Prediction of the Caspian Sea Level
6 months ahead using ECMWF seasonal forecast and reanalysis data

Klaus Arpe
Max Planck Institute for Meteorology, Hamburg

Suzanne Leroy
Institute for the Environment, Brunel University, West London

Valentina Khan
Hydrometeorological Research Center of the Russian Federation, Moscow

Fredrik Wetterhall
European Centre for Medium-Range Weather Forecasts, Reading
Overview

• Introduction
• Earlier work on the Caspian Sea Level (CSL)
• Importance of the Volga River
• Connections with ENSO
• European Russian drought 2010
• Parameterization of the delay along the VOLGA River
• Simulating the CSL from P-E provided by the ECMWF interim Reanalysis
• Using also seasonal forecasts by ECMWF
• Validation is a main task
• Outlook
The Caspian sea is positioned in a closed basin without any outlet. It is surrounded by countries with very different climates: Desert in Turkmenistan and very humid climate at the Iranian coats.

The main water source is the Volga which has its catchment in a mid-latitude climate and which was severely affected by the summer 2010 drought in European Russia.
**Annual mean precipitation**

The Caspian Sea is positioned in an arid area, as shown by annual mean precipitation maps. The heavy black lines indicate the catchment areas of the CS.

**ERA** is the ECMWF interim reanalysis which uses almost all possible observational data from surface pressure to radiances measured by satellites except precipitation observations. The precipitation data result from two 12 hour forecasts every day. ERA provides also evaporation and many other data.
The annual water balance equation for the Caspian Sea

\[ \text{CSLinc} = R + P + S - E - KBG \]

CSLinc - the annual CSL increment,
R - the total river inflow,
P - the precipitation over the sea,
S - the subsurface runoff into the sea,
E - the evaporation,
KBG - the water discharge into the Kara-Bogas-Gol

Some old estimates
R= 77, E-P=76, S=1, KBG=4,
CSLinc = near zero over long periods.
## Water budget components for the Caspian Sea.

**Units:**
change of the Caspian Sea Level per year in cm.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>VB precipitation ERA (GPCC)</td>
<td></td>
<td>232 (207)</td>
</tr>
<tr>
<td>VB evaporation</td>
<td></td>
<td>-167</td>
</tr>
<tr>
<td>VB P-E = Volga discharge</td>
<td></td>
<td>66</td>
</tr>
<tr>
<td>Volga discharge (observed)</td>
<td>60</td>
<td>71</td>
</tr>
<tr>
<td>Other rivers</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>CS precipitation</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>CS evaporation</td>
<td>-95</td>
<td>-81</td>
</tr>
<tr>
<td>CS P-E including KBG</td>
<td>-75</td>
<td>-56</td>
</tr>
<tr>
<td>Entire Caspian catchment P-E</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>CSL change</td>
<td></td>
<td>-2</td>
</tr>
</tbody>
</table>
The Caspian Sea level during the last millennium

The changes of the CSL were 3 m during the last century but during the last millennium they were much larger perhaps more than 10 m.

Two completely different sources have been used here to show the CSL during the last millennium. Only the pink and red pieces of the curves show observations. Although they differ in absolute numbers, they agree in many aspects of the variability.

Karpychev YA 2001, Brückner, E., 1890

The length of this low level is unsure but the steep increase around 1300AD is well documented

The 2 low-stands in the 2 curves could be at the same time because of uncertainties in the dating.
Caspian Sea level change and Volga discharge

The importance of the Volga River for the Caspian Sea Level (CSL) can be shown by integrating the observed precipitation anomalies over the Volga River catchment in time. Integrating annual means of precipitation over the Volga basin (year) reproduce the CSL very well. Estimates from seasonal means (spring, summer, fall and winter) are shown as well.

From 1950 onwards the estimates from annual mean precipitation gives higher values than the observed CSL, due to the building of dams.

Summer precipitation gives the best similarity to the annual mean.
**CSL as observed and estimated from observed SOI and NINO4 SST anomalies.**

Integrating anomalies of indices of the southern oscillation in time gives a similar variability as that of the CSL.

**ENSO and CSL variability**

The figure (top) shows the CSL changes in time (CSLc), the Volga River discharge (VRD) and the ONI (another index for ENSO) in the lower panel. A 9 month smoothing is applied, also for the numbers given below.

