**Review of the Article gmd-2013-137**

# GEOtop 2.0: simulating the combined energy and water balance at and below the land surface accounting for soil freezing, snow cover and terrain effects

**by S. Endrizzi, S. Gruber, M. Dall'Amico, and R. Rigon**

## General comments:

This paper presents a novel modeling approach to simulate the surface energy and water budget in mountain terrain, solving in a coupled way water and energy fluxes, considering snow and freezing soil dynamics in a numerically consistent way. The presented model could lead to major advances in cold processes science and engineering applications, and I recommend its publication in GMS after minor revision.

The paper presents a new version of the existing GEOtop model with significant new improvements. The GEOtop model has been already widely applied in a variety of contexts, ranging from catchment scale hydrological applications, hillslope hydrology, runoff prediction, surface energy fluxes and vegetation dynamics, snow modeling, comparison with remote sensing products.
The application presented in this paper is limited to snow and permafrost modelling over bare soil. However, the GEOtop 2.0 simulator, presented for the first time in this paper, could also be applied to the above-mentioned research topics. This enhances the impact of the work presented in this paper.
This is also a point that could be better highlighted in the paper introduction.

Regarding the paper content, I believe that the presentation of the model is accurate and the validation exercises are sufficient and present quite good results. However, I have some minor concerns mostly regarding:

- The organization of the Introduction.
  Some parts could be rearranged in order to improve clarity and logical flow. See specific comments with some suggestions.
- The presentation of what is different in this GEOtop version with respect to the previous version.
  On the one hand, the major advancements in this version are substantial and could be better underlined in this paper (see previous comment). On the other hand, the contributions of the developers of the previous versions of the code could be acknowledged more in detail.
- The presentation of the results and validation exercise. This part is quite compact and some good results are moved to the supplementary material. The presentation lacks of many details on test sites characteristics and input data that can be useful to better understand the results.
  I understand the authors' choice, given the length of the paper and the space needed for the model description. I understand also how, when a new model is published, we reviewers want a detailed model description, an extensive validation and a short article, which are needs almost

impossible to fulfill altogether. So I leave to the authors to evaluate what is feasible with a reasonable amount of work.

I propose two options to improve this part:

1. Move the very technical paragraph 5.6 to the Appendix and expand the paragraph 6 including some figures from the supplementary material. Please see the suggestions the specific comments section.
2. Split the paper in two, if the Journals Editor allows it. GEOtop 2.0 (I) model description; GEOtop 2.0 (II) model test and validation. This second option would certainly require more work, but the valuable results shown in the supplementary material could deserve a second paper.

## GMS evaluation questions:

1. *Does the paper address relevant scientific modelling questions within the scope of GMD? Does the paper present a model, advances in modelling science or a modelling protocol that is suitable for addressing relevant scientific questions within the scope of EGU?*
   Yes, the paper presents a new model, which simulates the combined energy and water balance at and below the land surface accounting for soil freezing, snow cover and terrain effects.
2. *Does the paper present novel concepts, ideas, tools, or data?*
   The presented model could lead to substantial advances in cold processes science and engineering applications.
3. *Does the paper represent a sufficiently substantial advance in modelling science?*
   Yes, the paper presents a new version of an existing model with substantial new improvements.
4. *Are the methods and assumptions valid and clearly outlined?*
   Yes, the modeling approach is valid. Some minor improvements are possible to improve clarity.
5. *Are the results sufficient to support the interpretations and conclusions?*
   Yes, the validation exercises presented are sufficient to show model reliability and potential.
6. *Is the description sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? In the case of model description papers, it should in theory be possible for an independent scientist to construct a model that, while not necessarily numerically identical, will produce scientifically equivalent results. Model development papers should be similarly reproducible. For MIP and benchmarking papers it should be possible for the protocol to be precisely reproduced for an independent model. Descriptions of numerical advances should be precisely reproducible.*
   Yes, the theoretical approaches are clearly described. The model code is available. May be the simulation input files of the presented simulations could be added as supplementary material.
7. *Do the authors give proper credit to related work and clearly indicate their own new/original contribution?*
   In general yes. In the introduction the originality of the presented new developments could be even better specified. Previous work can be reported more in detail. See general comments above.
8. *Does the title clearly reflect the contents of the paper? The model name and number should be included in papers that deal with only one model.*

