

Validation of Satellite-based Rainfall Products over Africa using TAHMO in-situ station data

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AGU Fall Meeting 2021 -
New Orleans, 13-17th
December, 2021

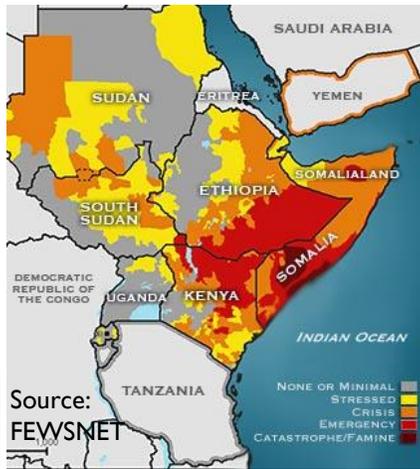
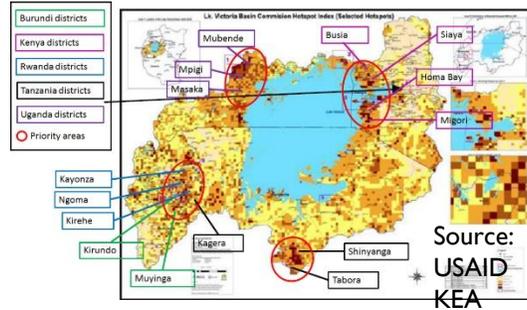


Why do we need accurate climate data?

- The changing climate will lead to changes in the **frequency, intensity, spatial extent, duration, and timing** of extreme weather and climate events

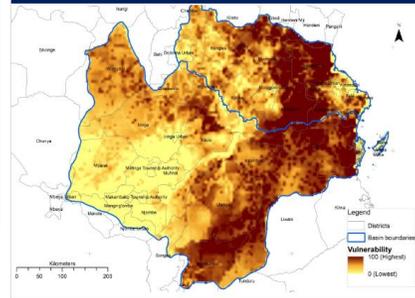
- To better deal with the impacts of a changing climate there is need to;

- understand emerging risks
- have seamless access to monitoring and early warning information
- enhance preparedness and response capacity
- invest in anticipatory approaches
- enabling DRM policy environment and sustainable funding



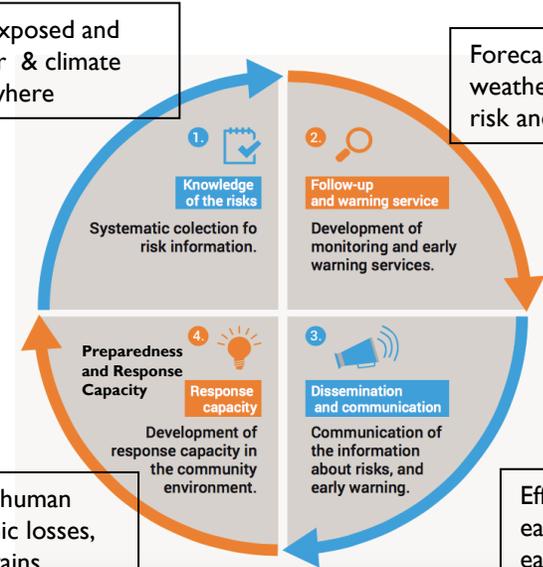
CLIMATE CHANGE VULNERABILITY AND ADAPTATION STUDY PHASE II: Wami Ruvu and Rufiji Basins Climate Vulnerability Mapping

MARCH 2018
This report is made possible by the support of the U.S. Agency for International Development (USAID). It is prepared for review and approval by the USAID Tanzania Water Resources Integration Development Initiative (WARDI). The contents are the sole responsibility of SERVIR Eastern and Southern Africa and do not necessarily reflect the views of USAID.



Who/ what is most exposed and vulnerable to weather & climate related hazards and where

Forecasts to anticipate weather & climate related risk and impacts



Early action to reduce human loss/ suffering, economic losses, protect development gains

