Updates on the NOAA Operational Snowfall Rate Product

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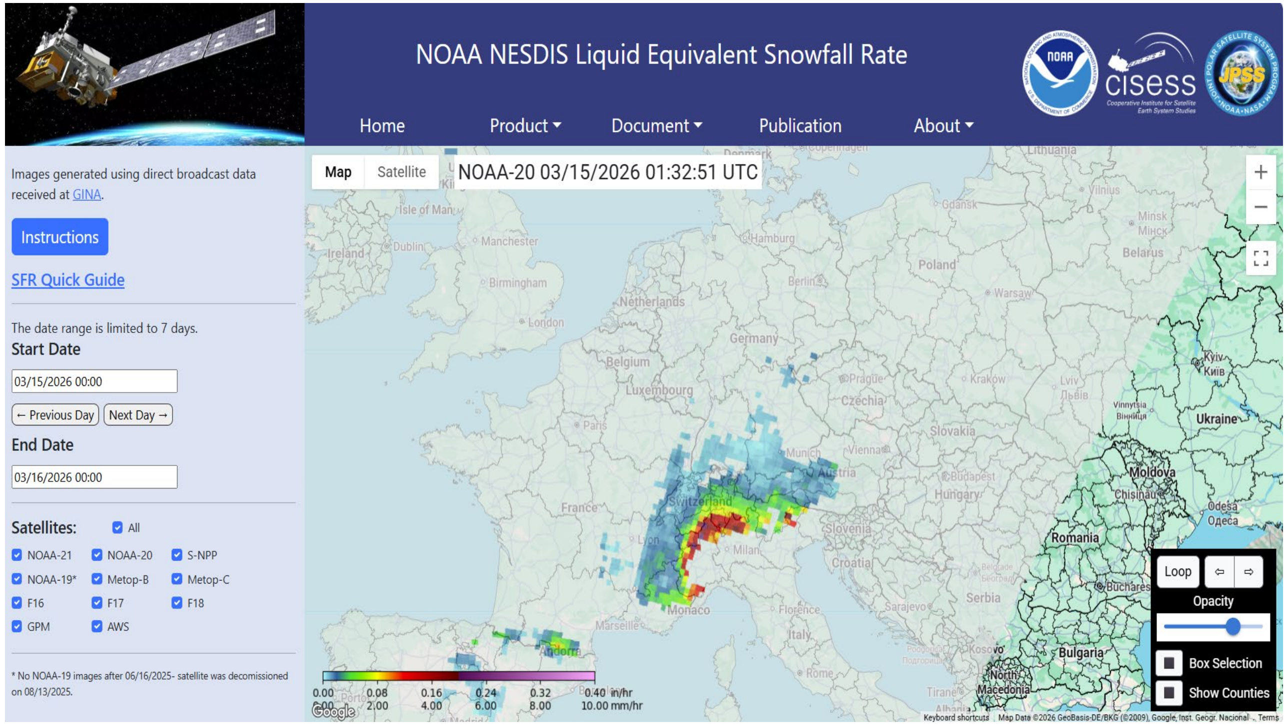
Introduction

- ❑ The NOAA/NESDIS operational global satellite snowfall rate (SFR) product is an instantaneous estimate of liquid-equivalent snowfall rate

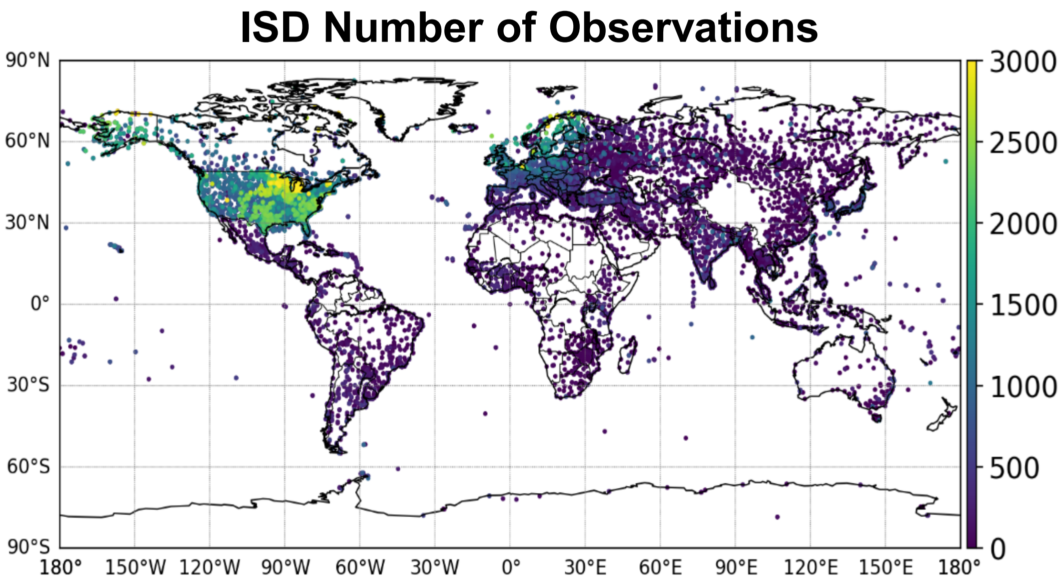
- ❑ SFR is retrieved from passive microwave measurements from Low Earth Orbit (LEO) satellites:
  - **ATMS** onboard **S-NPP, NOAA-20, and NOAA-21**
  - **AMSU-A/MHS** onboard **Metop-B**, and **Metop-C**
  - **GMI** onboard **GPM**
  - **SSMIS** onboard **DMSP-F16 and -F17** (experimental)
  - **MWR** onboard **AWS** (experimental)
  - Recent & Future sensors
    - **ATMS** onboard **QuickSounder**
    - **AMSR3** onboard **GOSAT-GW**
    - **MWS** onboard **Metop-SG A1**
    - **MWI** onboard **Metop-SG B1**
    - Microwave Sensors from **Commercial satellites**

