Under the High Patronage of His Majesty King Mohammed VI

International Water Resources Association
IWRA

XIX WORLD WATER CONGRESS
International Water Resources Association (IWRA)
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Kingdom of Morocco
Ministry of Equipment and Water

Snowpack Decline and Its Implications for Future Water Resources in the Atlas Mountains of Morocco under a High-Emission Climate Scenario

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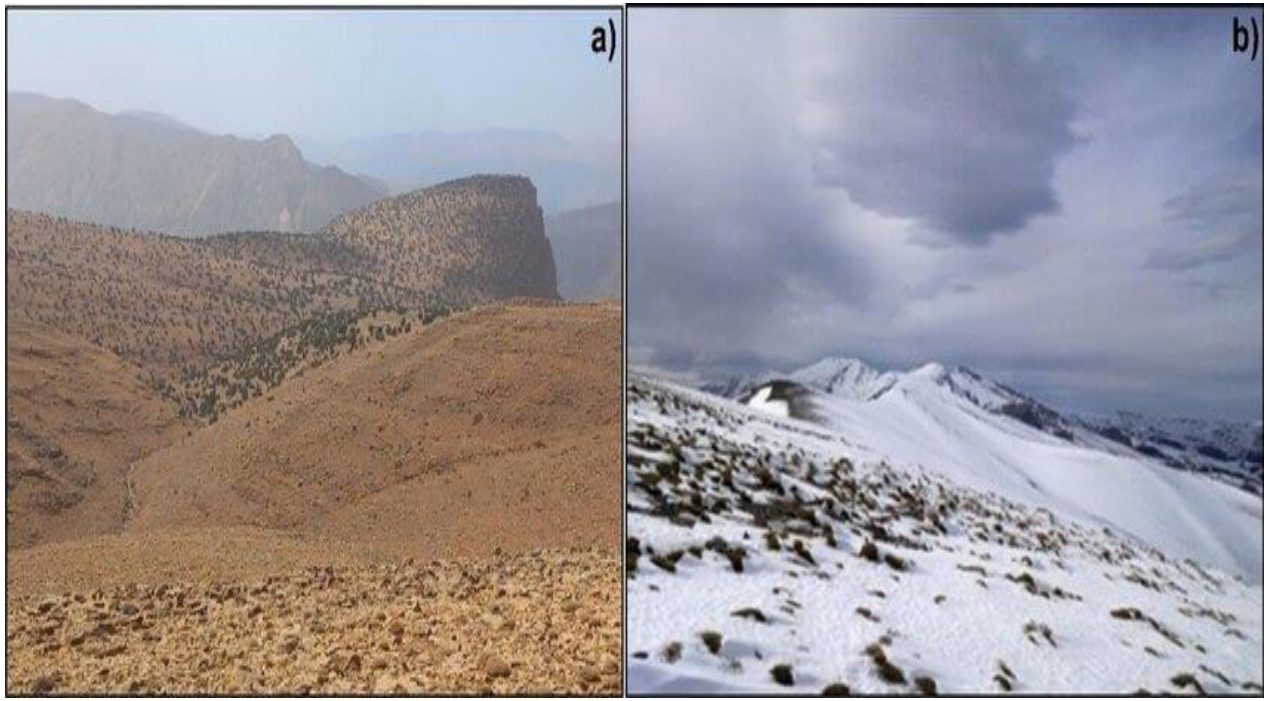
Background and Motivation

- In the Atlas Mountains, snow acts as a **natural water reservoir**.
- Climate warming threatens this regulation function.
- Snowmelt sustains streamflow during the dry season.

(Ourika Valley Stock Photos, High-Res Pictures, and Images - Getty Images)



