Validation and intercomparison of satellite-based rainfall products over Africa using TAHMO in-situ rainfall observations

Denis Macharia[1], Katie Fankhauser[2], John Selker[3], Jason Neff[4], and Evan Thomas[4]

[1]Regional Centre for Mapping of Resources for Development
[2]University of Colorado Boulder
[3]Oregon State University
[4]University of Colorado at Boulder

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Abstract

Sparse rain gauge networks and declining observations in Africa limit climate research in the region. However, the proliferation of satellite-rainfall products (SRPs) and the growth of citizen-science-driven in-situ observations driven by cheaper data collection technologies have provided a pathway to overcoming the data scarcity problem. In this paper, we used rain gauge data from 596 stations operated by the Trans-African Hydro-Meteorological Observatory (TAHMO) across Africa to evaluate the performance of two widely-utilized satellite-based rainfall products: the Climate Hazards InfraRed Precipitation with Stations (CHIRPS) and the Tropical Applications of Meteorology using Satellite data (TAMSAT), and two under-validated and underutilized products: the satellite-only Global Satellite Mapping of Precipitation (GSMaP) and the gauge-corrected GSMaP version (GSMaP_Gauge). We also inter-compared the performance of the four products over Africa, East Africa, Southern Africa and West Africa at daily, pentadal, and monthly timescales. Our findings indicated that the GSMaP products had better performances at daily timescales whereas CHIRPS and TAMSAT matched or outperformed the GSMaP products at pentadal and monthly timescales. GSMaP_Gauge daily rainfall detection was almost 1.5 times the CHIRPS detection scores at the same temporal scale. The Pearson correlation coefficient increased with temporal aggregation but the volumetric errors increased for all products. Additionally, all the products overestimated (underestimated) low (high) intensity rainfall events. Our analysis adds to a growing number of validation studies in Africa and presents an opportunity for developers of satellite-rainfall products to integrate the new TAHMO observations in bias-correction algorithms to improve the accuracy of SRPs in the region.

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

Denis Muthike*, Katie Fankhauser, John Selker, Jason Neff, Evan Thomas
University of Colorado Boulder

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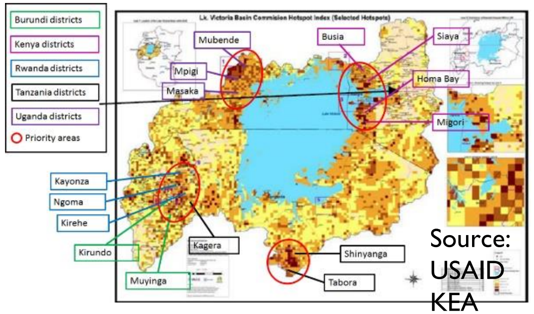
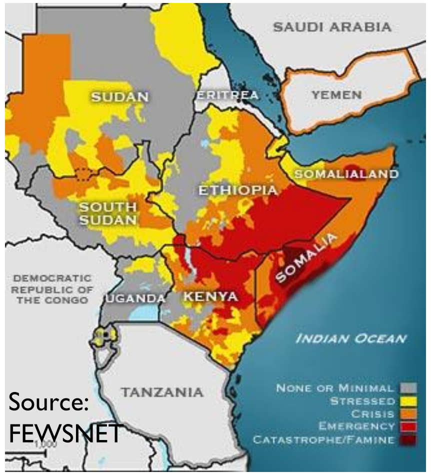
Why do we need accurate climate data?

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



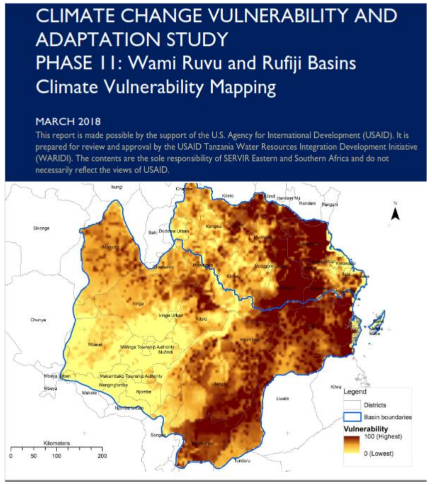
Source: USAID KEA

Kenya, 2011



Source: FEWSNET

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


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

MARCH 2018

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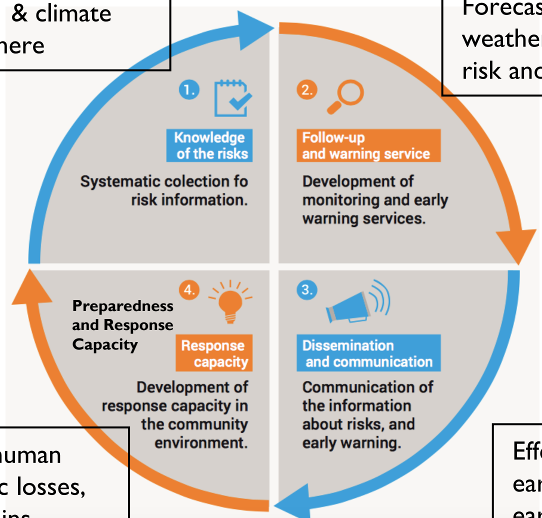
Macharia et al. 2020: https://doi.org/10.3390/su12104102

