Title: **Synthesis of water balance data and simulation of the shrinking process of the Aral Sea.**

Authors: **Sirjacobs D. *, M. Gregoire, E. Delhez, J.C.J Nihoul**
GeoHydroEnvironmental Research (GHER)
Liege University Belgium.
* D.Sirjacobs@student.ulg.ac.be

1. Introduction

1.1 The Aral-Kum Project and the Aral Sea Hydrodynamic modelisation

The present research is part of the EU funded Inco-Copernicus Project concerning « Desertification in the Aral Sea Region: A study of the natural and Anthropogenic Impacts », with the GHER department of Liege University as Coordinator and involving international collaboration with the following institutions : General Mathematics Service of Liege University, Department of Multi-Purpose Water Use and Agricultural Water Supply – Tashkent, Central Asian Scientific Research Institute for Irrigation – Tashkent, P.P. Shirshov Institute of Oceanology - Russian Academy of Sciences – Moscow, Moscow State University, Marine Planctonology Department of Kiel University, Marine Hydrophysical Institute - Ukrainian Academy of Sciences – Sevastopol, Department of Meteorology and Geophysics – University of Sofia and the Institute of Marine Sciences – Erdemli-Icel.

The final objective of the project is to develop a mechanism of basin-scale / regional integrated management of the Aral Sea region based on an identification of linkages between socio-economic human dimensions and air-sea-land interaction aspects of the climate system, to prevent or mitigate the effects of ongoing desertification. Practically, the project realizations will be the establishment of an international Aral Sea data and Information System (ASIS), the development of an integrated mathematical modeling tool for a sound environmental management of the basin, identification of environmental control criteria and formulation of recommendations to combat desertification. Those concrete output will be made available to politicians, water resource managers and decision-makers and a web site will give broad public access to the fruit of this international and multidisciplinary realization. The particular task of the GHER department is the implementation of a 3D coupled physical-biological model of the Aral Sea, which will provide seasonal simulation of the 3D circulation, temperature, salinity and water-mixing fields for particular years of interest. As a important step towards this, a 0D water balance model was build for a general quality assessment of the water components dataset and of the digital bathymetry used for simulation of Aral Sea characteristics during its shrinkage process (Level, Volume, Area, Salinity). This first model is also an efficient tool for long term evaluation of those parameter according to various future water management scenarios.

1.2 The anthropic factor in Aral Sea watershed

As an introduction, figure 1 summarizes the evolution of the water balance components of the Aral Sea and the correlation with anthropic influence from the global watershed. Data concerning river, precipitation and evaporation flow of the Aral Sea are gathered from UNEP (1992), Micklin (1996), Glazovsky (1995) and the Russian Hydrology and Meteorology Institute (1990). The total water withdrawall, total runoff losses and annual water ressources of the Aral watershed are extracted from Demente'ev (1993), whereas total population and irrigated area were found in Micklin (1996) and the sea level evolution results from a UNEP study (1992).

Amongst well known evolutions of the watershed hydrology, it is interesting to notice that although total water withdrawal increased regularly since 1930, a significant increase of total runoff losses only appears in the end of the 50's, when total (anthropic) water withdrawal reach the total runoff losses. Thus, we can suppose that a total water withdrawal inferior to 35 km3/year may constitute a sustainable limit under which total runoff losses would not be affected by human activities, as part of it would anyway be naturally lost due to infiltration through river banks, for instance. Another well known confirmation from this figure is the similar time scale and amplitude between the anthropic influence on the hydrology of the basin and the Aral Sea dynamical characteristics : in 1960, the human water consumption level is 51,5 km3/y and we can consider that the doubling time of the both watershed population and its water consumption is then of 20 years (see data from 1950 to 1970) ; in the same year, the river inflow to the Aral Sea is around 56 km3/y leading to a total renewal time (or residence time of the river inflow) of 19.6 years for the 1100 km3 of the original Aral Sea water body.

