Reply to referees Ver 25.5.2018

Anonymous Referee #1
Received and published: 26 February 2018

Laakso et al. One hundred years of atmospheric and marine observations at Utö Island, the Baltic Sea Ocean Sci. Discuss., https://doi.org/10.5194/os-2017-105

Review

RC1_1: The paper presents long-term meteorological and oceanographic data from the Utö station in the north-eastern part of the Baltic Proper (Archipelago Sea). It is a very valuable source of information for meteorologists, oceanographers, and climate researchers. I strongly recommend publication of the results.

The authors thank the anonymous referee 1 for his/her positive words on this manuscript.

RC1_2: However, the paper could be improved by adding more scientific discussion points. My main concern is that the statistical analysis results are presented, but not properly discussed. Much more can be done/analyzed that would help to put the results into a wider context.

We have added more discussion and compared the results with previous studies. All addition in the manuscript are written in red font.

RC1_3: Physical processes, which could cause the observed changes in stratification and deep layer characteristics are oversimplified in the analysis – mostly the changes are explained by vertical mixing. As shown in the Gulf of Finland, the stratification very much depends on wind conditions – winds from a certain direction tend to strengthen the stratification and opposite direction weaken it. Thus, bidirectional lateral transport is an important factor.

We added more discussion and references related to this topic.

RC1_4: I think, a look at the topography of the study area (and connections, sills between the Utö Deep and Baltic Proper) could be relevant.

This is a good an a relevant comment, which we further analyzed the following way:

1) We compared the available data between Utö and observation point LL15 (59°10.99'N;021°44.80'E, approximately 70 km SSE of Utö, max depth 130 m). Unfortunately, we do not have very well overlapping data period, but we made a short gif-animation (Figure R1) which clearly shows that the salinities start to deviate at 60 meters, indicating indeed that the water below this depth do not always represent the central Gulf of Finland.

