The Caspian Sea Level Fluctuations as an Example of Local/Global Climatic Change

Gennady N. Panin, Institute of Water Problems, RAS, 117333 Moscow, Russia, panin@aqua.laser.ru

ABSTRACT

The Caspian Sea being the largest inner sea and, thus, considered to be a lake, has its surface level below the level of the World Ocean and unites quite a big watershed areas of such deliberate rivers as Volga, Uhral, Kura, Tereck and etc. and has no connection with the World Ocean. Having its level below the one of the World Ocean and the evaporation area the largest among the all inner lakes on Earth, the Caspian Sea apparently earlier than other places has reacted on the global climate change. Therefore investigation of the Caspian Sea turns out to be extraordinarily important for the climate changes analysis and prediction.

The perennial level variations of the Caspian Sea and components of its water balance are investigated on the basis of the different approaches. But still the physical mechanism generating the long-term directed level changes of the Caspian is not understood. In this study testify to the climatic nature of modern level variations, and also water and heat balance of the Caspian Sea.

1. Introduction

Investigation of the formation and redistribution of water resources on the Earth's surface is getting more important as recently some catastrophic changes occurred in water resources in some regions, including the Caspian Sea region. The sea level rise, which started in 1977 and came up to 2.5m in 1996, has already led to a number of adverse consequences.

The perennial level variations of the Caspian Sea and components of its water balance are investigated on the basis of the different approaches. But still the physical mechanism generating the long-term directed level changes of the Caspian is not understood. Researches of GOLITSYN and PANIN (1989), PANIN et al. (1991, 2003) testify to the climatic nature of modern level variations, and also water and heat balance of the Caspian Sea.

A reliable foresight of the Caspian Sea level behavior is very important as applied and fundamental problem, and its solution is impossible without an adequate description and diagnosis of the causes of the water balance components variations that occurred in the last decades.

Different approaches have been used to study long-term variations of the Caspian Sea level and water balance components. In most cases, the hypothesis of the climate stability within the last decades was assumed. These studies used linear and nonlinear stochastic models with either discrete or continuous time, physical models of interaction between the inner dynamics and the outer medium noise, and other methods. However, the physical mechanism that generates long-term directional changes (tendencies) in the Caspian Sea level is still incompletely understood (see Figure 1).

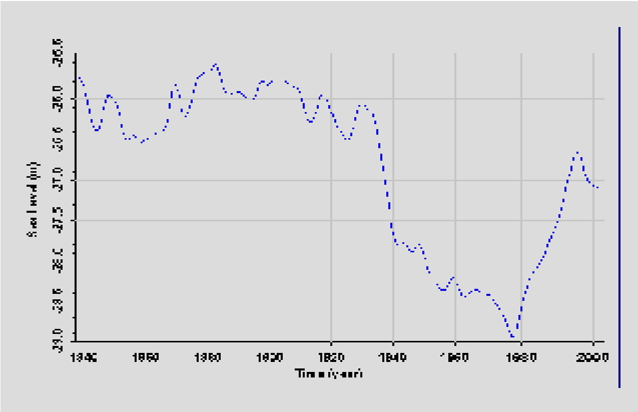

Figure 1. Annual levels of the Caspian Sea measured in the Baku post

In this study, an attempt is made to recognize and describe the causes and principal features of these variations. The study is based on the data of instrumental observations of the surface wind speed vector and represents a stage in developing a deterministic model of the global climate change as applied to certain regions.

These results on one hand are interesting because they evidently shown local climate changes already taken place, on the other hand they prove that modern global climate models (GCM) may be successfully used not only for prediction of global climate changes but also for local climate change.

2. ANALYSIS OF VARIATIONS IN THE CASPIAN SEA WATER REGIME

Analysis [2, 3, 7, 8] of calculated monthly and annual values of evaporation from the Caspian Sea surface and the data of evaporimeters located in different parts of the Caspian Sea catchment area testify to the presence of a statistically significant (at a 95%-level) linear trend in evaporation series. The trend averages to-86 mm/10 yr, or about 8% of the annual norm of evaporation from the sea surface. Results of the joint analysis of variations in the Caspian Sea evaporation and sea level over a long period [5, 6] show a high coherence of these processes during the period of the current sea level rise. Therefore, the question arises: what physical processes caused the decrease in evaporation in the Caspian Sea region over more than 30 years?

