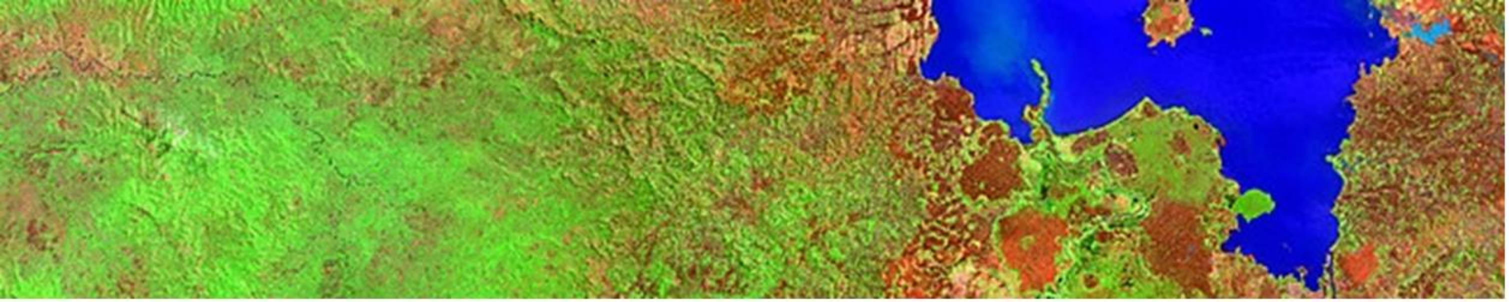

University of Twente
The Netherlands

# Satellite based rainfall estimation for hydrological modelling

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Twente University

# Outline

- Objectives
- Intro to RS based estimation principles
- Satellite Rainfall Estimation (SRE)
- Findings on performance
- Findings on modelling

# Objectives

**To improve our understanding of the hydrological cycle by integrating Remote Sensing and Hydrological models**

Or in other words:

- To better understand role of rainfall images (SRE products) for water resources and hydrology in time and space dimensions
- To assess accuracy and their effects on simulated water cycle processes and water resources
- To improve our modeling capacity by considering Remote Sensing
- Also to better understand reliability of RS data..
- **For ETa we said "to test effectiveness of use of Satellite data (ETa) in a mass conservative, catchment scale hydrological model" now we do Precipitation (i.e. rainfall).**

# RS Rainfall estimation…. how does to work?

✓ **Satellite image-based estimation**

➢ **Geostationary satellites (VIS/IR- approach) :**

- Rainfall relates to cloud properties observed from space
- Cloud top reflectance and temperature are converted into a rain rate
- Radiation doesn't penetrate cloud top

➢ **Orbiting Satellites (MW-approach) :**

- Rainfall relates to microwave emission from rain drops and scattering from ice
- More "physical" than VIS/IR channels.

# Cloud detection and rain…. (IR)

**Principles:**

1) **High clouds indicate rain**

2) **Cold cloud tops indicate rain (cloud top temperatures ═► thermal RS 10.0-12.5 μm ═► TIR channels)**

3) Water particles cause attenuation of radiation ═► MW RS ═► 19.3 – 85.5 Ghz ═► MW channels)


So how much does it rain ?

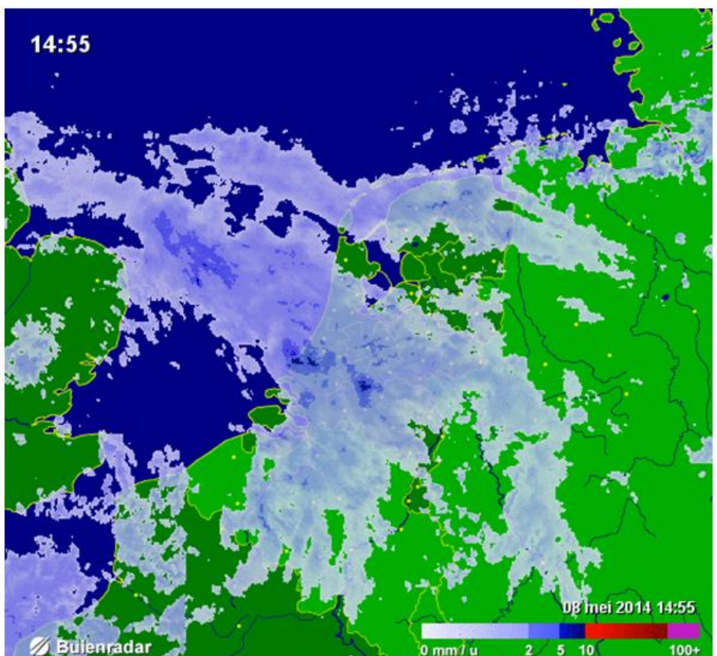
# Cloud detection and rain…..(MW)

**Principles:**

1) **High clouds indicate rain**

2) Cold cloud tops indicate rain
(cloud top temperature =► thermal RS 10.0-12.5 μm)

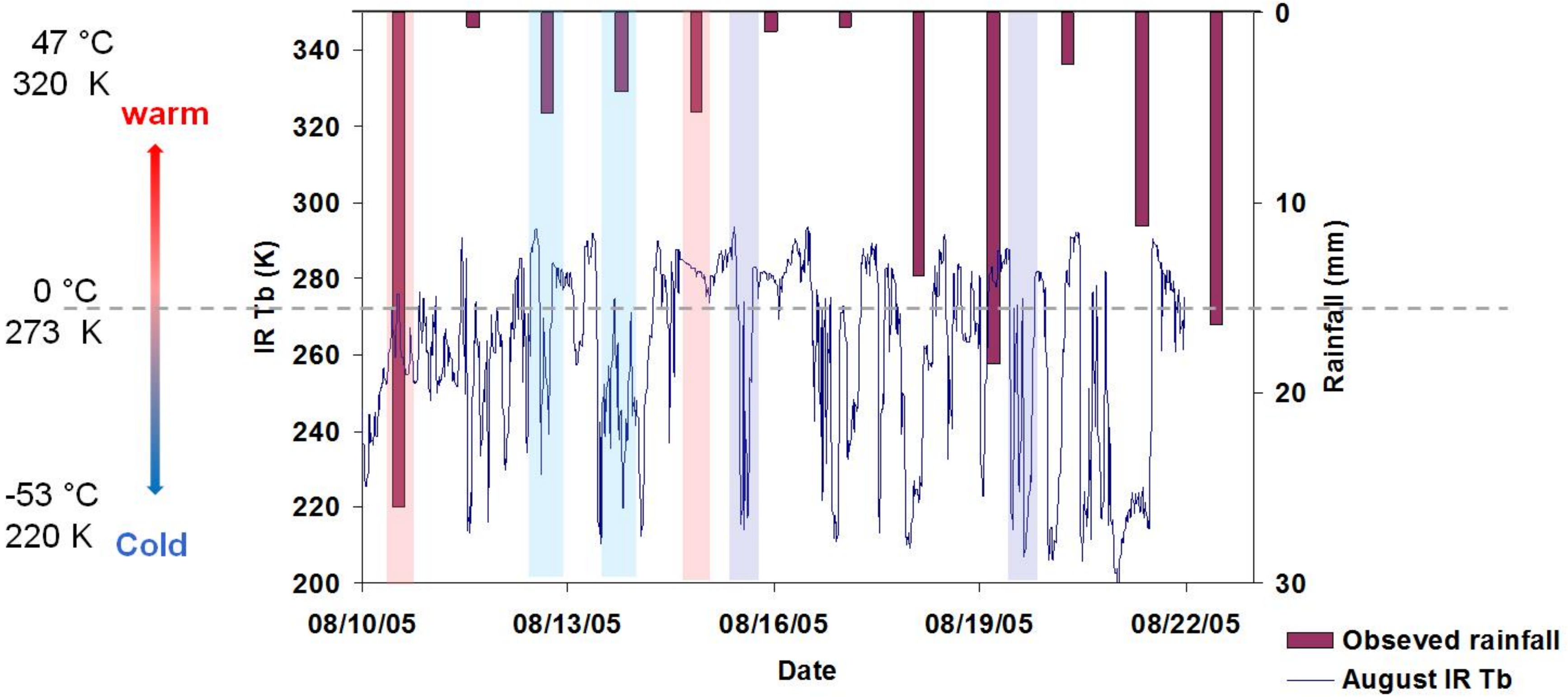
3) **Water particles cause attenuation of radiation =► MW RS 19.3 – 85.5 Ghz)**




So how much does it rain ?

# Rain detection: IR Cloud Top temperature

**Relation between image based variables and rain rate is poor !**




Cold clouds produce rain !

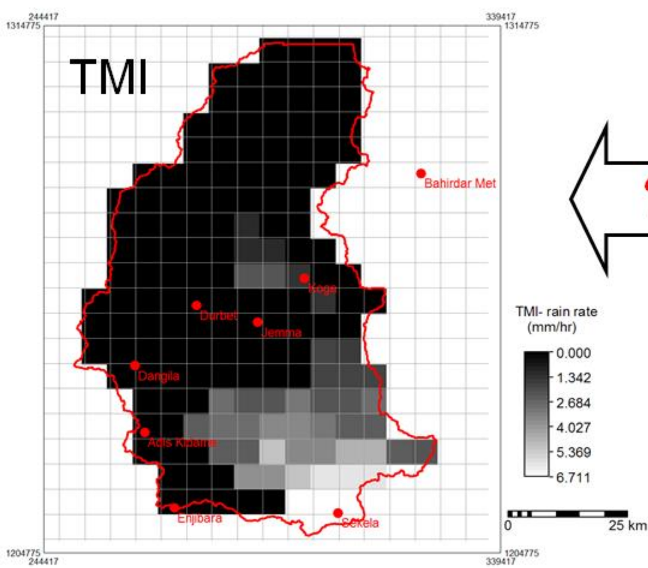
Not all cold clouds produce rain.

