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Interactive comment on "Historical reconstruction of the Aral Sea shrinking by a full 3-D wetting and drying model ECOSMO" *by* I. Alekseeva and C. Schrum

I. Alekseeva

alexeevai@mail.ru

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First reply to the major remarks of Referee 1 and 3.

We are thankful to Referee1 and Referee3 for the time spent on our manuscript and for the constructive comments!

Both reviewers raised similar major concerns about the need for employment of a full hydrodynamics 3-D sea-ice model for the historical reconstruction of the Aral Sea shrinking. Both raised the question whether the complexity of a full 3-d sea-ice model is required while simple budget models can be used instead.

In the manuscript, we have already clear and rather obvious answers to these concerns. However, despite we have tried to describe the advantages and perspectives of the full 3-D hydrodynamics sea-ice model in comparison with the simple budget models this message has not come through in the manuscript, since objections were indicated by both reviewers. Therefore, we would like to clarify these important aspects at the discussion stage before providing our reply on all other comments done by reviewers.

We structure the discussion by providing our answers on the detailed statements and questions which we combined from the major remarks of the review 1 and 2.

Q. 1. Referee1 and 3. The main objective of the paper is to give a historical reconstruction the water level, fresh water budget and area/volume changes of the Aral Sea.

We have to note that the title of our manuscript 'the historical reconstruction of the Aral Sea shrinking' does not imply only 'the reconstruction of the Aral Sea water budget'. Perhaps, this misunderstanding led partly to questions discussed below.

In the manuscript, we focused on the long-term simulation of fundamental hydro- and thermodynamic processes by a state-of-the art 3-D model with developed wetting and drying scheme and investigated the predictive potentials of its new and specific Aral Sea application. To demonstrate that the model is accurate we involved all available long-term observations which are time-series of water budget, salinity and 2-D data on ice extent. Despite our discussion was limited by lack of observations, it was shown that the potential capacity of this specific model application to predict a wide range of dynamical processes is at least as high as that of the original application of the sea-ice 3-D model used in pervious investigations of shelf seas.

Q. 2. Referee 3. Why do we need a full 3D model to reconstruct the Aral Sea shrinking?

In general, advantages of 3-D models in comparison with 1-D models (which also may be resolving vertical dynamics, air-sea exchange and empirical relations between area and water level) are well known and comprise high spatial-temporal resolution and a

GMDD

1, S92–S98, 2008

wider range of prognostic processes whose interplay allow for the non-linear spatial-temporal interactions and thereby provides more realistic predictions. In the Aral Sea, the dependence of both the local thermal regime and salinity on geographic latitude and depth and the importance of non-linear small scale processes, which particularly influence evaporation, were identified and discussed previously (Sirjacobs et al. 2004; Ginzburg et al., 2003). Furthermore, spatially resolved reconstructions provided by 3-D models are required to answer a number of research and water management questions, e.g. about the rule of the shrinking Aral Sea in local and regional climate, improvement of understanding of consequences of the water budget and salinization for groundwater and marine ecosystem and the development of effective environmental monitoring.

Furthermore, in terms of numerical modelling the implementation of a 3-D ice-hydrodynamics model with wetting and drying scheme is a challenge which we addressed in our contribution. The problems connected with modelling the hydrodynamics in the special environment of the Aral Sea became quite clear by the work published by Sirjacobs et al. (2004). Their state of the art 3-d hydrodynamic model does not allow for wetting and drying and hence continuous 3-D reconstructions and scientific contributions to the long-term water budget problematic were impossible for these authors. Technical and modelling challenges are enormous and require revision of the whole coding of a 3-D model. Such an implementation is still very advanced and yet only available for a terrain-following sigma-coordinate model (Oey et al., 2007) and not for a 3-D z-level model. The mass conservative implementation of a 3-D wetting and drying scheme in a similar robust test case like the Aral Sea has yet not be shown and is of special interest not only for the Aral Sea community but as well in climate research, allowing for a better consideration of lakes and shelf seas and their particular dynamics in the climate system.

Q. 3. Referee3. 3-D models may be useful to investigate distribution of 3-D fields, for which the present model should be an excellent choice, but the authors only showed 1

GMDD

1, S92–S98, 2008

plot with 2D distribution of ICE.