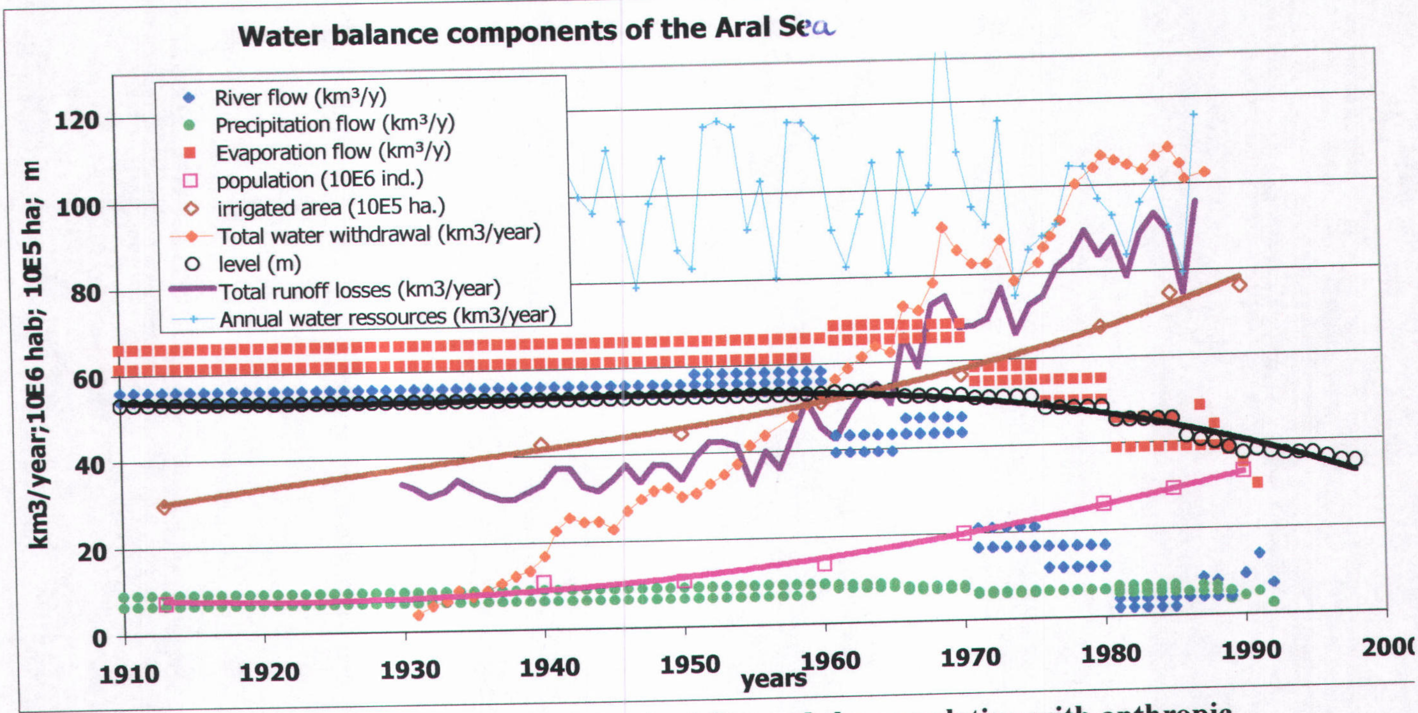

Figure 1 - Water balance components of the Aral Sea and the correlation with anthropic influence from the watershed.

2. Annual water balance components: synthesis of available data

Data of annual river flow to the Aral Sea were collected from various literature sources (Figure 2) and show good general agreement except for particular wet years like 1969 and 1973. The water balance model used these different total river inflow to simulate the evolution of the Aral Sea from 1961 to 1991. Less data were available concerning the evaporation and precipitation flows of the Aral Sea (Fig. 3 and 4). For the two last parameters, we decided to use for our simulation the annual data from the Russian Hydrology and Meteorology Institute for the years 1961 until 1985, followed by the annual data from the UNEP study for 1987 until 1991, with a simple interpolation for the missing data of 1986. This was chosen because before 1985, data from the UNEP are only 5 years means, and because the data from the ECMWF results themselves from a large scale atmospheric modelisation with only one point from its grid over the Aral Sea, leading to apparent general under-estimation of the evaporation and over-estimation of the precipitation over the sea point compared to UNEP and RHMI data.

