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SNOWFALL RATES FROM SATELLITE DATA HELP WEATHER FORECASTERS

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A red semi-truck is driving on a snowy road, splashing snow. The truck is moving from right to left, and a large cloud of snow is being kicked up behind it. The road is covered in a layer of snow, and the sky is overcast.

A new data product calculates snowfall rates from weather data beamed directly from several satellites, helping meteorologists provide fast, accurate weather reports and forecasts.

In the early morning hours of 28 January 2014, satellite data showed snow accumulating in the clouds over Birmingham, Ala., but weather forecasters predicted only a light dusting of snow for the day ahead. Over the course of the next several hours, snow began to fall—and kept on falling. Although the area got only a couple of inches of snow, it was enough to bring this southern city to a standstill. Commuters abandoned their cars on freeways and spent the night in office buildings and shopping centers. Children slept in classrooms and day care centers because their parents could not come to bring them home.

Rainfall rates derived from satellite data have a long legacy in operational weather forecasting because their information complements ground observations such as weather



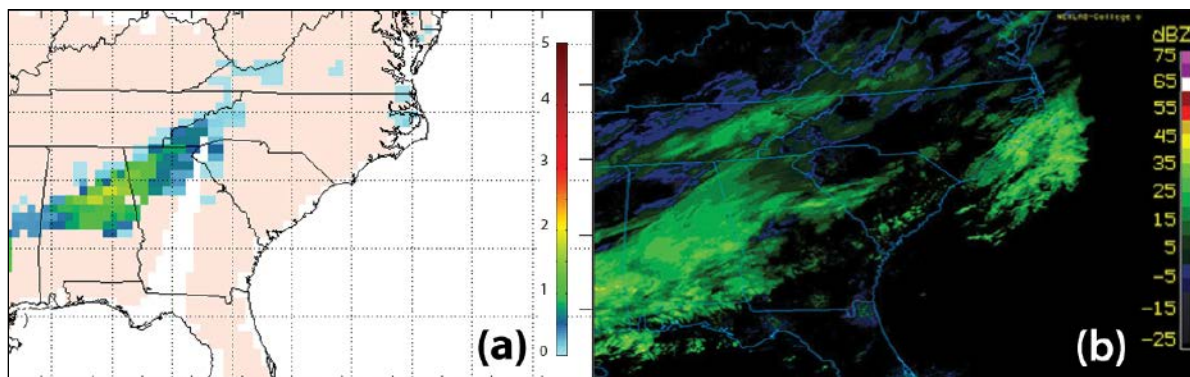


Fig. 1. Snowfall rate estimates for a 28 January 2014 storm that blanketed the southeastern United States. (a) Satellite snowfall rates captured by the SFR product at 11:19 a.m. and (b) the corresponding Next Generation Weather Radar (NEXRAD) composite radar reflectivity map. Credit: UCAR

radar and rain gauges. Satellite precipitation estimates also fill in voids where ground measurements are lacking, for example, in mountainous regions. Until recently, however, satellite-derived snowfall rates have been difficult to achieve because of the challenges in detecting and quantifying them from space.

Recently, our multiagency team of scientists developed an operational data product that uses satellite data to calculate snowfall rates (SFR) over land, stated as a water equivalent intensity (in millimeters per hour) at a satellite footprint diameter of approximately 15 kilometers on the ground (see Figures 1, 2, and 3). Previously, satellite data were downloaded in batches after the completion of each full orbit, creating about 2 hours of lag time between observations and data delivery. This new product, however, exploits direct broadcast (DB) capability from several satellites in low-Earth orbit that take microwave measurements over the continental United States and Alaska. These satellites send SFR measurements directly to ground-based receivers within 20–30 minutes of satellite observations.

These estimates aid National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) forecasters during snowfall events. Data-sparse forecast regions of the NWS like Alaska can benefit from using all available low-Earth-orbiting satellites and the DB capability to obtain regular, timely updates of the SFR.

The Need for Real-Time Snowfall Information

Snowstorms are among the most significant weather events, yet historically, accurately measuring snow has been challenging. Satellite snowfall retrievals can help fill in surface observational voids.

Falling snow can have significant economic impacts and can interrupt transportation on the ground and in the air. Major storms regularly cause disruptions over the course of several days in highly populated regions; however, even minor snowfall affects local commuting and highway travel, disrupting the commercial trucking industry.

The satellite maps that hinted at the impending “Snowpocalypse 2014” (see <http://bit.ly/snowpocalypse-2014>) are examples of data products. These maps rely on mathematical models that process raw data on the

amounts of microwave radiation that reach a variety of satellite sensors from cloud ice content and the land and ocean surfaces below. The maps display the relevant data (e.g., rainfall or snowfall rates) in a form that weather forecasters can interpret and use.

