Extreme rainfall over West Africa: Current state and projected impacts of climate change

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FURIFLOOD:
A German-West African partnership

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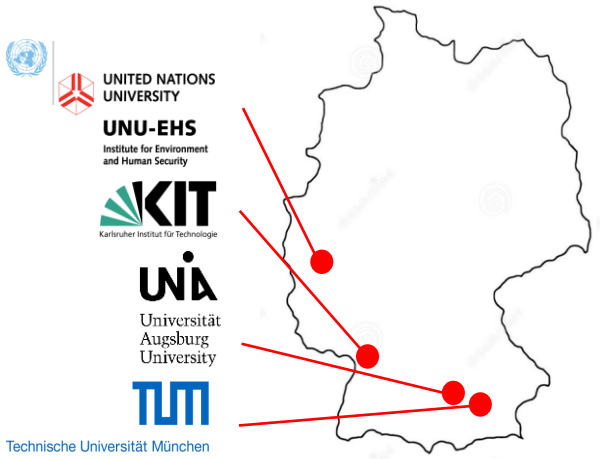
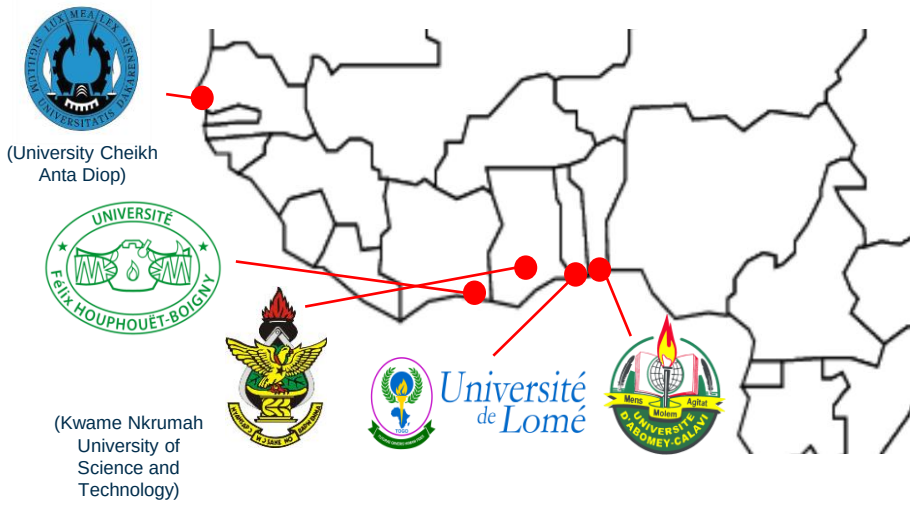
FURI FLOOD

- **Current and future risks of urban and rural flooding in West Africa – An integrated analysis and eco-system-based solutions**
- Funded by the German ministry of education and research (BMBF)
- Project period: August 2021 – December 2024





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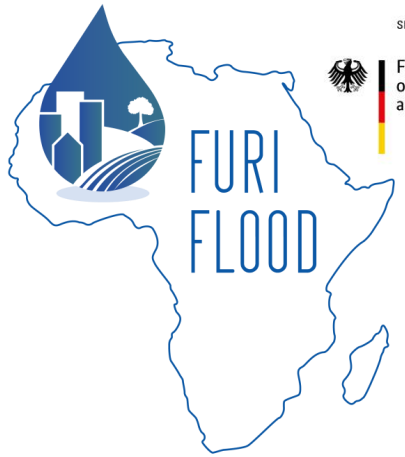

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Meteorology | **Hydrology** | **Risk assessment**

Karlsruher Institut für Technologie

Technische Universität München

UNITED NATIONS UNIVERSITY
UNU-EHS
Institute for Environment and Human Security

Université de Lomé

Current (+ Future)

Universität Augsburg University

Why FURIFLOOD?
Current challenges…

Petrol station explosion after consecutive days with heavy rainfall (Accra, Ghana, 5th Jun 2015)

