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Interactive comment on "Sensitivity of airborne geophysical data to sublacustrine permafrost thaw" *by* B. J. Minsley et al.

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General comments

The paper examines the potential of AEM to detect the thawing stage of talik structures in sublacustrine permafrost. The study is working purely with 2D (?) synthetic data. The geophysical approach presented here is of high interest and importance for near-subsurface geophysical surveys and can be considered an example for hydrogeophysical studies in different environments. Studies, such as the presented one, can be used to enhance interpretation of AEM surveys over permafrost terrain. I would like to see this paper published in TC, but would appreciate if the following comments could be addressed:

I summarize the workings steps of the presented approach. If I made a mistake here, you could consider changing your text to a better understanding of this fact:

1. Obtainment of a realistic subsurface model for a talik structure. A previously developed hydrological algorithm (SUTRA) is used, to simulate a 1000 years of talik development, for a couple of different starting models with different lake levels and hydraulic gradients.

2. Derivation of electrical conductivity from the hydrological model parameters. An advanced form of Archies law was used. A variety of parameters are considered, as for instance temperature and ice-content.

3. For the derived electrical conductivity models (for various Talik evolution stages) 1D AEM forward calculations were done, in order to calculate synthetic AEM surveying data. Such data were calculated for subsurface models of every time step of the Talik evolution within the 1000 years.

4. A study to examine, how accurate the synthetic AEM data can be inverted to true subsurface conductivity models, using statistical approaches. Goal is to obtain likelihoods for parameters such as: number of layers, thickness of layers etc.

The Abstract and Introduction should more prominently state, that this paper describes a study with synthetic data ONLY. 2D or 3D?

I understand, that the study examines the ability of AEM to detect not only Talik structures in general, but to detect different stages of a 1000 years of Talik evolution. If this is correct, please state this more clearly already in the Abstract and Introduction. However, I doubt, that in reality you can assign an inverted AEM resistivity model to a stage of a 1000 years of Talik evolution. You rather will obtain a general idea of where thawed areas are situated.

TCD

8, C2883–C2889, 2015

Can you explain in the text how the variance of 100'000 different resistivity models is created by the McMC appoach? Changing starting models? Changed inversion parameters?

Please specify which kind of inversion the McMC approach uses. I understand that also the McMC study needs a "normal" inversion algorithm?

How large is the noise added to the synthetic data?

I would appreciate if the study addresses, how accurate the resistivity models would be, without the McMC method, just simple inversion with one result and one RMS value, as this is the standard you are going to improve.

I would appreciate, if the novelty in this approach is more clearly stated. For me as a reader it was not entirely clear, whether the novelty was in the combination of several other studies to a new approach or the application of other approaches in a series, or whether there was a significantly new calculation step involved?

Specific comments

I needed quite some time to extract important information about the study from the text (synthetic only, AEM study for a lot of stages throughout the 1000 years, ...). I made suggestions to improve the text towards a quicker understanding of these facts. In italic are text passages from the paper, in red I put questions and comments from my side, where I think more stringent and exact writing could improve the understanding and clearness of the text.

Abstract Page 6080: Sorry for being pedantic but the abstract is the most important section of a paper, and I would like to understand it, without reading the entire paper:

Several scenarios are evaluated that consider the response (of what???) *to variable hydrologic forcing from* (better at?) *different lake depths and* for different *hydrologic gradients*.

TCD

8, C2883–C2889, 2015

The model includes a physical property relationship that connects the dynamic distribution of subsurface electrical resistivity based on lithology as well as ice-saturation and temperature outputs from the SUTRA groundwater simulator with freeze/thaw physics. Can you break it into two sentences? It took me quite some time to get the meaning of the sentence ... After I have read the entire paper, the sentence was easy to understand, but anyway, in the Abstract it should be easy to understand without any prior knowledge about the study.

Electrical resistivity models are used to simulate AEM data in order to explore the sensitivity of geophysical observations to permafrost thaw. It is clear that you need electrical resistivity models as an input to simulate AEM data. Can you state more specifically what is special about the resistivity models? Something like a range of resistivity models, which reflect the progressing permafrost thaw, are used as an input to calculate synthetic AEM data in order to ...