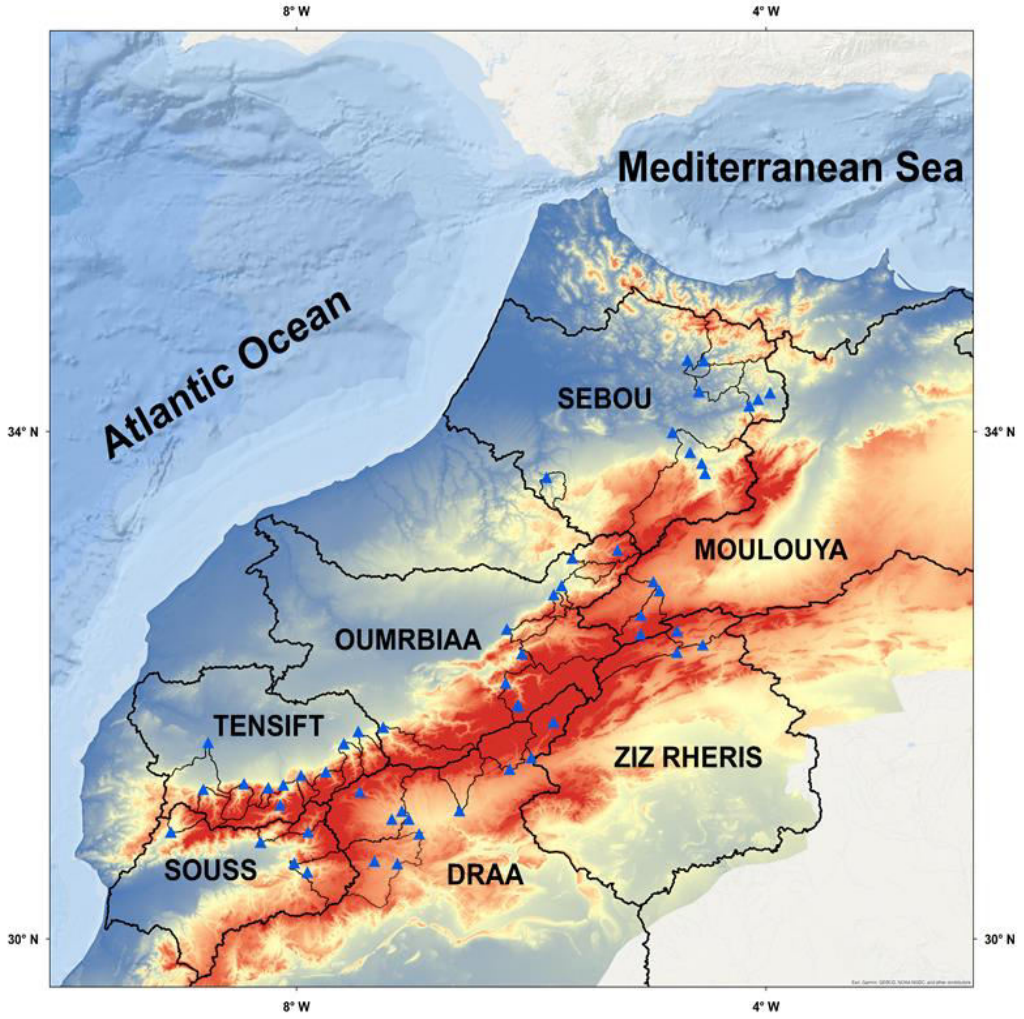
(Mohamed et al., 2025)

Objectives

- Quantify future changes in snowpack dynamics.
- Assess impacts on hydrological regimes.
- Identify implications for water-resource management.

Study area

- **36 snow-affected basins** across the Atlas Mountains.
- Elevations from **400 m to over 3200 m.**
- Mixed pluvial–nival regimes.