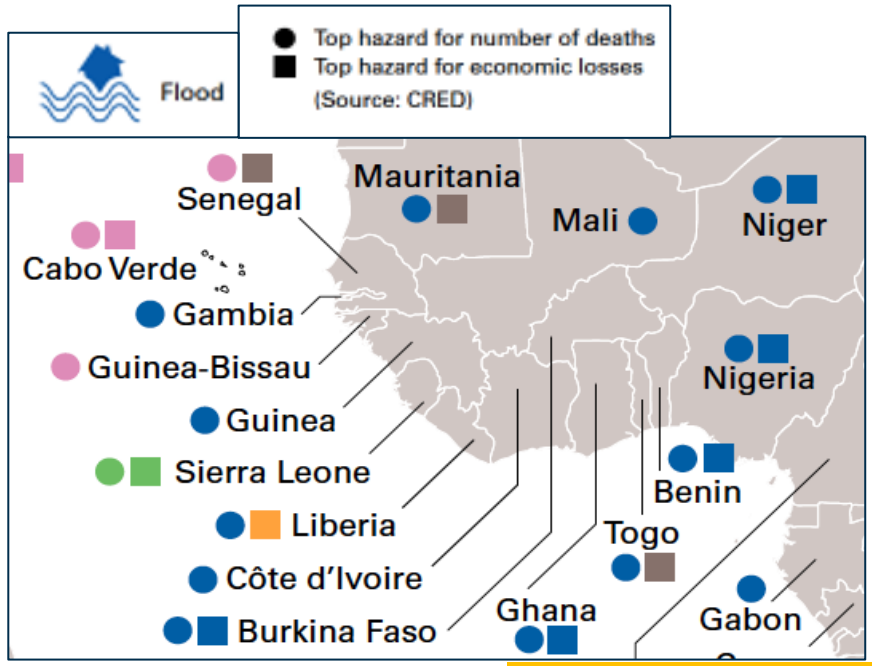
Kumasi 28th June 2018 flooding

Accra, 18th June 2018 flooding

Floods Kumasi/Accra (Ghana) in June 2018

Floods Lower Mono (Togo) in October 2019

Floods are the most frequent, costliest or deadliest hazards in West Africa

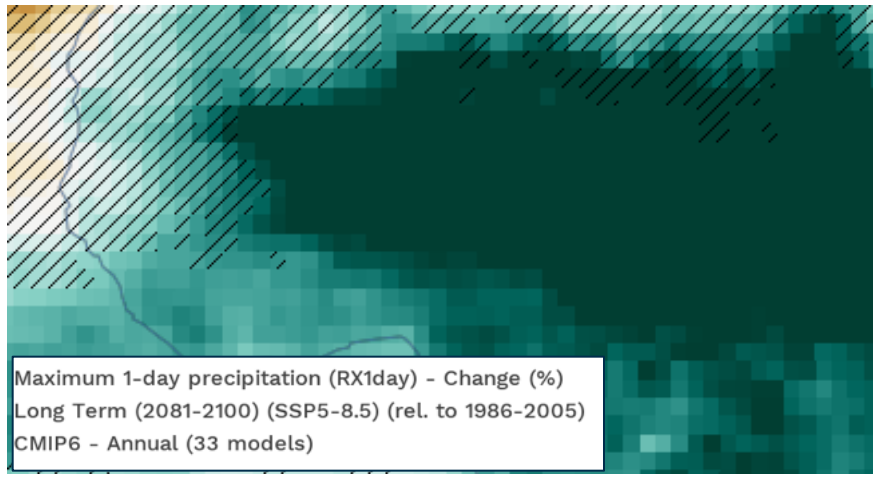


Cullmann et al. (2021)

Why FURIFLOOD?
… and future challenges

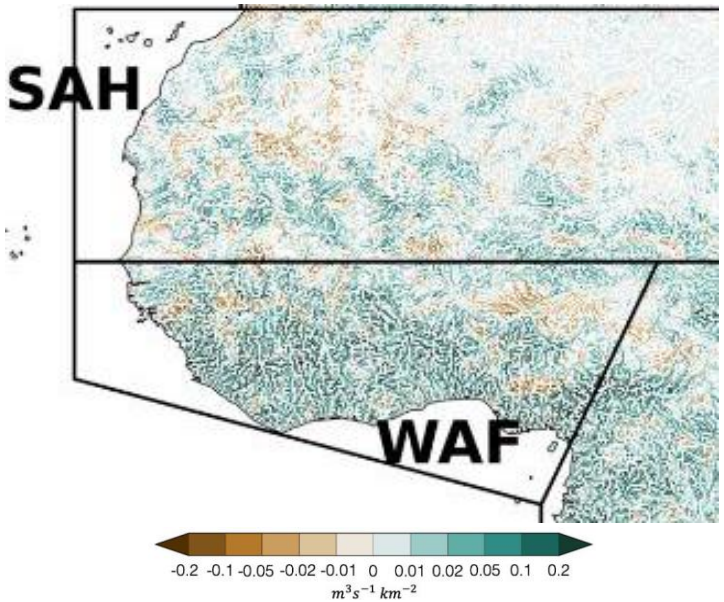
Source: IPCC AR6 (2021)

More intense daily (extreme) rainfall in the future



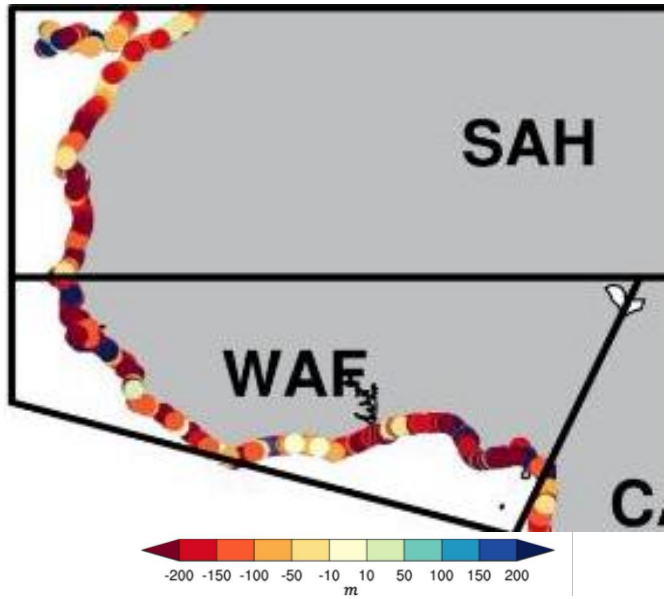
Change in daily rainfall maximum is projected to be **positive over whole of West Africa**

Higher discharge in the future



Strongest projected increase for the West **African forest zone**

Retreating shorelines in the future



Retreat of coastline likely **exacerbates urban flood risk**

Why FURIFLOOD?
Research questions

Source: IPCC AR6 (2021)

1. What is „extreme“ rainfall **in present days** over West Africa?
2. What can extreme rainfall be **in future times**?

Meteorology | **Hydrology** | **Risk assessment**

Change in daily rainfall maximum is projected to be **positive over whole of West Africa**

Strongest projected increase for the West **African forest zone**

Retreat of coastline likely **exacerbates urban flood risk**

Datasets and methods

Extreme value analysis (EVA): Modeling the tail end of the rainfall distribution

„Block maxima“ approach“

- Sampling of annual rainfall maxima
- Fitting of „**Generalized extreme value distribution (GEV)**“ via maximum likelihood estimation (MLE)