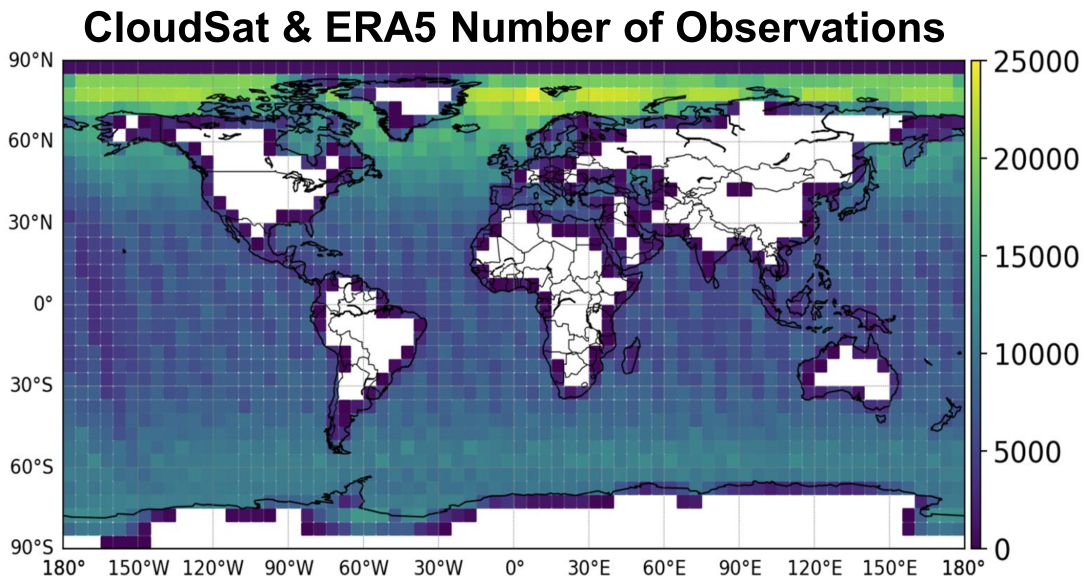


- ❑ Algorithms
  - Snowfall detection (SD) – Machine learning (ML) model
  - Snowfall rate estimation (SFR) – physically-based algorithm enhanced with ML

Snowfall Detection (SD)

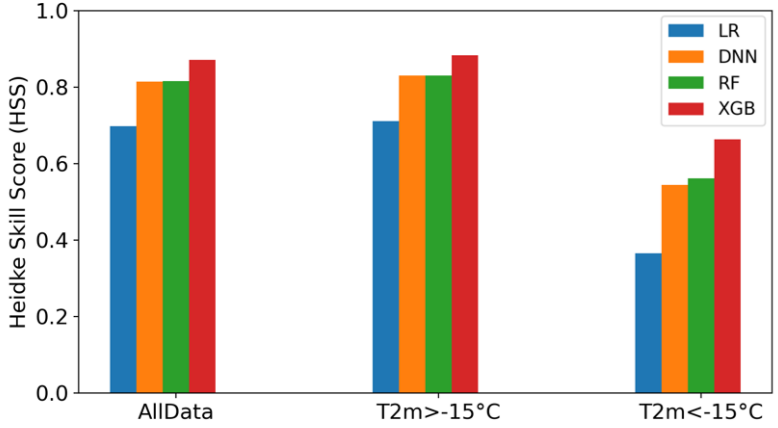
- **Machine learning (ML) algorithm** (Fan *et al.*): Selected XGBoost from 4 ML models
- **Targets**
  - Land: Global manual weather reports (NOAA/NCEI Integrated Surface Database, ISD)
  - Ocean: CloudSat CPR spaceborne radar precipitation type and ECMWF reanalysis ERA5 snowfall
- **Features**: Collocated satellite measurements and NOAA GFS model data





Snowfall Detection Validation

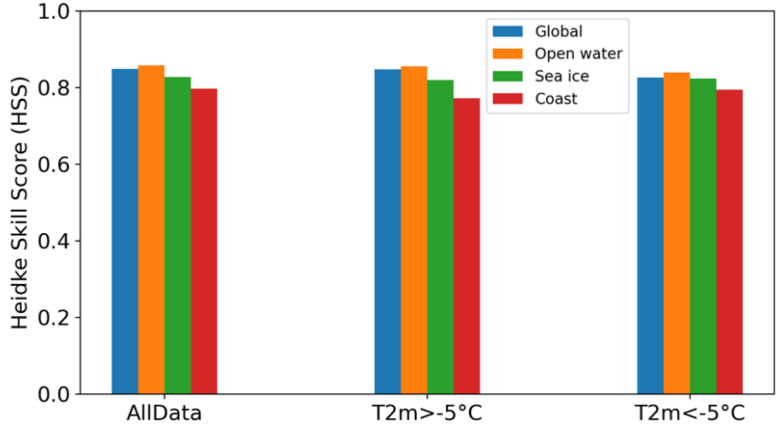
NOAA-21 Land SD Heidke Skill Score



Land SD Heidke Skill Score

	NOAA-21	NOAA-20	S-NPP	MetOp-C	MetOp-B	NOAA-19	GPM
T_{2m}>5°F/-15°C	0.88	0.88	0.84	0.88	0.85	0.83	0.86
T_{2m}<5°F/-15°C	0.66	0.67	0.65	0.64	0.65	0.61	0.59
Global	**0.87**	**0.87**	**0.83**	**0.86**	**0.84**	**0.82**	**0.85**

NOAA-21 Ocean SD Heidke Skill Score



Ocean SD Heidke Skill Score

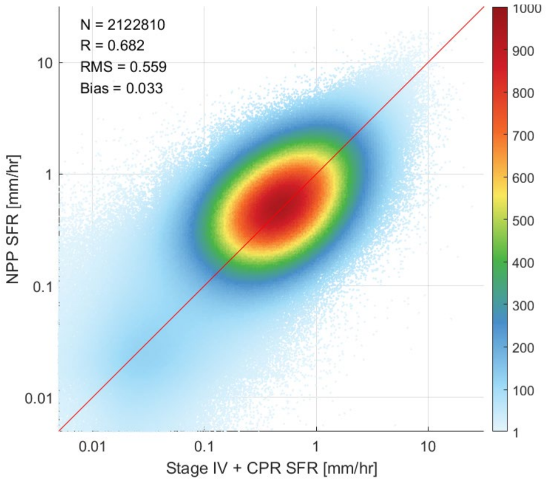
	NOAA-21	NOAA-20	S-NPP	MetOp-B	MetOp-C	NOAA-19	GPM
Open Ocean	0.86	0.81	0.82	0.84	0.85	0.84	0.85
Sea Ice	0.83	0.73	0.74	0.76	0.75	0.80	0.81
Coast	0.79	0.71	0.73	0.73	0.72	0.76	0.76
Global	**0.84**	**0.77**	**0.78**	**0.80**	**0.80**	**0.82**	**0.84**

Snowfall Rate Estimation

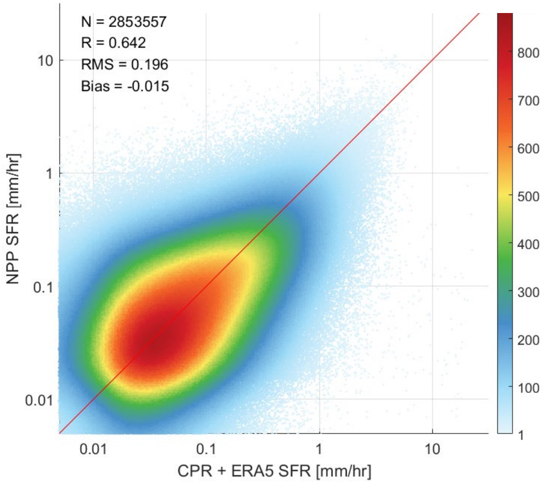
- **1DVAR-based physical algorithm** (Meng, *et al.*, 2017)
  - Cloud properties retrieved from 1DVAR model (Yan, *et al.*, 2008)
  - Snowfall rate derived from cloud properties and ice particle fall velocity (Heymsfield & Westbrook, 2010)
- **Machine learning enhancement**
  - NN model for Ice Water Path initialization
  - NN model for SFR bias correction
- **Histogram matching for inter-satellite consistency**
- **Validation datasets**
  - Stage IV: radar, gauge, and manual QC; hourly; CONUS
  - CloudSat 2C-SNOW-PROFILE near surface snowfall rate
  - ERA5 hourly snowfall rate

