Response to reviewer 1

We thank reviewer Howard Conway for his evaluations and suggested improvements. We have addressed all the concerns and made the suggested revisions to the text and figures. Below we show the reviewer comments in black, and our response in red.

ORIGINALITY

The manuscript reports glaciological field studies conducted as a part of the Antarctic Circumnavigation Expedition during the 2017 austral summer. Here the authors present depth profiles of density and melt layers from short (14-24m) firn cores extracted from three sub-Antarctic islands and two coastal domes. Short radar surveys in the vicinity of the cores are also presented. The study is a reconnaissance to evaluate potential ice-core sites that preserve records of past climate and atmospheric circulation in this important, data-sparse region.

SCIENTIFIC QUALITY

Concerning eqn.1, does ph denote density at depth h? Is model parameter “a” equivalent to the “Zero-depth intersection (m)” given in Table 3? Is model parameter “b” also given in Table 3?

Yes, ph is density at depth h. This has been added to the text. The values of a and b are not currently provided in the table but they could be added.

How does the presence of melt layers affect the Herron and Langway age-density model?

Based on the Herron and Langway densification model the dominant densification process in the upper part ($\rho \leq 550$ kg m−3) are grain settling and packing of snow grains (Herron and Langway, 1980). However, undoubtably refreezing of melt water and/or liquid precipitation also cause firn to densify. Thus, our approach is very simplified. It would have been preferable to use an improved model that can account for the influence of melt (eg Lightenberg et al., 2011), however the current observations for these sites do not allow for this.

In a steady-state profile, the meltwater refreezing and densification cannot be modelled, as they move to greater depths with time. If we assume that heat is released upon refreezing, the local firn temperature will increase, further accelerating the densification. At the same time, ice layers lead to a higher average density, thereby reducing the potential densification rate.

Although not ideal, the measured density value used in the equation will reflect the presence of melt. The values of surface snow (or zero-intersection depth) are considerably higher than those modelled or observed for coastal Antarctica.

As discussed below, we have only annual layer counted the Bouvet core to date. However, this allows us to demonstrate that the simple age-density model produced the same bottom age using both methods. Although we appreciate that the Bouvet core was less susceptible to melt than the other island sites.

The scope of this paper was to present the new data collected from these remote islands as a first step to establishing if deeper drilling projects would be feasible. We suggest adding additional caveats and expand the explanations about the influence of melt on the depth-age model used.

How do you estimate the age uncertainties given in Table 3? How might annual or decadal variations in accumulation impact the age-scale? A more rigorous analysis of uncertainties is needed.

Snow accumulation variability at both annual and decadal timescales will undoubtably impact the estimated age-scale. These alterations were considered when estimating the errors presented in table 3, however we agree a more detailed description of how those numbers were derived is required. We note that ERA-5 does not indicate a notable trend in snow accumulation over these timescales, however as we have already established ERA-5 does not have the resolution to capture the islands. Observational records from coastal Antarctic ice cores confirm large trends in snow accumulation are possible, however generally not since 1997 (the estimated length of our records).

The age-density calculations were run using the annual average snow accumulation from ERA5. We added (subtracted) one standard deviation to represent an upper (lower) accumulation estimate. The estimated error in the bottom age is simply the difference between the upper and lower age estimates.

We have updated the text to include a more comprehensive description of error calculations.

Detailed measurements of stable isotopes, ions, and organic chemistry from the Bouvet Island core have been previously reported and interpreted (King et al., 2019). The 14.2m core was dated using annual cycles in deuterium and calcium. Assuming data shown in Fig. 11 are correct (see comments below about inconsistencies), the core from Bouvet Island appears to be the least affected by melt layers. However, Fig. S1 in King et al. (2019) shows the isotope and chemistry signals are strongly attenuated near the bottom of the core. I see (line 309) that annual layer counting of the other SUBICE cores has not yet been completed. Is it in progress? The paper would be much stronger if measurements of isotopes and chemistry and an associated age scale for the other cores are included. An age scale for each core is needed to validate the use of the ERA-5 derived accumulation rates, and to establish the fidelity of the age-scales.

We are not able to present the annual layer counting for all the sites presented. The dating and climatological interpretation is currently being completed as part of multiple PhD projects. As such I would prefer to keep those studies separate. To date, only the Bouvet record has been dated and presented in King et al., 2019.

