A Finite Element Sea Ice Model of the Arctic: Comparison of rheologies

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Introduction

A coupled finite element sea ice ocean model has been developed. The unstructured mesh used in finite element models allows for local refinements of the computational grid in regions of specific -dynamic or scientific- interest. An uncoupled version is used to analyse and improve sea ice dynamics. Here, ice thickness and ice drift of two rheology approaches, namely the traditional viscous-plastic (VP) rheology and the elastic-viscous-plastic (EVP) approach, are analysed and compared to observations. Model optimisation will be aspired with the help of ice drift data assimilation.

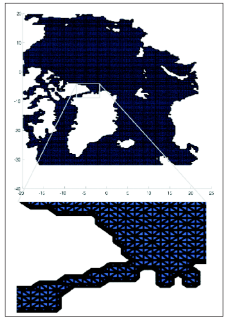

Figure 1: Surface grid of the Arctic finite element sea ice ocean model

Model description

The finite element dynamic-thermodynamic sea ice model is able to compute ice dynamics with the VP or EVP rheology approach. The theoretical formulation of the dynamic part is based on Hibler (1979) and Hunke & Dukowicz (1997), respectively, and the momentum balance is solved with the finite element method. The thermodynamic part solves the one dimensional energy budget and is based on Semtner (1976), Parkinson and Washington (1979). A prognostic snow layer (Owens and Lemke, 1990) with snow ice conversion (flooding) is included . Model time step is 2h. For both rheologies the momentum balance is computed with explicit time stepping, whereby internal time steps differs, namely VP with 14.4 s, which can not be increased further without changing results significantly, and EVP with 30 s, which can safely be increased to 60 s. The model grid covers the entire Arctic as can be seen in Fig. 1. It is almost regular and has a mean resolution of about 25 km. The model is forced by daily NCEP/NCAR reanalysis data for air temperature and wind velocities, by monthly means of humidity and dew point temperature and by climatological means of cloudiness and precipitation. Monthly means of ocean currents derived from coupled simulations are prescribed. Vertical ocean heat flux follows a turbulent mixing approach. Long integrations with both rheologies are conducted with identical forcing and parameters, e.g. P* = 15 000, h0=1.0, e=2.

Ice drift

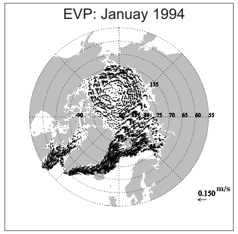

Figure 6: Simulated ice drift pattern in a situation with a dominant Beaufort Gyre using the EVP rheology.

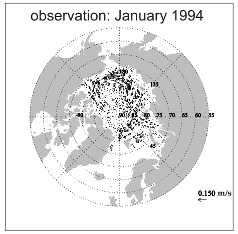

Figure 7: Monthly mean drift of January 1994, provided by Cersat (based on SSM/I data): dominant pattern is the Beaufort Gyre; no observed drift available in Greenland Sea due to filter mechanisms for satellite data.

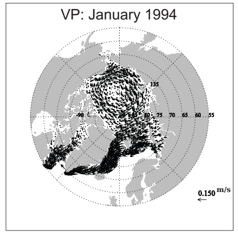

Figure 8: Same as in Fig. 6, but for VP.

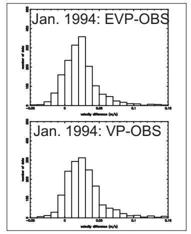

Figure 9: Ice drift velocity difference histograms of modelled and observed data: for both rheologies the model seems to overestimates the velocity and have a mode at 2.5 cm/s.

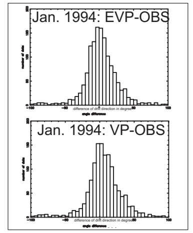

Figure 10: Ice drift direction difference histograms of modelled and observed data: both rheologies provide similar frequency distributions with modes at 0 degree.

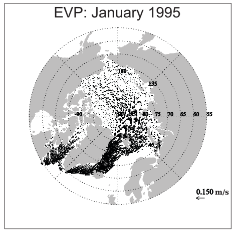

Figure 11: Simulated ice drift pattern in a situation with a dominant (displaced) Transpolar Drift Stream using EVP rheology.

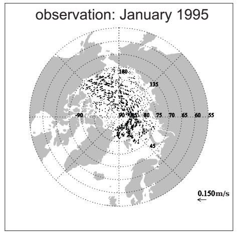

Figure 12: Monthly mean drift of January 1995, provided by Cersat (based on SSM/I data): dominant pattern is a displaced Transpolar Drift Stream, no observed drift in Greenland Sea due to filter mechanisms for satellite data.