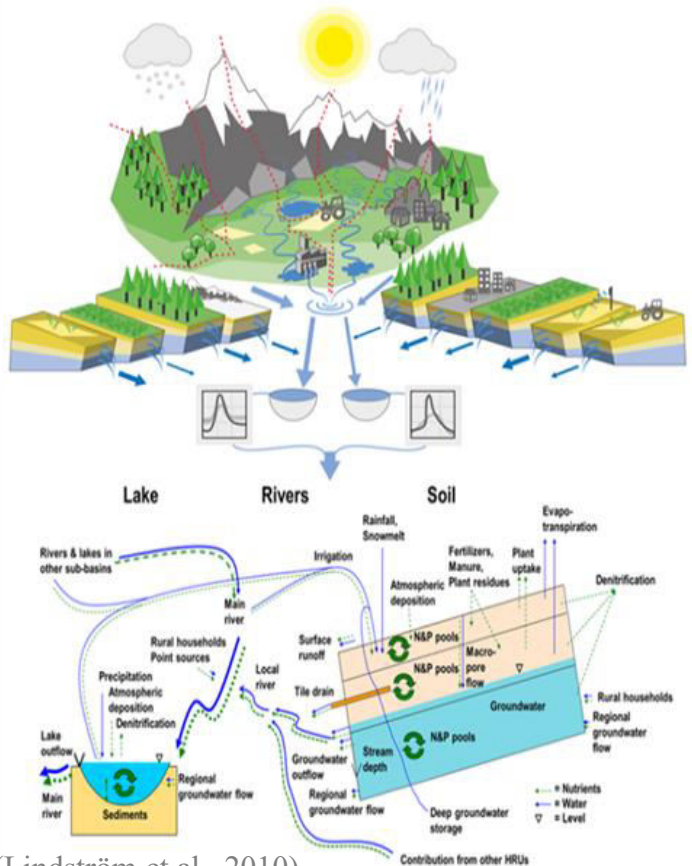


Data and Models

Hydrological Modeling

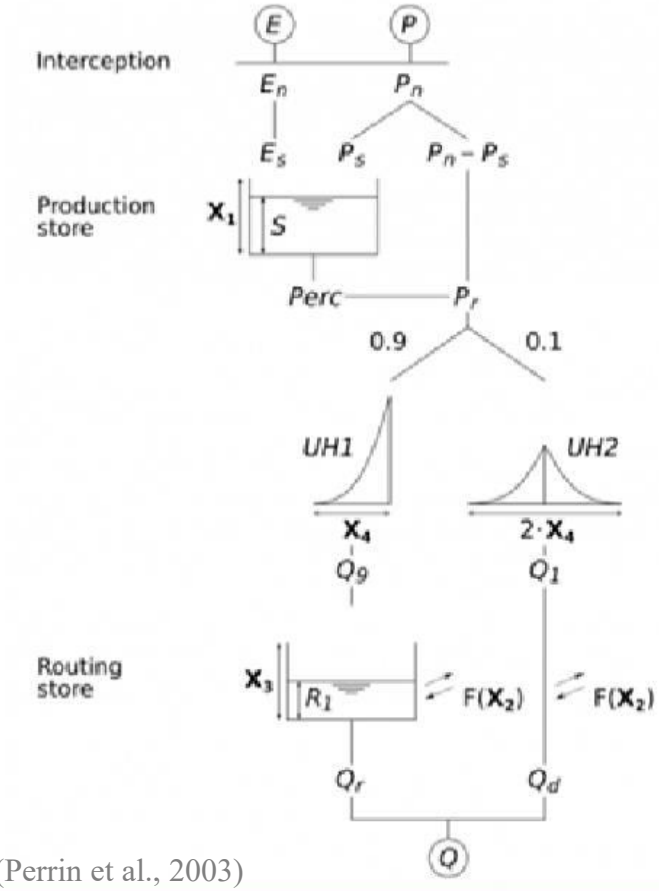
- **Models Applied:**
  - **HYPE** – semi-distributed model with 11 calibrated parameters (semi-automatic).
  - **GR4J-CemaNeige** – lumped conceptual model with 6 automatically calibrated parameters.
- **Scope of Analysis:** 36 watersheds across the Atlas Mountains.

HYPE Model



(Lindström et al., 2010)

GR4J-CemaNeige Model



(Perrin et al., 2003)

