Satellite Microwave Snowfall Rate Retrieval Cal/Val and Application

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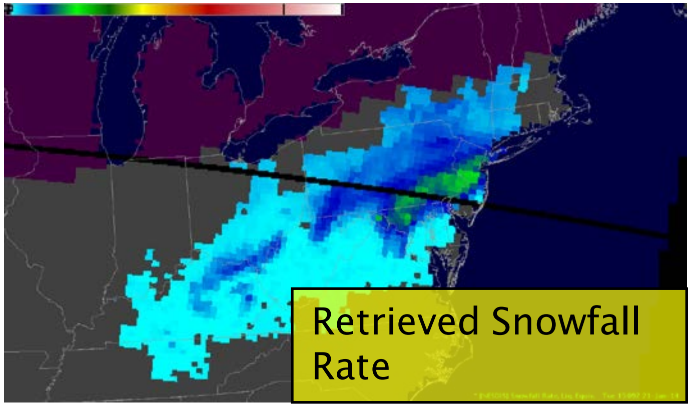
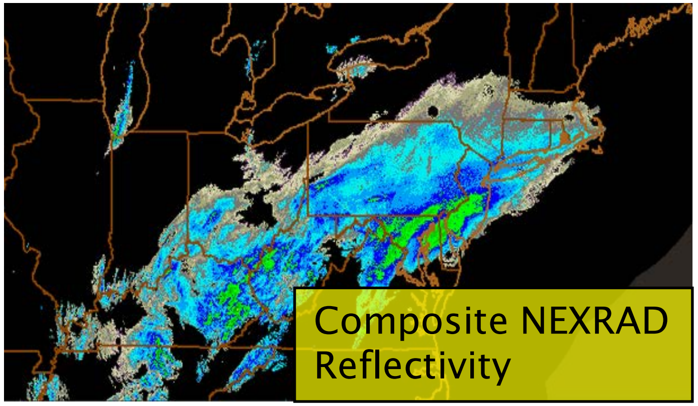
Outline

- Overview
- SFR Algorithm
- Calibration and Validation
- Applications
- Future Development
- Summary

Background

- A satellite water equivalent Snowfall Rate (SFR) product has been in operation at NOAA since 2012
- Passive microwave sensors: AMSU, MHS, and ATMS; AMSU/MHS SFR is operational, ATMS SFR will go into operation in 2016
- Satellites: NOAA-18, NOAA-19, Metop-A, Metop-B, and S-NPP (and future JPSS satellites)
- The product has wide ranging applications in hydrology and weather forecasting





Algorithm Methodology

1. Snowfall detection (algorithm embedded in SFR) (C. Kongoli's talk today at 4:30 pm)

2. Retrieving cloud properties with an inversion method

3. Computing snow particle terminal velocity and then snowfall rate

Retrieval of Cloud Properties

- Inversion method
  - ✓ 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

T_{Bi}: brightness temperature at 23.8, 31.4, 89/88.2, 157/165.5, and 190.31/183±7 GHz

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

E: error matrix

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

Snowfall Rate

- 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

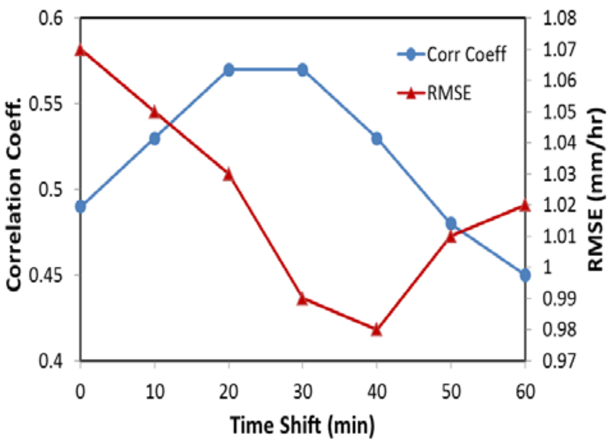
$$SR = A \int_{D_{min}}^{D_{max}} D^2 e^{-D/D_e} \left[\left(1 + BD^{3/2}\right)^{1/2} - 1 \right]^2 dD$$

$$A = \frac{\alpha I_c \delta_0^2 \eta}{24 H \rho_w \rho_a D_e^4}, \qquad B = \frac{8}{\delta_0^2 \eta} \sqrt{\frac{g \rho_a \rho_I}{3 C_0}}$$

  - ✓ An adjusting factor, α, to compensate for non-uniform ice water content distribution in cloud column; derived from collocated satellite and StageIV radar and gauge combined hourly precipitation data
  - ✓ Integration is solved numerically

SFR Recalibration (1)

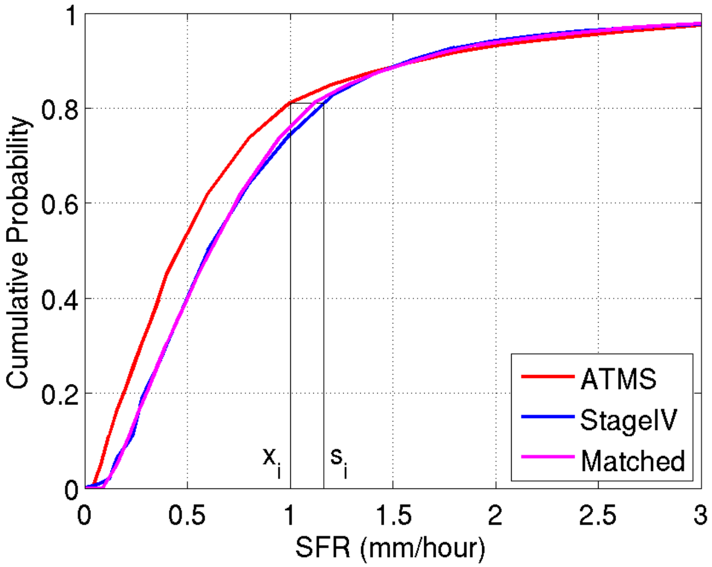
- The adjustment was found to be inadequate with a dry bias
- SFR algorithm is recalibrated using Multi-Radar Multi-Sensor (MRMS) snowfall rate data
- MRMS is more suitable for SFR calibration than StageIV
  - ✓ Instantaneous MRMS precip rate vs. hourly StageIV
  - ✓ MRMS is radar only, StageIV is adjusted with gauge data which has a notable time delay from satellite observations
  - ✓ MRMS includes precipitation phase while StageIV does not
- MRMS data (high resolution) is convolved to satellite footprint (low resolution)
- Matching MRMS data has a 30 min lag from SFR
  - ✓ The highest correlation between the two products usually has a time offset due to the fact that i) satellite observation includes info from entire precipitation layer, much of it is from levels higher than the typical snowfall level observed by radar, ii) slow terminal velocity of snow particles



SFR Recalibration (2)

