MODELING OF HYDROPHYSICAL PROCESSES IN THE ARAL SEA*

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Изменения, произошедшие в Аральском море за последние 40 лет, являются одним из наиболее ярких примеров возможных экологических изменений, вызванных человеческой деятельностью. Рассмотрению возможных вариантов стабилизации и восстановления гидрологической и экологической обстановки Аральского моря посвящен проект ИНТАС REBASOWS, в рамках которого выполнялись данные исследования. Настоящая работа посвящена обсуждению результатов численного моделирования по возможным сценариям сохранения и реабилитации частей Аральского моря на основе трехмерной модели ИВМиМГ СО РАН.

Introduction

The problem of the Aral Sea is an example of ecological hazards caused by the human activity. In the 1960-s, the intensive use of water from the Amu-Darya and the Syr-Darya for irrigation changed the water balance in the Aral Sea resulting in the excess the evaporation over the precipitation and the river runoff. In 1989, this caused separation of the Northern and the Central Aral basins, and in 2000, the connection of the Lazarev, the Vozrojdenija islands with the mainland and the formation of a single Peninsula separating the Western (deep) and the Eastern (shallow) basins with connection only in the Northern part. As a result, the Aral Sea level height decreased from 53 m to 29 m (in the Baltic system), has lost more than 80 % of water volume and more than 60 % of the sea surface. The salinity increased from 10 to 140 g/l. The ecological and social consequences are very dramatic. This work is done under the support of the INTAS Grant 01-0511-REBASOWS. Objectives of the research are as follows: forecasting the future Aral Sea water and salt balance under different scenarios of the water inflow to the Aral coastal zone; definition of a sustainable ecological profile of a closed water body and selection of a strategy of a possible ecosystem, biodiversity and bioproductivity restoration in a part of the Aral Sea.

Possible ways for rehabilitation of the Aral Sea are as follows:

— reducing up to 70 % of the Amu-Darya water for irrigation, which would increase the Aral Sea level up to 38.5 m. This scenario is unrealistic because of the impossibility to exclude this amount of the water from the human use;

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— separation of the Western and Eastern parts and keeping only one of them with 20–35 % reduction of water for irrigation.

In this paper, some results of the numerical modeling of the Aral Sea Circulation, temperature distribution as well as demineralization during a high-water period are presented. The 3D ICM&MG circulation model was used in the numerical experiments.

1. The description of the model and the data

1.1. A 3D hydrodynamic model of hydrophysical processes in the Aral Sea

The circulation model of the Aral Sea circulation model was created in the Laboratory of Mathematical Modeling of the Hydrosphere ICM&MG SD RAS [1–3].

The general features of the models are as follows:

— mathematical model is based on the complete "primitive" nonlinear equations of the thermo-hydrodynamics of the ocean;

— temperature and salinity distributions are calculated;

— the model has a possibility to include the calculation of the pollutants;

— the interaction with the atmosphere is realized via the upper mixed layer with the possibility to include the ice formation;

— the model has a possibility to include the inflows and outflows from the basin;

— the models are based on a combination of the finite element and the splitting methods.

1.2. The INPUT and the OUTPUT of the model

The INPUT of the model is as follows

At the sea surface:

— wind-stress calculated by the wind at 2 m height;

— temperature, salinity (fresh water) fluxes;

— at the inflow lateral boundaries:

— fresh water mass flux (the river inflow);

— temperature and salinity prescribed.

Initial state: temperature, salinity climatic 3D distribution.

The OUTPUT of the model:

— 3D velocity field;

— temperature and salinity fields in the seasonal cycle.

Data sources:

— meteorological data for the calculations of the temperature and salinity fluxes;

— the Amu-Darya river runoff;

— The NCEP/NCAR reanalysis wind for the wind-stress calculation;

— the climatic wind from measurements in the hydro-meteorological stations in the Aral Sea region.