Effective communication of early warning >>> to enable early action

Source: Kenya Red Cross Society

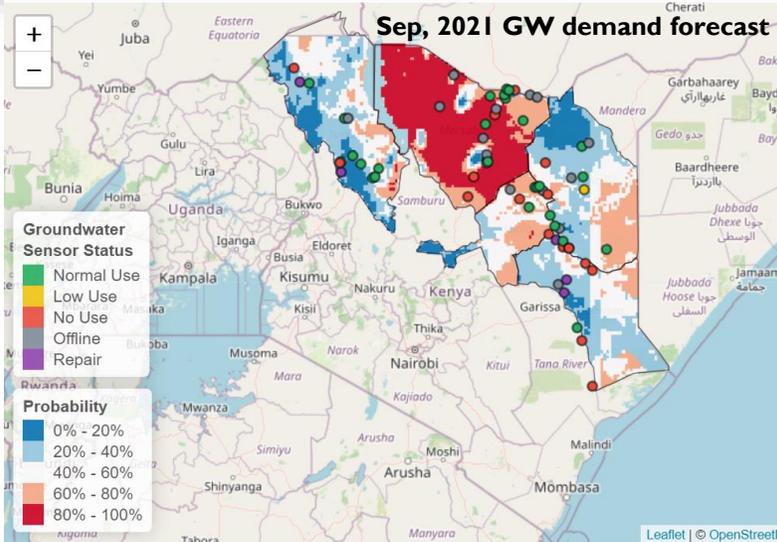


11 million people affected by severe drought in 2011, up to 260,000 deaths

Kenya, 2011

Macharia et al. 2020: <https://doi.org/10.3390/su12104102>

Why do we need accurate climate data?

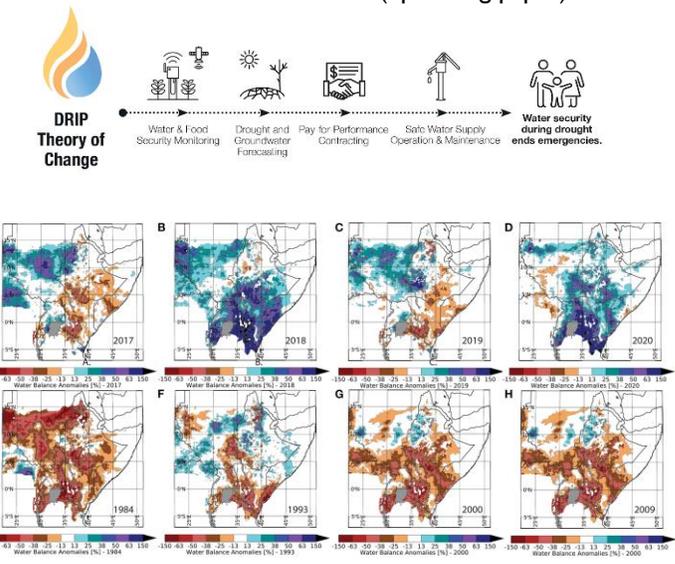


Katie et al. (upcoming paper)



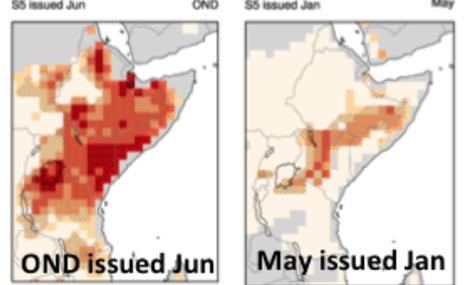
Photo credit: Evan Thomas, MCGE

- As climate change increases the **frequency and intensity of extreme events** and hence impacts on the most vulnerable, **Early Warning Systems** have become a **critical component of disaster risk reduction (DRR) efforts**
- Using early warning information to **anticipate disasters**, implement anticipatory actions, **prevent impacts**, if possible, and **reduce human suffering and losses**.



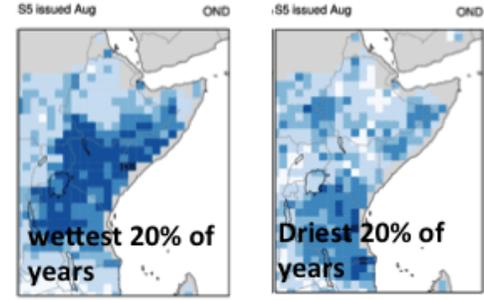
Funk et al. 2021: <https://doi.org/10.3389/fclim.2021.716568>

