SENSITIVITY OF ARCTIC SEA ICE THICKNESS DISTRIBUTION TO SEA ICE INTERNAL DYNAMICS IN A CHANGING CLIMATE

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EXECUTIVE SUMMARY

Changes in sea ice are a critical indicator of the climate system state. However, uncertainties exist in understanding, simulating, and predicting sea ice thickness distributions in the Arctic Ocean. In particular, the drastically thinned sea ice and more frequently occurring intense storms might have dramatically changed sea ice dynamic properties and air–ice momentum flux, raising further challenges to reducing the uncertainties. By conducting sensitivity experiments using the coupled sea ice–ocean component of the Community Earth System Model, the research team examined the interactive process between sea ice internal dynamics and thickness distribution. The results suggest that sea ice thickness distribution is highly sensitive to the treatment of its internal force in collaboration with air–ice momentum flux. A decrease in ice strength causes more energy conversion to potential energy, leading to an increase in the ridging process and thickness but a decrease in export via the Fram Strait. A decrease in air–ice momentum flux, however, demonstrates the opposite effect.

RESEARCH CHALLENGE

Arctic sea ice thickness is nonuniformly distributed in space, resulting from the complex interactive processes of dynamic and thermodynamic forcings across atmosphere, sea ice, and ocean interfaces and within sea ice itself. The realistic simulation and understanding of sea ice thickness distribution have been long-standing challenges. Along with amplified warming in the Arctic Ocean, dynamic and thermodynamic forcings across the atmosphere and sea ice interfaces have experienced pronounced changes. In particular, intense storms have more frequently occurred in the Arctic Ocean [3], causing even larger fluctuations or changes of atmospheric forcings on underlying sea ice. All of these further complicate the problem of how sea ice internal dynamics influence sea ice thickness distribution in the context of a changing climate and, in turn, contribute to the large-scale Arctic sea ice and climate system changes.

METHODS & CODES

The coupled sea ice–ocean component model of the National Center for Atmospheric Research's Community Earth System Model was employed to conduct 25 sensitivity experiments with prescribed different sea ice strengths. The model experiments were initialized using the Polar Science Center hydrographic climatology data [2] and forced by the monthly mean climatological forcing data constructed from the ERA-Interim reanalysis data set [1]. Each experiment covered a period of 100 years, allowing the sea ice and upper ocean to reach a quasi-equilibrium state.

RESULTS & IMPACT

Through examination and comparison of the results from the sensitivity experiments, the PI found that sea ice thickness distribution and sea ice motion are highly sensitive to perturbed sea ice strength prescribed in the model in collaboration with different air–ice momentum fluxes. Using a default sea ice strength defined as the ratio between total sea ice energy loss and potential energy changes, thick sea ice occurs along the Canadian Archipelago and greatly decreases toward the central Arctic Ocean and Eurasian Arctic shelf seas (Fig. 1). This pattern is similar to the observed sea ice thickness distribution, although the simulated sea ice is too thin in the central Arctic Ocean. At the same time, a basinwide, clockwise sea ice motion pattern appears with obviously large sea ice export via the Fram Strait. When sea ice strength decreases, sea ice thickness largely increases from the Canadian Archipelago to the Eurasian Arctic shelf seas. As a result, there is an increase in total sea ice volume for the entire Arctic Ocean throughout the year. All of these changes can be attributed to an enhanced conversion of kinetic energy to potential energy to build up sea ice ridges instead of frictional loss and a decreased sea ice export via the Fram Strait. A close examination also suggests that decreased sea ice strength causes a larger sea ice velocity.

To further investigate the upscaling impacts of the small-scale sea ice internal dynamics on shaping basinwide sea ice thickness distribution, the PI implemented tracers at the beginning of the modeling experiments with two of them in the Beaufort Sea: one in the East Siberian Sea and the other in the Laptev Sea. The PI then identified the pathways of the tracers, showing the origins of the tracked sea ice and its variation along the paths. The results indicate that decreased sea ice strength or increased air–ice momentum flux cause a clockwise rotation of the ice transpolar drift, resulting in a decrease in sea ice export via the Fram Strait and, therefore, an increase in the basinwide sea ice thickness. In contrast, counterclockwise rotation of the sea ice transpolar drift leads to less sea ice circulation and accumulation in the central/western Arctic, increasing sea ice export via the Fram Strait.