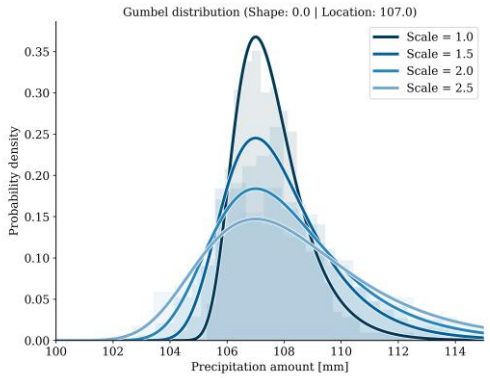
$$GEV(x) = \exp\left(-\left[\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right)$$

ξ, σ, μ = shape, scale, location parameters

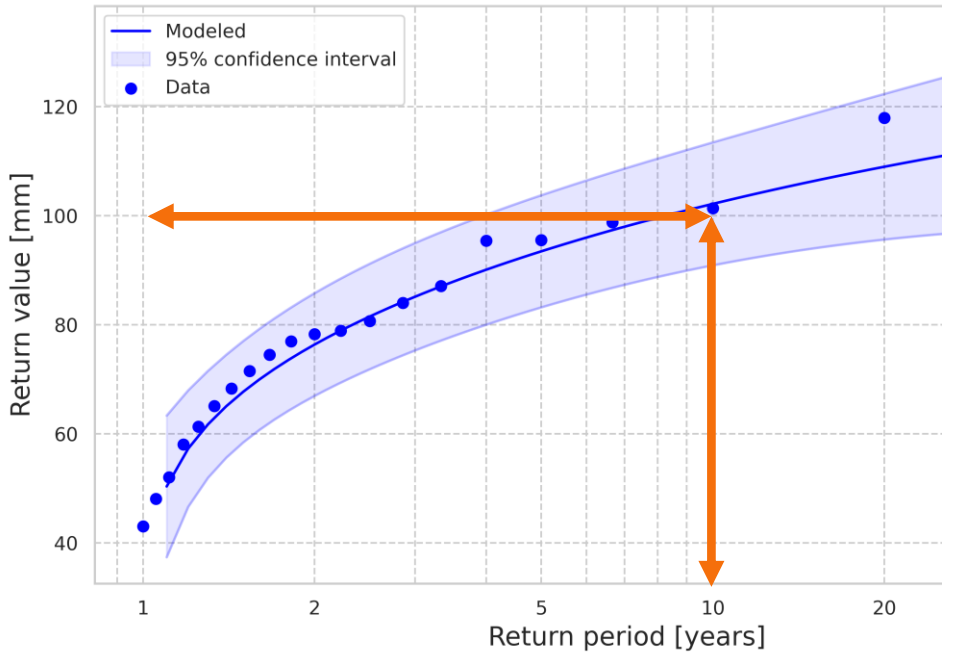
Return value (RV) and Return period (T)

- $T = 1/p$ = Average „waiting time“ until considered RV is exceeded
- e.g., $p = 0.01 \rightarrow T = 100\ years$

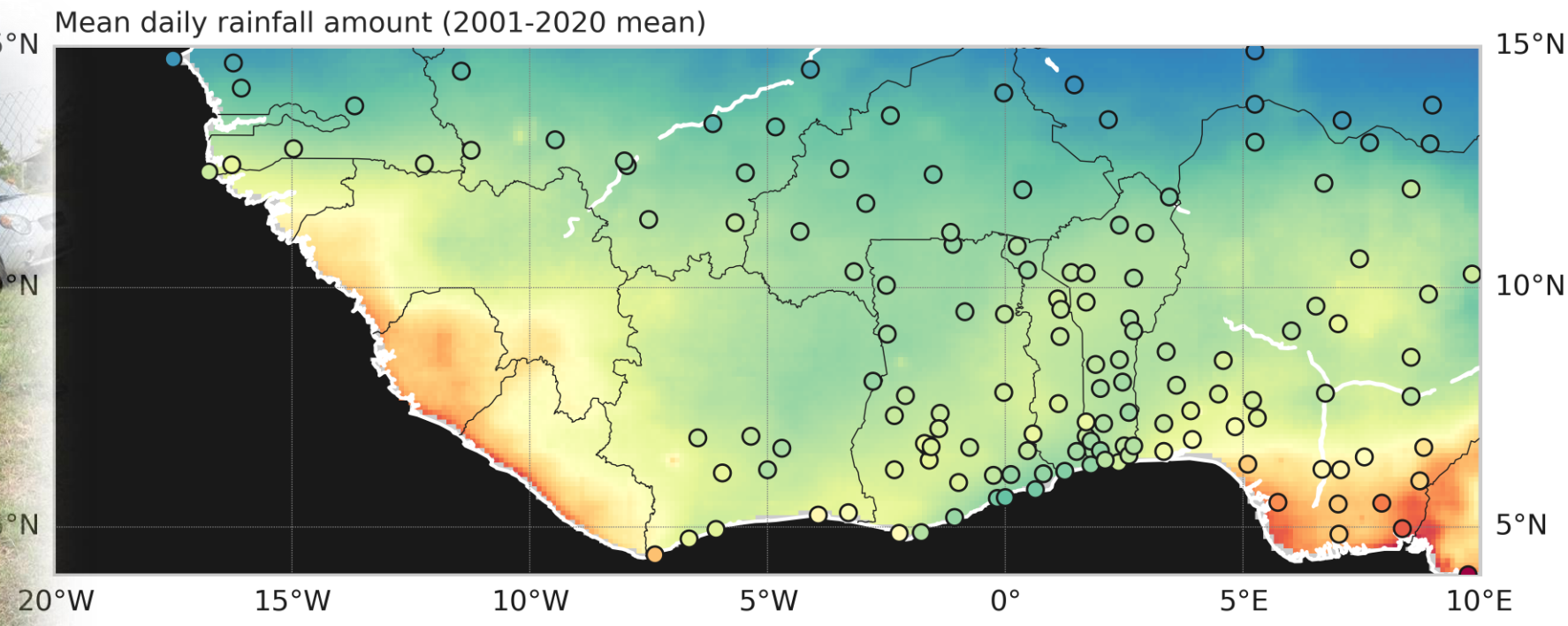
$$RV = GEV^{-1}(1-p)$$



Here: Fitting with **Gumbel distribution** (ξ = 0)