Snowfall Rate Validation

S-NPP Land SFR



S-NPP Ocean SFR



Land SFR Validation against Stage IV and CPR

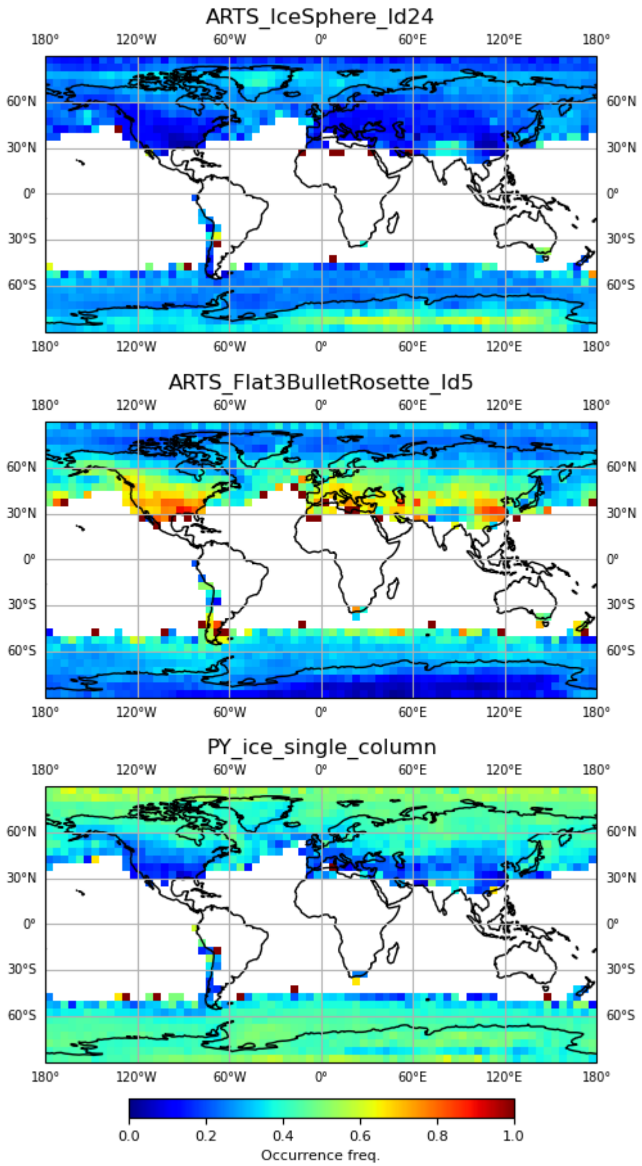
	NOAA-21	NOAA-20	S-NPP	MetOp-C	MetOp-B	NOAA-19	GPM
R	0.72	0.69	0.68	0.66	0.63	0.66	0.60
RMS (mm/hr)	0.54	0.58	0.56	0.63	0.62	0.58	0.68
Bias (mm/hr)	0.016	0.028	0.033	0.014	0.015	0.033	0.009

Ocean SFR Validation against CPR and ERA5

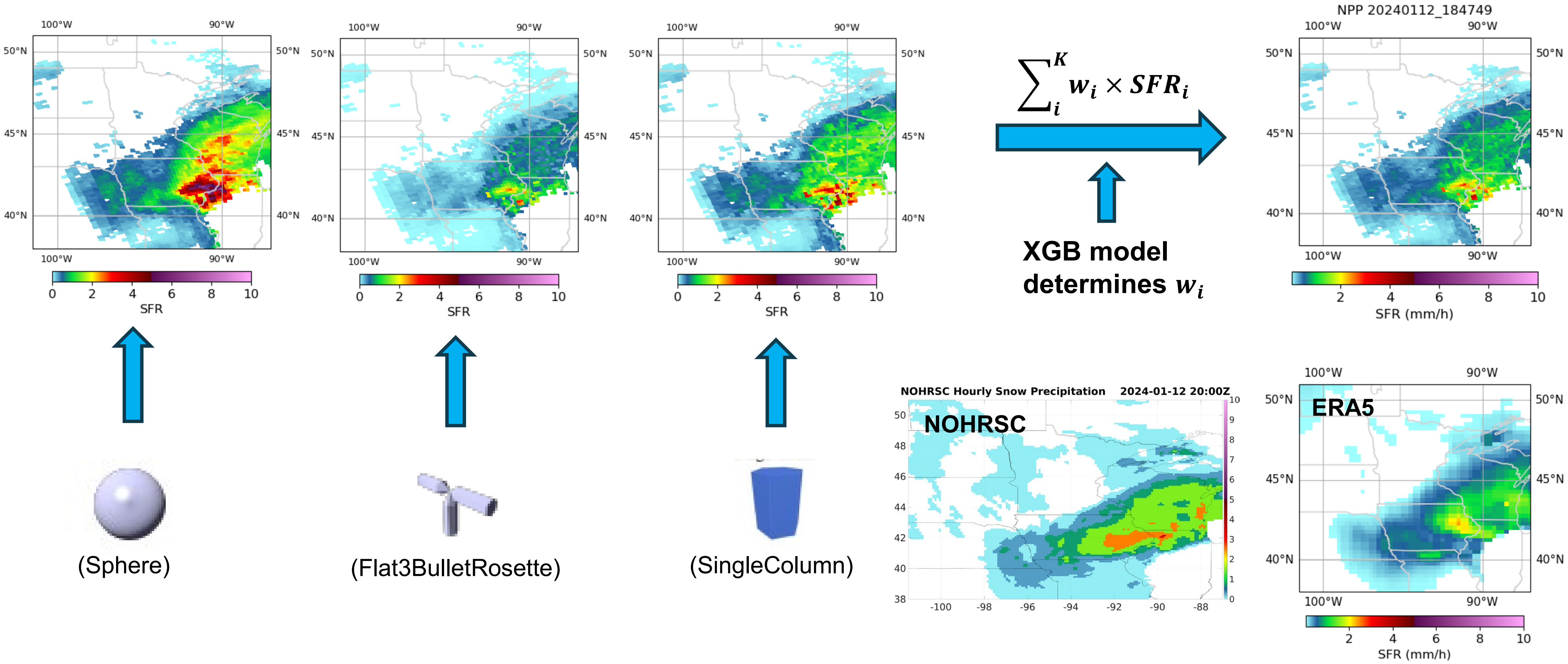
	NOAA-21	NOAA-20	S-NPP	MetOp-C	MetOp-B	NOAA-19	GPM
R	0.63	0.63	0.64	0.63	0.61	0.64	0.67
RMS (mm/hr)	0.20	0.20	0.20	0.18	0.20	0.20	0.23
Bias (mm/hr)	-0.026	-0.020	-0.015	-0.023	-0.022	-0.014	-0.039