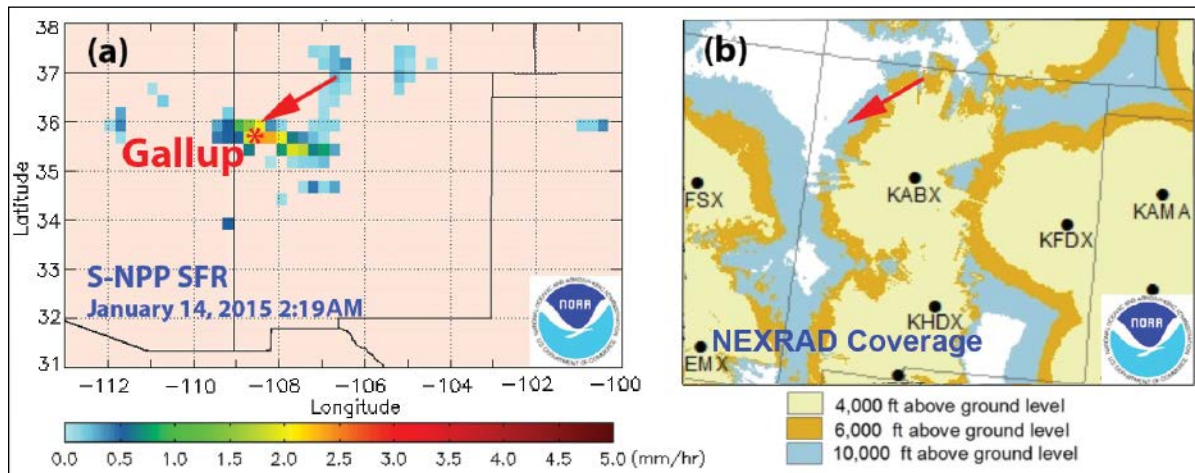
Geostationary satellites are capable of frequent infrared measurements, but these measurements correlate poorly with snowfall rates on the ground. Conversely, low-Earth-orbiting passive microwave measurements can reliably detect snowfall within clouds, but these observations are less frequent, and there is a longer lag between when the observations are made and when they are received at ground-based stations (data latency).

Product Motivation, Development, and Evolution

In 1998, the first advanced microwave sounding unit (AMSU-B) was placed into operation on board the NOAA-15 satellite. After several years of demonstrating the utility of AMSU-B for monitoring global rainfall [Ferraro *et al.*, 2005], many studies showed the potential for monitoring falling snow as well [e.g., Kongoli *et al.*, 2003; Skofronick-Jackson *et al.*, 2004]. The AMSU-B sensor was followed by the Microwave Humidity Sounder (MHS) on NOAA and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) satellites. The most recent instrument, the Advanced Technology Microwave Sounder (ATMS), flies on board the Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 satellites and the NASA Global Precipitation Measurement Microwave Imager (GMI).

All these sensors take measurements at critical frequencies at and above 85 gigahertz; sensors measure microwave emissions at 183 gigahertz, the signature frequency band emitted by water vapor, making it feasible to detect frozen hydrometeors (snow, ice, and the like) in the atmosphere. Earth’s surface is generally masked enough by atmospheric water vapor to isolate the 183-gigahertz signal associated with snow in the atmosphere from the signal at this frequency originating from snow on the ground [Kongoli *et al.*, 2015; Meng *et al.*, 2017].

The current operational SFR product was developed by scientists at NOAA and the National Environmental Satellite, Data, and Information Service (NESDIS), working in conjunction with training and product assessment special-



ists at NASA's Short-term Prediction Research and Transition (SPoRT) Center.

Product Assessment

To evaluate the usefulness of the SFR product for NWS forecast operations, NASA's SPoRT Center led product assessments in collaboration with NOAA algorithm developers at several NWS weather forecast offices from 2014 to 2016. Important feedback from the first winter season indicated that latency was a major factor limiting its application.

To solve the problem, the project team turned to DB data. With DB, a satellite can instantaneously transmit its observations to any ground station on Earth that has the appropriate antenna; most of the continental United

Fig. 2. (a) The Suomi NPP SFR data product captured a snowfall event in northwestern New Mexico on 14 January 2015 that was also observed at the local weather station at Gallup. (b) The white areas in the NEXRAD coverage map show that radar coverage is limited to nonexistent in this area (indicated by the red arrow).