Datasets and methods

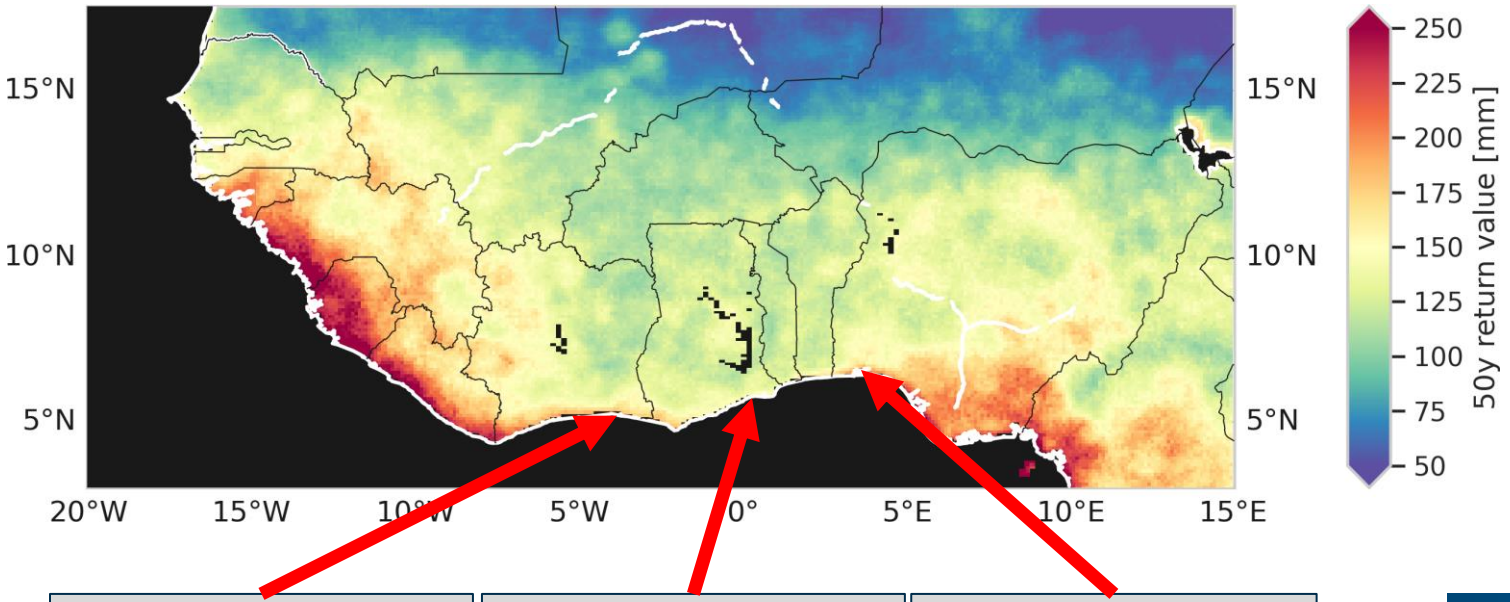


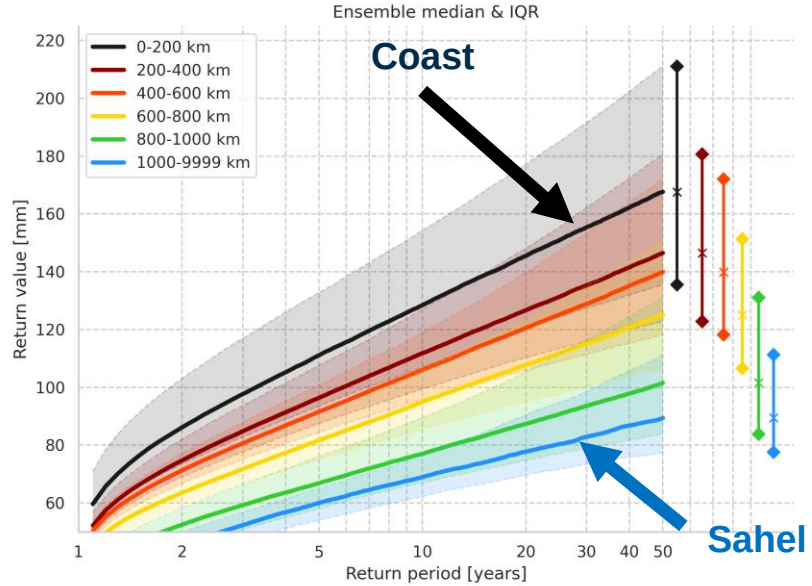
Availability of rainfall stations from the **Karlsruhe African Surface Station-Database** (**KASS-D**, Vogel et al. (2018)) with at least 80% data coverage in 2001-2020

Integrated Multi-satellite Retrievals for GPM (**IMERG V6B**, Huffman et al. (2015)), $\Delta x = 0.1°$ / $\Delta t = 30$ mins, data availability since June 2000