Also rain falls from warm clouds

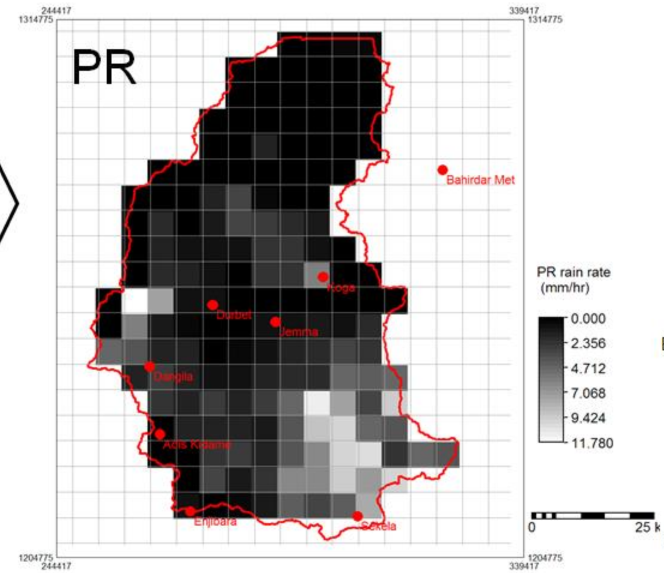
0°C ≈ 273 K
-273°C ≈ 0 K

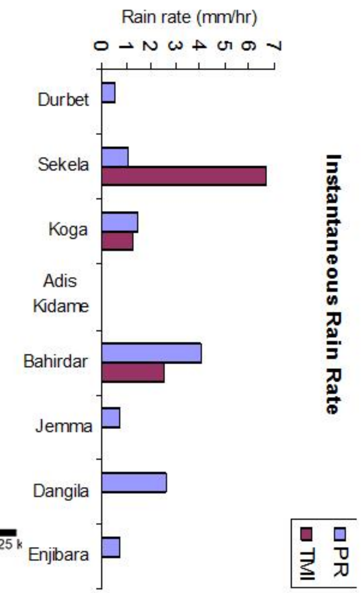
# RS estimates (TRMM)

