NESDIS Snowfall Rate Product Assessment

Introduction

National Oceanic and Atmospheric Administration (NOAA) National Weather Service Forecast Offices (NWSFO) are tasked with issuing public watches and warnings on winter weather. These offices have traditional tools like ground-based radar and visible and infrared satellite imagery at their disposal to make situational awareness decisions regarding snowfall location and rate. Ground-based radar provides information on where precipitation is falling and information of precipitation type (through use of dual-polarimetric capabilities); however, even these radars are still limited in some parts of the country where there are gaps in radar coverage, beam blockage issues in mountainous terrain, or simply areas where the beam overshoots the low-level precipitation due to distance from the radar. Visible and infrared satellite imagery can only infer precipitation from conditions at cloud top but cannot independently confirm precipitation or type of precipitation (i.e., rain, snow, ice, sleet, mixed). As a result, NWSFOs sometimes lack the proper observational datasets to detect snowfall location and to estimate snowfall rates. To address these forecast challenges, researchers at NOAA/National Environmental Satellite, Data, and Information Service (NESDIS) have developed a Snowfall Rate (hereafter referred to as SFR) product using data from NOAA and EUMETSAT polar-orbiting passive microwave sensors. This constellation of polar orbiting satellites uses space-based observations of precipitation to generate a product that can supplement information from ground-based radar and visible and infrared satellite imagery providing a more comprehensive analysis of snowfall events.

This report describes an assessment of the SFR product conducted during winter 2014 to determine its operational utility in the forecaster environment as it relates to radar gaps, beam blockage and overshooting, and in combination with satellite imagery for tracking snowfall rate maxima. Forecasters from Albuquerque, NM (ABQ), Burlington, VT (BTV), Charleston, WV (RLX), and Sterling, VA (LWX) NWSWOs and the NOAA/NESDIS Satellite Analysis Branch (SAB) participated in the assessment. This evaluation was conducted from 6 January to 15 April 2014, which generally coincides with climatological peaks in North America snowfall events. The results of the assessment described in this report are intended for NOAA and NASA program managers, operational forecasters, product developers, other institutions participating in NOAA Proving Ground activities, and the general satellite remote sensing community.

Product Description

A land snowfall rate (SFR) product was developed at NOAA/NESDIS using measurements from Advanced Microwave Sounding Unit (AMSU) and Microwave Humidity Sounder (MHS) passive microwave sensors. The AMSU/MHS sensors are cross-track scanning radiometers and the spatial resolution of each channel varies from 16 x 16 km at nadir to 26 x 52 km at limb. Currently, there are four NOAA and EUMETSAT polar-orbiting satellites that carry the AMSU/MHS sensors: NOAA-18, NOAA-19, MetOp-A, and MetOp-B. These satellites provide up to eight SFR retrievals per day at any location over land in the mid-latitudes. The temporal coverage of the data increases at higher latitudes due to overlapping orbits. While the timing of the overpasses will vary slightly depending on the satellite orbit, the swaths will always be grouped into four morning overpasses and four afternoon overpasses. The data are processed in a near-real-time at NOAA/NESDIS and the SFR product is generated with a latency of between 30 minutes and 3 hours depending on the satellite orbit.

Clouds are relatively transparent to microwave energy giving microwave measurements a distinctive advantage in measuring precipitation over infrared measurements which see only cloud top properties. The SFR algorithm (Meng, et al., 2012, 2013) utilizes multiple microwave channels that are sensitive to the scattering effects of precipitation-size ice particles from different levels, so they can be used to identify snow in the entire precipitation layer and the location of the most intense snowfall within the storm extent. The retrieved SFR parameter is actually an estimate of the liquid equivalent of the snow; therefore, it must be multiplied by an appropriate snow-to-liquid ratio based on local climatology and environmental conditions at the time of the snowfall to estimate a solid snowfall rate. Details of the retrieval process can be found in the above references.

The 53.6 GHz channel is used for as an atmospheric temperature filter for snowfall detection but is highly correlated to 2-m temperature. As a result, this constrains the retrieval of snowfall information to regions where the surface temperature is above approximately 22^{o}F. Also, the product represents snowfall in the entire precipitation layer. Because snow particles have relatively slow terminal velocity, there usually is a time lag between the retrieved snow and that same snow reaching the ground. Thus, forecasters need to take this time lag into account when using the product. Future iterations of the product will attempt to quantify some of these lags. Forecasters during this assessment noted what they thought were lags between 30 and 90 minutes for different cases when they compared the SFR product to ground reports, but these numbers seemed to vary on a case-by-case basis. The maximum and minimum snowfall rates detectable by the product are 5 mm/hr (0.2 in/hour) (liquid) and 0.1 mm/hr (0.004 in/hr) respectively. The developers have implemented a minimum threshold in the algorithm to reduce the false alarm rate for very light snowfall.