Results: Present-day return values over West Africa

Return values (RVs) of daily rainfall at 50-year return period



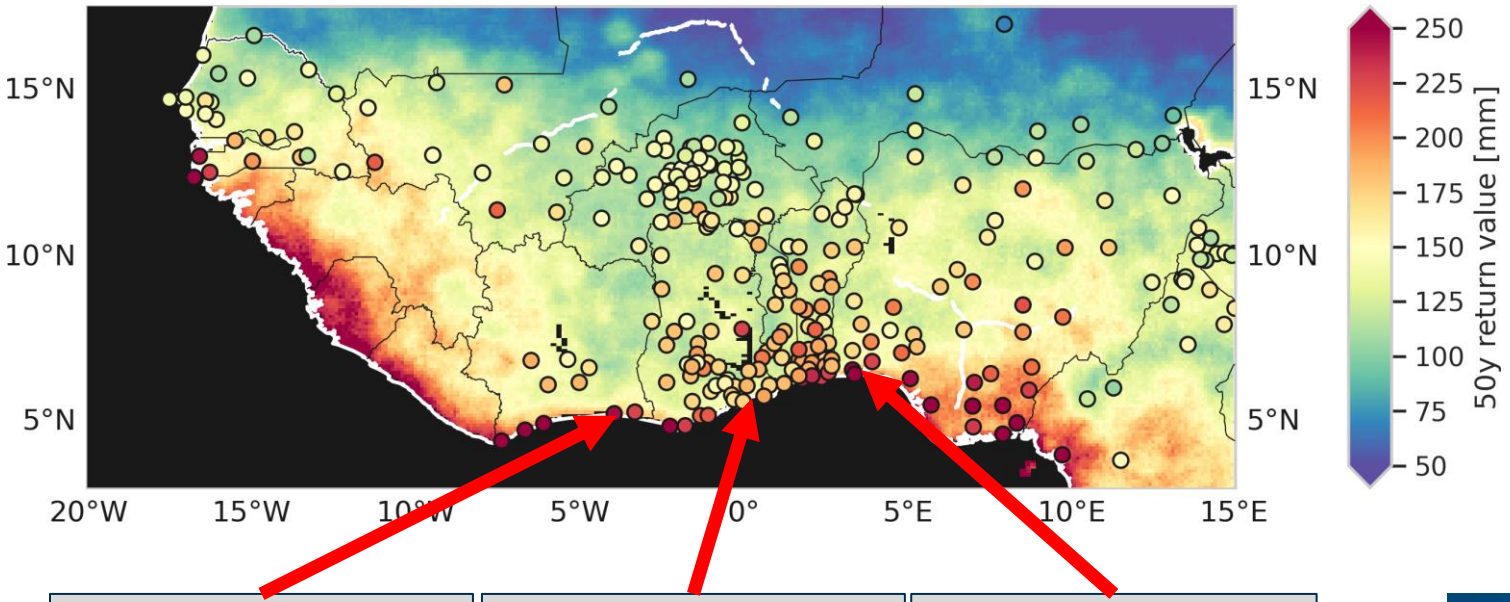


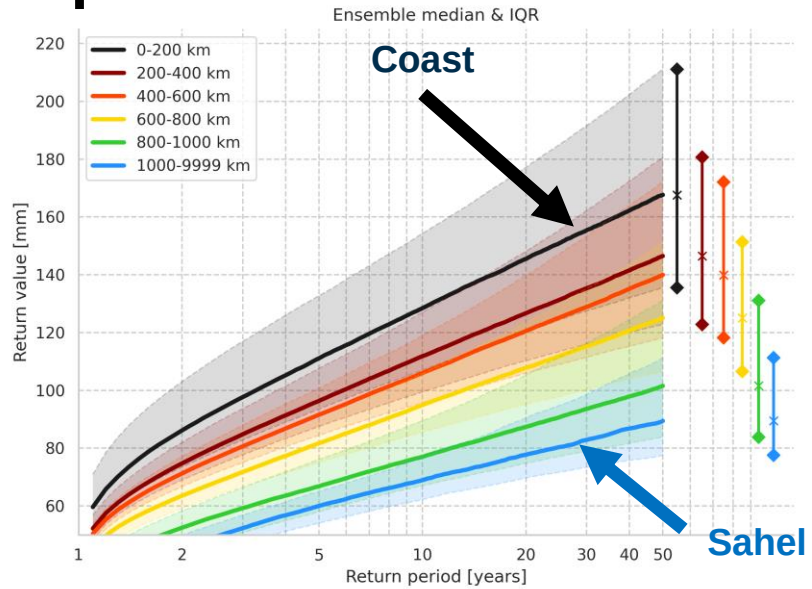
Abidjan (CIV):	Accra (GHA):	Lagos (NGA):
IMERG: 171 mm	IMERG: 154 mm	IMERG: 188 mm

- RV magnitudes are a function of the distance to the coastline (see right plot)
- Coastal regions are exposed by highest RVs in the West African domain

Results: Present-day return values over West Africa

Return values (RVs) of daily rainfall at 50-year return period





Abidjan (CIV):	Accra (GHA):	Lagos (NGA):
IMERG: 171 mm	IMERG: 154 mm	IMERG: 188 mm
Station: 247 mm	Station: 218 mm	Station: 249 mm

- RV magnitudes are a function of the distance to the coastline (see right plot)
- Coastal regions are exposed by highest RVs in the West African domain
- RVs underestimated by IMERG

Projection of **future** return values over West Africa

Approach: Adjusted Delta method (Fontolan et al., 2019)

- Imprint climate change signals from global circulation models (GCM) on GEV parameters of IMERG and stations

$$X_{GCM\_future} / X_{GCM\_present} = \boldsymbol{\Delta X}$$

$$\boldsymbol{X_{IMERG\_present}} \times \boldsymbol{\Delta X} = \boldsymbol{X_{IMERG\_future}} = \boldsymbol{X^*}$$

with $X = GEV\ parameter$

$$GEV^*(x) = \exp\left(-\left[\xi^*\left(\frac{x-\mu^*}{\sigma^*}\right)\right]^{-1/\xi^*}\right)$$

ξ^*, σ^*, μ^* = shape, scale, location parameters in a future state

Projection of **future** return values over West Africa

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$$\boldsymbol{X_{IMERG\_present} \times \Delta X} = \boldsymbol{X_{IMERG\_future} = X^*}$$

