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Simulating long-term Caspian Sea level changes: The impact of Holocene and future climate conditions

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Abstract

To improve our understanding of the relationship between climate change and variations in Caspian Sea level (CSL), we performed simulations of annual CSL for the period 8 ka to 2100 CE using a coupled model setup representing climate, hydrology and sea level. We forced our climate model with long-term changes in orbital parameters and atmospheric greenhouse gas concentrations, using the IPCC A1b scenario for the 21st Century. Our simulations produce an orbitally forced, long-term decline in CSL of 5 m from 5.5 to 0 ka, caused by a decrease in river runoff and over-sea precipitation that is not fully compensated by a decrease in over-sea evaporation. Superimposed on this long-term downward CSL trend we simulated centennial-scale fluctuations of up to 4 m and decadal-scale variations of up to 2 m, caused by the internal variations of our modeled climate system, amplified by the sensitivity of CSL to small changes in river runoff and in the over-sea P–E budget. The A1b anthropogenic emission scenario causes a 4.5 m fall in CSL in the 21st Century, due to a pronounced increase in over-sea evaporation that is stronger than the enhanced river discharge. This decline in CSL is of the same order of magnitude as the orbitally-forced millennial-scale downward CSL trend simulated for the last 8000 years. Our results are generally consistent with CSL estimates based on geological, historical and measured data, as well as with most other model studies.

Keywords: Caspian Sea; sea level; Volga; Holocene; model simulations; future climate

1. Introduction

The Caspian Sea level (CSL) has experienced substantial fluctuations during the 20th Century. In the 1930s, the level fell abruptly by about 2 m, whilst a rapid rise of the same order of magnitude was observed after 1977 (Rodionov, 1994). These decadal-scale variations are superimposed on a long-term downward trend in CSL, as suggested by geological evidence derived from the dating of deltas and terraces (i.e. CSL high stands, Rychagov, 1997). This geological evidence shows a decrease of about 5 m from a level of −20 mbsl (meter below sea level) in the early Holocene (around

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8 ka) to a mean level of −25 mbsl in the 18th–19th Centuries CE (Rychagov, 1997). It is generally accepted that climate-induced changes in the hydrological budget of the Caspian Sea are the main cause of such CSL fluctuations (Rodionov, 1994; Elguindi and Giorgi, 2006a,b). However, as noted by Rodionov (1994), geological processes are also thought to influence the CSL, including tectonic movements (Vdovykin, 1990) and deep groundwater flows between the Aral Sea and the Caspian Sea (Shilo, 1989). In addition, anthropogenic activities such as land-use change and reservoir development have affected the CSL during the 20th Century (Rodionov, 1994).

In view of ongoing global warming, it is important to gain a thorough understanding of the relationship between climate and CSL. Recently, several modeling studies have been performed that shed light on this relationship. Elguindi and Giorgi (2006a) were able to reproduce the decadal-scale CSL variations observed during the 20th Century, using a regional climate model for the Caspian Sea basin combined with a simple hydrological water-balance equation. The same model was applied to estimate the future CSL evolution following the A2 IPCC (2001) scenario, suggesting a large CSL decrease of about 5 m by the end of the 21st Century due to increased evaporation loss (Elguindi and Giorgi, 2007). However, a much more ambiguous picture of the future emerged from an analysis of CSL variations using seven different Atmosphere–Ocean general circulation models (AOGCMs) forced by the same A2 scenario (Elguindi and Giorgi, 2006b). Some of these models produced a CSL drop of more than 10 m by the end of the 21st Century, while other models suggested a stable or even increasing CSL (Elguindi and Giorgi, 2006b; Arpe and Leroy, in press).

The uncertainty about future CSL shows that it is necessary to improve our understanding of the mechanism behind CSL variations. One way forward is to analyze long-term variations that have occurred during times predating significant anthropogenic influences, and to compare these 'natural' fluctuations with projections of future CSL changes. We have therefore simulated the variations in CSL for the period 8 ka until 2100 CE, using a hydrological model that is specifically setup for the Caspian Sea basin in combination with a simple model for the CSL. The climatic data used to force our hydrological model are derived from a transient climate model simulation of the same period, performed by Renssen et al. (2005), extended with an IPCC A1b scenario run for the 21st Century. Compared to earlier studies of past CSL variations, our transient coupled climate-hydrological model approach is novel,

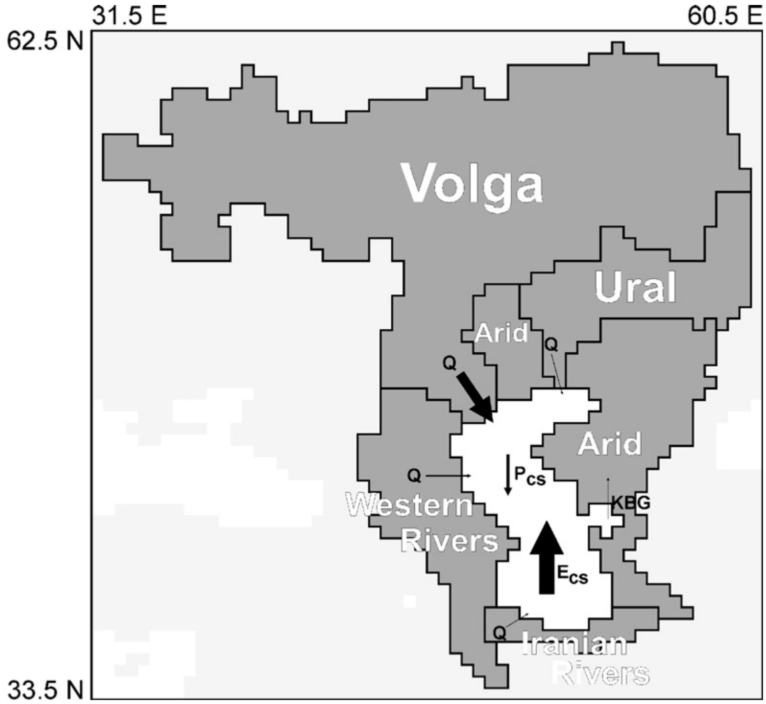

Fig. 1. Overview of the Caspian Sea drainage basin on the STREAM grid, showing the catchments of the main contributing rivers (Volga, Ural, Iranian Rivers and rivers to the West of the Caspian Sea). Also shown are the principal elements of Eq. (1), i.e. river runoff (Q), over-sea precipitation (P_{CS}) and evaporation (E_{CS}), and flow to Bay of Kara–Bogaz–Gol (KBG).