

3.1.13 Caspian Sea level fluctuations as a consequence of regional climatic change

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SUMMARY: *The Caspian Sea, the largest continental lake, without discharge, has experienced a sea level decrease of nearly 3 m since approximately 1930. This process was inverted in 1977 so that the earlier conditions are nearly replaced again. Based on climate data covering the period 1961–1990, it is statistically shown that this recent sea level increase was caused by a significant change of the regional wind patterns. A detailed analysis of this phenomenon shows how large-scale climate change can lead to pronounced consequences at the regional scale.*

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

The Caspian Sea being the largest inner sea has its surface level below the level of the world ocean and unites a large watershed including the rivers Volga, Ural, Kura and Terek. It has no connection with the world ocean. With the largest evaporation area of all lakes on Earth, the Caspian Sea has shown earlier than others a reaction to global climate change. Therefore investigation of the Caspian Sea characteristics turns out to be extraordinarily important for climate change analysis and prediction.

The long term level variations of the Caspian Sea and its water balance components have been investigated by different approaches. But still the physical mechanism generating the long-term level changes are not understood. Studies by GOLITSYN & PANIN (1989), PANIN et al. (1991, 2003, 2005) testify to the climatic nature of recent level variations, and thus also of the water and heat balance.

A reliable projection of the Caspian Sea level behaviour is very important as an applied and fundamental

problem, and is impossible without an adequate description and diagnosis of the causes of the water balance components variations that occurred during the recent decades.

In most cases, the hypothesis of climate stability within the recent decades had been assumed. Most studies used linear and non-linear stochastic models that described the interaction between the inner dynamics of the sea and the high frequency stimulation by the atmosphere. However, the physical mechanism that generates long-term changes (tendencies) in the Caspian Sea level is still not completely understood. A decrease in the Caspian Sea level was predicted by RATKOVICH (1994). Contrary to that GOLITSYN et al. (1998) projected a sea level rise up to 2010. The sea level in 2000 had been expected to be -28.0 (PANIN et al. 2005) and from -27.0 to -26.0 m (GOLITSYN et al. (1998); actually, it was -27.1 m (see Fig. 3.1.13-1).

Efforts to estimate the Caspian Sea level in the near future made by BUDYKO et al. (1988) also cannot be considered fully successful. In this study, an attempt is made to recognise and describe the causes and principal features of these variations. It is based on the observations of the near surface wind speed vector at 10 m height and represents a new stage in developing a deterministic model of global climate change impact to a certain region.

These results on one hand are interesting because they



Fig. 3.1.13-1: Annual levels of the Caspian Sea measured at the Baku station (Source: <http://www.caspinfo.net>).

evidently show that local climate changes already take place, on the other hand they prove that modern general circulation climate models (GCMs) can be successfully used not only for prediction of global climate change but also for local and regional climate change.

Analysis of variations in the Caspian Sea water regime

Analysis (GOLITSYN & PANIN 1989, PANIN et al. 1991, PANIN & DZUYBA 2003) 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 point to the presence of a statistically significant (at a 95%-level) linear trend in evaporation series. The trend averages -86 mm/10 year, or about 8% decrease of the annual mean evaporation from the sea surface. Results of the joint analysis of variations in the Caspian Sea evaporation and sea level over a long period (PANIN 1987, 1999) 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, humidity, 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, absolute humidity of air, and the wind speed) in 1960–1990 at coastal and island stations within the Caspian Sea and stations in the sea catchment area was made (PANIN et al. 1991, PANIN & DZUYBA 2003). No statistically significant linear trends were recognised in air and water temperatures and absolute humidity. These variations can be reliably described by autoregression models of the first order with average values of the regression parameters: 0.3–0.4, 0.4–0.5, and 0.25–0.35, for air and water temperatures and absolute humidity, respectively. In such cases, the predictability of changes in the above hydrometeorological characteristics of the Caspian Sea region is rather low (as a rule, the limit of predictability does not exceed 1–2 averaging time steps).

At the same time, statistically significant (at a 99% level) trends in the long term variations of wind speed were found at most coastal and island stations of the Caspian Sea and at stations in the catchment area. A general tendency toward a decrease in the mean annual wind speed was observed in the region under study from 1960 to 1990. The average trend lies between -0.3 and -0.4 m/s per decade, or 10% of annual mean wind speed. The correlation

analysis of long term variations in wind speed and evaporation rate in the Caspian Sea region give a close cause-and-effect relation between these processes (PANIN et al. 1991). The behaviour of anomalies of the above parameters in 1960–1990 is as follows. Prior to 1972, positive anomalies of evaporation prevailed; after 1972, negative anomalies were predominant. The anomalies of wind speed preceded the evaporation anomalies by 2–3 years.

