Combining CMIP data with a convection-permitting model and observations to project extreme rainfall under climate change

Cornelia Klein[1,2]
L Jackson[3], D Parker[3], J Marsham[3], C Taylor[1], D Rowell,
F Guichard, T Vischel, AM Famien, A Diedhiou

1: UK Centre for Ecology and Hydrology (UKCEH)
2: University of Innsbruck, Austria
3: University of Leeds, UK
4: UK Met Office
5: University of Grenoble Alpes, France
6: LOCEAN, Sorbonne Universités, IPSL, France

UK Centre for Ecology & Hydrology

universität innsbruck

EGU General Assembly
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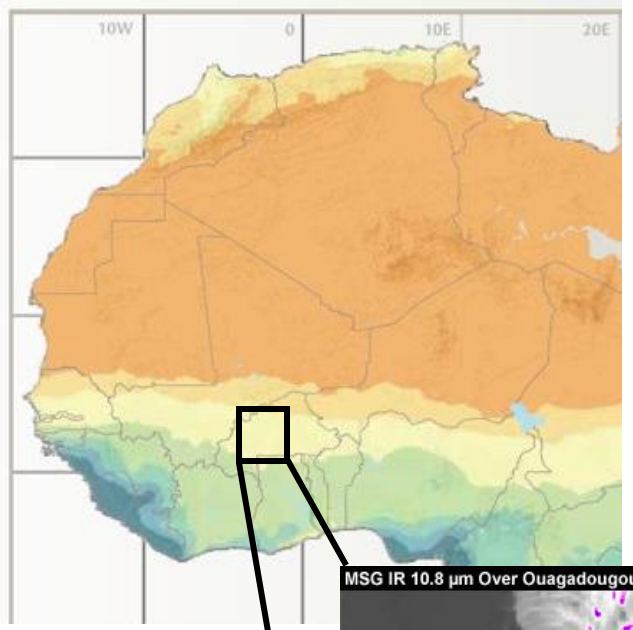
Global warming is making rainfall more extreme

West Africa

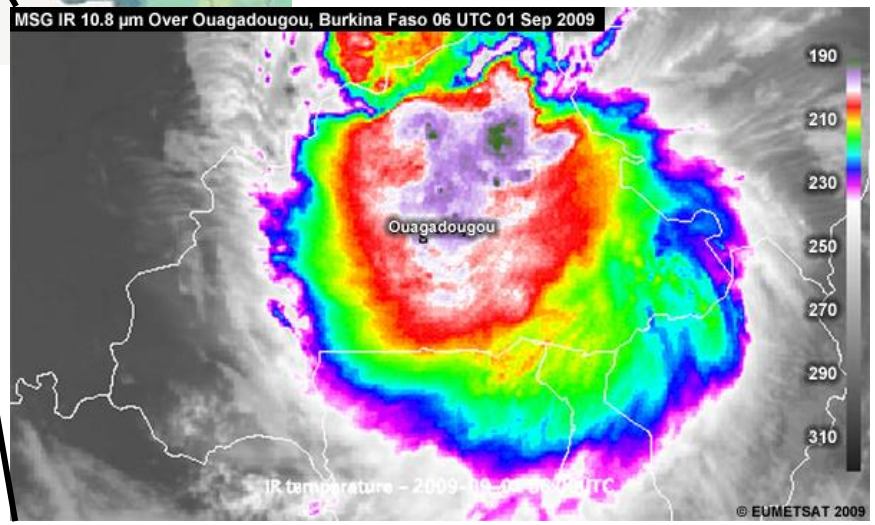


We know that global warming is increasing rainfall intensities with associated on-the-ground hazards!

Risks for dams / hydro-power, urban infrastructure, health, crops etc.

Large tropical thunderstorms during monsoon seasons can be particularly destructive:

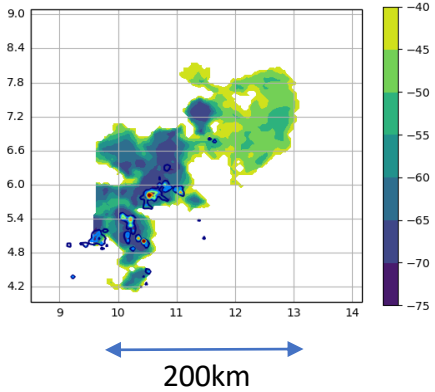
2009 Storm cloud and flooding in Ouagadougou (Burkina Faso)



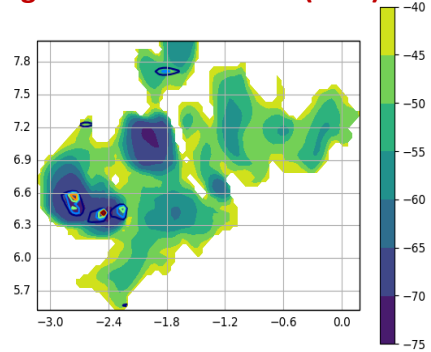
To understand future risks, we need to be able to model such storms..

