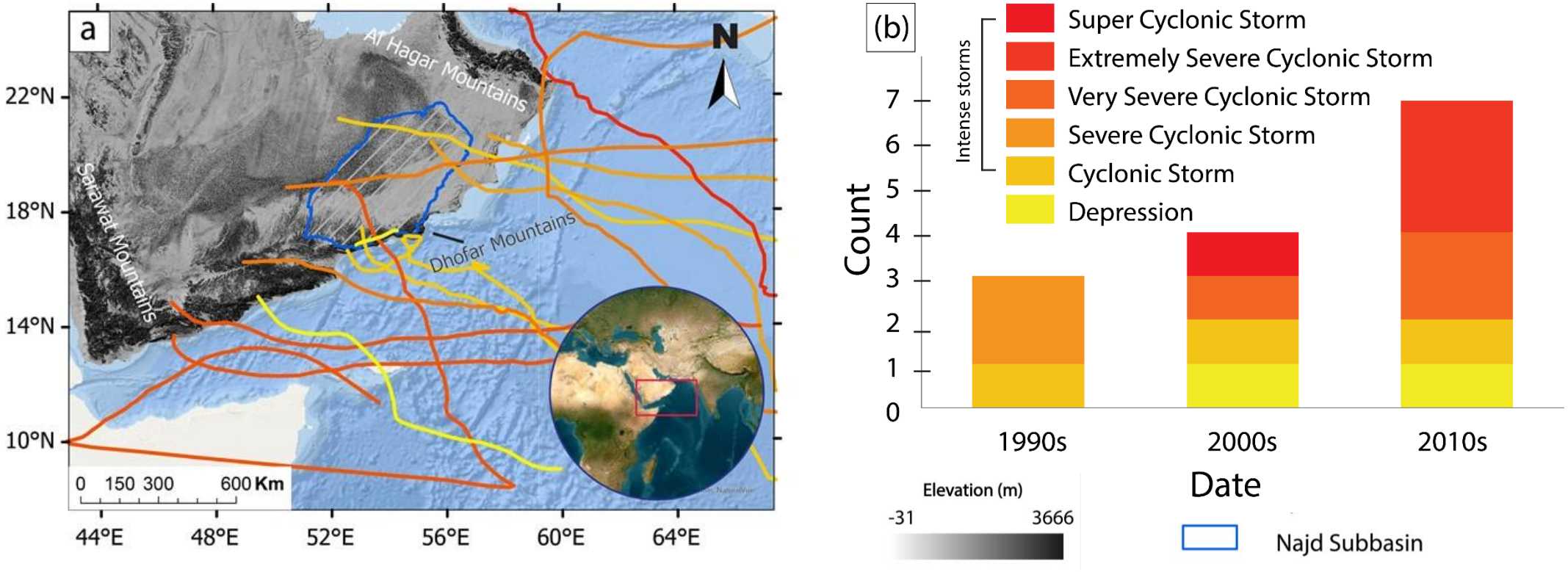
Aquifer Recharge in Arid Lands from GRACE and Modelling: Present and Future

Mohamed Sultan
Hassan Saleh, Hadi Karimi
Department of Geological and Environmental Sciences,
Western Michigan University
Kalamazoo, MI

