Calculation of evaporation from the Caspian Sea surface

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1 INTRODUCTION

Calculation of evaporation is a part of the forecasting problem of long-term water level fluctuations of the Caspian Sea. It is one of the most complex geophysical problems due to specific features of this unique geographical object. Having the significant size and being the remainder part of the ancient ocean, the Caspian Sea has many features common for a sea. On the other hand, it has no connection with the ocean, so it has also features typical for the closed water body. In particular, its sea level is especially sensitive to changes in climatic conditions.

The water level of the Caspian Sea has been fluctuating dramatically during all its history because of different factors, such as tectonic conditions, climatic factors and anthropogenic activity. During recent century, the main purpose of such changes was proved to be the climatic fluctuations [4, 8]. Therefore, to forecast the water level changes, it is necessary to study elements of water balance of the sea, which includes the following main components:

- total river inflow,
- outflow from the Caspian Sea to Kara-Bogaz-Gol,
- ground water run-off,
- precipitation,
- evaporation.

The first two elements of water balance can be found more or less accurately by direct hydrometeorological measurements. The ground water run-off can be defined only by indirect methods, so the values received by different researchers have significant deviations. The observations of the precipitation are carried out mostly on the coastal meteorological stations, the data obtained being not representative for the precipitation over the open sea.

As for the evaporation, there is no any device allowing carrying out accurately direct measurements of the evaporation from the sea surface. Different methods have been developed for its estimation. Some of them concern the evaporation as the remainder term in the water balance equation, but results cannot be accurate enough as the other terms in the equation may contain some error. Other methods are based on empirical and semi empirical formulas, that associate evaporation with some meteorological elements. We used methods of the second type.

2 THE DATA

To estimate the evaporation from the Caspian Sea using formulas, we need annual average values of the following variables:

- water vapor pressure
- wind speed
- water surface temperature
- air temperature

We used the following sources of the information:

1. Daily meteorological observations from island and coastal stations for the period of 1977- 1999. There are several problems concerning this data.
   - The number of meteorological stations is decreasing every year, especially after 1994. Some of them do not carry out the full program of measurements.
   - The data does not include absolute air humidity itself, but only the temperature of dry and wet thermometers, therefore, we have to define it with the use of psychrometric tables by hand. The data on the temperature of dry and wet thermometers is available only for the period until 1984.
   - There is lack of information from the southern - Iranian - part of the sea.
   - At last, the data obtained from the coastal meteorological stations may be representative only for some local part of the coast but not for the whole sea. Meanwhile, the meteorological parameters change greatly over the territory of the Caspian Sea. For example, annual average air temperature varies from 8^{o} in the north up to $15\text{-}16^{o}$ in the south. The values of meteorological parameters change not only from north to south but from east to west as well.
2. Ship measurements for the period from1938 up to 1987. Average values of air temperature, wind speed, water vapor pressure were calculated in 1x1-degree squares for each month. This information is also far from satisfactory as it depends on ship routes and is therefore distributed unevenly on the territory of the Caspian Sea. Large

territories have no information at all, especially concerning air humidity. There are too many errors in this data as well.

On Fig.1 meteorological stations and ships observations in 1x1 squares are represented. The size of yellow circles coincides with the total number of ship observations in the square. The largest circle corresponds to 31000 measurements, the smallest one - to 10000 observations.

3. Because of all this we decided to use the reconstructed data to carry out some preliminary estimations and then to verify them using the available real observations. The main advantage of such a sort of information is its regular net with the uniform coverage.

