Reviewer #3: Prof. Masaki Hayashi (doi.org/10.5194/egusphere-2024-3933-RC3)
GENERAL COMMENTS

The manuscript presents an application of microgravimetry to estimate seasonal and long-term changes of water mass within a rock glacier. Using a case-study example, the authors present creative and innovative methods of data acquisition and analysis, which have the potential to provide a new tool for alpine permafrost research in broader regions around the world. The study will make significant contribution to advancing our understanding of rock glaciers and other permafrost landforms. The manuscript is very well written and organized. The data analysis is rigorous and figures are of high quality. I have a few minor suggestions to improve the clarity (please see below for specific comments). One important issue that needs a bit more careful attention is the attribution of observed mass changes to solid and liquid water. I feel that the authors dismiss the contribution of liquid water too casually. I will elaborate more on this in my specific comments below.
We thank Prof. Hayashi for his thoughtful review of our manuscript. As he is one of the most well-known researchers working on alpine hydrogeology, receiving his positive assessment of our work is highly encouraging. We will make sure to give more weight to the role of groundwater as a Δg source in Section 6.4 in the final manuscript (see comments below). The majority of the considerations in our manuscript were focused on Murtèl, but it is important that we remain general in scope in the relevant parts of the Discussion.

SPECIFIC COMMENTS

Line 97. Its thickness. Does this refer to the thickness of the rock glacier or the active layer? I had to stop and think for a moment. Please explicitly state it.
Another reviewer mentioned this, too. We will clarify.

Line 113. The reader expects the 'Method' section here. I later discovered that both 3 and 4 are describing methods. Please change the section title to '3 Methods: Gravimetry' and '4 Methods: Snow ….'.
Correct, we did split the methods into 2 separate sections. We will modify as suggested.

Line 216-218. Usually, there is a significant correlation between depth and density of snowpack. Therefore, depth-dependent snow density function is commonly used in hydrological studies. It becomes evident later that the effect of snow is secondary to gravity measurements, but at this point the reader does not know how (in)significant it is. Please add a sentence to justify why a single value of density is used in calculation.
We will clarify this in the final version.

Figure 2. Please annotate '01', '02, … in Figure 2a, so the reader does not have to go back and forth between Figure 1, Figure 2, and Table 1.
Figure 3. Please annotate '05', '06', … in Figure 3b.
Another reviewer also suggested this for Figs 2 and 3. We will annotate.

Line 314. The authors attribute the 'dominant' gravity-change signal to ice storage. This is not unreasonable, but the justification is not convincing. Changes in the water table of supra-permafrost groundwater has been observed at numerous locations around the world, both in alpine and subarctic environments. Also, a quick glance of Figure 3 gives the impression that 08 is not likely underlain by ground ice. Please add a few sentences here to present a convincing justification for dismissing liquid water storage. The authors can also refer the reader to Figure 5h.
Gravimetry is not selective on the type of water/ice changes. Several pieces of independent evidence do suggest that supra-permafrost water export is negligible on Murtèl on a seasonal scale:

- **Surface outflow is flashy and not perennial once snowmelt is completed. After precipitation events in late summer, the supra-permafrost aquifer drains within a week and the rock glacier springs dry out. The active layer is coarse-blocky, on average not thicker than 2-3 meters, and inclined (10-12°), resulting in a small water retention capacity.**
- **Electrical resistivities of the Murtèl active layer are high and injecting current has been notoriously difficult, also suggesting a low water content.**

Additionally, the estimated ice storage changes match 2021-2023 observations (below-ground stake measurements) of ice loss made in the active layer (and no reason to assume it was much different in 2024). We cite all relevant literature (the body of which is quite significant as Murtèl is well studied), but we will be sure to discuss these points more carefully, also noting that Murtèl is on the coarser end of typical Alpine rock glaciers.

Line 374-376. Groundwater export … is expected to be rather limited. From an objective reader's viewpoint, this sentence contradicts with Figure 5h, which clearly shows the drainage of groundwater. It is true that unweathered granodiorite has low hydraulic conductivity, but overlying sediments may have high enough conductivity, or the top few meters of granodiorite may be weathered. Please present more careful discussion of solid vs. liquid storage of water in both supra- and sub-permafrost zones.
We agree that groundwater export from a sub-permafrost aquifer or aquifer located away from the permafrost zone cannot be excluded based on our data. Indeed, it is highly likely that some degree of large-scale seasonal groundwater storage decline occurred over the Summer 2024 period, as is commonplace in alpine systems. The porosity of the granodiorite bedrock, which does have some degree of fracturation, is expected to be very small, meaning that changes in hydraulic head would result in relatively small Δg signals. Survey points 01 and 08 (the latter located in the permafrost-free forefield which has no sedimentary cover) are located off-RG. As gravimetry is a spatially integrative method, it is sensitive to mass changes that may occur with some lateral displacement relative to the measurement location. We will nonetheless reinforce the discussion around groundwater storage change contributing to measured Δg and also reiterate that TLG is a non-selective method.