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Integrated modelling to assess the impact of climate change on the groundwater and surface water in the South Aral Sea area

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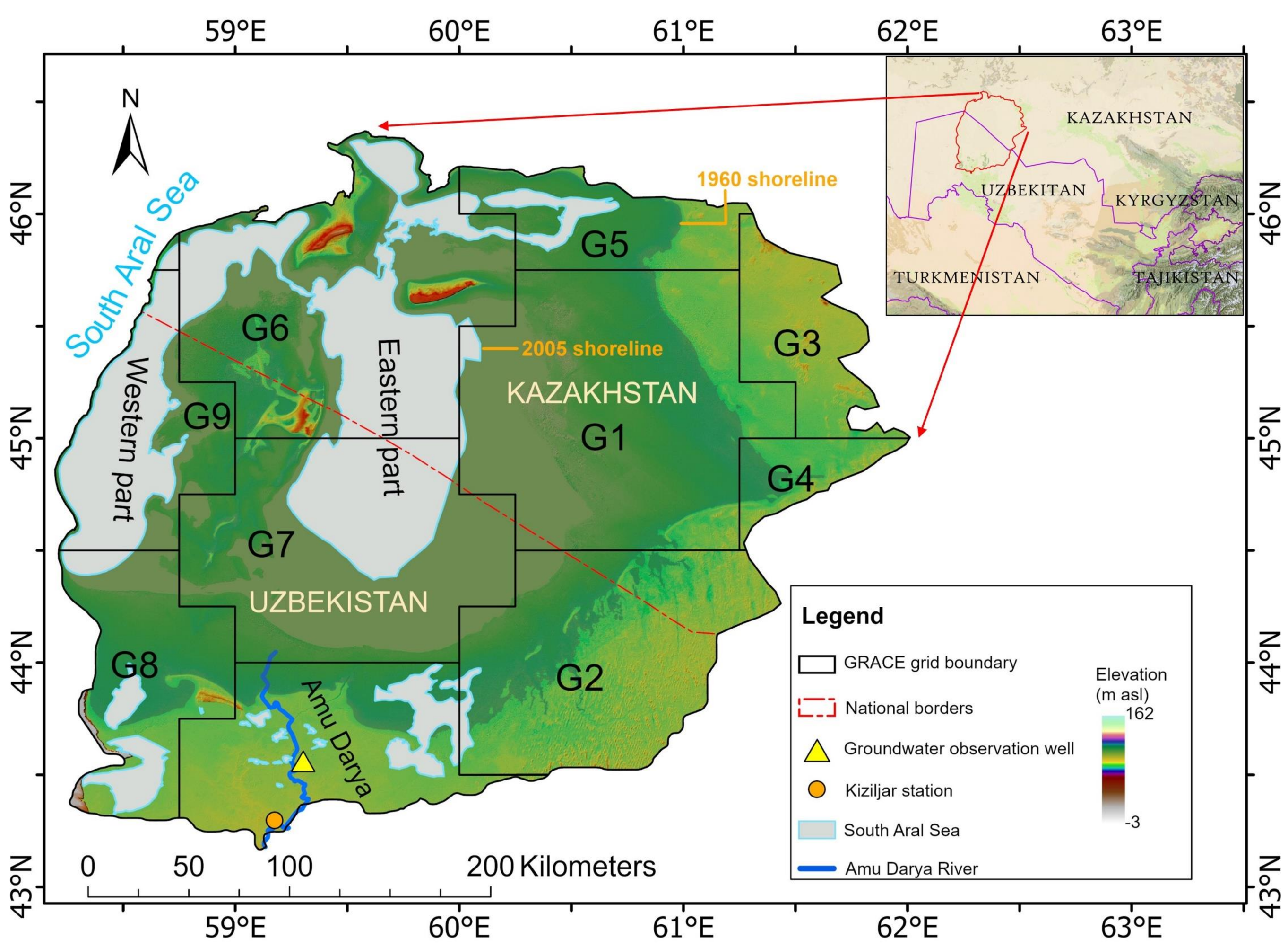
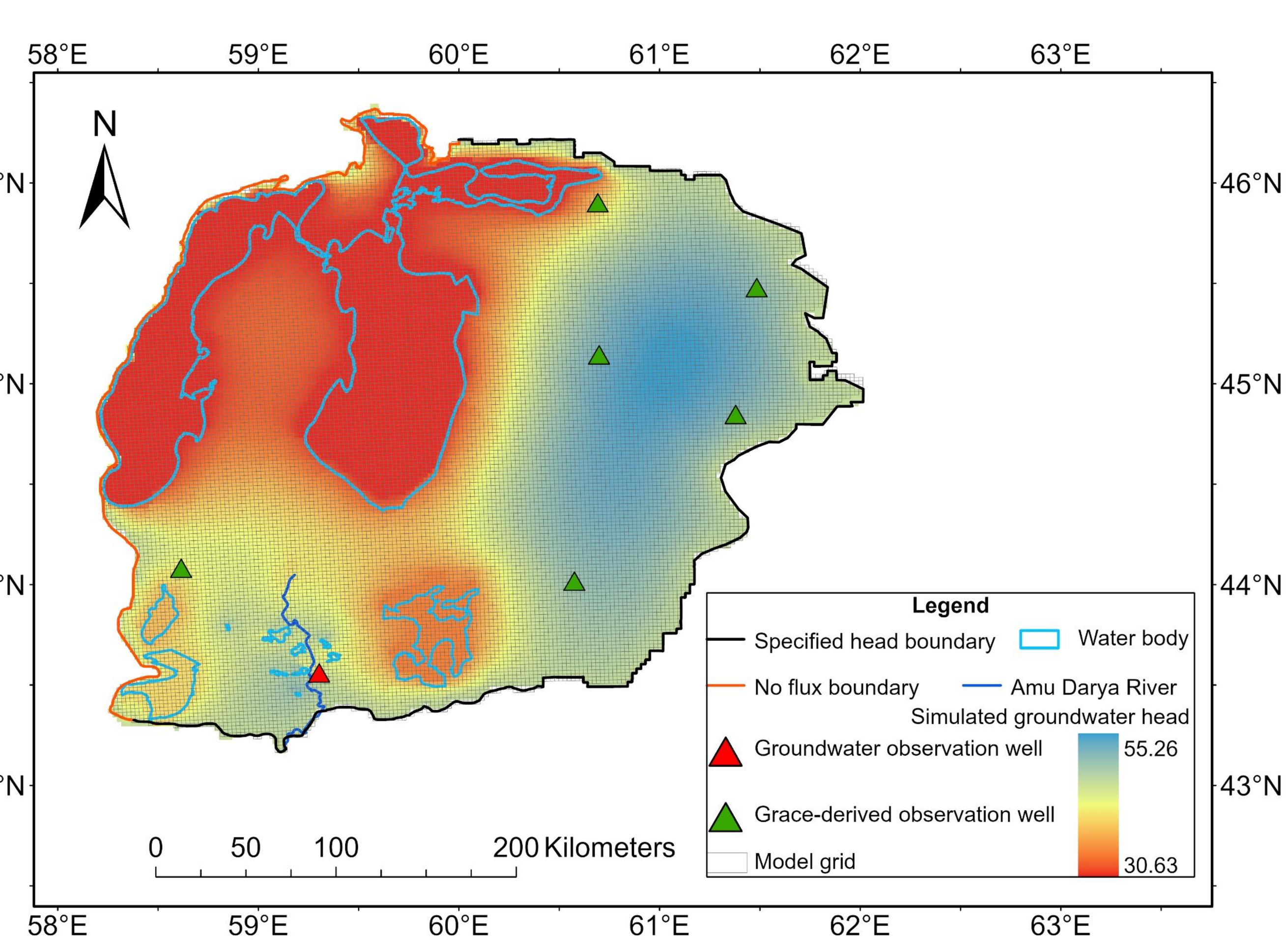
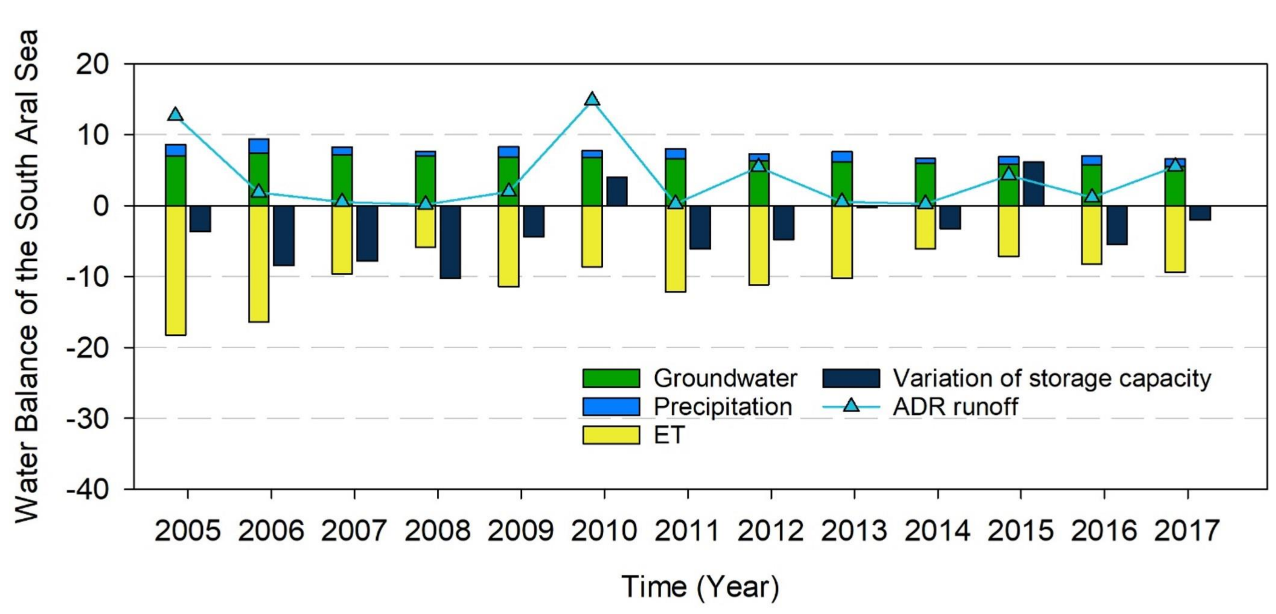
The recession of the South Aral Sea over the last few decades has become a great environmental challenge in Central Asia. Due to declining inflow and irrigation exhaustion, the Amu Darya River is vanishing before reaching the South Aral Sea. Based on numerical models (MODFLOW and SWAT) and with the support of observed data, remote sensing data, reanalysis data, and the output of Global Circulation Models (GCMs) of the Coupled Model Intercomparison Project Phase 6 (CMIP6), the hydraulic connection between a shallow aquifer and the lake was investigated and projected for future change. The groundwater model was calibrated by one in-situ groundwater well and six Gravity Recovery and Climate Experiment (GRACE) derived groundwater heads.



