Modelling of Projected Caspian Sea Level under Increasing Anthropogenic Climate Change and Human Water Withdrawals during 21st Century

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Background and motivation: The Caspian Sea

Largest inland water-body and third deepest lake in the world

- **Input**:
  - **Runoff** (>80% from Volga river)
  - **Precipitation** over the sea
- **Output:**
  - **Evaporation** over the sea
  - **Water extraction?**

Background and motivation: The Caspian Sea

Large inter-annual fluctuations in water level during the 20th century: -26 m to -29 m (currently ~-28 m)

- **Majority attributed to climate-driven changes of the basin's hydrologic regime**

  (e.g., Rodionov, 1994, Elguindi and Giorgi, 2006)

- **NAO and ENSO**

  (e.g., Arpe et al., 2000, Nandini-Weiss et al., 2020)

- **Anthropogenic impact**
  - Artificial connection: **Kara-Bogez-Gol** (KBG): 1983 disconnection and 1992 connection (Kosarev et al., 2009)
  - Water extraction (e.g., Golitsyn, 1995; Rodionov, 1994)

Drowned mosque along the south-eastern Caspian shore, Iran

Background and motivation: The Caspian Sea

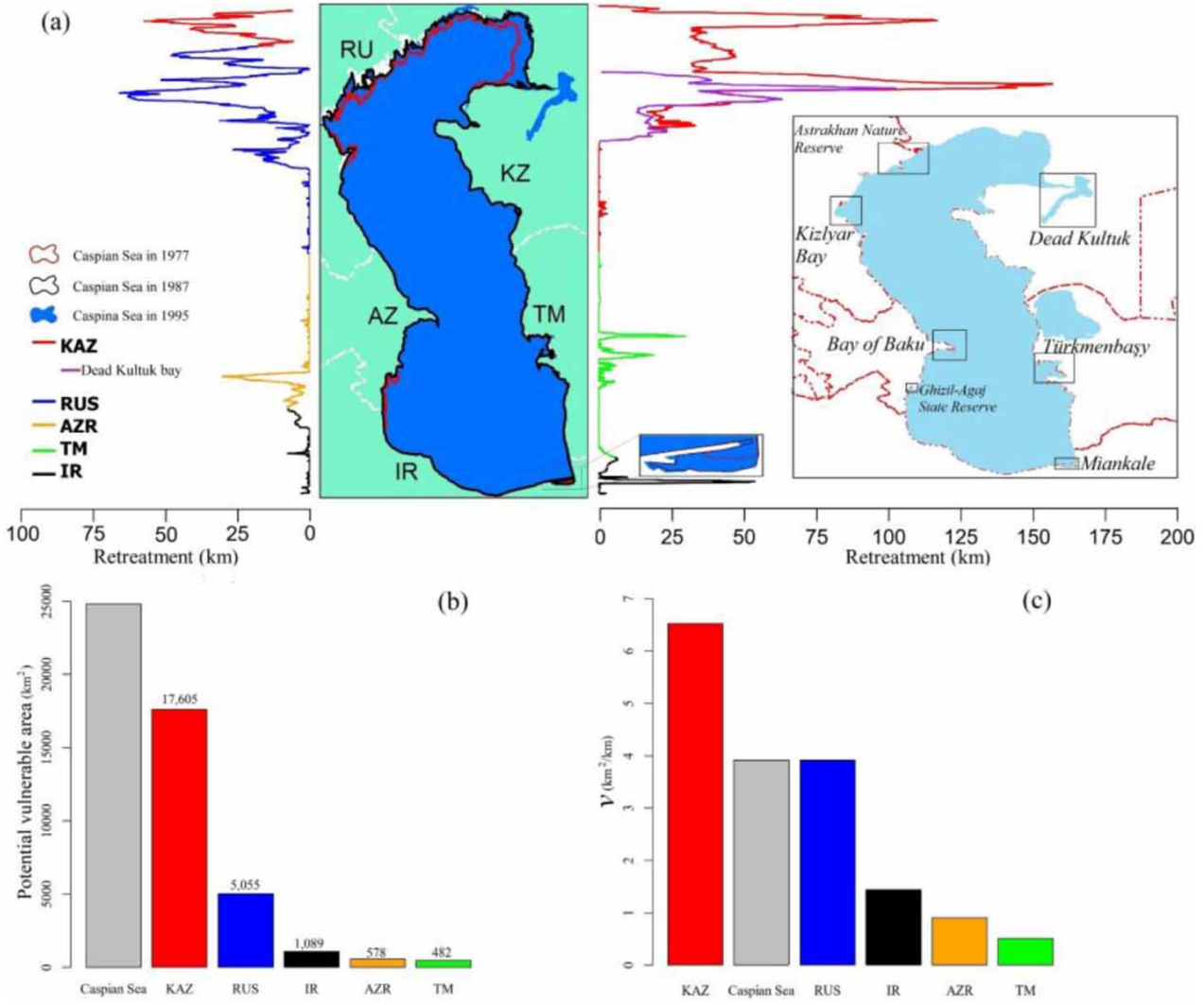
- Ecosystem services to more than 14 million people (Leroy et al., 2020)

