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Ocean Science
Discussions

Interactive comment on "Combining in-situ measurements and altimetry to estimate volume, heat and salt transport variability through the Faroe Shetland Channel" *by* B. Berx et al.

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Final Response to the Referees' comments for Combining in-situ measurements and altimetry to estimate volume, heat and salt transport variability through the Faroe Shetland Channel (os-2012-119)

We would like to hereby thank both referees for their encouraging reviews of the manuscript. We will address their comments below in *italic text*. Where relevant, changes have been made to the text to improve the manuscript. A revised version of the manuscript has been attached as supplemental material.

Response to Anonymous Referee 1

This paper sets out to summarise results from 8 years of velocity data in the Faroe-Shetland Channel, in order to calculate the net transport of Atlantic Water into the Nordic Seas through the channel. The paper is well written, has good, clear figures, and fills a sizeable gap in the literature. The results include a new mean volume transport estimate, with associated heat and salt transport, and an absence of a discernible multi-year trend in them.

My one major comment is that there is considerable repetition in Section 6, which is called discussion, but largely consists of summaries of results presented earlier, with a few paragraphs of true discussion. Some points are repeated a third time in Conclusions. I recommend that the paper be shortened by redrafting section 6 to remove the repetition. I give specific examples below.

We have tried to reduce the repetition in the Discussion section and added a more in depth discussion of our results.

Abtract: the first line contains the acronym ADCP which needs to be expanded. Otherwise, the abstract is very well written and a nice summary of the paper.

The text has been edited accordingly.

p160 line 18, this may be a wording issue, which has led me to misunderstand – here you mention the average $\pm$ stdev of the 5C isotherm being at least 320m, but in Table 2 you show the range of the depth of the isotherm, which isnt quite the same thing. Could you clarify?

We can understand the confusion as the two numbers in the table looked as a range, but these were the average – stdev and average + stdev. The table has been edited to show only the average and standard deviation.

p161 first paragraph, and later through the text. You test the significant of a seasonal cycle here, and elsewhere, and provide some discussion about whether it is believable or not, but you avoid discussing whether the fitted curve is what you might expect. There has been some literature about seasonal cycles in velocity and transport in nearby regions, so some discussion about what the expected cycle might be, and whether it is what you observe, would be useful.

We have added references to seasonality observed by other researchers in the area in Section 5.

p161 second para. Some clarification is needed here - you say there is a statistically significant trend (decrease in inflow) but then qualify it in a way I dont quite understand (do you mean that it is probably not significant after all?). I was surprised by the noting of a significant trend because it is counter to what I had just read in the abstract.

One of the assumptions in regression analysis is that the error terms are uncorrelated. However, in time series analysis, it can be expected that error terms of an observation at one time are correlated to those at the next time instance. Serial correlation leads to a reduced estimate of the standard error terms, influencing the estimate of the t-statistic (erroneously high). The calculation of slope and confidence interval relies on this t-statistic, and therefore these cannot be estimated reliably. The Durbin-Watson statistical test can be used to test for serial correlation. For the data collected at site E, the test statistic d equals 1.077. Based on the number of observations (n=138) and estimators, the critical value for positive serial correlation at the 0.05 significance level is 1.707. As our test statistic falls below this critical level, we may conclude there is significant positive serial correlation and the results of the linear regression model should be interpreted with caution. Our comment regarding serial correlation has been elaborated in the manuscript.

p161 line 16, I think this is actually shown in Fig 5 isnt it?

Yes, the average ADCP profiles at four of the monitoring sites are shown in Fig 5 allowing the reader to determine the relatively small vertical variation in the near-surface velocities. The text has been corrected accordingly.

p161 and Table 4. Are the statistics in the last column of Table 4 from altimeter-adjusted AW velocities? If so, it would be better to label them as such.

