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## Comparison of elastic-viscous-plastic and viscous-plastic dynamics models using a high resolution Arctic sea ice model

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**TITLE: COMPARISON OF ELASTIC-VISCOUS-PLASTIC AND  
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# COMPARISON OF ELASTIC-VISCOUS-PLASTIC AND VISCOUS-PLASTIC DYNAMICS MODELS USING A HIGH RESOLUTION ARCTIC SEA ICE MODEL

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## 1 INTRODUCTION

A nonlinear viscous-plastic (VP) rheology proposed by Hibler (1979) has been demonstrated to be the most suitable of the rheologies commonly used for modeling sea ice dynamics (Kreyscher et al., 1997). However, the presence of a huge range of effective viscosities hinders numerical implementations of this model, particularly on high resolution grids or when the ice model is coupled to an ocean or atmosphere model. Hunke and Dukowicz (1997) have modified the VP model by including elastic waves as a numerical regularization in the case of zero strain rate. This modification (EVP) allows an efficient, fully explicit discretization that adapts well to parallel architectures.

We present a comparison of EVP and VP dynamics model results from two 5-year simulations of Arctic sea ice, obtained with a high resolution sea ice model. The purpose of the comparison is to determine how differently the two dynamics models behave, and to decide whether the elastic-viscous-plastic model is preferable for high resolution climate simulations, considering its high efficiency in parallel computation. Results from the first year of this experiment (1990) are discussed in detail in Hunke and Zhang (1997).

The model equations were solved on a  $300 \times 360$  mesh with a resolution of about 18 km and a 4 hr timestep, and driven by 1990–1994 ECMWF atmospheric data above and 1992 ocean model output

below. The two runs are identical except for the ice rheology; the EVP and VP dynamics models used here are documented in Hunke and Dukowicz (1997) and Zhang et al. (1997), respectively. For further details about the model specifications and experiment design, see Hunke and Zhang (1997).

## 2 RESULTS

The essential difference between the EVP and VP dynamics models is the addition of an elastic contribution to the EVP rates of strain. Hunke and Dukowicz (1997) demonstrate that the resulting elastic waves allow ice motion in the EVP simulations to adjust quickly to changing wind forcing, while not significantly altering the VP solution on longer time scales.

Elastic waves in the EVP model affect the velocity distribution of the ice pack, which in turn affects the ice concentration and thickness distributions. The area-averaged ice velocity differences, shown in Fig. 1, indicate that mean velocities produced by the two models are generally within  $1 \text{ cm s}^{-1}$ , with EVP ice moving slightly faster. Note that the velocity difference between the two models is least in the summer months when ice compactness is low, compared to other times of the year. The summer ice pack is thinner, has less strength, and rheology plays less a role in determining ice motion.

Conversely, the feedback from ice motion to ice distribution is strongest during the summer months. Fig. 2 shows that ice thickness in the two models (dashed) are most similar in the winter months, with the largest differences occurring in summer. EVP

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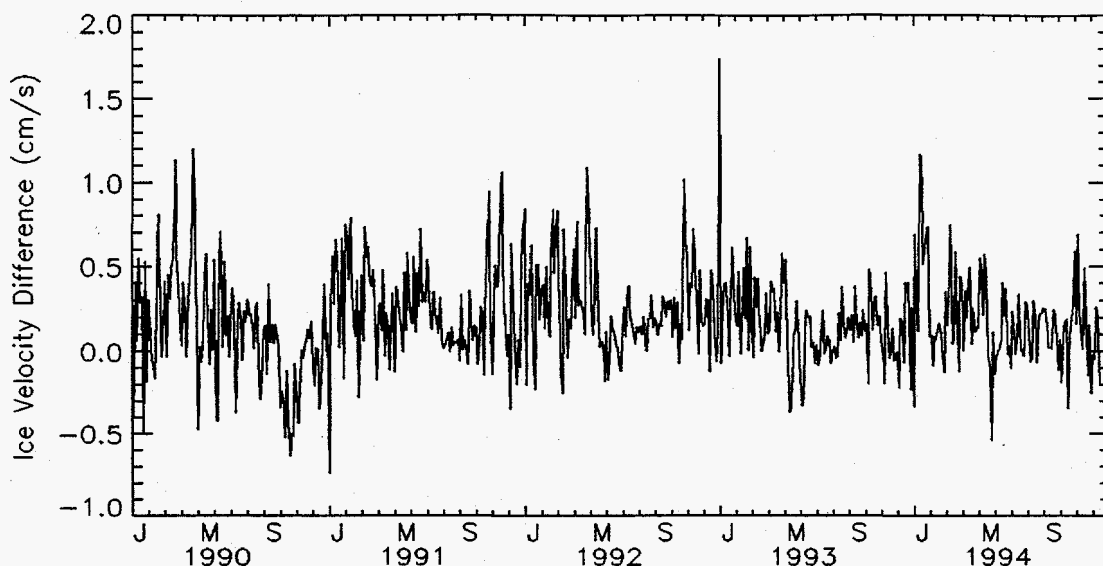


Figure 1: EVP-VP differences of mean ice velocity. Averages were taken over the ice covered area.

Year	Sync. Wind		Lagged Wind	
	EVP	VP	EVP	VP
1990	0.67	0.63	0.16	0.22
1991	0.68	0.64	0.16	0.22
1992	0.68	0.65	0.13	0.19
1993	0.67	0.64	0.18	0.23
1994	0.68	0.63	0.16	0.22

Table 1: Linear correlation coefficients between ice and geostrophic wind speed, averaged over the ice-covered area, for synchronous and 3-day lagged winds.

ice concentration and thickness are both typically slightly less than in the VP model, but concentration differences are only a fraction of a percent and thickness differences are on the order of a few centimeters at most. The model results are much closer to each other than to physical data such as ice concentrations computed from SSM/I brightness temperatures (NSIDC, 1997), as shown in Fig. 3.

