

We thank the reviewer for his careful and constructive comments and inputs. Here below are reported our answers to the questions raised by the referee starting with “Reply”.

“Dating of an East Antarctic ice core (GV7) by high resolution chemical stratigraphies” Nardin et al. (2021)

Climate of the Past

Referee: D Emanuelsson

Summary

The age scale for a new ice core GV7, Oates Land, is presented.

The paper needs major revisions. There is no clear display material from which the reader can gain confidence in the age scale. This can be addressed by showing a figure with nssSO₄ versus time and indicate volcanic events that stand out from the background any by updating Table 1.

The novel aspects of the core, deepest and oldest core in the Oates region, the trace element records can be highlighted to increase the impact of this study. The writing needs to be improved and checked for clarity.

Comments to the authors

This is interesting work with some unique aspects. I hope the number of comments doesn't discourage you. Keep at it and this study will provide important records that can be used in future studies.

Major comments:

- Be clearer about the method you use. You use nssSO₄ peaks as your main indicator for assigning annual-layer counts, and you have $\delta^{18}\text{O}$ as additional support. Then this method is evaluated by checking the dates against the volcanic events horizons. If they do not agree, you will have to check if your method is wrong, perhaps another chemical works better.

Reply: Thanks for the comment. We actually have worked as the Referee guessed: nssSO₄ peaks were used for the annual layer counting and $\delta^{18}\text{O}$ record was used as a confirmation of the correct (or most reliable, anyway) assignment. We have indeed checked the possibility of using other seasonal chemical markers or a combination of them (as briefly described in the text) but their seasonal signals are generally less clear than nssSO₄ and, mostly, they are not accountable on the long-term, being barely detectable in some depth intervals. Sections from Methods and Results will be rewritten accordingly.

- Your pick at 4.67m (2005) could be questionable. As it is on a shoulder of the isotopes and the nssSO₄ is low. Close to the surface, it is easy to overcount using the isotopes, as diffusion has not smoothed the signal as it has for a deeper section. Are there any other impurities to look at? It almost looks like the trace elements could be helpful for the annual-layer counts. Check the figure that I merged below. (and the trace elements would maybe indicate that this is a pick?).

If you remove this pick, the years that you have marked with text around the Pinatubo eruption will be 1993 and 1992. Then the rise in the trace elements does not occur before the eruption. The depths that you report for the trace element rise seem wrong (11.0 and 12.5 m). If you correct them (11.6 to 12.2 m) the trace element increase will not occur before the eruption. Don't eyeball this, use the criteria that you used in your earlier paper (2std or 3std above background), to find the exact depth/timing for these events.

Reply: Thank you for pointing this out. We had noticed that this peak was just a shoulder on both the records we showed in the paper, and therefore the date assignment could be questionable. Anyway, we decided to choose it as a summer maximum due to the following points:

1. We did consider other ions, as reported in the figure below. Sodium profile showed a clear minimum corresponding with the shoulder at 4.67 m. Although this cannot be considered as a conclusive evidence, it suggests that such a peak is likely to have occurred in summer rather than in winter.
2. Without considering the peak at 4.67 m depth as a seasonal maximum, we would obtain an unrealistic value of the accumulation rate between the previous and the following maximum. In fact, missing this year would yield a two-fold annual snow accumulation rate with respect to the average observed at the site.

As for the trace elements, we agree that removing the peak at 4.67 m depth would make more coeval the peaks of trace elements and nssSO₄ corresponding to the Pinatubo eruption but we would be in favour of keeping the year assignment as it is since this one-year change would shift the age scale within the estimated uncertainty interval.

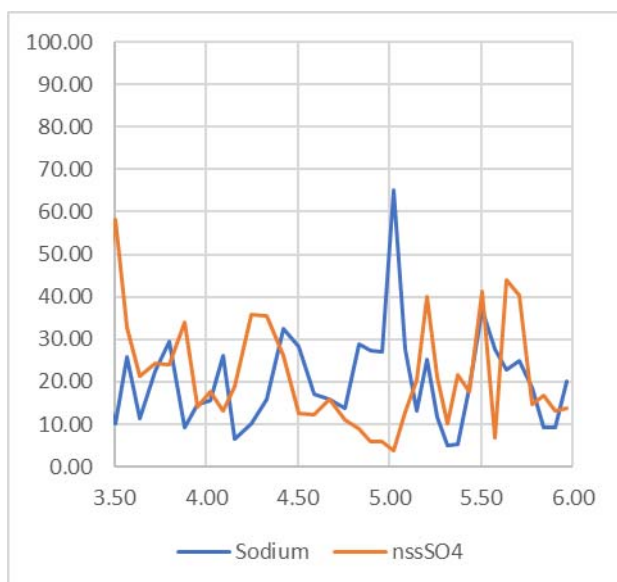


Figure REW1. nssSO₄ (orange line) and Sodium (blue line) profiles between 3.5 m and 6 m below surface; y axis = concentration as ppb; x axis = depth as meters down from surface

