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## ***Interactive comment on “Numerical modelling of climate change impacts on freshwater lenses on the North Sea Island of Borkum” by H. Sulzbacher et al.***

**Anonymous Referee #1**

Received and published: 8 May 2012

General comments The manuscript discusses the calibration and application of a large-scale 3D numerical variable-density flow model to the Borkum island in the Wadden Sea. One main objective is to investigate the impacts in 2100 of climate change (sea level rise, increased recharge) on the fresh water resources on the island (fresh water lens). To get to this a significant amount of hydrogeophysical data has been acquired from land- and airborne surveys along with a comprehensive analysis/transformation of these data to proxy data for “salinity” in the aquifer. The application part not only consists of trying to predict the consequences of climate change, but also what can be done to mitigate the simulated increases in salinity in production wells, like re-locating

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the wells.

I have to congratulate the authors with an impressive amount of work consisting of compiling and analyzing hydrogeophysical data, setting up 3D million-node flow model, and calibrating and using this model. I also find the results very interesting and most of it well-supported by data.

However, the paper is not easy to ready, mainly because it wants to present and discuss many data and results. It could also be better organized, see below. It is a long paper and having 22 rather complicated figures (often with 4 sub-figures) is in my opinion a little too much. I also find that it is a pity, because, inevitably it makes the presentation and discussion of the individual parts less focused.

My first major recommendation is therefore to split the paper in two and I think you have the material to do it. It will also make the organization of the paper more transparent. Paper #1 should be on the hydrogeophysics and paper #2 on the modelling. I am not an expert in the hydrogeophysics, but to me it seems like you have plenty of good results, e.g. those reported in sections 3.1.2 and 3.2 look like a large-scale up way of producing (proxy) maps of salinity that is not seen that often. Having a separate paper would allow for more detailed explanations, which probably would be nice for real experts? The rest could still be in a modelling paper, with some overlap in terms of still having the geophysical interpretations like in Figure 13 etc. This would also allow for a more detailed presentation of the construction of the model and especially the parameterization, see also below.

If you choose to stay with one paper then the hydrogeophysical issues could be reflected in the title (since it is very important and new?).

Technically I have a problem with the assignment of boundary condition. I understand it so that the water table also has fixed concentrations like at the latera boundaries, so that the island of Borkum in the model has known concentrations at all sides except for the bottom. In flow modelling it is not good practice to have fixed head values all

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around, the same must go for solute transport. Maybe this is why you get very good results? See comments below.

Also, there could be a few more details about the variable-density flow modeling, e.g., anisotropy ratio, porosity, dispersion parameters, density-ratio etc.. It is not often you see this type of large-scale 3D simulations so I think the readers will be interested in knowing what parameters were used, were they guessed?, and are the simulation results sensitive to changes in these?

In summary I find that the manuscript addresses very relevant questions and presents some novel aspects in the way it combines large-scale hydrogeophysical data and simulation results. The scientific significance is therefore very good. I am not an expert on the hydrogeophysics and can therefore not say anything about the scientific quality on this aspect, but, on the modeling side the paper the quality is good, but with room for improvement in the sense of better explaining the use of the boundary conditions and parameterization. Still, I am impressed by the large-scale 3D application. The presentation quality is fair, here I urge the authors to re-organize the manuscript and improve the quality of the figures, even to consider splitting the paper into two. In the very end, this work merits publication.

#### Specific comments:

â€¢ The use of references is at times a little odd, and not really up to date. For example, on page 3476, line 13 a few citations are given on modelling, but some are very old and I could have found a number of other more relevant citations. Also, about 1/3 of the citations are to German papers/reports even though I find that at times it is possible to find a much better reference from the international scientific literature. â€¢ The organization should be improved. Results are presented in Section 3 on “Material and Methods”, e.g., section 3.2 is almost all the geophysical interpretation. I suggest making a separate section on “Results”, move 3.2 to this one, move sections 4.1 and 4.2 to the “Material and Method”, and split the “Results” into sub-sections on hydrogeo-

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physics, calibration, climate change scenarios etc. → The English language could be improved. Below I just list a few examples. → Many of the figures are small and have a lot of information. Some are of rather low quality and looks like screen-dumps from Feflow. → Try to trim the paper as much as possible, here a few suggestions; Take out the tritium/helium discussion, data is simply not used anywhere except for saying that the simulated travel times matches data; is figure 2, 8, and 16 needed?