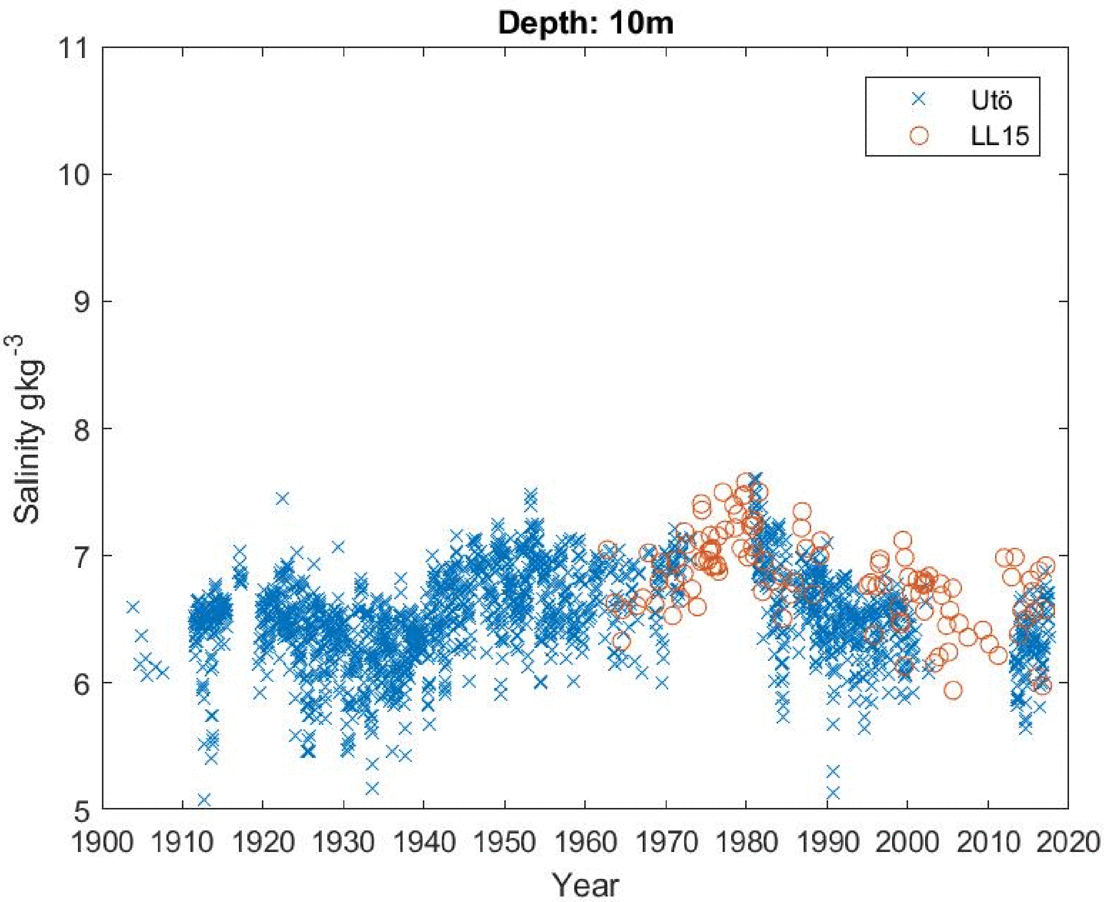

Figure R1: Time series of salinity at different depths in Utö and observing point LL15. This figure is also given as a separate file.

2) However, this is not always the case: we see sometimes saline bottom water reaching our measurement location and a halocline between 50 and 70 meters depth (Figure R2). Such periods may last for several months. These situations and reasons behind are interesting, and worth of another study.

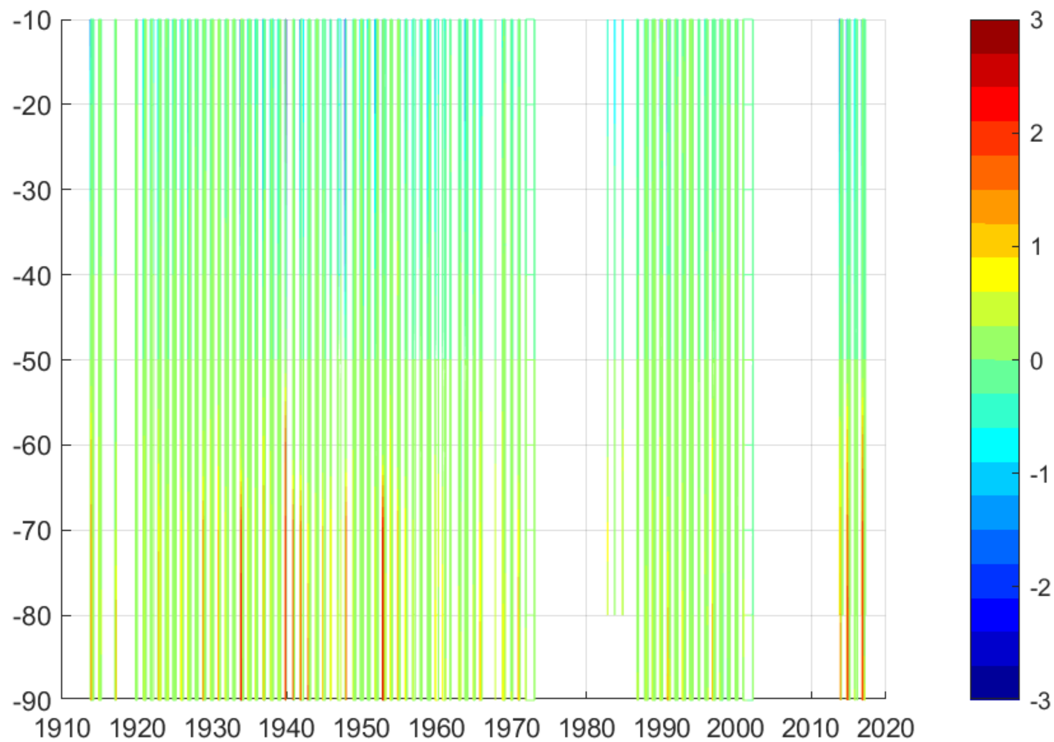

Figure R2: winter months (Oct - March) salinity difference between 50m and other depths (salinity at depth X divided with salinity at 50 meters).

