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Discussions
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Interactive comment on "Travel time based thermal tracer tomography" *by* M. Somogyvári et al.

Anonymous Referee #1

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General Comment

Somogyvari et al. present in their manuscript a method which extends the approach of hydraulic tomography to thermal tracer test in order to characterize the heterogeneous structure of hydraulic conductivity. The approach combines well established tools of tracer tomography, like inversion schemes and grid methods, with tracer methods using heat. Problems arising from the non-conservative behaviour of heat are captured by early time diagnostics. The performance of the method was tested on a aquifer analogue, which allows to apply the method in a virtual reality. Simulated thermal tracer test were analysed with the tomography inversion procedure to gain hydraulic conductivity tomographs. The comparison with hydraulic conductivity profiles of the underlying aquifer analogue allowed to evaluate the performance of the method. Results were presented graphically and discussed, followed by conclusion on the benefits

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Discussion paper

and limitations of the method for aquifer properties characterization.

In general, the presented work is a novel and promising new method for small scale aquifer characterization. The manuscript is written in a well structured, easy understandable, clear and precise style, with a few exceptions (in sections 2 and 4, see below). The citation style - not distinguishing between "citep" and "citet" - is slightly confusing. Furthermore, the discussion on the limitation of the method could be outlined in a more elaborate way (spatial limitation of the method due to experimental conditions, "bias" of method to highly conductive material). Finally, given that the authors improve the few passages of their manuscript considering the remarks listed below, I highly recommend the manuscript for publication in HESS.

Specific Comments

1. Introduction

line 38: aspect of conservativeness should be mentioned in this context

2. Tomographical inversion procedure

line 144: The line integral appears from nowhere. A short introduction of the fundamental (transport) equation and a general/physical explanation of the line integral would be beneficial for the reader, who is not familiar with previous papers (e.g. Vasco and Gupta, 1999).

line 155: The sentence is quite unspecific. The solution refers to what, the line integral? Is it the goal or a step of the method to find a solution? What exactly is determined, $t_{tt}(x_r)$ or K?

line 157: The sentence is hard to understand in this context: "The presented method" refers to what? To the calculation of the line integral or the experimental setup of the procedure ("step-function injection temperature signal"), which was not yet introduced. I cannot see the link between the content of the paragraph and the previous subsection on the line integral.

line 176 ff: Most of the variables in Eq. 4 are not formally introduced: T, u, t, x, D. The same for T_0 and $erfc$-function in Eq. 5. Please give short explanations.

line 178-179: Please specify why the breakthrough time is associated with the peak in T'. Please state explicitly how t_{peak} is determined analytically from T' (respectively from T''; is it $T''(x, t_{peak}) = 0$?).

line 179-181: Is the sentence a general statement or an announcement of experimental adaption to the analyzing procedure?

lines 183-186: For the understanding of the derivation, it would be beneficial to introduce the proportionality factor α, the relative time to the peak time τ_α and the transformation factor f_α at the beginning, give the reader an impression on their physical meaning and then derive the explicit expressions.

line 187-190: This is a statement, which requires a certain proof. Please give a mathematical or visual argument for the validity of the simplification.

line 192 : At this stage there is no solution for τ_α presented, so the statement in brackets should be postponed to the according position.

line 194: Please introduce the Lambert Omega function and give reference how LambertW(..,..) is calculated in Eq. 12.

Eq. 12: If the authors announce a solution for τ_α they should give it in line with f_α or at least as $1/f_\alpha$.

line 201 - 212: the paragraph should be re-structured with respect to (i) the purpose of early time diagnostic, (ii) the procedure and (iii) the reasoning for the procedure.

3. Application Case

line 270: Please specify the "expansion" of the original data set (procedure of extension, new dimensions etc.)

line 284 - 298: see comment to line 507 - 515.

