

Author's response

We thank both referees for their constructive comments to improve and clarify the manuscript. They were carefully considered. Detailed replies to the referees and corresponding changes in the manuscript are listed below.

Anonymous Referee #1

Overall

In this paper the climate record from the upper 411 m from a 724 m deep ice core from the Akademii Nauk Ice Cap on Severnaya Zemlya is presented and discussed in terms of mainly temperature and sea ice variability. The core has been dated to cover the period between AD 900 and 1998.

There is generally very little paleo-data available from this part of the Arctic so therefore this paper is of particular high interest from that aspect. In the light of the dramatic changes that we are now seeing in the Arctic proxy-climate records like the Akademii Nauk ice core are extremely valuable in order to improve our understanding of the different processes and dynamics being important for the Arctic climate.

I consider the Akademii Nauk ice core being well-dated and very suitable using for various paleo-climatic studies. Despite the fact that the ice core is retrieved from an ice cap with seasonal melt and thus has the potential of melt-water infiltration, the annual layer counting has been possible using high-resolution stable isotope data differencing single years using $\delta^{18}\text{O}$ and δD . In addition detectable peaks from nuclear bomb tests and several well-known volcanic eruption ensures that the dating error is within the ± 5 year limit. Specific details around the dating is not presented in this paper because it has been discussed in previous published work in Journal of Glaciology in 2009. However, since dating of cores from lower elevation ice caps is often the issue that many in the scientific community are particularly concerned about I suggest including a figure showing examples of the $\delta^{18}\text{O}$ stratigraphy in detail- also for deeper layers.

The paper clearly suffers from poor language which makes it sometimes hard to understand. Therefore, it is very important to focus on improving this.

In summary, the paper includes important data but presentation is not the best.

Specific comments

Abstract

The first sentence is not a good introductory sentence to the abstract. In fact, the text in the abstract does not reflect or give justice to the content of the paper. It should be rewritten.

[T.O.] → We revised the abstract and in particular the beginning.

Introduction

p. 2404, line 11.

[T.O.] → ???

Methods and data

This is a very brief chapter and does not include all the necessary items. I think that the meteorological data should be presented here. Why has not the whole core been analyzed?

[T.O.] → *This chapter was extended and provides now more details. A section on the meteorological data was included. The analysis of AN ice core samples is close to be finished. At the end of the introduction is mentioned that we present only time-series based on a well-established age-depth relation (i.e. for the upper 411 m of the core).*

Ice core dating

2405 line 14-19. "For an independent annual-layer counting we used the seasonal signals of the high-resolution stable-water isotope data". Because major conclusions are based on the annual resolution and I think that the reader should get to see an example of what that looks like, i.e the d18O raw data. This is not shown in Opel (2009) either. . . .

Also I wonder if annual layers were detected throughout the 411 m upper core? I would be very curious to see what it looks like at 400 m compared to the upper core part. . . .

[T.O.] → *We added an additional Figure (Figure 3) displaying raw data of $\delta^{18}\text{O}$ and d excess for four core sections: A: 2-8 m w.e (3.35-12.05 m), B: 87-93 m w.e. (100.22-106.75 m), C: 216-222 m w.e. (240.30-246.92 m), and D: 361-367 m w.e. (397.97-404.49 m). The combination of $\delta^{18}\text{O}$ and d excess data allows annual layer counting.*

2406 line 5-10. This makes the reader curious about the lower part of the core. Have there been any preliminary analyses done that support the statement " might be a remnant of an older, but post-glacial ice-cap stage" ?

[T.O.] → *We added some information on $\delta^{18}\text{O}$ values that point to a post-glacial origin of this core section ("as indicated by a mean $\delta^{18}\text{O}$ value of -20.1‰ (range: -23.7 to -16.8‰)").*

Results and discussion

In this chapter the language makes it more difficult to follow. Sentences are in many cases constructed in a very complicated way. It will benefit greatly from being rewritten.

[T.O.] → *We revised the language in the manuscript.*

Below are a number of examples- but there are many more. . . .

2407 line 14. weaker than those reported. . . .

[T.O.] → *Changed accordingly!*

2407 line 18 different elevations. Actually the whole sentence line 16-20 would benefit from being rewritten- it is very long.

[T.O.] → *We rewrote the sentence and replaced altitude levels by elevation.*

2407 line 21. Remove “this area”, it is enough with the “the Barents and Kara seas region”

[T.O.] → Changed accordingly!

2407 line 23-24. Remove “and less maritime”

[T.O.] → Changed accordingly!

2407 line 27. The expression chosen here “climatic fluctuation” does not describe that this is actually a warming.

[T.O.] → The expression “climate fluctuation” chosen here refers to the paper of Wood and Overland (2010) cited in this sentence. The warming is already included in the term “Early twentieth century warming”. Therefore we didn’t change it.

