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The use of GPS and reanalysis data for validation of precipitable water vapor in regional climate models over Ethiopia

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11/12/2023 AGU23

Context: Water vapor & climate models

- **Water vapor** is the most important natural greenhouse gas, water vapor affecting water and energy balance and therefore **climate change**.
- PWV provides upper limit to the potential precipitation which could fall from that column of air. Therefore very relevant for **extreme rainfall**.
- Critical to **validate water vapor** in models used for future projections

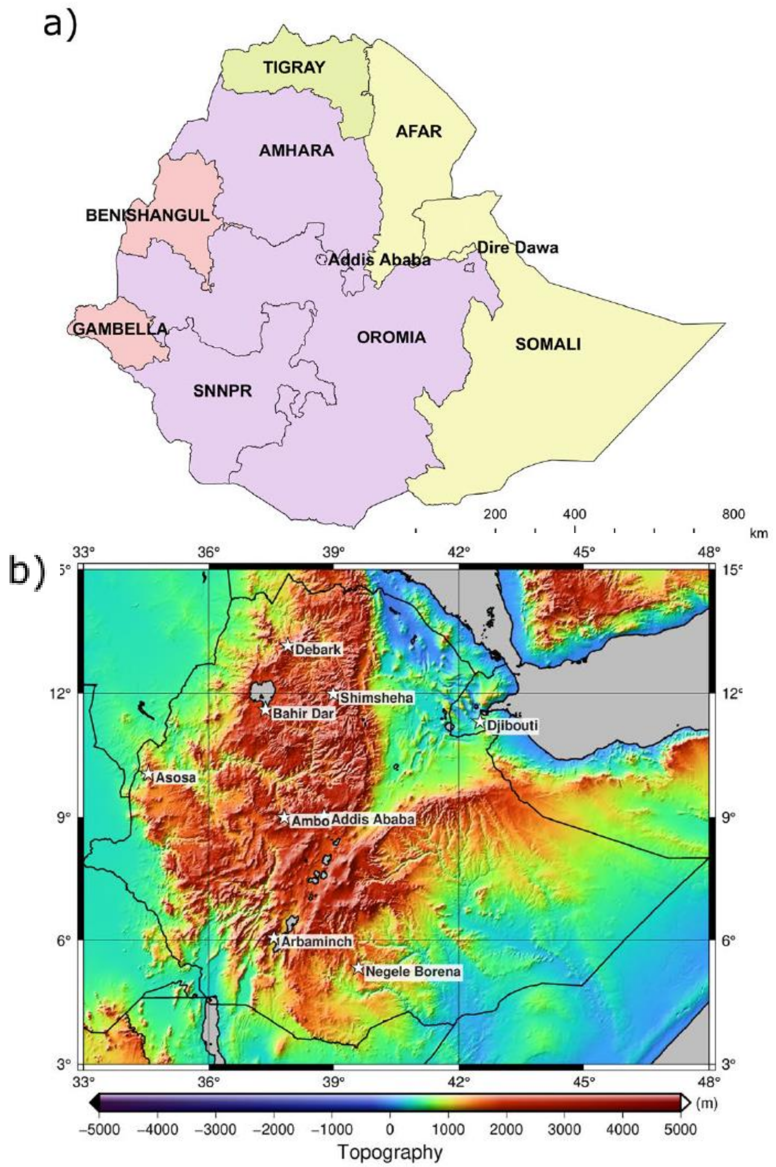
Context: Research questions

- Can we use **reanalysis** data over **tropical mountainous** regions?
- How do Regional Climate Models (RCMs) reproduce precipitable water vapor (PWV) over Ethiopia?
- What is the **impact of climate change on PWV** and how does it relate to the changes in **temperature and heavy rainfall**?