4. Results and Discussion

line 362: Please specify the upscaling procedure.

line 414-417: It should be shortly stated, why a factor of 2 is regarded as good match.

line 498: Subtitel "Sensitivity Analysis" suggest a rather strict mathematical analysis of the methods parameters. See also the general statement on section 4.3 below.

line 507-515 in combination with line 284 - 298: Simulating viscosity and density effects of heated water on flow requires a coupling of the flow and heat transport processes. It renders the system non-linear and makes simulations more complicated and error prone. The sentence in line 284 suggests, that these effects are taken into account, but I see a need for further explanations, especially a few more words on the density model used. It would be beneficial to convince the reader that the reported low sensitivity of the method on temperature differences is properly tested and not due to an incomplete simulation setup.

line 564-570: Why was this quantitative analysis not already used in the previous sections 4.1 and 4.3. A separate introduction of the two analyzing strategies (visual inspection and quantitative analysis) and the use - especially in section 4.3 - would be beneficial to substantiate the sensitivity analysis.

Line 569: The specification of the quantity for evaluating the result quality is quite unspecific. Maybe give a mathematical statement of how the difference between the connectivity time of the original model and the inverted results is used as measure. Are there thresholds defined or are the scenario results all compared relative to each other?

571ff: What is the motivation to use these two parameters and not other? Why are they useful, especially with regard to the fact, that they are not independent?

Line 576: It would be helpful to state again what C_w is.

Line 584-585: It is not clear to me, how the application window was constructed from connectivity time in combination with Pe_t and P'. Furthermore, please specify what marks feasible and unfeasible regions and how boundaries between them were defined.

Line 589: How was the critical value for Pe_t determined and what is the value/range (reference to Fig. 10)?

General statement on section 4.3: After reading section 4.4, I wonder why the authors separate this two sections? The basic parameters tested in section 4.3 (injection rate and temperature difference) seem to mark the most important factors in section 4.4 as well. Furthermore, in section 4.4 qualitative and quantitative criteria are introduced, which would be beneficial to substantiate the sensitivity analysis in section 4.3.

Conclusion

line 616: "of K" - Please, avoid or explain abbreviation in conclusion.

line 623-625: The sentence is not fully clear: Do the three and five orders of magnitude for Pe_t and P' refer to the tested parameters or the appropriate parameters for method application?

line 632: Specify "the values of K". State clearly what is "closely matched".

Figures and Tables

The figures should be at best comprehensible only with the aid of the legend and caption (without the running text). In this line, the following comments should be understand as advises for improving the readability.

Table 1: Superscript "1" and "2" for reference to Hyöng et al, 2014 and Bayer et al., 2015 might lead to confusion with exponents of units.

Table 2: Leave the value of groundwater temperature out, since this parameter was not varied.

Figure 1: State what ETD means or leave the abbreviation out.

Figure 3, Caption: Specify "Distribution of hydraulic conductivity K", since K in the legend is currently not defined in the caption.

Figure 5, Caption: The figure contains only to 50$\%$ reconstructed hydraulic conductivity profiles. Generally, hydraulic conductivity profiles are shown. The formulation "original" is misleading, better specify as "aquifer analogue" and "reconstructed tomograms".

Figure 6, Caption, the same as in caption of Figure 5: Specify "3D distribution of hydraulic conductivity K: a)...b) reconstructed tomograms".

Figure 7, Results are difficult to see due to figure size/visualization of results. Maybe chose different scale/range (e.g. broken y axis). Caption: Specify plot type as Histogram plot; state the total number of samples.

Figure 8, Caption: Specify "injection temperature differences ΔT".

Figure 9, Caption: Specify "injection rates Q".

Figure 10, The caption description is not appropriate: Instead of generally stating what is seen an explanation of the figure construction is given. The figure shows the method performance with respect to the dimensionless parameters thermal Peclet number Pe_t and effective injection power P' (state in word, not only using the abbreviations P' and Pe_t), including the favourable application window. The explanations on how the figure was created and the other regions should be transferred to running text and omitted from the caption.

References

Update reference of Doro et al., 2015

There are multiple typos as well as inconsistency in the use of upper and lower case letters in the references. Please check.

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