National Environmental Satellite, Data, and Information Service

IPWG-11, July 15-18, 2024

NOAA Operational Snowfall Rate Product – Recent Developments and Applications

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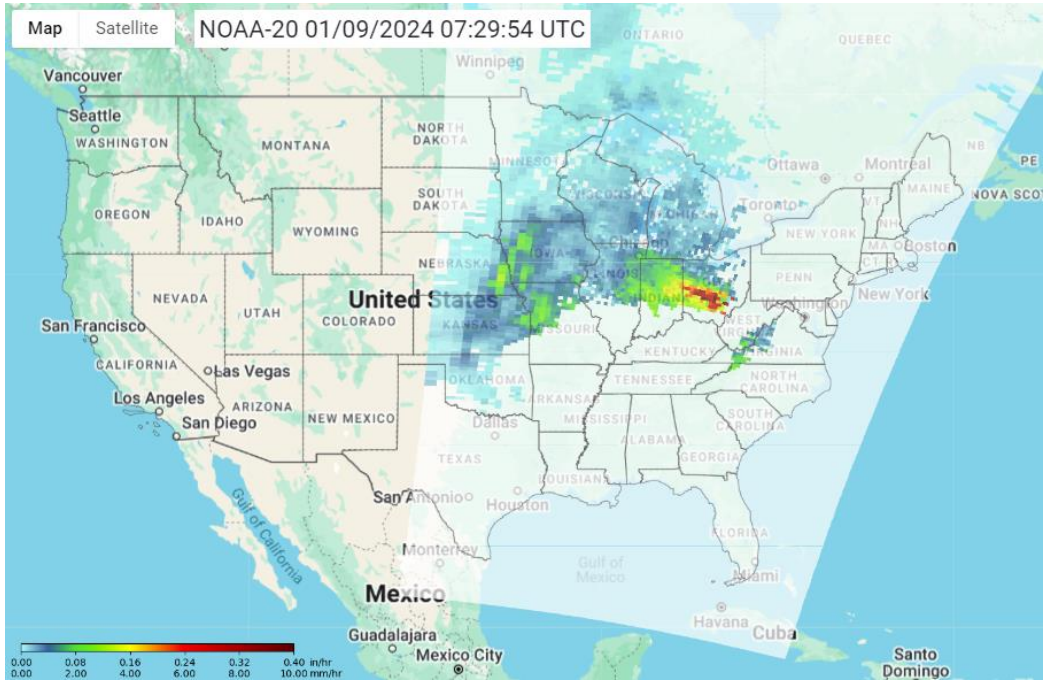
Overview

- The NOAA/NESDIS operational land snowfall rate (SFR) product is retrieved from passive microwave measurements taken by:
  - **ATMS** onboard S-NPP, NOAA-20, and NOAA-21
  - **AMSU-A/MHS** onboard NOAA-19, Metop-B, and Metop-C
  - **GMI** onboard GPM
  - **SSMIS** onboard DMSP-16/-17/-18 (experimental)

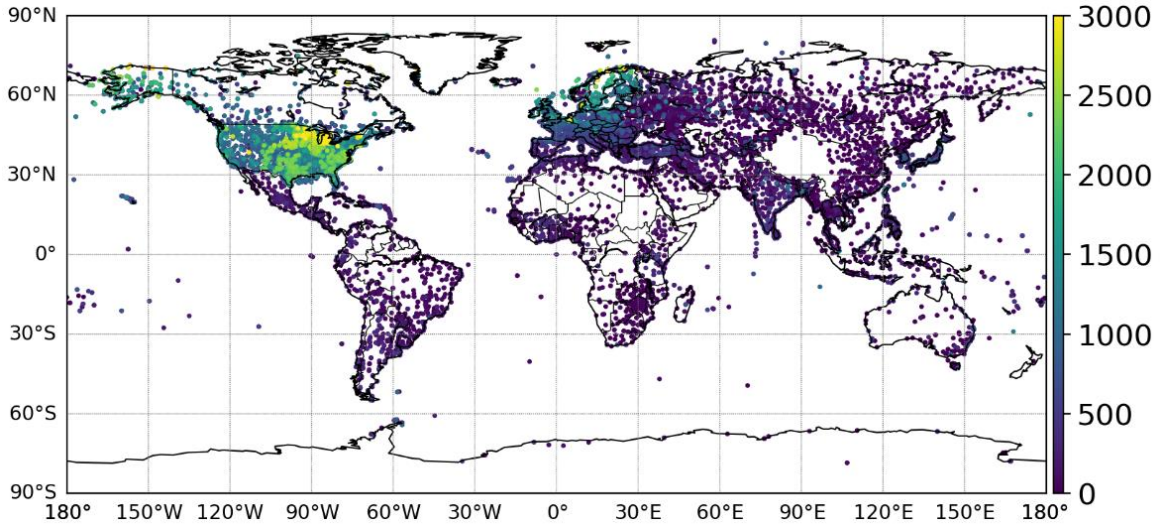
- Algorithms
  - Snowfall detection (SD) – ML model
  - Snowfall rate estimation (SFR) – physically-based algorithm enhanced with ML



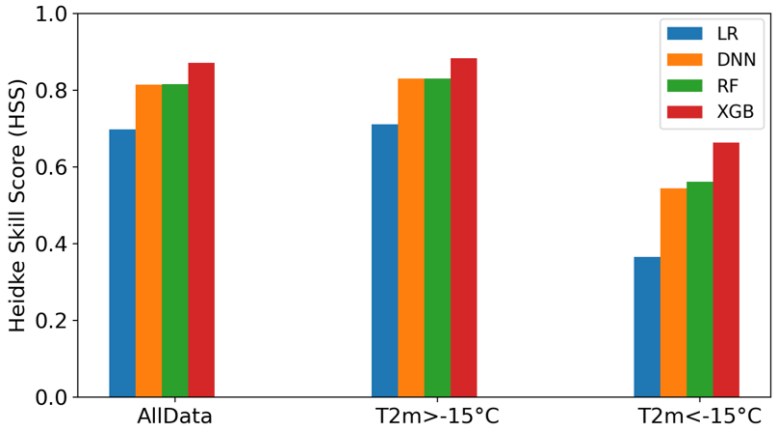
Snowfall Detection

- Machine learning (ML) model: selected XGBoost from 4 models
- Target: Manual weather reports (NOAA ISD)
- Features: Collocated satellite brightness temperatures and Global Forecast System (GFS) model data (Fan et al., submitted)

