Ocean Sci. Discuss., 12, C294–C313, 2015
www.ocean-sci-discuss.net/12/C294/2015/

Ocean Science
Discussions
Open Access

Interactive comment on "The Barents Sea polar front and water masses variability (1980–2011)" *by* L. Oziel et al.

L. Oziel et al.

laolod@locean-ipsl.upmc.fr

Received and published: 18 June 2015

Dear editor,

Please, find below the answers to the comments and suggestions of the referees of the manuscript "The Barents Sea polar front and water masses variability (1980-2011)" which has been submitted to Ocean Science Journal.

REVIEW #1

The first reviewer wished that we address three important issues, one about the database, one about the low frequency variability and its links to the AO, NAO and AMO, and a last one about the links between observations and model. They are recalled below in bold and our answers are given just below. Some less major comments were added. We list them and also give our answers.

FIRST ISSUE: " Firstly, there is a new online "Climatological Atlas of the Nordic Seas and Northern North Atlantic" by Korablev et al (2014) that includes the Barents Sea with 1/4-degree resolution: http://www.nodc.noaa.gov/OC5/nordic-seas/. The database of the Atlas is quite large, so a comparison of the database used in the reviewed research and the one in the Atlas of Nordic Seas would be a good addition." "The paper by Seidov et al (2015) discusses the World Ocean Database holding in the high latitudes, so, again, it is important to compare the database employed in the reviewed research with the WOD depository".

ANSWER: Thank you very much for these references. We failed to notice the existence of the new database by Korablev et al. (2014) and the corresponding publication. This database is very close to the one we built (their data come from the European ICES database and the Russian database from AARI as ours; the number of station involved in both database is almost equal). However, our interpolation technique seems more appropriate to the detection of the frontal structure (Fig.1). The database discussed by Seidov seems to be less complete (the amount of profiles is significantly smaller).

CHANGES IN THE MANUSCRIPT: The section 2.1 Data (p. 454, line 15-19) will be modified as follows. The following text should appear and replace the original text:

"The International Council for the exploration of the Sea (ICES, http://ocean.ices.dk, see for example Nilsen et al., 2008) and the Arctic and Antarctic Research institute (AARI, Russia, Ivanov et al., 1996; Korablev et al., 2007) provide processed hydrographic data sets which document the BS area. We have merged these data sets to constitute a new database which parallels the "Climatological Atlas of the Nordic Seas and Northern North Atlantic" by Korablev et al. (2014). Both databases contain more than 130 000 CTD profiles; they include the BSO section repeated 6 times a year every other months, and the Vardø section repeated twice a year, in winter and summer (see Fig.1a). They probably constitute the most complete hydrographic collection for the

OSD
12, C294–C313, 2015

Barents Sea. By comparison, the World Ocean Database discussed by Seidov et al. (2015) contains less than 85000 profiles for an even larger area.

The techniques used to build these database however slightly differ. Korablev et al. (2014) used the Data Interpolating Variational Analysis (DIVA) and thus obtained smoothed fields on a regular 0.25° × 0.25° latitude – longitude grid. This method has the advantage to take into account topographic and dynamics constraints. We chose to use an unbiased kriging technique which is described in the following subsection. The gridded field are computed on a 0.5° × 0.25° latitude – longitude grid. The field we obtained are generally less smooth than those obtained by Korablev et al. (2014). They allow us to visualize the fields with more details, particularly around fronts. The accuracy of the data is..."

SECOND ISSUE:

First point: "... the authors (Seidov et al.,2015) provide a new research of the NAO and AMO correlation with observed ocean variability in Greenland-Iceland-Norwegian Seas where Atlantic water impact is quite strong. Another paper, by Yashayaev and Seidov (2015), focuses directly on the Atlantic Water inflow in the Norwegian Sea and its transformation as it progresses northward up to the western part of the Barents Sea. It is shown that the salinity and temperature signal splits, presumably because of the sea-air interactions. Levitus et al (2009) have shown that there was a shift in the Barents Sea thermohaline regime in the 80-es of last century and then a substantial warming in the beginning of 21st century. It was also shown that the upper layer temperature correlates quite well with Atlantic Multidecadal oscillation index, so the BS variability may be more dependent on thermal regime in the northern North Atlantic than on the processes in the atmosphere reflected in the AO and NAO."