Data sources available to inform projections of extreme storm rainfall

Observed (Meteosat, 3km)

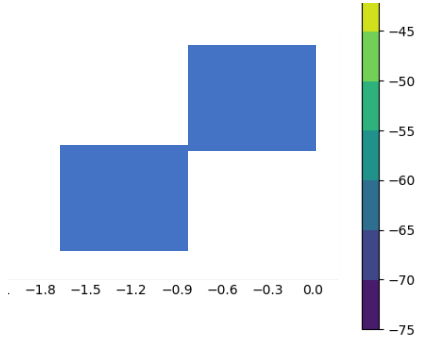


High-resolution model (4km)



More realistic storm rainfall but very few simulations

Standard (CMIP) model (~100km)



Many simulations provide information on uncertainties in climate simulations

Our ideal extreme rainfall projections should:

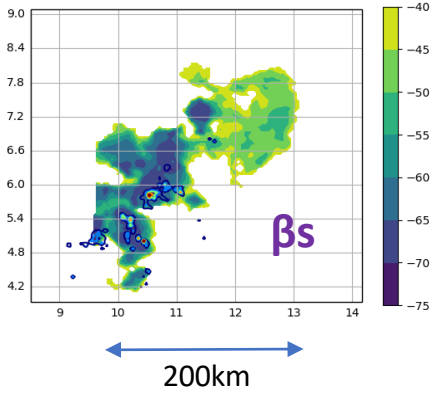
- Resolve storm structures (like convection-permitting models)
- Reflect real world response of storms to their environment (like observations, hopefully)
- Give information about projection uncertainty (like CMIP ensembles)
- Be available over medium- and long-term future period (like CMIP ensembles)

How to combine these sources?

Estimating rainfall from large-scale moisture and wind shear change

Information on future changes

Observed (Meteosat, 3km)



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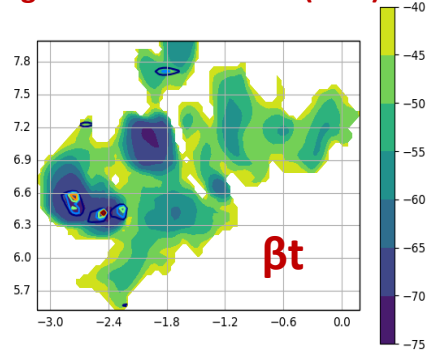

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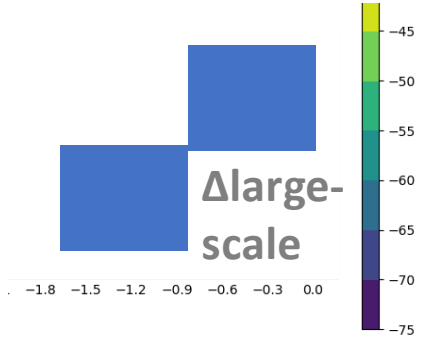

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Rainfall-driver scaling: ΔPmax95 = βt × ΔTCW(CMIP) + βs × ΔShear(CMIP)

We trust CMIP changes in large-scale storm drivers more than in extreme rain!

Δ: future – past

Pmax95: 95th percentile of maximum rainfall within MCSs

TCW: total column water (precipitable water), Shear: 600-925hPa u-wind

β: extreme rainfall scaling with TCW and shear [derived from OBS or CP4]

The first convection-permitting projection over Africa

Information on large scale / storm scaling

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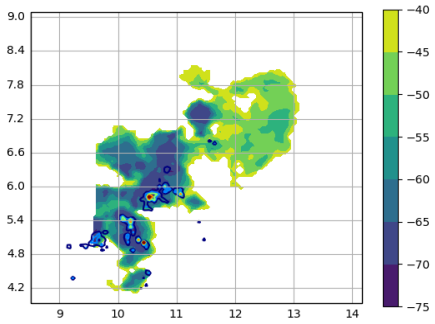

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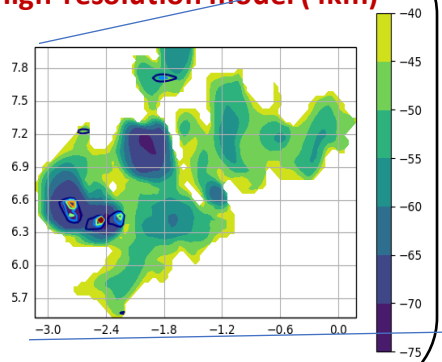


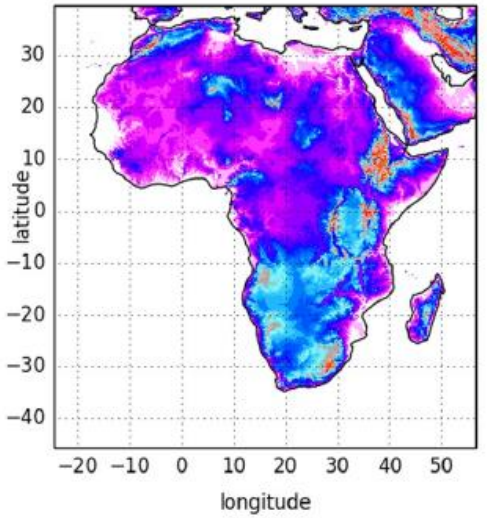
MetUM **CP4-Africa** simulation

- ~ 4km resolution
- 10 years historical (~2000)
- 10 years future (~2100):