Number of Observations



NOAA-21 Land SD HSS



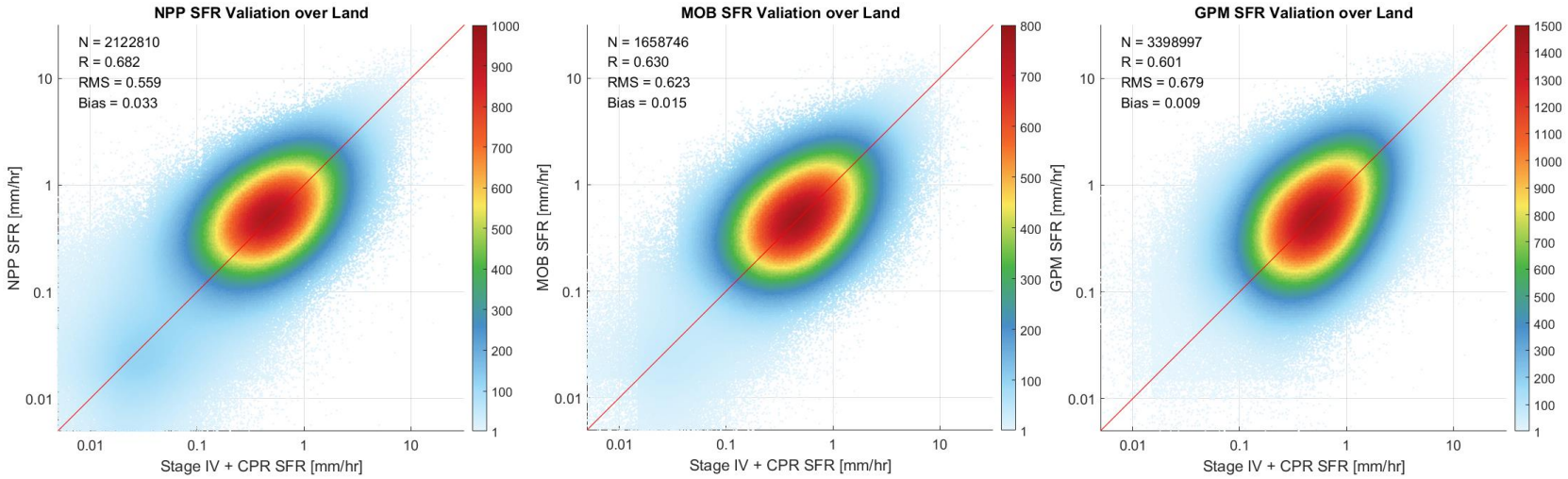
Land SD HSS

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

Snowfall Rate

- 1DVAR-based physical algorithm (Meng, et al., 2017)
- Machine learning enhancement
  - NN model for Ice Water Path initialization
  - NN model for SFR bias correction
- Histogram matching
- Validation
  - Stage IV – radar, gauge, and manual QC; hourly; CONUS
  - CloudSat 2C-SNOW-PROFILE near surface snowfall rate
  - ERA5 hourly snowfall rate for NOAA-21

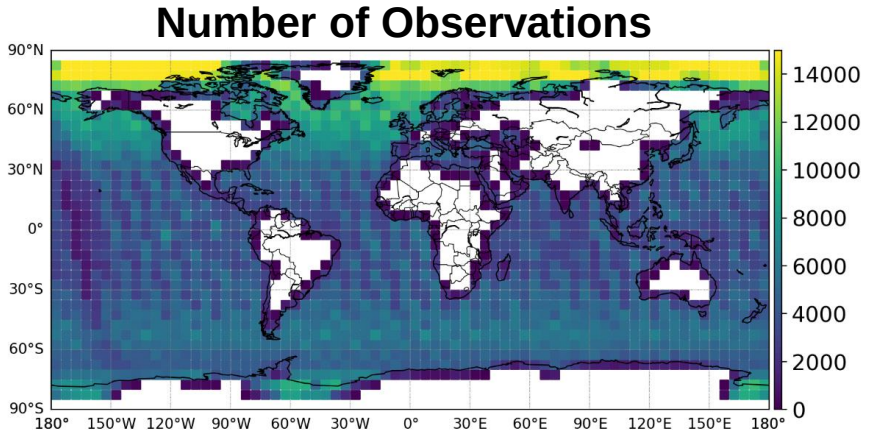
Land SFR Validation against Stage IV & CPR*

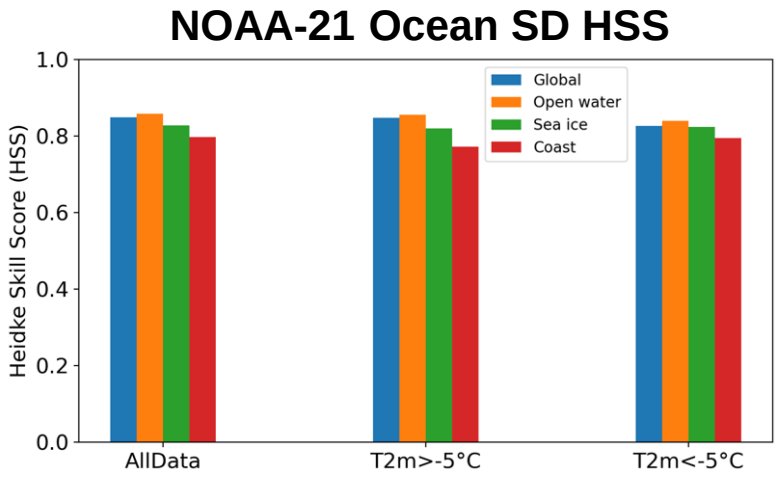


	NOAA-21	NOAA-20	S-NPP	MetOp-C	MetOp-B	NOAA-19	GPM
R	0.72	0.69	0.68	0.66	0.63	0.66	0.60
RMS (mm/hr)	0.54	0.58	0.56	0.63	0.62	0.58	0.68
Bias (mm/hr)	0.016	0.028	0.033	0.014	0.015	0.033	0.009

New Development – Ocean SFR

- Expand the operational land product to over ocean (open ocean, coast, and sea ice)
- Snowfall detection – same framework as land SD
  - XGBoost model
  - Target: CloudSat 2C-SNOW-PROFILE and ERA5
  - In order of performance: open ocean, sea ice, and coast





