



# The NOAA NESDIS Snowfall Rate Product: Development and Applications

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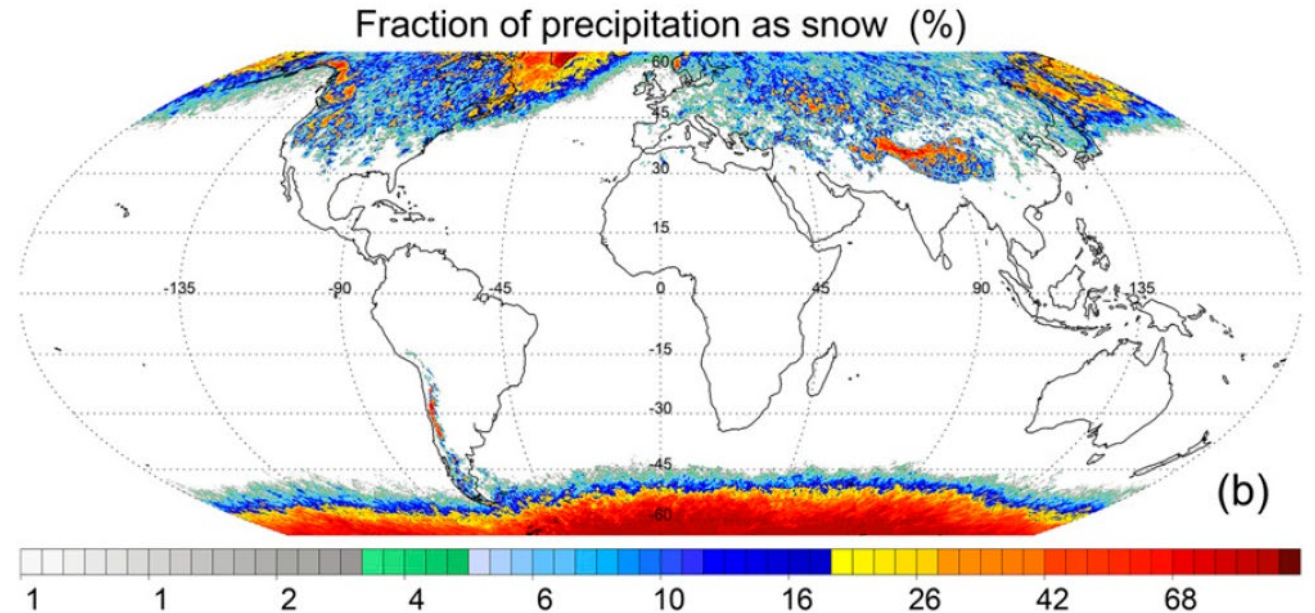
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# Background

- Snowfall plays an important role in energy balance and water cycle in our Earth-atmosphere system.
- Snowfall is the most common type of precipitation in high latitudes, providing a major source of freshwater for many countries.
- Snowfall affects our social and economic activities such as transportation disruptions, risk of accidents, school and work closures, etc.



