Ocean Sci. Discuss., 11, C1126–C1134, 2014
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Ocean Science
Discussions

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Interactive comment on "Reconstructing bottom water temperatures from measurements of temperature and thermal diffusivity in marine sediments" *by* F. Miesner et al.

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Received and published: 8 December 2014

First of all we whish to thank you for the comments and suggestions. We will carefully consider them. We will answer to all your points in the following:

1 Comment: "The main point of the paper is to present an inversion scheme to reconstruct bottom water temperature variation over one annual cycle. The authors argue that this is use- ful for climate change studies though I would argue that one annual cycle is not nearly long enough to resolve much about climate. Further, the fact that solutions are param- eterized in terms of a one-year-periodic function, discounts the usefulness for climate studies. It is likely that the bottom water is slowly warming (or

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cooling) in time so that a small linear trend would be added (subtracted) to the periodic annual wave. As the in- version algorithm is presently parameterized warming (or cooling) trends would not be recovered. Would this linear trend be included in the determination of the background (steady state) gradient?"

Reply: Yes, the main point is the reconstruction of one annual cycle. We are fully aware that one year is not the time scale in which climate is to be studied. Also we neglect any background trend with purpose. Our results are meant to help understand the short-term charackteristics and are therefore more usefull for oceanographers than for climate researchers. To make this clearer in the text, we will change some expressions in the review. Nevertheless, repeated measurements are simply feasable.

2 Comment: "I also think this paper would benefit from being more general. The examples are based on a single probe design, constructed by FIELAX with 22 thermistors over a 6-m length. How would the results change as a function of probe length or number of thermistors? If one is really interested in the amplitude of annual cycles on the seafloor can the probe design be optimized for this problem?"

Reply: The paper is based on measurements from a standard hetflow probe. The device is designed to measure in-situ temperatures, which can be processed to obtain thermal properties and the background heat flow. As the upper metres of sediment are "disturbed" by the bottom water temperature deviation, the device was redesigned to cover 6m depth (3m before). With a 6m-probe the heat flow can be determined even in areas with high bottom water temperature variation. A design optimization for the inversion problem is not needed.

3 Comment: "This problem is extremely similar to that of inverting continental borehole tempera- tures for ground surface temperature histories. There are already quite a few inversion schemes to handle this problem and I think this paper would be better if it built on this previous work. Previous papers have already explored many aspects of this prob- lem (noise level, tradeoffs between resolution and variance, measurement

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spacing, etc.) Good examples of these studies include Clow (1992), Shen and Beck (1991), and Shen et al., (1996) among others. What insight does this new inversion scheme give us? Is this current inversion scheme better in someway than previous inversion schemes?"

Reply: We would like to thank you for the mentioned references. The main differences between the cited papers and our approach is the representation of the forcing temperature function. It is merely our interest to reconstruct one annual cycle of the bottom water temperatur and in consequence model it as a shifted cosine. The cited authors are interested in larger time scales, which results in a high-dimensional but linear problem, while our approach leads to a low-dimensional but non-linear system. For this reason, the technique presented by, e.g., Shen and Beck (1991) is in our opinion an inadequate tool for our problem: First solving a large ill-posed system to afterwards extract a much smaller number of parameters should be avoided by directly determining the parameters.

4 Comment: "Discounting advection. The authors are working at shallow seafloor depths where bottom water temperature variations are large. They present the full forward equation (one-spatial dimension) on page 2394 and then simplify. The authors discount the advection term, because the fluid flow is likely to be low, claiming the pore volume is rather low (line 10, page 2395). In fact porosity in the upper 6 m is typically quite high with values greater than 50% (see IODP drilling results). I agree that advective fluid flow is likely negligible, but would not rule it out a priori because of the presence of seeps, etc. However, of greater consequence in these shallow continental margin settings may be heat advection due to sedimentation effects. The sedimentation effect is not discussed but should be mentioned and criteria for when both of these effects can be neglected should be given. In the context of the problem defined by the authors (in my view overly restrictive), i.e., large seasonal amplitudes, neglecting advection is probably okay. The issue is really at deeper depths where seasonal amplitudes are significant but smaller than those addressed by the authors."