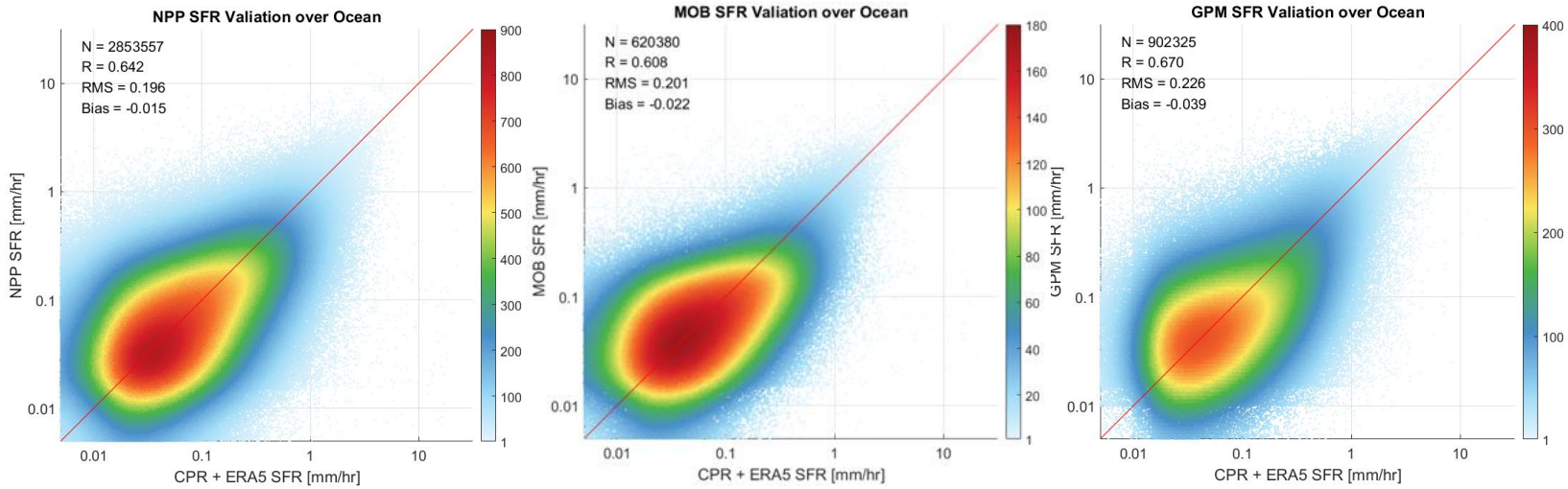
Ocean SD HSS

	NOAA-21	NOAA-20	S-NPP	MetOp-B	MetOp-C	NOAA-19	GPM
Open Ocean	0.856	0.809	0.823	0.839	0.847	0.835	0.851
Sea Ice	0.832	0.734	0.741	0.756	0.754	0.799	0.808
Coast	0.787	0.713	0.727	0.727	0.720	0.755	0.759
Global	**0.844**	**0.773**	**0.784**	**0.795**	**0.800**	**0.815**	**0.842**

Ocean SFR (2)

- Snowfall rate estimation – same framework as land SFR
  - 1DVAR-retrieved cloud properties
  - Snowfall rate estimation from cloud properties and ice partical fall velocity
  - ML snowfall rate bias correction
  - Histogram matching
- Validation
  - CloudSat 2C-SNOW-PROFILE near surface snowfall rate
  - ERA5 hourly snowfall rate

Ocean SFR Validation against CPR and ERA5

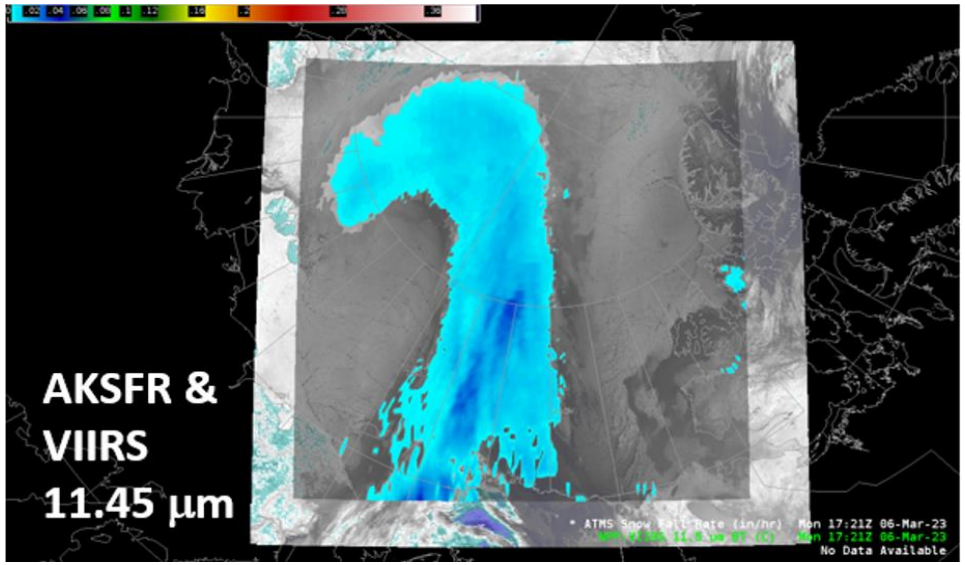


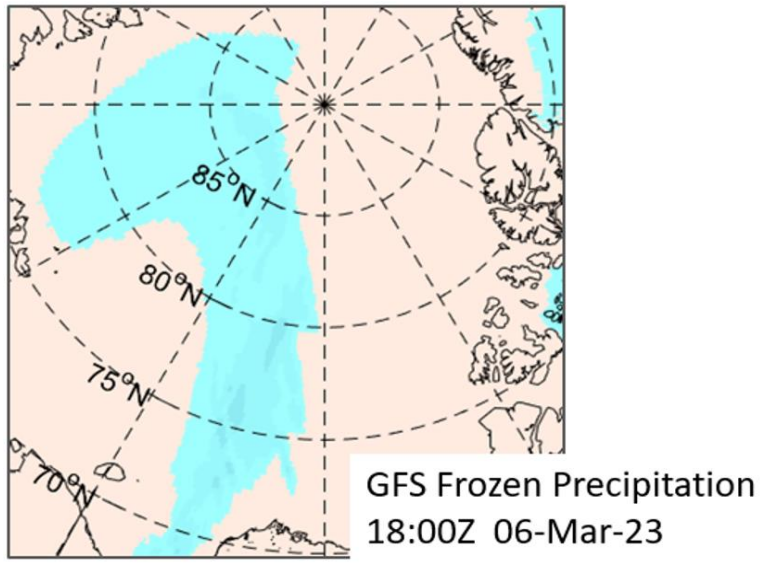
	NOAA-21	NOAA-20	S-NPP	MetOp-C	MetOp-B	NOAA-19	GPM
R	0.63	0.63	0.64	0.63	0.61	0.64	0.67
RMS (mm/hr)	0.20	0.20	0.20	0.18	0.20	0.20	0.23
Bias (mm/hr)	-0.026	-0.020	-0.015	-0.023	-0.022	-0.014	-0.039

