Elastic Viscous Plastic dynamics in HadCM3

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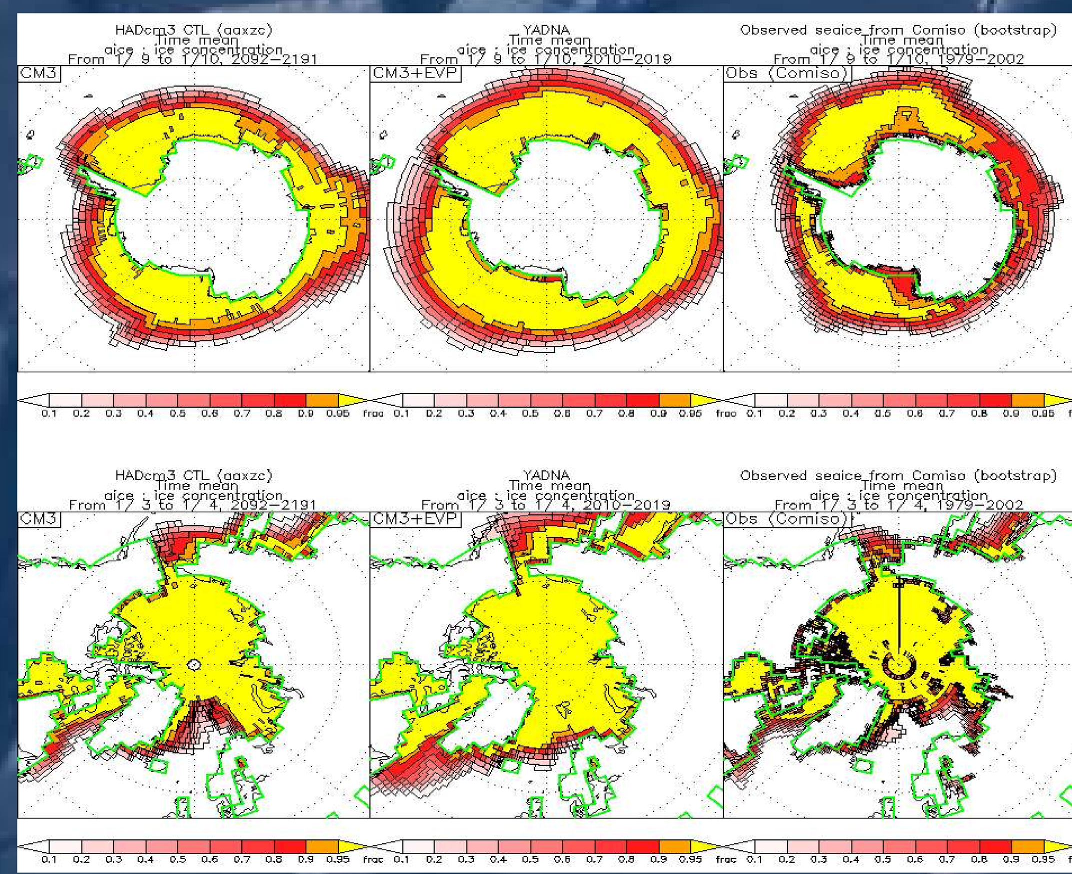
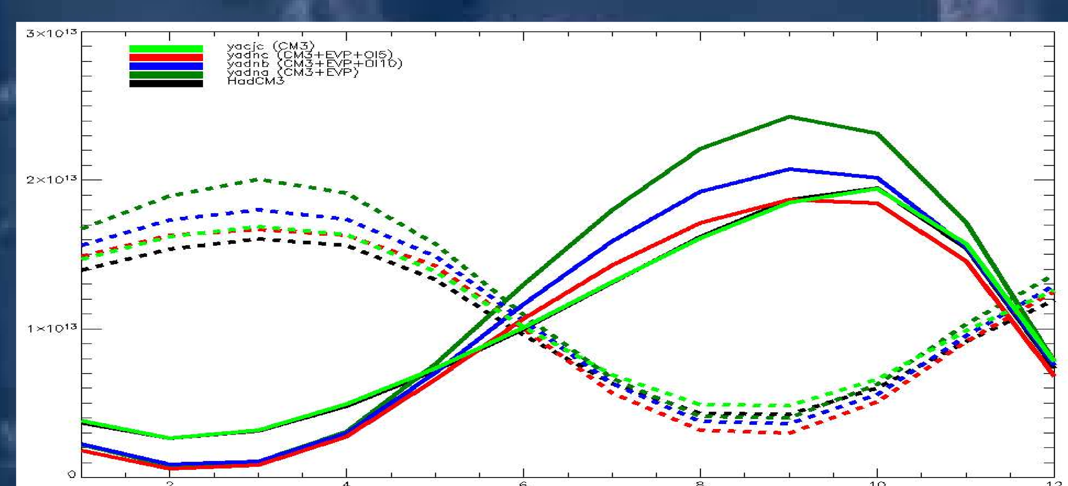
ABSTRACT We present results of an implementation of the Elastic Viscous Plastic (EVP) sea ice dynamics scheme into HadCM3. The existing HadCM3 seaice dynamics was an "ocean drift" model in which the sea ice moved with the top level of the ocean. This is better that static sea ice but, physically, amounts to neglecting all terms except the water stress in the sea ice dynamics equation. Although the large-scale simulation of sea ice in HadCM3 is quite good with this model, the lack of a full dynamical model incorporating wind stresses and internal ice stresses leads to errors in the detailed representation of sea ice and limits our confidence in its future predictions. Accordingly we decided to implement a full dynamical model into HadCM3, and chose the EVP model because of its excellent parallel scaling properties and ease of implementation.