- Very sensitive to changes in climate and human interventions
  - Roughly 25,000 km2 (6-7%) of the CS is now vulnerable to desiccation as CS levels fluctuate (Akbari et al 2020).

- Therefore, robust **scenarios of future Caspian Sea level** are vital to inform environmental risk management and water-use planning

(Akbari et al., 2020)

Spatial vulnerability of coastal areas of the Caspian Sea to SWL fluctuation



Projection of Caspian Sea Level

$$\Delta CSV^t = [(P^t_{land} - E^t_{land})A^{t-1}_{land} + (P^t_{sea} - E^t_{sea})A^{t-1}_{sea} - \Delta WE^t]\Delta t$$

- Precipitation dominates
- Evaporation dominates
- Water extraction

Climate change impact

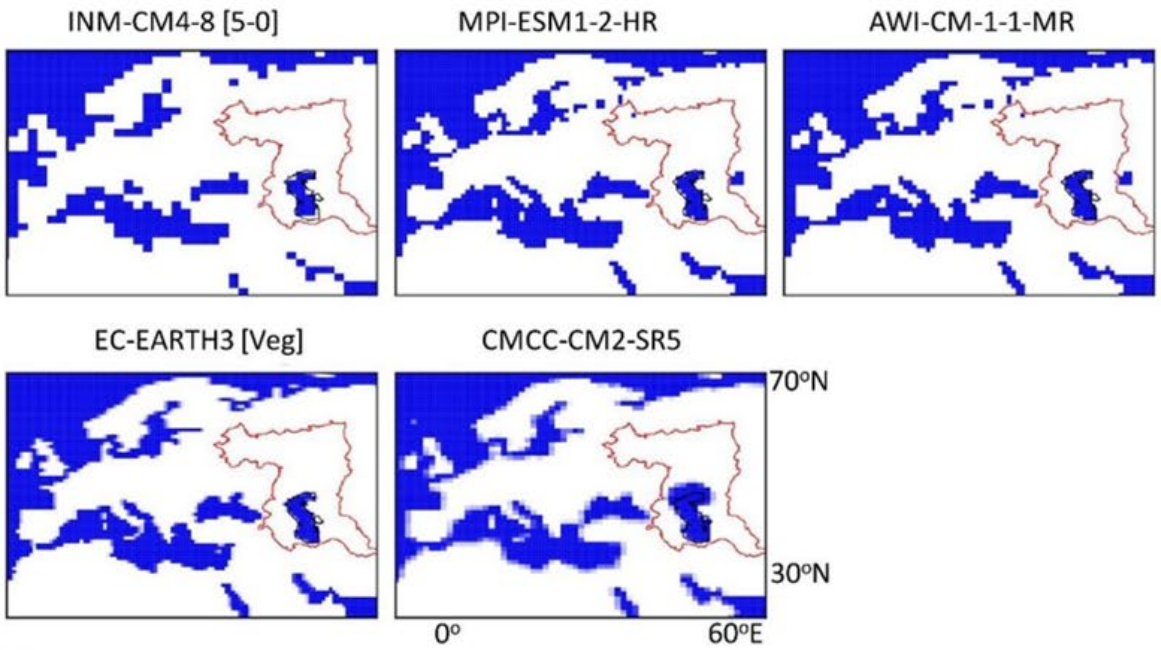
- How well is the Caspian Sea represented in the climate models?
- How does this influence future climate projections: Caspian Sea water budget change in the **CMIP5 and CMIP6** models in the 21st century?