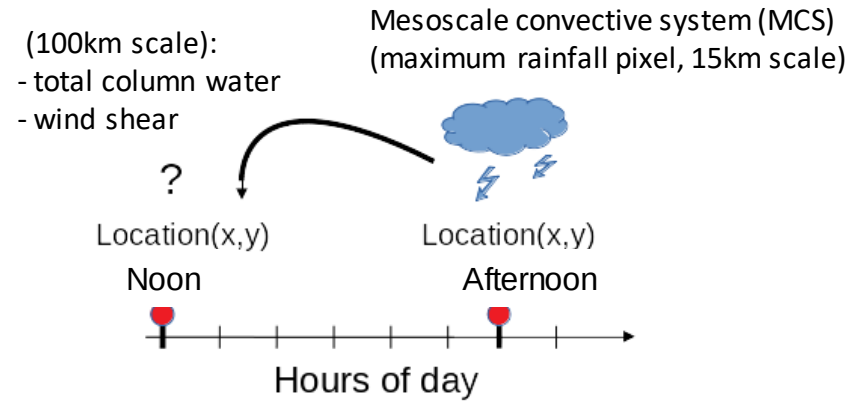
RCP8.5, 10-yr slice only

-> no medium-term information

-> publicly available data



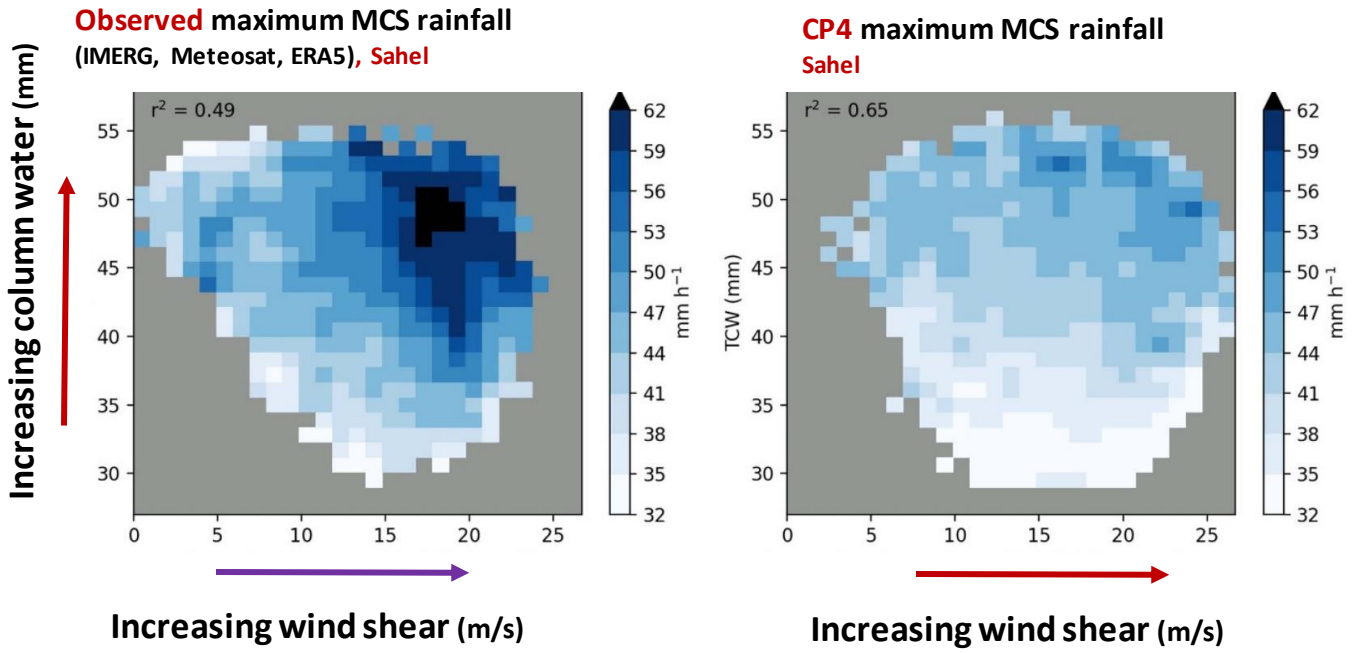
Sampling of storm rainfall scaling from observations and CP model



- **MCS = < -50C contiguous cloud > 5000 km2 from OLR (model) or satellite**

Maximum storm rainfall change with binned moisture and wind shear in observations and CP4-Africa

(MetUM CP4-Africa: 10 years historical, 10 years ~2100 for RCP8.5 at 5km)



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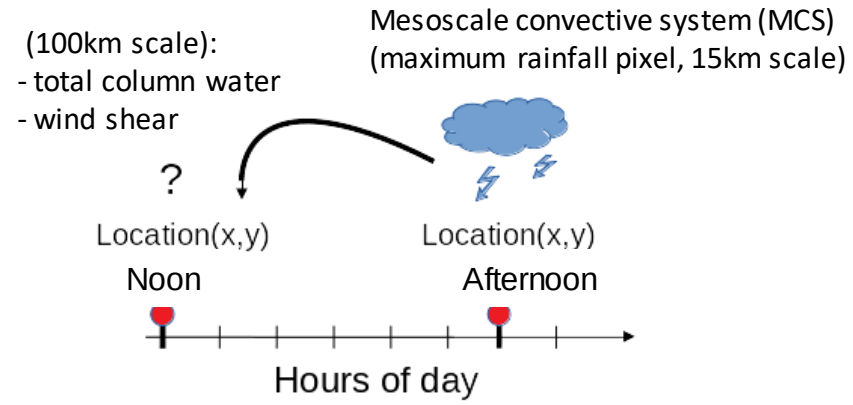