- Histogram matching (Kidder and Jones, 2007) to adjust SFR towards MRMS
  - ✓ CDF adjustment
  - ✓ Use least square method to achieve optimal overall agreement between SFR and MRMS CDFs

$$s_j = \sum_{i=0}^{3} a_i x^i$$



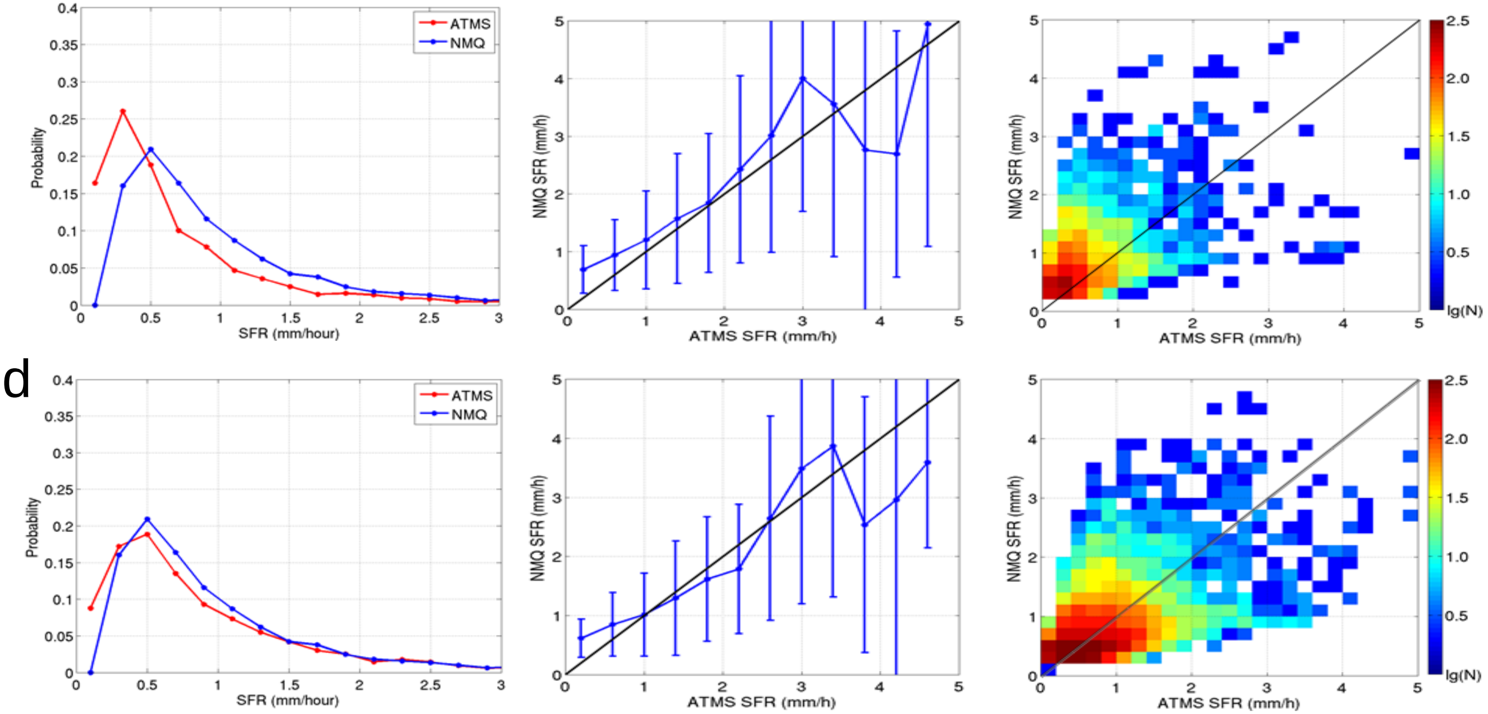
- Fitting of binned averages through regression

ATMS SFR Recalibration

- Calibration with histogram matching is adequate

Original

Recalibrated

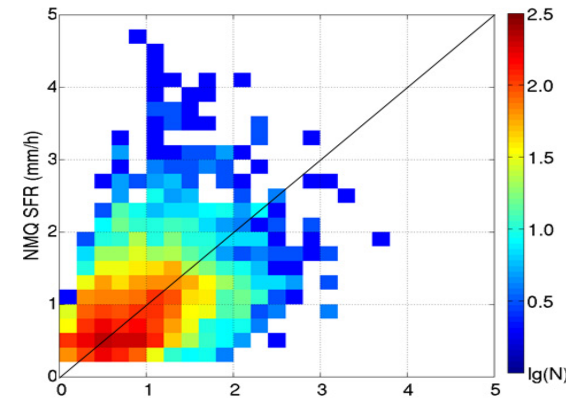


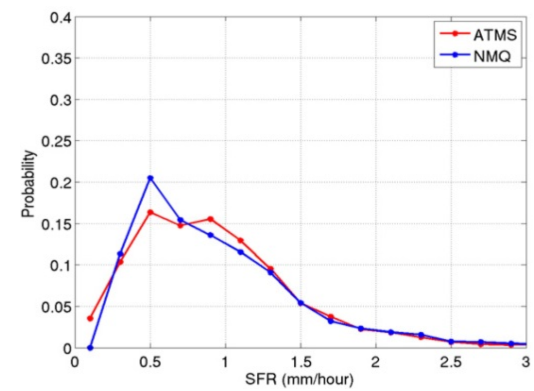
	Correlation Coefficient	Bias (mm/hr)	RMS (mm/hr)
Original	0.55	-0.30	0.77
Recalibrated	0.56	-0.10	0.73

ATMS Validation

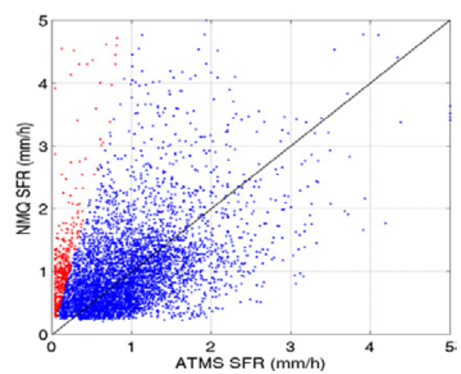
- Validation data: MRMS
  - ✓ Six multi-day snowfall events
  - ✓ 7794 matching points
- Performance

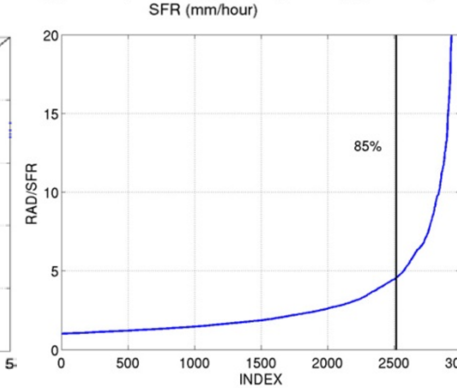
Data removed	Corre. Coe.	Bias (mm/hr)	RMSE (mm/hr)
15% liquid water contamination	0.56	0.04	0.60
0%	0.49	-0.02	0.65





