

PROJECTING FUTURE CASPIAN SEA LEVEL CHANGES IN RESPONSE TO CLIMATE CHANGE

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INTRODUCTION

The Caspian Sea (CS), the world's largest lake, is a hydrologically sensitive water body, with a water level that has been experiencing significant fluctuations (Figure 1). Figure 2 illustrates historical observations of the Caspian Sea level (CSL) in Makhachkala station from 1900 to 2021 (CASPCOM Working Group, 2021). Between 1930 and 1977, the CSL decreased dramatically by more than 3 m, reaching 29 m below sea level (Baltic datum). Subsequently, from 1977 to 1995, an unexpected CSL rise of approximately 2.5 m (reaching -26.5 m) led to extensive flooding and various challenges in neighboring countries. Following this sharp increase, the CSL gradually decreased, with the current value of about -27.8 m in 2023. The decline in CSL has detrimental effects on naval facilities, ports, fisheries, shipping industries, and power plants. These fluctuations have also affected residential areas, ecosystems, biodiversity, and coastal wetlands, particularly those registered under the Ramsar Convention in 1975 (Ramsar List, 2023).

Previous researches have widely acknowledged that climate-induced changes in the CS water budget, including precipitation over the sea, evaporation from the sea surface, and riverine input, play a significant role in controlling CSL fluctuations (Rodionov, 1994). However, limited studies have been conducted to investigate the effects of climate change on the CSL using either General Climate Models (GCMs) projections or Regional Climate Models (RCMs) (Elguindi & Giorgi, 2006; Elguindi & Giorgi, 2007; Renssen et al., 2007; Nandini-Weiss et al., 2020; Koriche et al., 2021; Samant and Prange, 2023). The validity of these studies has also been undermined by several factors, including limited use of GCM/RCM and climate change scenarios, lack of evaluation models, reliance on a single ensemble member of GCMs, and the neglect of the changing CS surface area's influence on the water balance equation.

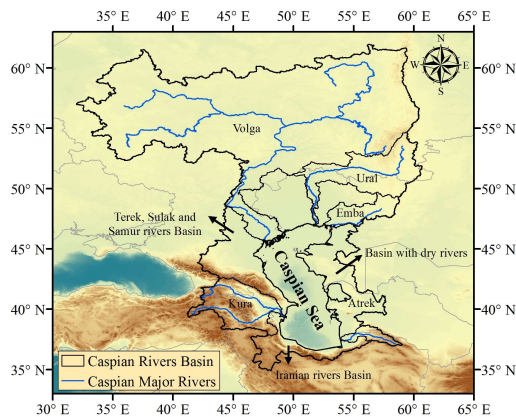


Figure 1- CS drainage basin and its major rivers

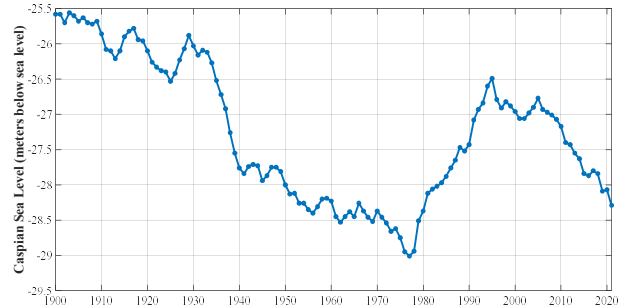


Figure 2- CSL fluctuations record at Makhachkala station during 1900-2021 (CASPCOM database)

CS WATER BUDGET AND CSL MODELING

In this study, the changes in the CS water budget are assessed by using projections of the main CS water balance components. These include over-sea precipitation (Hoseini et al., 2024), sea surface evaporation (Hoseini et al., 2023), and riverine input (calculated as precipitation minus evaporation in the basin of inflowing rivers into the CS). The water budget during the 21st century and the reference period (1988-2014) is calculated from a bias-corrected multi-model ensemble of CMIP6-GCMs under the low, medium, medium-to-high, and high emission scenarios. Available CMIP6-GCMs are ranked based on their performance in simulating the temporal and spatial variability of precipitation and evaporation over the study area during the reference period. A weighted Multi-Model Ensemble (MME) is subsequently created by incorporating the high-ranked GCMs. Furthermore, effective bias correction techniques are applied to reduce the biases within MME. By incorporating the CS's surface area as a variable in the water balance equation, this study aims to enable more accurate predictions of the CSL.

