

INTRODUCTION ON BIAS CORRECTION METHODS

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ICIMOD



- 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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I. Introduction and discussion of Satellite Precipitation Products and Bias Correction Methods

a. Introduction to Precipitation Remote Sensing

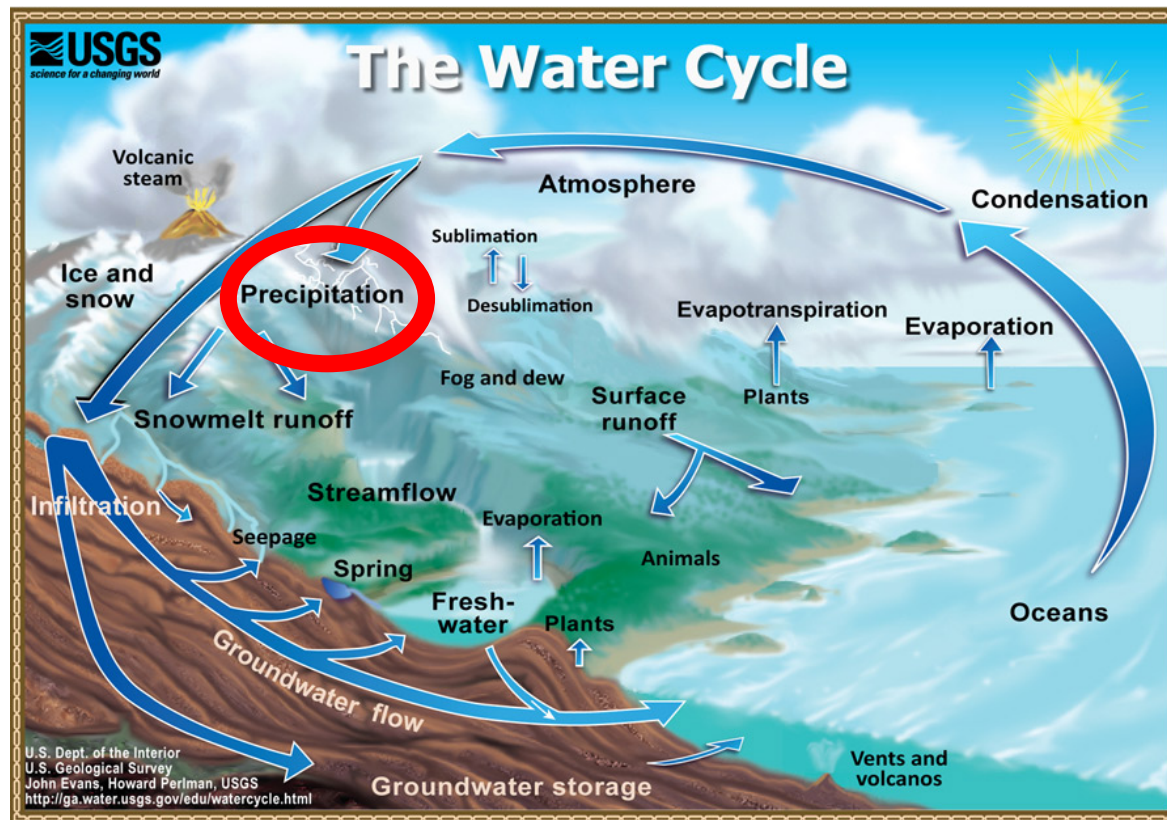
******adapted from ARSET webinar materials******

- 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

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

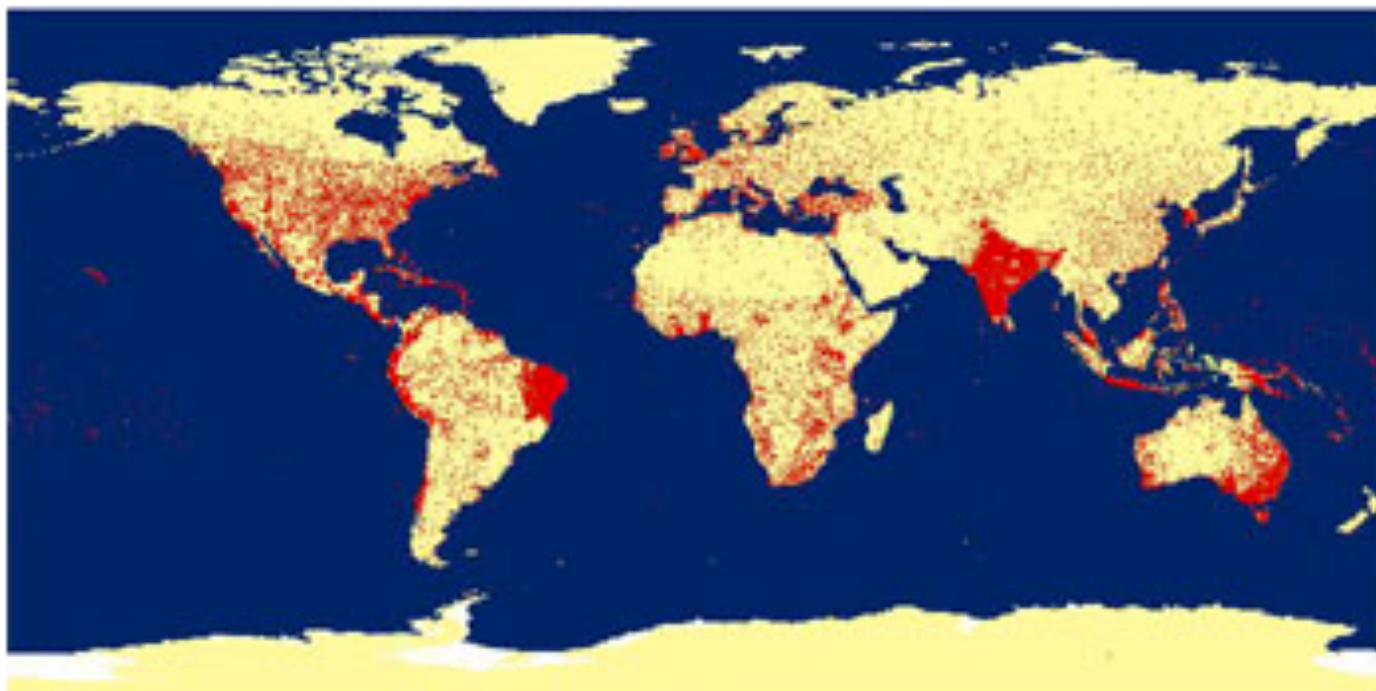


Water availability = (Precipitation + runoff in) – (ET + runoff out + infiltration)

- 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



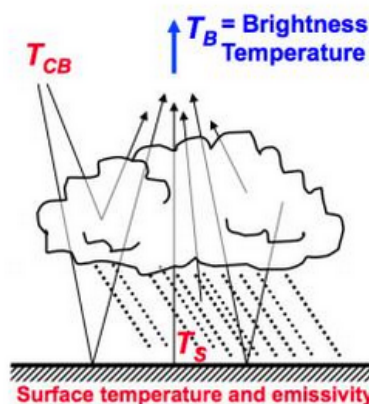
Global distribution of rain gauges incorporated into the Global Hydroclimatic data sets (GHCN)

Source: NOAA

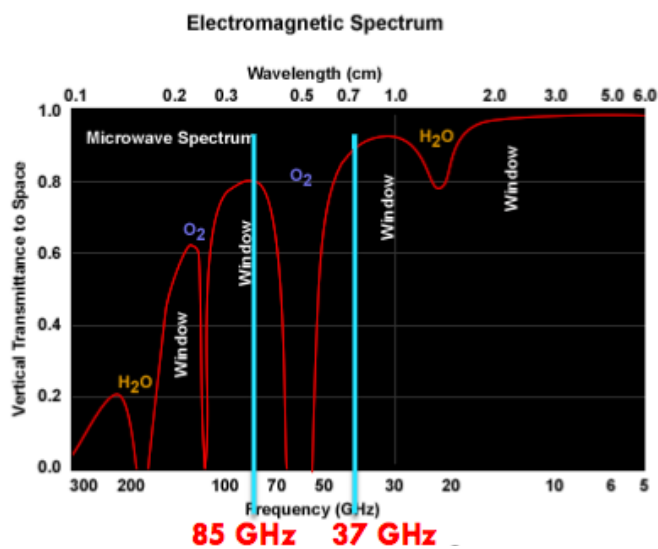
Passive Remote Sensing

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

Sources: surface emission, cosmic background, rain emission



Source: NASA ARSET

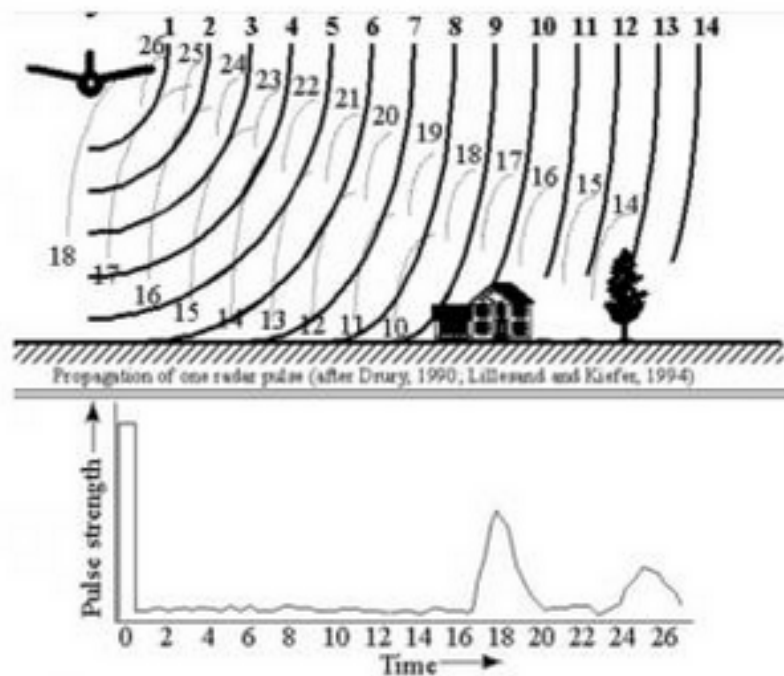


Source: NASA ARSET

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

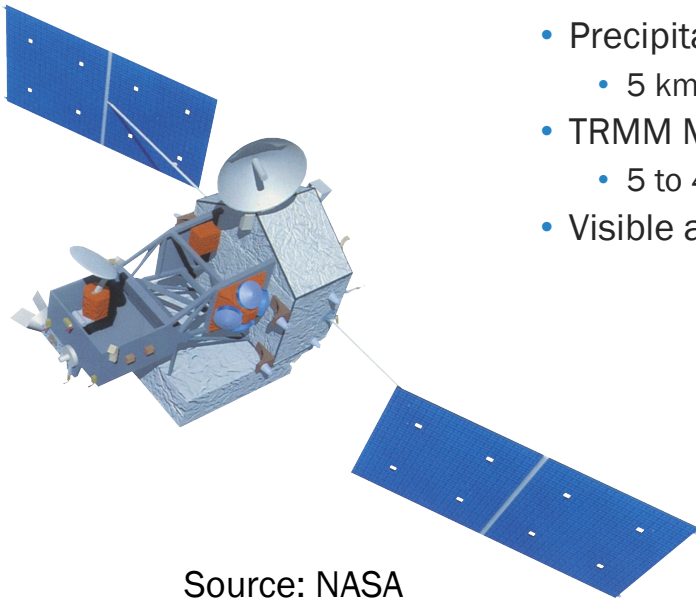
Active Remote Sensing

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



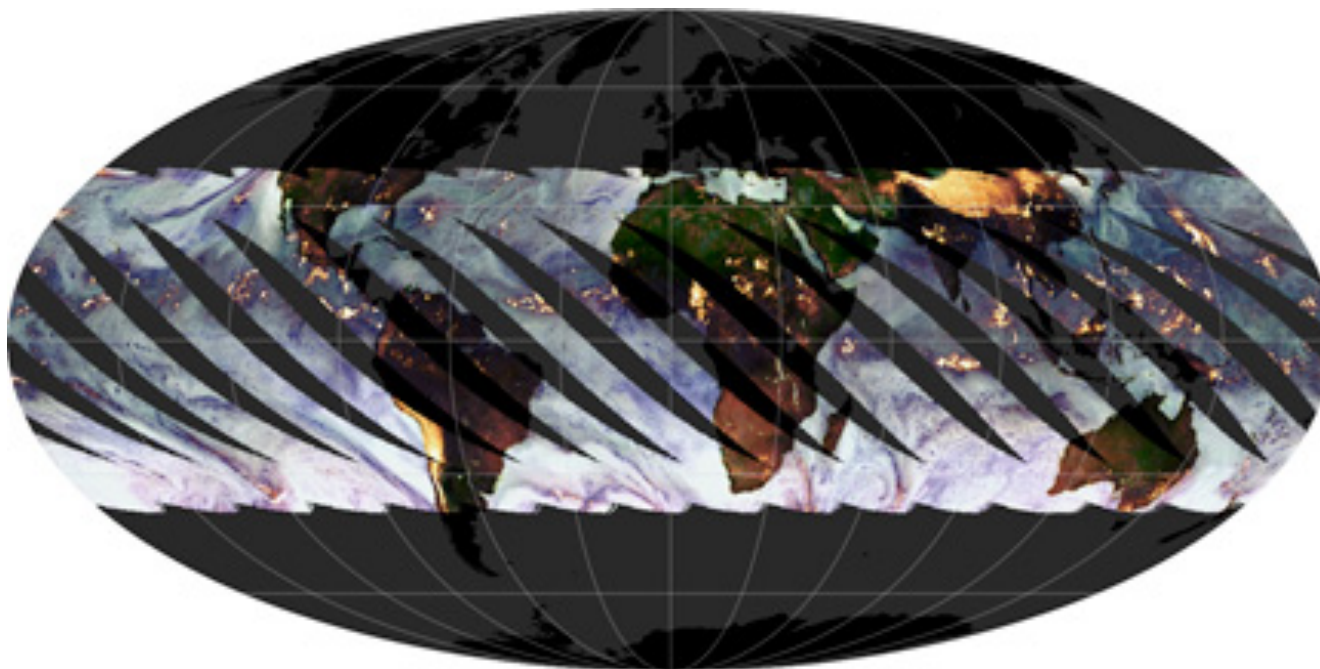
Source: NASA ARSET

- 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

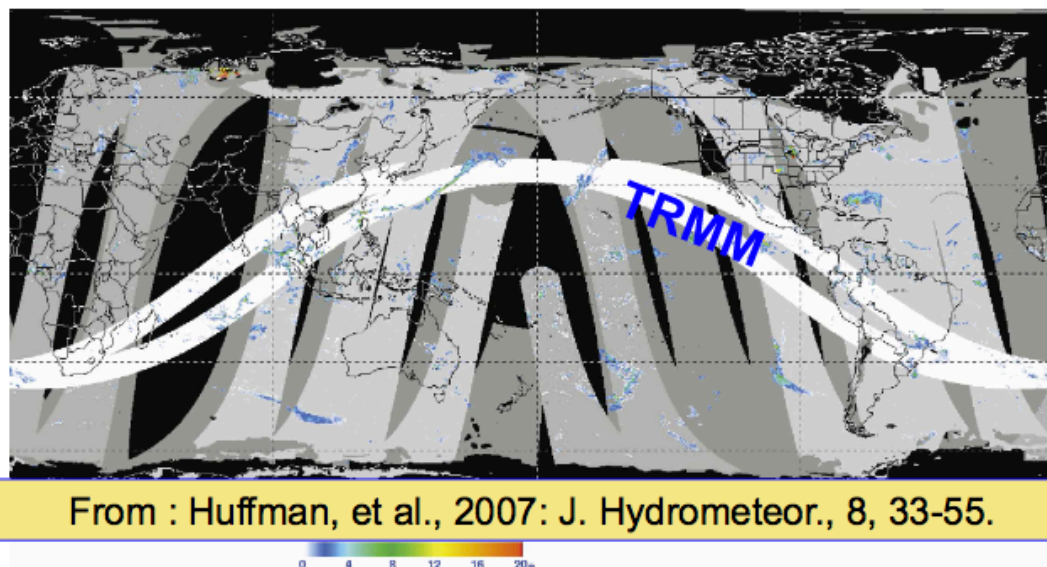
- Strengths: High pixel resolutions, accurate measurements
- Limitations: No global, diurnal coverage on a daily basis, only measures liquid precipitation



Source: NASA

- **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>

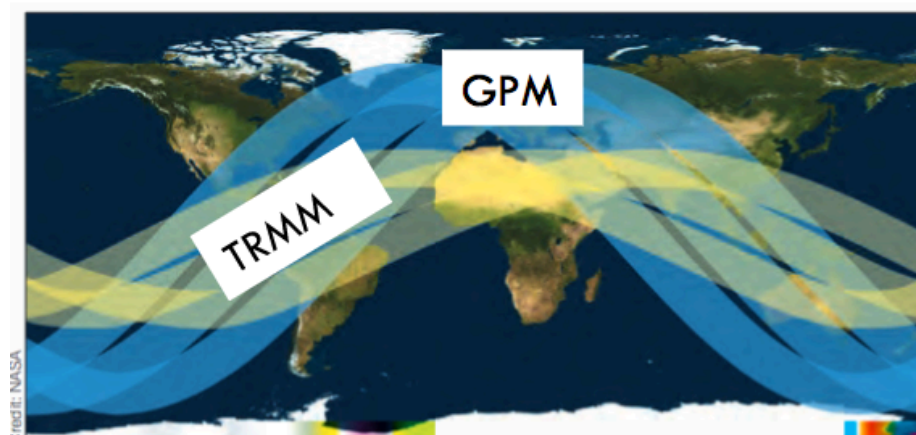
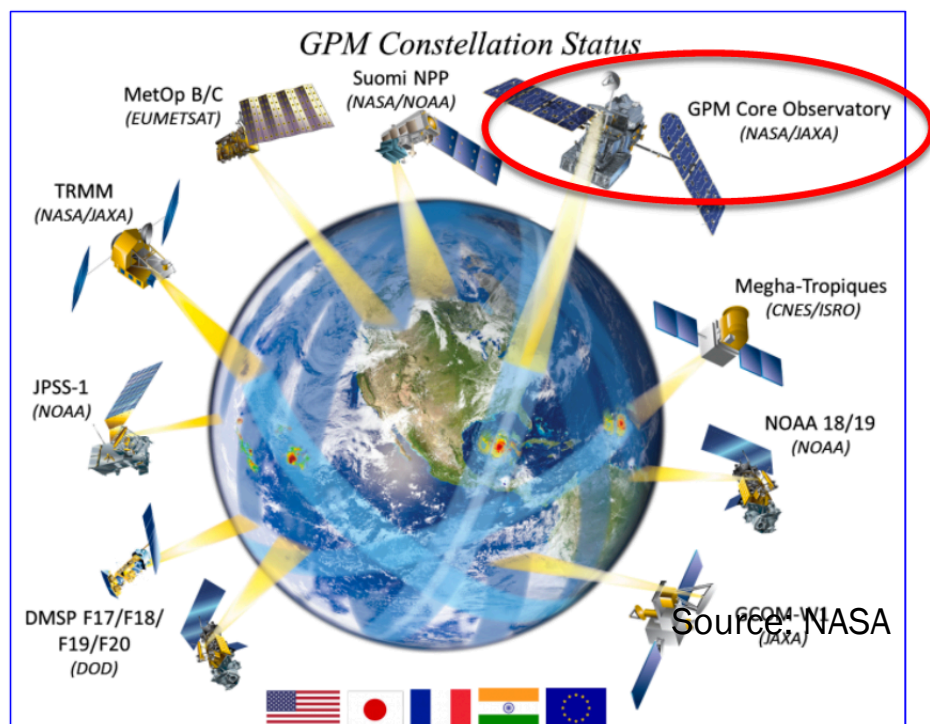


Microwave Measurements in TMPA for the 3-hour period at 0 UTC on 25th May 2004

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

• 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>

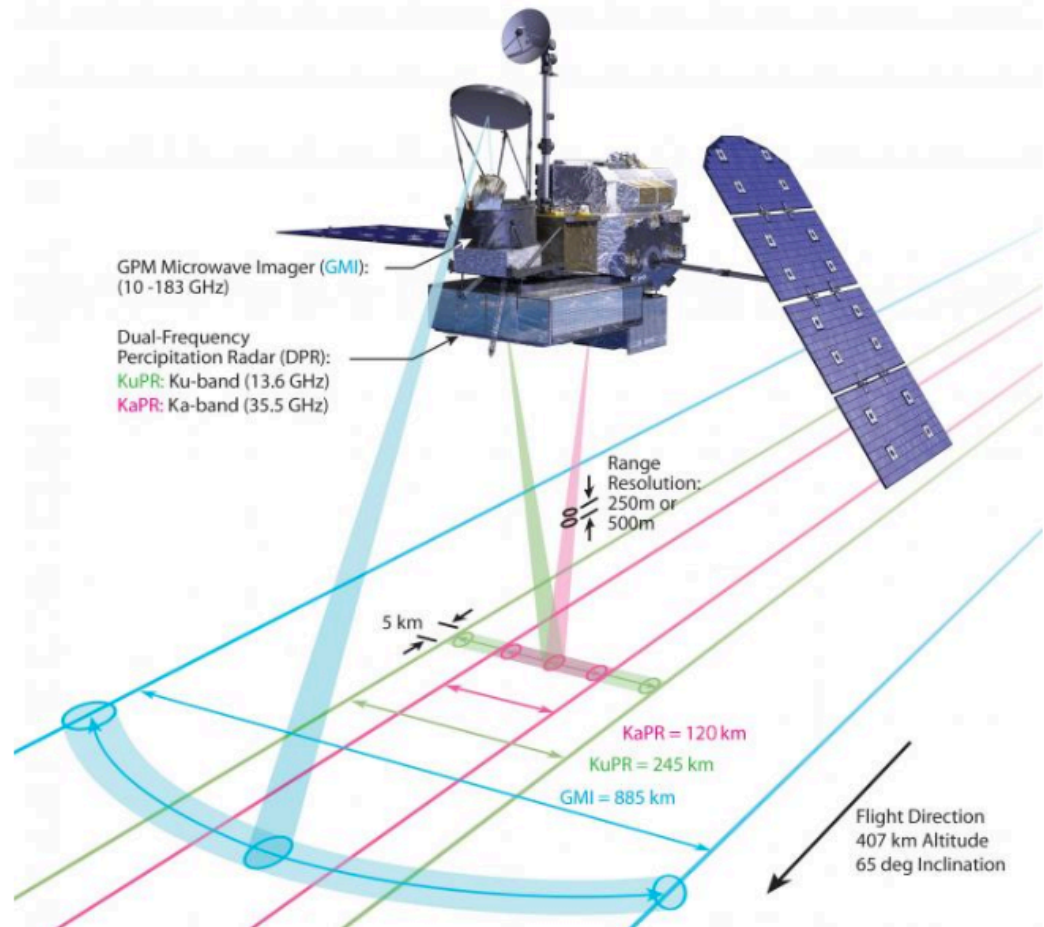


the area covered by three TRMM orbits [yellow] versus orbits of the GPM Core Observatory [blue]

Source: NASA ARSET

Multiple Sensors:

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



Source: NASA ARSET

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

- 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 60°S to 60°N	Global 50°S to 50°N

- 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.

- Spatial Scale: $0.25^{\circ} \times 0.25^{\circ}$ 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://chrdata.eng.uci.edu/>

- 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

- 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

- 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

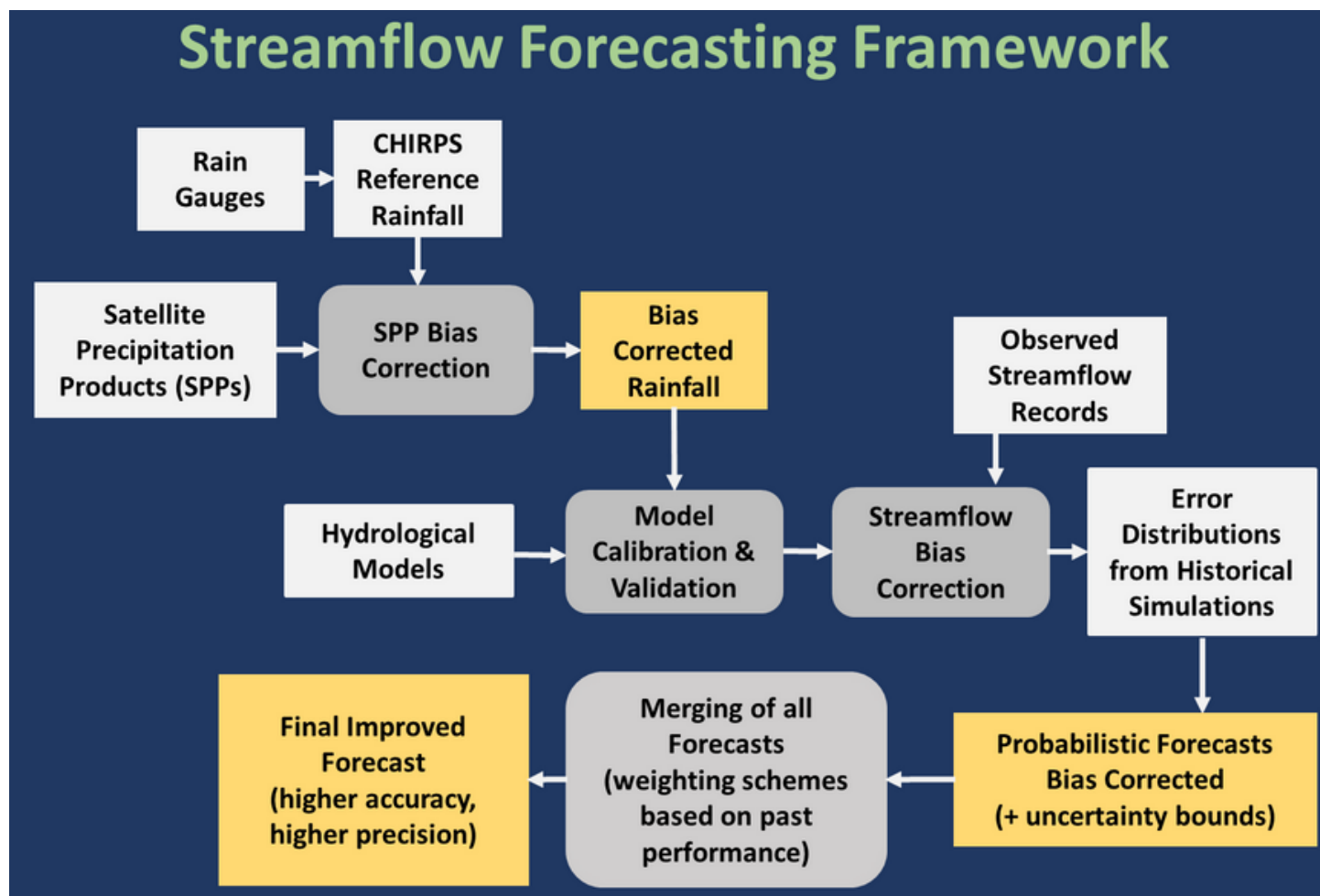
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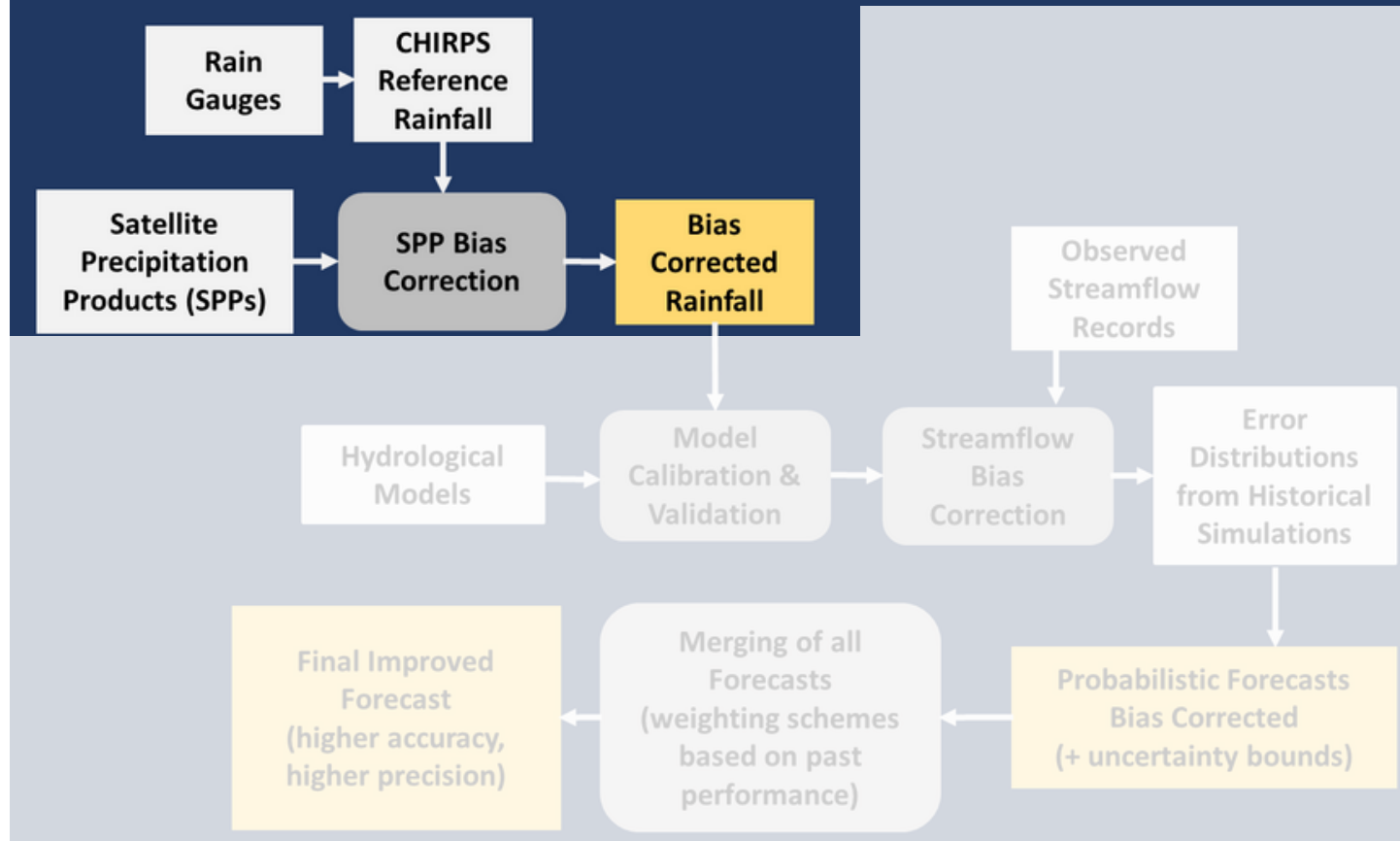
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Streamflow Forecasting Framework



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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- 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

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

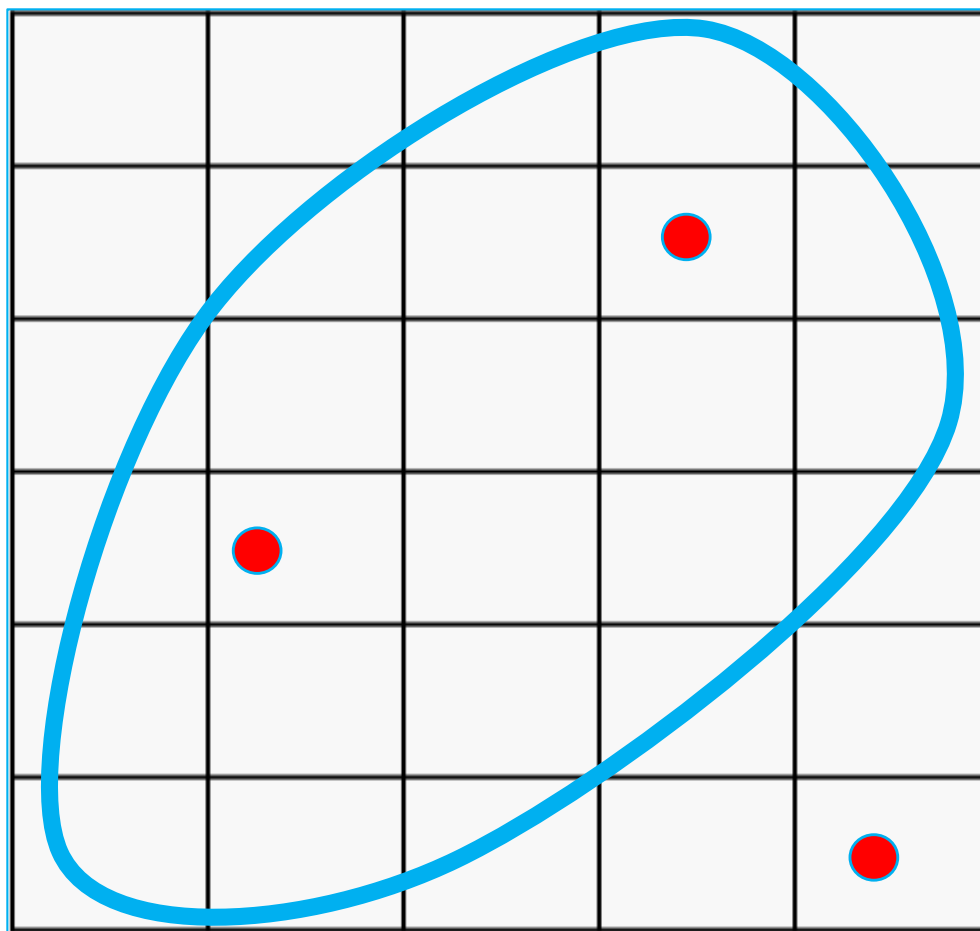
F_{mon} = Monthly Bias Factor

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

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

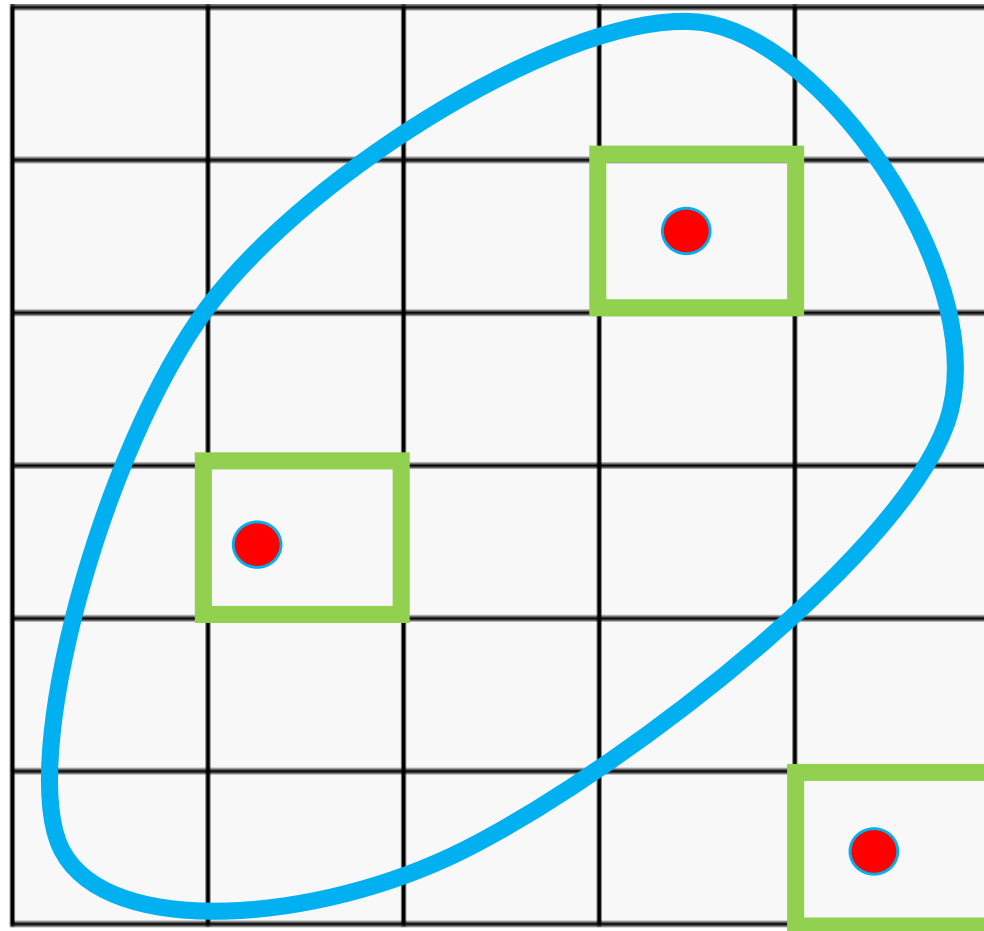
1. Point based

- Station data corrects a grid based satellite precipitation product



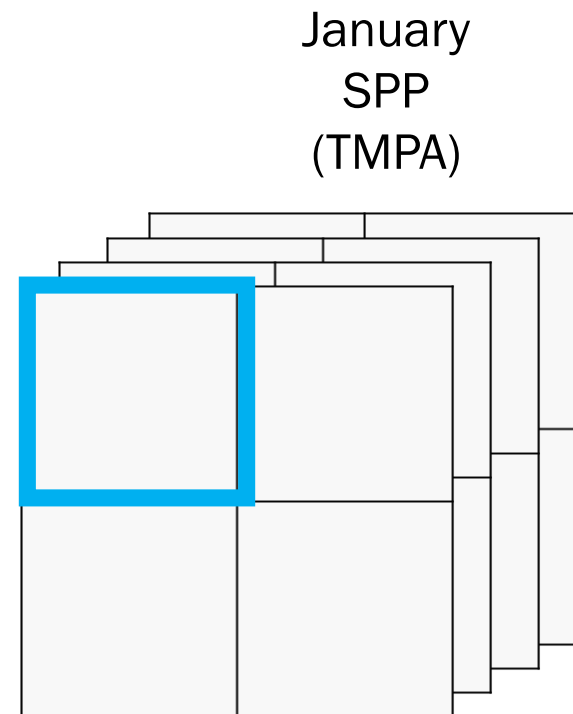
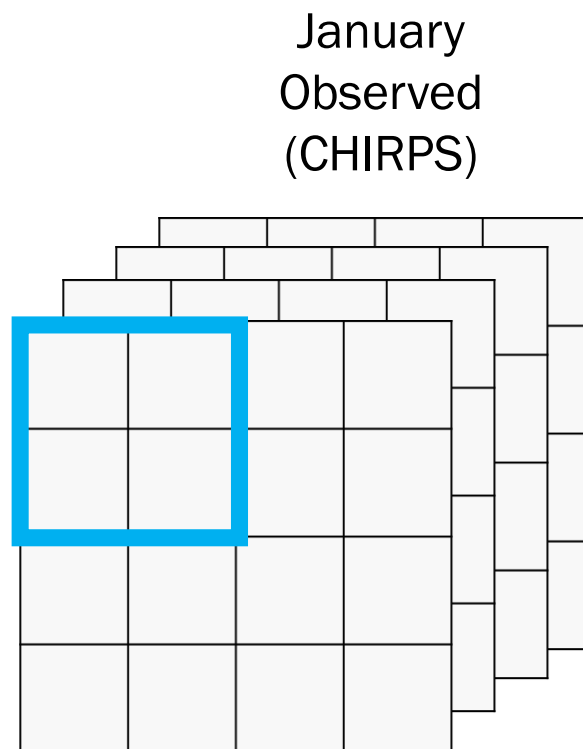
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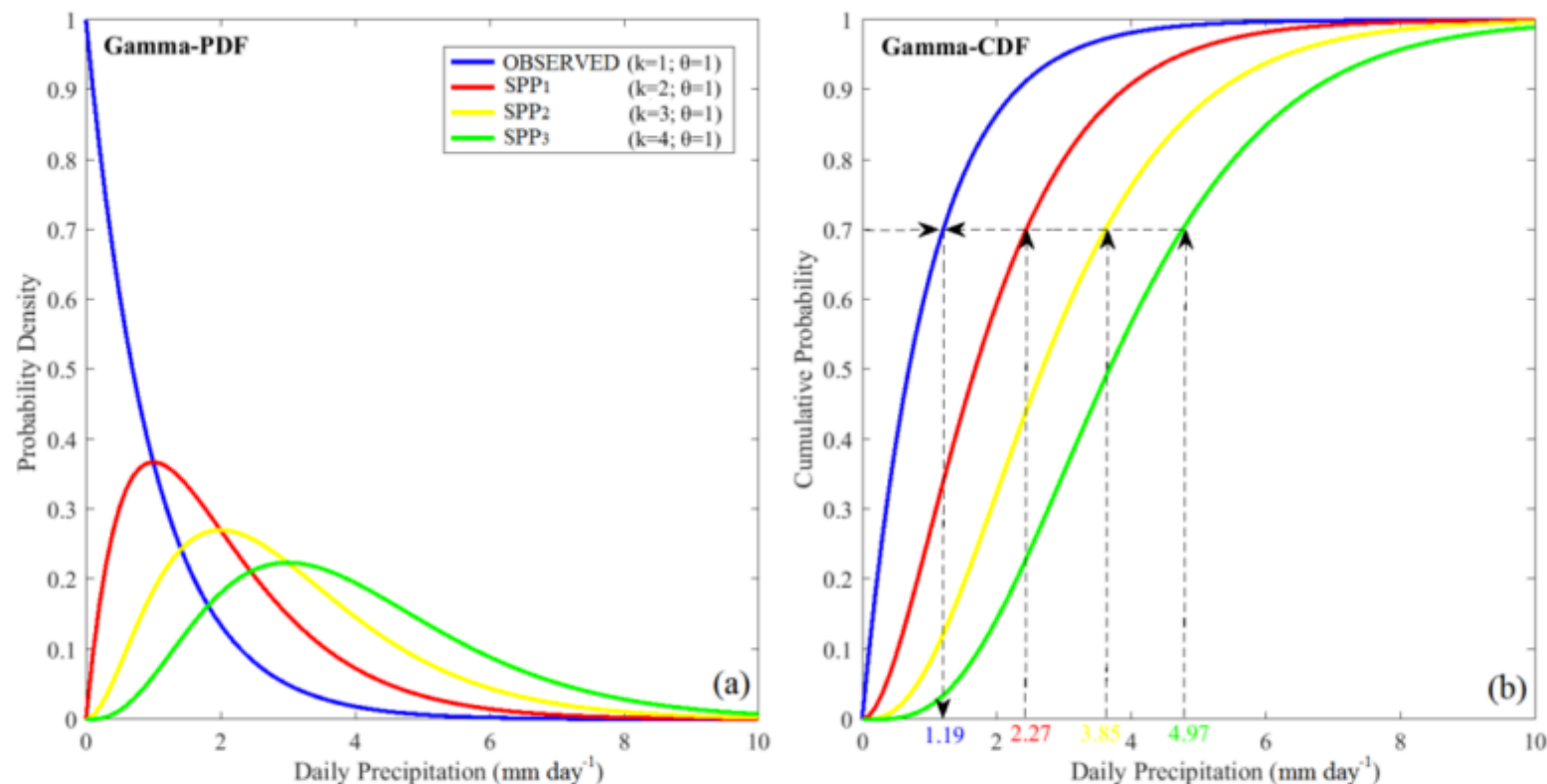


2. Grid Based

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



- 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



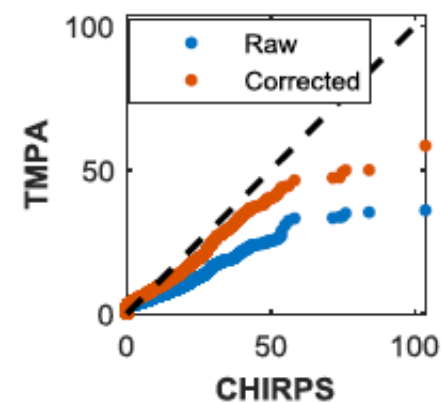
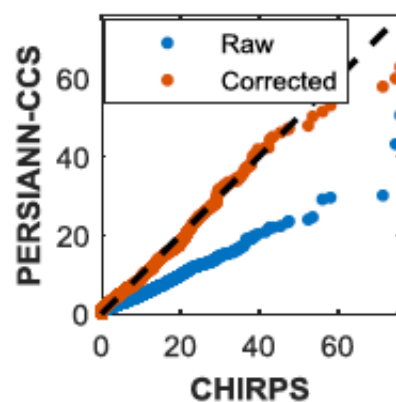
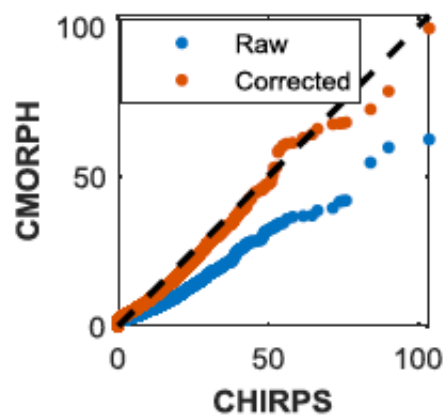
a) The Gamma Probability Density Function (Gamma-PDF) is applied assuming different shapes (k parameter) for each dataset.

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.

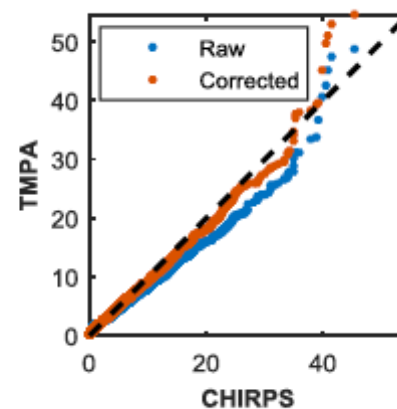
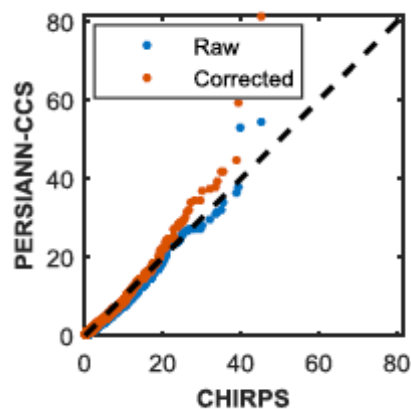
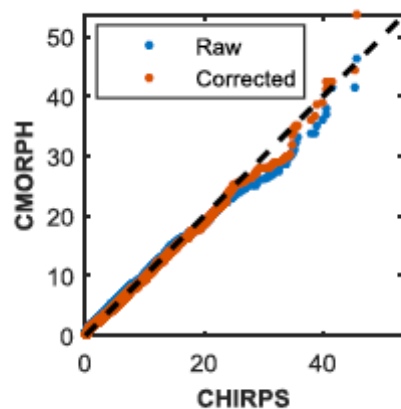
From Valdés-Pineda et al. (2016), Open Access Article in Hydrology and Earth System Sciences Discussions

RESULTS: LINEAR SCALING

MARA
BASIN

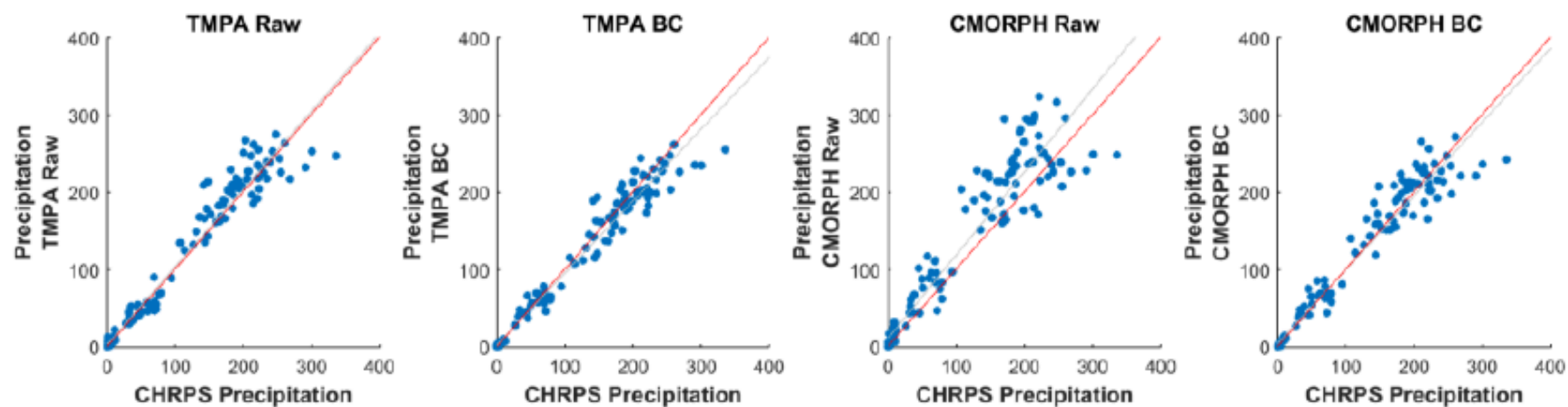


TEKEZE
BASIN



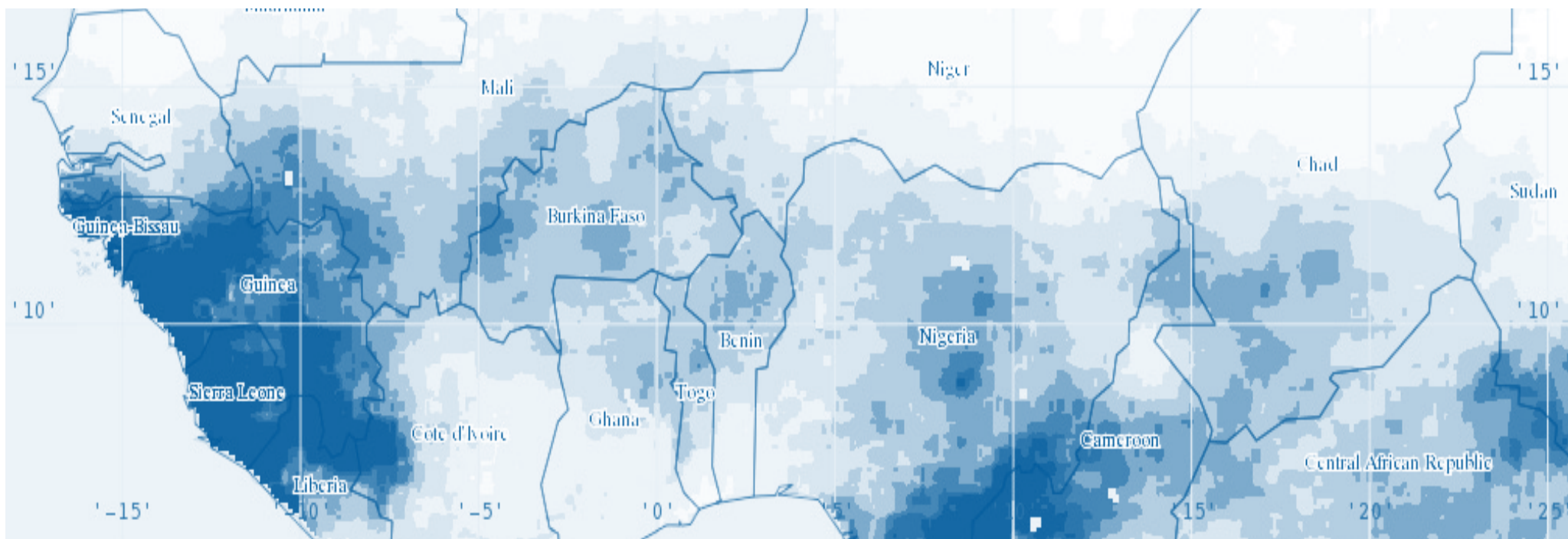
Used with author's permission (Roy et al. 2016)

RESULTS: QUANTILE MAPPING



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- <https://arset.gsfc.nasa.gov/disasters/webinars/global-precipitation>
- http://chrs.web.uci.edu/research/satellite_precipitation/activities00.html
- 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, 2015.
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Thank you

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