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Energy Dissipation in Viscous-Plastic Sea Ice Models

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In viscous-plastic (VP) sea ice models, small elastic deformations are approximated by viscous deformations, or creeping flow. The resulting numerical treatment is much simpler but, unlike elastic deformations, viscous deformations are irreversible and introduce a non-physical energy dissipation in the models. In fact, the amount of viscous points (and therefore of viscous dissipation) increases with the resolution and the number of outer loops of the numerical solver because the deformation lines are getting better refined. As models are run at increasingly high resolution and are now iterated to full convergence, the validity of the VP approximation is questioned.

To study the characteristics of energy dissipation in sea ice models, we derive an equation for the kinetic energy (KE) balance by coupling the 2D sea ice momentum equation and the continuity equation for sea ice thickness. This method applies to any rheology, but we focus on the classical VP model with special attention to viscous dissipation. Results from a 40km-resolution run show that the main KE balance is between the atmospheric wind input, the oceanic dissipation, and the internal stress term (p_i) . A major part of the energy input by the atmospheric drag is dissipated by the oceanic drag but some energy is redistributed/dissipated in the pack due to ice-ice interactions ($\sim$ 20% of the energy input in average for March). The internal stress term is a first order term in the balance in winter and in regions where interactions are maximal. Seasonal cycle investigation shows that p_i is about five times stronger during winter than summer. It is found that one of the main roles played by the internal stresses is to laterally redistribute the input energy in the pack in regions where deformation lines (or linear kinematic features-LKF's) are active. The energy in those regions is then stored as potential energy in ridges and dissipated by friction in ridging and shearing.

Frictional energy dissipation in the model can be decomposed in plastic and viscous dissipation. The monthly mean viscous dissipation is found to be approximately a thousand times smaller than the monthly mean plastic dissipation in all seasons. This suggests that the VP approximation is valid on a monthly time scale at 40 km resolution. We explain this by the fact that large plastic deformations dissipate much larger amount of energy and occur more frequently in the model than smaller viscous deformations. A good representation of those large-scale LKF'S in sea-ice numerical models is therefore crucial for accurate and realistic sea-ice simulation and energy dissipation. Preliminary results at higher resolution suggest that the previous results also hold for a 10 km resolution version of the sea ice model. Results on the dependence of the energy dissipation on the degree of convergence of the numerical solver will also be presented.