Good forecasts are available many months in advance for the short rains



Ensemble mean correlation with observations

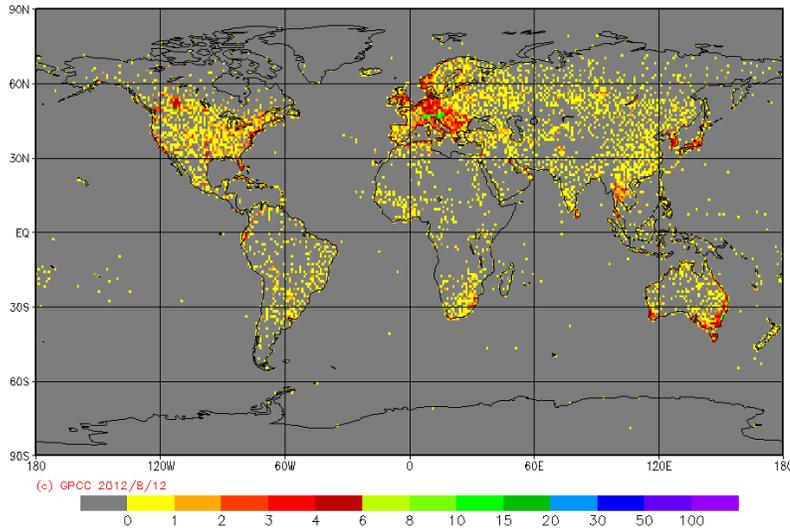
Skill is higher for extreme event (esp wet)



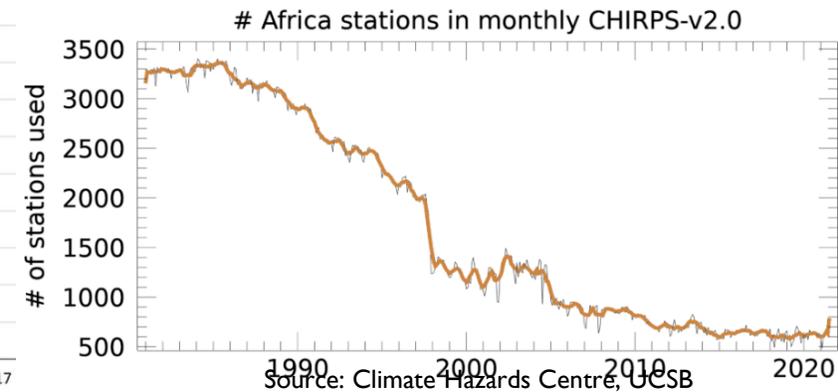
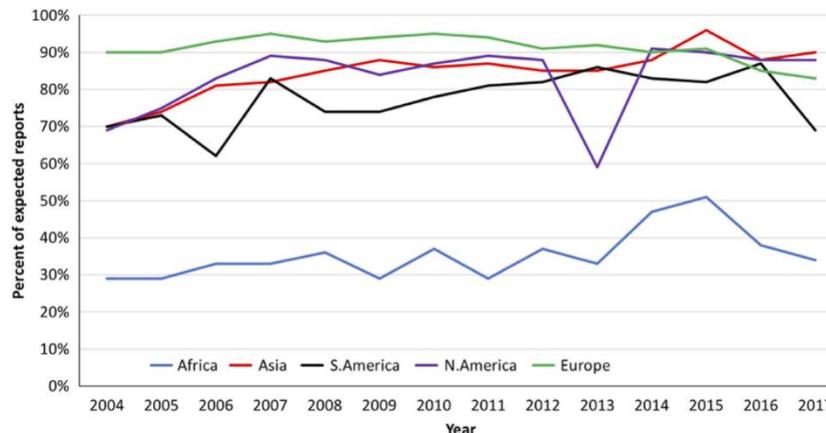
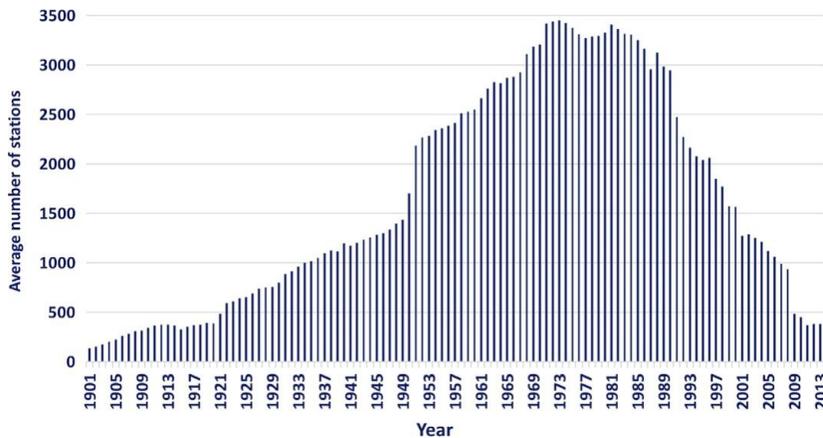
Hit rate: % events successfully anticipated
Based on acting if $P(\text{event}) > 30\%$

Challenge with climate data in Africa

GPCC Monitoring Product Gauge-Based Analysis 1.0 degree number of stations per grid for May 2012