We do not agree with the way this statement was posed by the reviewer, leading to the conclusion that the focus on the integrated characteristics as it is done in the manuscript may cancel the usefulness of 3-D model itself for our study.

In the study, we aimed to develop an application of the 3-D model for the long-term simulation of the Aral Sea. Validation of the model performance is a necessary step in model development. We have mentioned (the manuscript: p. 247, lines 8-14) that the only available observations comprise the averaged time-series of water budget and salinity and 2-D data on ice extend. In our opinion, demonstrating the snapshots of the 3-D modeled fields alone is not relevant for the validation of the model long-term run.

However, because of the integrated time-series of the modeled sea level, evaporation, salinity and ice extend are on the one hand well compared with the observation and on the other hand they are well informative characteristics to prove the accuracy of the model we may state that the model application was successful. Thus, we may assume that the developed Aral Sea application of the 3-D model must simulate the standard model variables and thereby the complex and interrelated dynamic processes well.

Q.4. Referee1 and 3. Can a simpler model (budget model, "box-model" or a 1D vertical model) be used with the equal success for the specific Aral Sea situation?

Even if one concentrates only on the reconstruction of the Aral Sea salt and water budgets this 3-D model has clear advantages.

Simple budget models as well as 1-D models were used for the Aral Sea (see Conclusion, the manuscript:p.266, lines 11-15). The simple budget models allow estimating ranges of variability of the water and salt budget terms by closing the water balance; thus they do not deal with direct independent prediction of at least one of the balance terms. In these terms, the box-models or 1-D models may have the advantage to account for the air-sea exchange and independently predict evaporations. In comparison

GMDD

1, S92–S98, 2008

with these models, the advantages of a full 3-D model arise from accounting for spatial heterogeneous conditions. As it was already noted (see Q. 2.) the consideration of spatial resolution in the Aral Sea is important.

Furthermore, in the specific Aral Sea problem, another advantage of 3-D models is obvious. We refer to Benduhn and Renard (2004) who considered a box model applied for the Aral Sea. They explicitly stressed the challenge which cannot be solved by simple models. These models will fail to reproduce the water and salt budgets on the long-term scale because of the Aral Sea separates into independent water bodies. Only 3-D models with wetting and drying schemes may reproduce realistic variability and inclinations of the local sea surface level and thereby be able to resolve the water and salt exchange between the basins during the periods of their separations. In our manuscript, we have noted that the 3-D sea-ice model predicted the separation of the Aral Sea into two main bodies in time and there was a period of the re-connection during January 1989. The importance of the models ability for the accurate prediction of the Aral Sea dynamics after the separation 1991 was stressed in the text (the manuscript: p 262, lines 5-15).

Q. 5. Referee 1 and 3 Why are the 3-D modeled evaporation more accurate in comparison with other estimates. With all the uncertainties simpler budget type models may have sufficed? Would be a simpler non-spatial or 1-D resolving model which can treat the average heat and water exchange with the atmosphere, modified by observed sea ice fraction, sufficed.

We summarized the expert estimates of the Aral Sea water balance terms in Table 2. The following conclusions were drawn: (i) the uncertainties in estimations of each of the contributions to the water budget, i.e. precipitation, runoff and evaporation is relatively large and (ii) the uncertainties are particularly large for the evaporation. We note that the increase of uncertainties for evaporation resulted from the water budget type models used in the most of the studies and the evaporation were found as a closing parameter in the water balance. Obviously, the estimates need improvements.

GMDD

1, S92–S98, 2008

Estimates of evaporation involving advanced state-of-the art understanding of the physical processes require resolving the sea thermodynamics including the sea ice. If observational data with sufficient spatial and temporal resolution were available (which is a major problem for the Aral Sea) to be used as the necessary forcing (i.g. sea ice fraction), it is would be possible to achieve the better quality of these estimates from the simpler models. However, a different approach aiming in independent calculations of evaporation derived from atmospheric boundary conditions (available with higher resolution and accuracy from global atmospheric analysis projects) and the realistically resolved sea-ice thermodynamics seems very appropriate and necessary to us.

The discussions summarized above are in principle addressed already in the paper. However, since this remained unclear to both reviewers after reading our paper, we have to sharpen and strengthen our discussion and develop it as part of the objectives already in the Introduction and in the Conclusion.

Irina Alekseeva and Corinna Schrum

Bergen, 4.11.2008.

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GMDD

1, S92–S98, 2008

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