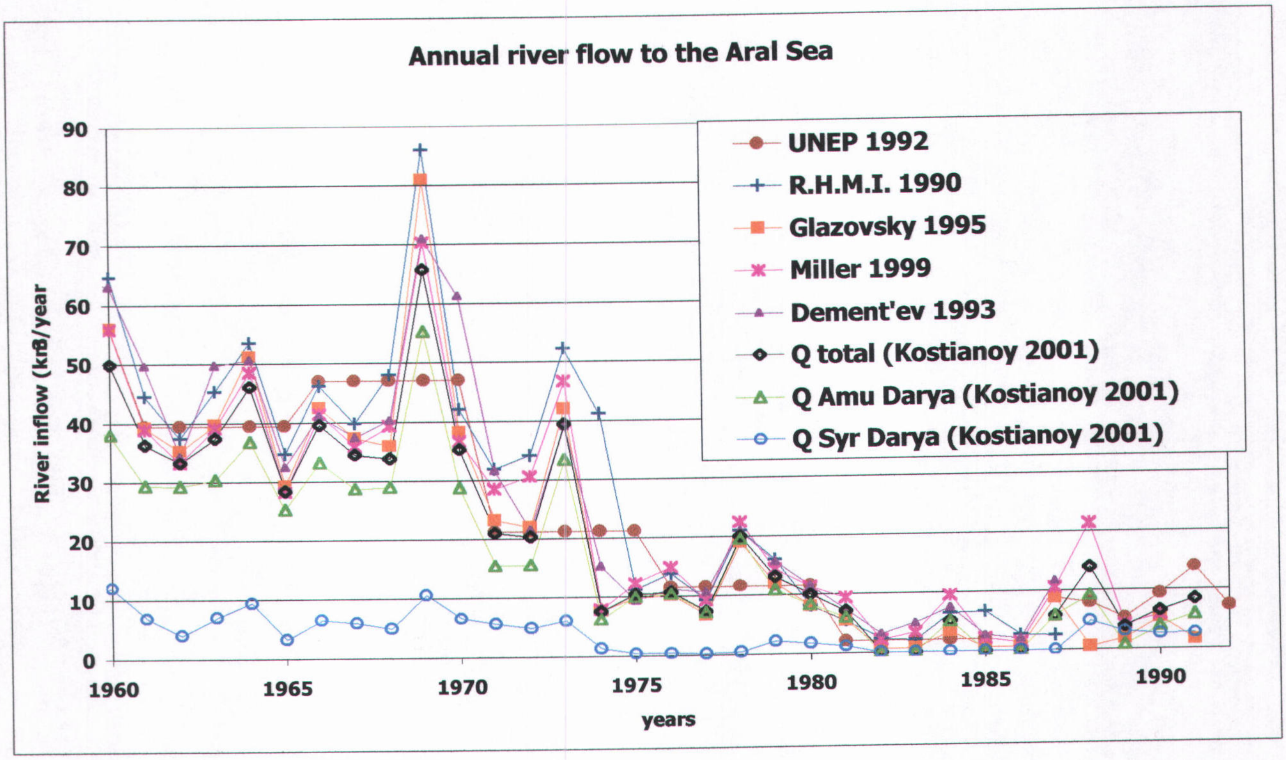

Figure 2 – Annual river flow to the Aral Sea according to various authors.