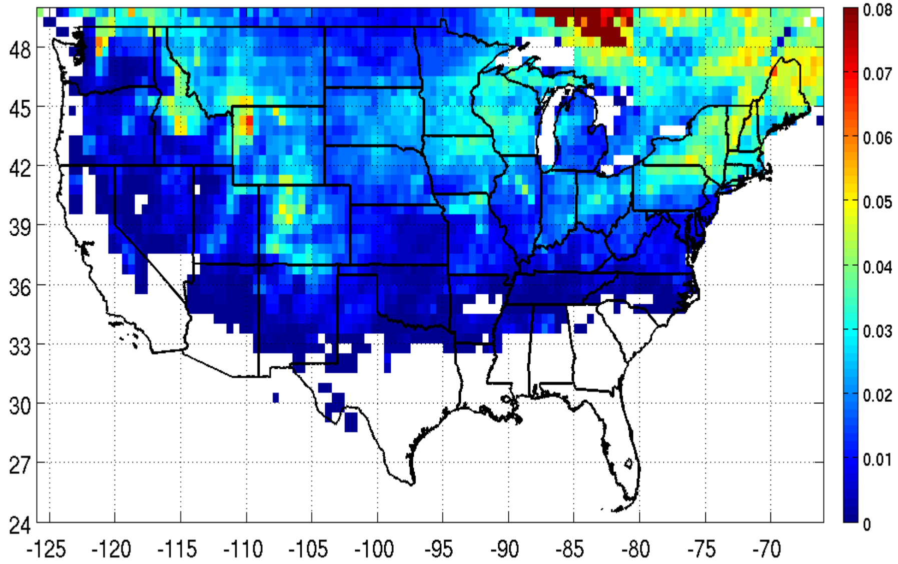
Large radar/satellite ratio is caused by not counting the effect of supercooled liquid water in the algorithm – focus of development in next phase



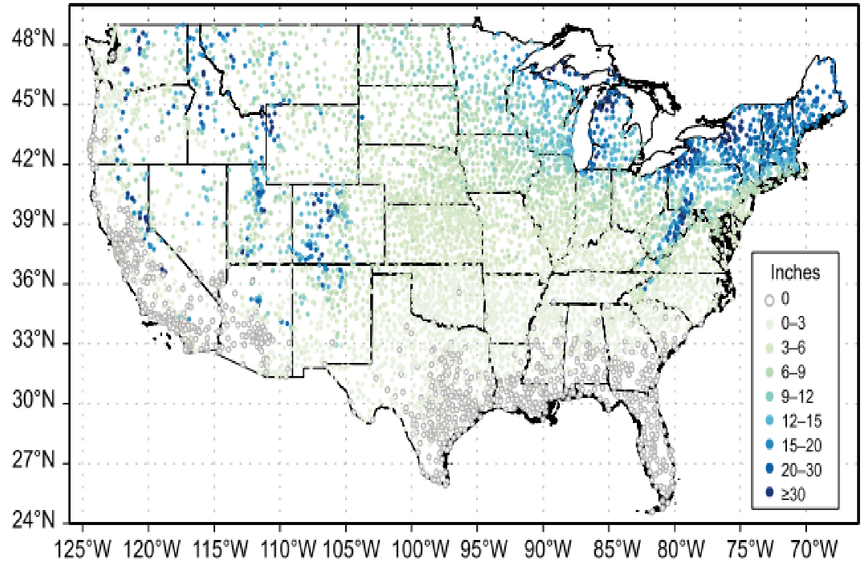


Validation - Climatology

Mean ATMS SFR in 2014



Gauge 30 years Climatology

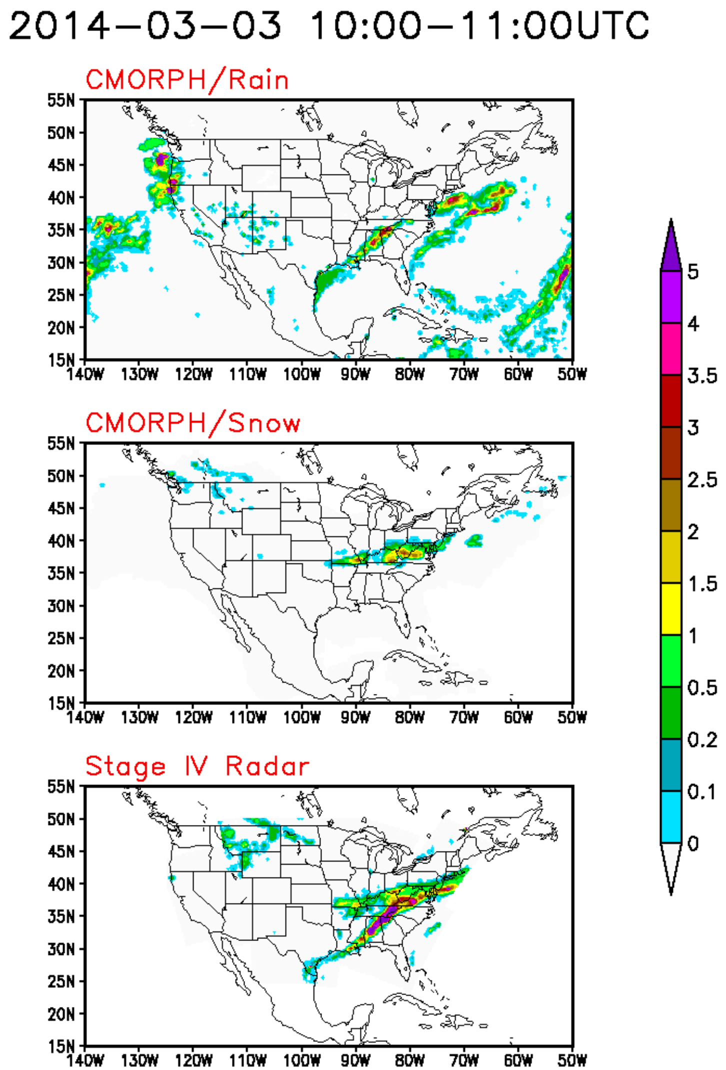


(Durre, 2013)

Application in Hydrology

Explicit Representation of Snowfall in CMORPH

- CMORPH: NOAA Climate Prediction Center Morphing Technique global precipitation analyses; a product widely used in hydrology
- Thanks to the operational production of snowfall rate retrievals from PMW sounders including those from SNPP/ATMS, we were able to develop integrated snowfall rate analysis under the CMORPH framework
- A sample for a major snow storm over the east coast of US in March 2014
- (Bottom) Radar image illustrates two bands of precipitation associated with the warm and cold parts of the frontal system
- (Top) CMORPH/Rain picked up the rainfall in the warm part of the system but missed the snowfall
- (Middle) CMORPH/Snow captures the snow in the cold part of the system



(Courtesy of Xie and Joyce, NOAA/NCEP)

