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Interactive comment on "Estuarine circulation reversals and related rapid changes in winter near-bottom oxygen conditions in the Gulf of Finland, Baltic Sea" *by* T. Liblik et al.

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We thank reviewer for the useful comments and suggestions which improve the manuscript significantly. All of the comments and suggestions were taken into account and respective changes were made in the manuscript.

General comments

It also discusses an open question which can be nicely addressed in a following work: An upwind barotropic flow in the thalweg in combination with a raising sealevel, suggesting a downwind transport of water at the shores.

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Interactive Discussion

Discussion Paper

For the better understanding of reversal physics and effect on nutrient conditions in the deep layer of the Gulf of Finland we have planned field measurements (CTD sections and collection of water samples for nutrient analysis; ADCP moorings equipped with CTD and oxygen sensors) during the winter 2013/2014. We also plan simulations with coupled circulation and ecological model to reproduce observed reversal events in winter 2011/2012 complementing field data.

A second question arises and is shortly discussed but could be formulated in a bit more detailed way: The quantification of mixing during the reversal events. The manuscript emphasizes the importance of advection. A discussion between the lack of vertical mixing, the advective transports and convective mixing during reversal periods would be informative.

We agree that the quantification of reversal induced vertical mixing is very important topic in terms of functioning of the Gulf in general. Traditionally it has been assumed that strong storms create intense vertical mixing and a significant decay of stratification. Our detailed observations reveal that differential advection in case of temporary estuarine reversal (anti-estuarine straining) is an important factor for the stratification collapse, as suggested earlier by Elken et al. (2003) and Elken et al. (2013). Unfortunately, within the present study it is not possible to establish the balance of different advection and diffusion terms during rapid changes of stratification because of the long time interval between the along-basin transects and missing information on transverse flow and density structures. We note that the point measurements of currents show events of strong along- and cross-basin currents; the corresponding mesoscale density variations remained unresolved in the observational data set. We hope to get more detailed insight to the advection-diffusion balance in future studies involving case-validated numerical models.

Detailed Comments:

Page 728, Line12: '. . . caused the vanishing of the stratification and oxygen concentra-

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tion that were almost . . .': Mention that the reversal caused the oxygen concentration to increase from 0 to 270 umol/L.

We changed the sentence accordingly: The first reversal event was well developed: it caused the vanishing of stratification and the increase of oxygen concentration from hypoxic values to 270 μmol l–1 (to 6 ml l–1) in the entire water column along the thalweg; and it lasted for about 1.5 months.

Page 728, Line 15: Add the direction (along-gulf) of the deep layer currents.

We added the direction: Shifts from estuarine circulation to reversed circulation and vice versa were both associated with strong along-gulf currents (up to 40 cm s–1) in the deep layer.

Page 729, Line 19, we replaced "The" by "A".

Page 730, Line 10-18: This is an important part of the introduction, add Elken 2003, who showed that vertical mixing alone cannot explain the observed changes of the vertical profiles.

We changed the text in the beginning of this part: Elken et al. (2003) showed on the basis of summer CTD measurements that the halocline weakening could occur in the Gulf, which cannot explained by vertical mixing alone. They suggested that southwesterly (nearly up-estuary) wind forcing caused the reversal of estuarine circulation in the gulf: the surface layer flows into the estuary and the deep layer flows out, in opposition to normal estuarine circulation.

Page 734, Line 8: What was the filter time? We added: . . .filtered with a 36-h cutoff Butterworth filter.

Page 738, Line 8: We added direction to text: The temporal course of cumulative wind stress showed that reversal-favorable winds (from SW) started on 25 November and lasted until 5 January (Fig. 6).

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Page 777 /, Line 15 and following: Please extent this part a bit more, discuss the origin of the anoxic waters and the consequences of estuarine circulation and reversals for estuaries ala the Tokyo Bay and the Gulf of Finland.

We extended this part. We discussed more on origin of hypoxic waters and long-term effects of Baltic Sea major inflows in the Gulf of Finland and in the Baltic Proper: Intensification of estuarine circulation often causes improvement in near bottom oxygen conditions in estuarine environments due to the import of oxygen-rich ocean waters (e.g. Sato et al., 2012). In that respect, the Gulf of Finland is a rather unique marine system, since imported open sea waters are often depleted from oxygen and here the intensification of estuarine circulation leads to an increase of hypoxic water area and volume. A similar estuarine system is found in the Lower St. Lawrence estuary, where bottom water, isolated by permanent halocline from the upper layer, has to travel several years before it arrives at the estuary (Gilbert at al., 2005). Since the hypoxic water origins from the intermediate layer of the Baltic Proper, oxygen conditions there often determine the oxygen conditions in the Gulf of Finland as well. Conley et al. (2012) showed that so called stagnation periods lead to oxygen deficiency in the deep layer of the Baltic Proper while the intermediate layer contains relatively more oxygen during such periods. The last longer stagnation period in 1980s caused weaker halocline (Liblik and Lips 2011) and higher deep layer oxygen concentrations (HELCOM 2009) in the Gulf of Finland while oxygen conditions in the deep layer of Baltic Proper deteriorated during the same period. Thus inflow activity from the North Sea has opposite effect to the oxygen conditions in the deep layer of the Gulf of Finland and the Baltic Proper.

Page 747, Line 25: It was not shown, that convection caused the complete mixing of the water column. This is very likely but needs to be proofed. This should be rephrased.

We rephrased the sentence: However, long-lasting counter-advective transports in the upper and deep layer probably caused convection and complete mixing of the whole water column.

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Fig. 1: Add a scale.

We added a scale.

Fig. 3: This is one of the most important figures, can be enlarged.

The final revised version will have a different format than the discussion paper, i.e. it will be larger. We spread the figure over two columns in revised manuscript.

Fig. 2, Fig. 5, Fig. 6: it would be nice to have the reversal events shown in Fig.4 be marked as well.

We added to these figures shaded areas indicating the period of two reversal events.

Interactive comment on Ocean Sci. Discuss., 10, 727, 2013.