ML-Enhanced Multi-Ice-Habit Microphysics

- The operational SFR algorithm assumes a single soft sphere ice habit in the RTM.
- This assumption often leads to SFR overestimation.
- An ML-enhanced multi-ice-habit model has been developed to improve the algorithm:
  - Examined 54 ice habits from wo single-scattering databases: ARTS (Eriksson et al. 2018) and Yang (Bi et al. 2013)
  - Selected three ice habits that dominate in different geographic regions and under various conditions
    - Sphere: Antarctica, Himalayas, Greenland
    - Flat3BulletRosette: Mid-latitude
    - SingleColumn: Mid-high-latitude
  - SFR is a weighted combination of retrievals based on the 3 ice habits
  - Trained an ML model to determine the weight assigned to each retrieval



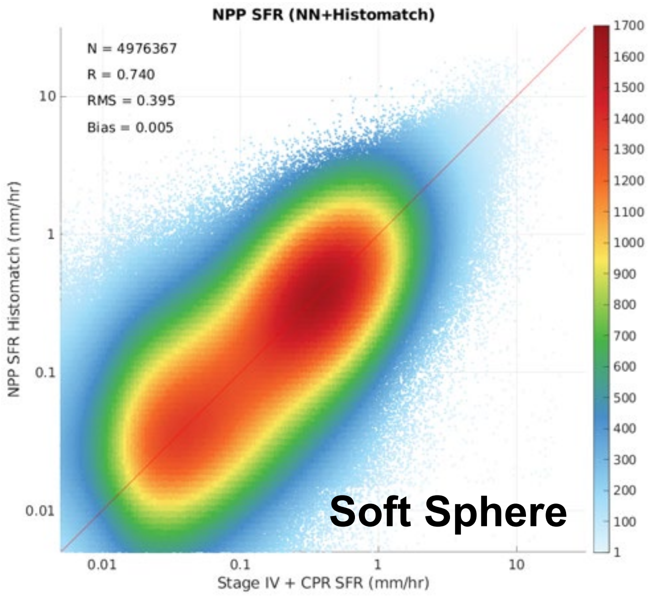
ML-Enhanced Multi-Ice-Habit Microphysics (2)

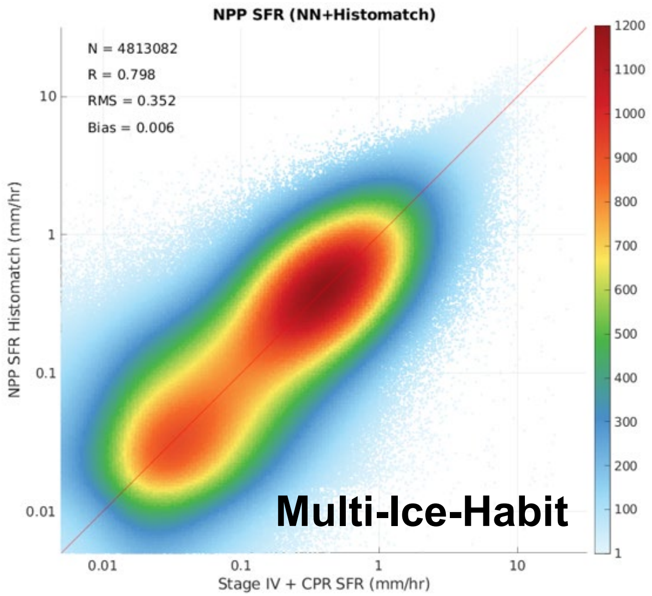


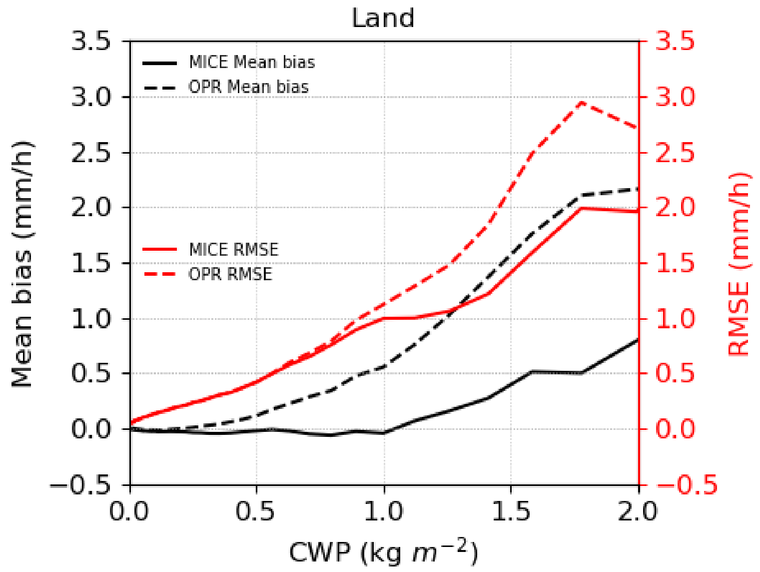
ML-Enhanced Multi-Ice-Habit Microphysics (3)

- ❑ The multi-ice-habit model improves SFR performance.
- ❑ The most noticeable improvement is with large cloud water path (CWP), e.g. in rain-snow transition zones.
- ❑ The updated algorithm will be transitioned to NOAA operations soon.

