

**We would like to thank you for your positive feedback and constructive comments. Please find below answers to your questions, and details of changes made based on your suggestions. The referee's comments are shown in italics, our responses in bold, and the revised text in standard font.**

*The authors investigate the origin of the salinity anomaly in the Denmark Strait overflow observed in 2004 at the Angmagssalik mooring array. Several hypotheses are formulated and tested using the mooring observations, outputs from a numerical simulation and reanalysis fields (for the wind fields).*

*Overall, the manuscript is very well structured and written and the figures are clear. The study is a welcome contribution to the current research effort to better understand the variability of the overflows, which feed the deep branch of the MOC.*

*Unfortunately, I have large concerns on the realism of the numerical simulation on which most of the conclusions rely. Moreover, the model flaw and its implications for the results are almost not discussed in the paper. These prevent the publication of the ms. as it is now.*

*Main point:*

*My main concern is the realism of the simulation, and the extent to which the results are model dependent.*

*- From Fig. 2, it is clear that the model does not represent correctly the salinity and density structures (but it is not stated clearly in the text!). From Fig.4, we see that the main core of current is situated close to the slope, but the realism of the velocity structure is again not discussed in the text. I'm afraid that the DSO is not separated in the model from the EGC, which might indicate a large misrepresentation of the mixing/entrainment on the sill.*

*- Moreover, the difference of both salinity and velocity structures might lead to large discrepancy in the mean DSOW. This question is eluded in Fig.5 as the anomalies are shown. The mean values need to be indicated somewhere.*

**Thank you for these helpful suggestions. We now discuss more explicitly in section 3 OCCAM's ability to realistically represent structure of the overflow as follows:**

'We are not expecting the model to represent accurately the details of the overflow downstream of the Denmark Strait sill. However the processes that occur in the ocean, especially upstream of the sill, should be represented by the model and therefore we use OCCAM as a tool to examine the mechanisms driving the variability of the salinity that are observed. We now examine the structure of the overflow at the moorings in OCCAM.'

**We now present in section 3 time series of observed DSOW transport taken from Dickson et al. (2008), and compare this with DSOW transport calculated in OCCAM (Fig. 5c). We show that the OCCAM DSOW time series is comparable with observations both in magnitude and variability.**

'The volume flux of the dense overflow in OCCAM from August 1998 to December 2004, calculated by integrating the net transport for potential densities greater than 27.6 from the Greenland continental slope to 150 km from point A (Fig. 2), is roughly consistent with

observations (Fig. 5c). The mean observed transport in the core of the overflow, calculated by integrating the fluxes measured by current meters UK1, UK2 and G1 for all potential densities greater than 27.85, was 2.2 Sv with a standard deviation of 0.3 Sv (Fig. 5c, see also Fig. 19.7 of Dickson et al., 2008). The transport calculated for the full mooring array of 6 current meters (F1, F2, UK1, UK2, G1, G2) for potential densities greater than 27.85 yielded a mean flux of 4.0 Sv with a standard deviation of 0.36 Sv (Fig. 5c, see also Fig. 19.7 of Dickson et al., 2008). For OCCAM, the transport of water denser than 27.6 was 6.0 Sv with a standard deviation of 0.83 Sv (Fig. 5c). Although transport calculations in both observations and model are compromised by the undefined boundaries, we conclude that OCCAM represents the transport at the core of the overflow to a reasonable degree of accuracy both in terms of magnitude and variability.'

**Given the differences in the overflow structure in OCCAM, the DSOW transport calculation is highly sensitive to the cross-section bounds used for the integration. The mean value of 6.0 Sv we now quote in the text was integrated over an area larger than the DSOW core and will include entrainment of ambient water. This value is therefore more comparable with the values determined by Dickson and Brown (1994) for the DSOW plume core plus downstream entrainment at Angmagssalik and 150 km upstream. A similar integration performed on the OCCAM DSOW plume core (defined approximately by the 15 cm s<sup>-1</sup> velocity contour in Fig. 2c), produced a mean transport of around 2 Sv, more consistent with the observational transport estimated from UK1, UK2 and G1 (Fig. 5c). We also suggest that limitations exist with the calculation methods used for estimating the observational transports shown in Fig. 5c. These were produced using velocity data from only a few current meters, interpolated over an area defined from temperature and salinity data obtained from a small number of CTD deployments. The section is not a closed section so transports depend greatly on the boundaries chosen. Any more quantitative comparison between model and observational overflow transport is therefore difficult.**

