Referee #2 Response Letter – Manuscript tc-2022-268

General Comment: TC-2022-268 is a timely and important contribution to quantify the snow depth on the north side of the Mount Everest summit. I congratulate the authors and the entire expedition team on a herculean effort to obtain such valuable data in exceptionally challenging conditions. Although the manuscript represents an important contribution to the cryosphere and broader geophysical communities, there are a number of issues referenced below that need to be addressed prior to eventual publication.

Reply: Thank you for your positive appreciation of our work and the constructive comments, which will help us to improve the paper considerably.

Specific Comment

1. More background is needed in the Introduction about the significance of summit snow depth in the context of climate variability and change. The geodesy discussion is relevant but perhaps a bit tangential to the climate change and cryosphere connection. Also, additional discussion about why/how the summit snow depth is an important indicator of the cryosphere response to climate change would be helpful. This could be done in the context of the Potocki et al. (2022) and Brun et al. (2022) articles which are already cited. I also recommend limiting citations to peer-reviewed scientific articles as much as possible.

Reply: Thank you for your suggestion. Some sentences will be added to address that snow layering at mountain summits contains information about local seasonal snow accumulation and climate history. Knowledge of snow depths is required to estimate the snow water equivalent. The comparisons of snow depth/stratigraphy during different time periods may be potentially helpful for understanding the possible influence of anthropogenic climate change at the extreme high elevations in the Himalayas. We will reorganize the abstract and first paragraph of introduction. The first part of introduction will be revised.

Following your suggestion, we will limit the non-peer-reviewed citations. And some new peer-reviewed scientific articles will be referenced in the revised manuscript.

1. Pepin, N., Adler, C., Kotlarksi, S., and Palazzi, E.: Mountains undergo enhanced impacts of climate change, Eos Earth & Space Science News, 103, 2022.
2. Hugonnet, R., McNabb, R., Berthier, E., Menounos, B., Nuth, C., Girod, L., Farinotti, D., Huss, M., Dussaillant, I., and Brun, F.: Accelerated global glacier mass loss in the early twenty-first century, Nature, 592, 726-731, 2021.
3. Kraaijenbrink, P. D. A., Stigter, E. E., Yao, T., and Immerzeel, W. W.: Climate change decisive for Asia’s snow meltwater supply, Nature Climate Change, 11, 591-597, 2021.

The relevant sentence in the background will be changed as following:

“In addition, snow layering at mountain summits contains information about local seasonal snow accumulation and climate history. Snow and ice displayed an accelerated losing rate in almost all regions on Earth (Hugonnet et al., 2021; Kraaijenbrink et al., 2021). Similar to other snow/glacier-covered summits (Thompson et al., 2009), the snow and glaciers at Mount Everest are the sentinels for climate change and therefore offer a potential natural platform for understanding ongoing climate change at such extreme high elevations (Matthews et al., 2020; Potocki et al., 2022) and their possible widespread influence on the Asian Water Tower (Immerzeel et al., 2020). The comparisons of snow depth/stratigraphy during different periods may be potentially helpful for understanding the possible influence of anthropogenic climate change at the extreme high elevations in the Himalayas (Brun et al., 2022; Pepin et al., 2022; Potocki et al., 2022).”

2. A bit more discussion about the hypothesized physical processes responsible for the seasonal and inter-annual variability of summit snow depth could be helpful. Do the authors suggest that the snow accumulation is the result of snowfall (precipitation) or primarily deposition (snow drift) from snow blowing up from lower slopes? How much ablation can be expected due to sublimation? Is there any evidence of melt in the GPR data, which both Matthews et al. (2020) and Potocki et al. (2022) suggest may now occur even at the summit?

