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Viscous-Plastic sea-ice solutions with Elastic-Viscous-Plastic sea-ice solvers

Overview

Most dynamic sea ice models for climate type simulations are based on the viscous-plastic (VP) rheology. The resulting stiff system of partial differential equations for ice velocity is either solved implicitly at great computational cost, or explicitly with added pseudo-elasticity (elastic-viscous-plastic, EVP). The more popular, because apparently faster EVP scheme has been found to create noisy solutions that do not converge to the VP rheology (e.g. Lemieux et al 2012). A slight modification re-interprets EVP as a pseudotime VP solver and thus salvages the convergence to VP (Lemieux et al 2012, Bouillon et al. 2015, Kimmritz et al 2015, 2016). In addition, the modification regularizes the EVP solutions so that they can be used in climate simulations at relatively low cost compared to efficient implicit methods.

Stable EVP schemes

$$\boldsymbol{\sigma}_{p+1} - \boldsymbol{\sigma}_p = \alpha^{-1}\Big(\boldsymbol{\sigma}(\mathbf{u}_p) - \boldsymbol{\sigma}_p\Big),$$

$$\mathbf{u}_{p+1} - \mathbf{u}_p = \beta^{-1}\Big(\frac{\Delta t}{m}\nabla\cdot\boldsymbol{\sigma}_{p+1} + \frac{\Delta t}{m}\mathbf{R}_{p+1/2} + \mathbf{u}^{n-1} - \mathbf{u}_p\Big)$$