**We agree that there are offsets in water properties and core depth at the array in OCCAM, but the fundamental argument that we present throughout the paper is that OCCAM identifies the salinity anomaly at the sill and the moorings with a correct time-lag, meaning that the ability of OCCAM to realistically represent the mixing and entrainment processes downstream of the sill is less important to our story. Our basic conclusion does not rely on the model, but identifies the relationship between the observed wind and observed salinity at the moorings. The model is then used to investigate how these changes related to upstream processes driving the overflow. We don't believe our conclusions are model dependent, but we would like to repeat our study using a different model in the future.**

**We have displayed the mean OCCAM salinity, velocity (and correlation) sections on the same figure with the observations (Fig 2). This clearly shows the differences in the mean salinities. Also, the magnitude of the OCCAM velocity is the same as the observations. This is discussed in section 3.**

*- From Fig. 5, the observation and the model times series seems to agree only in 2004 (what might be enough to get a correlation over the whole time series, as the 2004 events is the main structure of variability for the time series from observations). Is there an explanation for that?*

**Thank you for this interesting comment. To investigate this, we ran the correlations excluding the year 2004. We now discuss this in detail in section 4 as follows:**

'In addition to 2004, Figs. 5a and 5b show that strong negative anomalies are measured by UK1 during 1999 and 2002 and are also present in OCCAM at the sill, and less convincingly in OCCAM at the moorings. In 2001 and 2003 only very weak negative anomalies are present at UK1. Weak

anomalies are present in OCCAM at the sill for both 2001 and 2003, and in OCCAM at the moorings for 2001. This suggests that the mechanism responsible for the 2004 negative salinity anomaly is probably always occurring throughout the time series, but other processes may dominate in different years. The UK1 time series correlates most highly with the OCCAM time series during 2004 both at the sill ( $r = 0.90$ ,  $p < 0.01$ , lag = 6 weeks) and the moorings ( $r = 0.96$ ,  $p < 0.01$ , lag = 0 weeks), and one could argue that this may skew the correlation coefficients of 0.67 and 0.54 obtained for the whole time series (Figs. 5a and 5b). This may indicate that any proposed mechanism for causing salinity anomalies at the moorings only pertains to 2004. However, regression analysis between UK1 salinity anomaly time series and OCCAM salinity anomaly time series at the sill and the moorings for 1999 to 2003 produced correlation coefficients of 0.65 ( $p < 0.01$ ) and 0.26 ( $p < 0.01$ ) respectively. This suggests that OCCAM is realistically representing the processes driving salinity anomalies upstream of the sill in all years, but that imperfect representation of mixing downstream of the sill in OCCAM results in the anomalies at the moorings in OCCAM being less clear for years other than 2004.'

*- Regarding the first hypothesis, how could it be tested in the model, as the model doesn't represent the mixing and entrainment processes correctly?*

**We acknowledge the limitations of OCCAM to correctly represent the mixing and entrainment processes downstream of the sill, and this has now been more explicitly stated in the text in section 3 (discussed in our response to your first question). However, we reject H1 on the basis that the salinity anomaly is present in OCCAM both at the sill and the moorings. In addition there is a realistic time-lag in OCCAM between the anomaly appearing at the sill and the moorings. If H1 were true, then the anomaly would not be present at the sill. We suggest it is highly unlikely given that the anomaly appears at the sill with the correct time-lag, that mechanisms downstream of the sill could be responsible for causing the anomaly at the moorings, regardless of the limitations of OCCAM to represent the mixing and entrainment processes in between the sill and the moorings. We argue that processes downstream of the sill in both the model and reality do have little influence on salinity anomalies and the high correlation is evidence of that.**

