Reply to comments of REVIEWER 2: Samuel Kachuck

Dear Editor, dear Dr. Kachuck,

Hereby we respond to the comments (in blue). In the annotated revised manuscript, the modifications made are marked in bold face and a label "R2-N" is found on the margin of the manuscript (where this is permitted by $\text{L\!A\!T\!E\!X}$), where R2 stands for Reviewer 3 and N is the point made by Reviewer 2 (labels are defined, in blue, in this letter).

We hope that we have responded satisfactorily to the constructive comments received, and we are looking forward to have your feedback.

Note that we have also corrected a few typos, added some references, improved the text in a few places, and re-edited some of the figures and tables.

Kind regards

Giorgio Spada & Daniele Melini

Urbino, 20 September 2019.

Interactive comment on "SELEN4 (SELEN version 4.0): a Fortran program for solving the gravitationally and topographically self-consistent Sea Level Equation in Glacial Isostatic Adjustment modeling" by Giorgio Spada and Daniele Melini

Comments by Reviewer: Samuel Kachuck

Point R2-0

This manuscript details the background and significant improvements to an opensource implementation of the sea-level equation. As solutions to this equation are essential to understanding relative sea level and geodetic evolution, the open-source method and documentation are welcome and the changes - including the physics of rotation and shoreline migration and the modularization of the code - warrant publication.

In addition, I believe the inclusion of the derivation to be useful to the community. Pursuant to that, there are areas where the derivation could be made even clearer, as noted below. Occasionally, a proliferation of variable definitions and abbreviations clouds the exposition, and a simplification would be welcome.

We thank Samuel Kachuk for his positive evaluation and for the suggestions made. We have made efforts to address all his comments; when not, a justification is given. See the details given below.

Point R2-1

Finally, as the authors have just used this code's predecessor to participate in the benchmarking exercises of Martinec, et al. 2018, I think updating the contributed results with the new capabilities is warranted. In particular benchmark E, in which it seems they did not participate. As this is perhaps a more technical detail, I think it should be satisfactory to put this in the supplement, with perhaps a comment in the introduction to section 3. To this end, it would also be very interesting to see some discussion of how the included physics of rotation affect the results of those benchmarking cases.

A prototype version of SELEN4 has been used to compute results for the Martinec et al., 2018 exercise in all the considered benchmarks, including benchmark E (see Table 6 in Martinec et al., 2018). As suggested by R1, we explicitly state in the revised manuscript that the version of SELEN4 that we are publishing, when configured without rotation and in the same conditions of the 2018 benchmark, give numerical results that coincide with those published in that context. We believe that recomputing benchmark results with rotational effects would not add insight to the discussion, since all the 2018 exercises assumed no rotational feedback and therefore we cannot use them to validate our approach to rotational feedback modeling (of course, a new benchmarking initiative with a specific focus on the rotational effects would be of great interest). A discussion the difference between different rotation theories on the true polar wander is given in the manuscript, while for a more detailed analysis of the impact of rotational feedback on GIA fingerprints we now refer the reader to a recently published paper (Spada and Melini, Water, 2019). See also response to point **R1-1**.

All further comments are presented in page-line format

Specific Comments

Point R2-3

1-15: I would like to mention that the python module, giapy, which was benchmarked in the Martinec, et al. 2018 paper (including shoreline migration and iteratively determined initial topography, though without rotation) is available for download, opensource (from https://github.com/skachuck/giapy), and similarly uses any normal-mode form love numbers. It is safe to say, however, that it has not yet been as comprehensively documented in its open-source release as SELEN.

We have modified the text accordingly, quoting giapy, in the abstract and in the introduction.

Point R2-4

2-15: "viscoelastic rheology...properly taken into account" see note to 1-15

Agree; see also point **R2-3**. We have been more specific, here.

Point R2-5

4-12: Could you use S instead of B to keep it all consistent?

No, we cannot, because we use S (in \cal style) to denote the relative sea level change. B has a sense, here, because it recalls the term 'bathymetry'.

Point R2-6

4-2: "ice and by the water in the ocean" refers to ice on the continent and water in the ocean, which is the basis for equation (2). Equation (1) refers to ice and water over the surface of the earth, i.e., $_e$.

We are not sure we can capture this point. Are the two equations in contradiction?

Point R2-7

4-13: given the detail of the surrounding derivation, could you spare a few words giving a precise definition of "topography"?

We define topography (T) in terms of sea level (B), which is a more intuitive definition. See alo points **R1-6** and **R3-1**, who have suggested a similar improvement.

Point R2-8

5-4: The meaning of "plausible" is not addressed in the referred paper beyond setting the integrated mass load variation, or equivalently the zero-degree coefficient, to zero.

A similar point has been made also by **R1** (see **R1-9** and **R1-10**). To respond to both, we have rephrased this part of the manuscript, and we are now more specific on the meaning of 'plausible load' and on the contents of the Bevis et al. paper. Thanks to both Reviewers for rising this issue.

Point R2-9

5-6: Could more interpretable labels be given to the components of the load variation than a, b, and c?

We have been thinking a lot to this opportunity, but we did not have any valid idea. Consider that labels (a,b,c) affect a number of other variables as the reviewer can see in the Supplement. And also the variable names that we use in the source code. Any suggestion about a more intelligent labeling is welcome.

