Virtual Workshop on "Precipitation Estimation from LEO Satellites: Retrieval and Applications"

# ASSESSING ERRORS IN SATELLITE-BASED PRECIPITATION PRODUCTS: PAST ACHIEVEMENTS, PRESENT SITUATION, FUTURE


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# INTRO

Precipitation products that are based on satellite retrievals are affected by errors and uncertainty

Errors: unintended, generally small and known problems that can (and should) be fixed

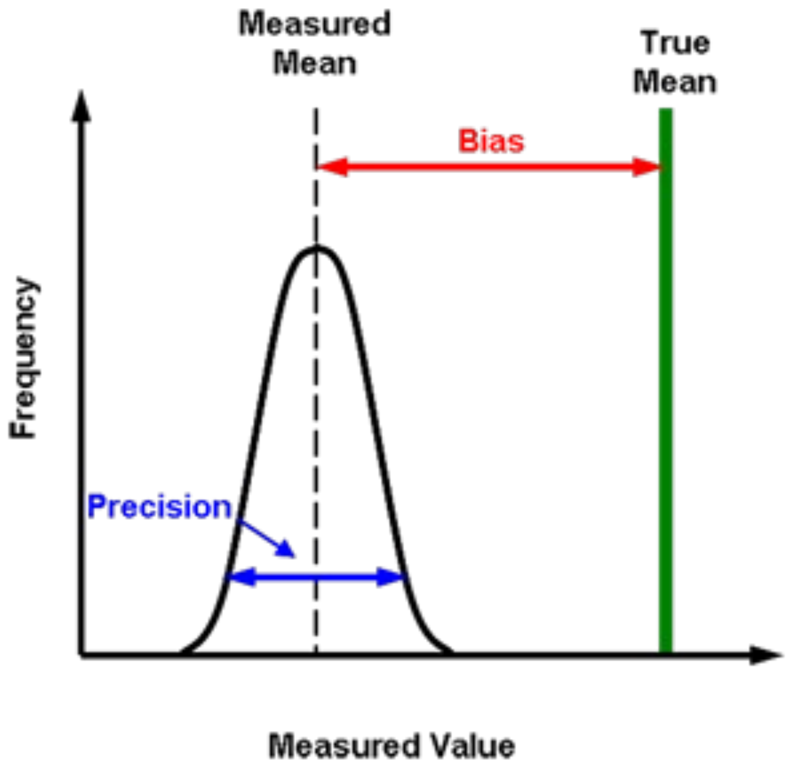
Uncertainties: those we do not (fully) understand

Quantifying such errors and uncertainties is essential for the appropriate use of satellite precipitation products in any applications

# ERROR vs UNCERTAINTY

Error:

- Commonly defined as the difference between the satellite product and a reference considered to be the "truth"
- Characterized by:
  - a *systematic component* – a shift of the mean from the reference
  - a *random component* – which varies in an unpredictable way