Other comments + technical corrections:

P. 3475

This introduction can be sharper with appropriate referencing to current similar work and even better stress the need for regionalized data on salinity and how to get this.

L. 3: Is “Interreg” known to readers? Furthermore, re-word the whole sentence so that you do not say “is aim ..” L. 6: Borkum, not known to the reader at this moment + delete “and enhanced”. L. 7: Drop last part of sentence from “caused by the ..” L. 8: Perhaps say “need to be defined and imposed”? L. 11: Essink et al. L. 12: “Many” instead of “A great deal of”? L. 13 ff: Odd choice of references. L. 14: Do you mean applications instead of models? L. 15: Is it easier to understand if you say salinity instead of density? L. 17: Perhaps “to obtain” instead of “with”? L. 19: Do you mean “monitor electrical data”? L. 20 ff: Re-word, more like “for the calibration of groundwater models using salinity data ..”

P. 3476

L. 5 ff. Drop this sentence, it is already discussing results?

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L. 15: Is Figure 2 needed? L. 20: Drop “some”. L. 23: Perhaps say “was believed to” instead of “had been”?

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Be aware if you also want to discuss results in a section on materials and methods.

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L. 21 ff: Why so low recharge?

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L. 3: What is actually shown? There are different T values? Again, be aware if you think this is results? L. 13: "Open water levels" are these ponds/lakes? L. 14: "Gimlet"? L. 17: Sounds like a very low precision with a Trimble, isn't it more on the order of 1 cm? L. 23: Replace "in the enviroment" with "near the fresh-water .."? L. 25: "non-saturated".

P. 3480

L. 4: open water systems. Are these canals/ditches/rivers? L. 6: here it says rivers, may show on map? L. 13: Say "type" instead of "kind"? L. 23: What does "bird" mean in Fig. 5?

P. 3481

L. 3: say "is" instead of "was"? L. 3: Is rare the right word? L. 13: Spell out m.s.l. first time L. 14: Delete "using". L. 20: "in order to achieve calibration using a pumping test". Sentence is unclear. L. 24 ff: Again results.

P. 3482

Drop Section 3.1.3, never really used quantitatively. Reference is Solomon or Cook? Spelling error "per bottle".

L. 9: I propose to call it simulations instead of calculations. L. 13: Replace "concerning" with "to in-situ"? L. 15: The temperatures; are they from shallow groundwater and what is the uncertainty in this. Like saying, if the temperature changes +/- 1 C what effect does this have on the estimated mass concentrations in the very end? In this section you say "strongly" so I think you should address how much it means.

P. 3483 L. 1: Do I read it correctly that Fa has no meaning at all, while later you say

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one Fa valued can reflect clay+fresh water or sand+ salt water. L. 7: Right panel. L. 10 ff: These are results. L. 29: Top right panel.

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L. 6 ff: Is this because of submarine groundwater discharge, ie. the dilution? L. 13-14: Say top instead of up. L. 16: Do you mean water table when you say “surface of the aquifer”? L. 20: I shouldn’t suggest an extra figure; anyways, it could be nice to see a profile of these results as it is difficult to detect the subtle changes in colors on the map. L. 21: Not clear what is meant by “124 water analysis probes”. L. 24: Say “initial mass”.

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Is it relevant to show a “real” geological profile (adding yet another figure)?

L. 9: Say “are” instead of “have to be”? L. 20: Many times you use adjectives like “sufficiently” close. If so, you need to define what you mean by this. L. 20 ff: I have not read these two editorials, but I find that they can not stand alone without arguing what is meant in the context of your modeling. Perhaps yes if it is to extend a model to year 2100. L. 22: Suddenly results again. L. 25 ff: Move to geophysics section?