- **Sparse** in-situ rainfall observations in Africa
- Persistent **data gaps** in available in-situ records
- Satellite-rainfall products (SRPs) as **alternative** sources of data
- Concerns on systematic **biases/errors** in satellite rainfall products
- Need to **evaluate the performance** of various SR products



Source: Climate Hazards Centre, UCSB

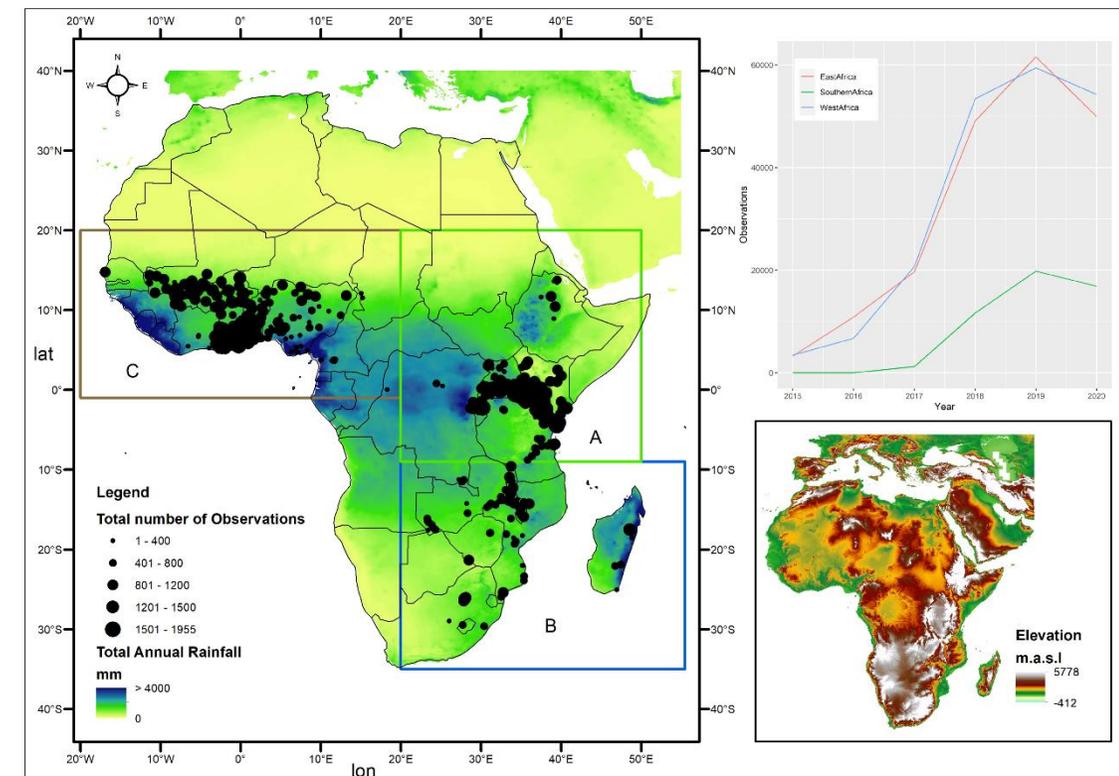
What are we doing?

Objective: Evaluate the performance of CHIRPS, TAMSAT, GSMaP-MVK and GSMaP_Gauge

RQ: How do these SRPs compare with TAHMO at different timescales in Africa, East Africa, Southern Africa and West Africa?

- TAHMO- Network of over 600 stations across Africa, with plans to expand to 20,000 stations- 2015- present; every 5 min, Van de Giessen 2014;
- CHIRPS- quasi global gauge corrected gridded rainfall at daily, pentadal and monthly timescales, 5km spatial res.; 1981-present- University of California St. Barbara- Funk et al. 2015; <https://data.chc.ucsb.edu/products/CHIRPS-2.0/>
- TAMSAT- quasi global gauge corrected gridded rainfall at daily, pentadal and monthly timescales, 4km spatial res.; 1983-present- University of Reading-UK; Maidment 2014; http://gws-access.jasmin.ac.uk/public/tamsat/rfe/data_zipped/v3.1/
- GSMaP-MVK- Global satellite only gridded rainfall available at daily and can be accumulated to pentadal and monthly scales, 10km spatial res.; 2000- present; Kubota et al 2007
- GSMaP-Gauge: Gauge corrected GSMaP available for the same period as above; <https://sharaku.eorc.jaxa.jp/GSMaP/>

Macharia et al. AMS Journal of Hydrometeorology (accepted with revisions)