We see that the saline water is sometimes able to reach Utö deep and there is a halocline between 60 and 70 m. However, it is observed only for short periods. This indicates in some cases, e.g. strong enough major Baltic Inflow or e.g. special situation with underwater currents, we have a halocline also at Utö deep.

Based on dataset used in this paper and the combined profiling buoy and ADCP-measurements started in April 2018, we may be able to understand this phenomenon better in the future.

3) The sea areas surrounding Utö are military areas and the depth maps publicly available do not necessarily represent the actual depths of the sea. Based on public data, we see (new Fig. A2 in the manuscript) that there is an area with depth of ~60 m on the western side of Utö and one further south, which may prevent the deep, saline water from entering the location of hydrographic observations. We composed a map based on public data, which is now attached in the appendix.

4) During the spring 2018, we have made some CTD-soundings (Figure R3) next to our new profiling buoy (Fig A2, location 6) and compared those with the observations on our long-term hydrographic observing location (Fig A2, location 1). The salinity profiles overlap between the surface and 60 m depth, while the salinity between 60 and 75 m is higher in the location South of Utö

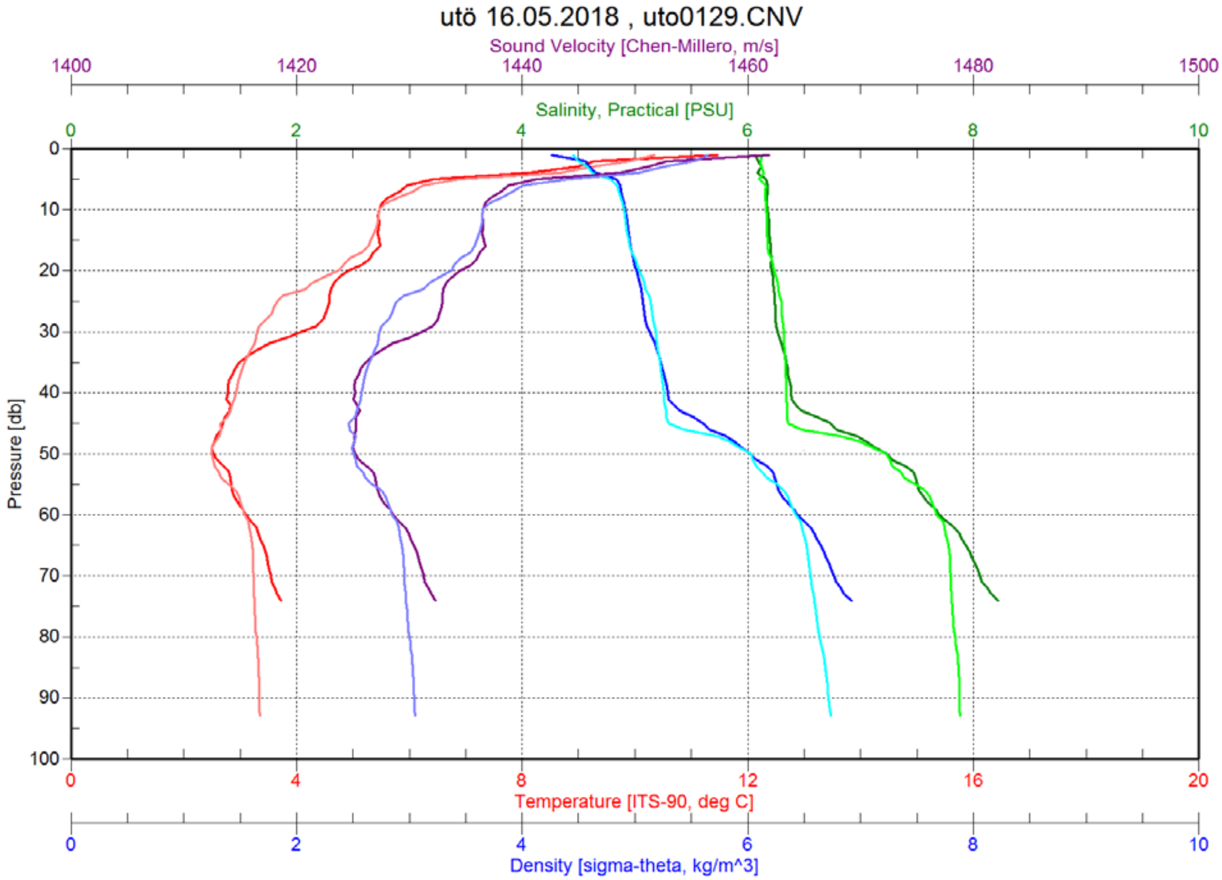

Figure R3: CTD profiles taken in the traditional measurement location (Figure A2, location 1: curves 0...94 m) and next to the profiling buoy (Figure A2, location 6, curves 0...75 m) in 16 May 2018.

This question is now shortly discussed in the paper

RC1_5: Also, as mentioned by the authors, this analysis sets the background for the further studies of biogeochemical changes. But no suggestions are made on this subject in the paper/discussion.

We added the following paragraph in the conclusions:

"An interesting study utilizing the time series presented in this paper together with the new observations will be to use the new cabled bottom profiler together with an ADCP (Fig. A2 and Table A1) to study the occasional inflows (briefly discussed in this paper) of saline bottom water which may have significant impacts on the Archipelago Sea ecosystem (Vuorinen et al., 2015).

Another planned study combining hydrographic observations with biogeochemistry and climate change is to use the profiler together with the flow-through system to analyze the thickness of biologically active layer and its connection to the marine carbon cycle.

Together with our new observations, the long data series represented in this paper will support better understanding of both the earlier observations and current, on-going physical, chemical and biological changes of the Baltic Sea."

Specific comments

RC1_6: Abstract