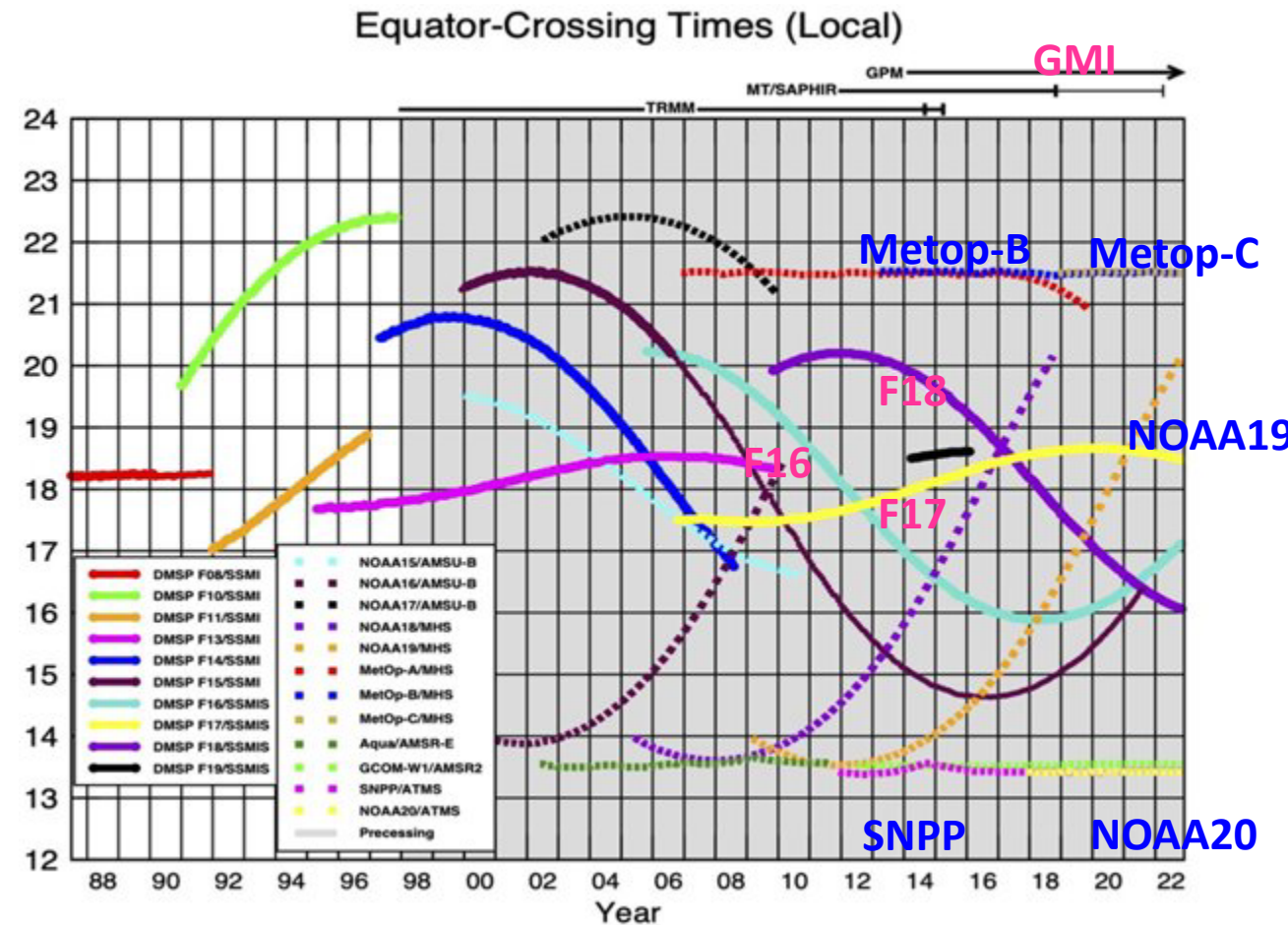
Adhikari et al. 2018

*Satellite observations continue playing significant roles in better tracking and predicting snowfall events.*

# Product Overview

- **Snowfall Rate (SFR) product derived from passive microwave measurements**

- Water equivalent snowfall rate estimate
- Operation at NOAA/NESDIS since 2012
- Operation for the sensors at five platforms: *S-NPP/ATMS, N20/ATMS, N19/MHS, Metop-B(C)/MHS*
- Experiment for sensors: *N21/ATMS, GPM/GMI, SSMIS on DMSP-F16, F17, F18*



Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.  
 Image by Eric Nelkin (SSAI), 29 November 2022, NASA/Goddard Space Flight Center, Greenbelt, MD.

## Training

**Land:** NOAA Integrated Surface Database (ISD), 2016-2020.

**Ocean:** Cloud Profiling Radar (CPR) near-surface precipitation product, 2012-2019.

**Features:** Satellite-observed brightness temperatures (Tbs) and GFS model data (temperature, humidity, cloud information, etc.).

