Dear reviewer：

We really appreciate your time and efforts put in the review of this manuscript. The constructive comments and good suggestions are really helpful to improve our manuscript greatly. Below are the comments (in black) and the corresponding responses (in blue).

I thought this was a good paper that applies a relatively novel method in an Antarctic environment. The paper is generally well-written, though could benefit from more quantitative discussion and consideration of its limitations. The scope of the paper matches that of The Cryosphere and, with revision, I think it will be a good addition to the literature. I make some specific comments on three main shortcomings below, then mention some smaller issues that would be required in a corrected manuscript.

SPECIFIC COMMENTS:

The authors show the application of the H/V seismic technique for quantifying the thickness of an Antarctic ice sheet. Two approaches are tested, based on the estimation of resonance frequencies and a more-developed inversion approach. Ice thicknesses are then compared to observed depths in Bedmap2, with the authors concluding that inversion approach is preferred but still acknowledging that some mismatch between the inversion and the Bedmap2 reference. In the paragraphs below I suggest some areas where the paper could be improved. I would emphasize that I do think the paper will make a good contribution to The Cryosphere with some attention to these issues.

1) For a paper that considers inversion and quantitative data interpretation, there's a lack of detail in the text. While I appreciate that a thorough description of the inversion approach is perhaps not required, it sits uncomfortably that there is only one simple equation in the paper – and no presentation of the raw data or the inversion approach.

Response：Thanks a lot for this constructive and helpful comment. We have added some texts regarding the H/V method and the inversion approach in the revised manuscript, as well as some relevant references for providing more details for the inversion approach. Besides, an example of raw ambient noise data (a 5-day long noise record) was shown in the supplement.

The authors also consider the uncertainty in Bedmap2, but give much less attention to the uncertainty in their approach (which seems counter-intuitive since I'd suggest that the uncertainty in Bedmap2 is always going to be much less than in the H/V method). Table 1 does list uncertainties in resonance frequencies, but how these are defined should be clarified. For example, peaks E012 and N148 in Figure 3 seem to be more poorly defined than others, yet their uncertainty in Table 1 seems to be consistent with the wider dataset. The lack of uncertainty analysis sits a little uncomfortably with the frequent description of the method being "reliable" (first instance in L16) and robust. These are subjective terms that would be best qualified with numerical evidence. This is not to say that the method is unreliable, but the authors could do more to demonstrate this rather than relying on qualitative descriptions. Just present the observations and let the readership decide!

Response: We agree with your comment that quantitative discussion instead of subjective terms should be used. We first would like to state the reason why we show the uncertainty of Bedmap2 ice thickness in this study. Due to the fact that the Bedmap2 ice thickness are associated with errors that are variable, only sites with small errors (57 stations) can be used as ice thickness validations. We therefore show the uncertainty of the Bedmap2 ice thickness at each study sites. Following your very helpful suggestion, we have calculated and listed relative errors of the calculated and inversion ice thickness to the Bedmap2 ice thickness for each station in Table 1. Relevant expressions were also modified or added in the manuscript.

The GEOPSY software used in this study calculate the peak frequency and its standard deviation using all selected signal windows (i.e. in case of no windows were discarded in the noise record, a 5-day long noise record generates 720 windows with 600 s length, the GEOPSY software calculates the peak frequency for each window and then calculate its standard deviation using all 720 windows, an example is shown in Fig. 1). We read the peak frequency and its standard deviation from the output file. Although the absolute uncertainty for peak E012 and N148 seems to be consistent with other stations, the relative uncertainty to its peak frequency (E012, 12.4%; N148, 12.4%) is larger than the other stations (GM02, 8.8%; P071, 9.3%).

