# Hydrophysical processes of the Aral sea desiccation: historical data and numerical modelling

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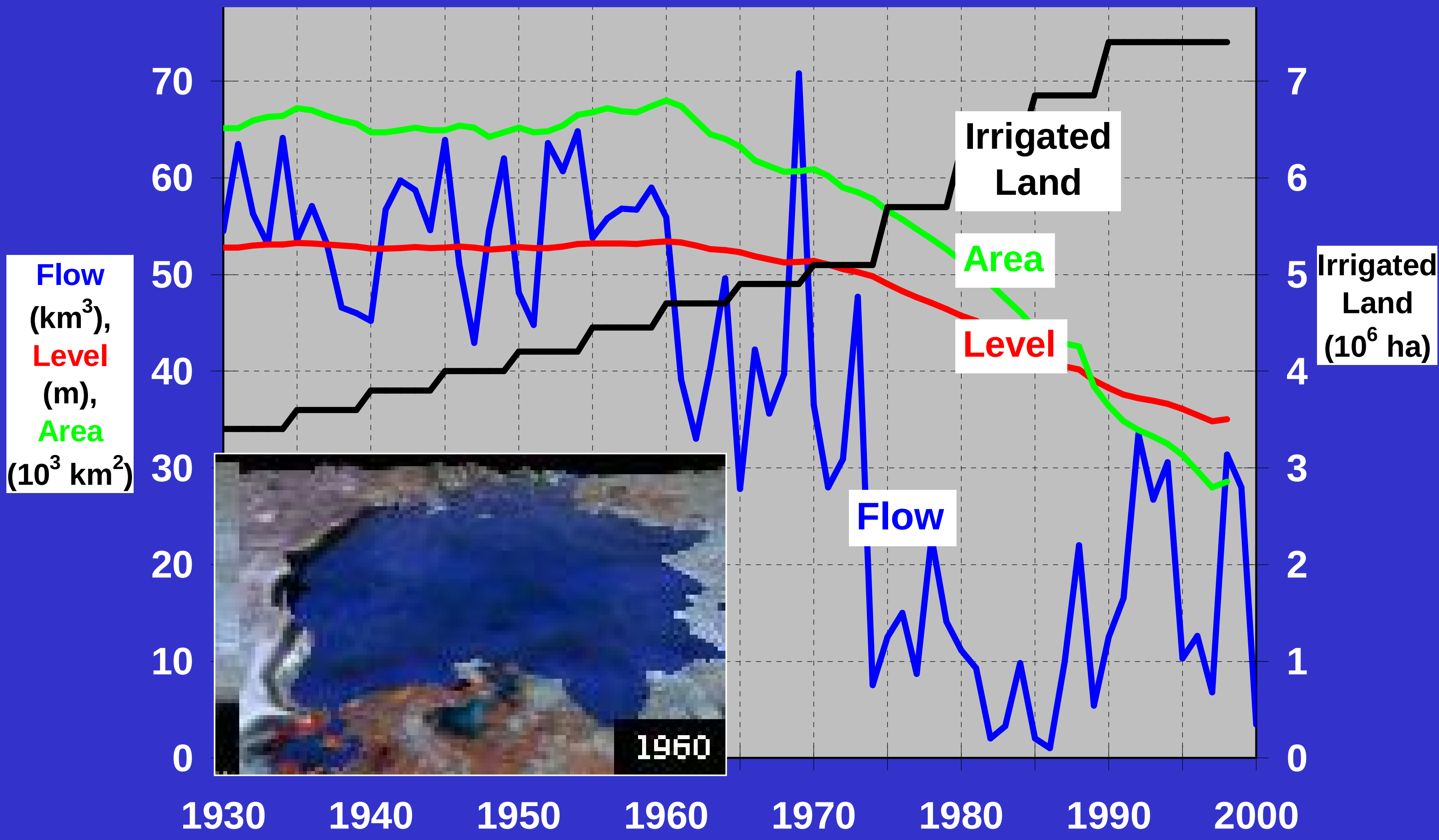
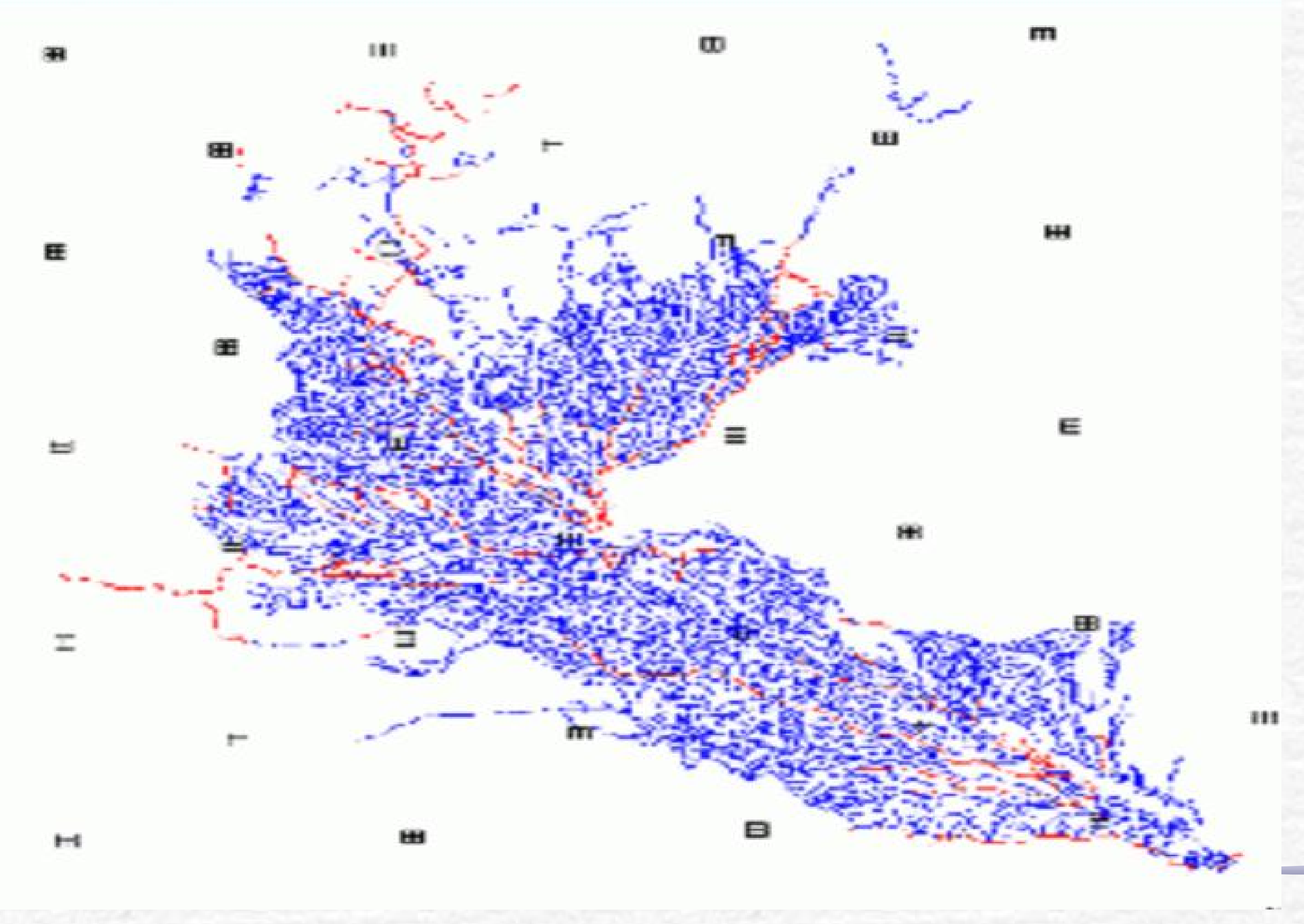
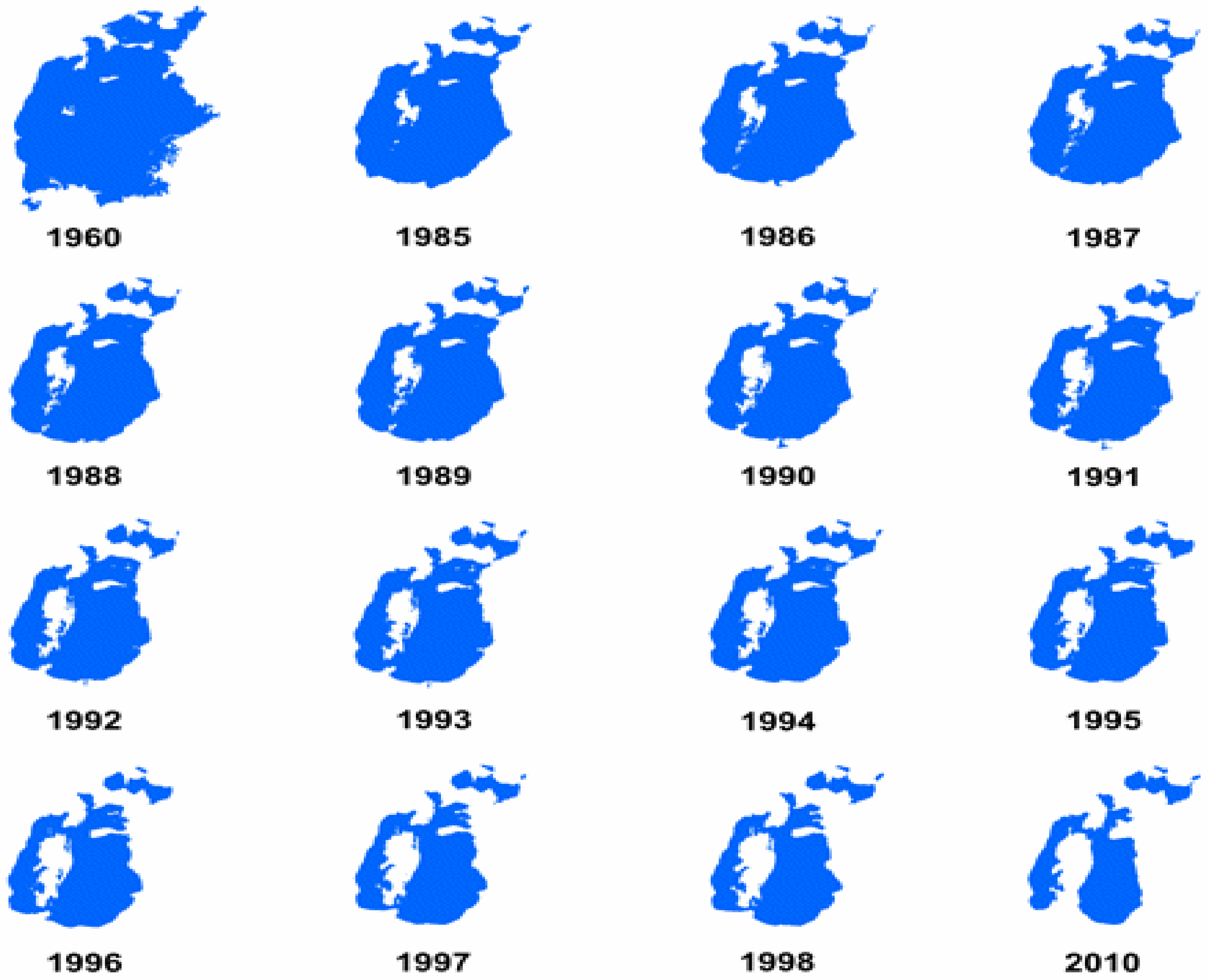
# Aral Sea Basin XX Cent.



