Large-Scale Benchmarking of a NRT Global Precipitation Ensemble: STREAM-Sat

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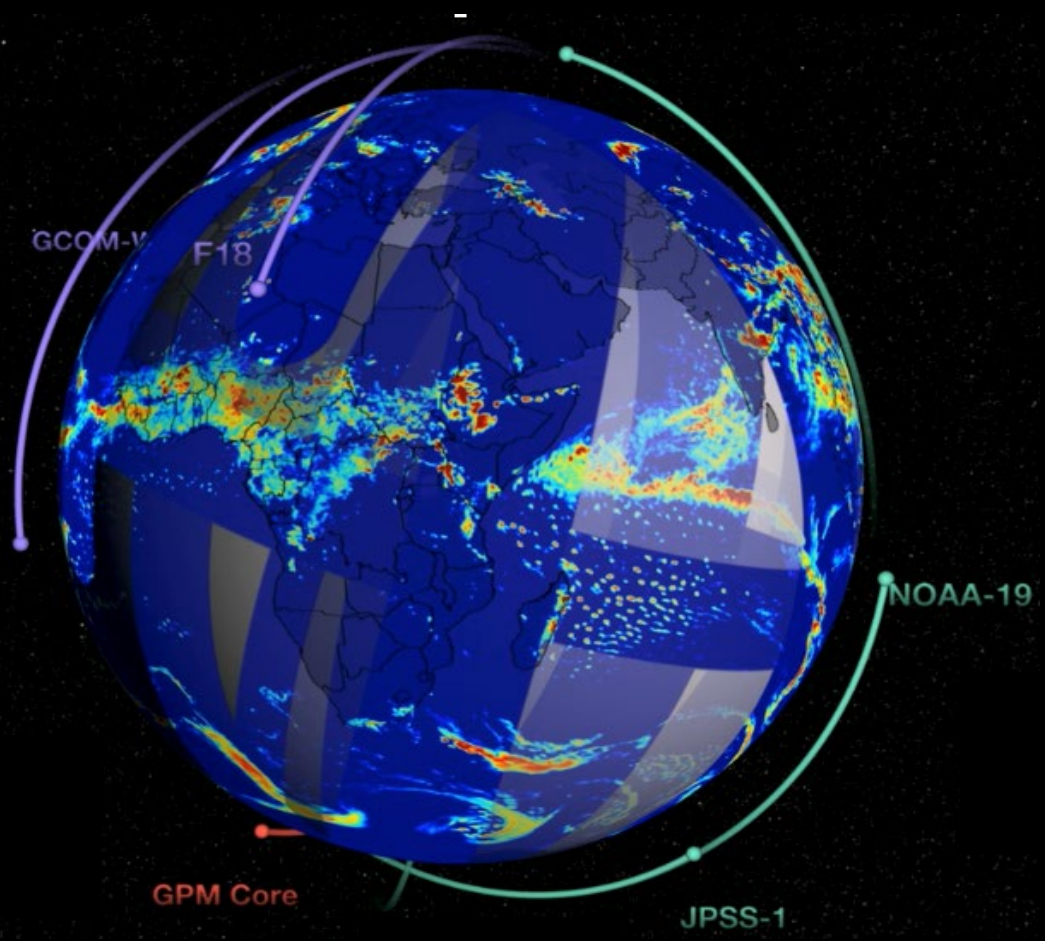
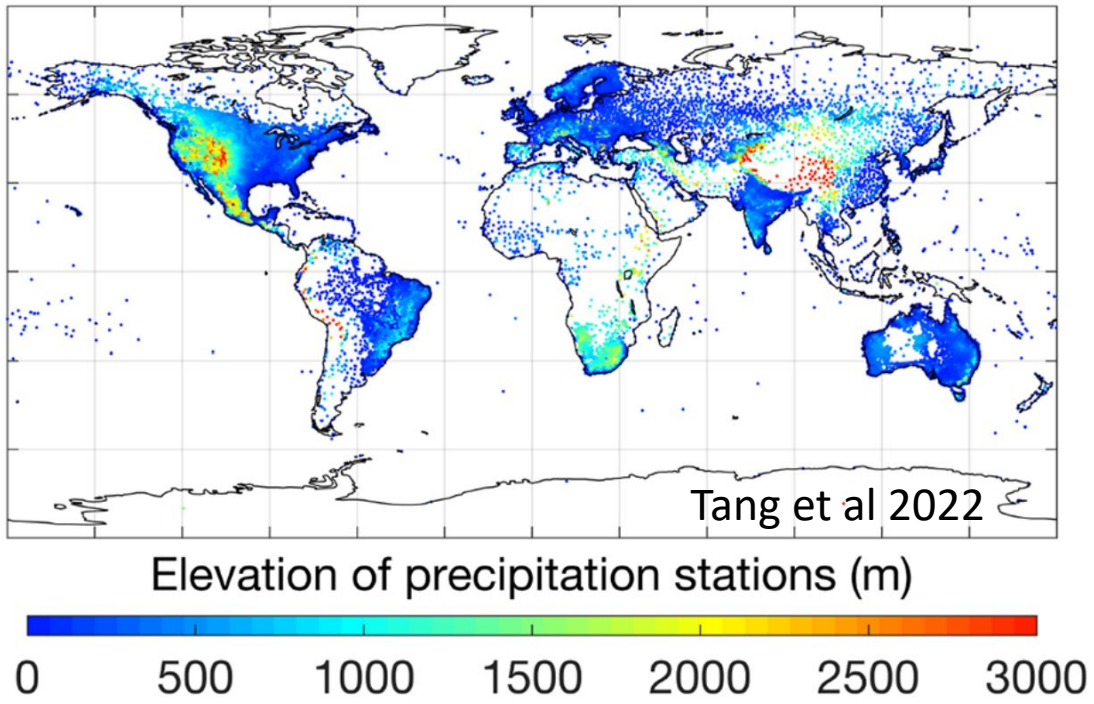
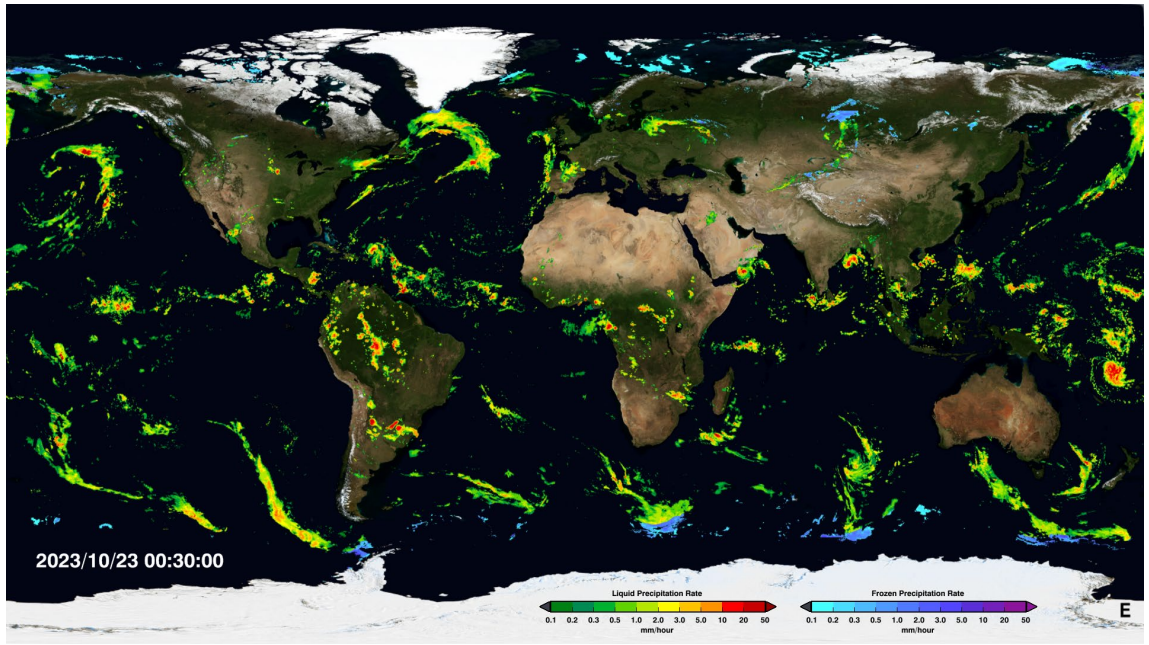


https://gpm.nasa.gov/resources/videos/gpm-constellation-clock

Gauge network VS. Satellite





- Globally sparse
- Low availability & Long latency
- Usually high accuracy

- Usually low accuracy
- High spatiotemporal resolution
- Global availability & Near Realtime

Others: Reanalysis (e.g., ERA5), Merged (e.g., MSWEP), Gauge-based (e.g., GPCP)
All has their own deficiency & strength

IMERG-Early

- The Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (IMERG) to estimate precipitation globally

IMERG-Final: 3.5 month

IMERG-Late: 14 hours

Pros:

- **Dates Covered:** June 2000 - Present
- **Spatial Resolution:** ~10km / 0.1 Degree
- **Minimum Latency:** 4 hours

Cons:

- **Accuracy:** Overestimate and Underestimate

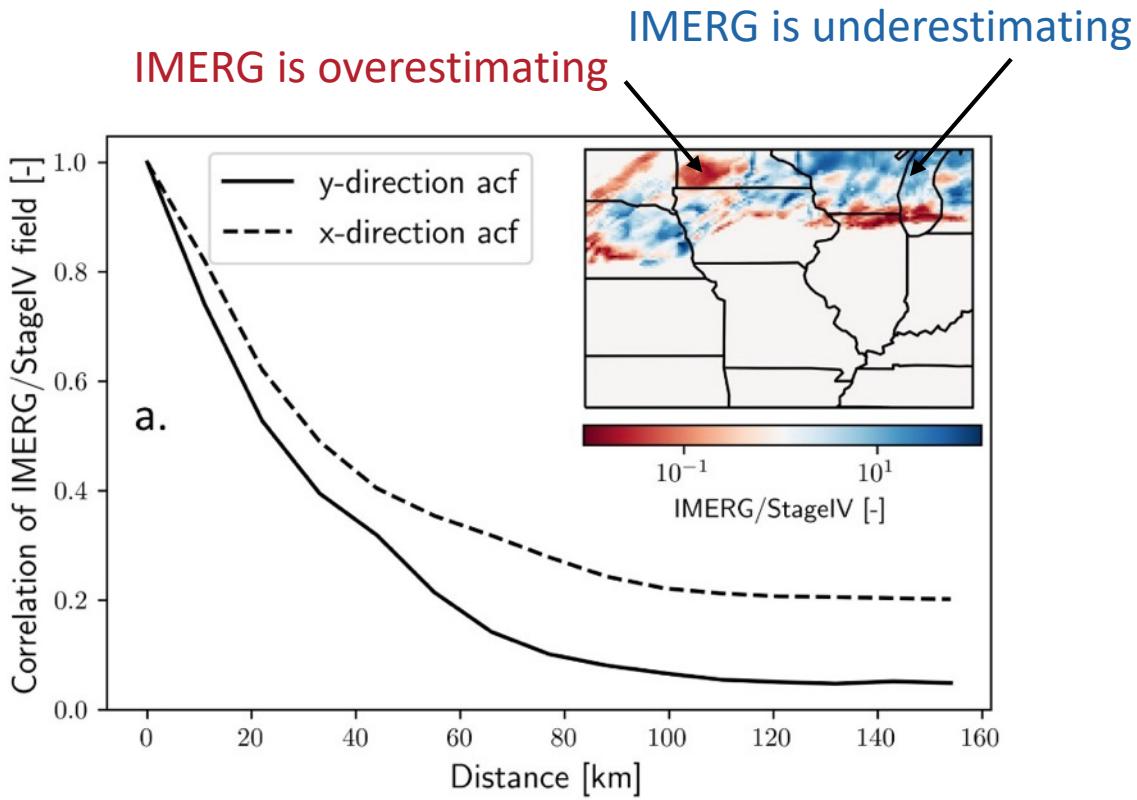
Satellite retrieval standard:
GPM Core Observatory Satellite

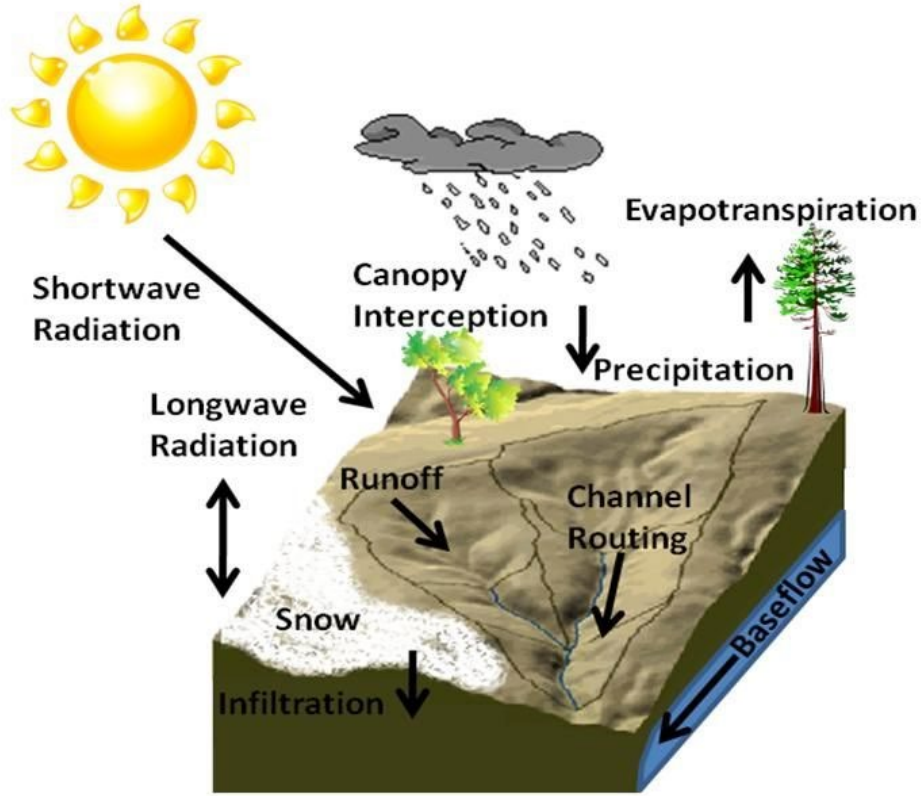
Uncertainty Estimation

But wait, what kind of attributes of IMERG error have been documented so far?

Multi-scale complexity… Magnitude & location dependent…

IMERG Uncertainty Across Space/Time





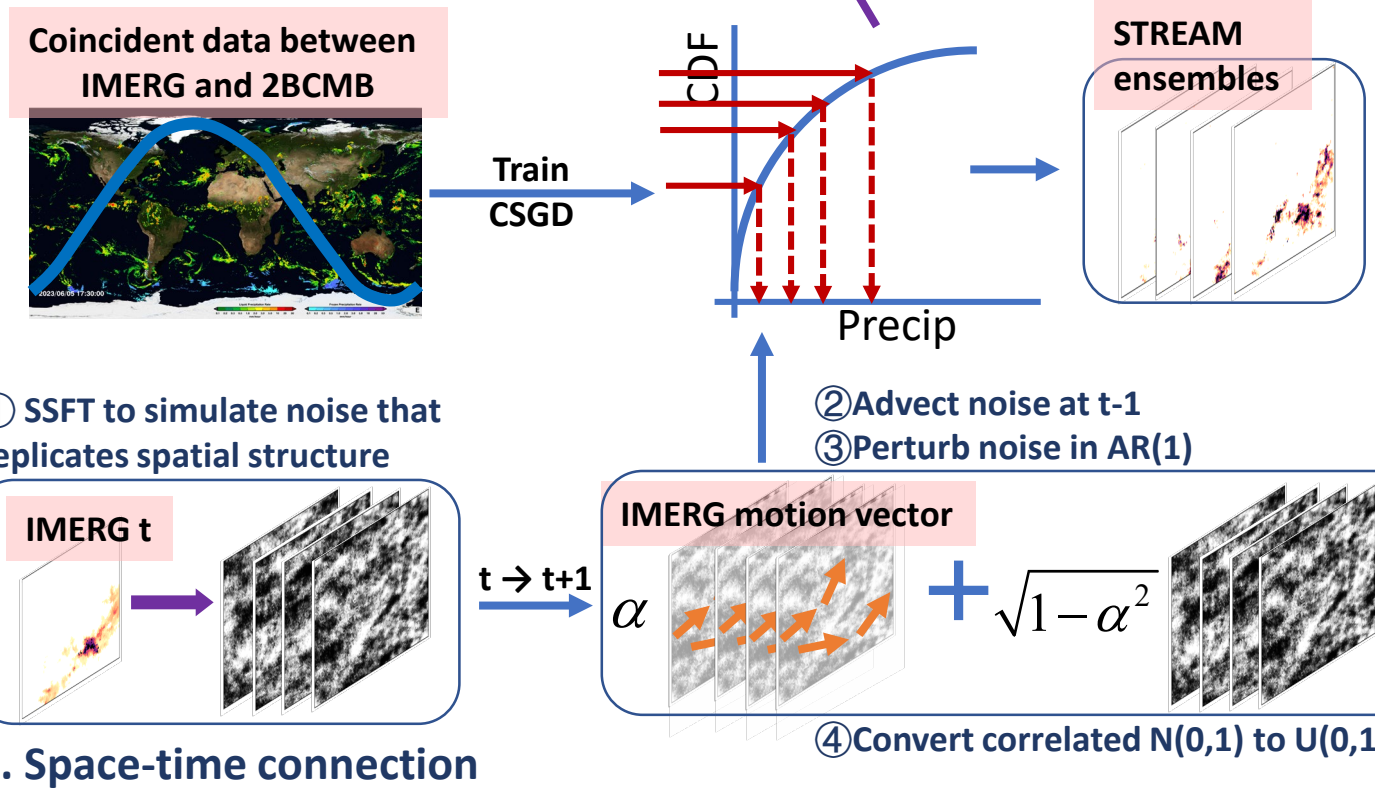
Precipitation uncertainty is one of the main sources of uncertainty in hydrologic models

Properties that change over time (or space) = **nonstationary**
Properties that vary with direction = **anisotropic**

1. Grid scale error model
2. Space-time connection

NRT Global Precipitation Ensemble: STREAM-Sat

1. Grid scale error model:
The distribution (CDF) of precipitation conditioned on observation



2. Space-time connection

No ground-based observations are used in STREAM-Sat

Peng, K., et al, 2023;

1. Grid scale error model

- The Censored Shifted Gamma Distribution (CSGD) error model

Fitting Distribution

$$\mu(t) = \frac{\mu}{\alpha_1}\,\mathrm{log1p}\left\{\mathrm{expm1}(\alpha_1)\left[\alpha_2 + \alpha_3\frac{R_s(t)}{\overline{R_S}}\right]\right\},$$

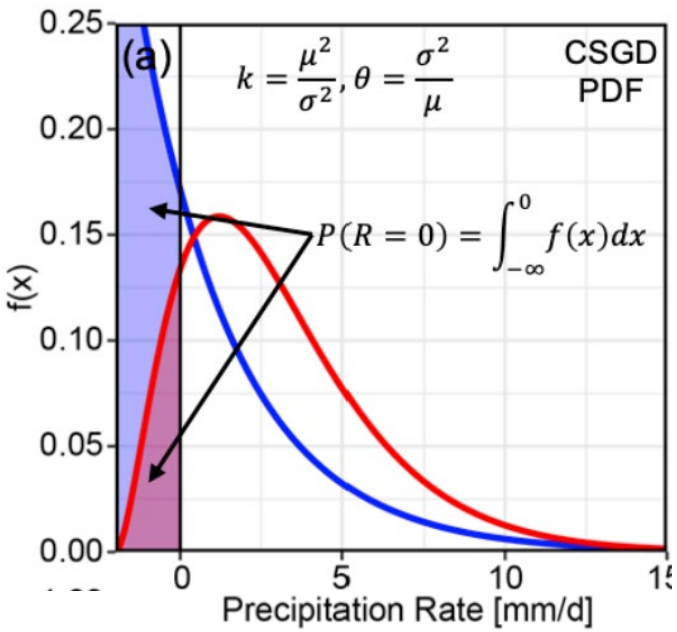
$$\sigma(t) = \alpha_4\sigma\sqrt{\frac{\mu(t)}{\mu}},$$

$$\delta(t) = \delta,$$

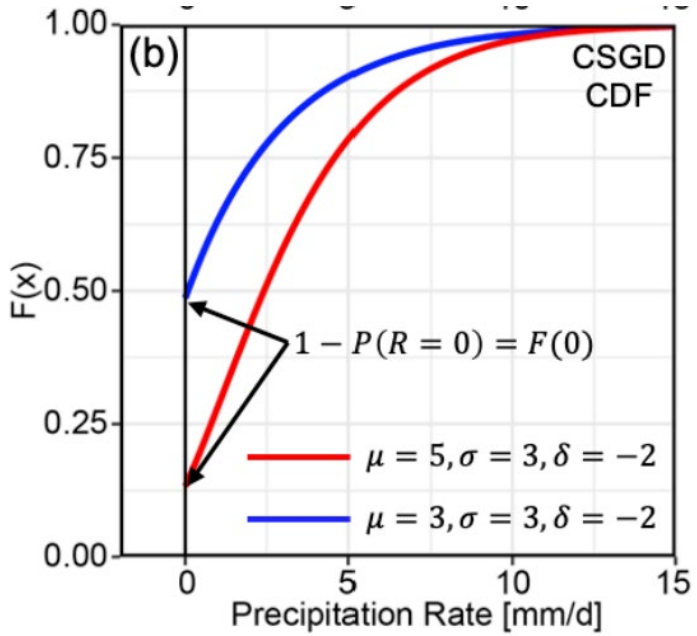
$$F_{\mu,\sigma,\delta}(x) = \begin{cases} F_{\mu,\sigma}(x-\delta), & for\ x \geq 0 \\ 0, & for\ x < 0 \end{cases}$$

Target Function

$$\mathrm{CRPS}(F_{\mu(t),\sigma(t),\delta(t)}, o_t) = \int_{-\infty}^{\infty}\left[F_{\mu(t),\sigma(t),\delta(t)}(x) - \mathrm{I}(o_t \leq x)\right]^2 dx$$



Probability Density Function



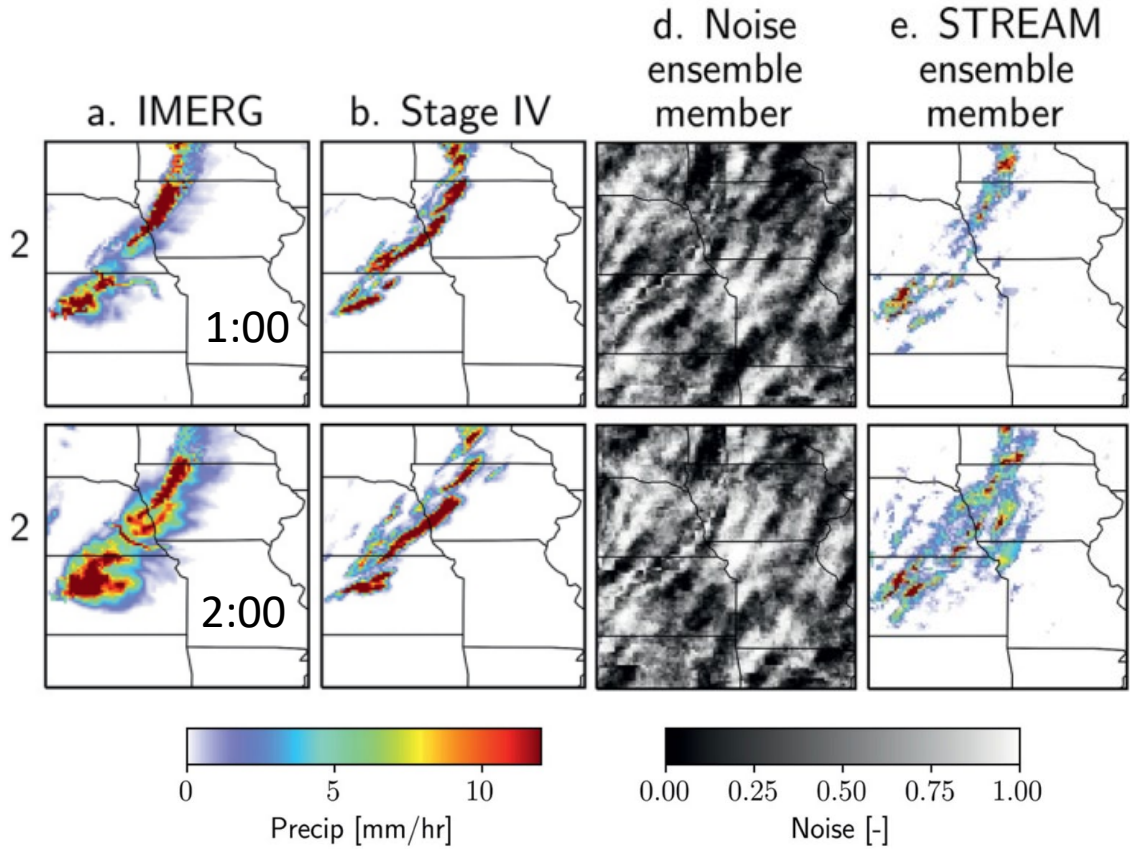
Cumulative Density Function

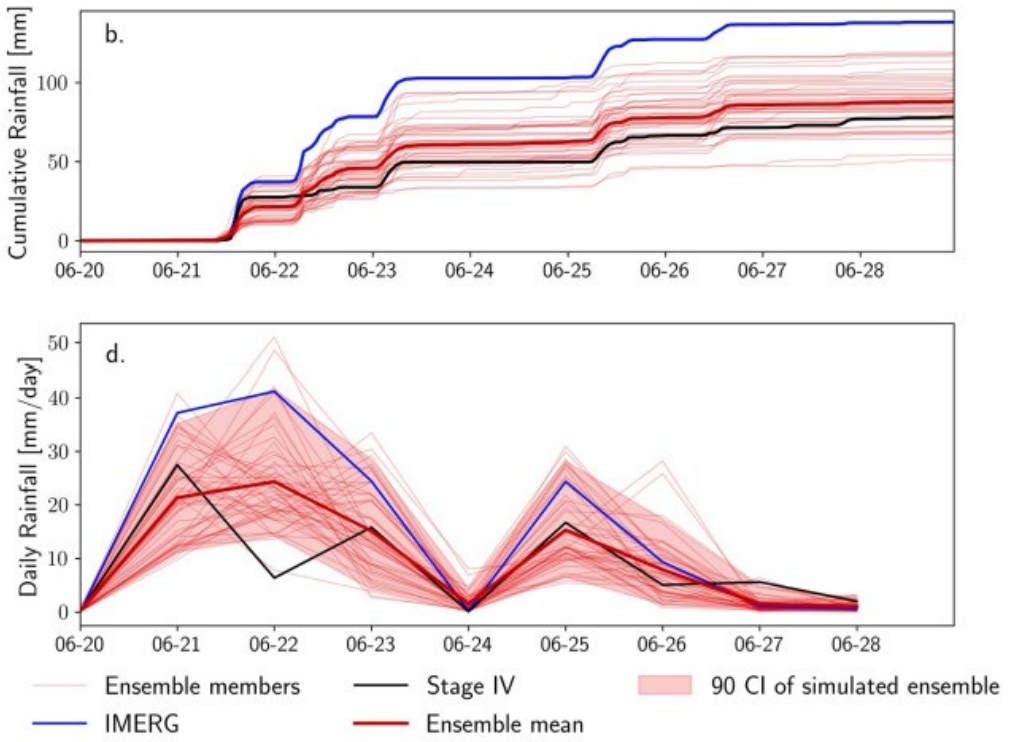
Real precipitation distribution conditioned on IMERG estimates

Wright, D. B., et al, 2017;

2. Space-time connection

- The Space-Time Rainfall Error and Autocorrelation Model (STREAM)

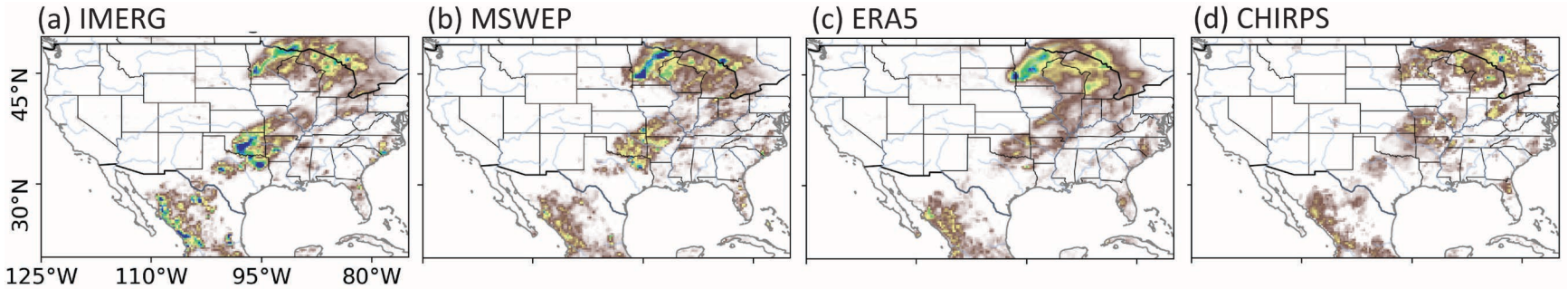


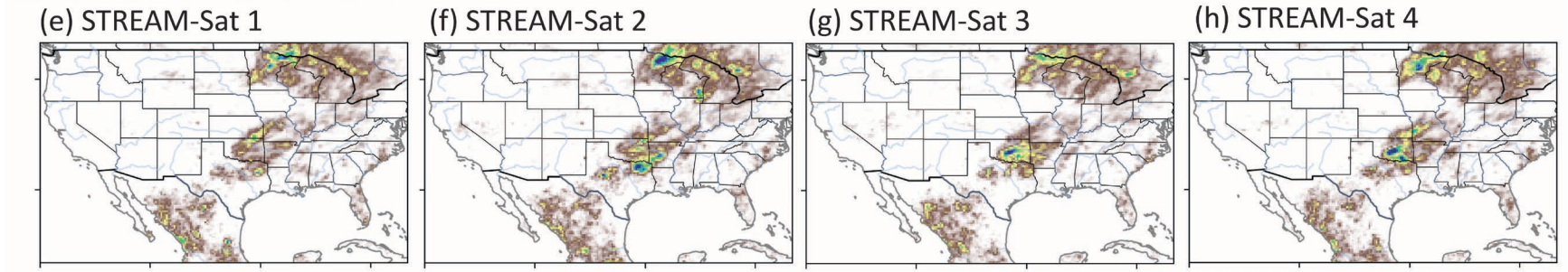


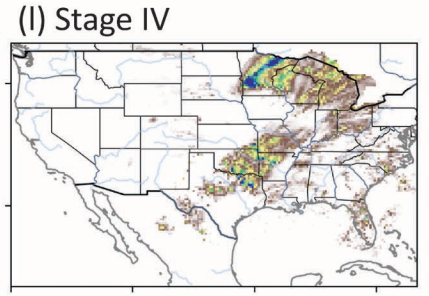
STREAM ensembles 1. replicate space & time autocorrelation; 2. resemble the real precipitation

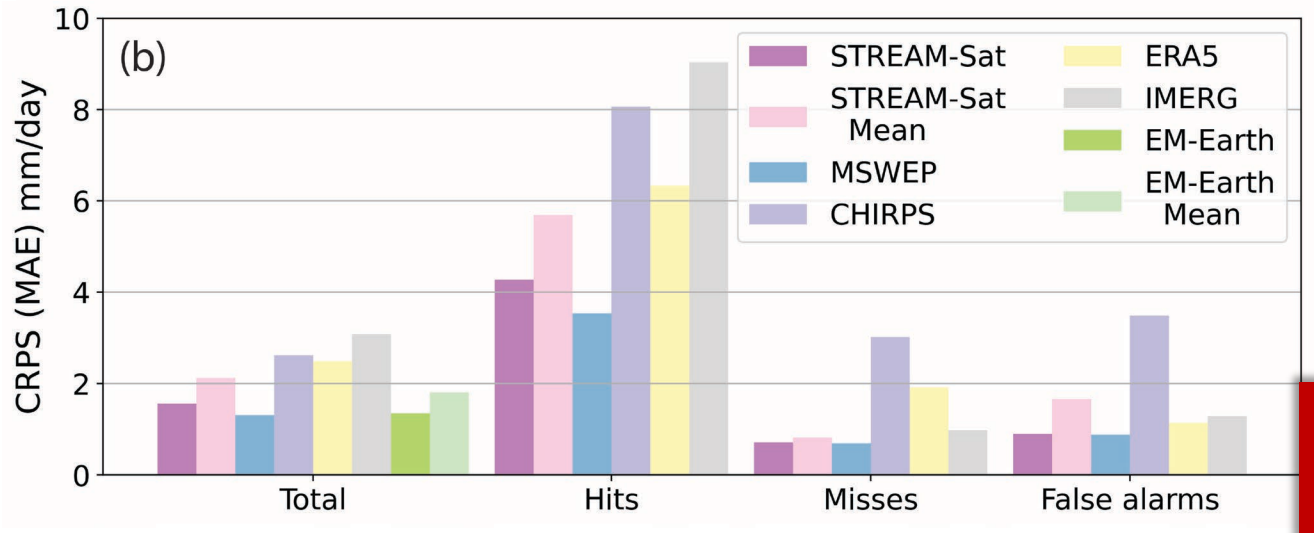
Hartke, et al. (2022)

Evaluation: comparison with “peers”

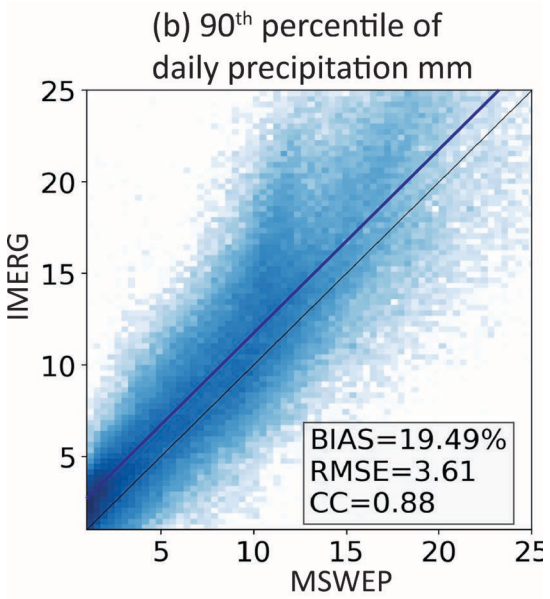


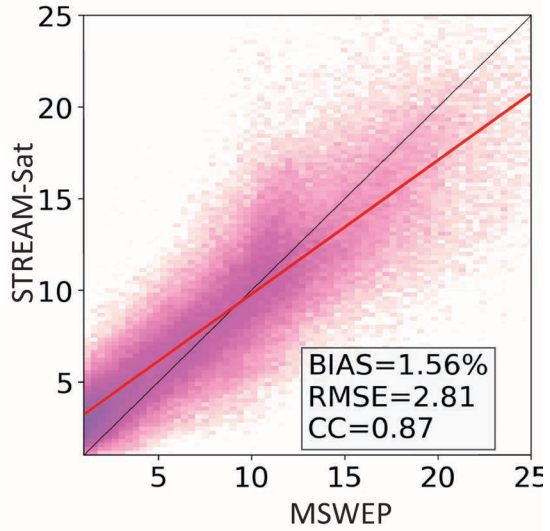




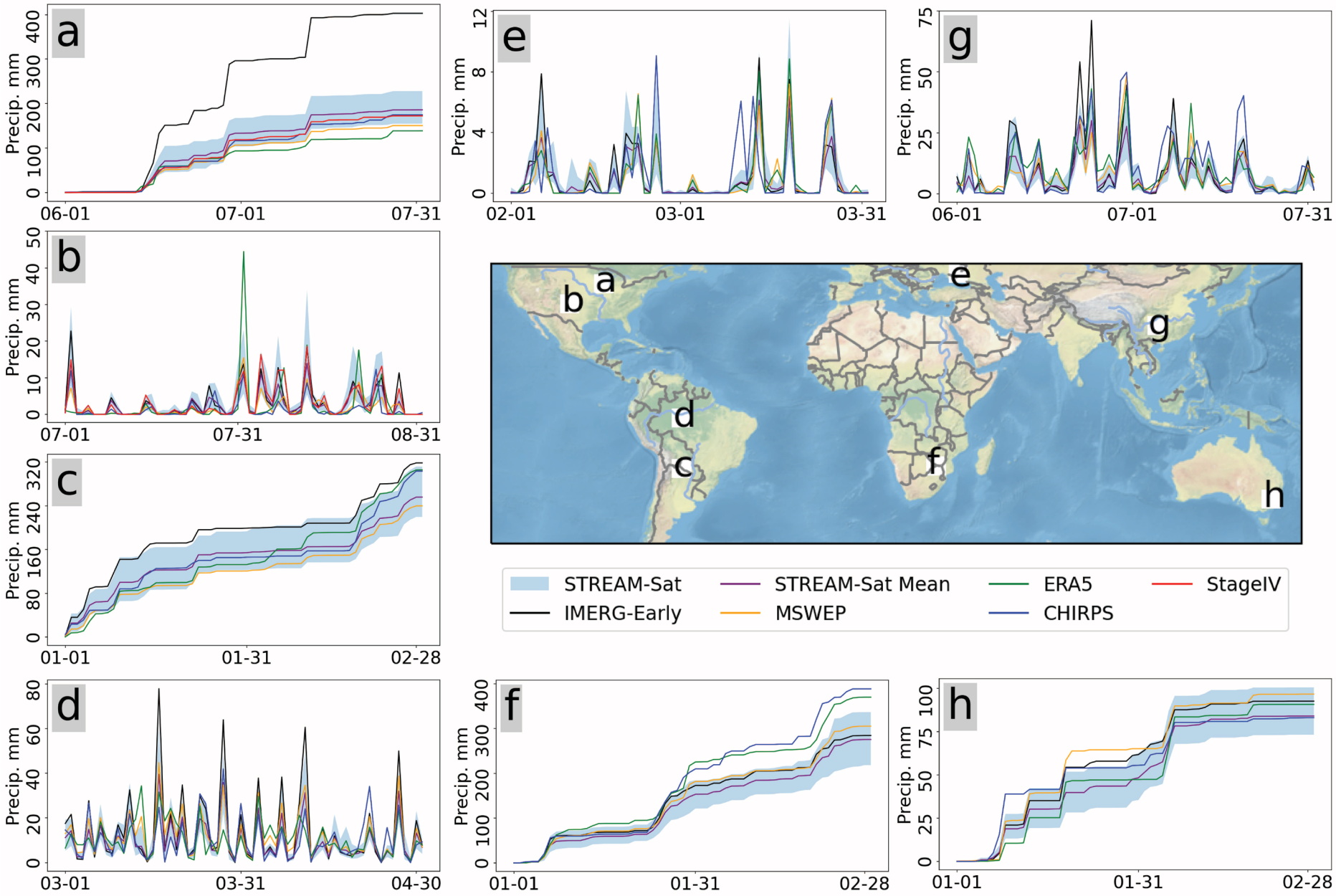


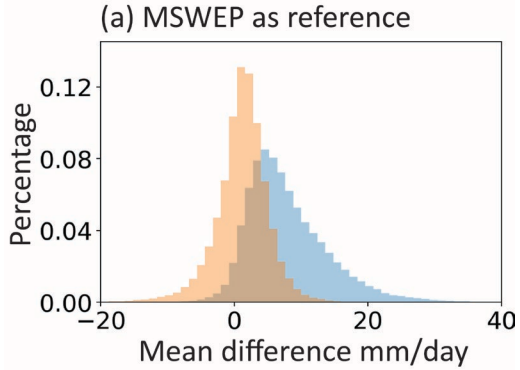
Validation against Stage IV

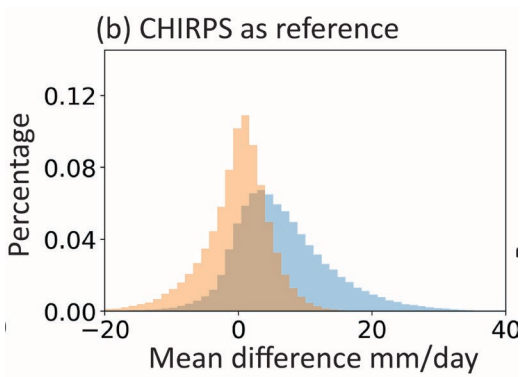


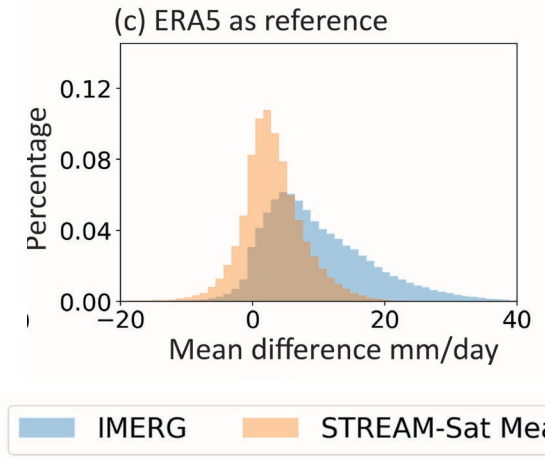


- Great improvement compared to IMERG
- Its performance is close to, if not better than, its peers
- No gauge used









Precipitation time-series reported across the globe

90-quantile daily rainfall

Comparison with “peers”

Name	Details	Resolution; coverage	Latency
IMERG Early	Satellite-based, Deterministic	0.1°, half-hourly; global	4 hours
MSWEP V2.8	Merged, Gauge corrected, Deterministic	0.1°, 3-hourly; global	available up to 2020
CHIRPS V2.0	Satellite-based, Gauge-corrected, Deterministic	0.05°, daily; 50°S-50°N, land	The third week of the following month
ERA5	Reanalysis-based, Deterministic	0.25°, hourly; global	5 days
EM-Earth	Reanalysis-based, Gauge-corrected, Ensemble	0.1°, daily; global land except Antarctic	Available up to 2019
STREAM-Sat	Satellite-based, Ensemble	0.1°, half-hourly; 50°S-50°N, land	4 hours

STREAM-Sat Highlights:

- This method is to produce ensemble precipitation fields using only satellite data. It can be applied globally, in near-realtime, and at high resolution (here, 0.1°, half-hourly over land, inherited from IMERG).

- STREAM-Sat exhibits clear improvement in detection ability and intensity compared to IMERG Early.

- Compared to precipitation datasets relying on ground gauge network, STREAM-Sat shows consistent ensemble range and performance skills. STREAM-Sat could be more favorable in gauge-limited regions.

- While STREAM-Sat's accuracy (e.g., in terms of CRPS) is not superior in all respects over all other evaluation datasets, its unique combination of traits—i.e., it is probabilistic via its ensembles, it has low bias, it can be produced in near-realtime, and it has high resolution—gives it certain advantages over the other benchmark global precipitation datasets.

- The method is particularly valuable in ungauged regions with large and unknown meteorological uncertainties that merit ensemble approaches, while its near-realtime potential offers notable benefits in water-related disaster early warning.

Reference

Algorithm:

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- Hartke, S. H., Wright, D. B., Li, Z., Maggioni, V., Kirschbaum, D. B., & Khan, S. (2022). Ensemble Representation of Satellite Precipitation Uncertainty Using a Nonstationary, Anisotropic Autocorrelation Model. *Water Resources Research, 58*(8). doi:10.1029/2021wr031650
- Li, Z., Wright, D. B., Zhang, S. Q., Kirschbaum, D. B., & Hartke, S. H. (2020). Object-Based Comparison of Data-Driven and Physics-Driven Satellite Estimates of Extreme Rainfall. *Journal of Hydrometeorology, 21*(12), 2759-2776. doi:https://doi.org/10.1175/JHM-D-20-0041.1

Application:

- Hartke, S. H., Wright, D. B., Kirschbaum, D. B., Stanley, T. A., & Li, Z. (2020). Incorporation of Satellite Precipitation Uncertainty in a Landslide Hazard Nowcasting System. *Journal of Hydrometeorology, 21*(8), 1741-1759. doi:https://doi.org/10.1175/JHM-D-19-0295.1
- Hartke, S. H., Wright, D. B., Quintero, F., & Falck, A. S. (2023). Incorporating IMERG satellite precipitation uncertainty into seasonal and peak streamflow predictions using the Hillslope Link hydrological model. *Journal of Hydrology X, 18*. doi:10.1016/j.hydroa.2023.100148


GPM Constellation
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