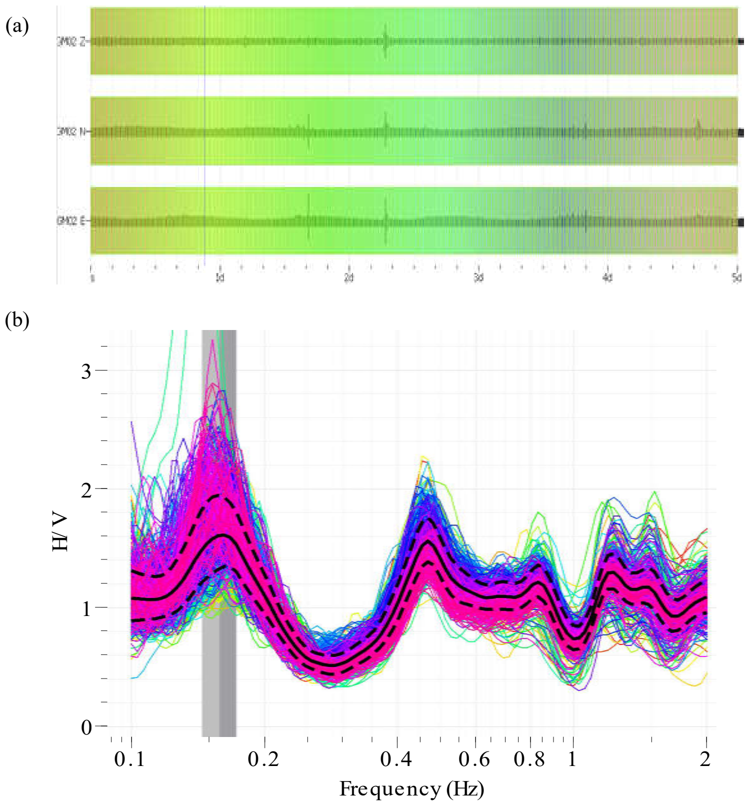

Figure 1. The windows (each window has a length of 600 s) used for H/V processing are colored in panel a, and each H/V curve is calculated using the corresponding selected window (panel b). The solid black curve (in panel b) represents H/V geometrically averaged over all used individual H/V curves.

2) The authors also seem very keen to justify the need for H/V analysis, in part by pointing out the drawbacks in other techniques (e.g., L40-96). Some of these points are valid – gravity modelling is clearly a rather low-resolution technique (although the reference to gravity data processing in L54 is very out-dated) – but I don’t see that the ‘economic and logistical’ requirements of H/V acquisition would be significantly less than RES or seismic. The authors could lessen the criticism of these methods, and

present the case for H/V analysis more simply as another interesting option for a field survey.

Additionally, the authors often point out that this is the first application of the technique on an Antarctic ice sheet: I'm also unsure that this in its own right is significant. While the logistics of an Alpine study are likely simpler than an Antarctic deployment, I would suggest that the 'seismically quiet' Antarctic – featuring simpler subglacial geometries-likely offers better-quality data than in the Alps (as mentioned in L314-5) so it should be no surprise here that promising results are obtained.

To summarise this paragraph, the justification for the authors' approach should be slightly moderated: just let the results speak in the own right, and suggest how they would complement (rather than replace) existing geophysical practice.

Response: Thanks for this constructive comments. We have revised relevant expressions according to your suggestions. First of all, we have removed some descriptions regarding the drawbacks of other methods. Secondly, we present the H/V method as a passive seismic method that provides independent constraints to ice sheet thickness and can be used to complement existing methods in the case of the inaccessibility of the active seismic and RES methods in terms of their large logistical support requirements.

3) The discussion section ends with some conflicting and speculative advice for H/V compliant seismic acquisition. In terms of the conflicting recommendation, the authors propose a desirable record length for acquiring useful H/V acquisition. In L320, the authors caution against using a record length that is only 1 hour long vs. one that is 5-days long. However, in L322-323, they suggest that a 'proper' record length of 1-2 hours would be sufficient. Firstly, the word 'proper' is misused here and it is unclear what the authors mean by this–presumably they mean "a record length suitable for reliable analysis"? But more importantly, there is an inconsistency between the recommended record lengths. I don't see how a 1-hour record would be inappropriate, but a 1-2 hour record would be fine. Additionally, in terms of the cost and logistic requirements of a deployment, if you're going to record seismic noise for 1-2 hours,

why not record for 3-4 hours?! The logistic cost is presumably the same, but you'd maybe get better data quality! In terms of the subjectivity of this recommendation, presumably the authors have longer record lengths from their seismic stations? It should be possible to show how the estimate of ice thickness converges (?) on the Bedmap2 thickness as a function of record length, and therefore remove the subjectivity from this argument.

