

## ***Interactive comment on “Barents Sea heat – transport, storage and surface fluxes” by L. H. Smedsrud et al.***

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We would like to thank for the time, effort, and interest taken to review our work. Most of the suggestions have been followed, and in the few remaining places the text has been re-phrased to clarify the issue raised. We now hope that the improved version is within the high quality of the Ocean Science journal. Original text from the reviewer is cited as Rudels: Our answers are cited as Reply:

We have updated and re-written the section on the Barents Sea Opening. The fresh-water forcing has been described in more detail, and the northern box has been discussed more thoroughly, as requested.

Rudels: Summary: I am hesitant to recommend publication, at least not without major

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revisions. Especially the volume and heat transports through the Barents Sea opening should be updated and the approach used for the freshwater forcing should be explained in more detail. Also the northern box should be discussed more thoroughly.

General: I have difficulties with this approach. The Barents Sea, especially its southern part, is not a horizontally homogenous box but a broad and long through-flow channel, where the inflowing Atlantic and Norwegian Coastal Current waters are transformed, cooled and freshened, before they are discharged into the Arctic Ocean via the Kara Sea. Therefore I would have taken the inflow in the western opening for each month and computed how the water column characteristics evolve as they flow through the Barents Sea subject to the monthly forcing and how the speed and width of the through-flow have to be adjusted to get the expected mean outflow characteristics and how these vary in the vertical and over the season. A very crude and simplified attempt to such approach was made by Rudels (1986).

Reply: We agree that the Barents Sea is an advective system, where water is cooled, or transformed, towards the east. The “channel model” suggested here is a good idea. Our approach is to establish a mean over this sea, not describe the gradual transformations. This is a basic, but also quite complex, approach, and with more focus on the vertical processes. The reason to do this is that it uses all available stations, and the existing flux estimates from the inflow and outflow sections. We find a direct relation between the heat transported into the sea, the heat content, and the heat fluxes at the surface. The advantages and limitations of our approach have been more clearly stated now, both in the introduction, and in the model description.

Rudels: Issues raised (matters of significance )

Page 1440, Barents Sea volume budget: I read this part with great expectations since some of the authors have been working on these problems for more than a decade in VEINS, ASOF and DAMOCLES. I became rather confused. The VEINS and ASOF number for the inflowing Atlantic water usually was a net inflow of 1.5 Sv, which in

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the ASOF book was increased to 1.8 Sv. To this was commonly added 0.7-0.8 Sv of Norwegian Coastal Current (NCC) water with a reference to Blindheim (1989). Here I find 1.0 net AW inflow and a NCC inflow of 1.0 Sv again with reference to Blindheim (1989). Now Blindheim (1989) does not give any estimate for the NCC inflow and I expect that it derives from Aagaard and Carmack (1989), who give the number with reference to Blindheim. It would be nice if the authors update this section thoroughly.

Reply:

The section has been updated, directly citing an upcoming paper by Skagseth (2009). This was previously cited in the “Heat Transport” section, but not here. The new budget is now +2.0 Sv of Atlantic Water, +1.2 Sv of Norwegian Coastal Current, adjusted slightly compared to earlier. The two outflowing branches south of Bear Island is subtracted from this (-0.9 Sv, Skagseth 2008 and -0.3 Sv Blindheim 1989).

Rudels: Pages 1451-1452, the Northern box: I am not sure if I understand this. Is the same volume input assumed but with different temperature (heat input)? Is there any justification for this?

Reply: The model boxes are defined based on the long-term mean temperature, and the southern box is designed to approximately follow the 0°C isotherm in the long-term mean temperature field (Figure 2). We prescribe that the southern box has a total inflow (and outflow) of 3.2 Sv with 73 TW of heat (referenced to 0°C). This box represents what we call “the cooling area”, and by using the 0°C isotherm most of the heat is lost in this area/box. In the real Barents Sea, the 0°C isotherm varies, and we address this by evaluating changes in the cooling area/the southern box. Thus a larger cooling area represents the situation when the 0°C isotherm is located further north in the eastern Barents Sea.

The northern box includes the area between Novaya Zemlya and Franz Josef Land (the BSX) where most of the through-flow leaves the Barents Sea (Figure 2). Thus 0.3 Sv enters at the northern boundary, and 1.7 Sv is through-flow that flow across from

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the southern box, but it carries close to zero heat (2 TW). The BSX temperature is based on observations and 3D modelling. The temperature results are actually quite good for the northern box, suggesting that the 2 TW total heat transport to this area is close to real mean. The outflow temperature is under consideration in other studies in preparation (Lien and Trofimov, in prep; Ingvaldsen et al., in prep), and will also be addressed when another year of mooring data in the BSX is released from inspection in Russia.

Rudels: What freshwater forcing/redistribution is used? If most of the heat of the Atlantic and NCC inflow is taken out in the southern box to me this suggests that the through-flow does not extend to the northern box. This is then a horizontally fairly homogenous area with sluggish exchange with the surroundings and the 1D model should actually work better here. The explanation of how the northern box is forced is not sufficient for me to judge what has gone wrong.

