

This discussion paper is/has been under review for the journal Hydrology and Earth System Sciences (HESS). Please refer to the corresponding final paper in HESS if available.

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe^{1,2}, S. A. G. Leroy², H. Lahijani³, and V. Khan⁴

¹Max Plank Institute for Meteorology, Hamburg, Germany

²Institute for the Environment, Brunel University, Uxbridge, London, UK

³Iranian National Institute for Oceanography (INIO), Tehran, Iran

⁴Hydrometeorological Research Center of the Russian Federation, Moscow, Russia

Received: 23 July 2011 – Accepted: 8 August 2011 – Published: 15 August 2011

Correspondence to: S. A. G. Leroy (suzanne.leroy@brunel.ac.uk)

Published by Copernicus Publications on behalf of the European Geosciences Union.

HESSD

8, 7781–7803, 2011

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Abstract

The hydrological budgets of the Volga basin (VB) and the Caspian Sea (CS) have been established. The components of the water balance for the CS were calculated for the period 1993 to 2010 with emphasis on summer 2010 when a severe drought developed over European Russia.

A drop in precipitation over the VB in July 2010 occurs simultaneously with a decrease in evaporation for the same area, an increase of evaporation over the CS itself and a drop of the Caspian Sea Level (CSL). The drop in the precipitation over the VB cannot have led to an instantaneous drop of the CSL because the precipitated water needs some months to reach the CS. The delay is estimated to be 1 to 3 months for excessive precipitation in summer, longer for other cases. However, the evaporation over the CS itself is considered to be responsible for a simultaneous drop of the CSL from July to September 2010. The impact on the CSL from the precipitation deficit over the VB occurs in the months following the drought. The water deficit from July to September 2010 calculated from the anomalous precipitation minus evaporation over the VB would decrease the CSL by 22 cm, of which only 2 cm had been observed until end of September (observed Volga River discharge anomaly), 7 cm from October to the end of 2010 and another 5 cm to the end of May 2011. From October 2010 to February 2011 excessive precipitation occurred over the Volga basin, equivalent to an increase of the CSL of 7 cm which might just compensate the 7 cm of the remaining deficit from the summer drought. A deficit of water took however already place in the months before July 2010. In previous studies the precipitation over the VB has been identified as the main cause for CSL changes, but here from a 10 cm drop from beginning of July to end of September, 6 cm can be directly assigned to the enhanced evaporation over the CS itself and 2 cm due to reduced precipitation over the CS.

Further periods with strong changes of the CSL are investigated as well which provide some estimates concerning the accuracy of the analysis data. The investigation was possible due to the new ECMWF interim reanalysis data which are used to provide

HESSD

8, 7781–7803, 2011

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

data also for sensitive quantities like surface evaporation and precipitation. The comparison with independent data and the consistency between such data for calculating the water budget over the CS gives a high confidence in the quality of the data used.

This investigation provides some scope for making forecasts of the CSL few months ahead to allow for mitigating societal impacts.

1 Introduction

A blocking anticyclone persisted for 55 days over the central part of European Russia including the Volga basin (VB) from the end of June 2010. Extreme hot air inflow from Middle Asia into European Russia occurred. Absolute maxima of mean daily air temperature were recorded during this period exceeding normal values by 6 to 10 °C (Parshina, 2010; Barriopedro et al., 2011). The extreme hot and dry conditions led to widespread crop losses and wild forest and grassland fires which were widely reported by the media. In this study the impacts of this drought on the Caspian Sea Level (CSL) are investigated.

The Caspian Sea (CS) (36–47° N, 47–54° E) is a closed basin without any outlet. Its sea level lies around 26 m below the mean sea level of the oceans (–25 to –29 m during the last 150 years). Its main water source is the Volga River (VR) whose catchment area reaches well into the humid mid-latitudes and which was widely affected by the recent Russian drought. The water inflow is balanced by evaporation (E) over the CS itself which in our study includes the Kara Bogaz Gol. The CSL variability and the water budget of the CS has been investigated in previous studies (e.g. Rodionov, 1994; Golitsyn, 1995; Arpe et al., 2000; Arpe and Leroy, 2007). Here we concentrate on CSL variabilities and CS budget changes on a much shorter time scale and also with smaller amplitudes using improved data.