States, Alaska, and Hawaii are equipped with such ground stations. Compared with the standard operational delivery options (batch downloads delivered to a few designated ground stations after the completion of each 100-minute orbit), DB of the data from the satellite to the user reduces the latency time by about 1 hour.

The SFR project team retrieves the DB data, generates the SFR product, and sends the SFR data to SPoRT for

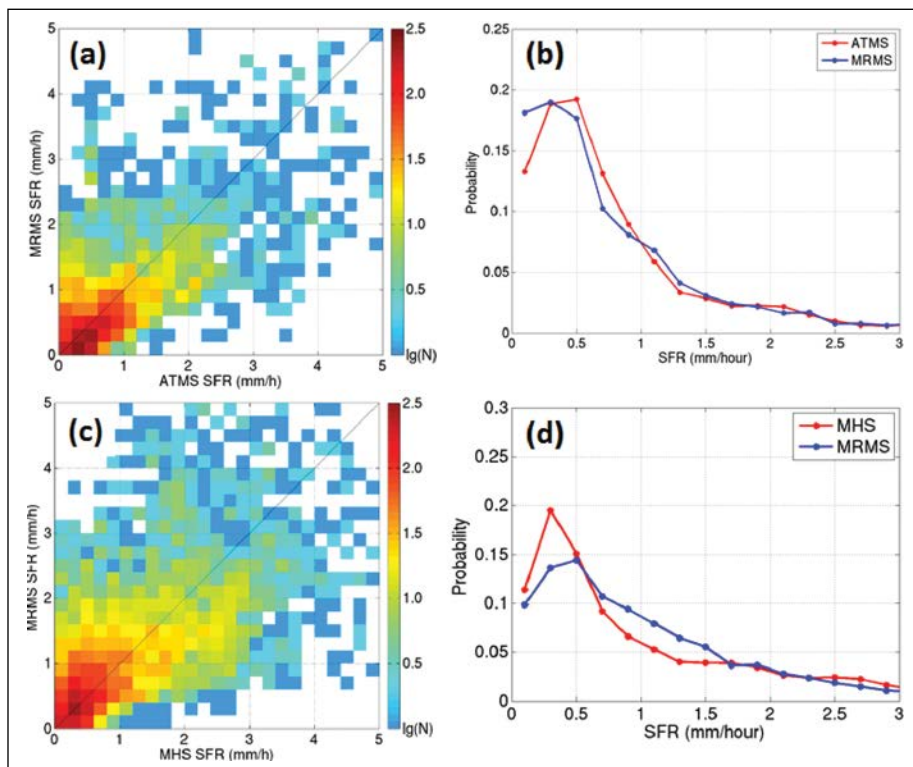


Fig. 3. SFR data product performance for the 14 March 2017 nor'easter on the U.S. East Coast. (a) Comparison of snowfall rates calculated using Advanced Technology Microwave Sounder (ATMS) data and the SFR product with those calculated using Multi-Radar Multi-Sensor (MRMS) radar precipitation data and (b) comparison between ATMS SFR and MRMS probability distribution functions. (c) A similar comparison between MHS SFR rates and MRMS radar precipitation data and (d) the corresponding probability distribution functions. The ATMS SFR performs slightly better than the MHS SFR: Note the smaller spread in the scatter-plots (Figure 3a versus Figure 3c) and the better fit of the SFR distributions (Figure 3b versus Figure 3d).

