Passive Microwave Snowfall Rate Product - New Calibration and Application

Jun Dong

Huan Meng[2], Cezar Kongoli[2], Ralph Ferraro[2]

[1] CISESS-MD
[2]NOAA/NESDIS/STA

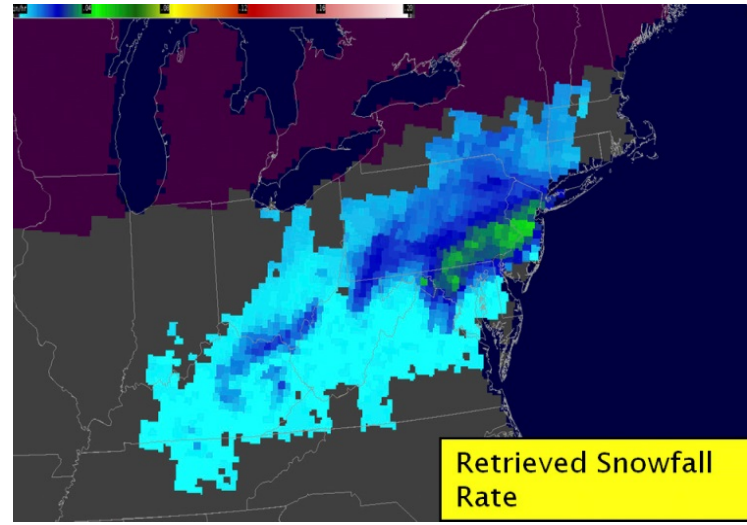
Outline

- Snowfall Rate (SFR) product
- Calibration and Validation
- Applications

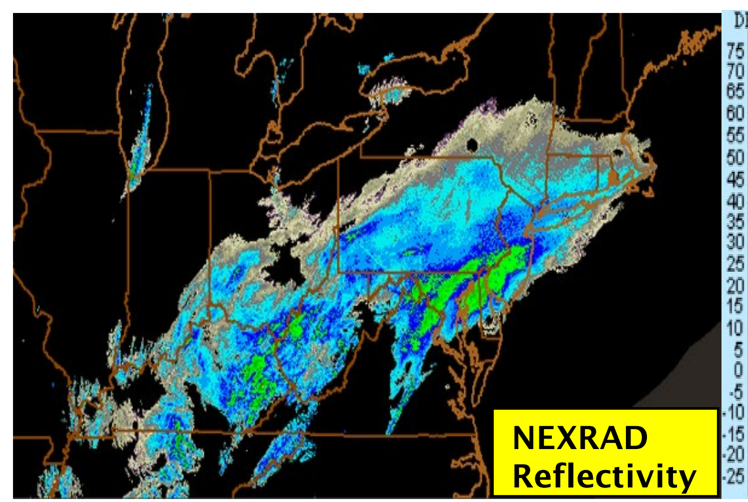
SFR - Introduction

The NESDIS Snowfall Rate product is <u>water equivalent</u> snowfall rate estimate (QPE) over global land

- ✓ Passive microwave sensors: ATMS, AMSU/MHS, GMI, SSMIS
- ✓ Eight (Ten) polar-orbiting satellites: JPSS, NOAA POES, EUMETSAT Metop, NASA GPM, DMSP



- Spatial resolution: variable from 4km x 7km for GMI to 16km at nadir for ATMS and AMSU/MHS
- Sixteen (twenty) overpasses (i.e. snowfall rate estimates) per day on average at a location in mid-latitude and more in high-latitude



SFR Algorithm

- SFR algorithm includes two main components
  - ✓ Snowfall detection (SD)
  - ✓ Snowfall rate estimation
- New calibration technique significantly improves retrieval accuracy
  - ✓ NOAA-20 and S-NPP have been recalibrated
  - ✓ Other satellites will be recalibrated

Snowfall Detection Algorithm

Satellite-based module – sensor/satellite dependent

- ✓ Coupled PC and logistic regression (LR) model or LR model
- ✓ One or two temperature regimes
- ✓ Training data sets: matching satellite data and ground snowfall observations (QCLCD), i.e. 'truth' data

NWP model-based module

- ✓ LR model
- ✓ Input data: RH, V Vel, Cloud Thickness

Optimal combination of two

- ✓ Output is probability of snowfall; use preset thresholds to determine snowfall

GMI SD Performance

	Warm Regime	Cold Regime
POD (%)	68	56
FAR (%)	15	14
HSS	0.55	0.45

Additional model-based filters to improve accuracy

- ✓ Relative humidity, temperature, cloud thickness

Snowfall Rate Algorithm (1/2)

- 1D-Var method to derive cloud properties
  - Forward simulation of T_B's with a radiative transfer model (RTM) (Yan et al., 2008)