- **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

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

Forecasts to anticipate weather & climate related risk and impacts



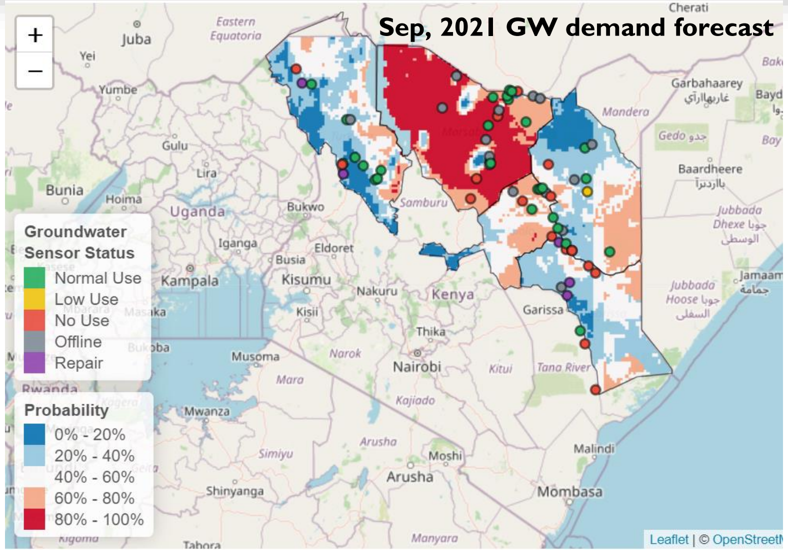
Early action to reduce human loss/ suffering, economic losses, protect development gains

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

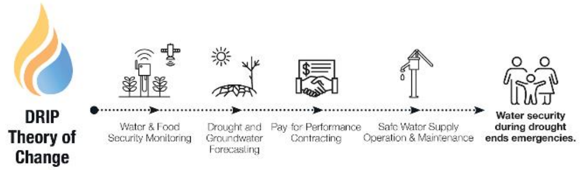
Source: Kenya Red Cross Society

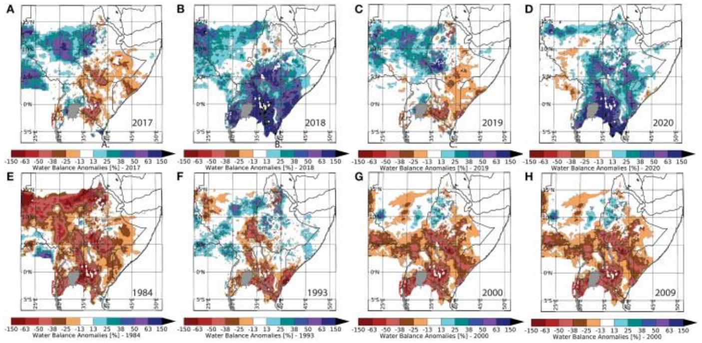
Why do we need accurate climate data?

- 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**.



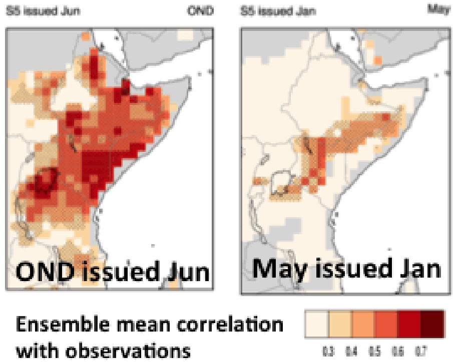
Katie et al. (upcoming paper)