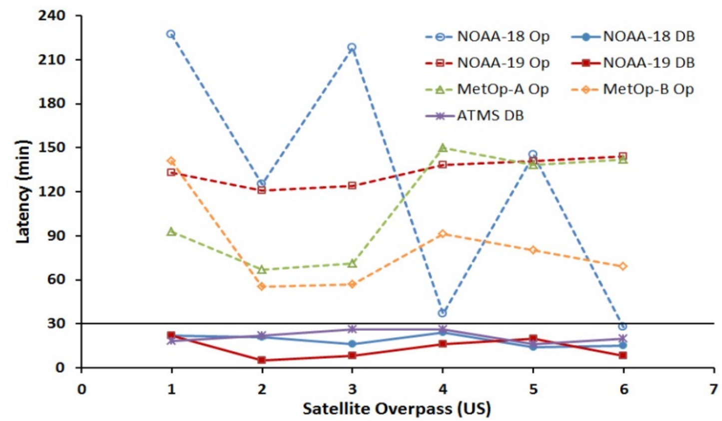
Application in Weather Forecasting

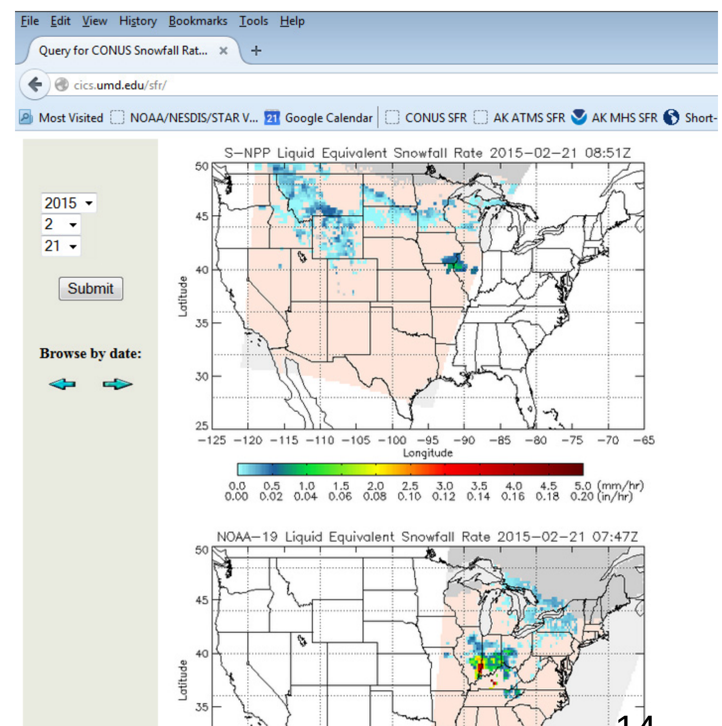
- Provide quantitative snowfall information to complement snowfall observations or estimations from other sources (stations, radar, GOES imagery data, etc.)
- Fill observational gaps in mountains and remote regions where radar and weather stations are sparse or radar blockage and overshooting are common

SFR using Direct Broadcast Data

- Reduce latency to meet requirement for weather forecasting – feedback
- Built processing systems to retrieve DB L1B data
  - ✓ CONUS: UW/CIMSS, ~15 min delay
  - ✓ Alaska: UAF/GINA, ~15 min delay
- Generate SFR within 30 min of observation; SFR with operational L1B data is 30 min ~ 3 hr
- Output:
  - ✓ Data online for SPoRT to download, reformat to AWIPS/AWIPS II/NAWIPS, and disseminate to WFOs
  - ✓ Images posted on SFR webpage at near real-time (< 30 min)
- Webpage:
  - ✓ SPoRT: http://weather.msfc.nasa.gov/cgi-bin/sportPublishData.pl?dataset=snowfallrateconus&product=conus_snowrate
  - ✓ NESDIS/CICS: http://cics.umd.edu/sfr

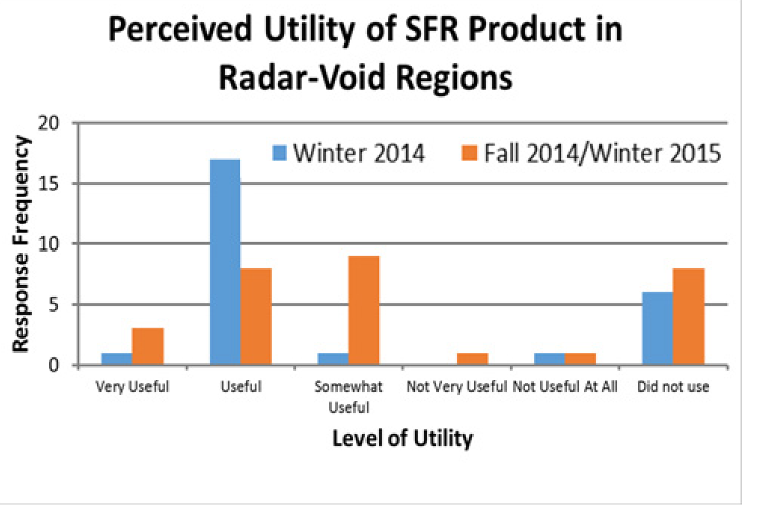
http://www.star.nesdis.noaa.gov/corp/scsb/mspps_backup/sfr_realtime.html