Yes, in the title there is the name GEOtop 2.0

9. *Does the abstract provide a concise and complete summary?*
   The abstract has an unconventional structure, but it is clear. It is even too concise and it can be expanded including more results.
10. *Is the overall presentation well structured and clear?*
    In general yes. The introduction could be better structured, as well as part of the results. Appendix order should be reorganized. I have some suggestions in the specific comments.
11. *Is the language fluent and precise?*
    Yes.
12. *Are mathematical formulae, symbols, abbreviations, and units correctly defined and used?*
    Yes very clear.
13. *Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated?*
    Yes, some part in the results could be expanded, a table added, and some supplementary material moved to the main text. I suggest moving some of the Figures contained in the supplementary material in the main text of the paper, since they contains valuable results.
14. *Are the number and quality of references appropriate?*
    In general yes.
15. *Is the amount and quality of supplementary material appropriate? For model description papers, authors are strongly encouraged to submit supplementary material containing the model code and a user manual. For development, technical and benchmarking papers, the submission of code to perform calculations described in the text is strongly encouraged.*
    Yes. The code is available. The supplementary material contains code configuration file. May be also a template for the simulations presented here could be added. The model manual is not fully updated to the presented code version, but I trust the Authors it will be available soon.

## Specific comments:

**Abstract**

See comment 9 above. This abstract is quite "minimalistic".
You may specify that the model allows for a complete treating of complex terrain. Also the potential of the model in terms of snow modeling and hillslope hydrology could be highlighted.

**Introduction**

Introduction is complete in terms of contents, but I've found sometimes hard to follow the logical flow. Below are some suggestions on how to improve it.

**P 6280 Line 21 "**representation of more complex systems can inform decisions about their simplification**"**

Please add a reference (may be some work of K. Beven? Or of R.A Freeze, 1969? Freeze, R. A., & Harlan, R. L. (1969). Blueprint for a physically-based, digitally simulated hydrologic response model. J. Hydrol., 9, 237–258.)

**P 6281 Line 4-12** where GEOtop is introduced. It seems to me this block alters the logic flow. I would better place it at page 6282 after line 17.

**P 6281 Line 7 "**GEOtop covers the full spectrum of hydrological fluxes**".** This seems, on my advice, a little reductive. GEOtop is much more than this and has a much larger application spectrum.

Other processes can be modeled. In fact, a unique feature of GEOtop is the fact that the new developments presented in this paper could be applied also in other contexts. This allows GEOtop to model the interaction with other hydrological, ecological and geomorphological processes in an interdisciplinary research framework (runoff production, evapotranspiration, vegetation, soil moisture dynamics, hillslope stability, …). Please incorporate this kind of considerations in the text.

Some more references on the model could be added. See also the considerations at the beginning of the general comment section.

**P 6281 Line 12-19** the block where permafrost models are reviewed and **P 6281-2 Line 20-7** the block where distributed hydrological models are reviewed. Paper writing praxis recommends moving from general to specific, so I suggest to shift the two blocks. Also, for symmetry reason, a table for hydrological models similar to Table 1 can make this paragraph smoother.

**P 6283 Line 14-17** This last sentence is almost "philosophical" and quite difficult to understand. Please extend it and explain better. I've understood the meaning only after I came trough Figure 4.

Mention here also Appendix A. It is not mentioned elsewhere in the text.

**P 6284 Line 5** Here I would put in the main body text the first two equations of Appendix B B1 and B2. It could be clearer introducing the main two heat and mass equation in the main text. Then leave all the other calculations in the Appendix.

**P 6284 Line 21** What do you mean with gauge pressure?

**P 6285 Line 12** "freezing soil characteristic curve" Which equation is? What about move the paragraph 2.1.1 here and make a separate paragraph for the thermal conductivity parameterization?

**P 6286 Lines 7-13** This could be moved before, immediately after mention Eq. 2.

**Eq. (9)** Psi is negative in unsaturated soil?

**Par 2.3 Water flow equation**. Is soil storativity considered?

**Eq. (13)** I do not understand well this equation. I went trough the Gottardi and Venturelli paper and I did not found this equation. I assume some new derivation it has been made. Could you add some further details on the physical meaning of the different terms of this equation?

**P 6292 Lines 9** I would add for more clarity: "Then, in Section 4 the case with complex terrain is presented."

**Par 3.1 Shortwave radiation**. Before it can be mentioned that in the model, depending on the input data available, radiation components can be either assigned directly in input or calculated by the model.