# Irrigation net of the Amu Dar'ja (8000 channels & collectors)

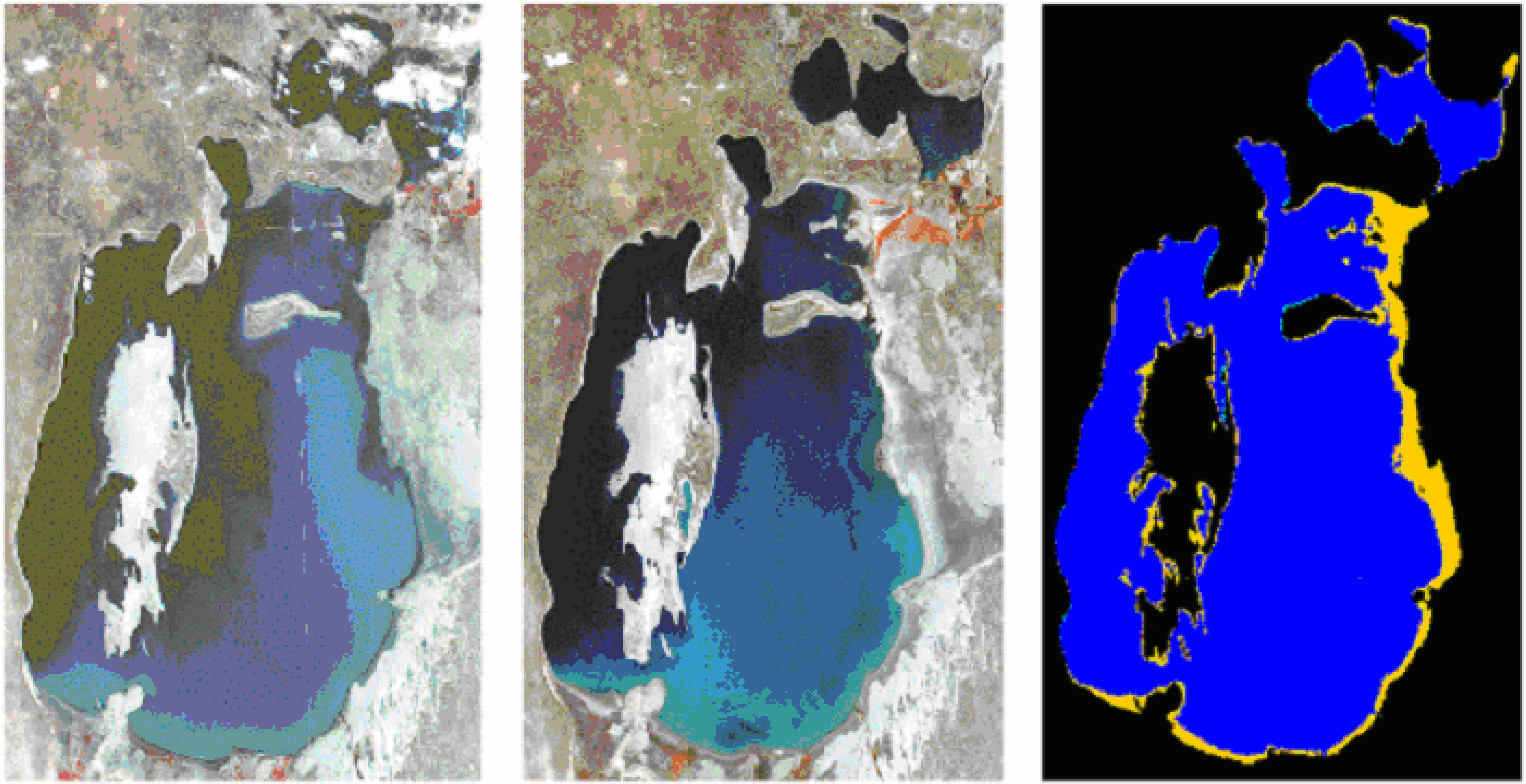


# Chronology of the desiccation of the Aral Sea (NOAA product)



# The desiccation of the Aral sea from 1995 to 1996
( Resurs-01, 1995, from Aral Sea site)

**1995** **1996** **Difference**



**Main events:**

- 1960 - intensification of the Amu Darja, Syr Darja water use for irrigation purposes
- 1989 - separation of the Northern and Central Aral basins
- 2000 - connection of the Lazarev, Vozrogdenija islands with mainland and formation of single Peninsula which separate the Western (deep) and Eastern (shallow) basins with connection only in the northern part

**Resulting:**

- Aral sea level height decreased from 53 m to 26 m (Baltic system);
- Aral Sea lost 70% of water volume;
- 80% of sea surface;
- salinity increased from 10 to 140g/l.

**Possible Ways for rehabilitation of the Aral Sea:**

**- Separation of the Western and Eastern parts and keep only one of them with reducing 30-40% water for irrigation.**

# Consequences of the Aral Sea desiccation

| **Climatic consequences** | **Ecological / economic consequences** | **Health consequences** |
|---|---|---|
| Mesoclimatic changes (increase of continentality) | Degeneration of the delta ecosystems | Increase of serious diseases( e.g. cholera, typhus, gastritis, blood cancer) |
| Increase of salt and dust storms 2 mln t/y | Total collapse of the fishing industry (originally 44 th. t/y) | Increase of respiratory system diseases (asthma, bronchitis) |
| Shortening of the vegetation period | Decrease of productivity of agricultural fields | Birth defects and high infant mortality |

PROJECT: REBASOWS, INTAS 01-0511

# The rehabilitation of ecosystem and bioproductivity of part water body of the Aral Sea under conditions of water scarcity

- Research Goal:
- Forecast of the future Aral Sea water and salt balance under different scenarios of water inflow to the Aral coastal zone;
- Definition of sustainable ecological profile of close water body and selection of the strategy of possible ecosystem, biodiversity and bioproductivity restoration in the part of the Aral Sea
- Teams:
- Austria (2), Uzbekistan (2), Russia (1)

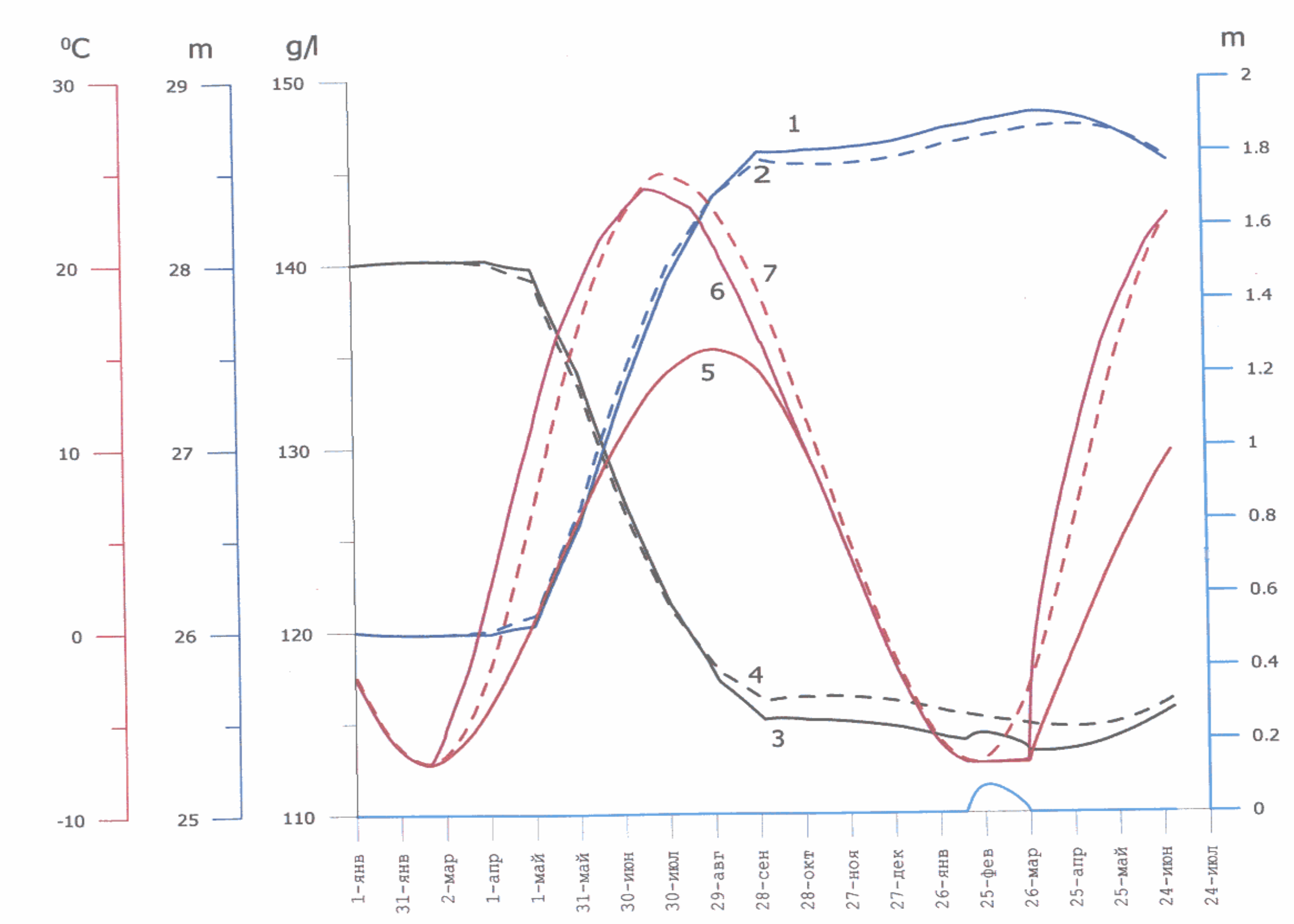
## Types of models which was used

- Integral Aral Sea models (0 dimensional models on the basis of the conservation lows for mass and salt)
- One dimensional model integrated by the area of the basin (z-coordinate)
- Tree dimensional thermo-hydrodynamic model