*- Finally, H3 doesn't seem to be fully tested in the model. This would add credibility to the results. All these model deficiencies need to be at least clearly acknowledged in the text, and the method dependency of the results need to be discussed as well.*

**Thank you for this valued comment. We agree that we have not been clear enough explaining the use of OCCAM to test H3. H3 was indeed tested using the model through the construction of composite sections, EGC volume flux calculations and the passive tracer experiment. We now make this clearer in our text in section 6 in the following sentences:**

*'To further test H3 using OCCAM as a tool, salinity, current velocity and sea surface height during times of positive and negative wind stress anomalies were composited as described above (Fig. 12).'*

*'Using OCCAM to analyse the volume and freshwater fluxes in the EGC at 75°N (Fig. 10b, section CD), and further south at 72°N (Fig. 10b, section EF) and 69°N (Fig. 10b, section GH), provides an answer for this.'*

**In addition we now also show that OCCAM represents a water mass at the correct time, with the correct density and salinity upstream of the sill in the EGC, capable of causing the 2004 anomaly at the moorings. This is shown in a new figure (Fig. 12), and discussed in the sentence below in section 6.**

‘One would expect a similar water mass to be present in OCCAM. So to further test H3 using the model, we extract salinity on surfaces of constant density from OCCAM 4 ½ months before the appearance of the anomaly at the moorings. Fig. 13 shows the mean January 2004 27.7 isopycnal in the Nordic Seas coloured by its salinity. This clearly shows water of the correct density and salinity to cause the 2004 anomaly, present in the EGC along the entire east Greenland coast 4½ months before the anomaly occurs at the moorings.’

*Minor points:*

*Title: the study addresses only the origin of the 2004 anomaly. It has to be clearly stated that the mechanism proposed here hasn't been tested for other salinity anomalies. I would recommend changing the title to "Wind forcing of the 2004 salinity anomaly in the Denmark Strait overflow".*

**We argue that the mechanism suggested is potentially applicable to other anomalies, and note that there is a correlation between the wind at 75N and the salinity anomalies at the moorings even when 2004 is excluded. Therefore we have not changed the title as suggested.**

*P. 1407 & Fig. 2: I would recommend adding the different water masses defined in the text on the salinity section. I also recommend using the same color scale in Fig. 2 to add clarity.*

**We agree with this comment. The same colour scale has now been used for each sub-plot as suggested, and the different water masses have been added to the figure.**

*P. 1408, L. 13-15: I do not understand how the authors can state something about the temporal variations of the salinity using one single section.*

**We agree with your comment. The sentence relating to the temporal variability of the plume based on a snapshot of June 2009 CTD data in section 2 has been removed.**

*P. 1408, L. 18-19: This sentence is purely speculative and should be removed. As I said before, the study deals only with the 2004 events and the results can not be extended to other events without further investigations.*

**Please see our response to your major comment.**

*P. 1409: I think that there is another possible hypothesis to explain the change in salinity of the waters feeding the overflow. One can imagine that the AW coming from the South presents a salinity anomaly, or that water flowing with the EGC from the Arctic presents a salinity anomaly. The anomaly doesn't need to be caused by the atmospheric forcing in the Nordic seas.*

**We had indeed already considered and investigated this interesting suggestion, and we now include two new hypotheses H2d and H2e in the text in section 2:**

‘H2d – the 2004 anomaly was caused by a change in the salinity of the source waters originating from the inflowing Atlantic Water to the Nordic Seas’

‘H2e – the 2004 anomaly was caused by a change in the salinity of the source waters originating from water flowing southwards in the EGC from the Arctic’

**A description of how these hypotheses are tested (and rejected) using OCCAM is now included in the manuscript in section 5.**

*P.1410, model description: The model needs to be described in more details. Is the model domain global? If not, the boundary conditions might have an impact on your results.*

**Yes the OCCAM model covers a global domain from the Southern Ocean at 78.5°S to 90°N. This is now explicitly stated in section 3.**