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L. 2: Delete “lain” L. 4: Better to say “higher-resolution”? L. 4-5: Say “The aquitard ... can also be”? L. 7 ff: Results? L. 9: What is the concept of leaky or missing aquitards? L. 10: Drop the “in” in the parenthesis. L. 11: Say “suggest” instead of “give a hint”? L. 11: Say “layers separating the aquifers”. L. 20 ff: Drop “assure numerical stability” already mentioned. L. 21: Recipients, are these the open water systems? L. 21: What is meant by complex devolution? L. 26: 35000 mg/L. L. 28: I am sometimes confused when you just say mass. You mean mass concentration?

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L. 1 ff: I am not sure if I find it acceptable to fix the mass concentration on the surface nodes (=water table). Shouldn't this be part of the solution? No wonder you get "nice results" as the whole Borkum is fixed by known concentrations at all sides. Or am I misunderstanding this? Wouldn't it be more logical to assign a recharge with an associated mass fraction (e.g. increased because of sea spray). A discussion of this would be appropriate, e.g. in relation to Figure 15, which shows an impressive fit of the simulated EC, the proxy HEM EC, and the EC estimated from the electrical chain. In the top (where EC is fixed?) there is a very good fit, which slightly gets worse with depth, although still impressive, and where you have good arguments why the electrical chain shows differences. L. 10: So there is an unsaturated zone in Feflow as well (parameters?). L. 10: Some where you should mention how you specified recharge. L. 26: Say large instead of great. L. 26: Is it true that I count only 9 (nine) time steps to take the model from 1934 to March 2010? I find that hard to believe?

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L. 10: I assume these relate to the 4 aquifers and 3 aquitards, perhaps show better? What did you assign for anisotropy, porosity, dispersion parameters, etc. L. 11: Perhaps add  $r^2$  to give real statistics of the fit? L. 16: Only place you mention tracer (=tritium/helium?), but not in quantitative way, thus I suggest to take this part out completely as it is not fair to the reader to have a section on its sampling/analysis and then not show how it was used directly.

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L. 7 ff: This sounds more like data, move to description of site? L. 8: Say show that during instead of "give a hint that" L. 14: I wonder if there are any remnants of the previous floodings? L. 14: Reword first sentence. L. 21: Explain better "Thinned by the system .." L. 25 ff: Say performed in transient state.

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Maybe the list here should come earlier as some looks like repetition.

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L. 6: Say WWI instead of Waterwork I L. 7: Sentence unclear. L. 8: "discretization of the delivery rate" do you mean time stepping? Which makes me think how you implemented this with maybe only 9 time steps? L. 17: Sufficiently? L. 23: Fairly?

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L. 2: Fairly? L. 16: Satisfying?

P. 3493

L 1 ff: delete + figure 16? L. 10 ff: delete .. for the area of the North Sea coast. L. 11: Say possible mean change? .. based . . . from multiple

P. 3494

L. 6: Why in good agreement with Chang? L. 10 ff: Here the figures are not so easy to understand especially the coloring scheme with hatched areas etc. L. 15: lying instead of lain?

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L. 4: WW L. 9: Maybe say which distances the wells are moved? How certain is this?

P. 3497

L. 13: Thoroughly. L. 15: Travel times, can not conclude since no data or analysis.

Table 1: What do the various T columns mean?

Figure 1: Show open water systems Figure 2: Needed? Otherwise, needs larger fonts.

Figure 5: What does the line bird mean? Figure 6: the sigma\_w has an odd scale

Figure 7: Is the right part needed? Figure 8: Needed? Figure 9: Nice, shows how

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complex the mesh is but also a bit difficult to see. Figure 11, 12, and 13: Low quality  
Figure 14: Is the right part needed? The dashed lines to the left, are they supposed to  
have the same color as the solid lines? Figure 16: Needed? Figure 17-19: low quality.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 3473, 2012.

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