Reply: Sorry that we have no evidence to quantify the relative contribution from snowfall (precipitation) and the snow deposition from snow blowing up from slopes. According to the climbers who reached the summit in both 2021 and 2022, the fresh snowpack near the summit is much deeper in 2022 than in 2021. We intend to install an automatic weather station on the rock surface at ~8800m, where there is free snow in May 2021. However, this site was completely covered by a snowpack of 60-70 cm in May 2022. Therefore, we believe that the snow depth at the summit of Mt. Everest should show the seasonal and inter-annual variability. In the section 3 of the revised manuscript, we will add this information to address the temporal changes in snow depth as follow.

“In fact, the snow depth on Mount Everest should show the inter-annual variability due to the influence of snow accumulation and snow drift. According to the experience of the mountaineers who reached the summit in 2021, the previously exposed rock surface in May 2021 was covered by a snow cover of about 60-70 cm in May 2022. Our reported snow depth on Mount Everest in 2022 is significantly deeper than the previously reported values during the last five decades (0.9~3.5 m). There is still no solid evidence that the snow cover has become thicker or thinner during the past decades. The future repeat radar measurement at the summit would be helpful to prove such dynamic changes under the background of climate change.”

Regarding the questions of sublimation and melting at the summit, we are sorry that our radar measurement cannot give the answer. In fact, we are also interested in the melting and sublimation at the summit. Therefore, during "The Earth Summit

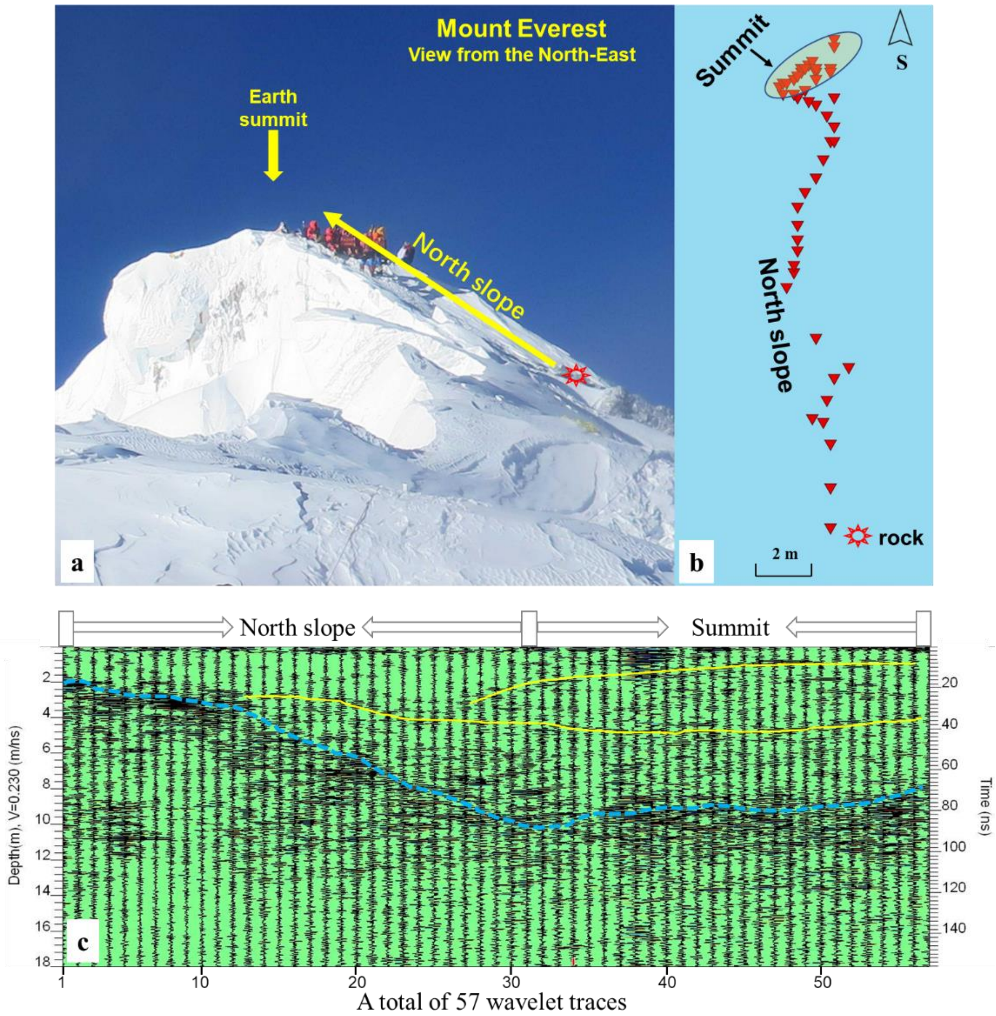
Missions 2022" expedition in May 2022, we installed an automatic weather station near the summit. Based on this meteorological data, we hope to get the final answer. However, it is beyond the scope of this manuscript. Sorry that we will not include the relevant information and discussion in the revised manuscript.

