

The Cryosphere Discuss., referee comment RC1  
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## Comment on tc-2021-255

Anonymous Referee #1

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Referee comment on "On the energy budget of a low-Arctic snowpack" by Georg Lackner et al., The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-255-RC1>, 2021

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### Overall Comments:

The authors have collected a nice dataset and have produced a potentially very informative and useful paper, examining the snowpack energy balance in a low-Arctic snowpack. I appreciate the difficulty of working in such an environment and I believe that the measurements and modelling have the ingredients for a paper that warrants publication. However, I think there needs to be some additional analysis in order to obtain the best possible interpretation of the data. Some of the time series presented would be much easier to interpret if temperatures were included. Important temperatures would include, air temperature, snowpack surface temperature, average or bulk snowpack temperature, and soil temperature at 4 and 14 cm depth. Soil temperatures would provide an indication of when the soil water was freezing. It would be helpful to be able to either see the separate shortwave and longwave radiation balances, or to augment the net radiation with observed and simulated albedo values. The authors need to state whether the precipitation data were corrected for gauge undercatch and if so, describe the procedure. The precipitation data cannot be used to force a model in their raw, uncorrected state. Some time series of simulated SWE (with points for late winter observations) and simulated and observed snow depth would be interesting. Since there is no mid-winter melt happening, I am interested in knowing how the observed snow depth time series are affected by snowfall events, whether some depth increases are caused by snowfall or drifting, and whether depth decreases are caused by drifting, sublimation or settling and wind packing. Definitive answers may not be possible but evidence in the data may produce some answers. There are not a lot of comprehensive energy budget studies on low-Arctic snowpacks and so making the most use of the data would result in a more useful paper.

### Specific Comments:

Line 7-10: I find the following a little confusing: "At the snow surface, the heat flux into the snow is similar in magnitude to the sensible heat flux. Because the snow cover stores very little heat, the majority of the heat flux into the snow is used to cool the soil." I understand that the sensible heat flux is usually downward and I assume that the heat fluxes calculated from the temperature gradients near the top of the snowpack showed a similar heat flux. However, I find "the majority of the heat flux into the snow is used to cool the soil" to be confusing. A downward sensible heat flux into the snow would not cool the soil. The upward soil heat flux into the snowpack would cool the soil. I would reword this part.

Line 15: One could surmise that the flora and fauna as well as the local populations have adapted to the conditions, which is why there is such concern about changes to the environment affecting the flora, fauna and the traditional way of life of the local inhabitants.

Equations 1 and 2: If  $Q_s$  is derivable for equation 1, it could inform the results from equation 2.

Line 40-42: I agree that lack of energy balance closure in eddy covariance systems is not restricted to Arctic environments or winter conditions. However, the ability of eddy covariance systems to measure fluxes has been documented in many papers as being severely limited under periods of low wind speed and strong stability, which damps turbulence. The prevalence of such conditions may therefore affect the degree to which observations at a given site are affected, even if the underlying mechanisms are the same. Was energy balance closure worse under calm, stable conditions? Figure 1 appears to show a ridge close to the site and I wonder whether drainage flows are affecting the energy imbalance because of the topography.

Line 95: The authors should specify that the CO<sub>2</sub>/H<sub>2</sub>O analyzer is an open path system which may experience interference from snow and blowing snow.

Line 111: Is a 10 cm spacing of thermocouples starting at -4 cm sufficient to compute the ground heat flux accurately?

Lines 125-130: Was coordinate rotation applied to the eddy covariance data to account for the slope? A brief summary of procedures for processing and QA/QC would be informative and useful. Were any  $u^*$  thresholds applied?

Line 147: What does the model suggest for the snowpack density evolution? How much did it vary from year to year in the snow pits and in the models? I see later that the error is considered greater than assuming a constant density but the sign of the error and reasons are not discussed.

Line 156: I would not classify a temperature error as a percentage. Is that in °C or K? I suspect that a percentage error for thermocouples would refer to the temperature difference between the thermo-junction in the snow and the reference temperature junction. An error in the accuracy of the reference temperature thermistor would likely be expressed in fractions of a degree Celsius over a range of temperatures.

Line 176: Again, a percentage error in a temperature is difficult to interpret.