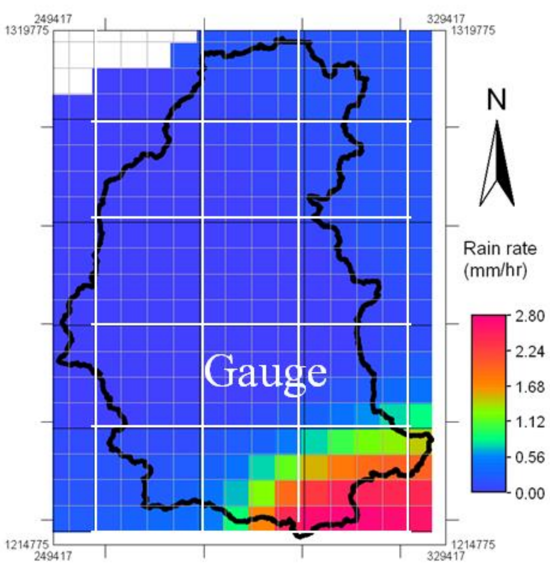
August 10, 2007



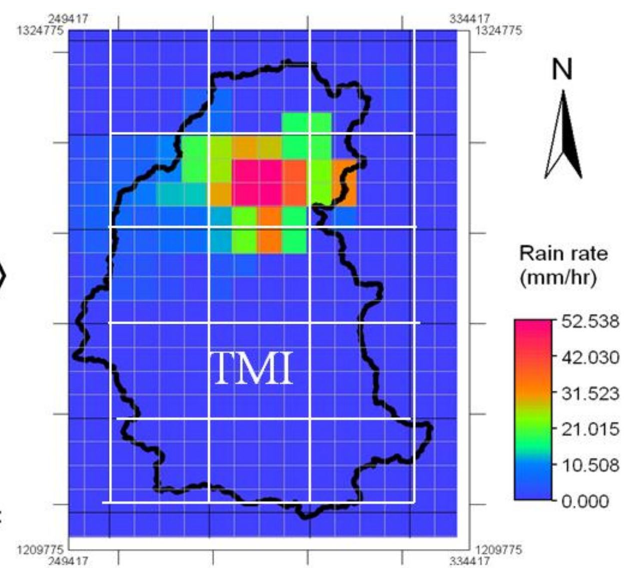




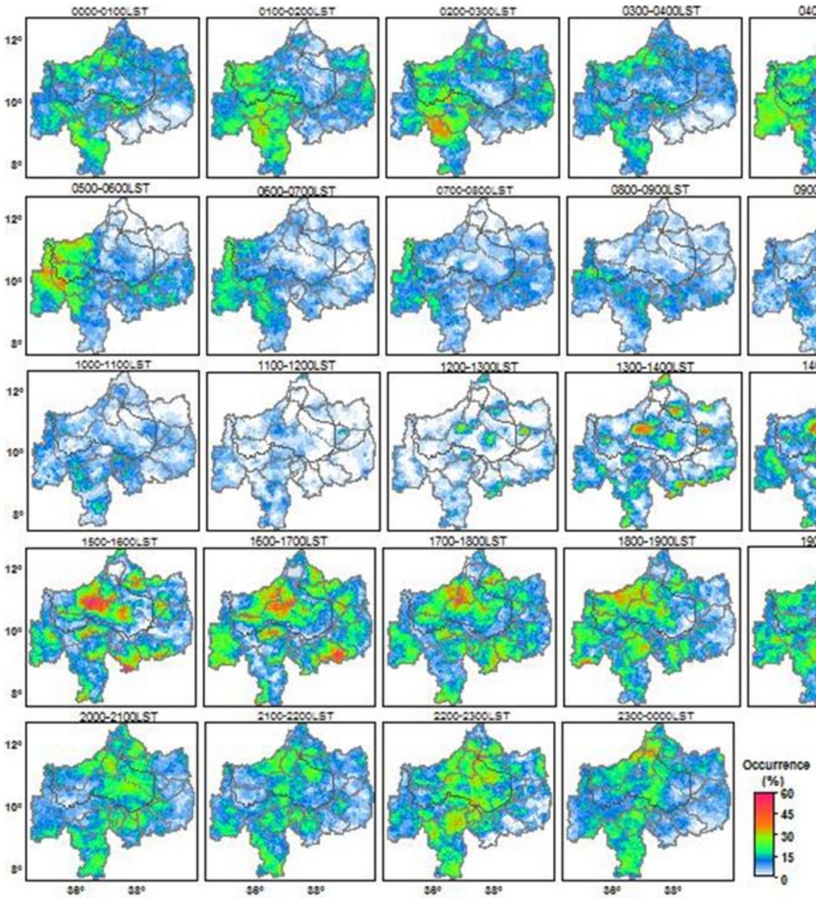


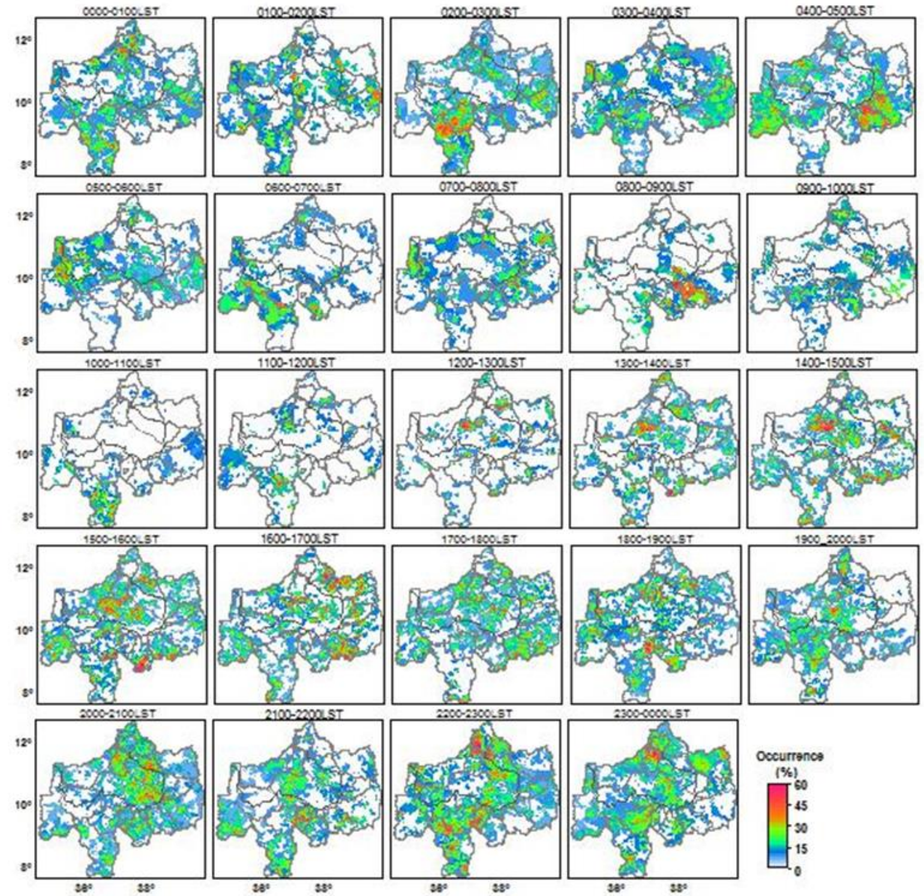


# Satellite based rainfall estimation : Rainfall occurrence

## Blue Nile basin Ethiopia : Diurnal cycle

**0-1 hr**




**23-24 hr**

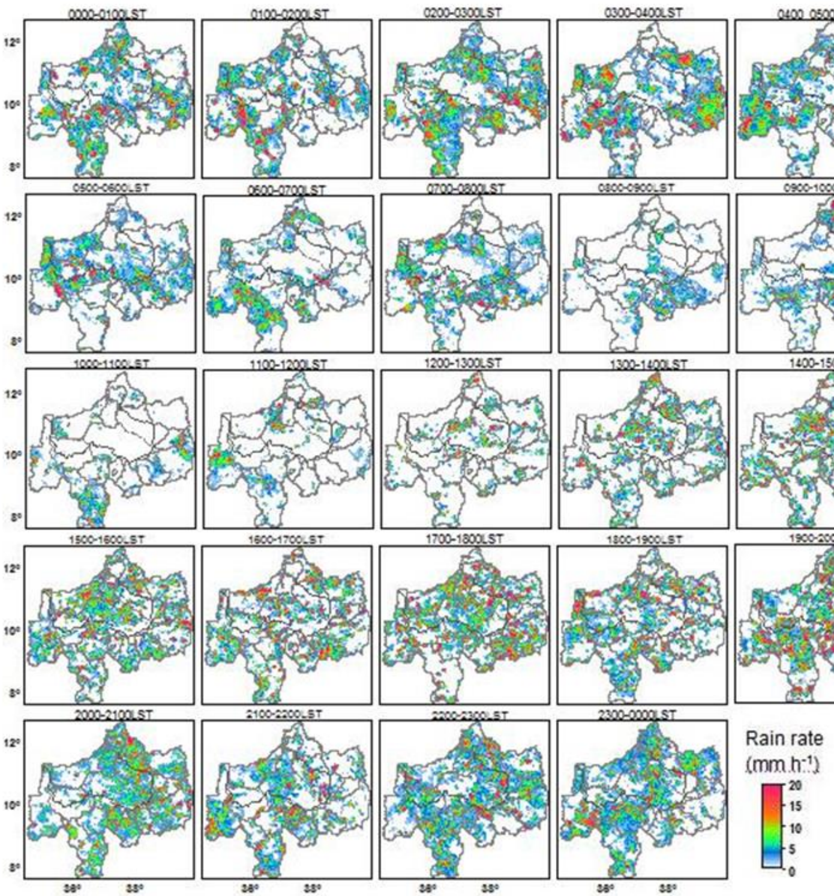
**TRMM PR**

**TRMM TMI**

# Satellite based rainfall estimation : Rainfall rates

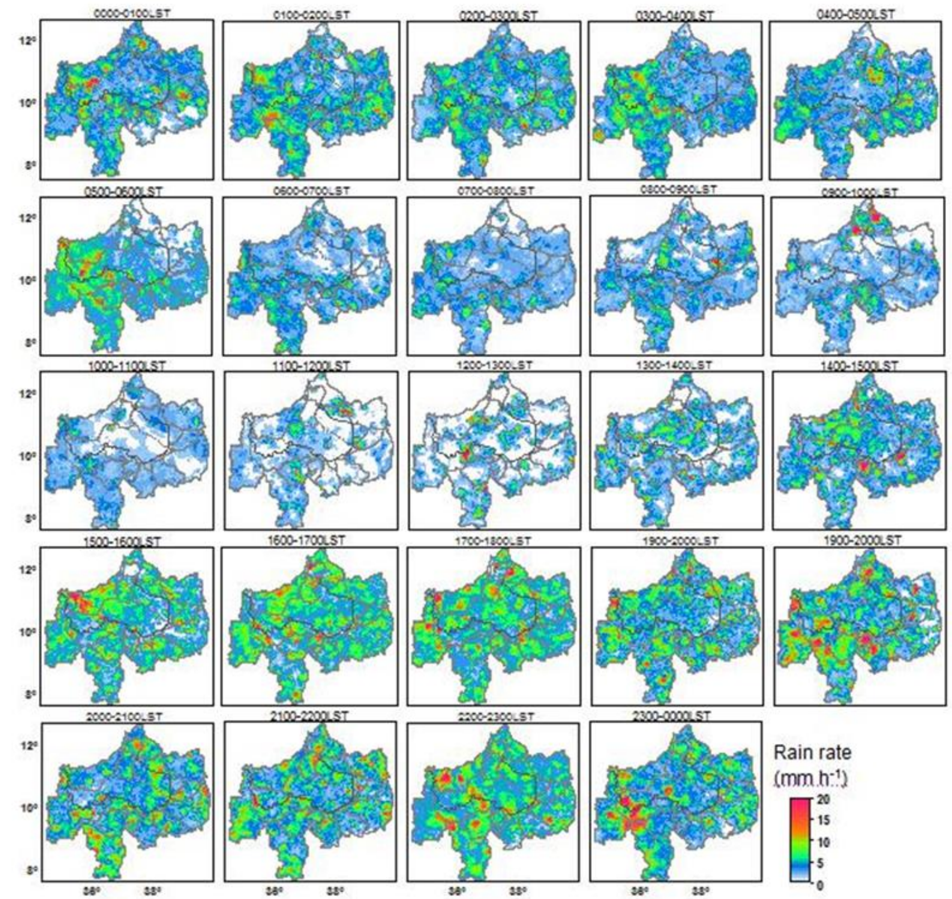
## Blue Nile basin Ethiopia

**0-1 hr**



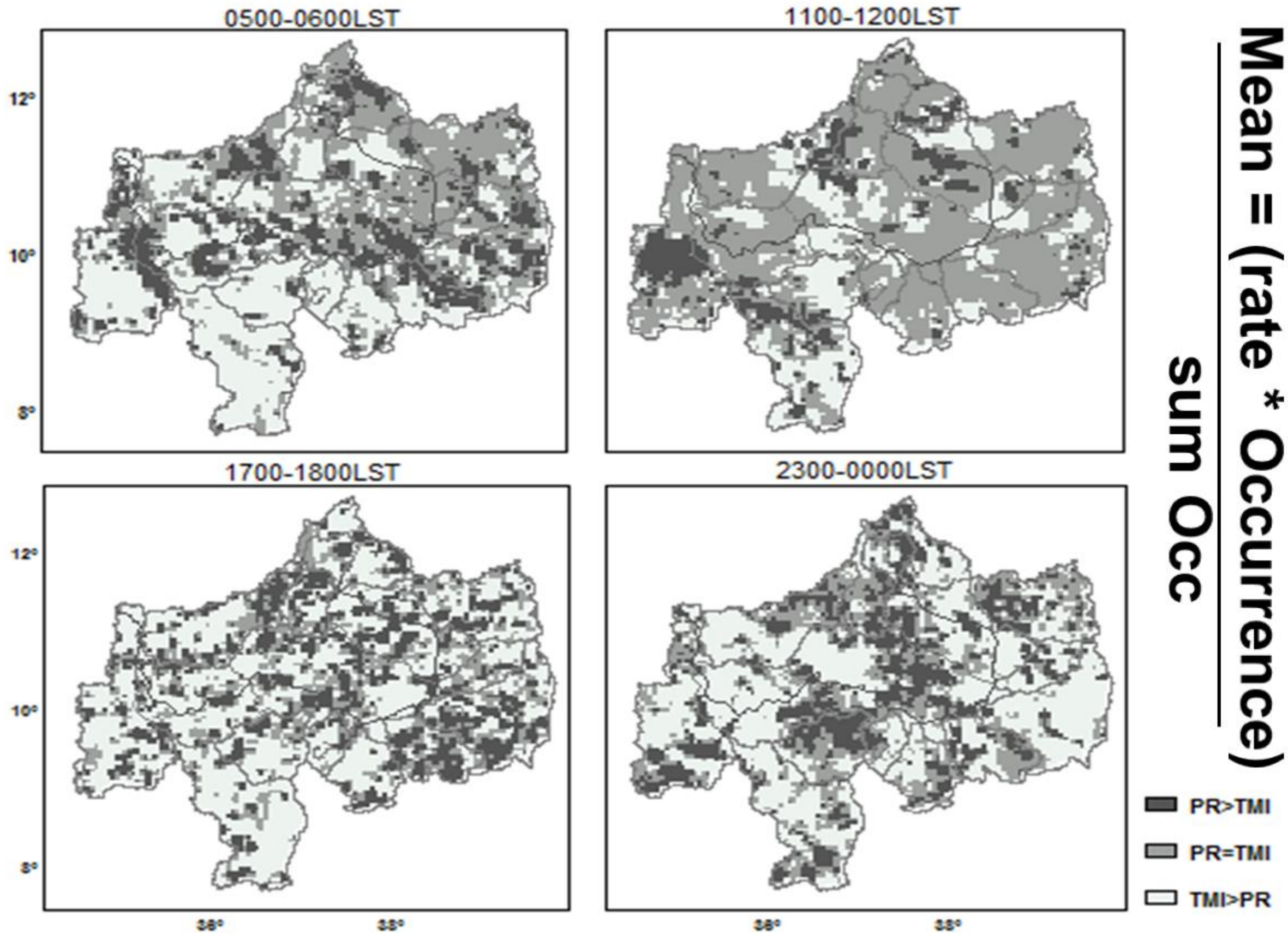

**23-24 hr**

**TRMM PR**




**TRMM TMI**

# Comparing TRMM PR and TRMM (TMI) mean rain rate for selected Local Standard Time (LST) (JJAS, 2002-2008)



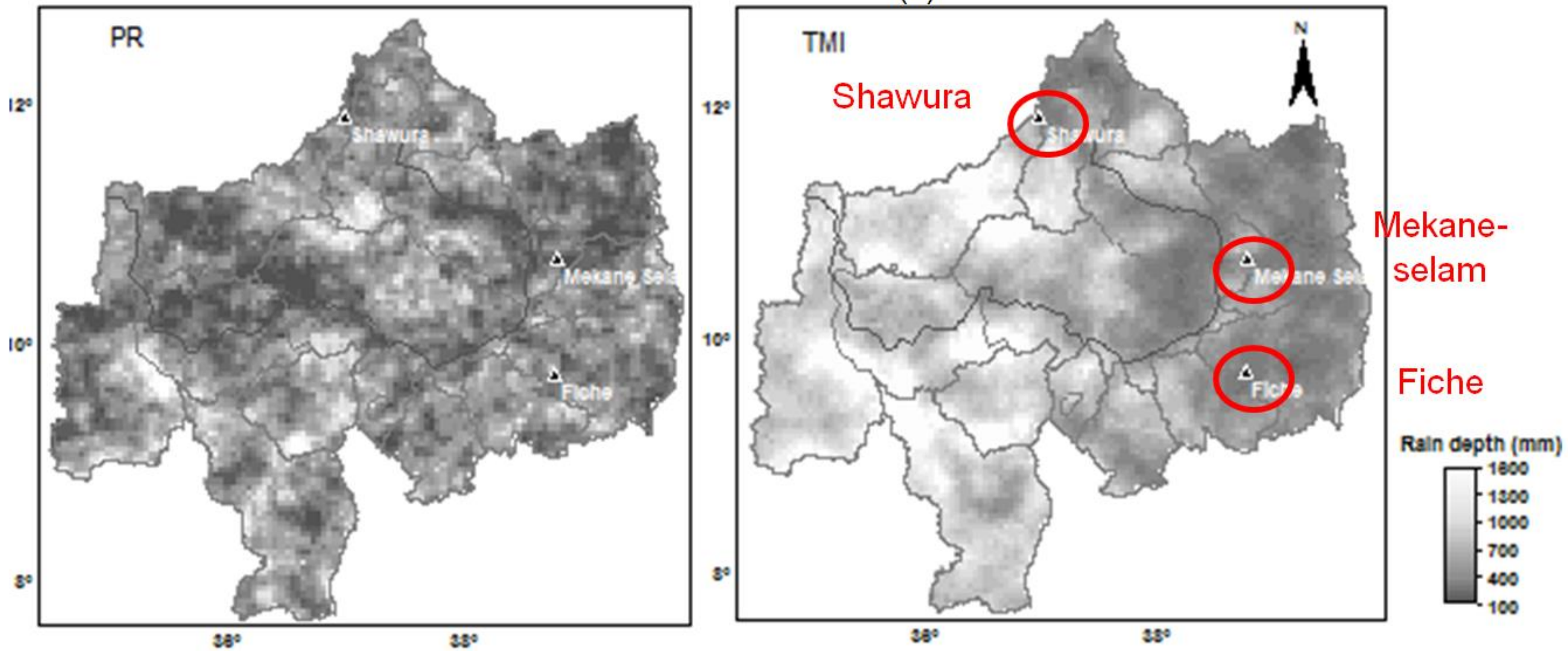

$$\text{Mean} = \frac{(\text{rate} * \text{Occurrence})}{\text{sum Occ}}$$

**So which product to use? ….**
**how is the water balance closed?**

# Atmospheric water : Annual rainfall Upper Blue Nile

## TRMM Precipitation Radar (PR) and TRMM Microwave Imager (TMI)

(7)




| | Rainfall depth (mm) | | |
|---|---|---|---|
| Station | Ground truth | PR | TMI |
| Fiche | 569 | 540 | 546 |
| Mekane-selam | 428 | 586 | 728 |
| Shawura | 458 | 449 | 928 |


Rientjes, T.H.M., Haile, A.T. and Fenta, A.A.(2013). Diurnal rainfall variability over the Upper Blue Nile Basin : a remote sensing based approach. In: Inter. J. of App. Earth Obs. and GeoInf. : JAG, 21 (2013) pp. 311-325.

