

Interactive comment on “The link between the Barents Sea and ENSO events reproduced by NEMO model” by V. N. Stepanov et al.

Anonymous Referee #1

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The manuscript “The link between the Barents Sea and ENSO events reproduced by NEMO model” by Stepanov, Zuo and Haines presents results from a global NEMO OGCM. The study analyses the state of the Barents Sea during different states of the ENSO.

The manuscript is written in a fair style, although clarification of some statements is needed. The topic of the manuscript is undoubtedly interesting and timely because of the recent changes witnessed in the Arctic and sub-arctic regions. The submission is relevant to the scope of the Ocean Science Journal.

The main shortcomings of the manuscript are a weak support of the model results by the observations and lack of a convincing explanation how the link between ENSO events and ocean temperature in the Barents Sea operates. On the other hand, the

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impact of the local forcing in the Barents Sea is clearly described and is an asset of the manuscript. The atmospheric teleconnections, frequently referred to in the manuscript, are not well explained. The study uses a forced OGCM with a strong restoring to climatology or with assimilation. This approach constrains the ocean model and does not allow it following freely the atmospheric forcing. Yet, the authors put an emphasis on the role of the atmosphere in ocean variability. A discussion on how the model setup affects the analysis is required.

The other minor criticism is that the model description needs tidying up. Overall, clarity of the text needs improving. The reviewer suggests that the manuscript could be published after a revision. Please see the comments below.

Specific comments

Title

The word “reproduced” does not sound right in this context. The model does not “re-produce” a physical event, but simulates it. The reviewer suggests that the authors may consider changing it to “simulated” or similar.

1. Abstract

Page 2122, Line 19 Please consider “. . . shows that the strength of the Atlantic inflow in the Barents Sea is the main source of heat content variability of the in the sea, . . .”.

2. Introduction

Page 2123, lines 1-3. “This is because the southern Barents Sea remains open during all year while other Arctic Seas are covered by sea ice that prevents further cooling.” The reviewer disagrees with the statement. First, the Siberian shelf seas, the Kara, Laptev and East-Siberian Seas were either partially or completely ice-free in summer during 1979-pres.; Chukchi Sea and Beaufort Sea were also ice-free. Since 2005 (except 2006) the Arctic Seas were summer ice-free. Please see the NSIDC website for the ice concentration fields

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ftp://sidads.colorado.edu/pub/DATASETS/nsidc0192_seaice_trends_climo/monthly-means/browse/. The 1979-2010 multiannual ice concentrations show that most of the Arctic Seas were ice free in summer during this period. Secondly, continental runoff brings very fresh water in the Siberian shelf seas and the Arctic Ocean, increasing upper ocean stratification and limiting upward heat flux from the Atlantic layer towards the sea ice. In contrast, the river runoff in the Barents Sea is less but the Atlantic water dominates the inflow in the sea, as a result the Barents Sea is much less stratified than the rest of the Arctic Ocean. This allows Atlantic water heat reach the ocean surface. Please give a better argument regarding the contribution of the Barents Sea seasonal heat storage and include relevant citations.

Same page, line 5. What does the “final winter mixed layer depth” mean? Is this the maximum winter ML depth or something else? Please clarify. Please also give references for the cited observed ML depth.

Same page, line 7. “...and therefore there is a very strong seasonal cycle in heat storage.” Do the authors mean the heat storage in the Barents Sea. Is this a full depth heat content or in the ML or in the top 200 m? Please clarify. Besides, the ML depth can be change not only through convection and heat loss but also by the Ekman pumping. Please comment.

Same page, lines 8-10. The sentence “It is natural therefore that any strong interannual anomalies, in either the surface heat loss or the inflow of heat from the North Atlantic, will have a signal in the heat storage and Barents sea temperatures for periods of up to a year at least.” is unclear. Is this that the inter-annual anomalies of the lateral oceanic heat flux convergence and these of the atmospheric heat would change heat content of the Barents Sea on the time timescale longer than a year? If so, it is true but trivial - It follows from averaging the data on the annual time-scale. Please explain in more detail.

Same page, lines 11-15. The paragraph starting from “A recent analysis of obser-

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vational data (for nearly a century) in the Barents Sea along a meridian at 33°30' E between 70°30' and 72°30'N (Byshev, 2003) showed...” The only reference to the observations in support of the whole study is a book in Russian. This makes difficult for the rest of the oceanographic community accessing the observational results. Moreover, there are no details in the manuscript regarding how “negative correlation between ENSO events and water temperatures in the top 200 m” has been obtained, what is the period of timeseries, degrees of freedom, where test on statistical significance have been applied, etc.. The reviewer suggests either including more accessible citations, or giving more details in the manuscript on the observational datasets, perhaps including plots from Byshev's monograph. TS data from the Barents Sea are publically available via the BARKODE or WOA.