## ML models

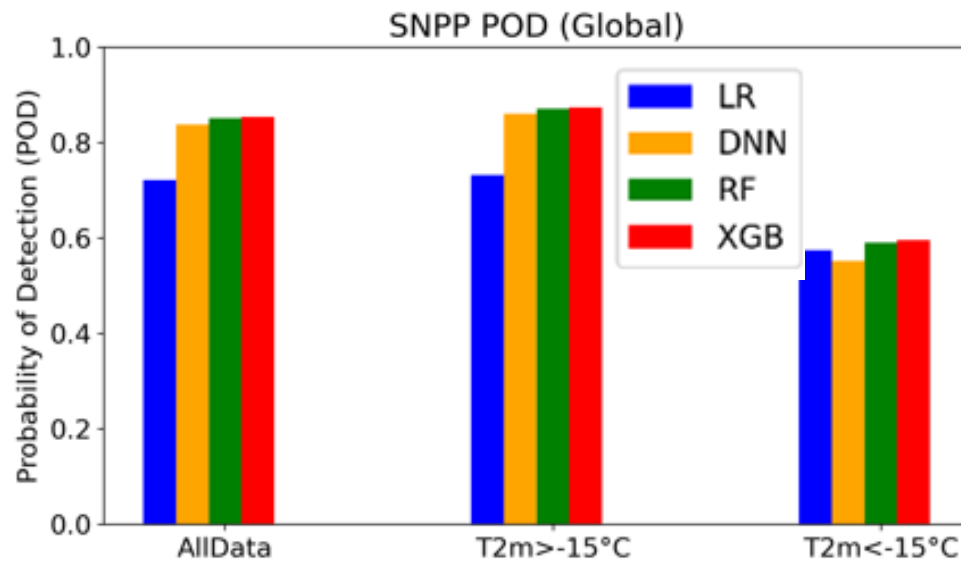
Logistic Regression (LR), Deep Neural Network (DNN), Random Forest (RF) and eXtreme Gradient Boosting (XGB)

## Validating

SD models were evaluated using an independent testing dataset.

*Performance is consistently good across different sensors;*

*XGB yields the best accuracy, which is now used in our algorithm.*



- POD = (snowfall pixels)/(true snowfall pixels)*

*POD ~ 0.8 for all data, better for warmer situation.*

## 1DVAR optimization framework

### Inverse model

$$\mathbf{x} = \mathbf{F}^{-1}(\mathbf{y})$$

$I_c$  and  $D_e$  are retrieved from the 1DVAR, then SFR is obtained.

$$SFR = A \int_{D_{min}}^{D_{max}} D^{b_m + \nu - 2} D \frac{D}{D_e} \left[ \left( \left( 1 + BD \frac{b_m}{2} \right)^{\frac{1}{2}} - 1 \right) \right]^2 dD$$

$$A = \frac{\eta I_w \delta_0^2 \Gamma^{b_m + \nu} (\nu + 1)}{4 \rho_l \rho_a D_e^{b_m + \nu} \Gamma(b_m + \nu) \Gamma^{b_m + \nu} (\nu)}$$

$$B = \frac{8}{\eta \delta_0^2} \sqrt{\frac{2 \rho_a g a_m}{\pi A_r^k C_0}}$$

$\Delta \mathbf{x}$

$\Delta \mathbf{y}$

$$\begin{bmatrix} \Delta I_c \\ \Delta D_e \\ \Delta \epsilon_{23} \\ \Delta \epsilon_{31} \\ \Delta \epsilon_{89/88} \\ \Delta \epsilon_{157/165} \\ \Delta \epsilon_{190/176} \end{bmatrix} = \left( \mathbf{A}^T \mathbf{A} + \mathbf{E} \right)^{-1} \mathbf{A}^T \begin{bmatrix} \Delta T_{B23} \\ \Delta T_{B31} \\ \Delta T_{B89/88} \\ \Delta T_{B157/165} \\ \Delta T_{B190/176} \end{bmatrix}$$

$I_c$ : ice water path

$D_e$ : ice particle effective diameter

$\epsilon_i$ : emissivity at 23.8, 31.4, 89(MHS)/88.2(ATMS), 157/165.5, and 190.31/183±7 GHz for AMSU/MHS and ATMS (similar channels for GMI and SSMIS)

$T_{B_i}$ : brightness temperature at 23.8, 31.4, 89/88.2, 157/165.5, and 190.31/183±7 GHz for AMSU/MHS and ATMS (similar channels for GMI and SSMIS)