Climate of Ethiopia

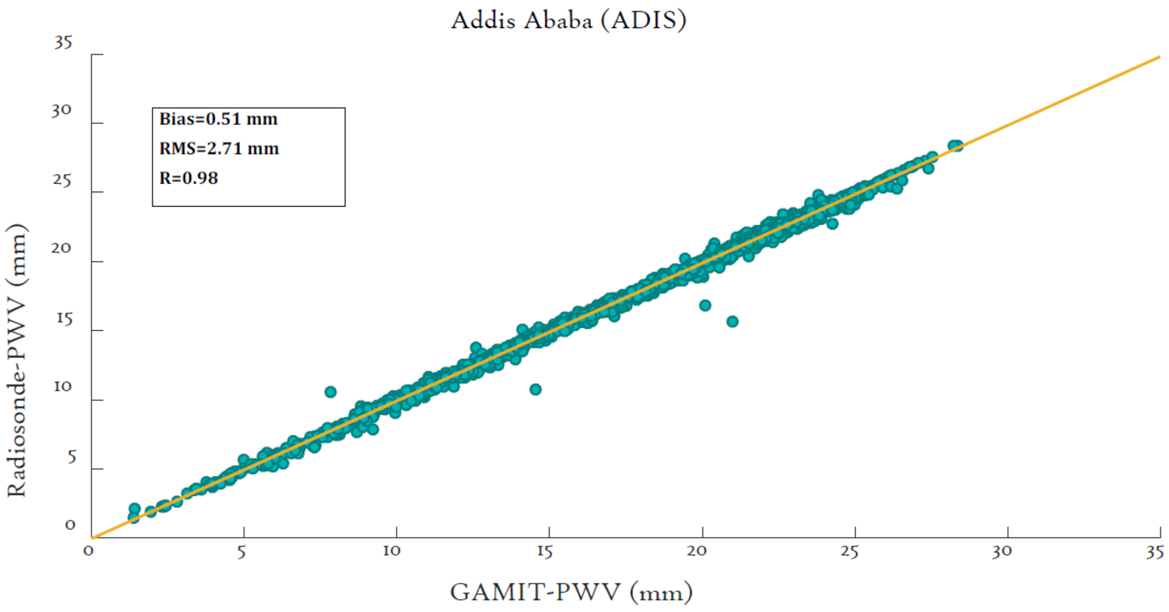
Ethiopia:

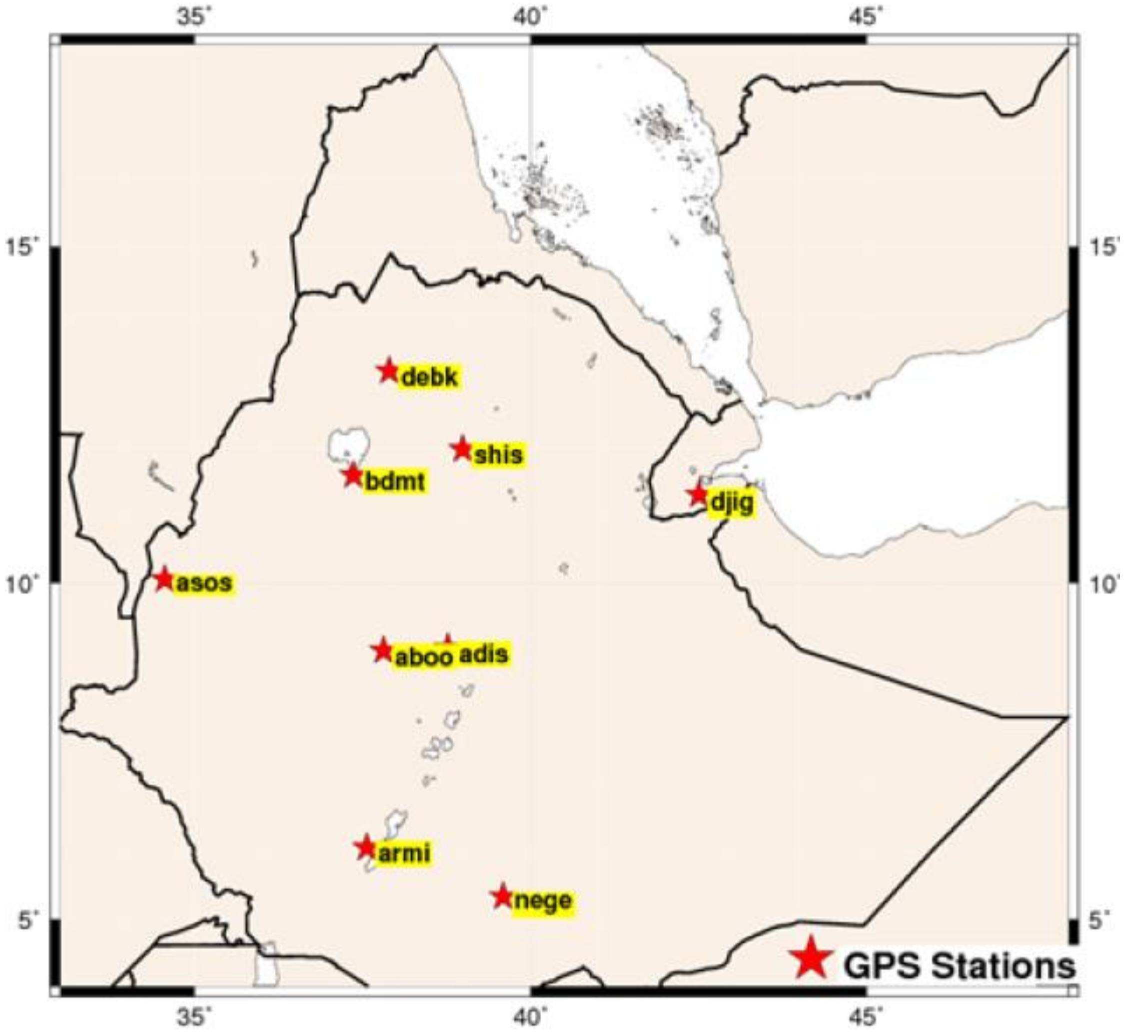
- covers diversity of climate zones tropical (red), dry (yellow), temperate (purple).
- Mountains exceed 4000m in elevation (see panel b)
- Suffers from a lack of long observational datasets