Location of the South Aral Sea basin, the topography and groundwater model domain of the study area. The area covered by shadows is the boundary of the lake in 1960. The G1 to G9 are gravity recovery and climate experiment (GRACE) grid names.



The discretized domain of the Modflow model and the simulated groundwater head. The Polygons surrounded by blue borders are specified head boundaries to simulate water body. The groundwater head is based on the simulation result of February 2005.



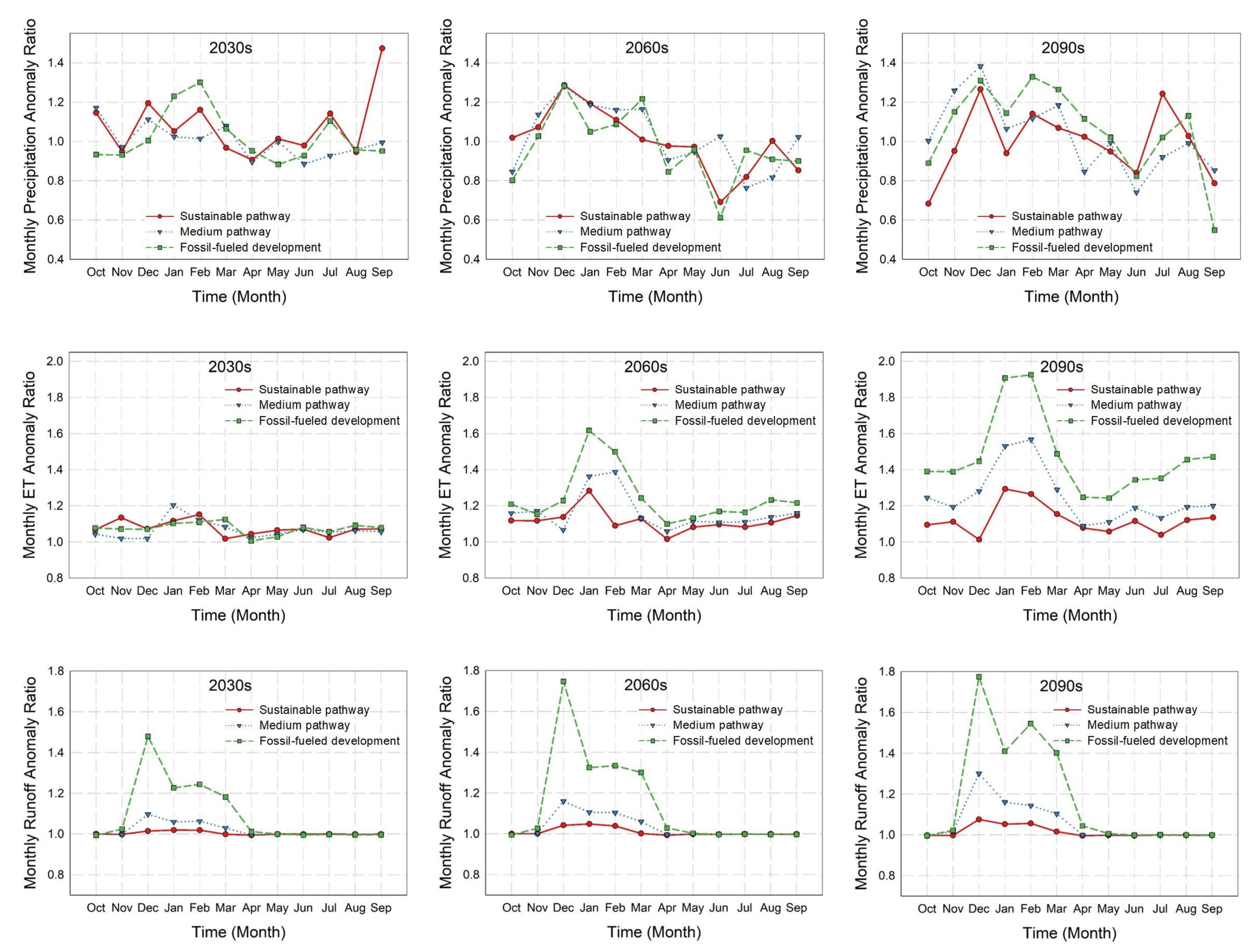
Water balance, Amu Darya River runoff and variation in storage capacity from 2005 to 2017.

- The precipitation will slightly increase in the future, with a range of 146.4–163.3 mm/yr.
- The exacerbated global warming will contribute to a rise in the ET: the bare land ET will range from 453.8–602.6 mm/yr, and the ET of the water body will fluctuate from 1,270.6–1,687.3 mm/yr.
- The runoff of the Amu Darya River determined by the snowmelt and glacier melt contributions in the upper mountainous area will also increase slightly, with a range of 107.8–118.4 km³/yr.