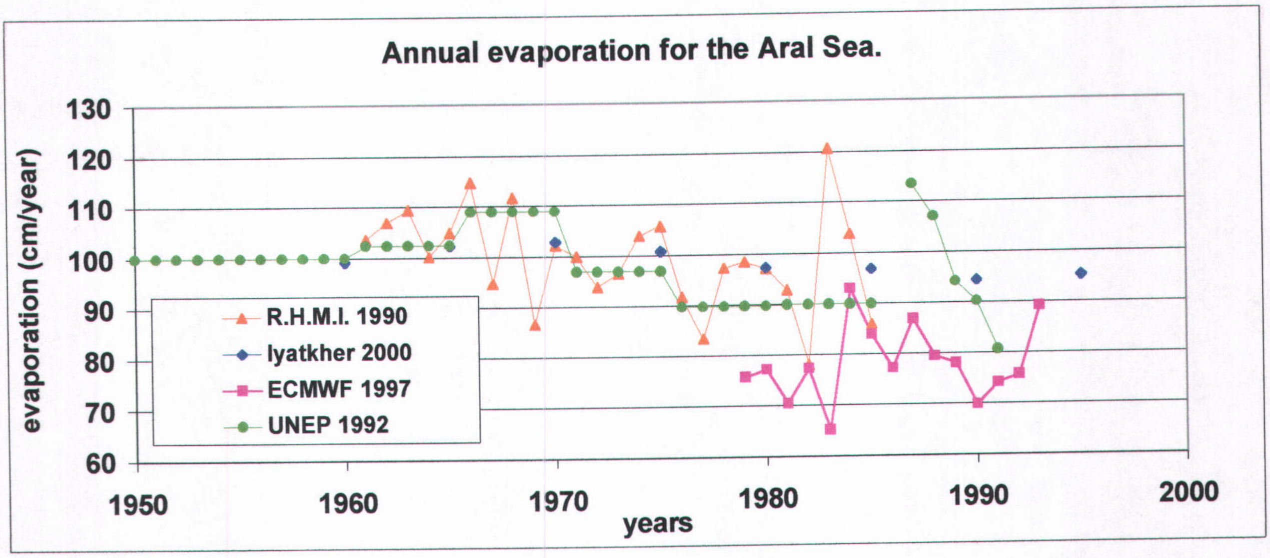

Figure 3 – Evaporation from the Aral Sea according to various sources

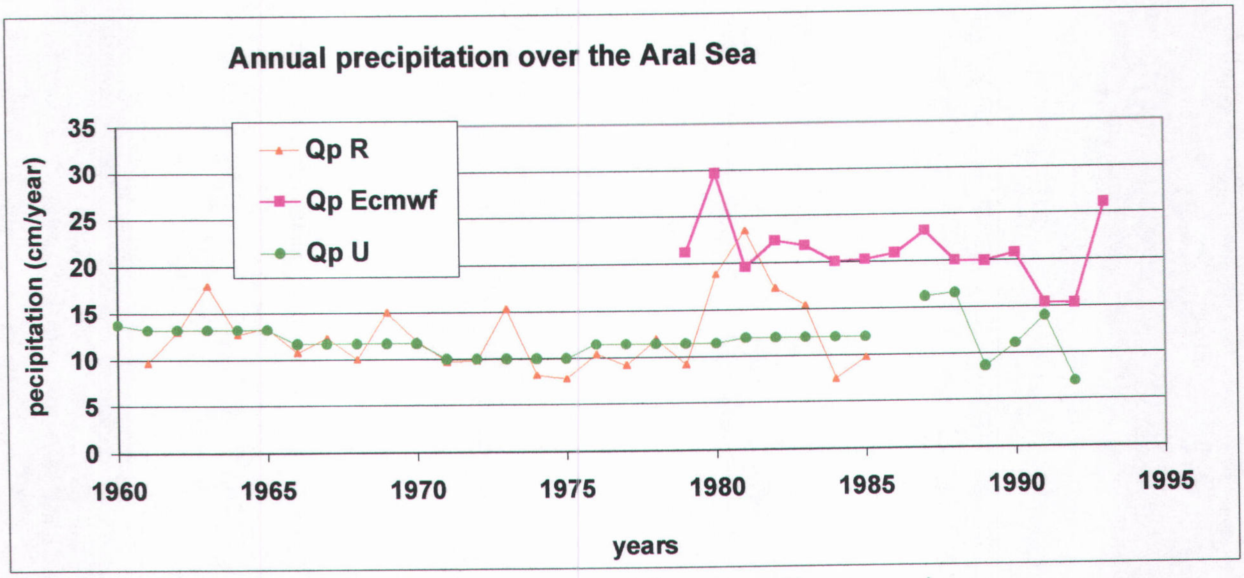

Figure 4 - Precipitation from the Aral Sea according to various sources

3. Simulation of the shrinking process of the Aral Sea

3.1 Bathymetry

Simulation of the shrinking process of the Sea used a digitized bathymetry (grid: 130 (latitude) * 100 (longitude) meshes of approximately 2,92 km side length) based on a precise bathymetric map of the sea in it's original state. The relations between the sea volume, area and level in the basin were calculated from this digitized bathymetry and showed satisfying agreement with similar relations built from the evolution of measured area, level and calculated volume of the Aral Sea given by Glazovsky (1995), Perminov (1993), RHMI (1990) and Ressl (1996).

3.2 Water balance model and quality assessment of the dataset

The water balance model of the Aral Sea was designed to calculate from the known initial conditions of 1960, the yearly variations of sea level, volume and area according to the selected evaporation and precipitation time series and to the 6 different river flow time series previously identified from the literature. The resulting simulations doesn't depend just on the differences between those river flow data because yearly evaporation and precipitation flows (in km3/y) are calculated with the updated superficy of the sea, which also depends on the particular level variations since the common initial conditions. The annual Aral Sea volume fluctuations obtained by simulation are following the general tendency of literature (Fig. 5) but suggest a general overestimation of the river inflow for the years 1969 and 1973. This may be due to the fact that during high river flow events, a more important part of river flow measured in the last hydrological station is afterward lost in the deltas, before reaching the sea.