$\mathbf{A}$ : Jacobian matrix, derivatives of  $T_{B_i}$  over  $I_c$ ,  $D_e$ , and  $\epsilon_i$

$\mathbf{E}$ : error matrix

Yan et al., 2008

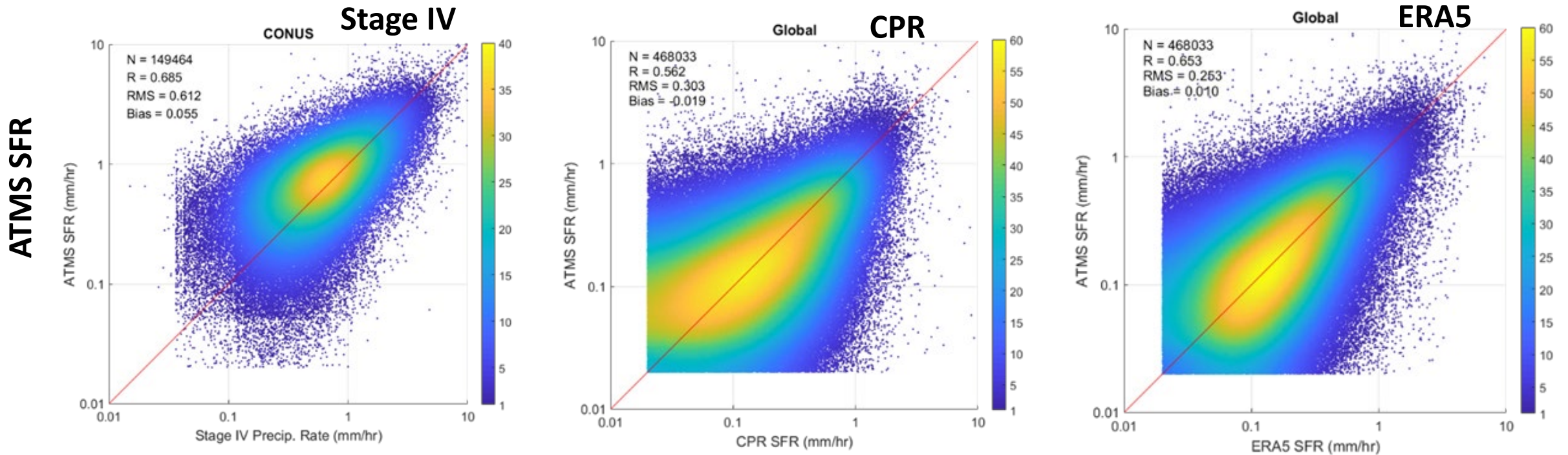
# Product Algorithms – ML-enhanced SFR

A Deep Neural Network was trained to correct the bias of SFR output from 1DVAR.

Training datasets:

SFR from **NOAA Stage IV + CPR**, satellite Tbs, and GFS model data.

*The ML-enhanced SFR shows good statistics compared with Stage IV, CPR, and ERA5:  $R \sim 0.6$  and low biases*

