A MAXWELL-ELASTO-BRITTLE MODEL FOR THE DRIFT AND DEFORMATION OF SEA ICE

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In recent years, analyses of available ice buoy and satellite data have revealed the strong heterogeneity and intermittency of the deformation of sea ice and have demonstrated that the viscous-plastic rheology widely used in current climate models and operational modelling platforms does not simulate adequately the mechanical behavior of the ice pack [1, 2, 3]. We developped a new mechanical model, named Maxwell-Elasto-Brittle, as an alternative to the standard viscous-plastic rheology in the view of accurately reproducing the drift and deformation of the ice cover in continuum sea ice models, at regional to global scales. The model builds on a damage mechanics framework used for ice and rocks (e.g., [4, 5]). A viscous-like relaxation term is added to the linear-elastic constitutive relationship together with an effective viscosity that evolves with the local level of damage of the material, like its elastic modulus. This framework allows the internal stress to dissipate in large, permanent deformations along the faults (or sea ice "leads") once the material is highly damaged, while reproducing the small deformations associated with the fracturing process and retaining the memory of elastic deformations over relatively low damage areas. A healing mechanism counterbalances the effects of damaging over large time scales. The numerics is based on finite elements and variational methods. The equations of motion are cast in the Eulerian frame and discontinuous Galerkin methods are implemented to handle advective processes.

Idealized simulations with mechanical parameters values consistent with sea ice on geophysical scales demonstrate that the Maxwell-EB rheological framework reproduces the main characteristics of sea ice mechanics: the anisotropy of the deformation, the strain localization and intermittency, as well as the associated scaling laws. Moreover, sensitivity analyses on the one model parameter setting the rate of viscous dissipation of the internal stress as a function of the increasing level of damage within the material show that the model, with few independent variables, can represent a large range of mechanical behaviours, from a regular, predictable stick-slip with a single damaging frequency corresponding to the prescribed rate of healing, to a marginally stable, unpredictable creep-like deformation with temporal correlations in the damaging activity at all time scales below the material's healing time. Over a range of values of this parameter, the model reproduces both the persistence of creeping faults/leads and the activation of new faults/leads with different shapes and orientations.

Idealized as well as realistic Maxwell-EB simulations of the flow of sea ice through a channel will be presented. These will demonstrate that the model reproduces the formation of stable ice bridges as well as the stoppage of the flow within the channel, a phenomenon observed in narrow straits of the Arctic [6] and common in granular materials [7, 8]. In agreement with observations, the propagation of damage along narrow arch-like features, defining ice floes moving like solid bodies, the discontinuities in the velocity field between the floes and the eventual opening of the channel are all represented.

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