During summer 2010, the precipitation was only 10 to 30 % of the normal value in the VB region (Parshina, 2010). As the precipitation (P) over the VB was especially strongly hit by the summer drought in 2010, it was most likely that this would have an impact

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



on the CSL as suggested already in September 2010 by Lahijani et al. (2010). The drought intensity and connections with other climatic parameters will be investigated in this study. It will be investigated how far presently available data will allow a calculation of various components of the hydrological budget and how far their impacts on the CSL can be identified. For such investigations, extreme events like this one are beneficial because of a better signal to noise ratio. As the complete set of data is available from 1993 onwards, other periods of CSL changes will also be studied for a better understanding of the quality and limits of the observed and analysis data.

2 Observational and analysis data

Different sources of observational data have been used for calculating the hydrological budget for the CS to get a full picture of the drought's impacts on the CSL. These data are mostly available on regular spatial grids which were then averaged for areas of interest.

The recent CSL observations by satellite (Cazenave et al., 1997) are taken from USDA (2011). The precipitation over continents up to 2009 is taken from the Global Precipitation Climate Center (GPCC) (Rudolf et al., 2003; GPCC, 2011). GPCC also provides a data set created within a period of two months after observation time which is based on a smaller amount of observational data, called "monitoring product". Because of the short time available for collecting the data, a lower quality of analysis than that of the final product is expected. The monitoring product is made available at a lower resolution than the final data set. GPCC therefore provides a warning not to mix time series based on their different data streams. However, both data sets are here merged to include also year 2010 (Fig. 1a).

The precipitation over continents and seas is available from the ECMWF interim re-analysis (ERA) (ECMWF, 2011). This is a further development of the ECMWF reanalysis ERA40 by Uppala et al. (2005). An important difference to ERA40 is the usage of a 4-dimensional variational analysis scheme instead of the former 3-D one (Dee et al.,

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



2011), by this the spin-up of precipitation and evaporation in the early forecasts, present in many reanalyses of this kind, has been largely removed. Precipitation in this data set is obtained by using many observational data except precipitation gauge observations and the precipitation is a product of two 12 hour forecasts per day. Anomalies of precipitation estimates by GPCC and ECMWF can hardly be distinguished as seen in Fig. 1a. They correlate well with each other with an anomaly correlation coefficient of 0.92 and one can assume that both are reliable, as they are based on very different observational data and analysis methods. Also the two GPCC data series can hardly be distinguished for the overlapping period. The 2m temperatures, wind and evaporation are taken as well from the ECMWF interim reanalysis.

Monthly mean Volga River discharge (VRD) data are taken from Dümenil Gates et al. (2000) complemented for the recent period provided by the Hydrological Forecasts Department of the Hydrometeorological Research Center of the Russian Federation.

Arpe et al. (2000) and Arpe and Leroy (2007) found a connection between the CSL variability and ENSO (El Niño – Southern Oscillation) and therefore this parameter is also investigated. The US Climate Prediction Center recommends the use of the Oceanic Nino Index (ONI) which is presented here (CPC, 2011). It is based on the eastern tropical Pacific sea surface temperatures (SSTs) in the El-Niño areas applying some standardization.

3 Results

3.1 Overall budget

The VRD observations at the Volgograd power plant were used to test the different components of the hydrological budget (Table 1). Also the estimates by Golitsyn (1995) are given for comparison. P-E values over the VB are too low compared the observed Volga discharge. Assuming the observed VRD to be correct, one finds an inaccuracy of the VB precipitation of 2 % (if this is the only erroneous quantity) or of VB evaporation

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



of 3% (if this is the only erroneous quantity). The VRD contributes normally 80% of the total discharge into the CS and therefore the values of E-P over the CS are too low as well by perhaps 21%. Obviously some biases are still present. However the ERA data, averaged for the entire CS catchment area, suggest a change of the CSL for the whole period which differs only by 7 cm per year from the observed one which is only 3% of the largest budget term. Our main interests are the changes in time of these quantities and therefore this study focuses on anomalies, this way the impacts of biases are reduced.