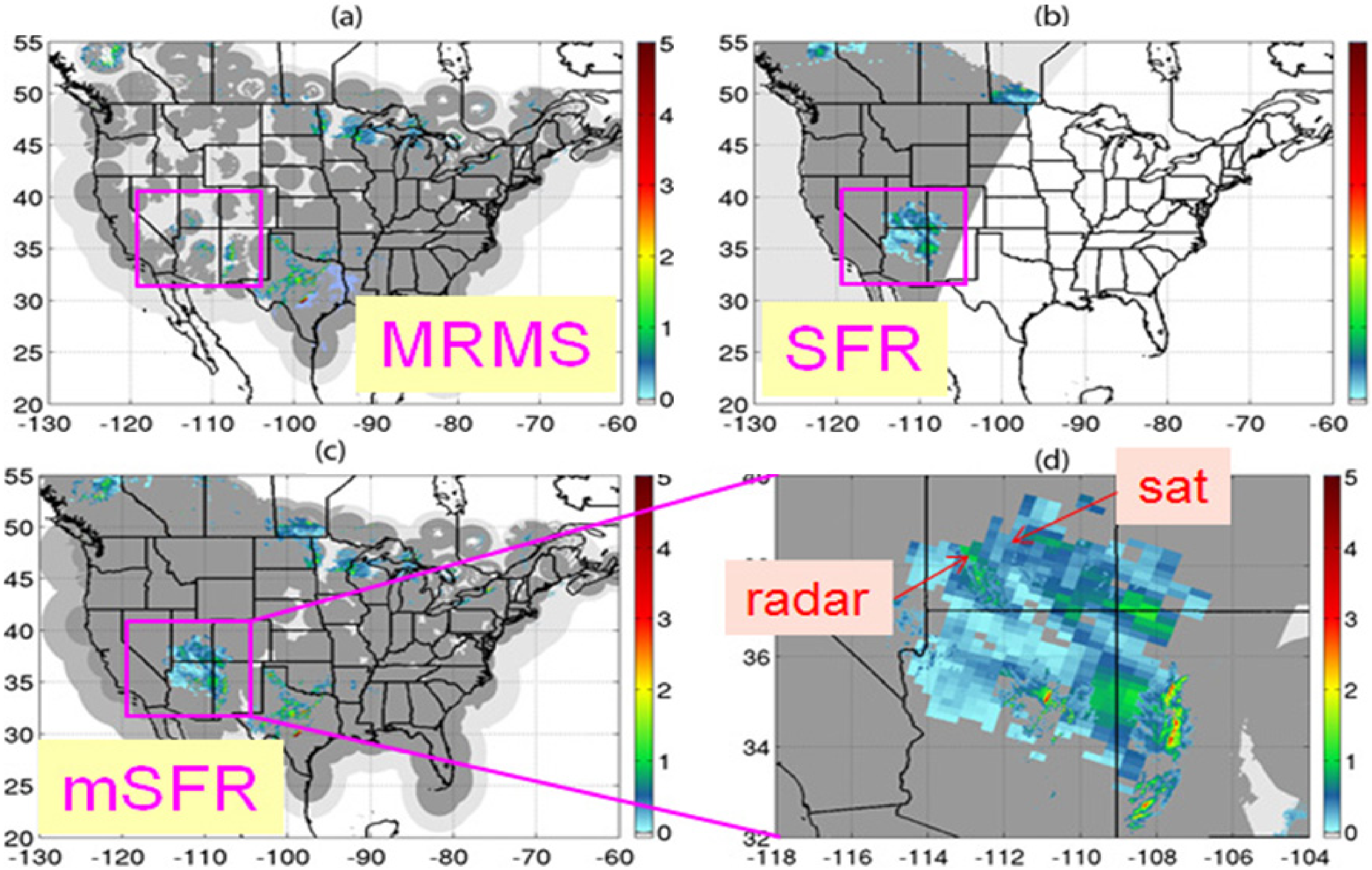
Product Assessment

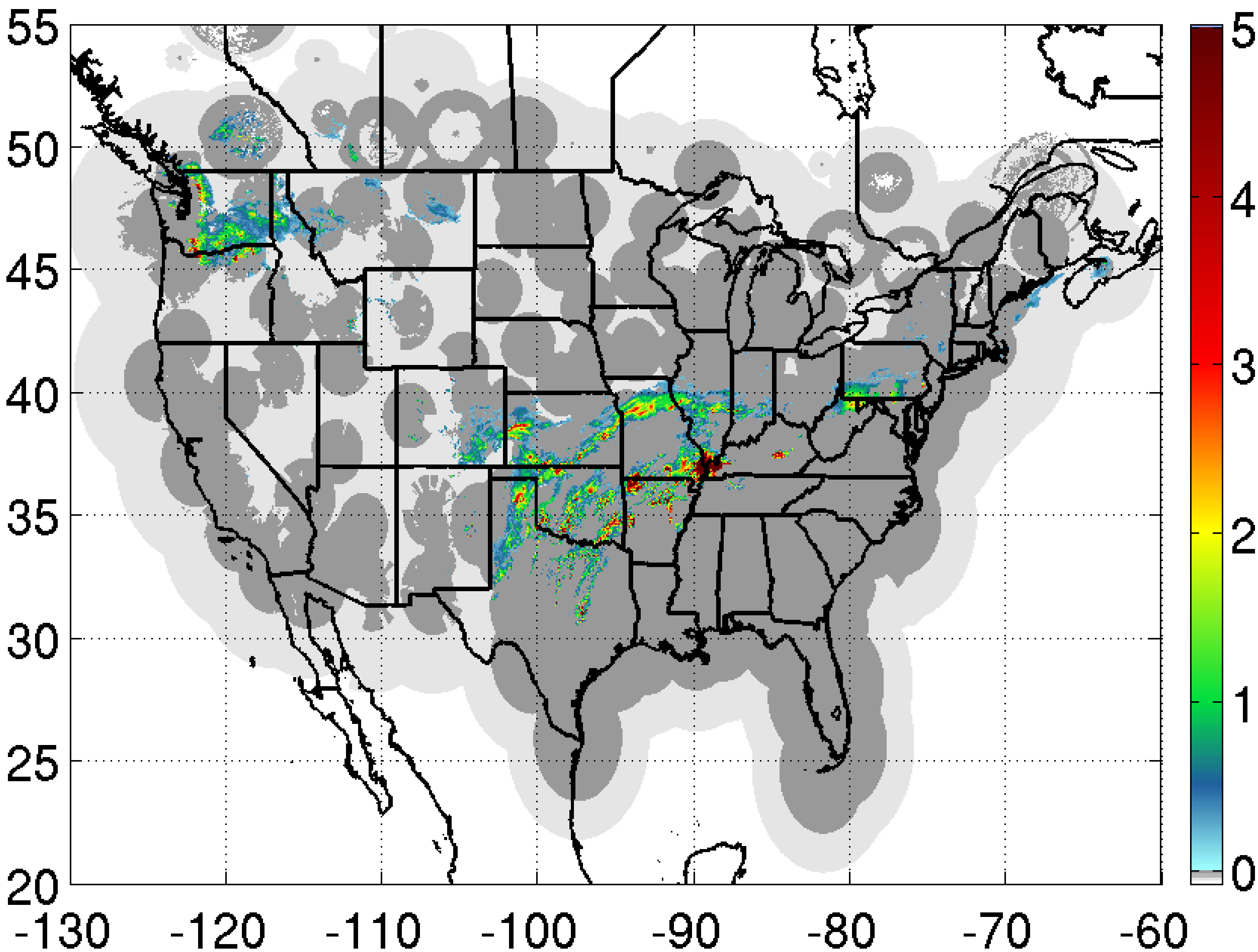
- Two SFR assessments led by NASA/SPoRT: 2014 and 2015
- Participants
  - ✓ 2014: Four WFOs from the Eastern and Southern Regions, and NOAA/NESDIS Satellite Analysis Branch (SAB)
  - ✓ 2015: Added several WFOs from the Central Region and Alaska
- Very valuable feedback!
  - ✓ Feedback was provided in many surveys, blog posts, and emails
  - ✓ Most forecasters rated the product 'Useful', 'Very Useful', or 'Somewhat Useful' – display and training issues caused some confusion in 2015
  - ✓ The SFR is most valuable in filling in observational gaps, e.g. in mountainous and remote regions
  - ✓ Feedback has been guiding new development



Radar and Satellite Merged SFR

- Merging MRMS instantaneous snowfall product and SFR to provide better spatial and temporal coverage
- Product assessment at WFOs in winter 2016