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Reply: The sedimentation affects the background heat flow. In this work we do not invert the background heat flow but only the annual forcing from the bottom water temperature deviation. The background heat flow is an a-priori know input to our inverse model. In the determination of the background heat flow the sedimentation effect is considered. Also advection does occur and the data sets should be carefully inspected on advective effects. We wanted to present a simple model and thus neglect advection and also only used data sets where no advection is expected. We could possibly make this more clear in the paper.

5 Comment: "Section 5.1 is an analysis of how well the inversion algorithms work with synthetic data. One of the powerful attributes of inversion is the ability to assess solutions. I think this aspect is under utilized in this study and am curious about a number of aspects. The authors add various amount of noise to the synthetic data. Although not stated I assume they are adding zero-mean Guassian noise to the temperature measurements. I do not see that the authors give the background gradient for the synthetic example or how well the inversion scheme recovers this value. This aspect is very relevant if there is also a long term warming or cooling trend. What is the impact of uncertainties in the thermal diffusivity with depth? Line, 16, page 2400, the authors state that the geothermal gradient is a priori known, but I do not understand how this can be the case. The temperature depth profile is a combination of both the bottom water temperature variation and the background gradient. Similarly the heat transfer coefficient is not a priori known. How are these parameters known a priori? For the synthetic example I would find the paper more compelling if a real bottom water temperature data set (say of a decade or more) were used as a forcing function at the seafloor to generate the temperature-depth profile and then inverted. How well would this more realistic case (that may or may be well characterized by a cosine) recover reasonable parameters. One issue with seafloor temperature-depth measurements is that one only knows the absolute depth of the thermistors to within the thermistor spacing. That is you can tell whether or not a thermistor is in the sediment, but you don't know how far into the sediment the top thermistor has penetrated. With a thermistor

string of 6-m and with 22 thermistors gives a thermistor spacing of about 29 cm. So the depth of any individual thermistor is not known to better than about 29 cm. Is this uncertainty included in the analysis and tested? These are clearly small uncertainties given the amplitude of the annual signals used in this paper, but will be relatively larger in regions with small (but significant) annual variation. If the background gradient is say 60 mK/m then a depth uncertainty of 29 cm translates to a temperature bias of X C. How does uncertainties in the thermal conductivity (or thermal diffusivity) impact the solution. How does the layering relate to the depth of thermistors. Where do layer boundaries occur?"

Reply: Yes, we are adding zero-mean Gaussian noise. We will mention this in the review.

We do not invert the background heat flow. It is determined during the processing of the measurements. The processing procedure is described by Hartmann and Villinger (2002). The heat flow probe penetrates the sediment to a depth of 6m. This is deep enough to determine the background heat flow. Some measurements were taken with an older device, with only 4m probe length and the heat flow could not be determined. Here we used literature values. We will make this more clear in the review.

The synthetic data is generated using the cosine function so that the stability of the inversion could be investigated. In Section 5.2 we used a Fourier series as a more realistic bottom water temperature function. These experiments showed that the main paramters (mean temperature, amplitude and phase delay) can be reconstructed even if the real forcing function is not a plain cosine. Experiments with real data sets could be done in future work.

The impact of uncertainties in the thermal diffusivity is not yet explored. Also the uncertainties in the depth are not inverstigated on their influence on the inversion results. As we don not invert the background heat flow we figure the effects are rather small. However, this may be investigated in the future.

The modeled layering is directly related to the depth of the thermistors: A measurement dictates the properties of the layer above it.

8 Comment: "The abstract reads more like an introduction than abstract. There is very little quan- titative information here. No results or conclusions are given. The first sentence does not convey much. I do not know of any studies where marine heat flow measurements are made to document steady state heat flow as a source of energy (2nd sentence). This point is not discussed in the main text. In the second paragraph the abstract states that the aim of the paper is to reconstruct bottom water temperature variations over the past two years. This statement should come at the top of the abstract, and in reality the paper discusses reconstructions over one annual cycle, not two. On line 3, page 2394, the paper says several years, and that deeper measurements are used to reconstruct older climate history. This statement is confusing because there is no deeper data presented in this paper. The third paragraph states that an inversion operator and two common inversion schemes are used, but doesn't specify them. Is there a reason to not to specify these?"

Reply: Yes, the abstract should be reviewed to read more specific and consistend. We reconstruct one annual cycle and it says somewhere two. This needs to be changed. The example you gave (line 3, page 2394) is reviewing other authors work and they do use deeper data. The sentence on heat flow as a source of energy should be deleted. The inversion schemes are specified in the main text.