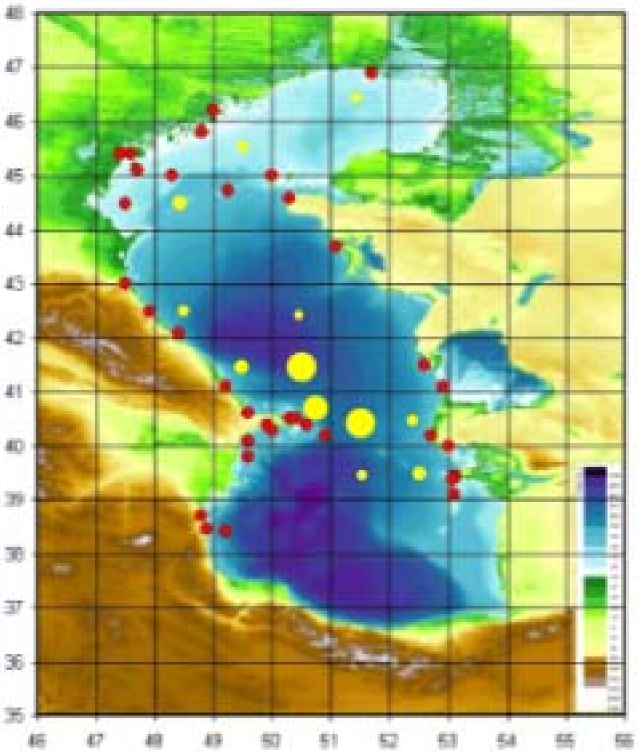

Fig.1. Meteorological stations (red circles) and ship observations (yellow circles) on the Caspian Sea.

3 REANALYSIS

We used the array of matrix NCEP/NCAR from Internet [6]. It contains the reconstructed data of the main hydrometeorological parameters for the whole surface of the earth for the period from 1948 up to 2002. We took the following reconstructed average monthly values:

1. atmospheric pressure
2. specific humidity
3. wind speed
4. water surface temperature
5. air temperature

Using 1 and 2 values one can estimate water vapour pressure.

We dealt with the grid problem. Atmospheric pressure grid has the step of 2.5 degrees in both directions; the grid of the rest characteristics has the step of 1.875 degrees latitude and 1.9 degrees longitude. First, we have reallocated the data to the uniform grid and then - to the denser one with the step of 30 minutes using bilinear interpolation method. After this, we had to separate grid units above the sea from those above land. For this, we used filtration to a mask. However, the sea border is not stable; it varies together with the sea level variations, therefore, a dynamic mask was applied determined for each current level value. The mask was built from Digital Elevation Model “Caspy-30 seconds” elaborated by [1].

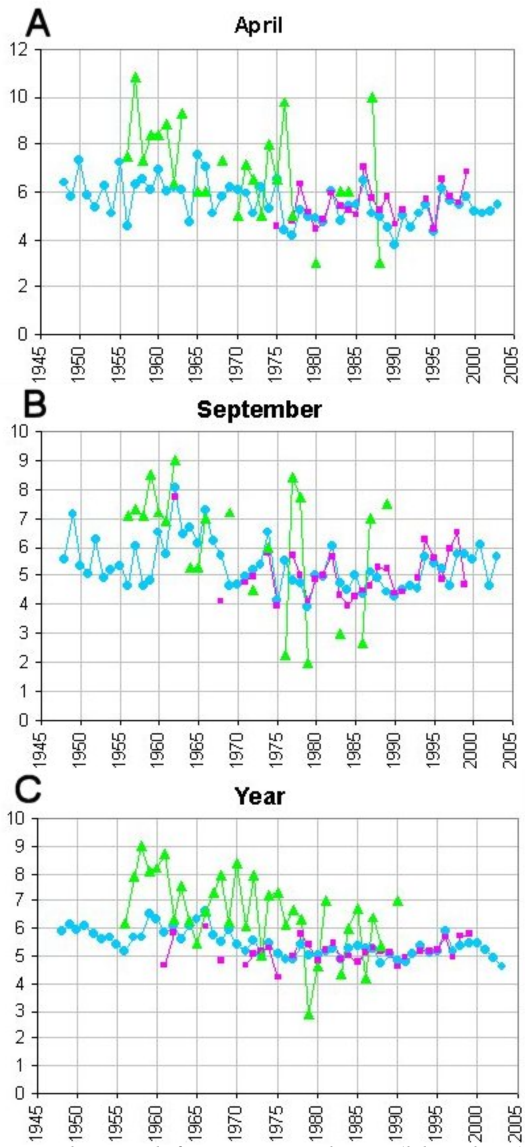

Fig.2. Wind speed from Reanalysis (blue line), ship observations (green line) and measurements on Tulenij island for April (A), September (B) and the whole year (C).

