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Ocean Science Discussions

Interactive comment on "Seasonal renewal time variability in the Curonian Lagoon caused by atmospheric and hydrographical forcing" *by* G. Umgiesser et al.

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Response to the review of os-2015-68

Journal: OS Title: Seasonal renewal time variability in the Curonian Lagoon caused by atmospheric and hydrographical forcing Author(s): G. Umgiesser et al. MS No.: os-2015-68 MS Type: Research article Special Issue: Oceanographic processes on the continental shelf: observations and modeling

Dear Editor, Please find here our responses to the questions of the referees. I think we have responded to all the major questions. One problem, however, still remains. Due

to the fact that I was in winter holidays until the 6th of January, I will only be able to provide a new manuscript for the end of January. I will have to carry out some more simulations, change most of the figures, and slightly change the formulation of the "ice model". I am only back to office after the 6th of January. Please let me know if this will be a problem. Sincerely, Georg Umgiesser and all co-authors.

Response to the editor: The ice cover treatment may need improvement. Depending on ice characteristics in the lagoon, thickness, concentration and extent, wind stress may or may not be able to transfer momentum. The lagoon is shallow enough for stationary land-locked ice to form.

Answer: We do appreciate this comment and we modified the manuscript to clarify the ice treatment in our study. Several ice characteristics (ice thickness, ice concentration and distance from shore) are daily observed in four stations in the lagoon. In our study we use the ice concentration, which is a dimensionless term that describes the relative amount of area covered by ice, to weight the wind momentum transfer in the hydrodynamic model. Ice concentration ranges between 0 and 1; a value of 0 means the lagoon is ice free, while a value of 1 means the lagoon is completely covered with ice and momentum transfer to the sea is completely switched off. Fractional values transmit parts of the wind stress. This approach is widely used in coupled ice-ocean models. No ice-ocean stress is considered in this study. Ice concentration is also used to properly calculate the albedo to be used in the heat flux model. We included a more detailed description of the ice treatment in the methods section. Please note that due to the shallowness of the lagoon the freezing (and melting) happens in a short period (days) and once the lagoon is frozen the ice is land locked, not transmitting any wind stress to the underlying water. This important aspect of ice dynamics in the Curonian Lagoon is now presented and discussed in the manuscript with the help of a new figure describing the ice concentration variation over time in the four observing stations.

The lagoon has a narrow strait as its outlet and this may entertain a classic two-layer density driven flow, with fresher water going out and saltier water pouring in. Question is how does that affect water residence time? Also, normalized values using a gross estimate based on lagoon volume and riverine (or strait) inflow rate might be useful.

Answer: The lagoon shows in fact sometimes a two layer flow at the inlet. The occurrence of this flow is depending on the strength of the riverine forcing and the barotropic water level forcing at the Baltic Sea. We have described this two layer flow in detail in Zemlys et al, 2013. We can show the influence of the two layer flow on the residence time by switching off the baroclinic acceleration. We have therefore carried out a new simulation to highlight this feature and have inserted the results into the text. We will also compare the residence time with the flushing time, which is basically a gross estimate of the time scale of water overturning. This number would be equal to the residence time only with perfect mixing of the waters inside the lagoon. For a mixing efficiency of less than 1 we will have flushing times that will be much lower than the residence time. We have included this into the discussion.

Response to Referee 1 (osd-12-C1252-2015): This is a good research article where the authors present the results of the validated hydrodynamic model (the 3-D SHYFEM) applied to the Curonian Lagoon to simulate the circulation patterns for ten years (2004-2013), forced by river runoff, wind and Baltic Sea level fluctuations. The main results are well explained briefly in the abstract – and later explained in further detail in Section 4 (Discussion and conclusions). Two main mechanics under wind forcing were identified (exchange with Baltic Sea, and internal mixing within the lagoon). The effect of the Nemunas River is discussed: a low effect on the internal water circulation but a strong influence of the river forcing on the water renewal time (WRT). The WRT at different seasons is compared, and the authors showed a low WRT in spring close to the Nemunas outflow and a high WRT in summer in the southern basin. Inter-annual low WRT are in winter and spring and highest in summer.