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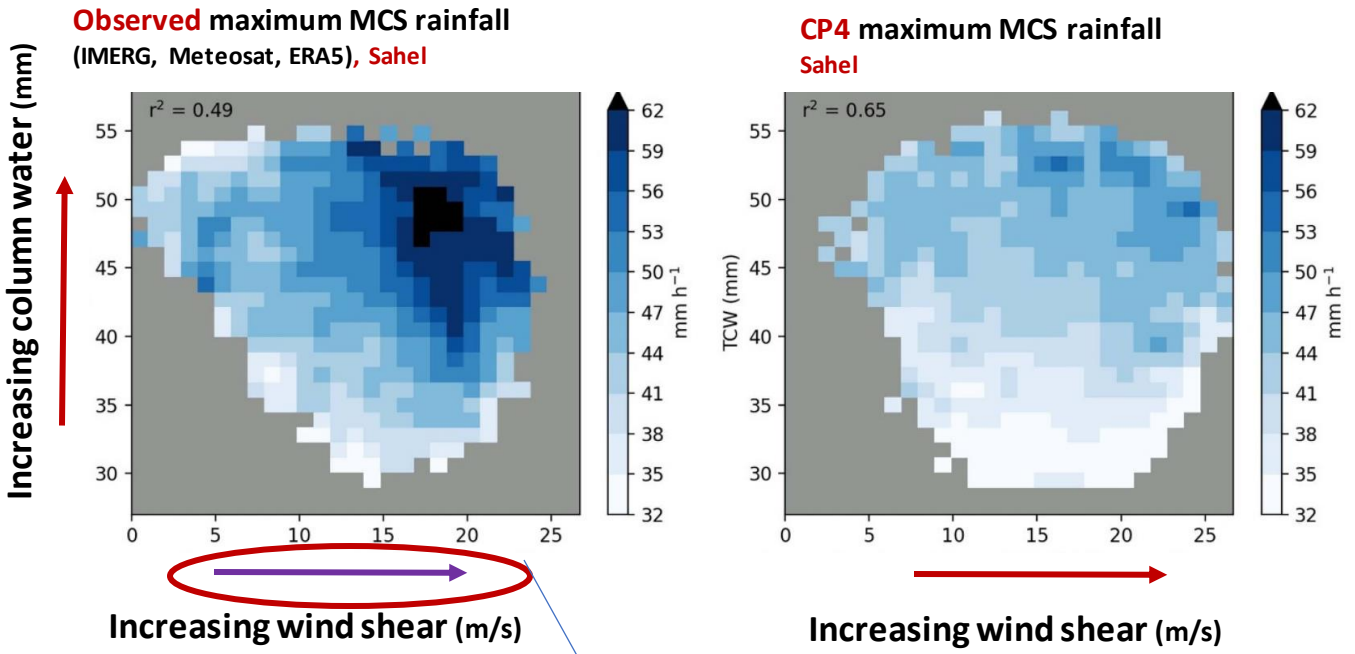


CP-model shows good moisture scaling BUT fails to reproduce observed shear response: Process-based evaluation of convection-permitting models is key

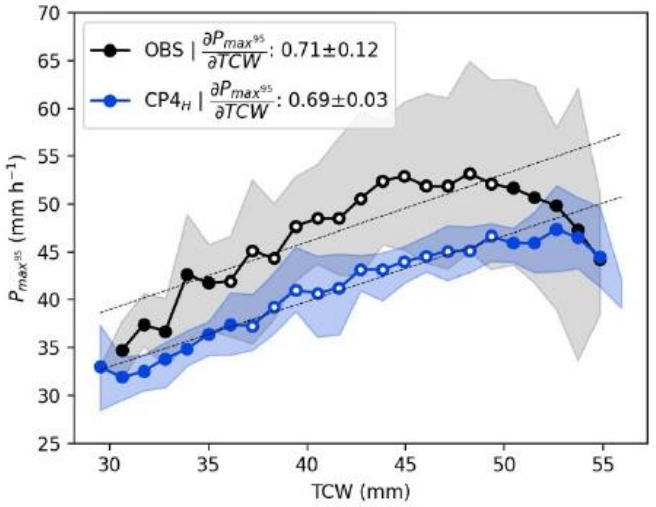
$$\Delta Pmax95 = \beta t \times \Delta TCW(CMIP) + \beta s \times \Delta Shear(CMIP)$$