A: East Africa, B: Southern Africa, C: West Africa

Categorical metrics

	Africa (N=441,768)				East Africa (N=194,364)			
	POD	FAR	Eff	CSI	POD	FAR	Eff	CSI
CHIRPS	0.46	0.28	-0.12	0.39	0.42	0.21	-0.36	0.37
TAMSAT	0.54	0.29	-0.02	0.45	0.47	0.22	-0.17	0.42
GSMaP	0.67	0.3	-0.07	0.53	0.67	0.25	-0.1	0.55
GSMaP_wGauge	0.72	0.31	0.11	0.54	0.75	0.3	0.07	0.57

	Southern Africa (N=49,509)				West Africa (N=197,895)			
	POD	FAR	Eff	CSI	POD	FAR	Eff	CSI
CHIRPS	0.44	0.26	0.08	0.38	0.53	0.3	0.07	0.43
TAMSAT	0.45	0.22	0.1	0.4	0.65	0.35	0.09	0.48
GSMaP	0.62	0.29	0.18	0.48	0.7	0.35	-0.12	0.51
GSMaP_wGauge	0.63	0.29	0.18	0.5	0.71	0.34	-0.14	0.52

Daily time scale

Volumetric metrics

Daily timescale

	Africa (N=441,768)				East Africa (N=194,364)			
	CC	MAE	Bias	RMSE	CC	MAE	Bias	RMSE
CHIRPS	0.36	3.82	1.15	10.45	0.35	4.39	1.26	11.5
TAMSAT	0.32	3.81	1.1	10.01	0.29	4.21	1.14	10.68
GSMaP	0.44	3.29	1.1	10.25	0.4	3.49	0.99	10.36
GSMaP_wGauge	0.44	3.15	1	9.31	0.42	3.48	1.05	9.51

	Southern Africa (N=49,509)				West Africa (N=197,895)			
	CC	MAE	Bias	RMSE	CC	MAE	Bias	RMSE
CHIRPS	0.38	3.12	0.93	10.24	0.39	3.45	1.09	9.36
TAMSAT	0.36	3.08	0.84	10.17	0.37	3.61	1.13	9.27
GSMaP	0.51	2.6	0.89	9.71	0.46	3.27	1.23	10.27
GSMaP_wGauge	0.48	2.67	0.86	9.67	0.46	2.94	0.97	9.03

Pentad timescale

	Africa (N=87,622)				East Africa (N=38,447)			
	CC	MAE	Bias	RMSE	CC	MAE	Bias	RMSE
CHIRPS	0.52	13.05	1.17	24.95	0.53	12.02	1.28	26.53
TAMSAT	0.45	13.73	1.1	26.6	0.41	14.55	1.13	29.76
GSMaP	0.5	13.15	1.07	27.54	0.47	15.41	0.97	28.89
GSMaP_wGauge	0.53	12.01	0.99	24.77	0.52	13.19	1.05	25.78

	Southern Africa (N=9,836)				West Africa (N=39,339)			
	CC	MAE	Bias	RMSE	CC	MAE	Bias	RMSE
CHIRPS	0.58	10.5	0.95	25.01	0.51	12.22	1.1	23.3
TAMSAT	0.52	11.09	0.84	26.2	0.5	12.76	1.13	23.23
GSMaP	0.61	9.55	0.88	25.12	0.5	13.23	1.23	26.75
GSMaP_wGauge	0.6	9.66	0.85	24.86	0.51	11.47	0.96	23.71

Evaluation metrics: **A, B, C, S & G** represent hits, false alarms, misses, satellite estimate and gauge measurement, respectively

Evaluation metric	Formula	Unit	Best Value
Probability of Detection	$POD = \frac{A}{A+C}$	None	1
False Alarm Ratio	$FAR = \frac{B}{A+B}$	None	0
Correlation Coefficient	$CC = \frac{\sum(G - \bar{G})(S - \bar{S})}{\sqrt{\sum(G - \bar{G})^2 \sum(S - \bar{S})^2}}$	None	1
Mean Absolute Error	$MAE = \left(\frac{1}{N}\right) \sum S - G $	mm	0
Root Mean Square Error	$RMSE = \sqrt{\left(\frac{1}{N}\right) \sum (S - G)^2}$	mm	0
Efficiency	$Eff = 1 - \frac{\sum(S - G)^2}{\sum(G - \bar{G})^2}$	None	1
Multiplicative Bias	$Bias = \frac{\sum S}{\sum G}$	None	1
Critical Success Index	$CSI = \frac{A}{A+B+C}$	None	1

	Africa (N=14,756)				East Africa (N=6,436)			
	CC	MAE	Bias	RMSE	CC	MAE	Bias	RMSE
CHIRPS	0.66	50.92	1.18	85.85	0.64	58.45	1.29	94.36
TAMSAT	0.6	53.79	1.12	89.8	0.53	63.23	1.16	102.84
GSMaP	0.59	57.89	1.08	96.32	0.53	64.02	0.97	103.89
GSMaP_wGauge	0.65	49.16	1	82.06	0.61	54.5	1.06	86.14