Anthropogenic impact

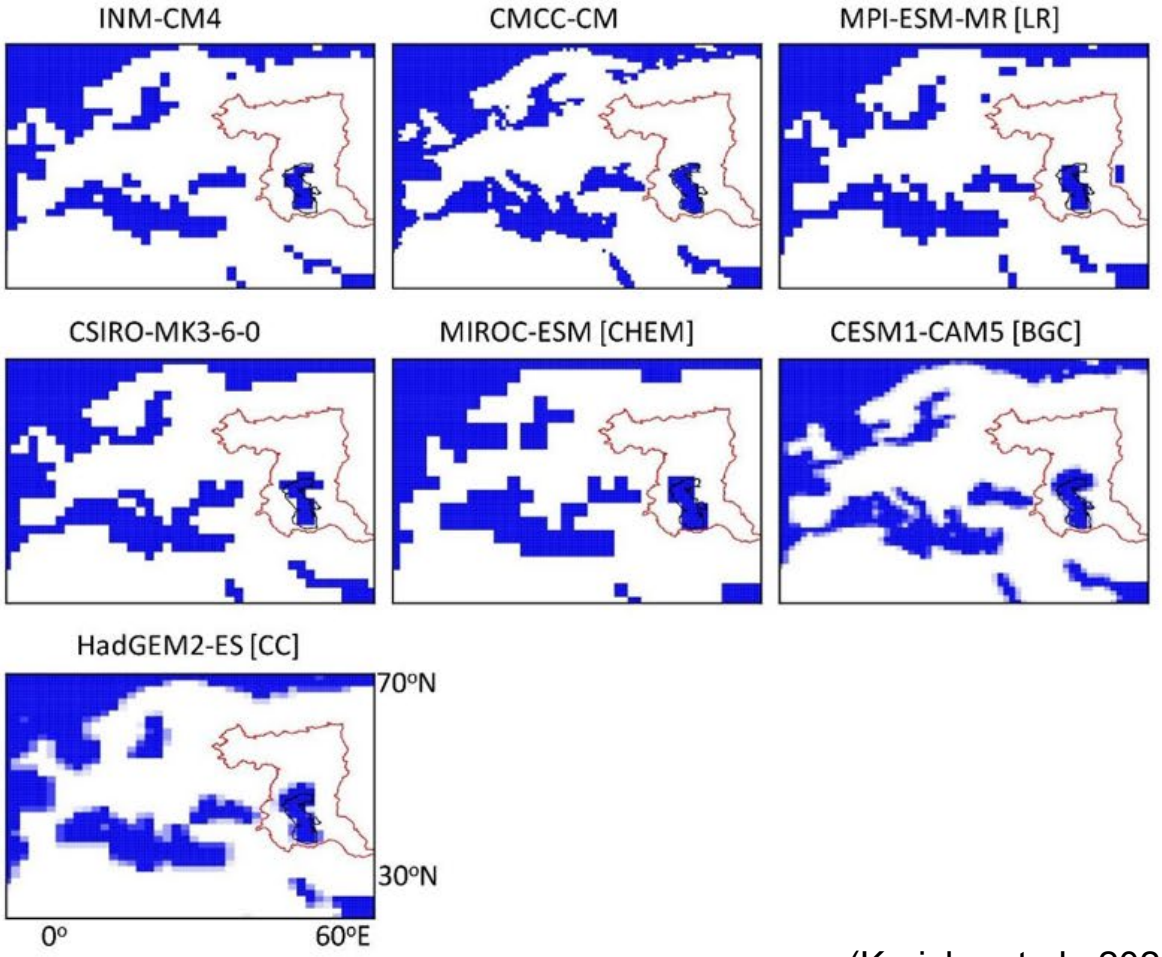
- estimated future water extraction based on present water use and projected population

How Caspian Sea represented in the climate models?