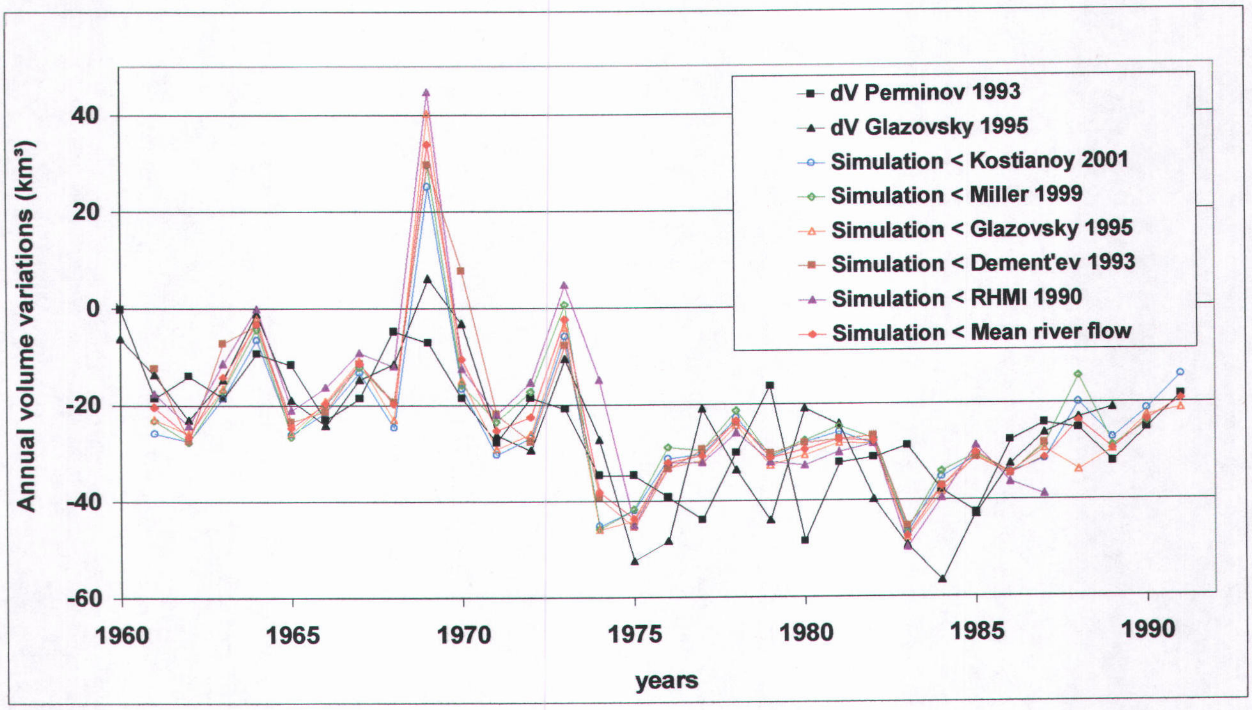

Figure 5 - Annual fluctuations of Aral Sea volume (data and simulations)

The simulated evolutions of Aral Sea level are presented in figure 6 with the mean level time series calculated from literature data (Kostianoy 2001, Glazovsky 1995, Mandych 1995, RHMI 1990 and Micklin 1988). With the simplified water balance model used, we can see that all the simulations have a correct general pattern, with the most part of discrepancy created during the years1969 and 1973 as described before. The most important water balance phenomena are thus well-described and other water exchanges (ground flows, local runoff…) must globally contribute to a smaller extend. Nevertheless, they also deserve particular interest for future studies as they may act as stabilizing factors of the sea water budget. A closer look to the progressive separation between mean literature level and the level simulated with the mean river flow suggests that part of the level drop is not explained (loss of the river inflow trough deltas, under estimation of export of water to the atmosphere, ground exchanges,...).