Response： We are sorry that we made an unclear expression here. Due to the "aseismicity" and very limited human activities in Antarctica, the quality of noise waveforms data is generally better than that found in other areas near the urban cities. We found that the shape of the spectra of the four tested record lengths (1h, 2h, 4h, 8h) are very similar to the shape determined using a record five days long. The peak frequencies of the four different length records are all within the margin of error for the peak frequency as determined with the record five days long. Thus, the ice thickness derived from Eq. (1) and H/V spectrum inversion using 1-hour long record would not result in substantial deviations from that of long records. However, we also found that the H/V spectrum exhibited less stability for thin ice sheet when the lengths of noise records decreased, which may be attributed to the interference of the high-frequency waves such as winds and other sources within short recording time intervals (Picotti et al., 2017). Such cases were found for stations BENN, E012, E018, E024, E026, and E028 (their ice thicknesses range from 500 m to 1.8 km) in this study. For these stations, two hours should be good intervals to conduct H/V processing. Therefore, we infer that two-hour long observation is better for areas with thin ice sheet (i.e. the ice thickness is less than 2 km in most places in West Antarctica). Although one-hour record can be sufficient to conduct H/V processing, we however, would like to follow your comment to advice a uniform two-hour recording interval for data acquisition in Antarctica.

SMALLER CORRECTIONS:

L11: "implemented at single stations using seismic ambient noise waveforms" seems rather specific for the first line of the abstract, which is just generally about H/V methods.

Response: We agree with your comment and have revised this sentence.

L16: "reliably measured" is subjective – objectify it with some performance metrics.

Response: Following your very helpful suggestions below, we have calculated the relative errors of the H/V results to the Bedmap2 ice thickness. It shows that the ice thickness derived from the H/V method has comparable accuracy to the Bedmap2 ice thickness. We therefore revised "reliably measured" to "has comparable accuracy to the Bedmap2 database". The detailed performance metrics were stated in the main text.

L31-33: "global climate change" is misplaced here. While ice sheet thickness is important to know for sea-level rise studies, linking it here to "global climate change" is a step too far.

Response: Thanks for this comments. We have replaced "global climate change" with "sea level change", which would be intimately connected with ice thickness.

L34: Logical jump. The sentence starting "Moreover" likely needs a new paragraph, or a bit more development from the previous sentence.

Response: "Morevoer" was modified to "Additionally".

L35: The need for accurate thickness measurements is true, but it's more likely achieved with RES than it is ever going to be with H/V analysis. Yes, there are places where RES is problematic, but the places that H/V offers better accuracy and/or precision will be few and far between. This links partly to Comment (2) that I made previously.

Response: We agree with your comments. RES method, as a very effective method for ice thickness measurements, played and will keep playing the dominant role in ice thickness investigation in Antarctica. The H/V method, as a passive seismic methods, provides independent and new constraints for ice thickness from other perspective with relatively lower cost and logistical support. Besides, we think the H/V method could be further used to infer basal properties as Picotti (2017) conducted in glacial studies.

L41-42: What is "deep seismic sounding" as opposed to the seismic reflection and refraction methods that are already mentioned?

Response: We made a mistake here and have modified "deep seismic sounding" to "drilling".

L45: Remove "While".

Response: Revised accordingly.

L49-51: Reference to Bedmap data seems misplaced at this point in a background

Response: Sorry we didn't write it clear. We refer to Bedmap data here as to state the contribution of the existing methods for obtaining abundant data.

L54: How big a problem would terrain corrections specifically be in Antarctica? Also, the gravity processing reference (Drewry, 1975) seems very out of date.

Response: We agree that in the year of 1975, the absence of high-resolution topography data may be a big problem for terrain corrections in Antarctica. We believe the recent SRTM high-resolution topography data my greatly improve the accuracy of the terrain corrections. We have deleted this expression in the manuscript.

L59: What complement, specifically, does H/V offer to established methods?