Data and Models

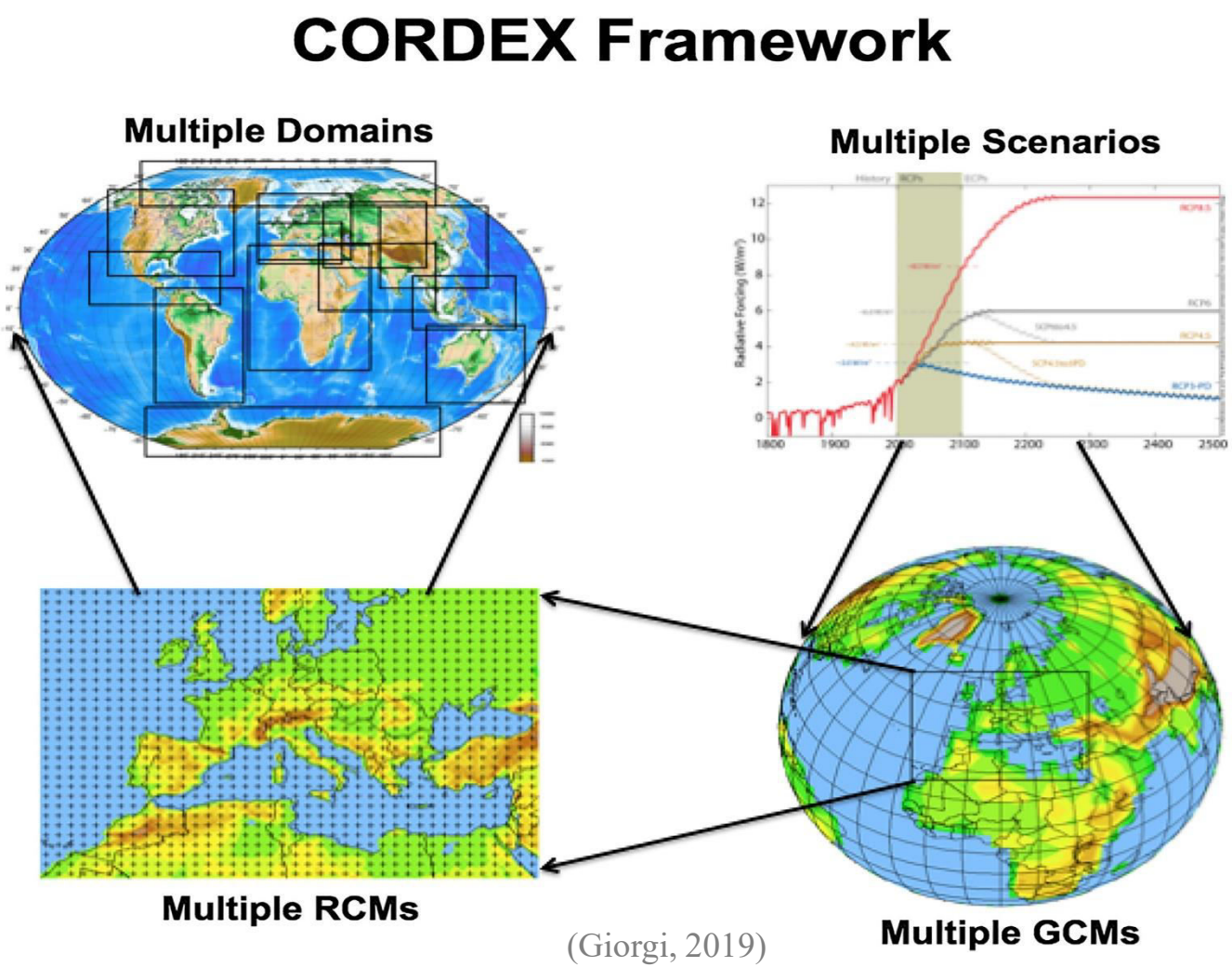
Climate Data

- **9 regional** climate models from the CORDEX-Africa ensemble (CMIP5).
- **Scenario:** RCP 8.5 (high-emission).
- **Variables:** Precipitation, evapotranspiration, streamflow.
- **Time periods:**

Historical (1975–2005)

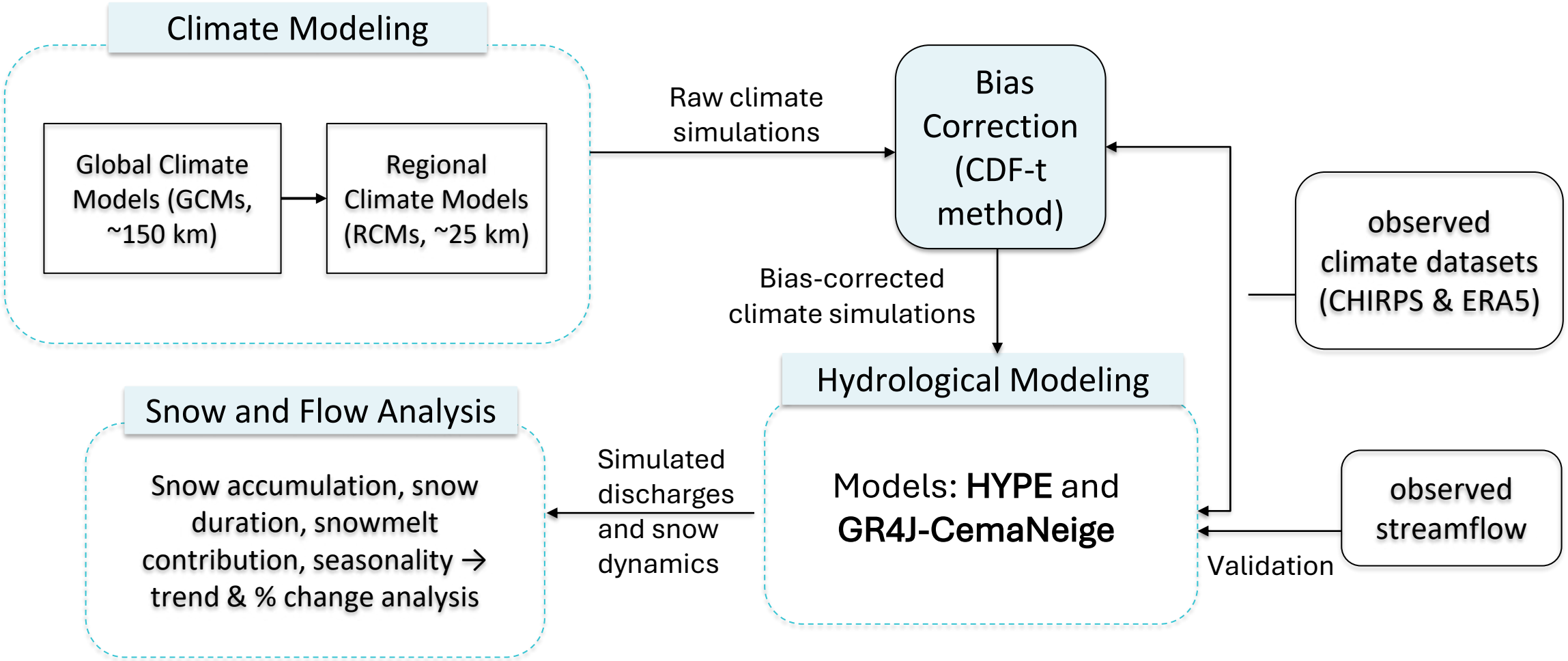
Mid-century (2040–2060)

