The Cryosphere Discuss., 5, C1031–C1035, 2011
www.the-cryosphere-discuss.net/5/C1031/2011/

The Cryosphere
Discussions

Interactive comment on "Modeling the impact of wintertime rain events on the thermal regime of permafrost" *by* S. Westermann et al.

S. Westermann et al.

swestermann@awi.de

Received and published: 29 September 2011

We are thankful for the constructive comments and thoughtful suggestions, which have contributed to improving our manuscript. In the following, we give a detailed response to all isuues raised. Text passages from the revised manuscript are in italic font, while the reviewer's statements are given in bold.

This manuscript presents modeling results of the effects of rain on snow on soil thermal regime under a warming scenario. The presented modeling is inspired/guided by observations in the Ny Alesund, Spitsbergen. The manuscript is well written, fluent, technically correct, but not surprising. However, this manuscript highlights the importance of the rain on snow that has been dis-

cussed in earlier papers but has not received as much attention as it probably deserves. In conclusion, although not very exciting, this manuscript describes in detail the potential and important effects of rain on snow on permafrost and as such deserves to be published. Below I have listed a number of minor comments that should be addressed prior to publication.

Page 1699, Row 27: In this context the publications of Ming-Ko Woo and his coauthors should be at least acknowledged if not further discussed. (Marsh and Woo, 1984, WRR; Marsh and Woo, 1984, WRR; Woo and heron, 1981, AAR; and Woo and Xia, 1996, Nordic Hydrology). Also Grenfell and Putkonen, 2008, WRR, document a severe rain on snow in Arctic Canada.
We have acknowledged the publications at the corresponding locations in the Introduction.

1700, 5: Also Putkonen et al, 2009, EOS.
Ciation added

1700, 13: "Drift" should be "current"
changed

1704, 28: Replace "the onset bedrock at this depth" with "that bedrock is found at this depth"
changed

Pages 1703-1704: I am afraid that the detailed derivation of thermal properties may give a bit of a misleading picture of the system. First, many of the methods applied are empirical and may or may not work well in this setting. Second,

frost heave is well known phenomenon in this area and will effectively throw off many of the above values as ice lenses will form within the soil. I do not suggest that the calculations presented in this paper cannot be done, but I suggest that we may not know the exact values of the thermal properties and resulting temperatures as well as the mathematics may imply.
Parameterizing natural processes is the only possibility in numerical earth system modeling. These parameterizations can not be more than approximations of the true natural processes. In any case, the chosen parameterizations must be adequately documented if not already presented in literature before which we do in this work. In addition, we compare the values obtained from the parameterizations with measured values from the study site. We find a satisfying agreement, which gives us confidence in our results and the applicability of the employed parameterizations. The in-situ values for the thermal conductivity have been obtained by fitting modeled to measured soil and snow temperatures (see Roth & Boike 2001, Westermann et al. 2009 for details) for soil domains of more than 30cm thickness, which is much larger than e.g. typical ice lenses. Therefore, these values must be regarded as "bulk thermal conductivities" representing the best approximation of a heat conductivity model to a naturally much more complex system.
We deeply agree with the reviewer about the general uncertainty of the parameterization of thermal properties, particularly for Arctic soils. Although these parameterizations are part of any Earth System Model, there is no comprehensive study available, that could recommend a certain parameterization based upon a statistical analysis of a sufficient number of in-situ measurements, conducted with comparable methods over a wide range of environmental and soil conditions.

1706, 18-22: It is unclear how critical these assumptions are as no justification is given for them. If this paper is a proof of concept type of analysis then it may suffice to say that such ratios are typical (the statement needs to be backed up by a reference).

These assumptions are naturally critical. It is, however, unavoidable to make such assumptions as a consequence of the slush-classification and the limited accuracy of the precipitation measurements. As this work is indeed a proof-of-concept-analysis, we have adjusted the liquid-to-sold ratio to obtain an adequate fit of the GST data, which we have clearly stated in the mentioned section.

1707, 8: It is unclear if the snow is settling in the model as I understand that the density is increasing which would imply settling. This is obviously important for the heat conduction through the snow pack.
In the model, the snow does not settle in the sense of a density increase. The snow density can only change as a result of refreezing rain, and this change is generally small, except at the bottom, where ice layers form. In measurements of snow density profiles performed in 2008 (Westermann et al. 2009), we found a relatively constant density throughout the snow pack, which is most likely related to the compaction of snow due to wind redistribution shortly after snowfall. However, we found increasing snow grain sizes towards the bottom of the snow pack in the 2008-measurements (unpubl. data), which is most likely the reason for the increasing snow conductivities noted by Westermann et al. (2009). As a rough approximation, we assume a linear increase of the snow conductivity over time, so that the aging of the snow is accounted for in a phenomenological way.

1710, 12: Change "weighting" to "weighing"
Weighting is a common term employed in statistics, and the usage is correct in this context.

1718, 16: Remove "a"
done

Literature:

Grenfell, T. and Putkonen, J.: A method for the detection of the severe rain-on-snow event on Banks Island, October 2003, using passive microwave remote sensing, Water Resources Research, 44, W03 425, doi:10.1029/2007WR005929, 2008.

Marsh, P. and Woo, M.: Wetting front advance and freezing of meltwater within a snow cover: 1. Observations in the Canadian Arctic, Water Resources Research, 20, 1853–1864, 1984a.

Marsh, P. and Woo, M.: Wetting front advance and freezing of meltwater within a snow cover: 2. A simulation model, Water Resources Research, 20, 1865–1874, 1984b.

Putkonen, J., Grenfell, T., Rennert, K., Bitz, C., Jacobson, P., and Russell, D.: Rain on snow: little understood Killer in the North, Eos Transactions AGU, 90, 221, doi:10.1029/2009EO260002, 2009.

Roth, K. and Boike, J.: Quantifying the thermal dynamics of a permafrost site near Ny-Å lesund, Svalbard, Water Resources Research, 37, 2901–2914, 2001.

Westermann, S., Lüers, J., Langer, M., Piel, K., and Boike, J.: The annual surface energy budget of a high-arctic permafrost site on Svalbard, Norway, The Cryosphere, 3, 245–263, 2009.

Woo, M. and Heron, R.: Occurrence of ice layers at the base of High Arctic snowpacks, Arctic and Alpine Research, 13, 225–230, 1981.

Zanotti, F., Endrizzi, S., Bertoldi, G., and Rigon, R.: The GEOTOP snow module, Hydrological processes, 18, 3667–3679, 2004.

Interactive comment on The Cryosphere Discuss., 5, 1697, 2011.