55
50
45
40
35
30
25
20
-130
-120
-110
-100
-90
-80
-70
-60
5
4
3
2
1
0

Future Development

- Algorithm enhancement
  - ✓ improve snowfall detection efficiency for moderately shallow snowfall
  - ✓ improve snowfall rate accuracy by incorporating cloud liquid water in RTM
- Development of SSMIS and GMI SFR algorithms
- Development of ocean SFR algorithm

Summary

- A NOAA operational snowfall rate product uses observations from ATMS and AMSU/MHS which are aboard five polar-orbiting satellites: S-NPP, NOAA-18, NOAA-19, Metop-A, and Metop-B, respectively
- More advanced ATMS SFR algorithm was developed and also applied to AMSU/MHS SFR. The algorithms have greatly benefitted from continuous development
- Validation study showed good agreement between SFR and radar snowfall rate; SFR also captures most snowfall patterns in CONUS compared to gauge observations
- As an example of its application in hydrology, the SFR product has been integrated in the NOAA/NCEP/CPC CMORPH global precipitation analysis
- Two product assessments were conducted at several NWS WFOs and NOAA/NESDIS/SAB in winter 2014 and 2015
- The assessments demonstrated that the SFR product can also help with weather forecasting, especially to fill radar gaps. The assessments also provided valuable feedback that has been guiding new product development
- A new radar-satellite merged snowfall rate product has been developed and will be evaluated in winter 2016

Acknowledgement

- JPSS Proving Ground and Risk Reduction Program
- NASA
- NOAA/NESDIS

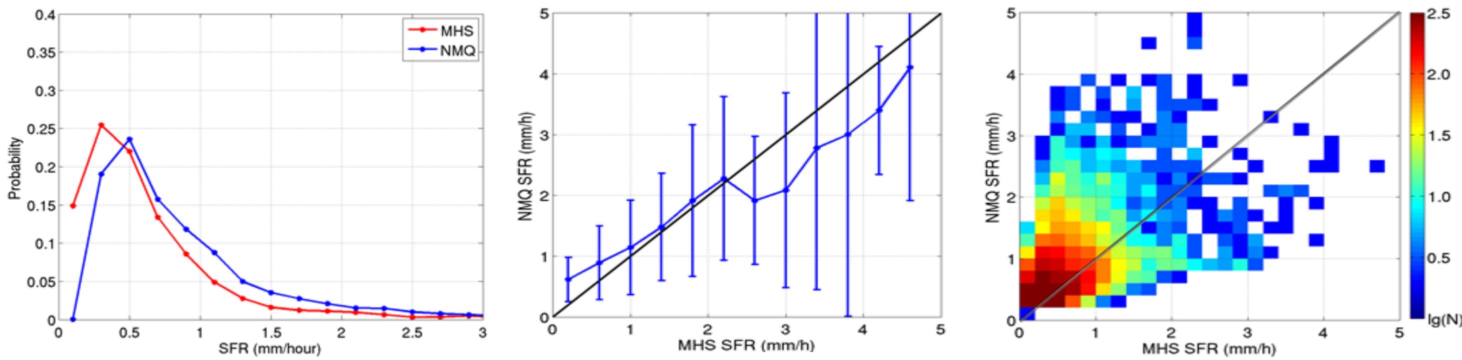
Thank You!

Backup

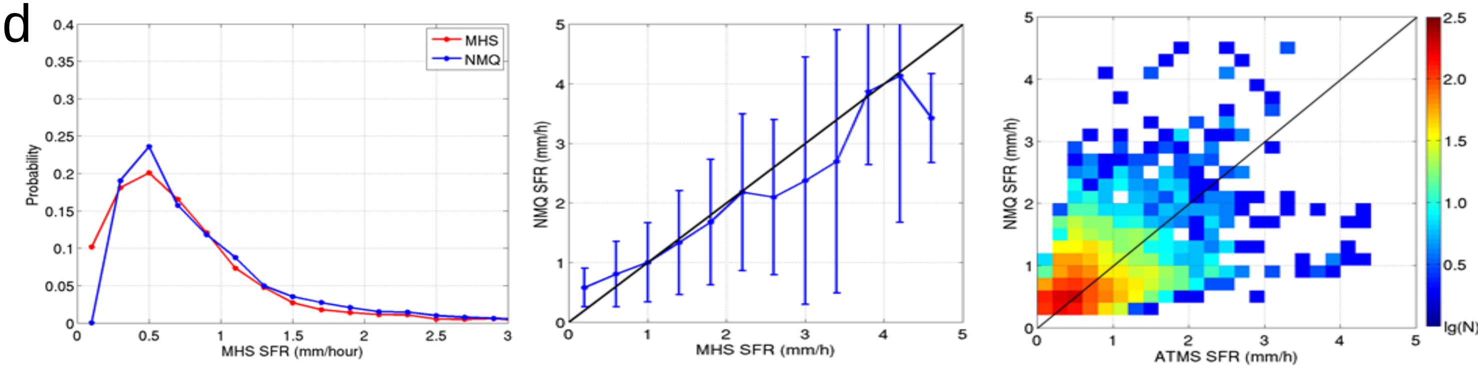
AMSU/MHS SFR Recalibration

- Calibration with histogram matching and binned-average fitting

Original



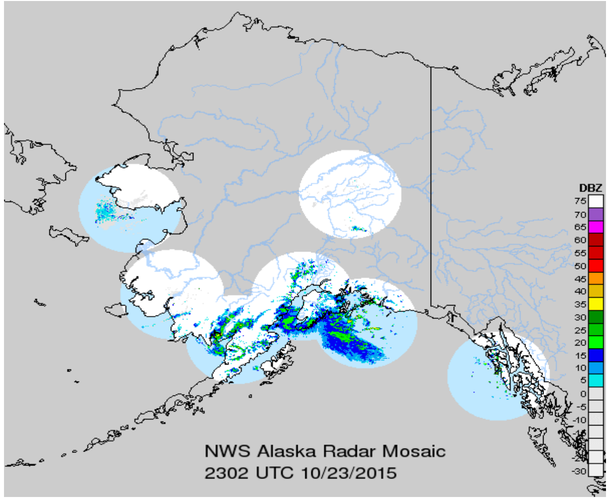
Recalibrated



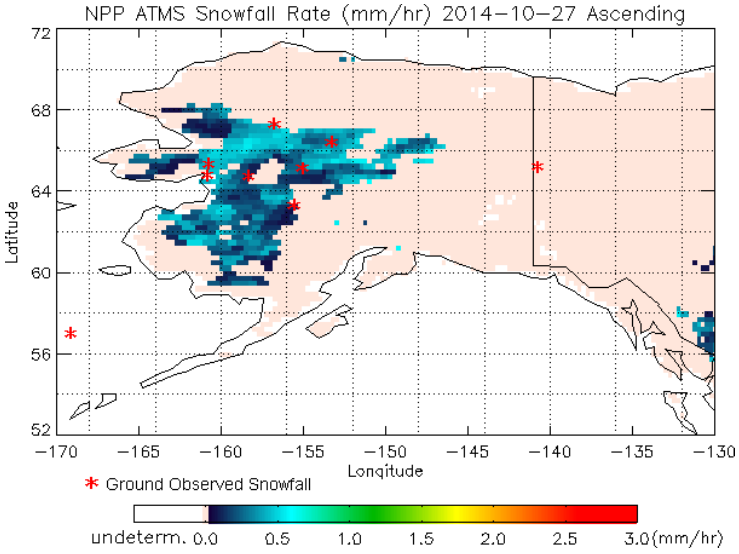
	Correlation Coefficient	Bias (mm/hr)	RMS (mm/hr)
Original	0.54	-0.27	0.68
Recalibrated	0.56	-0.15	0.66