For this assessment, the SFR product was produced at NOAA/NESDIS and made available to SPoRT for dissemination. The product files were re-formatted and provided to participating NWSFOs for use with other products in the Advanced Weather Interactive Processing System

(AWIPS). A different file was processed for each individual satellite swath (i.e., the 4 instruments mentioned above were not blended into any sort of composite product). This was done to ensure that the time of each overpass would be unique for determining both product latency and estimating the lag component between the in-cloud observations and ground reports. The latency of the products from satellite observation time to the end users ranged from 30 minutes to 3 hours depending on the orbit.

Methodology

SPoRT discussed a product assessment with the developers and relevant NWSFOs that were interested in this evaluation. Training modules were developed jointly by SPoRT staff and the product developers describing the SFR product, discussing its strengths, weaknesses, and limitations and included specific case study examples demonstrating how it was anticipated that forecasters would use the product. In addition, the product developers and SPoRT collaborated on a one-sheet quick guide that briefly describes the product and illustrates how it can be used in operations. These one-sheet quick guides were produced in a laminated form and sent to each office before the start of an assessment to be placed next to forecaster workstations for rapid reference in lieu of pulling up the full set of training slides. Both the training module and an electronic form of the quick guide can be viewed by going to the Training Page under the Transition tab on the SPoRT website (http://weather.msfc.nasa.gov/sport/training/). Teletraining was also conducted as part of a GoToMeeting in early December that also worked as a "kick-off" meeting for the assessment. During the kick-off meeting, expectations regarding forecaster participation (e.g., filling out online assessment forms, writing blog posts, participating in e-mail communication) were discussed, and all parties verbally agreed to these particular terms.

A key component to SPoRT product assessments is the use of online surveys to quickly capture forecaster impressions of the product being evaluated following its use. To strike a proper balance between the needs of the assessment and the often busy operational forecast environment, these surveys are designed to be completed by forecasters in a just a few minutes. The survey questions were generated jointly by the NESDIS product developers, WFO forecasters, and SPoRT transition training and assessment experts to address specific questions regarding the operational utility of the product (more details can be found in Appendix A).

While the surveys were filled out only by forecasters participating in the evaluation process, valuable interaction occurred between forecasters, SPoRT, and the NESDIS product developers during the course of the assessment. Case study examples and other interesting product developments were shared via the Wide World of SPoRT blog (nasasport.wordpress.com). Additionally, e-mail exchanges between the forecasters, SPoRT, and product developers enabled discussion of the strengths, weaknesses, and utility of the SFR product. While SPoRT did not specifically use NWS Chat as a tool during this assessment, the developers and forecasters at the SAB communicated with NWSFOs using this tool.

Results

At the close of the assessment period on 15 April, personnel at the participating NWSFOs and SAB had completed 26 surveys providing significant insight into the product utility. In total, 10 blog posts were made describing various use cases for the product. There were also more than 50 e-mails exchanged between the forecasters, SPoRT, and NESDIS product developers.

Survey Results

Product confidence and latency are the two key components to the transition of experimental and research data and products that are necessary for successful product use in an operational environment. Figure 1 indicates that despite the 30 minute to 3 hour latency of the snowfall rate product, the majority of the forecasters indicated that the product was quite useful for verification of ground reports of snow in regions where radar coverage was lacking. However, a large number of responses indicated that the product was not timely enough for nowcasting applications at the current latencies. Forecasters responded that a product latency of less than an hour would be optimal for this product to have stronger nowcasting utility. Forecasters had a high amount of confidence in the SFR Product. Of the surveys submitted during the assessment, 22 out of 26 responses pointed to a forecaster having medium or high confidence in the product (Fig. 2). Thus, it appears that the product utility in the operational environment is fairly high based on the high number of forecasters that found the product timely enough to play some role in the forecast process and confidence that they had in the product. Out of the 26 survey responses, 7 indicated that the product had a large impact on their forecast process for a given event. Despite product latency limiting applications as noted above, 2 of the surveys indicated that the SFR product was used in the issuance of a nowcast, 11 surveys indicated that the forecaster had an improved understanding of the current situation and communicated something that they saw in the product either on social media (including the SPoRT blog) or to forecasters either in their office or in another office. Only 3 responses indicated that the product was not useful enough for any purpose.