There are some spelling errors in Abstract. Please, correct them.

Corrected.

RC1_7: P1, L14-15: The last sentence of Abstract has to be rephrased. If I understand the results correctly, the ice does not cause large local effects anymore in this new phase. In the present form, the sentence has an opposite meaning that the ice does not reduce local effects. Did it reduce or cause the local effects earlier?

Clarified. The aim is to say that we see increase in local atmospheric temperatures at Utö only after the duration of ice cover has significantly decreased.

RC1_8: 1. Introduction
I miss a broader problem setting. Also, a scientific aim of the study could be formulated.

Clarified and better stated aims added.

2. Measurement site and general characteristics

RC1_9: P2, L29: I would avoid using the term "seasonal sea" which is not commonly used in the scientific literature.

Changed

RC1_10: P3, Fig. 1: It is quite empty. At least the sub-basins of the Baltic mentioned in the text should be shown (Archipelago Sea, Baltic Proper, Gulf of Finland, etc.). Also, consider presenting a local map where the oceanographic measurement site with the topography of the surrounding area could be seen.

Added to the map. We also added a local map around Utö in the appendix (Figure A2).

RC1_11: P4, L3-5: I agree that saline water inflows and freshwater input keep the stratification strong, but I do not agree that it causes the deep water to be anoxic. It could be opposite – saline water inflows could ventilate the deep layer. Moreover, the main reason for oxygen depletion is consumption of oxygen.

Removed

RC1_12: P4, L13-15: It is not obvious how the bottom topography and prevailing winds cause strong currents in the Utö Deep. Please, give a reference or explain it (also providing a map with topography if appropriate).

Finnish Geological Survey has mapped the areas close to Utö and found eroded areas at the bottom. We have access to this data, but are not able to publish it. The potential for strong flows is clearly visible in the canyon-like shape of the Utö deep (Figure A2).

In October 2017, we deployed an ADCP in the area, but unfortunately the acoustic releasers did not function, so we haven't been able to obtain the data yet (we try a ROV recovery later this year). We deployed a new ADCP in April 2018, so current data will become available in spring 2019.

3. Observations and methods

RC1_13: P4, L28-29: Please consider other options for sub-titles, e.g., "Observations and methods" instead of "Observations and methods used in this study"

Changed.

RC1_14: P6, L25-26: I do not understand the last sentence of this sub-chapter "In aim to keep the focus of this paper solid, we focus on a selection of the variables instead of all possible seasonal data." Please, rephrase it.

