Referee #1 Response Letter – Manuscript tc-2022-268

General Comment: The authors present a unique dataset - a geophysical survey acquired on the north ridge of Mount Everest, that shows snow depth with distance from the peak. It provides more detailed observations than are otherwise available, and suggests overall that the snow/firn is deeper than previously thought. I am not entirely convinced that these measurements are critical for studies of the cryosphere and climate change (line 25), but they are certainly of broad interest and provide a small window into one of the most inaccessible places on our planet, and for that main reason I'd be pleased to see them published. However, before they are, I would suggest some revisions are required in the way the manuscript is presented:

Reply: We would like to thank the anonymous reviewer for her/his helpful comments on our manuscript, and would hereby like to address the concerns your raised. We think that snow layering at mountain summits contains information about local seasonal snow accumulation and climate history. 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 as the following:

"Mount Everest, one of inaccessible places on our planet, is considered to be the most iconic peak (Kang et al., 2022; Matthews et al., 2020). There are very strong scientific and public motivations for determining the snow depth at Mount Everest. Although China and Nepal jointly declared that the snow height of Mount Everest is 8848.86 metres above sea level (m asl) in 2020, the true rock height was not precisely determined due to the unknown snow depth below. The snow depth at extreme high elevations may vary dynamically with different seasons and years. Knowledge about snow depth during different periods will be helpful for explaining the discrepancy of reported snow heights at Mount Everest, which has been introduced by repeated surveys (Angus-Leppan, 1982; Chen et al., 2010; Xie et al., 2021). 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)."

Specific Comment: - the paragraph starting line 26 provides a critical assessment of previous attempts to measure snow depth at the summit, but I can't find any suggestion in the cited papers that there were major doubts in the measurement. I can easily imagine that there is great variability in snow depth depending on exactly where you acquire it from, and at what time of the season you take the measurement. I suggest the authors repackage the paragraph as being a summary of previous work rather than those previous attempts not being successful?

Reply: We agree with your comments. In the revised manuscript, we will repackage the paragraph as a summary of previous works. We will point out the inconsistency of the published snow depth and their possible uncertainties by different methods. We propose to clarify this as follows.

"Previously reported snow depths derived by different methods and instruments range from 0.92 m to 3.5 m at Mount Everest. In 1975, a Chinese expedition team reported an estimated snow depth of 0.92 m by inserting a wooden stake into the snow (Chen et al., 2010). In 1992, a China-Italian joint expedition team estimated a thickness of 2.52 m by inserting a steel stake into the snow (Chen et al., 2010). These results derived by stake methods suffered from many factors such as snow density, stake length, and manpower in such harsh altitude. Radio echo sounding is a suitable technique for imaging snow-ice environments and their internal structures (Rignot et al., 2013). In 2005, a Chinese mountaineering and surveying team claimed a snow depth of ~3.5 m by utilizing ground penetrating radar; however, the reported boundary between the snow and rock on the radar image was too ambiguous to provide an undisputed depth (Sun et al., 2006). In 2019 and 2020, various Nepalese and Chinese expedition teams measured the snow depth using different radar instruments; however, no results were reported. Supported by the Second Tibetan Plateau Scientific Expedition and Research, we organized "The Earth Summit Missions 2022" expedition during the period from April to May 2022. One of our key goals is to measure the snow depth at Mount Everest."

- Related to this, I'd be interested to hear the authors view on whether the timing (season) of the survey makes much of a difference to the snow depth at the summit. Might these results differ if acquired in the post-monsoon, or can we consider them to be consistent throughout the year? I think this is needed to put this snapshot into some sort of broader (longer) context - and very pertinent as the authors themselves state the temporal variability is significant (line 18). A couple of lines added to Section 3 would be good to see in this regard.