Line 178: Is the error for precipitation 0.15 mm per half-hour, 0.15 mm per precipitation event, or 0.15 mm per time interval during which precipitation was recorded? Okay I looked it up. Accuracy is specified as 0.1% of full scale, and 0.15 mm is the repeatability, while sensitivity is 0.1 mm. If the 1500 mm version of this gauge was employed, then the accuracy is 1.5 mm over a season, based on what actually entered the gauge and closer to 0.15 mm per event, but this does not account for snow undercatch caused by wind deflection around the gauge. Were the snowfall data corrected for undercatch of snow. There are equations available for correcting this gauge with a single Alter shield based on wind speed at the gauge height. Smith (2006) found that a Geonor T200B with a single Alter shield caught only 36% of the snow caught by a Double Fence Intercomparison Reference (DFIR) gauge (the WMO standard) in Bratt's Lake Saskatchewan. Were the precipitation gauge data corrected for undercatch, and if so, which equation was employed?

Figure 2: Do the tick marks for each month represent the start of the month or the mid-point? It appears to be the start.

Regarding discussion of sensible and latent heat fluxes: Rather than using the terms 'increases' and 'decreases', it may help to include direction, such as strong upward or strong downward or weak upward or weak downward fluxes.

Line 298-302: Errors in the simulated snowpack albedo could cause differences in daytime net radiation, and this could be checked and plotted, although I suspect there is more error in the longwave component. A phase shift may be a result of poor thermal conductivity simulations or issues related to simulated fluxes and stability corrections. Figure 8 would be easier to interpret and would be more informative if air temperature and the radiative skin temperature of the snow surface (based on outgoing longwave radiation) were also plotted. QG while not at the surface, could inform Figure 8.

Figure 9: This figure would be easier to interpret if air, snowpack and soil temperatures (and snow surface radiative temperature) were plotted as points or lines. Early in the season, the sensible and soil heat fluxes to the snowpack are not enough to balance the radiative losses. Soil temperatures would provide information about when the soil water is freezing, which represents an energy source under the net radiometer although below the

snow/soil interface. The differences between soil and snowpack temperature and the timing of soil freeze are important pieces of information that would help to interpret what is happening. Given that the soil heat flux is supposed to represent the flux at the ground surface, or in this case at the soil/snow interface, what sort of values for QG would be obtained by using the gradient between the lowest snow temperature and the 4 cm soil temperature with an average thermal conductivity?

Line 409-414: Flow separation and drainage flows may be a factor at this site. Could a temperature profile be examined using the radiative temperature of the snowpack surface, the air temperature from the tower, and any unburied snow temperature sensors? It might give some idea of the level of stratification at night. Radiation errors might prevent the use of unburied snow temperature sensors during the day.

Line 415-418: It would be interesting to see the heat fluxes calculated at the bottom of the snowpack, compared with those calculated in the soil column (and those using the 4 cm soil temperature and the lowest snow temperature).

### **Corrections and minor suggestions:**

Line 14: I would change "freezing air temperatures" to "air temperatures less than 0°C".

Line 15: I am not sure that "constraints" is the right word here. Perhaps "challenges".

Line 30: Just to be precise, I would state "...and QG is the ground heat flux at the snow/soil interface".

Line 38: Change "snow" to "snowpack".

Line 53: Since the term "sublimation" can refer to the conversion of water vapour to ice, even though the authors use "condensation" for this process, I would change the wording from "However, according to Liston and Sturm (2004), sublimation in the Arctic can make up as much as 50% of the total winter precipitation" to "However, according to Liston and Sturm (2004), sublimation losses in the Arctic can deplete as much as 50% of the total winter precipitation."

Line 186-7: Do the authors mean that when there is snow on the ground in the model, the surface is always 100% covered with snow, as opposed to a fractional cover based on SWE or depth?

Line 225: This sentence is written with the assumption that the reader is familiar with the low pressure systems in the region. I would reword it as: "Snow usually accumulates quickly in the fall as precipitation events are more frequent due to the large low pressure systems which are prevalent at that time of year."

Line 226: Change "rates drops" to either "rates drop" or "rate drops".

Line 362: Change "recomnd" to "recommend".

Line 369: Change "sublimation accounts for only 5% of winter precipitation" to "submiltion losses represent only 5% of winter snowfall".