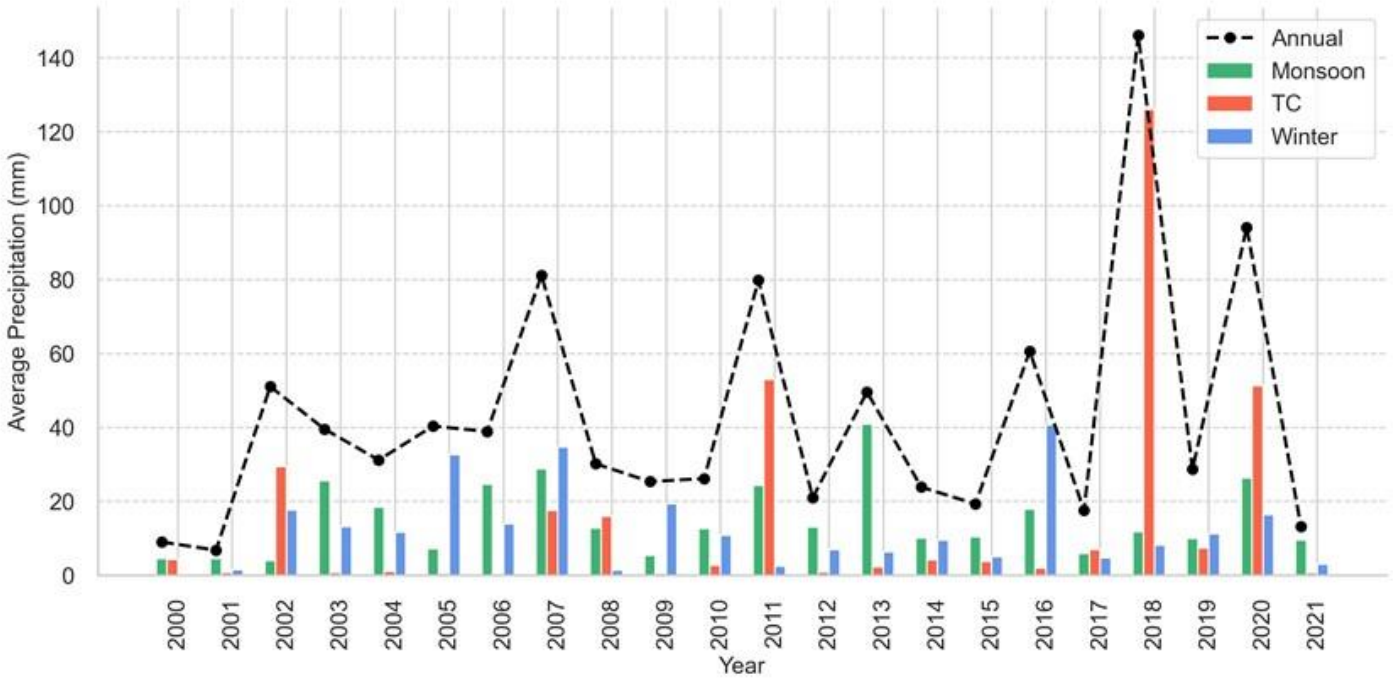
October 7-9 2025

Cyclones in Southern Arabian Peninsula



Intense precipitation events, including cyclones, are projected to become more frequent and severe across many arid and semi-arid regions in the 21st century due to global warming. In these regions, groundwater serves as the primary source of freshwater.