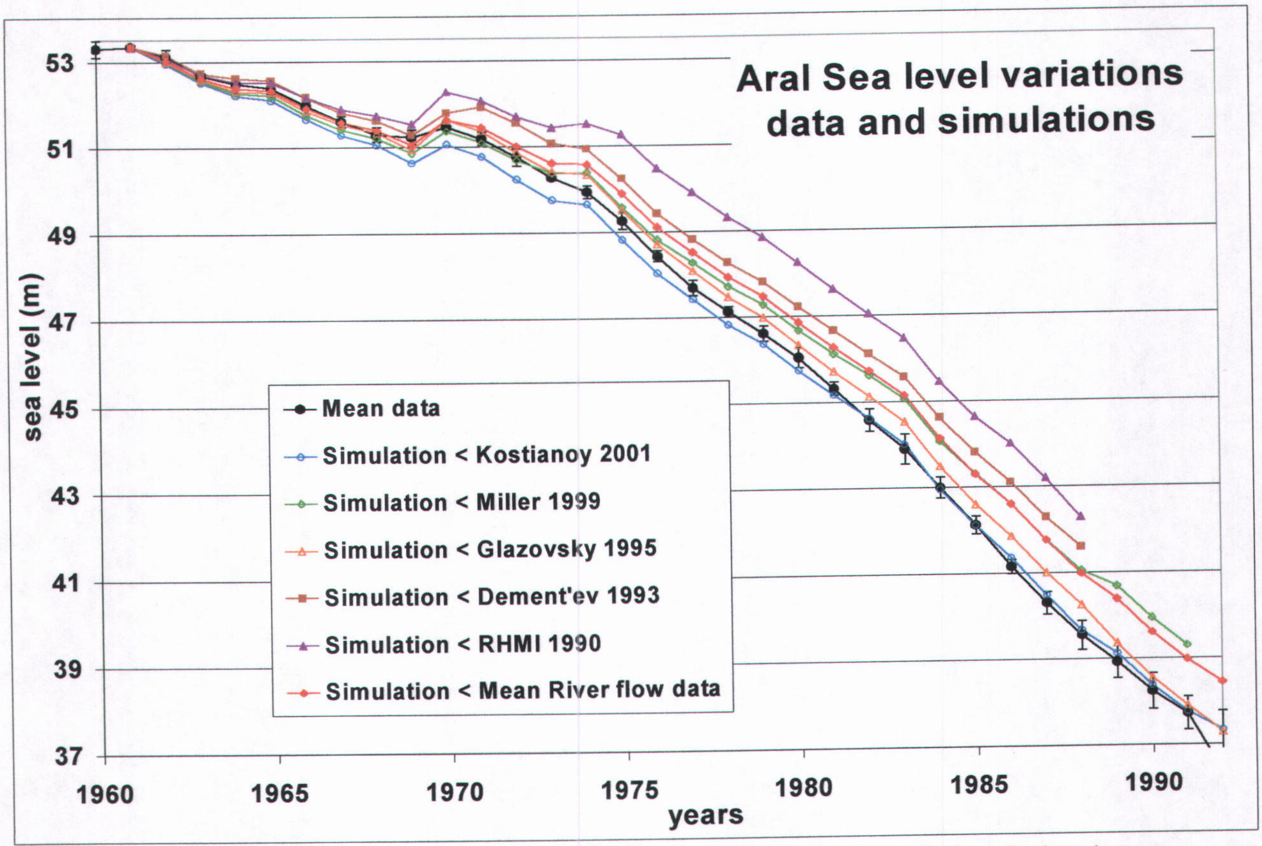

Figure 6 - Annual fluctuations of Aral Sea volume (data and simulations)

River flow data from Kostianoy and Glazovsky allowed the closest reproduction of the Aral sea level drop between 1961 and 1991. An illustration of this is given in figure 7 by the correct reproduction of the drying up of Berg's straight in 1989 obtained during simulation with Glazovsky's river flow data. Using data of the evolution of salinity of Amu Darya and Syr Darya water discharge from Glazovsky (1995), the salinisation of the Aral Sea was also simulated as a result of simple concentration due to the sea volume reduction (Figure 8). As for the sea level simulation, good agreement was observed between results and the mean salinity calculated from literature data (Glazovsky 1995, Aladin 1995, Micklin 1988 and 1996, RHMI 1990 and Koltiakov 1991). Except during years with particularly high river flow (1969 and 1973) which bring back all the simulation closer from the mean truth curve, a general over estimation of the salinity can be observed, mainly after 1983. This is because other phenomena influencing the salt balance should be taken into account as the global increase of gypsum sulfate precipitation and general authigenic mineral formation on the sea bed (Zhanoida 1997) occurring with the salinity raise.