The correlation analysis was performed on the monthly averaged AW-velocity measured by ADCP and the sea level change between corresponding altimeter grid points. The last columns show the average velocity of Atlantic Water based on either the ADCP observations or the altimetry data. The column header of the final column has been modified to clarify that this is the altimetry-adjusted AW velocity.

p162 line 12, this reference to Table 4 is probably not necessary since you refer to it just above.

The second reference to Table 4 has been removed from the text.

p162 last para, and elsewhere. Your argument for using the core interpolation in the eastern part of the section is perfectly reasonable and makes sense. Yet you chose not to do the same for the other, albeit less strong, current core in the west. It looksto me as though the linear interpolation underestimates the southwestward flow too, which might impact on all your subsequent calculations.

We chose not to use the core interpolation scheme for the western part of the section as the core here is significantly weaker, and the wider spacing between observations at sites A and X makes it more difficult to decide on the width of this core. Additionally, vertical variability in the temperature and salinity at CTD stations 4 and 5 does not suggest a uniform current here. The text has been changed to clarify this.

p163. On this page you present the transport as inflow =3.5Sv and outflow = -3.1Sv, and from this inflow you calculate the heat and salt transports. But later (p168) you say that the mean Atlantic inflow is 2.7 Sv. It would be worth more fully describing Table 5 in the text and how the 2.7 Sv relates to the property fluxes here on p163 to avoid confusion later.

The difference is that the first numbers relate to the transport across the entire section, *including the dense water overflow which flows through the Faroe Bank Channel and Wyville Thomson Ridge, and the second is the transport of only the Atlantic Water. The text has been changed to discuss Table 5 in more depth, and clarify this difference.*

p163. There have been previous estimates of heat and salt transport in the Rockall Trough and Iceland Basin - how do your results compare with those? I'm thinking in particular that the Rockall Trough results should compare with your NEward transports... and if you look in Holliday et al 2000 you will find that they are 130TW and 123 x10**6kg/s in the mean for an earlier period, which is surprisingly, and encouragingly similar.

The comparison with our observed relative heat and salt transports has been added to the discussion section.

Discussion. As I said above, there is quite a bit of summary/repeated information here - there is nothing wrong with a summary of results of course, but I think some trimming here would be beneficial to the paper, giving more room for real discussion about comparison with previous results, or implications for volume/heat/salt budgets of the subpolar and Nordic Seas. In section 6.1, the only piece of information new to the document is around line 4 on p169. Paras 1 and 4 of section 6.2 are simply summary of results, as are sections 6.4 and 6.5.

We have distilled the discussion section, removing some of the repetition, as well as including some further discussion of our results in relation to previous published research.

Response to Anonymous Referee 2

General Comments:

This paper is very well written and an impressive effort to pin down the total transport through the Faroe Shetland Channel using hydrography, ADCP and altimeter. This is focused on the Atlantic water inflow to the Nordic Seas in both the Shetland branch

and a recirculation of the Faroe branch. They combine all three types of measure to estimate a mean value for the period since 1995, and then they combine all three again (but principally ADCP and altimetry) to examine variability and determine whether there is a 15-20 year trend.

There is a lot of work here and in trying to cover all the bases I think they leaving a number of questions hanging particularly not fully justifying some of the assumptions or choices (particularly i: 5degC isotherm boundary, ii:core interpolation and iii:beta). I almost think the paper could work as a pair of papers a) mean transport b) variability which could add a bit more detail on sensitivity to the choices that have been made for both. But it does work as one paper, if you can add a bit of extra detail.

We agree with the reviewer that the manuscript incorporates a lot of work. We have tried to improve our justification for the assumptions where possible. However, we consider the best option to proceed and publish the manuscript as one. It will allow further publications on the dataset to build on the methods and initial analysis presented here.