End-century (2070–2100)



(Giorgi, 2019)

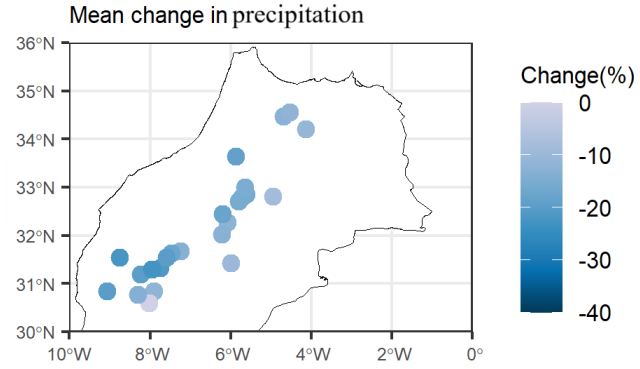
Methodology Overview



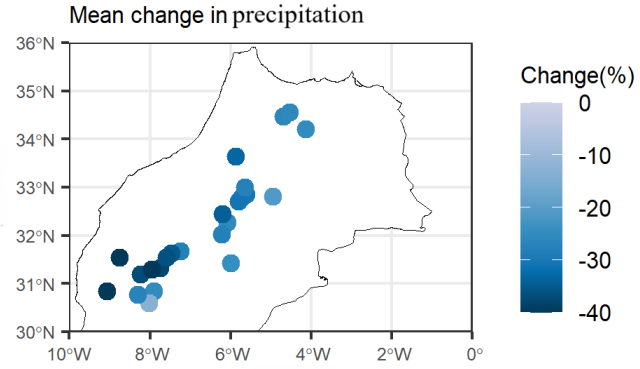
Results – Impacts on Climate Variables

Mid-century vs end-century mean changes

RCP8.5 2040-2060



RCP8.5 2070-2100



Precipitation :

- Widespread decline across all basins.
- Strong spatial (**–10% to –40%**).

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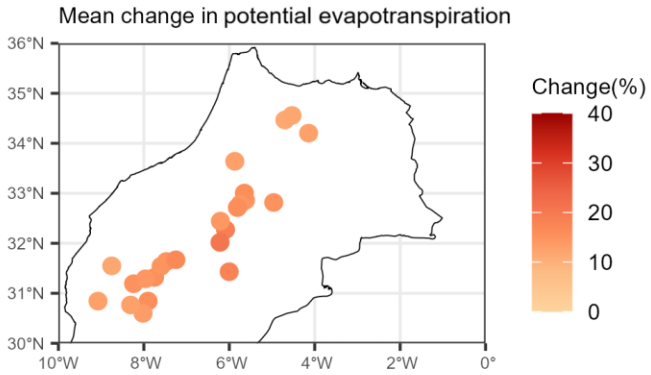
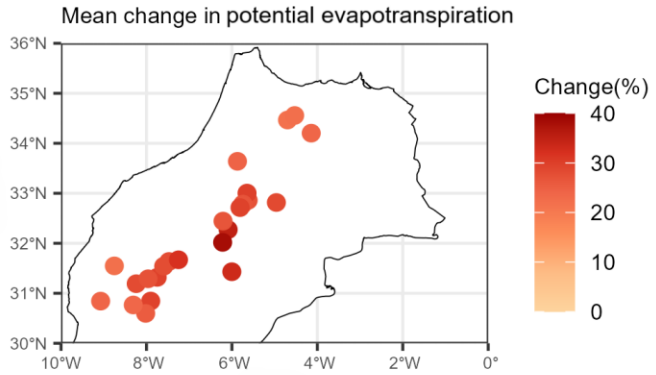
RCP8.5 2040-2060



