Multivariate and Spatially Calibrated Hydrological Model for Assessing Climate Change Impacts on Hydrological Processes in West Africa

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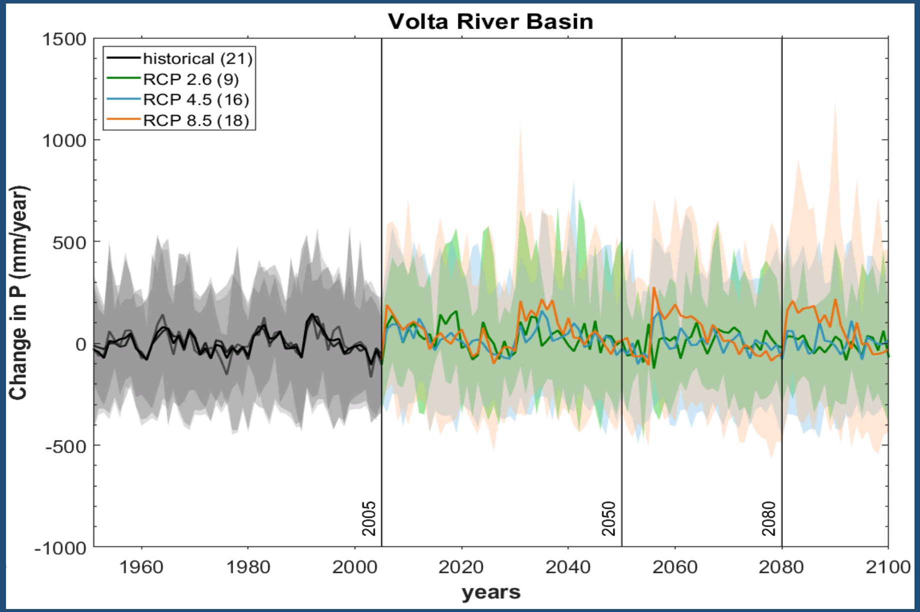

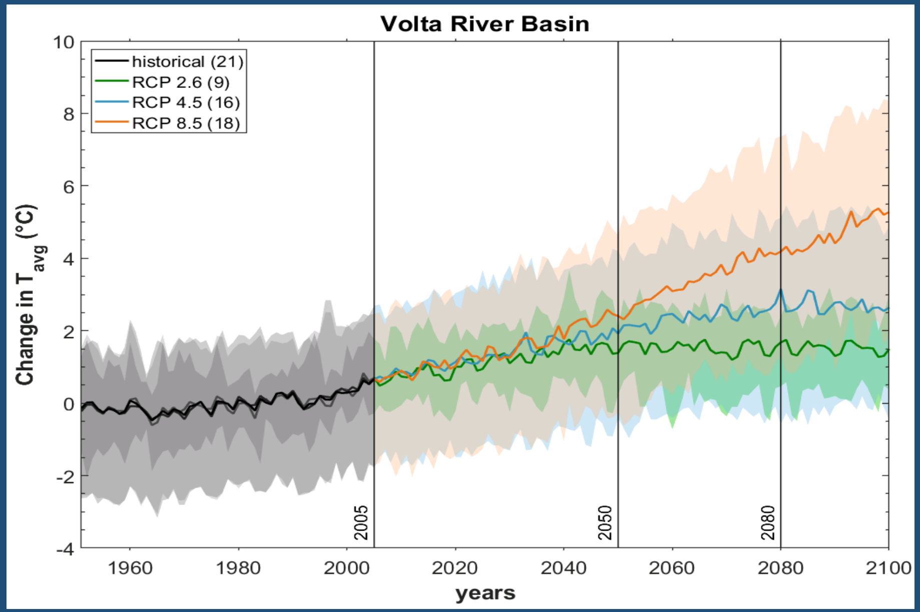

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IWMI International Water Management Institute

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[2]International Water Management Institute, Ghana
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Research Motivation

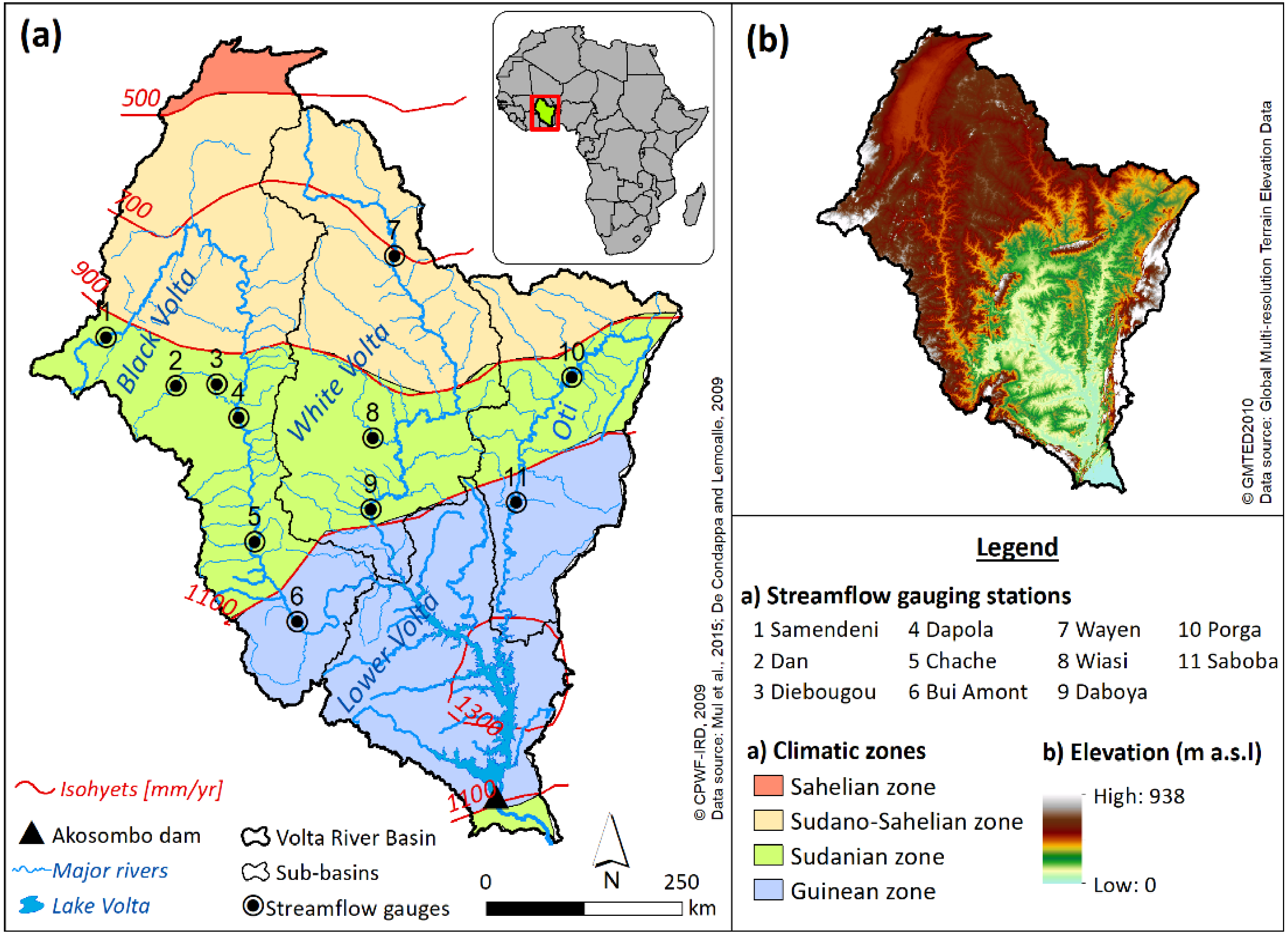
Water stress in river basins → Inadequate level of water security