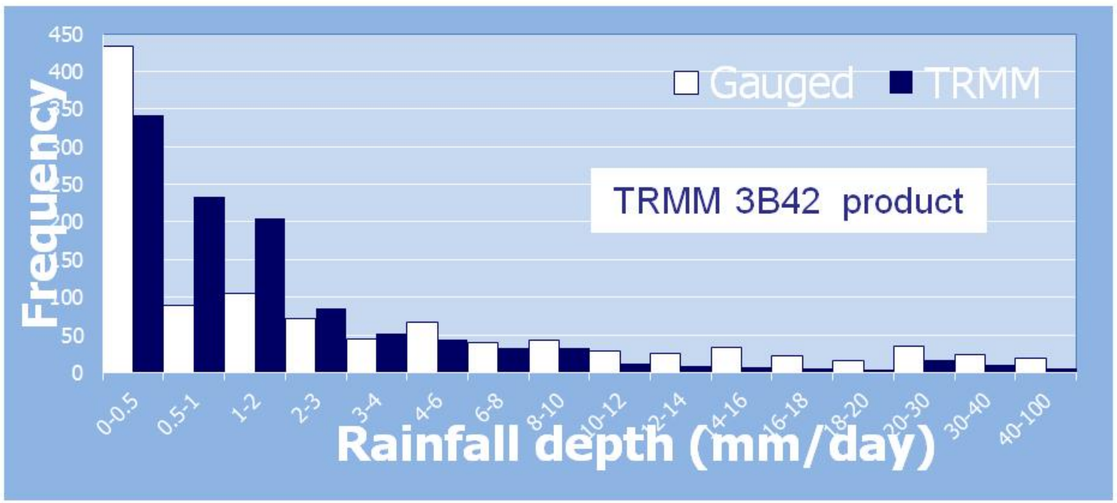
# Rainfall comparison (Gauge vs TRMM)

## Descriptive statistics:

| Description | Gauged | TRMM |
|---|---|---|
| Mean | 5.63 | 2.98 |
| Standard Deviation | 10.23 | 6.45 |
| Minimum | 0.00 | 0.00 |
| Maximum | 88.10 | 65.41 |
| Sum | 6171.31 | 3265.50 |

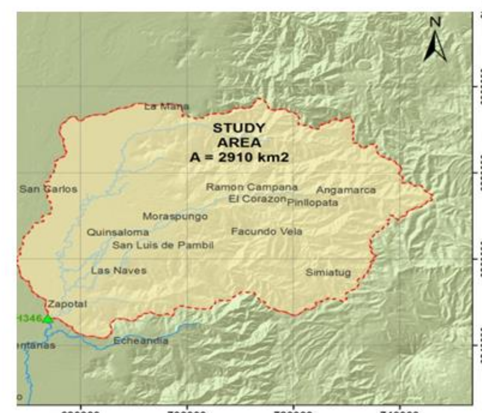
## Total rainfall and ratio:

| Total rainfall (mm) | |
|---|---|
| Meteorological stations | 17863219.66 |
| TRMM 3B42 product | 9450503.36 |
| **Ratio:** | **1.89** |