Cyclones in southern Arabian Peninsula

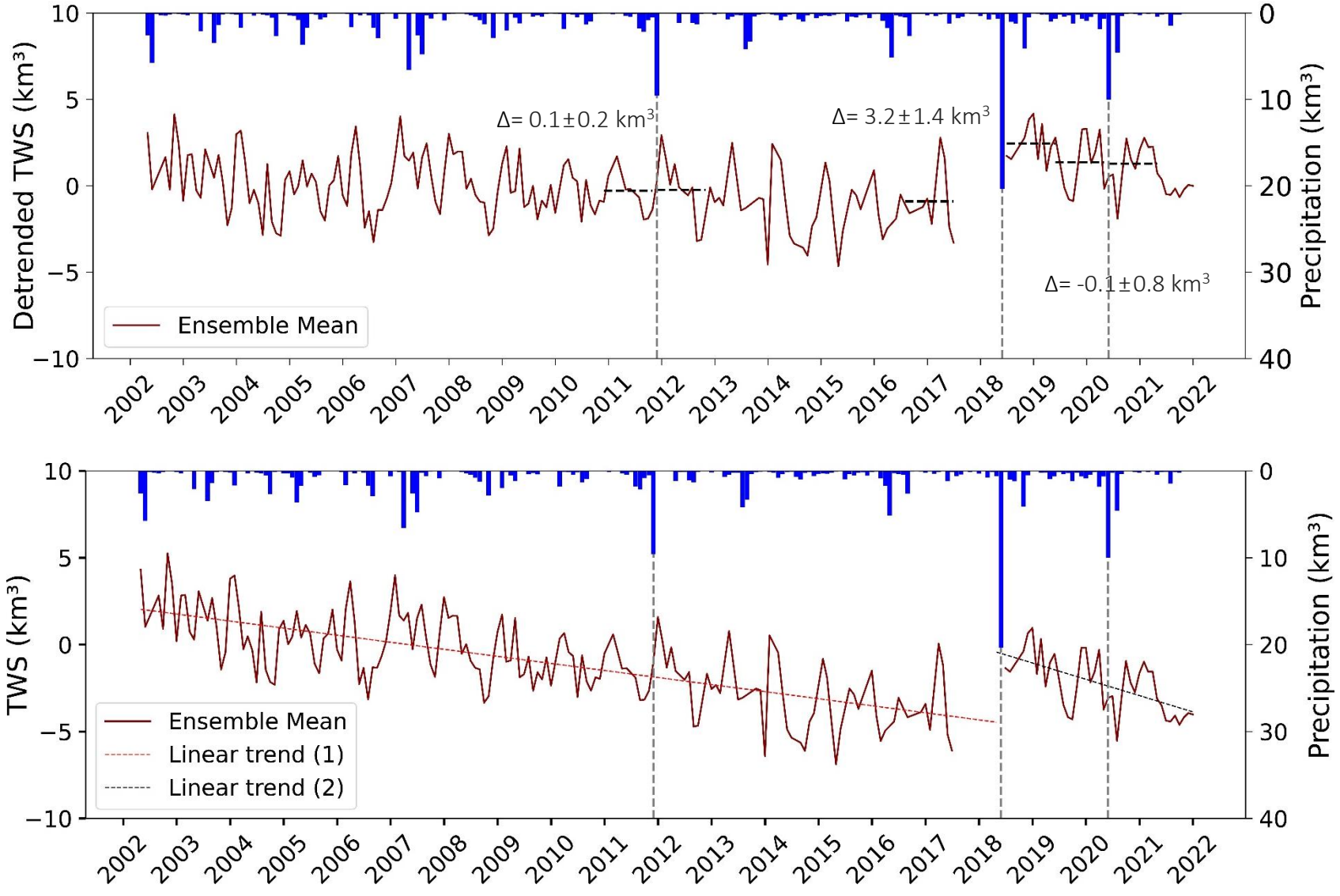


- Highest annual rainfall intensities during cyclone years (2011, 2018, 2020).
- TC contributions far exceeded those from monsoons, & winter precipitation
- Mekunu delivered 100 mm of rainfall over the Najd subbasin in three days, nearly three times its average annual precipitation.
- Mekunu accounted for 67% of the precipitation in 2018, Keila 61% in 2011, and 48% for Cyclone 2020

Recharge from GRACE &GRACE-FO

- Cyclone Mekunu (2018) delivered 20.1 km^3 of rainfall to the Najd and recharged groundwater by 3.2 ± 1.4 km^3.

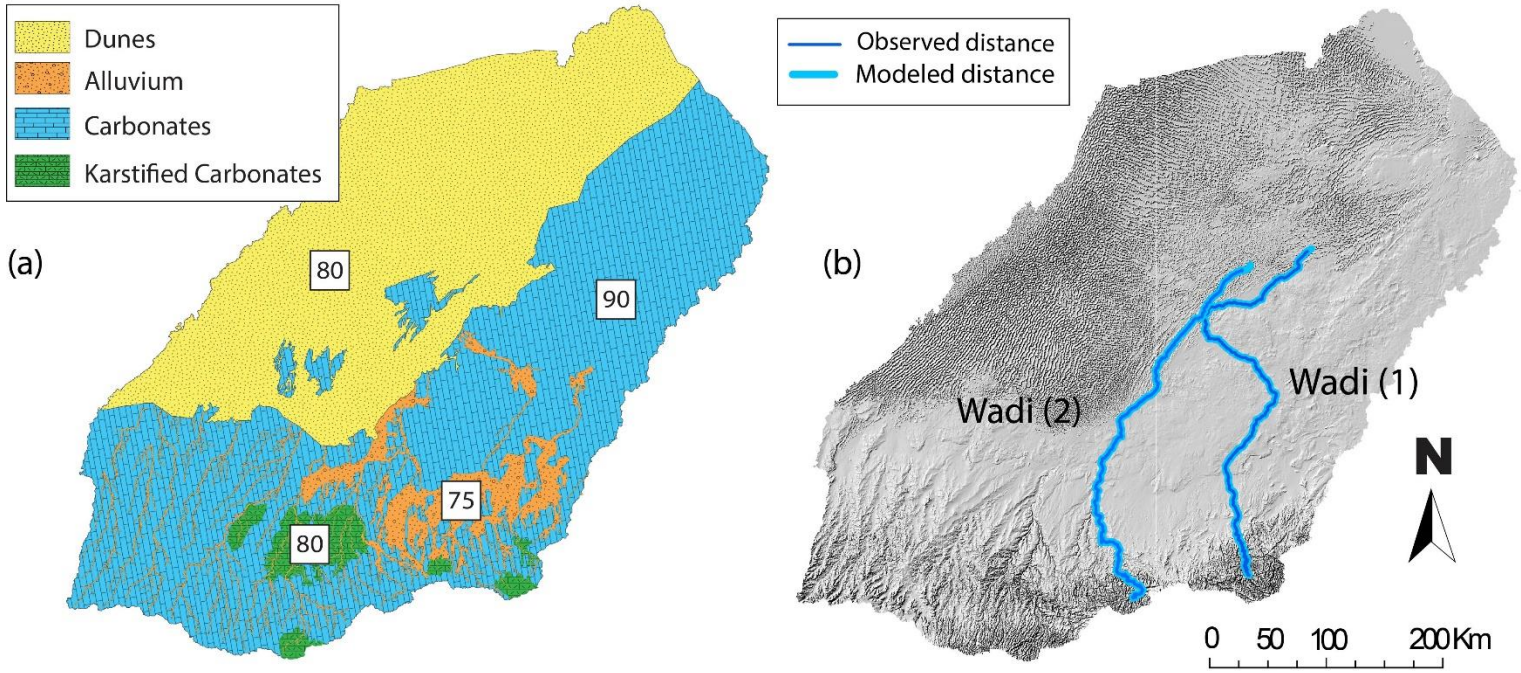
- Ensemble: CSR, JPL, GSFC mascon solutions



Construct, calibrate, & validate rainfall-runoff/hydrodynamic models using observed runoff & recharge