Impacts:

Climate change
+
Land use change
→ Uncertainty in water availability

People live with inadequate level of water security in many regions around the world. Climate change is expected to increase the frequency of extreme events and exacerbate water scarcity. Knowledge of the evolution of hydrological processes in the future is essential for sustainable water resource management.

Volta River Basin – West Africa



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Transboundary basin shared among 6 countries (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo)

Area ≈ 410,000 km^2

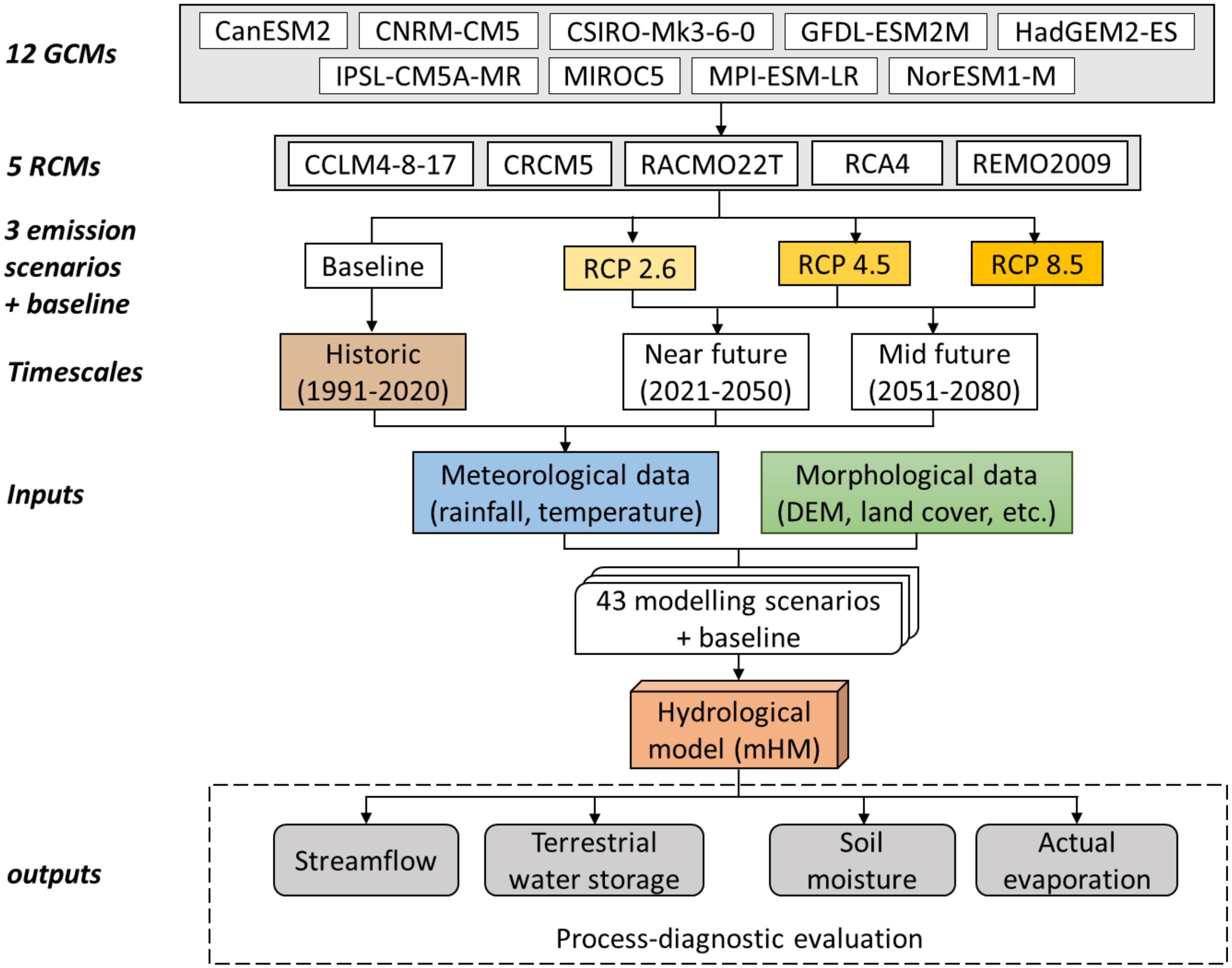
Climate is driven by the ITCZ

North → Semi-arid climate

South → Sub-humid climate

Water demand is projected to increase by more than 1000% between 2000 and 2025 (Biney, 2010).

Methodology for Hydrological Projections



Dembélé et al., in prep.

CORDEX-Africa climate projection data obtained from 12 Global Circulation Models (GCMs) downscaled by 5 Regional Climate Models (RCMs) are used.
Three Representative Concentration Pathways (RCP) are considered (i.e. RCPs 2.6, 4.5 and 8.5).