Same page, lines 15-19. The statement “During warm ENSO events atmospheric teleconnections lead to an anticyclonic atmospheric circulation...”. needs references. The next sentence is unclear. Is this “ocean mean temperature” in the top 200-m? Please explain. Besides, it is not clear what the “atmospheric teleconnections” are. Please explain in the text and give appropriate references.

Same page, line 20. Please give more explanation about ocean re-analysis techniques. Not everybody in the oceanographic community is familiar with this.

Same page, line 22 and line 29. Please consider “Section 2 described the NEMO...” and “Section 6 provides discussion and conclusions...”

2. Model description

The description resembles a cut-down extract from the NEMO documentation. It is unnecessary detailed but is also lacking some vital information. In the present study the 1/4 degree model setup is the same as the one used for the DRAKKAR run G70, described in detail by Barnier et al., 2006, Penduff et al. 2007, Lique et a., 2009 and 2010. What is really needed in this section is a description of the model features which are important for the simulations in the Barents Sea (i.e., inflows/outflows, circulation

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and watermasses properties). For example, a combination of EEN advection scheme, partial bottom cells and free-slip lateral boundary condition improves simulations of the along-shelf flows in the Arctic in ORCA025 (Penduff et al., 2007), whereas ORCA1 needs including the Neptune effect to simulate the topographic currents (Holloway and Wang, 2009). Since both the Atlantic inflow in the Barents Sea and the outflow of the modified Barents water occur via the topographically guided jets, (the Nordkapp Current, the Western Novaya Zemlya Current, and the outflow through the Victoria Trough), the accurate simulation of the dynamics of these currents is essential for the study. Both the ORCA1 and ORCA025 model do not resolve Rossby radius in the Arctic, despite the grid convergence; please comment how this shortcoming affects the analysis. Does GM improve ORCA1 results?

The mixed layer model should be described more. TKE has been briefly mentioned but it should be put in the context of the simulations. - Does it perform adequately in the Arctic? Please comment. Description of the forcing is good, except for the small correction (see below), however the river runoff scheme is not mentioned, it should be. Please also describe the model bathymetry, most likely the one used in ORCA1 has changes, compare to the ORCA025 version, straits have been widened and deepened, etc.. Please give relevant references for the source of the bathymetries in the both models (e.g., ETOPO and IABCO). Please state temperature and salinity restoring timescales (if any) in the control runs. How different they are in the ORCA1 and ORCA025? The restoring could lead to large differences in the simulations. G70 used a strong restoring to the annual climatological cycle; this can be an issue in analysing the impact of the atmospheric forcing on oceanic variability. Please comment in the text.

Page 2124, lines 9 and 11. It should be : "linear free surface" Please consider: "...tripolar "ORCA" grid (the poles are in Canadian Arctic Archipelago, Northern Siberia and at the Geographical Southern Pole)...".

Same page, line 13. Please describe ORCA1 and ORCA025 horizontal resolution in C800

the same detail. Presently there is no such description for ORCA1. The authors could say something like: "The model configurations are (i) a global 1° resolution ORCA1 and (ii) a global 1/4° resolution (ORCA025). Both the models are configured on the same (except for the resolution) horizontal C-grid. ORCA025 has a horizontal resolution of 27.75 km at the equator and of 13.8 km at 60°N. North of 60°N the resolution increases due to the grid convergence, resulting in the resolution of 6-12 km in zonal and of ~3 km in meridional directions in the Arctic Ocean." ORCA1 grid is four-times coarser than ORCA025 with a tropical refinement to 1/3° in the meridional direction (Reference)."

The same paragraph: The ORCA1 configuration has NOT been developed in the DRAKKAR, only the ORCA025 has been.

Same page, line 21. "...using a one-equation turbulent kinetic energy scheme.." what does "one equation" mean here?

Same page, line 26. Air to sea and air to ice fluxes are NOT calculated as the 6-hourly fields, but every coupling timestep. Please correct.

3. Description of numerical experiments

Page 2125, line 7. Does "cold-start" mean ocean and sea ice are initially at rest? Please rephrase.

Same page, lines 13-17. There is an apparent contradiction between Section 3 and Table1 in describing UR025.3; the former says the initial conditions came from G70, whereas the latter states they came from "EN3 in situ data assimilation experiment". Please check which one is right.

Same page, lines 17 and 19. Consider: "The forcing blends..." Consider: "...from 1989-2008 also used hydrographic data..."

Page 2126, lines 4-7. Please re-write the sentence: "The assimilation increments are determined...", it is incomprehensible in the present form.

4. Interannual variation in the Barents Sea during ENSO events

Section heading: "Interannual variation" of what, temperature? It is worth changing the heading.

Page 2126, lines 4-7.