ANSWER: In our previous analysis of the links between the AO and the variability in the Barents Sea, we have not considered the NAO and the AMO, and consequently the articles quoted just above. We introduce these references in the introduction where the

OSD
12, C294–C313, 2015

problematic is presented. The discussion of the results is also modified to take them into account. The paper will thus be modified as follows.

CHANGES IN THE MANUSCRIPT: The Introduction is modified (from p. 452, line 15 to p.453 line 6). The following text should replace the original text:

"... The low frequency variability of the Arctic is commonly associated with the North Atlantic Oscillation (NAO) or the Arctic Oscillation (AO) (Thompson and Wallace 1998). Indeed, the AO and the NAO are highly correlated and both are useful to analyze the impact of the atmospheric circulation on the Arctic. A negative (positive) AO generally corresponds to a cold (warm) atmospheric event over the eastern Arctic, a high (low) pressure anomaly and an anticyclonic (cyclonic) mode of the atmospheric circulation. Proshutinsky and Johnson (1997) showed that the AO affects the conditions along the western edge of the BS by modifying the Atlantic Water inflow through the BSO, between Fugloya and Bjornoya, and consequently the circulation in the BS. Indeed, a lower pressure over the Arctic (corresponding to a positive AO) strengthens the westerly winds in the inflow area and then increases the Atlantic Water penetration in the BS (Ingvaldsen 2004). This would bring warmer Atlantic Water, decrease sea ice extent, enhance heat loss from the ocean to the atmosphere, and increase fresh water content coming from the ice melting.

This simple scheme has been recently questioned. In a study limited to the 100-150 m layer of the Barents Sea, Levitus et al. (2009) also found that the multidecadal variability was correlated with the Atlantic Multidecal Oscillation (AMO), which is rather an indicator of the temperature of the Atlantic water and consequently of the Atlantic inflow. More recently, Seidov et al. (2015) analyzed the multidecadal variability of the ocean north of 60°N and found that the waters are warming as a whole. However, they emphasize the fact that the average hides a very complex situation, where some areas may even experience cooling episodes. They also find that multidecadal variability of the ocean is more closely connected with the Atlantic Multidecal Oscillation (AMO) than with the North Atlantic Oscillation (NAO), though the year to year changes of the AMO index are inversely correlated with those of the NAO (Yashayaev and Seidov, 2014). Note that the role of the AMO is not investigated in this paper since the latter mainly helps to characterize the mutidecadal variability; the period we consider here is slightly too short to authorize such an analysis.

The role of the Atlantic Water in multidecadal ocean variability has been analyzed in depth by Yashayaev and Seidov (2014) from the World Ocean Database. They found that the temperature records show a warming trend and a series of relatively warm and cold periods which lag the periods of relatively low or high NAO with a delay of about 4-5 years (the inverse for the AMO). They also show that the Atlantic water is transformed following two processes as it progresses northward. The progression of salinity anomalies would be mainly due to the horizontal advection whereas the evolution of the temperature anomalies would be also controlled by the air-sea interactions. As a consequence of this two different processes, the temperature, salinity and density anomalies split and propagate separately in the Barents Sea.

Though these recent progresses, the impact of the atmospheric interannual variability on the water mass transformations in the BS are still in debate. In winter, cold conditions favor ice production which releases a large amount of salt, making the water denser. The production of Barents Sea Water would then be intensified. On the contrary, the impact of warm conditions is less clear. The ice formation is inhibited and consequently the open ocean area is larger, which facilitates the cooling of the ocean. It creates large heat loss to the atmosphere, making once more the water denser. This may still intensify the production of Barents Sea Water.

CHANGES IN THE MANUSCRIPT: the discussion on p.470, from line 21 will be modified as follows:

... This might suggest that our data analysis based on the observations should be extended to winter data, even though the latter are scarce, to verify if this contrast persists.

OSD
12, C294–C313, 2015

Our results agree with Seidov et al. (2015) or Yashayaev and Seidov (2014). They emphasize the role of the AMO in comparison with that of the NAO. The AMO, which is a good indicator of the temperature of the Atlantic water, is more directly linked to the Atlantic Water which flows into the Barents Sea than the AO or the NAO. The role of the latter is thus more elusive: these indexes characterizes global atmospheric changes and their local impact on the BS is more difficult to detect. Moreover, the AO, the AMO and the NAO are strongly correlated and a simple statistical analysis is not sufficient to discriminate between their respective roles.