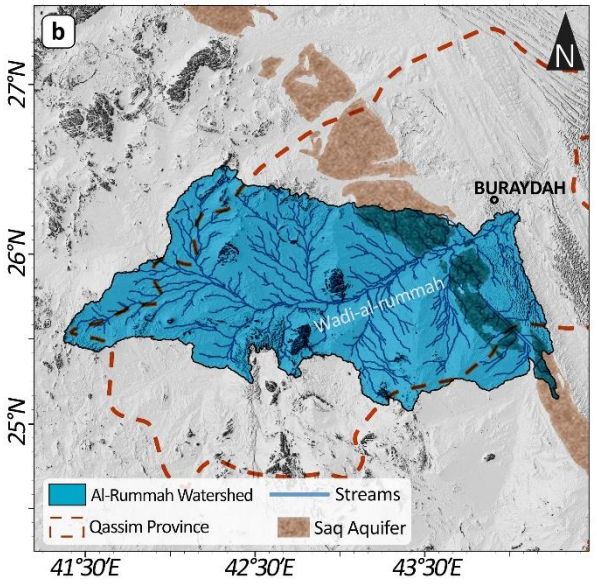
- Once a model is calibrated/validated it could be used to estimate recharge & runoff for any extreme event

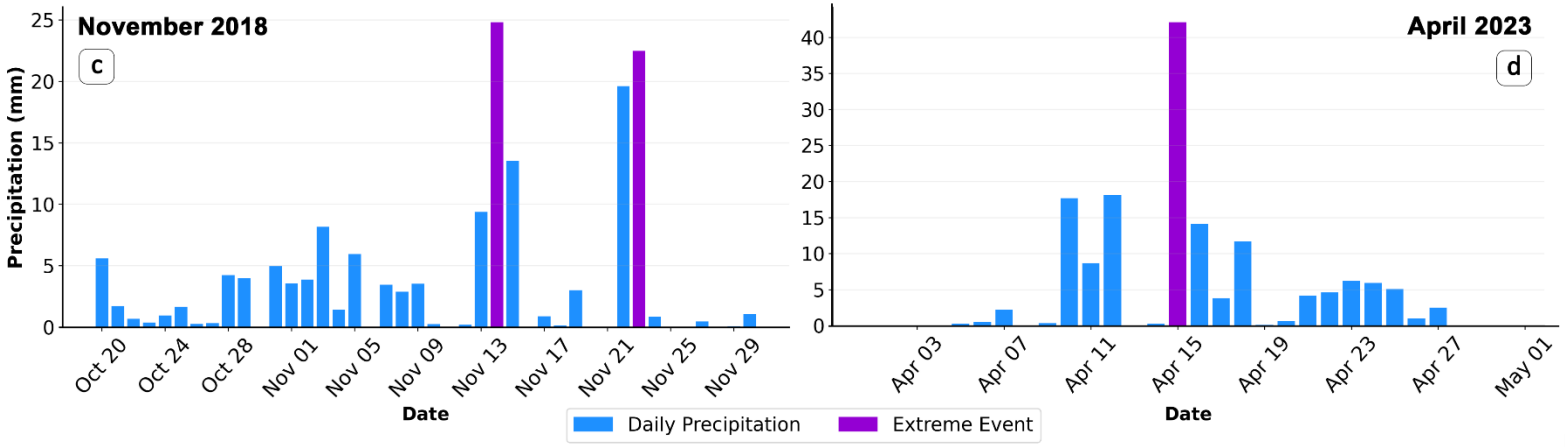
- Moreover, the calibrated model could be forced by bias-corrected climate models (e.g., CMIP6) under various scenarios (e.g., SSP2-4.5 and SSP5-8.5) to estimate recharge & runoff for the investigated aquifers in the 21st century