HadCM3 (left); Initial HadCM3+EVP (middle); SSMI obs (right)

Initial implementation of EVP into HadCM3 produces results that are somewhat disappointing. In winter, the ice extent of HadCM3 was greater than observations, and adding EVP makes it even worse. In summer, in the SH, the ice extent was about right; adding EVP removes too much ice. In the northern hemisphere (NH), the summer extent was too great, and EVP reduces the ice extent to about the right value. EVP improves the simulation in some respects around Antarctica: the ice in the Amundsen-Bellingshausen sea is now about right in winter: the lack of ice there in the standard HadCM3 run hinders interpretation of climate change in the Antarctic peninsula, which is closely linked to the sea ice. Also, the phase of the maximum in ice area in the SH is correctly in September in EVP whereas it ws in October in HadCM3.

The degredation of some aspects of the simulation by adding EVP should not be too surprising as several of the thermodynamic parametrisations of HadCM3 had been developed to work with the ocean drift sea ice. Hence, we examine some physically based improvements to the thermodynamic parameterisations to see how these affect the results.

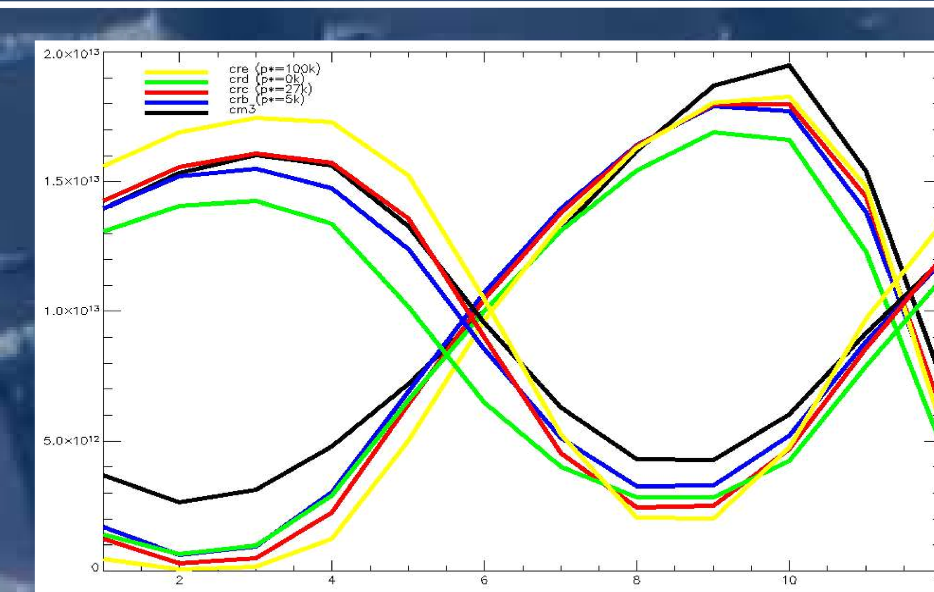


Effect of varying the ice-ocean flux parameter. Light green/black: HadCM3. Red: highest heat flux. Dashed lines: Arctic.

Ocean Ice Heat Flux The standard HadCM3 parametrisation for the ice-ocean flux is based purely on the temperature difference between the topmost ocean layer and the sea ice, assumed to be at -1.8 oC. A more physically based parametrisation would include the effects of turbulence via the ice-ocean velocity shear. This cannot be done in the ocean drift version, of course, because the ice moves with the same velocity as the ocean. Based upon McPhee (1992) and analogy with the atmospheric model parametrisation of the surface flux we write