The variability ...

Second point: “Regarding the model part, there were several recent modeling efforts, some with a very fine resolution. For example, Aksenov et al (2010) conveyed a high-resolution study of the Atlantic Water inflow to the Arctic Ocean; I advise the authors of the reviewed manuscript to cite this paper and to outline how their results differ from those by Aksenov et al.”

ANSWER: This study will be cited and some comments added. The paper will thus be modified as follows.

CHANGES IN THE MANUSCRIPT: p.471 from line 5.:

"... The Barents Sea water would then move further north.

Aksenov et al., (2010) performed a high resolution (1/12°) model study to determine the pathways of the North Atlantic Water into the Arctic Ocean. They found that the branch which flows into the Barents Sea shows complex circulation patterns. The bottom water which is identified in their study lies in the southeastern Barents Sea, close to the area where we observe the Barents Sea Water. Their model study allows them to elucidate the mechanisms which drives its formation namely full depth convection and mixing. The paths they identify for the Atlantic Water (the Franz Joseph branch and the western part of the Novaya Zemlya Branch) are reminiscent of the frontal structures we

OSD

12, C294–C313, 2015

Interactive Comment

describe in the eastern Barents Sea (The northern front and the southern front). Note that Karcher et al., (2003) had also suggested a similar pattern in a high resolution model study. The North east... "

THIRD ISSUE: "I have some difficulties in navigating the text. It is not always clear where does the observational part end and the model one begins. Did the authors apply the same analysis to model data as they did for observations? Why they don't compare data and model analyzes for summer and why the results might differ (if they do)?"

ANSWER: Part 3 only deals about observations as indicated by the title "Summer climatology of the water masses from the observations". Part 5 "Variability of the fronts: a model study" (p.465, line 5 to p.468, line 22) is based only on the model. The confusing part is thus part 4 which mixes model and observations. To make this part clearer we decide to split it into subsections. The following changes in the manuscript will be done:

CHANGES IN THE MANUSCRIPT: We propose to insert sub-parts:

4 Variability of the water masses of the Barents Sea

4.1 Environmental parameters variability (p.462 line 20 to p.463 line 15).

4.2 Water mass variability from observations study (p.463 line 16 to p.465 line 4)

4.3 Water mass variability from model study (p.465 line 5 to p.466 line 29)

In new subsection 4.3, we will recall that the model has been previously validated by its authors and is used here in order to complete the study when observations are lacking (i.e. in winter). We also emphasize the same methods are applied for both observations and model (water mass index, front detection).

#4 - "There are some contradictory statements. For example, the authors say that "Barents Sea Water does not strongly vary seasonally." Then why on p. 466 authors

OSD

12, C294–C313, 2015

Interactive Comment

indicate that the volume of the BSW is small – relative to summer? If this is true, then seasonal variability is not small."

ANSWER: The sentence on page 460 line 1-3: “Note, however, that seasonal variations of Atlantic Waters at Vardø remain small and no seasonal variability is found for the Barents Sea Waters (not shown)” was confusing and will be modified as shown below. We have defined here ‘ideal water masses’ to study the changes in the hydrological properties. So the two sentences are not contradictory since we are talking here about temperature and salinity characteristics whereas p.466 (“the volume of the BSW is small – relative to summer”), we are talking about the relative volume occupation of the water masses.

CHANGES IN THE MANUSCRIPT: (from p 460, line 1)

"... Atlantic Water in the western Barents Sea. Note however that the seasonal variations of the temperature and salinity remain small for the Atlantic Water and nearly vanishes for the Barents Sea Water along the section Vardø. We will show below (see Sect.4) that the volume of Barents Sea Water on the contrary sustains considerable seasonal changes without involving important hydrological changes."

#5 - "On page 455, line 21, there is a statement “However, this (density of data coverage in the eastern part of domain –reviewer) does not seem to have an impact on the results shown below." This statement has no proof anywhere in the text."

ANSWER: Thank you. This sentence will be suppressed.

