*Dear Dr. Pelto,*

*We thank you for providing thorough and constructive comments on our manuscript. They highlight important gaps in our workflow, analysis, and discussion. In response to these comments, we significantly revised the manuscript. Our response to each comment can be found below in italicized, blue-faced font.*

*The main changes to the manuscript are:*

1. ***Refined Objectives:*** *We improved and clarified the objectives and made sure to clearly link them into discussion and conclusion of the paper. The objectives of the paper are to: 1) Describe the design and performance of smart stakes in a data rich environment; 2) Combine smart stake and remotely sensed data to inform a simple distributed mass balance model; and 3) Demonstrate how real–time ablation data can be used to examine the role of individual events on ablation.*

2. ***Enhanced Temperature-Index Model:*** *We integrated the Enhanced Temperature-Index model (ETI), while retaining the original Temperature-Index model (TI) from our original submission, and ran each model with multiple air temperature models. The ETI allows us to add incoming shortwave radiation, albedo, and snowfall to the analysis.*

3. ***Remote Sensing Analysis:*** *We added Sentinel-2 and Landsat 8/9 satellite imagery from the Harmonized Landsat Sentinel (HLS) dataset for snow cover mapping on the glacier. This HLS data is free and publicly available and complements the PlanetScope data that we used previously. We also use the HLS data to calculate broadband albedo over the glacier in the revised modelling framework.*

4. ***Lapse Rate Analysis:*** *We expanded our analysis of air temperature lapse rates and options for estimating air temperature across the glacier. We now test different combinations of stations (e.g. on glacier, off glacier) and different regression formulas (e.g. linear, polynomial). The highest performing model is a linear daily lapse rate of air temperature using only the on-glacier weather stations.*

5. ***Addressing the Katabatic Boundary Layer:*** *We discuss the importance of the katabatic boundary layer, and how future work could implement a study design that accounts for katabatic effects. We stress, however, that our experimental design is not ideal to evaluate the impact of katabatic flows on temperature downscaling to the glacier survey (investigating this phenomenon was never our stated goal in the paper).*

6. ***Geodetic Mass Balance:*** *We added lidar derived geodetic mass balance as a second independent validation dataset for our model. In our initial submission, the model did not perform very well against the independent mass balance data from manual ablation stakes. We suspect this poor performance was due to differences in the start/end dates of our logger experiment and those of the WGMS stake measurement program. Our hypothesis is partly supported by the good agreement between the geodetic and modeled mass change. We now discuss this in both the results and discussion section of the revised paper.*

7. ***Financial Cost:*** *We clarified the "low-cost" argument of the smart stakes. We moved the description of the overall cost of the smart stakes from the supplementary materials, where it was more cumbersome to find, to the main body of the paper. This strengthens the rational of the "low-cost" aspect of the project.*
8. ***Workflow Clarification:*** *We improved the description of the overall workflow in the methods and added a flowchart to simplify the explanation of the workflow. The flowchart helps guide the reader.*
9. ***Further Discussion of Site 4:*** *The model does not perform well at Site 4. We expanded our discussion on why this may be – the most likely contributor to the poor performance is that the stake was only drilled into snow (not into ice, as the snow was too deep) in the spring of 2024 and the stake likely shifted, tipped, or settled over time.*

*This significant re-working of the paper strengthened the quality and defensibility of the science and the overall relevance of the work.*

*We would like to emphasize that our smart stakes remain, to our knowledge, the first low-cost and open-source solution to real-time ablation data using satellite telemetry.*

*To reduce the length of the manuscript resulting in the new additions, we moved the "Future Smart Stake Development" section to the supplement.*