Removed. The aim is to simply state that with the available data set, we can calculate a lot of different things, but decided to focus on certain aspects only, to limit the length of this paper and keep it easier to read.

4. Results

RC1_15: P7, L9-13: Is the annual mean NAO index the best parameter to use here? For instance, Lehmann et al. (2011) did use NAO winter index (from December to March). Also, I do not see that the highest negative NAO values and low temperatures are connected (e.g., 2009 has far lowest NAO but not the lowest temperature).

We slightly modified the sentence as it was not accurate.

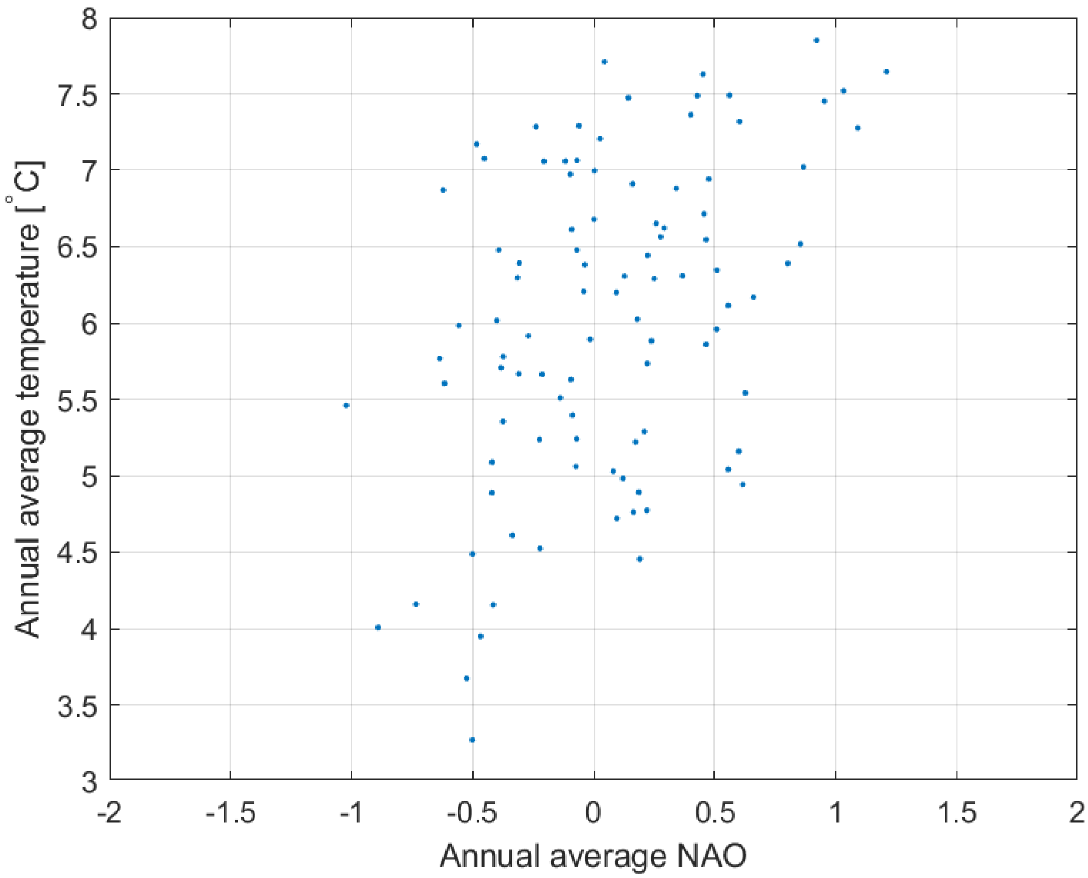

Figure R4: Annual average temperature as a function of annual average NAO. The average temperature for NAO < 0 is 5.7°C and for NAO>0 it is 6.3°C .

There is a lot of scattering in the data (Figure R4), but we see that the warmer years are typically with higher NAO index values and vice-versa. If we plot instead of annual average temperatures the winter time temperatures as function of winter time NAO, we see somewhat higher correlations.

RC1_16: P9, L9 and Fig. 6: Why median values are used here?

There was no particular reason to choose between mean and median. The resulting figure is not sensitive for this choice.

