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An Energy Dissipative Sea-Ice Dynamics Model for Use in Climate Studies

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An important part of a properly formulated and implemented sea ice dynamics model is the dissipative character of the sea ice rheology: a dissipation that must be present both theoretically in the rheological formulation and in the numerical implementation of this rheology. These issues are particularly pronounced at high spatial and temporal resolution where oriented linear kinematic featues (Hutchings et. al. 2005) and sub-daily variability (Heil and Hibler, 2001) are naturally simulated in properly formulated ice-ocean models.

To investigate these issues two lines of numerical studies have been undertaken with some of the results reported here. In the first we examine two numerical simulations of the Arctic ice cover over the 1979-85 time period; one simulation with an energy dissipative (Ip et. al. 1994) elliptical rheology (ice pressure a function of deformation) and one simulation with a non dissipative rheology (ice pressure a function only of the thickness distribution. Convential quadratic ice drag is used so high frequency variability is damped. The results are compared in detail to available Arctic buoy drift data over this same time period. The numerical formulation is shown to be fully dissipative, reflecting the theoretical rheology provided the simulations are close enough to plastic flow at each time step. The buoy comparison show marked differences between the two simulations, especially in the distribution of buoy drift speeds with the non energy conserving cases showing excessive stoppage compared to observations. An energy conserving rheology, on the other hand demonstrates realistic reduction of speeds in agreement with observations which differ markedly from a distribution wind forcing speeds. Results from periods of low and high compactness ice conditions also agree particularly well with the energy dissipative rheology.

For a second level of investigation we make use of sea ice dynamics model imbedded in the oceanic boundary layer (Heil and Hibler, 2002) so that no artifical dissipation by boundary layer drag is present. In this case it is found that with a fully energy dissipative viscous plastic (Hibler, 1979) rheology hardly any non dissipative energy is present. Moreover the spectral characteristics of the simulated motion is coherent with observed semi-diurnal motion and has very artifial energy present. This is found to be true even for time steps as large as .5 hours with only one implicit solution of the full linearized viscous plastic equations. In contrast if an artifical elastic term is added to the the equations so that explict time stepping procedures are utilized excessive elastic energy is found to substantially distort the spectral characteristics compared to control runs. Similarly if splitting' type implicit solutions are utilized (eq. Zhang and Hibler,) the convergence to plastic flow is found to be two slow and the energy characteristics again result in excessive spurious high frequency power compared to control runs, which results in poor correlations with obseverd ice drift especially at high frequencies.

Finally, an energy dissipative numerical formulation of the full viscous plastic equations including all metric terms in presented for general orthogonal curvilinear co-ordinates. This formulation differs from those in the literature where all metric terms are not included in a flux conservative form. The formulation is shown to be analytically energy dissipative and numerical comparisons to control simulations in rectangular co-ordinates bear out the numerical dissipation and yield excellent agreement with control simulated buoy and observed buoy drift even at high frequencies.