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Subject: Review article submission to Climate of the Past

Dear Editor,

We here submit the revised version of the manuscript "*Antarctic sea ice over the past 130,000 years, Part 1: A review of what proxy records tell us*", by Crosta X et al., as part of the Special Issue Reconstructing Southern Ocean sea-ice dynamics on glacial- to historical timescales

Our responses to the reviewers as well as the details of the changes done on the main text are described in blue here below. Changes in the revised version appear in yellow. The revised version contains :

- A summary of ~425 words
- A main text of ~11000 words
- Four color figures (~400 words in the captions)
- One table (of pros and cons)
- One appendix (presenting the sea-ice records)
- ~300 references

We thank you in advance for your consideration.
Cordially.

Dr. Xavier Crosta.

Response letter to RC1

The paper by Crosta et al. reviews the current knowledge in terms of i) the use of both marine and ice core sea ice proxies in Antarctica, ii) reconstructions so far produced on Antarctic sea ice changes for the last 130,000 years. This review is more than welcome and useful for a broad audience. The introduction brings the reader into the Southern Ocean setting and Antarctic sea ice is described as one of the players in this environment. The interplays between sea ice and the ocean, atmosphere, biosphere and the cryosphere are presented. The mechanisms for sea ice formation are described in Section 2.1, along with the geographical sea ice distribution during the modern time. The authors then describe the satellite-era sea ice trends (1979-present) and the difficulty of climate models to reproduce them, hence highlighting the difficulty to isolate the main forcings responsible for such trends (Sect. 2.2). One way to go is look at the past, and the authors do that by first introducing the marine and ice core proxies (Section 3). A review of the available sea ice reconstructions are presented for the Last Glacial Maximum (Sect. 4.1), the Holocene (Sect 4.2), and for the Last Interglacial (Sect. 4.3). A shorter section presents the results during the glaciation and deglaciation shorter periods (Sect. 4.4). The work ends the authors recommendations on how to use and combine the records together to squeeze out further knowledge and fill the spatio-temporal gaps in Antarctic sea ice reconstructions.

My general comment is that this review is very well structured and I appreciated the combination between marine and ice core data. The phrasing is also very clear and well balanced in highlighting the assumptions behind the proxies and their limitations. It was a great pleasure to read.

We thank Reviewer 1 for his very positive comments.

Below a list of mostly minor suggestions and typos:

- Decide on “sea-ice” or “sea ice”. I’d use the latter but that’s just my taste.

We followed English grammatical rules on the use of hyphenation. In this case, « sea ice » is used when a noun (Antarctic sea ice expanded…) and « sea-ice » is used when an adjective « Antarctic sea-ice concentration declined….). We were very careful in using the hyphenation adequately and have checked again for possible mistakes.

- L75: “cores” should be “core”.

It has been corrected accordingly.

- L120: in the Figure caption I’d define again the acronyms.

Acronyms have been defined again in the figure caption for more readibility.

- L141: I’d add “sea ice” after “observed”.

Sea ice has been added to this sentence.

- L144: I’d remove “in ice area trends”.

Mesoscale eddies have strong implication for many oceanographic processes (circulation, energy exchange, nutrient input, etc..) that are beyond the reach of this review paper. We believe it is better to keep « in sea-ice area trends » to avoid any confusion or over-interpretation of our scope.

- L152: I’d insert a new line or a new paragraph here to introduce the paper. Here or at the end of L149.

Lines 154-158 present the rationale that has led to the creation of C-SIDE. Breaking down a new paragraph after line 149 will disconnect the issue from how the compilation is designed to solve the issue.

- L185: 18.10 should be 18 x 10. Also at L201.

It has been corrected accordingly.

- L200: I’d replace “decay” with “retreat”.

It has been corrected accordingly.

- L255: after reading Sect. 3 I asked myself whether it would be beneficial to have a table summarizing the various proxies with their salient features, as well as pros and cos. I redirect the question to you.
A summary table with pros and cons is now presented. It is however quite large and might not fit into a single page within the main text. It can be displayed as a supplementary table but will lose its interest as most readers won't look at the supplementary files. We therefore let the Editor decide whether the table is necessary or not.

- L288: maybe replace "anti-coherence" ? Negative correlation ?
It has been corrected accordingly.

- L291: it should probably read "produced in this way".
It has been corrected accordingly.