2. Numerical experiments and analysis of the results

The Aral Sea domain for the calculation of the 3D currents, thermodynamics as well as spreading of the fresh water is constructed on the basis of the bottom topography. The level of 29 m is set as the initial value for the determination of the basin area. The bottom topography is presented in Fig. 1.

The numerical model has 1000×1000 m horizontal grid resolution. By the vertical, the non-uniform grid is used (35 levels for a maximum depth). In the regions with a minimum depth of 2 m, five levels are included.

2.1. The first experiment

At the first stage of the numerical experiment, the Aral Sea basin was taken in a total configuration with the narrow straight between the Eastern and the Western parts. The Amu-Darya river inflow was directed to the Eastern part.

At the initial stage the constant values of the temperature (25 °C) and salinity (68 g/l) corresponding to the summer season were set in the whole basin. The integration of the model was carried out during the period of two years with the wind-stress produced from the NCEP/NCAR wind. On each step, the following 3D hydrophysical fields were calculated: temperature, salinity, velocity and fresh water as a tracer.

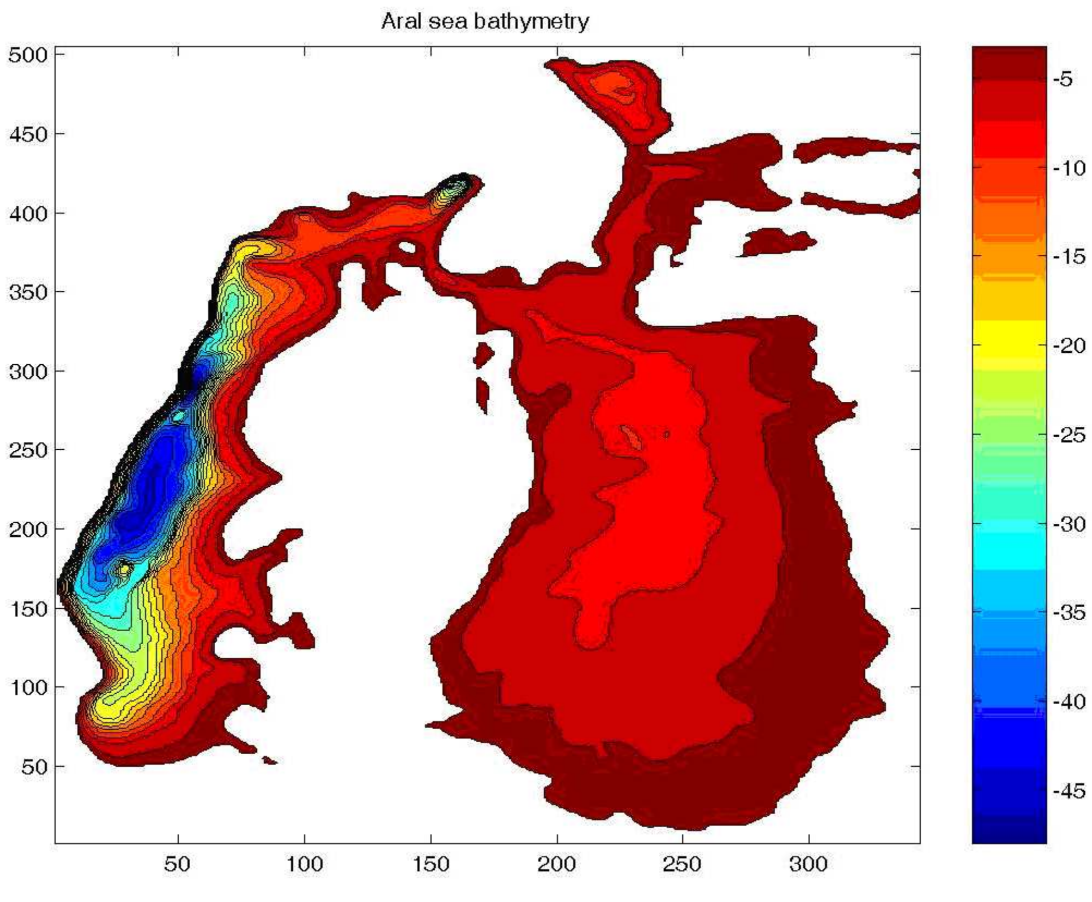

Fig. 1. The levels of height (Baltic system) for Aral Sea basin in meters.