There is a **high similarity** between the CSL changes and the Volga River discharge with an **anomaly correlation of 0.71** and between the CSL change and ONI of 0.47.

<table>
<thead>
<tr>
<th>CSLchg-VRD</th>
<th>precipVB-VRD</th>
<th>CSLchg-ONI</th>
<th>VRD-ONI</th>
<th>precipVB-ONI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.71</td>
<td>0.39</td>
<td>0.47</td>
<td>0.13</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Anomaly correlations of monthly means between the CSL change, ENSO index (ONI), Volga River Discharge (VRD) and precipitation over the Volga basin (precipVB). A 9 month running mean has been applied.

I always assumed that ENSO affects the precipitation over the Volga and that influences then the CSL. These correlations do not support such a sequence.

Walker circulation displayed by wind at the equator in the ECM analysis and anomalies during El Niño.

During El Niño events the Walker circulation is weakened and during La Niña events it is strengthened.
200hPa wind change in 80 years time (top panel) and 200hPa wind anomalies during El Nino events (bottom panel) during DJF.
Conclusions 1

a) Small differences between the river inflow and the evaporation over the sea create the variability of the Caspian Sea level (CSL)

b) The CSL variability is dominated by the Volga river discharge.

c) The variability of the Volga river discharge is dominated by the precipitation over its catchment area.

d) The Southern Oscillation (ENSO) has a clear impact on the CSL variability
The summer 2010 drought

Time series of monthly mean anomalies since 2009, i.e. with the mean annual cycle removed, for a selection of variables. No smoothing.

a) Precipitation over the Volga basin using ERA and GPCC data
b) Evaporation over the Volga basin using ERA data.
c) 2m temperatures averaged for the Volga basin, using ERA data.
d) Evaporation over the Caspian Sea itself using ERA data.
e) Volga discharge as observed
f) Caspian Sea Level

## Water budget component anomalies for summer 2010. Units: cm change of the Caspian Sea Level per month.

<table>
<thead>
<tr>
<th></th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSL change</td>
<td>-4.4</td>
<td>-2.8</td>
<td>-3.3</td>
<td>-10.5</td>
</tr>
<tr>
<td>Observed Volga discharge</td>
<td>-1.0</td>
<td>-0.6</td>
<td>-0.8</td>
<td>-2.4</td>
</tr>
<tr>
<td>VB precip. ERA (GPCC)</td>
<td>-20.6 (-19.6)</td>
<td>-4.0 (-2.3)</td>
<td>-3.3 (-5.0)</td>
<td>-28.0 (-26.9)</td>
</tr>
<tr>
<td>VB evaporation</td>
<td>+2.0</td>
<td>+2.6</td>
<td>+1.6</td>
<td>+6.3</td>
</tr>
<tr>
<td>VB P-E (ERA)</td>
<td>-18.6</td>
<td>-1.4</td>
<td>-1.7</td>
<td>-21.8</td>
</tr>
<tr>
<td>CS precipitation</td>
<td>-0.7</td>
<td>-0.4</td>
<td>-1.1</td>
<td>-2.2</td>
</tr>
<tr>
<td>CS evaporation</td>
<td>-3.2</td>
<td>-1.5</td>
<td>-1.5</td>
<td>-6.3</td>
</tr>
<tr>
<td>CS P-E</td>
<td>-3.9</td>
<td>-1.9</td>
<td>-2.6</td>
<td>-8.4</td>
</tr>
<tr>
<td>Entire CS catchment P-E</td>
<td>-34.4</td>
<td>-5.6</td>
<td>-8.9</td>
<td>-47.9</td>
</tr>
</tbody>
</table>

- The drop of the CSL during summer can already be explained by the increased evaporation over the CS itself which has an immediate effect.
- For the impact from the drought over the Volga basin one has to wait a few months longer because of a time delay.
Comparing the CSL variations with the impacts of the different components of the CS water budget gives a **consistent picture** of the impacts of the recent drought in European Russia. This gives **confidence in the quality of the data**.

During the heat wave in summer 2010 an increase in evaporation over the VB might have been expected and indeed such an increase was found in the early stage of the heat wave in May. But the opposite was observed further on, probably because the precipitation deficit led to drier soil which then became a limiting factor for the evaporation.