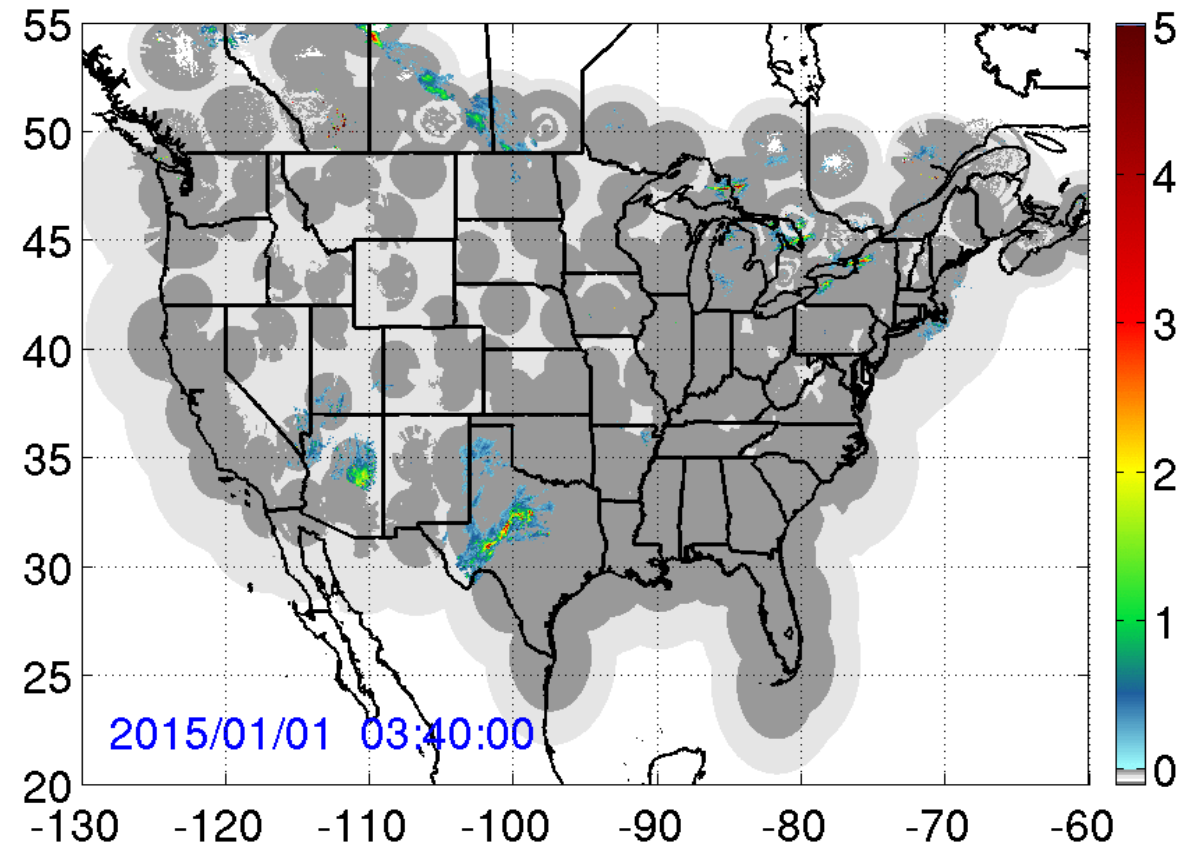


# Snowfall Product Applications

- **mSFR (Satellite-radar merged snowfall rate product)**

*A combination of PWM-based SFR and Multi-Radar Multi-Sensor (MRMS) radar precipitation.*

*Fill observational gaps in mountainous and remote regions where radar and gauges are sparse, or radar blockage and overshooting are common.*



# Direct Broadcast-Based Snowfall

website <http://sfr.umd.edu> Latency < 20 min

NOAA SFR

Not secure | sfr.umd.edu/?page=SFR-CONUS

Apps research hobby living others website

**NESDIS Snowfall Rate (SFR)**

Home **Product** Document Publication About

Map Satellite **NOAA-19 01/02/2023 14:46:19**

**Start Date**  
01/02/2023

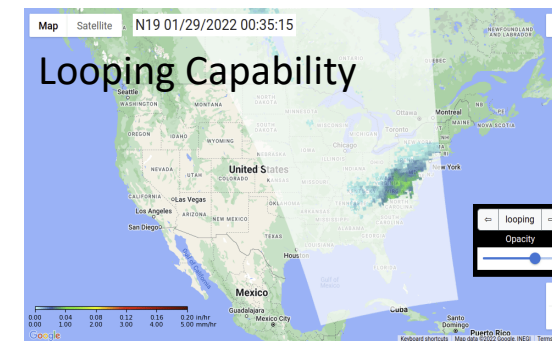
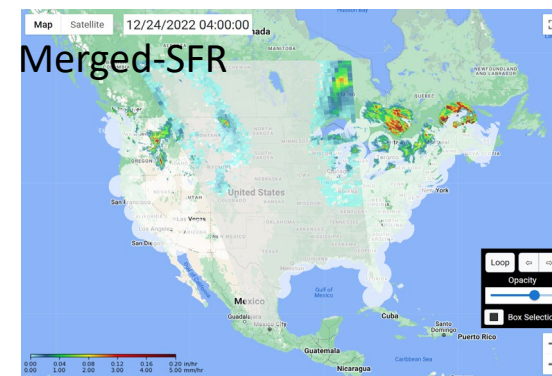
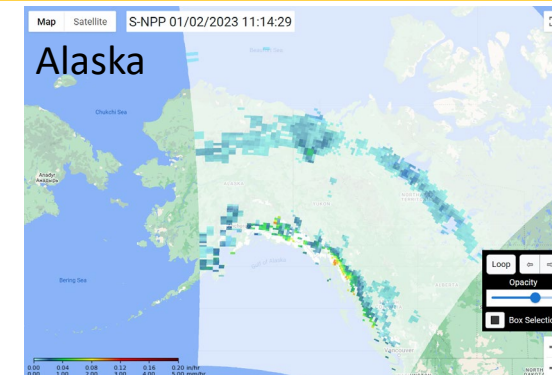
**End Date**  
01/02/2023