- Merge figures 2 and 3. Align b (now figure 3) with depth axis in the top panel of a (similar to like I've done below). How does it look for Agung and other volcanic events? Or even better if there are trace elements for all the depths add two panels with trace elements (b, d). If there are trace elements for the core. It would be interesting to look at this closer and it could increase the impact of the paper.

Reply: Thank you for the comment. As suggested by the reviewer, we merged the two figures and aligned the three (six) records in order to make the whole dataset easier to read and to understand. Unfortunately, the trace element record below 20 m depth is not yet available and to date it is not possible to infer any information about a possible signature of the Agung eruption from trace metals.

Fig. R1

- How do the gaps in the gaps affect the accuracy of the dating? Add a supplementary table that provides % missing for each record.

Reply: Thank you for pointing this out. The missing ice certainly affects the accuracy of our dating because we have to rely on a continuous record in order to be able to date the core. For the missing section of the core we estimated the number of the missing years on the basis of the annual peak frequency in the time window spanning 20 years and centered on the missing ice section. We will add a section in Table 2 with the missing percentage of the core for each section between volcanic signatures.

- For uncertainty estimates, I prefer a method that compares ice core ages at volcanic event horizons.

Reply: Thank you for pointing this out, the uncertainty levels were re-evaluated. Table 2 will be revised according to your inputs and those from Reviewer #2 adding more detailed information.

- Does the accumulation record have a correction for ice layer thinning? Please provide details. A long-term trend might be introduced by not making this correction.

Reply: Thank you for pointing this out. Ice layer thinning was kept in consideration when evaluating snow accumulation rate on site. A constant ice thinning function was used to correct the data considering an ice thickness of 1530 m. This information will be added in the main text.

Specific comments:

Title

Change title. 'stratigraphies' typically is used when you refer to physical properties in a core, not chemical.

Reply: we thank the reviewer for the suggestion. The term "records" will be used instead of "stratigraphies".

According to your advice for rephrasing and following on the suggestion by the Editor for better addressing the reader we would be prone for the following new title:

"Dating of the GV7 East Antarctic ice core by high resolution chemical records and focus on the accumulation rate variability in the last millennium"

Abstract

L21. Stratigraphic dating, you could say this, but you can be misunderstood. The reader might think that you use layering in the ice from say radar scans not chemistry for dating. I suggest that you change this throughout the document.

Reply: thank you for the comment. We'll revise the wording of the text in order to avoid misunderstandings.

L21. Say just 'drill site'.

Reply: it will be done.

L21. Provide the region where it was drilled Oates Land, East Antarctica.

Reply: it will be added in the text, where needed.

L23. Say 'and water stable isotopes ($\delta^{18}O$)..' instead, or

Reply: Thank you, it will be changed as suggested.

L23. Rewrite. ...sea salt ions contain a clear seasonal cycle and was therefore used for the annual-layer counting.'

Reply: Thank you, it will be corrected

L25. Delete 'correlation' say 'age-depth relationship' instead.

Reply: Thank you, it will be changed

L25. '1179-2009' change the type of dash you use.

Reply: it will be changed

L27-28. 'A small, yet consistent, rise in accumulation rate was found for the last 830 years since the middle of the 18th century.' Is it significant? If not, it is not a trend. Provide trend and pvalue. Middle 18th century, approximately 1750, now it is 2021, that is about 370 yrs, not 830 years.

Reply: p value and trend for the investigated period will be added in the abstract. Table 3 will report the trend values of the accumulation rate between consecutive eruptions.

Introduction

L47. PNRA explain acronyms and explain them at their first occurrence (IPICS).

Reply: all the acronyms will be made explicit at their first occurrence

L58. Mention the work that Winstup et al. has done for constraining ice core chronologies (Winstrup et al. 2012, 2017)

Reply: Thank you for bringing this to our attention, they will be added

L77. A too general statement, is it true for all Antarctic cores, or for GV7? If GV7 it should be reported in the result section.