OI_h_new = OI_h_old * OI_shear / C

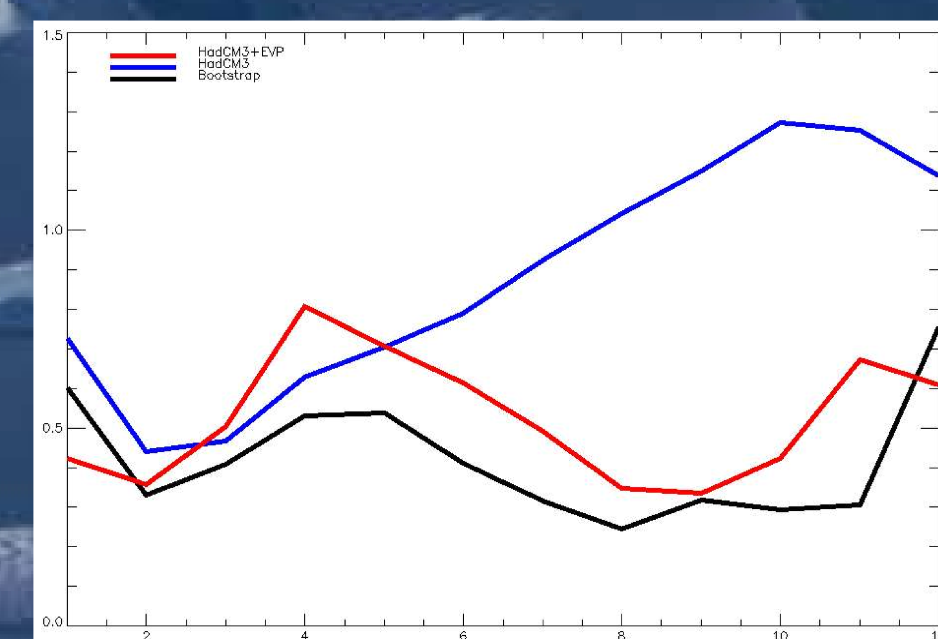
where C is a tuning constant with units of velocity. When the OI shear is above C, the new parametrisation results in more heat flux from the ocean into the ice, tending to melt the ice. From McPhee, a value of 0.1 m/s is reasonable for C, although it is not well constrained by available measurements. The ocean-ice shear is highest near the edge of the pack, with values above 0.2 m/s. Happily the new parametrisation makes a substantial contribution to reducing the error. We attempted to "tune" the model by adjusting the value of C within the physically reasonable range. However, whilst changes do have an effect there is a trade-off between summer and winter ice; we settled upon 0.05 m/s (the run shown in red).



Effect on overall ice extent of varying Pstar

PSTAR Implementations of (E)VP have tended to standardise around a value of 27k for the ice strength parameter P*. Nonetheless there are no clear grounds for choosing it, and it may well be resolution-dependent. We find that higher values of pstar lead to more winter ice and less summer ice. The sensitivity to P* in this case is quite small – considerably smaller than the sensitivity to changes in the thermodynamic parameters. These runs are variations around the base state of HadCM3+EVP+OI5+CM4th. Greater sensitivity, with changes in the same sense (i.e. higher P* leading to more winter ice) is seen in runs using plain HadCM3+EVP as the base state – without the thermodynamic modifications.

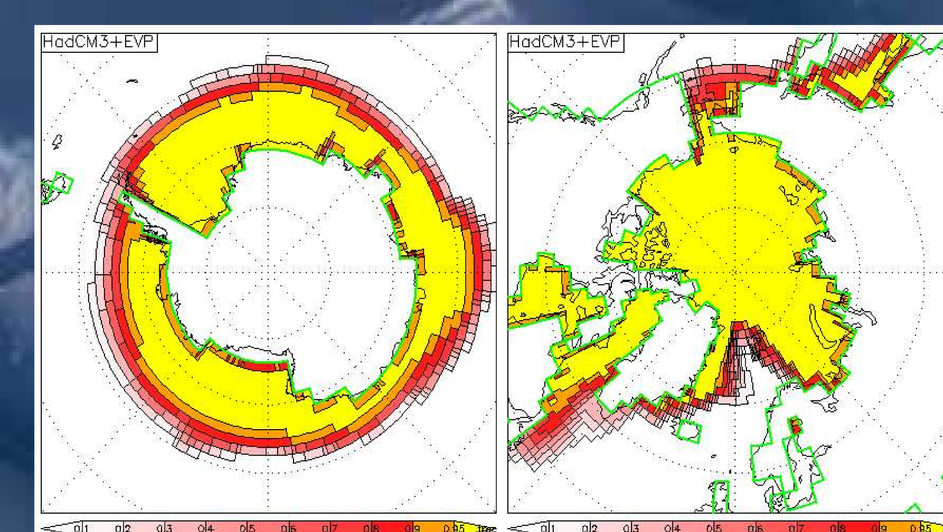
In summer, in the SH, the (unreasonably high) value of pstar as 100k causes all the summer ice to disappear. Based on the SH results, one would choose a value of pstar as low as possible (even zero, which is free drift) for the best possible simulation of the ice extent. However, this is not compatible with observations and theory. Also, in the NH, a pstar of zero degrades the summer simulation. Based on these results and the range of values in the literature, we choose a value of 5k for pstar.