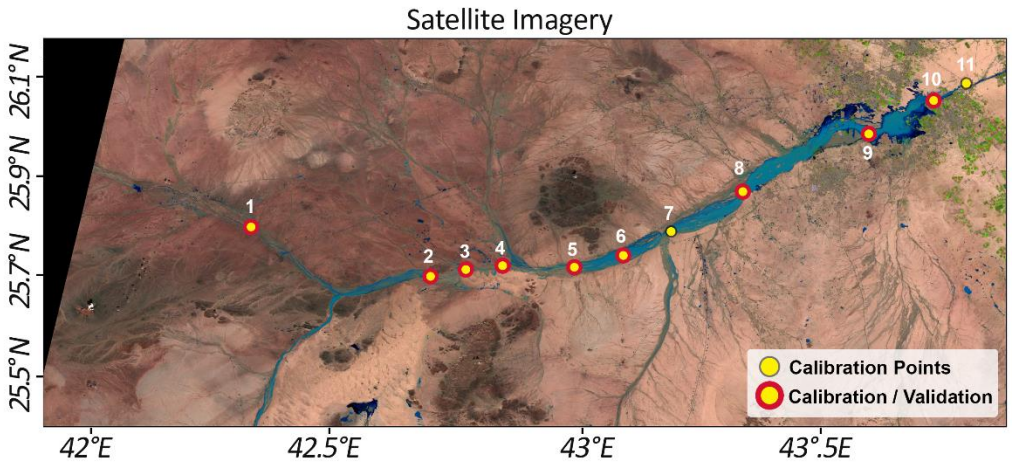


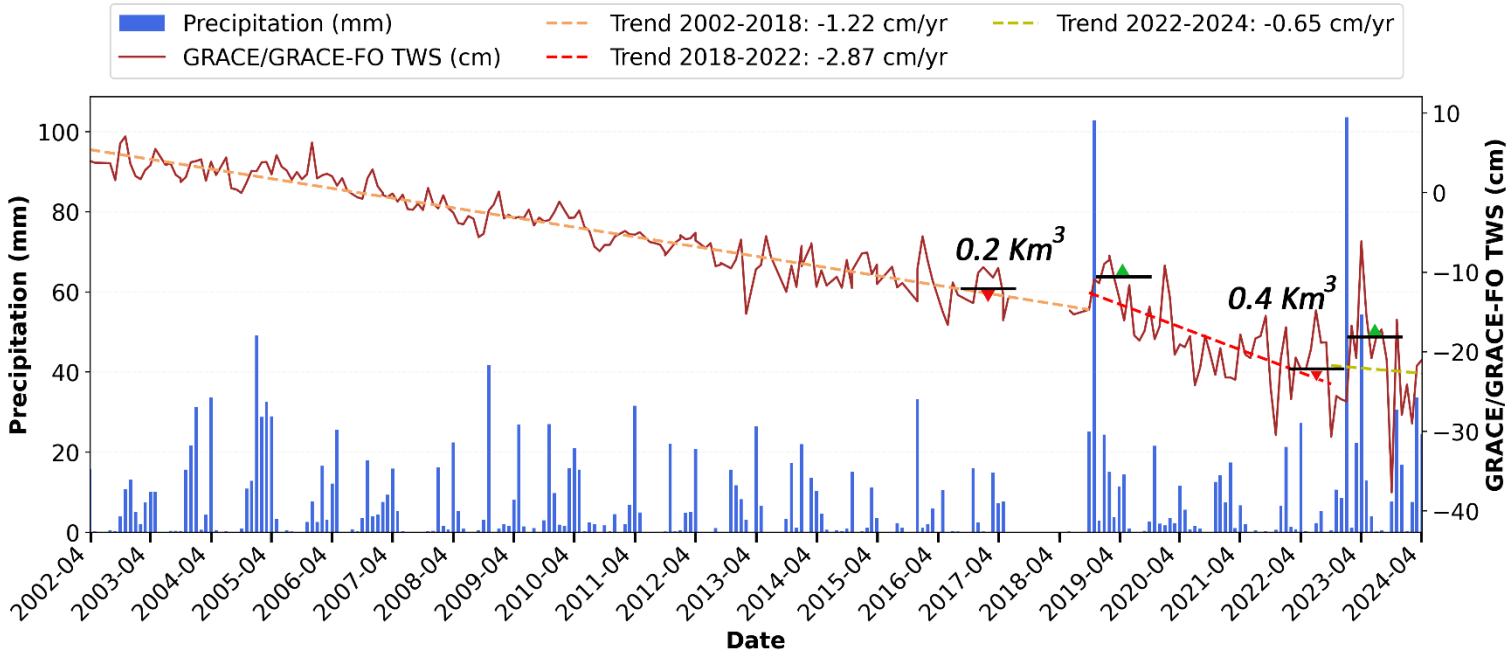
Saleh et al., (2025)