#6 - "Why the very old version of the World Ocean Atlas published in 1998 is used for model initiation? A much more up-to-date version WOA13 was published in 2014 and is now available online: http://www.nodc.noaa.gov/OC5/woa13/."

ANSWER: When I began this study and used the data coming from the model SINMOD, the up-to-date version WOA13 did not exist. The model was therefore initialized by the very old version of the World Ocean Atlas, concomitant to its creation.

#7 - "On page 60, line 12, the authors say “The computation has been done for the summer data . . .” Is this a model computation or data processing?"

ANSWER: You refer to p.460 line 12-13: “The computation has been done for the summer data, between 50 and 100 m (see Sect. 2), where the Atlantic Waters is easily found”. The sentence refer to data processing. It belongs to the part 3: “Summer climatology of the water masses from the observations”.

#8 - "On page 469, line 1, it says: that Arthun et al (2011) defined the “Atlantification” process as an increase . . .,” while in fact the Atlantification was defined in Arthun et al (2012)."

ANSWER : We will correct this mistake. Arthun et al (2011) will be replaced by Arthun et al (2012).

#9 - "Page 471, line 19, “Atlantic Waters used to invade this area . . .” I guess it should be simply “Atlantic Waters invade . . .”

ANSWER: Thank you. We shall correct this.

CHANGES IN THE MANUSCRIPT: Page 471, line 19, “Atlantic Water invades this area . . .”

#10 - "On the same page, lines 21-22, it should be “ . . . the BS accounts for 40% . . .”"

ANSWER: Thank you again for this correction.

CHANGES IN THE MANUSCRIPT: Page 471, line 21-22: “Lastly, the BS accounts for 40 % of the primary productivity of the Arctic (Sakshaug, 2004). . .”

#11 - "There are quite a number of grammatical errors throughout the text. Just one example on page 453, line 15, “ ...Arthun et al (2012) is defined by this author as ...” should be plural – “ ...Arthun et al (2012) is defined by these authors as ...” The authors need to edit their text to improve grammar and style. Although it is not critical for understanding, correcting small grammatical blunders can improve overall readability

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

of the manuscript."

ANSWER: Thank you for this recommendation. The last version of the paper will be proofread by a colleague in the laboratory whose English is the native language. We hope that these grammatical blunders will be thus corrected.

REVIEW #2

The second reviewer invites us to emphasize the results about the frontal zones and quotes two publications where a slight increase of the Atlantic Water volume were mentioned. We now insist further on the results about the frontal zones. We also emphasize the difference between our results about the "Atlantification" of the BS and those found by Johannesen et al. (2012) and Dalpadado et al. (2012). Indeed, the methodology is different (the salinity is used here to characterize 5 water masses) and the amplitude of the increase is much larger than that mentioned in these articles. The answer to the minor comments are also given.

#1 - "The paper should be rewritten somewhat to be more directly focused on the southern and northern fronts. Location, variability and characteristics of the frontal zones in the Barents Sea are important and not well studied, and this study is a highly relevant contribution on the topic. Climate variability in the Barents Sea, on the other hand, is relatively extensively studied. The main results given in the abstract, that Atlantic Water occupies larger volumes of the Barents Sea, has been published before, although then with focus on climate impacts on the ecosystem (Johannesen et al., 2012; Dalpadado et al., 2012)."

ANSWER: We will rewrite somewhat the paper to focus on the southern and northern fronts. An example of this rewriting is given in the answer to the remark #4. Note however that we do not change the global structure of the paper, because it is difficult to define the fronts if the water masses have not been previously defined. We have not previously read the articles of Johannesen et al. 2012 and Dalpadado et al. 2012. We thus have modified the text in several places to take into account these papers.

OSD
12, C294–C313, 2015

CHANGES IN THE MANUSCRIPT: (p 453 from line 13): “The BS water masses delimited by several fronts are of particular interest. In this paper, we try to specify the mean state and variability for the last 30 years (1980-2011) of

1) The water masses distribution in a context of “Atlantification”. Arthun et al. (2012) defined this process as an increase of the heat transport from the Atlantic towards the BS due to an increase of the Atlantic Water transport and temperature and showed that it had occurred for at least for the last decade. Johannesen et al. (2012) and Dalpadado et al. (2012) showed that the area covered by the Atlantic water and the “mixed water” had slightly increased since 1970.

