Interactive comment on “Seasonal variability of the Caspian Sea three-dimensional circulation, sea level and air-sea interaction” by R. A. Ibrayev et al.

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We thank the referee for his constructive comments (shown in “quotes”)

> “General Remarks: The paper is dealing with interesting aspects of the Caspian Sea circulation and sea level variations, and tries to disentangle also the relevance of the different external driving forces. In order to investigate this phenomenon, the three-dimensional circulation model MESH was employed, which has especially been developed for enclosed seas like the Caspian Sea.
>
> This paper provides a good general overview over the hydrodynamics and its variability in the Caspian Sea. Such a comprehensive overview has not been given before, but it is definitively needed. Therefore, the paper is certainly worth to be published.”

No response required

> “However, the paper has one major shortcoming, which has to be discussed in much more detail. The entire discussion in the paper is based only on a model simulation, which has been performed for one single year, i.e., 1982. This selection was justified, because 1982 was a year with a nearly balanced water budget. But is this the correct measure to select a representative year? Moreover, for some of the forcing parameters like river runoff, the authors already state that values have been exceptional in 1982. Thus, the representativeness of the simulation results is not clear. I even miss a discussion about this problem. At least the possible uncertainties due to investigation of only one single year must be presented.”

Technically, modeling of the seasonal cycle implies integration of the model equations for several years subject to periodic annual atmospheric and river forcing, based on the assumption that the solution does not have a long term trend. If a climatological steady state exists, this assumption is valid. For the Caspian Sea it is rather difficult to find a 30-year period with stable sea level, especially after the 1950-es, when corresponding atmospheric observations have become more abundant. It should be noted that the sea level response is an integrated function of the forcing and internal dynamics. Use of forcing with trend in water balance will mean that the yearly net sea level change will not be zero. Consequently, the simulation with an inaccurate forcing (possibly with an unrealistic trend) for about 10 years (otherwise sufficient for getting a quasi-periodic solution for the relatively small Caspian Sea) will result in a solution that diverges from reality. The means to escape this are either i) to artificially balance the water budget of the basin; or ii) to adjust solution so as to have zero mean sea level at the end of every model year. Both of these methods have drawbacks. We have therefore chosen to force the model with data corresponding to a period with nearly balanced water budget.

One of the choices resulting from our approach would have been to force the system with climatic atmospheric forcing. This would have the above stated disadvantage of having an unrealistic trend in it, reflected in the observed evolution in sea level after the 1950-es. The other choice, which has been adopted, is to simulate a single year in which the net sea level change between the first and the last day is minimal. Our analyses, based on a literature search and discussion with experts showed 1982 to be a candidate satisfying the above criteria within the 1979-1993 period, corresponding to the ERA15 atmospheric re-analysis data that has been used. 1982 had been a balanced year with respect to water budget while the Volga river run-off (222.3 km^3/yr), was at a medium range that is still larger than 11 other years in the 37-year period from 1961 till 1997.

Considering the general lack of understanding of the Caspian Sea circulation and sea level variability pointed in Introduction section of our paper, we directed our attention to a single year with balanced water budget so as to investigate dynamical linkages of the system, and to establish a good starting point for future investigations. The one-year simulation obviously will not answer all the questions with respect to the multi-decadal climatic oscillations of the system, especially at the present level of availability of observational data, but we hope further studies will be made of the inter-annual variability aspects. One of the questions in this respect is the role of the changing volume and surface area of the Caspian Sea, modifying its response characteristics as a function of sea-level. This important aspect can only be answered by including flooding/drying processes in the models.

In the revised version we will give a better discussion of our choice for simulating a single year and describe the technique for simulation of the seasonal cycle.

> "Overall, the paper will be suitable for publication after a moderate revision.
> Specific Comments:

> Page 1914, line 19: THE model successfully . . . .

Response: It is corrected.

> Page 1917, line 10: Please specify the recorded period.'

Response: It is corrected. The recorded period is 1900-1990.

> "Page 1917, line 18: Sentence: "The water budget depends on climate" must be clarified. It is mentioned that also anthropogenic effects such as water regulation schemes are of importance for the water budget. However, it is not clear whether these regulation schemes concern only the fresh water inflow into the Caspian Sea or also the water outflow is regulated. If the latter is true, it will not be possible to close the water budget just by accounting for the river runoff and evaporation minus precipitation. Possibly, the water regulation will dominate the entire system in this case."