9 Comment: "I think this paper could be improved by a reorganization. In that way there would not need to be so many parenthetical statements that refer to other sections. The forward model can be completely discussed before the inverse problem is introduced. Personally, I would like to see the synthetic example fully developed before moving to real data. In this way one would defer the discussion of example data (line 12, page 2397) until after the synthetic data had been analyzed."

Reply: This is an interesting suggestion. We will think about this.

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10 Comment: "I am wondering if a different terminology for steady state can be used. In marine environments the thermal field is never really in steady state."

Reply: In the introduction we are stating that the heat flow is steady only in time scales of decades (line 8, page 2393). As is is the solution to the steady state heat equation we would like to stick to this terminology.

11 Comment: "Line 9, page 2393. The statement that periodically changing water tempera- tures propagate into the sediments to different depths is incorrect. The heat equa- tion shows that the earth is a low-pass filter with different frequencies attenuating at different depths. This phrasing is repeated multiple times through the paper."

Reply: This is maybe a little INAPPROPRIATE expressed. We will think of better ways to describe this.

12 Comment: "Line 15, page 2393. The statement that constant surface tempera- ture leads to a linear increase of temperature with depth neglects heat sources or sinks, advec- tion, and potential changes in material properties. The second part of this sentence that heat production of the lower earth can be determined from a linear temperature increase is also wrong. Wish it were true though."

Reply: Yes, we will rewrite this.

13 Comment: "Line 7, page 2399. Can references be given for the determination of thermal diffusivity from the temperature decay of a heat pulse?"

Reply: Hartmann and Villinger (2002) describe the whole processing method.

14 Comment: "Line 9, page 2399. The statement that the in-situ thermal gradient can ‘then’ be calculated should probably come before the discussion of the thermal conductivity determination."

Reply: Yes, we will change this.

15 Comment: "Line 18, page 2399. The authors cite the accuracy of the thermistor

string just after discussing the vibrocorer system. I assume that the accuracy of the thermistor string is for both systems, but it is not clear. Also the accuracy of the thermal conduc- tivity and thermal diffusivity need to be given since these quantities play a role in the determination of inverted parameters."

Reply: Yes the accuracy is the same for both systems. We will make this clear in the review.

16 Comment: "The paragraph starting line 1, page 2402 seems out of place."

Reply: We will consider this in the review.

17 Comment: "Why are so many decimal places retained in the solution parameters, line 1, page, 2405, and Table 1? Are the authors really implying their results are good to tenths of milliKelvin?"

Reply: No this is not what we wanted to imply. The decimal places are retained in the tables so that the difference between the two inversion schemes could be seen. However, you are right, this is confusing. We will round the results in the text and in the tables to 3 decimal places. Also we may write a short sentence on the accuracy of the results.

18 Comment: "Section 5.2, page 2405 and Table 1. Here the Fourier series is first introduced but again only a single annual cycle is estimated."

Reply: Yes and this is done on purpose. Further experiments could try to invert more than one cycle but here it would go beyond the scope of this paper. As mentioned in comment 5, the Fourier series is used to simulate more realistic bottom water temperature data.

19 Comment: "Section 6, line 24, page 2408. Here the authors state they are assuming a ho- mogenous half space. I thought we were dealing with a layered media."

Reply: Yes, we are sorry, this is out of space and will be deleted in the review.

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Interactive Comment

20 Comment: "Line 2, page 2409. Here the authors state that the mathematical model in equation 6 neglects a lot of short periodic noise. I am not sure what they mean by noise in this context. Is not this part of the signal? Given that the model solves for only one period I would say it neglects a lot of short and long period information."

Reply: Yes, the formulation is better. We will consider it in the review.

21 Comment: "I do not understand the point of section 6.1. Here the authors are discussing the accuracy of reconstructed parameters and contend that an accuracy of less than 1 K in their A and B parameters is all that is needed. I think this statement needs to be better supported."

Reply: Thank you for this comment, we will rewrite this Section in the review.

22 Comment: "The Conclusion section reads more like a section on future work."

Reply: Yes, maybe it does. We may change the title to "Conlcusions and future work".

Interactive comment on Ocean Sci. Discuss., 11, 2391, 2014.