The results of the numerical experiment allow us to obtain some specific features of the Aral Sea circulation, thermodynamics and fresh water spreading.

The circulation

The circulation in the Aral Sea basin is highly varying, and although there are no strongly dominating pictures of the main circulation, it is possible to distinguish some specific features. First, the circulation is very sensitive to the wind and is mainly derived by the wind, except a short period of the ice covering the sea surface. The circulation variations during the seasons of the integration period may roughly be described in the following way. The Eastern part is very shallow and has the fast feedback to the wind change. A wide area of the Eastern part allows a well-manifested anticyclonic or cyclonic circulation to be formed. The transition period between them is characterized by the dipole circulation. In the summer period, in the Eastern part, there was a cyclonic circulation The velocity value attains 30 cm/s. During the winter period the circulation is mainly anticyclonic. When the wind is blocked by the ice cover, this circulation is weakening until the ice cover disappears. In spring, the reconstruction of the circulation in some periods leads to a sufficiently chaotic circulation, becoming stable enough by May.

The Western basin is narrower and deeper. So, the circulation consists of more local gyres, but the feedback to the wind change is slower than the one of the Eastern basin. The circulation

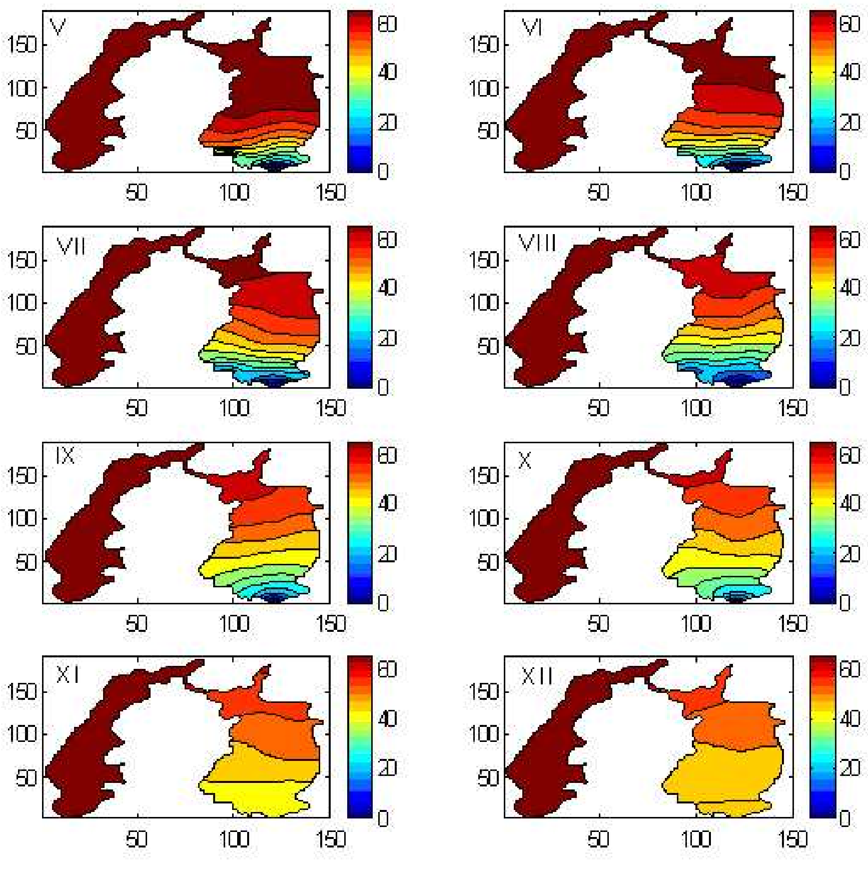

Fig. 2. The salinity field at depth 2 m during the period of V–IX 1998 — a high Amu-Darya inflow and X–XII 1998 — a low inflow.

in the Western basin is cyclonic in the South and anticyclonic in the North. There also exist some local circulations caused by the bottom topography and the basin configuration.