Comparison between NPP SFR and ERA5 for January 2024

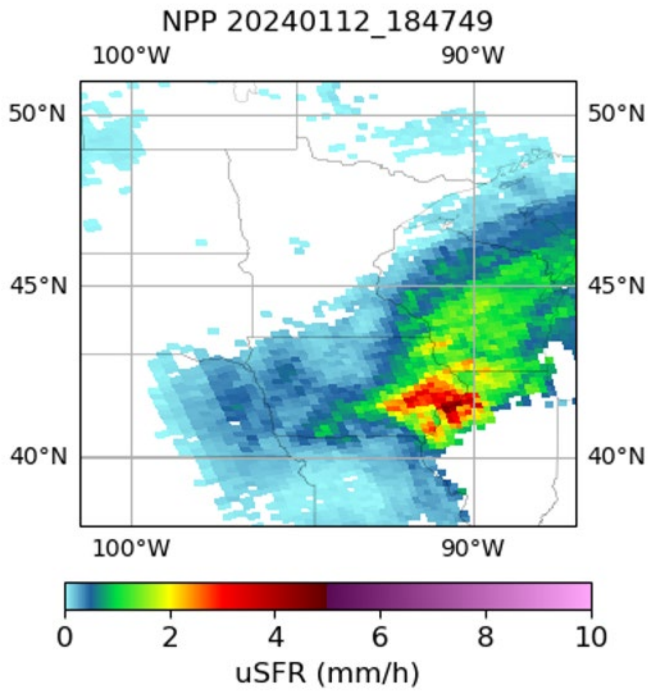




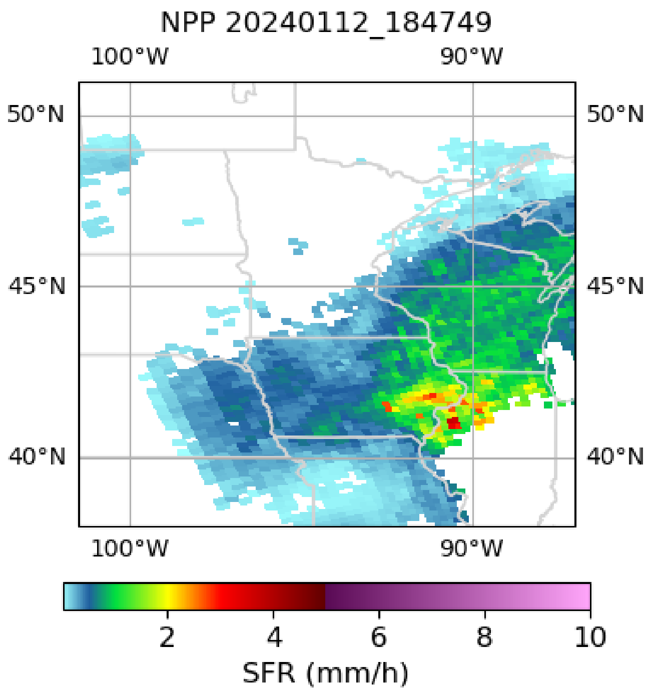


Snowfall Case in Transition Zone

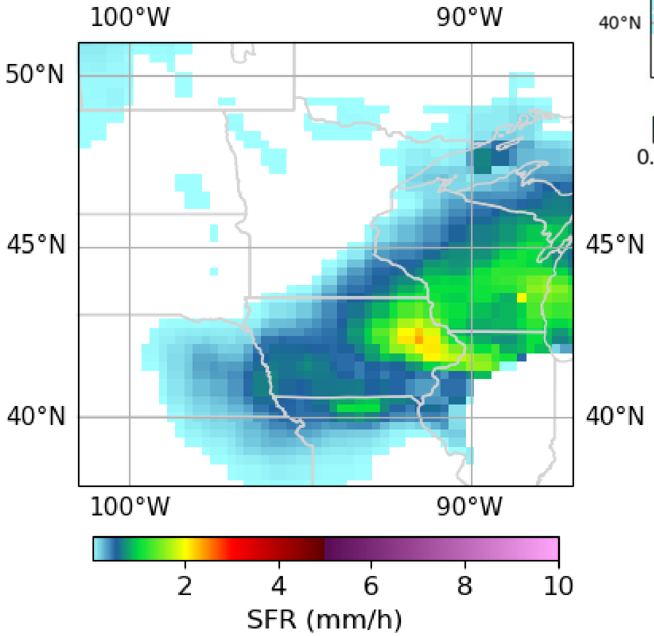
Soft Sphere



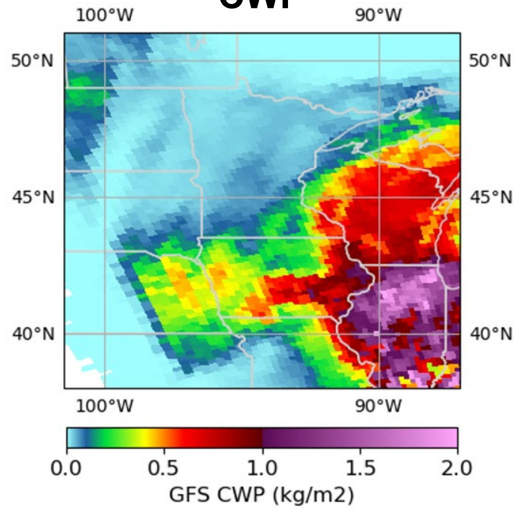
Multi-Ice-Habit



ERA5

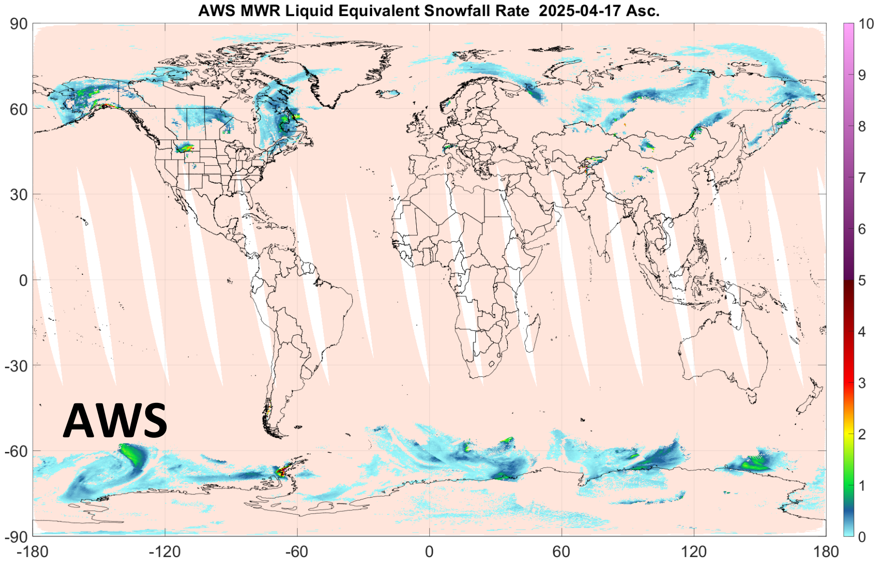


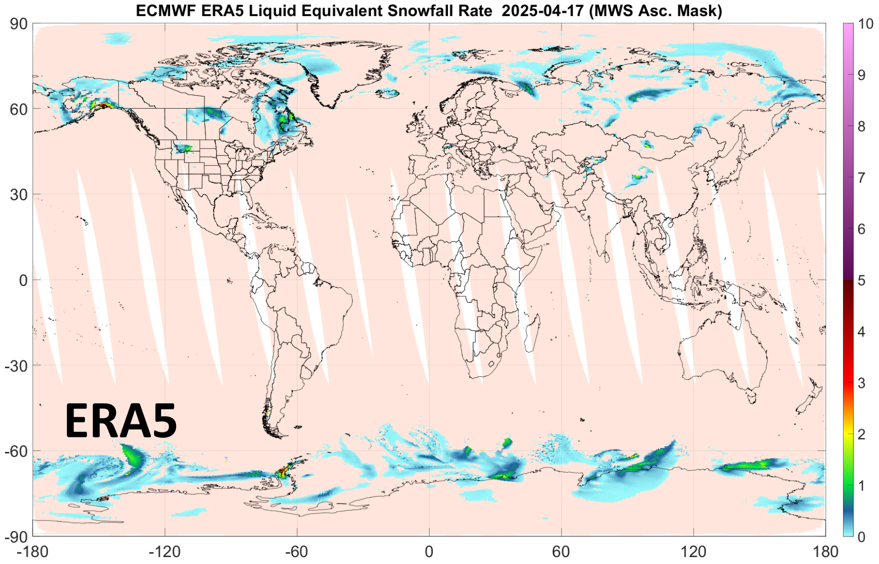
CWP

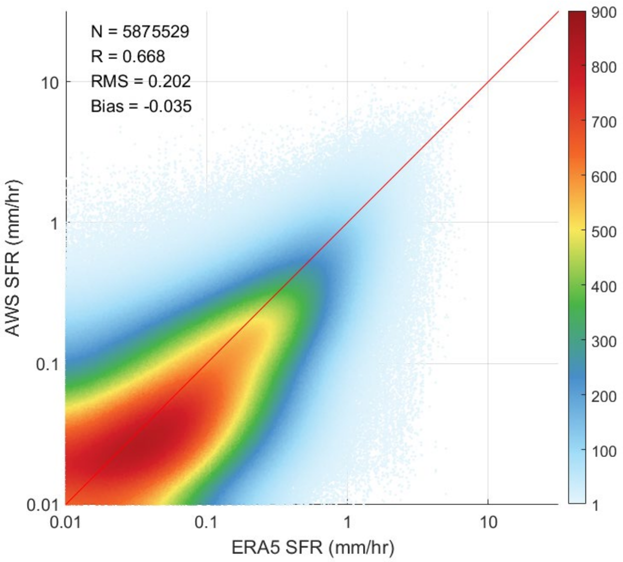