Additionally, value-added experimental products that address a specific forecast challenge or problem will have a greater use and impact. The two specific forecast challenges being addressed by the SFR product were 1) obtaining information about snowfall rates in data-deprived regions, such as mountainous terrain and radar gaps and 2) tracking areal coverage and snowfall maxima compared to GOES VIS/IR imagery. Based on the 26 surveys taken during the assessment, the utility of the product was positive with 18 of the 26 responses indicating

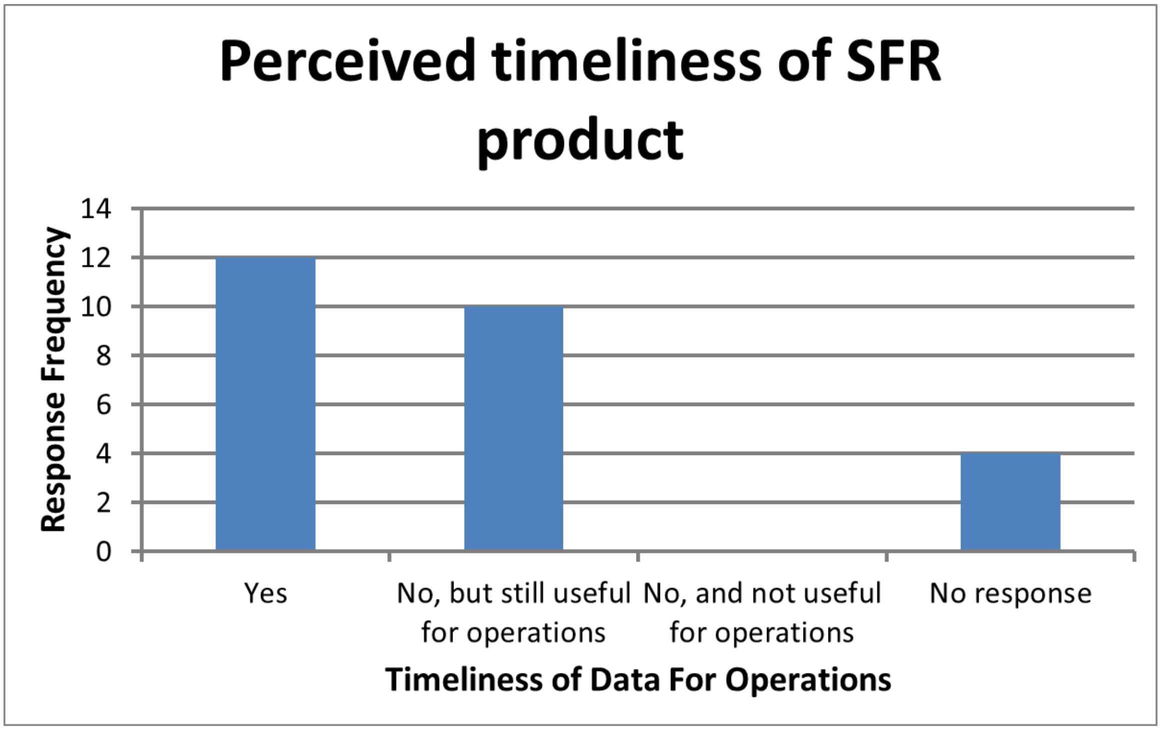

Figure 1. Forecaster feedback on timeliness of SFR product for operational applications