Synthetic geophysical data (Too general, what kind of data, the AEM data?) *are analyzed with a Bayesian Markov chain Monte Carlo algorithm that provides a probabilistic assessment of geophysical model uncertainty* (too general, what kind of model?) *and resolution*.

Major lithological and permafrost features are well resolved (by the resistivity model inverted from the AEM data?) *in the examples considered.*

A final example compares AEM and ground-based (on a lake? Maybe the title sublacustrine is not entirely correct?) *electromagnetic responses for their ability to resolve shallow permafrost* (still sublacustrine? .. After I have read the paper it was clear that this ground study was done for the regions outside the lake, however, then the title is not covering this part of the study) *and thaw features in the upper 1–2 m below ground.*

Introduction: Page 6082

...*expected for various permafrost hydrologic conditions* occurring within the 1000

TCD
8, C2883–C2889, 2015

years of simulated Talik formation.

Methods: 2.1. Is the model 2D or 3D? How is ice content calculated? I would appreciate a sentence or two describing the major factor responsible for thaw in the simulation?

2.2. The theory seems to be well described and cited with literature. I could not see any major flaw on the theory how it is introduced, but must admit, that I am not an expert in the presented Theory. It might be good when a dedicated expert to electrical conductivity material relations is having a look on chapter 2.2.

Page 6081: *However, few techniques are capable of assessing the distribution of permafrost, and most approaches only capture a single snapshot in time.* Are you talking about geophysical surveying techniques? In a 1000 years evolution, isn't every geophysical survey just a single snapshot in time?

... physical properties (e.g. electrical resistivity) are only *indirectly sensitive to physical ...*

Chapter 2.2.

. . . associated magnetic fields created by *the transmitter coils induce electrical currents in the*

Data are simulated at the nominal survey elevation of 30m above ground surface using the one-dimensional modeling equations described in Minsley (2011). Please explain what is special about the equations in Minsley (2011), or add something like . . . which follow the standard theory given in e.g. Ward and Hohmann (1988)

2.4.:

resistivity values throughout the 1000 year lake talik simulations. . . . resistivity values for various (or yearly, what was the time resolution of the SUTRA model?) stages throughout the 1000 years of Talik evolution?

an ensemble of 100 000 resistivity models is inverted from the same synthetic AEM

TCD
8, C2883–C2889, 2015

data set (did I understand this correctly?) *,according to the Metropolis–Hastings algorithm (Hastings, 1970; Metropolis 5 et al., 1953).*

3.2.:

Geophysical data (not shown) are simulated AEM data? Please specifiy.

Discussion Page 6095:

Understanding the hydrogeophysical responses to permafrost . . . You mean the AEM responses? Please specify.

. . . *coupling geophysical predictions* . . . Please specify geophysical

... analysis of geophysical uncertainty ... Please specify geophysical

as well as thermally and hydrologically induced changes in permafrost over time (Figs. 8 and 9). Are you talking about the 1000 years period? Can you dicuss how resistivity changes over 1000 years is of practical use in real surveys? . . . Okay,later in the discussion chapter you address this issue. But the sentence confuses at this position in the text.

The Bayesian McMC analysis provides useful details about model resolution and uncertainty that cannot be assessed using traditional inversion methods that produce a single "best" model. I would appreciate a discussion about how wrong you are, when using traditional inversion, without McMC. Isn't traditional inversion also a part of the McMC analysis? See General comments as well.

Summary:

. . . *associated with the co-evolution of permafrost and hydrologic systems*. . . The evolution happens over hundreds of years, how is AEM useful here. Are you saying, that the presented model study allows to assign inverted AEM resistivity models to a stage of permafrost evolution?

TCD
8, C2883–C2889, 2015

Table 1: How is the difference between Unit 1 and 2 characterized? Both have the same porosity. Okay, at the end of chapter 2.2. you tell it is differentiated by Xi. You could make this clearer in Table 1 and earlier in the text. I understand Xi to be the major controlling quantity and should be highlighted more prominent.

Figure 10c. Can you comment on the deeper high conductivity artifact at app. r=750 m? How is this possible with synthetic data?

Technical corrections

Interactive comment on The Cryosphere Discuss., 8, 6079, 2014.