2) The fronts associated with the Atlantic water, the Arctic Water and the Barents Sea Water. These fronts constitute a major oceanographic feature of the BS (Johannessen and Foster 1978; Pfirman, Bauch et al. 1994; Gawarkiewicz and Plueddemann 1995), but have not been well studied. Only a few studies (e.g. Parson et al. 1996; Våge et al., 2014) provide local descriptions of the polar front, which separate the Atlantic Water from the Arctic water in the western part of the Barents Sea. And, to our knowledge, no detailed description of the frontal structure has been done in the eastern part of the Barents Sea. Fronts are associated with some vertical mixing concomitant with vigorous ocean-air heat loss (∼70TW just for BS) of the Arctic (Serreze, Holland et al. 2007; Smedsrud, Ingvaldsen et al. 2010), which favors the winter Barents Sea Water production.”

Våge, S., Basedow, S. L., Tande, K. S., & Zhou, M.. Physical structure of the Barents Sea Polar Front near Storbanken in August 2007. Journal of Marine Systems, 130(August 2007), 256–262. doi:10.1016/j.jmarsys.2011.11.019, 2014.

(p 464 from line 1): “The climate change observed in the atmosphere in the BS area is also clear in the ocean data. The Atlantic water index (resp. Arctic Water index) shown in Fig.9a presents a trend over the last 30 years, with perhaps an amplification during the last decade. The volume occupied by the Atlantic Water (Arctic Water) is about twice as large (as small) at the end of the series than at the beginning. On the contrary, no important trend can be detected on the Barents Sea Water index.

This is compatible with the recent sea ice loss caused by an "Atlantification" of the Barents Sea, due not only to an increase of the Atlantic water temperature as described by Årthun et al. (2012), but to the increase of the Atlantic Water volume present in the BS. This is also compatible with the results of Johannesen et al. (2012) and Dalpadado et al. (2012) who have already found an increase of the area covered by the Atlantic water in the Barents Sea since 1970. However, our result differs from theirs. Indeed, the increase they found is much less important than that found here. The methods described in their articles to obtain this result is noticeably different from the one used here, which could explain the differences between the results. Indeed, they computed the area covered by the Atlantic water by considering the only temperature between 50 and 200m (against 0-200m in our study) in the area 20-50°E and 72-80°N (against 10-60°E and 70-80°N) and they used a threshold value of 3°C to define the Atlantic water. By using the salinity to characterize the water masses, we were able to distinguish between five water masses (Atlantic Water, Arctic Water, Barents Sea Water, Norwegian Coastal Current Water, Melt Water). The analysis made here is therefore probably more precise.

The processes..."

(p 469 from line 1): "Johannesen et al. (2012) and Dalpadado et al. (2012) showed that the area covered by the Atlantic water and the "mixed water" had slightly increased since 1970. The new database revealed that this increase is more impressive than expected. Indeed we found that the Atlantic water volume had approximately doubled for 30 years. We associated this doubling to the "Atlantification" process defined by Arthun et al. (2011) as an increase of the Atlantic inflow towards the Barents sea. A saltier and warmer inflowing Atlantic water was observed..."

#2 - "As also stated by the other reviewer; usually Atlantic Water and Arctic Water is named in singular form without the “s” at the end."

ANSWER: Thank you. This correction will be made.

#3 - "Polar front is usually used when separating Atlantic Water from Arctic or Polar Water. This is the case in the western Barents Sea (along the Spitsbergen Bank). In the eastern Barents Sea, the fronts are found to be separation between Atlantic Water and Barents Sea Water (“southern polar front”, which is essentially a temperature front) and Barents Sea Water and Arctic Water (“northern polar front”, which is essentially a haline front). Thus, these are not true polar fronts. I suggest to simply naming them “southern front” and “northern front”. I also suggest changing the title to “The Barents Sea frontal zones and water masses variability (1980-2011).”"

ANSWER: As you suggest, the previous “southern polar front” and “northern polar front” will be renamed southern front and northern front. We will also change the title of the paper and modify the summary to insist on the fronts. The changes in the summary are given just below (remark #4).