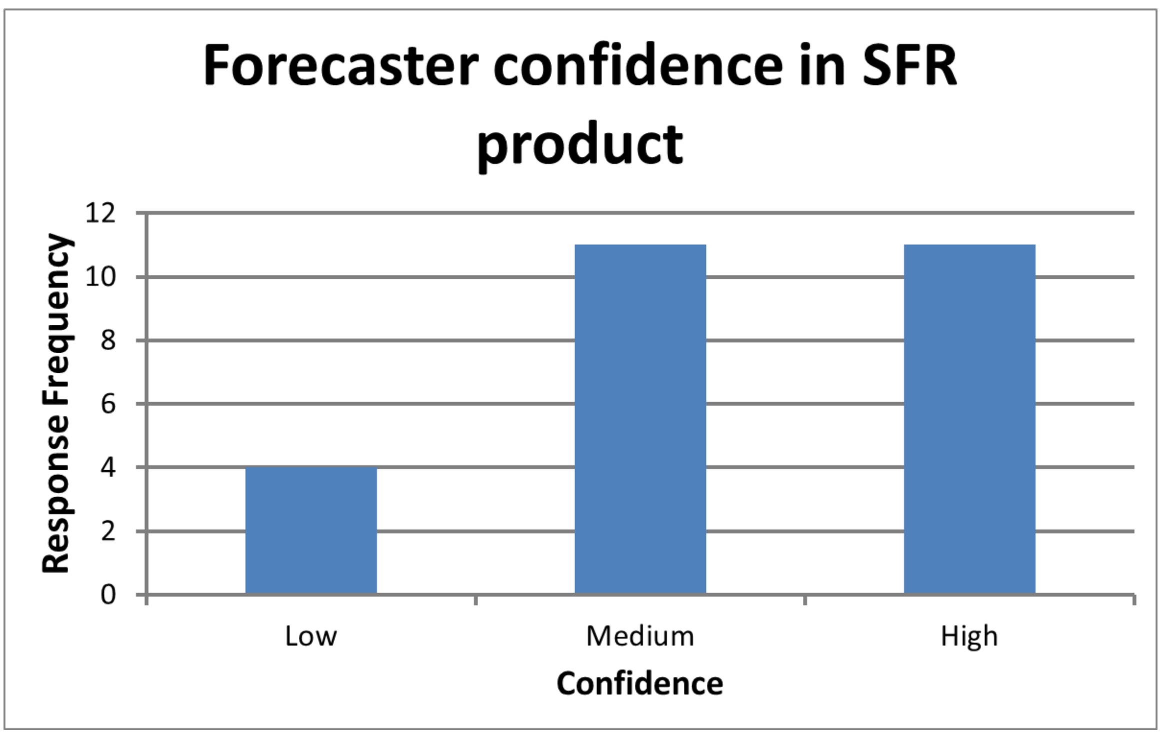

Figure 2. Forecaster confidence feedback from all users for SFR product.

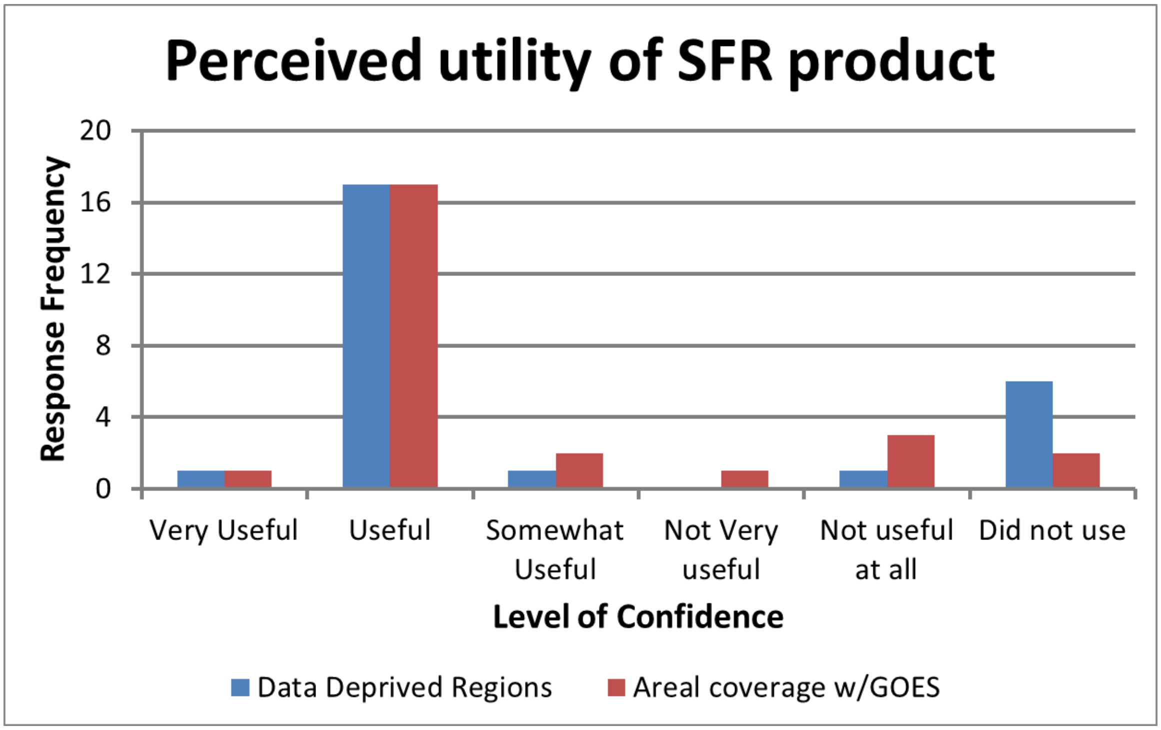

Figure 3. Perceived utility feedback for each of the specific forecast challenges from all users for the SFR product.

that the product was Useful or Very Useful for both of the operational challenges (Fig. 3). Of the other 8 responses, 4 of those were related to the fact that the product was not timely enough to be useful and 4 were associated with forecasters that were looking at the SFR product for only one of the two operational challenges.

Case Study Examples of Product Application

This assessment featured a robust exchange of ideas regarding the SFR product and its application for operational forecasting. As previously mentioned, 10 blog posts were made showing application of the product. There were also more than 50 e-mails were exchanged between the forecasters, SPoRT, and NESDIS product developers. The outcomes of the blog posts (and associated comments) and e-mails were 1) forecasters gained additional insight into the strengths and limitations of the products as they continued to apply them within their forecast process and 2) the product developers could better understand how the products were being used and what specific components were most useful in the operational process.

