Fundamentals in sea ice rheology

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Perennial pack ice was predominant in the Arctic a half century ago, which led to a widely used formulation of the viscous-plastic rheology model with an elliptic yield curve. There has been no major update in the formulation itself except some numerical aspects, i.e. elastic-viscous-plastic formulation. Meanwhile, the sea ice field has undergone significant changes in its extent and thickness. Seasonal evolution of sea ice is quite different from what it was 50 years ago. All this change requires a critical review of the formulation of sea ice rheology.

Does present day sea ice behave as a viscous-plastic flow? More fundamentally, what do we mean by a viscous or plastic flow/regime? Reflecting a myriad of development histories, rheological terminologies are not uniquely defined across different disciplines and applications. In facing drastically changing sea ice conditions, clarification of mathematical and physical foundations of sea ice rheology is urgent.

I will discuss some key concepts such as viscous and plastic flows, viscosities, yield curves, and isotropy. The emphasis is given to duality in stress-strain rate relationships. In solid mechanics strain/strain rate is thought as a function of stress (applied force) whereas in fluid dynamics stress is treated as a function of strain rate (motion). Linear rheology models such as the Newtonian one stress-strain rate relationships are reversible, and thus duality is satisfied. However, this is not the case for sea ice where convergence and shear motion jointly determine both normal and shear stress components. As such extra consideration of duality is required to ensure the well-posedness of the stress-strain rate relationship. In a discussion I will advocate and show the usefulness of the general rheology relationship formulated in globally fixed coordinates, instead of in locally transferrable coordinates implicit in the tensor notation, which would help though not guaranteed to place the duality condition.