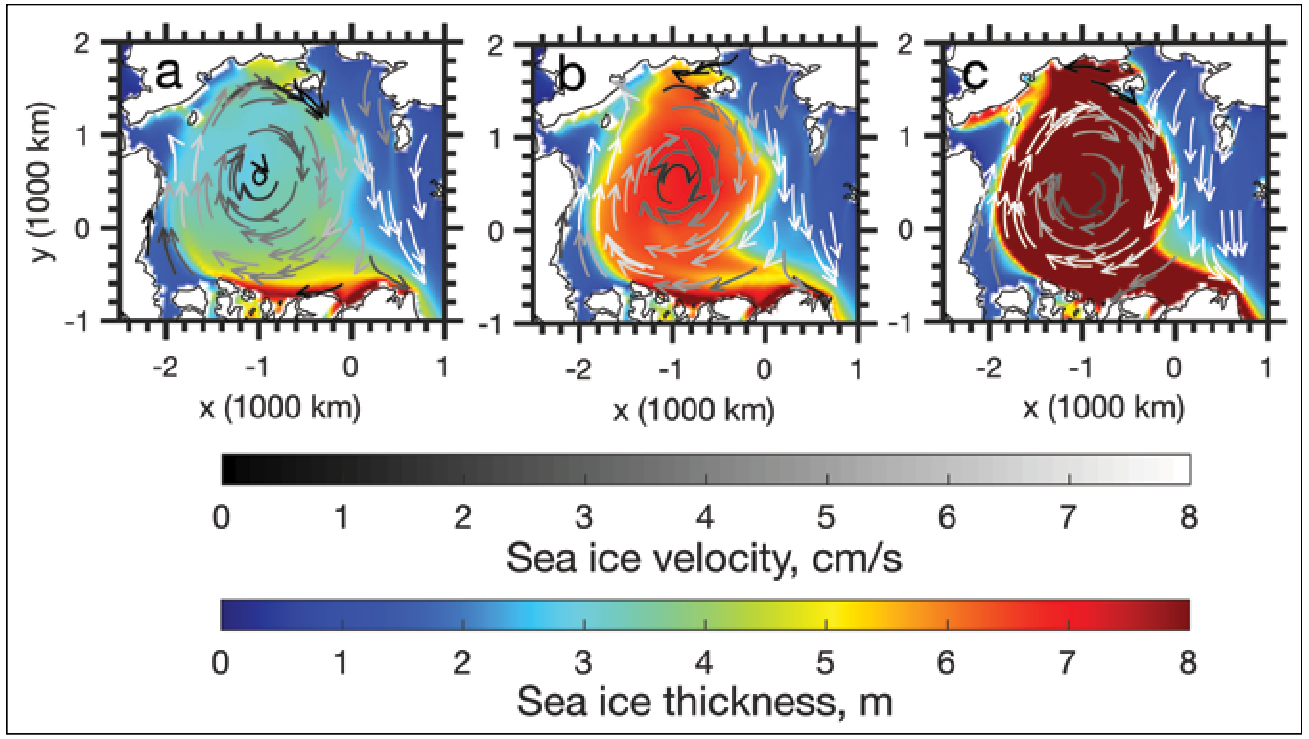

Figure 1: (a) Arctic sea ice thickness distribution and sea ice motion when the ratio between loss of total sea ice energy and change in sea ice potential energy (a nondimensional parameter) is defined as 17, which is a default value commonly used in ocean–sea ice climate modeling studies. (b) and (c) are the same as (a), but the sea ice strength is reduced to 60% and 20% of its default value, respectively. The sea ice strength represents the conversion ratio between kinetic energy and potential energy of sea ice due to its dynamic deformation, which is a measure of sea ice internal force (Peng and Zhang, 2019).

WHY BLUE WATERS

Blue Waters provided a unique opportunity to conduct modeling experiments at an ultrahigh resolution. Dynamic processes associated with sea ice thickness occur at small spatial and temporal scales. The only way to solve these problems with higher accuracy is through model simulation at superhigh resolutions. Furthermore, high resolution simulations also improve the understanding of upscaling impacts on basin scale sea ice thickness distribution. In addition, synoptic-scale intense storms and the resulting large fluctuation of forcings occur at small spatial and temporal scales. The state-of-the-art climate modeling studies generally do not take this into account. The Blue Waters system and staff paved the way for successful implementation of these model experiments.

PUBLICATIONS & DATA SETS

L. Peng *et al.*, "Impacts of intense Arctic storms on the melting process of sea ice in summer 2016," to be submitted, 2019.

L. Peng and X. Zhang, "Modeling study on sensitivities of Arctic sea ice thickness distribution to momentum flux and ice strength," to be submitted, 2019.