Interactive comment on "Effects of Transient Processes for Thermal Simulations of the Central European Basin" *by* Denise Degen and Mauro Cacace

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This paper investigates the effects of paleoclimate variation on conductive heat transfer in sedimentary basins. The authors demonstrate an impact that is too often neglected and quantify robustly the effects of surface temperature evolution on the subsurface at various depths, depending on the timescales considered, through a global sensitivity analysis (GSA). This work is very relevant for the geoscientific modelling community and the workflow presented shows clearly the importance of GSA - possible thanks to efficient surrogate models – to not only identify the parameters of importance but also their correlations. I found the study particularly well adapted for the journal as it

presents a novel modelling workflow to alleviate many of the issues arising from local sensitivity analyses and manual calibrations. Overall, the manuscript is well structured and the message really clear. In my opinion, the impact of this works certainly warrants its publication in GMD, even though I recommend quite a few minor revisions to clarify some points detailed below and improve the manuscript.

General comments:

* All figures showing indices (e.g fig.2,3,4,5,7,11,12. . .) would make more sense plotted as (2 colour pairs of) histograms since the x-axis is not continuous but represents the discrete parameters. The legends of those figures should also point the reader to a table (or the new figure) describing the acronyms of the geological units.

* Across the whole manuscript, the main text should be more self-contained in the sense that description and results of the figures should appear explicitly in the text as well. This is currently done for figs.1,2,7,11 but not the others. The text only mentions that "the results are shown in fig." 3 (L.187), 4(L.200), 10 (L.283) and makes implicit references to figs.5,6,8,9,13,14,15. I don't think fig.12 is even referenced in the text.

Specific comments:

* A figure is missing to display the geological model, so that the reader can understand better the (implicit) links between the geological units' names (i.e ages) and depth, which is an important aspect of the results. I understand and agree with the approach of not focusing too much on the geologic model (which is quite irrelevant for this study) but a minimum must be mentioned including the number of units, which could maybe be listed in some sort of order of depth (of the centre of mass?) as this is the most relevant aspect.

* Please check equations 1 and 2 which seem to have a few problems and confirm these typos don't affect any of the results

|— Eq. 1, elements to check/correct:

|—— Minus sign for the diffusion term

|—— l_refˆ2 in the source term

|— Eq. 2:

|—— Minus sign for the diffusion term

|—— l_refˆ2 in t_ref

|—— S_ref instead of S_(s,ref) in the second term (heat production)

|—— S_(s,ref) seems to include C_p and is therefore not necessarily the standard definition of "specific radiogenic heat production", so please specify your definition (and adapt the name if needed).

|—— missing "\partial" in front of time

* The second part of the introduction (L.48-80) needs some touches to improve the reading flow. The mention of all components of the paper could benefit from adverbs and some reordering to emphasise the logic in which the info is introduced: first "why" some work needs to be done, then "what" are the goals of the paper, and finally "how" you're going about it. For all points, the justification of the work should indeed appear before the mention of the elements themselves, instead of afterwards (which weakens the points by following more of a "report" format, e.g. L.57-59 before L.55; L.61-64 before L.60; L.71-73 before L.70). More explicit logical links will help transform the current impression of a listing of elements ("the main goal of this study" L.48, "we will describe and discuss" L.50, "we will demonstrate" L.52, "the aim of the study" L.54, "in this paper we present" L.60, "our case study is" L.74), which currently leaves the task of connecting them to the reader.

* L.58 mentions that paleoclimate effects on subsurface heat have only been looked at in 1D and provides a good but old reference from 1984. The impact of paleoclimate on deep heat flux is indeed often underestimated, but more recent work should be

mentioned as well (and again as a justification for the work beforehand). See for instance (Dentzer et al, 2016, http://doi.org/10.1016/j.geothermics.2016.01.006) and all references therein.

* Sec. 2.1, a short sentence would be welcome to actually explain/summarise what the Sobol sensitivity analysis and Saltelli sampling routines are.

* Sec. 2.3, briefly mention what kind of constraints are used to calibrate that model, which initial conditions are used.

* Sec. 2.3, which absolute time period are the relative time steps 0-26ka supposed to represent? (Reader is only learning l.248 that the number 26k results from the reconstructed paleotemperatures available. This info should appear with the first mention of "26k")

* L.172, the contributions being "negligible" imply some relative thresholds that are not specified. An extra sentence would be nice to comment on absolute and relative thresholds the authors used for all indices in this study. For instance, are you choosing three(x2) parameters L.190 because you consider 0.1 to be a good threshold?

* L.174, the number is not 5 but actually 5x2=10 since later examples show that you're not picking geological units but parameters which are not necessarily in the same units. Please check the whole text for consistency (e.g. "three" L.190,...)

* L.205, this information should appear at the beginning of the section (as mentioned above, justifications should appear before descriptions): from what I understood, you want to end up with a manageable number (arbitrarily 8) of most sensitive parameters overall but it would be too expensive to run a GSA with all parameters at once, so you break down the problem to first identify the most sensitive in the sediments, then in other areas, and then pick those parameters for further study.

* L.212 "higher accuracy than typical temperature measurements" -> what does that mean exactly? You mentioned that you're not solving for temperature but heat, so how

does 5e-4 accuracy on a model translate into temperature measurement precision? (Similarly L.222, why 4e-3 rather than 5e-3 to relax by one order of magnitude?).

* Sec. 3.3.2, I only understood what was being simulated in this section after analysing fig.9 (mentioned L.273). Indeed, Fig.7 (mentioned L.251) shows an average initial temperature around -5C and a final temperature around 8C, which I could not instantly reconcile with applying a Dirichlet boundary condition of 1.6C mentioned L.246.