Response: The main reason for sea level changes, observed throughout history, is the climate variability affecting the Caspian Sea basin. Anthropogenic factors such as the construction of water reservoirs on the Volga river after 1940-ies have caused changes in the water budget. As estimated by Rodionov, 1994, the mean rate of decline of the sea level in 1941-1977 is 3 cm/year. If anthropogenic activities are corrected for and only natural factors (i.e. runoff without water withdrawal) are considered, a sea level rise of about 1.5 cm/year is estimated. Part of the water budget of the Sea in addition to the main terms (river runoff + evaporation – precipitation) is the exchange with the Kara-Bogaz-Gol, a small interconnected basin on the arid eastern coast, which acts as an important sink in the water balance. Annual discharge in the 1900-1990 period has been about 10 km^3/yr, corresponding to a 3 cm/yr change in Caspian Sea level. Normally, the Caspian Sea level controls discharge into the Kara-Bogaz-Gol. However, as a remedy for strong sea level decline in late 70-ies, the outflow to Kara-Bogaz-Gol Bay has been blocked by a dam constructed in early 1980-ies.

> "Page 1919, line 21: We use THE kinematic boundary . . .. . ."

Response: It is corrected.

> Page 1920, line 10: we use THE free-surface . . ..

Response: It is corrected.

> Page 1925, line 10: The northern part of the model domain looks extremely shallow. What is about drying and flooding in this area? As far as I understood, such an algorithm has not been implemented.

Response: This is a valid point. The sea level changes result in flooding and drying of flat land surrounding the Northern Caspian Basin, which is an important factor contolling air-sea exchange and therefore modifying its climate response. In this paper we have fixed our attention to intra-annual variability of the sea level and air-sea interaction. Seasonal changes in water masses normally result in sea level variations of about 0.25 m, corresponding to about 1.3% change in the sea surface area, neglected in the present study. The change in sea surface area is an important factor in stabilizing sea level variations on inter-annual timescales. For example, a 2 m rise in sea level would result in 10% increase in sea surface area, giving rise to increased evaporation, which would then have a feedback on sea level response. In continuing studies of inter-annual variability aspects, we plan to use flooding and drying algorithms to answer these questions.

> Page 1926, line 4: The employment of ERA15 data is very questionable. Due to the coarseness of this data set, probably only 3 X 5 = 15 ERA grid cells could be used for the Caspian Sea and I would assume that this number is even reduced when using a land sea mask. This problem should be discussed in particular since the Caspian Sea shows extremely high spatial gradients for the different meteorological parameters.

Response: It is generally problematic to obtain atmospheric forcing with sufficient resolution for a relatively small area like the Caspian Sea.

Data and analyses on hydro-meteorological conditions in the Caspian Sea region are available in the Russian literature, although the data are often not on regular time-space grid. Especially standing out among these sources is the 'Complex hydro-meteorological Atlas of the Caspian and Aral Seas' edited by Samoilenko and Sachkova, 1963, including charts of monthly mean air-sea fluxes. As many later publications have done, we have accepted this Atlas as a key reference. Yet, because of the need to assess synoptic and inter-annual variability of the Caspian Sea, digital data produced by NCEP/NCAR and ECMWF re-analysis projects, continuously covering several decades at regular grids of 1.875° and 1.125° deg respectively, were found to be more suitable. Comparison with climatologic analyses of Samoilenko and Sachkova (1963) showed that the NCEP/NCAR were far from climatic charts, while the ECMWF ERA15 data were very close. Although the resolution of the atmospheric data (only 11 cells) was not very good, the better agreement of wind fields and air-sea fluxes with climatology, both in geographical and seasonal distribution, and similar comparisons for the adjacent Black Sea convinced us that the ERA15 data would be the best choice.

Page 1927, line 1-21: The use of monthly mean wind fields is extremely questionable, since it is known that short-term variability has a significant influence in particular on the depth of the thermocline. I cannot see any argument, why the authors should not make use of the available 6-hourly values.

Response: We would agree with the reviewer on this comment. At the beginning of our study, we were faced with the dilemma of what time scale to be investigated. The reason for using monthly average forcing in this paper was in fact a choice we had to make. Considering that our contribution to Caspian Sea modeling is a first attempt at a time with general lack of understanding of its circulation, we persisted to go forward with this first step, where we addressed the basic thermodynamics of the Sea at minimal complication. Meso-scale variability resulting from synoptic scale atmospheric forcing would have 'contaminated' the solution in a model, which was not eddy-resolving in the first place. Meso-scale dynamics under synoptic atmospheric forcing will be addressed in work under way towards a new paper.

Page 1929, line 7: Please explain why there was no outflow to the Kara-Bogaz-Gol Bay in 1982. What stopped evaporation in this bay? On page 1929, line 4 it is stated that this bay is an important sink for the water balance. This would mean 1982 is extremely exceptional.

Response: After the dramatic drop in sea level in the late 70-ies, a government decision was applied to block outflow to Kara-Bogaz-Gol to remedy water loss. As often happens, real work on constructing the dam was delayed and only started in a period when sea level actually start to rise. The dam was in place from 1980 till 1984, and was opened later. Only in 1992 the natural discharge of the Caspian Sea water into the Bay was restored. In 1982, there was no outflow to Bay.