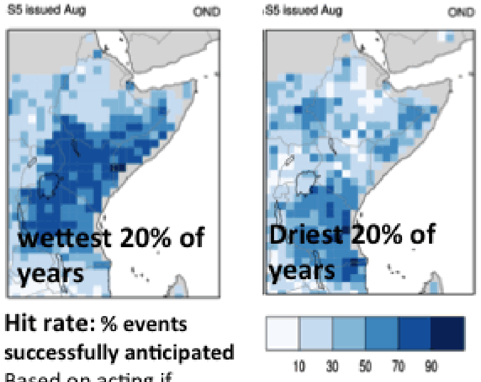


Funk et al. 2021: https://doi.org/10.3389/fclim.2021.716568

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

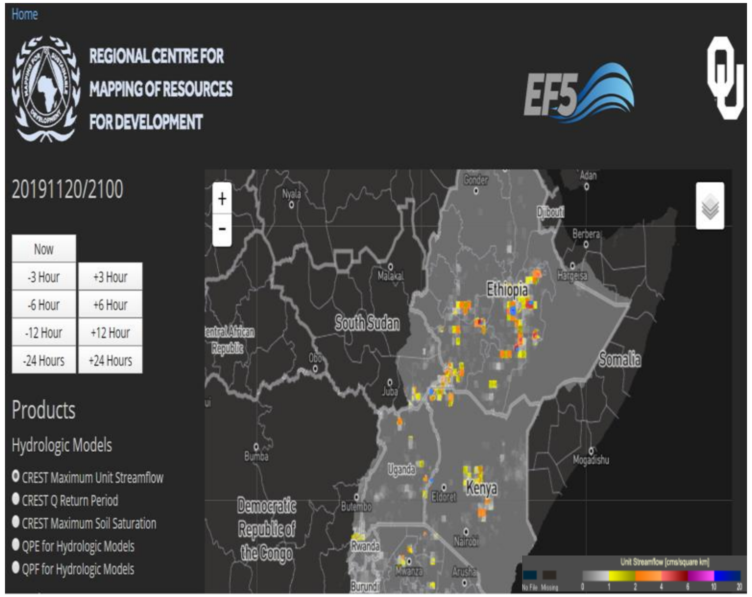


Skill is higher for extreme event (esp wet)