**Display Instructions**

- Select product from the Product drop-down list on the top
- Select starting and ending dates below
- Use Box Selection (lower right corner) or the Google Maps zoom and pan tools to select the area of interest; toggle the Box Selection button to turn the function on and off
- Use the slider to adjust opacity
- Use the arrows to scroll through the images manually
- Toggle the Loop button to start and stop looping

**Satellites**

S-NPP  NOAA-20  NOAA-19  
 Metop-B  Metop-C





# Snowfall Product Applications

- **NCEP/CPC CMORPH** group is ingesting in the **Second-Generation CMORPH (CMORPH2)** to improve CMORPH2 for the support of nowcasting/short-term forecasting.

[https://www.star.nesdis.noaa.gov/jpss/EDRs/products/blended\\_cmorph.php](https://www.star.nesdis.noaa.gov/jpss/EDRs/products/blended_cmorph.php)

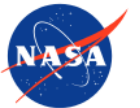
- **NASA/SPoRT** converts the DB SFR data to AWIPS-ingestible format and distributes it to several WFOs (weather forecast office).

<https://weather.ndc.nasa.gov/sport/jpsspg/snowfall.html>

- The Geographic Information Network of Alaska (**GINA**) produced DB SFR is distributed to NWS Alaska.



Short-term Prediction Research and Transition Center



SPoRT is a NASA project to transition unique observations and research capabilities to the operational weather community to improve short-term forecasts on a regional scale.

Real-Time Data

Core Projects

GOES-R PG

JPSS PG

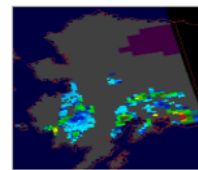
Transitions

Library

Organization

## NESDIS Snowfall Rate Product Details

### RESEARCH



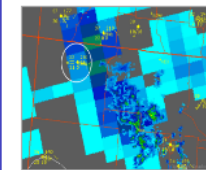
#### NESIDS Snowfall Rate

Passive microwave swath snowfall rate derived from polar-orbiting sensors onboard S-NPP, GPM, NOAA, MetOp, DMSR. The product is displayed in liquid equivalent inches per hour with a maximum snowfall rate detection of 0.2 inches per hour when the snow to liquid ratio is 10 to 1 (i.e. 2 in/hr). The product is useful

anticipating or validating snowfall in radar-deprived regions and tracking snowfall maxima.

real-time data ([Alaska](#) | [CONUS](#))

### RESEARCH



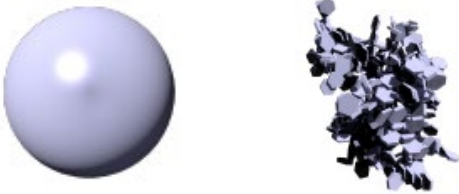
#### NESDIS Merged Snowfall Rate

Passive microwave swath snowfall rate (product described above) combined with the NSSL Multi-Radar/Multi-Sensor data to fill in the temporal gaps between polar-orbiter overpasses. A 10-minute temporal refresh between available passive microwave measurements increases situational awareness and ability to track snowfall rate maxima.