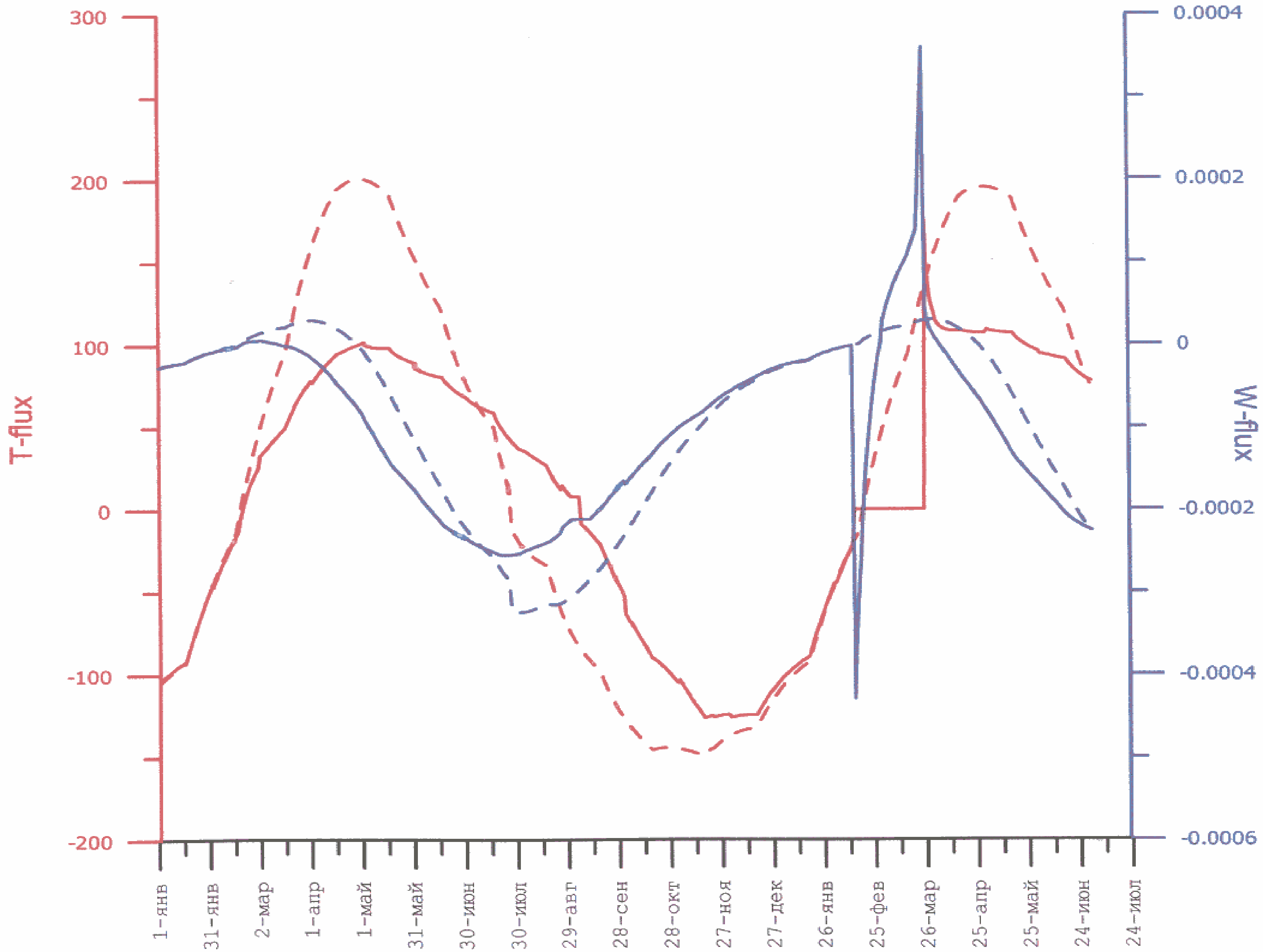
## 0-D model of water balance, salt balance and ice-thermal conditions of the Aral Sea includes:

- **Submodel of water balance**, taking into account evaporation (depending on water temperature and atmospheric conditions), discharge of tributaries, precipitation and water exchange with ice-snow cover.
- **Submodel of thermal balance**, taking into account heat exchange through water free surface or ice-snow cover, heat income with water of tributaries, precipitates, evaporating water and by water exchange with ice-snow cover.
- **Submodel of salt balance** is based on mass balance of chloride-ion and empirical dependence of salinity of chlorinity. Income on chorine-ions with water of tributaries and its loss with water remaining in bottom asperities of drained area.
- **Submodels of ice and snow cover**

# Results of modelling by the 0D and 1D models during 1.5 year period
# 1,2-sea level, 3,4-averaged salinity, 5,7-averaged temperature, 6- averaged temperature



# Fluxes calculated by the 0D and 1d models



## General features of the 3D models are as follows:

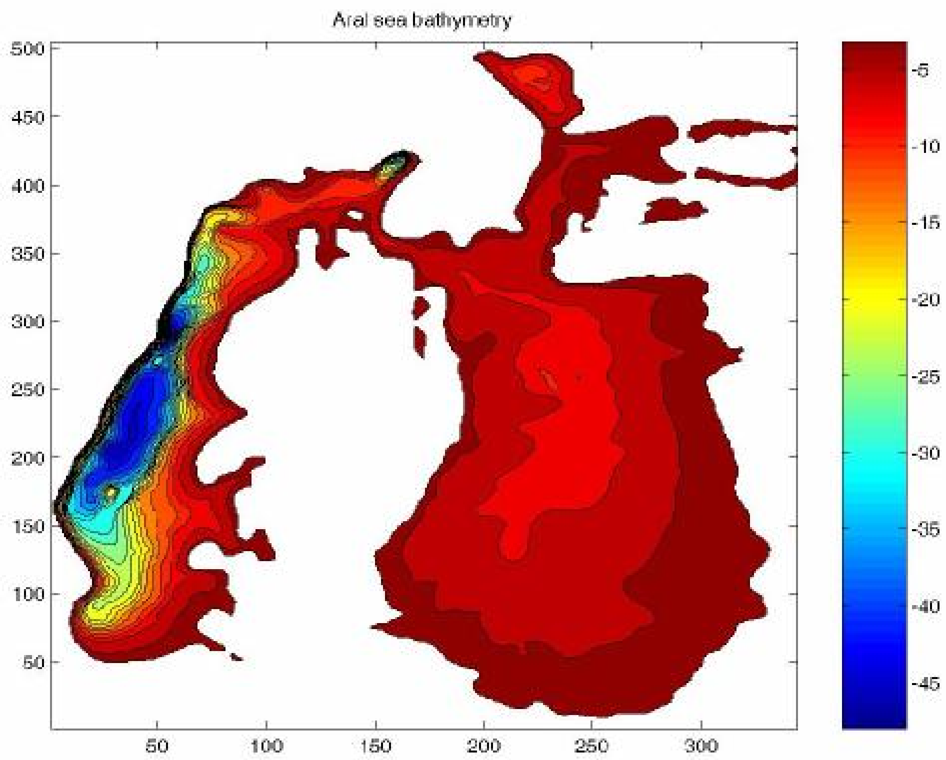
- Mathematical model is based on the complete "primitive" nonlinear equations of the thermo-hydrodynamics of the ocean;
- Temperature and salinity distributions are calculated;
- The models have a possibility to include the calculation of pollutants;
- The interaction with the atmosphere is realized via the upper mixed layer with the possibility to include the ice formation;
- The models have a possibility to include inflows and outflows from the basin;
- The models are based on a combination of the finite element and splitting methods;
- The triangulated quasi-regular B-grid is used in the models, which enables one to easily change the configuration of basin;
- The models differ in the method of the vertical levels distribution: the sigma-coordinate model and the z-coordinate model.

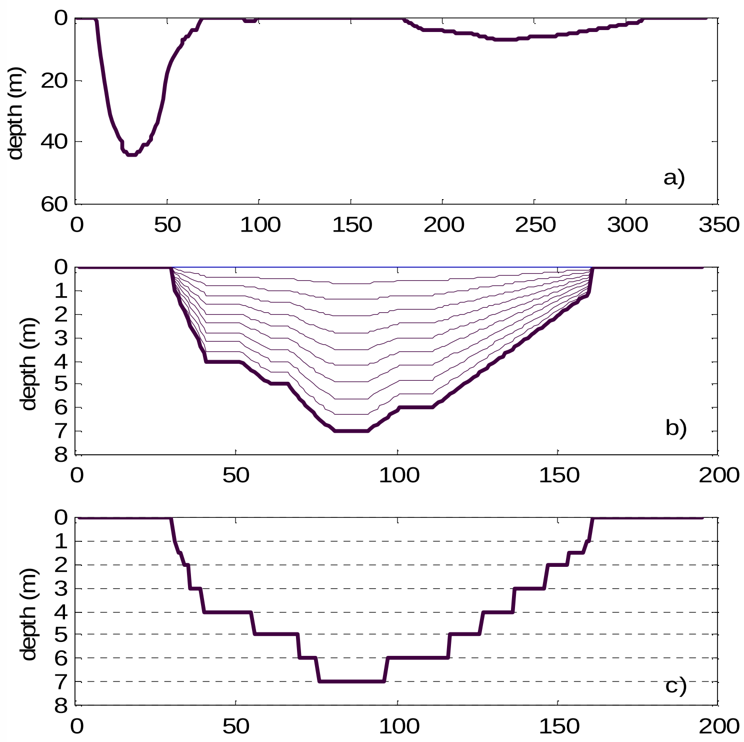
Left: The levels of height (Baltic system) for Aral Sea basin in meters.