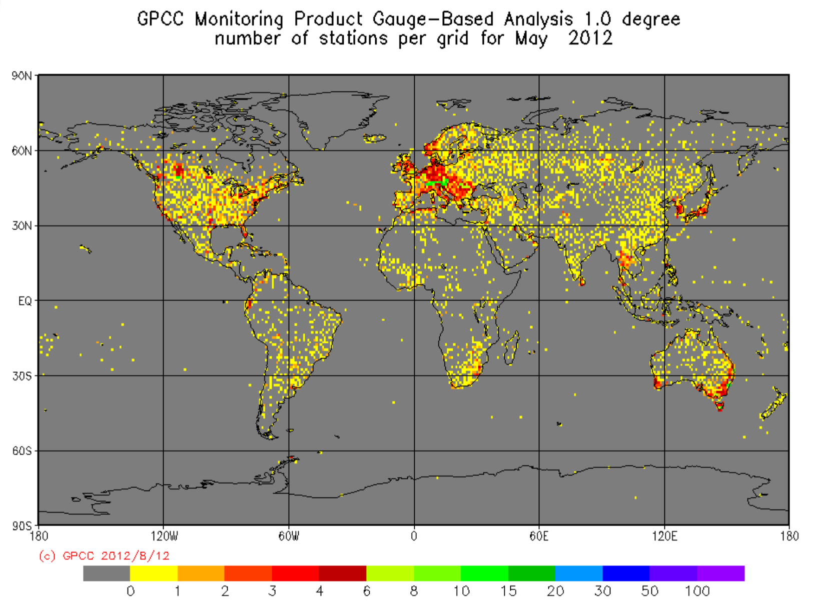


Hit rate: % events successfully anticipated

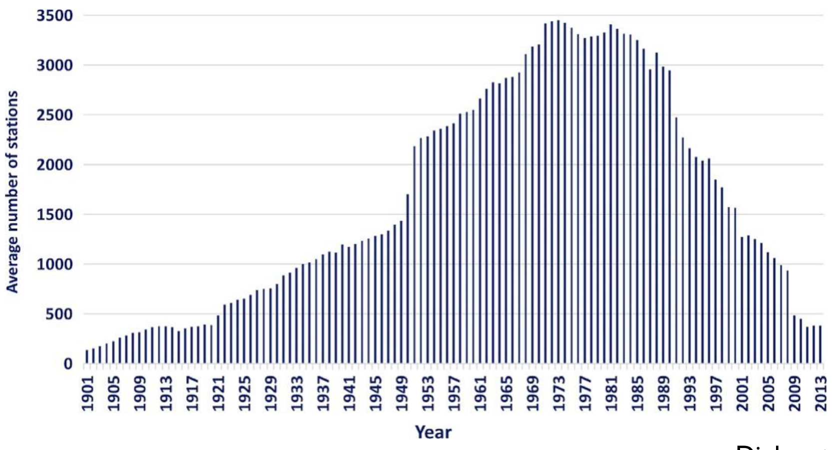
Based on acting if P(event)> 30%

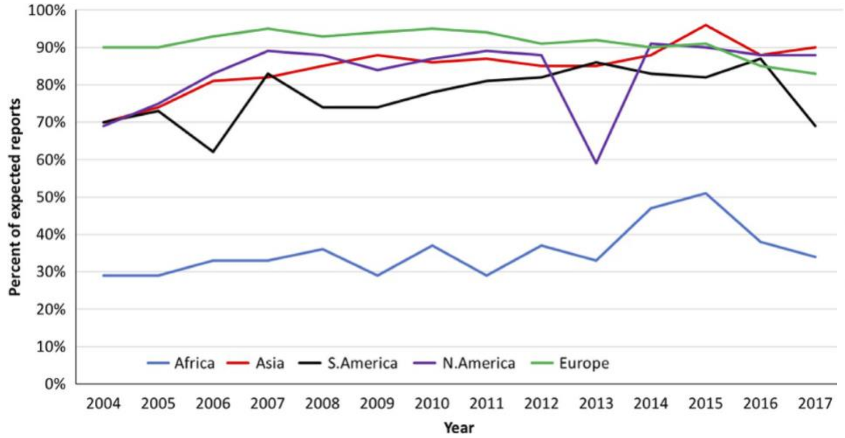


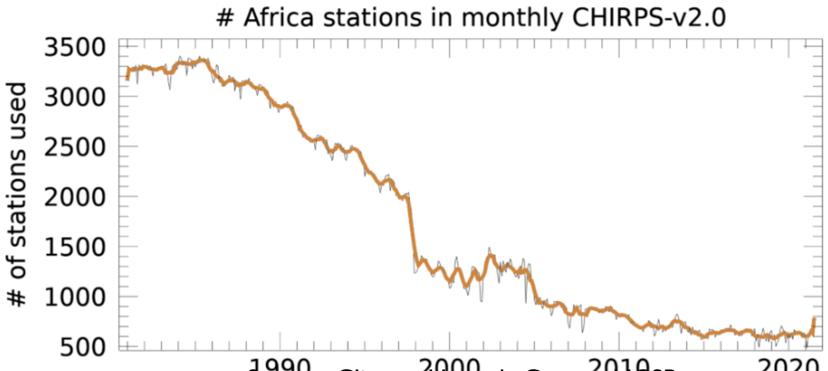
Challenge with climate data in Africa



- **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

Dinku et al. 2019: https://doi.org/10.1016/B978-0-12-815998-9.00007-5

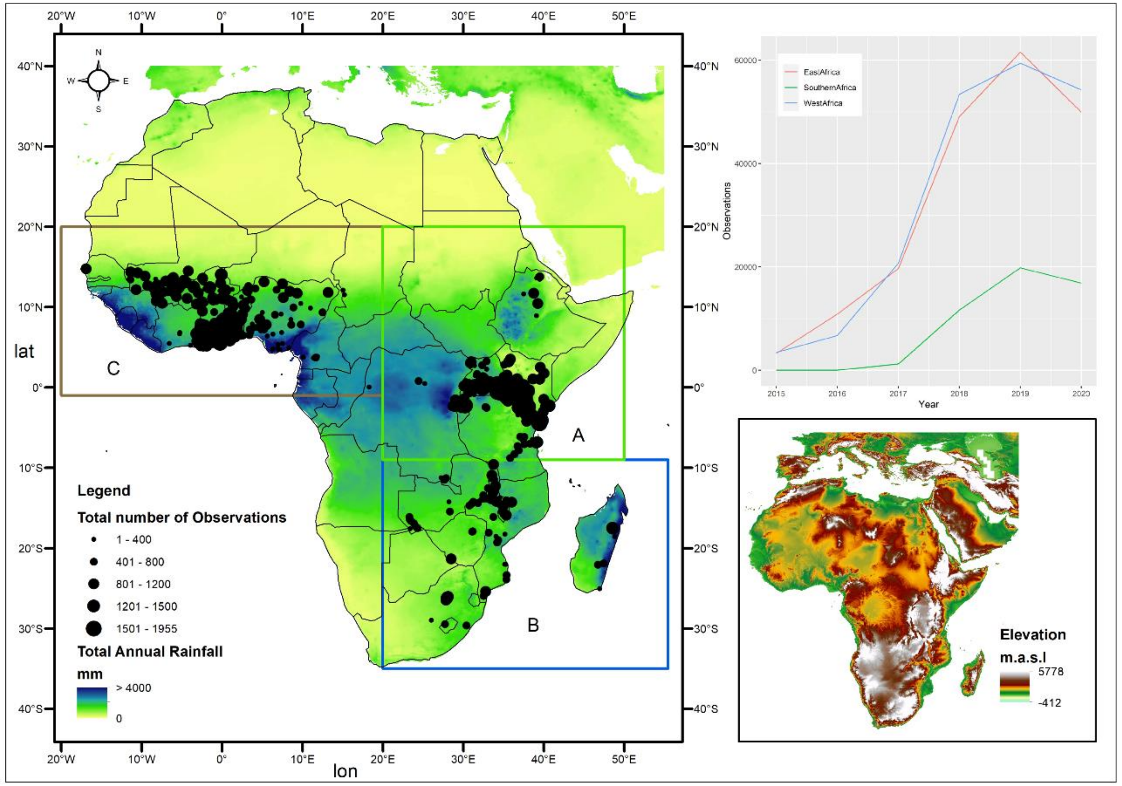
What are we doing?