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

I_c: ice water path

D_e: ice particle effective diameter

ε_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_{Bi}: 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)

A: Jacobian matrix, derivatives of T_{Bi} *over* I_c, D_e, *and* ε_i

E: error matrix

  - Iteration scheme with ΔT_{Bi} thresholds
  - I_c and D_e are retrieved when iteration stops

Snowfall Rate Algorithm (2/2)

- Terminal velocity is a function of atmospheric conditions and ice particle properties, Heymsfield and Westbrook (2010)

$$v(D) = \frac{\eta R_e}{\rho_a D}$$

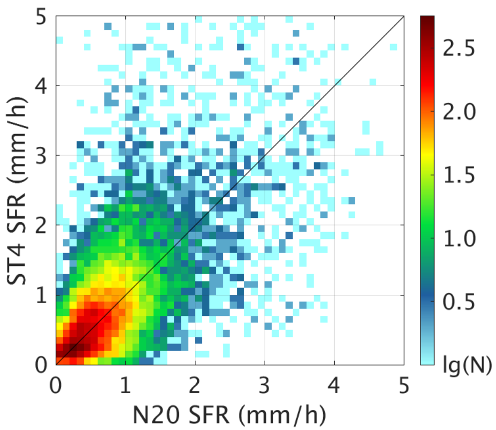
- Snowfall rate model

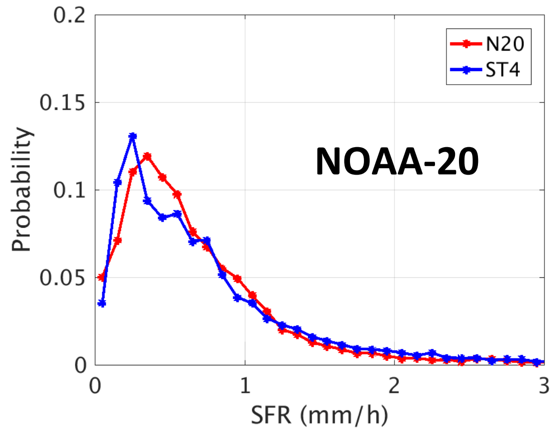
$$SFR_i = \frac{I_c\ \eta\delta_0^2}{12\rho_w\rho_a D_e^4}\int_0^\infty D^2 e^{-D/D_e}\left[\left(1+\frac{8D^{3/2}}{\eta\delta_0^2}\sqrt{\frac{g\rho_I\rho_a}{3C_0}}\right)^{1/2}-1\right]^2 dD$$

  - Assumption: Ice water content has a linear distribution through cloud column
  - Calibration: use “truth” data to compensate for non-uniform IWC distribution through cloud column and correct systematic bias

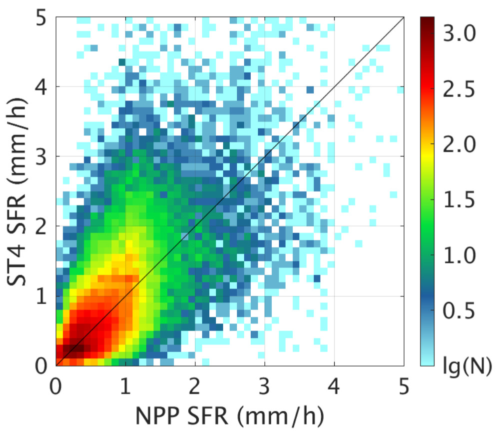
SFR Calibration

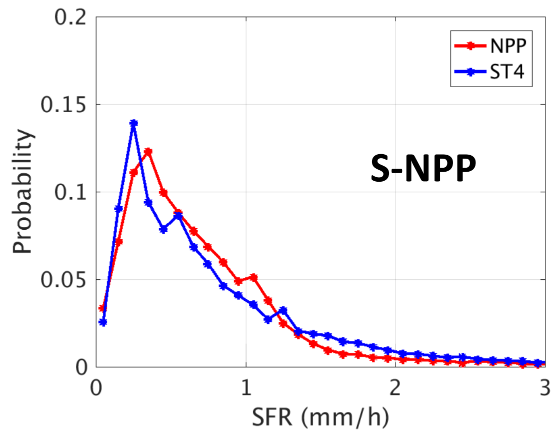
- SFR calibration data: Stage IV precipitation analyses
  - Stage IV: Uses MRMS precipitation data as input, incorporates ground observation, and applies human quality controls
  - Snowstorm data from 3 winter seasons for NPP and 2 for N20