Apart from identifying a possible basal reflection at Bouvet Island, it is not clear how the discussion of the radar profiles support the focus of this study. At 400MHz reflections are more sensitive to changes in density than changes in chemistry. In this case, one might expect that shallow radar reflections (where the background density is less that ~700kg/m3) might correspond to melt layers. However as presented, it is difficult to determine if there is such a correspondence. As mentioned in the text, the radar system records the two-way travel time (TWT time) to a reflector. For matching radar layers with the core stratigraphy, rather than using an average wave speed (as implied in Table 2) it would be best to use an appropriate depth profile of the dielectric constant to estimate variations in the wave speed through the firn. Further, it would be informative to show the location of the core site directly on the radargrams, and to evaluate the mismatch between radar-detected layers and the melt stratigraphy in the cores.

The reviewer has correctly pointed out that in our case the reflections are given by density changes. The aim of the GPR data in this paper was a description of the observations made and a preliminary analysis to characterize each ice core site. For this purpose, as we stated in Line 220, we used the density profile to estimate the mean velocity propagation for each site.

We initially omitted to perform a detailed analysis of the detected layers depth given the propagation velocity variations through the firn. However, we have now performed a (graphical) comparison of layers detected in the GPR data with the corrected depth estimation based on the variability of the velocity propagation, and the melt layers from the ice core.

The analyses had the following steps:

1. Using the density data to get a propagation velocity/depth profile.

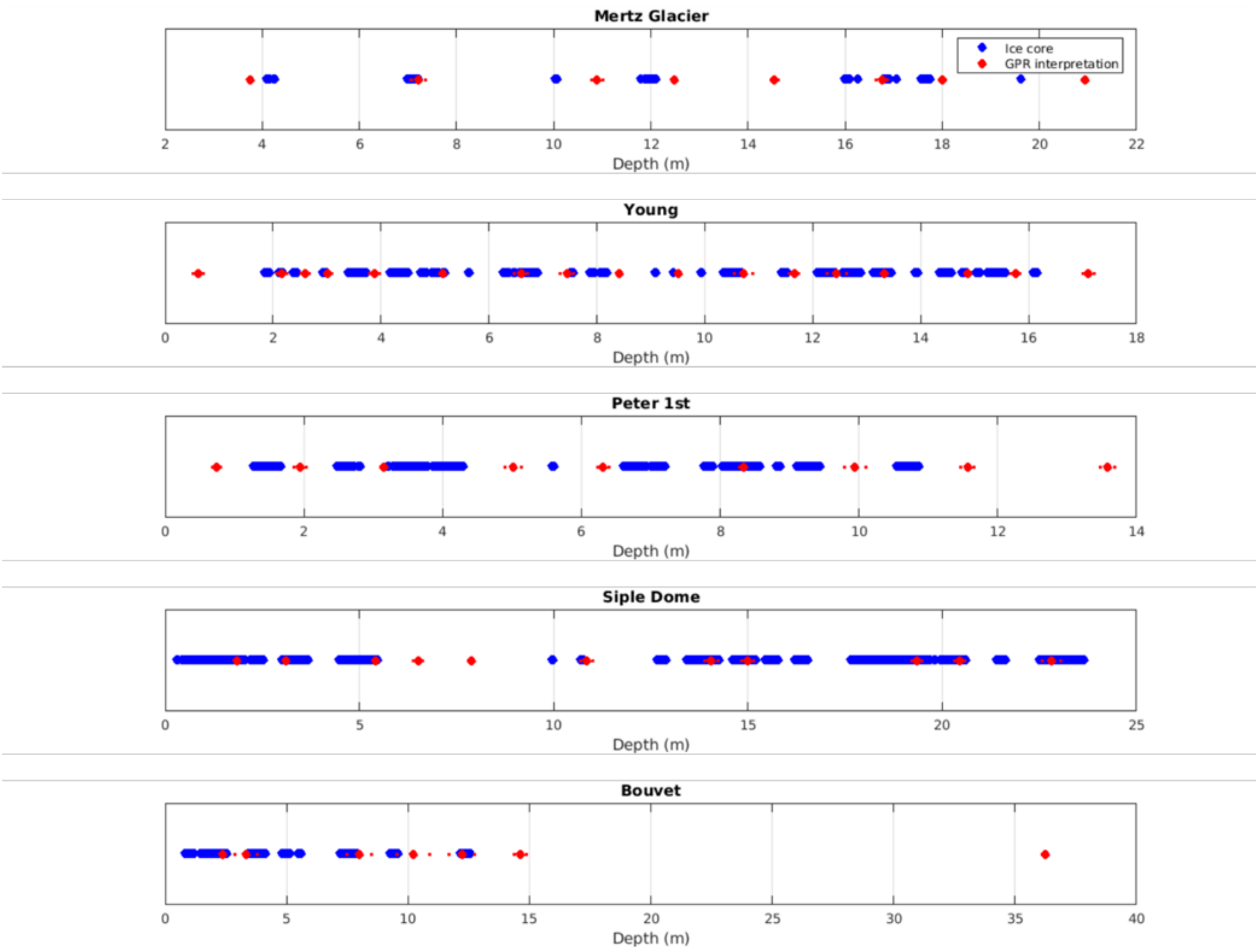
2. Manually picking of layers in the radargram section close to the ice core. Estimating the layers depth according to the velocity for each layer.