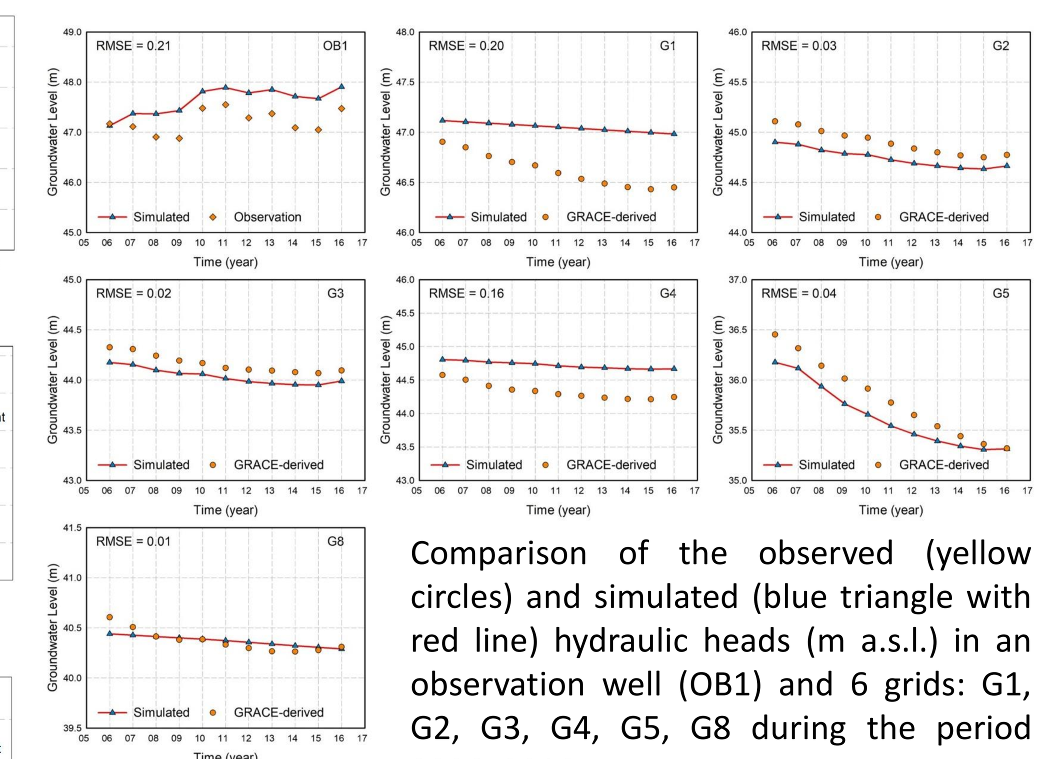
The critical factor affecting the South Aral Sea is the ET increase, which potentially influences the lake surface area and water consumption for irrigation in the future.

- The groundwater recharge to the South Aral Sea is situated between 5.5–7.7 km³/yr.
- The South Aral Sea may maintain a surface area of 4.47×10³ km², which means the shallow lake on the eastern part will disappear completely.