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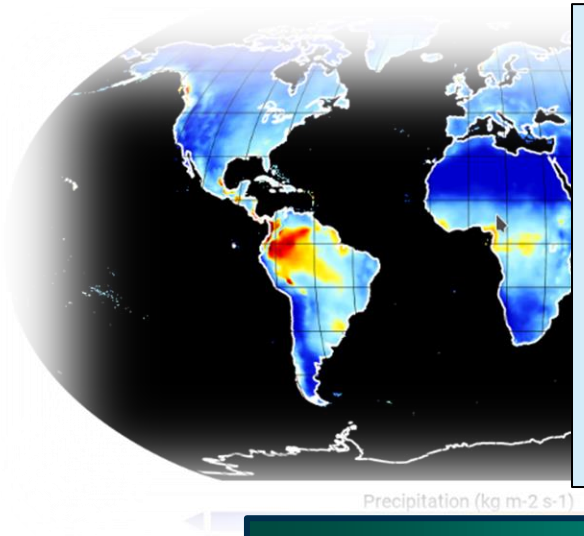
ξ^*, σ^*, μ^* = shape, scale, location parameters in a future state

Dataset: NEX-GDDP-CMIP6 (Thrasher et al., 2022)

- NASA Earth Exchange Global Daily Downscaled Projections

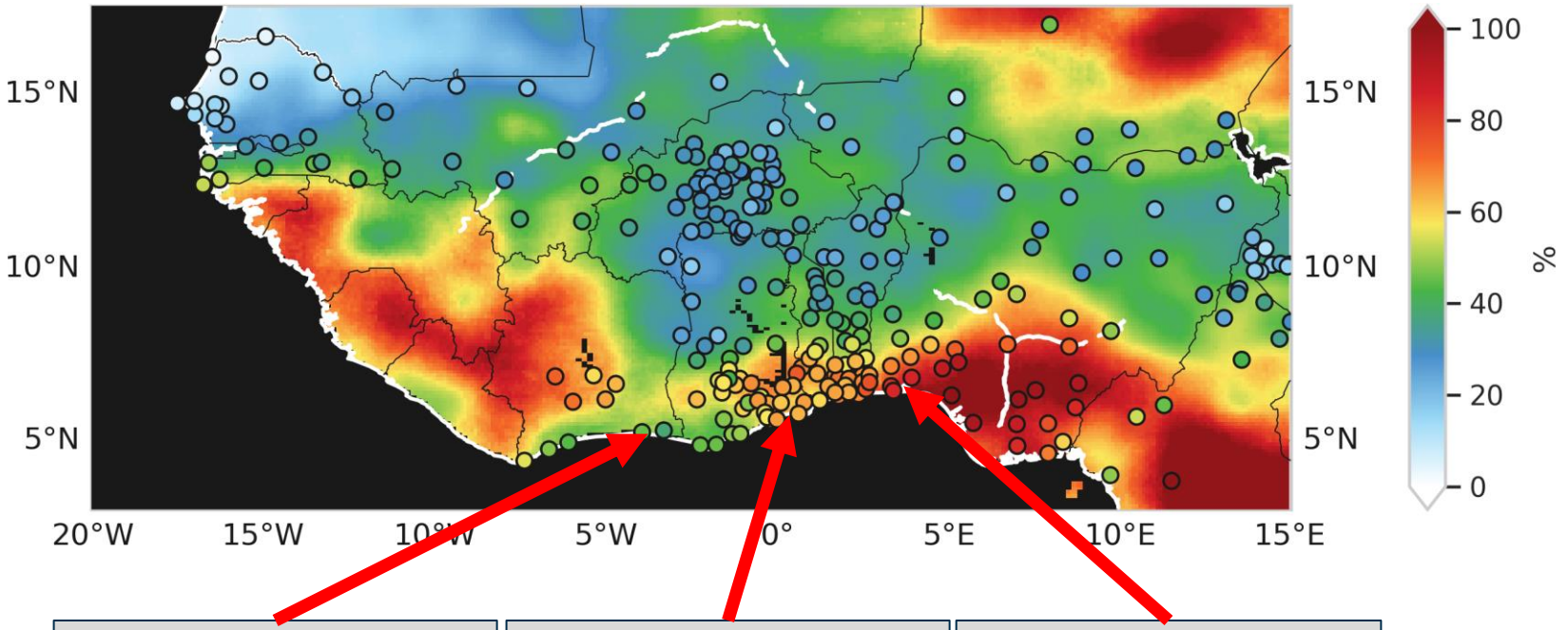


- 24 statistically downscaled CMIP6 climate models used for Delta method, daily rainfall, temperature, radiation, etc. data at **0.25°x0.25°**
- Bias-corrected and spatially disaggregated daily data of precipitation
- „Historical“ run (1950-2014) → 1985-2014 used here

Shown here: Results for **longterm period (2071-2100)** and **SSP5-8.5**

Results: Projected return values over West Africa

Median change [%] of 50-y Return values (RVs) (2071-2100 / SSP5-8.5)