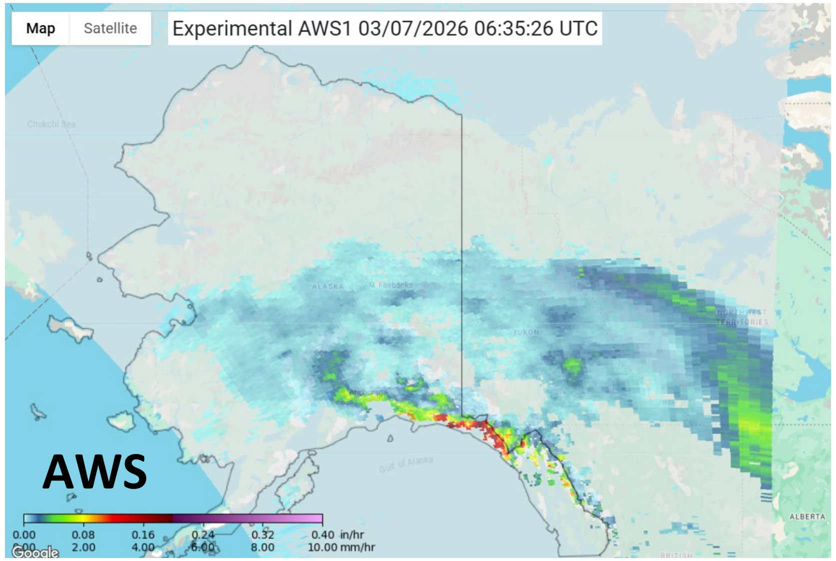
AWS MWR Snowfall Rate

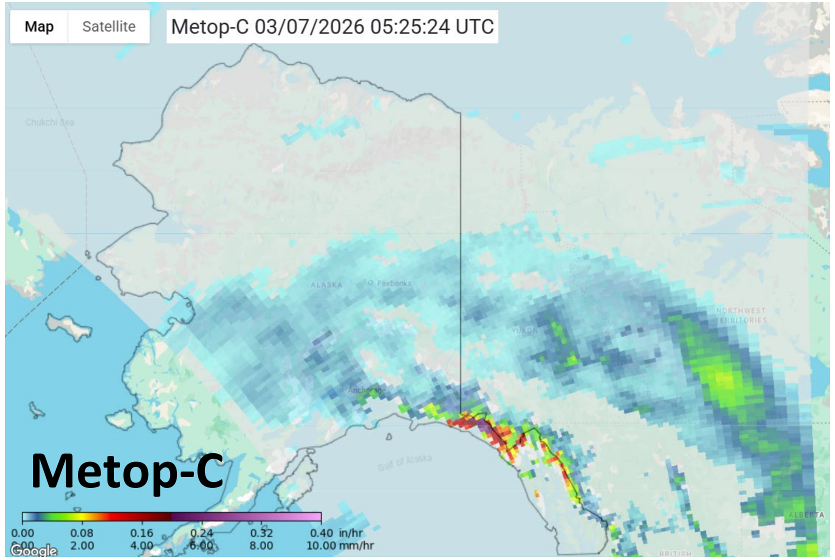
- The AWS SFR algorithm has been developed.
- Evaluation shows good agreement between AWS SFR and ECMWF ERA5 total snowfall rate, as well as SFR from other satellites.
- AWS SFR is generated from direct broadcast data in near real-time in Alaska and distributed to Weather Forecast Offices to support nowcasting