The thermodynamics

The seasonal variations of the Aral Sea are influenced by the seasonal cycle, but the processes of the seasonal variations in the Western and the Eastern parts are different. In the Eastern part, the temperature is determined by the heating and cooling processes on the surface and the mixing by wind. This brings about a homogeneous distribution of temperature in the Eastern part within the range from 27 to 0 °C. In contrast to this, the result of the calculations shows that the thermal conditions of the Western part of the Aral Sea, determined by a seasonal cycle are divided into two main states: summer stratification and winter homothermy. The summer distribution has the temperature stratification of about 20 degrees, with a strong thermocline. The horizontal distribution is characterized by the lower temperature values in the western deep part and higher values in the eastern part. Cooling in the autumn and the winter seasons results in the density convection and the homothermy.

The salinity distribution and the fresh water propagation

The salinity conditions during the integration period are defined by the Amu-Darya inflow during May-September, 1998. In this period, the river inflow was extremely high. The pictures present the propagation of the fresh water through the Eastern basin. In Fig. 2, the horizontal salinity distribution during the period of the refreshing are presented. After the river inflow stops, the horizontal distribution becomes nearly uniform, but the salinity is lower than that at the initial moment. One can see a well-manifested movement of the low saline water from South to North. The pool of the freshened water has a tendency to turn to the East under the influence of the circulation (Fig. 3). The fresh water reaches a narrow straight between the Eastern and the Western parts of the basins and propagates to the Northern part of the