The intensity of interaction between the underlying surface and the atmosphere, including the process of evaporation, is controlled by the thermal, moisture, and dynamic characteristics of boundary layers. To establish the reasons for the trends in the rate of evaporation from the Caspian Sea a comprehensive analysis of variations in the hydrometeorological characteristics (the air temperature, water surface temperature, air absolute humidity, and the magnitude of wind speed vector) in 1960-1990 at coastal and insular stations within the Caspian Sea and stations in the sea catchment area was made [7, 8]. No statistically significant linear trends were recognized in local variations in the air and water temperatures and air absolute humidity. These variations can be reliably described by models of autoregression of the first order, the average values of parameters of regression being 0.3-0.4, 0.4-0.5, and 0.25-0.35, of the air and water temperatures and air absolute humidity respectively. At the same time, statistically significant (at a 99% level) trends in the long term variations of the wind speed vector magnitude were found at most coastal and insular stations within the Caspian Sea and at stations in the sea catchment area.

A general tendency toward a decrease in the mean annual wind speed was observed in the region under study in 1960-1990. The average trend is about -0.3 to -0.4 (m/s)/10 yr, or 10% of the annual norm for the wind speed magnitude. The correlation analysis of long term variations in the wind speed magnitude and the rate of evaporation in the Caspian Sea region gives a close cause-and-effect correlation between these processes [7]. The behavior of anomalies of the above parameters in 1960-1990 is as follows. Prior to 1972, positive anomalies of evaporation prevailed; after 1972, its negative anomalies were predominant. The temporal course of anomalies of the wind speed magnitude appeared to precede the respective course of evaporation, leading it by 2-3 years.

3. PRINCIPAL FEATURES OF REARRANGEMENT OF THE SURFACE ATMOSPHERIC CIRCULATION IN THE CASPIAN SEA REGION

Let us write the system of two equations:

$$dH / dt = RF + P_L - E_L + GF \qquad (1)$$

$$dW / dt + AF_1 - AF_2 \approx P - E \qquad (2)$$

Equation (1) characterizes the water balance of the closed water body. Equation (2) characterizes the region water balance, including the water body itself and its basin [10]. In equations: RF- river run-off, GF - underground run-off, W- moisture content of atmosphere above the basin, AF_1, AF_2 - horizontal moisture fluxes.

Let us assume, as in the case of the Caspian Sea $GF \approx 0.01E_L$, and also that the river run-off is determined mainly by the difference of precipitation and evaporation of the water catchment area $RF = F(P_C - E_C)$. Equation (1) it could be rewritten as:

$$dH / dt \approx F(P_C - E_C) + P_L - E_L \approx P_C - E_C + P_L - E_L \qquad (3)$$

At $P = P_C + P_L$; $E = E_C + E_L$ equation (3) it could be rewritten in form:

$$dH / dt \approx P - E \qquad (4)$$

Comparing equations (2) and (4) we find that the water level change may be determined from:

$$dH / dt \approx dW / dt + AF_1 - AF_2 \qquad (5)$$

From (5), in particular, it follows that the water level change essentially depends on horizontal transfer of the air mass, and the direction of its transport (depends on wind direction and wind speed).

Thus, as we have shown, the above analysis in combination with the trend of wind velocity value, gives us a basis to assume the possibility of the existence of certain trends and wind direction changes in the environments of the Caspian Sea. Clarifying of these circumstances is the primary task of new investigations to find out the causes of the Caspian basin evaporation, precipitation and sea level changes.

In this research the linear trends and assess to their statistical significance were examined in time series for stations of Bektash, Kara-Bogaz-Gol, Kuuli-Mayak, Isl. Ogurchinskii, and Gasan-Kuli. The array of representative data on wind speed formed at the Water Problems Institute allows us to analyze the mean monthly values of wind speed for 16 rhumbs (the discreteness is 22.5^0). For every rhumb and for every month, the following parameters of the wind speed vector are calculated: the linear trend and its statistical significance at a 95%-level, the normal annual value, root-mean-square deviation, normal frequency, and frequency trend (Figure 2).