Right: a) The vertical cross-section of Aral Sea alone latitude;

в) Schematic representation of the sigma-coordinate grid;

c) Schematic representation of the z-grid.



# Numerical experiments description

The first experiment

At the first stage of the numerical experiment the Aral Sea basin was taken in a total configuration without damn between the Eastern and the Western parts. The Amy-Darya river runoff was directed to the Eastern part.

The integration of the model was carried out during the period of about two years with the wind-stress produced from the NCEP/NCAR wind. The Amu-Darya runoff was taken from the estimates of the hydrologists. The initial salinity was taken 60 g/l (1998). The ice sea model includes only the thermodynamic part without dynamics, reology and drift of ice.

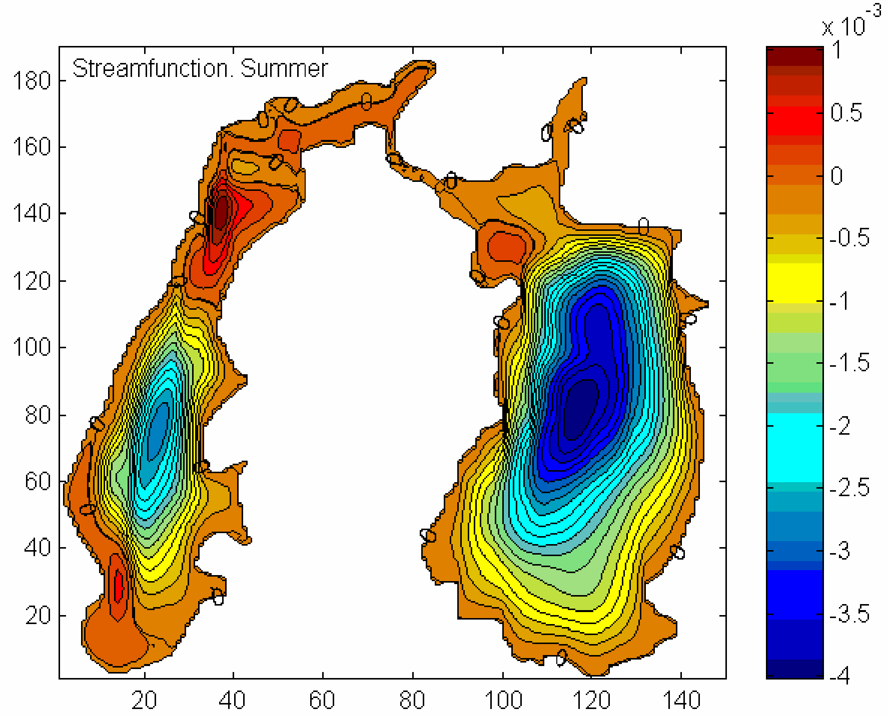
On each step, the following 3D hydrophysical fields were calculated: temperature, salinity, velocity.

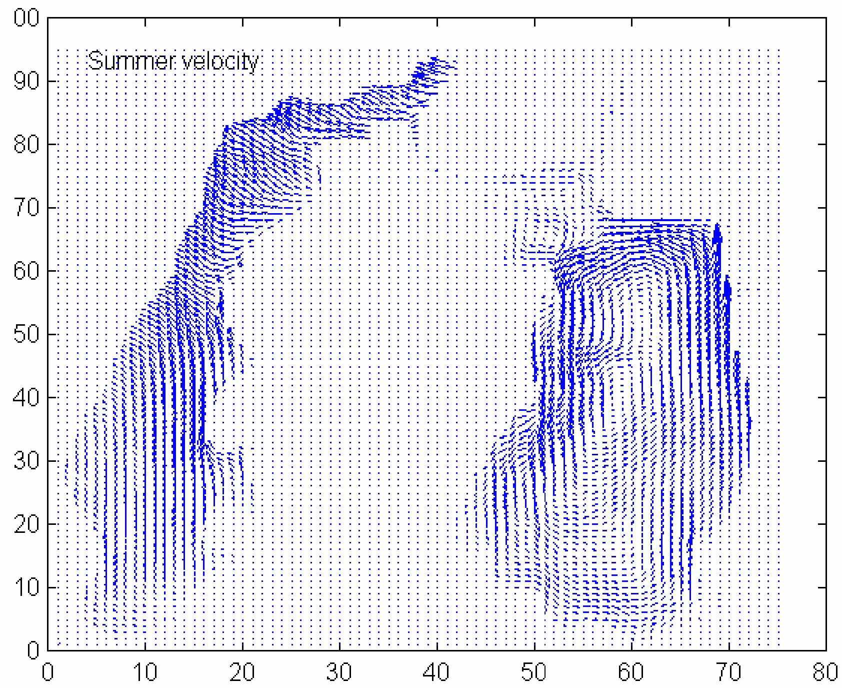
The results of the numerical experiment allow as obtaining some specific features of the Aral Sea circulation, thermodynamics and fresh water spreading.

# The circulation

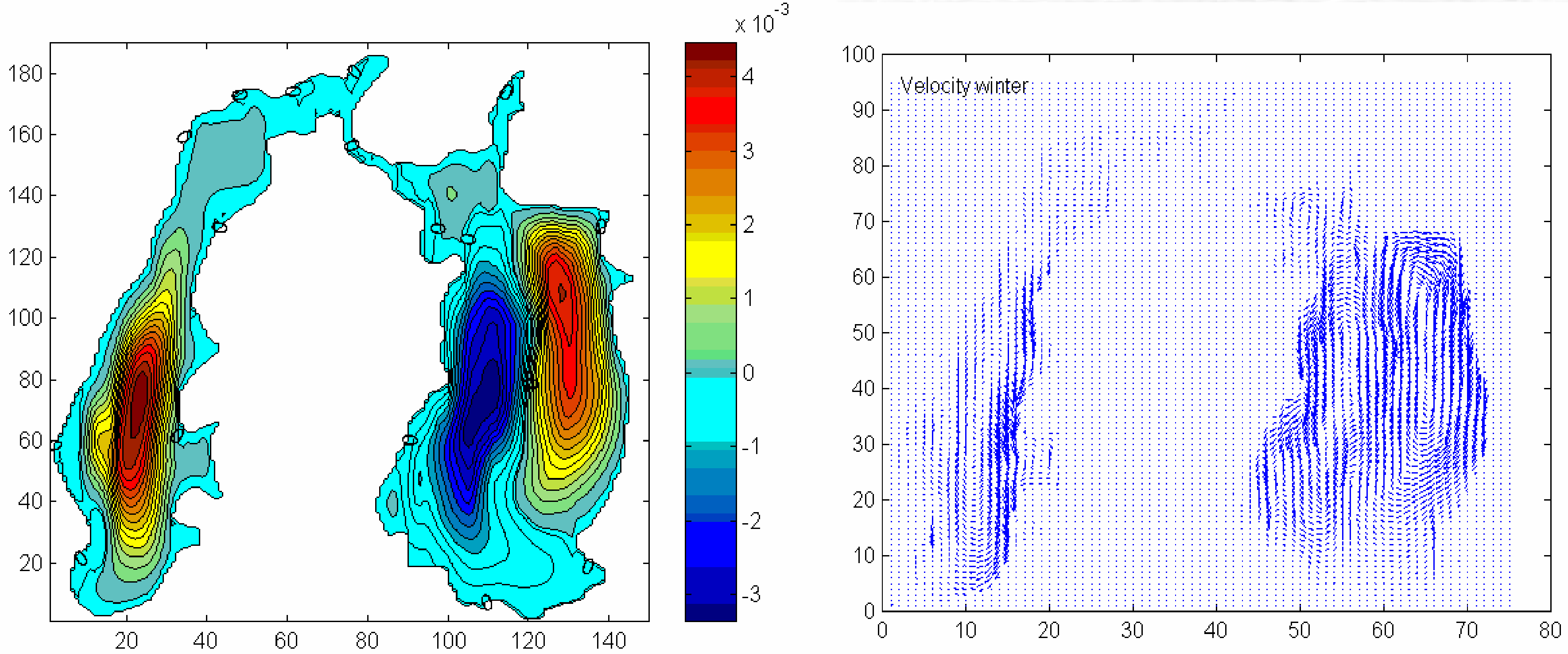
The circulation in the Aral Sea basin is highly varying and although there are no strongly dominated picturers of the main circulation, it is possible to separate some specific features. First, the circulation is very sensitive to the wind and is mainly derived by the wind, except a short period of the ice covering the sea surface. The Eastern part is very shallow and has the fastest feedback to the wind change. Wide area of the Eastern part allows a well-manifested cyclonic or anticyclonic circulation to be formed. The transition period between them is characterized by the dipole circulation. The Western basin is more narrow and deep. So, the circulation consists of more local gyres, but the feedback to the wind change is slower then this of the Eastern one. The circulation variations during the seasons of the integration period may roughly be described in the following way. In the summer of the integration period in the Eastern part there was a cyclonic circulation. The velocity value reaches 30 cm/s. The circulation in the Eastern 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. In autumn the circulation in the Eastern basin becomes anticyclonic via the dipole circulation. During the winter period, when the wind is blocked by the ice cover this circulation is weakening, until the ice cover disappeares. In Spring, the reconstruction of the circulation in some periods leads to the chaotic enough circulation certain periods, becoming sufficiently stable by May.