Interannual SD, by month, over overall SH ice extent for SSMI (black), HadCM3 (blue) and EVP (red)

Effects on variability The picture shows the interannual SD of total ice extent in the southern hemisphere, by month. Holland and Raphael note that the variability of sea ice in climate models is significantly larger than in the observations. For September in the Antarctic, over the period 1979-2002, the standard deviation (in 10^6 km^2) of ice extent from the Bootstrap alrorithm is 0.32. HadCM3 gives a substantially larger value, 1.13. HadCM3+EVP has a variability of 0.54, much lower than the basic HadCM3 but still somewhat larger than the observations. However the results are improved further using the "best" run, above. Looking at the variability throughout the year, the picture (see figure 7) becomes more interesting.

EVP correctly reproduces the form of the curve, with maxima in January and April and minima in February and August. EVP is somewhat too variable, especially at times of larger ice extent. By contrast, base HadCM3 has completely the wrong pattern of variability throughout the year, and shows far too much variability, especially in winter and spring.



Best Run Combining all the changes, we come to a "best" HadCM3+EVP run with: OI5; CM4th; p*=5k. Of these changes, adding the improved (EVP) dynamics has a substantial effect on the sea ice simulation. Having done that, further tuning of the dynamics (via p*) has comparitively little effect. Tuning the thermodynamics has rather larger effects. The sucessor to HadCM3, HadGEM, uses much the same EVP scheme as here for the dynamics but introduces ice categories for the thermodynamics and this has further large effects (ref McLaren et al).

SUMMARY/CONCLUSIONS

The implementation of the more physically based Elastic Viscous Plastic sea ice rheology within HadCM3initially degrades the sea ice simulation. A number of the thermodynamic parametrisations relating to the ocean-ice heat flux within the default HadCM3 sea ice scheme ca be improved, and following this the overall sea ice simulation is better than HadCM3. Also, since it is now more physcially based, we have more confidence in the model both for hindcasts and forecasts of climate change. Further work on the sea ice model will take place within the framework of the HadGEM model (McLaren et al., 2005), centering on the issues of multi-category sea ice and further improvements to the thermodynamics.

Comiso, J. 1999, updated 2003. *Bootstrap sea ice concentrations for NIMBUS-7 SMMR and DMSP SSM/I*, June to September 2001. Boulder, CO, USA: National Snow and Ice Data Center. Digital media.
Comiso, J.C. and K. Steffen (2002), Studies Of Antarctic Sea Ice Concentrations From Satellite Data And Their Applications, J . Geophys . Res . 106 (C12): 31361 - 31385 Dec 15 2002 (http://nsidc.org/data/nsidc-0079.html)
Connolley, W. M. Sea ice concentrations in the Weddell Sea: A comparison of SSM/I, ULS, and GCM data. GEOPHYSICAL RESEARCH LETTERS 32 (7): art. no. L07501 APR 2 2005
Hunke, E.C. and J.K. Dukowicz (1997), An Elastic - Viscous - Plastic Model For Sea Ice Dynamics, J . Phys . Oceangr ., v27, #9, 1849-1867
Gordon, C., C. Cooper, C.A. Senior, H. Banks, J.M. Gregory, T.C. Johns, J.F.B. Mitchell and R.A. Wood (2000), The Simulation Of Sst , Sea Ice Extents And Ocean Heat Transports In A Version Of The Hadley Centre Coupled Model Without Flux Adjustments, Clim . Dyn . 16 : (2 - 3) 147 - 168 Feb 2000
McLaren, AJ, H. T. Banks, C. F. Durman, J. M. Gregory, T. C. Johns,
A. B. Keen, J. K. Ridley, M. J. Roberts, Lipscomb, WH ,Connolley WM, Laxon, SW (2005) Evaluation of the Sea Ice Simulation in a new Coupled Atmosphere-Ocean Climate Model (HadGEM1), *Journal of Geophysical Research (Oceans), in revision 2005.*
McPhee, M. G. (1992), Turbulent heat flux in the upper ocean under sea ice, *J. Geophys. Res., 97*(C4), 5365-5379.
Semtner, A. J. (1976), A model for the thermodynamic growth of sea ice in numericalinvestigations of climate, *J. Phys. Oceanogr., 6,* 379-389.
Turner, J., W. M. Connolley, D. Cresswell, and S. A. Harangozo (2001), The simulation of Antarctic sea ice in the Hadley Centre Climate Model (HadCM3), Ann. Glaciol., 33, 585– 591.
Turner, J., W. M. Connolley, T. A. Lachlan-Cope, and G. J. Marshall (2005), The performance of the Hadley Centre Climate Model (HadCM3) in high southern latitudes, Int. J. Climatol., in press.

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