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?

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

- 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/



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

Results

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
0.44	0.26	0.08	0.38	0.53	**0.3**	0.07	0.43
0.45	**0.22**	0.1	0.4	0.65	0.35	**0.09**	0.48
0.62	0.29	**0.18**	0.48	0.7	0.35	-0.12	0.51
0.63	0.29	**0.18**	**0.5**	**0.71**	0.34	-0.14	**0.52**

Daily time scale

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	$CC = \frac{\sum(G-\bar{G})(S-\bar{S})}{\sqrt{\sum(G-\bar{G})^2(S-\bar{S})^2}}$	None	1
Mean Absolute Error	$MAE = (\frac{1}{N})\sum\lvert S-G\rvert$	mm	0
Root Mean Square Error	$RMSE = \sqrt{(\frac{1}{N})\sum(S-G)^2}$	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

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

	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**

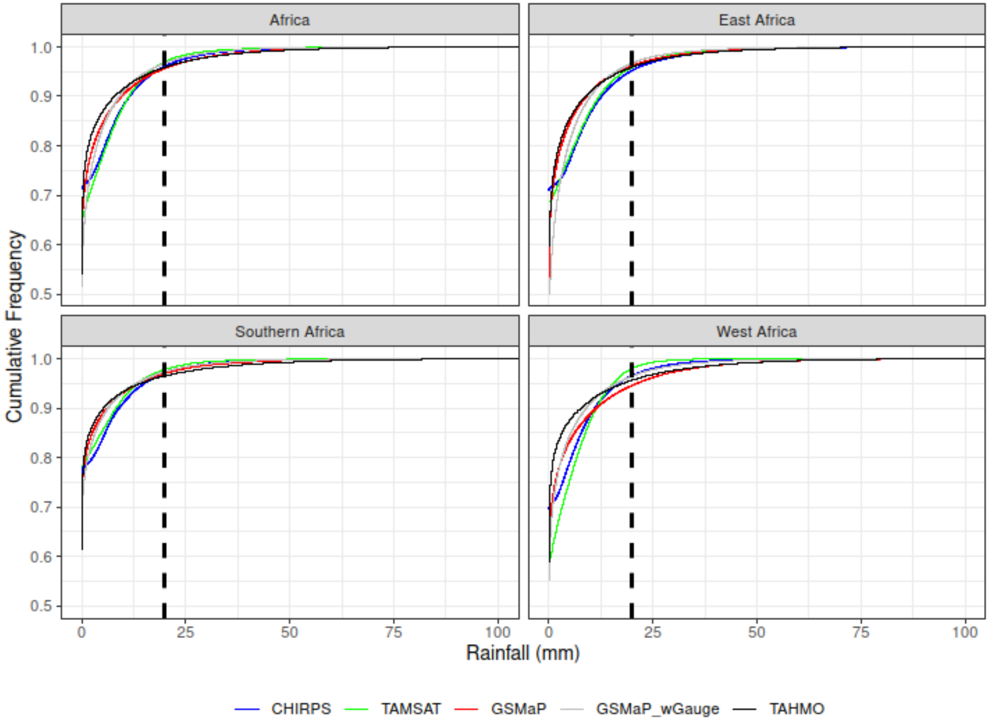
	Southern Africa (N=1,678)				West Africa (N=6,642)			
	CC	MAE	Bias	RMSE	CC	MAE	Bias	RMSE
CHIRPS	**0.73**	43.57	**1**	**80.73**	**0.67**	45.47	1.1	78.1
TAMSAT	0.7	45.11	0.87	82.43	**0.67**	46.84	1.14	**77.13**
GSMaP	0.72	**42.13**	0.9	81.25	0.63	55.93	1.23	92.11
GSMaP_wGauge	0.71	42.4	0.89	82.02	0.66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