3. Using melt layers from the ice core data to compare with the depth layer interpretation.

Result:

We assumed a range of visibility of 35 cm for the GPR (theoretical resolution) and counted the amount and thickness of the melt layers observed in the ice core within this range. We analyzed how strong the reflector would be given the amount of ice and plot the depth points that would be strong enough to be detected by the GPR. The figure shows the potentially visible patterns of ice for the GPR (blue dots) and the depth of the layers interpreted in the radargram (red dots). The layers continuity has been assessed in profile sections of 20 m length near the ice core extraction and the mean depth layers has been used (±std in small red dots).

The GPR detection is subject to several sources of uncertainty. Two of which are particularly decisive in the error: manual picking of the layers in the radargram and the distance between the ice core extraction and the actual radargram profile.



The comparison is very poor particularly for Young Glacier, which ice core had a high amount of thin ice lenses. The radargrams for this site show unclear continuity of the layering and merging of single reflectors.

Some sites show layers detection shifted in depth. This can be due to the spatial variation of the layer depth, given that the radargrams were taken in the surrounding area of the ice core extraction (separation 10-20m),

Other differences can be attributed to the fact that some ice lenses are local and although an ice lens has been detected in the ice core, it does not correspond to a continuous layer through the surrounding area.

SIGNIFICANCE This reconnaissance study identifies several potential sub-Antarctic ice-core sites that contain a centennial-scale climate record. All sites contain melt layers, but progress has been made dating cores in sub-polar and maritime climates (e.g Abram et al., 2013; Neff et al 2017). Although perhaps more logistically challenging, it may also be possible to find suitable sites at higher elevations on Bouvet Island, Mount Siple or South Georgia.

PRESENTATION QUALITY

Are columns “melt frequency”, “average thickness” and “maximum thickness” given Table 2 derived from “visualization of the radargrams” or are they derived from the cores?

This is from visual interpretation from the ice cores. We will make this clearer in the text.

Results shown and discussed in the text, Table 2, and Fig. 11, are inconsistent. For example, Table 2 indicates the thickest ice layer at Mt Siple is 61cm, while Fig. 11 indicates that it is about 12cm, and at Peter 1 Island the thickest layer is 8.1cm, but Fig 11 suggests it is >30cm. Text (line 303ff) states: The average melt layer thickness in the Bouvet core is 0.3 cm, observed at a frequency of five layers per meter; with the largest measured melt layer just 3.98 cm (Table 2)....., in contrast, Table 2 shows values 0.69cm, 6.5 layers/m, and 3cm for the largest melt layer.

Apologies, the site names were incorrect in the table. Table 2 has been updated with the correct values to match figure 11.

Section 2.2.5 It is not clear why the two cores from South Georgia are mentioned here since they ..."do not provide contemporary climate information". However interestingly, Mayewski et al(2016) presented results of an initial reconnaissance for an ice core site on South Georgia and suggested that annual stratigraphy might be preserved at sites with elevations above 2000m.

Agreed. Reference to the South Georgia cores has been removed.