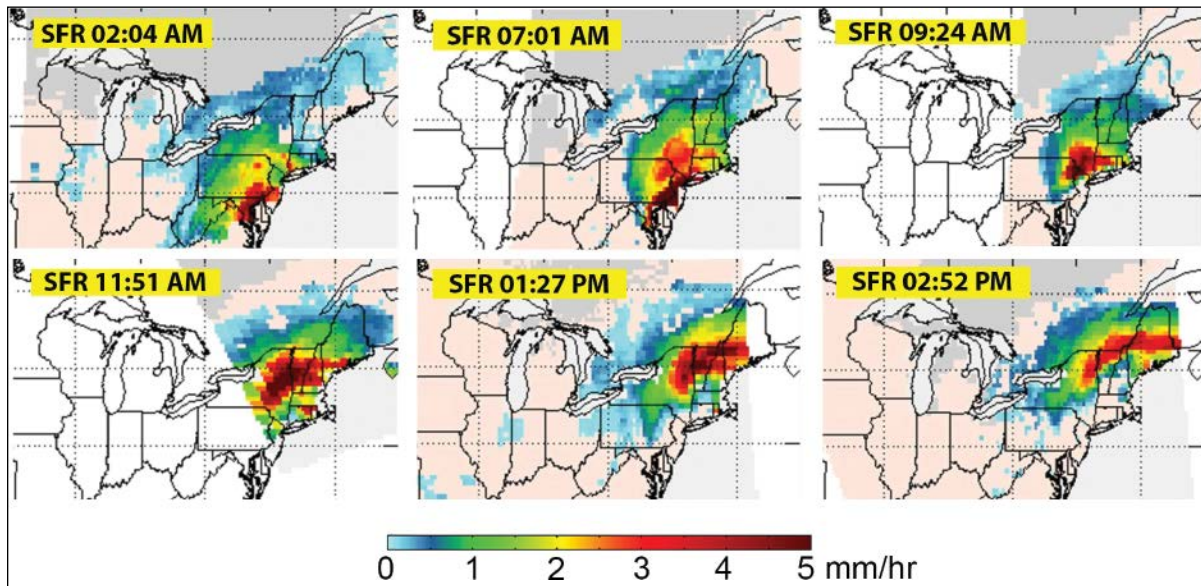


Fig. 4. SFR time series showing the evolution of the 14 March 2017 nor'easter. The scale indicates the water equivalent of the SFR, ranging between 0 and 5 millimeters per hour. Satellite data were obtained from the areas shaded in pink; no data were available from the white areas.

reformatting within 30 minutes of satellite observations. SPoRT then delivers the resulting imagery to the weather forecast offices. SFR developers at NOAA and NASA also maintain web pages where SFR images are posted in near-real time (see <http://bit.ly/NOAA-SFR> and <https://go.nasa.gov/2K0Ixn6>).

Testing the SFR Product in Albuquerque, N.M.

The SFR product provides a unique, space-based perspective from which to easily identify the extent of a snowstorm, the location of the most intense snowfall, and the rain-snow boundary. These features are not generally apparent from traditional satellite imagery or surface radar.

On 14 January 2015, the Albuquerque weather forecast office used the SFR product near the northwestern New Mexico town of Gallup, an area with very limited radar coverage. Feedback from this office indicated that the 2:19 a.m. Suomi NPP SFR image (Figure 2) matched ground-based observations better than did the precipitation forecast from the North American Mesoscale Forecast System (NAM), a NOAA weather forecast model, within this data-sparse region.

The NWS Albuquerque forecaster said, "From this information I was able to determine [that] the NAM forecast was too slow with the evolution of the precipitation. The radar values dropped off away from the KABX [Albuquerque] radar, which is expected, whereas the SFR product increased in the area of heaviest snowfall. Rates were close to the observed value at KGUP (Gallup)."

Ground observations also included information from the web page for the New Mexico Department of Transportation (<http://bit.ly/NM-roads>), which showed difficult driving conditions within this region. Although New Mexico is not a very densely populated state, the commercial trucking industry relies heavily on its interstate highways. Thus,

knowing the likelihood of snow-covered conditions or active falling snow (which reduces visibility) in remote areas is vital to the NWS for issuing travel advisories.

SFR Product Maps the March 2017 Nor'easter

A major nor'easter (a storm that blows in from the northeast) swept over the U.S. East Coast on 14–15 March 2017. The SFR product retrieved data from five satellites to capture the evolution of the snowstorm. Comparison of the SFR data with Multi-Radar Multi-Sensor (MRMS; <http://bit.ly/NOAA-MRMS>) radar precipitation data produced by NOAA [Zhang *et al.*, 2016] yielded strong correlations and low bias.

These results create confidence in the reliability of the SFR in other regions where radar observations are limited. Figure 3 shows scatterplots and probability distributions of ATMS and MHS SFR compared to MRMS. Because the ATMS sensor has a fuller set of channel complements at the 183-gigahertz water vapor band, it performs slightly better than the SFR from MHS. Figure 4 provides a series of satellite SFR images, showing the progression of the snowfall rates during the storm.

Meeting the Snowfall Rate Challenge

Snowfall is an important weather element, yet it is challenging to measure accurately and consistently, especially because ground measurements are limited in many regions. By exploiting DB data from low-Earth-orbiting satellites, an operational snowfall rate product can play an important role in providing timely observations for improved situational awareness, short-term forecasts, warnings, and verification in these regions. Operational weather forecasters have provided valuable feedback on the product's strengths and limitations, and this feedback has led to substantial improvements to the algorithm over the past several years [Meng *et al.*, 2017].