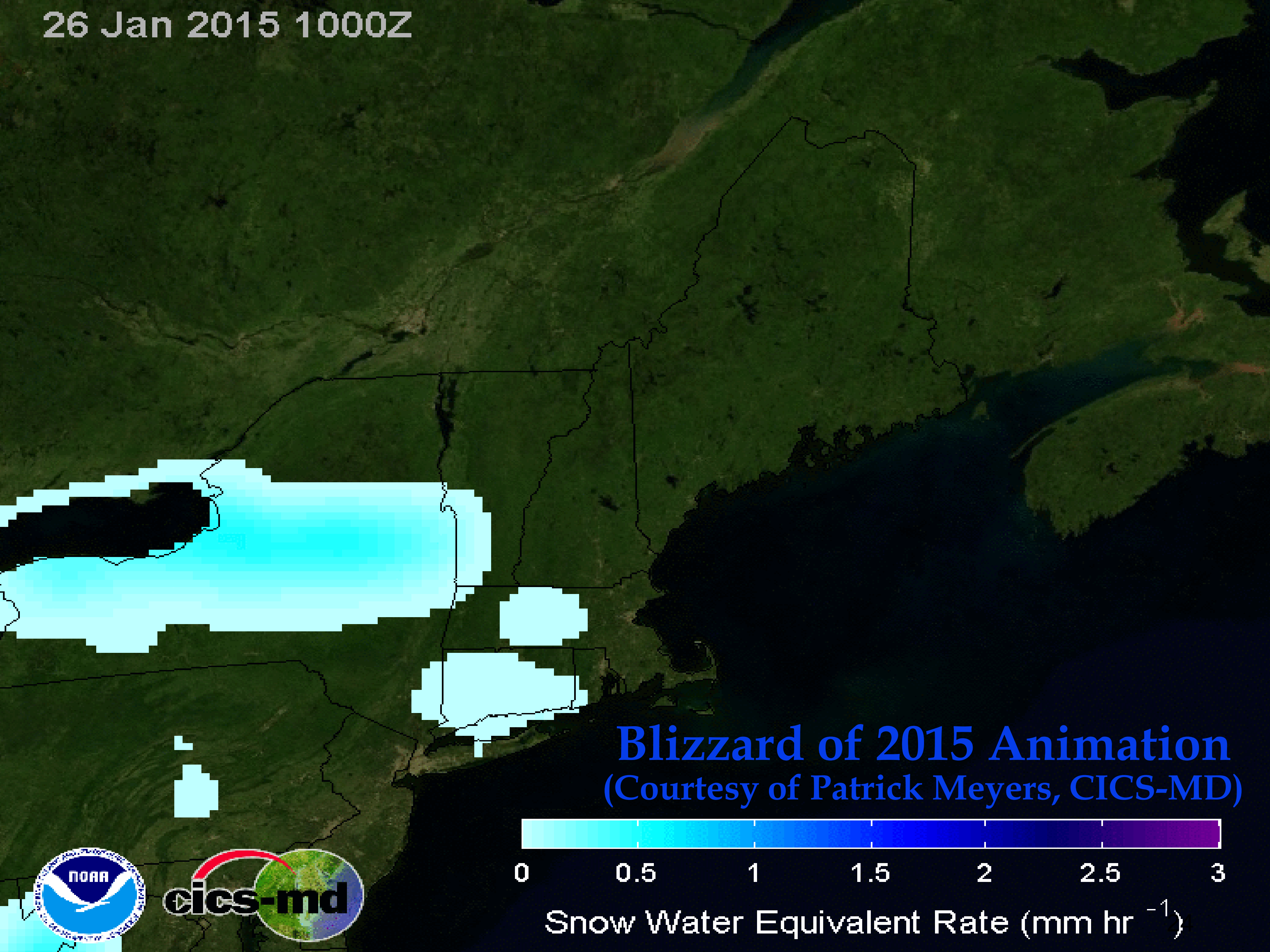
Application in Alaska

- Limited radar coverage in AK
- Many more satellite overpasses in AK than in CONUS, 25-50 vs.10
- Example in Alaska



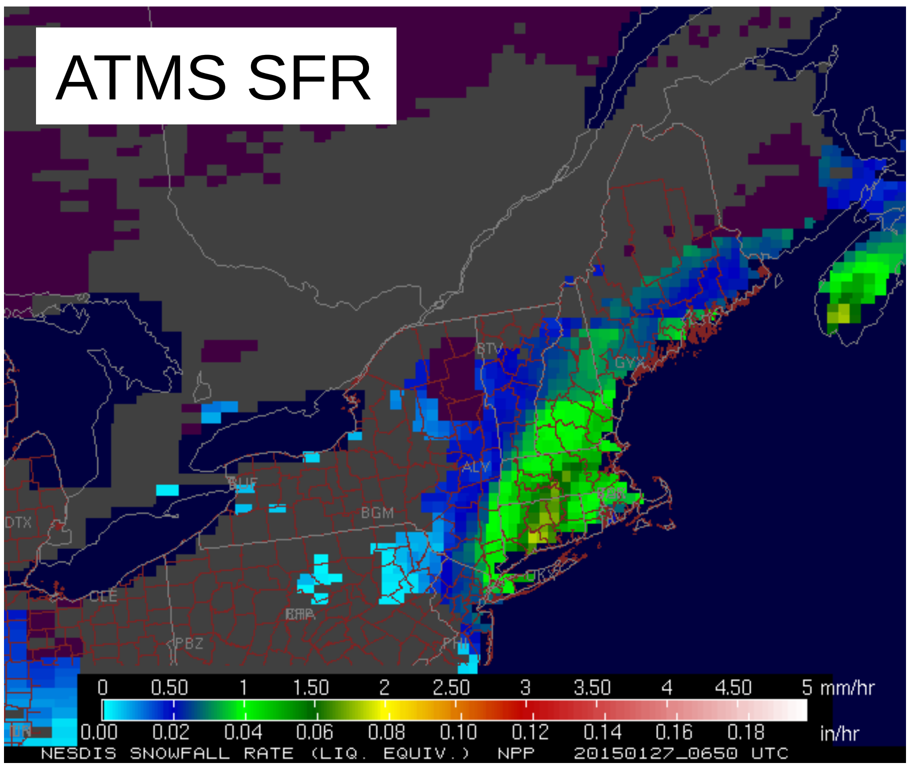
Juneau, AK WFO (AJK): There was a pass early this morning at 1113z that verified trace amount of snow near the Haines border. The SFR data reported 0.012 in/hr and that correlated well with snow rate and detection.