CMIP6 (Eyring et al., 2016)



CMIP5 (Taylor et al., 2012)

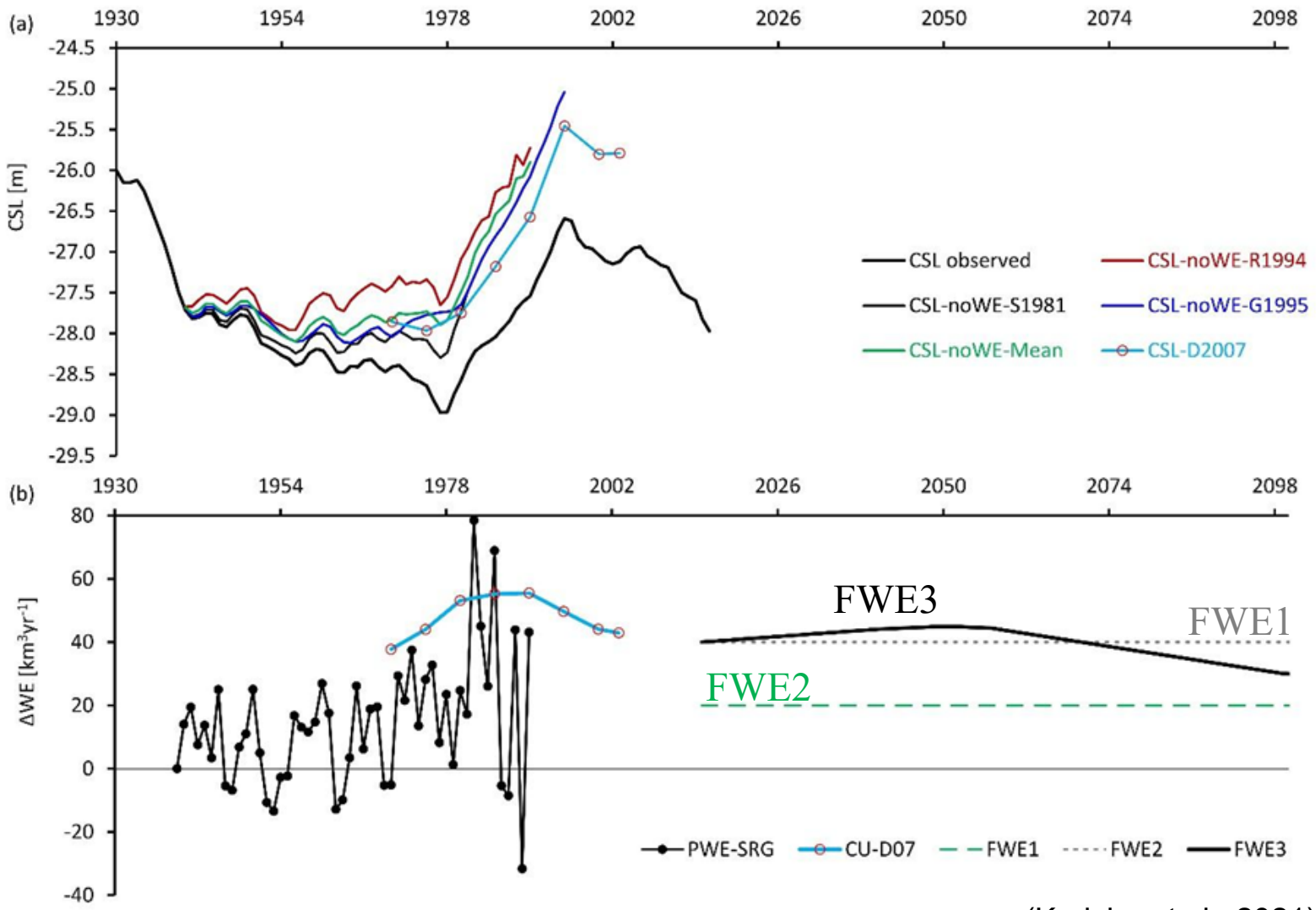


(Koriche et al., 2021)

Future water extraction Scenarios

Three scenarios

- **Scenario-1 (FWE1):** a constant extraction rate of 40 $km^3\ yr^{-1}$ (Demin, 2007; Kudekov, 2006).
- **Scenario-2 (FWE2):** constant annual withdrawal at 20 $km^3\ yr^{-1}$ (half of FEW1)
- **Scenario-3 (FWE3):** based on population projections for nations within the catchment (Vollset et al 2020).