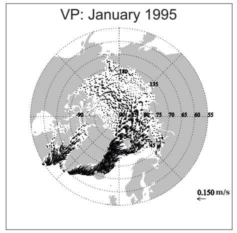

Figure 13: Same as in Fig. 11, but for VP

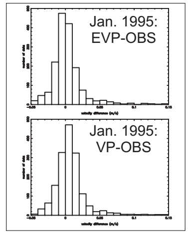

Figure 14: ice drift velocity difference histograms of modelled and observed data: both rheologies provide a similar frequency distribution with modes at -0.5 cm/s for EVP and 0.5 cm/s for VP case

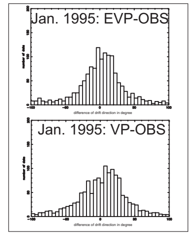

Figure 15: ice drift direction difference histograms of modelled and observed data: both distributions show a wide scatter; the modes are -2.5 degree for EVP and 7.5 degree for VP case.

For (almost) free drift, EVP and VP rheologies produce very similar drift velocities. The difference increases with thickness, e.g. in the central Arctic, where EVP computes smaller velocities than VP due to the elastic approach. Agreement between modeled and observed drift varies according to the drift regime: The velocities agree well in a situation with a dominant Transpolar Drift Stream and seem to have some kind of systematic shift in case of a dominant Beaufort Gyre. Contrary, the drift direction is represented fairly well in case of a dominant Beaufort Gyre and considerably worse for the Transpolar Drift Stream regime.

Ice thickness

mean winter (March 1990-2005) situation

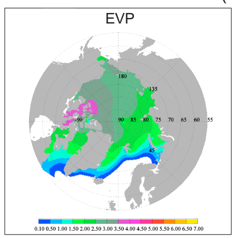

Figure 2: Simulated mean winter ice thickness features the typical pattern of decreasing ice fromGreenland and Canada towards the Siberian Shelf. Ice thickness in Beaufort Sea and north of Greenland and Canadian Archipelago is underestimated.

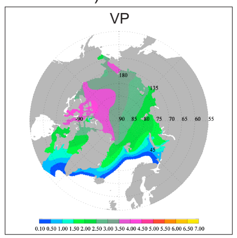

Figure 3: Ice thickness distribution and extend in the VP experiment is very similar to to EVP simulation (Fig. 2); maximum ice thickness differs by 0.5 m.

mean summer (September 1990-2005) situation

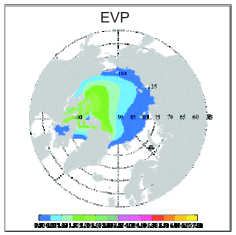

Figure 4: Summer ice extent is in good agreement with observations. Mean ice thickness is underestimated. Occurence of thick ice north of Greenland and Canadian Archipelago and decreasing thickness towards the Siberian coast are well represented.

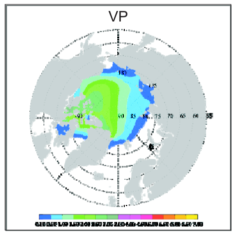

Figure 5: Ice thickness distribution in the VP experiment is similar to EVP (Fig. 4); ice extent is almost identical. Ice thicknesses from VP and EVP differ by about 0.5 m.

Ice thickness differences between EVP and VP rheology are smaller than 0.5 m, where EVP shows a smaller ice thickness in regions of thick ice. Ice thickness distribution patterns are very similar. In regions of thin ice, mainly along the ice edge in winter, the ice thickness is identical. This is not surprising because the EVP rheology renders the VP solution for thin ice. Maximum ice thickness is underestimated, especially in regions where thick ice of more than 4 m is expected, e.g. in the Beaufort Sea, north of the Canadian Archipelago and north of Greenland (Bourke and Garrett, 1987).

Conclusion & outlook

The finite element sea ice model is able to reproduce the large-scale sea ice distribution with thick ice north of Greenland, the Canadian Archipelago and in the Beaufort Sea, and decreasing thickness towards the Siberian coast with the VP rheology as well as with EVP approach. Maximum ice thickness is underestimated compared to the observations (Bourke and Garrett, 1987); which feature ice of more than 5 (4) m in winter (summer). Maximum ice thickness in EVP is smaller by 0.5 m compared to VP, but near the ice edge, where free drift is assumed, EVP renders the VP solution. Modifying the ice pressure parameter is expected to cure this deficiency.

Ice drift patterns agree very well with SSM/I derived ice drift for both EVP and VP, where EVP is slightly closer to the observations than VP. To further improve sea ice dynamics assimilation of sea ice drift data with the help of the Singular Evolutive Interpolated Kalman Filter (SEIK) (Pham et al., 1998) is planned. This filter analyses statistically the model and observation data, including their errors, to correct sea ice drift. The drift correction will be done by an additional advection of sea ice in order to get a physical impact for ice thickness distribution despite the short 'memory' of the sea ice momentum balance.