Same page, lines 25-26 and also Figure 1. "...and the NINO3 index (using the temperature scale)." – this is confusing. Please plot a separate scale for the index and correct the text accordingly. Please describe NINO3 index and make relevant citations. Not all readers will be familiar with it. If the authors wish their paper to reach a wide scientific community the terminology needs to be explained.

Page 2127, lines 1-5. "There are three strong ENSO events: a warm event in 1997–1998 and two cold events in 1999–2000 and 2007." – is this according to the NINO3? Does a positive NINO3 index corresponds to the warm ENSO, and a negative to the cold ENSO? Please explain in the text. "...the annual mean model temperatures in the Barents Sea..." - Is this top 200-m mean ocean temperature? Please make an explanation in the text.

Same page and paragraph. There seems to be a correlation between sea ice volumes and ocean temperatures almost without a time lag. However the relationship between NINO3 index and model ocean temperature is less clear. One could argue for example, that instead of being delayed by approximately one year the ocean temperature signal precedes the NINO3 index by about two years and is positively correlated to ENSO. There is more analysis of the correlations further in the manuscript, so please make a reference to support the statement in the current paragraph.

Same page, lines 15-17. "Both the 1° models CTL1 (3.8 Sv) and ASSIM1 (3.9 Sv) also overestimate the volume inflow into the Barents Sea compared to inverse model results (3.5 Sv) (Tsubouchi et al., 2011) which probably explains the higher Barents Sea temperatures." – the statement is interesting, but unsupported. Apparently, on

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the next page there is a discussion that volume flow anomalies dominate heat flux variations. Please make a reference to the analysis.

Same page, lines 20-23. "The variability however does not substantially depend on model resolution ... and we therefore assume the mechanisms of variability are not sensitive to resolution." – the variability based on what, monthly means, annual? There is a gap in logic here. If the authors used monthly means to calculate STD, it will include seasonal cycle and, as the seasonal change is mostly governed by the atmospheric forcing, one would expect it to be the same in the ORCA1 and ORCA25 runs. It is possible to calculate in the both models variability in the oceanic heat convergence and in the atmospheric heat flux and then make a conclusion. Please support the statement with some evidence.

Same page, lines 24-26. The sentence is unclear: either JFM 1989-2008 mean SLP is plotted or JFM for 1998 and for 2008 are. Which ones? The figure caption says these are JFM for 1998 and 2008. Please explain. Please consider changing as: "Figure 2 shows mean January-February-March (JFM) sea level pressure anomalies in 1998 (warm ENSO) and in 2008 (cold ENSO) from the ERA-Interim". Please state here and in the figure caption the sign of the net heat flux. Is it positive in the ocean? Please explain large negative winter anomalies of the surface heat flux (more cooling of the ocean in 2000?) in the northern and northeastern Barents Sea; these seem to be due to the ice edge displacement.

Same page, lines 26-29. "During JFM 1998 global atmospheric teleconnections lead to higher atmospheric pressure (Fig. 2a), and hence lower air temperatures over the Barents Sea, while during JFM 2000 lower atmospheric pressure (Fig. 2b), lead to warmer air temperatures over the Barents Sea." Please include details and references how teleconnections resulted in the anomalies in the atmospheric pressure and temperature in the Barents Sea. Presently this is not clear in the manuscript.

Page 2128, from line 3. It is very difficult to see the ocean velocity vectors in ORCA025

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in the Figure 3. The reviewer suggests plotting vector differences between 2000 and 1998 instead of vector anomalies. In the ORCA025 plots please extend the left border farther west to include the Barents Sea Opening in full.

Same page, line 14 and throughout the text. Please explain (perhaps in Section 3) how oceanic heat fluxes have been computed. For the monthly mean and annual mean values averages of UT and VT products should be used rather than products of these averages. Please also give a value of the reference temperature.

5. Heat Budget variability

Page 2129, line 1. “..red, peaking in June. . .” – red curve in Figure 5 is the net heat flux, not short wave radiation. Please correct.

Same page, lines 2-4. “The Barents Sea total heat content (green, the top 200m mean temperature) shows every sign of being controlled primarily by the surface shortwave cycle, being 90° out of phase with the surface forcing.” What does it mean, “90° out of phase”? Please explain.

Page 2130, lines 9-11. “It can also be seen that strong ENSO events (blue dashed) are negatively correlated with the Barents Sea inflow.” – the reviewer disagrees with this statement. The NINO3 and inflow timeseries do not appear correlated. Please cite correlations with levels of significance.

Page 2131, lines 1-5. “Though Fig. 8 shows some reverse correspondence between major number of peaks and troughs of NINO-index with ones of the temperature curve, however only for 3 of 7 strong ENSO events (1 warm: 1982 and 2 cold: 1973 and 1984, when the values of NINO3-index deviate more than 1 standard deviation) a negative correlation with the Barents Sea temperature 5 is observed in the same year.” – this is a long and unclear sentence, please revisit it. Please list the correlations between NINO and the Barents Sea temperatures with levels of significance.