Assumption of stable storm-shear scaling across climates

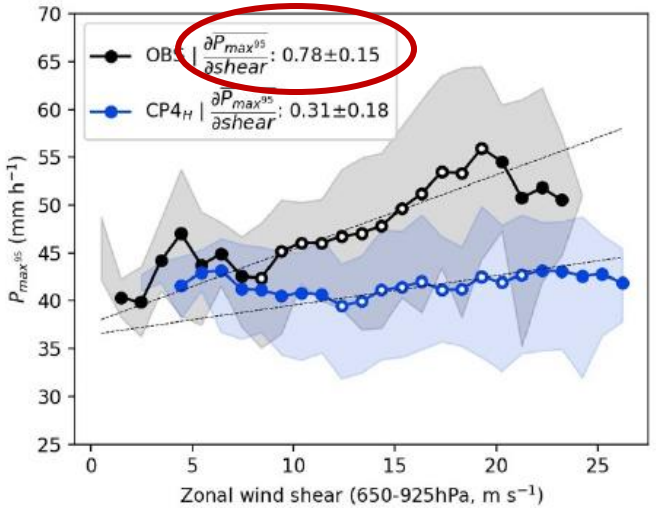
"Observations" vs **convection-permitting model** (MetUM CP4-Africa)

Afternoon-MCS rainfall intensity scaling with pre-existing...

Total column water



Wind shear

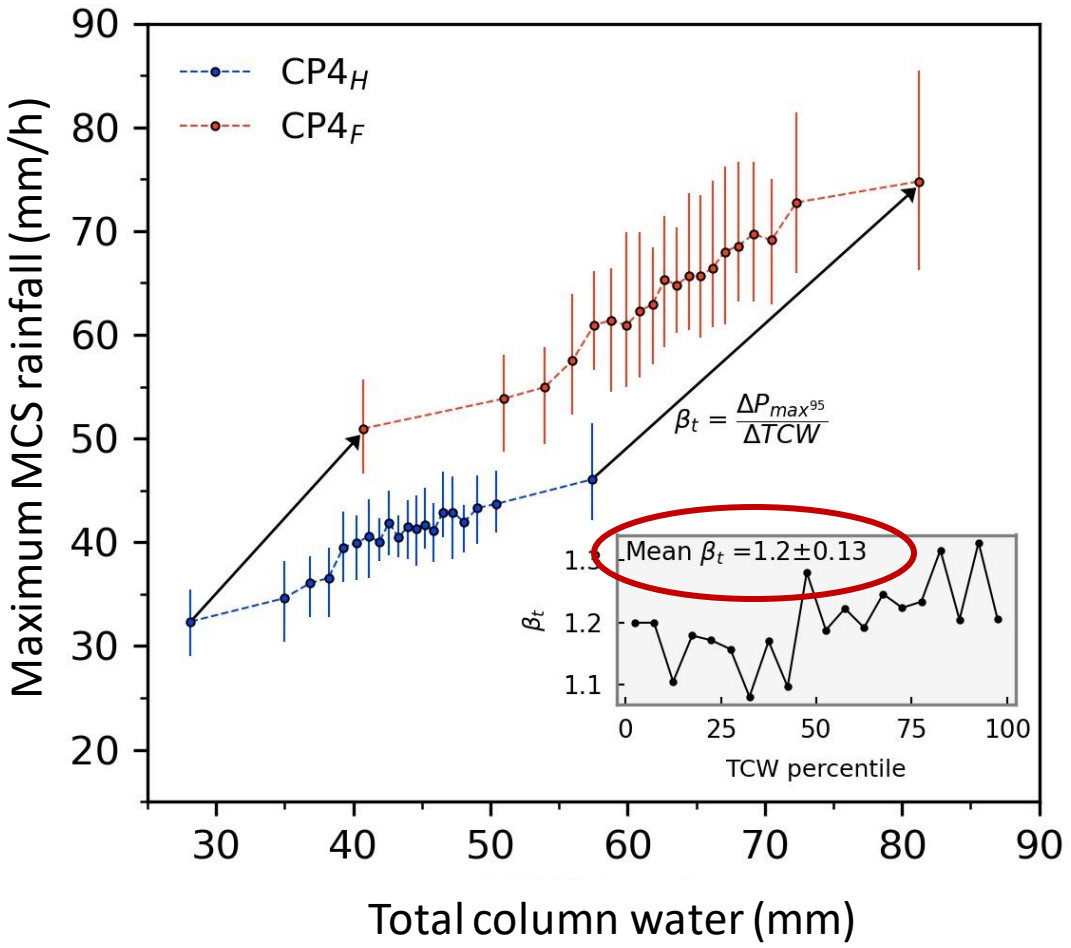


Rainfall scaling with wind shear much too weak in the model.

-> use historical wind-shear scaling based on OBS

Deriving moisture scaling of extreme rain across climates

CP4-model: p95 max. MCS rainfall in **historical** and **future** period



10 years historical (1997-2007) and future (~2100, RCP8.5)

