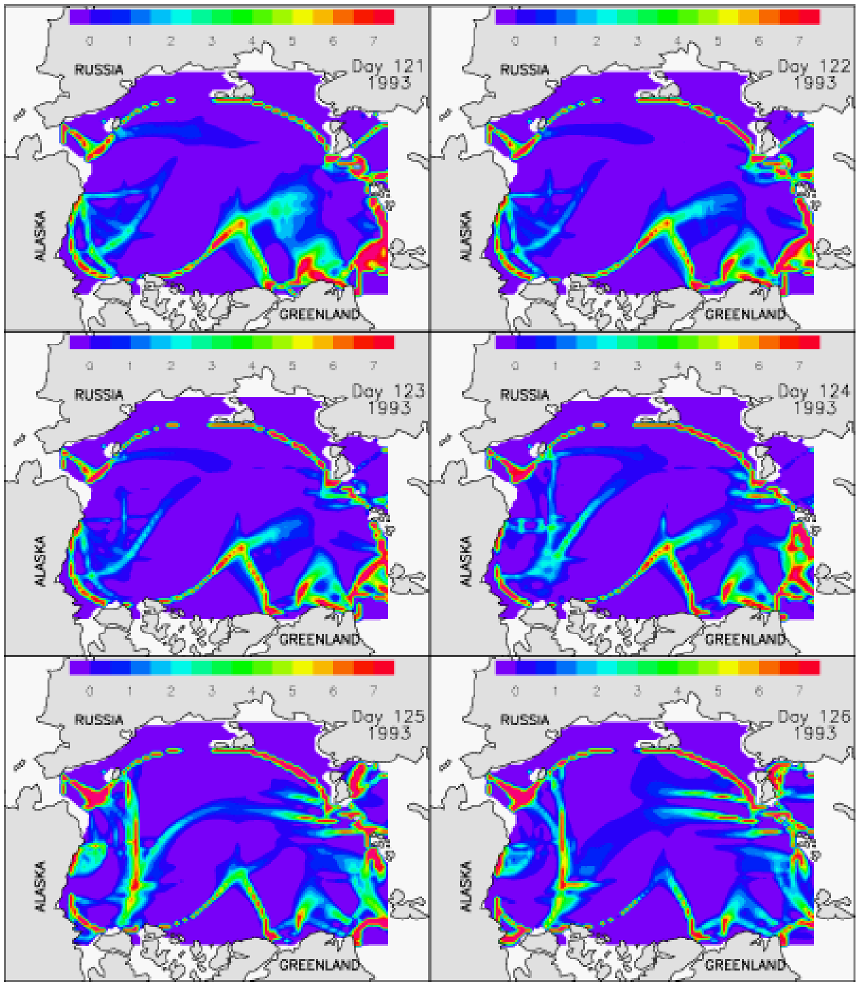

Figure 2. Simulated shear deformation (in units of 0.5%/day) of sea ice in the Arctic for May 1 to May 6, 1993. The figure shows that the high-resolution sea ice model, with a viscous plastic rheology of a elliptical yield curve, creates long shear deformation zones. This indicates that the model is able to simulate major oriented leads, cracks, or ridges. From the figure we can see the formation and propagation of major sea ice flaws.

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Zhang, J., and D.A. Rothrock, 2000: A thickness and enthalpy distribution sea-ice model, submitted to *J. Phys. Oceanogr.*