2408 line 2-6. Complicated sentence with many commas

[T.O.] → We changed this sentence.

2408 line 7. Please specify “these processes” when you start a new paragraph

[T.O.] → We changed the wording to “these positive feedback processes”.

2408 line 7-15. “peculiarity” is not the best choice of wording here. Please rewrite these sentences.

[T.O.] → We replaced peculiarity by “special feature” and “specific regional feature”.

2408 line 16-23. This paragraph does not fit into the topic of this chapter. There is a very abrupt transfer to the sodium record from d18O without much introduction. Please delete or rewrite and move to p. 2409 where you discuss the sodium record more.

[T.O.] → We moved this paragraph to the next section and added an introduction to sodium as potential sea-ice proxy.

2409 line 4. “too” looks wrong here. Please rewrite, maybe using “in addition” instead.

[T.O.] → Changed accordingly!

2409 line 8. I assume that you with “d18O derived temperature” mean the proxy temperature and not a reconstructed temperature. Maybe best to specify so that there is no misunderstanding.

[T.O.] → We changed the sentence to clarify the meaning.

2409 line 9. I think that the use of the sodium records as a sea ice proxy needs/deserves a little better introduction here. I recommend starting a new paragraph.

[T.O.] → We added an introduction to sodium as potential sea-ice proxy.

2410 line 10-12. Something is wrong here. Please rewrite sentence.

[T.O.] → We rewrote this sentence.

2410 line 20-25. This seems quite speculative so I suggest expanding text a little more. Exactly what is the meteorological data showing?

[T.O.] → *We weakened the argumentation in this section and deleted the reference to the meteorological data after checking them again.*

2410 line 27. This statement should either be supported in this paper or have a reference to Opel et al., 2009.

[T.O.] → *We added a “rather” to annual temperatures here and sharpened the corresponding section in chapter 4.1.*

2411 line 23-26. You mean “no similar” pattern? Please rewrite

[T.O.] → *Yes, changed accordingly.*

Figures

I suggest to replace the running mean with a more robust and better –suited low pass filter which will not “re-place” the peaks.

[T.O.] → *We did not replace the running mean with another filter. Running mean is a standard low-pass filter that is widely used in ice core studies. We did not understand what the reviewer means with “replacing the peaks”, but the running mean has no phase shift.*

The figures with the time series would benefit from having denser tick marks at least for the time (x-axis).

[T.O.] → *We increased the tick-mark density in all figures.*

Fig. 4. Please merge panel A and B to one since they are showing the same variability.

[T.O.] → *We did not merge panels A and B as we think it is important to present not only the standardized variability (which is, however, important for the comparison to the meteorological data) but also the original d_{18O} values.*

N. Abram (Referee)

Overall, this is a very interesting new ice core record for the Arctic. I think that the paper will be suitable for publication in *Climate of the Past*, but the work does first require some revisions to clarify and fully justify the main points being made.

Please note, that as editor on this paper I am submitting this review because the second reviewer has not completed a referee report yet and I think that it would be best to keep progress on this paper going forward rather than waiting longer or seeking out a new referee. I would now ask you to look over my review comments as well as those of the first reviewer and proceed with preparing a revised manuscript and response to the reviewers comments.

Sincerely, Nerilie Abram

Main points:

Na/sea ice discussion:

The use of Na as a sea ice/circulation proxy could be better developed and needs to be supported by references. For example: page 2409, line 12 onwards – the use of increased Na to reflect lower sea ice near this location needs some evidence to support it. Also, in figure 5 it would make more sense I think to compare the Kinnard sea ice reconstruction to the Na record which is being used as a proxy for sea ice. Perhaps to avoid confusion the Na-T comparison and comparison to Kinnards sea ice reconstruction could be grouped together as a separate panel at the bottom of this figure (i.e. keep the temperature proxies together and the sea ice proxies together)

[T.O.] → We added an introduction on the approach for long-term interpretation (increased Na → low sea ice, and vice versa) and expanded the discussion of the sodium record. In addition, we changed Figure 5 (now 6) and grouped the SAT and sea-ice proxies according to the suggestion.

Trends vs multi-decadal variability:

It would be good if the text could be made clearer regarding discussion of multi-decadal variability vs long term trends. E.g. page 2409, line 25: it is the multi-decadal variance that appears to come out of “strong accordance”, the long-term pattern still looks similar I think – are there some correlation statistics that you could use to back this up? Also, the paper would benefit from statistics to back up some of the main points. For example, page 2411, starting at line 12: what is the “dominant range” in your record, by what statistical measure do the anomalies in the 15th, 16th, 18th and 20th centuries exceed it by?

[T.O.] → The corresponding discussion was partly restructured and sharpened, focusing more on long-term trends and multidecadal variability. Information on correlations between Akademii Nauk $\delta^{18}\text{O}$ and the other records was included in the text. In addition, we added information on how we measured that the abrupt changes exceeded the dominant variability in AN $\delta^{18}\text{O}$.