RC1_17: P9, L13-14: I do not agree with the suggestion that the relatively strong currents are the reason for the absence of the halocline. Could the bottom topography restrict saltier water transport into the Utö Deep?

We agree with the comment and have modified the article accordingly.

RC1_18: P11, L7-9: What do you mean by “we calculated the top and bottom of mixed layer depths”? I did not find a method in Lips et al. (2016) for that.

Reference left out and text modified.

What we actually did: We used a method inspired by the paper by Lips et al (2016) to determine the location of mixed layer. We basically described the top of the thermocline to be the location where the density had increased 0.25 kg/m3 from the density at 5 m and the bottom of thermocline the location where the density was 0.25 kg/m3 less than the density at 50 m. We also required the total density difference between 5 m and 50 m to be at least 0.5 kg/m3. Visually, this gave quite reasonable values. But this is now left out.

RC1_19: P11, L13-16: What could be these other phenomena responsible for deep water temperature increase in the 1980s and 1990s and recent decrease?

We do not know. In aim to see the potential effect of river runoff, we combined a data series for total Baltic Sea river runoff for the period 1900-2016. As we think these data will support the discussion in the paper, we included it as third panel in the Fig. 10.

We also added the following paragraph in the section 3.1 Observations and other data:

“River run-off data for the period 1900-2016 is a combination of observations for the period 1900-1995 (Hansson et al., 2011) and modeling for the period 1996-2016 (Johansson, 2018). The offset between the two data sets was corrected by calculating averages for both data sets for the overlapping period 1950-1995 and correcting the modeled data with the difference “

We also studied data by plotting e.g. monthly averages of sea water temperatures and salinities at different depths and tried to see if we can better figure out the differences. For example, we saw that during the period 1990-2000 the autumn time salinity difference between 90 and 50 meters was ~0.1-0.2 g/kg, while in 2013-16 it was almost 1 g/kg. As the the vertical mixing takes place during this period (Fig. 6), there is more resistant for the vertical mixing during the later period.

We will understand this phenomenon better in the future, when we have collected at least one year of high time-resolution data on sea water temperatures, salinities, underwater currents with the new instruments installed in April 2018.

RC1_20: P12, L3: Stratification should not be large and small, but rather strong and weak.

Corrected.

RC1_21: P12, L9-11: Do you explain the observed changes in deep water temperature by vertical mixing and stratification only, or is it possible that these changes are related to lateral exchange? Please, explain it because it is not clear what are “these changes... responsible for the increased water temperatures at 50 m and 90 m depths”.

There has not been significant changes in the wind pattern during the period 1960-2016, as seen from Fig. R5 below. Thus, while for individual periods the lateral exchange has definitely a strong impact, we do not assume it has influenced the trends.

RC1_22: P12, L14: What is meant by “We also see a rapid increase in 1940s”?

Added word “salinities”

RC1_23: P13, L7-8: Why these 30-year periods were selected for the comparison. It could be reasonable for the atmospheric data, but not for the oceanographic parameters which revealed a rapid change in the 1990s.

We decided to use the standard climate periods. However, we added a clarification in the text stating this.

RC1_24: P13, L14-15: Has this sentence (“However... ”) the meaning of the previous comment that the chosen periods hide the rapid change after the 1980s?

Sentence improved

RC1_25: P14, Table 1: How these averages and standard deviations were estimated?

Simply calculated from the data using standard Matlab functions. We found a small inconsistency in our calculations and re-calculated the values and updated the table accordingly.

5. Conclusions

RC1_26: P15, L15: The saline water inflows increase salinity in the deep layer, but they could cause either an increase (mostly) or decrease in temperature. This change is not directly connected to the reduced vertical mixing. Do you have any pieces of evidence that the observed decrease in deep water temperature was due to the reduced vertical mixing?

If we look Figs 7 and 8, we see that there is larger salinity gradients in 1910-1920, 1960-1970 and again after the last increase (2013→) in salinity. In all cases, the bottom water temperatures have been lower as well. It is not of course possible to definitely say this is the case, but based on the data, we think is may be the case. Please see also reply to RC1_19.