Reply: Thank you for the comment. This is generally true for a number of high accumulation sites where nitrate is preserved and was observed to show a seasonal pattern (Stenni et al. 2001 JGR; Wolff, 1995; Wagenbach, 1998 JGR). GV7 is a coastal-like, relatively high accumulation site, not showing the post-depositional processes usually affecting nitrate in inner plateau sites and it was worth trying nitrate as seasonal marker.

Some information will be added in order to clarify the statement, also complying with the remarks coming from Prof. Cole-Dai.

L91 $\delta^{18}\text{O}$

Reply: Thank you, it will be corrected

L92 You mean that you linearly interpolate for the dates between annual markers? You can say that, but it should be in the method section not here.

Reply: Thank you for your comment. The reviewer got it right: we have linearly interpolated between annual maxima. As suggested, we will move this information to the Methods section.

L93 Just report on the methods that was successful here.

Reply: Thank you, the sentence will be rephrased in order to stress the chosen dating approach.

Materials and methods

- Why wasn't $\delta^{18}\text{O}$ analyzed throughout the core at high resolution? It would not be affected by contamination like the ions, so you could get a record with fewer gaps.

Reply: Thank you for the comment. Unfortunately, high resolution $\delta^{18}\text{O}$ measurements are not yet available and cannot be added to this manuscript.

However, thanks to the manual decontamination of ice section that we have accomplished, the contamination was found only for a few samples. The main reason for gaps in the records is mainly due to breaks and missing core sections, rather than contaminated samples.

L98 insert a space, 1700 m.

Reply: Thank you, it will be corrected

L104 'Estimates of snow accumulation has been calculated from GPR layers from the 2001-2002 ITASE...'

Reply: Thank you, it will be changed

L111 '(ranging in length between 5 to 50 m)'

Reply: Thank you, it will be corrected

L112 'The 250 m deep core, GV7(B) is used in this study. The ice core (Fig. 1) was retrieved using an electromechanical drill (Eclipse Ice drill Instrument).'

Reply: Thank you, it will be corrected

L119. Do you mean that you kept a 4 m of fluid measured from the drill bit to have the drill submerged but not more? The drill fluid surface was not kept at 80m by adding more fluid. This practice could perhaps be better when drilling a brittle core.

Reply: thank you, the reviewer is right. A level of 4 m of fluid able to submerge the driller was chosen as the best compromise between drilling efficiency and quality of the core.

L123 be concise '...only the upper 194 m were analyzed.' Should suffice.

Reply: Thank you, it will be changed

L128 and 133. Say cubes instead. The 4x4 cm core cubes for...

Reply: I think the text was probably not clear enough, they're not cubes. We received ice 4x4x60 strips to be decontaminated. This information will be added to the text.

L143 and L144 Change to 'cations' and 'anions', remove the mentioning of the pump to be brief.

Reply: Thank you, the paragraph will be rewritten without Ion Chromatography technical details

L147. 'while the analytical performance of the methods was tested and described in Nardin et al., (2020).'

I do not think you can claim that you did this in your paper. You showed a high resolution record, but no specific tests of the performance.

Reply: Thank you for pointing this out, it will be removed from the text

L156. Remove the dash and add punctuation.

Reply: Thank you, it will be done

L174 and L175 Do you use these ratios in the manuscript?

Reply: Thank you for your comment, these ratios were used in the paper.

L179. Rewrite this section ...was used to identify volcanic.. end sentence after 'ice cores'.

Reply: Thank you, the sentence will be rewritten

L184. Delete 'where an in-depth discussion....' While this is true, it is not relevant here. Mention it in another section.

Reply: Thank you, it will be removed from this section.

L200. Due 'to' possible noise...

Reply: Thank you, it will be edited

Result and discussion

L211. You use nssSO₄ and $\delta^{18}\text{O}$ together to make a judgment for the annual marker, correct? Here it sounds like you make to age scales one using $\delta^{18}\text{O}$ and one using nssSO₄.

Reply: the reviewer is correct: the original sentence in the paper was misleading. As above said, nssSO₄ record was selected to lead the counting of annual maxima and $\delta^{18}\text{O}$ was used to support in the detection of single years. The sentence will be rephrased to avoid misunderstandings.

L215. You cannot expect the peaks of $\delta^{18}\text{O}$ and nssSO₄ to always align. Especially not for deeper sections when diffusion has acted on the isotopic signal. It is not caused by the different depth resolution of the records. Remove the last two sentences of this paragraph.

Reply: Thank you for pointing this out, the referee is right. The sentences will be removed.

L256. This sentence is way too long. And the end can be misunderstood. It is enough to say. '..., suggesting a lack of seasonality.'