New Development – Cold Extension

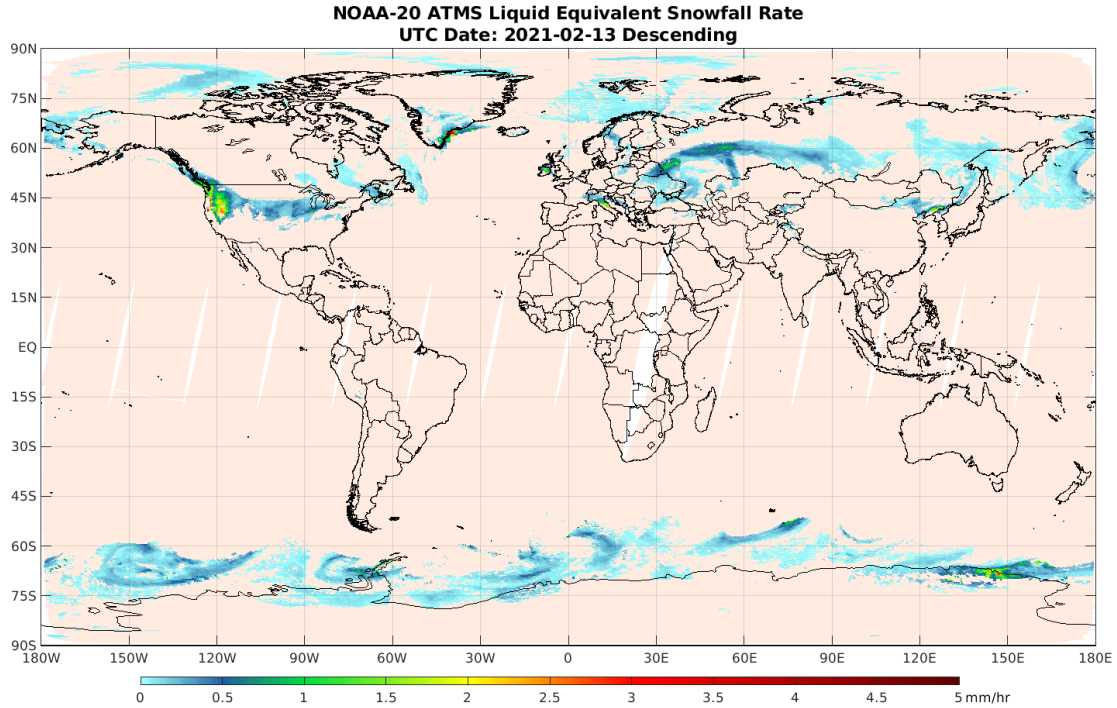
- Extension to extremely cold conditions
  - Previous SD required T_{2m} > ~ -13°C (limb-corrected 53 GHz > 240K)
  - SD extension through ML
- SFR extends to pole-to-pole coverage with no temperature limitations

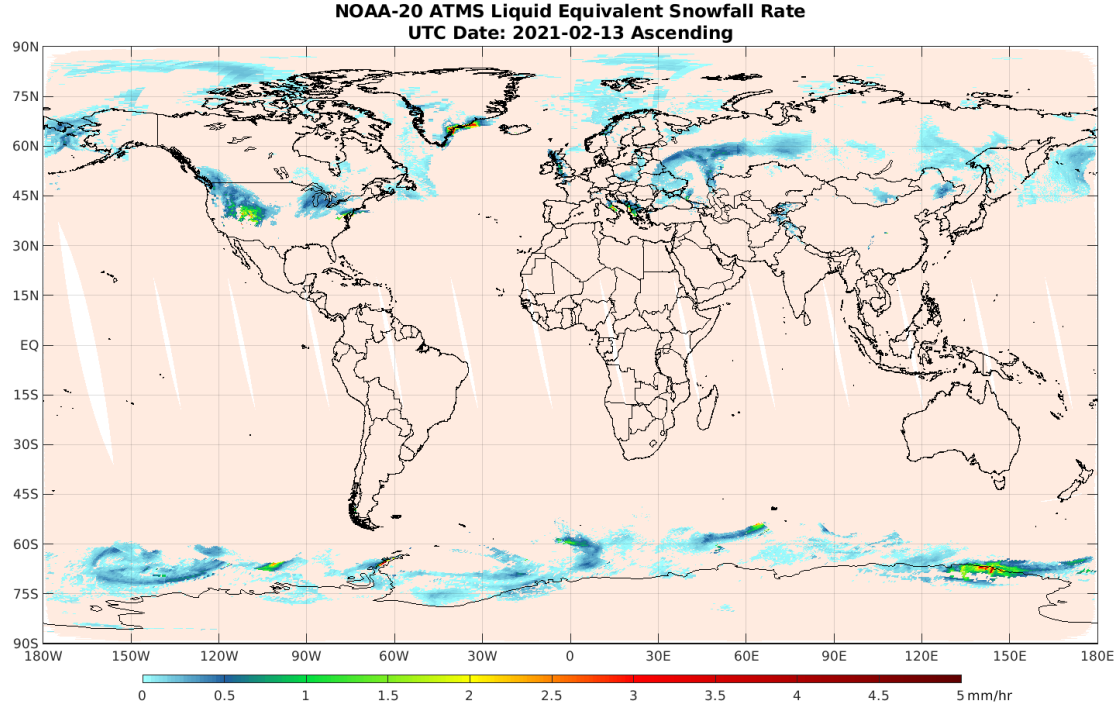
SFR captures light snowfall over the Arctic