*We thank you for your time and efforts reviewing our revised work.*

*Kind regards,*

*Alexandre Bevington*
*on behalf of the authors*

# Community Comment 1 (CC1)

The authors have provided a detailed examination of the efficacy and operational approach to using smart stakes. Place Glacier, British Columbia is the location for this detailed field test. This location has a combination of long-term mass balance records, ongoing mass balance observations, automatic weather station, PlanetScope and recent annual Lidar observations. This makes for a perfect test site location. The authors emphasize repeatedly that smart stakes are low cost as a key part of this study but have not provided a cost range for the product or its operation. The cost is as essential as identifying their accuracy, for determining if they are best suited as a supplement to an existing stake network, adding high temporal resolution data or can be deployed in place of that network. There have been other detailed ablation surveys conducted during specific heat events that should be noted as part of this important growing data set. Smart stakes can be a valuable tool for expanding this data set. Melt models based on data with limited temporal resolution can be impaired by temporal and spatial variations in ice dynamics, albedo variations, and wind effects. The smart stakes can be effective in identifying the temporal variations that impact all ablation stake studies.

I applaud the authors for a thorough test of a new system and providing a best-case approach to utilization of extensive complimentary data sets for both analysis and validation. In future it would be wonderful to see how much melt context smart stake data can provide from a glacier that otherwise has limited field monitoring but has ongoing LIDAR or other geodetic observation.

*We thank Dr. Pelto for his community comments on our paper. We appreciate the enthusiasm around our efforts to produce a rich dataset from the smart stakes. The detailed costs have been moved from the supplementary materials to the main body of the paper in **Table 1**.*

## Specific Comments

93: It is noted the upper part of the accumulation area was not instrumented due to logistical and safety reasons. However, earlier it was noted that the glacier has minimal crevassing. Is it worth being more specific on this constraint.

*Dr. Pelto raises a fair point. It is true that minimal crevassing lowers the safety risk of glacier travel, however there are still crevasses. We decided to not travel to the top of the glacier on the original installation date due to low visibility. We added: "The uppermost region of the accumulation area was not instrumented due to field safety and logistical constraints during the May 2024 fieldwork, namely poor visibility at higher elevations caused by low cloud." **L198-200***

220: Other studies have utilized snow line migration across areas of previously measured snow depth to identify ablation. Is this what is being done with PlanetScope?

*The Planet data is now combined with Landsat and Sentinel to determine the surface cover of the glacier at the ablation stakes (either snow or ice). This facilitates the determination of snow vs ice melt factors and is used in the distributed melt model. We do not explicitly calculate the snowline elevation in this paper. See updated **Section 4.2.4**.*

269: This is substantial tipping, did the manual stakes suffer this level of tilt due to near melt out? Are the smart stakes not emplaced as deeply or are they simply top heavy and prone to tilt earlier? The 4.88 m long stakes were drilled how deeply, it is noted that at least 0.8 m is exposed?

*There are two sets of manual stakes at every manual stake site: one set is drilled deep and dropped into the glacier, the other (at the same locations), is drilled in less deep and is exposed above the glacier. This allows for substantial melt to occur and there is always one of the sets of stakes that is exposed. The manual mass balance stakes were conducted independently from the smart stakes, and these programs did not coordinate drill depths. In addition, the manual stakes are not top heavy.*

*We added a description of the tipping mechanism and some ideas around solutions in future deployments: "Based on our observations, the tipping over of the smart stakes arises from a feedback between heating of the aluminum pole and heat transfer to one ice edge along the pole: as the pole melts into the edge more of the pole is in contract with the ice thereby accelerating leaning of the pole. This effect could potentially be mitigated in the future with a longer stake that is drilled deeper in the glacier, or by developing a self–adjusting tripod. Similarly, an inexpensive tiltmeter could be added to the stake to identify tilting." (**L597-501**)*

286: Figure 4A provides an excellent visual of snowpack variation. I recommend that the accumulation area ratio be reported for each. Given the difference in melt rates for snow surface vs ice surface this is important.

*Thanks for the comment. We separated the figure into two: Figure 4 and Figure 6). We also added the AAR over time in **Figure 6B**.*

316: This similarity in ablation from stake to stake has been noted for other regional glaciers, which maybe worth noting that this is not unusual.