Monthly timescale

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

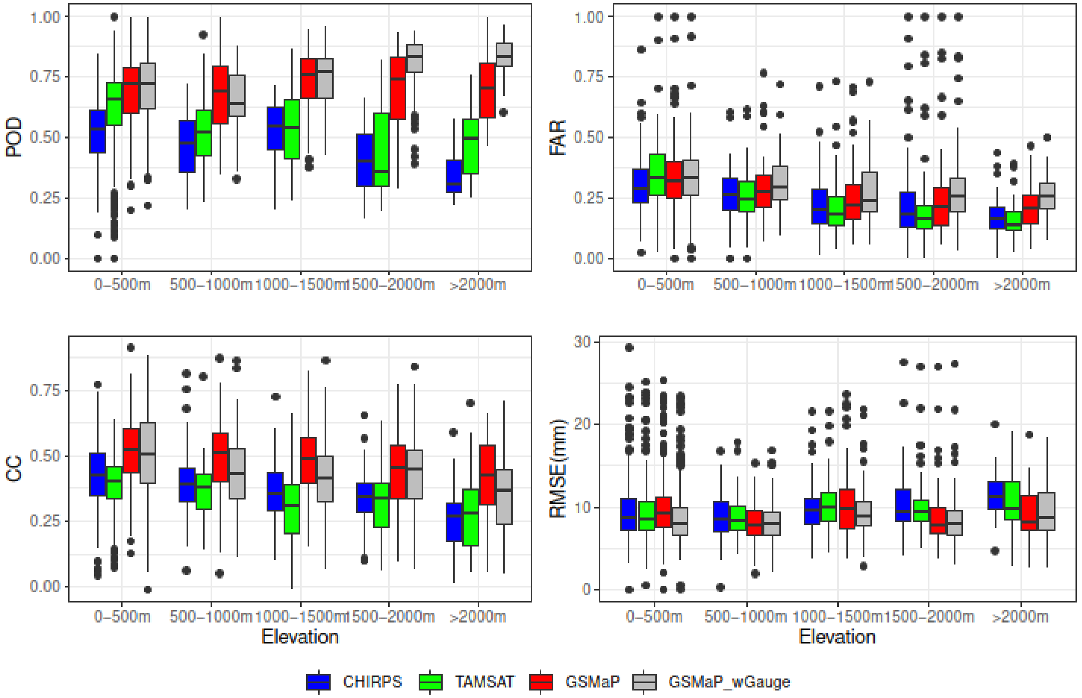
Results

Ability of SRPs to capture daily rainfall events



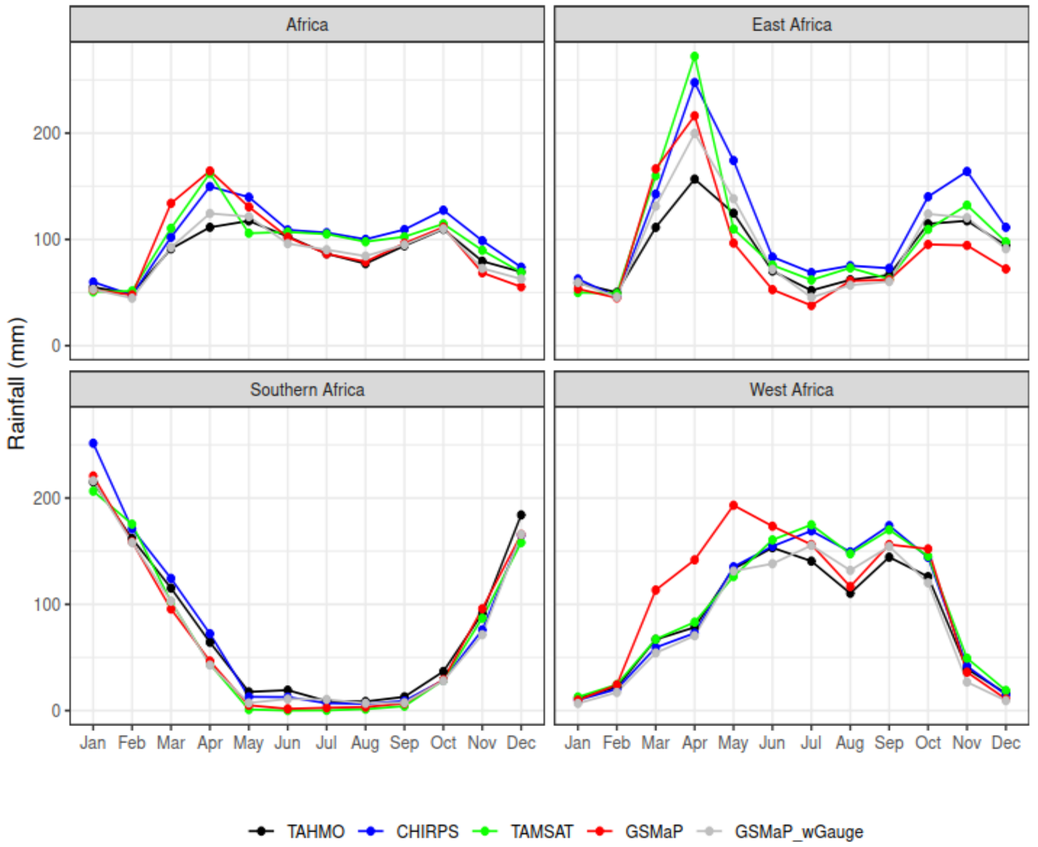
- Generally, all the SRPs overestimate (i.e. their CDF curves are below the TAHMO CDF) low intensity rainfall events (<20 mm/day) while all except GSMaP underestimate high intensity rainfall events (>20 mm/day)
- CHIRPS and TAMSAT CDFs show similar patterns; both have a higher overestimation of low rainfall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