For the most part, heavy snowfall events in warmer temperature regimes were captured well by the SFR product. A good example of this came later in the assessment period for a snow event over Colorado and New Mexico on 13-14 April 2014. In this event, a fast-moving upper level trough and a backdoor cold front moved southward from the eastern plains of Colorado to

New Mexico. Snow was reported throughout western Kansas, eastern Colorado, and northeastern New Mexico. Figure 4 compares the SFR product to radar reflectivity early in the morning on 14 April. The Albuquerque, NM NWSFO reported that *"The 0429Z SFR product has the greatest values observed in NM for this event. Our Clayton (CAO – orange oval [in Fig. 4]) observer did call in at 06Z with a report of 1.5 inches of snow. We don't receive snowfall at the Las Vegas ASOS (LVS – pink oval [in Fig. 4]). Another spotter call from 05Z reported 2.5 inches of snow at a location near the purple arrow [in Fig. 4]."*

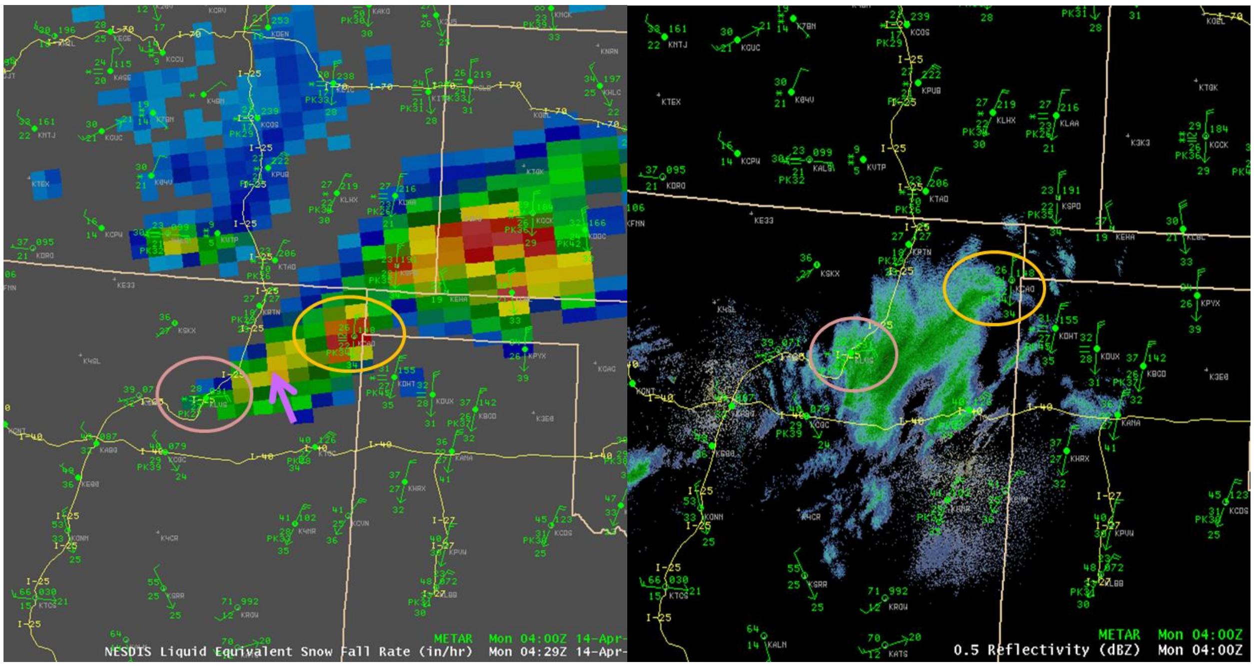

Figure 4. SFR product at 0429 UTC (left) compared to reflectivity at 0400 UTC (right) on 14 April. The orange circle and purple arrow highlight spotter reports of 1.5 and 2.5 inches of snow, respectively; the pink oval highlights an area where there was no snow reported.

However, earlier in the event, lighter snowfall rates were not detected by the SFR product in areas where METAR observations were detecting snow falling (not shown). The inability of the snowfall rate product to detect lighter amounts of snow was one of the biggest weaknesses of the product exposed by the assessment. This limitation was first demonstrated by Jeffrey Hovis, the Science Operations Officer (SOO) at the Charleston, WV NWSFO, in a series of blog posts in late January. Figure 5 highlights some of the challenges that forecasters encountered when applying the product. Hovis wrote, *"It looks like the SFR product did not detect all of the snow that was falling around 11 UTC. But the misses can generally be described as either (1) the surface temperatures being too cold or (2) the probabilistic model that is part of the calculations, indicating probabilities that were too low to determine if there was snow."* This quote provides some operational guidance on the how the forecaster interpreted the product, but also shows how the concept of the cold temperature limitation (described in the training module) was applied by the forecaster when interpreting the product.