Point R2-10
5-10: The repeated definition of the variation variables gets confusing. Could the font used throughout be defined as the variation with respect to some reference level?

On the contrary, we think that it becomes more clear, although redundant. We believe that we cannot omit these fundamental variables. See also our response to Point **R1-7.** To help the readers, we now say that we use calligraphic capital letters to denote variations of the corresponding fields.

Point R2-11
5-19: Can you give a physical meaning to the height variable Q? "Auxialliary variable" and "arbitrary reference density" are a little confusing and undermotivated. If you selected $\rho^r = \rho^w$, then it takes the form of a free water column, positive where there is liquid water, negative where the water is frozen, and zero otherwise.

The Reviewer is right, in the sense that other choices could probably provide a physical interpretation, which however could be become too complicated and misleading. By Occam's Razor, we prefer to leave this definition, leaving a more in-depth analysis of the possible physical meanings to a future study or to the readers.

Point R2-12
7-9: Throughout, when referring to equations in the supplement, could you refer to specific equations?

Revising the paper, we have done this in a number of places to respond to **R1**. These equations/sections are marked by Sx or Sx.y.

Point R2-13
9-12: Could you briefly describe the significance of the external and internal iterations?

The same was essentially requested in **R2-23**, to which we have responded by adding a new short paragraph in which we summarise the meaning of external and internal iterations.

Point R2-14

16-12: You could cite somewhere the work done by Barletta and Bordoni (2013) on the effects of implementation of ice histories.

We would be happy to cite it, but we do not see in which part of our manuscript this could be useful. Any suggestions?

Point R2-15

17-27: see note to 1-15.

Yes, we agree. The text has been modified accordingly.

Point R2-16

Table 2: For clarity, you might articulate that these are piecewise constant layers whose upper radii are given by the variable r.

We have modified the style of the Table, giving both the lower and the upper radius, which makes things clearer, in our opinion. Note that the rigidities in the lower mantle where erroneously multiplied by a spurious factor of 10. This has been fixed.

Point R2-17

Figure 4: Is the ordering significant? If so, state what guides it. The non-numerical ordering makes it difficult to locate them from the text quickly.

The reviewer is definitively right here. Form the numbers, one cannot 'see' where the location is. We have added a map to help the reader. Thanks.

Point R2-18

Figures 5 and 6: the color scale looks different between these figures for the resolutions in the manuscript draft. Make sure to check this as it goes through editorial.

Thanks, we shall pay attention to this.

Technical corrections

Point R2-19

2-2: "available since" is a bit awkward, consider "dating from"

OK.

Point R2-20

2-10: "Despite GIA is now tightly" missing clause between "Despite" and "GIA"

We have rephrased into "Despite the GIA phenomenon is now tightly..."; we hope that this can be considered correct.

Point R2-21

2-16: "limited the" missing word "to"

The whole paragraph has been rephrased in response to Reviewer **R1**.

Point R2-22

2-16: "elastic rheology" to "elastic deformation"

Yes, we have changed this, also in response to **R1-2.**

Point R2-23

2-20: "Love numbers" to "Love number"
OK.

Point R2-24

2-28: "is hosting" to "has hosted" for tense agreement

OK.

Point R2-25

2-30: "Since year" missing work "the"

OK.

Point R2-26

3-24: "taken by the SLE" to "the SLE takes"

OK.

Point R2-27

3-24: remove "an"

OK.

Point R2-28

6-6: Should $\hat{\ }{ss}$ be $\hat{\ }{se}$?

Yes, indeed. A Major typo that has been noted also by others.

Point R2-29

8-25: "accomplished projecting" missing word "by"

Yes.

Point R2-30

11-14: "with origin in the whole Earth's: : :" to "with the origin at the Earth's: : :"

Yes.

Point R2-31

12-7: "from high-resolution but also from" to "from both high-resolution and"

Yes.

Point R2-32

12-21: The first clause "Differently...program" is awkward to read and the sentence would be fine without it.

Agree, 1st clause removed.

Point R2-33

13-5: The meaning of the word "safely" is not clear.

Agree, word 'safely' removed.

Point R2-34

13-25: "since" used twice in one sentence.

Agree, one of the two 'since' has been substituted by 'because'. See also **R1-32**.

Point R2-35

13-27: Consider adding "and shown in Figure 7" at the end of that sentence for a smoother transition.

Agree on the smooth transition.

Point R2-36

13-30: The sentence beginning with "Further results" could be revised to "Dashed curves show results obtained with the traditional theory."

Much better.

Point R2-37

14-9: Inconsistent abbreviations in section headings; "GIA versus "Glaical Isostatic Adjustment"

See also point R1-28, we are now consistent with the use of <<GIA>> in the section headings.

Point R2-38

14-25, 14-31: "regardless the" missing word "of"

OK.

Point R2-39

15-3: "very affected by" to "sensitive to"

OK.

Point R2-40

16-8: "Disclosing" to "Tracing"

OK.

Point R2-41

17-6: "which has been" to "which was"

OK.

Point R2-42

17-14: move "in SELEN" to the end of the sentence

OK.

Point R2-43

17-15: "increased physical realism" is a little odd

Yes, we change into realism, see also **R1-45**.

Point R2-44

Figure 7: label 'x' and 'y' in the right-hand panel.

OK.