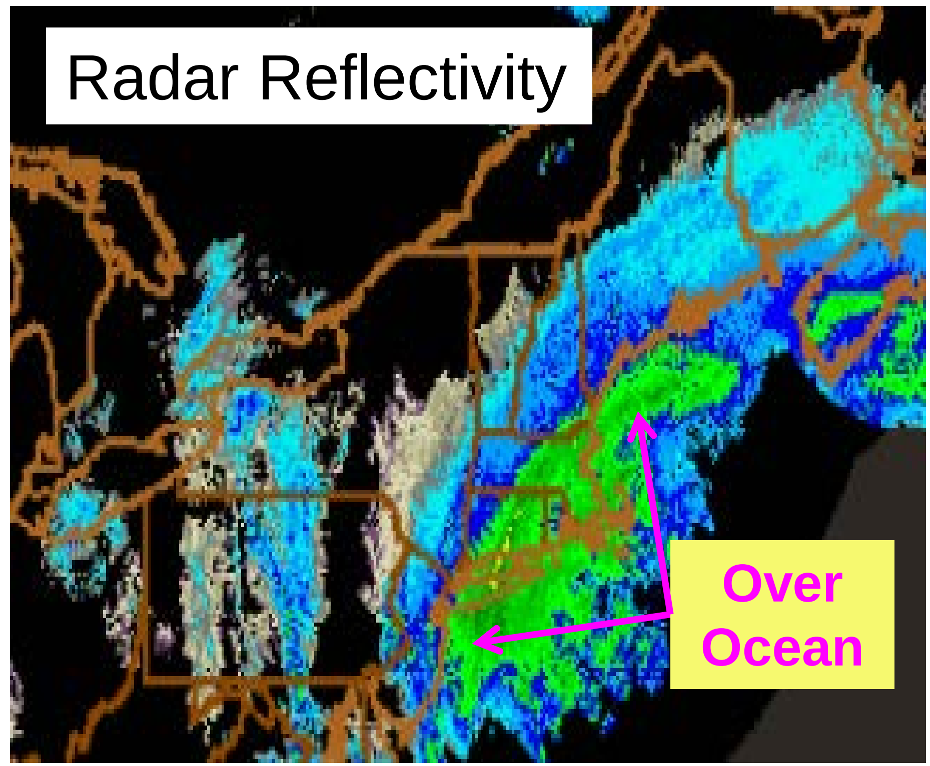



26 Jan 2015 1000Z
Blizzard of 2015 Animation
(Courtesy of Patrick Meyers, CICS-MD)
0
0.5
1
1.5
2
2.5
3
Snow Water Equivalent Rate (mm hr $^{-1}$)
NOAA
cics-md

Example, Northeast Blizzard of 2015

- ATMS captured the historic blizzard of 2015 in the Northeast
- 1-1.5 in/hr solid snowfall rate is consistent with ground observations

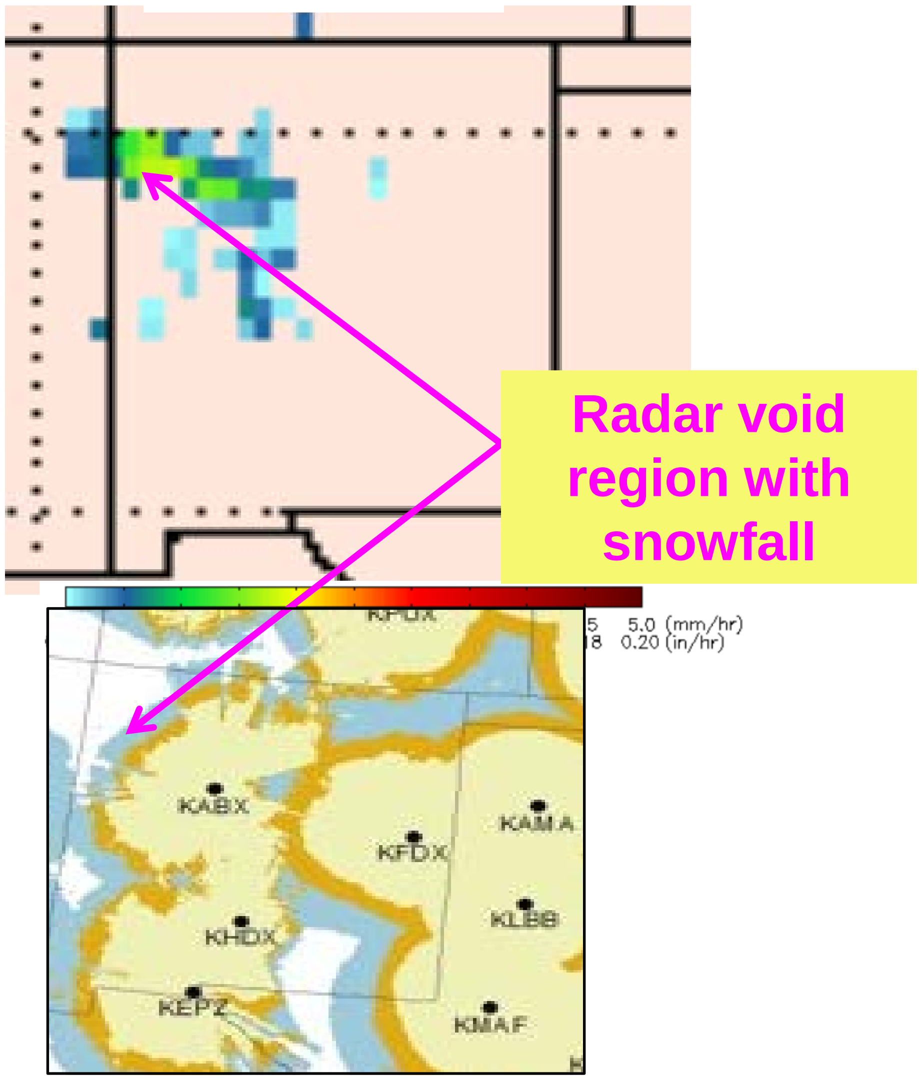




Example, Jan 14, 2015

Albuquerque, NM WFO (ABQ): The 919UTC image matched the NAM12 QPF forecast very well within a data void region. From this information I was able to determine the NAM forecast was too slow with the evolution of the precip. The NT microphysics product and IR at the same time actually showed the band along Interstate 40. The radar values dropped off away from the KABX radar which is expected, whereas the SFR product increased in the area of heaviest snowfall. Rates were close to the observed value at KGUP. The NM DOT web page indicated difficult driving conditions within this region.

ATMS SFR



Radar Coverage Map