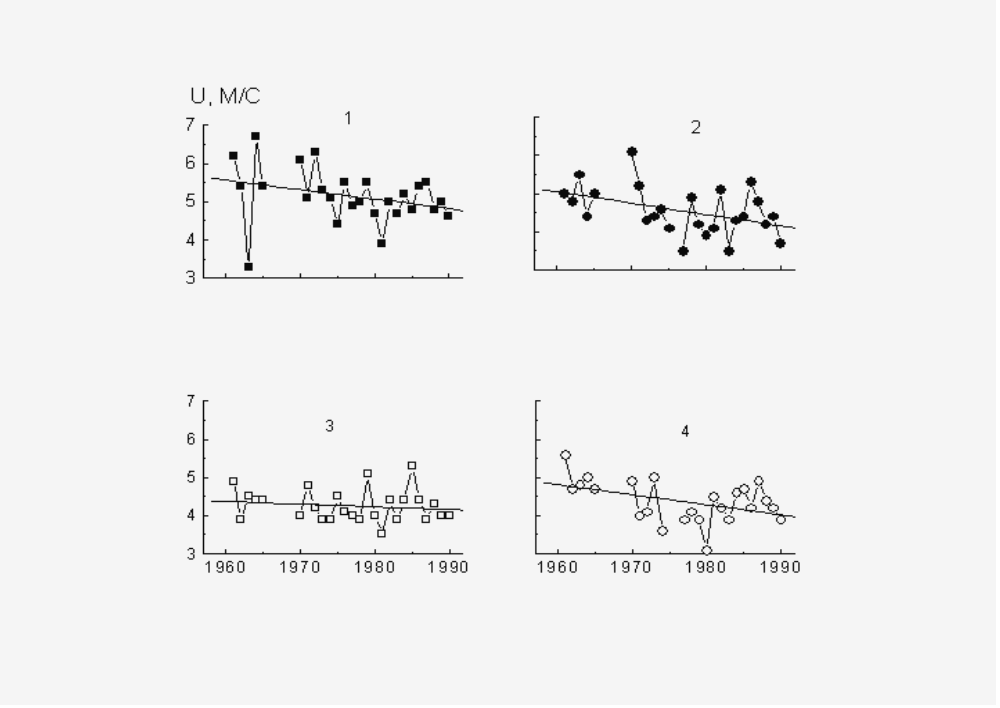

Figure 2. Perennial alteration of speed of the different directions winds on station Bectash. By 1- winter, 2 - spring, 3 - summer, 4- autumn, straight line - shows rectilinear trend.

For western winds, the value of the trend averages 0.23 m/s over 10 years. The value of the rectilinear trend of eastern winds averages for one year 0.38 m/s over 10 years. In a perennial course of the meridian directions winds there are not known statistically significant rectilinear trends. The presently accomplished studies allow us to state that the change of climate in the Caspian Sea area within recent decades was not connected so much with the change of thermal regime, but more with the rearrangement of atmosphere circulation. Such rearrangement of the dynamics of the atmosphere is the physical reason for the formation and development of observed modern directional changes in the movement and intensity of atmospheric masses. The steady nature of such tendency in the wind changes creates statistically significant negative rectilinear trend in the perennial course of intensity of evaporation and precipitation in the area of the Caspian Sea.

The mean long-term annual course of the intensity of interaction between the Caspian Sea and atmosphere, as well as of the thermal and moisture regimes at the interface between the two media (including the differences of temperature, water vapor pressure, and surface wind speed), were studied in [6, 8]. The annual course of evaporation from the Caspian Sea surface is found. In the middle and southern parts of the Caspian Sea, evaporation is most intensive in winter about 80 mm/month on average and 100 mm/month near the eastern sea coast, where the stations included in the study are situated. The minimal rate of evaporation is observed here in the late spring-early summer (E = 30 mm/month); in autumn, the rate of evaporation grows. The annual difference between monthly values of evaporation from this water area averages about 90 mm/month, or about 10% of the annual norm.
As mentioned above, the long term variations in the rate of evaporation from the Caspian Sea correlate not only with the thermal and moisture regimes in the layer of interaction between the sea and atmosphere but also with the regional rearrangement of the surface atmospheric circulation. Long term variations of evaporation are characterized by a linear trend equal to 86 mm/10 yr, which approximates the amplitude of

the annual course of evaporation. The long term distribution of statistically significant trends in wind speed, which reflects the seasonal dynamics of the atmosphere, has yet to be studied. For this purpose, monthly series of wind speed modulus are analyzed for the presence of trends and their significance at a 95%-level.

Thus, the analysis of variations in the speed of surface winds of different directions over the long period shows that for most stations, statistically significant trends in the mean annual wind speed are due to respective trends observed in the winds of zonal directions (whose speed is the highest) in the seasons remarkable for high rates of evaporation from the sea surface (winter, autumn). At the stations, where statistically significant trends are not recognized in the mean annual magnitudes of wind speed, statistically significant negative trends are found in winds in winter (mainly in winds of zonal directions). As mentioned above, winter is remarkable for a high rate of evaporation and high wind speed. Evidently, it is the negative trends in the winds of zonal directions in the autumn-and-winter season that are mainly responsible for the decrease in the rate of evaporation over the last 30-40 years.