In lines 3-5 of page 2057, the authors refer to high WRT in the southern basin (and a minor increase in the northern part) – can they perhaps explain why?

Answer: In the northern part there is always a strong forcing of the Nemunas River that drives the water out from the lagoon. Therefore, even with lower winds the renewal times of the northern part are less affected. In the south, however, there is only wind forcing, and the Nemunas River does hardly influence the situation. Therefore, stronger effects can be found here, and higher renewal times are the consequence.

The ice cover during long strong winters increases the WRT in the south and decreases in the north. Here the authors provide a possible explanation which explains such result. Finally, the strongest impact on the WRT distribution is shown to be the Nemunas inflow (7 months WRT for northern lagoon and 5 years for the southern part) – with the authors justifying such result. Section 1 (introduction) provides a good introduction to the Curonian Lagoon and a review of past numerical studies on the lagoon.

In line 28 page 2045 maybe the authors meant "... Lagoon is also characterised by ..." or "Also the Curonian Lagoon is characterized by ..."?

Answer: it is the first choice. We adjusted the sentence.

In Section 2 the authors described the study area (the lagoon), the different sources of data for boundary conditions to the model and numerical modeling framework (the title in section 2.3 should read "modelling" [is using UK English]).

Answer: we were always trying to use US English. We would prefer to continue to do so, unless the editor has some specific requests.

Furthermore, the WRT computation is clearly explained in section 2.4, with reference to other articles for further details on the algorithm. In line 24 of page 2050, are there references or reasons for fixing the parameter of the Smagorinsky type closure to 0.2?

Answer: In another paper (Zemlys et al., 2013) we have used this value and had good agreement with data. We will insert a reference to this paper in the text.

Interesting to note the energy budget being symmetric with wind speeds of opposite direction, followed by an explanation. Table 1 explains well to the reader a summary of simulations carried out. The WRT for different seasons and different regions (northern and southern parts of the lagoon) are compared over the 10 years period.

Reviewer's Conclusion: The article is well structured: approaches are explained and results are identified and discussed. General comments are positive

Answer: We are pleased with the positive comments of the referee and thank him/her for his review.

Response to Referee 2 (osd-12-C1307-2015):

The authors have applied their well-known 3-D finite element model SHYFEM developed at ISMAR, CNR, to the Curonian Lagoon to explore the factors that influence the water renewal times (WRTs) in the lagoon. The study is interesting and a straightforward application of a numerical model, although the conclusions are quite obvious a priori. The lagoon is very shallow (3.8 m average depth) and is connected to the Baltic Sea via a very narrow strait that restricts the water mass exchanges between the lagoon and the sea. In addition, the tides in eastern Baltic are negligible and so tidal variations in the sea level in the Baltic are unimportant as far as the lagoon is concerned. However, wind-induced sea level changes in the Baltic Sea might be significant and that is where the Baltic Sea could influence the lagoon, albeit with the Strait restricting the exchange. The authors should have investigated this scenario as thoroughly as they have done the obviously influential river discharge. The Namunas river discharges a significant volume of fresh water into the very small lagoon, making it, as the authors point out, nearly a fresh water lagoon and hence plays a dominant role in WRT.

Answer: The wind-induced sea level changes have been considered in the manuscript by switching off the water level variations in the Baltic Sea. In fact, as can be seen, these water level changes do influence the renewal time, but only to a minor extent. The other forcing that influences the exchange is the baroclinic driven two layer flow through the strait. Since also the editor has asked about this feature we will add another

simulation where we will treat the equations without the baroclinic acceleration and see how strong this influences the renewal time.

As an exercise in numerical model application, the study is fine. But it does not shed any light on physical processes underpinning the WRT. For example, I find it hard to understand why not even a single plot of the circulation in the lagoon is presented. Obviously, the prevailing circulation must affect WRT in various parts of the basin. And the restricted exchange through the Strait must affect the entire basin. Without a clear picture of what the circulation in various sections looks like, it is very hard to understand why the model is producing the results it is producing. The discussion of various energies is interesting but not illuminative. The emphasis should have been on circulation. So I urge the authors to include currents in their analysis of the model results. It would also be nice to see a plot of the flow volume through the Strait over the 10 years of model simulation. It should be included in Figure 8.

