粒子追跡法によるフラジルアイスの数値モデリング

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Lagrangian Modeling of Frazil ice

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Sea ice cover controls the atmosphere-ocean heat exchange in the polar regions and hence plays very important role in the Earth's climate system. However, the mechanism of new ice formation is not yet sufficiently understood. In the case of a calm ocean surface, cooling by cold air leads to formation of a solid ice cover. By contrast, if the ocean surface is under turbulent conditions due to strong wind forcing, a large number of fine crystals called frazil are formed in supercooled seawater at first, then they gradually concentrate near the surface and constitute grease ice, a mixture of solid ice crystals and seawater. Such difference of the state of newly formed sea ice has a great impact on the heat budget between the atmosphere and the ocean, since a solid ice cover effectively insulates the atmosphere-ocean heat exchange due to its low thermal conductivity but grease ice keeps relatively greater surface heat loss.

To simulate such small scale processes of sea ice formation, a new framework for modeling of dynamic and thermodynamic effects of underwater frazil ice using a Lagrangian particle tracking method is developed. In the present study, we developed a numerically efficient and fully parallelized on-line Lagrangian particle tracking system based on a linked-list data structure, and integrated it into a nonhydrostatic ocean model. The newly developed frazil ice model treats a Lagrangian particle as a bulk cluster of many frazil crystals, and calculates thermodynamic growth of each particle and corresponding budget of latent heat and fresh water. An on-line Lagrangian particle tracking system has several significant advantages compared with a traditional Eulerian approach that deals with cell-averaged concentration, for example, it can deal with the non-uniform buoyant rise velocity and the rate of thermodynamical growth of frazil particles depending on its size. The mass fraction of underwater frazil ice also changes the effective density and viscosity of seawater, thereby it affects the ocean convection.

An idealized experiment using this model successfully reproduces the formation of underwater frazil ice and its transition to grease ice at the surface. Figure 1 shows the distribution of underwater frazil particles in an idealized experiment where the model domain is 64 m × 64 m × 64 m rectangular with horizontally periodic boundaries. Because underwater frazil ice does not reduce the atmosphere-ocean heat exchange, surface heat flux and net sea ice production in the experiment with frazil ice is relatively high compared with the experiment in which surface cooling directly leads to columnar growth of a solid ice cover that effectively insulates the heat flux. An idealized simulation of a coastal polynya successfully reproduces the characteristic streak structures of grease ice (Figure 2.) which is typically found in SAR images.

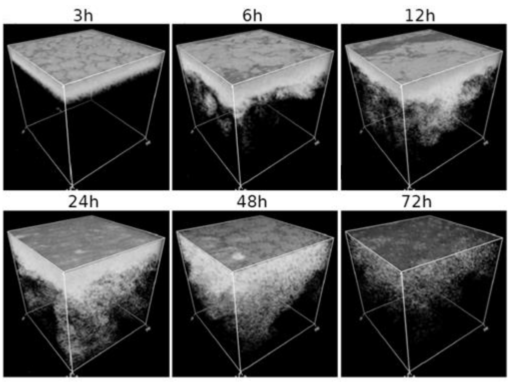

Figure 1. Three dimensional volume rendering images of the concentration of underwater frazil ice in the idealized experiment.

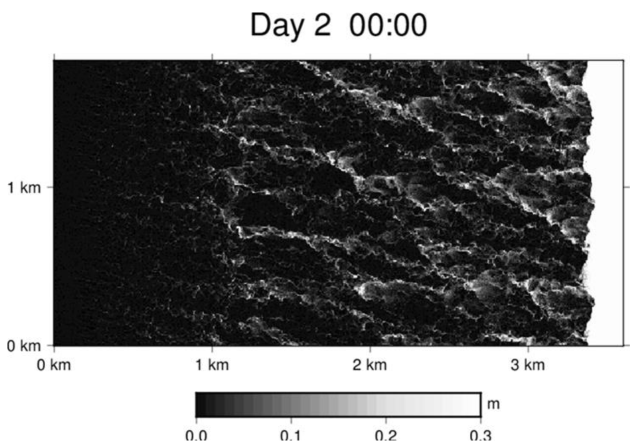

Figure 2. Grease ice streaks reproduced in an idealized coastal polynya simulation