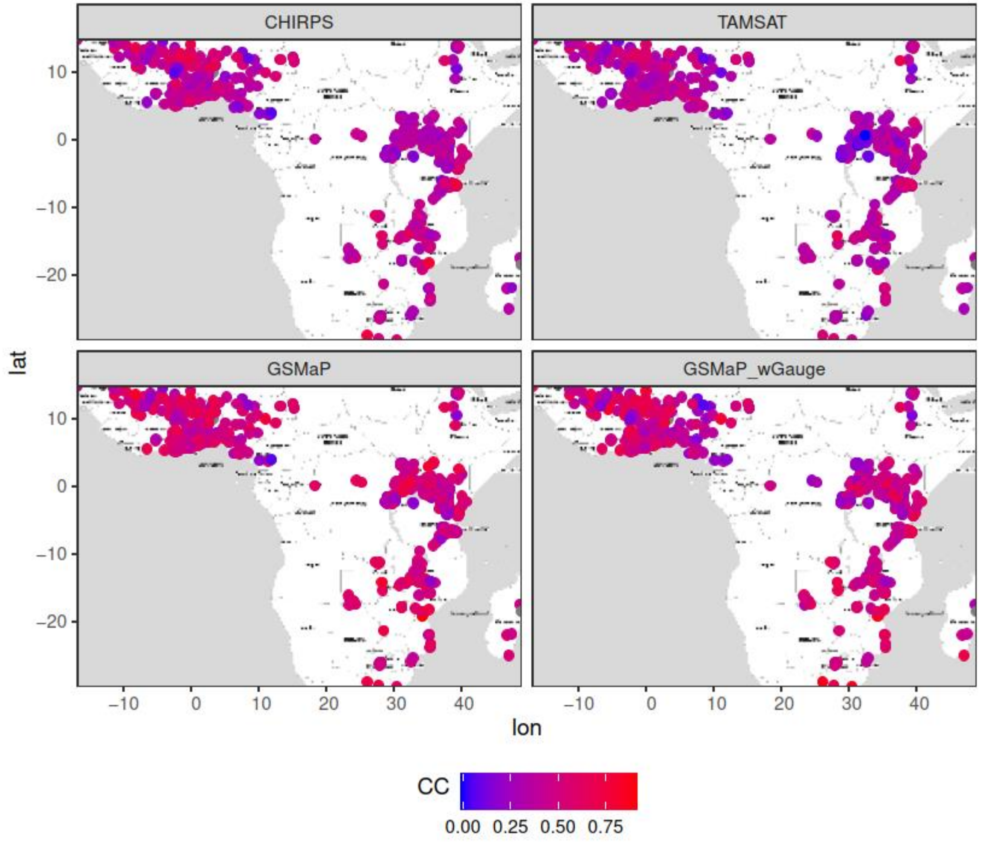
Impact of elevation on rainfall errors



- 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

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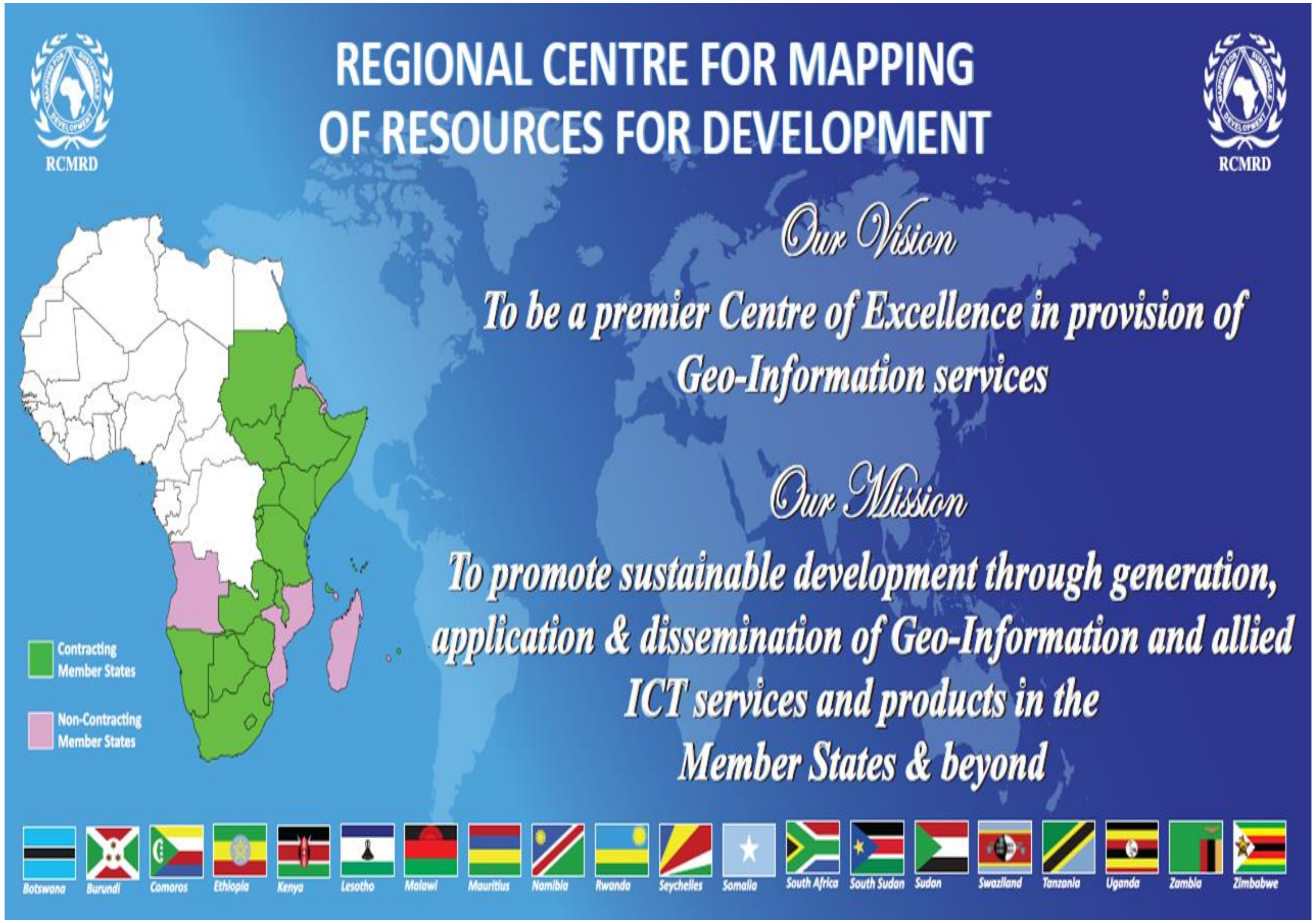
- Correlation between CHIRPS, TAMSAT, GSMaP, GSMaP_Gauge and in-situ data improves with temporal aggregation. This improvement would