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Interactive comment

Interactive comment on "A Simple Temperature-Based Method to Estimate Heterogeneous Frozen Ground within a Distributed Watershed Model" *by* Michael L. Follum et al.

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We would like to thank Referee #2 for their comments and suggestions. We appreciate all their insights about the paper and hope our responses address their suggestions and facilitate further discussion.

Main Issue #1, The frozen ground index method proposed is highly parameterized and requires many forcing data often not measured operationally (cloud cover and other radiation parameters).: The modCFGI method still requires fewer types of forcing data

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and fewer parameters than energy balance models. For example, the attached figure compares the forcing data requirements for two energy balance models (COUP and SHAW) along with the data requirements for the pre-existing CFGI model and the new modCFGI model. The energy balance models both require radiation data that, as the reviewer mentions, are not readily available for many watersheds. In contrast, modCFGI model requires cloud cover data, which are routinely measured at most airports (data archived in the U.S. at the National Centers for Environmental Information, https://www.ncdc.noaa.gov/) as well as many meteorological stations. Although it is difficult to determine the total number of parameters that are required by the energy balance models, the modCFGI likely requires specification of many fewer parameters, which reduces the potential for equifinality. The modCFGI method can use soil moisture to simulate the depth of frozen ground (as presented in this study), but soil moisture is not required to simulate the presence/absence of frozen ground in this model. If only the presence/absence of frozen ground is required, the number of parameters further reduces. In the revised paper, we plan to include a short discussion of the data and parameter requirements in the Model Application section and a discussion of the model's use in data-sparse environments in the Conclusions.

Main Issue #2, New methods include some improved representation of the snowpack, but not all parts of the snowpack (e.g. sublimation).: The RTI snow model (see Section 2.3 on Page 5) maintains the same structure as the TI snow model, which is based on SNOW-17 (Anderson 1973; Anderson 2006). Like SNOW-17, both the RTI and TI models can account for interception / sublimation /condensation through an adjustable factor (SCF) (Anderson 2006; Follum et al., 2015), but this factor is typically applied uniformly to the watershed. Lines 19 and 20 on Page 3 will be modified to better reflect how the TI snow model accounts for interception and sublimation (via the SCF parameter). A clearer statement on page 5 will describe how in watersheds with multiple forest types (deciduous, evergreen, mixed, etc.) the interception, sublimation, and drip from the various canopies can be very different, and therefore a method (as applied in the RTI snow model) is needed to estimate these processes based on land cover type.

Main Issue #3, Modified model improves physical representation, but it does not represent an advancement of our understanding of frozen ground processes and is not transferable.: We believe this paper provides three significant advances in our understanding of frozen ground. First, it provides an evaluation of an existing temperature-index frozen ground model (the CFGI model). Although temperature index methods are often used in practice (lines 13-16, page 2), they have been rarely tested against observations of frost depth. Thus, the results provide useful insights into the performance of this class of models. Second, the new modCFGI model is better suited for use in a wide range of watershed models than other existing frozen ground models. Existing temperature index methods poorly reproduce the spatial variations in frozen ground because they do not fully account for the influence of topographic and canopy variations, as shown in this study (Conclusions 3-5 on page 24). Reproducing the spatial pattern of frozen ground is expected to be critical in capturing its role in flood production. The modCFGI model has better performance than the CFGI model in this respect (Figure 6 on page 19, and Table 6 on page 21). In comparison to energy balance models, the modCFGI model requires less forcing data and fewer parameters, and it does not require simulation of soil moisture (which is not explicitly simulated in many watershed models). Thus, we believe the new modCFGI model has significant practical value beyond its use in this study. Third, the study shows that much of the spatial variation of frozen ground in the watershed is controlled by insulating ground litter (Lines 5-7 on Page 2). We believe the role of litter cover has not been fully appreciated in previous studies. The method used to represent litter depth is also transferable to other models. In the revised paper, we plan to include a clearer statement of the paper's goals (in relation to the literature) in the Introduction section, a short discussion of data and parameter requirements in the Model Application section, and a discussion of the model's use in data-sparse environments in the Conclusions.

REFERENCES:

Anderson, E.A.: National Weather Service River Forecast System - Snow Accumulation and Ablation Model, Technical Memorandum NWS Hydro-17, November 1973, 217 pp., Silver Spring, Maryland, 1973.

Anderson, E.A.: Snow Accumulation and Ablation Model - SNOW-17, NWSRFS User Documentation, U.S. National Weather Service, Silver Springs, MD, 2006.

Bayard, D., Stähli, M.: Effects of frozen soil on the groundwater recharge in Alpine areas, Climate and hydrology in mountain areas. Wiley, Chichester, 73-83, 2005.

Flerchinger, G., Saxton, K.E.: Simultaneous heat and water model of a freezing snow-residue-soil system I, Theory and development, Transactions of the ASAE, 32(2), 565-0571, 1989.

Follum, M.L., Downer, C.W., Niemann, J.D., Roylance, S.M., Vuyovich, C.M.: A radiation-derived temperature-index snow routine for the GSSHA hydrologic model, Journal of Hydrology, 529, Part 3, 723-736, 2015.

Molnau, M., Bissell, V.C.: A continuous frozen ground index for flood forecasting, Proceedings 51st Annual Meeting Western Snow Conference, Canadian Water Resources Association, Cambridge, Ontario, 109-119, 1983.

Scherler, M. Hauck, C., Hoelzle, M., Stähli, M., Völksch, I.: Meltwater infiltration into the frozen active layer at an alpine permafrost site, Permafrost and Periglacial Processes 21(4), 325-334, 2010.

Shanley, J.B., Chalmers, A.: The effect of frozen soil on snowmelt runoff at Sleepers River, Vermont, Hydrological Processes, 13, 1843-1857, 1999.

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	Energy Balance COUP Model (Scherler et al., 2011)	Energy Balance SHAW Model (Flerchinger and Saxton, 1989)	Temperature-Index CFGI Model[1] (Molnau and Bissel, 1983)	Modified Temperature-Index modCFGI Model Proposed
Precipitation	✓	✓	✓	✓
Air Temperature	✓	✓	✓	✓
Relative Humidity	✓	✓		✓
Wind Speed	✓	✓		
Global or Net Radiation	✓	✓		
Incoming Long-Wave Radiation	✓			
Cloud Cover				✓

[1] Assumes CFGI is combined with a Temperature-Index Snow model (which requires precipitation)

[2] Using the RTI snow model which requires precipitation and relative humidity (both RTI and modCFGI require cloud cover)

Fig. 1. Required forcing data for the COUP, SHAW, CFGI, and modCFGI frozen ground models.

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