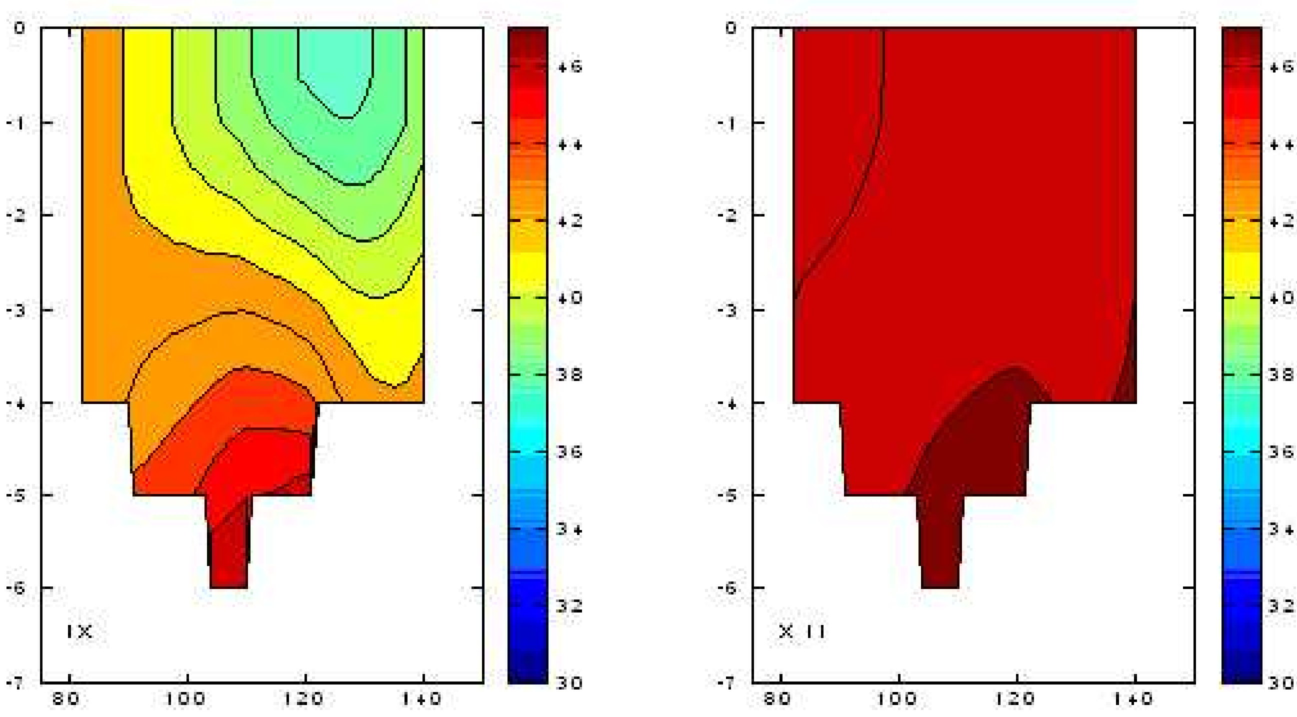

Fig. 3. Latitudinal salinity cross-section for June, December 1998.

Western basin. The disadvantages of this scenario is that after decreasing of the water inflow the salinity become increase rapidly because of the intensive evaporation from the wide surface area of the Eastern basin.

2.2. The second experiment

At the second stage of the numerical experiment, the Aral Sea basin was taken in a configuration with a dam between the Eastern and the Western parts. The Amu-Darya river runoff was directed to the Western part as compared to the first experiment.

The circulation is also derived mainly by the wind-stress and influenced by the bottom topography and configuration of the basin and is very similar to that of the first experiment.

As it was mentioned above, the Western basin is narrower and deeper than the Eastern one. This leads to some spesific features during the refreshing of the Western basin. The fresh water propagates from South and after the period of integration comes to the North of the basin. In this case the spreading of the fresh water is restricted by the dam and does not come to the Eastern basin. The salinity distribution is presented in Fig. 4. The vertical cross-section along the longitude from the river inflow up to the coast is presented in Fig. 5. One can see that the fresh water comes near the surface. After the homogenisation of the temperature and salinity in the wintertime, the refreshened water distribution became uniform. As a result, after the one and a half year, the mean value of the salinity decreased to the value of 100 g/l. The total