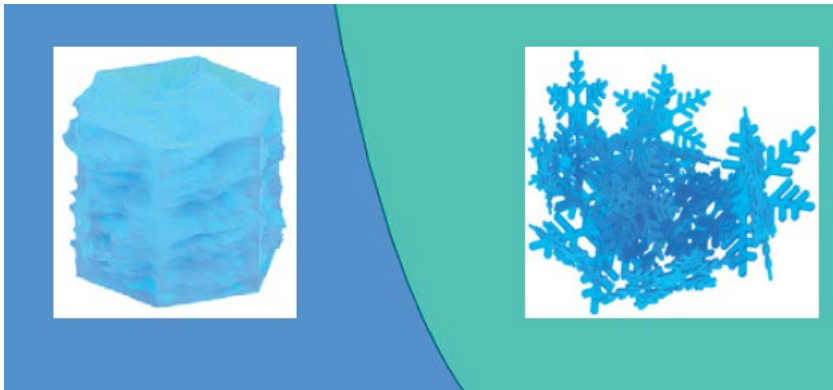
real-time data ([CONUS](#))

# Challenges: Snow Microphysics

The ARTS dataset (Eriksson et al. 2018)



Ping Yang's dataset (Ren et al. 2023)



## Current used ice habit: Sphere

Too heavy mass, fast terminal speed, and strong extinction could lead to overestimated SFR.

## A first trial of non-spherical ice habit

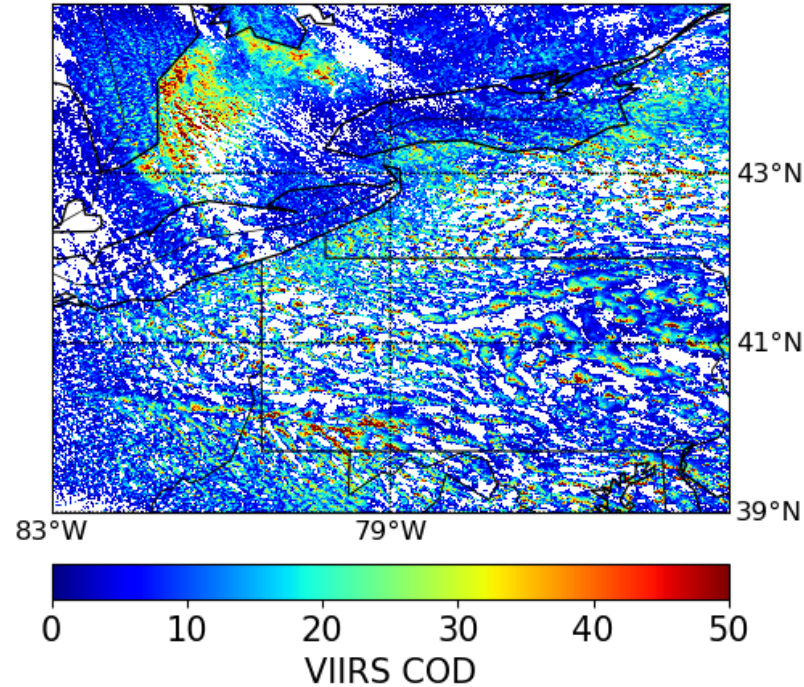
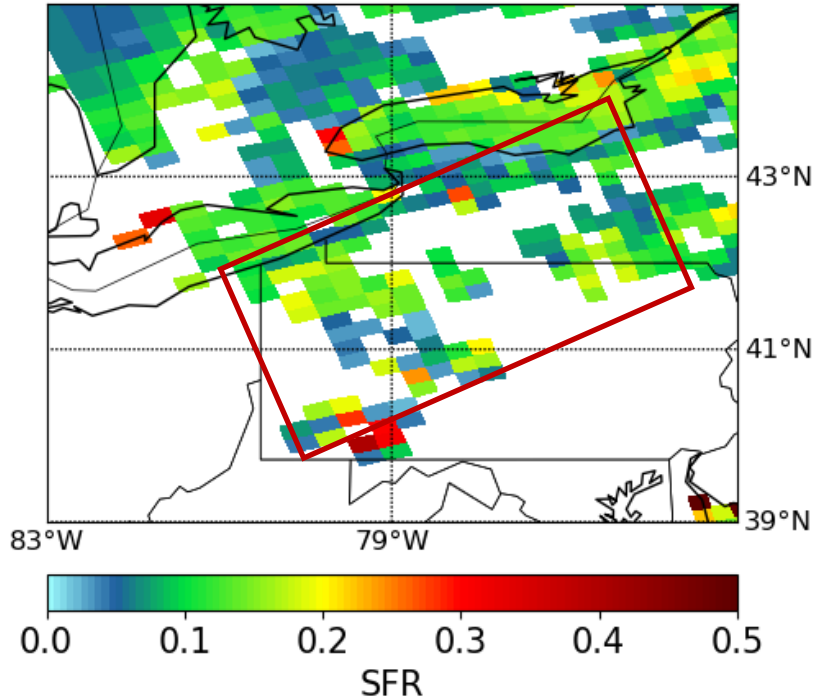
Comparison between PMW SFR with MRMS and Stage IV in brackets