This drop in precipitation could not have led to an **instantaneous drop in the CSL**; for that the **evaporation over the CS itself is responsible**.

The **impact from the precipitation deficit over the VB deficit occurs at a later stage, until summer 2011**.

Some scope for **making forecasts of the CSL a few months ahead** seems to be feasible and triggered the present investigation.

The assumption that it is the **Volga River discharge variability which determines the CSL variability** has generally been found also with the new data but at some periods the evaporation over the CS itself became important too.
Making forecasts

For input of such a forecast we have the ECMWF reanalysis data and the seasonal forecasts for 6 month ahead every month. The latter are ensemble means over 11 or 41 simulations.

The first task is to parameterize the delay between precipitation events over the Volga basin and the discharge of the Volga river into the Caspian Sea.

The second task is to sum up all components of the water budget of the CS and integrate them in time.

The forecast data can be used the same way as the analysis data. As there is a long delay along the Volga river the forecasts are extended to 9 months using climatological values after 6 months.

The third task is to validate the results.
What is ECMWF

The primary task of ECMWF is to make medium range weather forecasts. To do that, the initial fields (analyses) are needed and that is used here. To avoid spurious changes in the analysis due to improvements of the analysis/forecasting scheme, the analyses have been redone (re-analyses) with a scheme which did not change throughout the period.
What is ECMWF

Recently ECMWF is carrying out as well seasonal forecasts over 6 months ahead. They are less accurate and should provide information, e.g. if the precipitation 40-90°E / 45-65°N (this example) will be above, below or similar as normal.
What is the time delay between precipitation events over the Volga and discharge extremes at Volgograd?

Precipitation maxima are followed by discharge maxima after 1 to 3 months; for precipitation minima, the delay is longer, probably due to the reservoirs which let water through according to energy demand.
"Modeling the VRD from P-E"

P-E comes in with a delay due to snow, ice and the time to reach the mouth of the river.

Typical weighting in winter:
0.2*X(mon-2)+0.4*X(mon-3)+0.4*X(mon-4)

Typical weighting in summer:
0.2*X(mon-1)+0.4*X(mon-2)+0.4*X(mon-3)

Questions:
Is the 20% optimal?  
How many deeper reservoirs to choose?
Delay along the Volga River

P-E direct values have a maximum from October to February (P-Ei) while the observed VRD (VRDo) has its maximum in May. Assuming that ice and snow will delay the flow of water by up to 4 months in winter and less in summer, the extremes are already shifted by several months in the right direction (P-Ec).

Applying as well a parameterization of effects reservoirs along the Kama/Volga but without a ground water parameterization (NoGW), a nearly perfect match with the observed VRD can be achieved.

Using as well the ground water parameterization (VRDc), the discharge becomes a little flatter.

Annual cycle of the Volga River discharge as observed (black) compared with P-E over the Volga Basin from ERA. Direct values of P-E from ERA (pink) and after applying a delay due to snow and ice for ERA (light blue)

Calculated VRD applying a delay due to snow and ice and a parameterization of the effects by reservoirs for ERA without ground water impacts (green) or with ground water (red).

Using the same procedure for FCST (purple for 6 months FCST and yellow for 9 months)
**Monthly variability of the VRD**

The summer maxima are often **over estimated by the estimates without using a ground water scheme (noGW)** and in 2010 the Volga would have run dry. Also the ERA maxima are too large.

The **winter variabilities (minima)** are partly well simulated by ERA.

Even when the mean annual cycles are removed forecasts and observations show similar variabilities though the correlation coefficients are low. The simulations without ground water have too large extremes.

<table>
<thead>
<tr>
<th></th>
<th>with annual cycle no smoothing</th>
<th>no annual cycle no smoothing</th>
<th>with annual cycle with smoothing</th>
<th>no annual cycle with smoothing</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBS-ERA</td>
<td>0.74</td>
<td>0.26</td>
<td>0.87</td>
<td>0.47</td>
</tr>
<tr>
<td>OBS-FCST</td>
<td>0.68</td>
<td>0.14</td>
<td>0.80</td>
<td>0.22</td>
</tr>
</tbody>
</table>

The smoothing is a 1-2-1 filter