Babahoyo basin, Ecuador

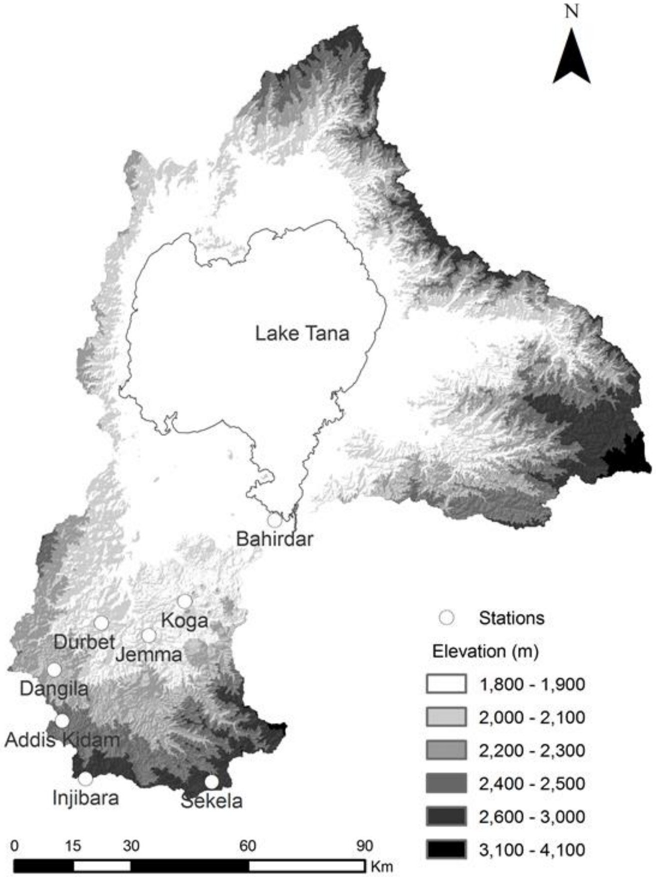


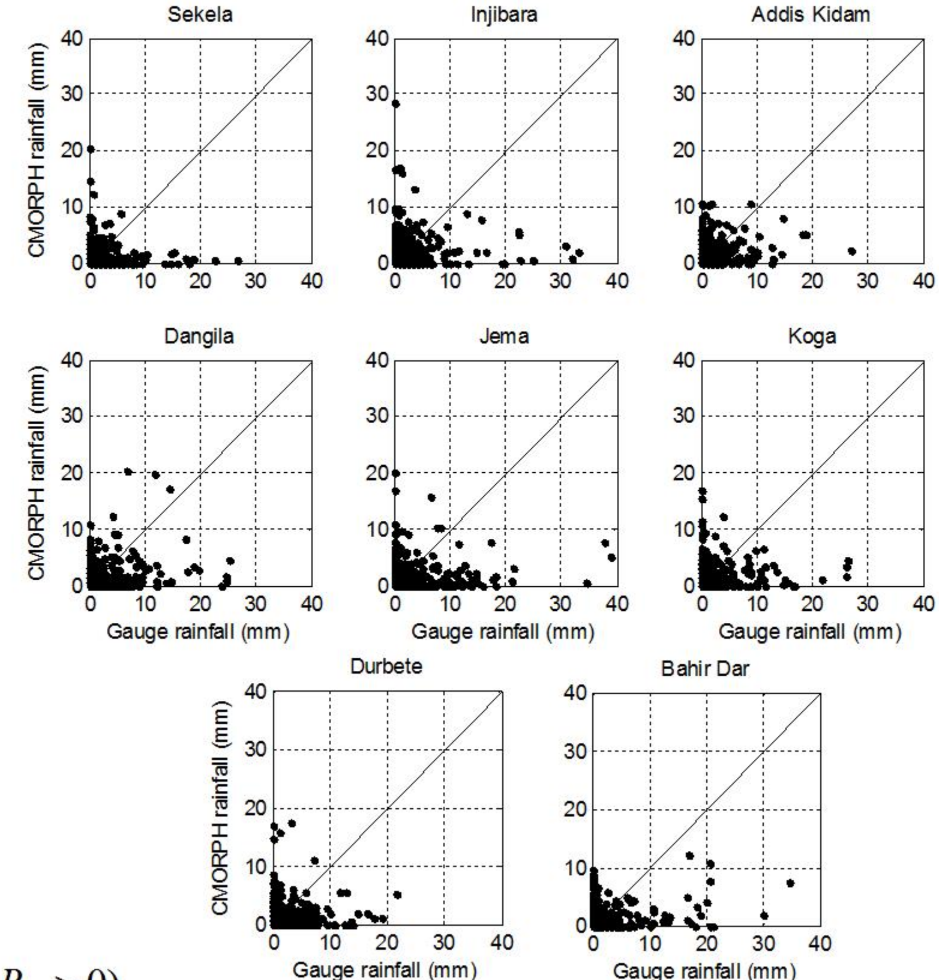

Hit bias
$$\sum (R_S - R_G) \big| (R_S > 0 \,\&\, R_G > 0)$$

Missed rain bias
$$\sum R_G \big| (R_S = 0 \,\&\, R_G > 0)$$

False rain bias
$$\sum R_S \big| (R_S > 0 \,\&\, R_G = 0)$$

# Scatter plot of CMORPH and gauge hourly rainfall rates



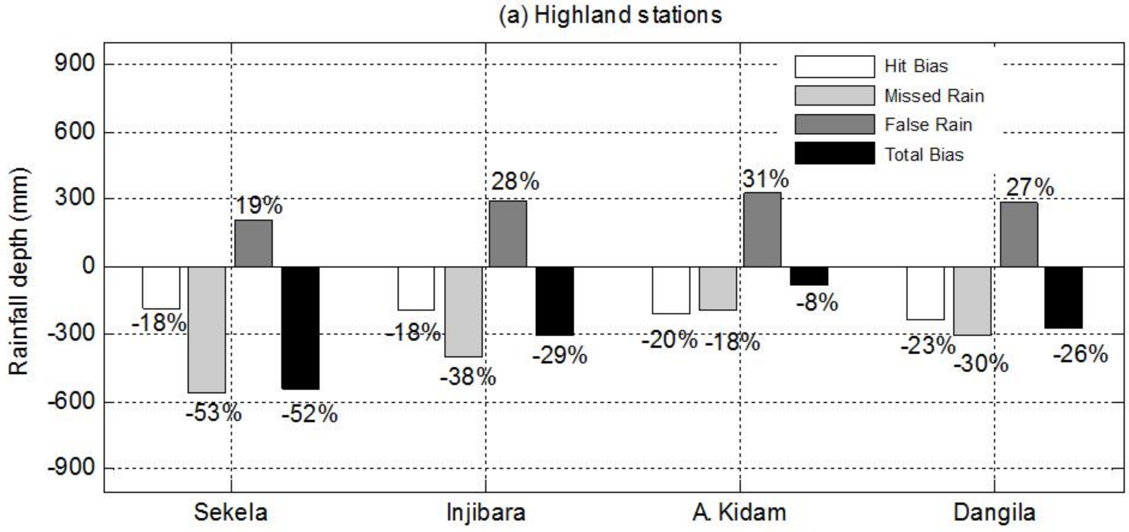



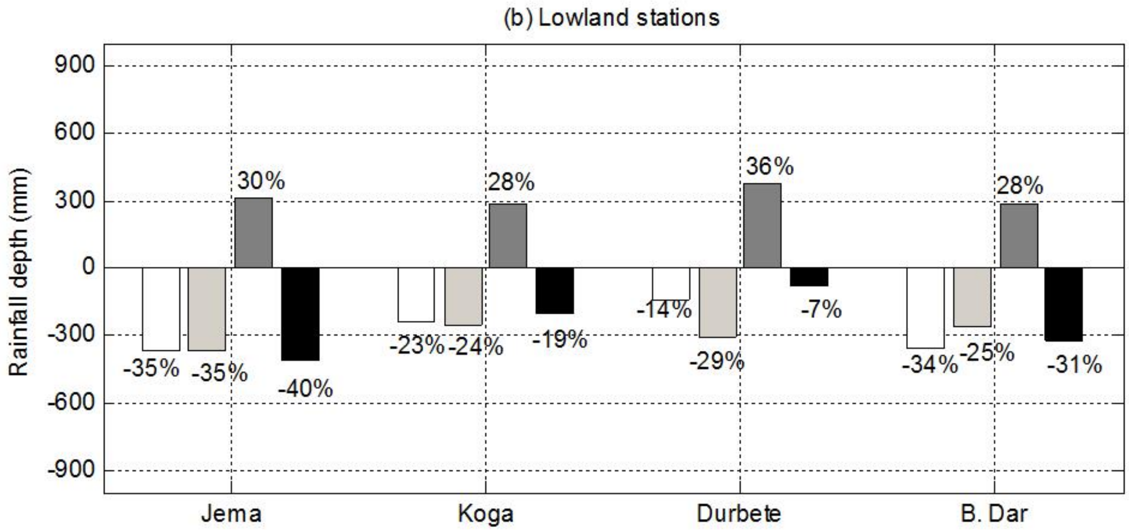

Hit bias $\sum (R_S - R_G) \middle| (R_S > 0 \,\&\, R_G > 0)$

Missed rain bias $\sum R_G \middle| (R_S = 0 \,\&\, R_G > 0)$

False rain bias $\sum R_S \middle| (R_S > 0 \,\&\, R_G = 0)$

# CMORPH Hit, missed rain and false rain biases JJA, 2007.



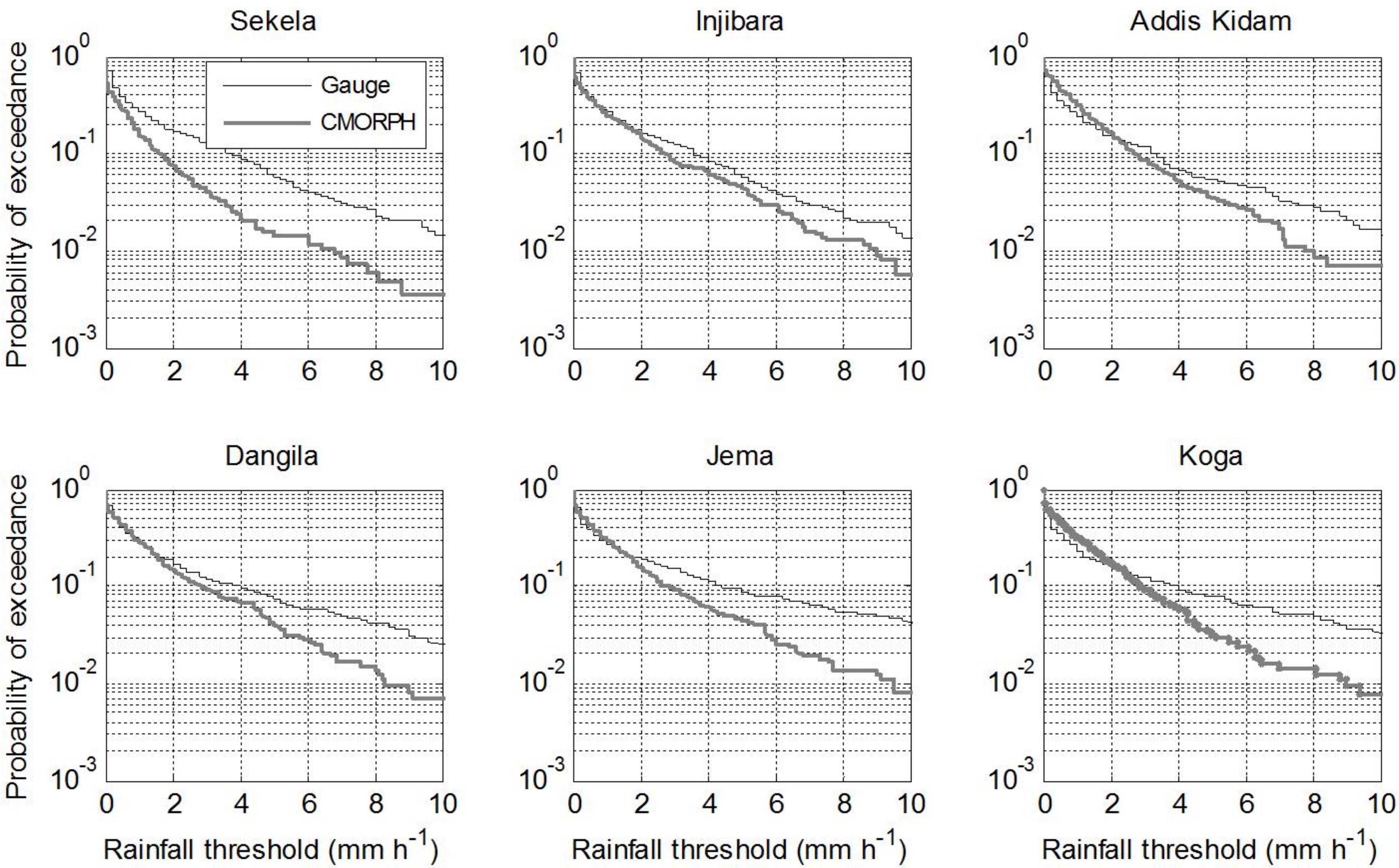




**Percentages shown above or below the bars represent the biases as a percentage of the total rainfall depth of each station in wet season (JJA), 2007.**

**The top panel shows biases of highland stations while the bottom panel shows those of lowland stations.**

# CMORPH and gauge hourly rainfall rates

## Exceedance probability plots for hourly rainfall rates

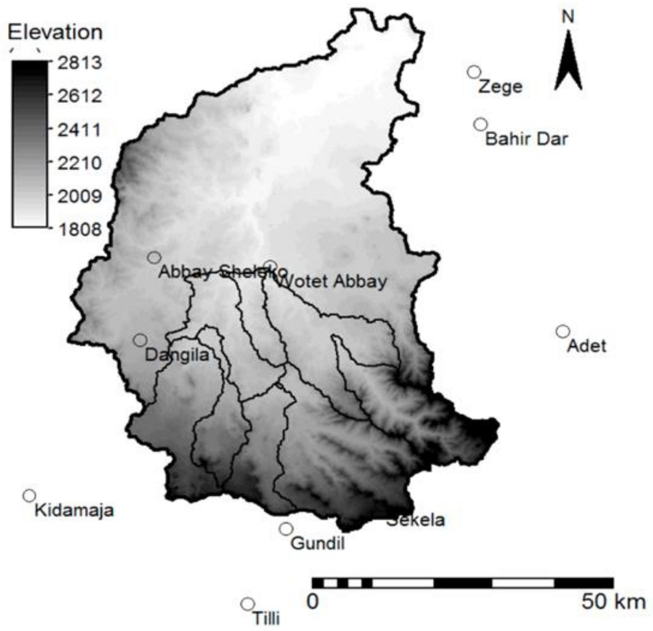


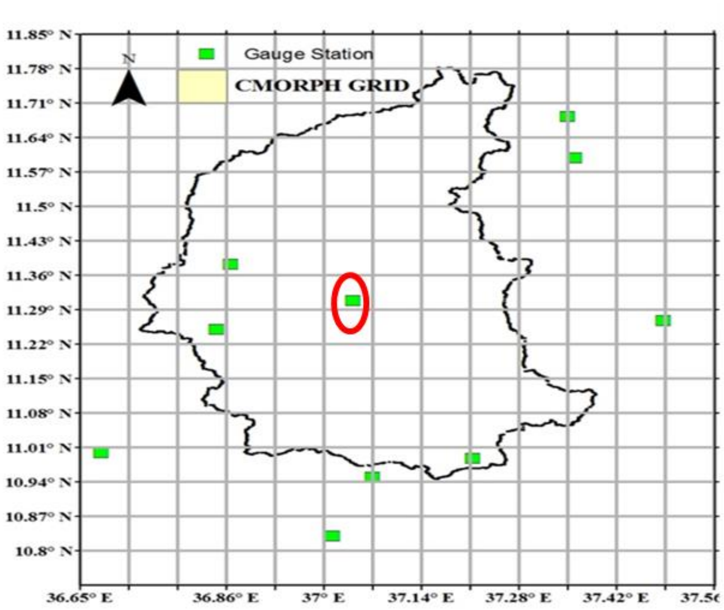
# CMORPH and gauge hourly rainfall rates

| | Sek | Inj | AKid | Dan | Jem | Kog | Dur | BD |
|---|---|---|---|---|---|---|---|---|
| [mm/h] | Rainy hours (%) | | | | | | | |
| Gauge (≤ 0.2) | 26.9 | 28.3 | 20.1 | 22.2 | 21.0 | 17.7 | 19.6 | **16.7** |
| CMORPH (≤ 0.2 ) | 16.7 | 21.0 | 21.5 | 19.8 | 19.4 | 18.2 | 19.6 | **15.8** |
| Gauge (0.2-5.0) | 24.7 | 26.3 | 18.3 | 29.8 | 18.2 | 15.5 | 17.7 | **14.8** |
| CMORPH (0.2-5.0) | 16.2 | 19.3 | 20.3 | 18.5 | 18.0 | 17.3 | 18.5 | **19.9** |
| Gauge (>5.0) | 2.2 | 2.0 | 1.8 | 2.4 | 2.8 | 2.2 | 1.9 | **1.9** |
| CMORPH (>5.0) | 0.5 | 1.8 | 1.1 | 1.3 | 1.4 | 0.9 | 1.2 | **0.9** |
| Max (mm $h^{-1}$) | | | | | | | | |
| Gauge | 26.6 | 33.0 | 48.8 | 25.4 | 39.0 | 55.2 | 21.6 | **34.6** |
| CMORPH | **20.4** | **28.3** | **10.6** | **20.4** | **20.0** | **16.7** | **17.3** | **12.1** |