During the periods in Fig. 1 when the EVP and VP velocities differ most, evidence suggests that the VP model lags behind the forcing while the EVP model appears to respond quickly. For example, in mid-April 1990 a strong low pressure system passed through the Arctic. The EVP model ice motion quickly develops a cyclonic gyre, but VP ice motion does not respond until several days after the storm passed through (Hunke and Zhang, 1997). Furthermore, correlation coefficients between ice motion and the geostrophic wind (Table 1) indicate that the EVP model response is more correlated with the synchronous winds, while the VP model response is more correlated with the winds 3 days earlier.

Finally, the EVP ice dynamics model is a computationally efficient alternative to the VP model. The VP numerical implementation used here employs Jacobi iteration to solve the momentum equations, which have been decoupled as in Zhang and Hibler (1997). This method effects a twofold improvement in performance over the SOR iteration scheme of Zhang and Hibler (1997). Autotasked on a Cray J90 series computer with 20 CPUs, the VP model required 16 total CPU hours per model year, on average. The EVP model required only 11.5 hours per year, a 30% improvement in terms of CPU time over the VP model with Jacobi iteration. Moreover, the EVP model exhibits even more significant improvements in terms of wall-clock performance on multiprocessor machines. Because of its explicit discretization, the EVP model obtains speed-up factors 3 to 4 times greater than the VP model Hunke and Zhang (1997).

### 3 CONCLUSIONS

Ice distribution and extent are the primary pack ice characteristics that the sea ice component of a coupled climate model must simulate correctly. These determine the amount of heat and radiation fluxes that pass back and forth between the atmosphere and ocean components. We have shown in a multiyear run that differences in ice motion computed by the EVP and VP ice dynamics models yield very similar ice concentration and thickness distributions. The differences are far smaller than differences between either model's output and observations. Therefore, the two dynamics models can be

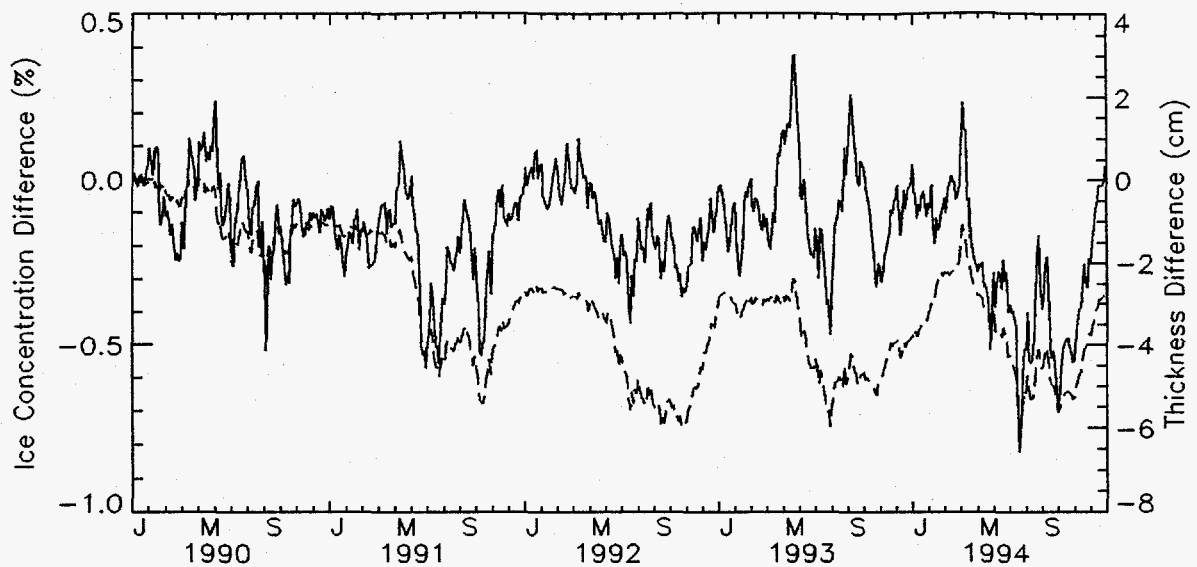


Figure 2: EVP-VP differences of areal-averaged ice concentration (solid) and effective thickness (dashed).

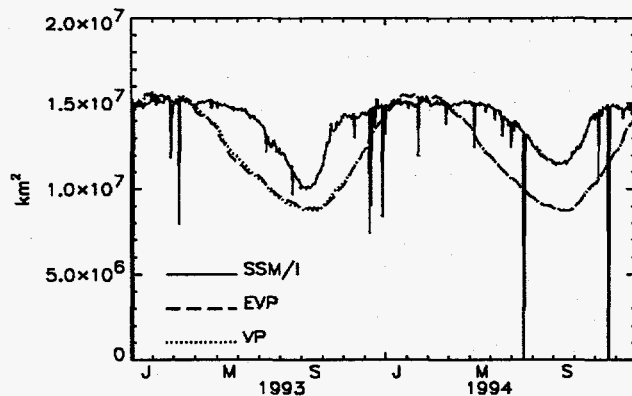


Figure 3: Total ice extent from the two models and SSM/I data. Spikes in the SSM/I curve indicate missing data.

considered equivalent for climate simulations. Furthermore, explicit discretization of the EVP dynamics model adapts easily to parallel architectures and overall improves the computational efficiency of viscous-plastic sea ice components for climate studies.

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