**Eq. (22-24)** mo and w are external input parameters or are parameterized by the model? And how?

**P 6293 Lines 25; P 6295 Lines 20; P 6296 Lines 13** What happens when vegetation is present? Such parameterizations will change. It might be worth to mention here that GEOtop deals also with the case of soil covered by vegetation, but that the topic has been presented elsewhere (Endrizzi and Marsh, 2010).

**P 6296 Lines 20;** Do you mean the concept of displacement height? (Stull, 1988; Garrat, 1992)

**P 6296 Lines 12-13;** Please reformulate. This ratio is not clear.

**P 6299 Lines 25;** Appendix D. It should C. The appendix C is not yet mentioned.

**P 6300 Lines 16;** Reformulate as: The effects … are also considered in a simplified way in the model.

**P 6304 Lines 3;** I do not understand … if the compactation rate increases with temperature, how can double with a very cold temperature of -17?

**P 6304 Lines 15-20 and 20-25;** You discuss here some limitations, but it is not clear at the end if the model deals or not with such issues.

**Par 5.6 Discretization**. This part is interesting and innovative. The approach with mobile layers seems smart, but it is also quite technical. To shorten the paper, an option could be to move this in Appendix.

**P 6308 Lines 4-10;** I suggest giving this information before at p 6307 line 20. A scheme with the snow layer discretization could clarify the approach.

**Par 6 Testing GEOtop**. This part is also interesting and deserves to be expanded.
I suggest to:

- Divide the text in separate paragraph for the different tests performed.
- Include more information on the input data, study area and model setup for the Col de la Porte case study, eventually expanding Appendix C or including the appendix in the body text.
- To put in the paper a Figure with the modeled and observed ensemble averages of the results of Col del la Porte.
- A little more information on what is Crocus.
- Add a scheme or a Figure with and some more information on the input data, study area and model setup for the Jungfraujoch steep bedrock case study, eventually expanding Appendix C or including it in the body text.

**Par 7 Simulation experiment**.

- Could be possible to add in the supplementary material also the model configuration files of such a numerical experiments?

**P 6311 Lines 5;** Which is the aspect of this synthetic catchment? S-N?

**P 6311 Lines 15;** May be a table with the 6 simulation settings could be clearer.

**P 6311 Lines 18;** Meteorological forcing is taken at 1595 m a.s.l., but the synthetic catchment is at 3000 m a.s.l. How data have been adjusted for elevation? With time-constant lapse rates?

**P 6312 Comments on Figure 3;** This part is quite confusing for me. To improve it I suggest split the discussion focusing on two points. 1) The effect of model configuration (1D vs. 3D); 2) The effect of slope (steeper vs. flatter hillslopes). It would be also interesting if the Authors were able to speculate if the observed differences could be related to some physical properties.
Figure 3 might become clearer if you join the symbols with lines or separate in different subplots the effect of model configuration from the effect of slope.

**P 6313 Comments on Figure 4;** Nice analysis! When you come to this Figure you understand the cryptic and almost philosophical last sentence of the introduction. I suggest only to put in the subplot labels of the simulation configuration, otherwise it is difficult to understand this from the caption (i.e 1) AL 5deg 0-D; 2) AL 10deg 0-D; …)

**P 6313 Comments on Figure 5;** Figure 5 is nice and full on information, a good scientific artwork. The discussion is focused on frozen soil, but it could be possible to use this Figure also to demonstrate model's capabilities in simulate snow pack evolution. In fact, the Figure nicely shows snowpack time evolution and its ice and water content partitioning, according to snowpack transformation. Moreover, there are two interesting features that it would be good to discuss with references on the existing literature on frozen soil.

- The presence of an intermediate "dry layer". It has been observed in nature?
- The fact that only at the end summer there is a single moment in which there is a water transfer from the surface layer to the deeper layers. I guess this is due to the nonlinear behavior of soil hydraulic conductivity with respect to temperature and water content, which is a distinctive feature of the GEOtop model. The fact that deep water table recharge is a quite nonlinear process in seasonally frozen soils could have several relevant implications. Please discuss this with references to literature.

**Conclusion**
Please add a final consideration that, while here only applications for cold region are presented, the model could be applied for a much wider range of environments and scientific issues.

**Appendix B**
The equations are very clear. Please add some more comments on their meaning and better highlight what is new and what is deriving from existing literature.

**Appendix C**
As already told, this part could be expanded. At least separate the different case studies in different paragraphs.

**Appendix D**
**P 6320 Lines 9;** Nothing is told on precipitation input, which data are used and how they are spatially distributed. Please add this.