I also worry that the two halves of the paper might be making slightly circular validations - Sections 3 and 4 use ADCP and altimetry to reference long term average geostrophic shear profiles while Section 5 creates a transport time-series from altimetry using ADCP data but then also adjusting the mean to match the long term average in Sections 34, the ADCP timeseries has a weaker dependence to the 2 other datasets, but uses the long term mean 5degC isotherm (from hydrography) and sets its end points using the AW altimeter corrected velocity. Essentially are there 3 independent transport estimates, or by using all three data sets in all three calculations have the degrees of freedom been reduced?

It is true that the three estimates presented are not independent, so indeed we have reduced the degrees of freedom. Instead, we have tried to synthesize all the data sets (CTD, ADCP, and altimetry) to give the most reliable average volume transport and its variation. We have elaborated where appropriate in the manuscript that these are not *truly independent estimates of the volume transport.*

This is a very important topic and a very important set of measurements so the results will have important implications as they re-budget previous (their own) estimates of the total Atlantic inflow to the Arctic Mediterranean down from 8.5Sv to 7.0Sv. It is important that the results in this paper, following revision, are published.

Specific Comments

1. Introduction:

p155 line 10-11 I think there are others that could be referenced here Im thinking particularly of SchlitzholzJankowski 1998, you could reference them here but not essential. More importantly their estimates are not Table 5b... was there a reason? They are at the low end 1.0Sv and 1.8Sv. van Aken and Becker, 1996 may be another, again low at around 2Sv

The estimate of van Aken Becker (1996) corresponds to the estimate of van Aken (1988) which has already been included in Table 5b (see the discussion on page 335 in van Aken Becker 1996). This estimate has therefore not been included separately. The omission of Schlitzholz Jankowski (1998) was entirely unintentional. The estimate has been included both in the text, and in Table 5b.

2. Data and methods:

This section is clear and well written. The availability of 99 hydrographic sections makes me wonder whether more could be done to look at variability in the geostrophic shear based transport estimates, but that may be for another study.

We agree that much more could be done to explore the variability in the hydrographic sections. However, we consider that including any further on this in the current manuscript would make it too long. This will be considered in future work.

3. Observational Results:

3.1 Temperature and salinity

This is a very brief discussion of the TS findings well written and concise, I agree you do not need too much detailed analysis of the hydrography for its own sake here.

p159 line 22 - p160 line5 suggests this data confirms findings in other papers /reports but are they are the same basic datasets in one form or another? So the confirmation is unsurprising?

Although the underlying data set of hydrographic measurements is the same (or has been integrated into this dataset, as is the case with Larsen et al. 2012), all three references consider changes in the properties of specific water masses in the FSC. Our approach considers the observations at all hydrographic stations on the section. We included the analysis as it is an important component when considering long-term trends in volume transport.

p160 line 6 Here is where the reader might benefit from some more detail. There is weak justification for the choice of 5degC as the AW boundary. The fluxes could be very sensitive to this choice and it is different to the other investigations cited in Table 5b. Why didnt you go for isopycnal 27.8 or 550m or S=35? You have the data it should be fairly simple to test the sensitivity of the transports in Section 34 to this choice.

We have performed an analysis of the sensitivity of the choice of the 5°C isotherm, but we hadn't included this in the original manuscript to keep it a manageable size. We have now inserted a new figure (Figure 7) and some text demonstrating that the volume transport is not sensitive to the choice of the 5 °C isotherm.

3.2 Atlantic water velocities from ADCP data

The AW velocity is calculated between 325m and 0m, and I can see the rationale for this, but looking at the ADCP ranges in Figure 3a this looks like significant chunk (10-30

The text has been extended to highlight that this is based on the extrapolated ADCP *data.*

3.3 Combining...

p162 lines 1-15 Can you clarify, is the average geostrphic profile calculated and then its upper 325m average matched to the AW. Or is every individual geostrphic shear profile matched to this velocity? Would it make any difference either way around? If it is the long term average geostrophic shear is that calculated for each set of data or do you use the average TS fields? Would that make any difference? Maybe I have misunderstood but by referencing the geostrophic shear tothe AW velocity in the top 325m are you saying that the transport in this part of the water column is effectively set by the ADCPs.