3.2 Precipitation – Volga discharge delay

One has to assume that there is a delay between a precipitation event over the VB and the VRD of some months. We tried to quantify the length of this delay. For that, single months with anomalous summer precipitation events were compared with monthly means of the VRD (Table 2). Winter events are avoided here because of extra delays caused by snow and ice. Generally deficient precipitation had less obvious impacts on the VRD than excessive precipitation, probably due to the existence of dams. These dams let the water pass according to the demand for electricity in the country. Normally the dams are filled in July after the snow melt and with the increase of precipitation during summer. After that, the VRD responds to the precipitation more directly. Arpe et al. (2000) therefore used annual means from July to June the following year to reduce the effect of the dam storage.

Further the VRD was correlated with precipitation over the VB using different time shifts. For that a smoothing in time was needed. An optimal delay of 6 months with a 9 month smoothing and a 2 to 3 month delay with a 5 month smoothing was obtained. By this method also delays caused in winter due to accumulations of snow and ice are included which were not considered when using Table 2. The correlation was slightly higher when using CPCC instead of ERA precipitation.

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



3.3 Earlier periods with larger changes of CSL – estimate of uncertainty

Figure 1 shows two periods, 1993–1994 and 1995–1996, which have especially strong changes in the CSL, i.e. an increase of 39 cm in 1993–1994 and a decrease of 21 cm in 1995–1996. For both periods the single components of the water budget are given in Table 3. The differences between anomalies of the observed VRD and P-E over the VB can partly be explained by the delay between precipitation and the VRD, discussed above. So part of the excessive precipitation from 1993–1994 would only be felt in 1995 and compensate the deficit from 1995. Also the deficient precipitation for 1996 may be felt in the year to follow. For 1993–1994, the different components of the budget fit quite well with mismatches in the order of 5 cm CSL change per year. From these numbers one can get a feeling of the uncertainty of the quantities. With these caveats in mind the accuracy of the single components seem to be in the order of 5 to 10 cm CSL change per year. In Table 3, the data for 2002 are given as well, a year with an increase of the CSL by 16 cm. None of the budget components suggest such an increase but none except the VB precipitation exceeds the estimated accuracy of 5 to 10 cm and the precipitation only by a small amount. The precipitation at the Iranian coast of the CS, an area with high precipitation rates (Leroy et al., 2011) not well resolved by the analyses, was also investigated in this study as a possible source for the CSL increase. However all observations in northern Iran show only reduced precipitation in that year. So this strong increase of the CSL is probably an accumulation of small anomalies, smaller than the uncertainty of our calculation, of several components of the water budget. In 2002 a change of satellites, used for calculating the CSL, occurred from Topex-Poseidon to Jason-1. Perhaps the adjustment between the satellite data created part of this increase of CSL and therefore the CSL changes may not have been as large as shown. Lebedev and Kostianoy (2005, 2006) compared gauge observations around the CS with altimetry observations from satellite. They point to many uncertainties in both data sets, e.g. large differences in the CSL in different basins and the existence of surges which can be as large as 2 to 3 m in the northern basin. Their

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



data were used to compare their CSL anomalies (annual cycle individually removed) with those from satellite. The 12 gauges at 6 sites generally give very similar variabilities like the satellite data with a typical range of 10 cm. A main exception is the second half of 2002 when all gauge observation show a decline of the CSL while the satellite data show a continuation of increase. The increase during 2002 is less than 6 cm in 10 gauge observations, only Makhachkala has 11 cm, while the satellite data give a 14 cm increase (monthly means).

Nevertheless in Table 1 a mean precipitation of 230 cm CSL change per year was given, so the accuracy estimated from these episodes is 3 to 5 % which is a very high demand on the precipitation analysis. The errors for monthly means would be $1/12 \cdot \sqrt{12}$ of the ones for annual means, if the errors are completely random, i.e. 1.4 to 2.8, say 2 cm CSL change per month.