- TCW scaling changes between climates

-> percentile mapping

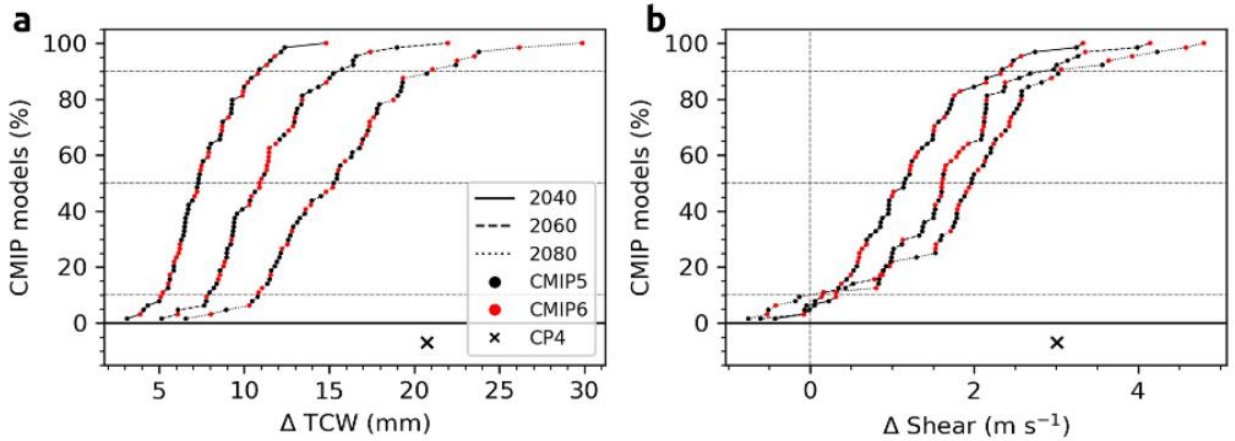
- Higher rain for same TCW and scaling factor >1: contribution of strengthened storm dynamics in the future?

ΔPmax95 = βt × ΔTCW(CMIP) + βs × ΔShear(CMIP)

Applying OBS & CP-derived scaling to CMIP models

CMIP5/6: 1950-1999 baseline period & 30yr future slices

CMIP storm driver changes for RCP8.5 & CP4 driver change (x)

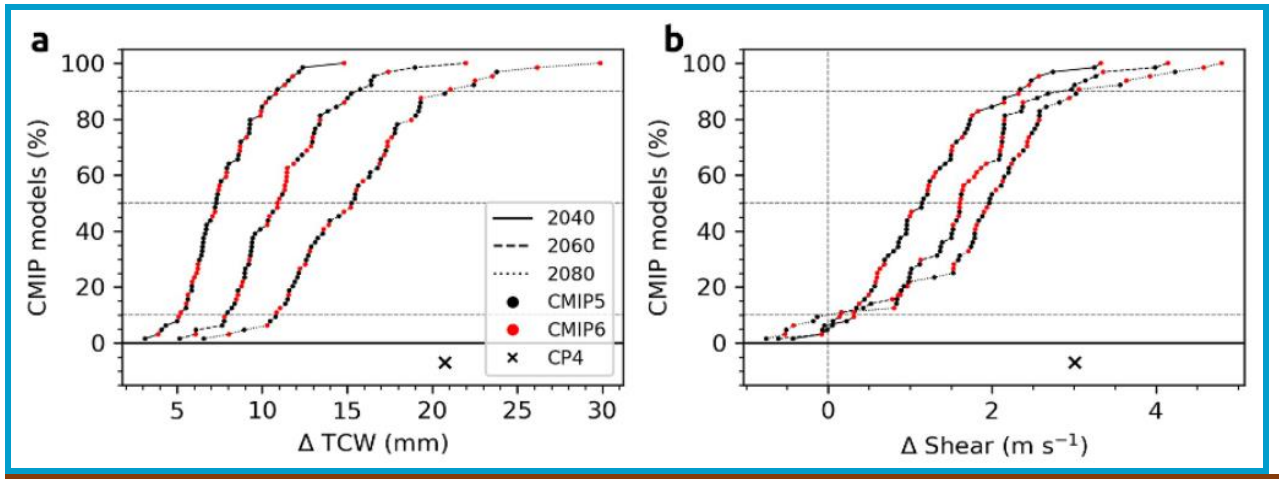


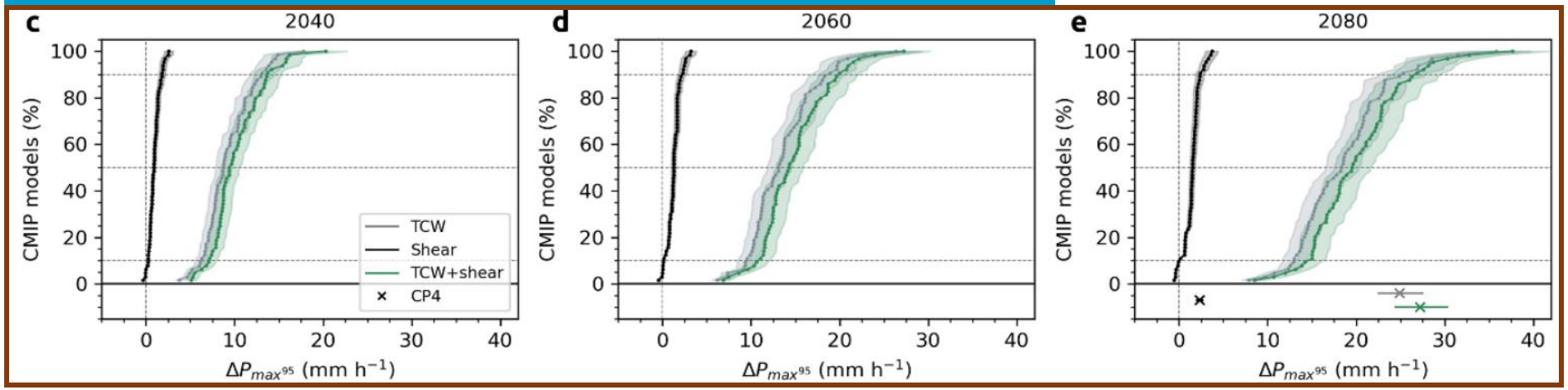
CP4 represents a "strong driver change" scenario compared to full CMIP range