Validation of ERA5 vs GPS-derived PWV

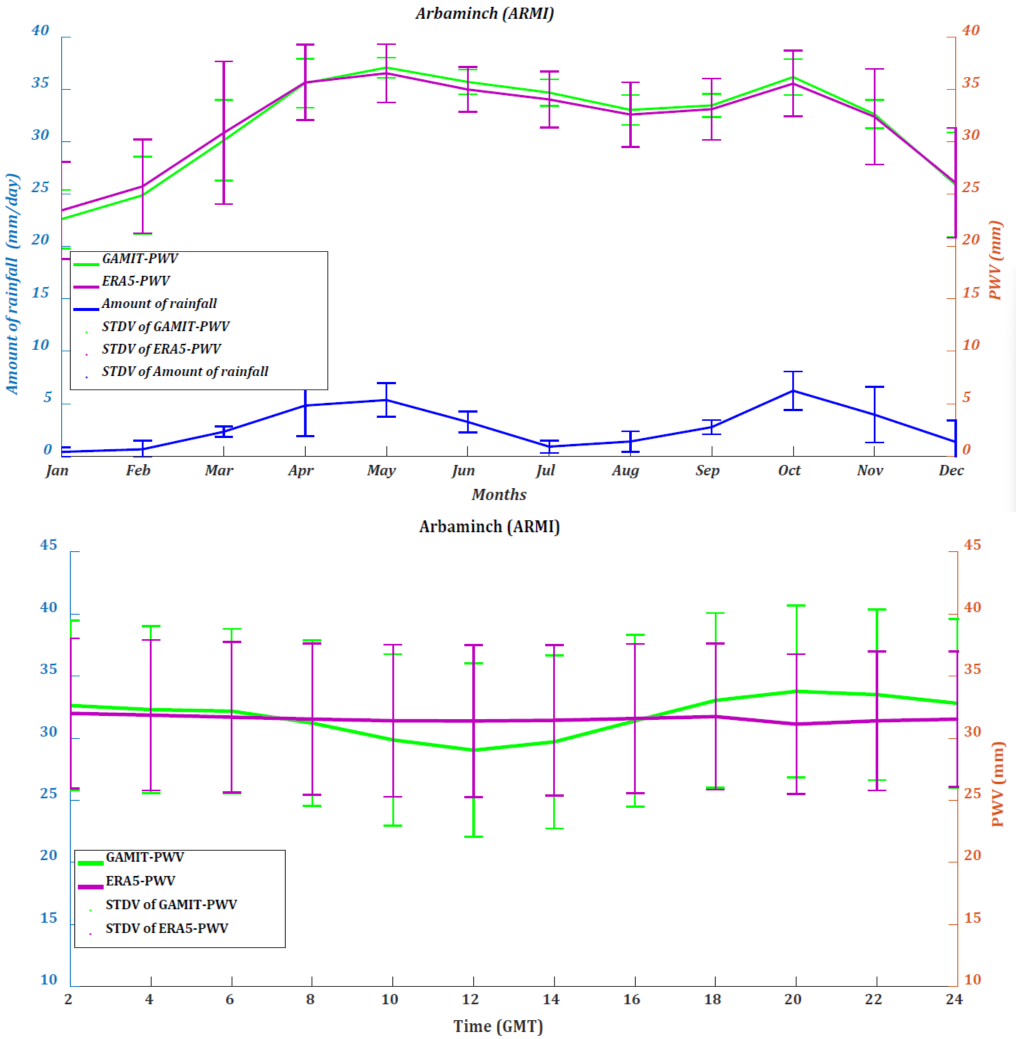
PWV over eight Ethiopian global positioning system (GPS) sites for period 2013-2020, and compare with the PWV retrieved from the state-of-the-art ERA5 reanalysis.