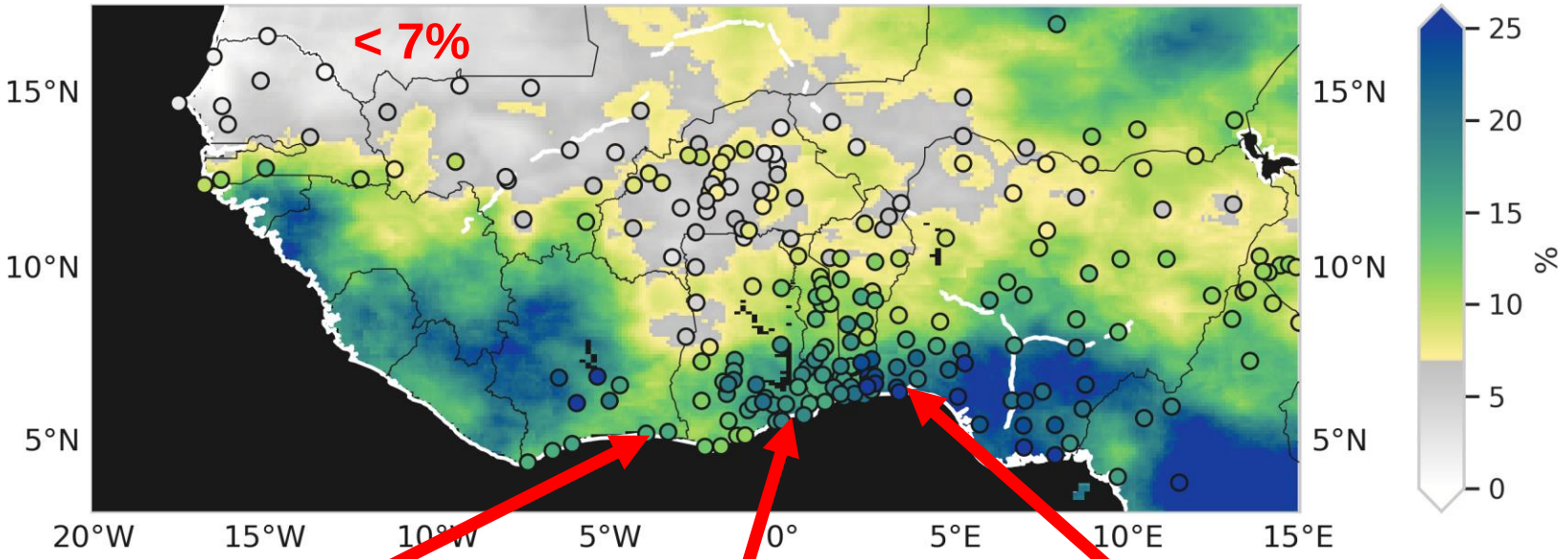


Abidjan (CIV):	Accra (GHA):	Lagos (NGA):
IMERG: 259 mm (+51%)	IMERG: 252 mm (+63%)	IMERG: 346 mm (+84%)
Station: 358 mm (+45%)	Station: 362 mm (+66%)	Station: 454 mm (+82%)

- Increase of extreme rainfall magnitude in entire West African domain
- Coastal regions and central Sahel with strongest relative increase

Results: Projected return values over West Africa

Clausius-Clapeyron (CC) considerations: Change of 50-y RV per K (in %) (2071-2100 / SSP5-8.5)

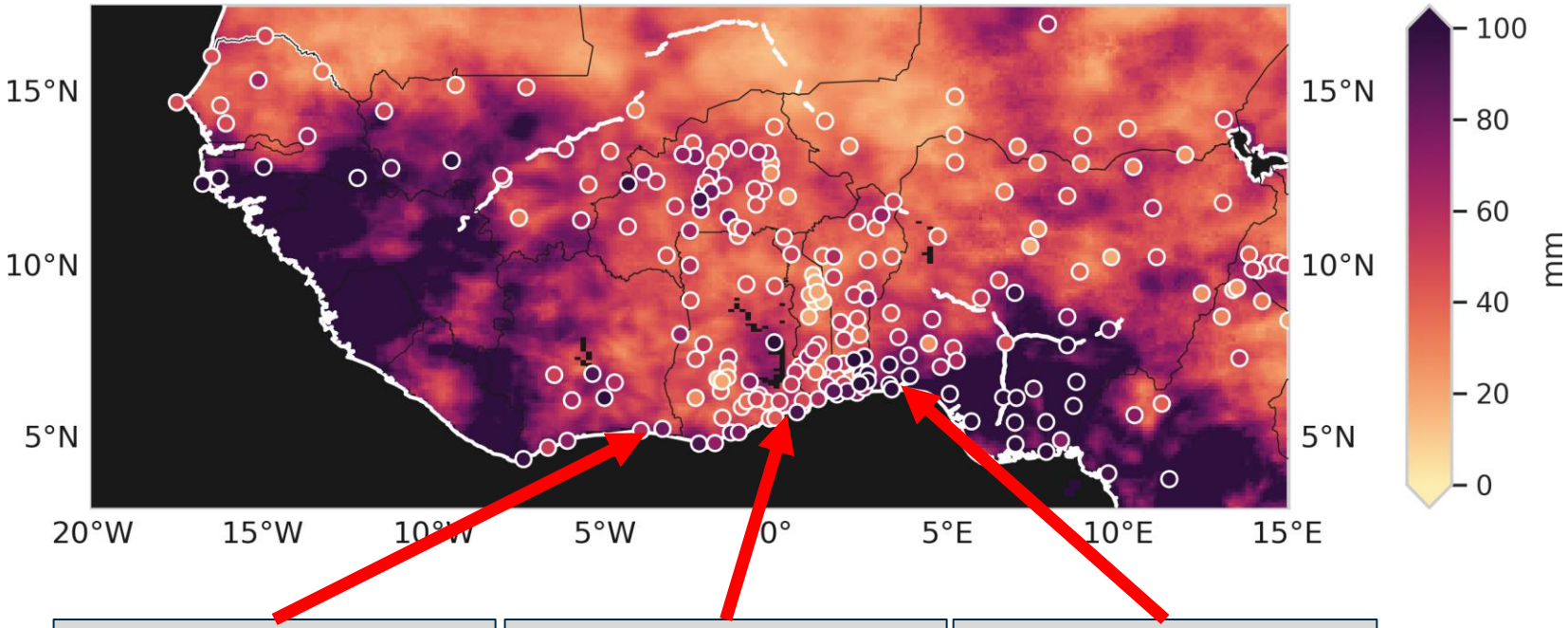


Abidjan (CIV):	Accra (GHA):	Lagos (NGA):
IMERG: + 15%	IMERG: + 18%	IMERG: + 22%
Station: + 13%	Station: + 17%	Station: + 23%

- Temperature data from NEX-GDDP-CMIP6
- Majority of West Africa beyond CC-scaling (>7%)
- RV increase in some coastal areas beyond x3 of CC-scaling