Page 2132, lines 7-8. “Figure 9a shows 1989–2008 correlations of zonally averaged

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monthly sea level pressure (SLP)” – is this SLP from the ERA-Interim? Please explain in the text.

The whole paragraph (lines 1-23) is very descriptive; it does not help the reader understanding how the ENSO events may affect the Barents Sea. Please consider revising it and including references, currently there are none. The same concerns the next paragraph (from line 24 and also on page 2133), it does not explain relationship between the ENSO and the variability in the Barents Sea. Please consider clarifying it.

Page 2133, lines 10-15. “Since the interaction between the tropics and high latitudes depends on the stochastic processes, which always occur during the interaction between the atmosphere and the ocean, therefore it is difficult to reveal a definite link between the low and high latitudes immediately: some interaction delay between these latitudes can be due to the strength of current and previous ENSO events.” – it is a very long and a rather unclear statement. What are “stochastic processes”? What is “interaction delay”? Which current is meant here? Please clarify.

Same page, lines 23-24. “The anticorrelations are clear to see and in particular in Fig. 10b shows the stronger winds blowing inflow towards the Barents Sea.” – the sentence does not seem to be right. Please rewrite it. Besides, the figure does not show “...winds blowing inflow towards the Barents Sea”, it only shows a negative correlation between SLP in the Greenland Sea and Barents Sea inflow, as well as high correlations with the SLP in the other parts of the world. The reviewer is uncertain about the high correlations between the Barents Sea inflow and SLP over land, but perhaps the authors can explain these.

6. Summary and Discussion

Page 2135, lines 13-15. “ORCA1 model with coarse resolution (experiments CTL1 and ASSIM1) overestimates the annual Barents Sea inflow about 0.5 Sv (due to not adequate resolution of Faeroe-Scotland channel).” – how did the authors come to this conclusion? There is nothing in the text to prove it.

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Same page, lines 20 and 21: TW not “TWt”.

Page 2136, line 11-14. The first sentence “. . .and atmospheric depression (higher sea level pressure) over the Western Europe are settled.” - What does “settled” mean here?

The next sentence “These changes in the atmospheric pressure substantially influence the westerly winds in the North Atlantic that in turn change the Barents Sea inflow.” is vague. Please be more specific.

Table 1.

The description of the Exp. 3 is lengthy. Please consider changing as: “Control 1/4° NEMO simulation forced with ERAInterim atmospheric forcing. The initial ocean and sea ice states are taken from G70 run, please text for details.”

Figures.

Caption for Figure 1. It is either “beginning” or “onset” of the ENSO events. Please correct. Please plot a separate scale for the NINO3 index. Please explain what the red curve in the panel (b) is – if these are the geographical boundaries of the Barents Sea, why the curve is so wiggly? Please explain in the caption that this panel also shows bathymetry in metres and include units for the colourbar.

Figure 2 and the caption the figure. Please check consistency between the text and the figure caption. For readers’ convenience, please consider either plotting the same regions for SLP and heat flux anomalies or marking the common area on the SLP plots. Please state the sign of the net heat flux here and in the text. Is it positive in the ocean?

Figure 3. Panels for wind stress, ocean velocities from ORCA1 and ORCA25 - all show different area. Please make area the same. Ocean velocity vectors are too small to see. Please also consider plotting vector differences between 2000 and 1998 rather than anomalies.

Caption: please consider changing as: “Winter (JFM) anomalies of wind stress over

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the North Atlantic and the Barents Sea (a, b) and these of ocean velocity, averaged for the top 200 m in the Barents Sea; (a, c, e) show anomaly in 1998 after warm ENSO event and (b, d, f) show the one in 2000, after cold ENSO event, respectively; (c, d) – is the experiment CTL1; (e, f) – is the UR025.3 run. All anomalies are taken relative to the 1989–2008 mean”.

Figure 5. Caption. There are no square brackets. Please consider change: “. . . (to have a zero mean and a standard deviation of one, mean and std of the original timeseries are given) . . . 1°C isotherm (solid blue line, mean and std are 267 ± 79 m) . . .”.

Figure 8, Caption. It should be: “. . . subsequent year mean of the Barents Sea heat inflow (dashed red),..”

Figure 9. Explain axes and include all necessary units in the panels (a) and (b).

Figure 10. Caption. The regions are marked by black crosses in the Figure 10 a,b not 9a,b.

References to consider

Holloway, G., and Z. Wang (2009), Representing eddy stress in an Arctic Ocean model, *J. Geophys. Res.*, 114, C06020, doi:10.1029/2008JC0051.

Interactive comment on Ocean Sci. Discuss., 9, 2121, 2012.