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Interactive comment on "Recent transient tracer distributions in the Fram Strait: estimation of anthropogenic carbon content and transport" *by* T. Stöven et al.

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In the reviewed paper authors propose several hypotheses, assumptions, simplifications and finally - conclusions.

Generally, the paper deals with three distinct issues: 1) direct observation of transient tracers (CFC-12 and SF6) distribution in summer 2012; 2) use of IG-TTD method for comparison of theoretically calculated and observed tracers ages and for anthropogenic carbon calculation based only on CFC-12; 3) transport of DIC and previously calculated anthropogenic offset in the upper/intermediate layer across the Fram Strait.

While the first part is rather trivial, the second is the most developed/discussed, the third is controversial and only briefly analyzed in the manuscript.

Nevertheless, presentation of any new observations concerning the ocean uptake capability for anthropogenic gases is valuable for the scientific community, especially considering the fact that the ice-covered polar regions are still under-sampled. The theories introduced in the manuscript, even though arguable, are interesting. Thus, in my opinion, the submitted paper should be published after some corrections and additional explanations – this means a major revisions.

Below are some specific comments which may help re-think the presented material:

Title

The title is misleading – it suggests broader look, as well as longer time perspective.

Abstract

Page 2190 - Current velocity measurements along the same section - it should be mentioned the measurements were performed in the previous years – mean flow.

Introduction

Page 2191 - The elevated heat flux of warm Atlantic Water into the Arctic Ocean – where and when? Higher temperature or volume of AW?

Page 2192 - a short meridional section along the fast ice edge in 2012 – how valuable is this section for the overall analysis and discussion? The data from several (1-2?) stations appear only in Figure 2.

Data and Methods

Water transport data

Page 2194 - gross assumption applied by authors is that the mean velocity field calculated for the years 2002-2010 represents particular situation in summer 2012. This is based on the authors' statement of small interannual changes and no trend in the flow. Previous studies indicated a non-steady situation, which is also confirmed by a

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recent work (Hansen et al., 2015). This study is based on a combination of the in-situ data (moorings and CTD stations) and satellite altimetry, and it shows a distinct trend in volume, heat and salt transports in the AW layer across the Faroe Shetland Channel (FSC) – the main AW entrance into the Nordic Seas. The mentioned paper also points out high interannual and seasonal variabilities. Since the AW transport across the FSC has increased in the recent period (9$\pm$8% in the last 2 decades), transport through the Fram Strait/BSO is also most likely to increase. Even though it is not clear how this additional volume has been distributed (FS, BSO and recirculation in the Norwegian and Greenland Seas), it is rather hard to claim that there is no trend in fluxes in the Fram Strait at all.

The second assumption states that the net transport beneath the upper/intermediate layer (the depth of the FBC sill being a part of the Greenland-Scotland-Ridge is 840 not 750 m) is equal to zero. Previous studies take into consideration various net values in the deep flow in the Fram Strait - from net southward transport (Schlichtholz and Houssais, 1999; Beszczynska-Möller et al., 2012, Marnela et al., 2013) to balanced exchange (Tsubouchi et al., 2012; Von Appen et al., 2015). The authors also point out that the moored instruments at the 78°50'N section do not resolve the mesoscale features and the local bathymetry very well.

Another explanation of the variable southward deep flow through the Fram Strait is discussed in connection to extreme air-sea exchange in the Barents Sea in strong winters (Moat et al., 2014). This study underlines the importance of the variable surface conditions in only one of many marginal seas affecting the deep circulation in the Fram Strait.

TTD method

Page 2195 – The Δ/Γ ratio equal to 1 seems to be used in many water mass productive regions, but is it best for the Fram Strait (strong advection)? In fact, the Section 3.3 answers this question.

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Page 2195 - similarly as for the CFCs input functions - it was recently described (Fang et al., 2014) that around the year 2000 there was a reversal in the global SF6 emission trend, from decreasing to increasing, which was probably caused by increasing emissions in the East Asian countries. This additional amount shall be detectable in the AO surface water through the Pacific inflow.

Furthermore, the changing sea ice cover of the Arctic Ocean needs to be mentioned as a potential source of anthropogenic gases content in the Polar Water of the Pacific origin – a recent study (Ballinger and Sheridan, 2015) describes changes in the western Arctic freeze-up pattern suggesting the changing ocean–atmosphere heat exchanges connected with prolonged melt period as a cause. This is also most likely to apply to the Siberian shelf seas.

Results and discussion

Water masses in Fram Strait

Page 2197 – "Note that this water mass classification is not based on an optimum multiparameter analysis and only serves as an indication for this specific purpose" – what is the reason for this explanation? Would OMP analysis provide more accurate classification? If yes, why not using it with so many data collected? This would be an additional work but perhaps a little more certainty would be beneficial for this paper. If not, consider this sentence redundant.