- L448: I would consider at least mentioning iodine and its linkages to both sea ice and productivity.
We consider iodine to be an interesting potential sea-ice and/or productivity tracer. However, it has not yet been employed in sea-ice reconstruction enough to merit discussion in this review paper focused on the past 130 kyr. Iodine is briefly covered by the 2kyr sea-ice review of Thomas et al., 2019 and in-depth by the halogens review of Vallelonga et al., 2021. We note that there are other chemical tracers (organic compounds or deuterium excess), potential sea-ice proxies, measurable in ice cores that are also not covered here because of their litlle usage so far.

- L512: "in the Dome C".
It has been corrected accordingly.

- L529: I'd rephrase in "This pattern was attributed to the..", "..location of the first year sea ice".
It has been corrected accordingly.

- L534: in this paragraph, maybe here, I'd specifically state that one of the hot topics in Brenr is the relative differences between ssNa and Br transport mechanisms, given the latter is also present in the gas phase.
A sentence outlining differences in ssNa and Br transport has been added lines 554-556.

- L615: I would consider showing the SSI lines in red in the upper panels and the F. obliquecostata as red shading in the panel below. I would also increase the lat,lon font.
We have modified WSI and *F. curta* color (to green), but preserved SSI and *F. obliquecostata* color (blue) to ensure that colors used for WSI and SSI are consistent in all figures.
A question I had while reading the figure is why EDML and PS1768-8 records specifically ? Maybe it could be worth adding a sentence on that somewhere. I would be also curious to compute a (normalized) ensemble of all the Winski et al. (2021) ssNa curves to compare to the EDML one - maybe an ensemble would be more representative on a spatially integrated sea ice signal over Antarctica ? That's just a curiosity.
PS1768-8 and EDML are included as reference points for the general trends in the marine and ice core records. Although they are not intended to be representative of the sea-ice signal everywhere in the Southern Ocean, these records adequately demonstrate the general trends (Chadwick et al., 2022, cp-2022-15).
Assembling stacks and discussing possible leads-and-lags as well as amplitude changes in the different basins of the Southern Ocean is beyond the scope of the present review. These aspects are developed in Chadwick et al. (2022). Additionally, the Winski et al. (2021) paper only presents Holocene ssNa data, which is much shorter than the temporal range on which C-SIDE focuses.

- L622. Insert a full stop before “Upper”.
It has been corrected accordingly.

- L744: I suspect the main reason is because the ice core signal integrates a wide region?
This is a good point. Lines 764-766 have been edited to include this idea.

Niccolò Maffezzoli

Response letter to RC2

The manuscript by Dr Crosta and colleagues provides an overview of the importance of Antarctic sea ice on the global climate system and oceanographic circulation, its present and past variations and a thorough revision of marine- and ice core-based sea-ice proxies for the reconstructions of sea-ice changes. Authors begin with a well structured and justified introduction, followed by a description of the processes and consequences of the sea-ice formation and an up-to-date description of the current trends in sea-ice dynamics in the Southern Ocean. Next, authors described with great detail the main proxies for the reconstruction of sea-ice changes in the past with particular emphasis on diatom valves and the key biomarkers produced by this group of organisms. Authors also dedicate a section to other microfossil groups used in sea-ice reconstructions and to geochemical and isotopic proxies. Lastly, authors summarize our current knowledge of past sea-ice changes, list the gaps in the knowledge and propose future directions for sea ice research in the Southern Ocean.
Overall, this manuscript is organized logically and well written, making it easy to follow. The figures are of high quality and the manuscript contains a wealth of information useful for the specialized and non-specialized reader. I enjoyed and learned much reading the manuscript and recommend its publication.
We thank Reviewer 2 for his very positive comments.

Next, I provide some minor points that authors may like to address:
Lines 88-90. Authors could underscore the importance of these waters fuelling primary production in lower latitudes (Sarmiento et al., 2004).
A sentence on the importance of AAIW/SAMW in the distribution of nutrients to low latitudes marine ecosystems has been added lines 90-92.

Line 112: Since diatoms are a critical proxy for sea ice reconstructions authors could include a general description of the dominant phytoplankton groups in marine ecosystems under the influence of sea ice. Two or three lines describing the distribution of the dominant groups (diatoms, Phaeocystis, etc.) could be useful for the non-specialized reader.
We have specified that diatoms and *Phaeocystis* are the main primary producers in sea-ice influenced environements (Wright and van den Enden, 2000, 2010) lines 112-115, but elaborating on the distribution (for example : diatoms abundances are highest on the continental shelves and at the APF but species are different ; similarly, there are very abundant *Phaeocystis* blooms in the Ross Sea and around SAZ islands, Wang and Moore, 2011), the driving parameters (light, nutrient, water column stratification, grazing, etc… Nissen et al., 2021), and the seasonality of these two groups is beyond the scope of the present review.