Validation of ERA5 vs GPS-derived PWV

- Seasonal and diurnal cycles are also well captured by ERA5
- Correlation of hourly PWV between ERA5 and GNSS-based is 96%-99%.
- ERA5 slightly underestimates PWV for the majority of the sites.
- Overall root mean square error of 3.4 mm.



Kawo et al. Remote Sens. 2022, 14, 686. doi:10.3390/rs14030686

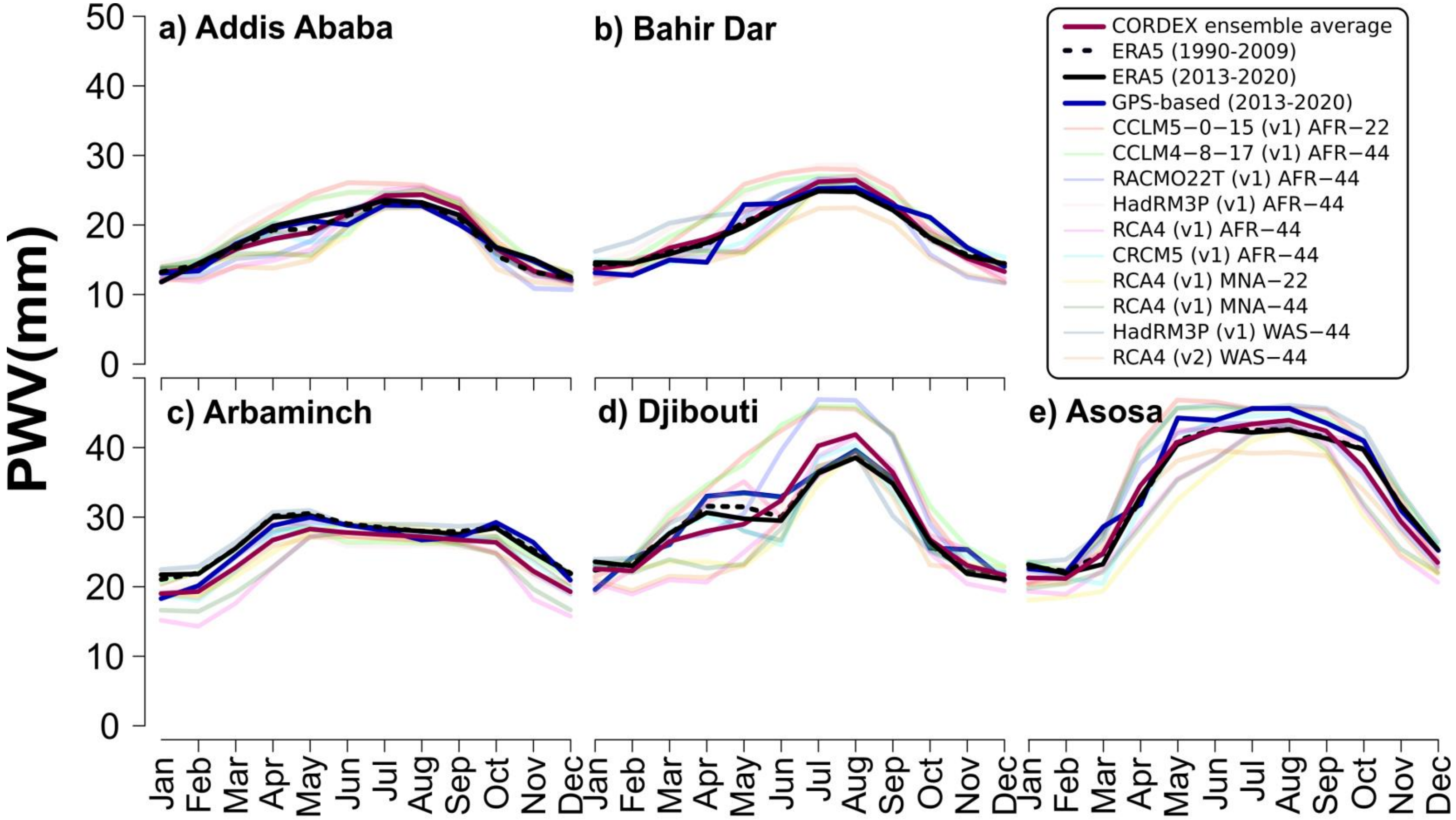
Data

- **Obs: GNSS-derived** PWV observations at 5 stations
- **Reference: ERA5** PWV 1990-2009
- **Model:** CORDEX (Coordinated Regional Climate Downscaling Experiment) over Africa (AFR), MENA (MNA) and West Asia (WAS) at 0.44° and 0.22° horizontal resolution.