Meteorological data from 43 RCM/GCMs under 3 RCPs are used to force a fully distributed hydrological model for the historical period (1991-2020) and near/long term future (2021-2080).

The R2D2 multivariate bias-correction method (Vrac, 2018) is applied to the RCM/GCMs datasets using the WFDEI data (Weedon et al. 2014) as reference.

A process-diagnostic evaluation of the model outputs is done for streamflow, actual evaporation, soil moisture, and terrestrial water storage.

Multivariate and Spatially Calibrated Hydrological Model

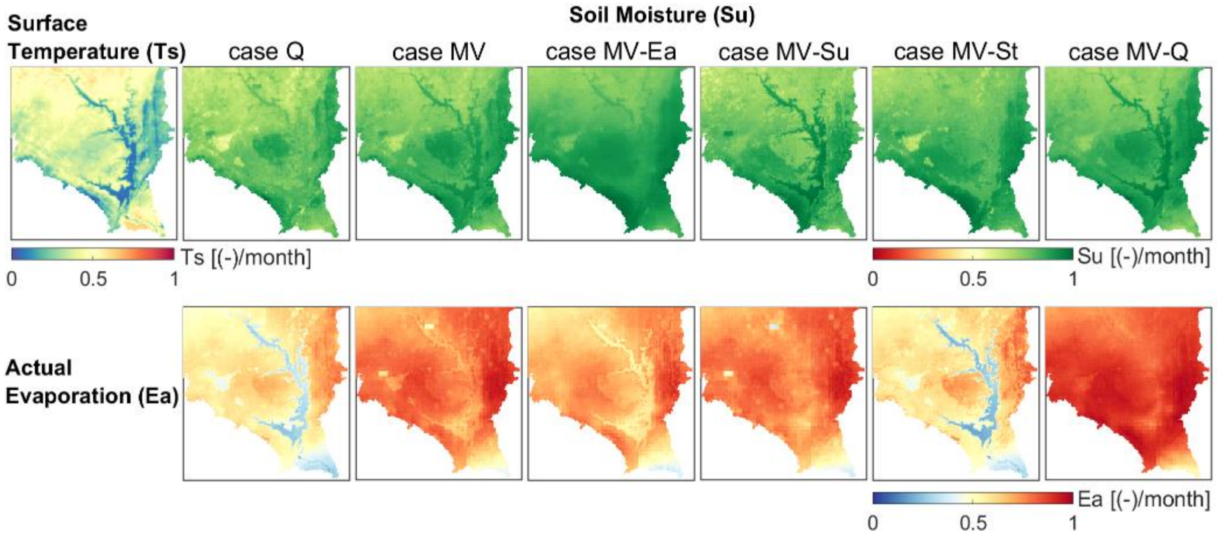
mHM model calibrated simultaneously with streamflow, evaporation, soil moisture and terrestrial water storage data.

Water Resources Research

Research Article | Free Access

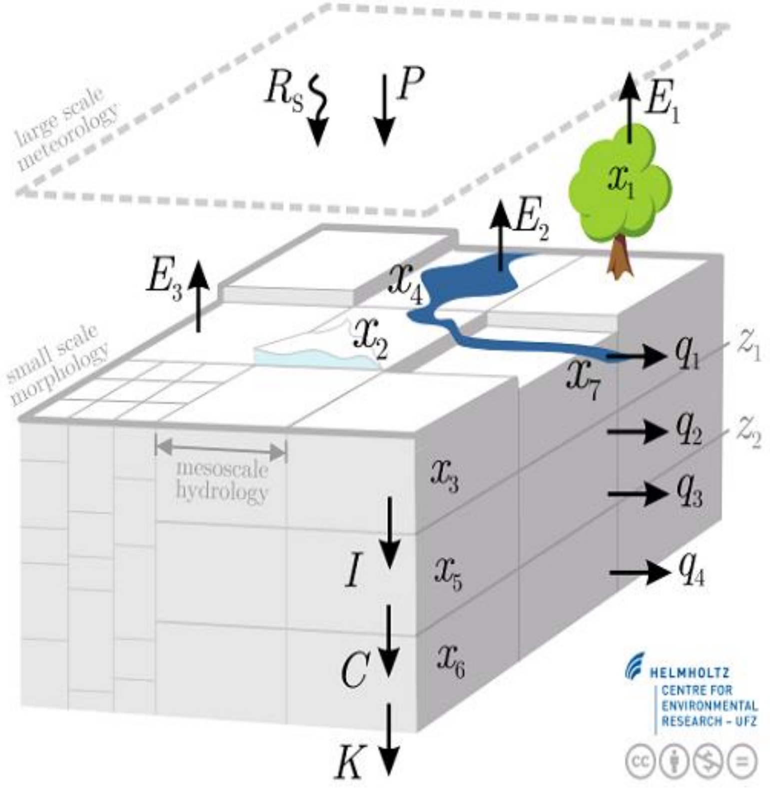
Improving the Predictive Skill of a Distributed Hydrological Model by Calibration on Spatial Patterns With Multiple Satellite Data Sets

Moctar Dembélé, Markus Hrachowitz, Hubert H. G. Savenije, Grégoire Mariéthoz, Bettina Schaefli



Dembélé et al (2020), https://doi.org/10.1029/2019WR026085

mesoscale Hydrologic Model (mHM)



Samaniego et al., WRR 2010
Kumar et al., WRR 2013

Results

- Selected scenario: RCP 8.5

- Historical Period: 1991-2020

- Near-Term Future: 2021-2050

- Long-term Future: 2051-2080

- Hydrological Projections:

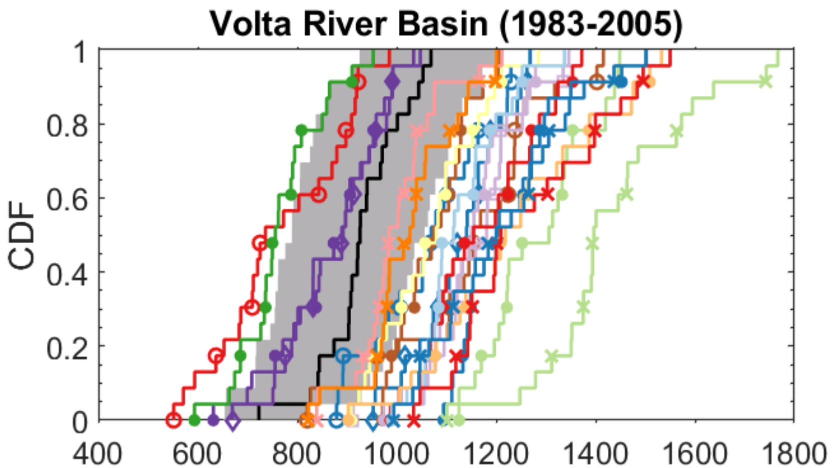
Streamflow, Evaporation, Soil Moisture & Terrestrial Water Storage

Bias Correction of Rainfall

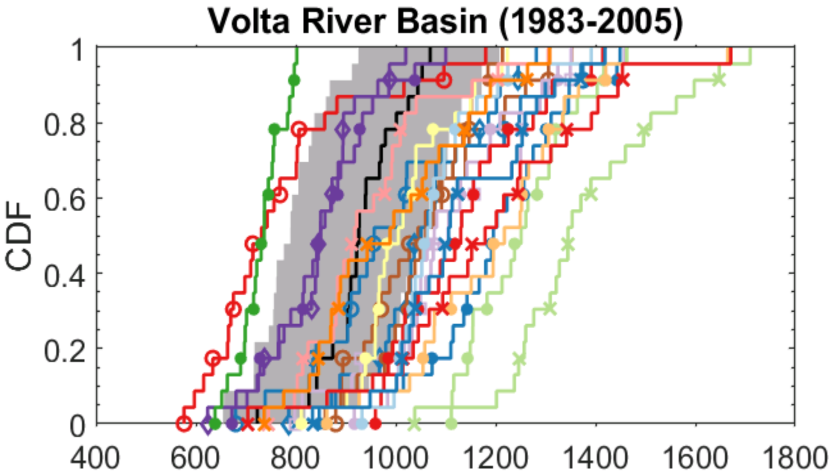
Multivariate Bias Correction with the R2D2 method (Vrac, 2018 HESS).
Daily rainfall and temperature datasets were jointly-corrected.

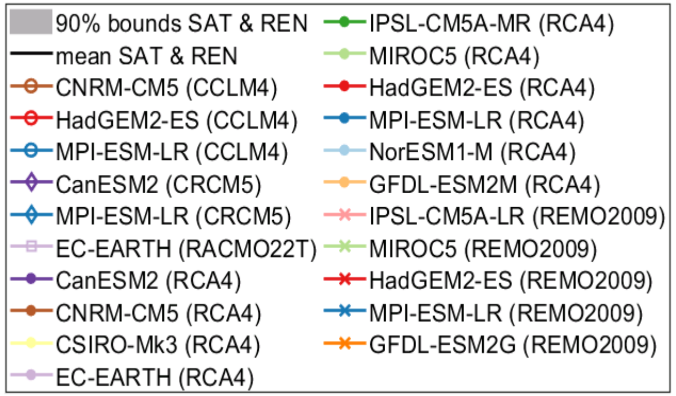
Bias correction did not perform as well as expected. To be improved in the future.

Raw Data



Bias-corrected Data





The RCM/GCM datasets are compared to the 10 best rainfall products (satellite and reanalysis) which have shown good performances in simulating various hydrological processes in the Volta River basin (Dembélé et al., HESSD). The mean and 90% bounds of the 10 rainfall products are shown by the black line and the grey-shaded area in the plots.

Suitability of 17 rainfall and temperature gridded datasets for largescale hydrological modelling in West Africa

Review status
This preprint is currently under review for the journal HESS.

Moctar Dembélé[1], Bettina Schaefli[1,a], Nick van de Giesen[2], and Grégoire Mariéthoz[1]
[1]Institute of Earth Surface Dynamics, Faculty of Geosciences and Environment, University of Lausanne, CH-1015 Lausanne, Switzerland
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[a]now at: Institute of Geography, Faculty of Science, University of Bern, CH-3012, Switzerland

Dembélé et al., in HESSD.
https://www.hydrol-earth-syst-sci-discuss.net/hess-2020-68/

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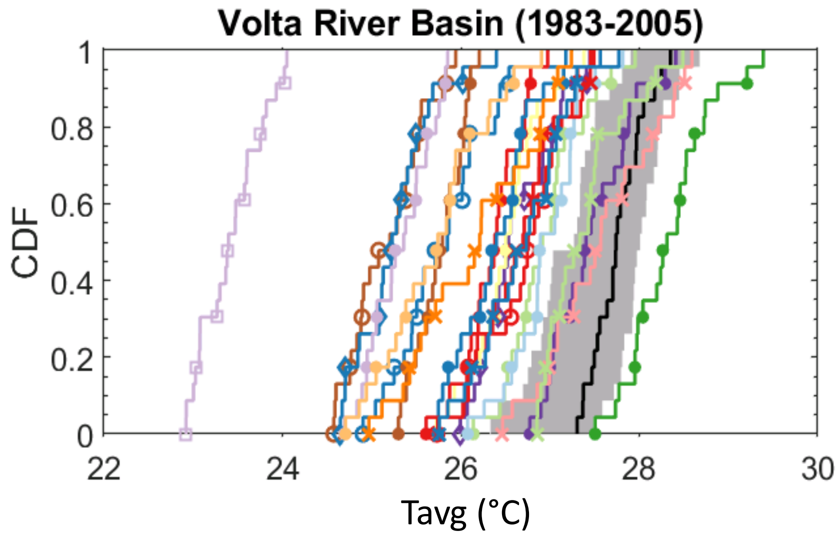
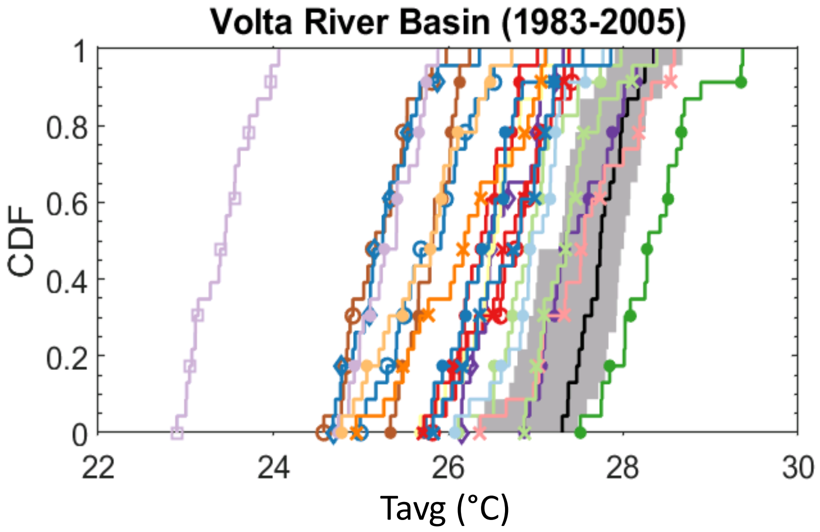
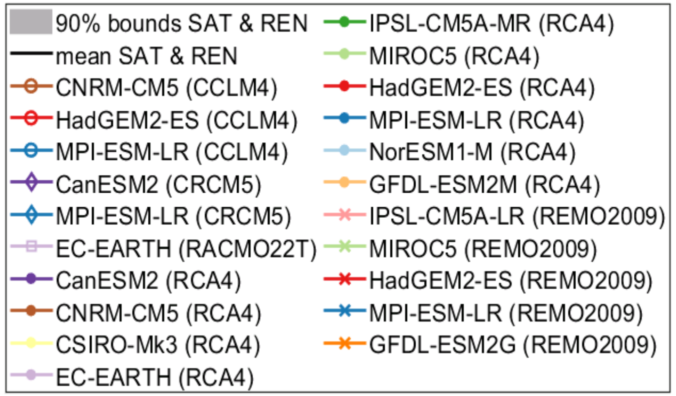