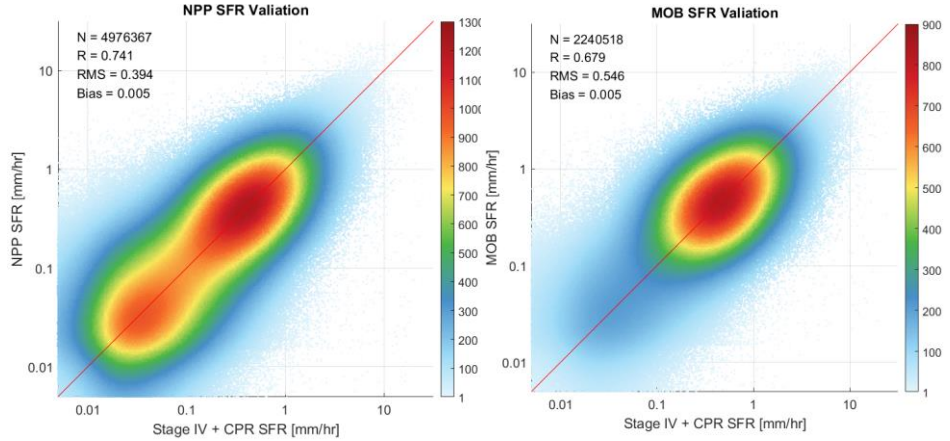


Global Validation



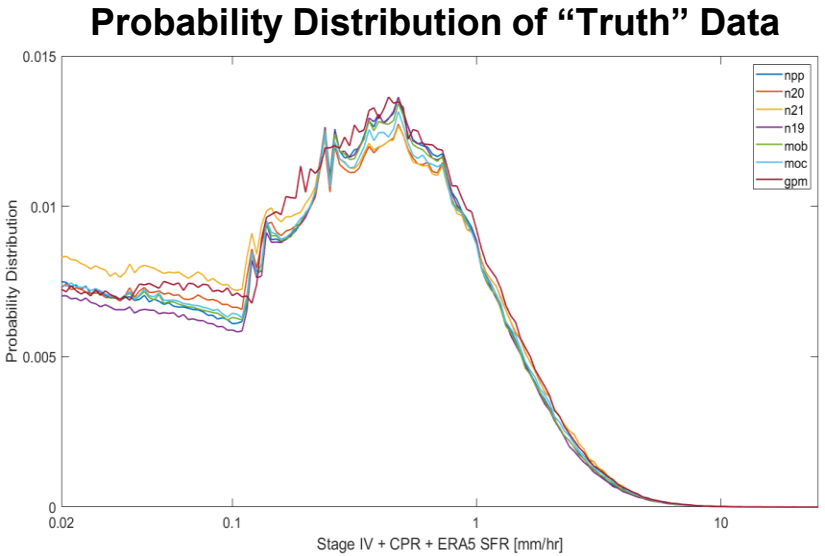


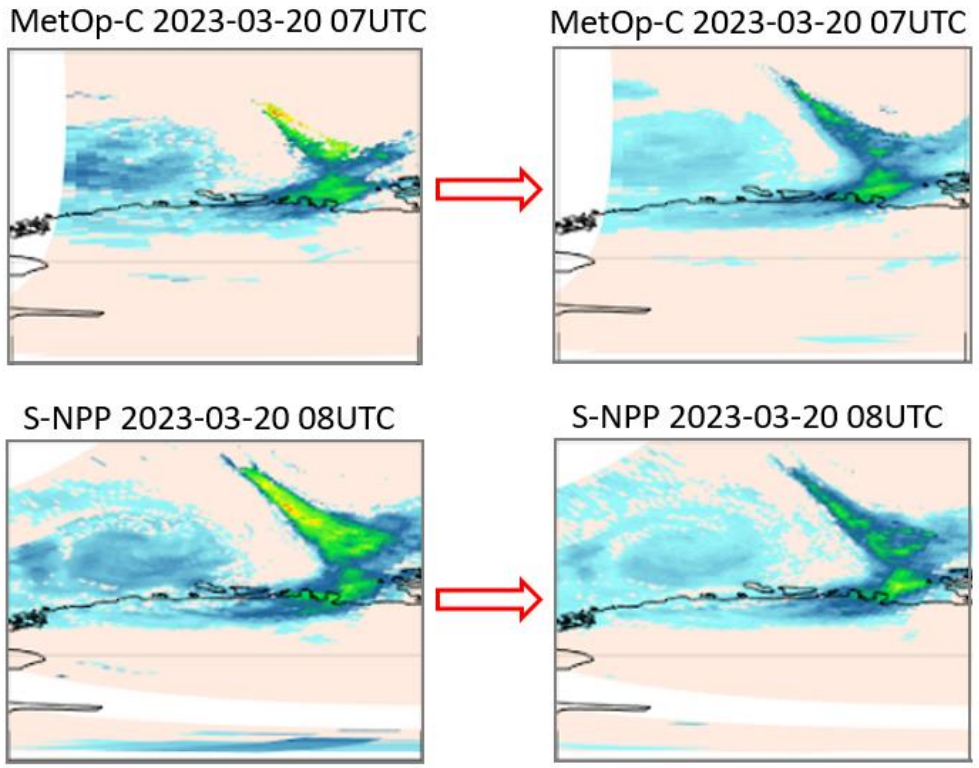
	NOAA-21	NOAA-20	S-NPP	MetOp-C	MetOp-B	NOAA-19	GPM
R	0.76	0.75	0.74	0.65	0.68	0.72	0.65
RMS (mm/hr)	0.36	0.43	0.39	0.64	0.55	0.42	0.61
Bias (mm/hr)	-0.011	0.003	0.005	0.014	0.005	0.008	-0.001