Answer: We have plotted the flow over a 10 year period through the strait. However, due to the strong variability of the flow due to water level changes and wind forcing it is really very hard to see anything useful in this plot. If we average over a longer period, the only thing we will find is that the net exchange through the strait closely resembles the Nemunas discharge inside the lagoon.

The model does a decent job on sensitivity studies but is woefully brief on the 10 year reference simulation (e.g. Figure 8). I would like to see more discussion of the 10-year simulations as presented in Figure 8 but supplemented with maps of currents and water mass properties.

Answer: We agree with the referee that a circulation plot is useful and we will produce a map of average seasonal water circulation. We will also add some more discussion to the 10 year simulation.

Overall, Major revisions addressing my concerns are in order before the manuscript can be accepted for publication in OS.

Answer: We are thankful for the constructive comments of the referee. We will try to revise the manuscript according to his guidelines.

Detailed Comments:

Page 2: Line 11-12: are mostly depended should be depend mostly Line 15: are only marginally determining should be only marginally determine Line 21: remove due The manuscript needs a thorough going through to improve the language and gram- mar. Especially bothersome is use of continuing tense such as that pointed out in Line 15 above, throughout the manuscript. There are too many language fixes needed and so it is impossible to point them all out. So I will not and instead will concentrate on the technical content. The authors should ask an English-knowledge person to go through the manuscript and correct the language deficiencies, before it can be accepted for publication in OS. However, that can be done during their response to reviewers and resulting revision of the paper.

Answer: Thank you for pointing this out. We will thoroughly review the English language of the manuscript in our final version

The figures are very poor. The different colors and lines are very difficult to see. Please re-plot ALL the figures with thicker lines, better color distinctions and bigger fonts. In their current form, they are not fit for publication.

Answer: all figures will be redone to better convey the information to the reader

Page 4, Line 1: Replace importance by magnitude.

Answer: done

Figure 1: I could not see the gray lines without expanding the figure a lot. Re-plot with a suitable color and thickness. Change the color of the thick line also. It merges with the FEM cell boundaries.

Answer: Figure 1 has been redone.

Page 5: List the average discharges of all rivers, even if Nemunas river dominates. A plot of the change in Nemunas discharge with time is necessary to understand its seasonal influence.

Answer: we will list the discharge of all rivers and will insert a plot of the Nemunas discharge in the lagoon.

Page 6: Explain how data from different sources for different years affects the results. How reliable are the data from the “forecast” models?

Answer: Data from a unique data source were not available, so we had to put together the open boundary data set from various sources. Water levels are reliable from all models. What concerns salinity and temperature, the model is not very sensitive to these parameters at the open boundary, because the flow direction is mainly from the lagoon to the sea.

Page 6: Ice cover is characterized by two quantities: fractional area covered and the ice thickness. Looks like only the fractional area covered is available. You also say you ignore ice cover. Explain why.

Answer: As also recommended by the editor, we have clarified how we treated ice in the model. Several ice characteristics (ice thickness, ice concentration, distance from shore) are daily observed in four stations in the lagoon. In our study we use the ice concentration, which is a unitless term that describes the relative amount of area covered by ice, to weight the wind momentum transfer in the hydrodynamic model. Ice concentration ranges between 0 and 1; a value of 0 means the lagoon is ice free, while a value of 1 means the lagoon is completely covered with ice and momentum transfer to the sea is completely switched off. Fractional values transmit parts of the wind stress. This approach is widely used in coupled ice-ocean models. No ice-ocean stress is considered in this study. Ice concentration is also used to properly calculate the albedo to be used in the heat flux model. We included a more detailed description of the ice treatment in the methods section. Please note that due to the shallowness of the lagoon the freezing (and melting) happens in a short period (days) and once the lagoon is frozen the ice is land locked, not transmitting any wind stress to the underlying water. This important aspect of ice dynamics in the Curonian Lagoon is now presented and discussed in the manuscript with the help of a new figure describing the ice concentration variation over time in the four observing stations. We ignored ice cover only in the open Baltic Sea, because the Baltic Sea is less likely to freeze at these latitudes and the wind stress over the Baltic Sea is not strongly affecting the dynamics of the Curonian lagoon.

