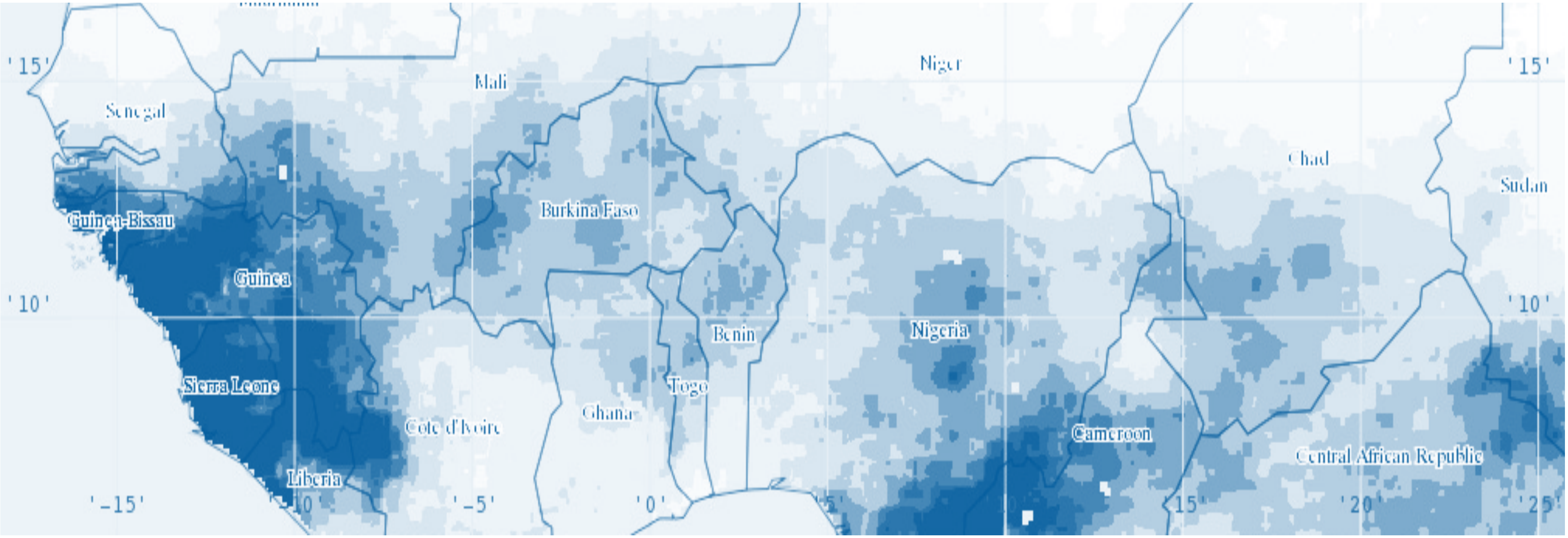


# INTRODUCTION ON BIAS CORRECTION METHODS

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NASA / SERVIR SCIENCE COORDINATION OFFICE

9 MARCH, 2017

VIC/BCSPP Training

Nairobi, Kenya

# OVERVIEW OF AGENDA

I. Introduction and discussion of Satellite Precipitation Products and Bias Correction Methods
II. Introduction to R / R Studio
III. Advanced Techniques in R
IV. Bias Correction Method 1 Introduction: Linear
V. Bias Correction Method 1 Exercise
VI. Bias Correction Method 2 Introduction: Quantile Mapping
VII. Bias Correction Method 2 Exercise
VIII. VIC Model Run using Bias Corrected Inputs

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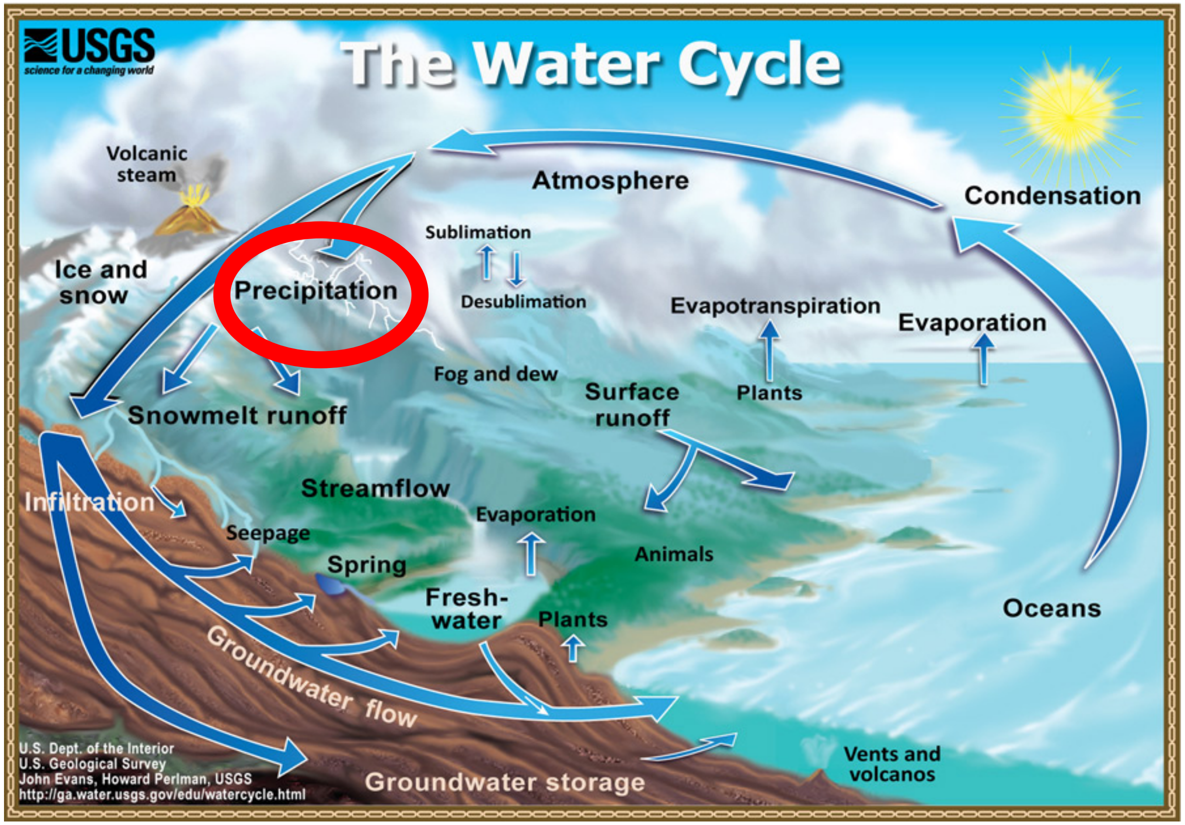
   a. Introduction to Precipitation Remote Sensing
      ****adapted from ARSET webinar materials****
      i. General Concepts
      ii. Sources of Satellite Precipitation Data (benefits and limitations)
         1. TRMM
            1. TMPA
         2. GPM
            1. IMERG
         3. PERSIANN
         4. CMORPH
         5. CHIRPS
   b. Introduction to Bias Correction
      i. General concepts
      ii. Overview of methods

# WATER RESOURCES MANAGEMENT

- For sustainable water management, it is critical to have accurate estimates of water components



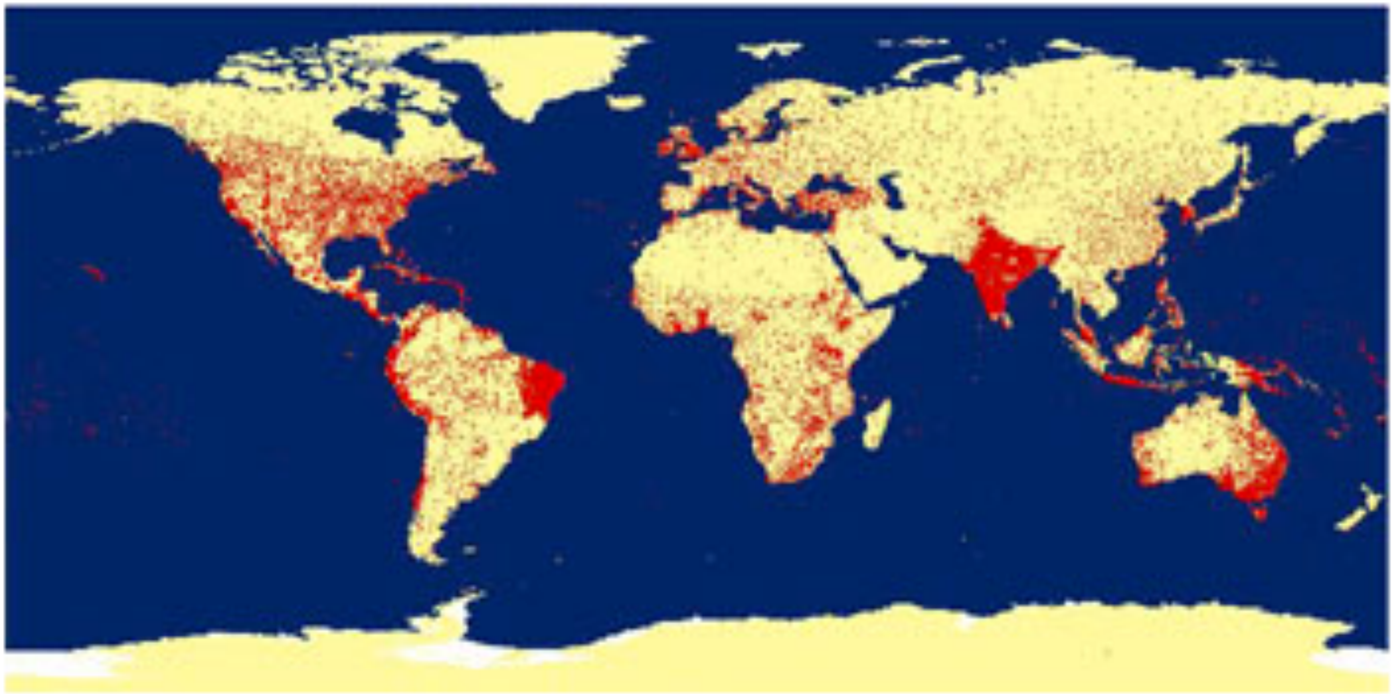
# WATER RESOURCES MANAGEMENT

Water availability = (**Precipitation** + runoff in) – (ET + runoff out + infiltration)

- With accurate precipitation measurements we can model the remaining water cycle parameters that affect water availability for:
  - Flood monitoring, assessment, and prediction
  - Hydropower
  - Ecosystem health assessment
  - Agricultural monitoring, assessment, and prediction
  - Drought monitoring, assessment, and prediction
  - …

## ADVANTAGES OF REMOTE SENSING

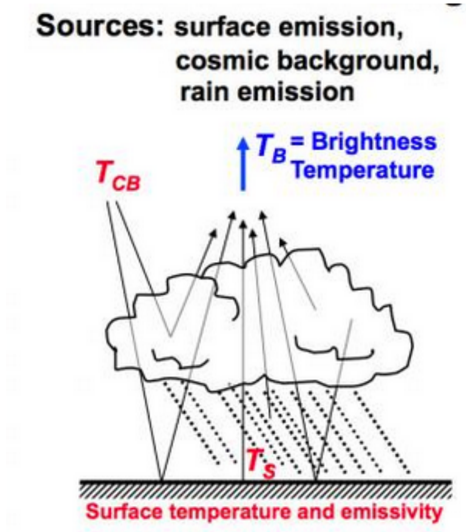
- Fills data gaps where there are no surface-based measurements
- Global (near-global) coverage consistently
- Continuous, large scale coverage compared to point measurements
- Free and open sources of data



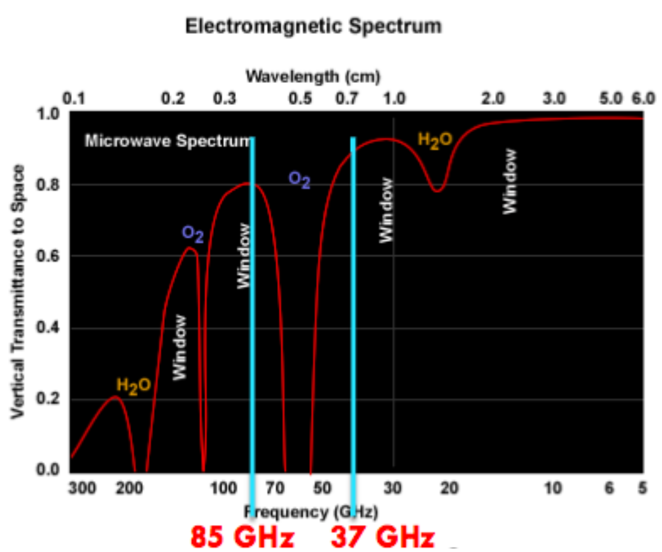
Global distribution of rain gauges incorporated into the Global Hydroclimatic data sets (GHCN)
Source: NOAA

# Passive Remote Sensing

1. Inferred (derived) indirectly from reflected solar radiation and emitted infrared radiation by the top of clouds




Source: NASA ARSET

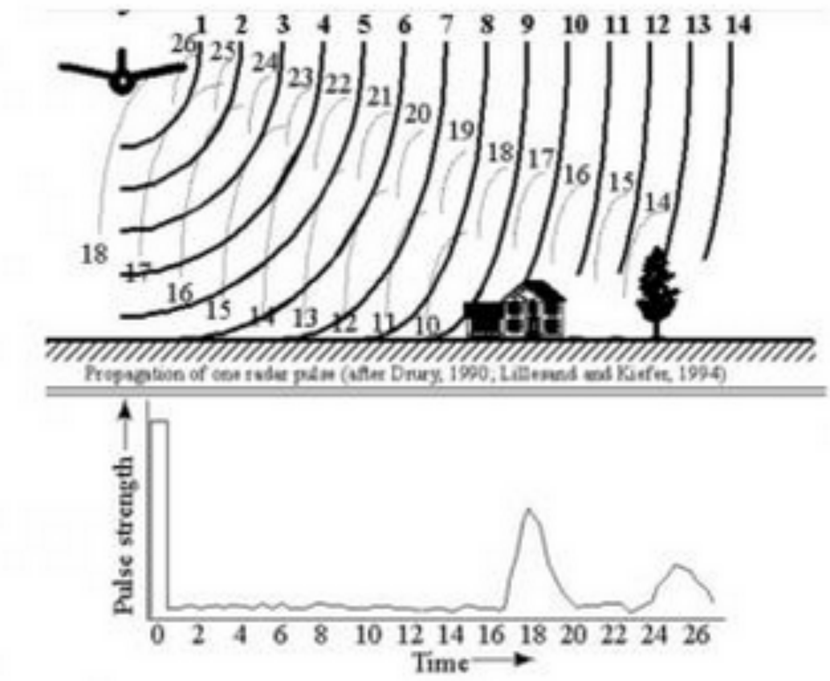



Source: NASA ARSET

2. Estimated from microwave radiation emitted or scattered by precipitation particles
   - 37 GHz – ”emission channel” – measures precipitation form energy emitted by raindrops
   - 85 GHz – “scattering channel” – gathers energy scattered by ice particles above the freezing level

# Active Remote Sensing

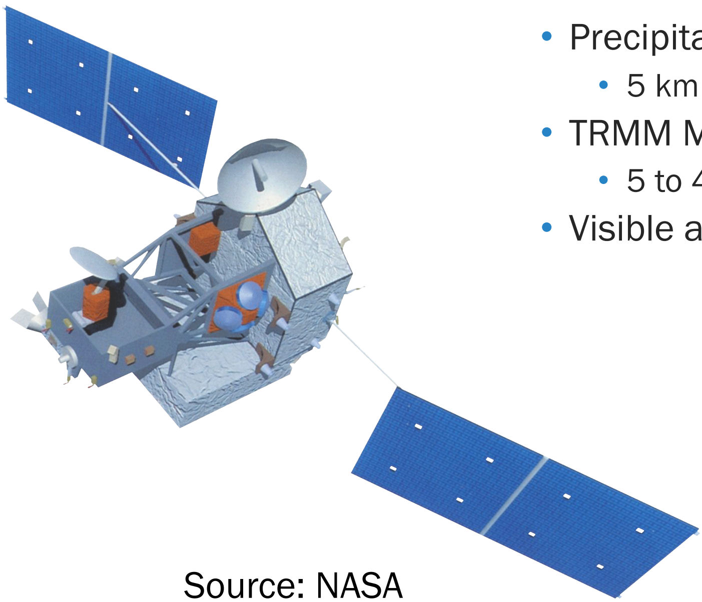
1. Estimated from back-scattered microwave radiation transmitted by radars




Source: NASA ARSET

# SATELLITE MISSIONS - TRMM

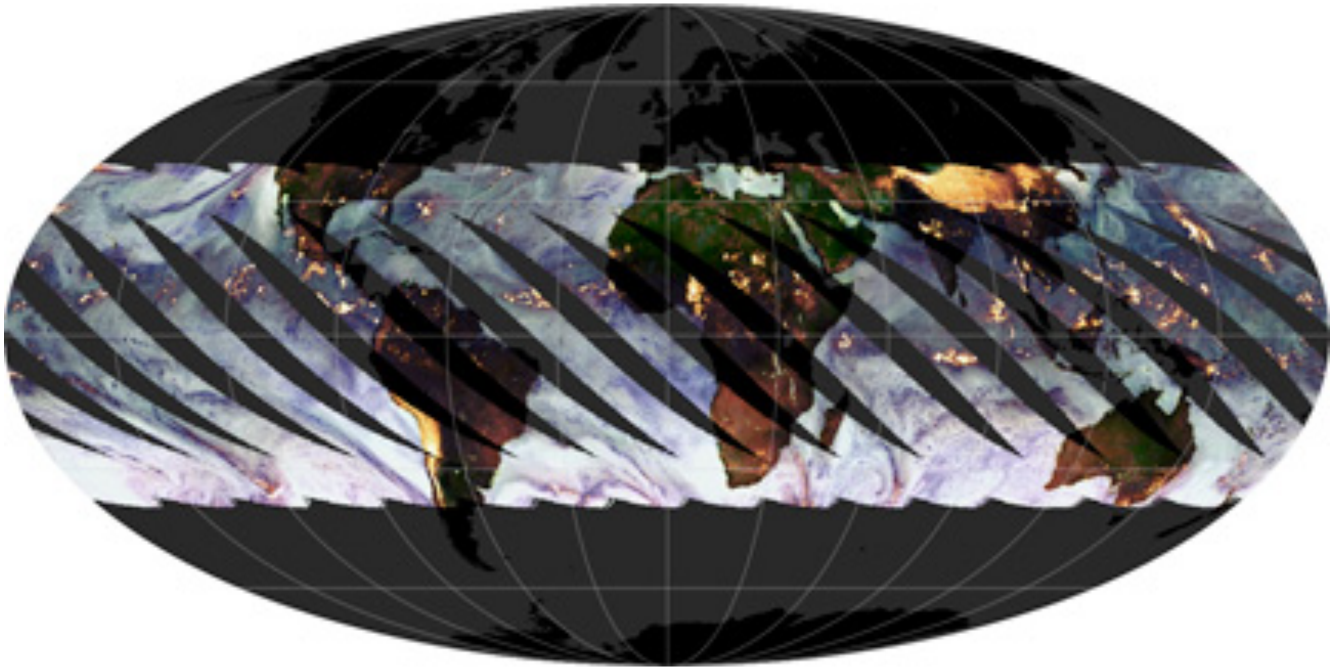
- Tropical Rainfall Measuring Mission
  - Launched November 1997
  - Data available from 1997 – April 2015
  - Revisit time ~11-12 hrs
  - Carries both active and passive sensors
    - Precipitation Radar (PR, Active)
      - 5 km spatial resolution
    - TRMM Microwave Imager (TMI, Passive)
      - 5 to 45 km spatial resolution (channel-dependent)
    - Visible and Infrared Scanner (VIRS, Passive)



Source: NASA

# SATELLITE MISSIONS - TRMM

- Strengths: High pixel resolutions, accurate measurements
- Limitations: No global, diurnal coverage on a daily basis, only measures liquid precipitation



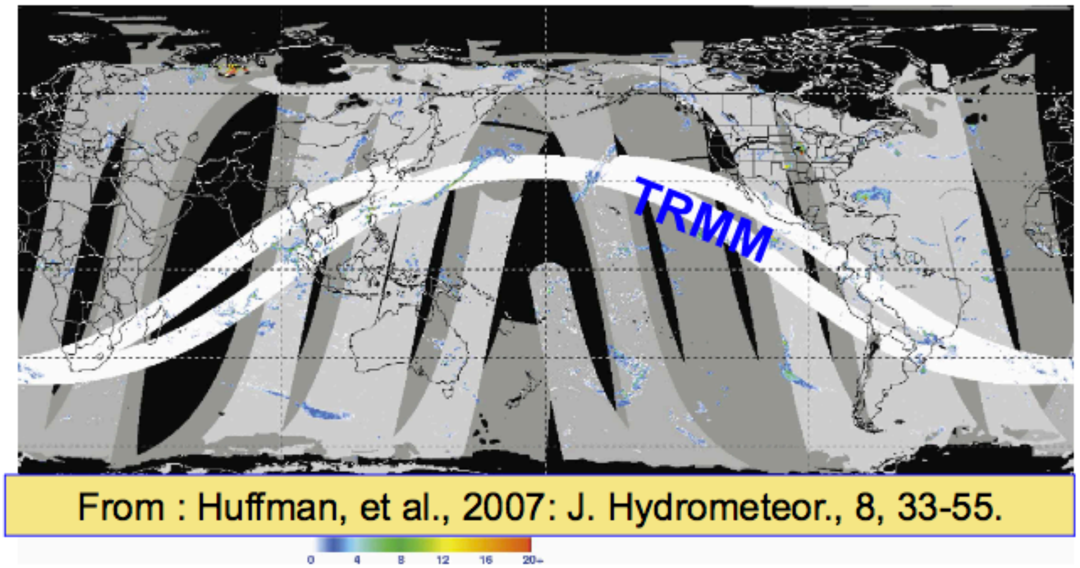
Source: NASA

# SATELLITE PRECIPITATION PRODUCT - TMPA

SERVIR

- TRMM Multi-satellite Precipitation Analysis (TMPA)
  - Also known as TRMM 3B42
  - Inter-calibrates passive microwave rain rates from:
    - SSM/II, AMSR, and AMSU-B
  - Inter-calibrates with national and international geostationary and NOAA low earth orbiting satellites infrared measurements by using VIRS
  - Final product is calibrated with rain gauge analyses monthly
  - 3- hourly temporal resolution
  - Quarter degree spatial resolution
  - Data available at: https://pmm.nasa.gov/data-access/downloads/trmm

# SATELLITE PRECIPITATION PRODUCT - TMPA




From : Huffman, et al., 2007: J. Hydrometeor., 8, 33-55.

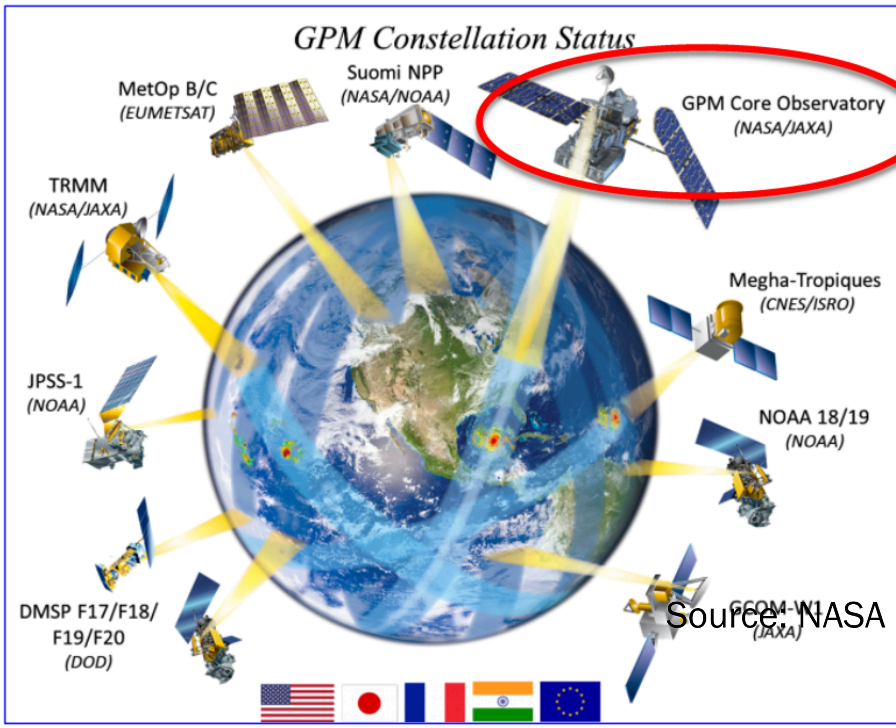
**Microwave Measurements in TMPA for y=the 3-hour period at 0 UTC on 25th May 2004**

TMI (white), SSM/I (light gray), AMSR-E (medium gray), and AMSU-B (dark gray). (In the TMPA the TMI, SSM/I, and AMSR-E are averaged where overlaps occur.) Blacked-out areas denote regions that lack reliable estimates

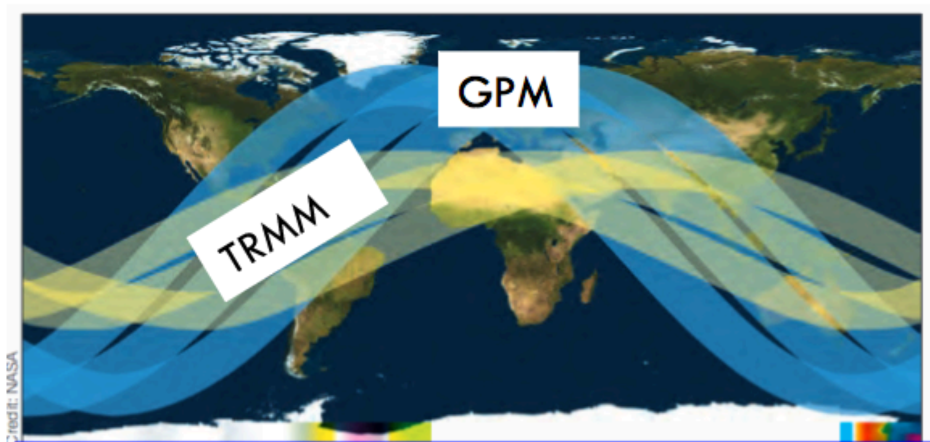
SERVIR

# Global Precipitation Measurement

- Designed to follow on to the TRMM mission while overcoming some of the short comings of the TRMM mission
- Network of satellites increasing revisit time to 1-2 hours
- Global coverage
- Data available from March 2014 to present at: https://pmm.nasa.gov/data-access/downloads/gpm




Source: NASA

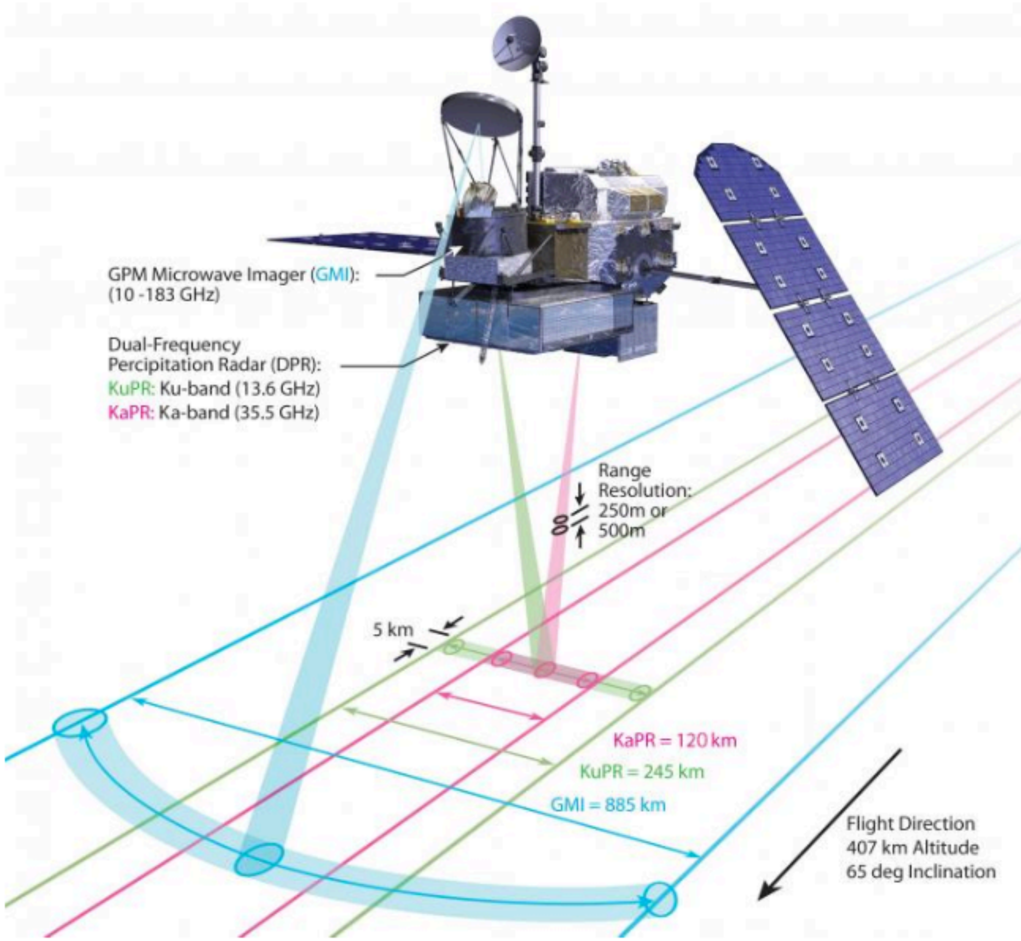



the area covered by three TRMM orbits [yellow] versus orbits of the GPM Core Observatory [blue]

Source: NASA ARSET

SATELLITE MISSIONS - GPM

Multiple Sensors:
- Active: Dual-frequency Precipitation Radar (DPR)
- Passive: GPM Microwave Imager (GMI)




Source: NASA ARSET

# SATELLITE MISSIONS - GPM

**GMI**

**Compared to TRMM TMI:**

- Higher spatial resolutions
- Improved light rain and snow detection
- Reference for constellation radiometers calibration

**DPR**

**Compared to TRMM PR:**

- Higher sensitivity to light rain and snow
- Better accuracy of measurements
- Better identification of liquid, ice, mixed-phase precipitation particles
- Reference standard for inter-calibration of constellation precipitation measurements

# SATELLITE PRECIPITATION PRODUCT - IMERG

- Integrated Multi-satellitE Retrievals for GPM (IMERG)
- Similar concept to TRMM TMPA
  - Combined GPM constellation satellites to yield improved spatial and temporal precipitation estimates

| | IMERG | TMPA |
|---|---|---|
| Temporal Resolution : | 30-minutes | 3 hours |
| Spatial Resolution: | 0.1°x0.1° | 0.25°x0.25° |
| Spatial Coverage: | Global | Global |
| | 60°S to 60°N | 50°S to 50°N |

# SATELLITE PRECIPITATION PRODUCT - PERSIANN

- Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) System
  - uses neural network function classification/approximation procedures to compute an estimate of rainfall rate
- The PERSIANN algorithm is based on the geostationary longwave infrared brightness temperature imagery to generate global rainfall.
  - GOES-8, GOES-10, GMS-5, Metsat-6, and Metsat-7
- Model parameters are regularly updated using rainfall estimates from low-orbital satellites, including TRMM, NOAA-15, -16, -17, DMSP F13, F14, F15.

# SATELLITE PRECIPITATION PRODUCT - PERSIANN

- Spatial Scale: 0.25° x 0.25° latitude/longitude scale
- Temporal Scale: 30 minutes accumulated to 6-hour accumulated rainfall
- Rainfall product covers 50°S to 50°N globally.

- Data available at: http://chrsdata.eng.uci.edu/

# SATELLITE PRECIPITATION PRODUCT - CMORPH

- NOAA Climate Prediction Center Morphing Technique ("CMORPH")
- Precipitation estimates derived from low orbiter passive satellite microwave observations “morphed / merged” with IR for the time periods where microwave estimates are not available
  - DMSP 13, 14 & 15 (SSM/I), the NOAA-15, 16, 17 & 18 (AMSU-B), and AMSR-E and TMI aboard NASA's Aqua and TRMM spacecraft, respectively
  - Note that this technique is not a precipitation estimation algorithm but rather a means by which estimates from existing microwave rainfall algorithms can be combined. Therefore, this method is extremely flexible such that any precipitation estimates from any microwave satellite source can be incorporated.
- At times when microwave estimates are not available, the IR data may be used to fill in those data gaps

- Data available at: http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html

# CHIRPS

- Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)
- Combining models of terrain-induced precipitation enhancement with interpolated station data and satellite observations
- 30+ year quasi-global rainfall dataset
- starts in 1981 to near-present
- Spanning 50°S and 50°N (and all longitudes)
- 0.05° resolution (~ 5 km )

- The creation of CHIRPS has supported drought monitoring efforts by the USAID Famine Early Warning Systems Network (FEWS NET).
- Data available at: http://chg.geog.ucsb.edu/data/chirps/#_Data

- More information about CHIRPS here: http://pubs.usgs.gov/ds/832/pdf/ds832.pdf
  http://chg.geog.ucsb.edu/data/chirps/
  http://chg-wiki.geog.ucsb.edu/wiki/CHIRPS_FAQ
- To view the stations used in CHIRPS:

ftp://chg-ftpout.geog.ucsb.edu/pub/org/chg/products/CHIRPS-latest/qc/stations_used/monthly/

# SUMMARY OF SPPs

| Name | Period of Record | Spatial Resolution | Temporal Resolution |
| --- | --- | --- | --- |
| TMPA | Jan 1998 – April 2015 | 0.25 x 0.25 | 3-hrly |
| PERSIANN | March 2000 – Present | 0.25 x 0.25 | 6-hrly |
| CMORPH | December 2002 – Present | 0.25 x 0.25 | 3-hrly |
| IMERG | March 2014 – Present | 0.1 x 0.1 | Half hrly |
| CHIRPS | 1981 – near present | 0.05 x 0.05 | Daily |

# REVIEW

- Understanding and performing hydrologic modeling to the best of our ability is paramount to decision making however:
  - Models typically require station data to drive, calibrate, and validate models
  - Satellite precipitation products can be used to fill in station data gaps or replace *in situ* data entirely
    - However:
      - Satellite precipitation products have their own accuracy / dependability issues

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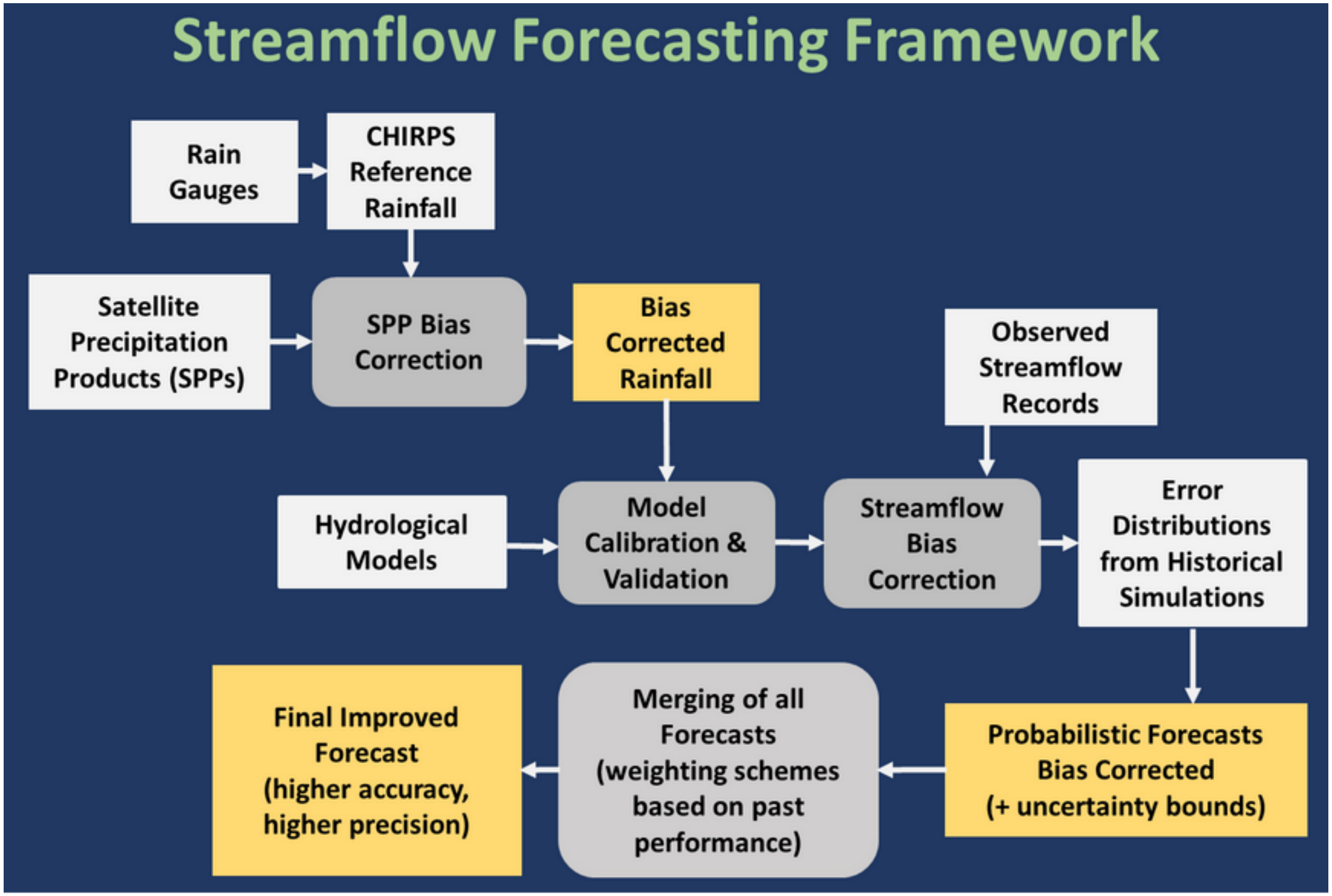
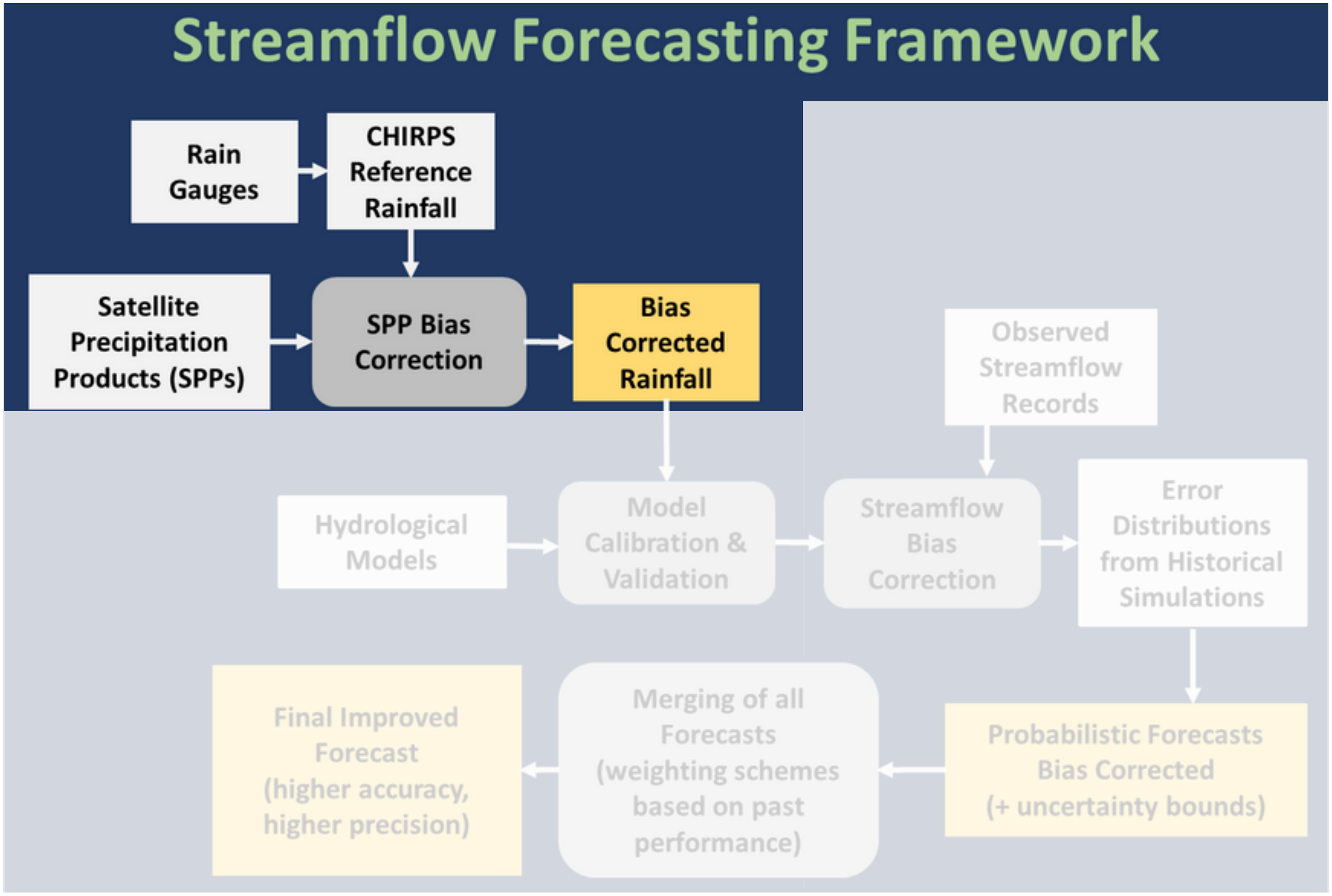
# SWAAT PLATFORM OVERVIEW




Streamflow Forecasting Framework
Rain Gauges
CHIRPS Reference Rainfall
Satellite Precipitation Products (SPPs)
SPP Bias Correction
Bias Corrected Rainfall
Observed Streamflow Records
Hydrological Models
Model Calibration & Validation
Streamflow Bias Correction
Error Distributions from Historical Simulations
Final Improved Forecast (higher accuracy, higher precision)
Merging of all Forecasts (weighting schemes based on past performance)
Probabilistic Forecasts Bias Corrected (+ uncertainty bounds)

# BIAS CORRECTION METHODS

1. Linear Scaling
2. Quantile Mapping
3. Principle Components Analysis

MATLAB

4. Intensity Scaling
5. Power Transformation

Fang, G., Yang, J., Chen, Y. N., and Zammit, C.: Comparing bias correction methods in downscaling meteorological variables for a hydrologic impact study in an arid area in China. Hydrol. Earth Syst. Sci., 19(6), 2547-2559, doi: 10.5194/hess-19-2547-2015, 2015.

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} R

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# LINEAR SCALING

- Aims to match the monthly mean of the values to be corrected with that of the observed means

1. Total monthly precipitation is accumulated from the observed data and the satellite product per pixel
2. Mean precipitation is determined for each of the months per pixel
3. Bias factor is calculated

## LINEAR SCALING

$$F_{mon} = \frac{P_{mon}^{OBS}}{P_{mon}^{SAT}}$$

$F_{mon}$ = Monthly Bias Factor

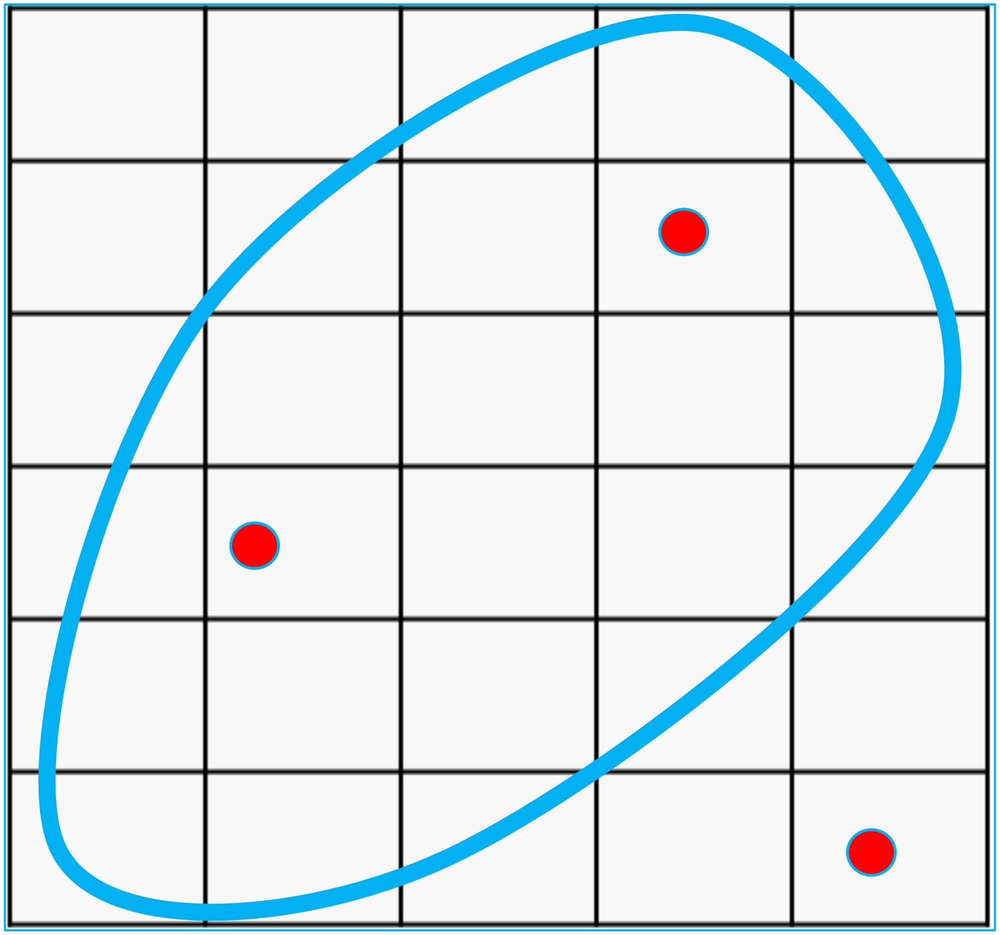
$P_{mon}^{OBS}$ = Observed Mean Monthly Precipitation

$P_{mon}^{SAT}$ = Satellite Mean Monthly Precipitation

# LINEAR SCALING

1. Point based

- Station data corrects a grid based satellite precipitation product



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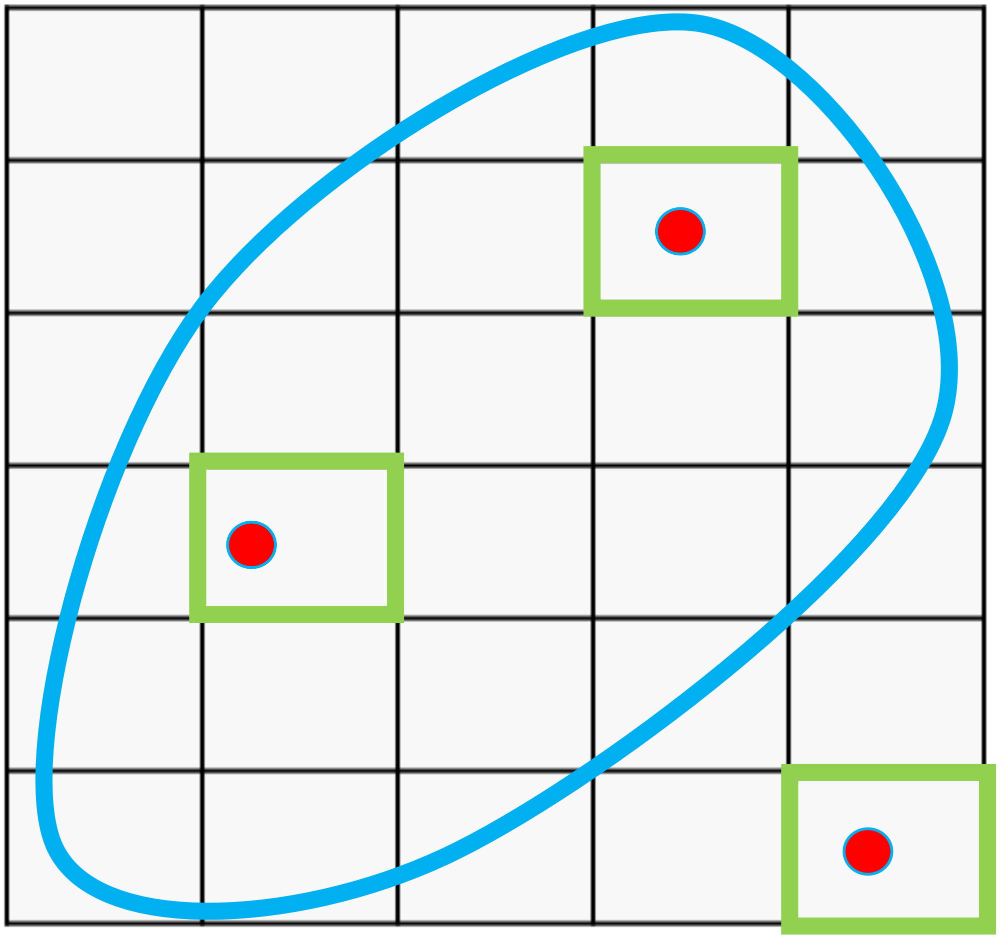
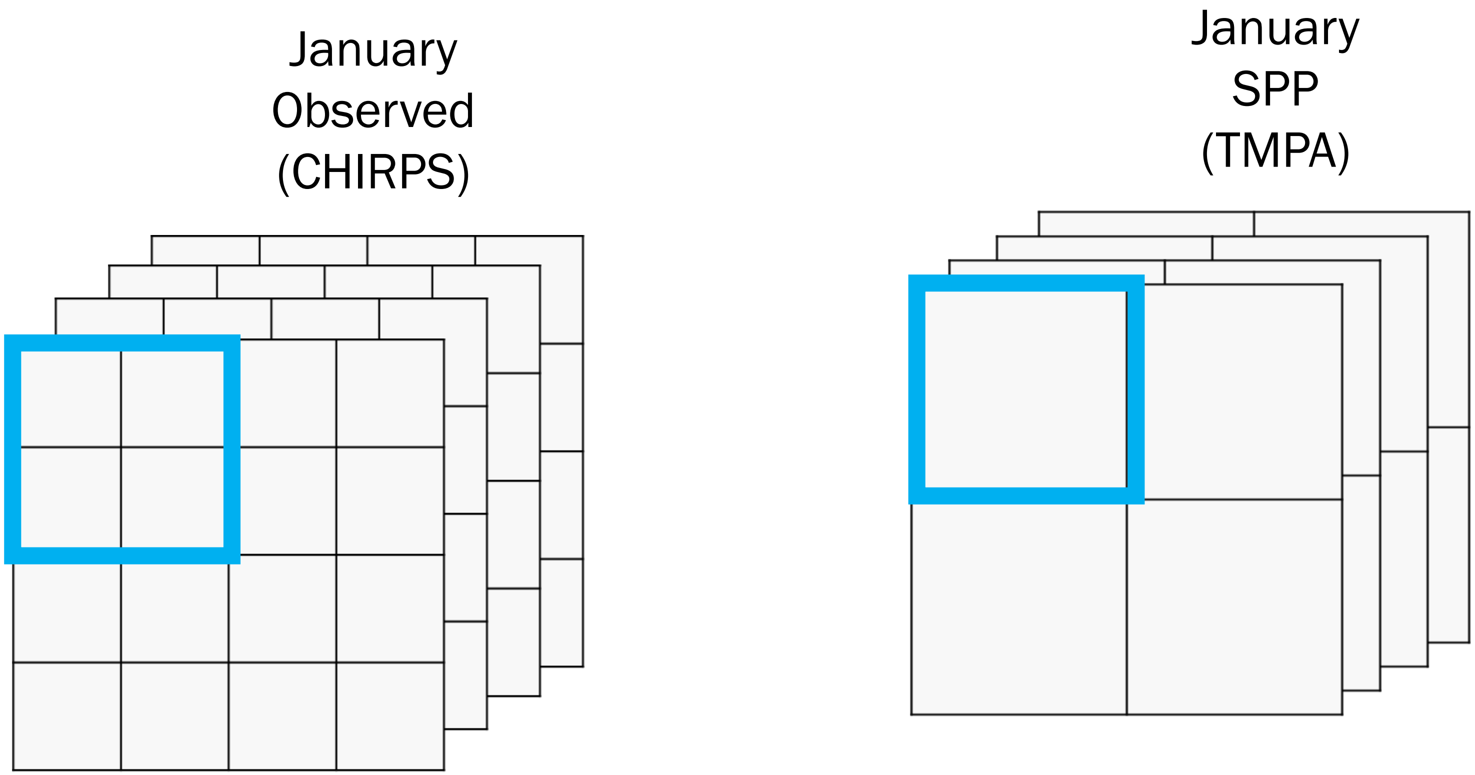


# LINEAR SCALING

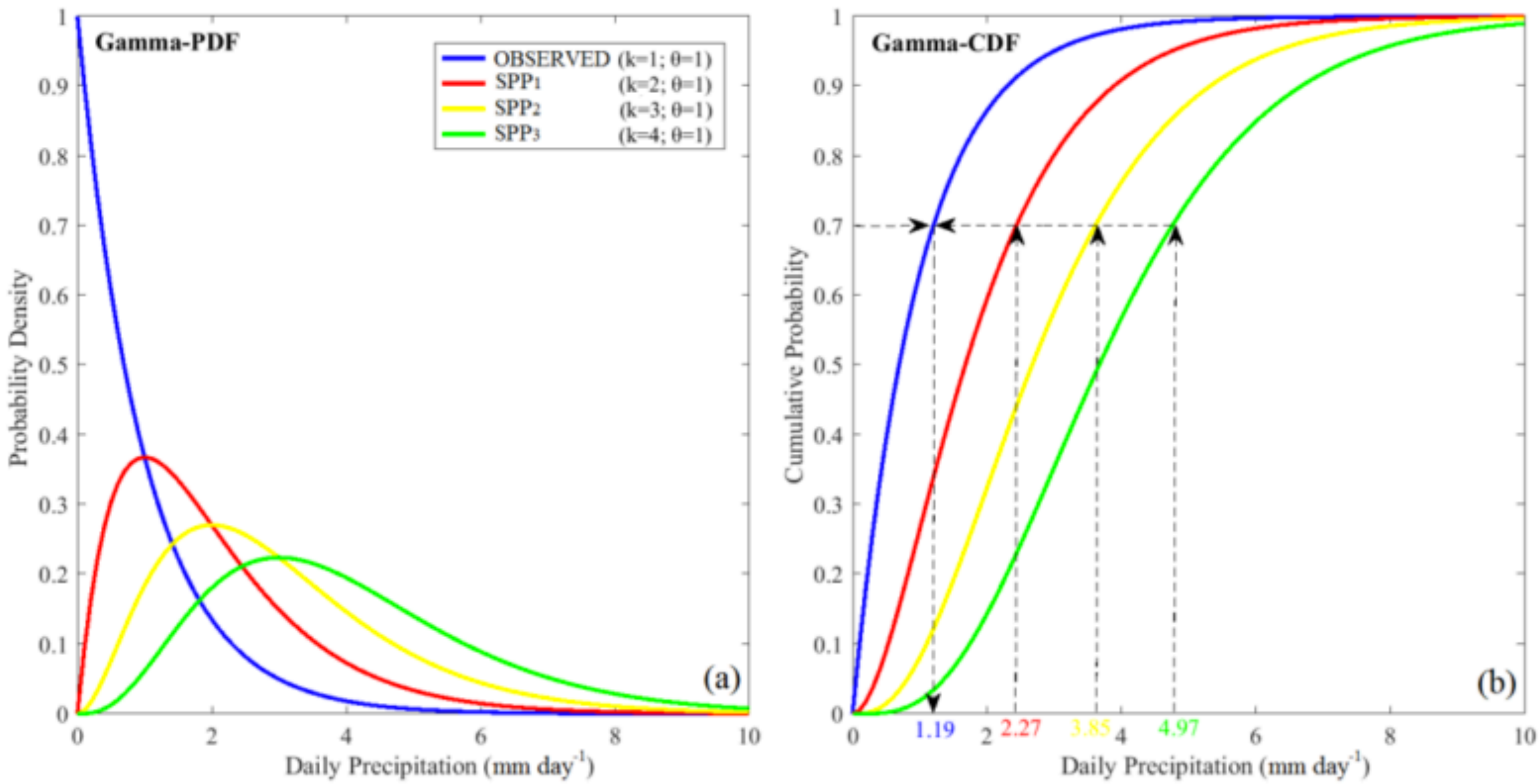
2. Grid Based

- Gridded data corrects a grid based satellite precipitation product
  - CHIRPS
  - Interpolated station data
- Downscales the SPP to the CHIRPS resolution



# QUANTILE MAPPING

- Non parametric method that is applicable for all possible distributions of precipitation
- Originates from empirical transformation (ThemeBl et al., 2012)
- Corrects for the errors in the shape of the distribution and is therefore capable to correct errors in variability as well as mean
- Satellite and CHIRPS data covering the same period of record are used to create a "quantile map" of each population
- Gamma Probability Density Function (Gamma-PDF) is considered for precipitation distribution
- The Gamma-PDF is fitted for CHIRPS and satellite products at every grid-point and for all 12 months separately (k parameter)
- The Gamma Cumulative Distribution Function (Gamma-CDF) is used for determining probability associated with precipitation




a)The Gamma Probability Density Function (Gamma-PDF) is applied assuming different shapes (k parameter) for each dataset.

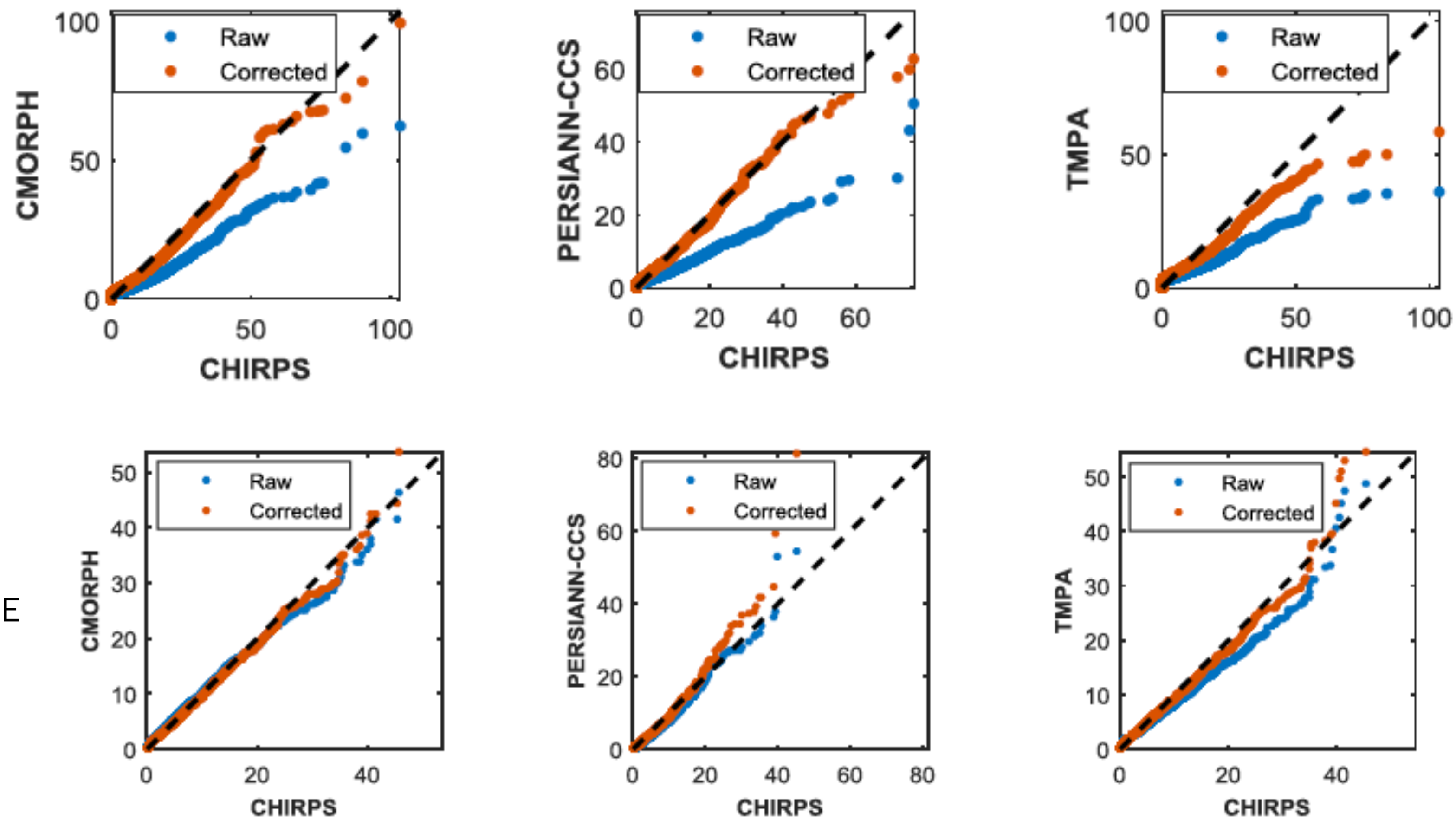
b) The respective Gamma Cumulative Distribution Function (Gamma-CDF) for CHIRPS and SPPs is matched for a Probability (P=0.7) using the Inverse Gamma Function, which is finally used to calculate the bias-corrected daily satellite precipitation estimates.

From Valdés-Pineda et al. (2016), Open Access Article in Hydrology and Earth System Sciences Discussions

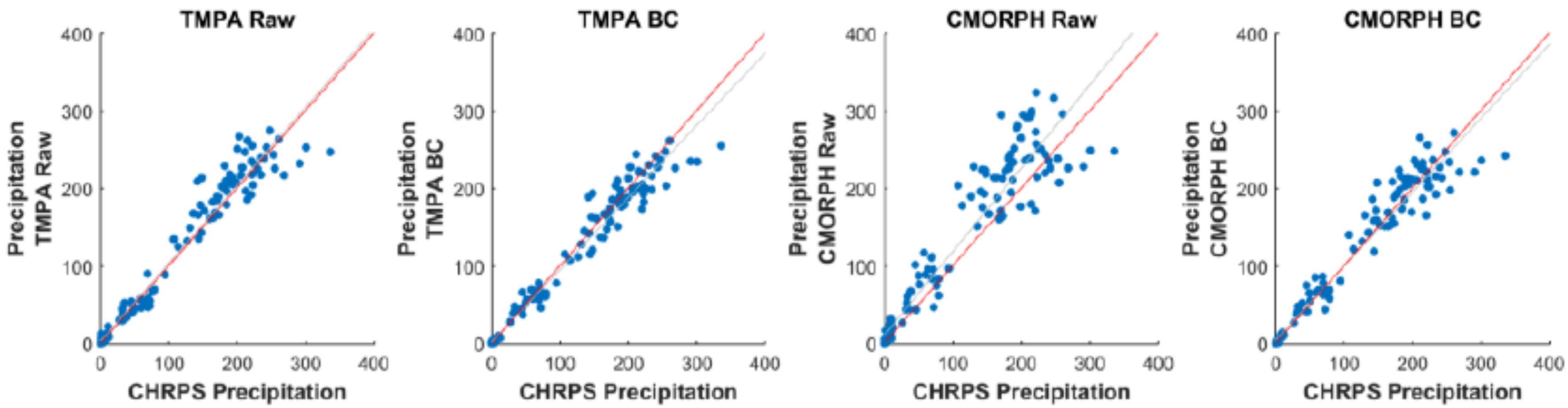
# RESULTS: LINEAR SCALING

MARA BASIN

TEKEZE BASIN




Used with author's permission (Roy et al. 2016)

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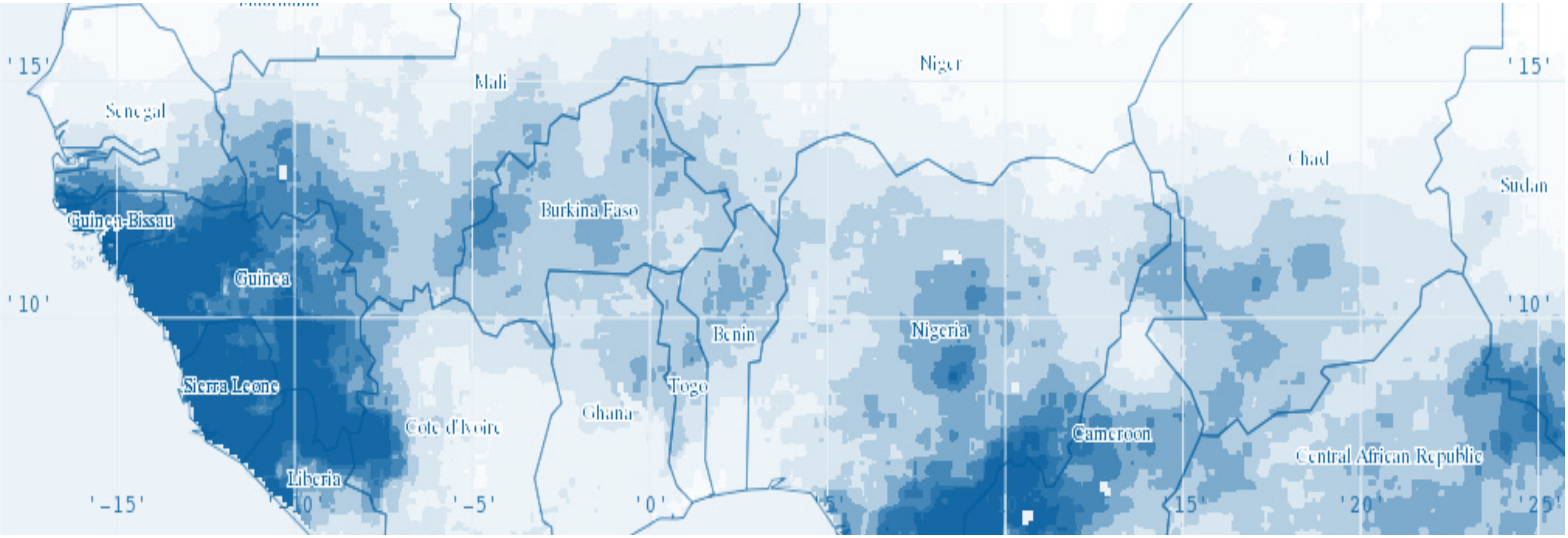


# Thank you

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