* Sec. 3.3.2, I also don't get the point of fitting the average temperature with a 4th order polynomial. Why not use directly the average temperature itself discretised at your transient time step? Why do you need a smoother version? As for the smoothing, it's impossible to judge a fitting quality without any mention the metric used to assess the impact. I agree (L.277) that the 5th order polynomial doesn't significantly improve the fit compared to the 4th order visually, yet the fit remains rather poor in my eyes (rough estimate of max(deltaT)∼3C) and the selection of the best fitting function is a moot point without specifying both the metric to assess the fit and the cost of using a higher order polynomial/smoother fit.

* L.280, what is this "scaling factor" and what is it applying to? (I can only start guessing after seeing fig.10, describe it explicitly in the text.)

* L.285, the mention of "glaciation times" comes out of the blue and should be introduced.

* Sec 3.3.3 looks a bit odd at first sight as it seems to draw an opposite conclusion to the paper itself, with the transient boundary conditions adding no value over constant ones (the main properties showing "no significant changes" L.292 and the others being "insignificant" L.293). Please manage the delivery of this message.

* L.416-419, I don't quite get the need to deduce the obvious, that heat moves upwards in this setting, nor the less obvious conclusion of why sediments at the uppermost part have therefore a more prominent influence.

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* L.443-446, this information would be better suited in section 3 to justify the approach when presenting it.

* Sec. 5, the conclusion needs some polishing. It looks a bit too much like a series of collated dot points with a succession of short sentences (e.g. last paragraph). The paragraph breakdown is awkward with two of them containing a single sentence (L.457, 464). Emphasise more the causal relationships by introducing some segways or logical links, and please amend the abrupt finish to leave the readers on a more impactful last sentence.

Technical corrections

* L.56 & L.58 "influence on [the calibration of] thermal properties"

* Sentence L.70-74 could be easier to read if reordered –> "In this study, we make use of the RB method . . . since it allows" (l.71) "the retrieval of the entire state variable (i.e. temperature)" (l.73), "in contrast to other statistical methods. . ." (l.71-73)

* L.96 add missing words: [It is] "worth mentioning. . ."

* The last two sentences of sec. 2.1 (L.108-111) should come L.93, after the mention of Sobol GSA (L.89-93) but before the description of the cost function (L.94-108)

* (For Eq.(1) and (2), you might want to add a note to point out that the Laplace operator applies with respect to the normalised space. I can see why you wrote those equations this way, to avoid defining all dimensionless variables and parameters, but since you're only using symbols carrying physical dimensions the Laplace operator is slightly misleading, strictly speaking. This pedantic comment is optional.)

* Legend of fig.1, not clear (at this point) if the times (0, 13, 26ka) refer to absolute dates (in which case they would be better displayed in inverse order) or are in chronological from an unspecified reference for 0ka.

* L.150,151 What are T31 and GR30? Specify a bit the nature of those models and/or

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add references.

* L.157, mentioning the depth of the LAB would be informative.

* Remove comma L.158 "throughout, the entire paper"

* L.174, why picking 5 parameters (rather than 4 or 6. . .)?

* Remove comma L.208 "the investigation[s] carried out so far, have enabled.."

* Legend of fig.2: Missing mention of the horizontal black line (separation of radiogenic heat and thermal conductivity parameters?) and two boxes (first five) in the figure legend.

* L.224 "However, with a significantly lower computational cost" (sentence segment, no verb. . .)

* L.224-227: a bit confusing, please rephrase with something along the lines of "Despite potentially introducing additional error sources with a relaxed tolerance, this accuracy drop can actually be considered insignificant. Indeed, sensitivity analyses are based on. . .. Since all simulations are . . . see Fig.5."

* L.230: is "however" the correct logical link?

* Sentence L.239-241 As an introduction sentence to the section, keep it at present tense, not past/conditional tense ("having been able". . . "could")

* Fig.6 branch2 should mention "with paleoclimate"

* L.251 "Fig. 7 compares the sensitivities of the thermal properties for the steady-state and transient system [with the selected initial and boundary conditions]". One would indeed expect the results of fig.7 to vary with different initial conditions and/or transient boundary conditions.

* L.267 "ar[i]sing"

* L.275, Eq(3), add something like T_top (t)=âŃŕ to make it a proper equation

* L.305 "a second discussion point [is]"

* Fig.12, the collage is appropriate, but all fonts need to be slightly increased accordingly

* L.319-320: "very similar" and "showing some major changes" are puzzling/contradictory in the same sentence

* L.343 not sure I fully understand the wording "combination of the volumetric contributions of the individual layers and their thermal properties". Thermal conductivity and radiogenic heat production are both volumetric properties. What does "and their" imply rather than " ' " ("individual layers' thermal properties")?

* L.355 "as apparent by the [insignificant] difference between. . ."

* L. 358: not sure why you put "base" between inverted commas(?)

* L.398, the wording "similar but not identical" doesn't do justice to the importance of this difference.

* L.402 "Fig. 6 branch 1 [b]"

* L.429 "a[n] additional"

* L.440 "Only the consideration of these variations could enable us.."

* L.448 "w[h]ere"

* L.450 "fourth" <- cardinal number needed (not ordinal)

* L.455: might want to rephrase "since the temperature diffuses over time towards the bottom of the model" as the heat moves upwards and the cold top Dirichlet boundary condition leads to a perceived propagation of a cold front downwards. . .

* L.474, reformulate sentence "Using the finite element method the here presented analyses computationally prohibitive, only the utilization of a surrogate model allows the execution of these analyses."

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