*Good point. Added a note in the methods: "Melt factors are often similar among stakes, and are often assumed to be constant over time, however in reality they have been shown to change day–to–day, highlighting then need for energy balance models." (**L312-313**)*

339: The number of melt days is a crucial variable to identify for a melt model to work accurately, the mapping of this variable in Figure 9 is quite valuable as a an example of best practice

*Thank you for this comment. We updated the figure (now **Figure 12**) so it now includes: The total snow days; the total positive degree days (PDD) using the on-glacier linear lapse rate; the mean incoming shortwave radiation (SR); the total melt from the ETI model with on-glacier linear lapse rate; the mean albedo (α); the mean temperature melt factor ($TF_{MLR}$); and the mean shortwave radiation melt factor ($SRF_{MLR}$).*

400: Important to note the increased specific melt rates observed during 24 recent heat wave event in the Nooksack Basin, North Cascades (Pelto et al. 2022) that supports observations provided here.

*Agreed, added reference to this observation: "These findings align with Reyes and Kramer (2023), who documented accelerated snowmelt during successive heat wave events in western North America, and with Pelto et al. (2022), who observed melt rates increase during heat waves in the Nooksack Basin, North Cascades." (**L511-513**).*

412: Providing a better reference to more specific regional studies where melt factors were derived demonstrates contrast and context. Bidlake et al (2010) noted melt factors for South Cascade Glacier of 0.0039+ 0.0006 for snow and 0.0056 + 0.0008 for ice. On Mount Baker in the North Cascades, Pelto et al (2022) reported under overall weather conditions DDFs for snow is 0.0035 m w.e. °C−1d−1. For ice, the DDFi is 0.0053 m w.e. °C−1d−1 During heat waves this rose to a DDFs snow of 0.0043 m w.e. °C−1d−1. For ice, the DDFi is 0.0067 m w.e. °C−1d−1.

*We added these values into the discussion about melt factors: "For example, Shea et al. (2009) reported TFi of -4.69 and TFs of -2.71 mm w.e. °C $^{-1}$ d $^{-1}$ for Place Glacier, whereas Wickert et al. (2023) found a range of melt factors from -3.9 to -10.3 mm w.e. °C $^{-1}$ d $^{-1}$ across multiple sites from Antarctica to Alaska. Bidlake et al. (2010) noted melt factors for South Cascade Glacier of -3.9 mm w.e. °C $^{-1}$ d $^{-1}$ for snow and -5.6 mm w.e. °C $^{-1}$ d $^{-1}$ for ice. On Mount Baker in the North Cascades, Pelto et al. (2022) reported -3.5 mm w.e. °C $^{-1}$ d $^{-1}$ for snow and -5.3 mm w.e. °C $^{-1}$ d $^{-1}$ for ice, and that these rose during heat waves to -4.3 and -6.7 mm w.e. °C $^{-1}$ d $^{-1}$, respectively." (**L524-528**)*

425: The four smart stakes did provide high resolution temporal data but at a low spatial resolution raising again the cost issue.

*Thanks for this comment. The costs were originally presented in the supplementary materials (Sup. Table 1), which has now been moved to the Main, in **Table 1**. The total cost is ~$1100 USD.*

442: Good description of the challenges posed by the vertical component of velocity. Make sure to note that this poses the same challenge for any ablation stake system . Smart stakes may in fact allow for better understanding of this.

*Excellent point. “Surface mass balance stakes, automatic or manual, do not account for the horizontal and vertical components of glacier dynamics (Beedle et al., 2014).” **L565-566***

References

Bidlake, W.R., Josberger, E.G. and Savoca, M.E.: Modelled and Measured Glacier Change and Related Glacioloical, Hydrological and Meterorological conditions at South Cascade Glacier, WA, Balance and water years 2006-2007. USGS Science Investigation Report 2010-5143, US Geological Survey, Reston VA USA, 2010.

Pelto, M. S., Dryak, M., Pelto, J., Matthews, T., & Perry, L. B.: Contribution of Glacier Runoff during Heat Waves in the Nooksack River Basin USA. Water (7), 1145. https://doi.org/10.3390/w14071145, 2022.