Principal features of rearrangement of the near surface atmospheric circulation in the Caspian Sea region

Here, we investigate how temporal variability of local hydrometeorological characteristics are connected to global climate change.

Let us write the water balance:

$$dH/dt = R + P_c - E_c + G \quad (1)$$

$$dW/dt + F_1 - F_2 = P - E \quad (2)$$

Equation (1) characterises the water balance of a closed water body. Equation (2) characterises the regional atmospheric water balance over the Caspian Sea and its catchment (RATKOVICH 1994).

R = river run-off,

G = underground run-off,

W = moisture content of atmosphere above the basin,

F_1, F_2 = horizontal moisture fluxes into and out of the basin,

P_c = precipitation rate and

E_c = evaporation rate

Let us assume for the Caspian Sea $G \gg 0.01 \times E_c$, and also that the river run-off R is determined mainly by the difference between precipitation P_b and evaporation E_b within the catchment area $R = f(P_b - E_b)$. Equation (1) could then be rewritten as

$$dH/dt \approx f(P_b - E_b) + P_c - E_c \approx P_b - E_b + P_c - E_c \quad (3)$$

With $P = P_c + P_b$ and $E = E_c + E_b$ equation (3) changes into

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

Combining (2) and (4) and introducing it into (1) a level change can be determined from

$$dH/dt \approx dW/dt + F_1 - F_2 \quad (5)$$

From (5), it follows that the water level change essentially depends on horizontal transfer of the air mass, and the direction of its transport. Thus, as we have shown, the above analysis in combination with the trend of wind velocity, gives us a basis for new investigation to find the causes of the Caspian basin evaporation, precipitation and sea level changes.

In this research linear trends and their statistical significance were examined in time series for the stations Bektash, Kara-Bogaz-Gol, Kuuli-Mayak, Ogurchinskii Island, and Gasan-Kuli. The data on wind speed from the Water Problems Institute allows us to analyse the mean monthly wind speed at 10 m height for 16 wind directions. For every direction class and for every month, the following parameters of the wind speed vector are calculated: linear trend and its statistical significance at a 95%-level, the mean annual value, root-mean-square deviation, mean frequency, and frequency trend (Fig. 3.1.13-2).

For westerly winds, the value of the trend averages -0.23 m/s per decade. The value of the linear trend of easterly winds is -0.38 m/s per decade. For the meridional directions no statistically significant linear trends were found. Caspian Sea climate within recent decades was not so much connected to changes of the thermal regime, but more with the change in atmosphere circulation. Such rearrangement of the dynamics of the atmosphere is the physical reason for the observed directional changes in atmospheric flow. Negative wind speed trend leads to a statistically significant negative linear trend of evaporation from 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 vapour pressure, and surface wind speed), were also studied by PANIN (1999) and PANIN & DZUYBA (2003). The annual course of evaporation from the Caspian Sea surface is as follows: In the middle and southern parts of the Caspian Sea, evaporation is most

intense in winter with about 80 mm/month on average and 100 mm/month near the eastern coast, where the stations included in the study are situated. The minimal rate of evaporation is observed here in late spring and early summer with 30 mm/month. In autumn, the rate of evaporation grows.

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 characterised by a linear trend equal to 86 mm/decade, which is close to 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 to be studied now. For this purpose, monthly series of wind speed are analysed for trends and their significance at a 95%-level.

For most stations, statistically significant trends in the mean annual wind speed are due to trends observed in zonal wind direction (whose speed is the highest) in the seasons with high evaporation rates (winter, autumn). At the stations, where statistically significant trends are not recognised in the annual wind speed mean, statistically significant negative trends are found in winter (mainly with winds of zonal direction). As mentioned above, high evaporation and high wind speed exist in winter. Evidently, it is the negative trends in zonal winds in autumn and winter that are mainly responsible for the decrease in the evaporation rate during the last 30–40 years.