Bias-corrected Data





The RCM/GCM datasets are compared to the 5 best reanalysis temperature products that have shown good performances in simulating various hydrological processes in the Volta River basin (Dembélé et al., HESSD). The mean and 90% bounds of the 5 temperature products are shown by the black line and the grey-shaded area in the plots.

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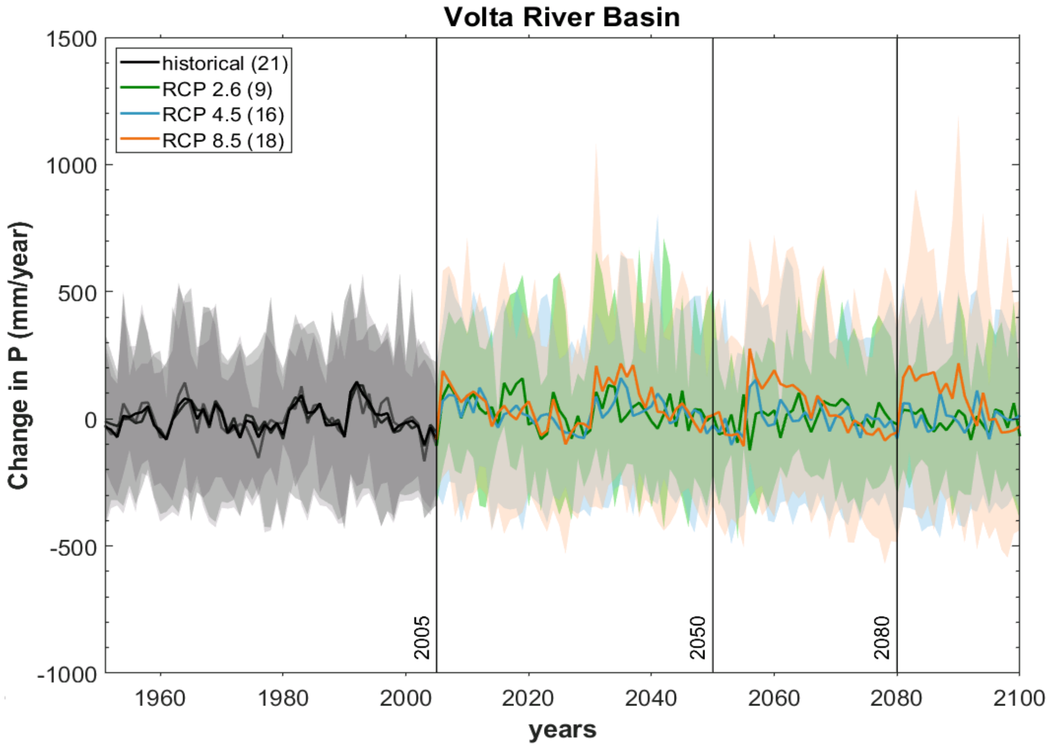
Rainfall and Temperature Projections

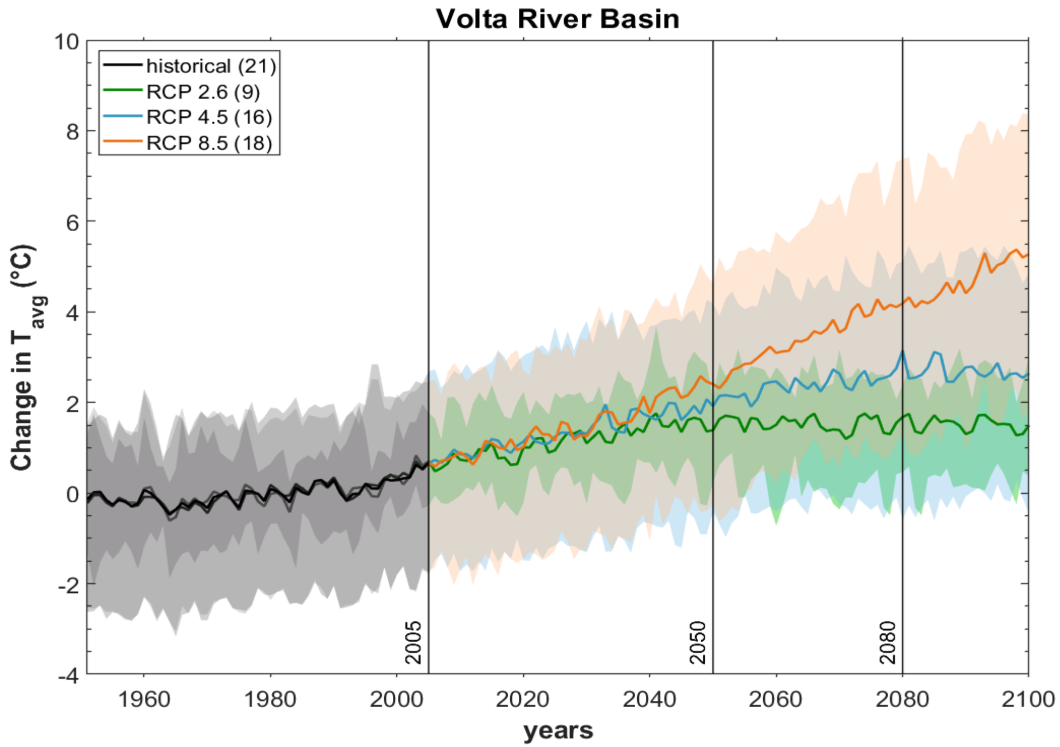
After Multivariate Bias Correction with the R2D2 method

