The Cryosphere Discuss., 7, C373–C377, 2013
www.the-cryosphere-discuss.net/7/C373/2013/

The Cryosphere Discussions

Interactive comment on "Data assimilation and prognostic whole ice-sheet modelling with the variationally derived, higher-order, open source, and fully parallel ice sheet model VarGlaS" *by* D. J. Brinkerhoff and J. V. Johnson

Anonymous Referee #1

Received and published: 26 April 2013

Review on "Data assimilation and prognostic whole ice-sheet modelling with the variationally derived, higher-order, open source, and fully parallel ice sheet model VarGlaS" by D. J. Brinkerhoff and J. V. Johnson

This paper describe a new 'next generation' ice-sheet model called VarGlaS. VarGlaS solves the full-Stokes equations as well as a first order approximation formulated as the minimisation of an energy functional, the equations of enthalpy and the free surface evolution. It includes inverse methods and mesh adaptivity. The model is verified against several benchmarks in ice-sheet modelling, ISMIP-HOM and EISMINT-II. Fi-

nally the model is used to simulate the evolution of the Greenland ice-sheet 500-years in the future under a constant climate forcing. The capabilities of the model are impressive and looks very promising.

The paper is rather technical with a large portion dedicated to the description of the equations and methods. The discussion on the "prognostic whole ice-sheet modelling" is rather short and could be expanded to make the paper more attractive to non-specialist of ice flow models.

VarGlas heavily relies on the FEniCS project that incorporate tools for automated solution of differential equations with the finite elements methods. This approach will be very new for most of the ice flow modellers. This is an important point and it should be mentioned in the abstract and introduction. FEniCS allows to work with a high level description of the problem while the low level code (with what most of ice flow modellers are used to) is generated automatically. Many capabilities of VarGlas rely on this particularity and on the fact that it eases automatic differentiation. This approach could be described in more details, to highlight its advantages.

I have noted also few minor points which deserve clarification:

- P1030, l11: "predicts an overall mass evolution ... that matches well with observational data...". Add that it still requires a relaxation period of 100 years.
- P1031,l5: among the references of higher order ice flow model add a reference to Gillet-Chaulet et al., Greenland ice sheet contribution to sea-level rise from a new-generation ice-sheet model, TC, 2012
- P1031,l23-29: Automatic code generation and FEniCS should be introduce before to better explain why "the procedure of generating the code ... is as simple as making a change to the variational principle."
- P1032, l15: ref to "Greve and Hutter (1995)" should read "(Greve and Hutter,

1995)"

- P1032,l18: idem for ref to "Rutt et al. (2009)"
- P1035, Eq.1: Is it really "P" the lagrange multiplier that is used to impose the non penetration condition (last term of eq. 1, $Pu.n$)?
- P1035, Eq.1: Explain the motivation, or provide a ref. to scale the basal friction with h^r
- P1035, Eq.1: At the marine termini, a Neumann boundary condition should be imposed (sea water pressure below sea level). Is it included in the Greenland application? How does it appear in the variational principle? (this could also affect the discussion on the future implementation of grounding line migration in VarGlas).
- P1039, l20: It would be more correct to say that the whole ice sheet is treated as grounded with a non penetration condition and a sliding law, so no shelf and no grounding line. This is more strict that a fixed grounding line (where proper treatment of the shelf could exist).
- P1041, section 2.2.2 Mesh refinement: It could be explicitly stated that the method allows only refinement and no coarsening, this is why the initial Greenland mesh is made coarse in the interior.
- P1041, l21: "the classic anisotropic error metric", please provide a ref.
- P1042, l12:"using Gauss-Seidl iterations", please explain and/or provide a ref.
- P1047, l4-10: please provide refs. for this shock-capturing artificial viscosity. Is Dshock(Eq. 28) added to Eq. 13? in thewhole domain of just at the boundaries?

- P1049,l13-21: inverse methods test with ISMIP-HOM C; is it done with the first order approximation or Stokes?
- P1051,l15: "with gradients between the two reduced by systematically exploring" please explain with more details.
- P1052,l10, see previous comment on the meaning of h^r in Eq. (1). H is "h" in eq. 1.
- P1052,: section Data assimilation , which cost function is used (19) or (20)? please justify. Could you give a mean rms erro in m/a?
- P1052,: section Data assimilation , how the weighting parameter α in Eq. 22 has been chosen?
- P1052: "The velocity field matches the observed closely". Please show the observed velocity in the Figure (or show the same area in Fig. 1).
- P1053,l7: Replace "Fig.12" by Fig. 11.
- P1053,l10:"An ice sheet model should have relaxed at least to this level..." Please say how long is this in your application.
- P1053,l16: add ref to Fig. 12.
- P1053: section Prognostic run: After the initial mass increase is seems from fig 11 that the ice sheet is increasingly loosing mass; Looking at Fig 12, after 500 years the margins in the south and the west coast are considerably thicker with higher velocities. It seems that the increase in mass loss is due to the increase of the ice flux leaving the domain through the edges (it would be interesting to compute this flux). So that if the total mass loss agrees with the observations it is at the expense of a divergence of the ice thickness and velocities from the

observations. This could be looked at more precisely and stated in the abstract and conclusion.

- P1054, l2: “in better agreement with a pseudo-analytical ...” this is not shown in the paper.
- P055,l26: “imposing a known-thickness boundary” is the thickness at the boundaries really imposed? The calving rate balance the ice flux leaving the domain but is not necessary constant if the velocity is not constant.

Interactive comment on The Cryosphere Discuss., 7, 1029, 2013.