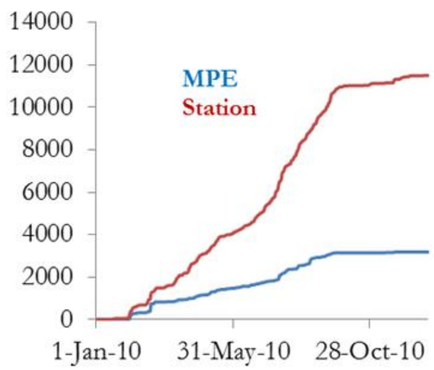
Occurrence of rainy hours and maximum hourly rainfall depth in the study area.
Sek = Sekela; Inj = Injibara; AKid = Akidam; Dan = Dangila; Jem = Jema;
Kog = Koga; Dur = Durbete; BD = Bahir Dar

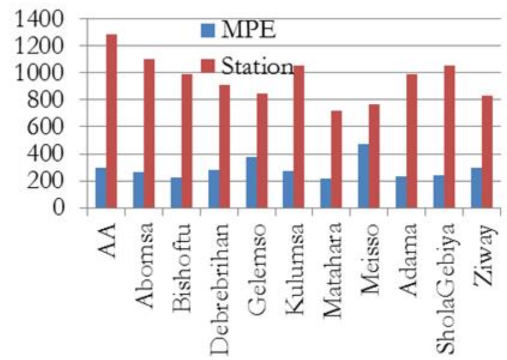
# We need to Correct our Satellite-Rainfall Estimates…



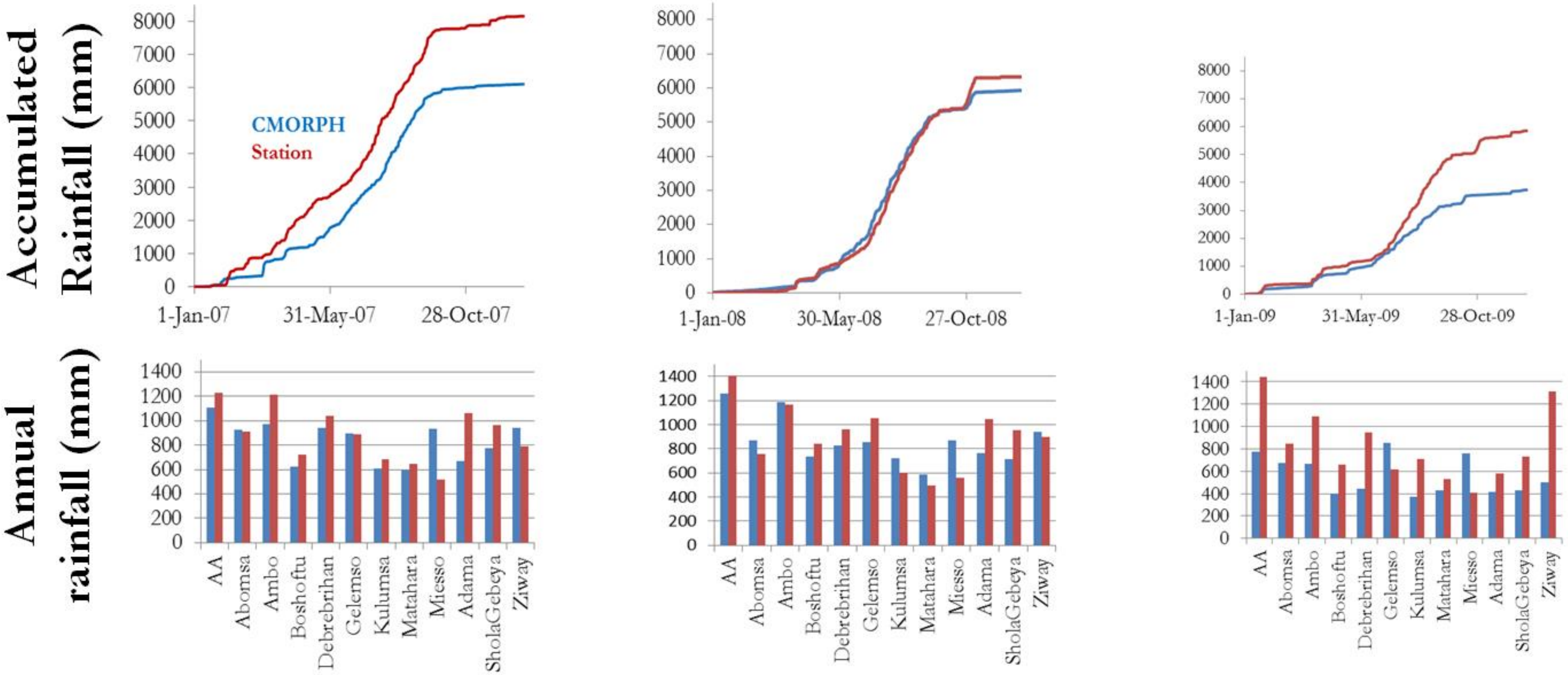




How to correct ? Base principle is the ratio of Satellite and Gauged rainfall !



# We need to Correct our Satellite-Rainfall Estimates…




| Year | Accumulated Rainfall of all stations [mm] | | Ratio (or Bias Factor BF) [Station/CMORPH] |
|---|---|---|---|
| | CMORPH | Station | |
| 2006 | 7609 | 10805 | 1.42 |
| 2007 | 7910 | 10600 | 1.34 |
| 2008 | 10322 | 10745 | 1.04 |
| 2009 | 6650 | 10041 | 1.51 |
| 2010 | 7273 | 10255 | 1.41 |

- Here we conserve spatial variability of RS image!....CMORPH = Station / Ratio
- And conserve all mass (water)!
- And we may correct for different time periods..

# Correction.. some more advancements

## See Habib et al., (2014)

**Time and space fixed (TFSF) bias correction:**

Same correction for all time steps and all pixels

$$BF_{TFSF} = \frac{\sum_{t=1}^{t=T} \sum_{i=1}^{i=n} S(i,t)}{\sum_{t=1}^{t=T} \sum_{i=1}^{i=n} G(i,t)}$$

**Time variable (TVSF) bias correction**

Correction at daily time step but the same for all pixels

$$BF_{TVSF} = \frac{\sum_{t=d}^{t=d-l} \sum_{i=1}^{i=n} S(i,t)}{\sum_{t=d}^{t=d-l} \sum_{i=1}^{i=n} G(i,t)}$$

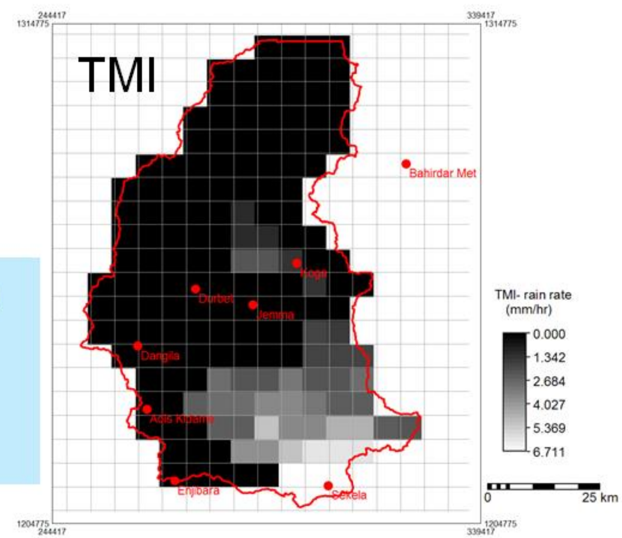
**Time and space variable (TVSV) bias correction:**

Correction at daily time steps and different for each pixel

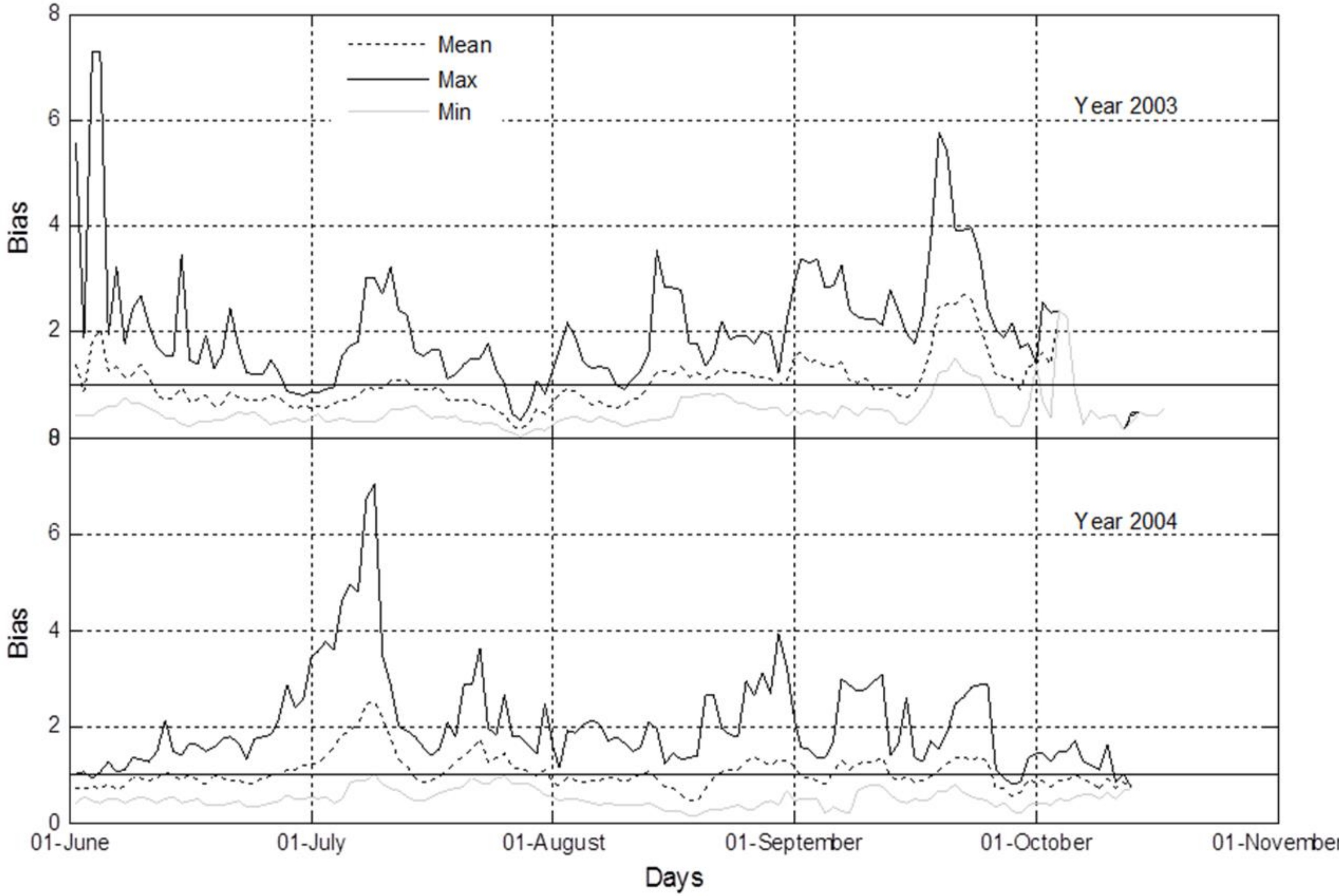
$$BF_{TVSV} = \frac{\sum_{t=d}^{t=d-l} S(i,t)}{\sum_{t=d}^{t=d-l} G(i,t)}$$