3.4 Russian drought

The changes of the hydrological budget for summer 2010 are highlighted in Fig. 3 and Table 4. From June 2010 onwards, one can find a steady decrease of the CSL. From the beginning of July to the end of September it is 10 cm (Table 4). Only 2 cm comes from a deficit in the VRD (observed) while the precipitation minus evaporation over the CS itself, which would have an instantaneous effect on the CSL, contributes for that period a decrease of 8 cm of which 6 cm is due to the evaporation alone. The VRD together with P-E over the CS explain the drop of the CSL exactly. From the P-E over the Volga basin of -22 cm only -2 cm has been felt at the CS in this period. The remaining 20 cm deficit of P-E will have an effect on the CSL in the following months. The CSL anomaly drops further by 7 cm from the beginning of October to the end of the year and further by 5 cm to the end of May 2011 and the remaining 7 cm could still be expected if all other components of the water budget stay normal. However from October 2010 to February 2011, excessive precipitation over the Volga basin equivalent to an increase of the CSL of 7 cm occurred and on the other hand a deficit of P-E over

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



the VB occurred already before July 2010 equivalent to a drop of the CSL of 24 cm (mainly May–June) of which only 6 cm was observed in the VRD anomaly.

Above, the uncertainty of the budget calculations had been estimated as 2 cm CSL change per months and this is clearly smaller than the signal shown here.

In Fig. 4, maps of precipitation, 2 m temperatures and evaporation over the CS catchment basin are shown for July 2010. The strongest deficit of precipitation in Fig. 4a lies over the Volga basin (heavy black line). The hottest temperatures (Fig. 4c) and the strongest decrease of evaporation (Fig. 4b) are found further south than the strongest decrease of precipitation (Fig. 4a). That is because the soil moisture, as a limiting factor for evaporation, comes into effect only where the absolute precipitation is low in relation to its anomaly. A marked southward decrease of the precipitation occurs in the area, and therefore the impact of the precipitation deficit on the evaporation for 2010 lies further south. Where the soil moisture is a limiting factor for evaporation, one may expect an increase in the temperature, which is indeed seen in Fig. 4c. However, the heat wave had already a precursor in May with only slightly lower anomalies than during July. At that time there was still enough water available in the soil and accordingly one finds excessive evaporation for this month over the Volga basin (Fig. 3b).

In Fig. 4b, a strong increase of evaporation can be found over the CS itself, meaning a direct loss of water for the CS. It starts already in June and continues until September as can be seen from Fig. 3d as discussed above. In July 2010, the surface wind entering the CS came from the E to NE, while in long-term means it is from the N. So the air reaching the CS was much drier and warmer in 2010 than normal, which favours enhanced evaporation over the CS.

3.5 ENSO impacts

Arpe et al. (2000) and Arpe and Leroy (2007) found a connection between the CSL variability and ENSO (El Niño - Southern Oscillation). It is interesting that in Fig. 2 the time series of the ONI index fits very well with the CSL changes. One finds a simultaneous development of a La-Niña events with a CSL drop and El Niño events

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



with increases of the CSL, e.g. positive in 1993–1994, negative in 1995–1996, positive in 2002, negative in 2006, 2008 and in summer 2010. Only a few times this correlation fails.

The CSL changes and the Volga River discharge curves are very similar from 1993 to 2010 (Fig. 2). In Table 5 the anomaly correlations between different parameters are given. Highest values concerning ENSO are between ONI and the CSL change and very low values between ONI and the VB precipitation. It has been assumed in earlier studies that ENSO affected the precipitation over the VB and by that the VRD which then had the impact on the CSL; however, the correlation coefficients just given does not support such a sequence of events.

It is planned to investigate this issue in more depth in a separate study.

4 Discussion

The coincidence of the CSL drop in summer 2010 with reduced precipitation over the VB and enhanced evaporation over the CS has been shown by our analysis. The drop in precipitation over the VB started in June and is strongest in July but its effect on the CSL is not expected to be noticed until some months after July, as the precipitated water needs time to flow into the rivers (having previously entered the soil) and then to flow down the VR into the CS. It has been shown above that such a delay in the VRD when there is an excess of precipitation is typically 2 months but for reduced precipitation it takes longer and is less easily seen in the data partly due to the existence of several dams which affect the water flow. The water inflow into the major reservoirs of the Volga-Kama cascade during summer 2010 was very low, i.e. 50–70 % of the normal. According to the Hydrometeorological Center of Russia estimates, in July 2010, the water inflow to the reservoirs of the Volga-Kama cascade was 9.9 km^3 (the long-term monthly mean value is 14.2 km^3). In August, the inflow was 6.5 km^3 compared to the climatological norm of 11.5 km^3 . A tense situation developed in the middle and low reaches of the VR. In November 2010, the water level in the Kuibyshev reservoir,