Then we compared reanalysis data with the observation data. Fig.2 represents the difference in wind speed taken from observations and from Reanalysis. We assumed that the data observed on Tulenij Island - a small flat island in Northern Caspian

- would be close to the data measured in the open sea. We also examined ship measurements in the nearest square for the months when the quantity of measurements was more or less sufficient. Fig.2 demonstrates that the Reanalysis wind speed and that measured on Tulenij show rather close coincidence. Wind speed measured on ships give large scattering and have poor coincidence with other two curves. In average, for the whole year wind speed values measured on ships are higher (Fig. 2, C), than that of tha Reanalysis, therefore evaporation estimated using this data would be higher too. Wind speed measured on coastal stations is less than that of Reanalysis. The coincidence of temperature from reanalysis and from observations is satisfactory.

4 THE FORMULAE

As the data from reanalysis differs from data got by observations then empiric coefficients in formulae may be not appropriate when used for reanalysis data. Therefore, we examined four formulae for the estimation of the evaporation from the Caspian Sea. All of them are semiempirical and are based on Dalton law, which declares that the evaporation is proportional to humidity deficit.

1. The semi empirical Samoilenko formula looks like [7]:

   $E = B'_z U_z (e_0 - e_z)$

   Here E - is evaporation

   U_z - is wind speed at the height z

   e_0 - is maximum water vapor pressure

   e_z - is water vapor pressure at the height z,

   B'_z is the coefficient that takes into account the influence of atmospheric turbulence on the evaporation. It depends on the height of the measurement, air temperature and atmospheric pressure.

2. In Goptariev's formula the coefficient $433.7 \cdot \delta_0$ takes into consideration not only the turbulence but also the temperature stratification influence on the intensity of heat exchange [3].

   We are going to use Goptariev's formula that takes into consideration the temperature stratification influence on the intensity of heat exchange.

   $E = 433.7 \cdot \delta_0 \cdot U_z \cdot (e_0 - e_z)$, where

   e_0 - is the water vapor pressure at the sea level

   e_z - is the water vapor pressure at the height z

   U_z - is the wind speed at the height z

   δ_0 defines the temperature stratification influence on the evaporation rate and depends on Richardson number

   $ri = \dfrac{t_w - t_a}{U_{10}^2}$, where t_w and t_a are water and air temperatures consequently.

   ri shows the influence of both thermic and dynamic factors on turbulence exchange.

3. In the formula of State Hydrological Institute (SHI) atmospheric turbulence and stratification are not taken into account [5]:

   $E = 0.14 \cdot n \cdot (e_0 - e_z) \cdot (1 + 0.724 \cdot U_z)$,where

   e_0 - is the water vapor pressure at the sea level

   e_z - is the water vapor pressure at the height z

   Uz - is the wind speed at the height z

   n is number of days in the time period under examination (a month).

4. Ivanov's formula does not take into consideration wind speed and atmospheric turbulence. Its main advantage consists in its simplicity.

   $E = 0.0018(25 + t)^2 (100 - f)$, where

   t is monthly average temperature of the water surface;

   f is relative air humidity.

Using these four formulae, we carried out estimations of the evaporation and attempted to compare the results. Since there is no method allowing to get real values of evaporation it is possible to do it only approximately. As the criterion for the comparison we took the evaporation values calculated from water balance assuming that changes in the sea level equal to the difference between income into the sea (river inflow and precipitation) and outlaw (evaporation and outflow to Kara-Bogas-Gol). Precipitation was taken from reanalysis, other components of water balance were taken from [2]. These evaporation values also are not perfect but they can be concerned as approximate estimations.

On Fig.3, evaporation curves are presented that were estimated with four formulas and by balance method. One can see that evaporation curves received using formulae of Samoilenko, Goptariev and SHI have the same shape. It is quite natural because these formulae have the same structure: they include the product of humidity deficit on wind speed. On Fig. 4, there are presented the graphics of wind speed from Reanalysis averaged for all the territory of the Caspian Sea for cold and warm periods and mean annual values. The shapes of evaporation curves received by the first three formulas coincide with that of wind speed. Therefore, it is wind speed that is mainly responsible for the shape of the evaporation curves. As for the curve of Ivanov formula which has different structure, it is smoother and its range is smaller.