Response: The H/V method provide new constraints on ice sheet thickness with seismic ambient noise data, which we think could also provide complementary information for the strong velocity contrast at the ice-bedrock interface. We acknowledge it may confuse, so we delete this expression in the revision.

L72: Over-selling the technique: "which suggests its powerful effectiveness … etc". As with all techniques, there will be places where H/V is problematic.

Response: We agree and have removed it.

L85: Another logical jump. Before talking specifically about the analysis parameters, you need to explain what the analysis requires.

Response: Thanks for this comments. We have added some texts regarding the reason why shear-wave velocity analysis is needed in the manuscript.

L96: Repetition of the complementary application of H/V spectra (again without clearly explaining the complement).

Response: We have removed this expression in the manuscript.

L103: "relatively sparse" – spares compared to what?

Response: The distribution of the stations was relatively sparse compared to many dense arrays on the other continents where it is relatively easy to deploy seismic stations. We have added some texts in the revised manuscript to make this point clear.

L106: how does burying a station "guarantee" data quality? Presumably, you mean "to improve data signal to noise ratio"?

Response: Yes, we mean to improve the data signal to noise ratio by burying a station below surface snow since it can ensure good coupling and reduce environmental noise (such as wind). We have revised it accordingly in the manuscript.

L124: "is not that robust" – very subjective. Defend and quantify what you mean by this. What kinds of errors result?

Response: We are sorry we didn't express it clear. The peak amplitude is assumed to correspond to the site amplification factor (which of engineering interest), while no agreement has been achieved to support the statement and many studies came to conflict and even wrong results (Lunedei and Malischewsky, 2015). As we are only interested in the peak frequency in this study, we therefore don't give a detailed description about the amplitude here.

L157: Repetition of this point about sedimentary structure investigations.

Response: This sentence was removed.

L162: Capitalise "Geopsy" for consistency with earlier instance.

Response: Revised accordingly.

L208-209: Give the frequencies in the main text. I appreciate that they are listed in the table and in the figures, but key observations could be usefully included here.

Response: Revised accordingly.

L246: Define what you consider to be "consistent" – consistent to within what threshold?

Response: Thanks for this comment. Following your very helpful suggestion, we have calculated the relative error of the inversion ice thickness to the Bedmap2 ice thickness. We found that the ice thickness at 26 stations and 46 stations out of the 48 stations along the profiles are within 10 % and 15 % threshold of the Bedmap2 ice thickness. We have revised this expression accordingly.

L273-274: Again, define what you mean by "adequately constrained" – to what threshold? You could just say (e.g.) that estimates are consistent within a 5% threshold and let the readership decide if this is adequate.

Response: Thanks again for this good suggestion. We calculated the relative errors of the inversion ice thickness to the corresponding Bedmap2 thickness at each station and found that the inversion ice thickness of 22 stations, 35 stations, and 58 stations are within 5 %, 10 %, and 15 % threshold of Bedmap2 ice thickness, respectively. Considering that the Bedmap2 ice thickness is associated with certain error at each site, we then modified this "adequately constraint" expression to "comparable accuracy to the Bedmap2 ice thickness" in the manuscript.

L282: "inverted" rather than "inversion".

Response: Corrected.

L284-287: what is it about these two stations that cause them to perform so differently?

Response: Previous finding shows there are sediment with 300—500 m thick squeezed between the ice and the bedrock layers beneath station N036 (actually, there are sediment layers beneath station N020 to N060, Anandakrishnan and Winberry, 2004; Wittlinger and Farra, 2012; Frederick et al., 2016). The synthetic H/V spectrum modelling shows that the existence of sediment will shift the resonance frequency of the ice layer in the H/V spectrum, thus leading to large uncertainty of calculated ice thickness (Fig. 2).