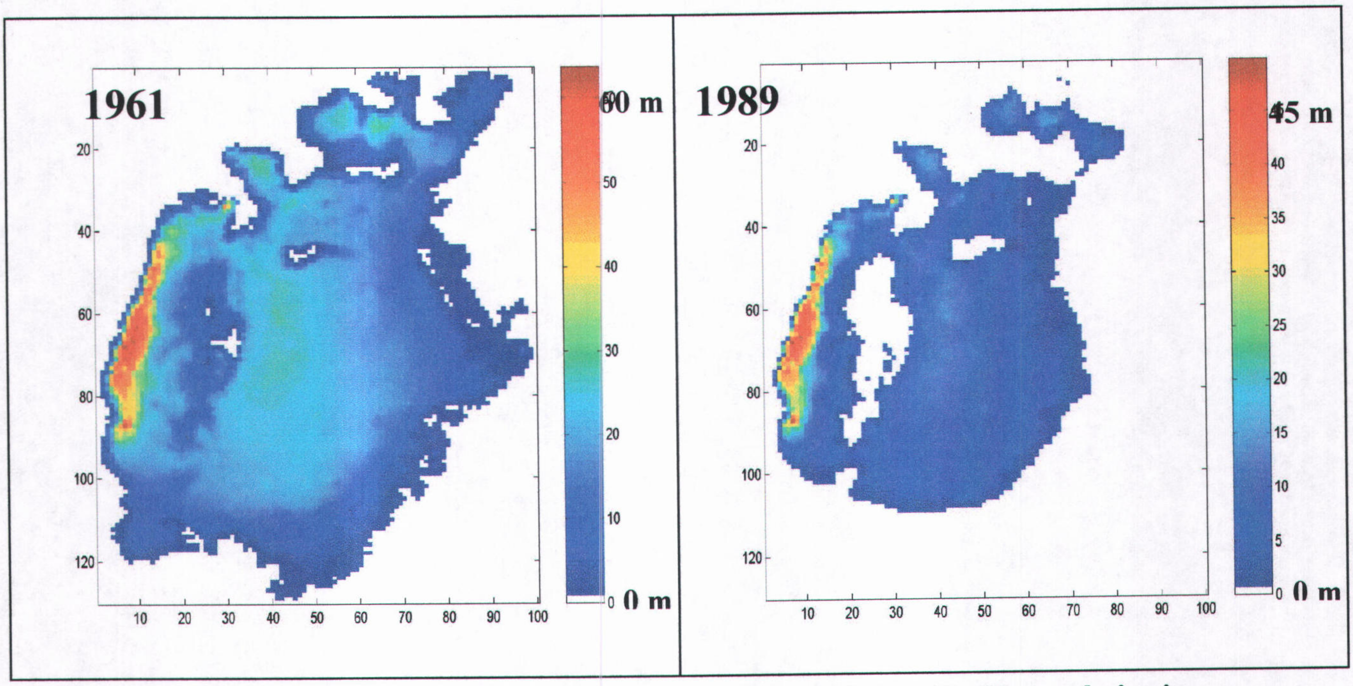

Figure 7 – Correct simulation of the drying up of Berg straight with Glazovsky's river flow data.

3.3 Further water balance simulations: goals and required informations

Further simulations will first focus on the separated evolution of the Aral Sea northern and southern parts water from 1989 until present time. We then require a maximum of information concerning separated river discharge and salinity, precipitation and evaporation over the Aral Sea, ground flows, flow through Berg 's straight and satellite derived features such as area and shape of water table. Later on this model will be used to predict evolution of the sea characteristics according to various future scenarios of residual river flow to the sea depending on possible water management strategies (irrigation efficiency improval, evolution of area and type of crops, population growth, industrial needs and saving,…).