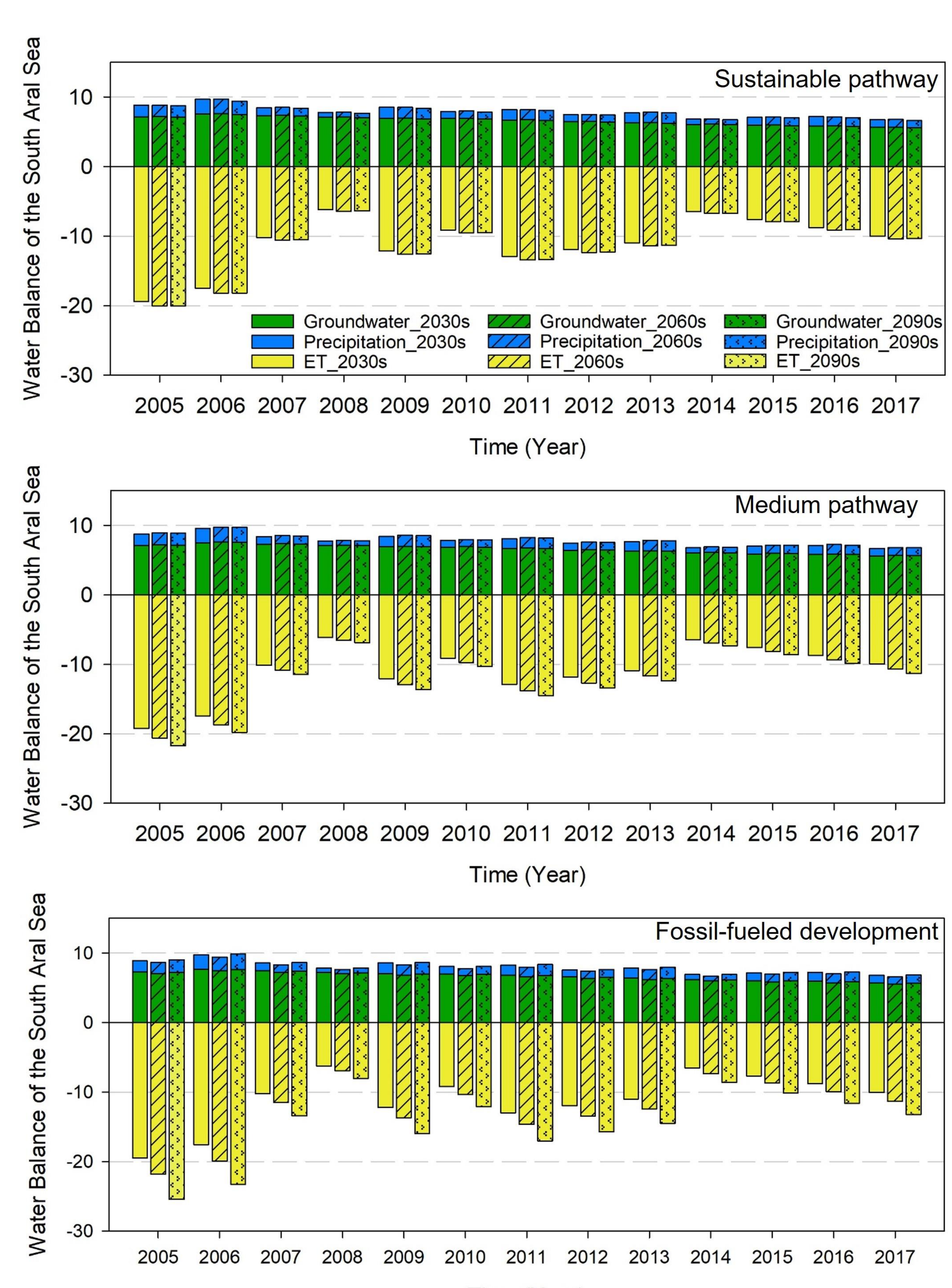
Based on the three greenhouse gas emission scenarios, we have predicted the volume of the groundwater flux into the South Aral Sea and future variations in the surface area of the South Aral Sea. In the long run, alleviating the Aral Sea crisis still requires a vast investment and fundamental political, social, and economic changes.



Monthly average precipitation, ET and Amu Darya runoff anomaly ratio (predicted value divided by historical value) of the three climate change scenarios for the 2030s, 2060s and 2090s.



Comparison of the observed (yellow circles) and simulated (blue triangle with red line) hydraulic heads (m a.s.l.) in an observation well (OB1) and 6 grids: G1, G2, G3, G4, G5, G8 during the period 2006–2016.



The water balance in the South Aral Sea proceeded by forcing the variation signals of climate change scenarios to historical data (the groundwater flux into the lake, ET and precipitation on the lake surface from 2005 to 2017).

General information of selected GCMs from the CMIP6 used in this study.

Climate variable	Model	Institute
Precipitation	ACCESS-CM2	Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia
	CanESM5	Canadian Centre for Climate Modeling and Analysis (CCCMA), Canada
	CESM2	National Center for Atmospheric Research (NCAR), USA
	CESM2-WACCM	National Center for Atmospheric Research (NCAR), USA
Evapotranspiration	CNRM-CM6-1	National Centre for Meteorological Research (CNRM), France
	CNRM-ESM2-1	National Centre for Meteorological Research (CNRM), France
	EC-Earth3-Veg-LR	EC-Earth-Consortium, Europe
	IPSL-CM6A-LR	Institute Pierre Simon Laplace (IPSL), France
Maximum and minimum surface temperature	ACCESS	Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia
	CanESM5	Canadian Centre for Climate Modeling and Analysis (CCCMA), Canada
	EC-Earth3	EC-Earth-Consortium, Europe
	IPSL-CM6A-LR	Institute Pierre Simon Laplace (IPSL), France

Predicting the South Aral Sea surface area (10³ km²) under three climate change scenarios in the 2030s, the 2060s and 2090s.

Scenarios	2030s	2060s	2090s
Sustainable pathway	6.05	5.79	5.78
Medium pathway	6.06	5.64	5.30
Fossil-fueled development	6.01	5.24	4.47

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