Yes, the average geostrophic profile is calculated and its upper 325m average is matched to the AW velocity. This was not done for each individual geostrophic shear profile. Since the averaging is a linear process, this should not make a difference. This would make a difference, in principle, if the calculation is based on the long-term average geostrophic shear (as we did), rather than the average TS fields. This is due to density depending non-linearly on T and S, but the difference between these two approaches should be small. We believe our approach to be the most appropriate in this instance.

Maybe I havemisunderstood but by referencing the geostrophic shear tothe AW velocity in the top 325m are you saying that the transport in this part of the water column is effectively set by the ADCPs.

Yes, we have adjusted the top 325m average velocity by the altimetry-adjusted ADCP velocities.

We have edited the text, in order to clarify the answers to these questions.

p162 lines 15-25 I think the justification for the Core interpolation method is not explained in enough detail, why here and not on the Faroe side around X? The use of

Core interpolation around E adds almost 0.5Sv about 20

In response to comments also received from Referee 1, we have modified the text to clarify the reason for only applying the core interpolation scheme on the eastern part of the section. We chose not to use the core interpolation scheme for the western part of the section as the core here is significantly weaker, and the wider spacing between observations at sites A and X makes it more difficult to decide on the width of this core. Additionally, vertical variability in the temperature and salinity at this site does not suggest a uniform current here. The manuscript has been changed to clarify this.

4 Long-term average...

p163 line 1 'Once the interpolation scheme has been chosen...' should be more explicit that the Core method has been chosen.

The text has been changed accordingly.

There is a paragraph here on net volume transport, and water colder than 5deg C but not a summary para on AW only its heat and salt transports.

An additional paragraph elaborating on the AW transports has now been included.

5 Temporal variations...

5.1 Transport variations ADCP data

p165 line 10 Explain in a little more detail why setting the edges as constant is necessary, and whether it has an effect on the results.

The need to set the edges constant is due to providing necessary constraints for the integration in the volume transport calculation. Both ADCP-based observations and altimetry-adjusted estimates show the speeds at the endpoints are not equal to zero. If the end points had been fixed at zero, the volume transport calculation would be erroneous. This has been clarified in the text.

p 165 line 24 the period where X is used looks (in Fig 7) to have a lower transport than when B is used. Might that be important?

This is the case, and currently being considered further for an additional manuscript. This lower transport is a combination of stronger velocities towards the south-west being observed on the Faroese side of the channel, and weaker transport in the slope current on the Shetland side. Initial work suggests this is not a measurement error by the ADCPs, but likely a change in conditions. Most recent observations from site E suggest the velocities in the slope current have increased again. Our main focus for this manuscript was to present the mean conditions, seasonality and an initial analysis of longer trends. These observations will be analysed further to investigate this interannual variability.

Overall Im not quite sure why the ADCP mean is so different to the ADCP referenced geostrophic shear mean. Have I misunderstood the strong control that the alt adj ADCP AW velocity has on the results in section 4?

The mean of the ADCP-transport for the whole period (3.1 Sv) is most of the time based on only 4 ADCPs (B, C, D, and E) whereas the average calculated in Part 4 is based on all the (altimetry-adjusted) ADCPs and geostrophy.When considering Table 4, it can be seen that there is a large difference between the altimetry-adjusted AW velocities and the ADCP AW velocities for the more recent and shorter duration deployments (sites X, Y and G). This could suggest a strong S Faroe current in these recent times, enhancing the ADCP transport estimate at sites X and Y, which was compensated by a north-eastward flow at site G. This occurs during a period when ADCPs were not deployed at the long-term mooring sites (such as B and D). As highlighted previous, these are also periods where low AW velocities were observed at site E. Unfortunately, exploring these more recent changes is beyond the scope of the current manuscript. We have added a sentence to Section 3.3 to clarify this.