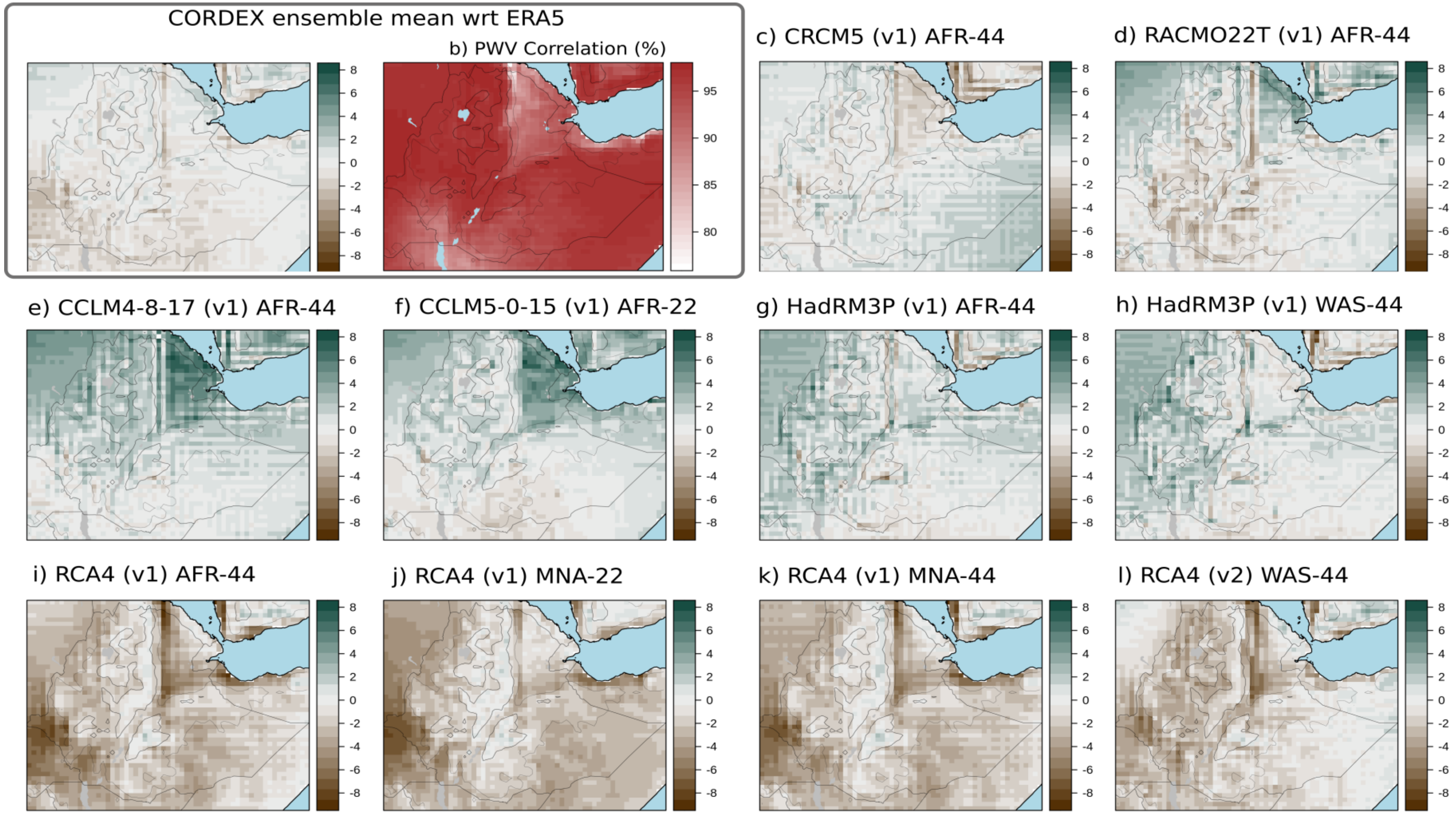
CORDEX Domain Resolution	Regional Climate Model (RCM)
AFR-22	CCLM5-0-15 (v1 CLMcom-KIT)
AFR-44	CCLM4-8-17 (v1 CLMcom)
	RACMO22T (v1 KNMI)
	HadRM3P (v1 MOHC)
	RCA4 (v1 SMHI)
	CRCM5 (v1 UQAM)
MNA-22	RCA4 (v1 SMHI)
MNA-44	RCA4 (v1 SMHI)
WAS-44	HadRM3P (v1 MOHC)
	RCA4 (v2 SMHI)

Annual cycle PWV

Model uncertainty large but on average in line with observations and reference



Bias & correlation



RCMs strongly correlate with ERA5 in most regions and have model-specific biases unrelated to orography.