Corre. Coeff.	0.66
Bias (mm/hr)	-0.07
RMS (mm/hr)	0.57



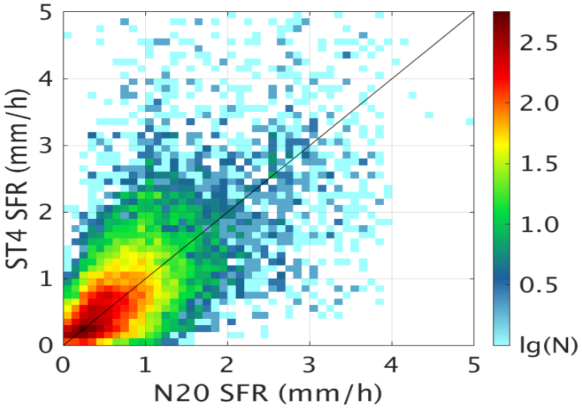


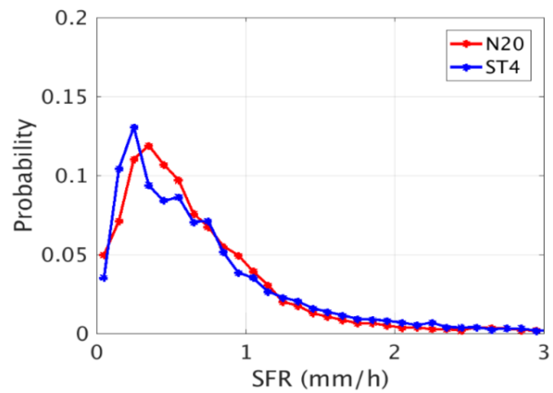
Corre. Coeff.	0.67
Bias (mm/hr)	-0.10
RMS (mm/hr)	0.56

SFR Validation (1/2)