RCP8.5 2070-2100



Potential Evapotranspiration (PET):

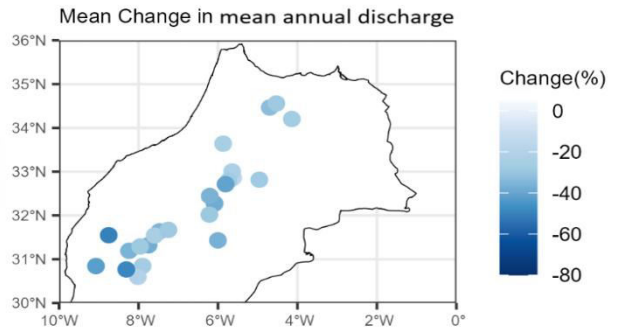
- Continuous increase throughout the century under RCP 8.5

Results – Impacts on Streamflow

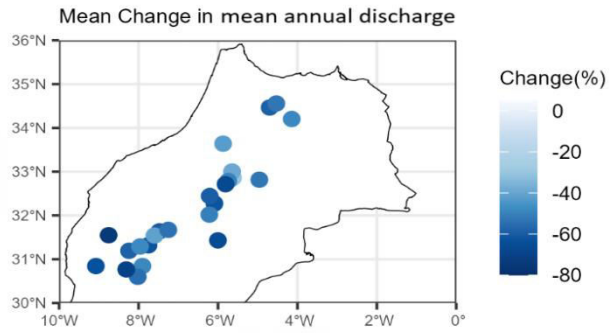
Spatial variability of streamflow changes for both time horizons

HYPE

RCP8.5 2040-2060

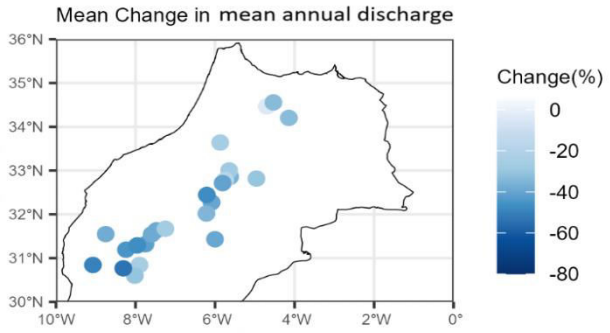


RCP8.5 2070-2100

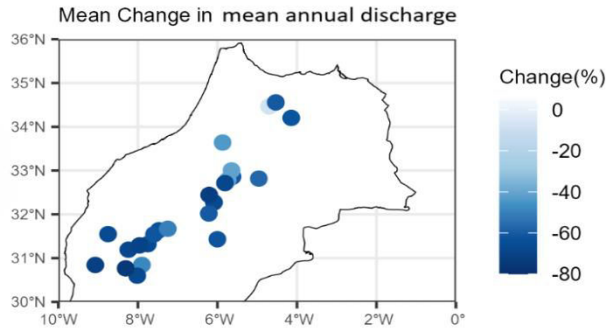


GR4J-CemaNeige

RCP8.5 2040-2060



RCP8.5 2070-2100



HYPE model:

- Mid-century: –10% to –40%
- End-century: up to –80% in several basins

GR4J-CemaNeige model:

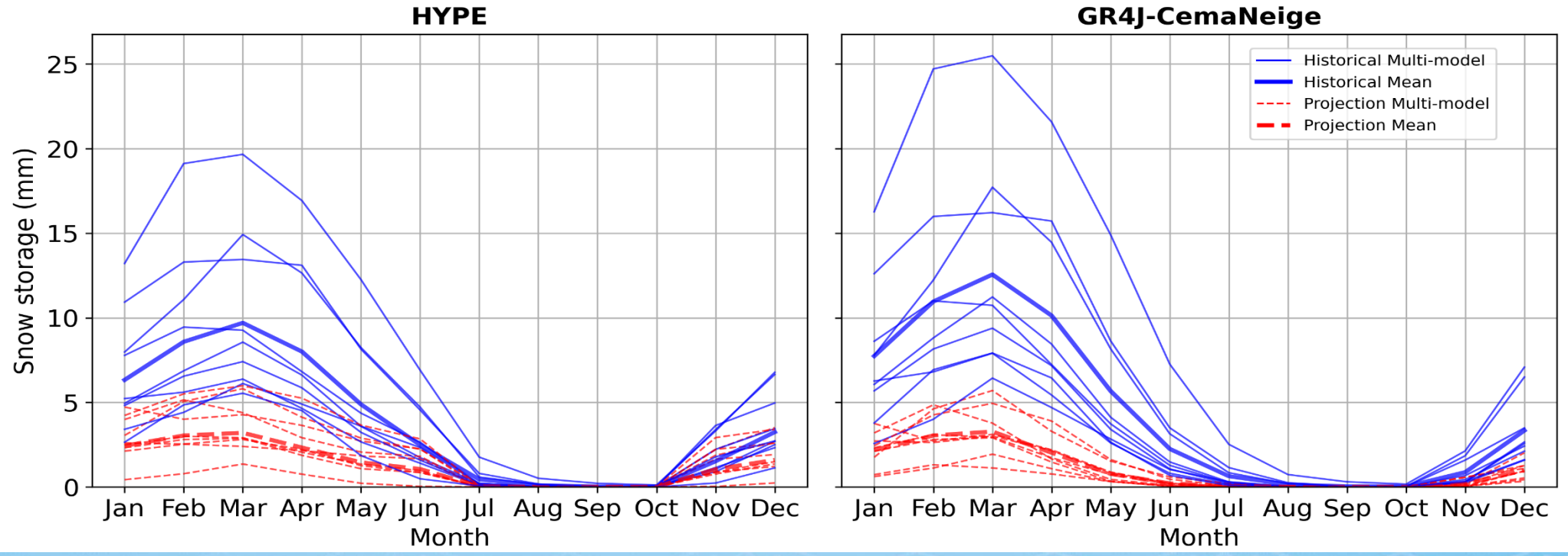
- Mid-century: –20% to –40%
- End-century: around –80% across most basins

Results – Snowpack Evolution

- Complete snowpack depletion earlier in the season (early summer).
- Under RCP 8.5, strong reduction in snow storage (>50% decrease) across the Atlas Mountains.

Consequences: less water available in summer and a shift in the hydrological regime..