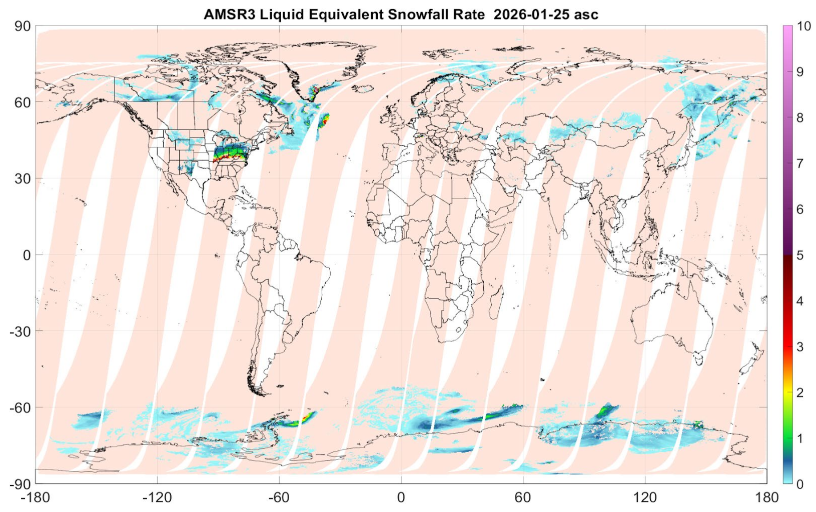


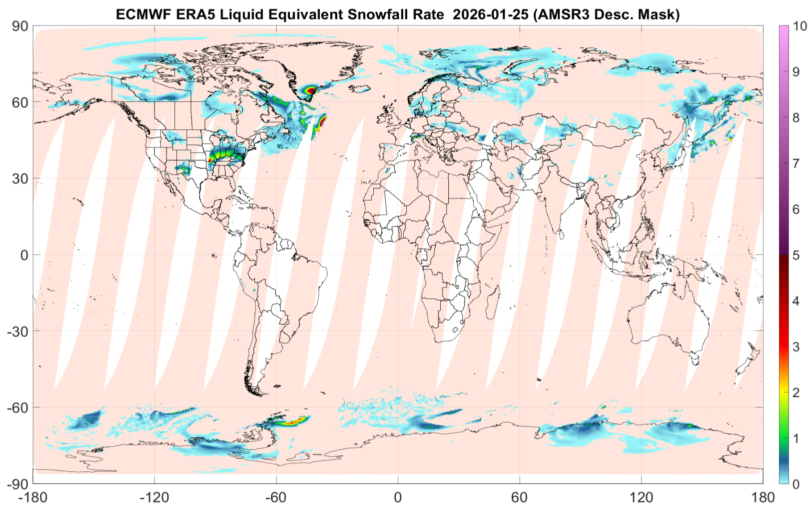


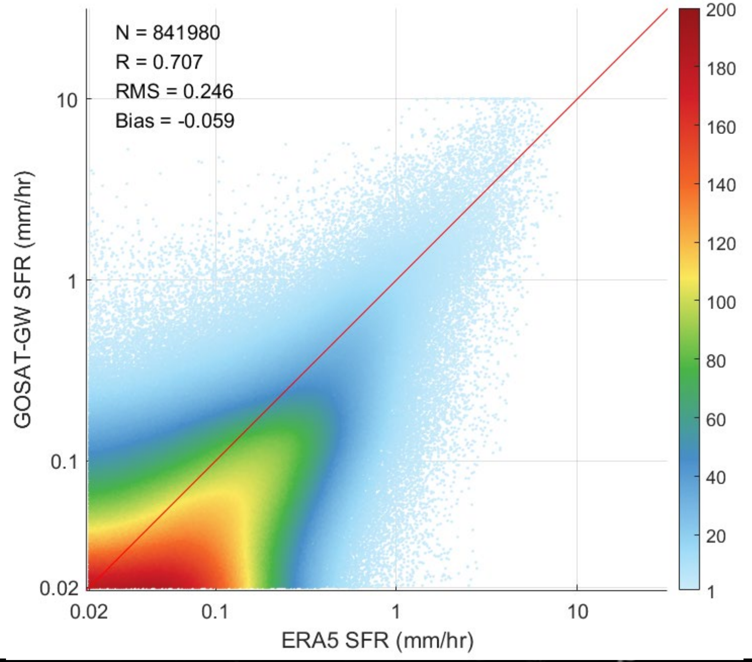


GOSAT-GW AMSR3 Snowfall Rate

- The addition of three high-frequency channels to AMSR3 enables snowfall rate retrievals.
- The preliminary AMSR3 snowfall rate algorithm was developed using GPM GMI data as a proxy.
- The algorithm will be updated using AMSR3 observations once sufficient snowfall data has been collected.
- The AMSR3 algorithm has reached Beta maturity.
- Evaluation of the Beta-level algorithm shows good performance compared with ERA5 total snowfall rate. The evaluation used AMSR3 early data provided by JAXA under an agreement with NOAA.
- The AMSR3 SFR is being transitioned to NOAA operations.