Vrac, 2018 HESS

Rainfall



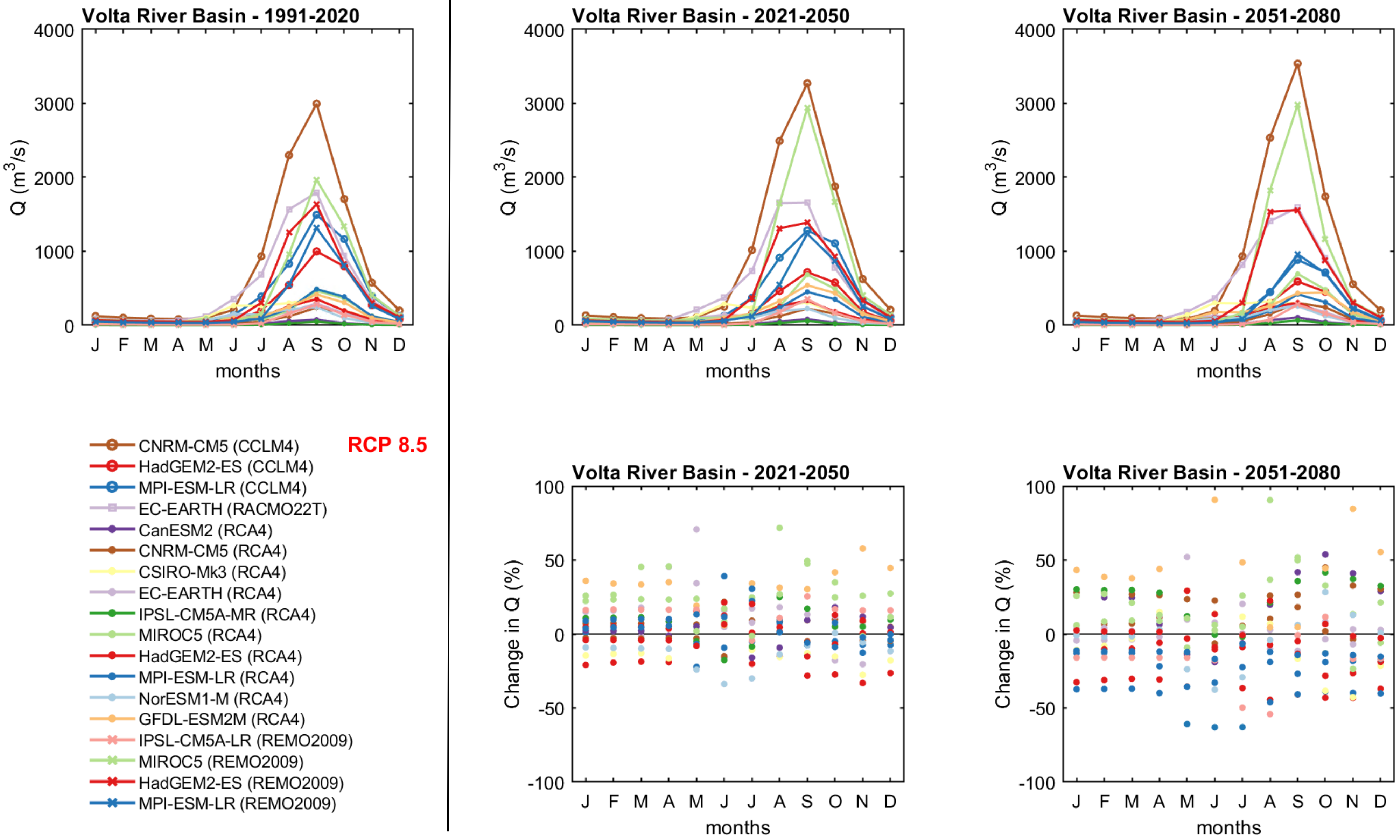
Temperature



Streamflow (Q) Projections

Work in progress and still subject to validation

<u>*Historic*</u>   <u>*Future*</u>



Most RCM/GCMs predict:

… increase in average monthly Q by +17% or +43 m³/s over <u>2021-2051</u>

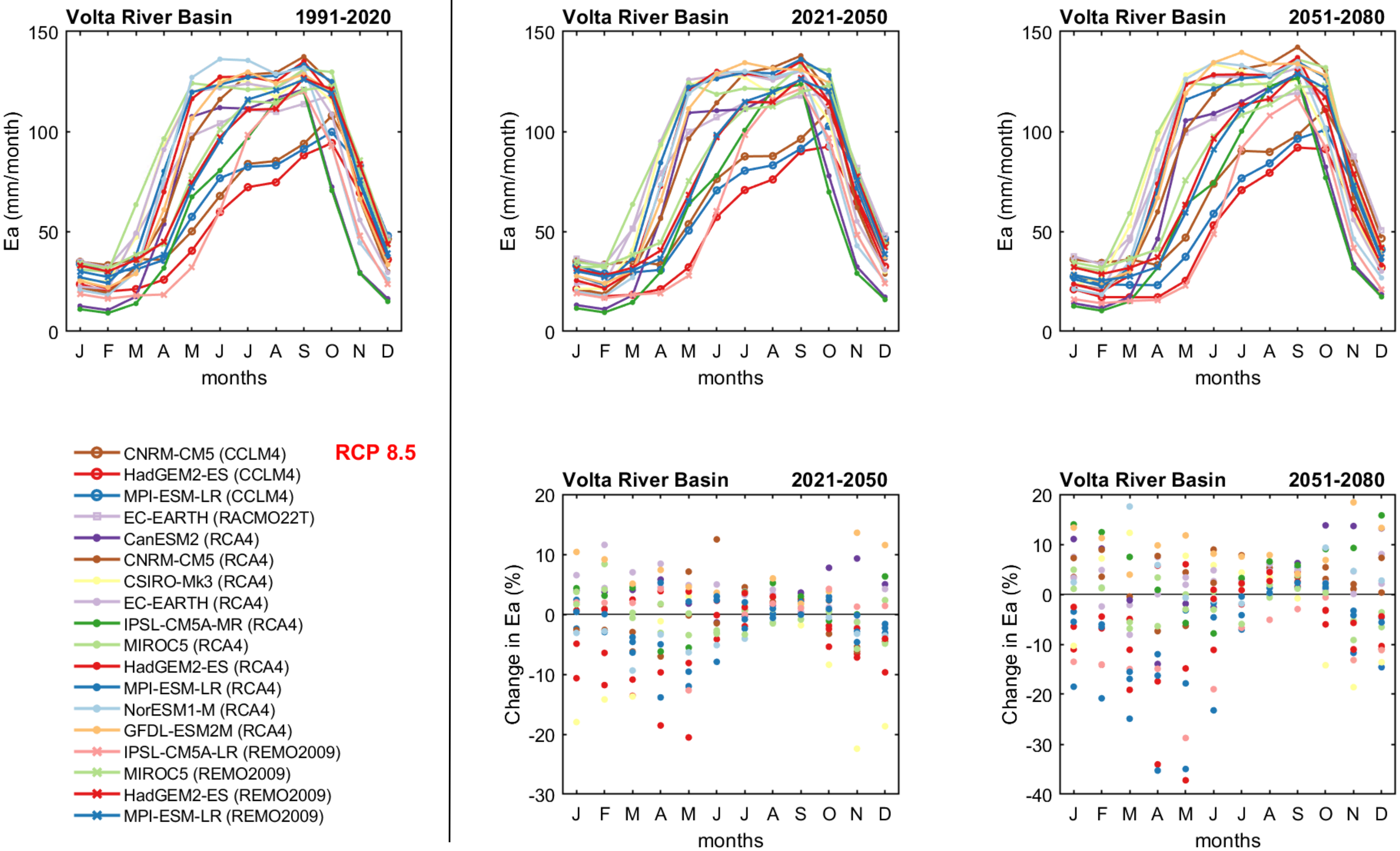
… decrease in average monthly Q by -20% or -47 m³/s over <u>2051-2080</u>

Dembélé et al., in prep.

Actual Evaporation (Ea) Projections

Work in progress and still subject to validation

Historic | *Future*



Most RCM/GCMs predict:

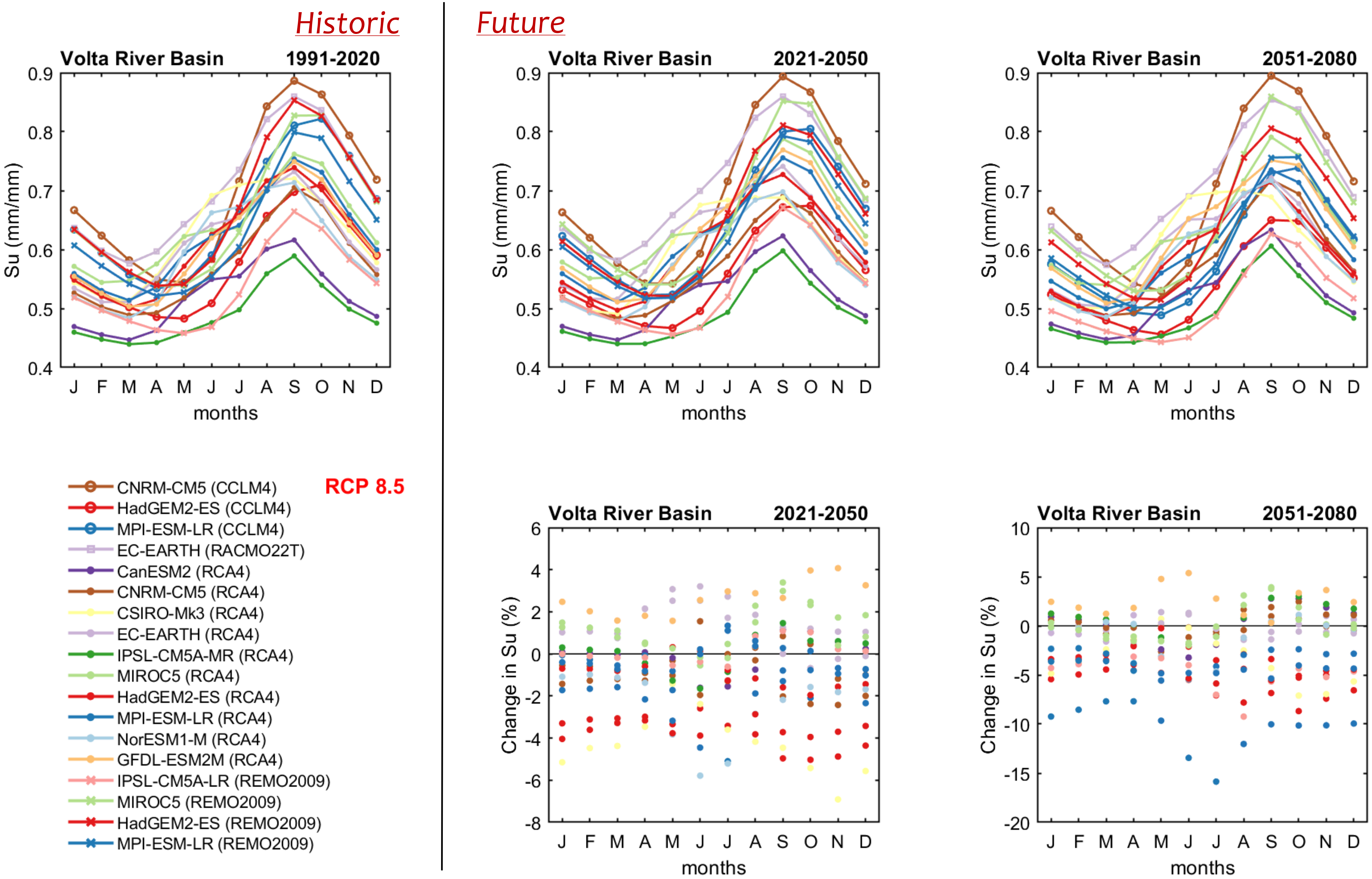
… increase in average monthly Ea by +4% or +3 mm/month over 2021-2051