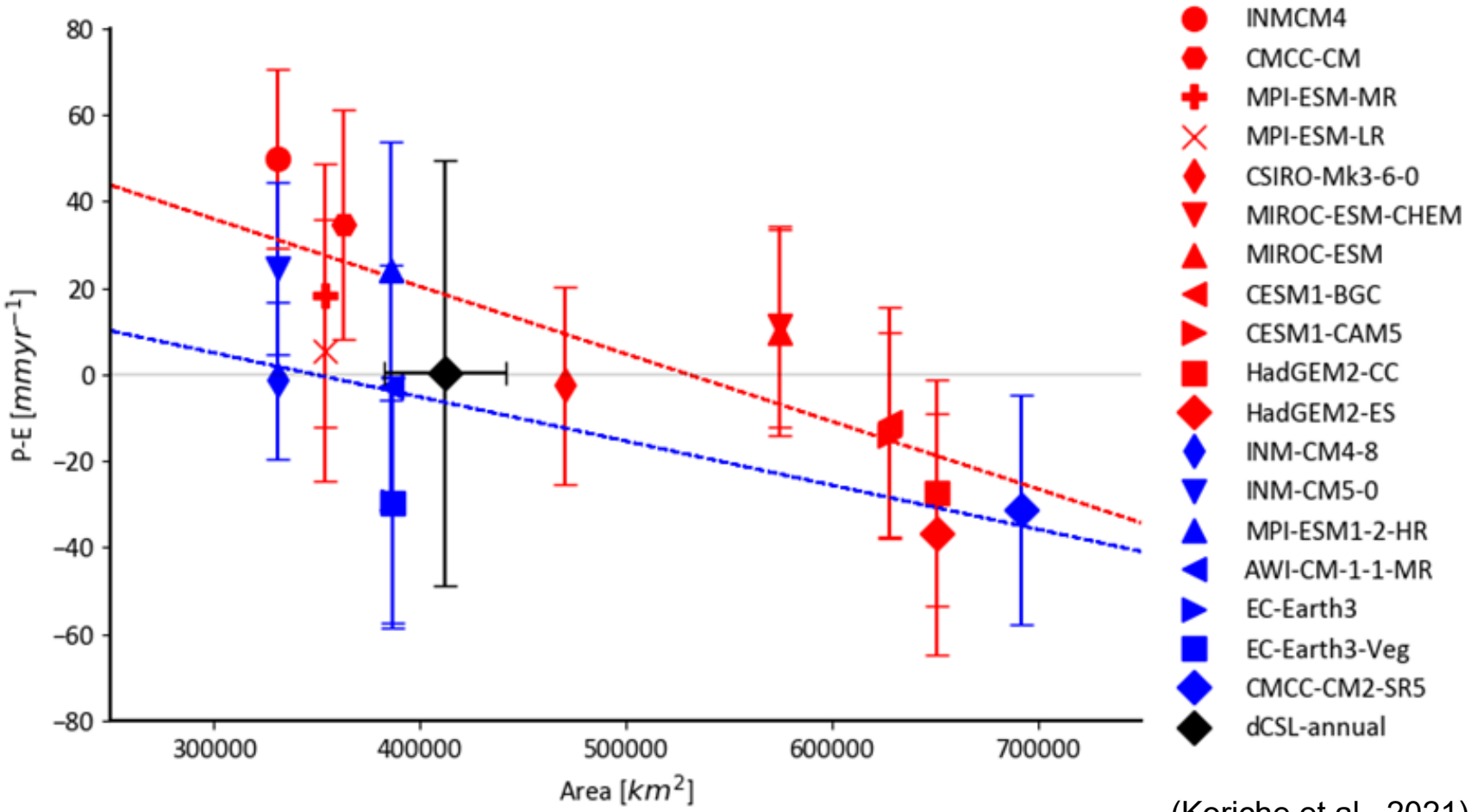


(Koriche et al., 2021)

20th C Caspian Sea basin Water budget vs CS area

- **A considerable spread in the annual mean water budget (20th C) of the CS catchment (P-E) between climate models in both CMIP5 and CMIP6.**

- Models with a **prescribed CS surface area closer to historical observations** generally also produce a **water budget closer to observationally-derived** estimate.

