

Interactive comment on “Large-scale forcing of the European Slope Current and associated inflows to the North Sea” by Robert Marsh et al.

Anonymous Referee #2

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General Comments

This is a nicely written and well set out paper and I found it easy to follow. The main results from the modelling study have the potential to add to our understanding of the drivers of North Sea inflow. However my main concern is in the analysis of North Sea inflow and the development of the SSH proxy, this aspect of the paper is poorly developed and I don't feel that the conclusions are not well supported. I feel there was limited effort made to validate the model observations, and as a result, that sections 3.4 and 3.5 in particular need some revision.

The use of the SSH metric is puzzling. The authors note that previous researchers have failed to establish a Shetland current transport series based on tide gauge records (Page2, Line 8) but then fail to return to the subject as promised. This statement

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should be revised to be more accurate; but more preferable would be a more explicit discussion of this result in Section 4. More importantly there is no mention in this paper of the established pattern of Faroe-Shetland Channel circulation, particularly the recruitment of an additional branch of Atlantic water from the Western Atlantic through the Faroe Bank/Wyville Thomson Ridge region and the recirculation of the North Faroe Current in the channel. Recent estimate of transport through the channel using altimeter data (Berx,2013) demonstrates for example, why a simple SSH metric might not be so useful.

Logically we would expect some relationship between SSH variability and slope current but it would be worth examining some the different mechanisms for transport of water into the NNS in the NE and the NW for example. This paper could be improved if there was some examination of the relationship between stronger slope current and/or stronger onshelf transport and/or stronger North Sea inflow - the links between these three transports could be the key focus of the paper.

There is no statement in the methods of how the particle backtracking was performed. The first mention of backtracking is in the results section. Also the depth distribution of the tracked particles within the North Sea are not described/discussed. This is of concern because the main Atlantic inflow in NW North Sea is known to flow at depth below the Baltic outflow.

Following on from this, it is not clear why the authors chose to examine surface (only) salinity data within the North Sea (only). Changes in salinity within the North Sea are not just linked to a change in transport of Atlantic Water but also the changing properties of the water that is transported. There was a strong trend of salinification in Atlantic water over the period of the 1990's. This trend is well documented and the reported/observed trend in the NNS is also one of salinification. Having modelled data should offer the authors a chance to investigate these trends and relationships. I believe that doing this would really add value to the paper. Alternatively can the authors explain why they chose surface salinity? Surely the surface salinity metrics are most

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likely to show the variability of freshwater flows.

The authors appear surprisingly unaware of the long time-series of data available, both in the northern North Sea and in the Faroe Shetland Channel where there are both hydrographic observations and long term transport estimates. And also the Ellet Line. Before extracting salinity metrics from the North Sea it might be valuable to check how the model represents other observed patterns of salinity

From my understanding of these observations, I am not convinced that there is evidence of a decline in salinity during the 1990's in the North Atlantic-influenced regions of the northern North Sea. Curiously, the modelled decline in salinity almost mirrors the actual increase in salinity observed over the same period in the Slope Current regions and the central North Sea.

I would suggest the following observational evidence be examined.

B. Berx, B. Hansen, S. Østerhus, K. M. Larsen, T. Sherwin, and K. Jochumsen, 'Combining in-Situ Measurements and Altimetry to Estimate Volume, Heat and Salt Transport Variability through the Faroe Shetland Channel', *Ocean Sci. Discuss.*, 10 (2013), 153-95.

Larsen, K. M. H., Gonzalez-Pola, C., Fratantoni, P., Beszczynska-Möller, A., and Hughes, S. L. (Eds). 2016. ICES Report on Ocean Climate 2015. ICES Cooperative Research Report No. 331. 79 pp

N. P. Holliday, S.L. Hughes, S. Bacon, A. Beszczynska-Möller, B. Hansen, A. Lavín, H. Loeng, K.A. Mork, S. Østerhus, T. Sherwin, and W. Walczowski, 'Reversal of the 1960s to 1990s Freshening Trend in the Northeast North Atlantic and Nordic Seas', *Geophysical Research Letters*, 35 (2008).

S. Dye, N.P. Holliday, S.L. Hughes, M. E. Inall, K. Kennington, T.J. Smyth, J. Tinker, O. Andres, and A. Beszczynska-Moller, 'Impacts of Climate Change on Salinity', in *MCCIP Science Review*, www.mccip.org.uk/arc, ed. by MCCIP, (2013).

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N.P. Holliday, S.L. Hughes, S. Dye, M. E. Inall, J. Read, T. Shammon, T. Sherwin, and T.J. Smyth, 'Salinity in MCCIP Annual Report Card 2010-11', in MCCIP Science Review, 16pp. www.mccip.org.uk/arc, ed. by MCCIP, 2010).

Data from the Feie-Shetland, JONSIS and UTSIRE sections can be obtained from the host institutes or extracted from databases such as BODC, ICES and WODC.

Specific comments:

Page2, Line 11. I'm not convinced that there is "some evidence of surface freshening through the 1990's". Established time series either show no trend in salinity or a slight increase during this period, following the increases seen in Atlantic Water. The freshening that has been observed is limited to the southern North Sea.