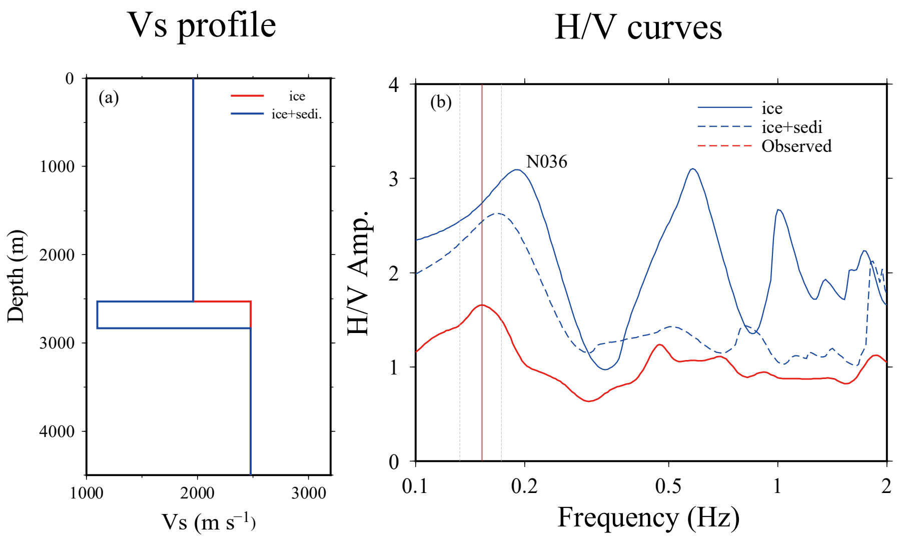

Figure 2. Effect of the sediment on the location of peak frequency. The Vs profiles (panel a) show the Vs structures with and without a 300 m thick sedimentary layer squeezed between the ice sheet and the bedrock layer. The corresponding H/V curve calculated using each Vs model is shown in panel b.

Table 1: Could be useful to have % error, relative to the bedmap thickness?

Response: Thanks for this helpful suggestion, we have revised it accordingly.

Figure 3: Needs a colour key.

Response: The GEOPSY software provides no colour key in the H/V spectrum calculation procedures. In fact, each colour corresponds to a signal windows used for computing the H/V spectrum (i.e. as a 5-day long noise record is divided into windows of 600 s length, the number of windows is 720 and there are 720 colours matching with the 720 H/V spectra, an example is shown in Fig. 1). As some windows were discarded due to transient signals (earthquakes) and some other high frequency signals, the number of windows (colours) used to compute (represent) the H/V spectrum varies for each station.

Figure 4: Plot the elevation panels at the same vertical scale. It's also a little unclear to me what the data in this figure show. If the red dots are the reference Bedmap2 thickness, how is the ice thickness defined in the panels showing the ice/rock interface? It can't be from bedmap, otherwise the red dots would coincide with this interface.

Response: We have tried to plot the elevation panels at the same vertical scale. The figure, however was not as satisfactory as it currently shows since the range of elevations largely varies in different profiles (i.e. the uniform elevation scale to plot the four panels should be 8 km, while the scale for CC' profile is only 4 km).

The elevation data along each profile were extracted using the geographical coordinates of the start and the end stations. We apologize that we made a mistake when extracting the AA profile elevation data by using a wrong longitude value of station N215 and have confused the colors marking the inversion thickness and the Bedmap2 thickness in profile AA and DD panels. This figure was corrected accordingly in the manuscript. Besides, due to the fact that some station sites are not exactly in the straight line defined using the geographical coordinates of the start and the end stations, some red dots still don't exactly coincide with the interface.

References:

Anandakrishnan, S., and Winberry, J. P.: Antarctic subglacial sedimentary layer thickness from receiver function analysis. Global and Planetary Change, 42(1), 167–176, 2004.

Frederick, B. C., Young, D. A., Blankenship, D. D., Richter, T. G., Kempf, S. D., Ferraccioli, F., and Siegert, M. J.: Distribution of subglacial sediments across the Wilkes Subglacial Basin, East Antarctica. Journal of Geophysical Research: Earth Surface, 121(4), 790–813, 2016.

Picotti, S., Francese, R., Giorgi, M., Pettenati, F., and Carcione, J. M.: Estimation of glacier thicknesses and basal properties using the horizontal-to-vertical component spectral ratio (HVSR) technique from passive seismic data. Journal of Glaciology, 63(238), 229–248, 2017.