*Does the model use any mixing parameterizations? It is stated that the overflows suffer from an unrealistic representation. This need to be discussed as it might again impact on the results presented here.*

**We reiterate in the text the unrealistic representation of the overflow plume in OCCAM (please see our response to your first comment), but highlight the fact that it is still a suitable tool to study the processes upstream of the sill responsible for causing the 2004 anomaly. We have added a few lines of text to section 3 to explain the mixing in the model in more detail:**

'Mixing in the model consists of (a) vertical diffusion, constant below the mixed layer ( $10^{-5} \text{ m}^2 \text{ s}^{-1}$ ) and dependent on the available energy in the mixed layer, and (b) implicit horizontal mixing resulting from the advection scheme, that increases with horizontal velocity. There is no explicit mixing along isopycnals or horizontally. Hence the numerical mixing smoothes tracer structure at the grid scale, and the resolved eddies mix at larger length scales. There is also convection where the water column becomes statically unstable, completely mixing any unstable part of the water column.'

*P. 1411 & Fig. 4: How does the observed velocity structure compare with the modelled one? As shown here, it seems to me that the DSOW core in the model is not separated from the EGC core. Thus the water mass properties of the so-called DSOW are totally unrealistic. On Fig. 4, there is also a signal of large correlation visible on the shelf? Is it discussed somewhere in the text?*

**We acknowledge the presence of a region of high correlation present on the shelf in Fig. 2c in addition to the high correlation in the DSOW core. We agree that this could indicate that the DSOW core may not be separated from the EGC core in OCCAM. When we initially identified this, we performed a passive tracer experiment in OCCAM to determine the proportion of tracer from various upstream density levels in the shelf and modelled DSOW core. This showed that only the tracer initialised at the densest levels were present in the DSOW core, and the tracer initialised at the least densest levels remained at the surface on the shelf. This demonstrated that the EGC and DSOW core are separated in OCCAM. We have added to the text in section 3:**

'Passive tracer releases in OCCAM showed that this plume is fed from denser water than the fresh current on the shelf, separated from the EGC core in the region of the sill.'

*P. 1413: Regarding the tracer experiment: as the model might not correctly represent the mixing/entrainment processes, the factor of dilution found here is probably unrealistic as well. It needs to be acknowledged in the text.*

**Indeed, the model is unlikely to represent entrainment well, as vertical mixing is not stratification-dependent, and the vertical resolution is insufficient to resolve the overflow plume. Excessive mixing in the model results in excessive entrainment, and the plume being too buoyant, and being too high in the water column. This is also consistent with the excessive volume flux seen in OCCAM at the mooring section. The approximate 50% excess volume flux at the moorings in OCCAM would suggest the 9:1 entrainment is more like 6:1 in the real**

**ocean, although the salinity anomaly is of a similar magnitude. We have added to section 4 the following sentence:**

'In the real ocean, this ratio is likely to be lower (~6:1) based on the higher volume flux found at the moorings in OCCAM than observed (Fig. 5c).'

*P. 1416 and after: Has H3 been somehow tested in the model? As H1 and H2 are rejected from model results, H3 needs to be fully tested in the model as well.*

**Please see our response to your major comment.**

*In particular, is the Greenland Gyre spinning up visible in the model? I was also wondering if altimetry could be used to assess the Greenland Gyre spinning up.*

**We acknowledge that our terminology was overly casual when referring to an increased circulation of the Greenland Sea Gyre in sections 6 and 7. We have now removed all references to a spin-up of the gyre, and focus in section 6 on the increased EGC transport and sea-surface height gradient of the EGC, which we have demonstrated both increase in OCCAM during times of increased southward wind stress.**

*P. 1420, L. 25-28: I don't think it is really clear that the NAO is controlling the Greenland Gyre strength. Local winds might also contribute.*

**We agree with your comments on this issue and have removed all references to the spin-up of the Greenland Sea Gyre, and other speculative statements regarding the NAO.**

*Fig. 5(c): It is difficult to read the different color on the plot.*

**We agree. The colours on Fig. 5(c) have now been changed to make it easier to distinguish the maxima and minima.**