Ice habits	Correlation Coefficient (R)	Bias (mm/h, %)
Sphere (ARTS)	0.48 (0.53)	1.07, 113 (0.80, 119)
LargePlateAggregate(ARTS)	0.43 (0.46)	0.61, 64 (0.45, 66)
Column+Dendrite (PY)	0.48 (0.50)	0.48, 45 (0.19, 29)

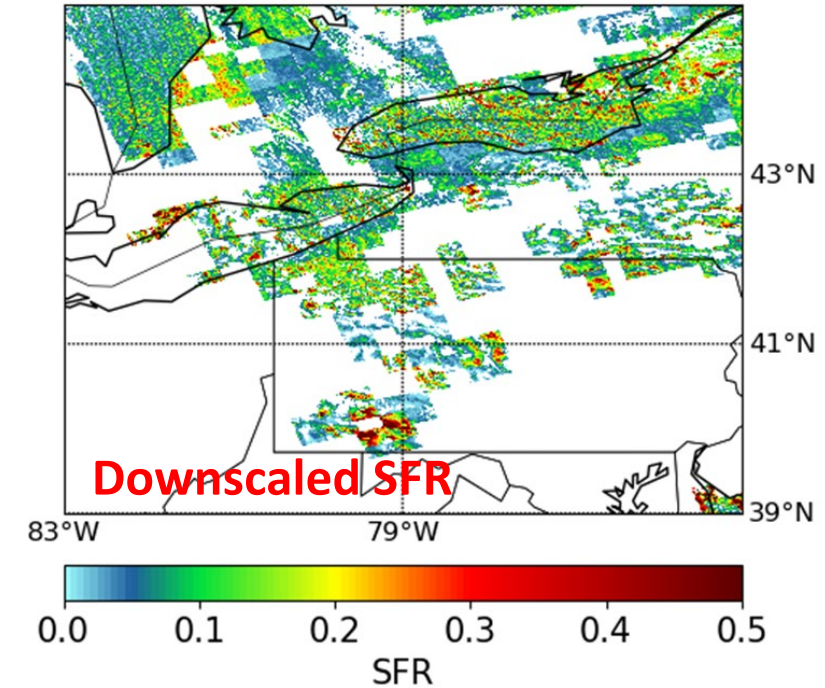
*Application of non-spherical ice habits can largely reduce the positive SFR bias from the spherical ice habit.*

# Other Challenges

- **Lake-effect and Orographic Snow**



## Can data from IR sensors help improve SFR?



- **Snow Variability in Small Scale**

GOES-R L1 and L2 data are also explored for SFR improvement.

# Summary

## The NOAA/NESDIS SFR product derived from Passive Microwave Sensors

- ML-based snowfall detection has an **accuracy ~ 0.8** globally, being consistent across different platforms.
- Physics-based and ML-based snowfall rate agrees well with other observations (e.g. CPR, Stage IV, etc.).
- Direct-Broadcast SFR retrieval system has been built with low latency (within 20 min), distributed to WFOs by NASA/SpoRT and GINA to support winter storm nowcasting.

## On-going and future work

- Preparing SFR algorithms that will run on new missions: NOAA-21/ATMS, Metop-SG-A MWI/MWS.
- Improving snowfall rate accuracy: spatial resolution, snow microphysical and optical properties etc.



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- Thanks for the team's contribution

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