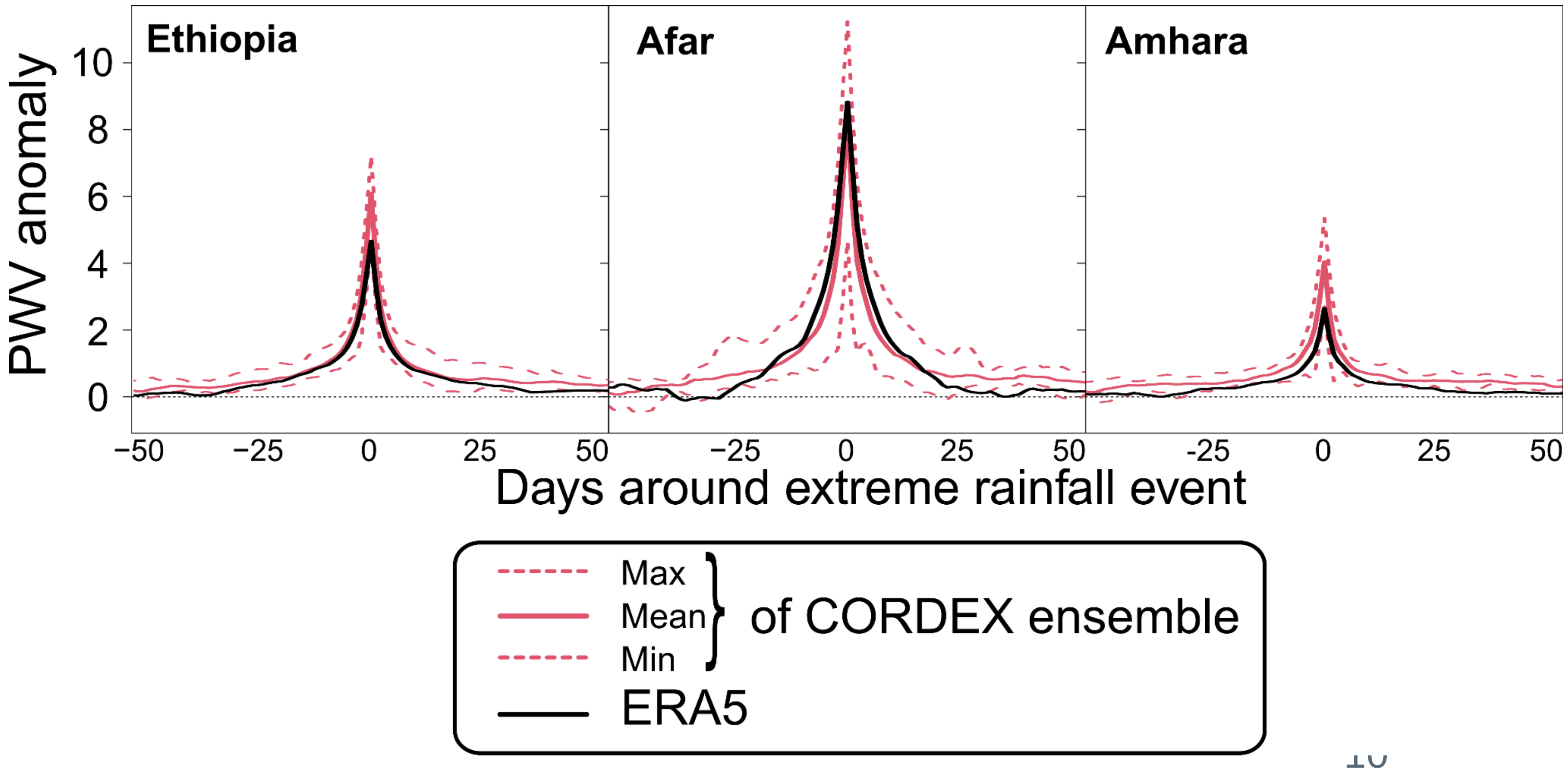
Kawo et al. Clim Dyn 61, 5287–5307 (2023).