#4 - "Page 450, line 5: Mixing alone cannot generate dense water. Additional modification of cooling and brine release is necessary."

ANSWER: Thank you. We have to add these processes.

CHANGES IN THE MANUSCRIPT: (Summary; from line 1): “The polar front separate the warm and saline Atlantic Water encountered in the western part of the Barents Sea from the cold and fresh Arctic water. These water masses can mix together (mainly in the eastern part of the Barents Sea), be cooled by the atmosphere and receive salt because of brine release; this processes generate dense water in winter which then cascade into the Arctic Ocean to form the “Artic Intermediate Water”. To study the interannual variability and evolution of the frontal zones and the corresponding variations of the water masses, we have merged data from the International Council for the Exploration of the Sea and the Arctic and Antarctic Research Institute and have built a new

OSD
12, C294–C313, 2015

database which covers the period 1980-2011. The summer data are interpolated on a regular grid. A “Probability Density function” is used to show that the polar front splits into two branches east of 32° E where the topographic constraint weakens. Two fronts can then be defined: the “northern front” is associated with strong salinity gradients and the “southern front” with temperature gradients. They enclose the denser Barents Sea Water. The interannual variability of the water masses is apparent in the observed data and is linked to that of the ice cover. The corresponding one for the fronts is found by using data from a general circulation model. The link with the atmospheric variability, represented here by the Arctic Oscillation, is not clear. However model results suggest that such a link could be found if winter data were taken into account. A strong trend is found: the Atlantic Water occupies a larger volume of the Barents Sea. This trend amplifies during the last decade and the model study suggests that this could be accompanied by a northwards displacement of the southern front in the eastern part of the Barents Sea and a decrease of the volume occupied by the Arctic Water. The results are less clear for the northern front. The observations suggest that the volume of the Barents Sea water remains nearly unchanged, which suggests a northwards shift of the northern front, whereas the model study does not show such a shift. Lastly, note that the seasonal variability of the position of the front seems to remain small."

#5 - "Page 451, line12: A reference should be added to support the statement of significant turbulent mixing. Sundfjord et al. (2007) is already in the reference list and should be appropriate."

ANSWER: Thank you. The reference will be added.

#6 - "Page 451, line15: “mass water transform “ is strange. I suggest rewriting to “water mass transformation”."

ANSWER: Thank you. We did the modification.

#7 - "Page 451, line 26: I suggest rephrasing to: “...into the Arctic Ocean along the bottom...”. Page 452, line 11: I suggest rephrasing to: ”...(together with the Baffin Bay)...”.

Page 452, line 15: I suggest rephrasing to: "... the region with air-sea exchanges in the BS increases"."

ANSWER: Thank you for these suggestions. The changes will be made.

#8 - "Page 453: objective 2 should be the most important."

ANSWER: Objective 2 is the most important. We try to make this clearer by modifying the summary and insisting on the results about the frontal zones. However the structure of the paper remain unchanged as explained in the answer #1

#9 - "Page 457, line 4: Why limit the period to 1980-1985 when documenting changes in the Norwegian Sea and the Nansen Basin? Seems very strange, and is not addressed at all. The same question applies to figs. 3 and 4."

ANSWER: The analysis has been made for all the periods. However, we only present a theta-S diagram for the period 1980-1985 (figures 3 and 4) in order to compare it to the period 2006-2011 (figure 10). This allows us to show the changes of the hydrological characteristics of the water masses which have occurred since 1980. For the Nansen basin, no hydrological changes have been noticed. Consequently, the choice of the period does not matter. The text on page 457 will be modified accordingly this answer.

CHANGES IN THE MANUSCRIPT: (page 457, from line 3): "The analysis of the Θ-S diagram from repeated sections data allows us to characterize the water mass initial hydrological characteristics for the 1980–1985 period (Fig. 3a) that will be compared with the ones of the 2006-2011 period (see Sect.4, Fig.10) and thus characterize the amplitude of the hydrological changes which occurred during the three last decades."

p.464, line 25: "At the Vardø section, the temperature and salinity of the ideal Barents Sea Water remains nearly constant. The Θ-S diagram from the Nansen Basin is not shown because no changes have been detected on the Arctic water."