# Stream function. Velocity field at depth 2 m. June, 1998.

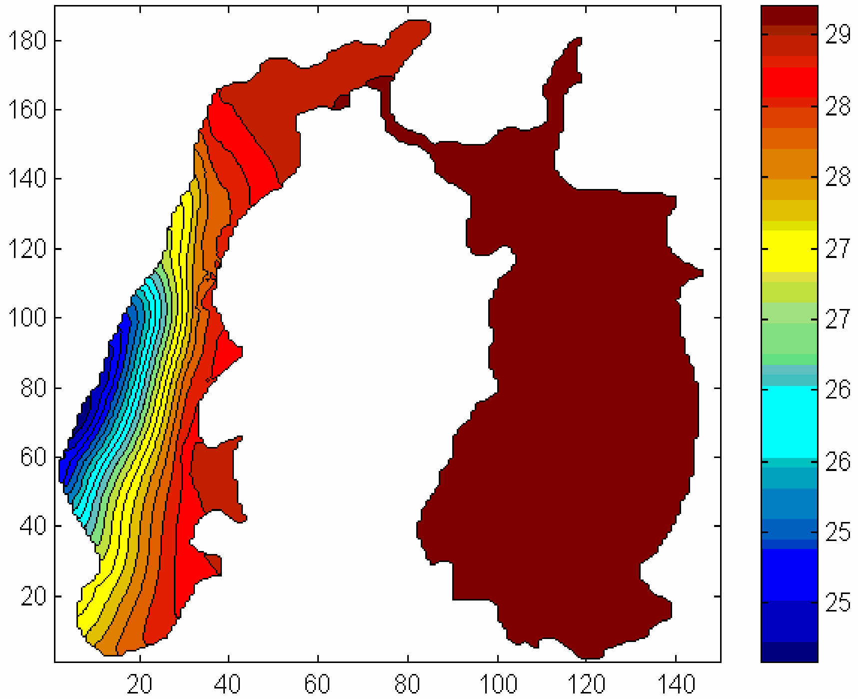


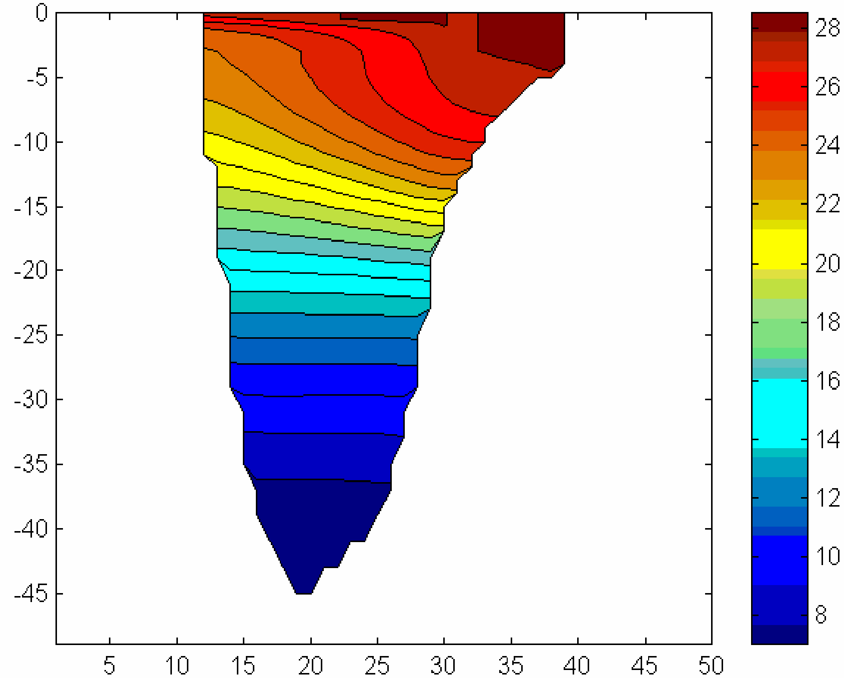



# Stream function. Velocity field at depth 2 m. December, 1998.



# Temperature at depth 2 m. June, 1998 (left). Latitudinal temperature cross-section. Western basin.

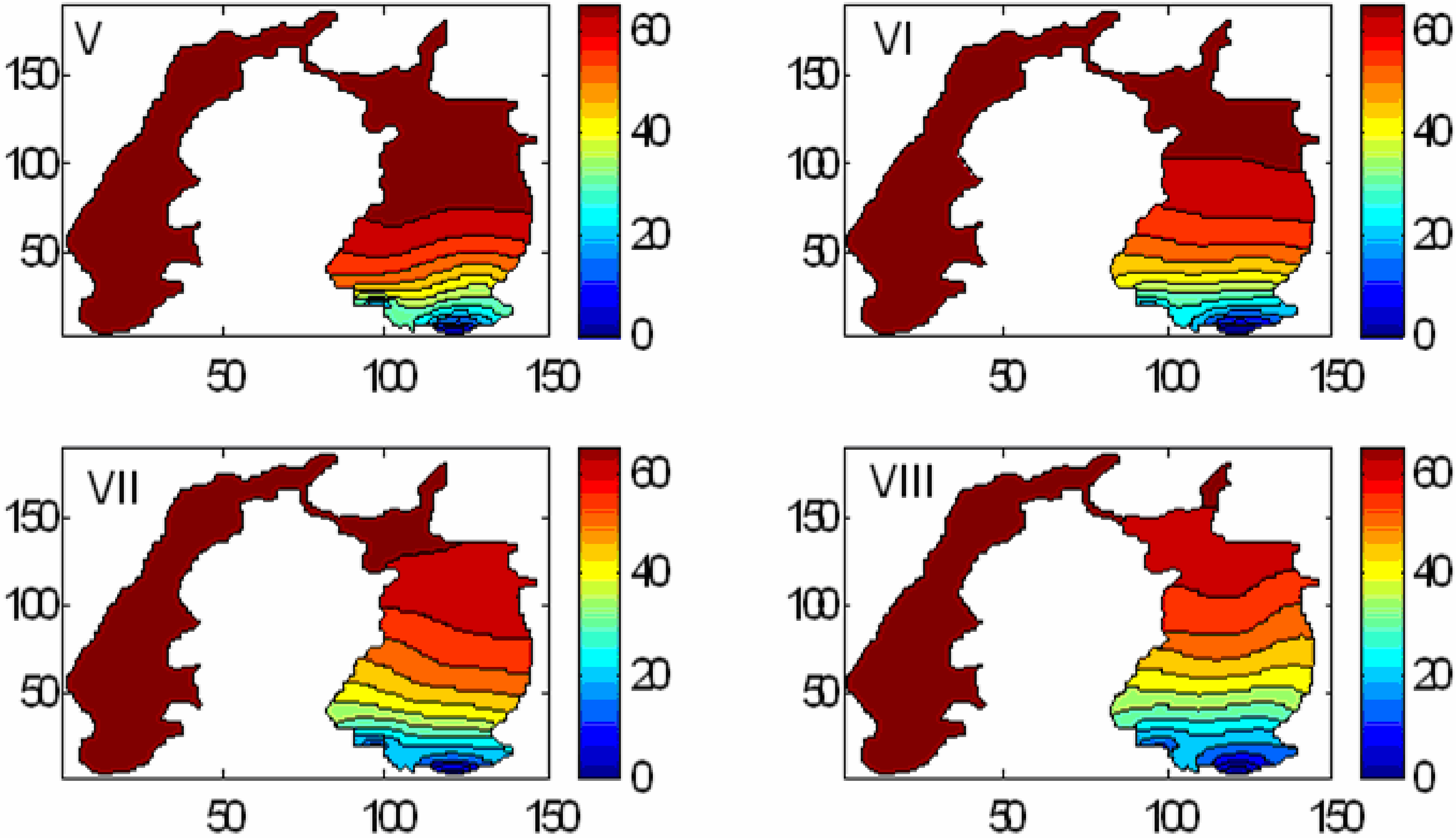


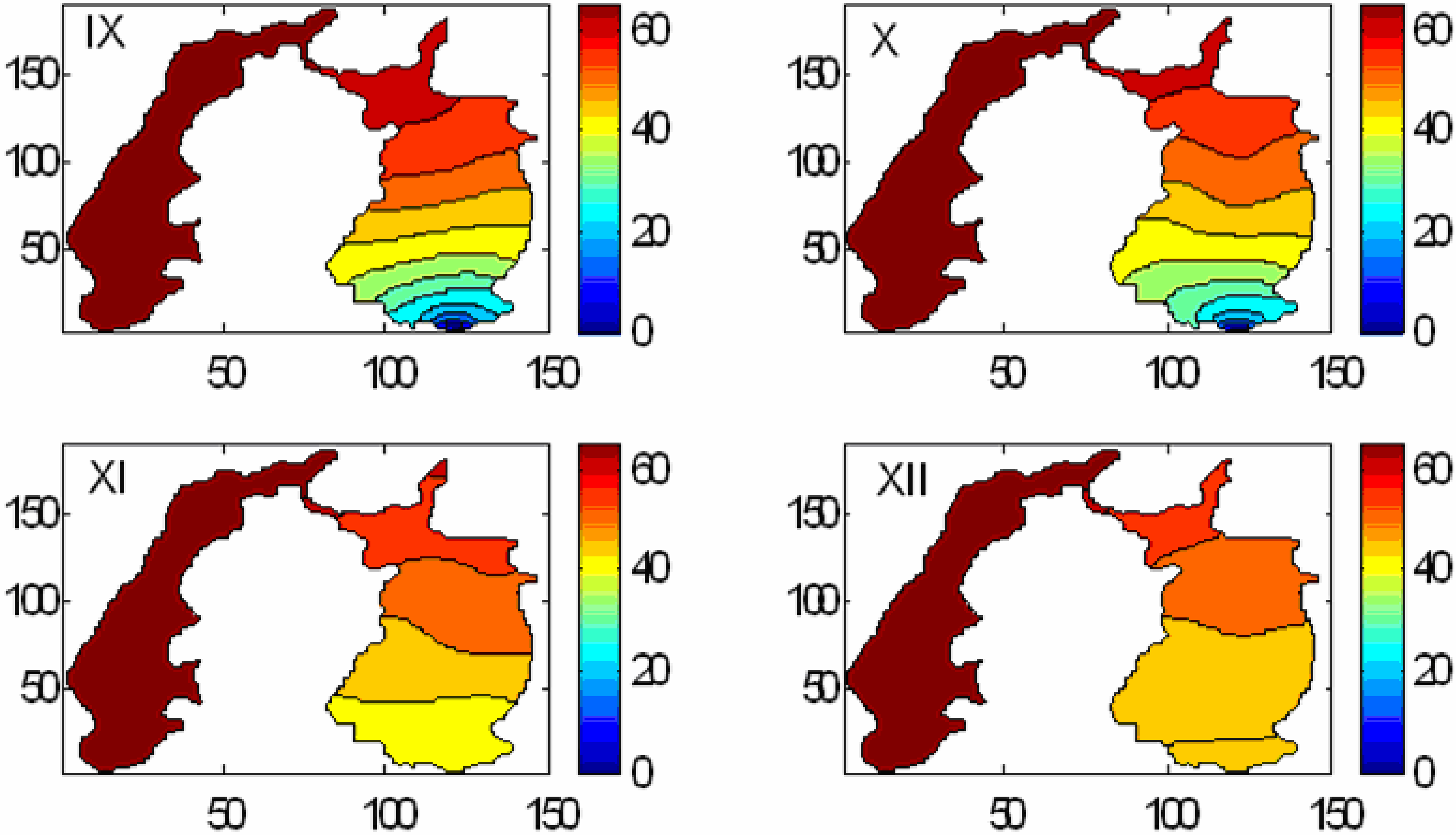
# The salinity distribution and the fresh water propagation