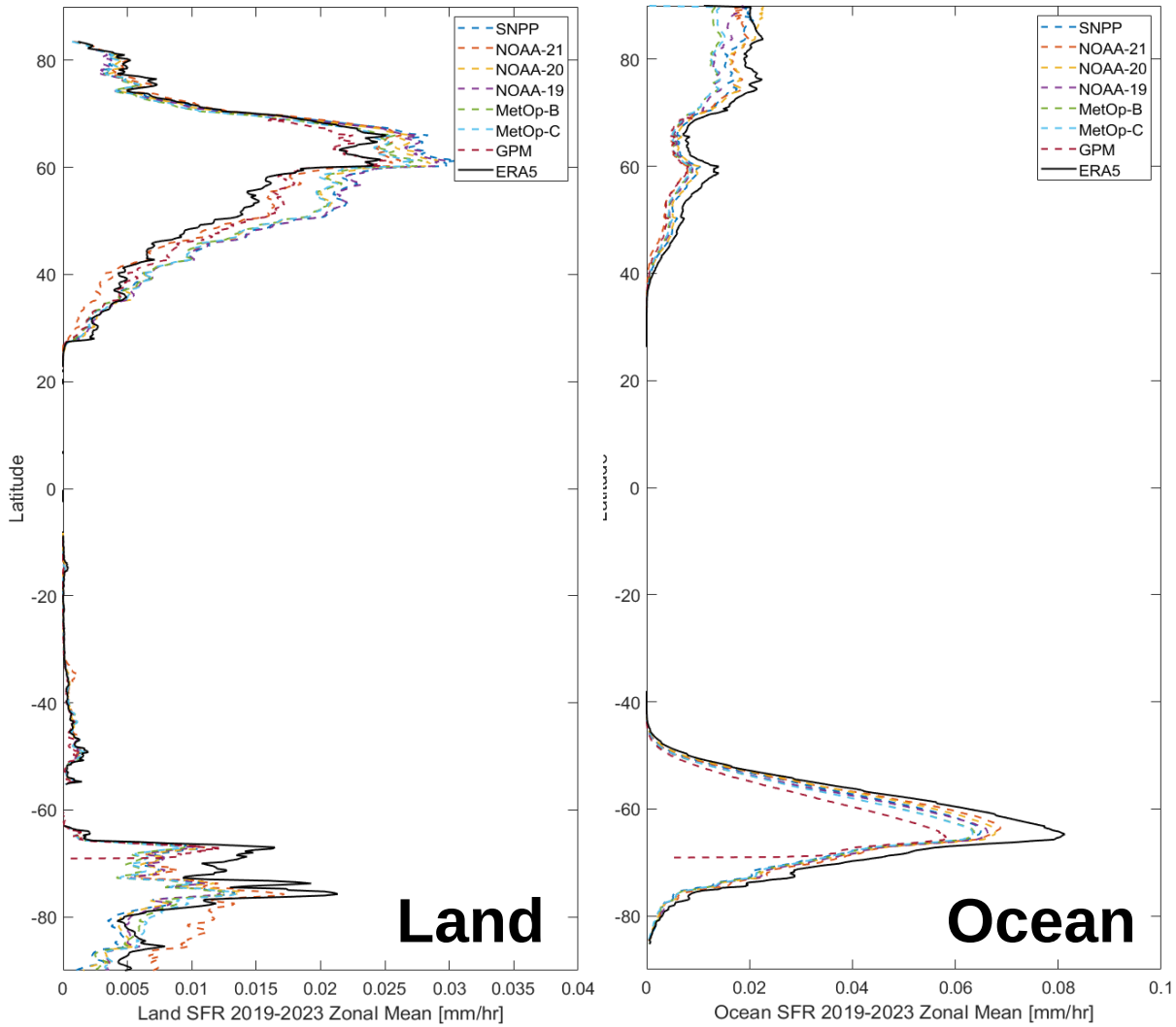
“Cross Calibration”

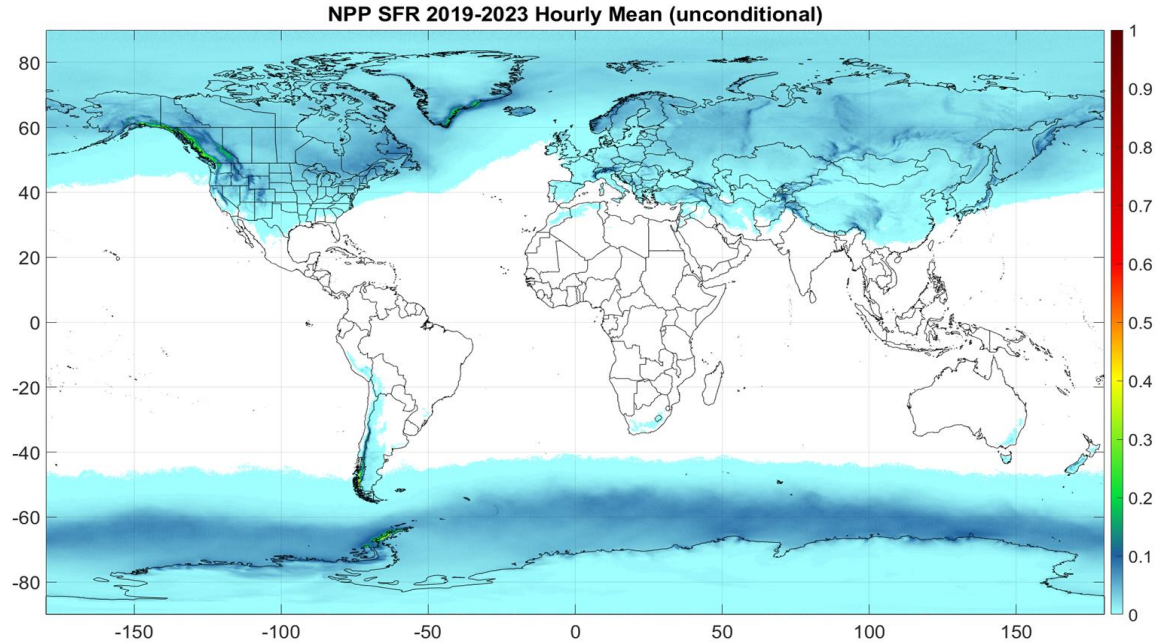
- Objective: Improve SFR consistency across satellites for effective applications
  - SFR algorithm for each satellite was developed independently using a different target dataset
  - Inconsistency exists among the SFR product for different satellites
- Histogram matching with consistent “truth” data