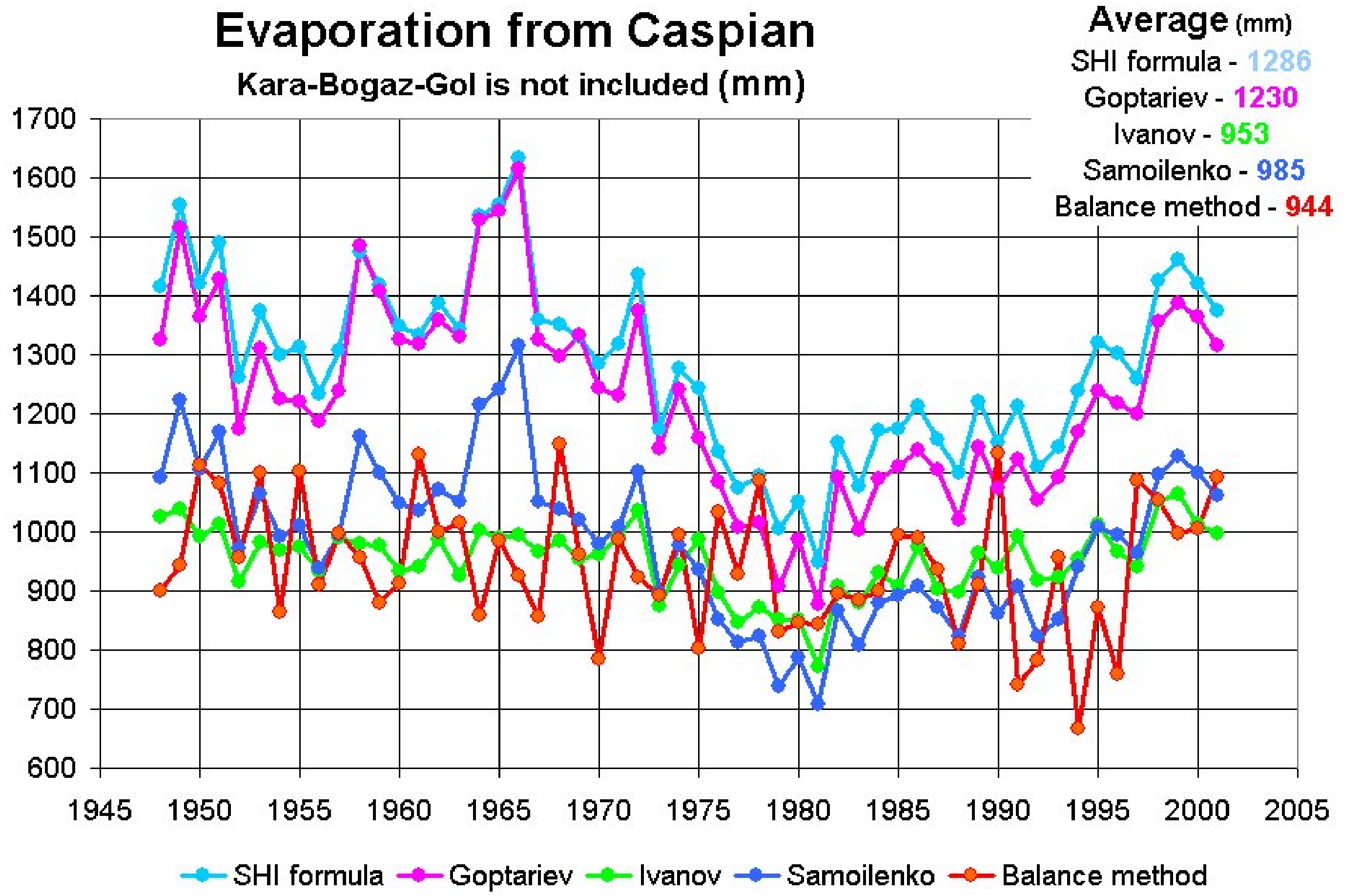

Fig. 3 Evaporation from the Caspian Sea (Kara-Bogaz-Gol is not included) in mm calculated with SHI formula (sky blue), Goptariov formula (pink), Ivanov formula (green), Samoilenko formula (blue) and by balance method (red).