**S = daily CMORPH rainfall estimates**
**G= daily gauge rainfall estimates**
**i = gauge location,**
**t = Julian day number**
**l = length of a time window for bias calculation**

We use a fixed time window of 7 days for rainfall accumulation with minimum of 5 rainy days (gauge)
with a minimum rainfall accumulation depth of 5 mm,
otherwise no bias is estimated (i.e. assigned a value of 1).



# Mean, minimum and maximum of CMORPH daily bias

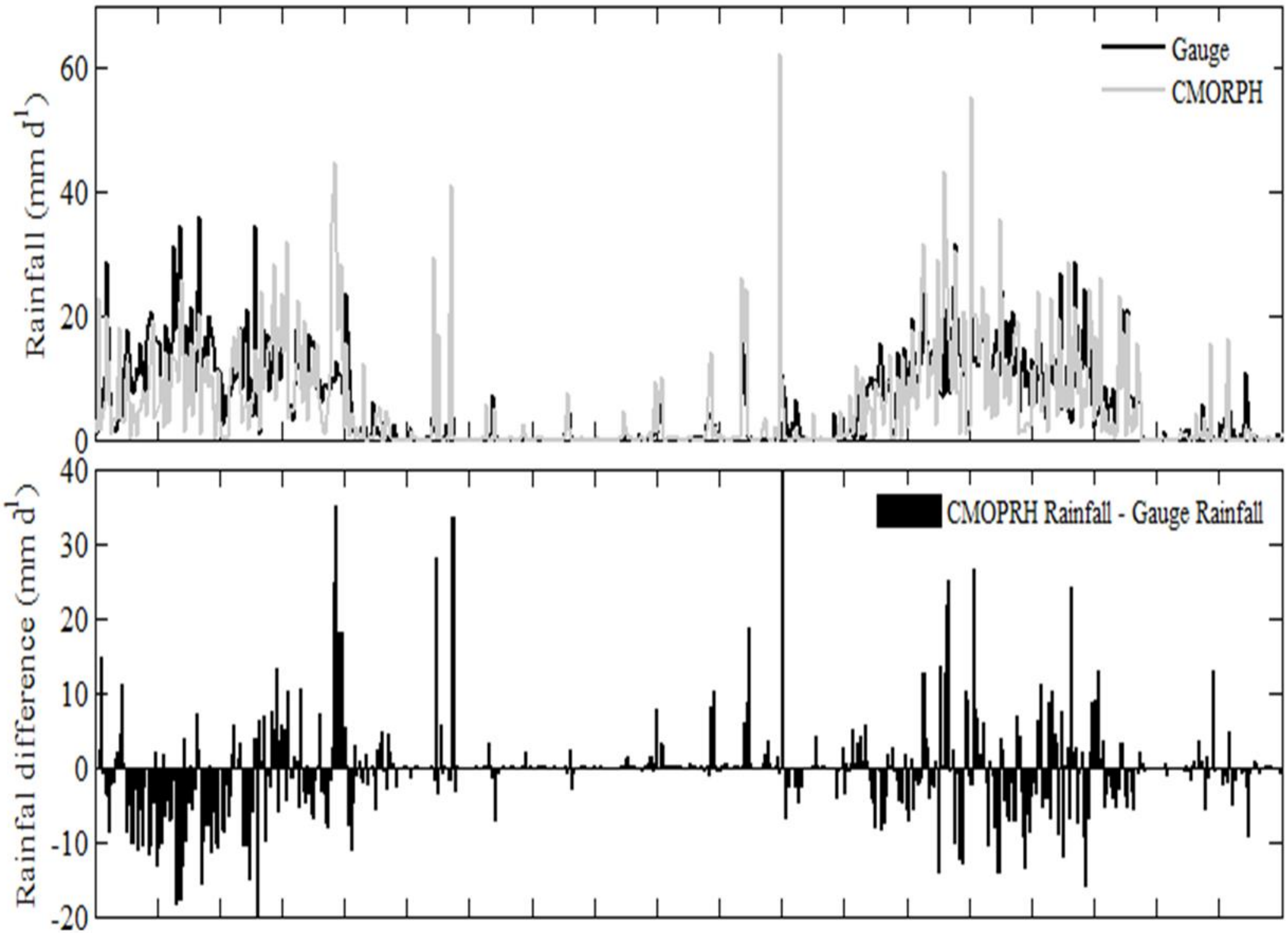



**Temporal and spatial variability in the CMORPH bias field (for 10 stations)**

**Pronounced variability is shown !**

# Gauge VS CMORPH at daily bias (Habib et al., 2014)

**Sheets are from Emad Habib, Alemseged Tamiru Haile, Nazmus Sazib, Yu Zhang and Tom Rientjes (2014) Effect of Bias Correction of Satellite-Rainfall Estimates on Runoff Simulations at the Source of the Upper Blue Nile,** *Remote Sens.* **2014**, *6*, 6688-6708; doi:10.3390/rs6076688



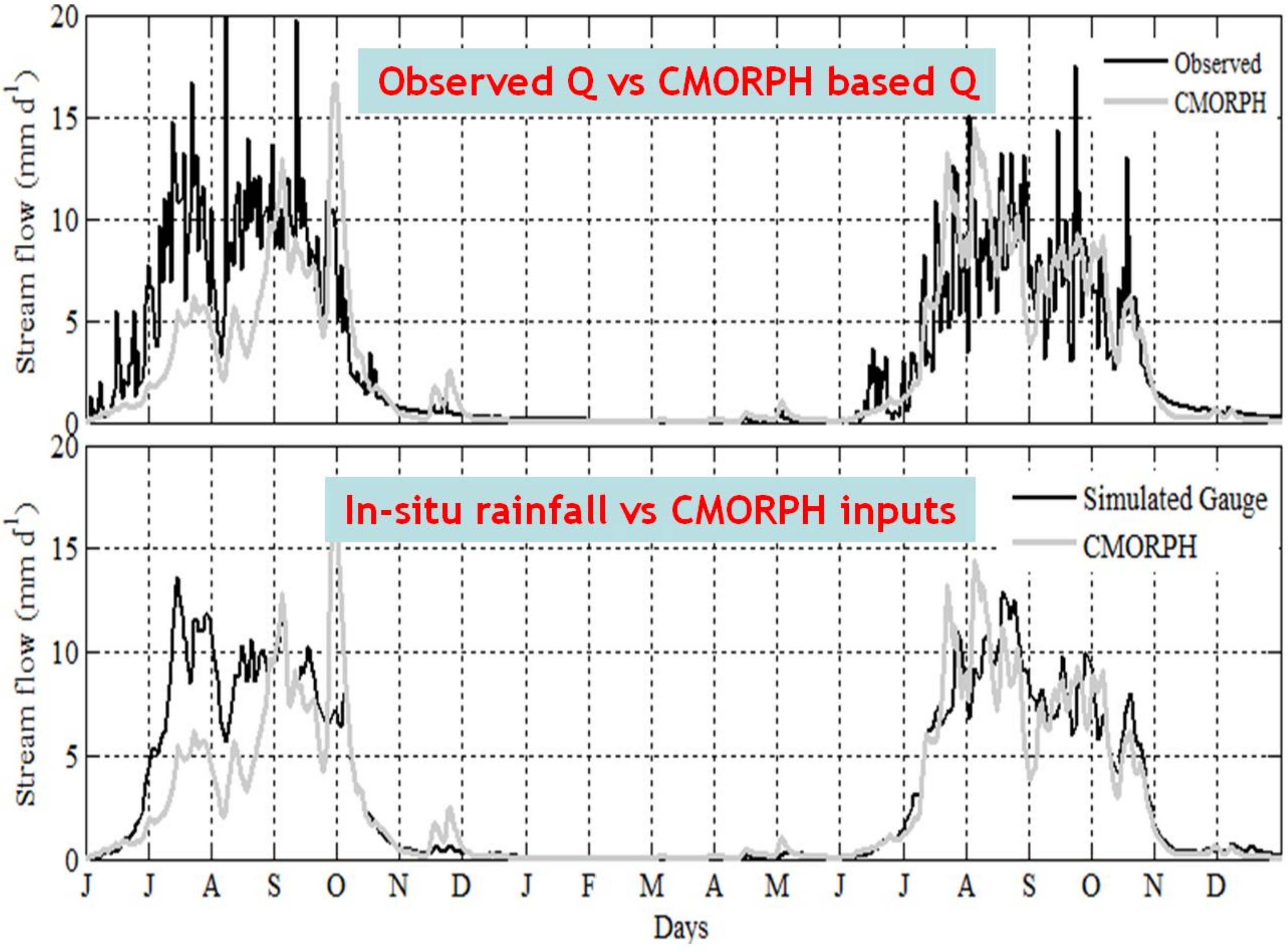
# Results of correction at monthly base.