Applying OBS & CP-derived scaling to CMIP models

CMIP5/6: 1950-1999 baseline period & 30yr future slices

CMIP storm driver changes for RCP8.5





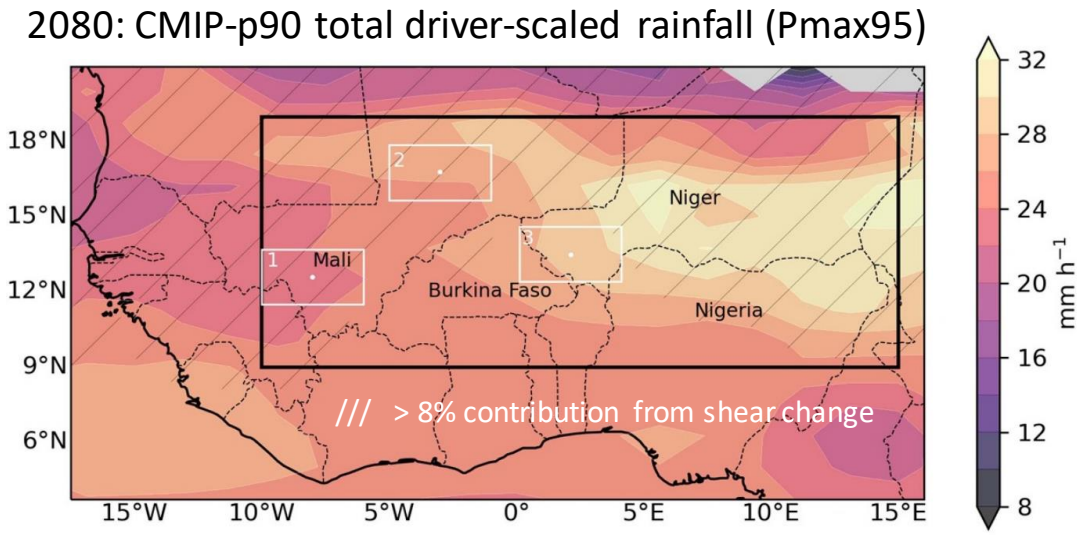
From CMIP storm-driver changes (top), we reconstruct rainfall changes reflecting CP-model intensities (bottom)

-> also allows to cover periods not covered by CP model.

$\Delta Pmax95 = \beta t \times \Delta TCW(CMIP) + \beta s \times \Delta Shear(CMIP)$

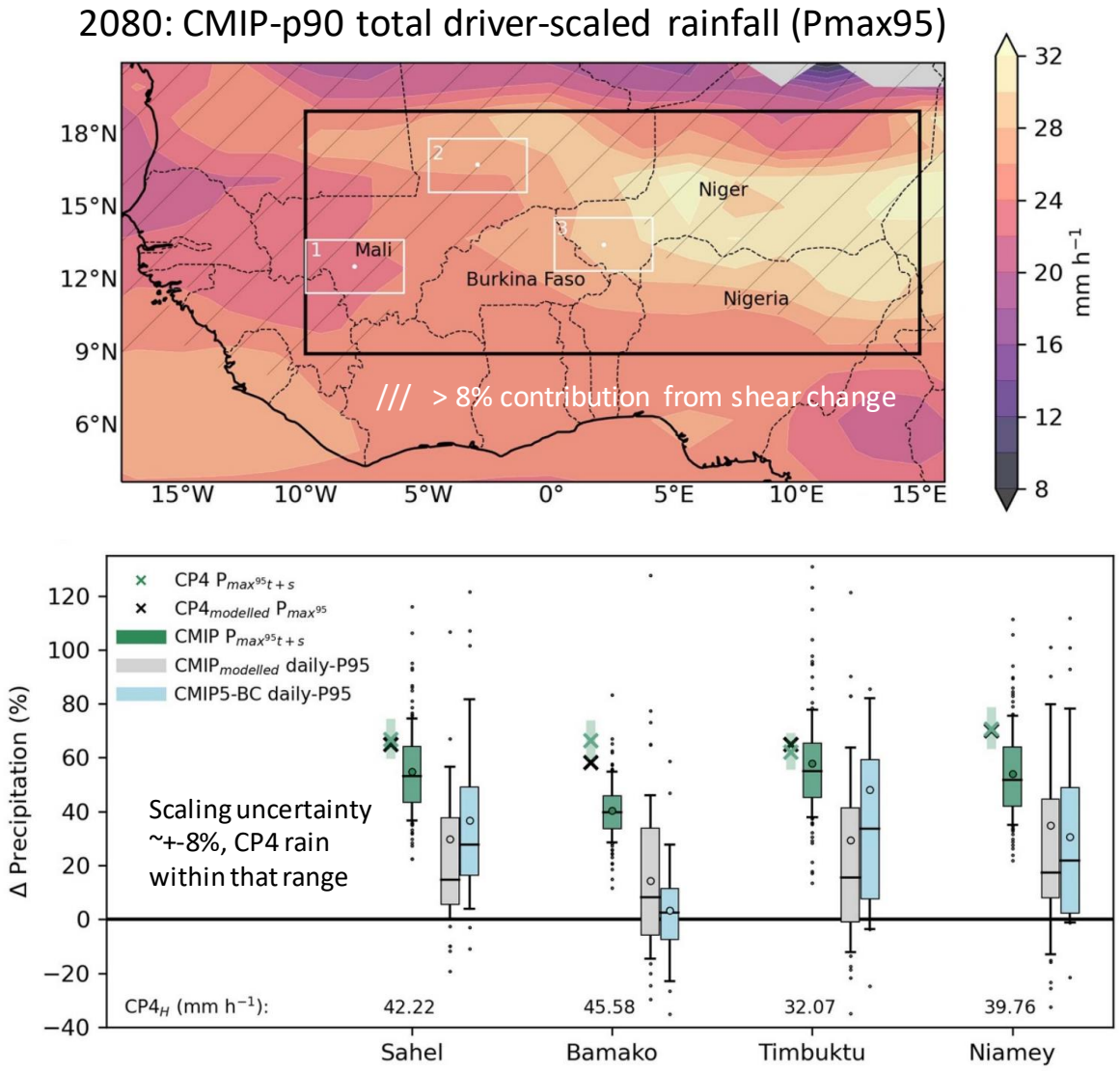
Regional differences and comparison to CMIP rainfall

