Author comment on Anonymous Referee #2

This paper discuss the grazing impacts on ground thermal conditions using onsite ground surface measurement, and snow and vegetation surveys. Writing style is well organized and text is understandable. Also the author's discussion and conclusion are consistent with the measurements, then I would recommend this acceptance after following revisions.

We thank the referee for the positive evaluation of our manuscript. In this response, we have gone through the comments and suggestions made by the referee, which are shown in *blue italics*. Our response is given in normal font whereas our suggestions for the revised manuscript are provided in **bold text**.

Methods

Resolution of GST measurements: the sensor accuracy is 0.5degree, is this enough to support your discussion?

We agree with the referee that the numerical accuracy can be a limitation for the analysis and discussion of temperature difference below this accuracy. However, the main discussion topics and conclusions of our study relate to the differences in annual and seasonal (summer and winter) ground surface temperatures between our plots, which generally are larger than this numerical accuracy of the iButton temperature loggers (Table 5 and 6). Also, we limit the impact of individual logger measurements on our results by using daily averages of several logger measurements within each plot (See caption Tables 5 & 6 and Figures 11-13). In the revised manuscript we suggest to include the following clarification in line 123: **From the individual logger measurements, we calculate daily average GSTs within each plot, which we use throughout our analysis (Section 4.3).**

Furthermore, the 0.5°C numerical accuracy of the iButton temperature loggers can preclude analysis and discussion of phenomena that are confined to temperature intervals below this accuracy, i.e. the phase change of water. For this reason, we have refrained from discussing differences between the plots with respect to the timing of thawing and freezing throughout the manuscript.

Your open site is just outside of the fence, where snow accumulation could be influenced wind disturbance of the fence and differ from site far from the fence.

We thank the referee for this remark. Local disturbances of the wind field can indeed drive differential accumulation of snow, typically leading to preferentially deposition of snow on leesides. During our winter surveys at the Terelj and Udleg sites, we did observe snow wind drifts behind topographic features in the wider area. These drifts indicate the main wind direction to be along the main valley, which at both sited is oriented roughly East-West (Figure 1). For our study, we have however selected our plots to be adjacent to fences that run parallel to the main valley, and the effect of any preferential snow deposition should thus be limited. To clarify this in the revised manuscript, we will include the following text:

Line 80: **We note that the main wind direction in Terelj along of the main valley (East – West, Figure 1c), and that plots are placed either side of a fence that runs roughly parallel to the main valley (Figure 1a).**

Line 101: **Similar as at the Terelj site, the main wind direction in Udleg is along the main valley (East-Northeast – West-Southwest, Figure 1d), and both the open and fenced plots are placed so they avoid lee effects behind the adjacent fences (Figure 1b).**

Can you show the location of vegetation, LAT and snow surveys on the map(Figure 1) ?

We agree with the referee that specific information on the location of our snow, vegetation and LAI samples should be included in the manuscript. Indeed, our field data includes both samples collected in the immediate vicinity (<= 2m) of the temperature logger locations (Figure 1c & d), as well as surveys conducted in the near surroundings (<= 10m, within the respective fenced/open plots). No data was collected at the exact logger locations as to avoid any disturbances of the ongoing temperature measurements. Throughout our manuscript, we have used the term “survey” for data collected in the near surroundings of the logger locations:

- The survey of vegetation height and litter layer thickness/bare soil fraction at 30 points in the open and fenced plot in Terelj (Section 4.1.1, Figure 3)
- The survey of 100 snow depths and 25 snow densities within a visually undisturbed and a disturbed area in the open plot in Terelj (Section 4.2.1, Figure 7).

Conversely, the remaining field samples are taken in the immediate vicinity of the logger locations:

- All hemispherical images used to estimate LAI (Table 3, 4 & A1)
- The vegetation and litter heights reported for Udleg and Terelj, except for the abovementioned survey (Section 4.1.1 & 4.1.2, Table 3 & 4)
- All snow depths and densities reported fin Section 4.2.1 and 4.2.2, except for the abovementioned survey

To properly identify the location of our field samples in the revised manuscript we will:

-Mark the sections in which the snow and vegetation surveys were done in Figure 1c.

-Add the following text passage:

Line 151: **These measurements of vegetation and snow properties were done in the immediate vicinity of the GST logger location (Table 1, Figure 1), as to avoid disturbance of the ongoing measurements. In Terelj, we also conducted a more comprehensive survey of vegetation and snow cover in winter and summer of 2023 to capture the small-scale spatial variability in the near surroundings of the logger locations (Figure 1c).**

Snow was measured only in one day. Did snowfall. clearing animal footprints, occurr before this day?