The salinity conditions during the integration period are defined by the Amy-Darya inflow during the 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 the slides the horizontal pictures of the demineralization is presented. After the river inflow stopped, the horizontal distribution became nearly uniform, but the salinity is lower then in the initial moment. One can see the well manifested moving of the low saline water from the South to the North. The pool of the freshened water has a tendency to tern to the East under the influence of the Coriolis parameter. Freshened water reaches the narrow straight between the Eastern and Western basins and propagates to the Eastern part as it is shown in the slides. The latitudinal cross-sections represent the vertical distribution during the river inflow and when it was stopped. The meridional cross-sections represent the propagation of the fresh water front with time.

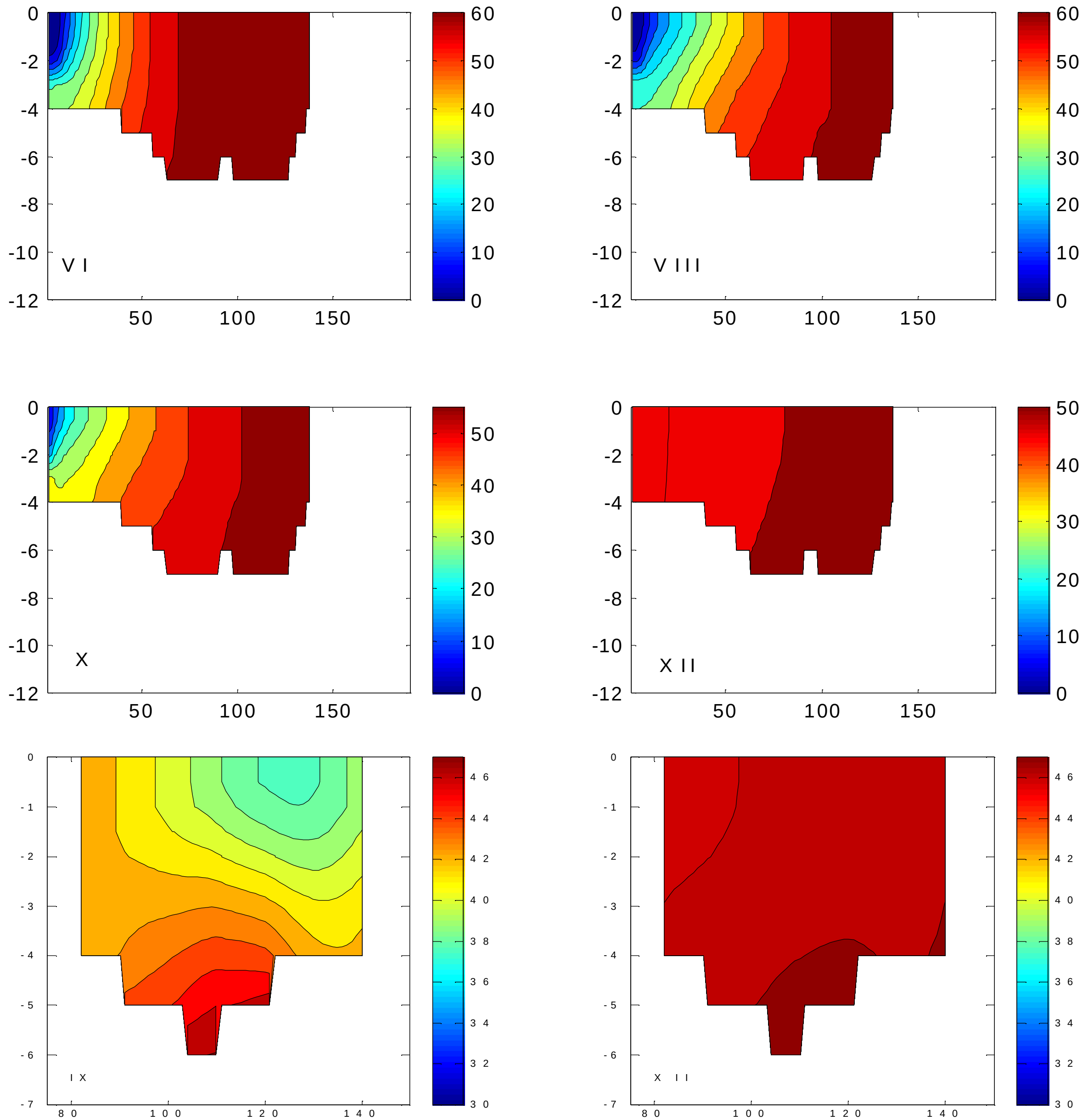
## Demineralization of the Aral Sea during the period of V-VIII 1998 – high Amy-Darya inflow



# Demineralization of the Aral Sea during the period of IX-XII 1998 – low Amy-Darya inflow



# Meridional salinity cross-section for June, August, October, December 1998
# Low two figures: Latitudinal salinity cross-section (September and December 1998)