Reply: The text has now been changed to make the model setup more clear and concise. The model volume transport has been lowered from 3.2 to 2.0 Sv for the northern box, and results are now closer to the observed profiles. The section has been re-written stating three factors that may contribute to the difference in salinity between the model and observations:

"The model deep salinity increases above 35 as there is nothing in the model that counter-acts the advection of salt in the deep layer. This discrepancy may be caused by a number of factors. The salt redistribution applied here assumes a salinity of 34.75 for the 2.0Sv exiting in BSX (Gammelsrød et al 2009). There are probably additional salt fluxes connected to the sea ice that are not resolved by the model. Firstly salt release from ice growth on shallow depth produces high salinity shelf water  $S_w > 34.8$  that escapes close to bottom. Secondly, some of the sea ice freshwater imported from the Arctic Ocean probably leaves in the coastal current along the eastern shores of Svalbard Islands. Thirdly, observations are quite scarce in the north, and high-salinity bottom water may largely have escaped sampling. These effects are all more

pronounced in the northern box than in the south because of the sea ice growth, the stable column, and the lack of deep convection during winter."

Rudels: Page 1448, lines 10-15: I think that this paragraph is in the wrong place. Also, being slow, I had some difficulties to figure out what "the sampled Atlantic inflow +  $1.3 \text{ Sv}$ " really meant. I think most readers like me will have forgotten the discussion in section 2.2 (page) 1443, and I believe that it is better to state the volume, heat and freshwater forcing used, where the transports are discussed, i.e. in sections 2.2 and section 2.3.

Reply: The budgets of volume, heat and salt are indeed important, and a matter of some controversy as the on-line discussion shows. Some of the discussion covers the likely real, but rather unknown, variation in outflow temperature. The other part relates to the volume budget, which in our case is closed. The forcing used has therefore been added to section 2.1 2.2. and 2.3, but is re-captured shortly here too (3.1 Model forcing). This section has been re-written to more clearly state the range in forcing used, compared to the mean state described in section 2.

Rudels: Language improvements ( Matters of smaller significance, in order of appearance ) Title: I think that the position of the dash (–) here is misleading.

Reply: The dash was there to state that both the storage, transport and fluxes are done to understand the heat budget of the Barents Sea. This was probably not perfect grammar, and we have now changed the title, using a colon instead as well.

Rudels: Abstract, line 19: I do not think that a heat loss can be robust, possibly the estimate of it.

Reply: Changed to ; "The Barents Sea responds to such large changes by adjusting temperature and heat loss."

Rudels: Page 1439, Line 2: change "allows" to "allow" Reply: OK

Rudels: Page 1439, line 6: change "remain" to "remains" Reply: OK

Rudels: Page 1439, line 6: "cooled to the bottom" I think that this is not generally true. Only in fairly shallow areas does this take place and as the dense water drains into the deeper depressions the ventilation there does not reach the bottom. See also the observed profiles in Fig 4, which are not homogenous in the lowest layer.

Reply: OK. Changed to : "for the major part of the water column."

Rudels:Page 1439,line 17: what does "recapture" mean here? Reply: OK Changed to "include"

Rudels:Page 1440,line 2: change "a necessity" to "necessary" Reply: OK

Rudels:Page 1440,line 25: "excluded from" Reply: OK

Rudels:Page 1443,line 23: change "were" to "where". Reply: OK

Page 1449, lines 1-8: I think that I understand what is done here but this part would benefit from a more detailed explanation.

Reply: OK. More details have been added now.

Rudels: Page 1455, lined 3: How is the Barents Sea flushing time estimated?

Reply: This was explained on page 1441, line 7. Some further detail, and a reference, has been given now; "This sets a flushing time (ocean volume divided by the 3.2 Sv throughflow) for the Barents Sea of 2.5 years, using the 230 m mean depth and the area of  $1.1 \cdot 10^6 \text{ km}^2$ ."

Rudels: Pages 1455-1457: This is a quite interesting discussion about possible effects of changes. Reply: Thanks !

Rudels: Page 1457, line 18: change "box is" to "boxes are" Reply: OK

Rudels: Page 1457, line 20: change "produce" to "produces" Reply: OK

Rudels: Page 1458, line 24: use "Bear Island" for consistency Reply: OK

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Rudels: Page 1459, lines 10-15 & table 2: Why does the outward going long wave radiation decrease in this case? I would expect that a colder atmosphere would have a smaller back radiation to the surface.

Reply: This is not a coupled model, the 1D model is forced by the atmosphere, as commonly also done with regional 3D models. When the atmospheric temperatures are decreased, the long wave down coming radiation is still the same as before. What changes is the surface ocean temperature, that gets colder, giving a smaller outgoing long wave radiation. New text added; “The colder air increases the sensible heat loss, but also decreases latent heat loss (Table 2). The long wave radiation heat loss also decreases as a result of the colder surface ocean temperature. “

Rudels: Page 1459, line 26: change "is" to "are" Reply: OK

Rudels: Page 1461, lines 18-23: To me the model approach does not separate but rather connects these three changes.

Reply: Has been changed to; “Our model approach reproduces the two mechanisms one by one, and can therefore explain their relative importance in nature.”

Rudels: Generally I find the figures very difficult to interpret, especially 6 and 8, and the choice of symbols in figures 4 to 8 leaves much to be desired.

Reply: We have now improved Figures 4 - 8, including better labelling of axes. Some of the details have been scarified to improve readability (only one year of fluxes in Figure 6). The figure captions have also been shortened. Lines have been made thicker, and some text has been exchanged with color boxes in Figure 8.

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Interactive comment on Ocean Sci. Discuss., 6, 1437, 2009.

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