additional term

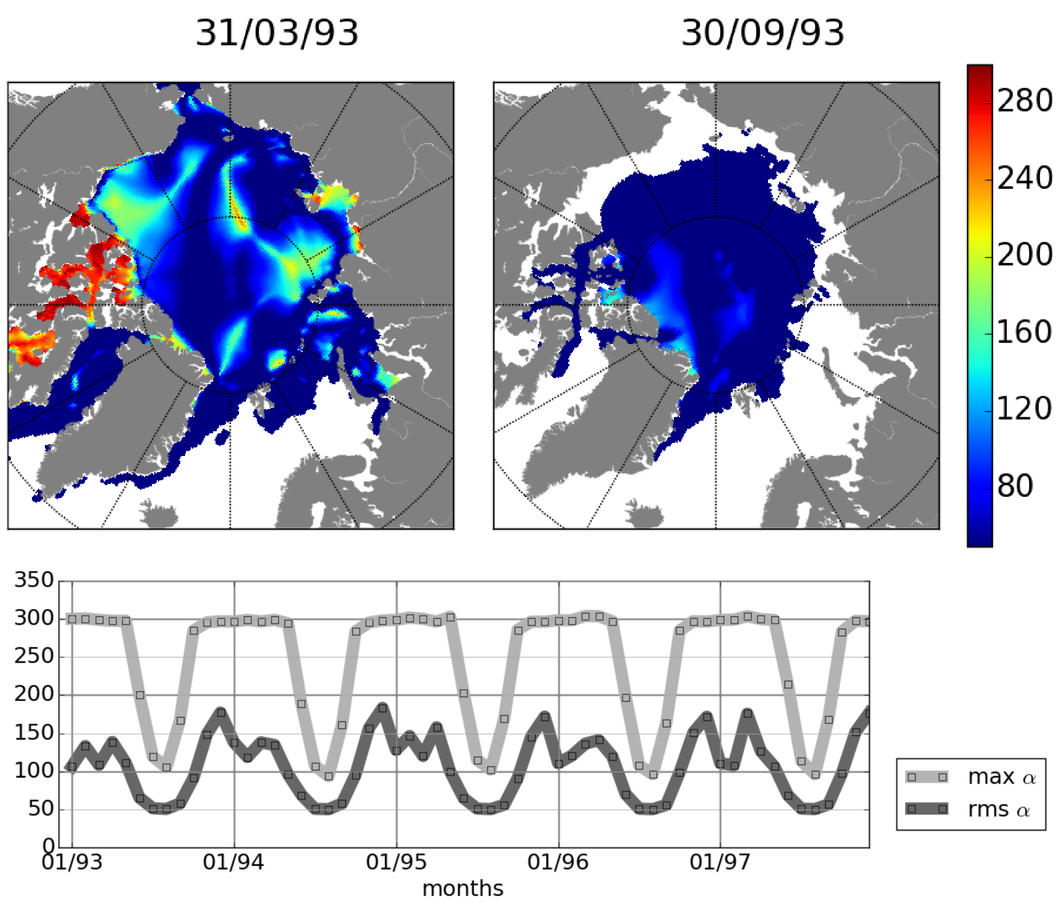
with

$$\alpha\beta \gg \gamma = \zeta\frac{(c\,\pi)^2}{A_c}\frac{\Delta t}{m}$$

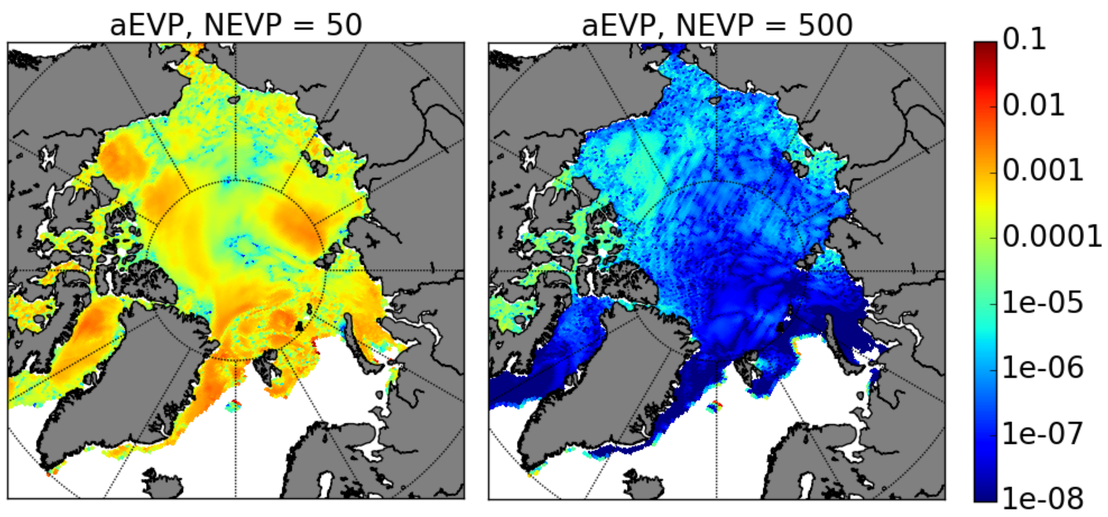
modified EVP: α, β = constant, order(300)

adaptive EVP: $\alpha = \beta = (4\gamma)^{1/2}$

Parameter α (aEVP, N = 500):

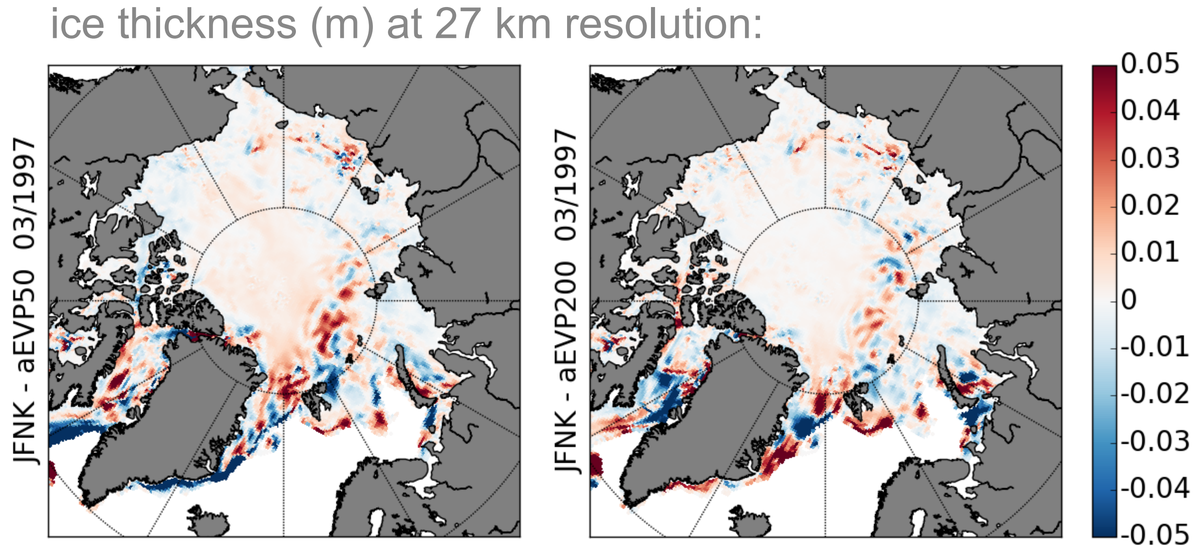


Residuals (momentum eq., m/s^2) after one month:

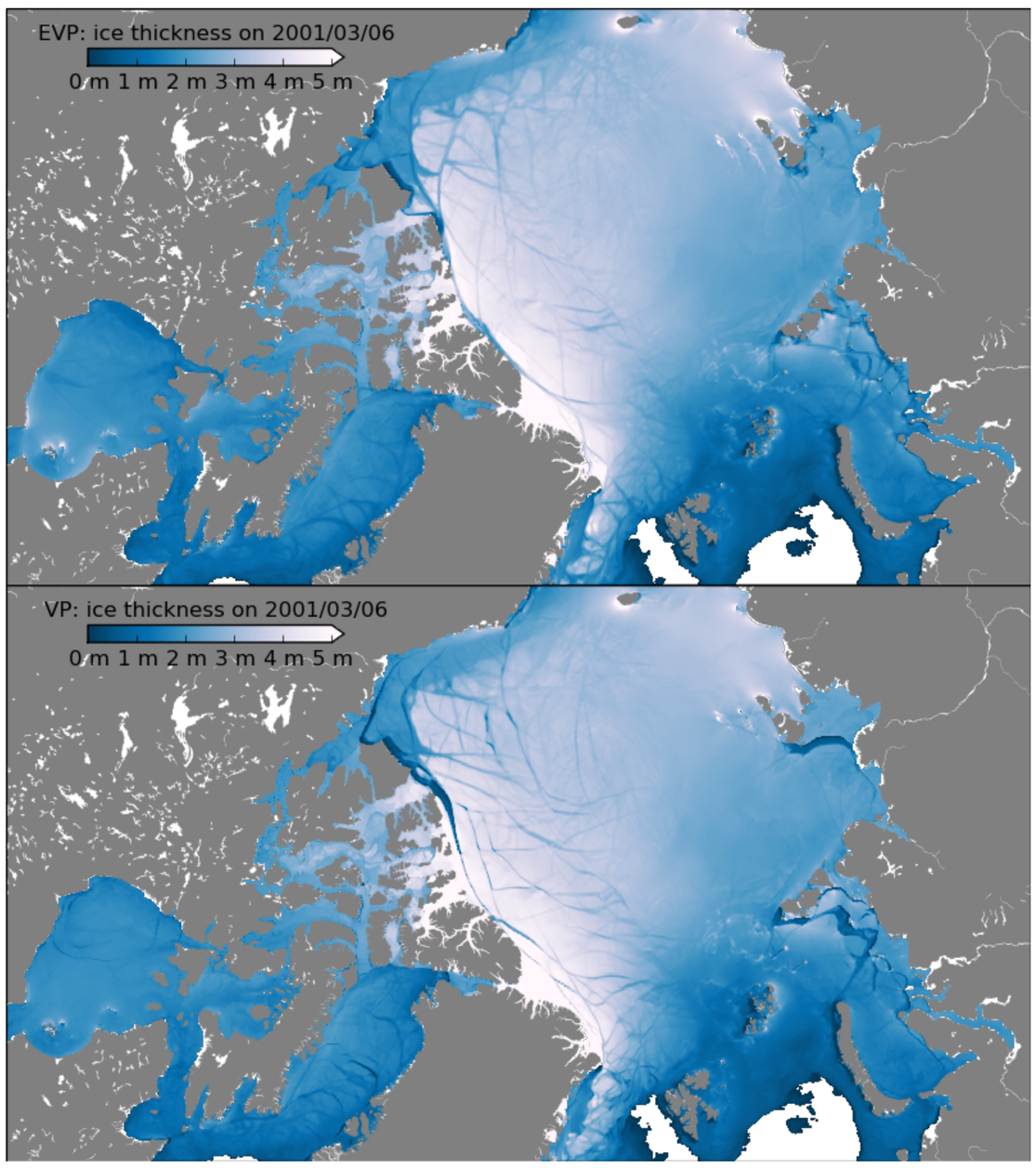


Convergence to VP-reference solution: ice thickness

ice thickness (m) at 27 km resolution:



ice thickness (m) at 4.5 km resolution:



At coarse resolution the EVP solutions converge to the VP solutions. At higher resolution convergence of all schemes is more difficult to achieve and the solutions are obviously different.

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