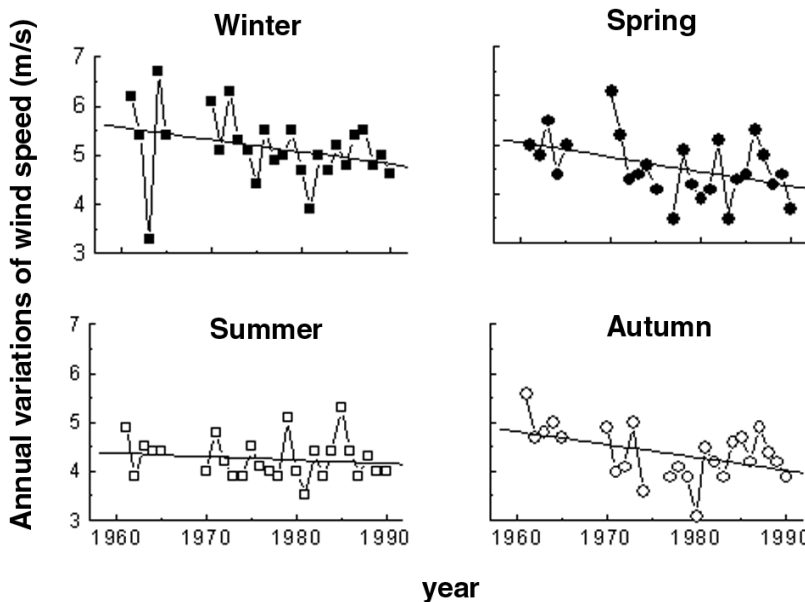


Fig. 3.1.13-2: Annual variations of wind speed at station Bektash for winter, spring, summer and autumn. The linear trends are also indicated (PANIN & DZUBA 2003).

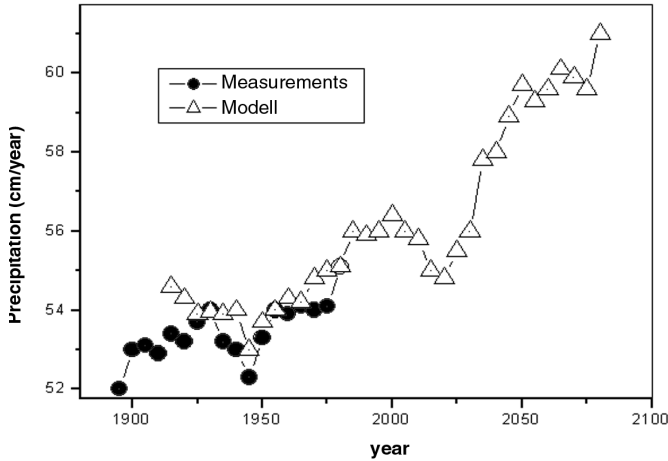


Fig. 3.1.13-3: The Caspian Sea precipitation in 20th century and forecast for 21st century (ARPE et al. 1999).

During nearly 20-years with a Caspian Sea level rise the non-stationarity of global climate manifested itself in a rearrangement of the near 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 wind speed, especially for zonal directions is found.

The trend is most pronounced in *winter* up to -0.9 m/s per decade for westerly winds and -0.5 m/s per decade for easterly winds and in *autumn* up to -0.3 m/s per decade for westerly and easterly winds. Trends of wind with meridional direction, especially in spring and summer, are of different sign; however, these trends are often statistically insignificant. Where no statistically significant negative trend in the annual mean wind speed had been detected a trend exists for zonal directions.

This trend is mainly observed in the seasons (autumn, winter), when the intensity of interaction between the water surface and the atmosphere is highest.

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 large extent control the water inflow into the sea (evaporation and precipitation within the Caspian Sea catchment area).

ARPE et al (1999) using a coupled atmosphere/ocean model of the Max Planck Institute for Meteorology (ECHAM4/OPYC3) were able to make a forecast of Caspian Sea level variation (see Fig. 3.1.13-3). Latest data of the Caspian Sea level changes confirm the tendency forecast given in Fig. 3.1.13-1.

Conclusion

Even when the magnitude of climate forcing by changes in external factors such as solar radiation or absorbing gas concentration is known, it is a major task to translate such changes into an accurate assessment of the resulting climate change. This difficulty occurs primarily because the terrestrial climate system can respond to the imposed changes by reinforcing their magnitude (a positive feedback) or by damping (a negative feedback). Without being comprehensive, here we could discuss a few of the better known climate feedback processes. We tried to explain the Caspian Sea level changes as an example of local climate change driven by global changes.

The combination of 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 non-stationarity of the global climate.

Over the last decades, the Caspian Sea catchment experienced a decrease in wind speed of zonal directions (the strongest and most frequent winds), mainly in autumn and winter, when the interaction between the underlying surface and the atmosphere is highest. A statistically significant negative linear trend in the rate of evaporation in the Caspian Sea region is the result causing a decrease in the major output component of the water balance. The consistency of the observed trends in wind speed with evaporation rate trends and sea level rise points to the above mechanism for the change of the Caspian Sea water regime over the last decades. 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's area over a long period is the next stage of our investigations ♦