Reply on RC2

Lianyu Yu et al.

Author comment on "STEMMUS-UEB v1.0.0: integrated modeling of snowpack and soil water and energy transfer with three complexity levels of soil physical processes" by Lianyu Yu et al., Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2020-416-AC2, 2021

Anonymous Referee #2

Referee comment on "STEMMUS-UEB v1.0.0: Integrated Modelling of Snowpack and Soil Mass and Energy Transfer with Three Levels of Soil Physical Process Complexities" by Lianyu Yu et al., Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2020-416-RC2, 2021

[1] RC2: This study presents a new integrated modelling of snowpack and soil water/energy transfers, called STEMMUS-UEB, presenting three levels of soil transfer complexities. The model is evaluated on one site equipped with soil temperature, moisture and energy fluxes sensors. The performances of the 3 options of the model are discussed. This is an interesting paper but quite difficult to follow and some questions need to be addressed before further consideration for publication.

Response: We thank the reviewer very much for the insightful comments. Please see our specific response below.

[2] RC2: A general issue is that the test site seems to be poorly influenced by snow. I am therefore wondering if it is really appropriate for the model evaluation.

Response: Great thanks for this critical comment. As partly explained in **[2] RC1**, this work is to describe the integrated soil-snow model STEMMUS-UEB and further confirm that the STEMMUS-UEB model can identify and understand the snowpack effect, even for regions with intermittent snowfall events.

The selected site is covered by seasonally frozen ground with mostly episodic snowfall events. Compared to the sites with heavy snow events and thick snow layers, this site is indeed less influenced in some sense, e.g., snowmelt runoff. Nevertheless, the snow accumulation and snowmelt infiltration and their effects on the subsurface soil can still be identified, which indicates how sensible the STEMMUS-UEB can represent such intermittent snowfall events.

In addition, such conditions (seasonally frozen ground with episodic snowfall events) commonly exist in the high mountain cold regions around the globe, while its implications for subsurface water and heat dynamics (therefore, the subsequent impact on land-atmosphere interactions) are rarely studied. Nevertheless, the STEMMUS-UEB can be applied for the sites with thick snow cover or perennial snowpack, since the coupled model is constructed to account for the physically-based processes.

From the perspective of experimental measurements, it is indeed helpful to enrich the snowpack-relevant data (e.g., high-resolution observation of the spatiotemporal field of wind speed, precipitation, and snowpack variations) and make them more constraint and less uncertain. We add some text in Section 4.1 Limitations.

[3] RC2: The model description in the main paper lacks on the description of the thawing/freezing processes: how is the fraction of liquid/solid water calculated and what about the soil hydraulic conductivity? how the rainfall/snowfall partition is done?

Response: We added the description of the thawing/freezing process in Section 2.1.

a. how is the fraction of liquid/solid water calculated and what about the soil hydraulic conductivity?

The mutual dependence of soil hydrothermal states makes the frozen soil a complicated thermodynamic equilibrium system. The frozen soil physics considered in STEMMUS-FT include three parts: i) the ice blocking effect on soil hydraulic conductivities (see Supplement Sect. 2.2.2); ii) the inclusion of ice effect in the calculation of soil thermal capacity/conductivity (see Supplement Sect. 2.2.8); iii) the exchange of latent heat flux during water phase change periods. Based on Clausius Clapeyron relation, which characterizes the phase transition between liquid and solid phase in a thermal equilibrium way, the soil water characteristic curve (e.g., van Genuchten, 1980) is extended to consider the freezing temperature dependence, i.e., soil freezing characteristic curve (Hansson et al., 2004; Dall'Amico et al. 2011). The fraction of soil liquid/solid water at a given temperature was then calculated prognostically with the soil freezing characteristic curve. The soil hydraulic parameters were further used in the Mualem (1976) model to compute the soil hydraulic conductivity. The ice effect is considered by reducing the soil saturated hydraulic conductivity as the function of ice content (Yu et al., 2018).

b. how the rainfall/snowfall partition is done?

Two precipitation types, i.e., rainfall and snowfall, are discriminated by the dependence on air temperature.

[4] RC2: Figure 2 is too small and difficult to read

Response: We rescaled the y-axis (from [0,1] to [0.1,0.7]) and enlarged Figure 2 to make it easy to read.

[5] RC2: Figures 6 and 7 are also difficult to understand: the precipitation events are rainfall or snowfall? what is the amount of SWE during that periods? It is surprising to see that the model without snow modeling performs generally better in the simulation of the latent heat flux compared to the snow model. It would be necessary to elaborate a bit

more on that result.

Response: Figures 6 and 7 were modified correspondingly. Both the precipitation amount and the simulated snowfall (SWE) component were presented in the updated figures. The rainfall is the precipitation minus the snowfall component.