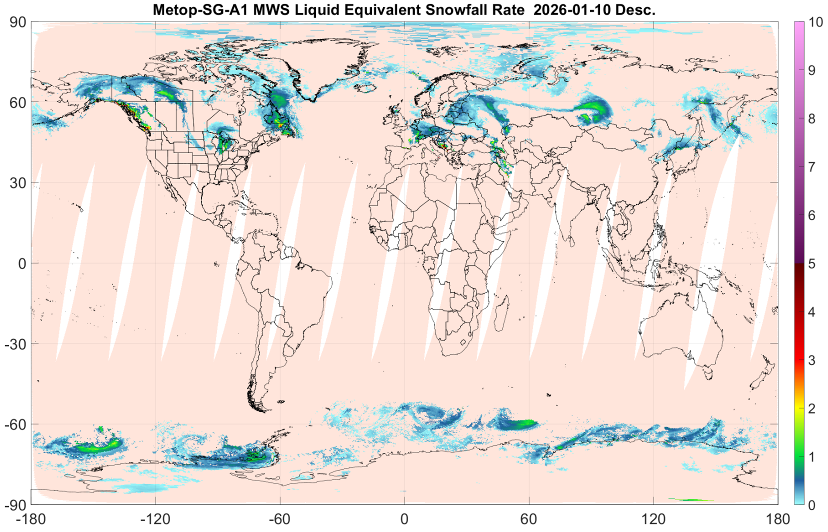


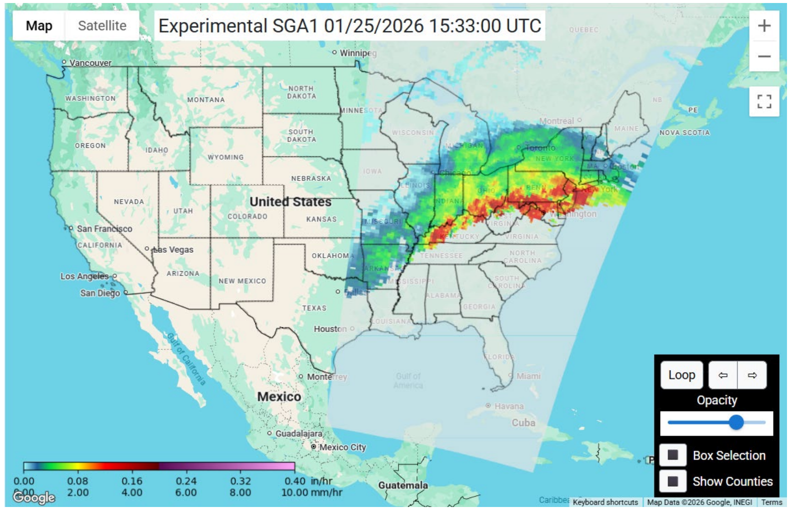


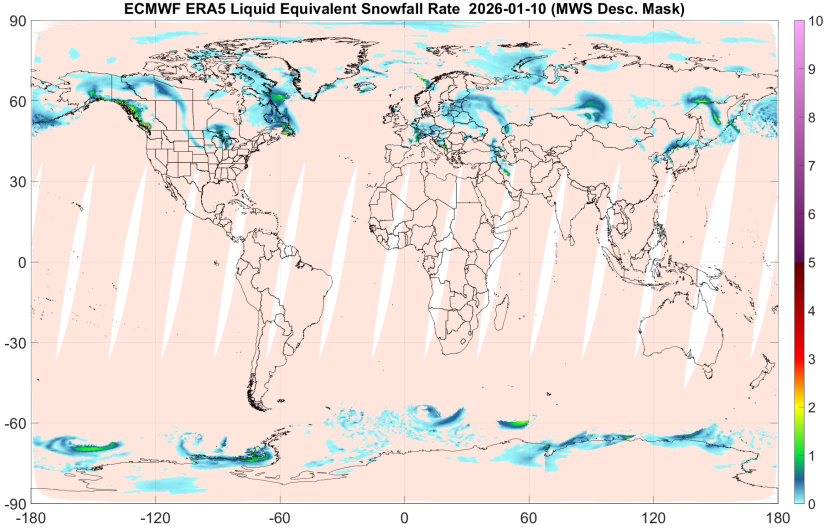


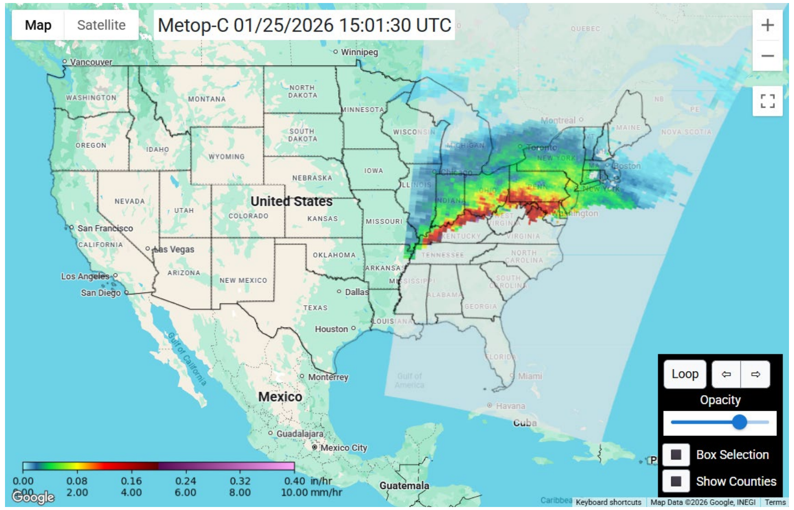
Metop-SG A1 MWS Snowfall Rate Product

- A preliminary SFR algorithm was developed for Metop-SG A1 MWS using ATMS as a proxy.
- Evaluation shows good overall agreement between MWS SFR and ECMWF ERA5 total snowfall rate, as well as SFR from other satellites. The MWS data was provided by EUMETSAT through an agreement with NOAA.
- Evaluation of the impact of the increased NEDT in the 183 GHz channels is ongoing.
- A preliminary SFR algorithm has been developed for Metop-SG B1 MWI using GMI as a proxy





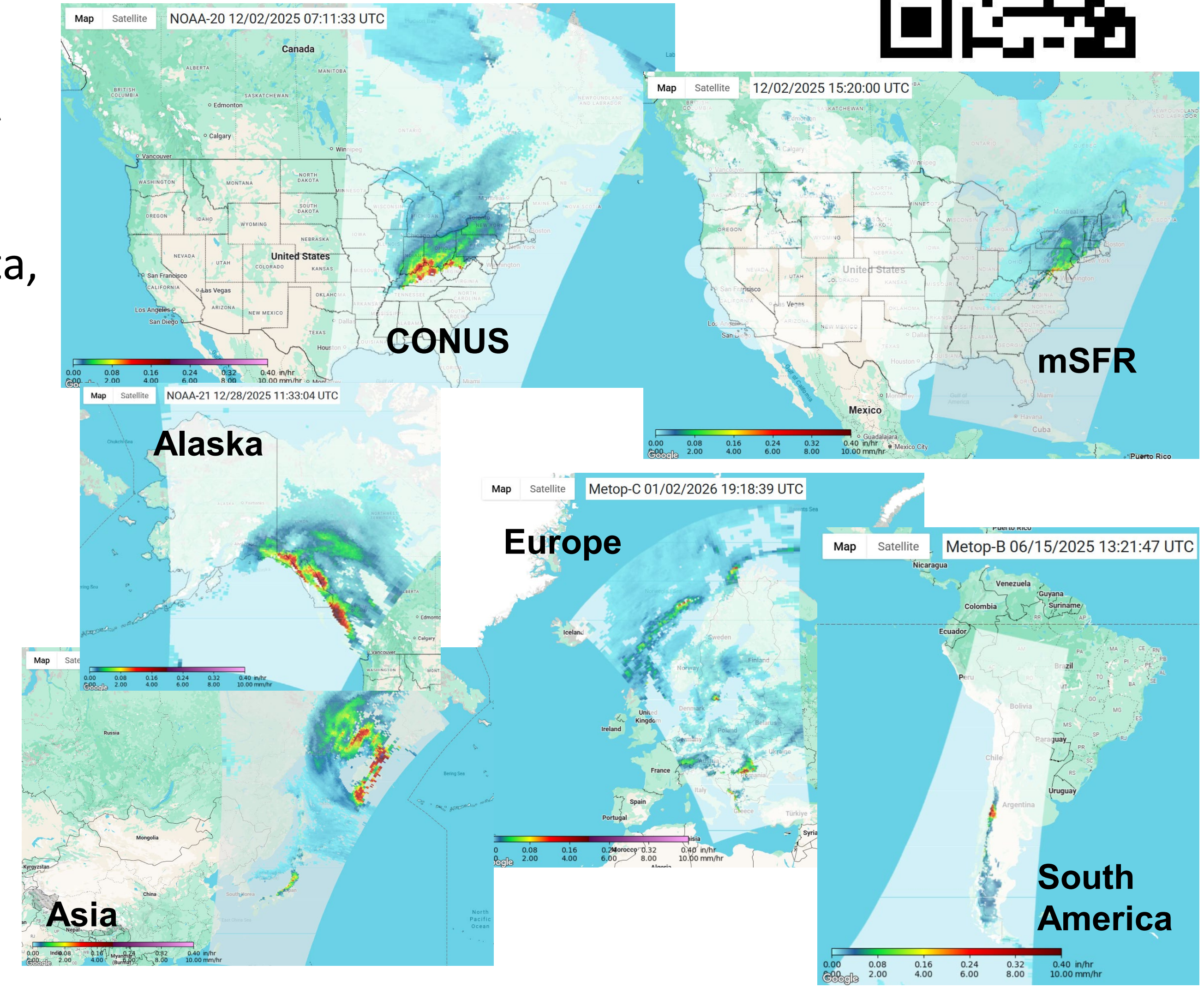




SFR Near Real-Time Webpage

https://sfr.umd.edu

- Google Maps-based direct broadcast (DB) SFR website (https://sfr.umd.edu)
  - Near real-time, 15-30 min latency with DB data, and 30 min to 3 hrs without DB access
  - Displays SFR over many regions and mSFR (merged MRMS radar snow and SFR) over CONUS
  - Includes many functionalities for nowcasting applications:
    - **Value sampling**
    - **Zooming**
    - **Gif generator**
    - **Looping**
    - **Transparency adjustment**
    - **County boundaries**



Summary

- NOAA NESDIS and UMD CISESS developed an operational snowfall rate (SFR) product for a constellation of polar-orbiting satellites
- The algorithm combines 1DVAR physical modeling with ML
- **A new ML-enhanced multi-ice-habit microphysics model significantly improves SFR, particularly for high-CWP cases in rain–snow transition zones**
- **SFR algorithms have been developed for several new and future missions with the goal of transitioning them to operations**
- Through a collaboration between NOAA, UMD, NASA, and University of Alaksa, the SFR product is made available to US NWS Weather Forecast Offices to support forecasting operations
- The SFR website features near real-time SFR images for many regions with low latency and functionality to support nowcasting

Acknowledgements

JPSS STAR

JPSS PGRR

JPSS PSDI

NOAA PPM

NASA SPoRT

NOAA HPCC

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