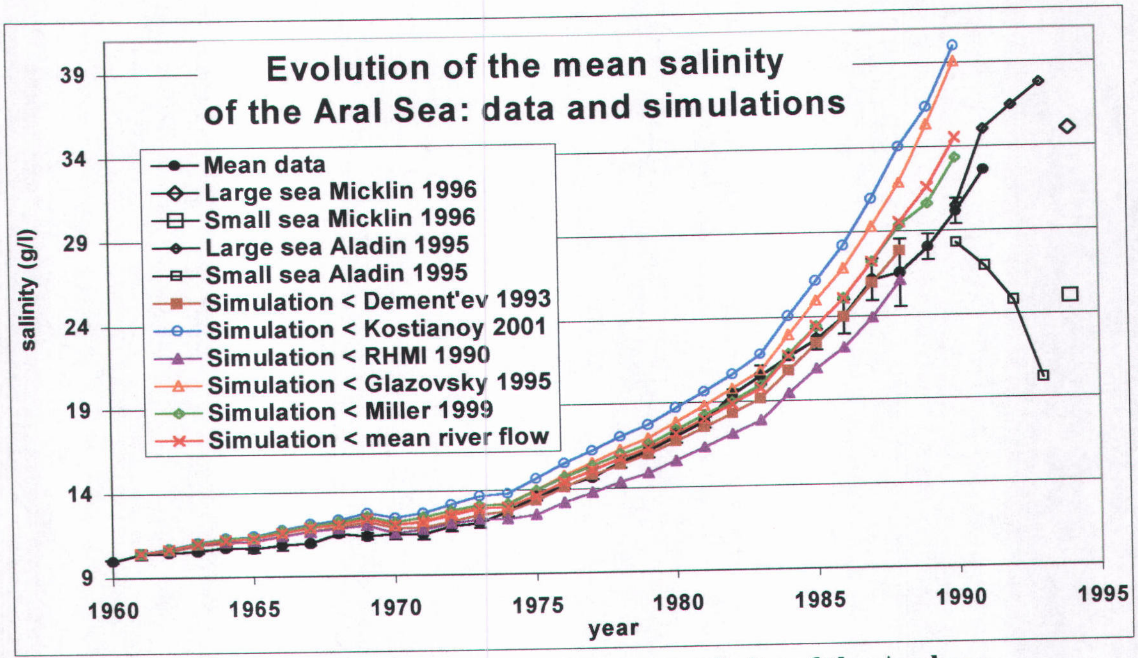

Figure 8 – Evolution of the mean salinity of the Aral sea

4. Seasonal 3D hydrodynamic modelisation

Another task of the GHER department is the seasonal simulation of the 3D circulation, temperature, salinity and water-mixing fields with a grid size of 2.9*2.9 km and temporal resolution of 1 month over few typical years. The forcing considered will be the seasonal fluctuations of wind fields, precipitation, evaporation, river discharge and salinity, radiation balance, air temperature and humidity, and ice cover. Validation data that will be required are any existing circulation, temperature and salinity maps or localized measures, seasonal level changes measurements, sea surface temperature from remote sensing. The identification of particular years for seasonal 3D hydrodynamic modelisation will be done according to 1) data availability (forcing and validation), 2) years of particular interest in the drying process with extreme river discharge or water body separation (1961, 1969, 1985, 1990, 1992), from a biological point of vue (seasonal and local critical salinity conditions, temporal drying of spawning site, …) and from hydrodynamical point of vue (change in the mixing induced by ice cover formation with the increasing salinity around 1985).

5. Conclusions

Concerning the quality assessment of river discharge data, the simulation suggested a general over-estimation of important river discharge (1969, 1973) and showed that data from Glazovsky (1995) and Kostianoy (2001) allow good simulation of the drying process (level evolution) with our simplified water balance model, whereas those from Dement 'ev, Miller and the Russian Hydrology and Meteorology Institute seem over estimated. The water balance model developed was proved to be an efficient tool for reproducing the shrinkage process of the Aral Sea on a long-term basis. It can then also be used as basis for the future 3D hydrodynamic modelisation of the Aral Sea.

Bibliography

Aladin, N.V., I.S. Plotnikov and W.T.W. Potts, 1995, The Aral Sea desiccation and possible ways of rehabilitating and conserving its northern part, Environmetrics, 6(1), pp 17-29.

Dement 'ev, N.F., 1993, Analysis of the causes of the Aral Sea Drying up, Russian Meteorology and Hydrology, 6, pp 59-65.

Glazovsky, N.F., Aral Sea, in Mandych (Mnd), pp 19-154.

Kostianoy, A., 2001, personal communication.

Lyatkher, M., 2000, Solar cycle length stochastic association with caspian sea, Geophysical Research Letters, 27(22), pp 3727-3730.

Micklin, P.P. and Williams W. D., 1996, The Aral Sea Bassin, Springer eds, Berlin.

Miller, J.R., R.F. Ferrari and G.L. Russell, 1999, Modeling the effect of wetlands, flooding, and irrigation on river flow : Application to the Aral Sea, Water Ressources Research, 35(6), pp 1869-1876.

Mandych, A.F., 1995, Enclosed seas and large lakes of eastern Europe and middle Asia, ed. by A.F. Mandych. –Amsterdam : SPB Academic publishing.-III.

Perminov, V.M., Yu.A. Reva, and A.G. Tsytsarin, 1993, Seasonal variations of the Aral Sea level under contemporary conditions, Russian Meteorology & Hydrology, 11, 1993 (1994), pp 67-73.

Russian Hydrology and Meteorology Institute, 1990, Synthesis of hydro-meteorological data of the Aral Sea, 200 p.

UNEP, 1992 in Barth, A., Modélisation mathématique et numérique de la mer d'Aral, Travail de fin d'études de Licence en Sciences Physiques, Ulg, 2000.

Zhanoida and al., 1997, Recent sedimentation processes in the northern Aral Sea, Int. J. Salt Lake Research, 6, pp 67-81.