Review of egusphere-2022-1328

by Calca et al.

Calca present a noval approach for coupling a dynamic ice sheet model with a GIA model. For this they apply ANICE and 3D GIA FE model developed by Wu et al. Both models are established model compartments and suitable for modelling ice dynamics and solid earth deformations, respectively in view of glacial processes covering a glacial cycle.

The authors focus on a new coupling strategy regarding the coupling interval in time at which surface mass change and vertical surface deformations are exchanged between the two compartments. Furthermore, they discuss aspects of spatial and temporal resolution when coupling earth and ice-sheet models.

Further advantages of a time domain code are summarised at the end where they hightlight the flexibility of their approach.

The main conclusion is that a coupling interval of 500 to 1500 yr is sufficient in case dynamics of the system during this interval is iterated. In order to improve efficiency they conclude that 2 iterations should be sufficient.

For this, they have to assume that the GIA process proceed on such large time scales, although it is known that ice dynamic processes, which impact the mass balance of Greenland or West Antarctica, can proceed on significantly shorter time scales. Accordingly, the authors should specify, why it is sufficient to consider 500 yr as a lower limit in this study. Also the response time of the applied 3D earth model due to two to three orders of magnitude lower viscosities than 10^{21} Pa s, might be less than 100 yr. This means, the interplay of a short-time ice-dynamic process of may be 100 yr with the solid earth-dynamic response of 100 yr might be masked out with such a coupling interval. During the 500 yr time interval, the solid earth would relax almost completely, and the interaction during the relaxation process could not be resolved (see alternatively also Points 14, 23 in the details).

I understand that the coupling between the two model compartments generates a bottle neck in exchanging the data, but it is not clearly presented what the concrete problems in this coupling are. So, if one could solve some of the technical aspects, would it be possible to reduce the coupling interval further? For instance, Konrad et al. 2015 considered a coupling interval of 20 yr and, doing so, did not consider futher iterations during this interval.

Concentrating on these aspects of the study, I rate this study between minor and major revision. I strongly recommend to elaborate on shorter coupling intervals. Furthermore, why is a crude coupling interval of 500 yr necessary? What is the bottle neck in the coupling? Can this problem be reduced? Some are details would help here.

With regards,

Volker Klemann

Details:

1. L. 50: You can cite here already van den Berg et al., 2008, https://doi.org/10.1029/2007JB004994.
2. L 59: You can also add here, that the effect of regional sea level change due to gravitation is not considered in ELRA.
3. L 82: 'The only model that coupled 3D GIA [...]' why past tense, as the model still exists.
4. Throughout the paper I would replace years and kyears by yr and kyr, as kyears is a mixture.
5. With respect to units I also wonder if a center dot follows general type writer conventions.
6. ~ L 100: Although the VILMA - PISM coupling is not published as peer review, there exist already presentations regarding this project, e.g., https://doi.org/10.5194/egusphere-egu21-8050. You could mention that there is an ongoing discussion on how to couple viscoelastic solid-earth and ice-sheet models.
7. In the introduction you concentrate on 3D FE codes, but with regard to coupling with time-domain codes, Konrad et al. (2015) did this also. As your discussion focus on the coupling in the time domain, you should also mention his approach. Therein, he coupled without internal iteration but with a time step which is defined by the Maxwell-time. In his case, he chose 20 yr for a standard upper mantle viscosity.
8. L 136: "GMSL is similar throughout Antarcrtica", I think you mean the farfield effect of northern-hemispheric GIA is similar around the Antarctic coast. GMSL by definition is spatially constant.
9. L 152: The inaccuracy of linear interpolation is clear especially for time steps at the order of the relaxation time of the loading process. Assuming 500 yr as minimum time step, in this regard is rather long.
10. L 185: 'applied linear change [...]', you could mention here that also the time step in the viscoelastic model is much shorter than the coupling interval.
11. L 197: Is the Earth's core not excluded from the solution domain?
12. L 218: You could separate also in the text the transition zone and the lower mantle, while reading I was puzzled by the statement and could only resolve this looking at the table.
13. L. 298ff: Is mass conservation considered in the applied interpolation algorithms.
14. The authors state, that they can choose the coupling time step freely. May be there is no demand for a shorter time step, but in order to represent Grounding-line

dynamics it might be of interest what happens for shorter coupling intervals. For instance a WAnt viscosity in some regions of $< 10^{19}$ will result in a response time of less than 100 yr, accordingly 500 yr timesteps seem to be too large in order to represent the feedback mechanisms discussed. this would be interesting especially at periods of strong variability like during strong ice mass changes or during meltwater pulses. This would also be of interest regarding the discussion of Fig. 5, where locally, alternating signs appear.

15. L 406ff: Some more details regarding the considered architecture of the two model codes would help here. Also an analysis wich model needs what amount of time. My impression from the given numbers is, that the solid earth part dominates here. Also it is not clear if the 51 coupling intervals represent one glacial-cycle integration or already the whole iteration procedure of 3 to 4 integrations through the last 40 kyr. From what is stated here, you conclude that only one iteration is reasonable to apply?

16. Furthermore I wonder, whether the number of necessary iteration steps -- at the moment they amount to $293/51 \simeq 6$? -- depend on the chosen coupling interval. What happens if they reduce to 250 yr for example? such an experiment I strongly suggest.

17. L 414: 'subduction' -> 'subsidence'?

18. L 429: In the abstract you state three to four iterations.

19. Also here, it would be interesting if you present a similar analysis like that you did for the iterations during each coupling interval.

20. L 485ff: Does your discussion mean, that you did not consider the sea-level equation in this analysis? If so, you should specify this more clearly from the beginning as the stabilisation of the ice sheet through sea level fall is an important direct response to the ice mass loss. And as this is an instantaneous response I wonder how this can be considered in your coupling scheme.

21. L 494ff: You should also state here that the Antarctic ice-mass variability is dominated by W Antarctica.

22. L 503: I agree, it is the first published study coupling a 3D earth with an ice sheet model, but not the first study published in coupling a solid-earth time-domain code with an ice-sheet model, as it was published by Konrad et al. (2015).

23. L 505: Still I am sceptical a bit to state that 500 yr is a short time scale for GIA feedback. On which assumption do you base this statement, considering that the response times of the Antarctic ice sheet are as long? The solid earth in the 3D case responses regionally much faster. Also the statement only one iteration is enough, depends strongly on the considered process. I can imagine that the gross evolution of the Antarctic ice sheet might be representable in this way, but with respect to more regional aspects I doubt that such a strategy would be sufficient.

24. L 509: Where is the spatial resolution discussed in the manuscript.

25. L 516: If WAnt is dominant, and the viscosities are about 10^{19} Pa s, what happens if one would use a 1D model with such a small viscosity value?

26. L 520ff: That with smaller grid cells the convergenve improves, I did not find a discussion for in the manuscript.

27. In Figure 4: The climate and sea level forcing appear to come from outside the system, but sea level change is one output of the GIA model. I understand that for the moment, you have not considered this, but you should indicate at least that for state of the art modeling the relative sea level is part of the GIA models.