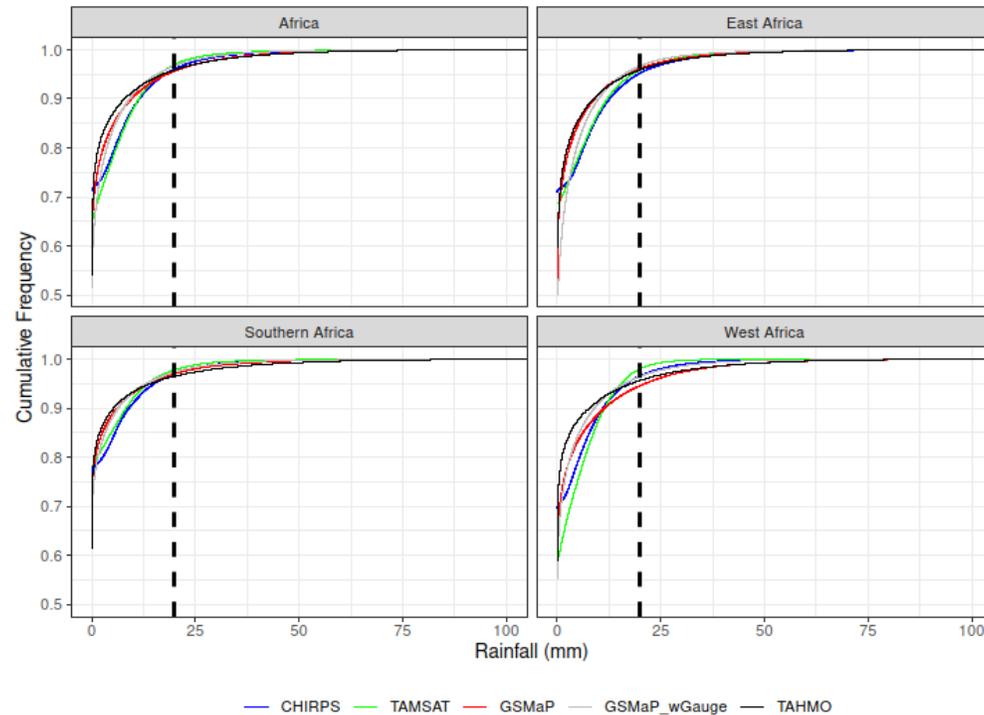
	Southern Africa (N=1,678)				West Africa (N=6,642)			
	CC	MAE	Bias	RMSE	CC	MAE	Bias	RMSE
CHIRPS	0.73	43.57	1	80.73	0.67	45.47	1.1	78.1
TAMSAT	0.7	45.11	0.87	82.43	0.67	46.84	1.14	77.13
GSMaP	0.72	42.13	0.9	81.25	0.63	55.93	1.23	92.11
GSMaP_wGauge	0.71	42.4	0.89	82.02	0.66	45.7	0.98	77.92

- Better rainfall events detection (POD, CSI) and skill (Bias, Eff) by GSMaP products
- Increasing RMSE and MAE with timescale aggregations

