The Cryosphere Discuss.,
doi:10.5194/tc-2016-54-AC1, 2016

The Cryosphere
Discussions
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Interactive comment on "Weichselian permafrost depth in lowland Europe: a comprehensive uncertainty and sensitivity analysis" *by* J. Govaerts et al.

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Received and published: 22 August 2016

Govaerts et al. conduct a study of potential future permafrost aggradation in the Netherlands in the context of nuclear waste repository installation. They go beyond most previously published studies in this area of research by conducting a sensitivity analysis to a number of factors including subsurface parameters as well as the forcing climate conditions. In general, this is a fairly clear, succinct paper that should garner some interest in The Cryosphere. I only have a few very minor comments for the authors to consider. Since these are all minor, I haven't structured the comments.

The authors wish to thank the reviewer for his/her time and positive remarks on the manuscript. We are also thankfull for the relevant remarks about the manuscript, which

in our opinion improved the paper.

P2, L3 Here and elsewhere, the authors interchange 'permafrost' with 'frozen ground'. Permafrost is only defined based on temperature (cryotic conditions) and does not necessarily imply the ground is frozen. This should be rewritten. Also in section 3.1 (first paragraph), the authors use -0.25C as their permafrost boundary. This makes no sense. By definition, the 0C isotherm is the permafrost boundary. The -0.25C level might be an indicator of frozen ground. In appendix A of Govaerts et al. (2011) which can be found on http://publications.sckcen.be/dspace/handle/10038/7377 , we demonstrated that the evolution of the the temperature profiles throughout the simulation time are not very sensitive to the choice of the width of the liquid-solid interval interval. However, concerning the safety of a radwaste disposal facility, the penetration depth of the fully frozen front is of more relevance than the temperature. On the other hand, the positions of the 0 and 100 % frozen isolines are severely sensitive to this width, and the exact value is uncertain as it can range from 0.5 to 2 °C depending on the material type (Noetzli & Gruber, 2009). Therefore, the choice for the -0.25°C as permafrost indicator was made (i.e. the center temperature of the 0°C to -0.5°C freezing interval which coincides with the 50% frozen isoline) as the main output of interest in this study, in order to present our results in a robust manner, independent from modelling assumptions. The 50% frozen isolines serves as a pessimistic indicator for the fully frozen front, including a safety margin. (the previous part has been added to the manuscript) In a first version of this manuscript, the freezing interval was chosen as 0.5°C to -0.5°C, and the 0°C – isotherm was used as the main output. However, the editor could not agree with the fact that water would start to freeze at temperatures above 0°C. Therefore, we have changed the offset and the width of the liquid-to-solid interval, now 0°C to -0.5°C and have rerun all the simulations, for the nationwide best estimate analysis and the stochastic runs. The new results where then added to the manuscript, but the differences with the previous results were rather subtle (see figure below). As such, no large changes were made in the results section, except for the figures, who were replaced with the latest results.

P2, L25-27, Kurylyk et al. (2014) review how permafrost separates surficial and deep subsurface water flow systems. They also discuss the role of advection in terms of the interactions between permafrost and climate. This would be useful in the authors' discussion on these topics later. Thank you for your suggestion, we have made a reference to this work. Equation (3). I am not used to seeing two derivatives (change in moisture content with temperature) in the effective heat capacity function including freeze-thaw. How do the authors reconcile this equation with Equation (14) in Kurylyk et al.? It must be noted that the two derivatives in equation 3 do not represent the change in absolute moisture content, but the change in the fluid fraction with respect to the total porosity. Inserting the relations of equation (2) in here and neglecting the difference in density between water and ice, will transform this equation into one comparable to Eq. 14 in Kurylyk et al., (2014) with only one derivative.

Section 2, The authors don't really present the soil freezing curve (relationship between temperature and unfrozen water). They state on P5, L31 that they use a smooth-Heaviside function. Heaviside function is not smooth, so this seems contradictory. Is it a linear function between 0 and -0.5C? If so, they should state that. If not, they should present the equation for it. 'Smoothed Heavised function' has been replaced by 'a fifth order S-shaped polynomial form (available in COMSOL as the inbuilt function flc2hs). The polynomial form is a smoothed Heaviside function with continuous second derivative without overshoot and takes on a value between 0 and 1.' P5, L5 and L8, heat capacity (in this paper) is volume based, so why do the authors present it in mass-based terms (J/(kg K)). Indeed, the Ceq of equation 3 is volume based. However, the values heat capacities of unfrozen and frozen Boom clay given here are mass based as they have been obtained by dividing the equivalent volume based heat capacity with the bulk density. This was done in order to make a straightforward comparison to values used by other authors. We have added a little clarification in this paragraph to avoid this confusion. P5, L19, it is a bit silly to say that the thermal properties of the geologic material agree with the values chosen for similar material in past studies within the same order of magnitude. Surely one can be more precise than that given