Reply: Thank you, the sentence will be split and the suggested change will be applied.

L271. The punctuation is missing.

Reply: Thank you, punctuation will be fixed.

L274. Change Factor 1 and 2 to PC1 and PC2 (principal components).

Reply: Thank you for pointing this out, PCA will be removed as suggested later

L275. The signs of the PCs are arbitrary.

Reply: Thank you for pointing this out, PCA will be removed as suggested later

L268. Delete the PCA analysis. I do not think it adds any value. Are you using it for dating?

Reply: Thank you for the comment. We agree with the Reviewer, it is not relevant for the purpose of the paper. It will be removed from the Supplementary information.

L278 In general, you do not need to report all approaches that you try that turn out to not be fruitful, this makes the paper long and hard to read.

Reply: Thank you for pointing this out. We are going to shorten this overview of dating approaches, but we think that such information could be useful for scientists involved in dating exercises, considering the site-to-site variability of chemical features.

L294 Should be 'unequivocal'.

Reply: Thank you, it will be corrected

L316. Rewrite this sentence. Suggestions, 'there are fewer major eruptions in this section of the core and as they are further apart the uncertainty becomes larger.

Reply: Thank you for the remark, the sentence will be changed as suggested

L328-329. The first sentences here should be in the method sections. Add a SMB section to the methods and provide more detail about thinning correction too. For example, Thomas et al. (2017) have a method section describing this correction. Present your results first here and then discuss with others' work.

Reply: Thank you for the comment, the sentences will be moved in a new Method section dealing with SMB.

L332. You use several symbols and abbreviations for standard deviation, stick to just one.

Reply: Thank you for the comment. The suggested changes will be applied.

L344. Rewrite for clarity. The mixture of trends and correlations in this paragraph is confusing.

Reply: Thank you for the comment. This paragraph will be rewritten in order to be clearer.

L349. What do you mean here by 'misinterpretation'? If you show that your annual layer counting method works. That is nssSO₄ peaks line up with known volcanic horizons. Then you cannot at the same time claim that you have done a misinterpretation.

Reply: the reviewer is right in noticing this possible contradiction. We agree with the reviewer that, once the dating is carried out, there is no space for "misinterpretation" but just uncertainty. The wording of paragraph will be checked and adjusted accordingly.

L350. Switch the order of the years around.

Reply: thank you for the remark; the reviewer is right. We will shift the order of the years.

L417. Change to 'Conclusions'.

Reply: Thanks. The correction will be accomplished.

L430. Change to 'The GV7 chronology covers the 1179-2009 CE period. The average annual snow accumulation for this period is 205 mm w.e.'

Reply: Thanks. The correction will be accomplished.

Add a data availability section.

Reply: Thank you. This section will be added to the manuscript.

Figures

Figure 1.

Zoom in on the region of interest. Show the whole Antarctic map as an insert. The figure will look better if you add topography (example from bedmap2).

L115 Change to '...1950 m a.s.l.) drill site...'

Reply: Thank you for pointing this out. The image was re-plotted using Matlab extension (bedmap2 and AMT) focusing on the region of interest.

The caption will be updated.

Figure 2.

Pinatubo is marked but not Agung.

Have you removed single value peaks, contamination? Using the code you described in (Nardin et al. 2020). Show lines for each annual pick. Zoom in a bit, so it doesn't become too cluttered. Change the coloring on the y-axes so they correspond to what is shown.

I prefer the figure you have in the supplementary material (Figs. S3 and S4) over this, as $\delta^{18}\text{O}$ is only available for the top part of the core.

Reply: Thank you for your comment. Figure 2 will be updated according to the reviewer's suggestions to provide more information.

The reviewer is right about the removal of single value peaks likely due to contamination.

Figure 4.

'Concentration bins have a three-month seasonal width..'. Tell the reader which intervals you use here, JFM, AMJ,...

'Upper concentration limits and bin sizes were chosen to keep between each ion's plot the same proportions in order to facilitate the interpretation of the data.' Do you need to say this, or do you mean that you have cut out some data with high concentrations?

As nssSO4 is used as the primary chemical for pick annual layers, it will because of this choice show more seasonality. I am not questioning your choice, I'm merely pointing this out.

Reply: Thank you for pointing this out, the plot was edited as suggested. The bin interval (JFM, AMJ, JAS, OND) will be reported both in the figure and in the caption.

We actually do not need to say "Upper concentration limits and bin sizes were chosen to keep between each ion's plot the same proportions in order to facilitate the interpretation of the data" and the sentence will be removed.