Results: Projected return values over West Africa

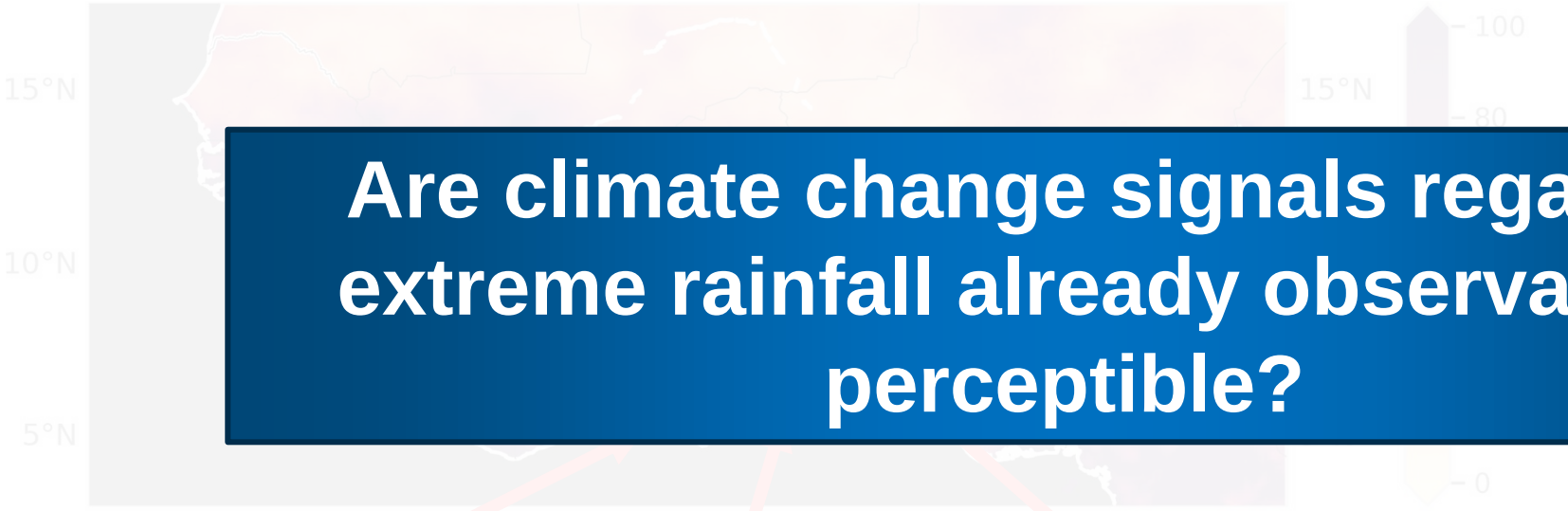
Uncertainty of projected 50-y RV estimation: Interquartile range (IQR)



Abidjan (CIV):	Accra (GHA):	Lagos (NGA):
IMERG: [215 mm, 292 mm]	IMERG: [228 mm, 279 mm]	IMERG: [292 mm, 407 mm]
Station: [270 mm, 352 mm]	Station: [285 mm, 327 mm]	Station: [341 mm, 491 mm]

- High uncertainty (large IQR) among CMIP6 models in regions with largest relative change in RV (→ coastal areas)
- Example Lagos:
  Median RV: 346 mm
  IQR = [292 mm, 407 mm]
- Uncertainty of CC-scaling accordingly

Uncertainty of projected RV estimation: Interquartile range (IQR)



Are climate change signals regarding extreme rainfall already observable or perceptible?

- High uncertainties (large CMIP6 models th largest ge in RV (→ s)

Lagos:
Median RV: 346 mm
IQR = [292 mm, 407 mm]

- Uncertainty of CC-scaling accordingly

Abidjan (CIV):	Accra (GHA):	Lagos (NGA):
IMERG: [215 mm, 292 mm]	IMERG: [228 mm, 279 mm]	IMERG: [292 mm, 407 mm]
Station: [215 mm, 292 mm]	Station: [215 mm, 292 mm]	Station: [215 mm, 292 mm]

… potentially yes

Multiple >300 mm/d events in Abidjan (CIV) in recent history

Source: Reuters

Source: africa.cgtn.com

302 mm
on 19 June 2018

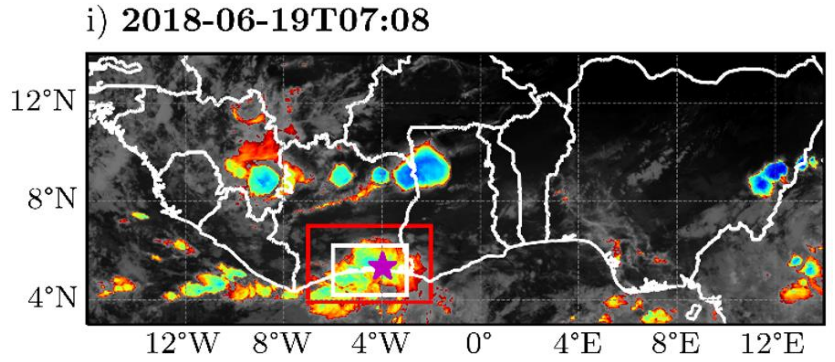
3rd highest ever

320 mm
on 13 June 2024

Highest ever

19 June 2018 case investigated in

Toure et al., (2025) (submitted to Monthly Weather Review)



Last event over 300 mm in Abidjan: 21 June 1983 (311 mm)

Summary & conclusion

- **Extreme value analysis (EVA) on in-situ and satellite-based IMERG rainfall data for West Africa:**
  - Highest return values (RVs) found along West African coast → dense and vulnerable population
  - IMERG underestimates RVs → necessity of reliable station data
- **Estimation of future RVs using NEX-GDDP-CMIP6**
  - Strongest positive change (with large uncertainty) of future 50-year RVs along Guinea coast
  - Super Clausius Clapeyron scaling (>>7% per K) at the West African coast region
- **Cases of unprecedented extreme rainfall in recent history in the West African coast region**