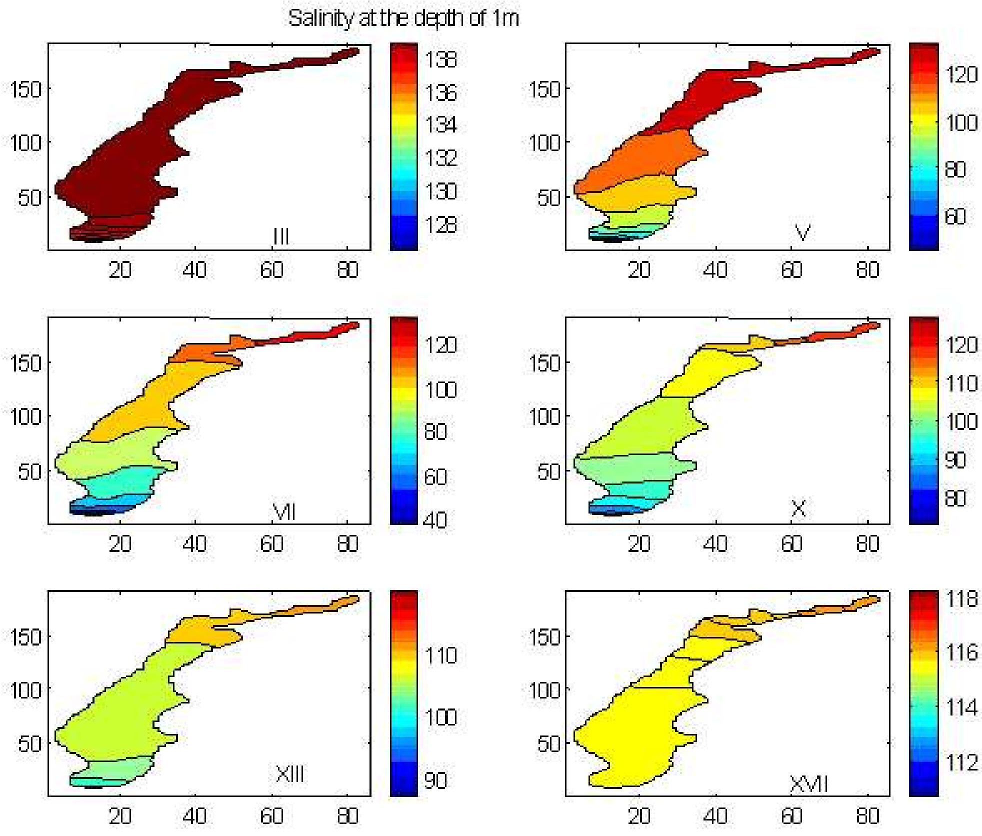

Fig. 4. Salinity distribution at a depth of 2 m for March, May, July, October, January, May. By the axis, the numbers of the grid points are presented.

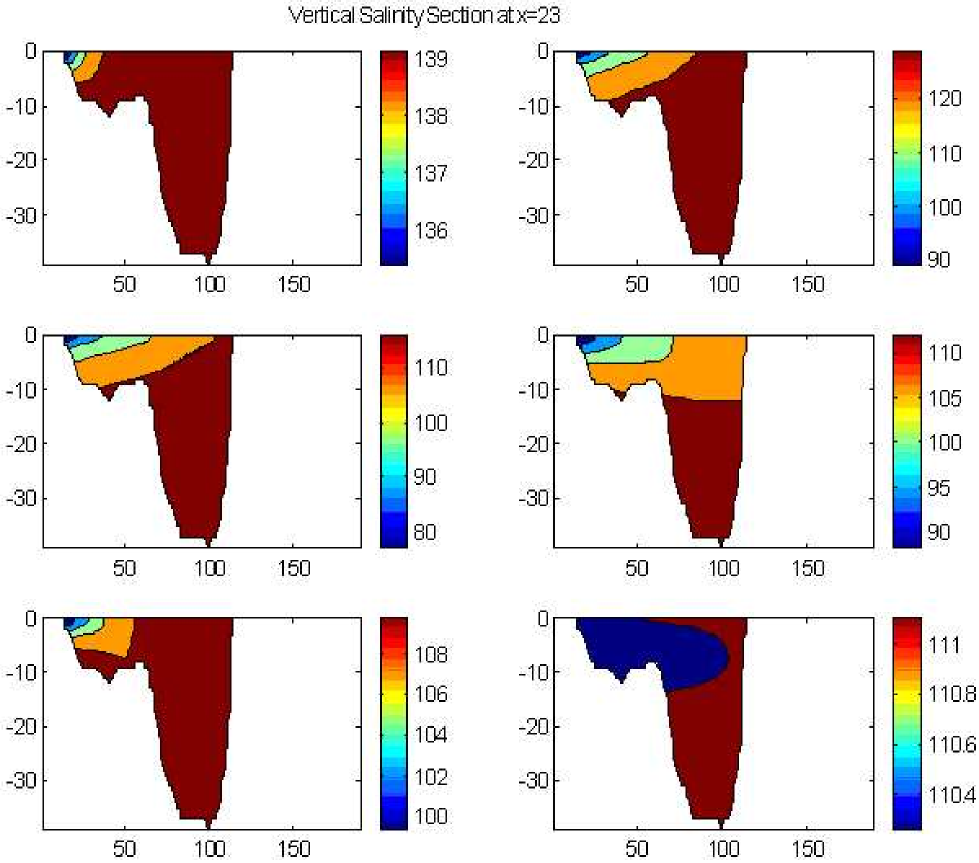

Fig. 5. Meridional distribution of the salinity during March, May, July, October, January, May. The vertical cross-section comes from the river inflow in the South of the basin. The vertical axis represent the depth in meters.

evaporation from the surface of the Western part area is much smaller then from the Eastern part, because of the much smaller surface area. The result of this fact is that after decreasing the fresh water inflow to the Western basin the increasing the salinity will come very slowly.

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