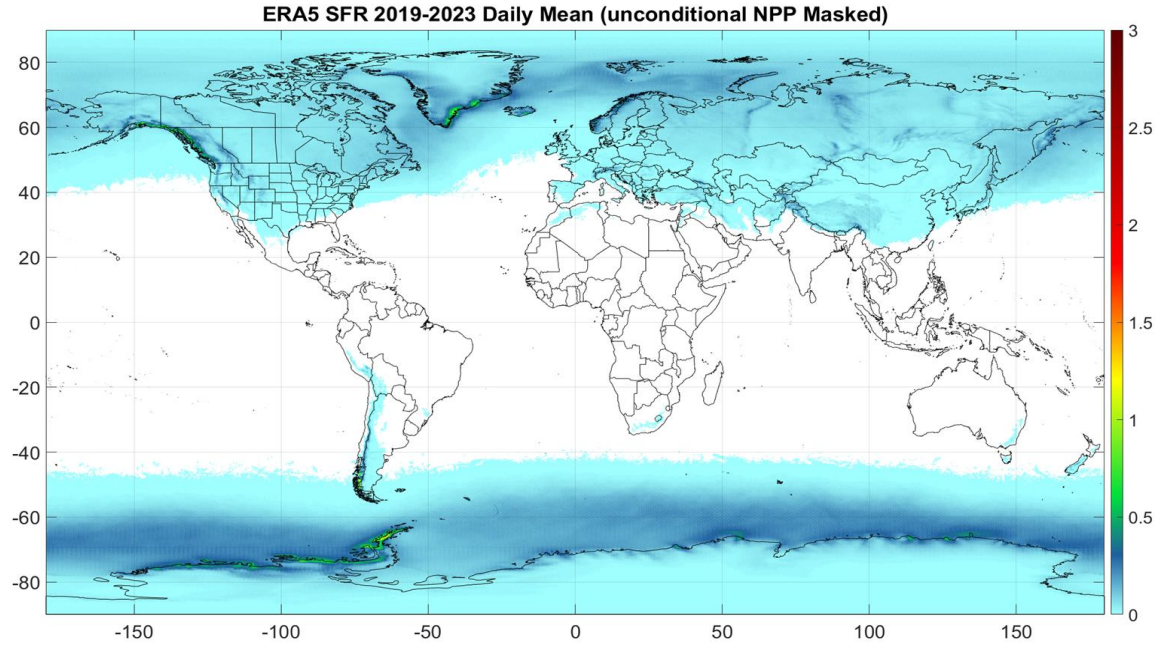




Comparison with ERA5

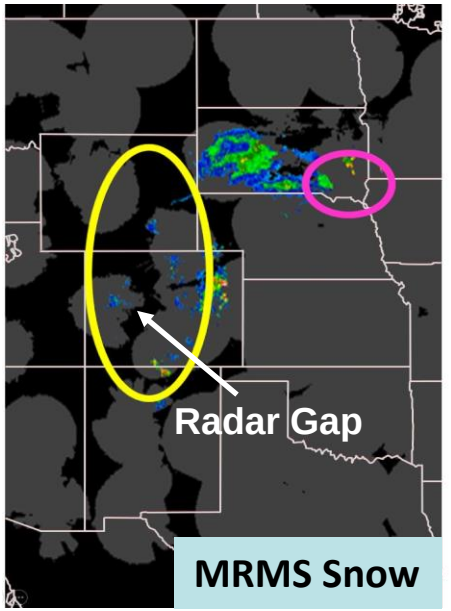


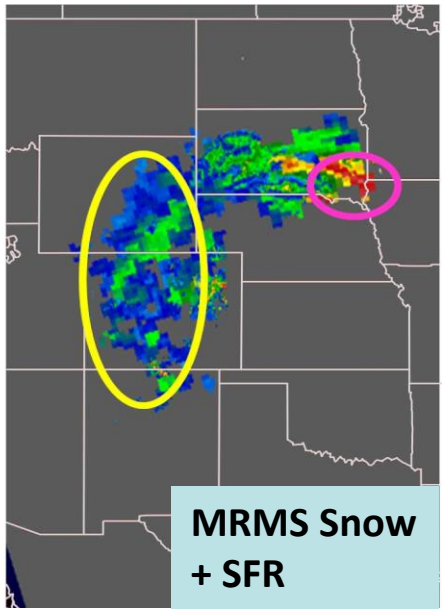


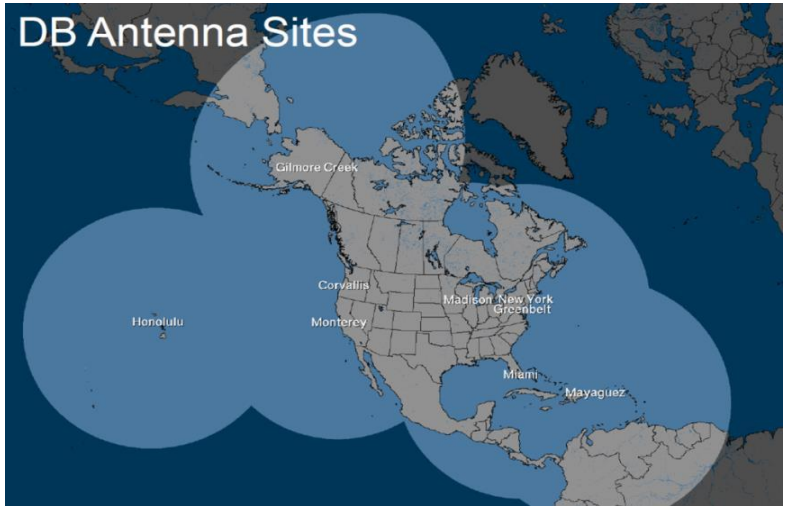


Applications

- Input to the blended precipitation product, CMORPH2
- Supporting nowcasting
  - Providing situational awareness for winter storms
  - Filling in radar gaps
- Reducing latency with Direct Broadcast (DB) data
  - Low latency is critical for nowcasting because snowfall is highly dynamic
  - Forecaster feedback: Weather Forecast Offices (WFOs) need satellite precipitation products with latency less than 60 min and preferably 15-30 min
  - Operational data often has latency ~ 2-3 hours
  - Direct Broadcast (DB) provide a solution to the latency issue
- SFR latency
  - **DB-based latency is 15-30 min**
  - DB stations: University of Wisconsin-Madison, GINA Alaska, and Monterey, California