Similar extreme events over watersheds in central Arabian Peninsula





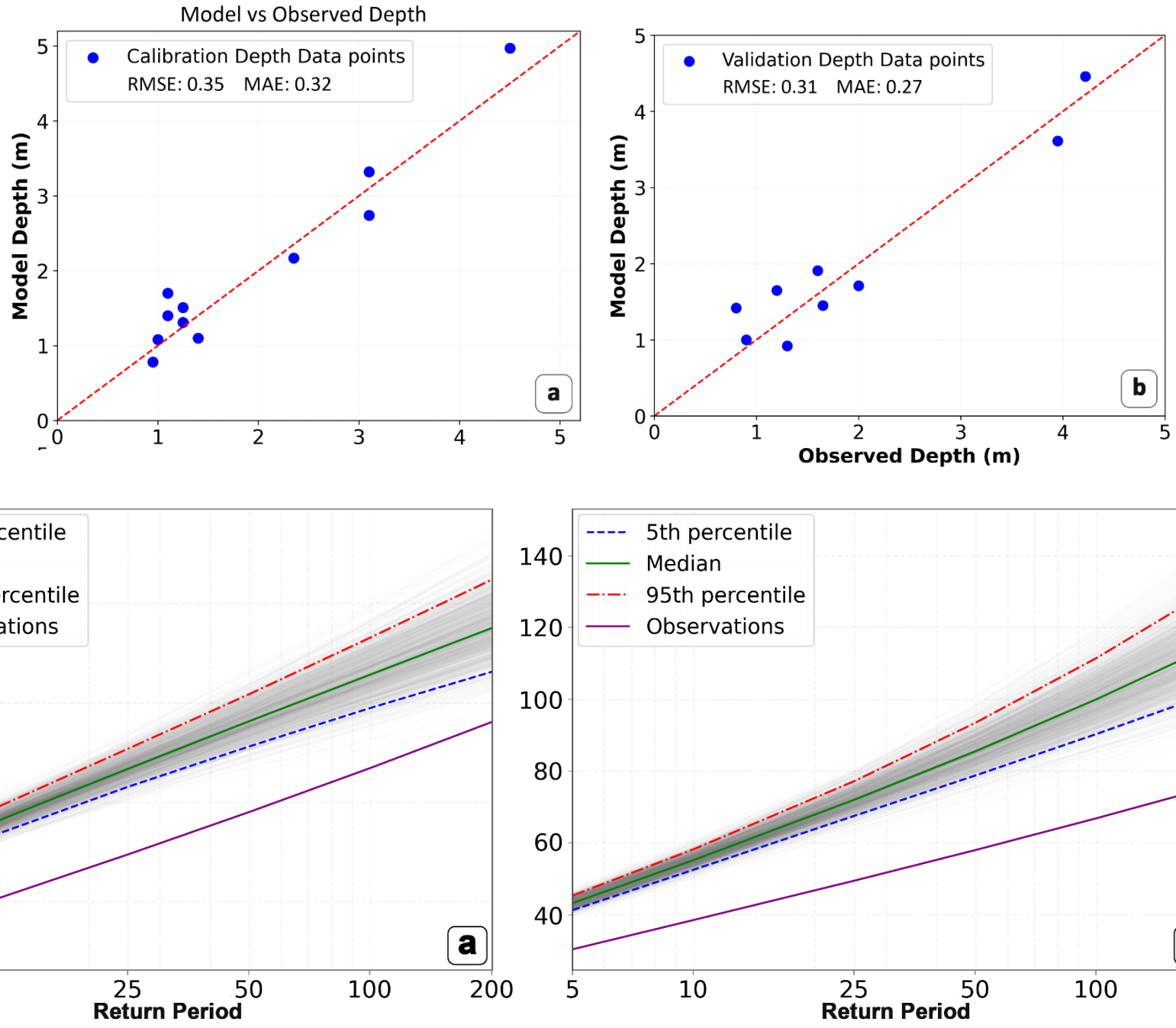




(Karimi et al., 2025)