We thank the referee for this remark. While we did only surveyed snow cover once, it is likely that areas trampled prior to previous snowfall events were covered with fresh snow. Indeed, our measurements of snow depths and bulk densities from fenced plot A in Udleg, where we observed extensive trampling by livestock (Figure 8a), suggest previous disturbances. Here, we observed a high variability of snow densities at locations with similar snow depths, ranging from ca. 110 to 300 kg/m^3 (Figure 9). These high densities could be the results of previous disturbances that compacted the snow cover, that since have been infilled during subsequent snowfall events. We discuss the effect of snow infilling of disturbed areas in lines 378-382 in the manuscript, while the effect of animal trampling on wintertime GSTs at our sites is discussed in line 429-437. Furthermore, we will include the following in the revised manuscript:

Line 248: **However, locations visually undisturbed at our time of visit could have experienced previous disturbances that since have been infilled with snow, which could lead to the large variability of snow densities in fenced plot B (Figure 9).**

Results

Consider the difference in daily cycles of GST at fenced and open sites?

We agree with the referee that the diurnal GST cycles are likely affected by the grazing intensity. However, the consideration of such short-term differences of GSTs is outside the scope of our study. Throughout the study we present daily average GSTs (Section 3.1), which we use to analyse and discuss grazing induced differences on monthly, seasonal, and annual timescales.

L235 doubled 'Figure 7' and L248 doubled 'Figure9'

We thank the referee for this remark and will correct these typos in the revised manuscript.

Discussion

L313-320 This part is just summary of previous chapter, and could be shortened or omitted.

We agree with the referee that this paragraph can be reduced, and suggest the following, shortened version for the revised manuscript:

In this study, we use measured GSTs and observations of grassland vegetation and snow cover from the Khentii Mountains in Central Mongolia to quantify and compare the different temperature regimes across contrasts of grazing intensity and topography. Overall, we find that the exclusion of grazing livestock allows for higher and denser vegetation cover (Table 3 & 4) and a dampened seasonal cycle in GST (Figure 11 & Figure 13). The largest differences between intensely grazed and ungrazed plots are observed at the south-facing Terelj site, with monthly GST differences ranging from -5.8°C colder to 6.8°C (Figure 12). The grazing induced differences are are less pronounced at the north-facing Udleg site, where monthly GST differences range from -4.1°C to 3.6°C (Figure 12). The effect of intense grazing on MAGSTs is however small, with the open plot being 0.7°C warmer than the fenced plot in Terelj, while it is 0.4°C colder in Udleg (Table 5 and Table 6).

L335 could be 'Grazing and snow impcat on ground surface temperatures'

We thank the referee for this remark. In section 5.1 “Grazing impact on ground surface temperatures” we do indeed also discuss how snow cover affects ground surface temperatures at our sites. The snow effects we discuss are however related to interactions with direct and indirect grazing effects such as: reduction of thermal insulation due to snow trampling by livestock (line 416-437), increased sublimation from disturbed snow surfaces (line 359-366), snow capture of standing litter at ungrazed sites (line 374-378), and snow infilling of disturbed areas by wind redistribution (line 378-383).

While studying the interactions between snow, terrain and vegetation at our highly continental sites would be interesting, it is outside the scope of the current study. We thus suggest keeping the original section heading also in the revised manuscript.

L364-366 Do you have any image of snow condition such as onsite photo or satellite image?

We agree with the referee that photographs of snow surface microtopography would strengthen the discussion. However, we were not successful in obtaining any photographs clearly showing the small-scale snow structures with the camera equipment available during our field visit. There is however available satellite imagery showing the intermittent nature of snow cover on steeper south-facing slopes. While we cite Sentinel-2 imagery (available through the Copernicus Browser; ESA (2024)), we suggest to include example images in the manuscript in the form of an appendix:

Appendix C – Satellite imagery of snow conditions

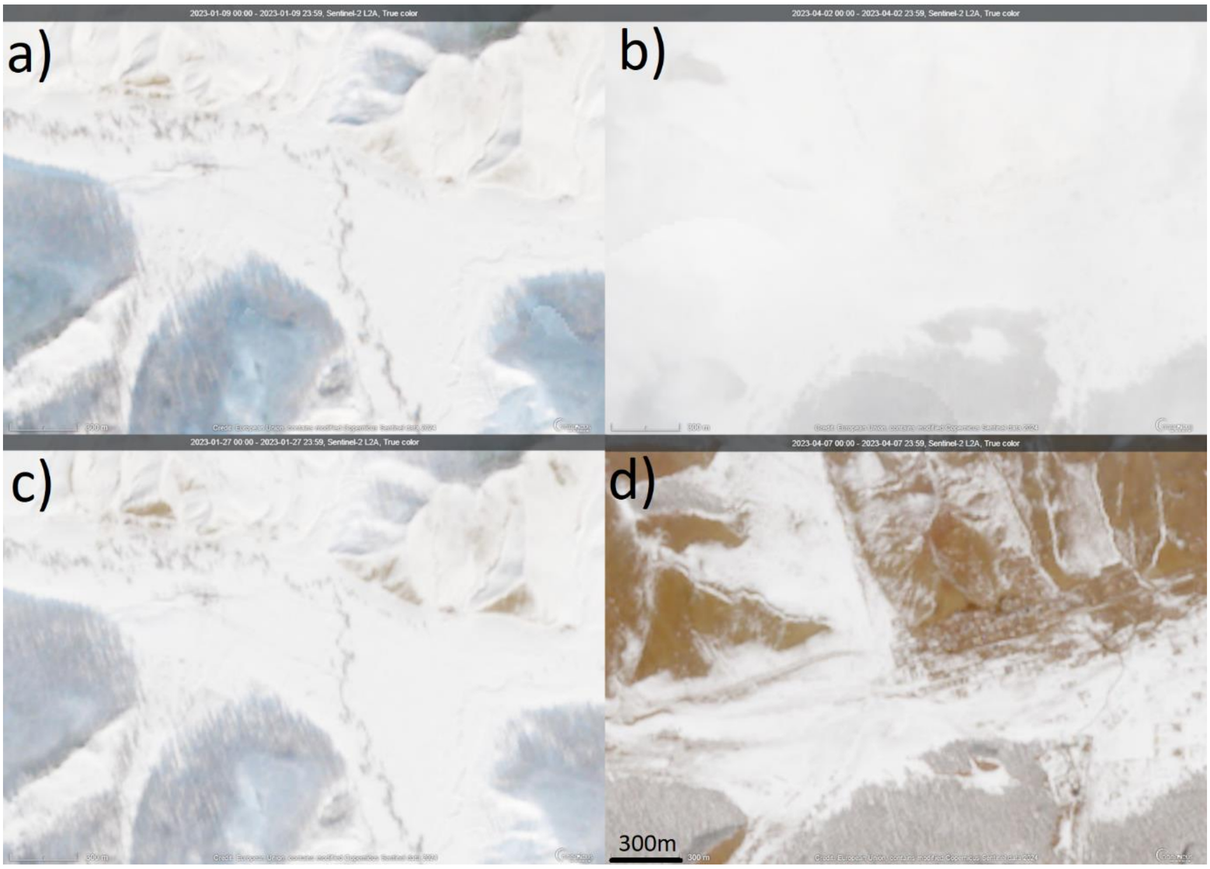

Figure C1: Sentinel-2 L2A true color composite imagery of snow conditions in Udleg on a) 9.1.2023 and c) 27.1.2023, and in Terelj on b) 2.4.2023 and d) 7.4.2023. The imagery from Udleg shows how snow preferentially ablating from steep south-facing slopes even during the low solar radiation available in mid-winter. The Terelj imagery shows widespread ablation of snow on south-facing slopes in late winter. All imagery has the same scale and is downloaded through the Copernicus Browser (ESA, 2024).

L369-371 Unclear to see snow drift in the Fig 8.

We thank the referee for this remark. Figure 8 does indeed not show wind drifts, but rather the classical features associated with wind erosion of the snow surface. We will clarify this in the revised manuscript by including the following modifications:

Line 251: **The variability in snow depths in the open is likely linked to local wind redistribution of snow, consistent with observed wind erosional features at the snow surface (Figure 8b).**

Figure 8: Snow conditions in the Udleg study area on 25. February 2023. a) Fenced plot A (left of fence) has received less trampling than fenced plot B (right of fence). b) Open site with scattered livestock tracks and wind erosional features at the snow surface.

Line 369: **In the open plot at Udleg, wind is channelled through the main valley, and we observe snow structures associated with wind erosion the measurement sites (Figure 8b), as well as deeper snow drifts in the surrounding.**