… increase in average monthly Ea by +6% or +4 mm/month over 2051-2080

Dembélé et al., in prep.

Soil Moisture (Su) Projections

Work in progress and still subject to validation



Most RCM/GCMs predict:

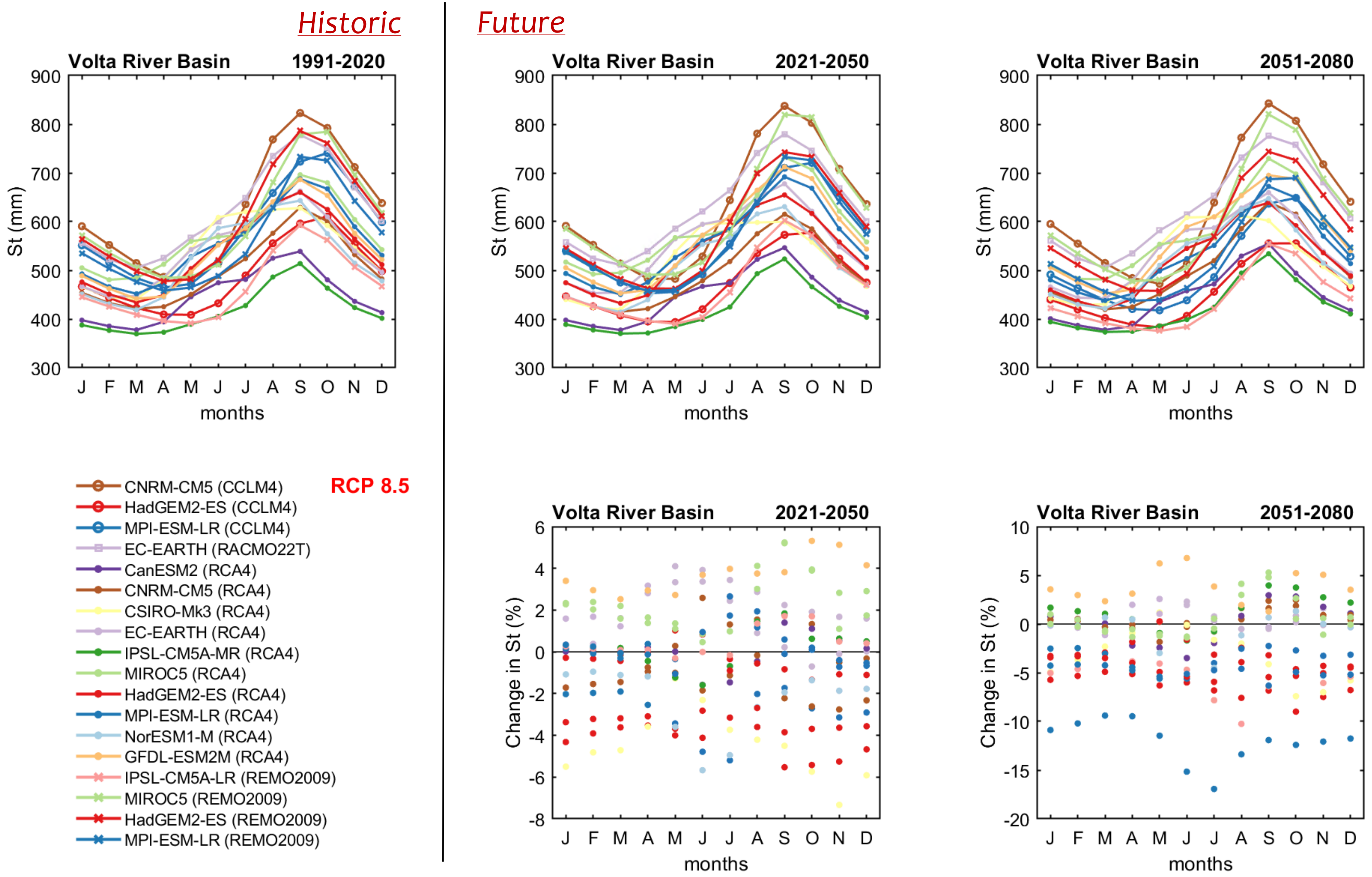
… decrease in average monthly Su by -2% or -0.01 mm/mm over 2021-2051

… decrease in average monthly Su by -4% or -0.02 mm/mm over 2051-2080

Dembélé et al., in prep.

Terrestrial Water Storage (St) Projections

Work in progress and still subject to validation



Most RCM/GCMs predict:

… decrease in average monthly St by -2% or -12 mm over 2021-2051

… decrease in average monthly St by -4% or -24 mm over 2051-2080

Dembélé et al., in prep.

Discussions

- Can we estimate future evaporation with hydrological models that do not inherently account for land-atmosphere feedback?

- With the contrasting hydrological projections obtained with RCM/GCM data, how can we select the most reliable RCM/GCMs for impact studies in a region?

Next Steps

- *Improve the multivariate bias correction of RCM/GCM data. How do different bias correction methods perform?*

- *Assess the impact of non-corrected and bias-corrected RCM/GCM data on hydrological projections. Is there any benefit in bias correction?*

- *Check the realism of the hydrological projections with the Budyko framework. Do they respect the Energy vs. Water limits?*

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Thank You

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SWISS NATIONAL SCIENCE FOUNDATION

Providers of datasets and tools :

- CORDEX
- mHM/UFZ
- VBA, DGRE (BF)