Validation data: hourly Stage IV radar and gauge combined precipitation analyses

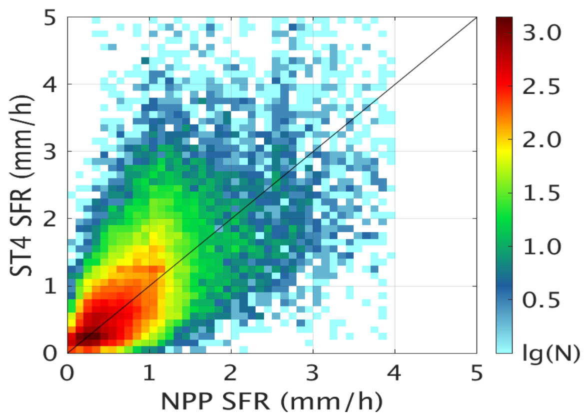
NOAA-20

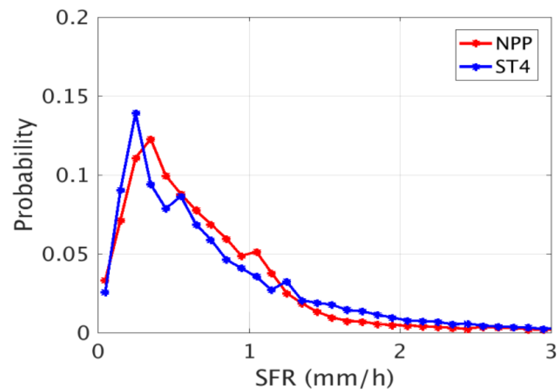




Corre. Coeff.	0.67
Bias (mm/hr)	-0.07
RMS (mm/hr)	0.56

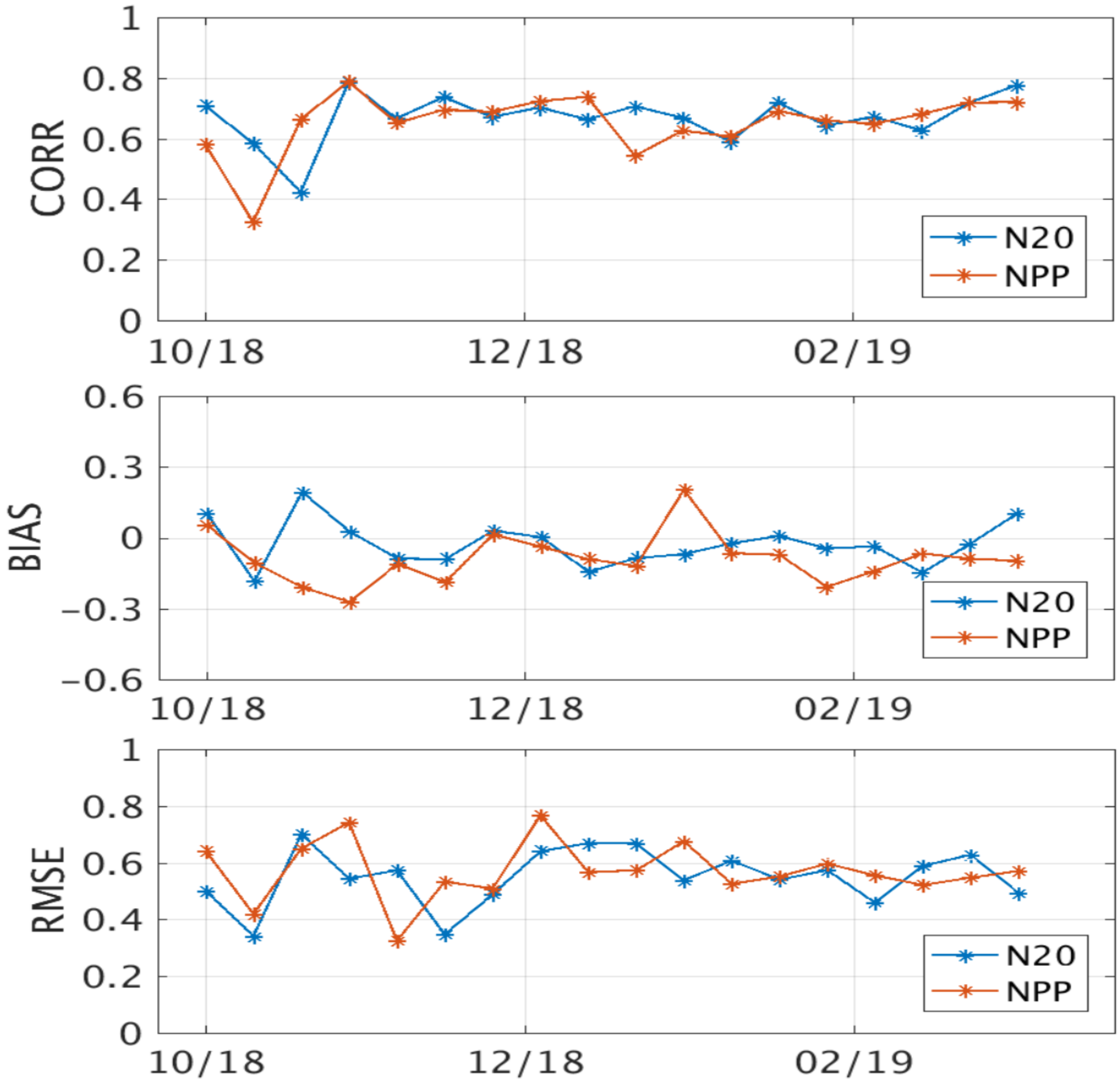
S-NPP



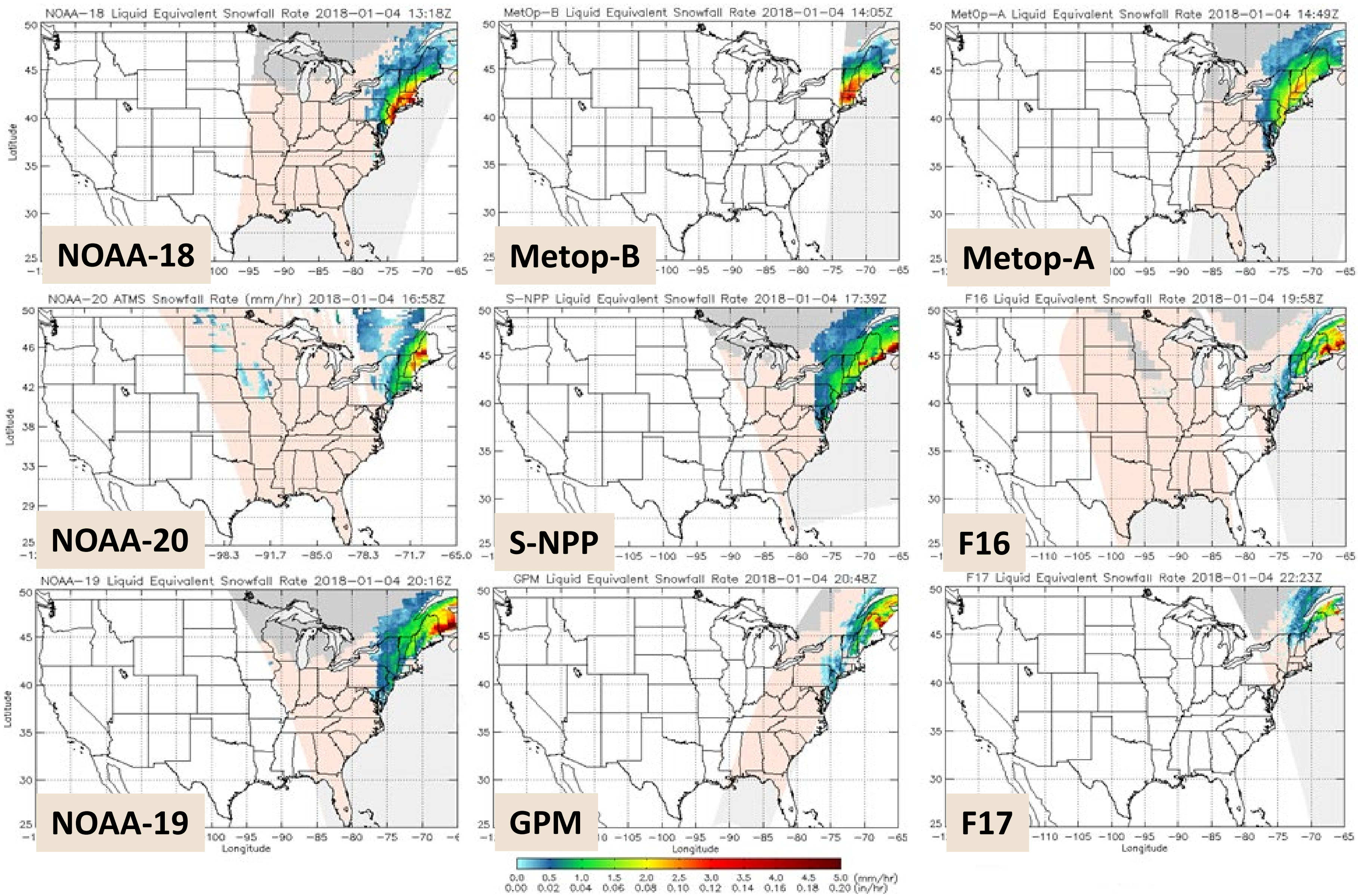


Corre. Coeff.	0.67
Bias (mm/hr)	-0.09
RMS (mm/hr)	0.56

SFR Validation (2/2)



Winter Storm Grayson, 3-5 Jan, 2018
(Images from 4 Jan, 2018, 13:18 - 22:23UTC)



Product Assessment

- Assessment in operational environment as part of the JPSS Proving Ground activities and was led by NASA SPoRT
- Collaborations among SPoRT, NESDIS, CISESS-MD and participating NWS Weather Forecast Offices
- Forecasters feedback indicates that the SFR product is useful for weather forecasting

SPoRT

NESDIS Snowfall Rate (SFR) Quick Guide by NASA/SPoRT

What is the NESDIS SFR product?

The NESDIS snowfall rate (SFR) product is derived using passive microwave measurements taken from the Advanced Technology Microwave Sounder (ATMS), Advanced Microwave Sounding Unit (AMSU)/Microwave Humidity Sounder (MHS), GPM Microwave Imager (GMI), and Special Sensor Microwave Imager/Sounder (SSMIS) aboard nine NOAA, EUMETSAT, NASA, and DMSP satellites. The product resolution varies from 4-km x 7-km for GMI to 16- km at nadir for ATMS. The microwave signal is able to penetrate clouds, hence bearing the signatures of the snow in and beneath the clouds.

What are its advantages?

The SFR product provides a unique, space-based perspective on the locations of frozen precipitation that can be used to easily identify the extent of a snowstorm and the location of the most intense snowfall. These two features might not be readily apparent from traditional IR or VIS satellite imagery or radar.

SFR is most valuable in filling observational gaps in mountains and remote regions where weather stations are sparse and radar blockage and overshooting are common. The SFR algorithm uses multiple channels that are sensitive to different atmospheric levels in order to sample the intensity of snowfall through the entire precipitation layer. This provides an advantage over ground-based radar, which scans single vertical levels and may miss higher concentrations of precipitation above or below the scan of the beam.

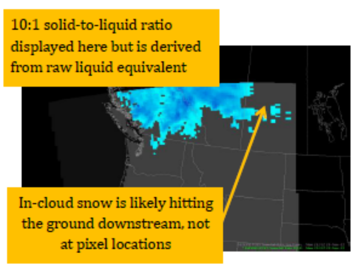
The algorithm performs best for medium to heavy snowfall in mesoscale and synoptic scale systems falling from non-shallow, stratiform clouds.

When and how often is it available?