Figure 5.

Change to: 'Age-depth relationship...'

Reply: Thank you for pointing this out, it will be edited

Figure 6.

Is there a periodicity in the data, is there an increase after a volcanic event?

To check this you can make a plot with all the events and put each event at time zero, so you can plot them together.

Change axis text from 'TIME' to Time and ACCUMULATION to Accumulation.

Add letters to the figure indicating subplots (a, b).

Start with the start year, i.e. 1849-2001 CE.

Indicate 'Tephra' with another color in the figure as it is not a well-established event.

Reply: Thank you for the hints. As regarding the figure, we will improve it taking into account all the reviewer's suggestions. About the study of periodicity of accumulation, also in relation with volcanic events, it is certainly something worth of further investigation, but we think that it is beyond the scope of the paper which is mainly focused on the production of a reliable age-scale for GV7 core.

Figure 7.

Say 'Accumulation records used for the core stack (gray lines), the stacked accumulation record (blue line)'

Add letters (a, b, c) to the figure.

'a' should not be capitalized.

Which specific ITASE core was this? There are many.

Reply: Thank you for the suggestions. They will be taken into account to revise the Figure.

Table 1.

'Pinatubo/Cerro Hudson'

Table captions usually go on top of the table.

Is it the start or end depth that you are providing? Provide an end and start date, which is more exact. You can get this from Figure S5. Pinatubo 1991.5 (start) 1993.5 (end) (e.g. from the WAIS core, (Sigl et al. 2013)).

Reply: Thank you for your comment. We will update the table being clearer about the start and the end of the signature but we would stick to the integer of the year. Unfortunately, our temporal resolution does not allow reporting accurately the beginning and end of each signature as accomplished by Sigl et al., 2013.

Table 3.

Rewrite caption. 'its'

If you smooth the record before the analysis that would affect the standard deviation.

Change to 'not significant' instead of 'No sign.' Or 'No trend'.

L414. Rewrite this sentence. Suggestion: 'the mean (M) and standard deviation (SD) of the accumulation record..'

It is also confusing that you call the stacked record used here the same name as the other single core.

Reply: Thank you for the comment. The reviewer is right: standard deviations will be removed from Table 3. Moreover, the stacked record reported in Table 3 is now called "GV7 stacked".

Supplementary material

Table S1 and Figure S1. Provide the same information. Stick with just the biplot.

Table S1 caption. The marked loading are $>.6$? PC1 explain 0.40 and PC2 0.184. (= 58.6% explained together)?

Do you mean that it has been varimax rotated?

You need punctuation at the end of each caption.

Reply: Thank you for the comments. Table S1 will be removed and we'll keep the biplot. Punctuation will be fixed.

Figure S3. Move one of these figures to the main text. Remove the normalized record, if it doesn't add anything. Check with a seasonal plot if you are not sure (like Fig. 4).

Remove the parentheses pair after used after 'layering (...)'.

Typo should be 'orange line'.

Reply: Thank you for the accurate remarks. We'll correct the caption as suggested. About the location of Figure S3 in the manuscript we would like to keep it in the Supplementary Information since it is made of two enlarged views of chemical records in sections recording volcanic eruptions, spanning short depth intervals. Moreover, it includes chemical markers that were tested but then not used for annual layer counting.

Figure S4. 'for a shallow (a) and a deep (b) section of the core'.

'Despite showing a similar...' remove this sentence. I would avoid having this discussion in the figure caption.

Reply: Thank you for pointing this out, the caption will be edited.

Figure S5.

Show the whole record. Do not start at 25 m.

Change to nssSO₄ versus time. What you show is the same as in Nardin et al. 2020 otherwise.

Add volcanic events. Like you did nicely in Nardin et al. 2020, but now do it versus time. Add the background + 2std and 3std levels. This way you can evaluate the timing of the volcanic peaks and the reader can gain confidence in the age scale. It is a large figure, but important, I would consider moving it into the main text.

Increase the line thickness of the nssSO₄ line and the box around the figure and make the text bold. This will improve the figure quality.

'with grey dashed and red lines, respectively.

'Other breakages are not highlighted' remove this sentence.

Reply: Thank you for your comment, the plots will be edited as suggested and moved to the main text.

References

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Sigl M, McConnell JR, Layman L, et al (2013) A new bipolar ice core record of volcanism from WAIS Divide and NEEM and implications for climate forcing of the last 2000 years. *J Geophys Res Atmos* 118:1151–1169. <https://doi.org/10.1029/2012JD018603>

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