Reply: Thank you for your suggestion. As you are concerned, the time (season) of the survey affects the snow depth on the summits and the north slope of Mount Everest. During the "Earth Summit Missions 2022" expedition, another important key task is to install an automatic weather station near the summit of Mount Everest. Based on the experience of mountaineers who have successfully climbed Mount Everest several times, we selected a suitable flat rock surface at about 8800 meters above sea level for installation. However, when we reach this altitude in May 2022. This selected rock surface was completely covered by snow with a depth of 60-70 cm. We need to move the AWS location to the upper zone. Therefore, we assumed that the snow depth at the summit may be variable at different survey seasons. In this brief communication, we have only reported the average snow depth at the summit of Mount Everest in May 2022. The future repeated radar measurements would give the answer whether there will be a big difference (decrease or increase) in different years with climate change. Following your suggestion, the above information on seasonal snow change will be added in section 3.3.

"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."

- I have never had the priviledge of summitting Mount Everest, but it looks to me from the photograph in Figure 1 that there is exposed bedrock very close to the surface at the summit location. According to the annotation, the survey profile passes almost directly over that exposed bedrock, but there is no evidence of it in the radargram. I'd be keen for the authors to provide some explanation for this.

Reply: Our radar measurement started near the exposed metamorphosed limestone, at an elevation of about 15 m below Mount Everest, to ensure a gradual transition in the radar reflection profile and thus make it easier to distinguish between snow and rock. Since the starting exposed rock, the measured profile is completely covered by snow. Please see the following screenshot of the video down perspective. Therefore, the radargram shows a gradual deepening trend along the north slope.

- The data presented here are along one survey line, chosen (presumably) to coincide with the established climbing route. I would like to see some acknowledgement that moving the profile several metres either side (even though this might not be safe in practice) could yield very different results. The way the data are presented at the moment is as if these measurements represent snow depth across the whole of the north ridge.

Reply: We agree with your concerns. Our radar line coincided with the established climbing route. Due to local topographic influences, the snow depth along the north slope is heterogeneous. As shown in Figure 1a, the snowpack is significantly deeper near the cliff. Therefore, as you stated, the snow depth would be very different if the radar measurement profile was several meters away from the profile. However, the main objective of this study is to provide the snow depth at the summit of Mount Everest. The radar profile from the exposed metamorphosed limestone to the summit is designed to provide a gradual transition in the radar reflectivity profile, making it easier to distinguish between snow and rock. The high concentration of radar measurements at the summit (No. 32-57) is intended to obtain the mean depth of the snowpack. The future repeat measurement at the summit would therefore be comparable to our measurements without taking into account the geographical differences. Following your suggestions, the relevant explanatory text will be added in the revised manuscript.

"It should be noted that such a measurement along the north slope was used only for the purpose of generating the post-discerning radar boundaries, and the measurement could give different results if the measurement profile were moved a few meters to either side."

- Related to that, since the exact location of the geophyical survey is critical to the data that are retrieved, I'd like to see some precise co-ordinates added to the manuscript (maybe as graticules on Figure 1b) so that anyone wishing to repeat the survey in the future can do so with confidence.

Reply: Thanks for this suggestion. We will provide a table of GPSs in the supplementary materials.

A few additional minor points:

- it would be normal to simply use the term 'Mount Everest' rather than 'the Mount Everest'.

Reply: We will use the term of Mount Everest in the whole text.

- given how critical the transmission velocity is in determining the thickness, I suggest adding an uncertainty range to each of the stated values (based on a min of 0.2 m/ns and a max of 0.27 m/ns).

Reply: Thank you for this suggestion. In the revised manuscript, we will report the uncertainty of the snow depth by applying the range of ±0.03 m/ns (the lower limit of 0.2 m/ns and the upper limit of 0.26 m/ns). Therefore, the mean snow depth at the summit of Mt. Everest in May 2022 was estimated to be 9.5 ± 1.2 m.

- I struggle to make out the red line on Figure 1c - experiment with some different (lighter?) colours?

Reply: For more clarify, we will change the red color to lighter blue colors in the revised manuscript.