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

which is the main regulator for the runoff in the VB stood at 49 m which is a drop of 1.05 m from the previous November. This means that only 37 % of the usable volume of the reservoir was filled by water. The Federal Agency for Water Resources had to establish during the summer-autumn period of 2010 an economic regime of water discharge. Appropriate measures to adapt to the normal operation of the engineering infrastructure and especially municipal water supply systems to conditions of low water have been taken (FAWR, 2011). Because of the low water level in the dams, the effect of the drought on the CSL is expected to be noticed also in 2011.

Evaporation over the CS itself has however an instantaneous effect on the CSL and the additional evaporation-precipitation of 39 mm month⁻¹ in July 2010 fits very well with the observed anomalous drop of the CSL of 4 cm (Fig. 3; Table 4). Also for the following months the CSL drop and the evaporation over the CS itself fit very well. After that, the CSL anomaly drops further by 7 cm to the end of the year. This is not explained by evaporation over the CS and probably represents the delayed impact from the Russian drought.

Arpe and Leroy (2007) stated that precipitation over the VB, especially that during summer, is the main driver for CSL changes. When discussing Fig. 2 and Table 5 the high anomaly correlation of 0.71 between Volga discharge and CSL change was pointed out but the connection with the precipitation was less clear. Here it was found that the evaporation variability over the CS itself can also have clear impacts for shorter periods e.g. 1996, 2003 and 2010.

5 Conclusions

Comparing the CSL variations with the impacts of the different components of the CS water budget show the impacts of the recent drought in European Russia. These new results could only be achieved due to the availability of accurate evaporation estimates provided by the ECMWF reanalysis since 1989. Data from different sources have been used in this study and it is encouraging that they are consistent with each other. This

gives confidence in their quality. In particular the ECMWF reanalysis data should be mentioned. These provide a wide range of data including precipitation and evaporation, the latter are created by a model. They are otherwise difficult to observe and analyze. Some biases in these data still exist, but their impact on our investigation was reduced by studying anomalies. The accuracy of the water budget data in these analyses have reached a level that an inconsistency in the satellite derived CSL data could be detected. The anomalies during and after the drought are clearly exceeding the level of uncertainty, which was estimated to be 2 cm CSL change per month.

The water deficit for June to September 2010 calculated from the anomalous precipitation over the VB (Fig. 3: Table 4) would result in a decrease of the CSL by 27 to 28 cm (GPCC and ERA respectively), it is compensated by increased evaporation of 6 cm, of the 22 cm water deficit, 7 cm had already been observed from October to the end of 2010 and a further 5 cm to the end of May 2011. A further drop, with impacts on human activities on and around the CS (e.g. harbour accessibility, petroleum and caviar industries), is therefore to be expected. Some scope for making forecasts of the CSL a few months ahead seems feasible. This may turn out to be an essential contribution to the mitigation of societal impacts of CSL changes.

Acknowledgements. This article is a contribution to the European project Marie Curie, CLIMSEAS – PIRSES-GA-2009-247512: “Climate Change and Inland Seas: Phenomena, Feedback and Uncertainties. The Physical Science Basis”. We thank Andrew Russell from Brunel University to comment on an earlier version of this paper. M. Turner (Brunel University) has kindly revised the English of the manuscript. We thank Andrey Kostianoy and Sergey Lebedev for providing the CSL gauge data.

The service charges for this open access publication have been covered by the Max Planck Society.