#10 - "Page 457, line 16: "Fresh Water" should be replaced by "Melt Water". Freshwater has salinity 0. Although "freshwater content" commonly is used in marine science, this

OSD
12, C294–C313, 2015
Interactive Comment

is used when calculating relative to freshwater (salinity 0)"

ANSWER: “Fresh Water” will be replaced by “Melt Water” on page 457 , line 16, in figure12, in table 1, page 451 line 17-18 and page 452 line 27.

#11 - "Page 459, line 10-15: defining Atlantic Water by maximum salinity probably work well here since it seems not to be any really dense water formed by brine release in the provided figures. Atlantic Water is not necessarily the most saline water mass, but it is the most saline of the main water masses (Atlantic, Arctic and Coastal)."

ANSWER: Thank you for this comment. Indeed, the dense water coming from brine release are saltier than the Atlantic Water. These very dense and salty water are located above shallow shelf banks (<100m) near Svalbard, Franz Josef Land, or Novaya Zemlya (Pfirman et al., 1994). On the hydrological section Vardo, dense water are mainly found under 150m. It is clear on Vardo section in the experiment reported by Field et al. (2015). The dense water have lower salinity than Atlantic Water because of the dilution of the brines.

Field, M. Beguery, L, Oziel, L, Gascard, J-C, Barents Sea Monitoring with a SEA EXPLORER Glider. OCEAN15 conference paper, Genova, Italy.

Pfirman, S. L., Bauch, D., & Gammelsrød, T.. The Northern Barents Sea: Water Mass Distribution and Modification. The Polar Oceans and Their Role in Shaping the Global Environment. Geophysical Monograph 85. DOI: 10.1029/GM085p007,1994.

#12 - "Page 460, line 5: here you state that the polar front separates Atlantic Water and Arctic Water. Then you cannot use “polar front” in the eastern region where you define Barents Sea Water. This section is by the way very interesting."

ANSWER: thank you. We will make, from line 5 to line 8 (page 460), the following modifications:

CHANGES IN THE MANUSCRIPT: “The front which separates the Atlantic Water from the Arctic Water in the western Barents Sea is denoted as the polar front. It follows the bottom topography in the western part and consequently remains stable from one year to the other. The frontal zone is less clear in the eastern part and the new database presented in Sect.2 will help clarify this."

#13 - "Page 463, line 5: Why is it expected that low AW is associated with maximum sea ice extent in the Barents Sea? If low AO index gives increased westerly's, which in turn will increase the inflow (as argued several times in the manuscript), this should imply minimum sea ice extent as stronger heat transport would melt ice/prevent ice freezing. This is also consistent with higher air temperature. So why is it more ice when there are stronger westerly's, higher air temperatures and stronger inflow?"

ANSWER: Thank you very much. This is our mistake lines 22 to 25 on page 452 in the Introduction. Only a positive AO strengthens the westerly winds.

CHANGES IN THE MANUSCRPIT: Line 22-25, p.452. "Indeed, a lower pressure over the Arctic (corresponding to a positive AO) strengthens the westerly winds in the inflow area and then increases the Atlantic Waters penetration in 25 the BS (Ingvaldsen et al., 2004)."

#14 - "Page 463, line 14: I suggest rephrasing to: "... and numerical modeling indicate that the heat losses of the ocean...""

ANSWER: Thank you again for this correction.

CHANGE IN THE MANUSCRIPT: Lines 12-15, p. 463: "For example, the maximum sea ice extent (Fig. 8b) has decreased by about 200000 km^2 between 1980 and 2011, the T2 (Fig. 8c) has increased by about 2°C and numerical modeling indicate that the heat losses of the ocean have been reduced by about -50W/m^2 (Fig. 9c)."

#15 - "Page 464, line13-14: "...Atlantic Water volume increase in the BS represents the major result of our study". This has been shown before. Your results on the frontal zones on the other hand have not been documented earlier, and should be emphasized."

ANSWER: This sentence has been deleted (See modifications in #1).

#16 – "Page 468, line 2-3: About seasonality. Very interesting and important. Should be emphasized"

ANSWER: This result is emphasized and included in the abstract (See #4).

#17 - "Page 468, line 8-11: About interannual variability. Very interesting and important. Should be emphasized."