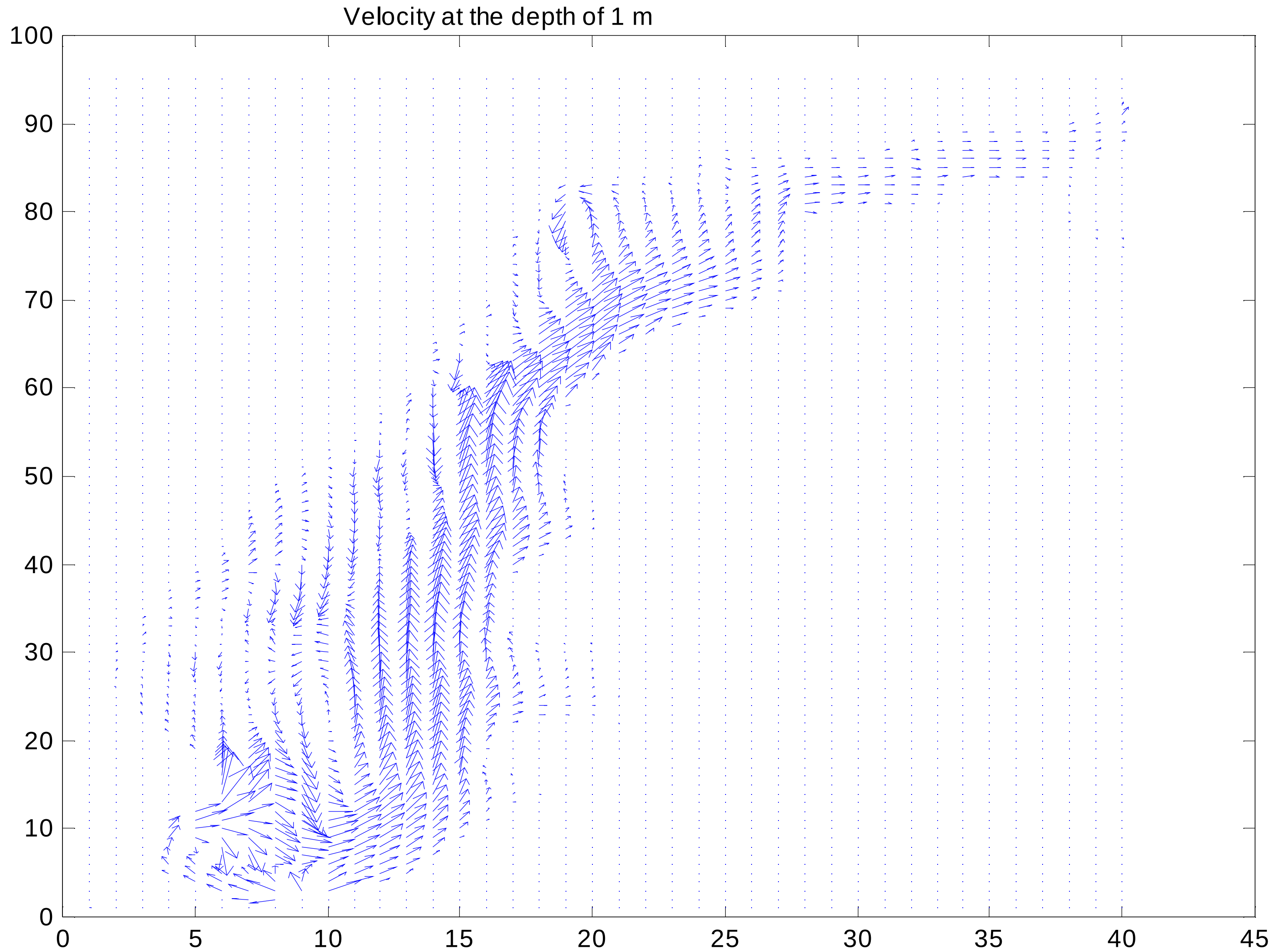


## The final experiment (the inflow to the Western basin)

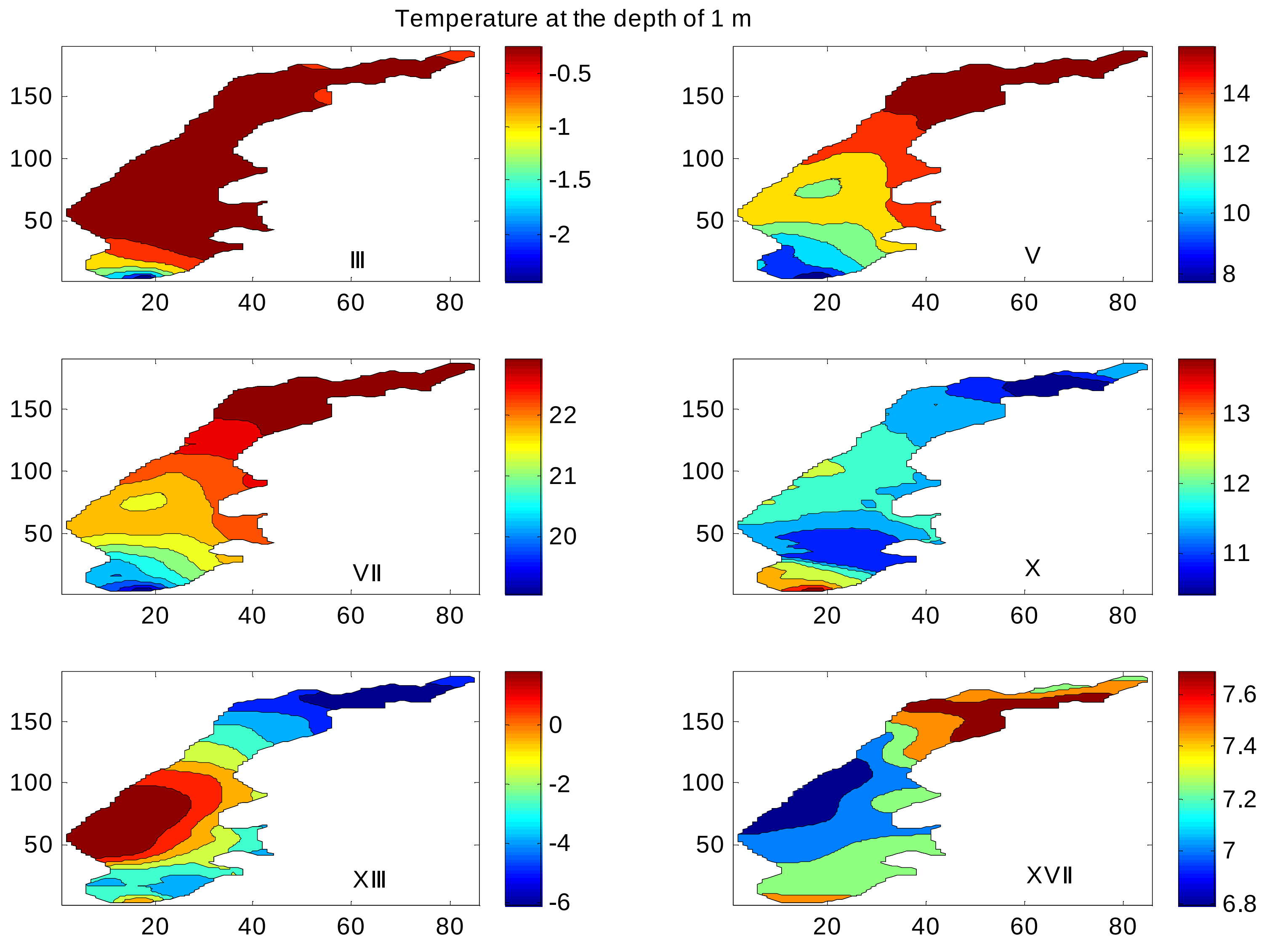
At the final stage of the numerical experiments the Aral Sea basin was taken in a configuration where exists only the Western part. The Amu-Darya river runoff was directed to the Western part with the amount estimated by the hydrologists.

At the initial stage, we have no spatial distribution of the temperature and salinity in the basin. So, the constant values of the temperature (-2.5 C) and salinity (140 g/l) corresponding to the winter season (January) were set in a whole basin. The integration of the model was carried out during the period of 18 months with the wind-stress produced from the climatic wind. The ice sea model includes only the thermodynamic part without dynamics, reology and drift of ice. The time step was one hour. On each step, the following 3D hydrophysical fields were calculated: velocity, temperature and, finally, salinity changes as a result of the refreshing by the river runoff.

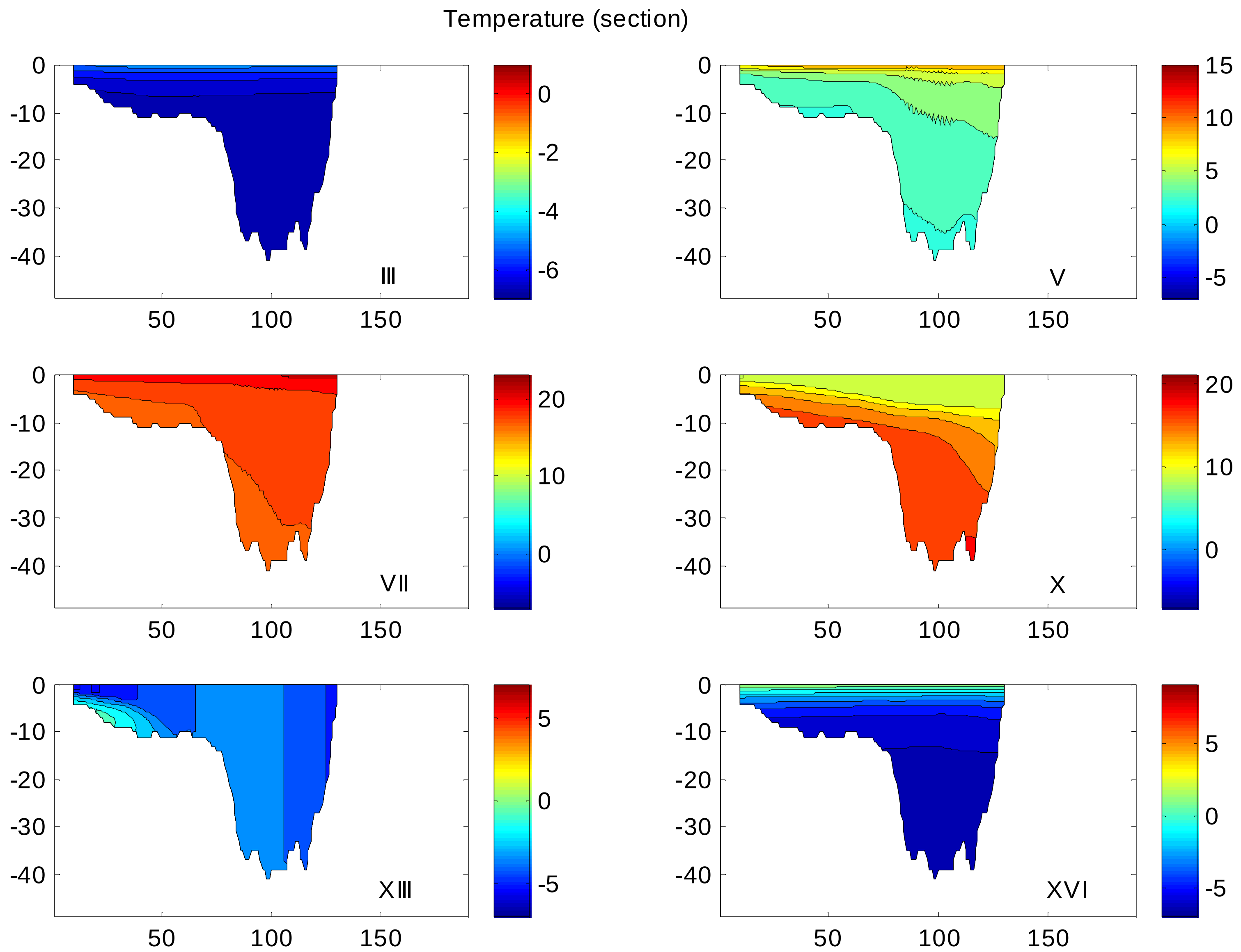
# Velocity field at the depth 2m (May)



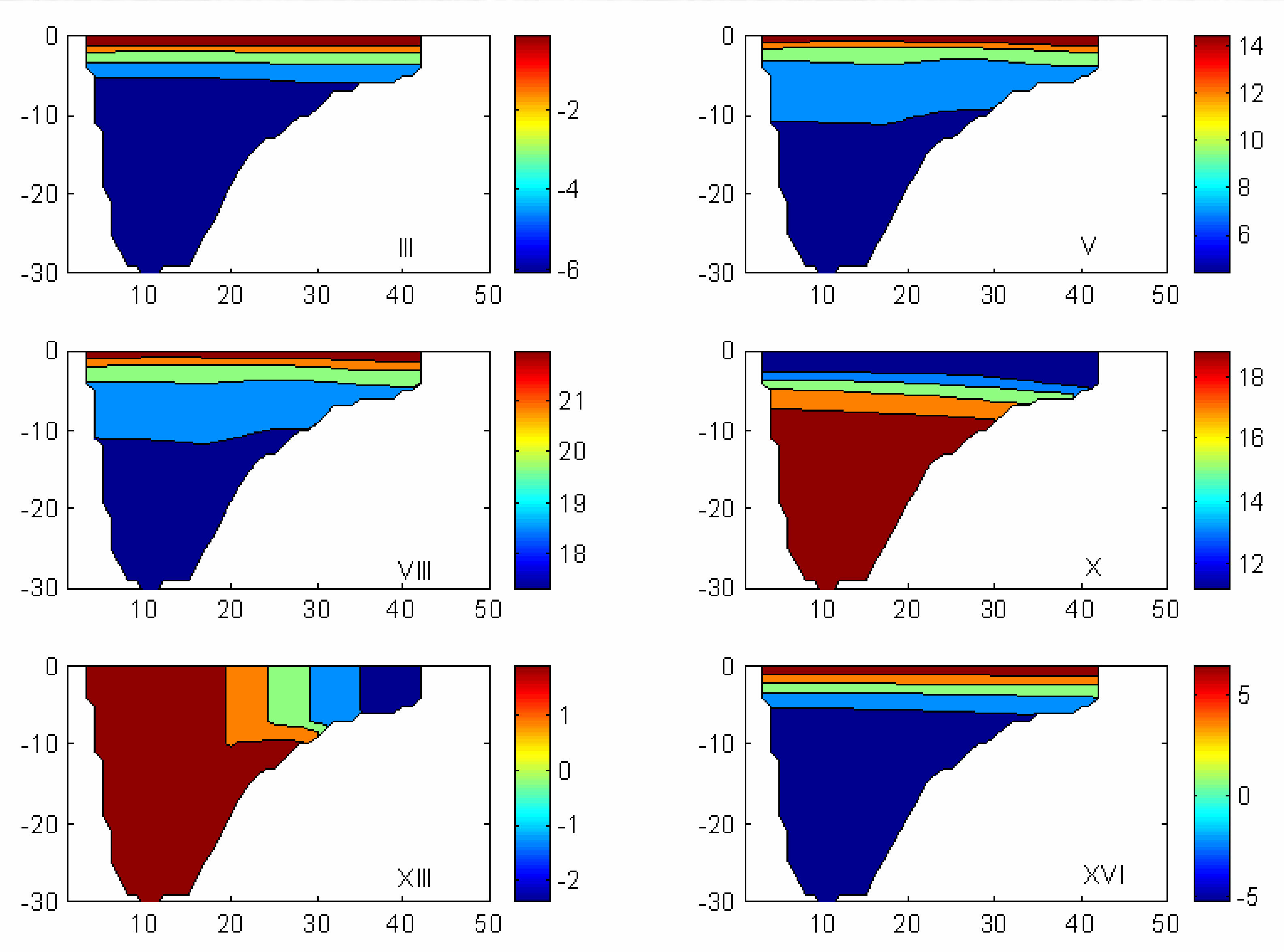
# Horizontal temperature distribution in the second experiment when the inflow is to the Western basin (March, May, July, October, January, May)