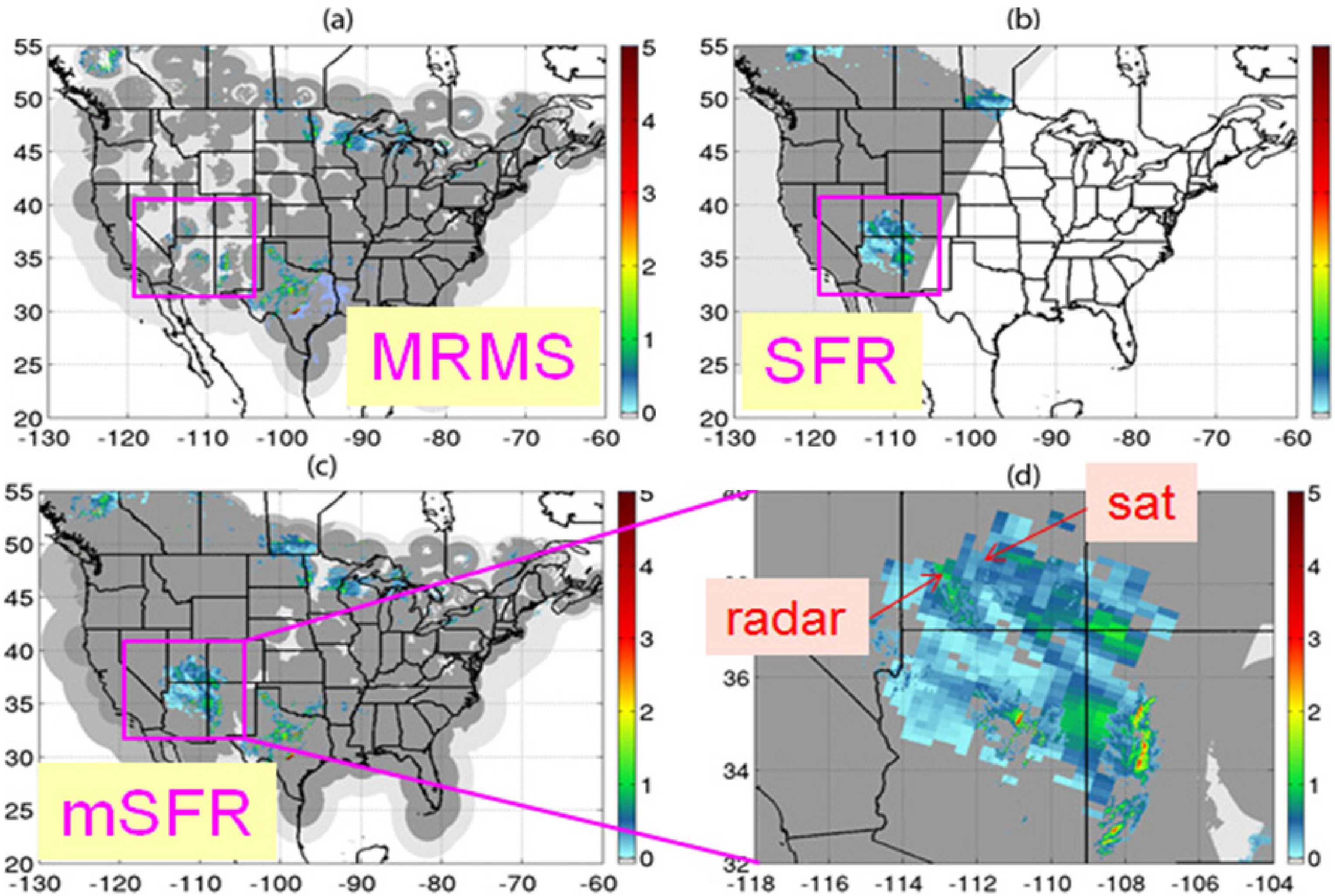
Currently, the nine polar-orbiting satellites provide up to forty SFR retrievals per day across Alaska. The timing and locations of the overpasses will vary slightly for most satellites, but generally there are enough overpasses to be able to track the movement of snow features. The data are processed in near real-time at NOAA/NESDIS with a product latency of less than 30 minutes for two satellites and 20 minutes to 3 hours for the other satellites.

What should I be aware of when interpreting?