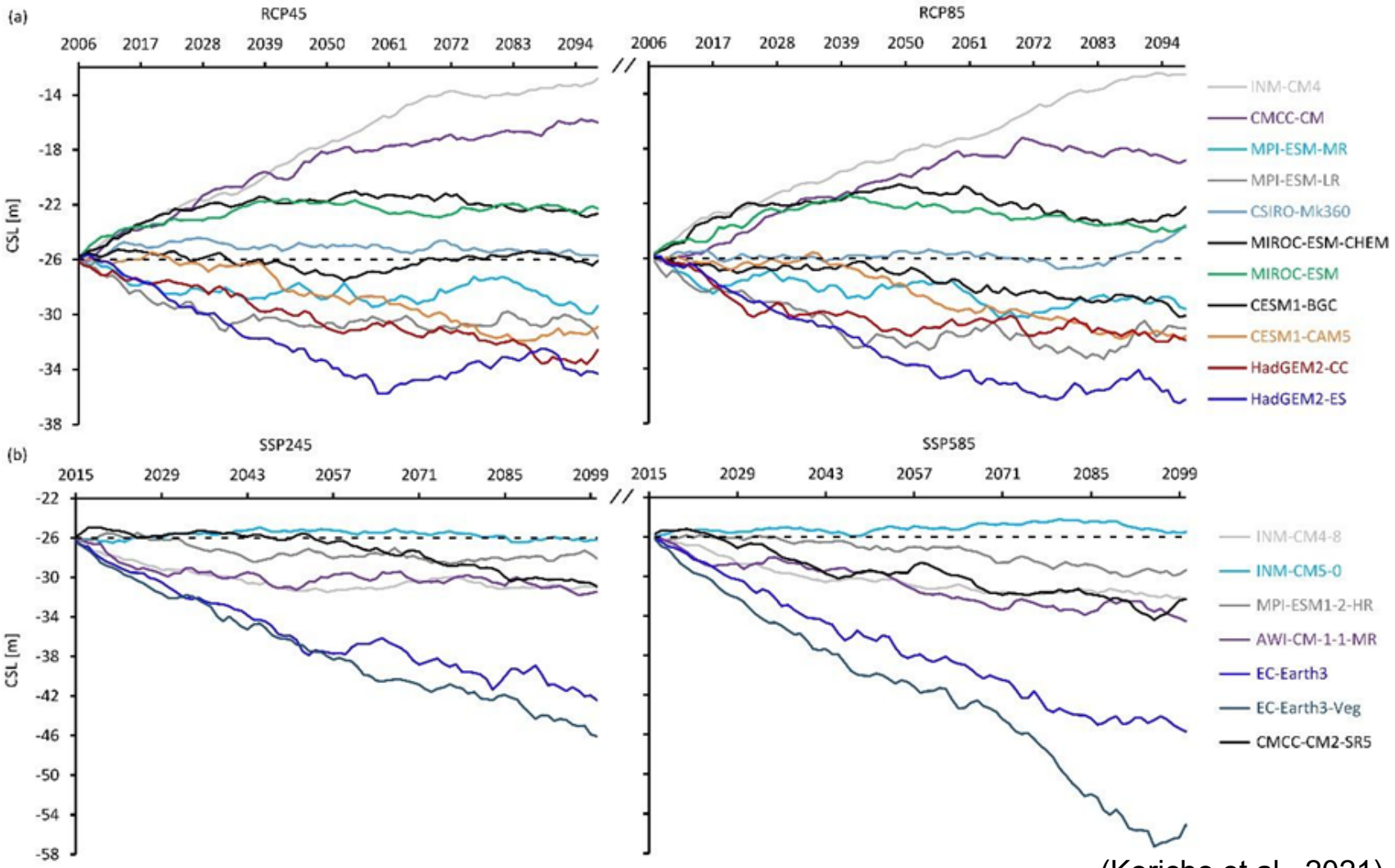


(Koriche et al., 2021)

21st Caspian Sea Level without water extraction

- The **declines in CS level** are larger with models where **larger CS is prescribed** in the climate model, and those with **higher projected evaporation** (e.g., EC-Earth3 and EC-Earth3-Veg, which have up to 70% higher evaporation than other models).