be beneficial to general applications that require longer timescale (i.e. monthly to annual scale) if the objective of such analyses is to detect long-term trends over 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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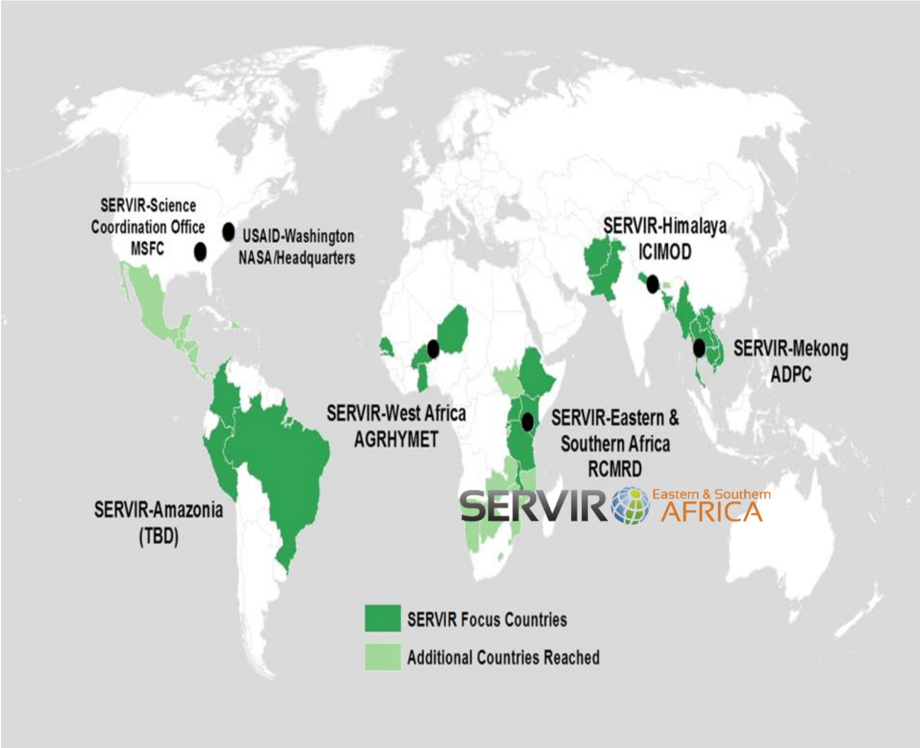
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