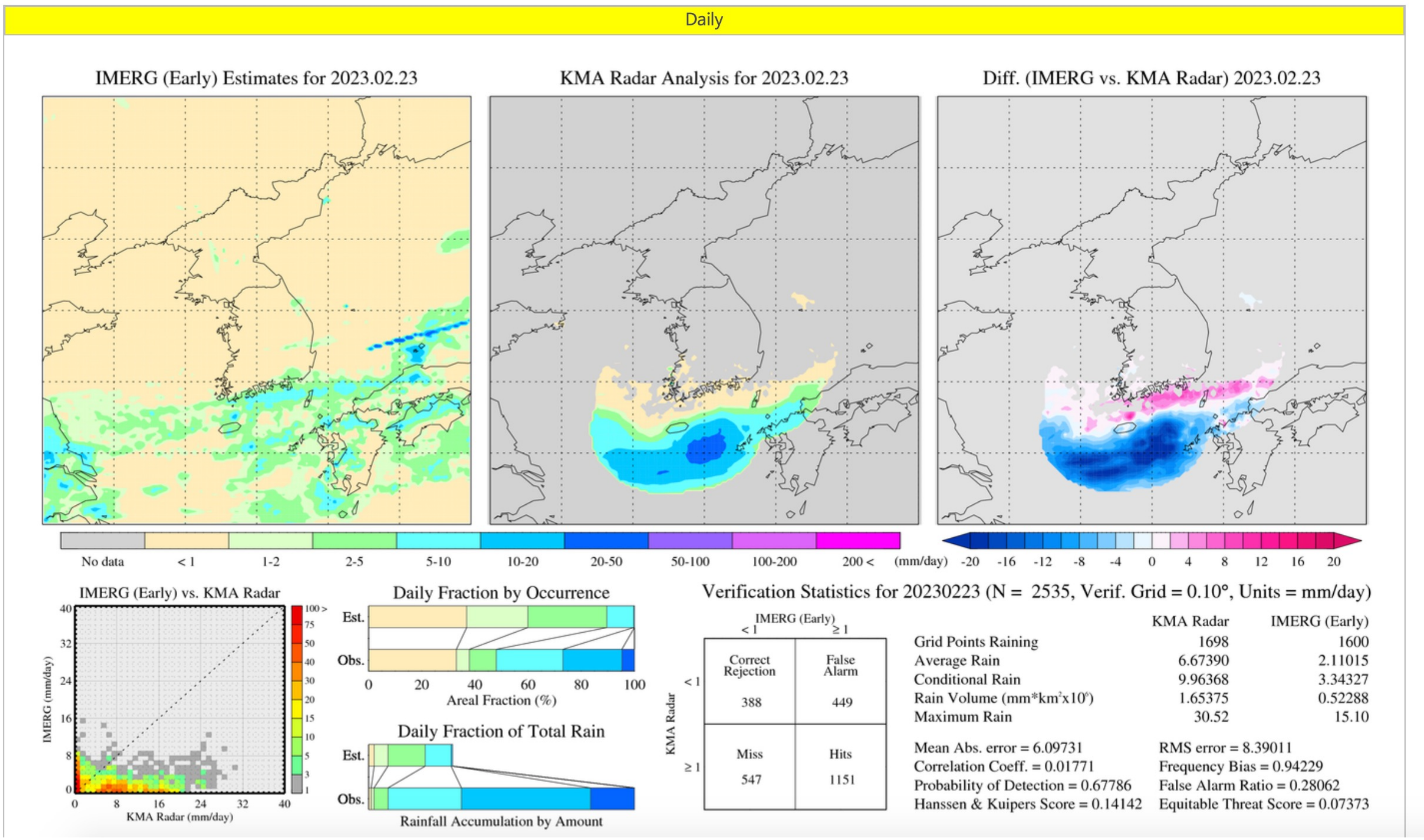

Uncertainty: Represents the range of values within which the true value lies with some level of confidence

# WHAT TYPE OF ERRORS/UNCERTAINTIES?

- **Sensor errors and uncertainties**: physical limitations of engineering and knowledge
- **Retrieval scheme errors and uncertainties**: assumptions, information utilization, and the mechanisms of the retrieval algorithm itself
- **Product errors and uncertainties**: progression from instantaneous to daily/monthly products, temporal and spatial sampling, and inheritance of errors and uncertainties

# HOW DO WE ASSESS SATELLITE PRODUCTS?

Quantifying the "distance" between the satellite estimate and the true precipitation → VALIDATION

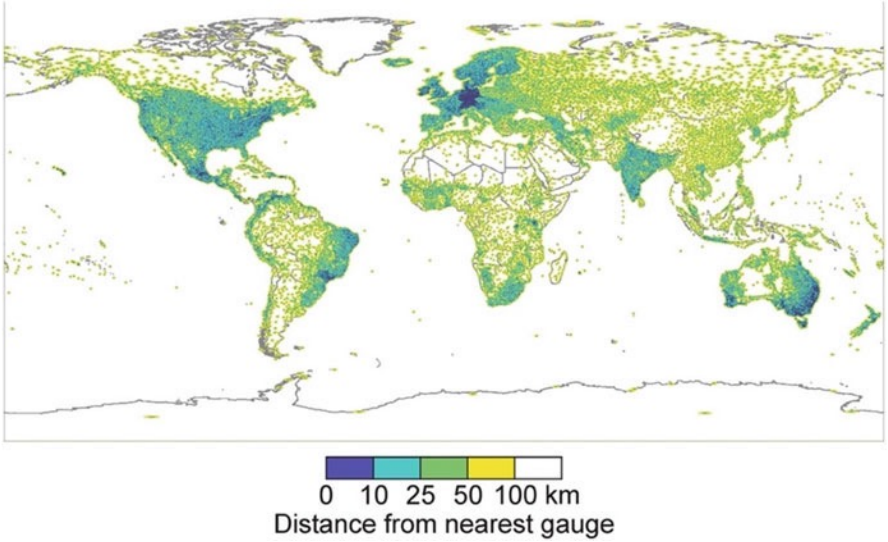



http://ipwg.isac.cnr.it/calval.html; http://nmsc.kma.go.kr/enhome/html/ipwg/viewer/selectIpwg.do

# REFERENCE? WHAT REFERENCE?

- However, we do not have knowledge of the “true” precipitation field, therefore validation is commonly carried out using an independent reference or benchmark, such as observations from rain gauges and/or ground radars, assuming that they are characterized by a much lower error than the satellite-based products.

- <u>Rain gauges</u>: directly provide a cumulative estimate, typically unrepresentative of the areal and instantaneous precipitation observed by satellites.




- <u>Ground radars</u>: provide a “snapshot” type of measurements with spatial resolution more similar to satellites. However, radars also provide an indirect rainfall estimate and are prone to errors and significant biases.

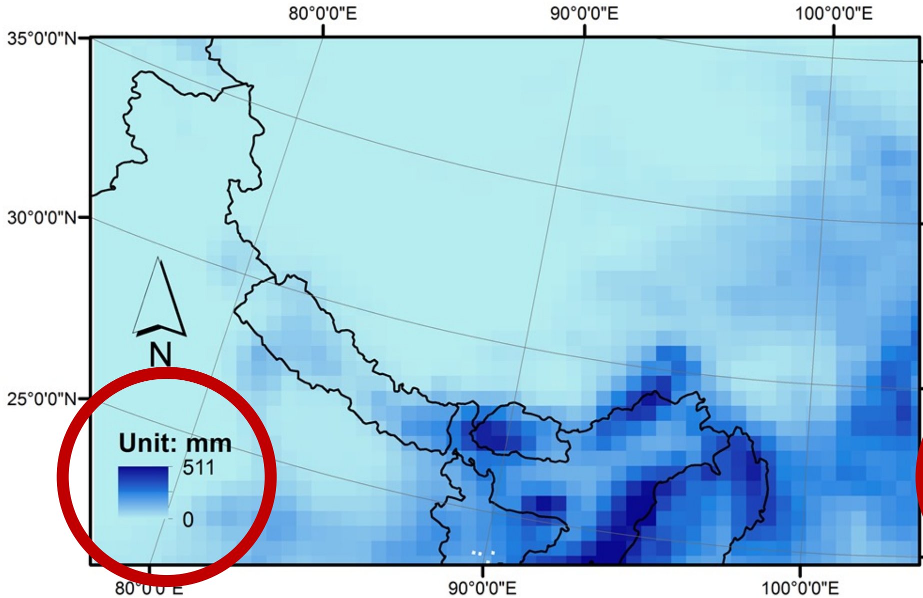
# REFERENCE? WHAT REFERENCE?

- Satellite-based radars: global and high resolution. Issues:
  - As calibrators of the passive micro- wave (PMW) sensors that equip most of the satellite platforms in the GPM constellation, they are used to populate the retrieval databases and train the PMW retrieval algorithms.
  - *Spatial discrepancies*. Radars offer orbital precipitation estimates at a spatial resolution from 1.5-km to 5-km (footprint size), which needs to be spatially re-gridded for com- parison with multi-satellite merged products like IMERG (10km).
  - Radar observations are near-instantaneous and therefore would have to be aggregated to the temporal scale of the merged products.

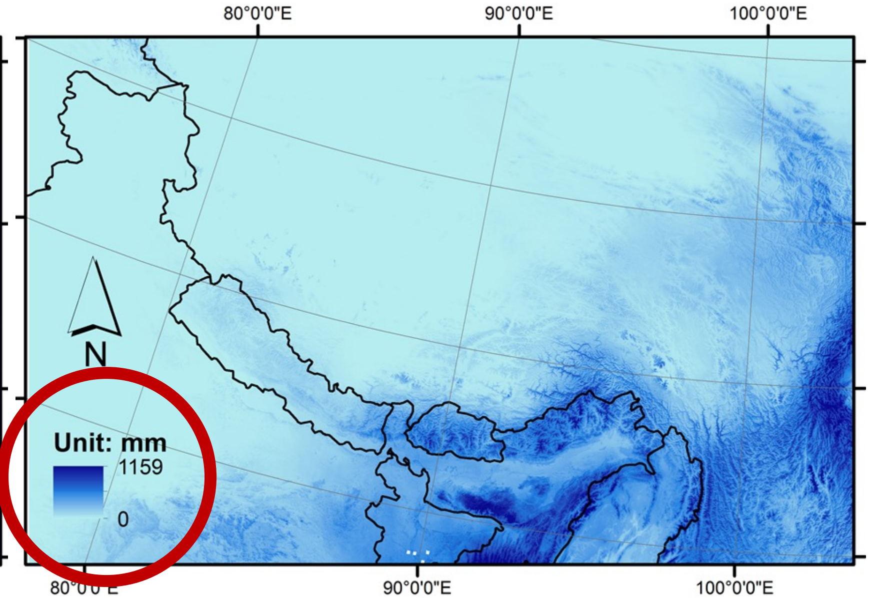
# MORE?

- Uncertainty is added to the validation process by the need to *map* and *aggregate* the datasets onto a common grid.
- This may result in reduced spatial detail and reduced maximum rain rates (i.e., smoothing of extreme events).

MERRA2 Original Resolution (~50km) – Oct 2007




Downscaled MERRA2 (1km) – Oct 2007

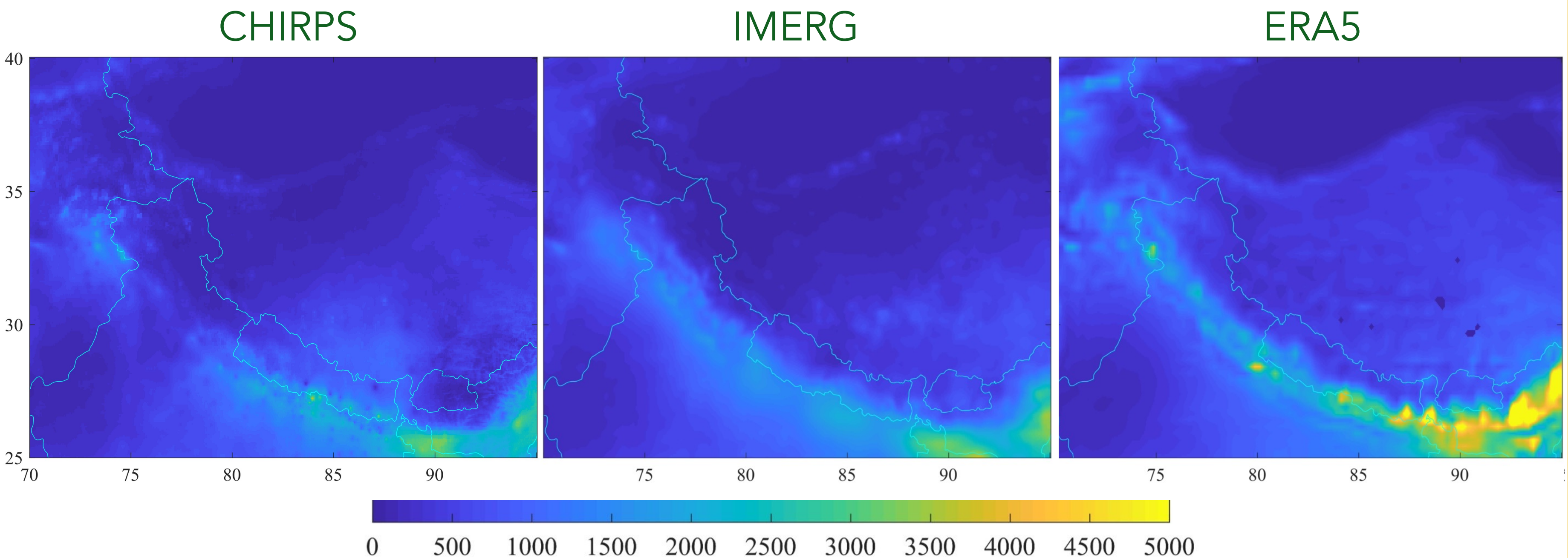



- It is also important to note that validation results depend on the spatial scale at which validation is performed, with coarser grids generally producing better results.

# VALIDATING PRECIPITATION DATASETS

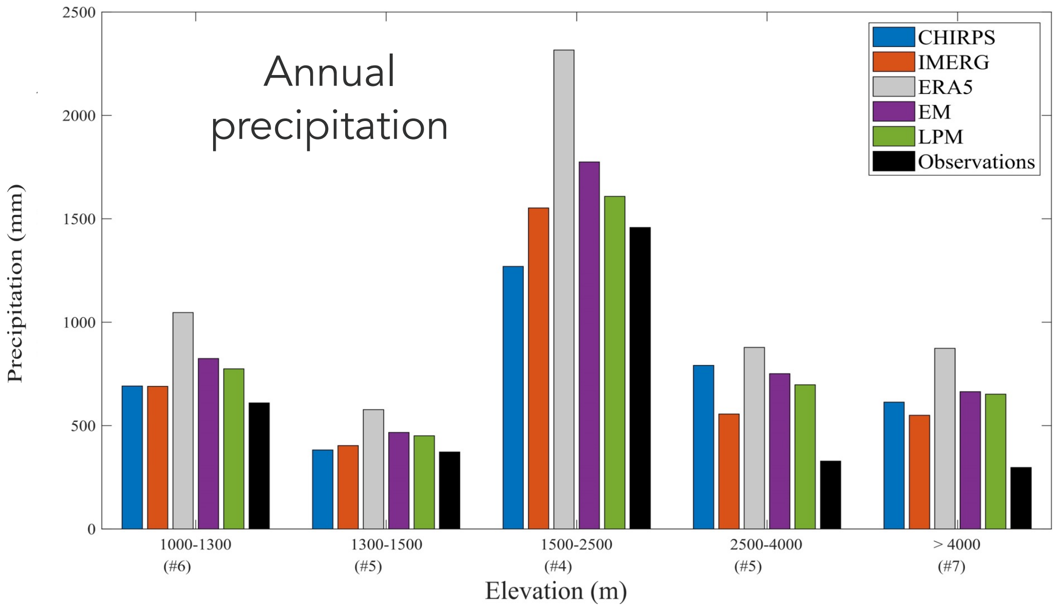
- Products:
  - CHIRPS
  - IMERG
  - ERA5
  - Ground-based observations

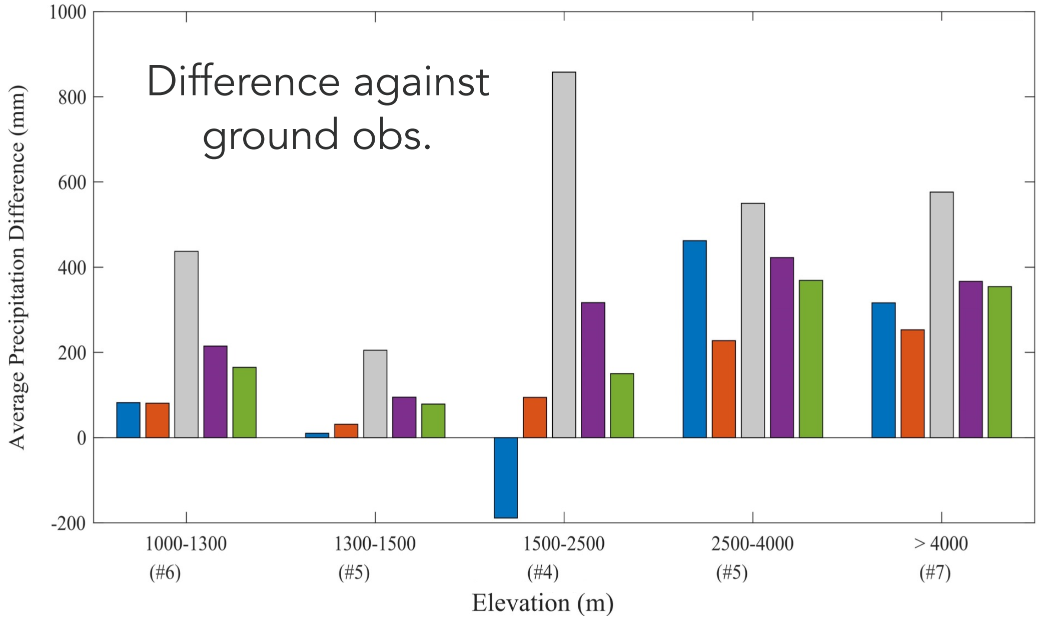
- 2001-2008; Daily/5km




Annual accumulation
(average during 2001-2008) in mm

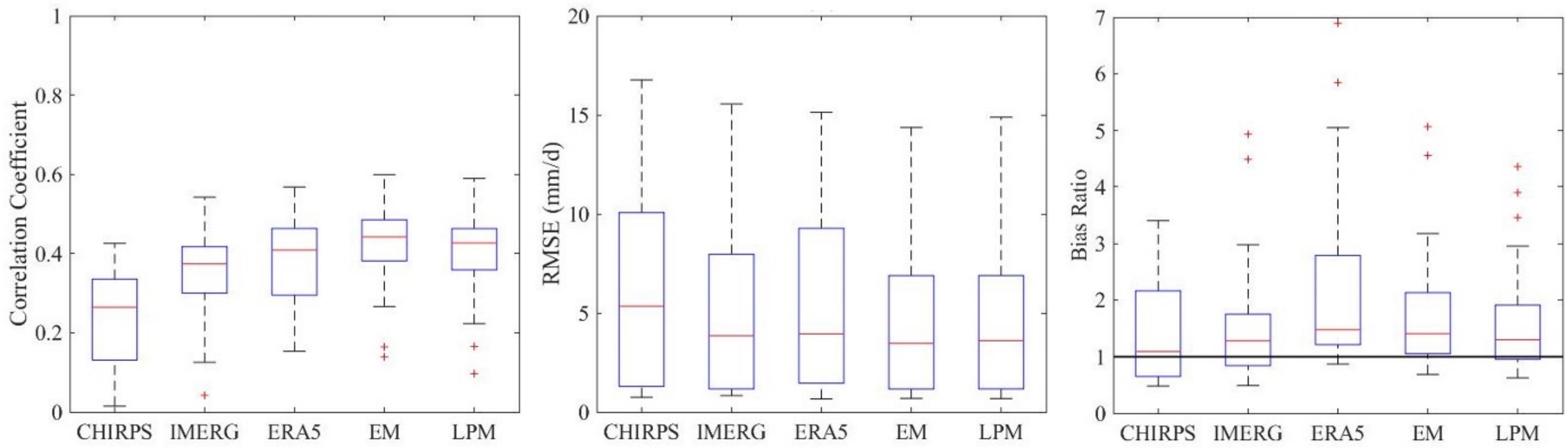
# VALIDATING PRECIPITATION DATASETS



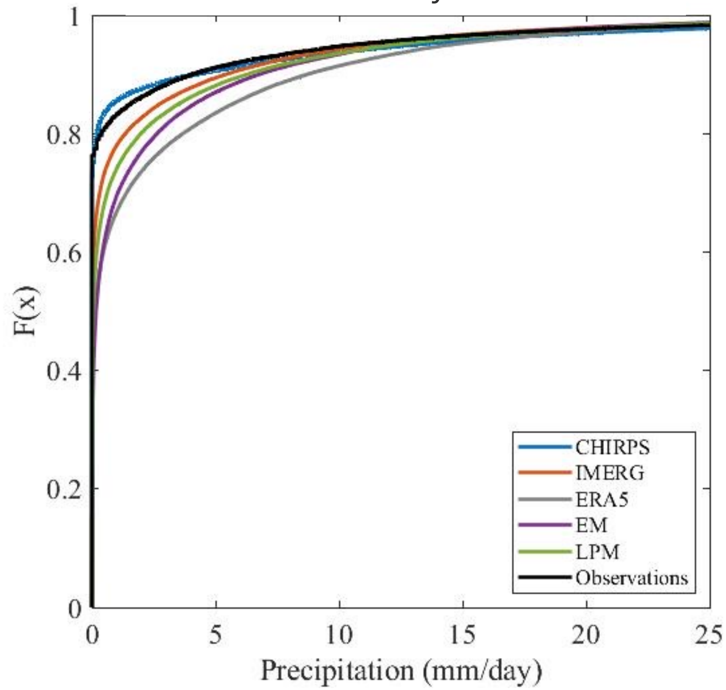




- 27ground stations
- Higher values at mid-elevations (1500-2500m)
- Overestimation of annual average is particularly pronounced at elevation ranges higher than 2500m