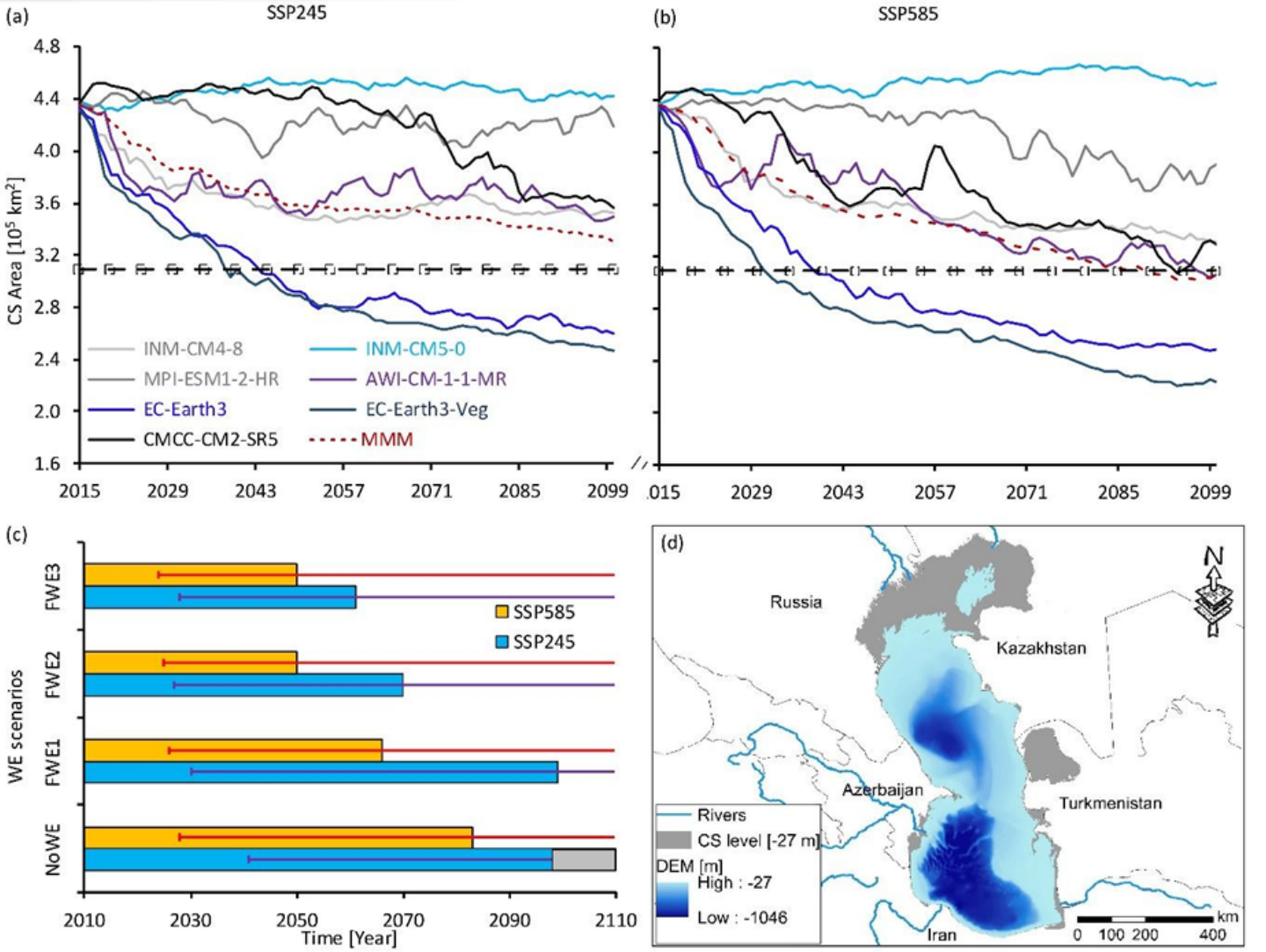
- Projected **CS level increases** in models with **cold bias and smaller Equilibrium Climate Sensitivity** (e.g., INM-CM model families).



(Koriche et al., 2021)

Projected Caspian Sea area of the 21st C

- The relationship between CS level and CS surface area is **highly non-linear.**
  - When CS level varies between -**27 m and -34 m** the **CS area changes** are proportionately large compared with when CS level is below this.
- In all scenarios, except for SSP245 with no water extraction, desiccation occurs at some point before the end of the century.