3. Do the GPR data provide any indication of whether some of the summit snow depth could be the result of rime ice accretion during the monsoon, similar to what occurs in Patagonia? See: Whiteman, C. D., and R. Garibotti, 2013: Rime Mushrooms on Mountains: Description, Formation, and Impacts on Mountaineering. Bull. Amer. Meteor. Soc., **94**, 1319–1327, https://doi.org/10.1175/BAMS-D-12-00167.1.

Reply: Thanks for providing this paper. We are sorry that the GRP data did not provide such information. However, we believe that the mechanism of snow accumulation at the summit of Mount Everest is different from that of rime ice, partly due to the extreme high altitude and contrasting climatic background. As shown in Figure 1a, the summit is covered by snowpack rather than rime ice. Furthermore, as stated by Whiteman and Garibotti (2013), "*The highest summits in the Himalayas have a more continental climate and are more likely to build up snow cornices downwind of obstacles rather than rime mushrooms on the upwind side*'.

4. Is a different photo available for Figure 1a? Are the darker colors below the summit old prayer flags, lower albedo snow, or rock? It is very hard to tell in this photo but I suppose old prayer flags? An improved photo could help this interpretation as the darker colors could easily be mistaken for rock?

Reply: Thanks for pointing that out. Yes, the darker colors below the summit are the old prayer flags. In the revised manuscript, we will update a new photo taken in May 2022 from the similar perspective.



5. The authors reference the importance of future snow core drilling and repeated GPR measurements. Are there any lessons learned from the 2022 expedition and/or suggestions for future expeditions/researchers? Additionally, are you able to offer testable hypotheses for future researchers?

Reply: Future synchronous snow coring and radar measurements at the summit would be valuable. The snow cores are useful to validate the radar measurements and thus to calibrate the snow transmission velocity. And more importantly, given your concerns about surface melting, the analysis of snow stratigraphy would provide important information by verifying the possible melt refreezing layers in the snow core. Such work, together with the ongoing AWS measurement near the summit, would possibly determine the influence of anthropogenic climate change on the Earth's summit. And the repeated radar measurements (perhaps several years later) would be helpful to understand the changes in snow dynamics at this extreme high altitude and to determine whether the snow height of Mount Everest (8848.86 meters in 2020) will change significantly in the future. Based on the dGPS measurement, some interesting scientific and public questions, such as whether the height of Mount Everest is increasing/decreasing, could be answered. Finally, we will briefly add some perspectives in the revised manuscript.

6. I suggest using either snow thickness, snow depth, or snow height and being consistent instead of using multiple terms to refer to the same thing which may confuse the reader. Snow depth is perhaps a more commonly used term?

Reply: We will use the consistent term "snow depth" in the revised manuscript.

7. I suggest consistent use of Mount Everest vs. Mount Chomolungma throughout.

Reply: We will use the consistent term Mount Everest in the revised manuscript.

8. Are there GPS height measurements for the rock indicated by the blue star in Figures 1a and 1b?

Reply: The portable GPS has large uncertainties in the vertical direction. As shown in Figure 1, the rock is about 15 m lower than the summits. Sorry that we will not added such information in the revised manuscript.