The investigations performed allowed us to diagnose the formation and development of steady directional changes in the intensity of processes of interaction between the underlying surface and the atmosphere (including evaporation) in the Caspian Sea region during nearly the 20-year period of the sea level rise. It is found that the global climate nonstationarity manifested itself in the Caspian Sea region during the last decades in the essential rearrangement of the surface atmospheric circulation. In the region as a whole, a tendency towards a decrease in the wind speed in the surface layer of the atmosphere is observed. Against this background, trends in the mean monthly wind speed vary with wind direction and season. A steady, statistically significant trend towards a decrease in the speed magnitude of the winds of zonal directions is found. The trend is most pronounced in winter (up to -0.9 (m/s)/10 yr for the western winds and -0.5 (m/s)/10 yr for the eastern winds) and in autumn (up to -0.3 (m/s)/10 yr for the western and eastern winds). Trends in the winds of meridional directions, especially in spring and summer, are of different sign; some trends are statistically insignificant. It was also established that at the stations, where no statistically significant negative trend in the mean annual wind speed had been recognized before, this trend exists in the speed of winds of zonal directions.

The above results show that in the studied region a steady, statistically significant decrease is observed in the speed of surface winds of meridional directions, which speed is about 20% higher than the speed of winds of other directions. This trend is mainly observed in the seasons (autumn, winter), when the intensity of interaction between the water surface and the atmosphere is maximal. This rearrangement of the atmospheric dynamics in the interaction layer is the physical basis for the formation and development of present tendencies in the rate of interaction between the atmosphere and the underlying surface and, as a consequence, in the Caspian Sea water regime.

The study shows that the deterministic approach is profitable for the diagnosis of both present variations in the most important output component of the Caspian Sea water balance (evaporation from the sea surface) and the processes that to a great extent control the water inflow into the sea (evaporation and precipitation within the Caspian Sea catchment area).

ARPE et al (1999) using the model of general atmosphere circulation and ocean of Meteorologic Institute of Max Planck (ECHAM4/OPYC3) produced good correlations and, accordingly, were able to make a forecast of the sea level variation. We shall put here outcomes of the precipitation forecast around the Caspian Sea (see Figure 3).

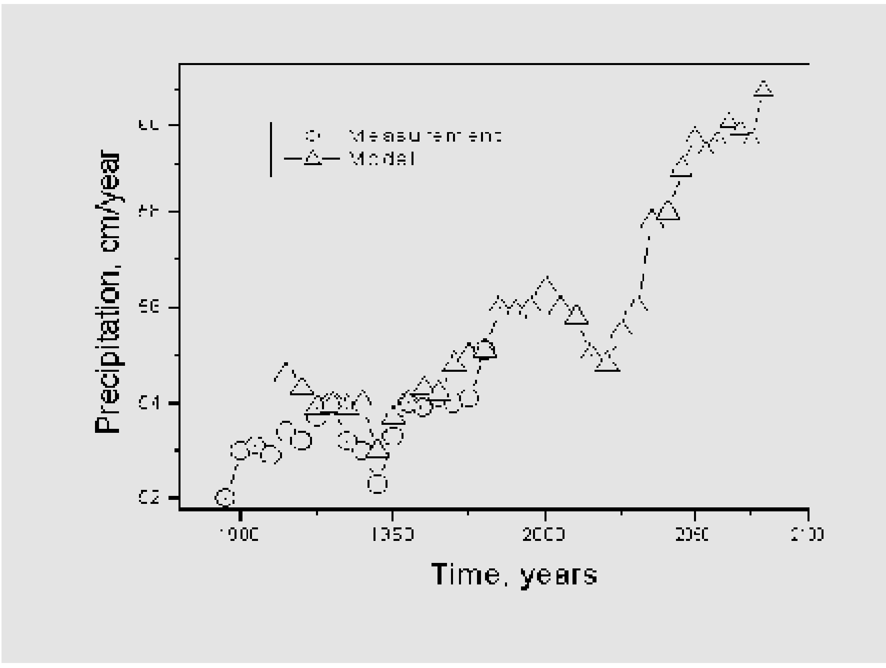

Figure 3. The Caspian Sea precipitation forecast (Arpe et al., 1999)

4. CONCLUSION

Here the Caspian Sea level changes as example of local climate change were observed. Information is presented so as to give a consequent description of the main water balance components of the present sea and to show their variability in temporal view. Particular attention is paid to the reason of sea level change.