PWV evolution during heavy-rainfall event

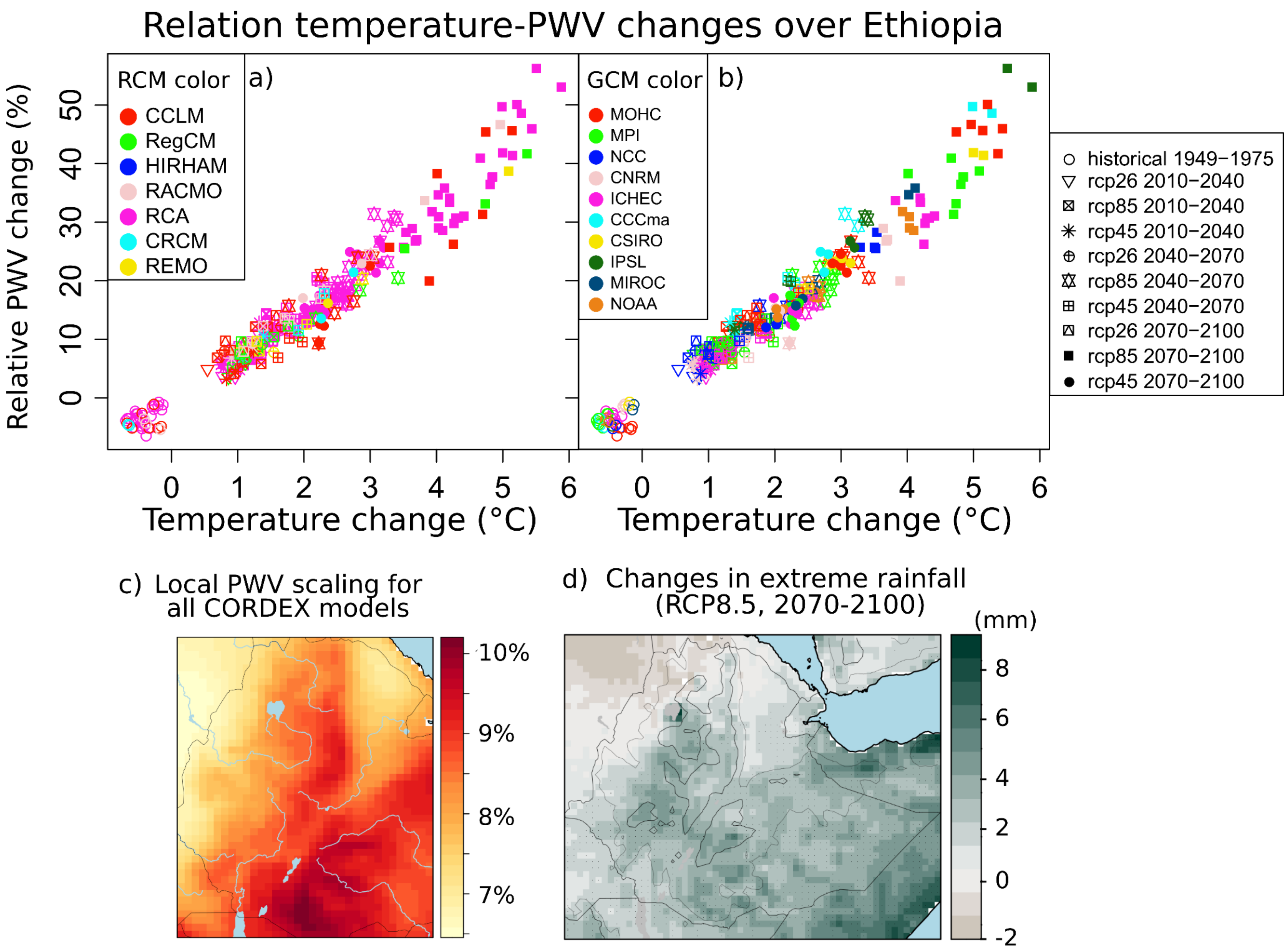
- PWV anomalies before and after the occurrence of heavy-rainfall events.

- These peaks are highest in the **driest regions** (e.g. Afar).

- CORDEX **captures** overall spatial patterns but **overestimates lowest and underestimates highest** PWV anomalies.



Relation PWV with T2M & extreme rainfall



- PWV scales with temperature at CC scaling but scaling higher over the mountains.
- Discrepancy between spatial patterns of extreme rainfall and PWV future changes

Conclusion

- Validation of ERA5 against GPS-based PWV shows **ERA5 is reliable climatological reference** in tropical mountains
- CORDEX **RCMs reproduce reasonably well the PWV annual cycle** but biases appear in the very dry and in the tropical climate zones. No elevation dependence.
- **RCMs simulate peak in PWV anomalies** at day of heavy-rainfall event but overestimate the timescales of buildup and decline.
- PWV changes align with near-surface temperature changes at a rate of **7.7% per degree local warming**.
- Changes in daily rainfall extremes are lower especially in northwestern Ethiopia potentially caused by an overall (rainfall) drying.

Kawo et al. Clim Dyn 61, 5287–5307 (2023).