Monthly timescale

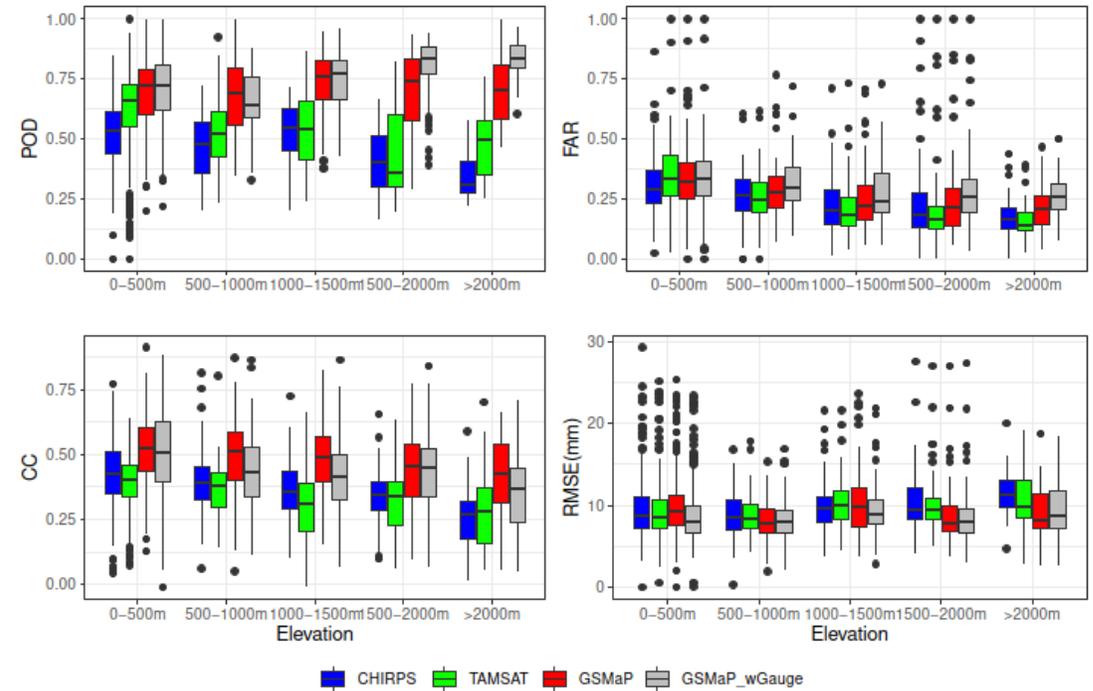
Results

Ability of SRPs to capture daily rainfall events



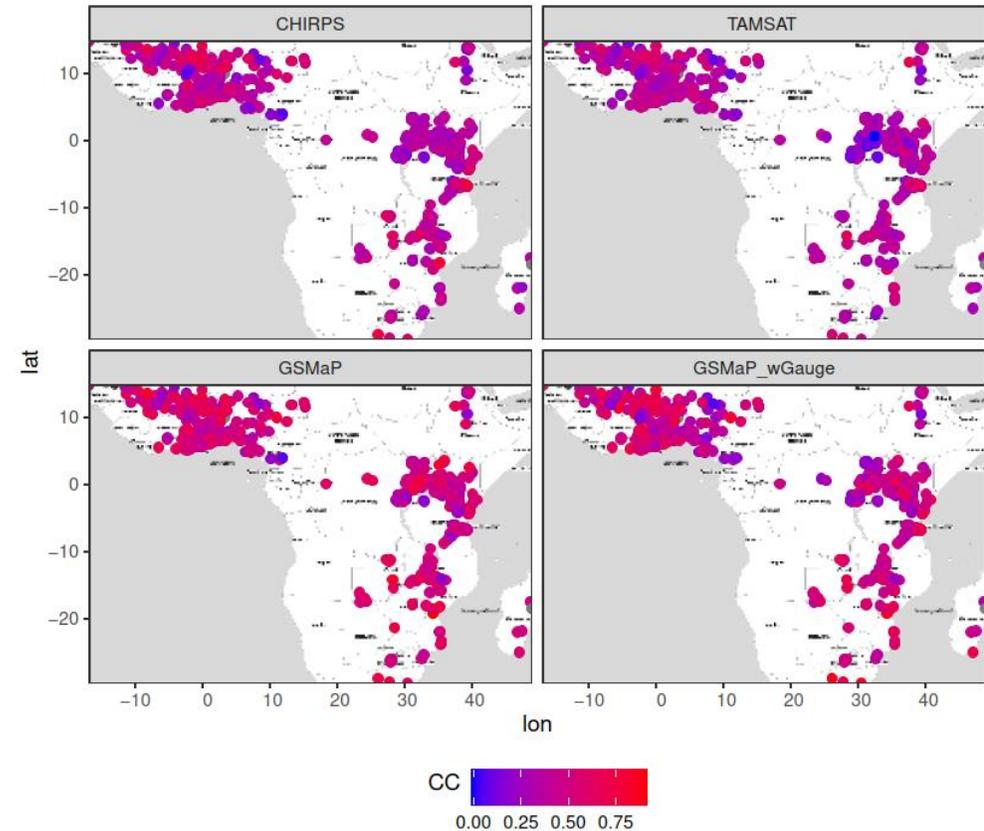
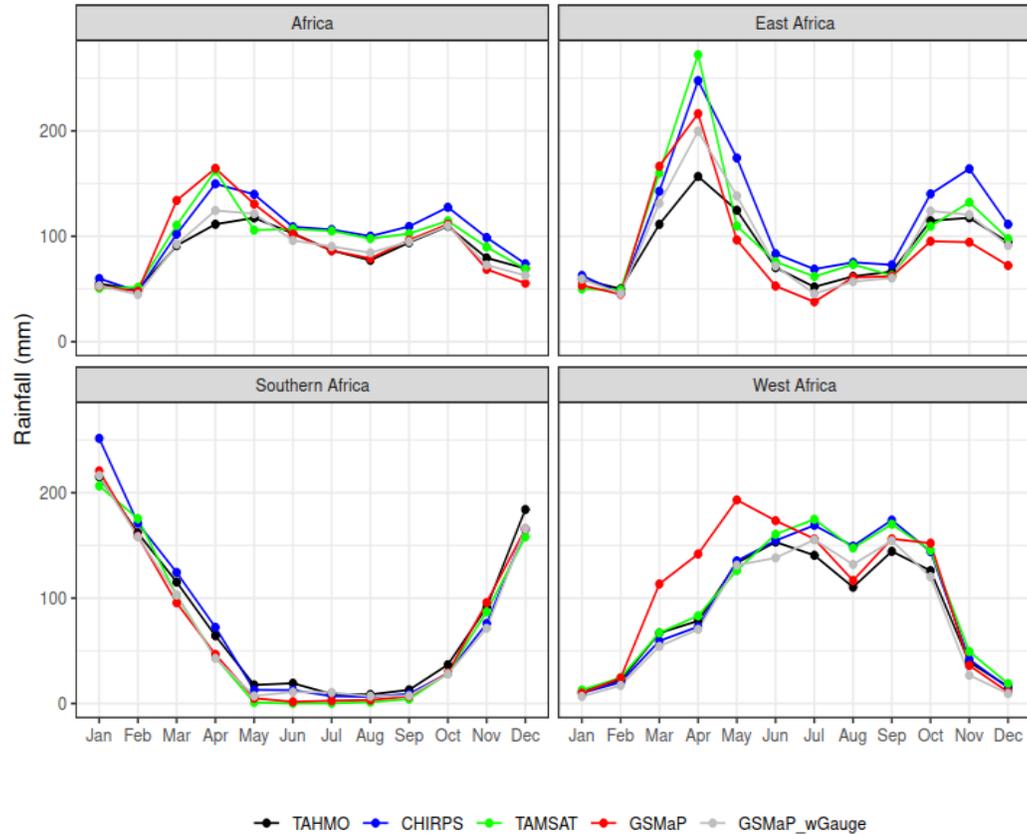
- Generally, all the SRPs overestimate (i.e. their CDF curves are below the TAHMO CDF) low intensity rainfall events (<20 mm/day) while all except GSMaP underestimate high intensity rainfall events (>20 mm/day)
- CHIRPS and TAMSAT CDFs show similar patterns; both have a higher overestimation of low rainfall events
- CDFs of the two GSMaP products is closer to that of the TAHMO in-situ gauge data for the low intensity rainfall events