Page 2197 – "the warm Polar Surface Water, defined by a potential temperature (θ) > 0, which comprises sea ice melt water due to interaction with warm Atlantic Water" – and due to solar radiation because it is summer.

Page 2197 – "Return Atlantic Water which derives from sinking Atlantic Water due to cooling in the Arctic Ocean" – in the applied classification (Rudels, 2005) the RAW originates in the West Spitsbergen Current – it is the water that recirculates in the northern Greenland Sea, not the water making a long loop in the Arctic Ocean and coming back

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– this one is called the Arctic Atlantic Water (AAW). This is also inconsistent in Section 2.2 (Page 2194).

Page 2197 – “the deep water masses are upper Polar Deep Water (uPDW), Canadian Basin Deep Water (CBDW) and Eurasian Basin Deep Water (EBDW) and the Nordic Seas Deep Water” – does the classification from 2005 still applies to these water masses? Are they within the range? The θS diagram would be helpful.

Transient tracer and DIC distributions

Page 2199 – “Both tracer maxima probably correspond to extensive ventilation events” – when and where? Obviously, this is more like guessing but indicate how little we still know about regions/periods favorable for the Greenland Sea convection.

Page 2199 – “0.2ppt of SF6” – is it not too close to the method accuracy?

Page 2200 – “two branches of tracer age relationships” – it is a misfortunate expression, since branches are associated with the water pathways. Perhaps “sets” would be better.

Page 2200 – “show a transition to the upper branch” – perhaps it is better to say that two sets merge or have an intersection area.

Page 2200 – “However, the upper branch does not correspond to the unity ratio and, moreover, it is outside the validity area of the IG-TTD” – does this mean that only the results below 20 years from “the lower branch” can really be used in the validation process? Well, yes, the answer is on the next page.

Saturations and excess SF6

Page 2202 – “These new boundary conditions are then applied to the measured tracer concentrations and the IG-TTD” – it would be good to see these corrected data.

Page 2202 – “The SF6 excess is estimated using the corrected CFC-12 concentrations and the IG-TTD (Δ /Γ = 1.0)” – I still think that this ratio may be too low.

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Page 2203 – “This indicates that probably an additional source of excess SF6 exists” – try to find an answer in references, it must be connected with the AW inflow.

Page 2203 – “the generally elevated tracer concentrations of CFC-12 and SF6 in the same area” – this contradicts with the conclusion from the Southern Ocean experiment on solubility.

Generally, the theory of SF6 excess source for is interesting, yet perhaps more study on gases solubility would be required. The previous paper (Alvarez and Gourcuff, 2010) indicates the difference between Cant and CFCs solubility affecting the gases concentration and transports. Could it be the case?

Anthropogenic carbon and mean age

Page 2204 – “show the highest mean current velocities in Fram Strait (see Sect. 3.7 below)” – there is no information about the mean currents velocity in Section 3.7 and nowhere in the manuscript (only transports).

Sensitivities on anthropogenic carbon

Page 2207 – “The mean flux of deep water layers below 750m was taken to be 0Sv and therefore not considered for this estimate” – this assumption means that only the upper/intermediate transport is considered in that manuscript, not the whole FS.

Page 2207 – “we cannot with great confidence decide whether more anthropogenic carbon is transported into or out of the Arctic region through the Fram Strait” – this is the weak point of the manuscript, though perhaps it could lead to some additional studies (better sampling coverage and current measurements).

Uncertainties

Page 2207 – “is supposed to be limited by complex water mass mixing and ventilation patterns” – this contradicts the theory of small mixing impact on the differences in the tracers age relationships.

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Page 2207 – “the IG-TTD model is valid for all water masses in the Fram Strait” – it was showed that the model is valid for some water masses, not for all of them.

Page 2208 – “recommend the use of data from the subsurface layer” – recommend using the data. Which data? Salinity?

Conclusions

This part is more of a summary than actual conclusions. There is no new information which has not been already mentioned in the previous sections.

Figures

Fig 5. and Fig. 6 are practically the same - is Fig 6 really necessary in that paper? Perhaps distinguishing between the data marks would be enough?

Fig. 7 – provides little information. In my opinion it should be more detailed (or maybe merged with subplots from Fig. 8) or removed.

A few technical corrections:

Page 2194 - Section 3.8, not 3.6

Page 2197 – von Appen et al., 2015 – already published

Page 2197 – A typo in the surname Beszczynska-Möller (check in the whole paper)

Page 2199 – “at $\approx$ 200m” – should be $\sim$ not $\approx$ (also in some other cases in the paper, but not everywhere)

Page 2206 – “100 % corresponds to a anthropogenic carbon” – delete the indefinite article.

“the” Fram Strait – correct in the whole paper

Interactive comment on Ocean Sci. Discuss., 12, 2189, 2015.