In the near term, SFR algorithms for the Global Precipitation Measurement Microwave Imager and the Defense Meteorological Satellite Program's Special Sensor Microwave Imager Sounder are undergoing final evaluation and will be ready for the 2018–2019 winter season, further improving the temporal coverage of the product. Within the next 3 years, we will focus on extending the algorithm to offshore retrievals. Radars in these areas have limited range but are important to weather forecasts as active areas of snow approach, then move over land.

Acknowledgments

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References

Ferraro, R. R., et al. (2005), NOAA operational hydrological products derived from the AMSU, *IEEE Trans. Geosci. Remote Sens.*, 43, 1,036–1,049, <https://doi.org/10.1109/TGRS.2004.843249>.

- Kongoli, C., et al. (2003), A new snowfall detection algorithm over land using measurements from the Advanced Microwave Sounding Unit (AMSU), *Geophys. Res. Lett.*, 30(14), 1756, <https://doi.org/10.1029/2003GL017177>.
- Kongoli, C., et al. (2015), A snowfall detection algorithm over land utilizing high-frequency passive microwave measurements—Application to ATMS, *J. Geophys. Res. Atmos.*, 120, 1,918–1,932, <https://doi.org/10.1002/2014JD022427>.
- Meng, H., et al. (2017), A 1DVAR-based snowfall rate retrieval algorithm for passive microwave radiometers, *J. Geophys. Res. Atmos.*, 122, 6,520–6,540, <https://doi.org/10.1002/2016JD026325>.
- Skofronick-Jackson, G., et al. (2004), A physical model to determine snowfall over land by microwave radiometry, *IEEE Trans. Geosci. Remote Sens.*, 42, 1,047–1,058, <https://doi.org/10.1109/TGRS.2004.825585>.
- Zhang, J., et al. (2016), Multi-Radar Multi-Sensor (MRMS) quantitative precipitation estimation: Initial operating capabilities, *Bull. Am. Meteorol. Soc.*, 97, 621–638, <https://doi.org/10.1175/BAMS-D-14-00174.1>.

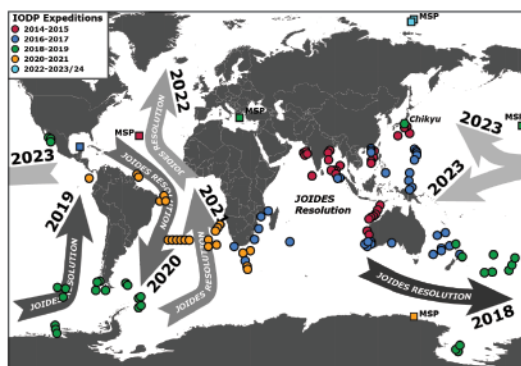
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CALL FOR PROPOSALS Scientific Ocean Drilling



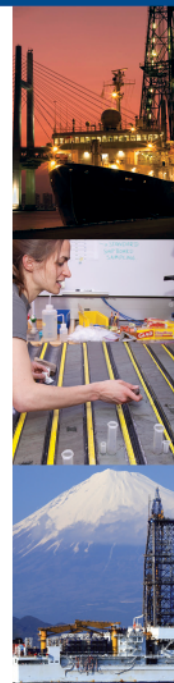
The International Ocean Discovery Program (IODP) explores Earth's climate history, structure, mantle/crust dynamics, natural hazards, and deep biosphere as described at www.iodp.org/science-plan. IODP facilitates international and interdisciplinary research on transformative and societally relevant topics using the ocean drilling, coring, and down-hole measurement facilities *JOIDES Resolution* (JR), *Chikyu*, and *Mission-Specific Platforms* (MSP). **All three IODP facilities are now encouraging new proposals.**



MSP expeditions are planned to operate once per year on average to recover core from targets that are generally inaccessible by JR and Chikyu. MSP proposals for any ocean are welcomed. To encourage exciting Chikyu expeditions in the future, new pre-proposals for both riser and non-riser Chikyu operations will be considered.

The JR is currently scheduled into early 2021 (iodp.tamu.edu/scienceops). The JR is expected to operate in the Equatorial and North Atlantic, Gulf of Mexico, Mediterranean, Caribbean, and the Arctic in 2021 and 2022, and to complete its circumnavigation with a return to the Indo-Pacific region by 2023. Proposals for these future operational areas are strongly encouraged.

Investigators are reminded that the interval from the first proposal submission to expedition scheduling is on the order of 4–5 years due to the science and safety review process and required lead time for scheduling. We also invite proposals that involve drilling on land and at sea through coordination with the International Continental Drilling Program (ICDP). Submission information can be found at www.iodp.org/submitting-proposals.



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