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



References

- Arpe, K., Bengtsson, L., Golitsyn, G. S., Mokhov, I. I., Semenov, V. A., and Sporyshev, P. V.: Connection between Caspian Sea level variability and ENSO, *Geophys. Res. Lett.*, 27, 2693–2696, 2000.
- 5 Arpe, K. and Leroy, S. A. G.: The Caspian Sea Level forced by the atmospheric circulation as observed and modelled, *Quaternary Int.*, 173–174, 144–152, 2007.
- Barriopedro, D., Fischer, E. M., Luterbacher, J., Trigo, R. M., and García-Herrera, R.: The Hot Summer of 2010: Redrawing the Temperature Record Map of Europe, *Science*, 332, 220–224, 2011.
- 10 Cazenave, A., Bonnefond, K., Dominh, K., and Schaeffer, P.: Caspian Sea Level from Topex-Poseidon altimetry: Level now falling. *Geophys. Res. Lett.*, 24, 881–884, 1997.
- CPC: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml, last access: 20 May 2011.
- Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., 15 Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge-Sanz, B. M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N., and Vitart, F.: The ERA-Interim reanalysis: configuration 20 and performance of the data assimilation system, *Q. J. Roy. Meteorol. Soc.*, 137, 553–597, doi:10.1002/qj.828, 2011.
- Dümenil Gates, L., Hagemann, S., and Golz, C.: Observed historical discharge data from major rivers for climate model validation. Max-Planck Institute for Meteorology, Hamburg, Report no. 307, 93 pp., 2000.
- 25 ECMWF: http://data-portal.ecmwf.int/data/d/interim_daily/, last access: 20 May 2011.
- FAWR: Press release of the federal agency of water resources of the Russian Federation, issued 15 November 2010, <http://gfu-volga.ru>, last access: 27 January 2011.
- Golitsyn, G. S.: The Caspian Sea level as a problem of diagnosis and prognosis of the regional climate change, *Izv. Russ. Acad. Sci. Atmos. Oceanic Phys., Engl. Trans.*, 31, 366–372, 1995.
- 30 GPCP: ftp://ftp-anon.dwd.de/pub/data/gpcc/html/fulldata_download.html and ftp://ftp-anon.dwd.de/pub/data/gpcc/html/gpcc_monitoring.v3_download.html, last access: 20 May 2011.

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Table 1. Water budget components for the Caspian Sea. Units: change of the Caspian Sea Level per year in cm.

	Golitsyn (1995)	1993–2010
VB precipitation ERA (GPCC)		232 (207)
VB evaporation		–167
VB P-E = Volga discharge		66
Volga discharge (observed)	60	71
Other rivers	15	
CS precipitation	20	25
CS evaporation	–95	–81
CS P-E including KBG	–75	–56
Entire Caspian catchment P-E		5
CSL change		–2

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 2. Time delays of Volga River discharge extremes after precipitation extremes over the Volga Basin.

Date	precipitation event	time delay
May 1965	maximum	1 month
July 1968	maximum	3 months, weak extreme over several months
May 1974	maximum	2 months, weak extreme over several months
July 1979	maximum	4 months, weak extreme over several months
May 1997	maximum	1 month
July 1970	minimum	3 months, weak extreme over several months
August 1972	minimum	3 months, weak extreme over several months
August 2005	minimum	3–4 months, weak extreme

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 3. Water budget component anomalies for the CS catchment area for three periods. Units: change of the Caspian Sea Level per years in cm.

	1993–1994	1995–1996	2002
CSL change	+16	–10	+16
Observed Volga discharge	+16	–6	+4
VB precip. ERA (GPCC)	+7 (+9)	–26 (–31)	–13 (–7)
VB evaporation	+5	+1	+3
VB P-E	+12	–25	–10
CS precipitation	+4	–2	+2
CS evaporation	–3	+2	–1
CS P-E	–1	0	+1
Entire CS catchment P-E	+27	–47	–7

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Table 4. Water budget component anomalies for summer 2010. Units: change of the Caspian Sea Level in cm. Differences between the sum and single month values might result from rounding.

	July	August	September	sum
CSL change	−4	−3	−3	−10
Observed Volga discharge	−1	−1	−1	−2
VB precip. ERA (GPCC)	−21 (−20)	−4 (−2)	−3 (−5)	−28 (−27)
VB evaporation	+2	+3	+2	+6
VB P-E (ERA)	−19	−1	−2	−22
CS precipitation	−1	−0	−1	−2
CS evaporation	−3	−2	−2	−6.3
CS P-E	−4	−2	−3	−8
Entire CS catchment P-E	−34	−6	−9	−48