SWE evolution for HYPE and GR4J-CemaNeige: historical vs future projections

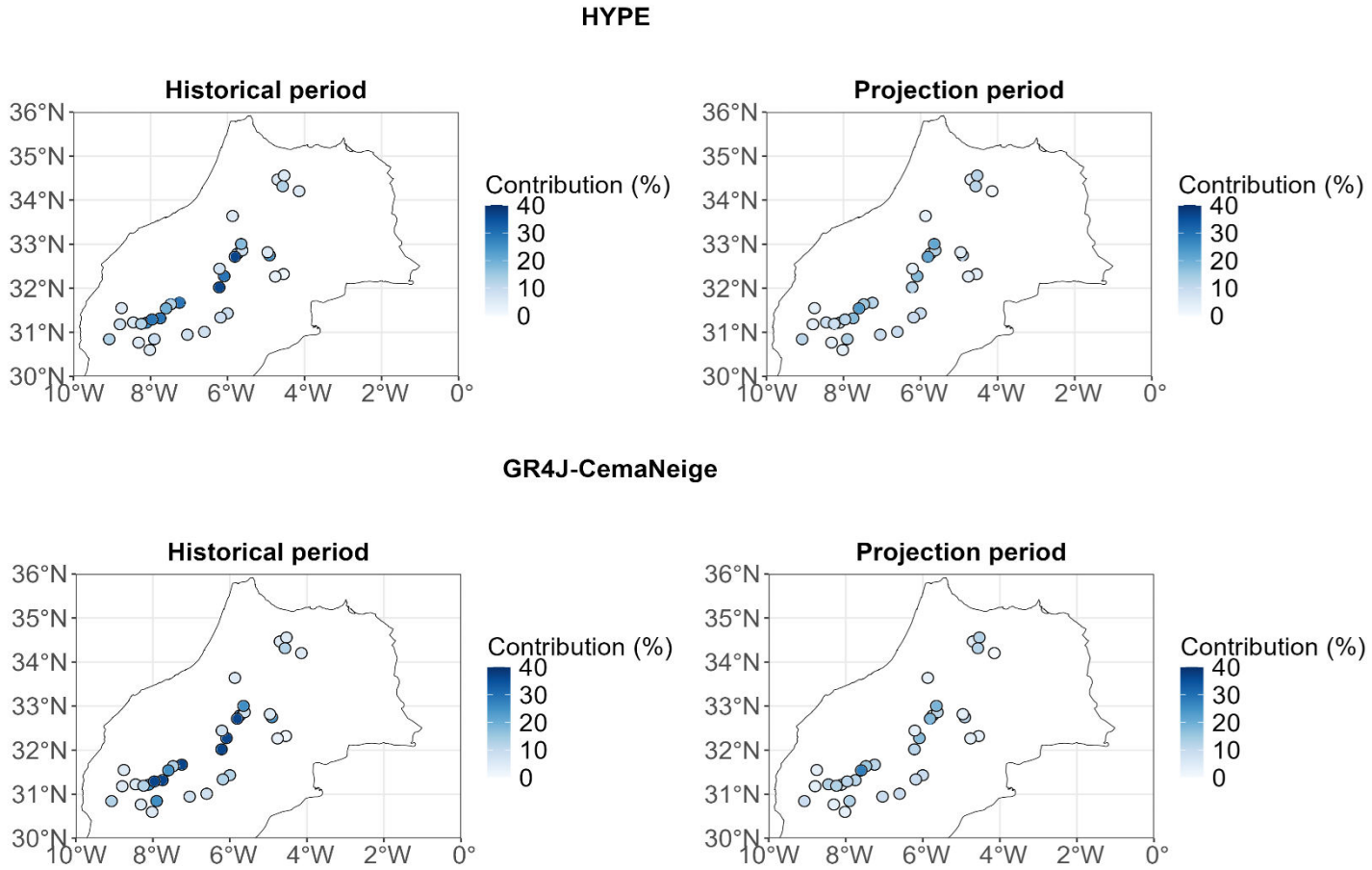


Results – Snowmelt Contribution

Under future scenarios (RCP 8.5), snowmelt contribution collapses to less than 5% in most basins.Historically, snowmelt contributed up to 40% of annual streamflow in several mountain basins.

Consequences: reduced role of snow in sustaining flows → lower water availability, especially in summer.

Snowmelt contribution during the historical period vs projection period for HYPE and GR4J-CemaNeige



Key Conclusions

•Strong decline in snowpack across the Atlas Mountains (–50% or more).

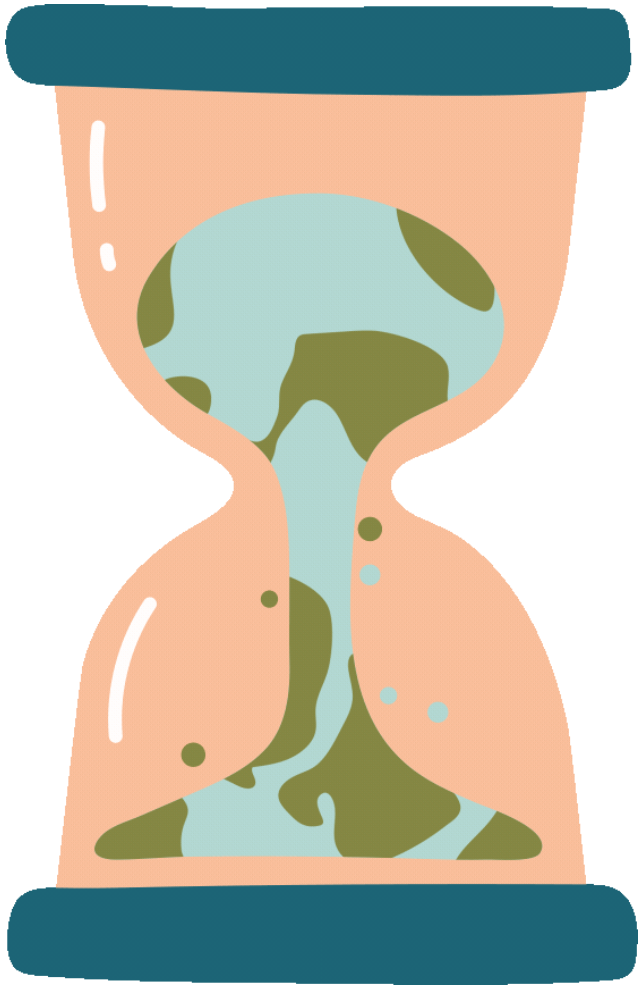
•Early and complete snowmelt, shortening the snow season.

•Snowmelt contribution collapses (from ~40% historically to <5%).

•Streamflow strongly decreases (–20% to –40% mid-century; up to –80% end-century).

•Combined climate trends (↓ precipitation + ↑ PET) intensify water scarcity.

•Major implications for water availability, hydropower, and irrigation planning.



Implications and Adaptation

Water Resources Management

•Reduced summer flows → need for adapted reservoir operation.

• Increased pressure on drinking water supply and irrigation.

Climate Adaptation Planning

•Prioritize demand management and efficiency (agriculture, urban).

•Integrate snow loss into long-term water strategies.

Hydropower & Energy

•Decreasing and more variable inflows → reduced generation reliability.

Monitoring and Early Warning

•Strengthen snow and climate monitoring networks.

•Improve seasonal forecasting for drought preparedness.

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Thank you!

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