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A Maxwell-elasto-brittle rheology for sea ice modeling

Véronique Dansereau (1), Jérome Weiss (2), and Pierre Saramito (3)

(1) Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France, (2) Institut des Sciences de la Terre, Grenoble, France, (3) Laboratoire Jean Kuntzmann, Grenoble, France

In recent years, statistical analysis of available ice buoy drift and RGPS data have revealed the strong heterogeneity and intermittency of Arctic ice pack deformation and thereby demonstrated that the viscous-plastic (VP) rheology widely used in climate and operational models does not simulate adequately the mechanical behavior of sea ice. A new rheological framework named "elasto-brittle" (EB) has therefore been developed as an alternative to the VP model, which combines the linear elasticity of a continuum solid, a Mohr-Coulomb criterion for brittle failure and a progressive damage mechanism for the elastic modulus that allows for long-range interactions inside the pack. Recent implementation of this rheology into 3-days stand-alone realistic simulations of the Arctic ice pack without advection reproduced the strong localization of damage and agreed well with the deformation fields estimated from RGPS data. In the context of longer-term simulations of ice conditions and coupling to an ocean component, a suitable rheological framework should however distinguish between the permanent and recoverable (elastic) deformations in order to estimate the adequate ice drift velocities from the computed deformations, i.e. allow the passage from small to large deformations.

To achieve this, a viscous relaxation term is added in the elastic constitutive relationship of the EB model together with an "apparent" viscosity that evolves according to the local thickness, concentration and damage of the ice, much like the elastic modulus. The coupling between the level of damaging and both mechanical parameters is such that within an undamaged ice plate the viscosity is infinitely large and deformations are strictly elastic, while along highly damaged zones such as leads the elastic modulus vanishes and most of the constrain is dissipated through permanent deformations. In this augmented EB model the irreversible and recoverable deformations are solved for simultaneously, hence ice drift velocities are defined naturally. This new rheological framework is presented along with numerical experiments over domains with simple and more complex geometries which show the Maxwell-EB model is able to reproduce the anisotropy, heterogeneity and intermittency of sea ice deformation.