ANSWER: This result is emphasized in the discussion (see #13) and included in the end of the abstract (see #4).

#18 - "Page 468, line 17: “As the volume of the Barents Sea Water remains unchanged,...”. According to fig. 12 the volume of Barents Sea Water changes from 20-25% in 1998 to below 5% in 2000. Thus it is reasonable that the southern front has moved north while the northern front has stayed put."

ANSWER: The text will be changed as follows. The BSW index from observation will be added in Fig.9a.

CHANGES IN THE MANUSCRIPT: Page 468, from line 14 to line 22: "This high resolution numerical experiment therefore suggests that the “Atlantification” of the Barents Sea observed during the last decade could induce a northward shift of the southern front. As the volume of the Barents Sea Water changes from 20-25% in 1998 to below 5% in 2000, the northern front stayed put.

Contrasting with this result, the observations suggest that the volume of the Barents Sea Water remained nearly unchanged from 1980 to 2011 (see figure 9a: no trend is found on the Barents Sea Water index). We thus can expect that the northern front shift northwards to accompany the northwards shift of the southern front. The idealized character of the numerical experiment – which compares two states of the ocean over a short period – easily explain this difference. "

#19 - "Page 469, line 14-24. This is interesting and important."

ANSWER: Thank you. This result will be emphasized (see for example the modified summary which is given above #4).

#20 – "Figures. Several of the figures are too small to read properly. This goes for fig. 1, 5, 6. There are 15 figures in the paper, and I am not convinced that all of them are needed. E.g. the TS-figures 3, 4 and 10 are hardly used. Are they really necessary? And the time series from the model (figs. 9 middle and lower panel, fig. 11); do you really need to show the time series as long as you state the correlations and the lacking trends? I could be possible to combine figs. 8, 9, 11 and 12 into one figure. Figure 3: "Nansen Basin", not "Nansen Bassin". Figure 11: It is hard to see the difference between blue and black in this figure."

ANSWER: Figures 1, 5 and 6 will be modified with bigger police to make them more readable. The Theta-S diagrams are important, in our opinion, because they show that the "Atlantification" is associated with changes from the Nordic Seas through the BSO and up to the Vardo section. They also show that the increase of volume of the Atlantic Water is accompanied by changes in the hydrological characteristics of the Atlantic Water, which become warmer and saltier. The panels b and c of figure 9 are not essential and will be deleted as you suggested. Figure 9 will be combined with Figures 11 and 12 to constitute a unique figure. The typo in figure 3 will be corrected (Nansen basin). In figure 11, the black/blue lines will be replaced by a solid/dashed black line that is more readable. New references from Reviewer1 and reviewer2 have been added.

Interactive comment on Ocean Sci. Discuss., 12, 449, 2015.

OSD

12, C294–C313, 2015

Interactive Comment

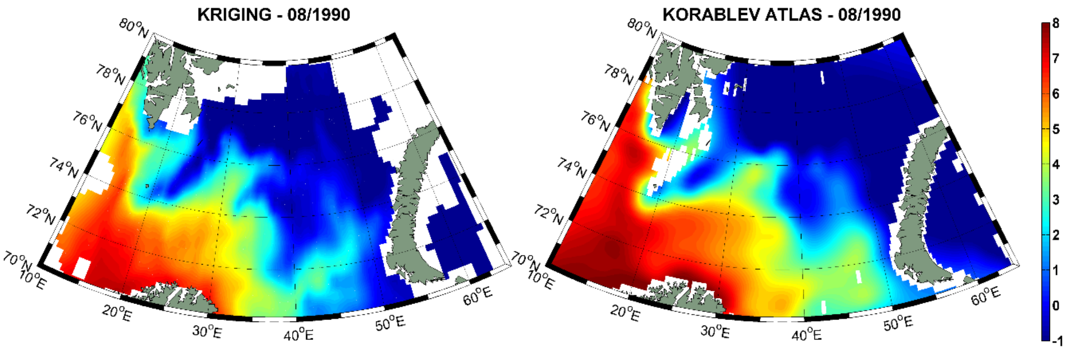

Fig. 1. Comparison between temperature fields (°C) at 50m from our dataset using kriging technic (a) and from the Korablev et al. (2014) Atlas using the DIVA technic (b) for the month of August 1990.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper