AI-Enhanced Satellite Precipitation Retrieval in MiRS: From Research to Operations

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National Environmental Satellite, Data, and Information Service

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MiRS: Microwave Integrated Retrieval System

CISESS
COOPERATIVE INSTITUTE FOR SATELLITE EARTH SYSTEM STUDIES

MiRS workflow: Physically based 1DVAR retrieval from passive microwave radiances

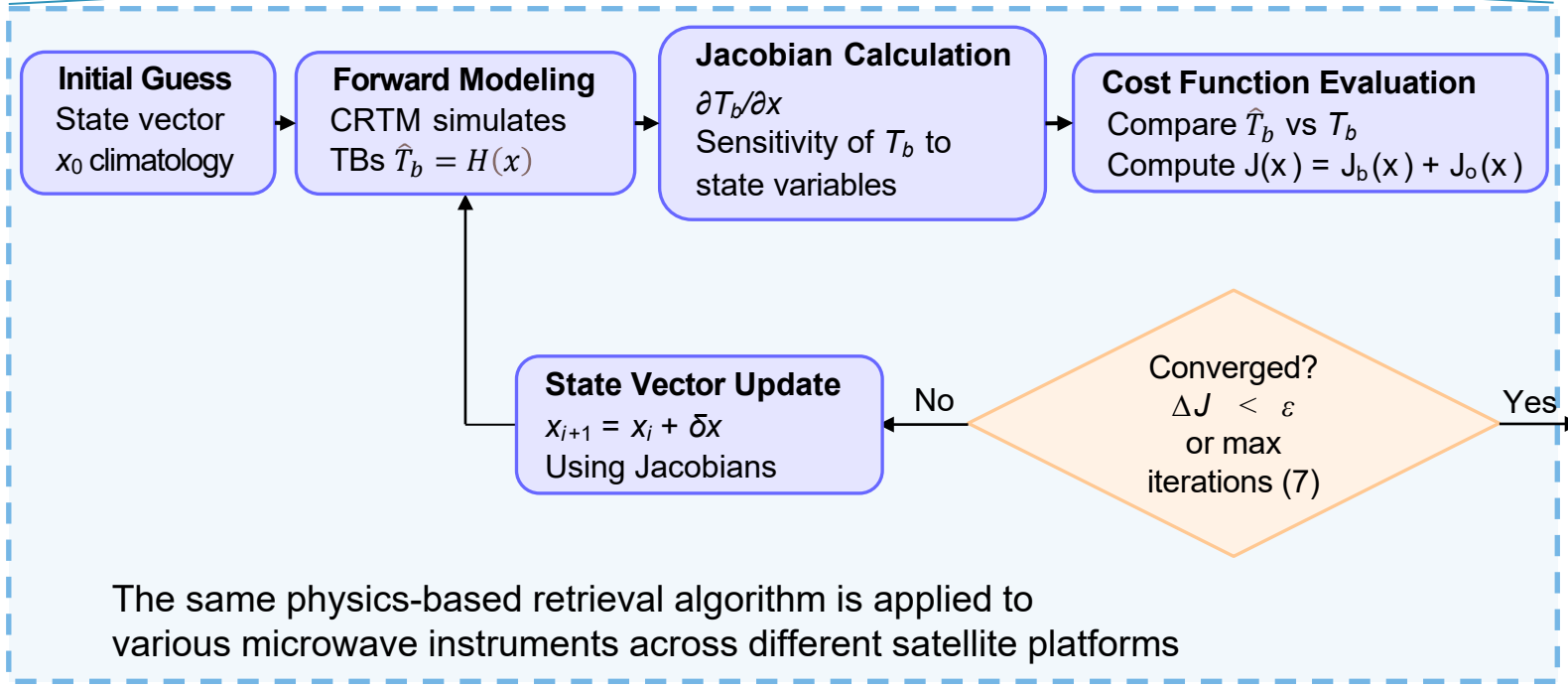
Inputs
- TBs (all channels)
- Geolocation
- Instrument NEDT
- Ancillary data
- First guess/EOFS

Preprocessing
- Format standardization
- Quality control
- Footprint matching
- Bias correction

1DVAR Retrieval
- CRTM forward model
- Jacobians
- Physically based inversion
- Uncertainty estimation

Core Products
- Temperature profile
- Water vapor profile
- Cloud/rain/graupel profiles
- Surface emissivity
- Skin temperature

Derived Products
- TPW
- CLW/RWP/IWP
- Rain rate
- SWE/Snow cover
- Grain size
- Sea ice age/concentration

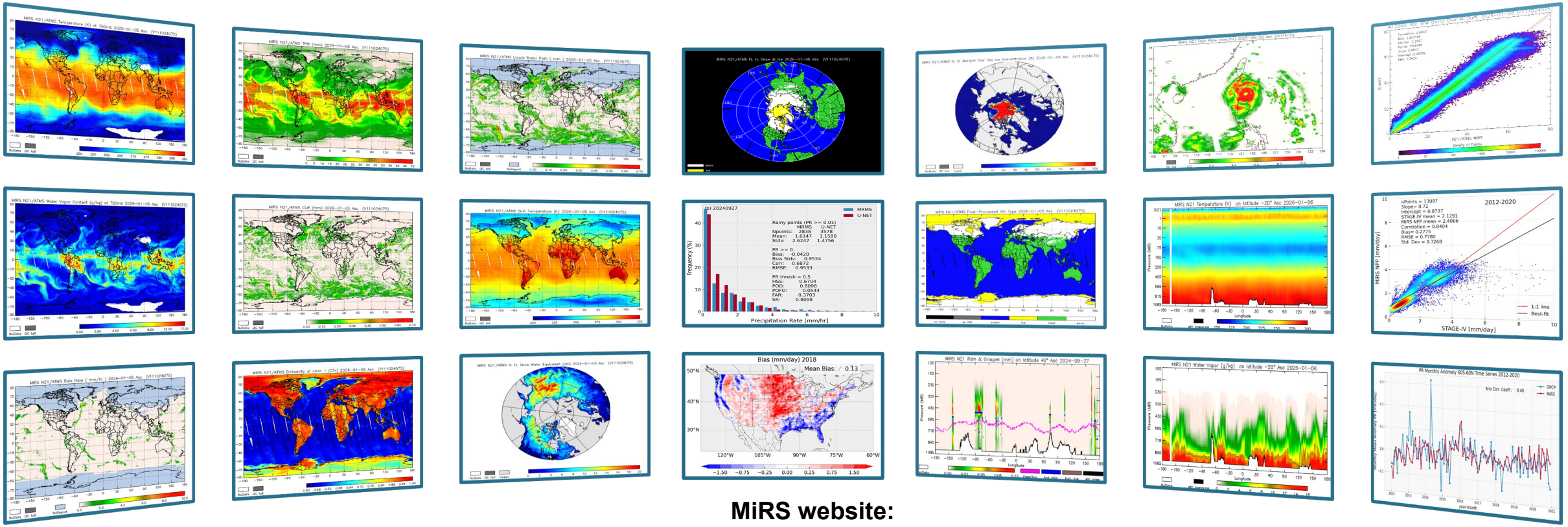


The same physics-based retrieval algorithm is applied to various microwave instruments across different satellite platforms

Current

Support Satellites

- **Current operational:** SNPP, NOAA-20, NOAA-21, MetopB, MetopC, GPM
- **Implemented:** QuikSounder, MetopSG-A1, AWS, Tomorrow.io, TROPICS
- **Decommissioned:** NOAA-18, NOAA-19, MetopA, DMSP-F16, DMSP-F17, DMSP-F18



MiRS website:

Near Real-Time: https://www.ospo.noaa.gov/products/atmosphere/mirs/index.html

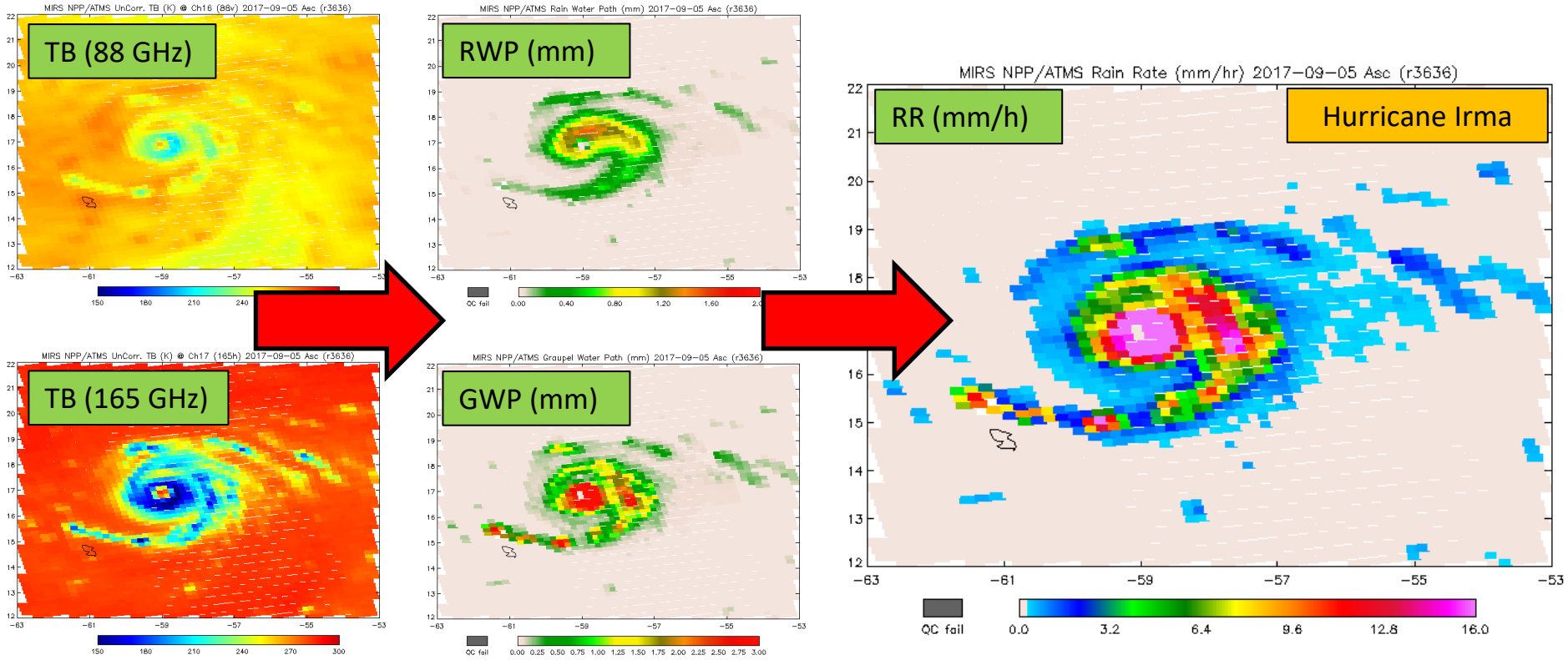
Research: https://www.star.nesdis.noaa.gov/mirs/index.php

MiRS Rain Rate Algorithm

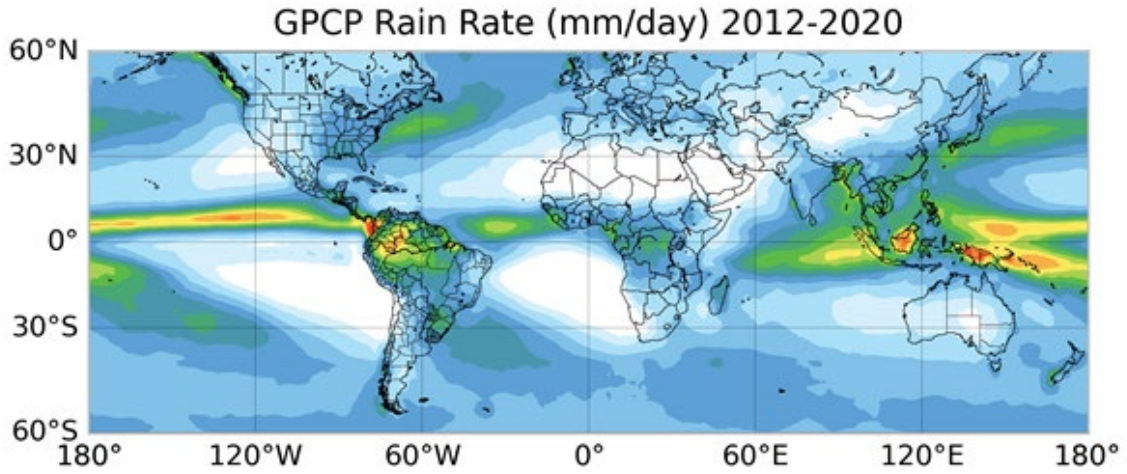
- 1DVAR retrieves cloud liquid water, rain water, and graupel water on 100 pressure layers
- Estimate RR from the integrated variables using empirical equations derived from mesoscale model simulations.

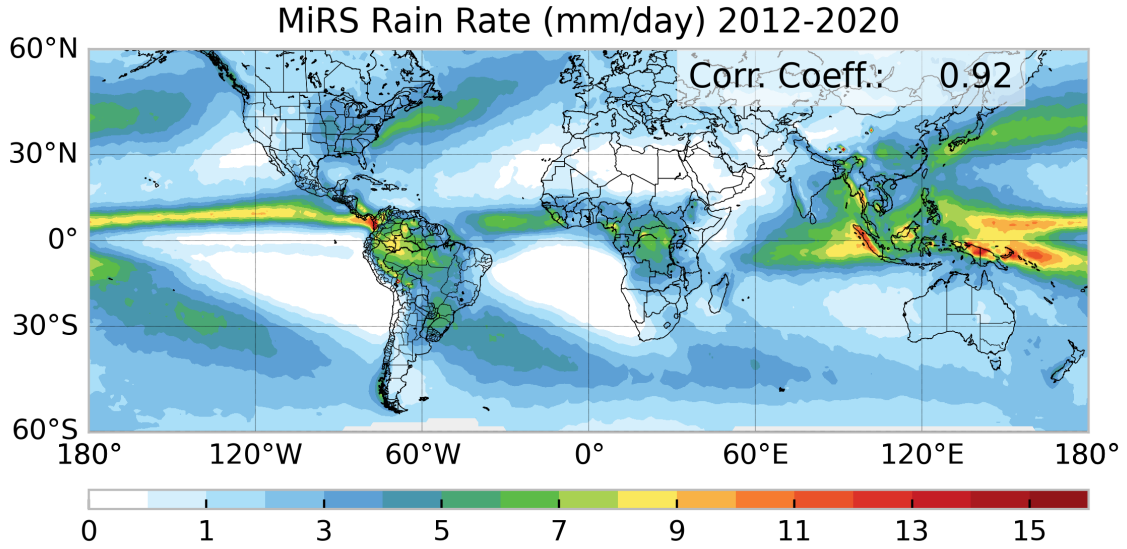
✓ Only the two channels with the strongest RWP and GWP signatures are shown for illustration.

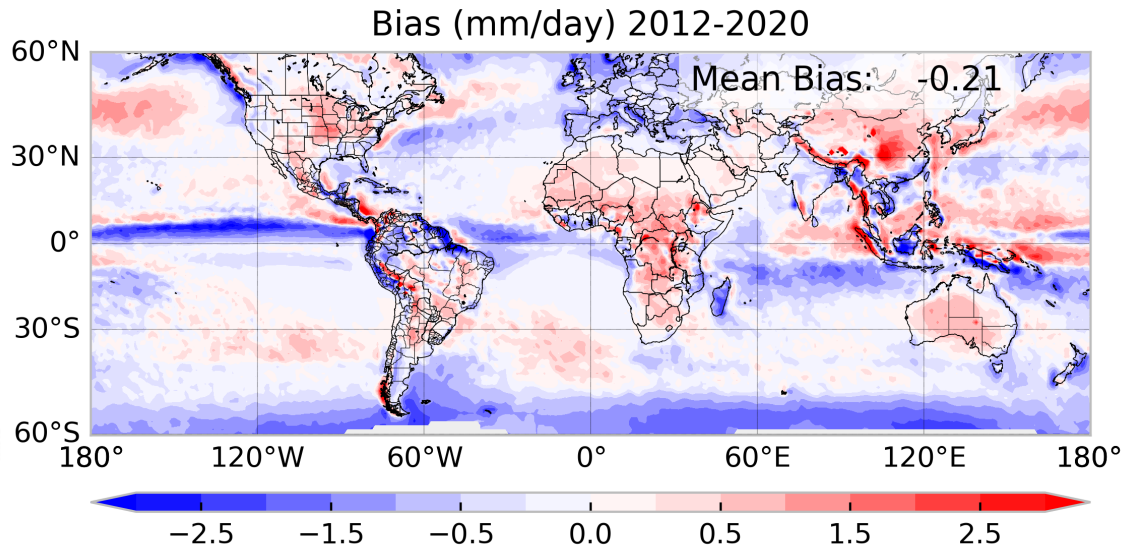
✓ The operational retrieval uses all available microwave channels to estimate CLW, RWP, and GWP

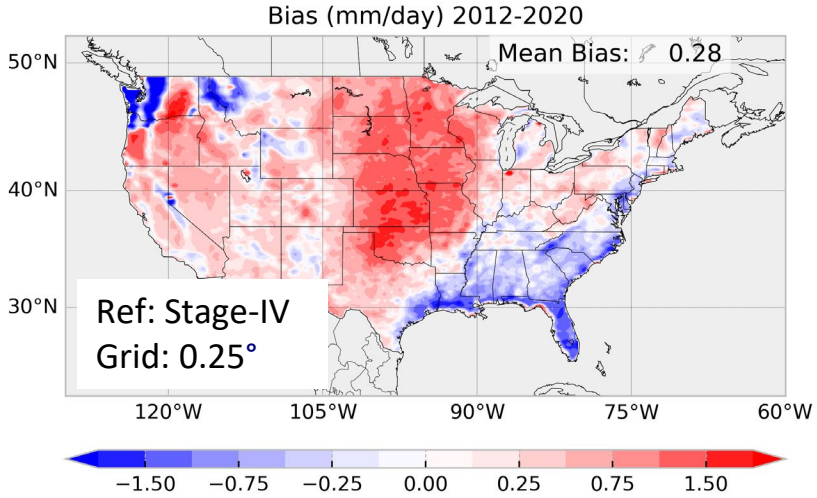


MiRS SNPP/ATMS Precipitation Climatology Compared with GPCP (1°)





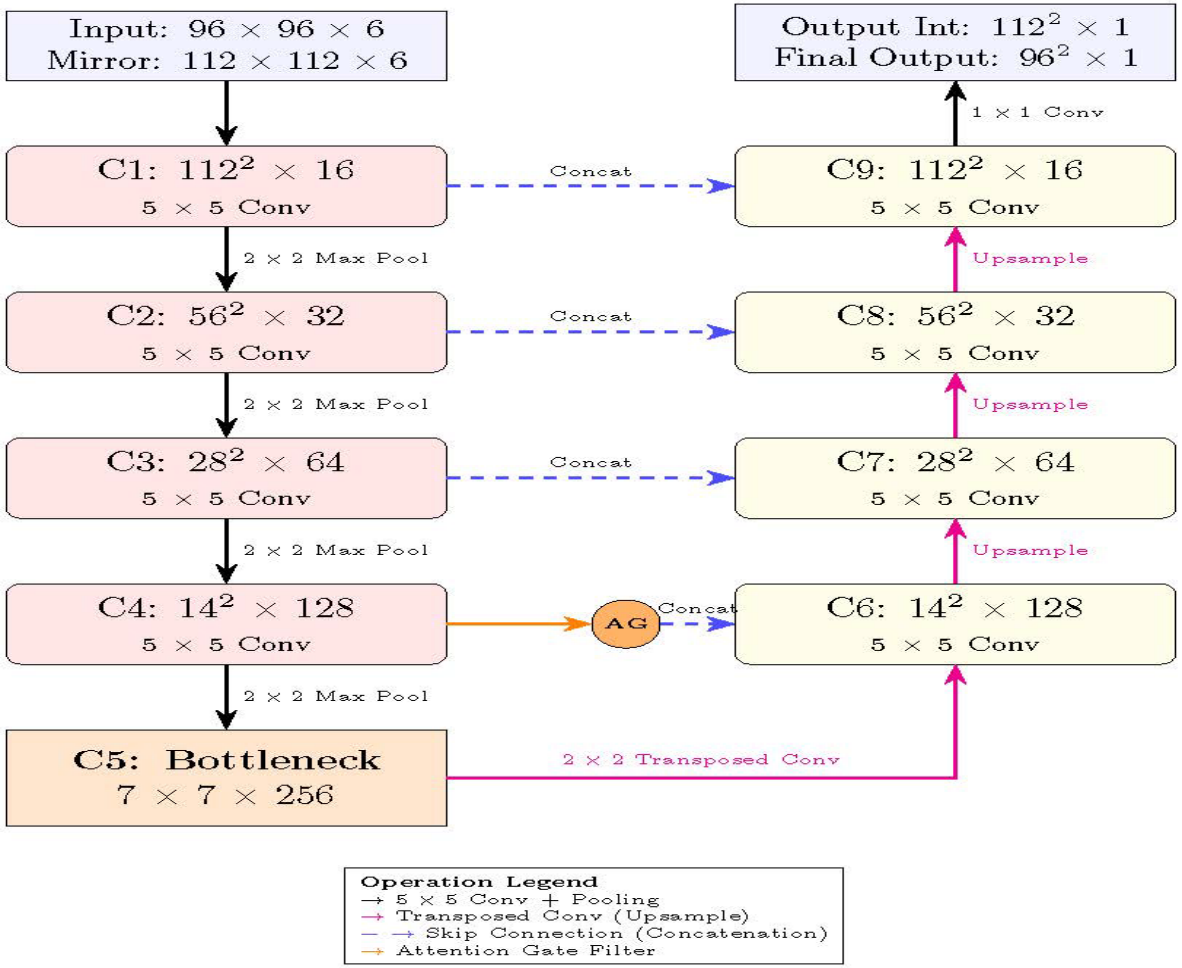




A similar regional bias pattern is observed relative to both Stage IV (CONUS) and GPCP (global), indicating consistent retrieval characteristics across independent reference datasets.

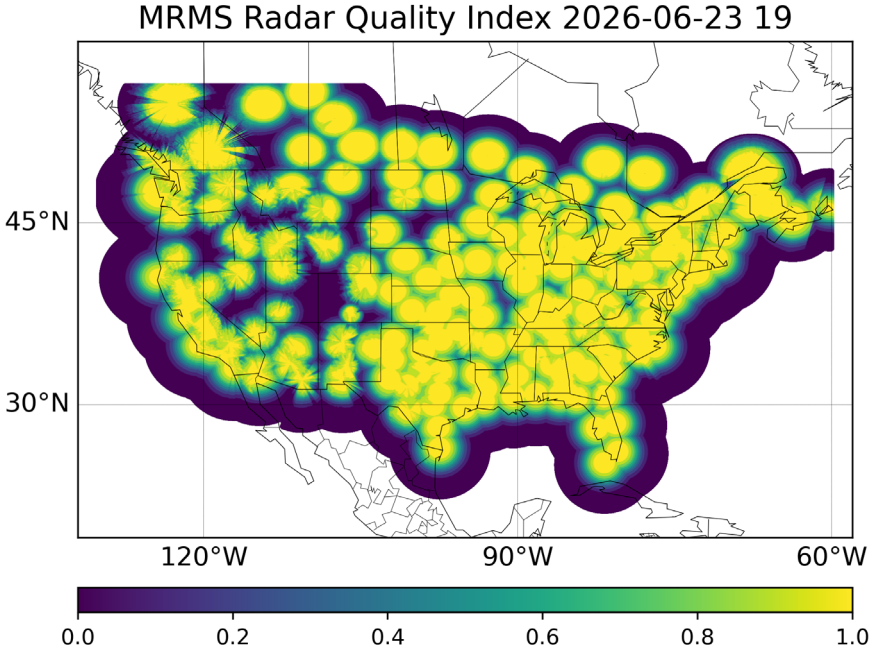
MiRS captures the large-scale precipitation climatology, but systematic regional biases remain

MiRS AI Rain Rate Enhancement: U-Net Framework



- **Architecture:** Classical U-Net
- **Training data set:** 2021–2024 CONUS, 8,301 image-like samples
- **Predictors:** Latitude, Longitude, TPW, CLW, RWP, and GWP
- **Reference target:** MRMS 2-Minute radar rain rate
- Training was performed on the **original satellite footprint** without interpolation to a regular grid

The results presented here are illustrated using NOAA-20 ATMS, the AI framework has been extended to multiple microwave sensors.



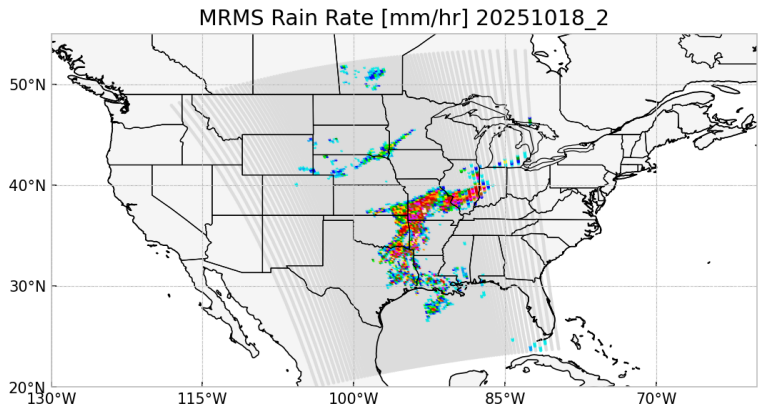
Note: MiRS satellite pixel data was first converted into image-like samples for U-Net training, regardless of the MRMS Radar Quality Index (RQI). Thus retrieval performance may be reduced in regions where the MRMS RQI is low.

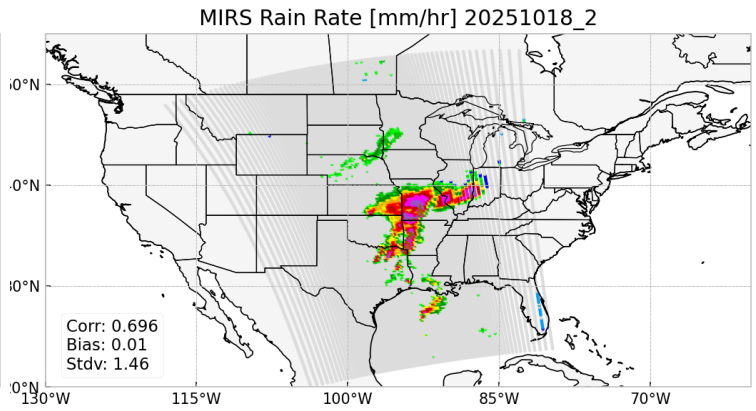
Case Studies: MRMS, MiRS, and U-Net Comparison

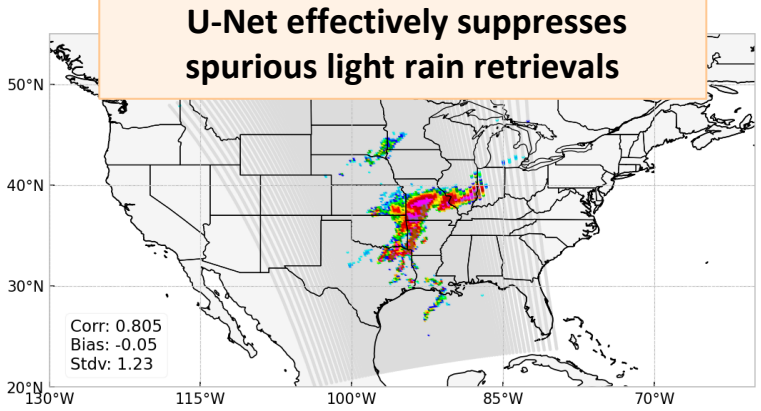
MRMS | **MiRS** | **U-Net**

U-Net effectively suppresses spurious light rain retrievals

2025-10-18







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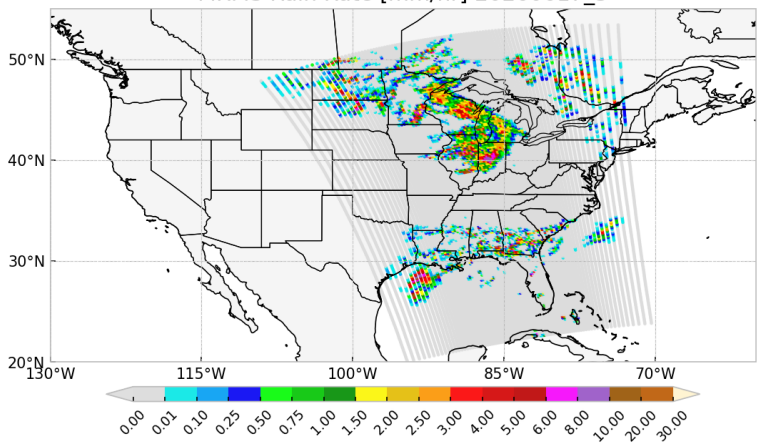

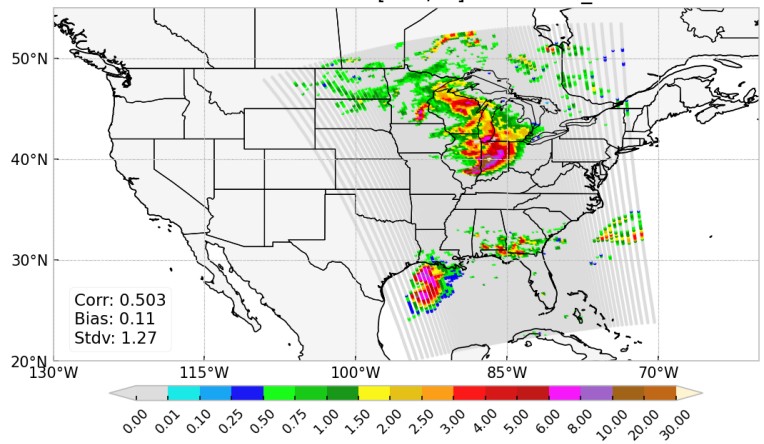

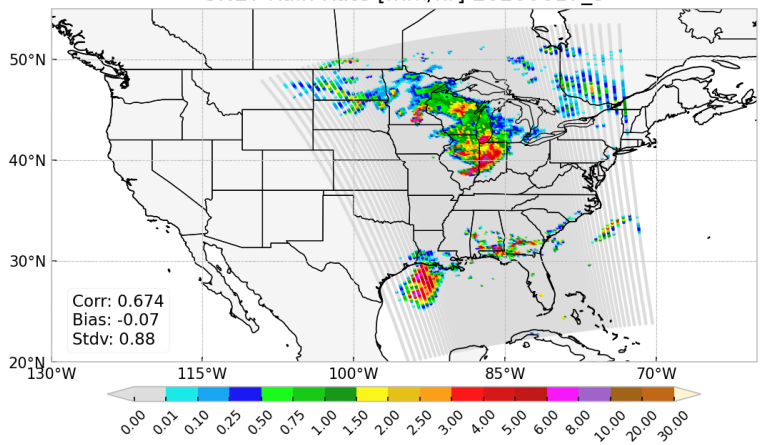

U-Net consistently improves the spatial distribution and quantitative accuracy of MiRS rain rates across representative precipitation events

MiRS | **U-Net**

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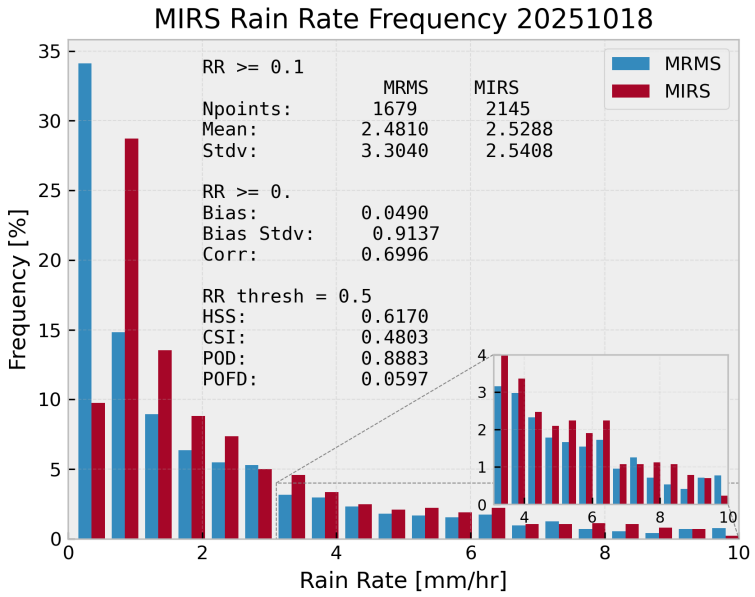

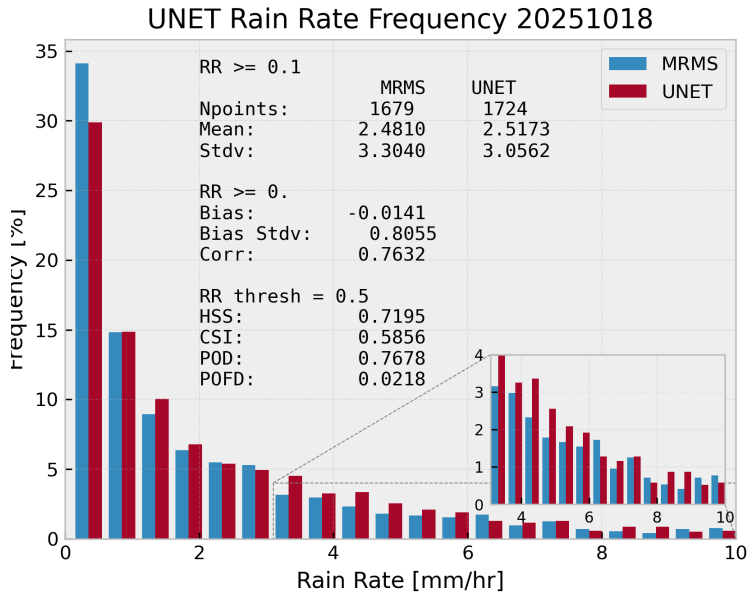

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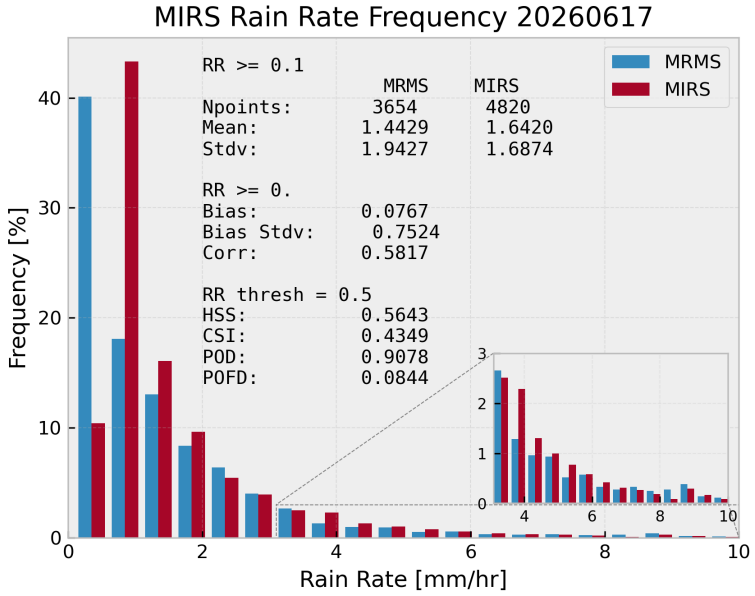
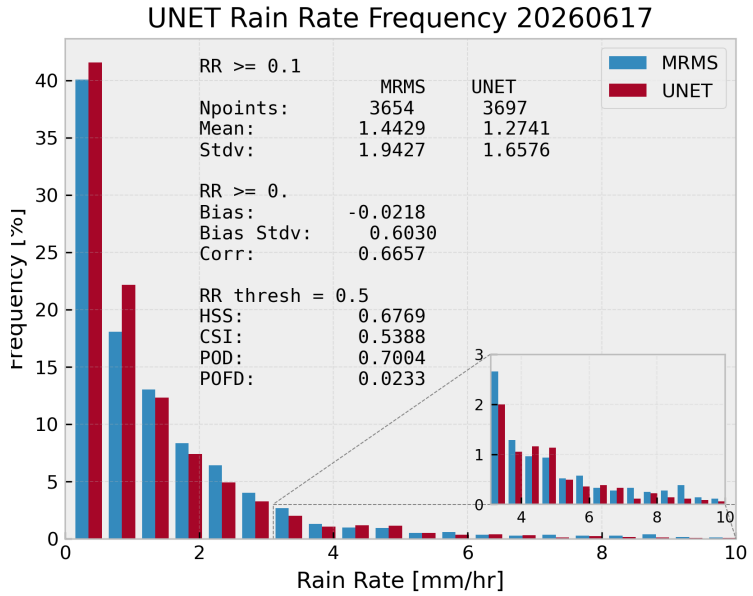
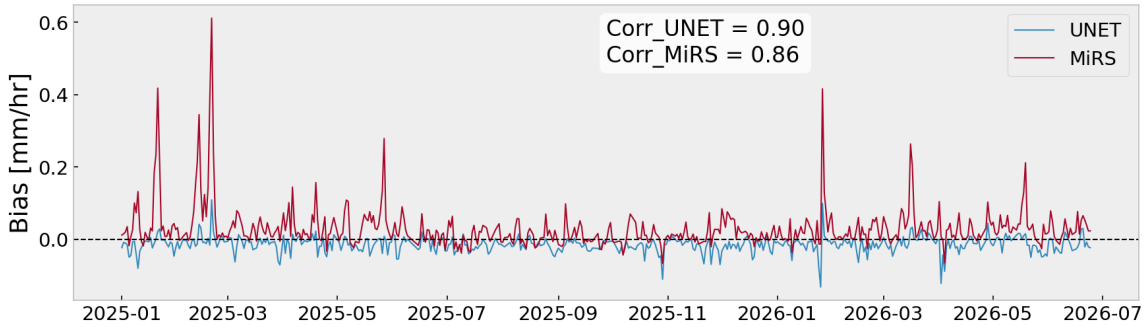
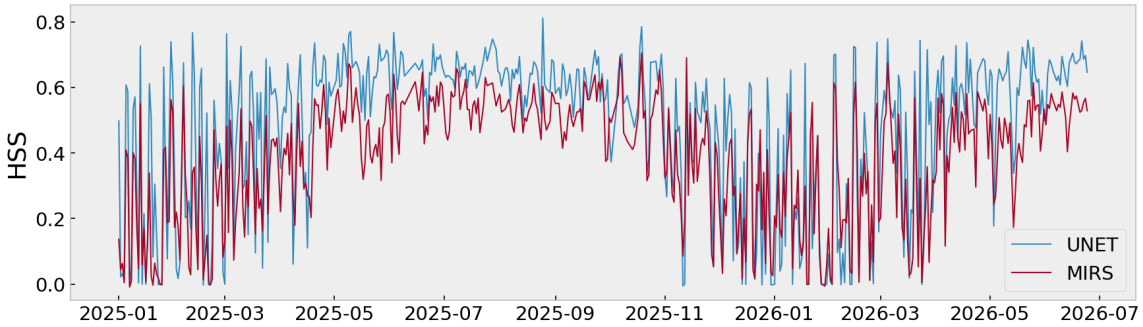


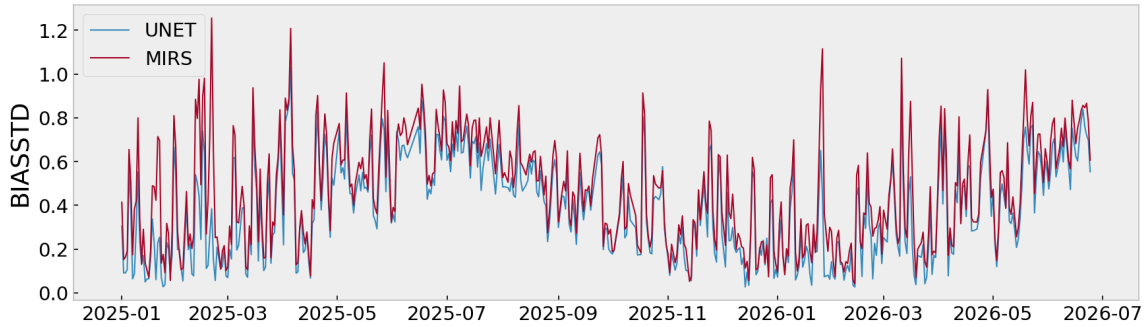


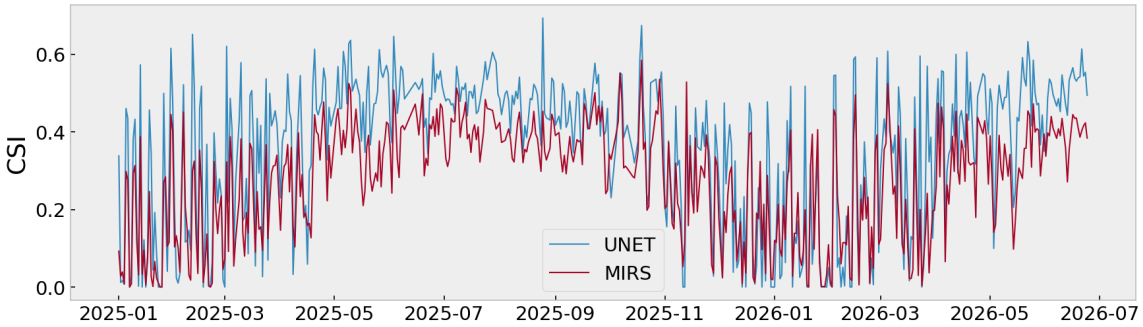
- U-Net produces a rain rate frequency distribution that more closely matches MRMS across a broad range of rain intensities
- Improvements are consistently reflected in both continuous (correlation, bias variability) and categorical metrics with POFD is reduced by approximately 75%, while CSI and HSS increase substantially
- The consistent improvements across representative cases provide confidence in the robustness of the AI enhancement prior to operational deployment.

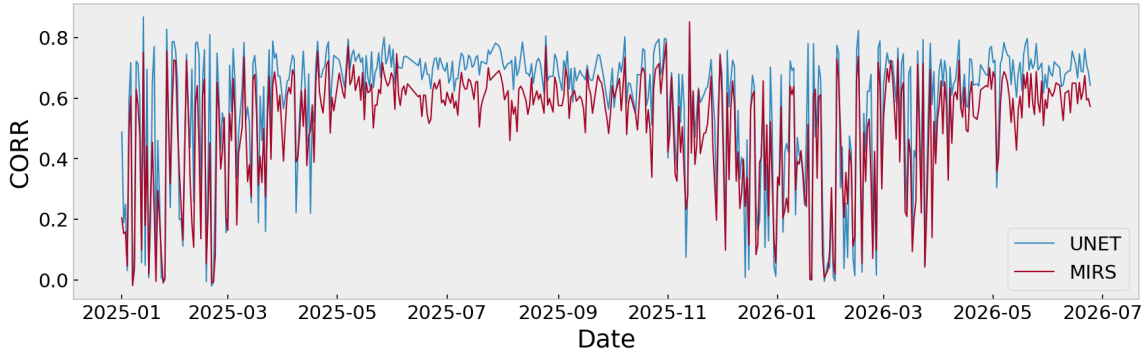
Daily Rain Rate Performance Time Series (1 Jan 2025 – 24 Jun 2026)

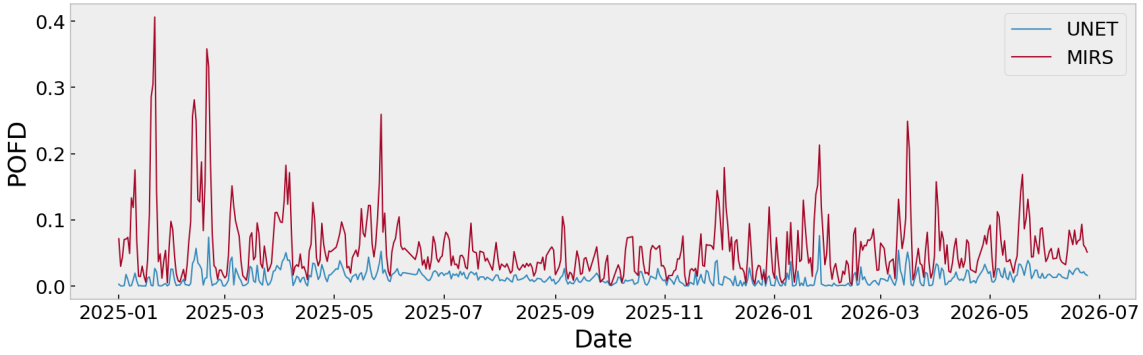






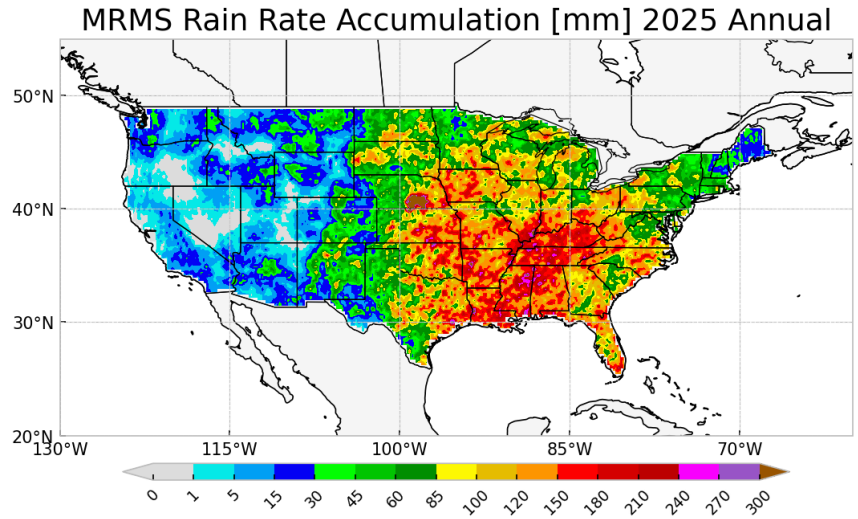


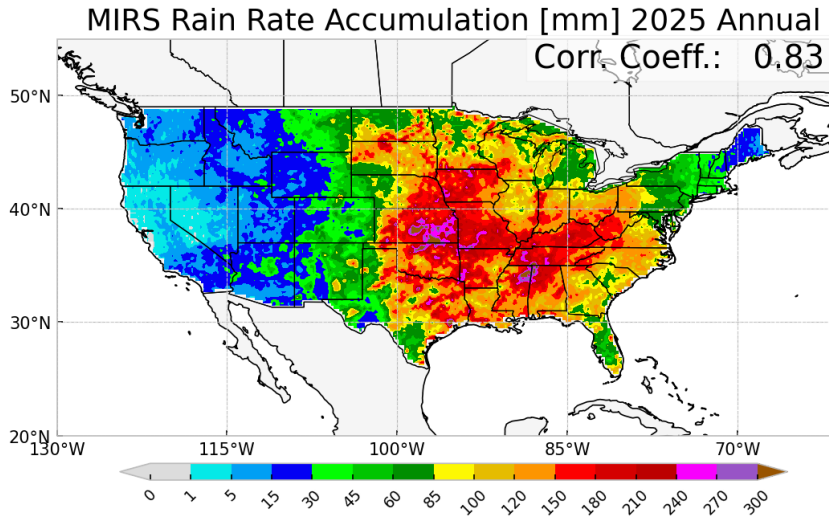


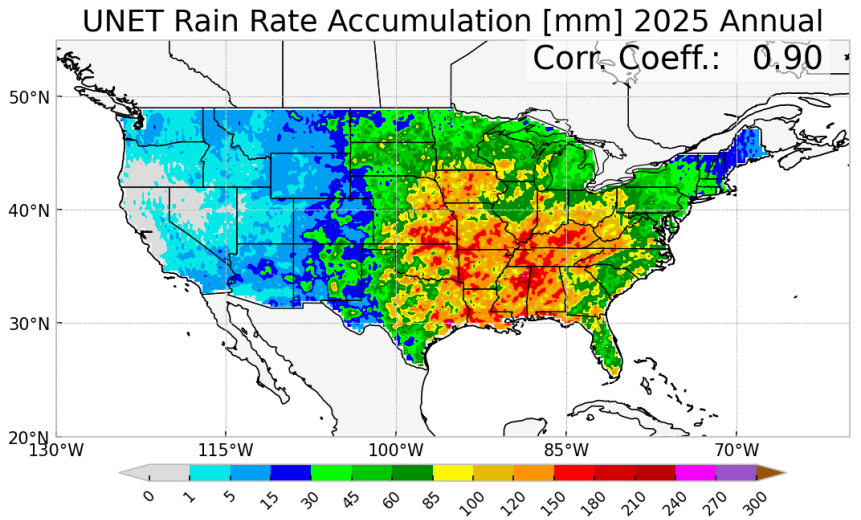


U-Net demonstrates consistent improvements in both continuous and categorical metrics, indicating robust and stable operational performance.

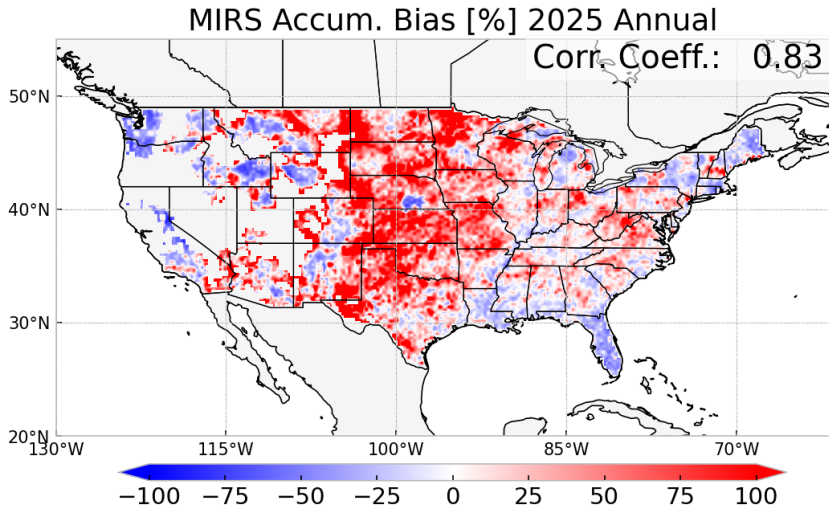
U-Net Significantly Reduces Climatological Bias in MiRS Annual Rain Rate

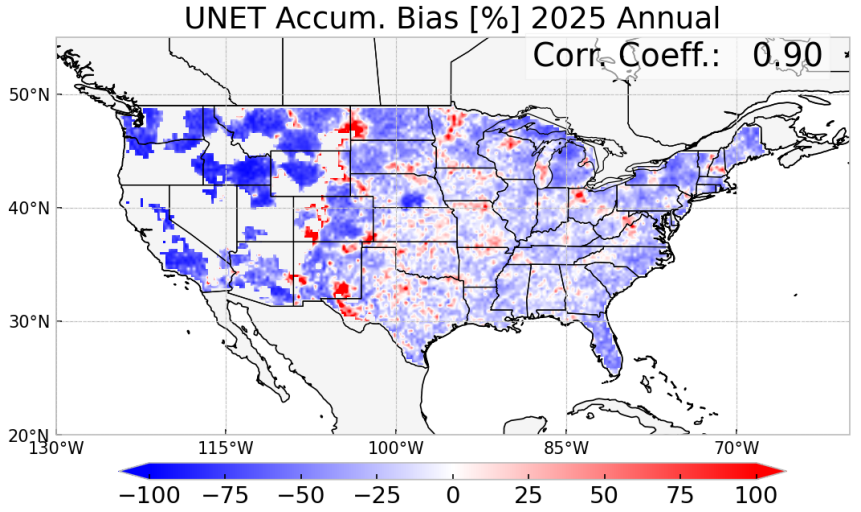




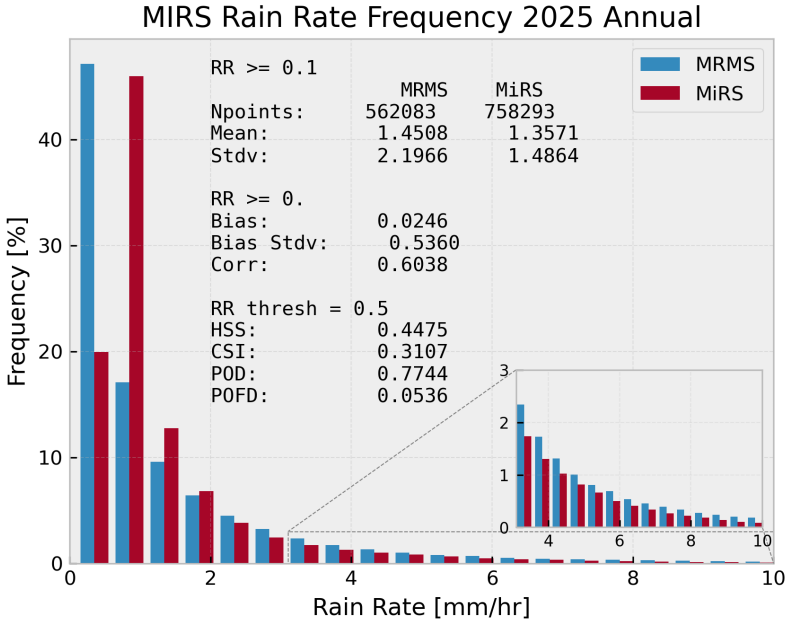


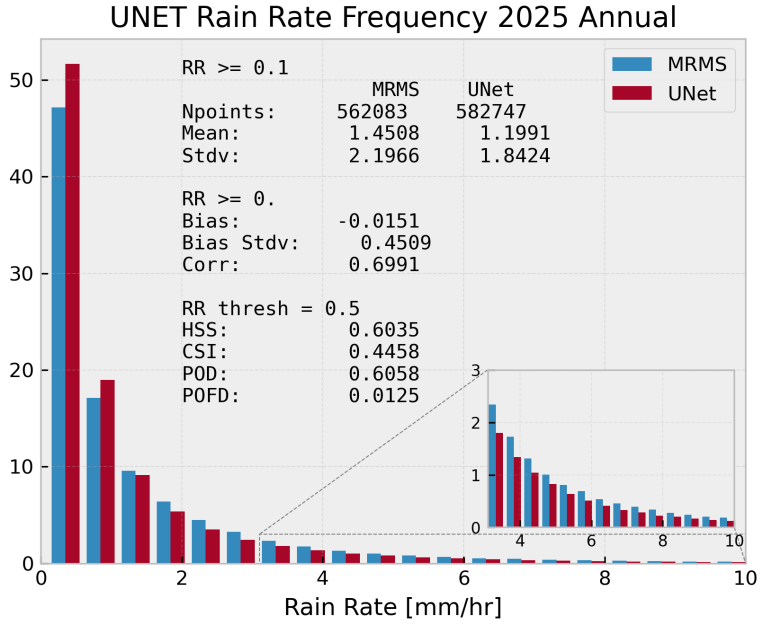
- The baseline MiRS reproduces the overall precipitation climatology but exhibits systematic regional biases, particularly an overestimation across the central CONUS.
- U-Net substantially reduces these biases while preserving the large-scale precipitation distribution.

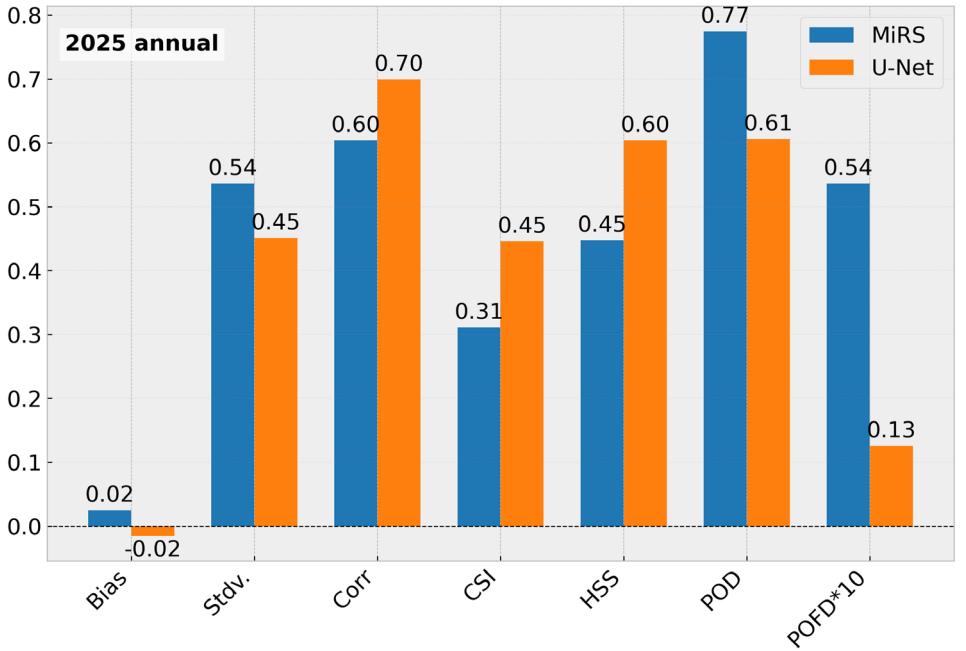


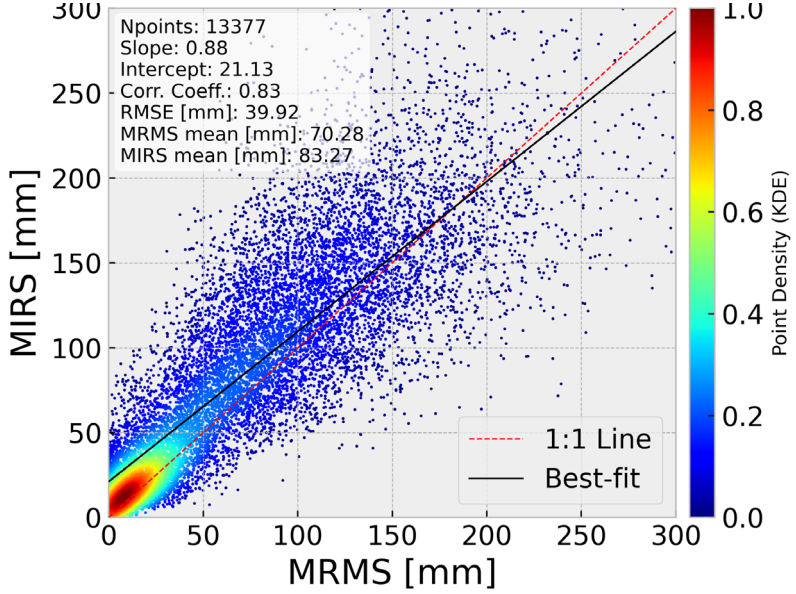


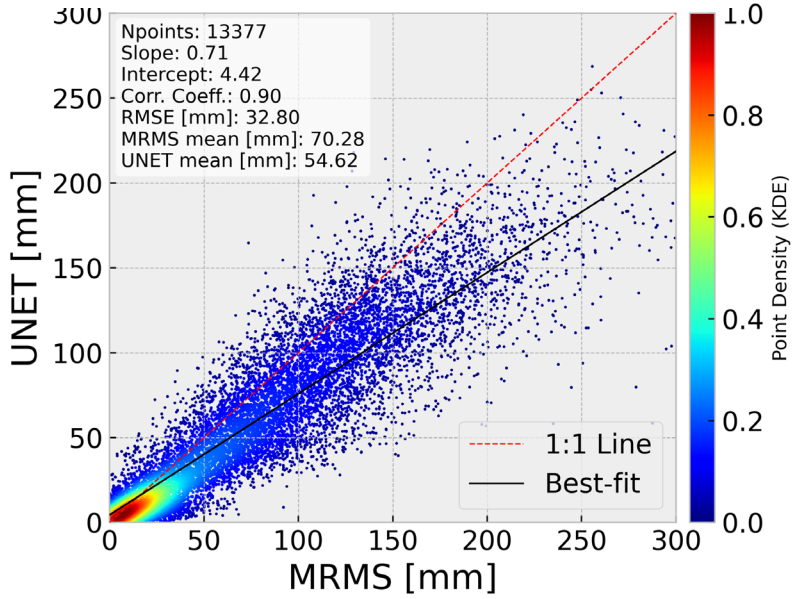
U-Net Improves Annual Accumulated Rain Rate Statistics







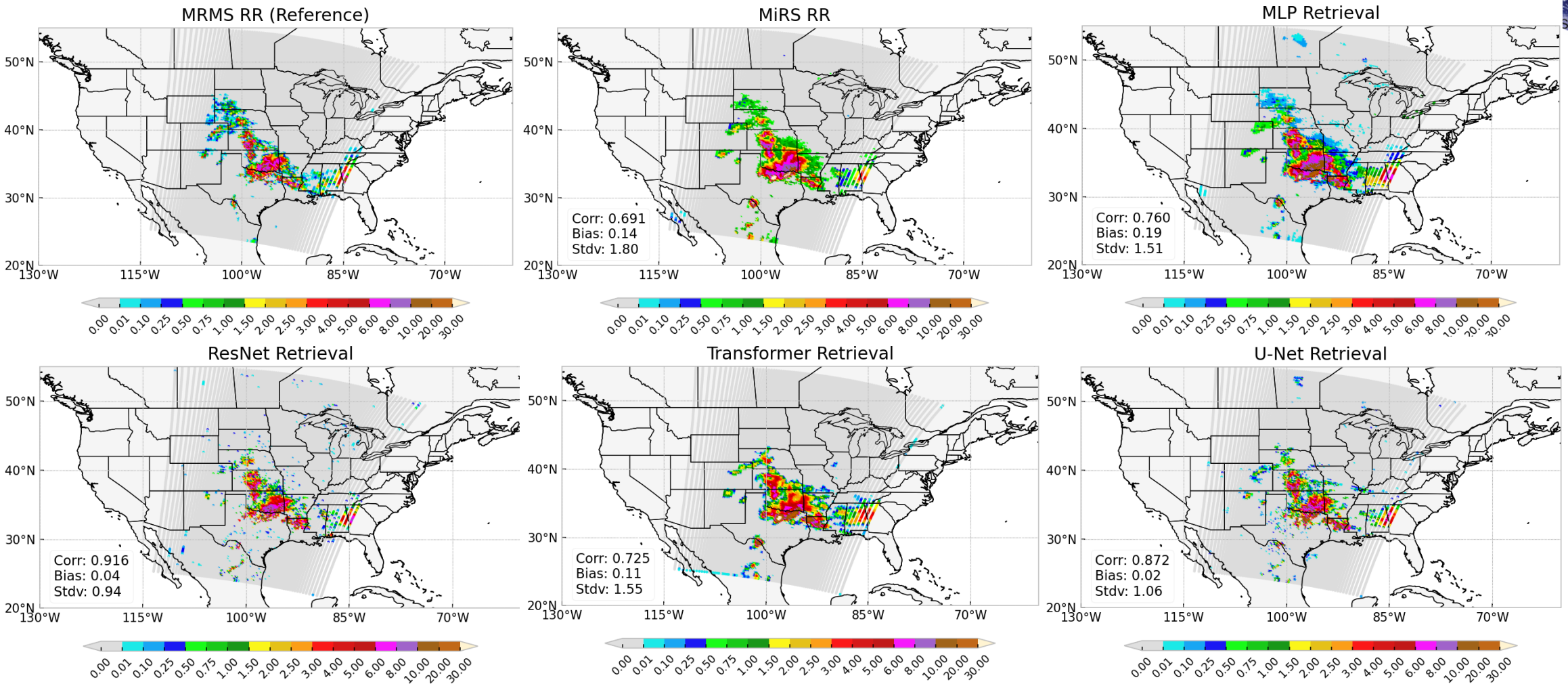




U-Net consistently improves annual precipitation distribution, spatial agreement, and both continuous and categorical metrics.

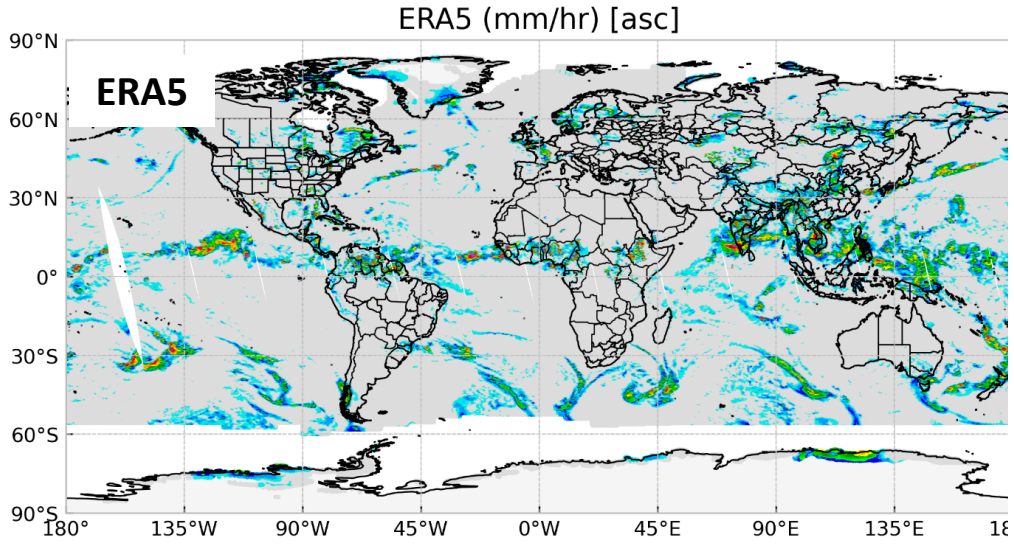
U-Net enhanced RR over CONUS will be transit to operational in September 2026

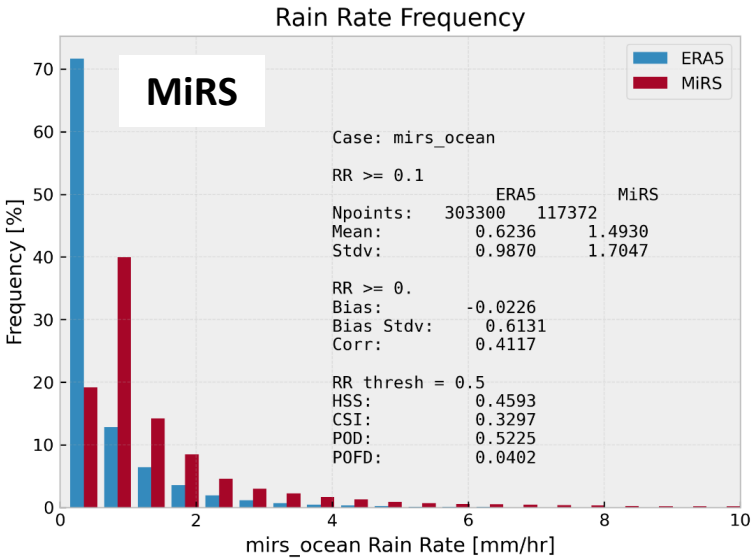
Evaluation of Multiple AI Architectures

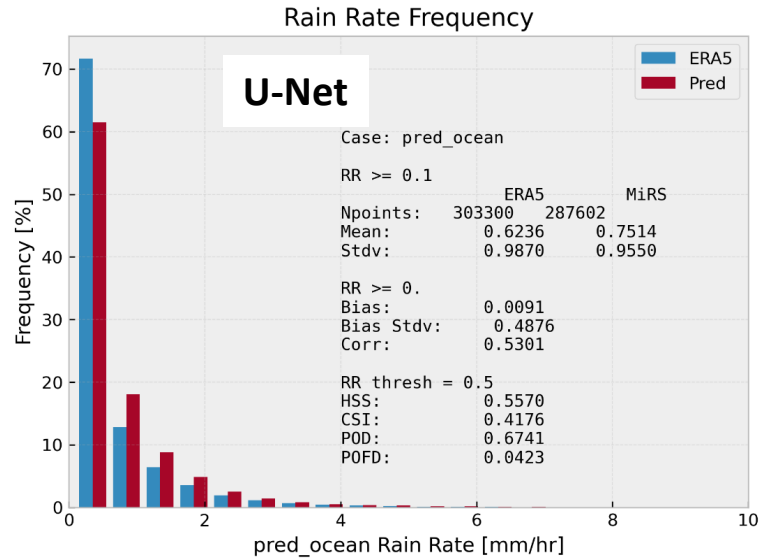


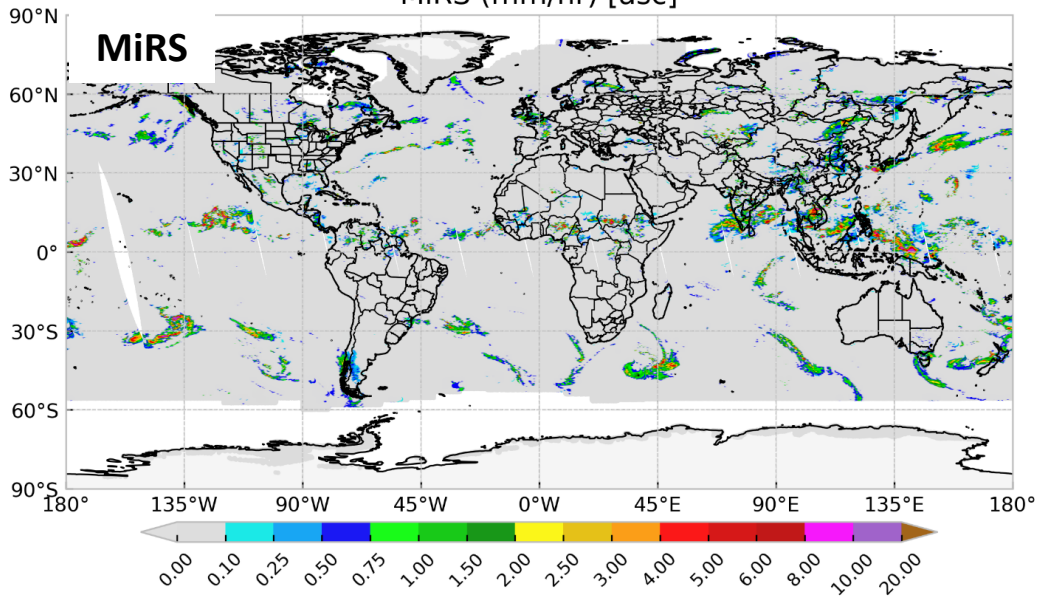
Multiple AI architectures demonstrate promising performance, providing opportunities for continued optimization beyond the current operational U-Net implementation.

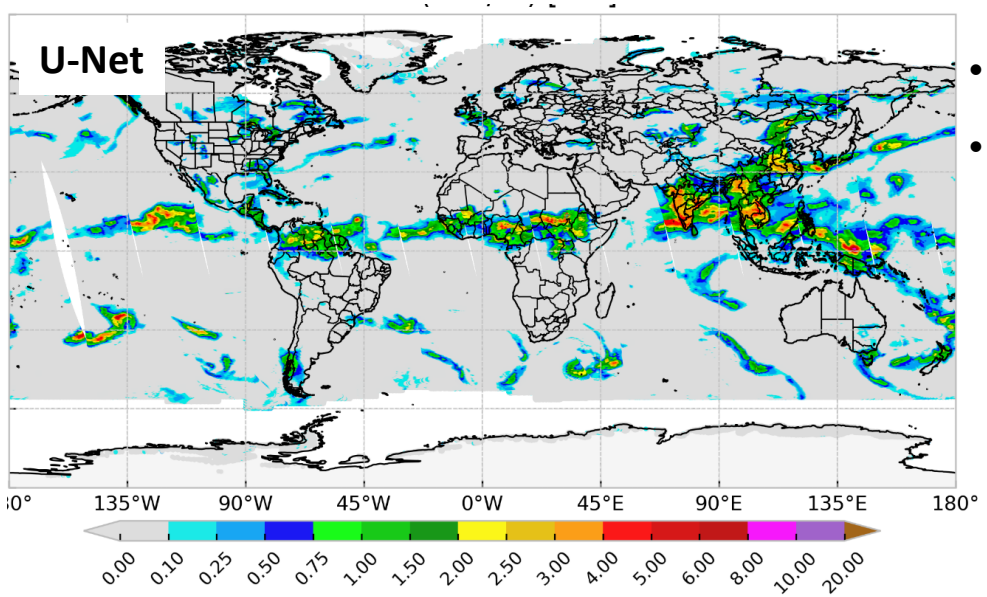
Global Demonstration: 20 July 2020











- Training: 12 days in 2021
- Preliminary global results are encouraging. Fine-tuning of the global U-Net model for both land and ocean is currently in progress to further improve retrieval performance.

Summary and Path Forward

Summary

- MiRS provides robust global precipitation retrievals but exhibits systematic regional biases.
- The U-Net AI framework substantially reduces these regional biases while preserving the native satellite footprint.
- Promising results have been demonstrated over CONUS, Europe, China, and in preliminary global applications.
- The AI rain-rate enhancement has been successfully extended to multiple microwave sensors, including ATMS, AMSU-A/MHS, and GMI.

Path Forward

- Operational deployment over CONUS for ATMS, AMSU-A/MHS, and GMI in September 2026.
- Complete global model fine-tuning and validation.
- Continue improving AI model architecture and training.
- Expand global training and validation using additional reference datasets.
- Extend the AI framework to additional MiRS Environmental Data Records (EDRs).

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