Section 3.1 (lines 269-369). Diatoms are powerful tools for sea ice reconstructions but they experience important dissolution in the water column and sediments that can introduce important bias in the interpretation of the fossil/sedimentary record. Since this is a review authors could briefly mention the limitations/problems associated with dissolution (if any).
Lines 364-369 already described such limitations, but few additional sentences on the biases resulting from dissolution in the water column have been added lines 372-389. For example, the preferential

preservation of robust diatoms (*F. kerguelensis, T. lentiginosa*) may lead to over-estimated SST and under-estimated SIC estimates in sea-ice environments.

line 314 Could authors find an alternative term/wording for “martheginal”or provide a brief description between brackets?
The word « martheginal » does not exist. Its presence in this sentence results from several iterations and spurious corrections. It has been deleted.

Lines 365-367 Could authors specify where this selective dissolution takes place? water column, surface-sediment interface? both? which one is more important?
Building on sediment trap studies (Rigual-Hernandez et al., 2015,2016), a couple of sentences have been added lines 372-376 to explain where selective dissolution occurs.

Andrés S. Rigual Hernández

References
Sarmiento, J.L., Gruber, N., Brzezinski, M.A., Dunne, J.P., 2004. High-latitude controls of thermocline nutrients and low latitude biological productivity. Nature 427, 56-60.

Response letter to RC3
Manuscript by Dr Crosta and colleagues provides a summary of the current knowledge and gaps in proxy (marine and ice core) based Antarctic sea ice reconstructions over the last 130ka.
Following the overview of the importance of Antarctic sea ice to global climate, authors introduce reader to Antarctic sea ice cycle and provide summary of the recent Antarctic sea ice changes and challenges associated with modelling of these. Authors than describe range of proxies (derived from sediment and ice cores) applied in current research to reconstruct historical Antarctic sea ice changes and further communicate the current knowledge and the gaps in these as depicted by proxy records. Finally authors provide suggestions for future directions of the Antarctic sea ice research.
Manuscript is well written and logically structured. Text is supplemented by great figures. This is really well constructed and presented review and I have no doubt that it will be of interest to both scientific and non-specialist community.
We thank reviewer 3 for their very positive comments.

Few minor suggestions are listed below.

L358: I would argue that all rather than most proxy methods are dependent on various assumptions
True. It has been corrected accordingly.

L375: I would suggest removing “dominantly”. Within Antarctic setting I believe thus far only B adeliensis was show to be $IPSO_{25}$ producer?
It has been corrected accordingly.

L389: You might want to include recent study by Weber et al (2022), which shows HBIs now measured back to ca 240ka. This further links to L566
This very recent reference has been added. Thanks for pointing it out.

L579: “ … focused on the LGM.” instead of centered on ?
It has been corrected accordingly.

L590: …during the LGM, instead of …at the LGM ?
It has been corrected accordingly.

General comment: I was wandering if authors considered record that perhaps do not cover one/more full temporal segments defined in Fig3? I am aware of at least one biomarker record covering last ca 2.5ka which I think authors do not include in their summery, hence more generalised question around selection criteria. Maybe it would be valuable to include a sentence to acknowledge reader that some partial records might not be included in this compilation.
We have used the compilation from Chadwick et al., 2022 (cp-2022-15) that presents records covering entirely or partially the 12-130 ka period with no particular focus on the Holocene. Late Holocene sea-ice records are presented in Thomas et al. (2019). As such records that do not cover at least half of the Holocene were here diregarded to avoid redundancy with Thomas et al. (2019). A second criterion was that the published records dealt specifically with sea-ice reconstructions, as many published diatom records were used to infer other parameters (ocean temperature, productivity,…). As such, we disregarded some records that we judged not informative enough. It is also possible that we missed some adequate records though we tried to be as exhaustive as possible.

Figure 1: I appreciate this might be slightly thorny task, but could text in Figure 1 be made larger. It is really nice figure, but text is hard to read.
We have enlarged the police font size and improved the overall readibility of Figure 1.

Appendix: Could author please provide full reference list: I think it will be useful to wider scientific community and not all the studies listed in the table are referenced in the manuscript.
A reference list has been added to Appendix 1.

Reference: Weber, Michael E., et al. "Antiphased dust deposition and productivity in the Antarctic Zone over 1.5 million years." Nature communications 13.1 (2022): 1-18.