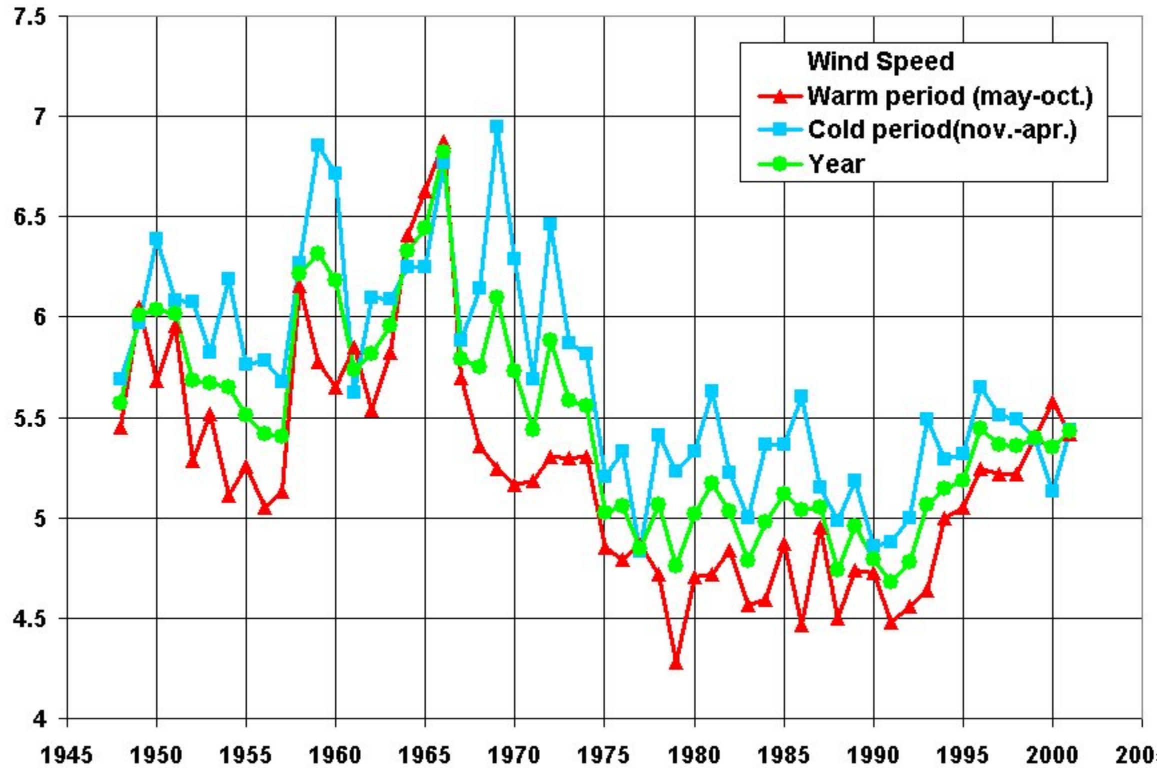

Fig. 4 Average wind speed from Reanalysis for warm period (red), cold period (sky blue), for the whole year (green).

5 CONCLUSIONS

As for the values, evaporation calculated using formulae 2, 3 is significantly higher than that received from water balance. Therefore, the best results have been received using formulae of Samoilenko and Ivanov. Comparison of Samoilenko curve with the balance curve gives acceptable coincidence except for the period 1964-1966. For this period, evaporation calculated using the first three formulae has its peak while that is not the case for balance curve. On Reanalysis wind speed curve (Fig. 4) the pick is also present, especially during the warm period when evaporation is maximal (about 75% of annual sum). Meanwhile, neither ships nor stations register any pick in this period. Hence, we should suspect some defect of reanalysis values of wind speed for the period 1964-1966. Evaporation calculated by Ivanov formula has no pick in this period because the formula does not include wind speed.

For final calculations, we choose the Samoilenko formula because wind speed is an important element for the evaporation process and must be taken into consideration.

Using this formula, we have carried out calculation of the evaporation at first for each month and then for each year during the period from 1948 to 2002. The average annual value of evaporation turned to be 985 mm; this figure coincides with figures got by other scientists [4]. During the period of 1949-1980, the evaporation was decreasing (not taking into account the pick of 1964-66); then it was increasing up to 1999. It had its maximal value in 1949 (1210 mm) and minimal one - in 1981 (700 mm), thus, the amplitude amounts 510mm. This figure is somewhat larger than that received by other investigators. Further research is required to find out the purpose of this.

1. Reanalysis is quite acceptable as a source of meteorological data in the problem of calculation of the evaporation from the Caspian Sea.
2. The most appropriate formula for this is Samoilenko formula.
3. Further investigations are required to choose to more acceptable empirical coefficients in the formula.

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