Page 1930, line 4: of THE surface circulation ....

Response: It is corrected.

Page 1932, line 26: . . . at first APPEAR totally . . .

Response: It is corrected.

Page 1935, line 1: Please use SI units for salinity.

Response: It is corrected.

Page 1936, line 14: Please at least present a hypothesis, why Panin's estimates are much higher in the southern part of the SCB.

Response: It's hard to say definitely why in June-August in the southern part of the SCB our model gives 75-100 mm/month evaporation rate, while Panin, 1987 estimates show 180 mm/month. The reason can be due to (i) the need for better space-time resolution of atmospheric dynamics especially in Southern Caspian Basin, where the sea is surrounded from the west and south by mountains and from east by flat deserts. The reviewer's comments on why we have used the coarse ERA15 data are appropriate here; (ii) the fact that we simulate a single year while Panin gives climatology; (iii) estimates of climatological fluxes are usually (and the Caspian Sea is not an exception) based on ship data which are rather non-uniform in space and time.

Page 1937, line 18: The statement that the good agreement between the observed and simulated sea level indicates the capability of the model to simulate the hydro- and thermo-dynamic processes correctly is questionable. If one specifies the river-runoff and precipitation and, moreover, tunes the radiation flux like the authors did, a simple box model would also be able to produce satisfactory results with respect to the sea level variations.

Response: Surely, a simple box model can give satisfactory sea level variations if one had reliable flux data or tuned the forcing. In this study we try to develop comprehensive physical model, including not only the sea level dynamics, but also the 3-d circulation dynamics, and try to establish linkages between the circulation, thermohaline fields, air-sea fluxes, as well as the sea level. The tuning of the solar radiation flux is justified by at least three points: (i) differences of ERA15 solar radiation fluxes from climatology; (ii) closeness of the sea surface temperature field with climatology when the flux was corrected, and (iii) good correlation in terms of amplitude and phase between simulated and observed sea level.

Page 1939, line 17: Please make clear what is meant by ECMWF estimated and observed sea level changes. Also Table 2 is unclear.

Response: Here, as well as in Table 2, we compare sea level increment estimated for 1982 based on observed river runoff together with ERA15 precipitation - evaporation with that obtained from the model solution. In the model we have found the annual increment to be +7.0 cm, while the estimate based on river runoff observation and ERA15 data is –2.2 cm. We also would like to state that sea level increment averaged over the four coastal stations gives a value of +6.75 cm.

Page 1940, line 18: How realistic is the 50% reduction of the river runoff? Please give an estimate how often such an event occurs.

Response: As we wrote in the introduction, annual average river runoff is~$3x10^{11}$ m^3 yr^{-1} within a range of $2.0\text{-}4.5x10^{11}$ m^3 yr^{-1} during the recorded period (1900-1990). Therefore, a 50% increase in river runoff in quite realistic. We have used an annual value of 222.3 km^3/year for the Volga river runoff. According to the hydrometeorology service data for 1961-1997 period, close to a 50% increase, i.e. runoff value of 318 km^3/year has been observed in 1979, as well as later in 1990 (318 km^3), 1991 (321 km^3), 1994 (339 km^3).

Page 1940, line 19: The major focus of the sensitivity study is put on the consequences for the sea level. However, in some cases it is obvious that the heat content or the circulation would react much more towards the induced changes. Thus, I would strongly recommend the calculation of changes of the total heat content and of transport rates through specific sections.

Response: These (sensitivity) experiments is included to estimate the sensitivity of the sea level to variations of external forcing. It is interesting to study in details the reaction of the Sea, but it would make the contents of another paper. We thank the reviewer for his recommendation. We plan to study more carefully these aspects in continuing studies of inter-annual variability.

Page 1941, line 21: . . ... in A more unstable . . ..

Response: It is corrected.

Page 1942, line 18: . . . to THE parameterization . . ..

Response: It is corrected.

Page 1943, line 4: From the values presented, the balance between sensible and latent heat flux has not changed very much. Please clarify this point.

Response: That is really the case. In control run ratio of sensible/latent heat flux in November equal to ~0.30, while in experiment #7 with absorption of solar radiation at the sea surface equal to ~0.26. We expect that the difference will be larger. It means that in exper.#7 heat flux downward through vertical mixing compensate the solar penetration in CR. Possible reason is that vertical grid it the model is not fine enough to reproduce strong temperature gradients in upper layer.

Page 1944, line 11: . . ... shows A persistent northward . . ..

Response: It is corrected.

Table 2: Please clarify what is meant by ECMWF data and observations presented in the last line.

Response: We talk about it earlier, in response to Comments to Page 1939, line 17.