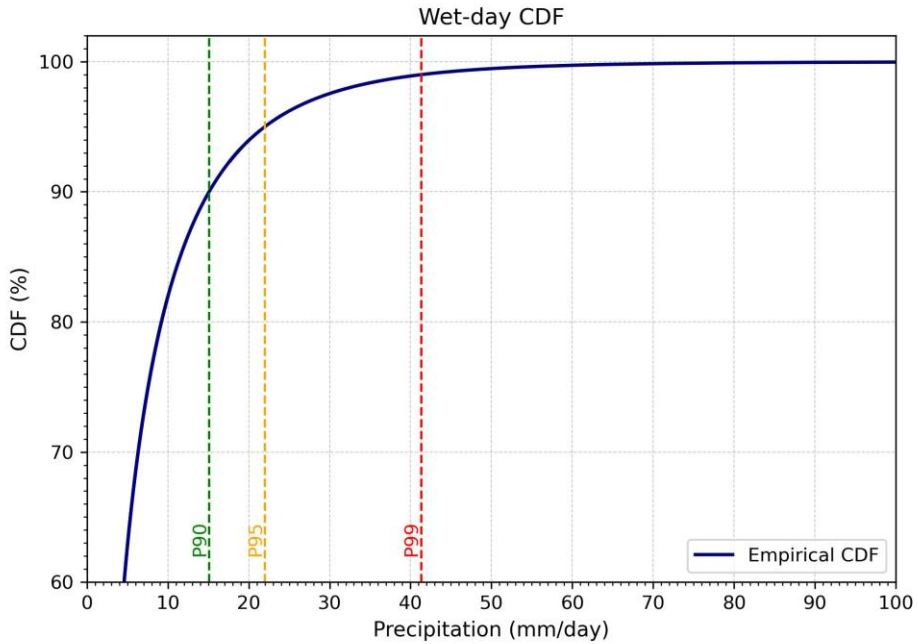
Future predictions

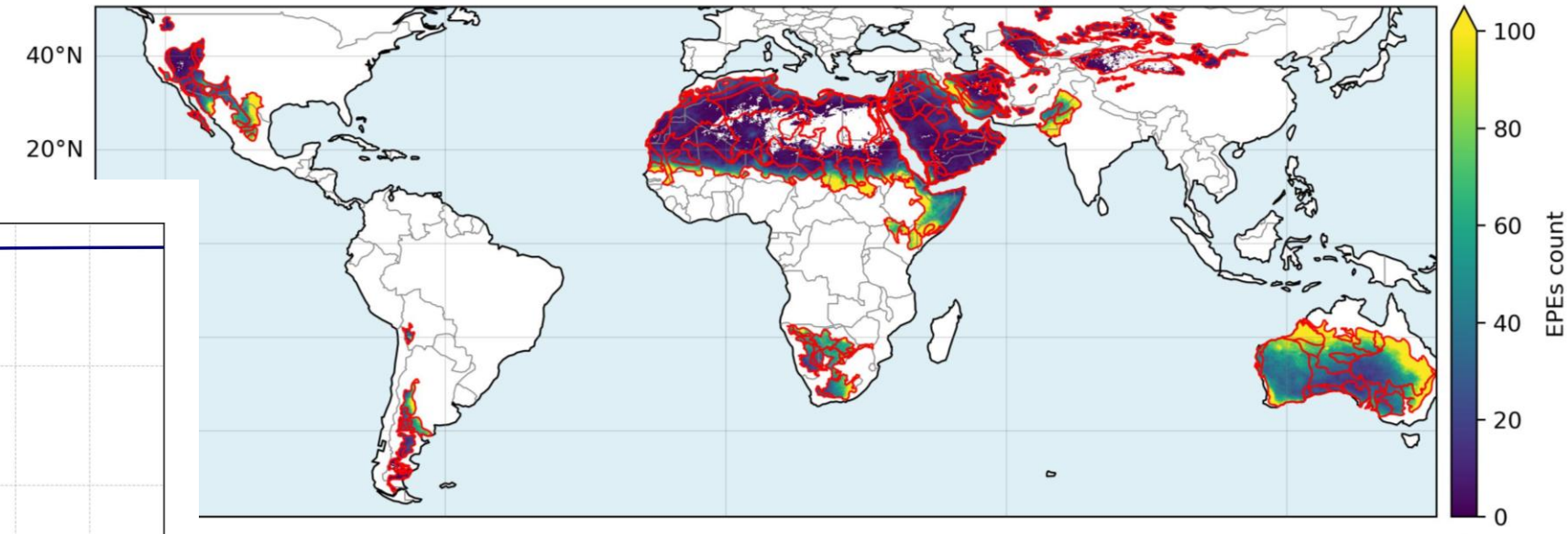
We assess 21st century precipitation, runoff, recharge using calibrated, climate-driven rainfall runoff/hydrodynamic model forced by bias-corrected CMIP6 models under various scenarios (SSP2-4.5 and SSP5-8).



(Karimi et al., 2025)