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

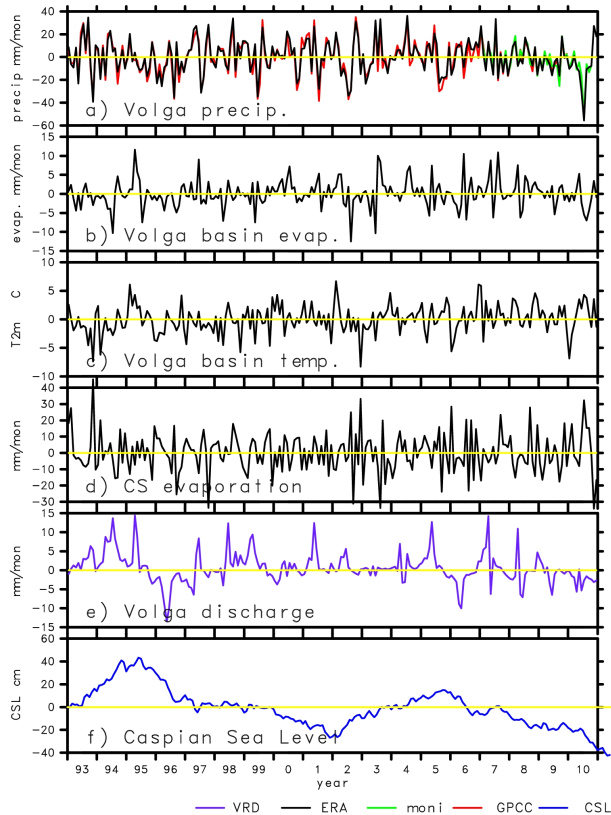


Fig. 1. Time series of monthly mean anomalies, i.e. with the mean annual cycle removed, for a selection of variables. A three month running mean has been applied for smoothing. **(a)** Precipitation over the VB using ERA and GPCP data, **(b)** Evaporation over the VB, **(c)** 2 m temperatures averaged for the VB, **(d)** Evaporation over the CS itself, **(e)** observed Volga River discharge and **(f)** CSL. Note that the CSL values are centred on the first of each month while the other quantities are monthly means.

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

Title Page

Abstract	Introduction
Conclusions	References
Tables	Figures

⏪
⏩

◀
▶

Back	Close
------	-------

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

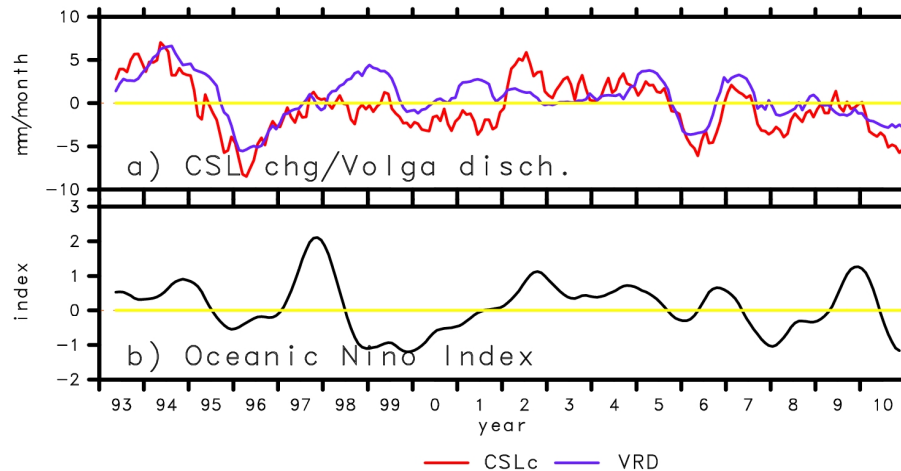


Fig. 2. Time series of monthly mean anomalies, i.e. with the mean annual cycle removed, for **(a)** the CSL change and the Volga River discharge (values are converted to P-E for the Volga basin catchment area and **(b)** the Ocean Niño Index. A nine month running mean has been applied for smoothing.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