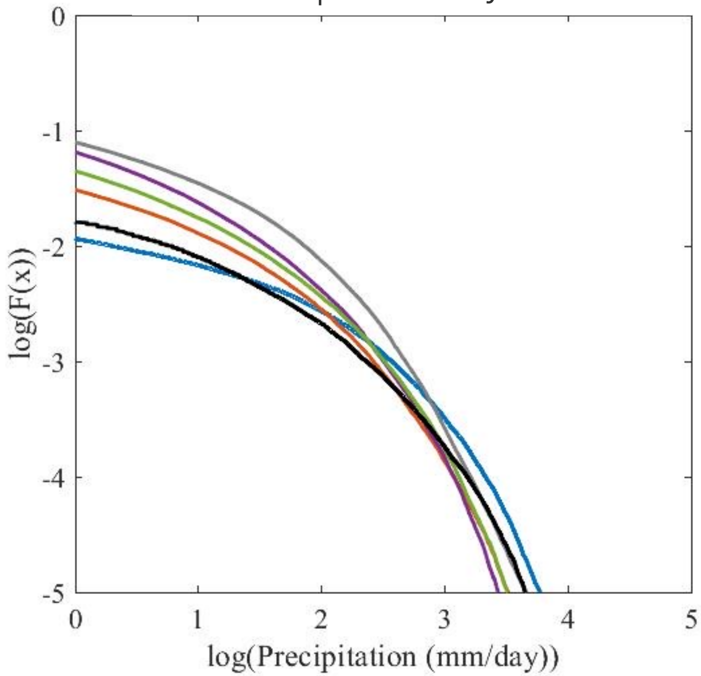
# VALIDATING PRECIPITATION DATASETS




CDF of daily rainfall

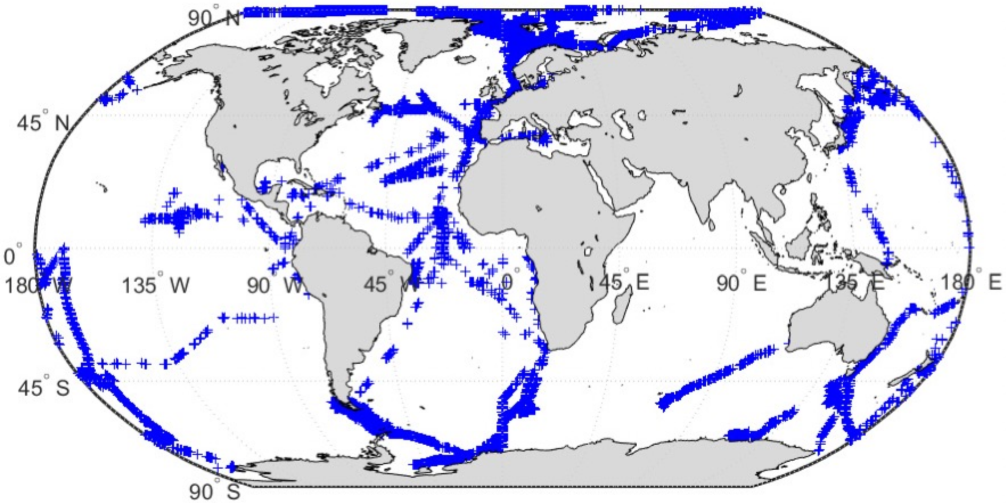



Complementary CDF



# OCEANS

- Validation is way more difficult because of their inaccessibility and extent.
- Available benchmark data:
  - weather radars located on islands and coastlines
  - rain gauges onboard cruise, merchant, and research ships
  - buoy gauge arrays
- These observations are affected by deficiencies due to high wind speeds and snowfall.
- Ocean Rainfall and Ice-Phase Precipitation Measurement Network (OceanRAIN), which has been sampling precipitation from optical disdrometers carried by various research vessels since 2010.




Ship tracks of OceanRAIN during 2014–2017 (Klepp et al. 2018)

# SO? WHAT REFERENCE?

- The choice of one type of the benchmark depends on:
  - data availability
  - the type of products to be validated
  - the specific objective of the validation study