Impact of elevation on rainfall errors



- Larger errors (RMSE) at higher elevations for all SRPs
- GSMaP products in general perform better for all metrics; GSMaP_Gauge shows better rainfall detection at higher elevation
- *GSMaP_Gauge shows a higher POD but also a higher FAR for all elevation categories

Results



- All the SRPs reproduce the annual rainfall cycle over each of the regions
- CHIRPS and TAMSAT overestimate (74% and 61%, respectively) the peak rain month in the long rains season in East Africa
- CHIRPS showed a wet bias (33%) for short rains peak month in East Africa while GSMaP_Gauge showed a dry bias (-21%)
- Small monthly biases in Southern Africa for all products compared with TAHMO station data

- In West Africa, all the SRPs overestimate rainfall; CHIRPS and TAMSAT show larger over-estimations in the monsoon season (June – September) of around 36% over that period.
- GSMaP shows wet biases of between 10-80% in the months of March - June in West Africa.
- Density of TAHMO stations with high correlations in West Africa and Southern Africa

Conclusions

- Correlation between CHIRPS, TAMSAT, GSMaP, GSMaP_Gauge and in-situ data improves with temporal aggregation. This improvement would be beneficial to general applications that require longer timescale (i.e. monthly to annual scale) if the objective of such analyses is to detect long-term trends over large geographical areas.
- Larger errors in CHIRPS and TAMSAT at daily timescale compared to the GSMaP rainfall products may be a limiting factor in water-balance modeling that requires higher rainfall detection capability at shorter timescales.
- Gauge-corrected products produced better correlations with reference gauge data but statistical errors increased with data aggregation over coarser timescales.
-
- The introduction of low-cost monitoring networks by TAHMO and the expansion of this network across Africa could provide a complementary and valuable new data resource for climate research in Africa.
- This research recommends the use of TAHMO data in validation of other satellite rainfall products over Africa and the integration of the TAHMO gauge data in gauge-satellite data integration algorithms.



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