9. Can contour lines and the international border be added to the map in Figure 1b?

Reply: It is a pity that there are no high resolution DEMs available to create accurate contour lines. We have tried several DEMs including SRTM DEM and High Asia DEM. But the performance is very poor. Therefore, in the revised manuscript, unfortunately, we will not add this information. Perhaps future unmanned aerial vehicle (UAV) survey by structure-from-motion/radar could possibly provide high-resolution DEM for making the contour line at the Earth's summit.

Minor Comments

Line 7: “the” preceding Mount Everest not needed here or elsewhere

Reply: We will change it.

Line 17: citation needed for China and Nepal height declaration

Reply: China and Nepal jointly declared that the snow height of Mount Everest is 8848.86 metres above sea level (m asl) in 2020 [http://www.xinhuanet.com/english/2020-12/08/c_139573400.htm]. However, no peer-reviewed scientific article on the snow height of Mount Everest of 8848.86 metres is published. Therefore, we did not add the website linage in the revised manuscript.

Line 18: considerable inter-annual variability in the snow thickness may also exist?

Reply: As above reply, we think that there is inter-annual variability on Mount Everest. However, the magnitude of such variability should be quantified by the next repeated radar measurements or core drilling at the summit.

Line 21: suggest changing “In additions,” to “In addition,”

Reply: We will change it.

Line 23: suggest changing “extreme high elevation” to “extreme high elevations”

Reply: We will change it.

Line 24: suggest changing “the state of snow at the Mount Everest are critical” to “snow depth at the Mount Everest summit is critical”

Reply: We will change it.

Line 49: remove “t” after “Mount Everest t.”

Reply: We will change it.

Lines 53-54: What were the snow properties at 6500 m and 7028 m in 2005 and how certain are you that these properties are representative of the summit snow in 2022?

Reply: In general, the transmission velocity in snow ranges from 0.20 m/ns to 0.27 m/ns, which depend on snow properties (Fortin and Fortier, 2001; Singh et al., 2017). It is pity that we did not measure common midpoint data to evaluate the transmission velocity of radar waves inside the snowpack at the Mount Everest because of the limited measurement time window in so-called ‘death zone’. The snowpack ridge of 7028 m asl was deposited by both snow fall and snow drift, which is similar to the summit. The previous measured transmission velocity of 0.23 m/ns was adopted in this study. As pointed by both reviewers, the possible uncertainties of transmission velocity should be addressed in the revised manuscript. Therefore, we will provide the uncertainty of snow depth by applying the range of ±0.03m/ns (the low boundary of 0.2m/ns and upper boundary of 0.26 m/ns). Therefore, the mean snow depth at the summit of Mount Everest was estimated to be 9.5±1.2m in May 2022. And the two-way wave travel time of radar also provided for future comparison by repeated radar measurements.

Line 55: suggest changing “processing package by apply a frequency” to “processing package by applying a frequency”

Reply: We will change it.

Line 69: space needed after “velocity.”

Reply: We will change it.

Line 81: suggest changing “was compacted for producing high snow density.” to “was compacted resulting in high snow density.”

Reply: We will change it.

Line 82: suggest changing snow density to kg m^{-3}

Reply: We will change it.

Line 85: suggest changing “In addition to reveal the” to “In addition to revealing the”

Reply: We will change it.

Line 87: suggest deleting “was” between “reflection layer was existed”

Reply: We will change it.

Line 88: suggest changing “maybe” to “may be”

Reply: We will change it.

Lines 92-93: suggest adding “the” between “of snowpack” and deleting “in the world”

Reply: We will change it.

Lines 96-97: incomplete sentence starting “It is worth noting . . .” and therefore suggest revising

Reply: We will change it.

Line 98: suggest changing “at the Mount Everest is also necessary” to “at Mount Everest are also necessary”

Reply: We will change it.

Line 99: suggest deleting “favor” and “source”

Reply: We will change it.