**Ratios of monthly rainfall amounts of CMORPH (without and with three bias correction schemes) to the corresponding gauge amounts (note that "1" is best)**

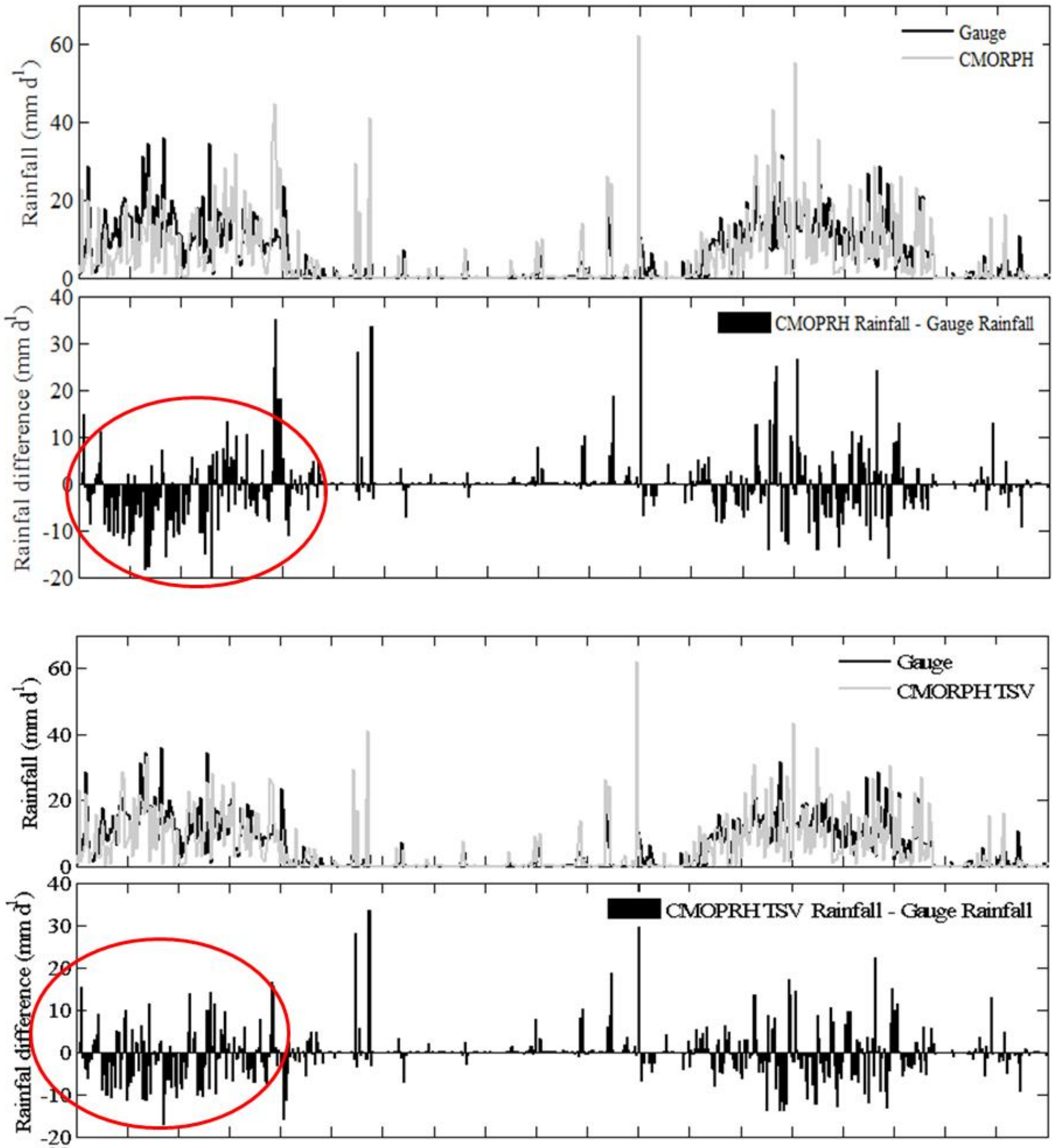
| Year | Product | June | July | Aug | Sept | Oct |
|---|---|---|---|---|---|---|
| 2003 | CMORPH | 0.69 | 0.63 | 0.88 | 1.25 | 0.74 |
| | CMORPH TFSF | 0.71 | 0.64 | 0.9 | 1.28 | 0.76 |
| | CMORPH TVSF | 0.74 | 0.82 | 0.94 | 0.9 | 0.63 |
| | CMORPH TVSV | 0.87 | 0.81 | 0.99 | 0.95 | 0.63 |
| 2004 | CMORPH | 0.83 | 1.15 | 0.8 | 0.99 | 0.84 |
| | CMORPH TFSF | 0.79 | 1.09 | 0.76 | 0.94 | 0.8 |
| | CMORPH TVSF | 0.9 | 0.87 | 0.87 | 0.93 | 0.93 |
| | CMORPH TVSV | 0.95 | 0.86 | 0.87 | 0.96 | 0.98 |

**TVSV Bias Correction in general gives best results !**

# Results of HBV modelling (uncorrected CMORPH)



# Gauge VS CMORPH at daily bias



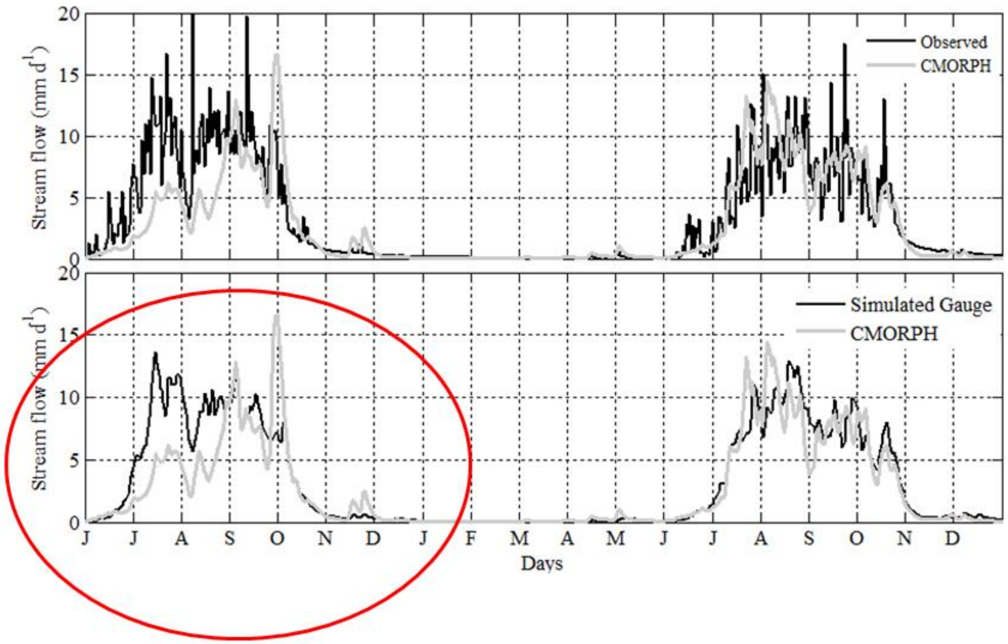

**Comparison Gauge to Uncorrected CMORPH**

**Differences between Gauge to Uncorrected CMORPH**

**Comparison Gauge to Corrected CMORPH**

**Differences between Gauge to Corrected CMORPH**

# Results of HBV modelling (corrected CMORPH)




**Observed Q vs**

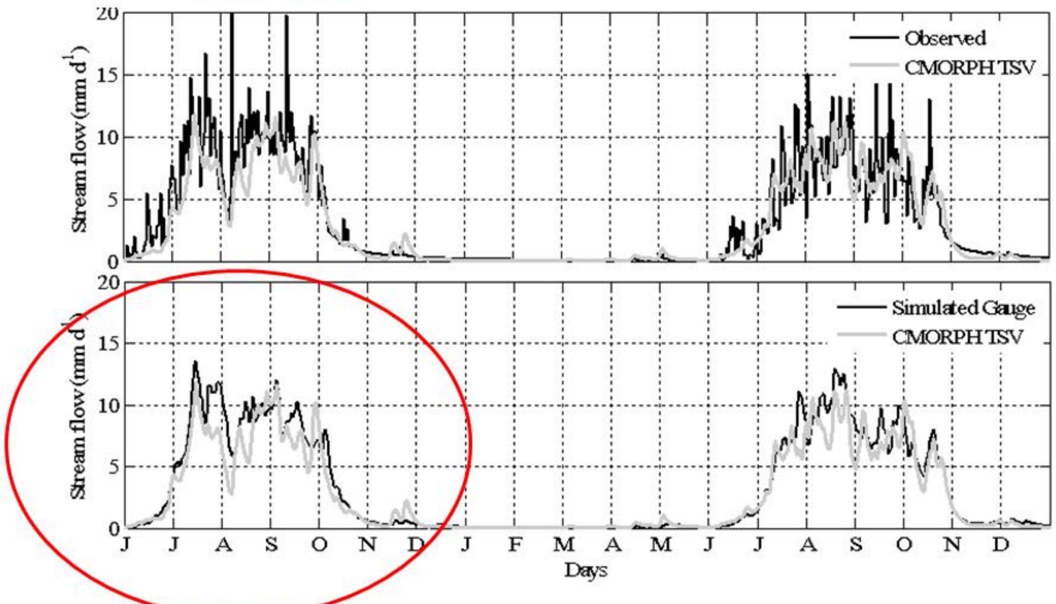
**Uncorrected CMORPH**

**based Q**

**HBV In-situ stream flow**

**vs**

**Uncorrected CMORPH**




**Observed Q vs**

**Corrected TVSV**

**CMORPH based Q**

**HBV Stream flow**

**vs**

**TVSV Corrected CMORPH**

# Results of HBV modelling (parameters)

| Par | Gauge | CMORPH with bias correction | | |
|---|---|---|---|---|
| | | TFSF | TVSF | TVSV |
| FC | 373 | 186 (-68) | 177 (-72) | **185 (-69)** |
| BETA | 1.351 | 1.599 (71) | 1.562 (60) | **1.625 (78)** |
| LP | 0.544 | 0.888 (77) | 0.905 (81) | **0.775 (52)** |
| ALPHA | 0.271 | 0.242 (-17) | 0.236 (-20) | **0.269 (-1)** |
| $K_q$ | 0.073 | 0.035 (-52) | 0.050 (-32) | **0.038 (-48)** |
| $K_s$ | 0.087 | 0.086 (-1) | 0.083 (-5) | **0.074 (-15)** |
| PERC | 1.348 | 1.422 (6) | 1.208 (-11) | **1.339 (-1)** |
| CFLUX | 0.886 | 0.898 (1) | 0.805 (-9) | **0.892 (1)** |
| NS | 0.82 | 0.70 | 0.80 | 0.82 |
| $Q_{Bias}$ | 0.995 | 0.982 | 0.988 | 0.982 |

# How to become a millionaire ?