On the basis of the above reasoning, the occurrence of present variations in the rate of evaporation and water balance of the Caspian Sea can be explained as follows. The combination of the global processes such as the interaction between the atmosphere and the underlying surface, human impact on the interacting media, and the long-period (of the order of decades) directional changes (trends) in geophysical parameters generates the nonstationarity of the global climate.

Over the last decades, the Caspian Sea catchment area experienced the effect of the global climate change, which manifested itself in the rearrangement of the surface atmospheric circulation. This makes itself evident in a decrease in the speed of winds of zonal directions (the strongest and most frequent winds), which is mainly observed in autumn and winter, when the rate of interaction between the underlying surface and the atmosphere is maximal. The steady character of this tendency in the dynamics of the surface air layer is largely due to a statistically significant negative linear trend in the rate of evaporation in the Caspian Sea region. In this case, the decrease in the rate of evaporation from the sea surface causes a decrease in the major output component of the sea water balance, whereas the observed decrease in the rate of evaporation from the surface of the sea catchment area is only one of the factors controlling the water inflow into the sea.

The consistency of the present variations in the wind speed vector in the region under study with variations in both the rate of evaporation from the Caspian Sea surface and the sea level counts in favor of the above mechanism of the formation and development of the Caspian Sea water regime over the last decades. It is shown that variations in the Caspian Sea water balance in this period might be caused by the effect of the totality of global hydrometeorological processes. This is the difference between the given approach and those based on the description of statistical properties of time series of the sea water balance components.

The change of sign in the long-term trend of the prolonged variations in the angular velocity of the Earth's rotation might serve as a predictor for the change of sign in the current trends of the hydrometeorological processes controlling the intensity of interaction between the underlying surface and the atmosphere in the region under study.

This study is a step for the development of a deterministic model of the global climate change manifestation at the regional level. The diagnosis of variations in the amount of precipitation in the Caspian Sea catchment area over a long period is the next stage of our investigations.

These results on one hand are interesting because they evidently shown local climate changes already taken place, on the other hand they prove that modern global climate models (GCM) may be successfully used not only for prediction of global climate changes but also for local climate change.

REFERENCES

1. ARPE K., L. BENGTSSON, G. S. GOLITSYN, I. I. MOKHOV, V. A. SEMENOV, P. V. SPORISHEV (1999): Analysis and Simulation of Changes in the Hydrological Regime in the Caspian Sea Basin, Dokl. Ross. Akad. Nauk, vol. 366, N. 2, 248-252.

2. BUDYKO, M.I., N. A. EFIMOVA, V. V. LOBANOV (1988) Future Level of the Caspian Sea, Meteorol. Gidrol., N. 5, 86-94.

3. GOLITSYN, G.S., G. N. PANIN (1989): On Water Balance and the Present Variations in the Caspian Sea Level, Meteorol. Gidrol., 1989, N. 1, 57-64.

4. GOLITSYN, G.S., D.Ya. RATKOVICH, M. I. FORTUS, A. V. FROLOV (1998): On the Present Rise in the Caspian Sea Level, Vodn. Resur., 1998, vol. 25, N. 2, 133-145.

5. PANIN, G.N (1987): Evaporation and Heat Exchange of the Caspian Sea, Moscow: Nauka, 89 pp.

6. PANIN, G.N (1999): Progress in Studying Evaporation from the Caspian Sea Surface, Vodn. Resur., vol. 26, N. 6, 643-651.

7. PANIN, G.N., DZUYBA, A.V., A. G. OSIPOV (1991): On Possible Causes of Changes in the Evaporation in the Caspian Sea Region during Past Decades, Vodn. Resur., N. 3, 5-16.

8. PANIN G.N., DZUYBA A.V. (2003): Modern changes of a wind vector and intensity of evaporation from a surface of the Caspian Sea. Wodnye resoursy, N. 2, Moscow, 198-207.

9. RATKOVICH, D.Ya. (1994): Probabilistic Prediction of the Level Regime in Inland Water Bodies, Vody sushi: problemy i resheniya (Continental Waters: Problems and Solutions), Moscow: Inst. Water Problems, 145-178.

10. RASMUSSON, E.M. (1977): Hydrological Applications of Atmospheric Vapor Flux Analysis, WMO. Rep. 1.