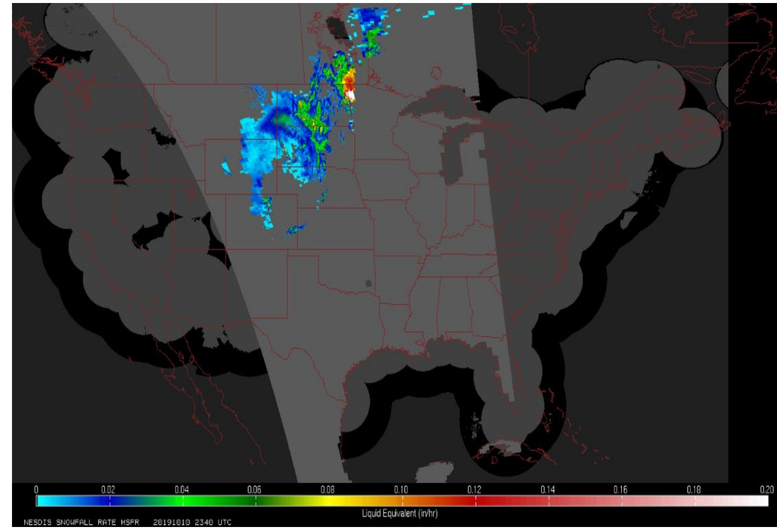
- **It's liquid:** This is a water-equivalent SFR product. Forecasters can now use knowledge the environmental conditions at the time of the snowfall to select one of three liquid-to-solid conversion displays. The maximum SFR detected by the product is 0.2 in/hour (liquid).
- **Not ground snow:** The SFR product represents snow in the atmospheric column, so there usually is a time lag (average: 1-1.5 hours) between the retrieved SFR and the best correlated ground observations. Thus, high SFR is not always associated with heavy snow at ground level.
- **Over land:** The current SFR product is only retrieved over land due to limitations of available observations over water to train the dataset (masked as dark grey in AWIPS II).
- **Not too cold:** The SFR product is limited to regions where the surface air temperature is about 7°F and above (masked purple in AWIPS II).
- **Light snow:** The minimum detection for the SFR product is 0.0012 in/hour (liquid), so light snows may not be fully detected.