Page 7, Line 6-8: The definition of the sections is based on the slope current in the model, but what criteria was applied to define the slope current? See also comments relating to the area of Atlantic water.

Page 7, Line 21 onwards: The authors fail to acknowledge the established knowledge of Faroe-Shetland Channel circulation, particularly the recruitment of an additional branch of Atlantic water from the Western Atlantic through the Faroe Bank/Wyville Thomson Ridge region and the re-circulation of the North Faroe Current in the channel. These offer some explanation as to why a single index of SSH might not represent slope current variability.

Page 11, Line 27. The strong freshening trend from your model data is in the surface salinity of the NW North Sea. Terschelling is a station in the central North Sea and as presented, offers little in support of your observations. The Utsire station as presented by Hjollo sits well within the Baltic Outflow which would link much more strongly to your NE time-series and as mentioned before is likely to mostly reflect variability of freshwater input.

Page 11, Line 34 to Page 12, Line 4: Could the authors elaborate on the spatial vari-

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ability of what would be their defined Atlantic water mass to highlight what this impact may be?

Page 12, I'm worried about these correlations. All three time-series have a similar downward trend and hence they would always be reasonably correlated. Has this been accounted for in the correlation analysis? If not then by the same argument the wind forcing metric that you include in Figure 8 would also be correlated.

Page 12, Line 4. Have you examined how the salinity of the slope water has increased over the period? Is this reflected in your model? During the periods of weaker modelled transport we know that the slope current became saltier.

Page 12, Lines 15-17: Are the seasonal cycles in the Shetland Slope transport and SSH differences in phase?

Page 13, Line 9. It would be nice to see some comparison of the modelled slope current with some of the observations of the slope current and more sophisticated estimates from altimeter data.

Page 14, Line 11. ref to limited observations. The Northern North Sea is relatively rich in observations, being sampled across two sections (Feie-Shetland and JON-SIS/Utsire) least 5 times per year by UK (Scotland) and Norway. These data are publically available for you to use in your research.

Page 15, Line 6. Sentence starting "These transient events..." In which case presumably we would see a return to higher salinities - has anyone noticed this? I'm not sure you can evidence this statement.

Page 15, Line 13. Reference is also made here to observed trends in the Ellet line data, this raises the question of why the authors did not examine/compare the trends in salinity from the EEL observations as these also shows an increase in salinity during the 1990's?

In methods/supplementary material.

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You examine average surface salinity values over a relatively large box areas (NW and NE). The size of these regions makes it likely that both of salinity time-series are capturing variability in Norwegian Coastal current. This is evidenced by the salinity minima in summer in this region. Away from the regions of Baltic influence, in the northern North Sea we would expect salinity maxima in Autumn(September) as a result of Atlantic Inflow. I think it might be valuable to consider different regions and examine data at depth - not just surface values?

Minor/Technical comments

The most common spelling is Faroe and not Faeroe.

Fig 1, Lerwick is not accurately positioned in Figure 1d. The position of the Shetland Slope transect (3) seems to have moved between 1c and 1d.

Fig 1, I find scales hard to read on Figures 1a and 1b, the fontsize used in 1c and 1d is more reasonable.

Fig 2, I note a reference to the log scale - but I think the scale used could be described more clearly.

Fig 5, the number of colours in the scale could align better to the scale intervals.

Page 3, Line 18: ...are used...

Page 6, Line 1. the position of the FASTNEt, EEL and Shetland Shelf sections should be defined. In section 2.3, floats are mentioned which were deployed for FASTNEt (but which aren't analysed in this manuscript and their position is not described). Is the "FASTNEt section" the line where the ORCA particles were released, if so it needs to be stated on Page 4, Lines 8-10 that this is henceforth referred to as the FASTNEt section. In Table 1 the central locations of EEL and Shetland shelf are mentioned, but the length/endpoints of each section is not defined.

Page 6, line 3. 'northwest' and 'northeast' sectors not adequately defined until 3.4

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(Page 11, Line 15) please move that to here or put into methods.

Page 7, line 9. referenced correctly as Sherwin et al 2007. Elsewhere in the paper and in the reference list it is incorrectly noted as Sherwin et al 2008.

Page 7, Line 16. I don't find the more vigorous transport in the early part of the year is 'clearly evident' in this figure. A monthly plot might demonstrate this better.

Page 7, Line 17. Is it possible to quite decadal mean figures rather than relying on our 'general impression'

Page 12, Line 13. Some statistics could be used to determine if this 'impression of generally smaller differences' is correct

Page 13, Line 4. It would be good to know how much smaller - please quote some numbers to back up your statement.

Page 15, Line 9. Please put a date/timescale on 'recent'. It might not be recent when someone reads this next.

Page 15, Line 11. It might be better to say that this study provides "an estimate of the fraction" or "quantifies the fraction".

Page 15, Line 13. starting "Existing EEL observations" These final two sentences feel to me oddly tagged on to the end and of little to do with the conclusion of this paper. If needed, they should be presented within the discussion.

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