5.2 Transport variations altimetry data.

p 167 lines 18 to 24 How big an effect does choosing the higher beta have? I think this is another choice that is not justified strongly. The mean altimetry transport is set later so would any impact be felt primarily in the std of the altimeter calculated transport? p168 lines 6-8 how big is the adjustment needed? Is this Q$_0 in equ 4?$

Since we do not want to rely on the accuracy of an absolute geoid, the altimetry data is used mainly to give transport variation in the Altimetry-transport. In order to obtain an absolute value for the volume transport, the Q_0 in equation 4 needs to be adjusted. This adjustment equals 2.49 Sv. This Q_0 could be considered as a term collecting the mean transport, as well as the time-mean of the errors and the influence of the geoid on the section, as equation 4 could be considered as $Q(t) = Q_a + \times(\Delta H + \Delta h(t) + \Delta\eta(t))$, where Q(t) is the total transport, Q_a is the true mean transport (= 2.7 Sv), ΔH is the unknown contribution from the Geoid, $\Delta h(t)$ is the observed sea level slope and $\Delta\eta(t)$ collects all the time varying errors and uncertainties. If the influence of the geoid and time-mean errors is not equal to zero, then the adjustment of equation 4 takes this into account by $Q_0 = Q_a + \Delta H + \Delta\eta(t)$, so that the average of the Altimetry-transport series equals the 2.7 Sv found in Part 4. Choosing a higher would increase the variability in the time series, but would also scale all other terms. In terms of one of our main interest of determining if there is a long term change in the volume transport of Atlantic Water, any trend estimated from a linear regression on time would be proportional to , but so would its confidence interval, so the statistical significance of the trend would be unaffected. We have tried to clarify this in the revised manuscript.

6.Discussion

The discussion is well written and uses the results as calculated well. But because the sensitivity to different choices is not really examined I think the paper misses valuable information out on how uncertain and how difficult it is to make robust transport estimates even when the area is data rich.My questions on this section almost all come back to those asked above so are not repeated. The long term mean 2.7Sv is much greater than the very recent estimate of Rossby and Flagg 1.5 Sv and a bit of discussion on the difference would be valuable. If the transports in this paper were of water above 27.8 would they also be lower?

We have elaborated the discussion in light of the comments above.

p 173 line 24 -25 Why with 100 sections can't the temporal variation of 5degC be examined?

We have added a paragraph in Part 6.2, which discusses the effects of the 5°C isotherm variations on both the average volume transport and its variations.

Tables:

Table 5b SchlitzholzJankowski 1998 and van Aken Becker 1996 are not included in the list.

Schlichtholz, P., Jankowski, A. 1993. Hydrological regime and water volume transport in the Faeroe Shetland Channel in summer of 1988 and 1989. Oceanologica Acta, 16, 11.

van Aken, H. M., Becker, G. 1996.Hydrography and throughflow in the north eastern North Atlantic Ocean: the NANSEN project. Progress in Oceanography, 38, 297-346.

As mentioned above, the estimate of van Aken Becker (1996) corresponds to the estimate of van Aken (1988) which has already been included in Table 5b (see the discussion on page 335 in van Aken Becker 1996). The estimate of Schlitzholz Jankowski (1998) has been added. The table has also been re-ordered to reflect the chronology of the estimates.

Table 7 column 5 units should be Sv /cm

The text has been edited accordingly.

Figures Figure 4 - colour scale makes it difficult to see the variations in T and S. I find a number of colour classes rather than a fully smoothed colour scale easier to

understand. Could a density section be included.

Figure 4 has been changed accordingly and its caption has also been edited.

Technical corrections

Table 7 column 5 units should be Sv /cm

The text has been edited accordingly.

Please also note the supplement to this comment:
http://www.ocean-sci-discuss.net/10/C182/2013/osd-10-C182-2013-supplement.zip

Interactive comment on Ocean Sci. Discuss., 10, 153, 2013.