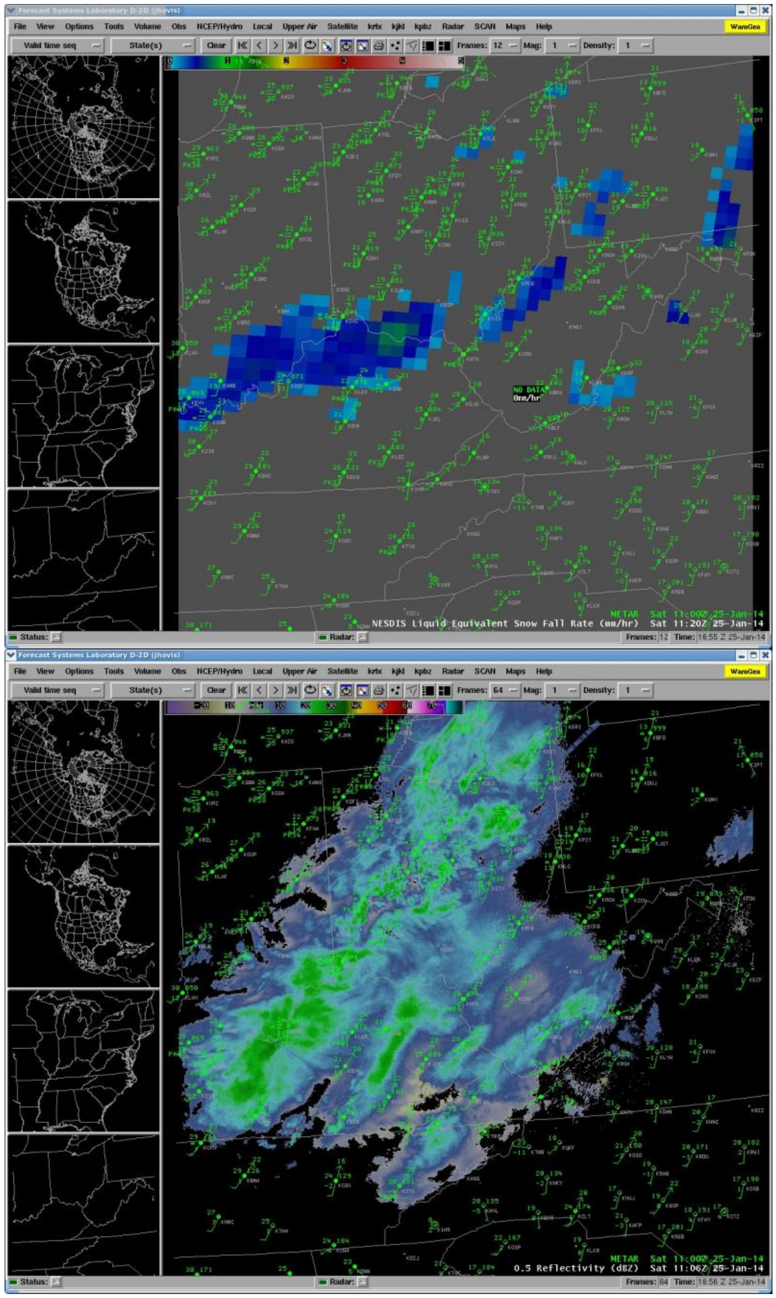

Figure 5. SFR product (left) and radar reflectivity (right) from Charleston, WV for 1100 UTC on 25 January.

One topic that was not in the training but was frequently discussed during the assessment was the idea of using the SFR product as a forecasting tool. In other words, the SFR detects snow in the cloud that might not be reaching the ground and also might not be detected by radar (beam overshoot). The most interesting application came from a snow and ice event that impacted central and northeast Alabama resulting in stranded motorists caught by surprise by the snowfall. The event was highlighted by Sheldon Kusselson (SAB) in a series of e-mails. The heaviest snow fell on the Birmingham area starting around 10:00 A.M. local time (1600 UTC). Figure 6 shows that both the SFR product at 1619 UTC (bottom left) and 1613 UTC radar image (bottom right) identify heavy snow consistent with ground reports. Radar scans earlier in the morning at around 1100 UTC (top right) did not give any hint that there was snow in the region; however, the SFR product at nearly the same time showed substantial snow to the west over Mississippi and through central Alabama. Because reports of snowfall were not coming in during this time, it is likely that the SFR product was detecting in-cloud snow. If forecasters were able to recognize this potential, it is possible that the product could be used in a way that would provide additional guidance or lead time on a snow forecast. This is a topic for future assessment and training.