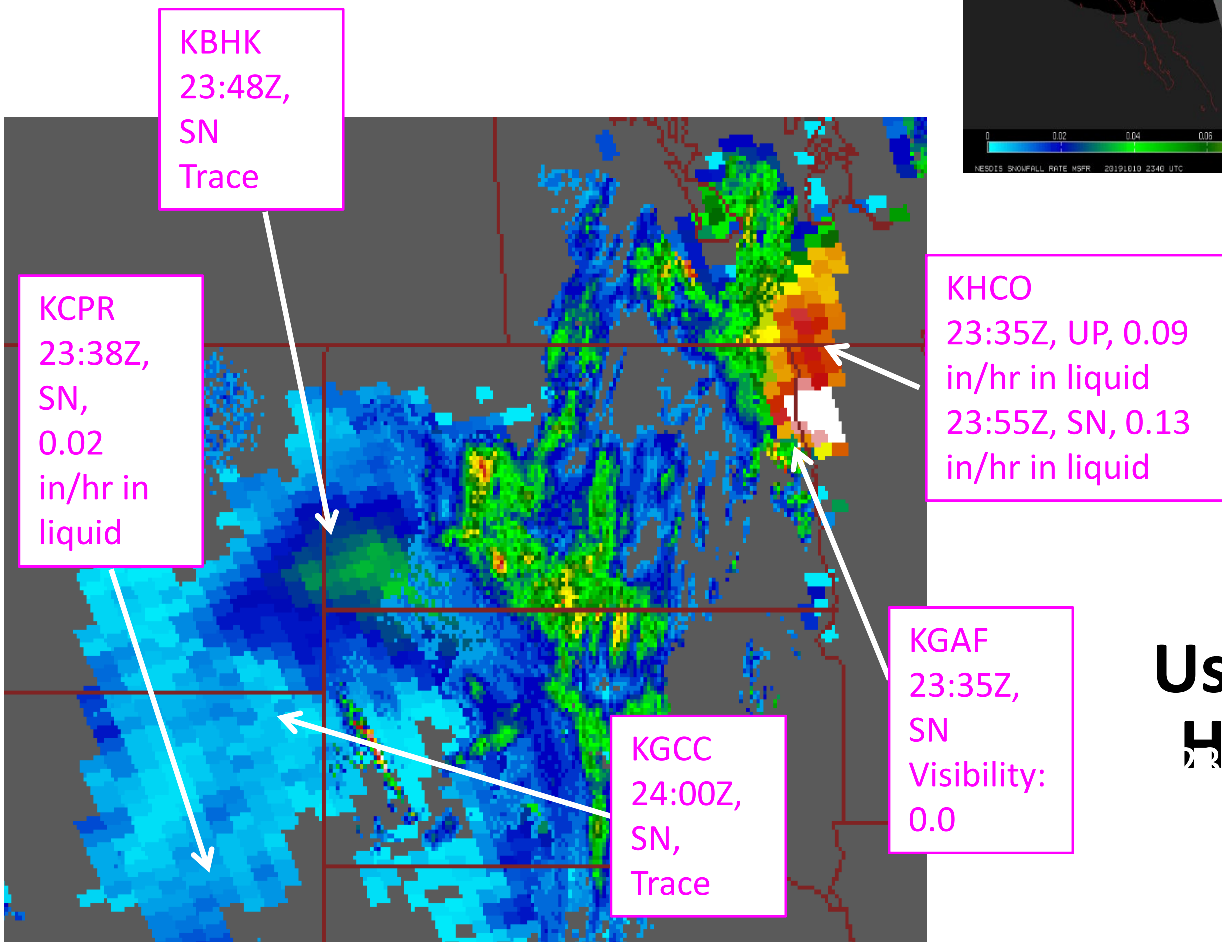


mSFR Introduction



mSFR AWIPS Display



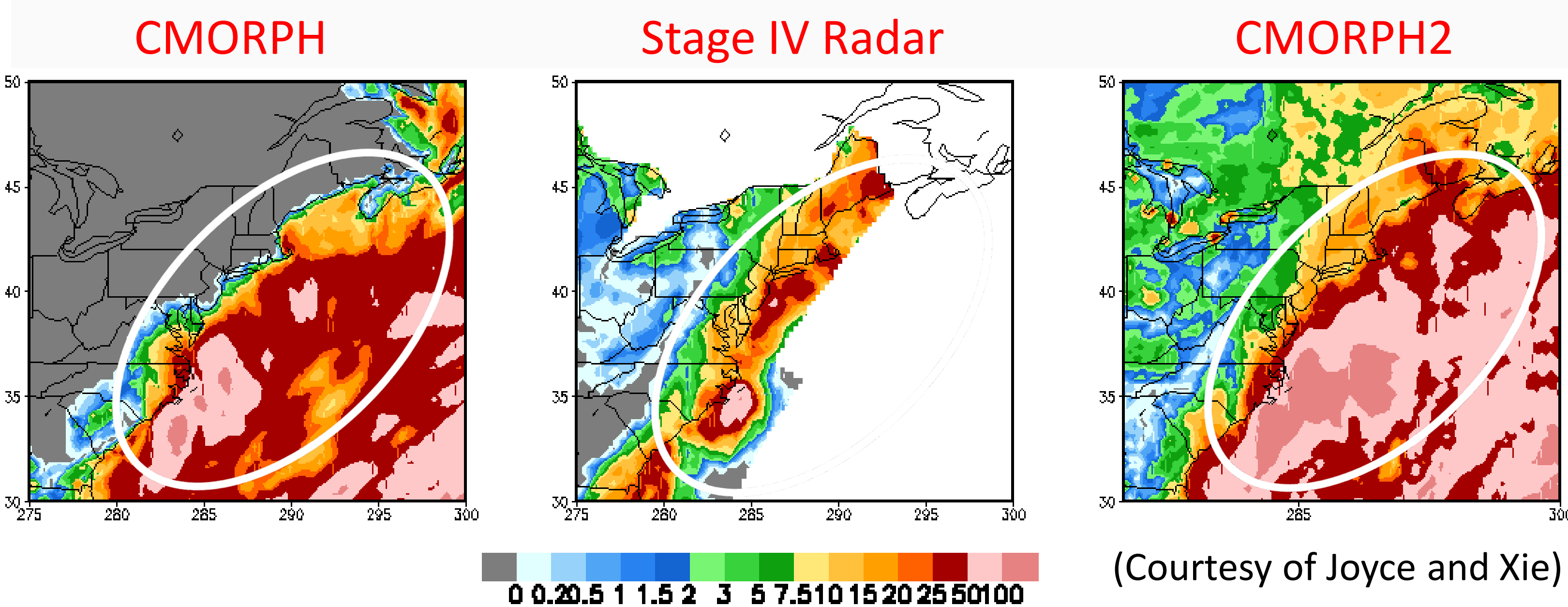


Use Case: Northern High Plains, 10/9-11/2019 (3)

Application - Second Generation CMORPH

- SFR has been integrated in the NOAA CMORPH2 blended precipitation analysis
- Accumulated precipitation (rainfall, snowfall, mixed) from the Stage IV radar observations (middle), the currently operational CMORPH (left) and the second generation CMORPH (CMORPH2, right)
- CMORPH2 is capable of capturing snowfall along the path of Grayson over the east coast

Winter Storm Grayson 3-5 January 2018



(Courtesy of Joyce and Xie)

Ongoing & Future Development

- Recalibrate SFR for all satellites against Stage IV and implement the new algorithms
- Further enhance the SFR product
  - ✓ Snowfall detection especially for light snowfall
  - ✓ Cold snow extension
  - ✓ Extend SFR retrieval to over ocean, coast, and sea ice
- Add more satellites, such as F18, to the SFR suite
- Improve mSFR product
  - ✓ Tracking snowstorm
  - ✓ Looping capability