Global applications



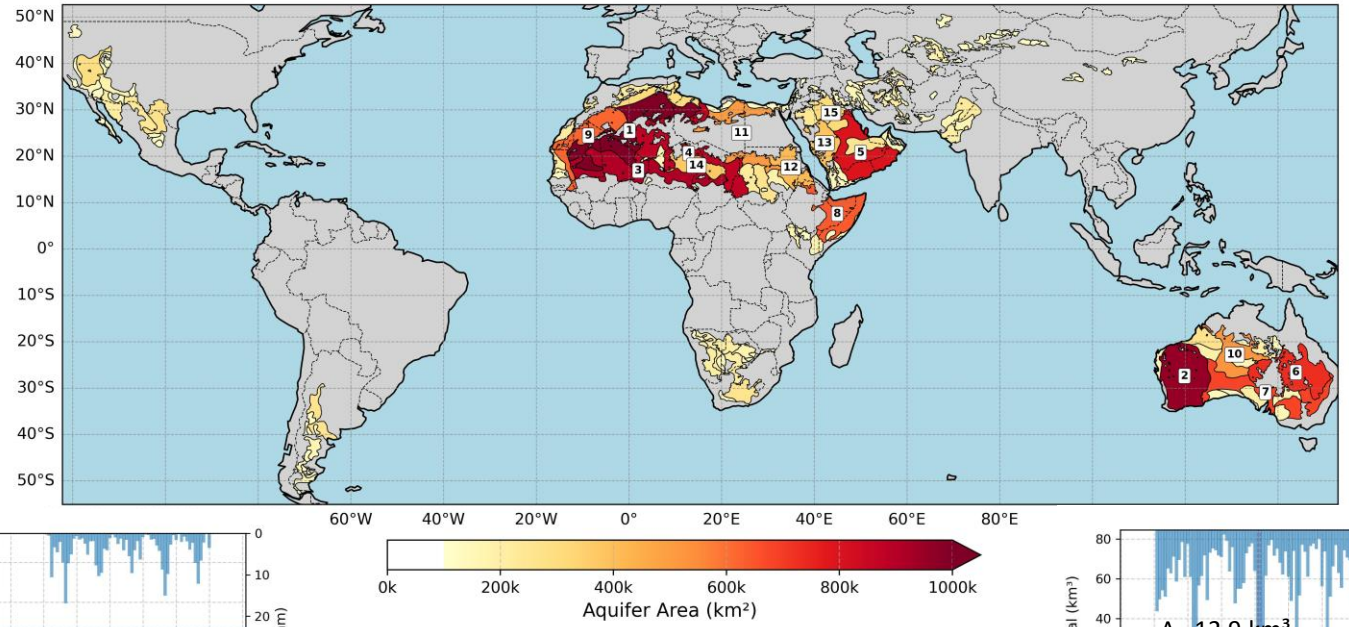


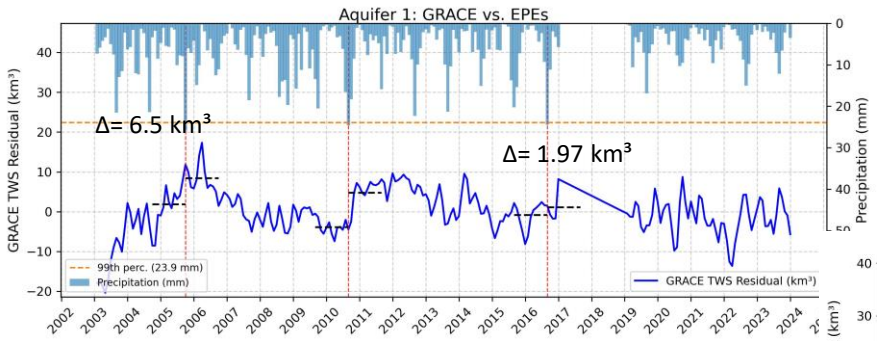
- The number of the EPEs that are more than the 95th percentile (22 mm) of daily precipitation in arid and hyper-arid regions.

Aquifers from: World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP) v1

Preliminary Recharge Estimates

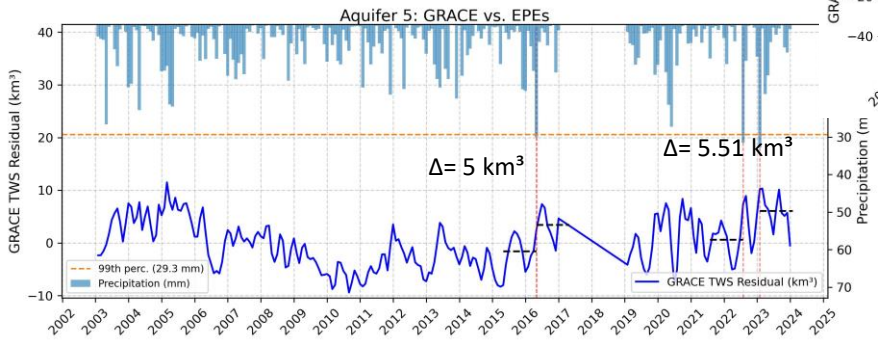
EPEs exceeding the 99th percentile of monthly precipitation distribution produce notable recharge in arid aquifers

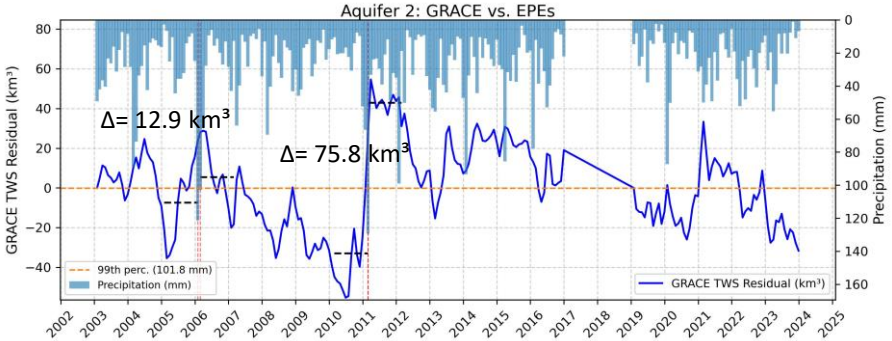




Taoudeni-Tanezrouft Aquifer

Western Australia





The southern Arabian Aquifer

For additional information

1. Elhaddad, H., Sultan, M., Yan, E., Tran, T.N.D., Torres-Uribe, H.E., Karimi, H., 2025, Nile Basin Flow Regimes Under 21st Century Climate Variability, Nature Communications Earth & Environment (in press).

2. Karimi, H., Sultan, M., Yan, E., Elhaddad, H., Saleh, H., Abdelmohsen, K., Emil, M.K., 2025, Climate-Extreme Modeling Framework for Sustainable Flood Management in the Arabian Peninsula, Environmental Management, https://doi.org/10.1016/j.jenvman.2025.127074

3. Saleh, H., Sultan, M., Yan, E., Save, H., Elhaddad, H., Karimi, H., Abdelmohsen, K., Emil, M.K., Qamshouai, S., 2025, Intensifying tropical cyclones in the Arabian Sea replenish depleting aquifers. Nature Communications Earth and Environment, https://doi.org/10.1038/s43247-025-02493-w

Thank You