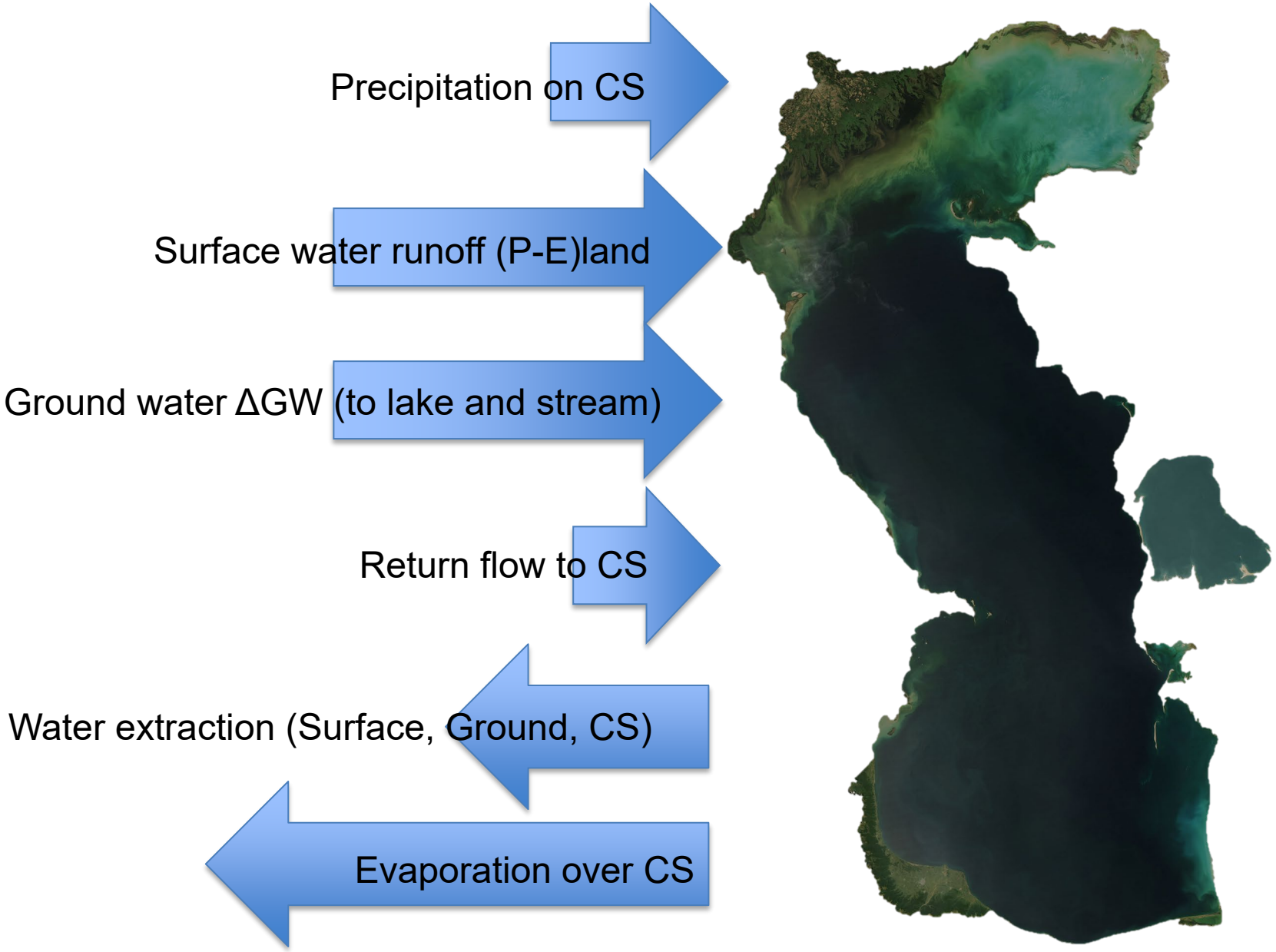
(Koriche et al., 2021)

Key points

- Many climate models either **ignore or do not properly prescribe Caspian Sea** area with considerable variations, and this is a **primary determinant in the modelled water budgets** for both historical and future projections
  - Therefore, **care needs to be taken when interpreting the future water budget variations over** the Caspian Sea basin from CMIP climate models.
- This is the first study to combine latest state-of-the-art projections with extraction scenarios based on historical water use and projected population for 21st century
- **Water extraction** rates are as important as climate in controlling future CS level, with potentially up to **7 m further decline**, leading to **desiccation of the shallow northern CS**.
  - increasing vulnerability to freshwater scarcity, transforming ecosystems, as well as impacting the climate system
- As result of the **combined impacts** of future water extractions and climate change, northern part of the Caspian Sea is at clear risk of **desiccation before 21st C**.

Key points

- A coordinated effort among the countries in the Caspian Sea basin is vital for the implementation of an integrated watershed management approach.



Thank You!

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