RESULTS AND DISCUSSION

Figure 3 illustrates the favorable agreement between simulated and observed annual CSL fluctuations throughout the reference period (1988-2014). Figure 4 shows the comparison between simulated and measured CSL with statistical indices in the reference period. The RMSE, bias, MAE, and correlation coefficient are found to be 0.15 m, 0.01 m, 0.13 m, and 0.47, respectively.

Figure 5 presents the time series of accumulated CSL changes in each year, relative to CSL in 2021, and simulated CSL under the low, medium, medium-to-high, and high emission scenarios in 21st century. The figure shows that CSL gradually increases until 2039 up to 0.5 m under the low emission scenario. This is followed by a slight decrease of water level that continues until 2052, after which the trend reverses and the increase of CSL is observed. Under the medium emission scenario, the CSL experiences a sharp

decrease until 2050, reaching 5 m below the 2021 level. Afterward, a period of water level increases or stability can be observed under this scenario.

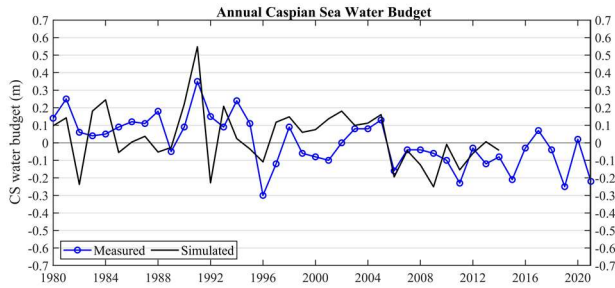


Figure 3- Simulated and observed annual CSL fluctuations (1988-2014) and future prediction

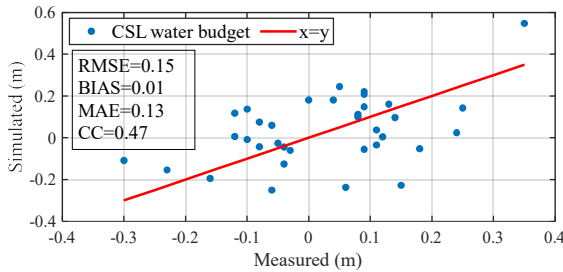


Figure 4- Comparison of the annual CSL changes from simulation and measurement with statistical indices showing validation of simulated CSL in the reference period

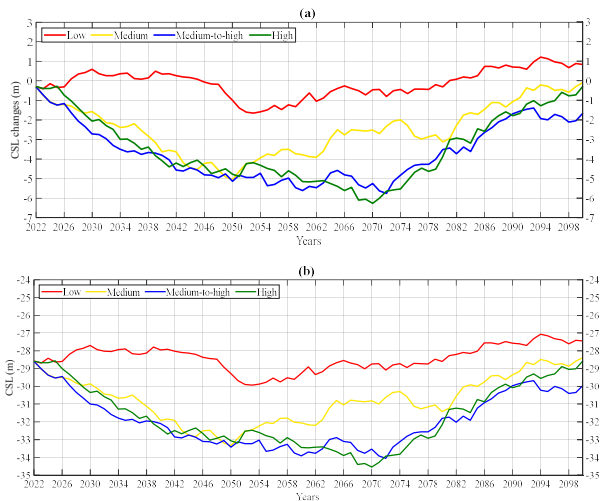


Figure 5- (a) Accumulated CSL changes in each year relative to CSL in 2021 and (b) the simulated CSL values under the low, medium, medium-to-high, and high emission scenarios in 21st century

Under the medium-to-high and high emission scenarios, a sharp decline in CSL is observed until around 2070, reaching 5.8 m and 6.3 m below the 2021 level, respectively. Afterward, a slight increasing trend begins until 2093 for the medium-to-high emission scenario and until 2100 for the high emission scenario. By the year 2100, the bias-corrected multi-model ensemble

(MME) projects the CSL to reach -27.4 m, -28.4 m, -29.9 m, and -28.6 m under the low, medium, medium-to-high, and high emission scenarios, respectively.

The CSL changes in the 21st century are primarily driven by variations in river discharge, and evaporation from the sea surface playing a significant role in determining the rate of change.

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