Page 10, Line 7: Replace Energy by Lagoon energy

Answer: done

Page 10, Line 26: Are these fluxes across the gray lines in Figure 1? If so, state it and refer to the figure.

Answer: yes. We will make it clear in the text that the sections shown refer to the lines in figure 1

Figure 3: Change the vertical scale of the bottom panel to 2500 mËĘ3/s also, so that the strait discharge can be compared visually to the river discharge.

Answer: done

Page 11, Line 19: How much of the results are affected by model discretization of the Strait? Comment.

Answer: The goodness of fit is only slightly lower when compared to a high resolution grid of the Curonian lagoon (Zemlys et al, 2013). The exchange mainly depends on barotropic forcing (river, water level in the Baltic Sea) and baroclinic two-layer flow. Both of these are quite insensitive to horizontal discretization. The latter one clearly depends on the vertical resolution, which was comparable to the aforementioned paper.

Page 11, Line 26: Reason for “reinitialization?”

Answer: After three months we start a new computation cycle for the renewal times. Therefore the concentrations have to be again initialized to 1.

Page 12: A plot of the temporal variability of various (especially Namunas) river discharges is essential to understand the results in Figures 4 and 5.

Answer: we have included a plot of the various river discharges over the 10 years.

Page 15: Discuss the dynamical reasons why the ice cover influence is small and why the influence of how the ice cover was taken into account in the model might or might not have affected the results. If the lagoon is completely covered by ice, as happened during 2009 and 2010, and if the ice is land locked, the wind stress is NOT transmitted to the water underneath. Has that been taken into account? Does that affect WRT or doesn’t it? Explain.

Answer: Yes, this has been taken into account. When there is ice cover, there is no transmission of momentum to the water column. Therefore, our “ice model” completely inhibits the momentum exchange. It is therefore the most severe case that can happen. We have inserted some explanation of this point into the text.

Figure 7: Once again, the plots are too poor and hard to understand. Thicker lines, better color selections to highlight different situations in a particular lagoon etc. are needed.

Answer: the figure has been redone.

Page 15: The paper draws obvious conclusions re WRT. The presence of the narrow Strait, which forms its outlet to the Baltic Sea and hence restricts exchange of water masses between the lagoon and the sea, must play an important role. And of course river discharge into such a small volume must also play an important role in WRT.

Answer: We agree.

Page 16: I do not understand why the lack of influence of ice cover is “astonishing.” All it does is mediate between the wind stress and the water column. So it affects vertical mixing in the water column mostly. WRT cannot be not sensitive to vertical mixing in such a shallow basin (3.8 m average depth), since even small winds mix up the water column, if the estuarine exchange through the very narrow Strait is highly restricted and so more saline water intruding along the bottom cannot be a major factor, at least in the southern section. A plot of the salinity in the basin would be very helpful. Actually, I would start the paper with a plot of the salinity and temperature (seasonal or average) in the lagoon immediately after Figure 1 showing the topography and the model cells.

Answer: Ice cover not only restricts vertical mixing, but also horizontal acceleration of the water masses and therefore horizontal mixing. Before this study we thought that wind stress was a major factor in shaping the horizontal exchange. As it turns out, during the years of ice cover this inhibition is less important for the renewal time pattern. What concerns the salinity and temperature map, I am not sure if they will give much information. Salinity is basically 0 in most parts of the lagoon, except in a small area close to the strait. And temperature, due to the shallowness of the lagoon, is quite homogenous over the whole lagoon. We will, however, produce these maps (seasonal) for salinity and temperature.

Interactive comment on Ocean Sci. Discuss., 12, 2043, 2015.