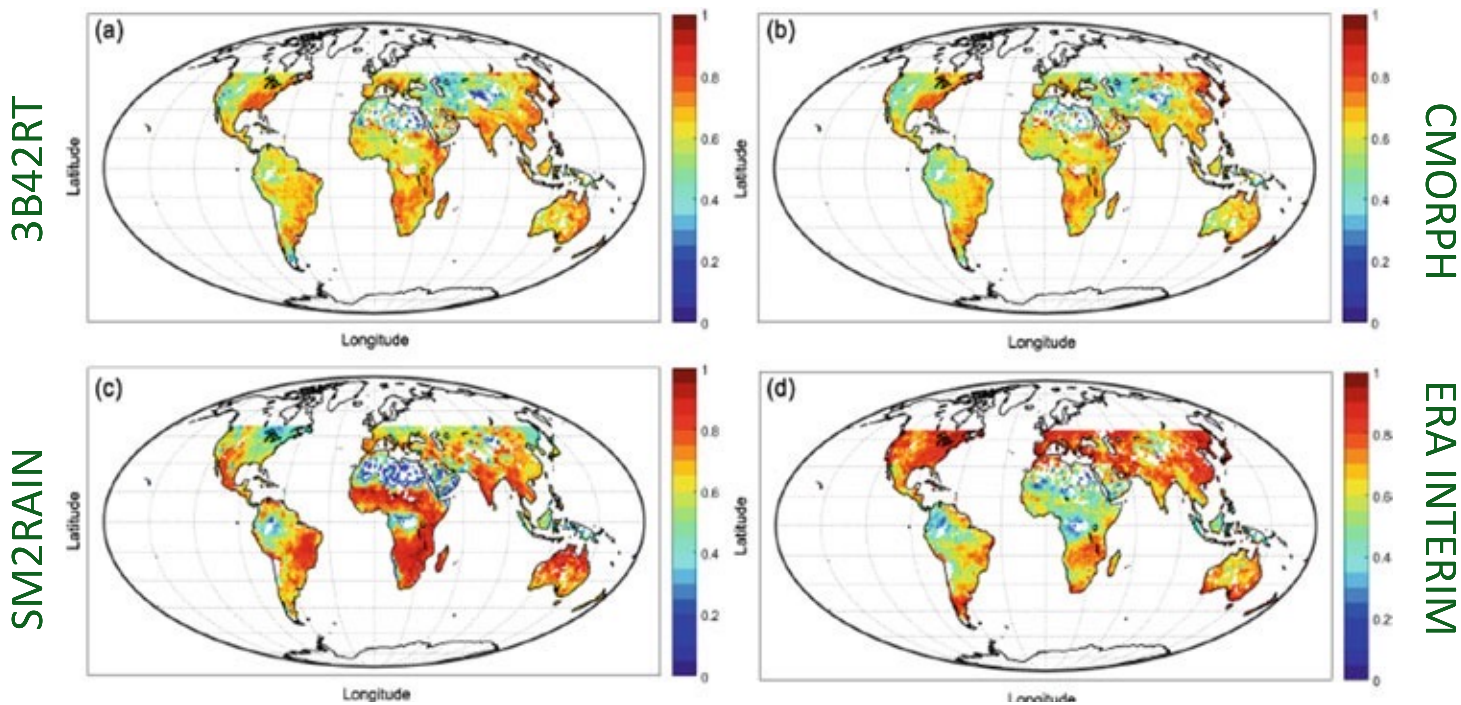
For instantaneous and high spatial resolution estimates → gauge-corrected radar estimates are generally preferable

For larger regions and timescales (6h to daily) → rain-gauge analyses or combined gauge/radar analyses should be preferred to raw gauge or radar observations

- The presence of errors in the benchmark dataset increases the apparent error of the satellite estimates and thus must be considered when validating satellite products.
- A common assumption is that as long as the observational error is random and is much smaller than the satellite error, then the reference can be reliably used to intercompare estimates from different products.

# ANY ALTERNATIVE?

- Alternative techniques in absence of ground-based observations, e.g., Triple Collocation Analysis (TCA).
- Given 3 estimates of the same variable characterized by (i) stationarity of the statistics, (ii) linearity between the 3 estimates across all timescales, and (iii) existence of uncorrelated error among the three estimates, TCA is able to provide error and correlation of each of the 3 datasets.




Global correlation obtained by TCA (Adapted from Massari et al. 2017)

# MODELING ERRORS AND UNCERTAINTIES

- Indispensable for the proper use of those products in hydrological modeling, water resources management, and

The same error model would unlikely perform similarly:

- everywhere in the world (oceans vs land, complex topography vs plains, tropics vs high latitudes)
- at any time (winters vs summers)
- for any precipitation event (solid vs liquid precipitation, convective vs stratiform systems)
- for any application (drought vs flood monitoring)

- Error models highly depend on the product temporal and spatial resolution, on precipitation rates and products, and on a priori error model structure.

**Error models are unlikely to be universal.**

# WHAT IS THE FUTURE?

MA

what is the future on estimating satellite precipitation products errors and uncertainties

Estimating errors and uncertainties in satellite precipitation products is an active area of research, and several approaches are being developed and tested to improve the accuracy and reliability of these products.

One promising direction is the use of machine learning techniques to identify and correct biases and errors in satellite precipitation products. For example, deep neural networks have been used to improve the accuracy of satellite rainfall estimates by learning from ground-based radar observations and other high-quality precipitation datasets.

Another approach is to combine data from multiple satellite platforms and sensors to improve the accuracy and consistency of precipitation estimates. This approach can also help to better characterize the uncertainties associated with each dataset, by taking into account the differences in instrument characteristics, calibration, and measurement methods.

In addition, there is a growing focus on improving the validation and verification of satellite prec Regenerate response n the use of ground-

https://chat.openai.com/

# WHAT IS THE FUTURE?

- In addition, there is a growing focus on improving the validation and verification of satellite precipitation products through the use of ground-based observations and other independent datasets. This can help to identify and quantify errors and uncertainties in the satellite products, and to develop better methods for integrating and combining different datasets.

- Overall, the future of estimating errors and uncertainties in satellite precipitation products is likely to involve a *combination of these approaches*, along with ongoing improvements in satellite technology and data processing algorithms.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