Point by point answers to the comments from reviewer#2 to the manuscript entitled "Effects of Transient Processes for Thermal Simulations of the Central European Basin" by Degen and 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.

The figures for the steady-state simulations (e.g., fig 2,3,4,5) have been modified accordingly. However, we did not modify the figures for the transient simulations. This was done because the use of bar-chart plots would have made a comparison hard. An explanation has been added to the paper.

* 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.

Explicit references and descriptions have been added for all figures.

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 refer also to our answer to a similar comment by reviewer#1. We have added all relevant information as Appendix to the revised manuscript.

* 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_ref^2 in the source term

|— Eq. 2:

|—— Minus sign for the diffusion term

|—— l_ref^2 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 “npartial” in front of time
Both equations have been corrected.

* 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.
We have rephrased the introduction following the main points raised by reviewer#2.

* 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.
We would like to thank reviewer#2 for the reference which we have added to the revised version of the manuscript.

* Sec. 2.1, a short sentence would be welcome to actually explain/summarise what the Sobol sensitivity analysis and Saltelli sampling routines are.
An explanation about the Sobol sensitivity analysis and the Saltelli sampling routine have been added.

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

The model description has been adopted accordingly.

* 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")

An explanation about the time steps have been added.

* 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?

An explanation of the selection of parameters and the threshold has been added.

* 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)

The text has been revised accordingly.

* 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.

The section has been changed and an explanation that the reduced parameter space is required for both the global SA and the surrogate model construction has been added.

* 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?).

The reduced model is constructed using a global error bound. This error bound evaluates the difference for the temperatures at every node between the FE and RB solutions. An explanation has been added to the paper.

* 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.

A detailed description about the chosen boundary condition has been added to Section 3.3.1.

* 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.

We added the assessment criterion for the fits. Unfortunately, with the current setup of the RB method we require an affine decomposable problem. Therefore, we require at least a piecewise linear function for the upper boundary condition. An explanation has been added to the paper.

* 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.)

The scaling factor is used to consider uncertainties of the paleoclimate data. An explanation has been added to the paper.

* L.285, the mention of "glaciation times" comes out of the blue and should be introduced.
We added an introduction to the term.

* 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.
A delivery message has been added to the end of the Section.

* 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.
In this paragraph we discuss the relative role of the different geological compartments (based on a gross differentiation between sediments and crustal and mantle domains) on the short to long(er) period effects. While it is true that in our system heat propagates upwards is an obvious conclusion (it could not be differently given the Earth's energy budget), this last statement has an important role in helping discriminating the physical reason why in our sensitivity study the sediments (upper layers) are more prominent over a relative short time period. Indeed, considering heat diffusion as the only energy transport process provides with a diffusive time scale for thermal effects to propagate, which scales as the square root of the system diffusivity over a unit of length scale. Therefore, for a thermal signal in the crust to exert an influence at the level of the sedimentary cover would require a time window of the order of its diffusive time scale times the cumulative thickness through which the signal propagates. A similar reasoning applies for a surface thermal signal to interact with the deeper domains. Based on this physical premise, it is then easy to explain why the sedimentary layers has the most prominent influence if we restrict our analysis to the short-term period. The same is true if we consider time scale of radioactive decay in the crust

which would require additional time to propagate at shallower level given tested values of production rates of crystalline rocks.

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

The sentence has been moved to Section 3.

* 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.

The conclusion has been modified accordingly.

Technical corrections

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

Has been corrected.

* 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)

Has been addressed.

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

Has been corrected.

* 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)

Has been corrected.

* (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.)

A note has been added at the end of Eq. 2.

* 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.

The legend has been modified to explain the times.

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

Explanations and references have been added.

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

We have provided a map of the topography of this isothermal and chemical boundary as a supplementary figure (together with all other main geological boundaries of interest) in the Appendix to the revised version of the manuscript.

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

Has been removed.

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

We chose five parameters because of our threshold of 0.1. An explanation has been added to the paper.

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

Has been removed.

* 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.

The meaning of the boxes and the horizontal (now vertical) black line has been added.

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

The sentence has been corrected.

* 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."

The sentences have been rephrased for clarification.

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

The logical link has been corrected.

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

The sentence has been corrected.

* Fig.6 branch2 should mention "with paleoclimate"

The figure has been modified accordingly.

* 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.

The sentence has been corrected.

* L.267 “ar[i]sing”

Has been corrected.

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

Has been addressed.

* L.305 “a second discussion point [is]”

Has been corrected.

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

The font size has been increased.

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

The sentence has been reformulated for clarification.

* 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”)?

The sentence has been changed accordingly.

* L.355 “as apparent by the [insignificant] difference between …”

Has been corrected.

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

We removed the inverted commas.

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

We provided a more explicit description.

* L.402 “Fig. 6 branch 1 [b]”

Has been corrected.

* L.429 “a[n] additional”

Has been corrected.

* L.440 “Only the consideration of these variations could enable us …”

Has been corrected.

* L.448 “w[h]ere”

Has been corrected.

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

Has been corrected.

* 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 …

Has been reformulated.

* 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.”

Has been removed since it follows in the next paragraph again.