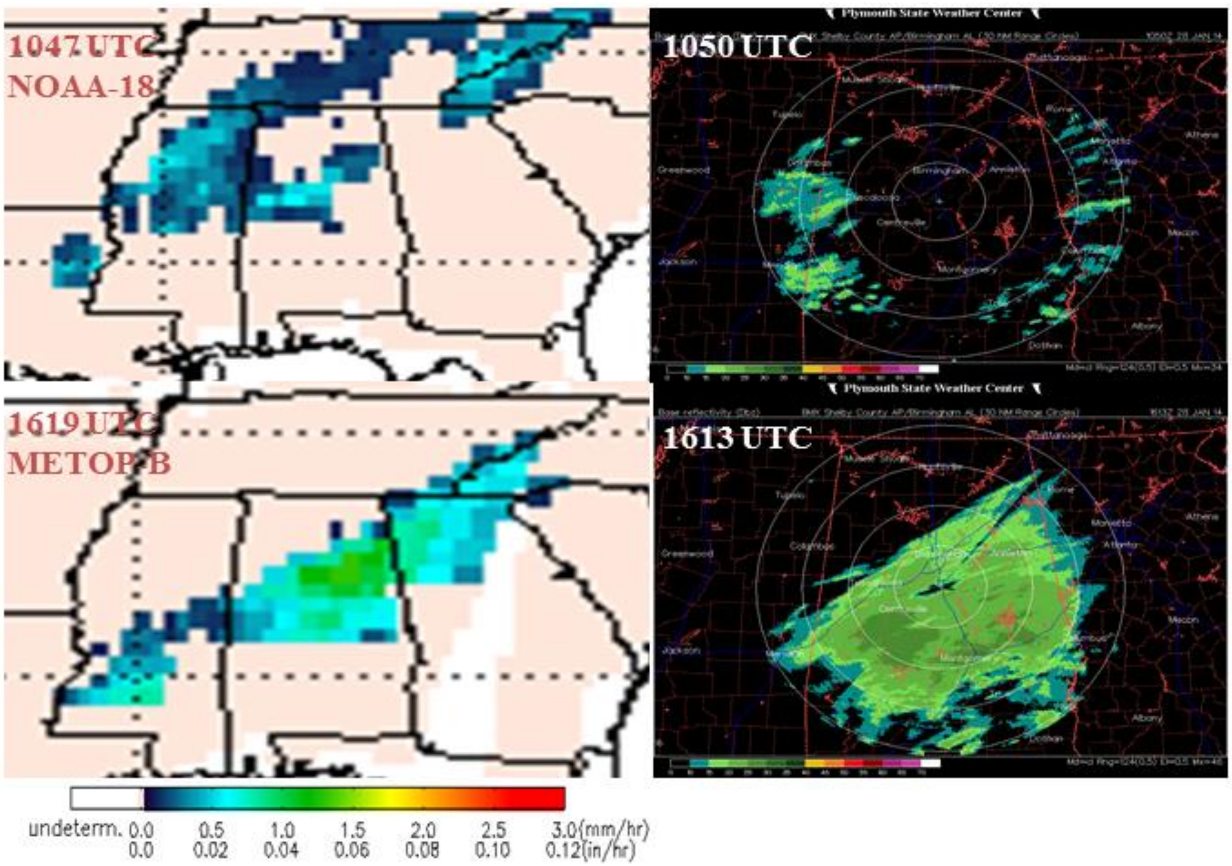

Figure 6. Web version of the operational SFR product at 1047 UTC from NOAA-18 (top left) and at 1619 UTC from METOP-B (bottom left) compared to radar reflectivity (from archived radar at Plymouth State) at 1050 UTC (top right) and 1613 (bottom right).

Summary and Recommendations

Forecasters at NWSFOs are responsible for issuing public watches and warnings on winter weather. While they have satellite imagery and radar to aid in making these forecasts, there are limitations to each of these datasets. Visible and infrared satellite imagery does not provide information on precipitation location or type; radar data are limited in mountainous terrain or if a location is too far from the radar location. NESDIS has created a SFR product that SPoRT transitioned to operational forecasters in Southern and Eastern Region for a formal assessment. The SFR product consists of single swath snowfall rate retrievals from passive microwave sensors aboard NOAA and EUMETSAT polar-orbiting satellites.