that thermal conductivities of ALL geologic material only vary by about one order of magnitude. 'Orders of magnitude' has been replaced by 'range'. I'm confused by the term 'unit thickness' followed by 250x250. I guess the authors mean the geologic unit, but in modeling, unit thickness usually means a thickness of 1. The sentence has been rearranged: "For each unit, vertical gridcells of 250x250m surface with a height equal to the thickness of the unit were constructed." P7, L12, porosity also affects the latent heat, not just the bulk thermal properties The following changes have been made for completeness: "Porosity is directly linked with water content as full saturation is assumed and thus thermal conductivity and the equivalent heat capacity of the soil. (see Table 1 and Equation (3))." P7, L22, perhaps it is stated elsewhere and I missed it, but what is the lower boundary condition? Is it specified flux or specified temperature? The authors could add a figure showing their domain and boundary conditions. I think that would be helpful. What is the time step size? Information about the bottom boundary condition is given in section 2.4. A separate paragraph concerning the model domain, boundary condition and computational settings has been added (2.5). P15, L17, Was Govaerts et al. (2011) only for one site? If so, this should be stated here. If not, the distinguishing factors between the present study and the Govaerts et al. (2011) study should be more clearly outlined in the introduction. "As such, the work performed in Govaerts et al. (2011), which was done for one potential site in the framework of the Belgian research programme on High-level waste disposal, is taken a few steps further." has been added to the introduction. P16, L4-7, wouldn't it make sense for the authors to include the fact that they ignored surface glaciation as another one of their 'conservative assumptions' that they list in two other locations? Maybe that's not relevant for the Netherlands. We ignored this as there were no ice sheets in the Netherlands during the Weichselian. In general, I would assume the authors are familiar with the depths of the proposed nuclear waste repositories in the Netherlands. How do those design depths compare with the depths of maximum simulated permafrost? Surely this would be of interest to most readers. "Note that in the OPERA-project the long term safety of a generic repository in the Boom Clay at a generic depth of 500 m will be assessed (Verhoef and Schröder, 2011).” Has been added to the discussion. Figure 4, why do the authors present results for these two specific polygons? “These two polygons (FRP and LBH) are at resp. the low and the high end of the resulting permafrost depths.” Has been added to the caption of the figures Figure 5, why do the authors show a binned color scale? Shouldn’t this be a gradient color scale, or do the authors actually bin their results? The results are not binned. The QGIS software does not allow to create a gradient color scale. Figure 6, I think it would be advantageous for the authors to present the location of the transect for this figure in Figure 1. This has been done. Figure 7, does this only show the maximum permafrost depth across the nation at any point in time, or is the spatial variability in permafrost included in the percentile calculations? This figure indeed shows the percentiles maximum permafrost depths as a function of time of 1000 simulations. However, spatial variability is implicitly included as the parameter ranges include this uncertainty. Figure 8, I’m confused by what T2-T19 refer to This is explained in the paragraph 2.6.3: “T1 to T26 are variables which are used to control the magnitude of the various temperature plateaus during the Weichselian temperature cycle. This allows to account for the actual parameter uncertainty on the temperature as well as the nation-wide spatial parameter variability. “

Table 2, is the porosity in Table 2 only the porosity of sand (Table 2 implies this). There are commas where there should be periods for the decimals. Yes, the porosity of the Clay material is kept constant, as the variability is much lower. We have adapted the table.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/tc-2016-54/tc-2016-54-AC1-supplement.pdf

Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2016-54, 2016.

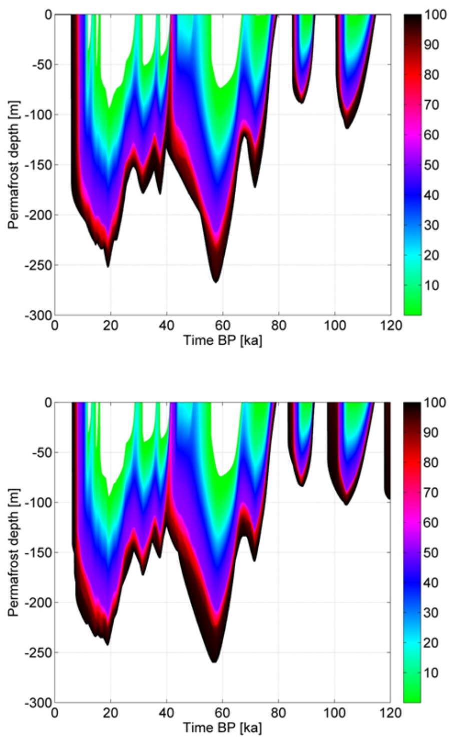

Fig. 1. Results of the uncertainty analysis. Top: previous version (freezing interval 0.5°C to -0.5°), bottom: after first revision (freezing interval 0°C to -0.5°). Differences on the extreme percentiles ar