ETCW and 1800 minimum:

The discussion of these features is quite prominent in the manuscript, but I feel that they could do with more clarification/exploration and also illustration in an additional figure. For example: some mention is made to leads/lags between sea ice and temperature. How significant /certain are these relationships?

[T.O.] → We expanded and sharpened the corresponding discussion and added the aspect of potential amplification of the 20th century sodium rise due to melt water infiltration. However, we did not add an additional figure as all relevant information (i.e. the lead of sodium over $\delta^{18}\text{O}$ as well as the lead the Barents and Kara seas region’s ice core records over the Arctic wide reconstructions regarding 1800 minimum and ETCW) is already displayed in the existing figures, i.e. in Figure 6.

Also, is it possible to plot the Meeker and Mayewski data for the Icelandic low/Siberian High reconstruction alongside the new ice core record to help support the interpretation that this meteorological change can explain the abrupt changes in your record.

[T.O.] → We did not include the Meeker and Mayewski data to the figure, but expanded the discussion and weakened the misleading statement in the corresponding section. Even though the Meeker and Mayewski reconstructions show significantly elevated values for the whole period 1400

to 2000 compared to 600 to 1400, they do not directly explain the abrupt changes in AN ice core records. They rather indicate a generally higher variability of atmospheric circulation in this period that might be a precondition for the abrupt changes in the Barents and Kara seas region observed in the AN and Austfonna ice core records.

It would also be helpful for people who aren't so familiar with the climate features in this area if you could have a map/schematic/spatial correlation plot, or something along these lines, to show how these features influence the climate at your ice core site.

[T.O.] → We added in a schematic way the positions of the Icelandic Low, the Siberian High and the major atmospheric circulation pathway (Westerlies) to Figure 1 (Map) to provide some additional climatic information.

Comparison to Arctic reconstructions:

it would be good to bring in the new PAGES2k synthesis (Nature Geoscience 2013, May).

Also how different is the more recent Arctic temperature reconstruction in that paper compared to the 2009 one? Page 2412, Line 5 onwards: does this interpretation still hold with the newer Arctic reconstruction? Are the difference a robust feature, or are they within the range of noise and chronological uncertainties within the Arctic reconstruction?

Also, to aid discussion of differences related to geographical distribution, would it be possible to add symbols to the map showing where the records for the Arctic synthesis come from?

[T.O.] → We added the new PAGES Arctic SAT record to Figure 5 (now Figure 6) and included it in the discussion of long-term changes. We did not add symbols for the records used by the Arctic reconstructions (Overpeck et al., Kaufman et al., 2009 and PAGES 2k Consortium, 2013) to the map because we think this would make the figure too confusing. However, for a better regional characterization we added the information, how many of the Eurasian Arctic records come from Scandinavia (the majority).

Minor:

- It would be good to provide some additional site information (e.g. temperature, accumulation)

[T.O.] → We added a short section in the introduction providing some basic information on temperature, melt water infiltration, and mean accumulation rate and the references to Fritzsche et al., 2005 and Opel et al., 2009 with more detailed information.

- Page 2407, line 16-20: this sentence is quite long and difficult to follow

[T.O.] → We rewrote the sentence.

- "peculiarity", in some instances might be better phrased as "localized feature" or something similar that is more specific for the feature that you are discussing.

[T.O.] → We replaced peculiarity by "special feature" and "specific regional feature".

- Page 2407, line 20: Can you elaborate on why/how it indicates a strong Atlantic influence?

[T.O.] → The strong similarity of AN $\delta^{18}O$ to more maritime SAT time series indicates the strong influence of the Atlantic on the SAT regime of the Barents and Kara seas regions (atmosphere and ocean circulation). We changed the section accordingly.

- Page 2409, line 1: how much elevation change would be needed to explain the long term trend? How likely do you think it is/what other evidence is there that this is influencing the trend, particularly given that it seems to be a consistent feature across many Arctic records?

[T.O.] → We added a section that discusses the growth of AN ice cap and its effects using isotope gradients from the literature and came to the result that the growth has an influence but less than the decreasing summer insolation.

- The Lomonosovfonna record is mentioned in the text but is not shown in the figures. It would be good to include this so that readers can visualize the differences that are mentioned in the text.

[T.O.] → We added the Lomonosovfonna $d18O$ record to Figure 5 (now Figure 6).

- Page 2410, line 20: this sentence was difficult to follow. Do you mean “. . .sites as being distinctly different to SAT patterns in the North American Arctic.”?

[T.O.] → Yes, but we rewrote this sentence.

- Table 1: it might be better to separate out into separate columns the raw and detrended correlation values, I found the use of brackets to denote this different to be a little confusing at first.

[T.O.] → Changed accordingly!