Winter 2014 provided an excellent opportunity to evaluate the SFR Product as a number of high-impact winter weather events occurred during the assessment period. While the product was limited at times by its latency, forecasters found the SFR product to be valuable in both an operational sense and also to help validate snow reports. Overall feedback on the SFR product was positive with more than three-quarters of the responses indicating that the product was useful in operations for questions related to improving data coverage in areas with traditional radar gaps (e.g., mountainous areas, regions far from radar) and in combining the product with geostationary satellite observations to track snowfall maxima.

A few product limitations were found during the course of the assessment. The limitations regarding colder temperatures were known issues going into the assessment; however, the assessment exposed a weakness detecting lighter snowfall rates. The developer-imposed low snowfall rate limit may need to be re-evaluated in light of this. Forecasters found the product was slightly discredited if it was missing snowfall that was detected by the radar. In general, forecaster feedback seemed to want to err on the side of capturing all of the possible snow even if that meant that false alarm rates might be a bit higher. On this matter, Sheldon Kusselson stated, "...from my point of view as a satellite analyst, I would like the SFR to capture all snow events, even though snow may not be reaching the ground...it gives me the chance to overrule the SFR with other observations in completing my analysis of precipitation type and also rate".

Specific recommendations to the product developers:

- Reduce product latency to <60 minutes for all images.
- Explore improving the low snowfall rate detection efficiency. An increased false alarm rate may be acceptable if more low snowfall rate events were captured by the product.
- Investigate the ability to retrieve snowfall rates under colder surface temperature conditions. Specifically, Burlington, VT found the product difficult to use because their surface temperatures were so cold this season. Extending the capacity of the product to

colder surface temperatures will also enable use in areas like Alaska where radar coverage is very sparse and polar-orbiting satellites make more frequent overpasses.

References

Meng, H., B. Yan, R. Ferraro, C. Kongoli, 2012: Snowfall Rate Retrieval Using Passive Microwave Measurements. *12th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment*, Frascati, Italy, 5-9 March, 2012

Meng, H., B. Yan, R. Ferraro, C. Kongoli, Snowfall rate retrieval using AMSU/MHS measurements. *93rd AMS Annual Meeting*. Austin, TX, January 6-10, 2013.

Appendix A: Survey Questions

Regarding the training of products being evaluated, check all that apply for this particular event

- I used/referenced one of the Quick Guide sheets in the operations area
- I used/referenced the teletraining slides
- I consulted with a fellow forecaster for help
- I was able to interpret the product(s) based on previous training or experience
- I was NOT able to interpret the product(s) based on current training/knowledge, and need additional help.
- I have not had training on the product(s) yet.

Product Timeliness for Operations

Indicate the timeliness of product application for operations.

- Yes – the product was timely
- No - the product was not timely but was still useful for operations
- No - the product was not timely and was not useful for operations

Impact and Confidence

Rank the impact of the SFR product on the forecast process.

- Very Large
- Large
- Some
- Small
- Very Small

Rate your confidence level in the SFR values.

- High
- Medium
- Low

How did the NESDIS SFR product influence your forecast process (check all that apply)?

- It did not: the product was too latent for operations or otherwise not useful
- Influenced the issuance of or cancellation of a warning

- Influenced the issuance of a nowcast
- Mentioned in an AFD
- Included in a social media post
- Communicated the information by other means (phone, email, webinar, etc.)
- Other:

Product Utility

What was the utility of the SFR product in data-deprived regions, such as mountainous terrain and radar gaps?

- Very useful
- Useful
- Somewhat useful
- Not very useful
- Not useful at all
- I did not use the SFR product in a data-deprived region

What was the utility of the SFR product to track the areal coverage and snowfall maximum compared to GOES VIS/IR imagery?

- Very useful
- Useful
- Somewhat useful
- Not very useful
- Not useful at all
- I did not use the SFR product to track areal coverage and/or snowfall maximum

Comparison to Observations

Were the SFR values compared to ground-based observations to gauge the accuracy of the product?

- Yes (if "Yes" was answered, then the participant moved on to Parts 2 and 3)
- No

Comparison to Observations - Part 2

What was the time lag between the SFR and the best correlated ground snow observation?

- < 30 minutes

- 30-60 minutes
- 60-90 minutes
- 90 minutes
- Could not determine

Comparison to Observations - Part 3

What was the difference between the expected SFR from the product and the observed snowfall?

- SFR product significantly underestimated observed snowfall
- SFR product slightly underestimated observed snowfall
- SFR product got it right!
- SFR product slightly overestimated observed snowfall
- SFR product significantly overestimated observed snowfall

Precipitation Type

Were there any areas where the SFR misidentified the precipitation type (i.e., SFR product detected snow but observations indicated rain or vice versa)?

- No - I found that the SFR product identified greater than 75% of the precipitation correctly
- Yes - I found that the SFR product identified between 25 and 75% of the precipitation correctly
- Yes - I found that the SFR product identified less than 25% of the precipitation correctly