- CMIP p90 shows absolute changes ~20-38 mm/h
- Large areas with shear contribution > 8%

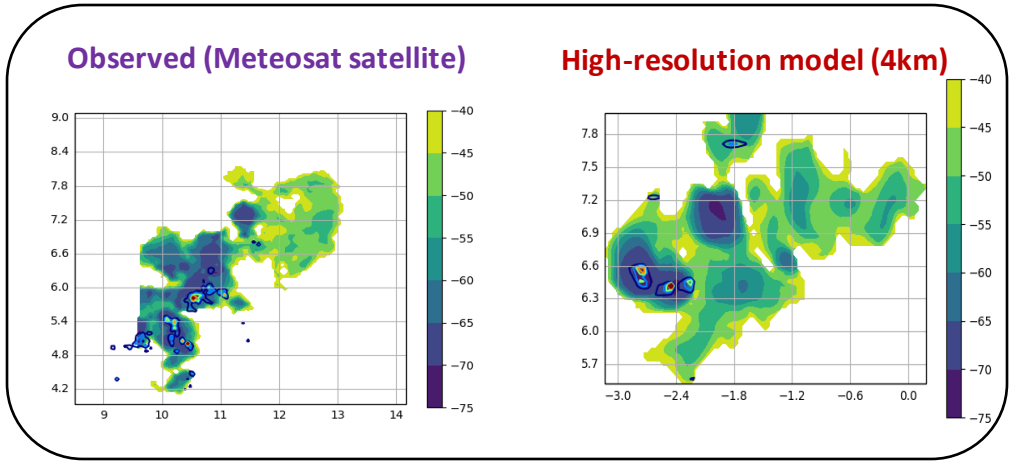


Regional differences and comparison to CMIP rainfall

- ΔPmax95 is *generally positive,* mean change of 40-60% across regions
- CP4 round-trip: differences within +-8% combined TCW+shear scaling uncertainty
- CP4 sits within highest CMIP quartile
- Mean underestimation from CMIP ~ 25% across Sahel



Enhancing convection-permitting climate models with uncertainty ranges

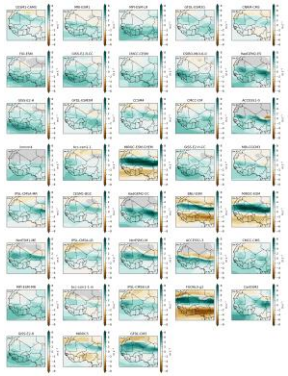


Result: the ideal extreme rainfall projection

- Resolve storm structures
- Reflect response of storms to environment
- Give information about projection uncertainty
- Be available over full future period

Much more useful for risk communication!

CMIP shear / humidity change

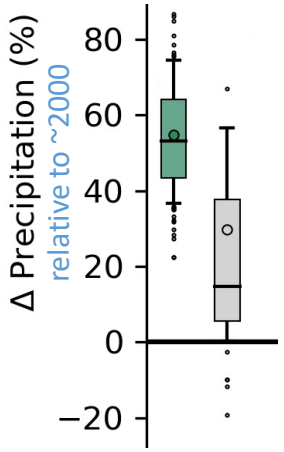


Realistic storm/atmosphere relationships = β-scaling factors

Statistical framework constructing rainfall extremes from CMIP **moisture & wind changes**

ΔPmax95 = βt × ΔTCW(CMIP) + βs × ΔShear(CMIP)

Range of future (~2100) changes in Sahel extreme rainfall from 64 CMIP simulations:



Raw CMIP rainfall

vs.

Constructed CMIP storm rainfall

~ 25% underestimation from raw CMIP by end of century
(RCP8.5 & SSP5-8.5)

Klein et al. ERL 2021