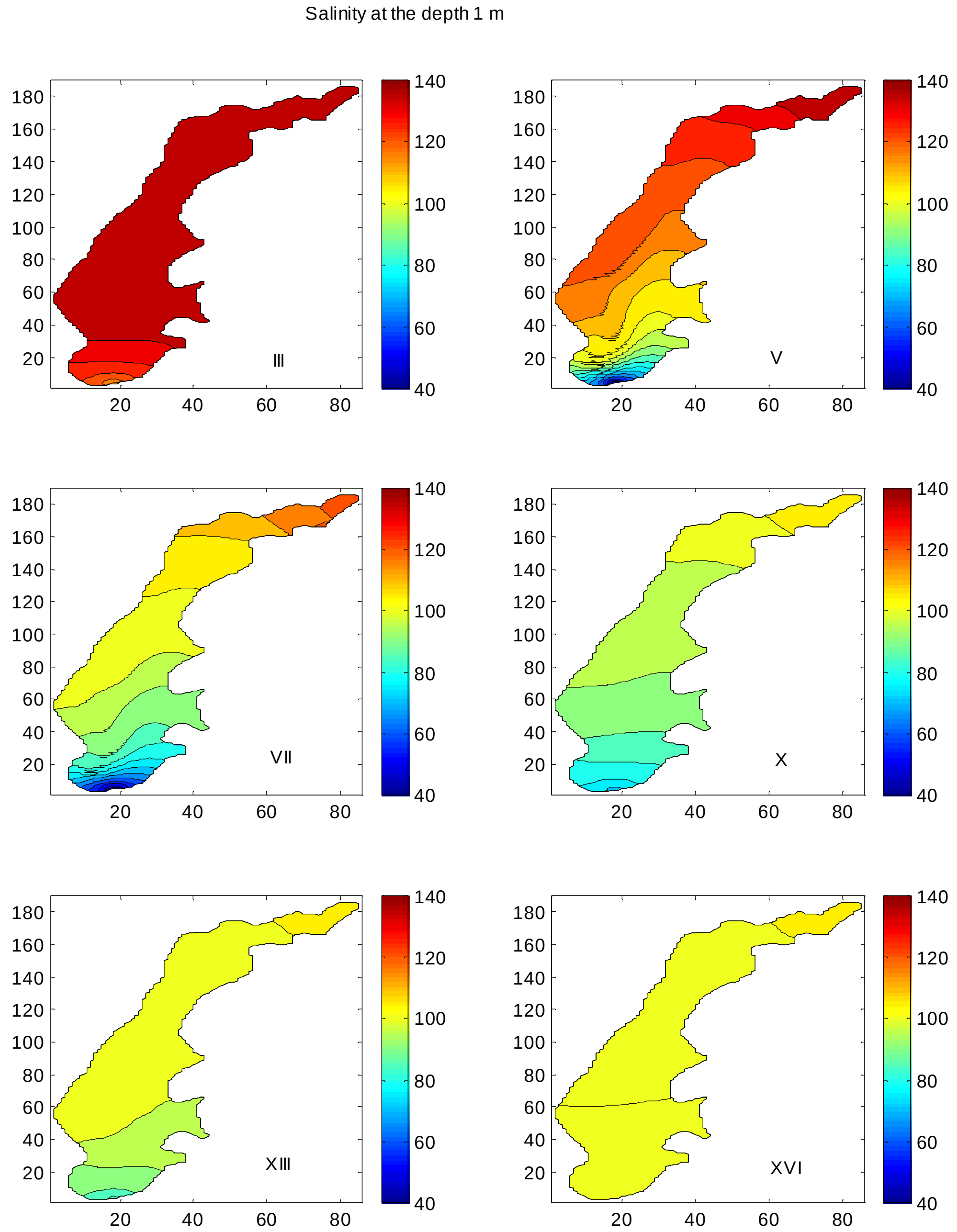
# Zonal cross-section of the temperature (March, May, July, October, January, April)



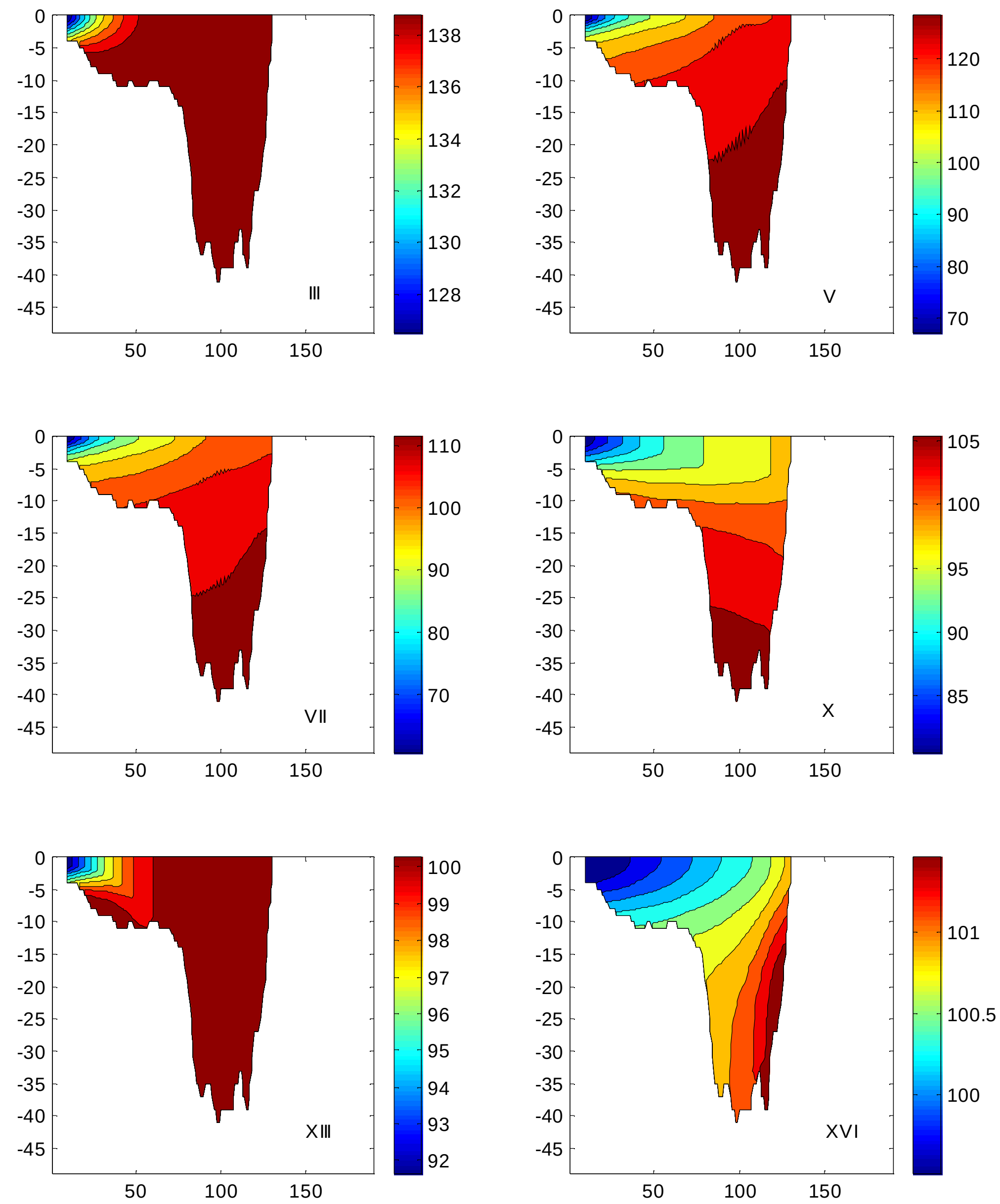
# Meridional cross-section of the temperature (March, May, July, October, January, April)



Horizontal salinity distribution in the second experiment when the inflow is directed to the Western basin (March, May, July, October, January, April)



# Zonal cross-section of the salinity (March, May, July, October, January, April)



# Conclusions:

- Processes in the Aral Sea region during the last 40 years is one of the most drastic example of the possible consequence of man-induced environmental changes
- The Aral Sea desiccation changed the regional climate and initiate the problems in ecology, agriculture, fishery, industry, health and social conditions;
- The use of the Amu-Darya, Sur-Darya water for the agriculture results to the loss 90% of the area and 80% of the volume with increasing of the salinity from 10 to 140 g/l;
- There exist the real possibility to save only one of the parts of the Big Aral (Western basin) with the reducing of the water use for the agriculture and with the transferring of the Amu-Darya runoff to the western basin.