For the discrepancies in terms of latent heat flux for the selected periods, it is possibly due to the inaccurate precipitation measurements and interpretation, in terms of either the amount, time of precipitation, or the partition of precipitation into solid and liquid forms. Moreover, the simple air temperature-precipitation type relation maybe not suitable for this region. As argued by Ding et al. (2014), air temperature is not the best indicator of precipitation types. Other factors, i.e., relative humidity, elevation, and wet-bulb temperature, are also very relevant and should be taken into account. The uncertainties in discriminating the precipitation types can be the possible reason here. The episodic snowfall events are challenging to be well captured and simulated by the current snowpack models. The snowpack accumulation, melting process and water and energy partitioning of snowpack into snow sublimation and the snowmelt are with uncertainties as well.

We add some more text to explain and discuss such limitations in Section 4.1.

Nevertheless, this work focused on identifying the snowpack impacts on the underlying subsurface water and heat dynamics. And, the difference between the model simulations with and without the snow module can be attributed to the different surface water and energy regimes. Models without snow regard the precipitation as the rainfall, i.e., liquid form of water, adds on the topsoil surface immediately. Most of the incoming water directly contributes to the infiltration process.

While for the model with the snow module, it considers snowpack-related processes, accumulation, sublimation, melting process and then the water infiltration process. Compared with the model without snow module, the increase of surface soil moisture is usually delayed and less significant.

The difference in surface water status results in different gradients of matric potential. Models without snow have a larger gradient of matric potential for the top surface soil layer. Then more amount of isothermal liquid and vapor fluxes (q_{Lh}, q_{Vh}) were generated contributing to the total latent heat flux.

Only with consideration of two-phase flow (ACD, ACD-air), the difference between models with and without snow module can be identified during the daytime after winter precipitation events. Generally, from the foregoing, considering the vapor flow/airflow retarded the total surface water transfer (Figure 6 a vs. b/c).

Identifying the difference and understanding what lies behind these differences between models with and without snowpack can be only made by the two-phase flow model (ACD, ACD-air). These are the highlighting points and benefits of the developed integrated soil-snow model STEMMUS-UEB.

[6] RC2: In the title, I suggest to replace "mass" by "water" to be more precise.

Response: We replace "mass" with "water" in the title.

[7] RC2: The English need to be revised

Response: We carefully revised the English as suggested.

[8] RC2: The abstract need to be rewritten to better highlight the main findings of the work

Response: We have rewritten the abstract to highlight the main take-home messages of this work.

The main findings of the work are briefly summarized here as:

i) we developed an integrated soil-snow-atmosphere model, STEMMUS-UEB, which takes advantage of the easily transferable and physically-based description of the snowpack process by UEB snowmelt model and the detailed interpretation of the soil physical process by STEMMUS-FT model.

ii) the proposed model can well capture the dynamics of daily average albedo, latent heat flux, and the snowpack effect.

iii) three mechanisms, i.e., surface ice sublimation, snow sublimation and increased soil moisture, contribute to the enhanced latent heat flux after winter precipitation events.

iv) Physically realistic analysis of the snowpack effects (e.g., LE enhancement) can only be reproduced by the advanced coupled STEMMUS-UEB (ACD, ACD-air). The basic coupled version of STEMMUS-UEB (BCD) models, however, cannot provide a realistic description of the soil water and heat transfer.

Reference

Dall'Amico, M., Endrizzi, S., Gruber, S., and Rigon, R.: A robust and energy-conserving model of freezing variably-saturated soil, The Cryosphere, 5, 469-484, https://doi.org/10.5194/tc-5-469-2011, 2011.

Ding, B., Yang, K., Qin, J., Wang, L., Chen, Y., and He, X.: The dependence of precipitation types on surface elevation and meteorological conditions and its parameterization, J Hydrol, 513, 154-163, https://doi.org/https://doi.org/10.1016/j.jhydrol.2014.03.038, 2014.

Hansson, K., Šimůnek, J., Mizoguchi, M., Lundin, L. C., and van Genuchten, M. T.: Water flow and heat transport in frozen soil: Numerical solution and freeze-thaw applications, Vadose Zone J, 3, 693-704, 2004.

Mualem, Y.: A new model for predicting the hydraulic conductivity of unsaturated porous media, Water Resour Res, 12, 513-522, https://doi.org/https://doi.org/10.1029/WR012i003p00513, 1976.

Van Genuchten, M. T.: A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, Soil Sci Soc Am J, 44, 892-898, https://doi.org/10.2136/SSSAJ1980.03615995004400050002X, 1980.

Yu, L., Zeng, Y., Wen, J., and Su, Z.: Liquid-Vapor-Air Flow in the Frozen Soil, Journal of

Geophysical Research: Atmospheres, 123, 7393-7415, https://doi.org/10.1029/2018jd028502, 2018.

Yu, L., Fatichi, S., Zeng, Y., and Su, Z.: The role of vadose zone physics in the ecohydrological response of a Tibetan meadow to freeze–thaw cycles, The Cryosphere, 14, 4653-4673, https://doi.org/10.5194/tc-14-4653-2020, 2020.

Please also note the supplement to this comment:
https://gmd.copernicus.org/preprints/gmd-2020-416/gmd-2020-416-AC2-supplement.pdf