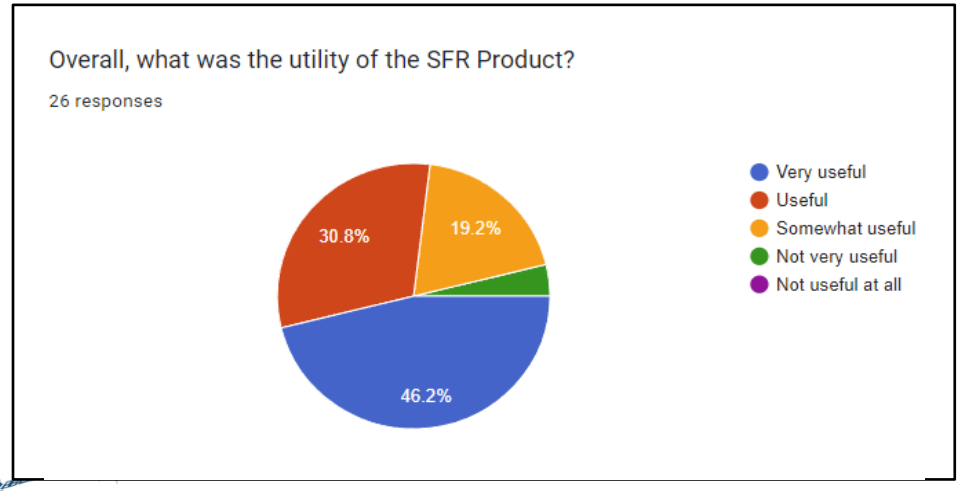


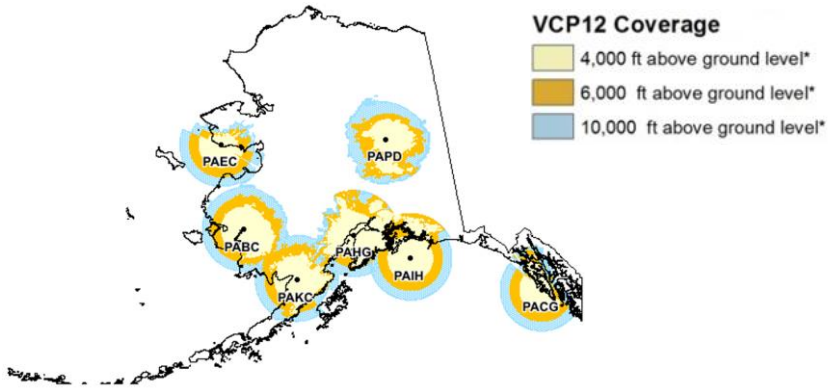


SFR Assessment and User Feedback

- The US National Weather Service (NWS) Alaska offices conducted SFR assessment over the last two winters
- Forecasters assessed SFR in their operational environment and submit feedback
- **77% of the responses ranked SFR as either Useful or Very Useful**
- SFR is made available to all NWS WFOs through a collaboration between NOAA, UMD, NASA, GINA, and NWS

Forecasters' Responses to a Question about SFR Utility





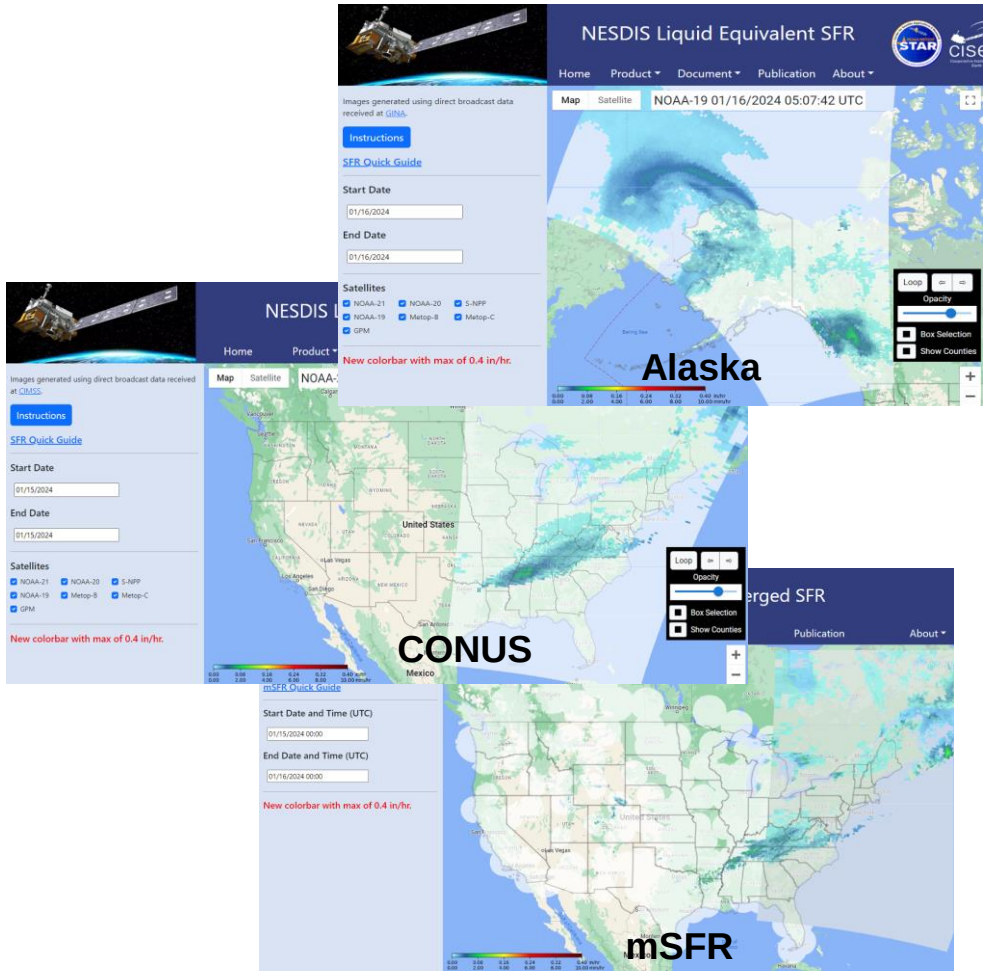
Some forecasts' Feedback on SFR

- Jan 15th, 2024: Fairbanks - Product was a big help in showing higher SFR rates in areas just outside radar coverage which seem to verify.
- October 2023: An NWS employee in a vessel in the Arctic Ocean, confirmed snowfall at the time the SFR product indicated snow could be occurring. Indicating the product was viable at higher latitudes in that synoptic scenario.

User Training and Support

- The Snowfall Rate product developers supported the NWS Alaska assessment
  - Developed SFR training materials
  - Created a Google Form to collect user feedback
- Google Maps-based DB SFR website (https://sfr.umd.edu)
  - Near real-time, 15-30 min latency
  - Displays SFR over Alaska and CONUS, and mSFR (merged MRMS snow and SFR)
  - Products are derived in near real-time from DB data
  - Includes many functionalities for nowcasting applications:
    - **Value sampling**
    - **Zooming**
    - **Gif movie**
    - **Looping**
    - **Transparency adjustment**
    - **County boundaries**

https://sfr.umd.edu



Summary

- NOAA NESDIS and UMD CISESS produces an operational snowfall rate (SFR) product from a constellation of polar-orbiting satellites
- The algorithm combines 1DVAR physical modeling with ML
- New developments have extended the land SFR product to over ocean and extremely cold conditions, making it a global product
- Histogram matching has significantly improved SFR consistency across satellites
- SFR can support nowcasting with low latency and broad spatial coverage, filling in radar gaps
- **Forecaster feedback has overwhelmingly indicated the usefulness of the SFR product for Alaska nowcasting operations**

National Environmental Satellite, Data, and Information Service

IPWG-11, July 15-18, 2024

Acknowledgements

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