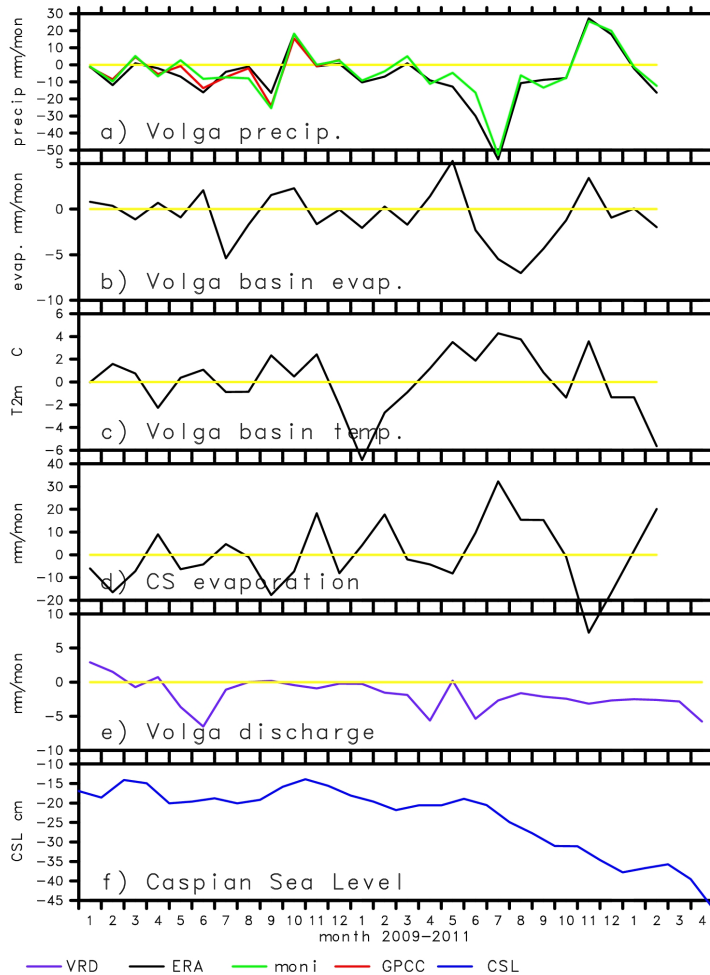


Fig. 3. Same as Fig. 1 but for 2009 to 2011 only and no smoothing.

Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

[Title Page](#)

[Abstract](#) | [Introduction](#)

[Conclusions](#) | [References](#)

[Tables](#) | [Figures](#)

[◀](#) | [▶](#)

[◀](#) | [▶](#)

[Back](#) | [Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Impact of the European Russia drought in 2010 on the Caspian Sea level

K. Arpe et al.

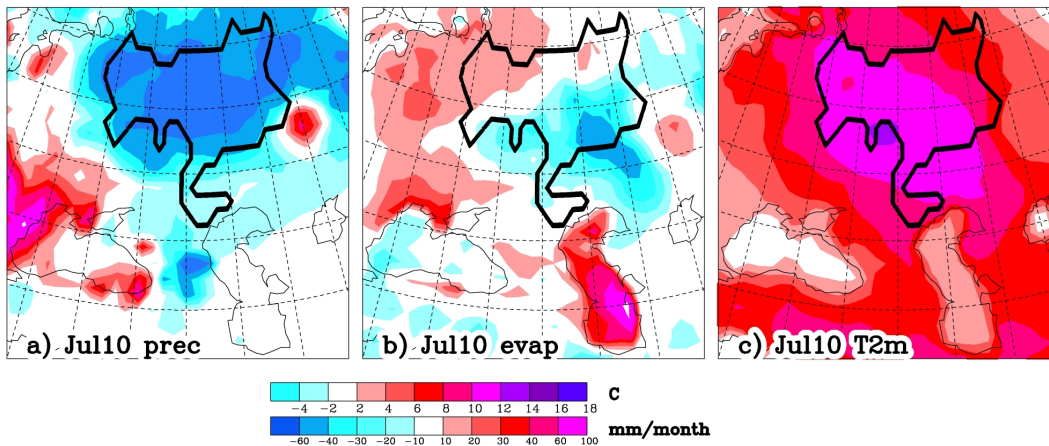


Fig. 4. Anomaly maps using ERA data. A black line indicates the Volga catchment area. **(a)** Precipitation for July 2010. Units: mm month^{-1} , **(b)** Evaporation for July 2010. Units: mm month^{-1} , and **(c)** Temperature for July 2010. Units: $^{\circ}\text{C}$. Red colours: increase, blue colours: decrease.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)