

# RAPID REFRESH INFORMATION OF SIGNIFICANT EVENTS

## Preparing Users For the Next Generation of Geostationary Operational Satellites

BY TIMOTHY J. SCHMIT, STEVEN J. GOODMAN, MATHEW M. GUNSHOR, JUSTIN SIEGLAFF, ANDREW K. HEIDINGER, A. SCOTT BACHMEIER, SCOTT S. LINDSTROM, AMANDA TERBORG, JOLEEN FELTZ, KABA BAH, SCOTT RUDLOSKY, DANIEL T. LINDSEY, ROBERT M. RABIN, AND CHRISTOPHER C. SCHMIDT

The *GOES-14* imager collected experimental rapid-scan 1-min data that emulated the high temporal resolution possible from the imager on the next-generation GOES-R series.

**T**his paper introduces unique high-temporal-resolution datasets, collected from a current geostationary imager, that are being used to

highlight future geostationary imager capabilities and are used as part of a Proving Ground project (Goodman et al. 2012; Ralph et al. 2013). All of the special *Geostationary Operational Environmental Satellite-14 (GOES-14)* GOES Variable (GVAR) rapid scan data have been archived, by the Comprehensive Large Array-data Stewardship System (CLASS), the Space Science and Engineering Center (SSEC) Data Center, or others. With many of the international geostationary satellite providers deploying advanced imagers beginning in 2015 (generally offering full disk coverage every 10 min and smaller mesoscale sectors every 2.5 min), these special *GOES-14* data can be used to research the benefits of higher-time-resolution information. This paper provides an overview of the data and showcases how the information can be used in real-world applications.

There are two scan modes envisioned from the Advanced Baseline Imager (ABI) included on the next-generation GOES-R series satellites (Schmit et al. 2005). The first is the “flex” mode consisting of full disk scans every 15 min, plus contiguous U.S. (CONUS) images every 5 min and two mesoscale (nominally 1,000 km by 1,000 km, at the satellite subpoint) images every minute. The second mode,

**AFFILIATIONS:** SCHMIT AND HEIDINGER—Advanced Satellite Products Branch, NOAA/Center for Satellite Applications and Research, Madison, Wisconsin; GOODMAN—GOES-R Program Office, NOAA/NESDIS, Greenbelt, Maryland; GUNSHOR, SIEGFALL, BACHMEIER, LINDSTROM, TERBORG, FELTZ, BAH, AND SCHMIDT—Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin—Madison, Madison, Wisconsin; RUDLOSKY—NOAA/Center for Satellite Applications and Research, College Park, Maryland; LINDSEY—NOAA/Center for Satellite Applications and Research, Fort Collins, Colorado; RABIN—NOAA/NSSL, Norman, Oklahoma

**CORRESPONDING AUTHOR:** Timothy J. Schmit, Advanced Satellite Products Branch, NOAA/Center for Satellite Applications and Research, 1225 West Dayton Street, Madison, WI 53706  
E-mail: tim.j.schmit@noaa.gov

The abstract for this article can be found in this issue, following the table of contents.

DOI:10.1175/BAMS-D-13-00210.1

A supplement to this article is available online (10.1175/BAMS-D-13-00210.2)

In final form 1 August 2014  
©2015 American Meteorological Society

continuous full disk (CFD), consists of sequential full disk scans every 5 min. Strong convection with active overshooting tops can evolve rapidly; therefore, 5-min scans could miss key periods of the cold signature as an overshooting top (OST) ascends, peaks, and begins to collapse. This could cause aliasing in the brightness temperature rate of change estimations. For example, during a 20 July 1986 microburst-producing storm in northern Alabama, a research dual-polarization radar observed rapid glaciation in less than 2.5 min. In fact, this same storm evolved from no total lightning to its peak lightning rate in just 7 min (Goodman et al. 1988; Gatlin and Goodman 2010).

Given that the ABI will scan the CONUS region every 5 min with either mode, the question becomes whether 5-min data are needed outside of CONUS on a routine basis over a large area, versus more frequent images of certain regions offered by the flex mode. The flex mode is one example of the “targeted observations” concept, outlined during The Observing System Research and Predictability Experiment (THORPEX;

Shapiro and Thorpe 2004). A targeted observation means taking more observations in regions of interest. In this scheme, data collection regions could be assigned weight based on many factors, including a region’s criticality to safety and commerce; the need for repeated rapid scans to reduce model uncertainty; the need for monitoring convection because of tropical cyclone activity; or the presence of any other significant, rapidly changing event such as convection. The improved spectral, temporal, and spatial capabilities of the ABI will provide many improved products (see sidebar on GOES-R series ABI baseline products). For example, the number of bands increases from 5 to 16, the coverage rate improves by a factor of 5, and the spatial resolution improves by a factor of 4 (2 in each direction) (Schmit et al. 2005).

**SRSOR OVERVIEW.** The *GOES-14* imager was operated by the National Oceanic and Atmospheric Administration (NOAA) in an experimental rapid scan 1-min mode during parts of 2012 and 2013 while the satellite was in its normal annual north/south maneuver and performance testing. This scan mode, known as the super rapid scan operations for GOES-R (SRSOR), emulated the high-temporal-resolution sampling of the mesoscale images from the ABI included on the next-generation GOES-R series (Schmit et al. 2005). This paper both introduces these unique datasets and highlights future satellite imager capabilities. The GOES-R also will carry the first Geostationary Lightning Mapper (GLM), which will monitor total lightning activity (Goodman et al. 2013) and, among many other uses, complement the ABI information in regions of overlap. GOES-R is slated to launch in early 2016. Many phenomena were observed from *GOES-14* during this experiment at unprecedented temporal resolution, including fog, clouds, severe storms, monsoon moisture, fires and smoke (including the California Rim Fire), and several tropical cyclones. These data help prepare users for the next-generation GOES-R imager, which will be able to routinely capture mesoscale (1,000 km × 1,000 km) images every 30 s over one location (or every minute over two separate locations).

The various *GOES-East* schedules—routine, rapid scan operations (RSO),

## BASELINE PRODUCTS FROM THE GOES-R SERIES ABI

**B**aseline products are those that are funded for initial operational implementation as part of the ground segment base contract. Not all products will be produced from the mesoscale scans. More information can be found online (at [www.goes-r.gov/](http://www.goes-r.gov/)).

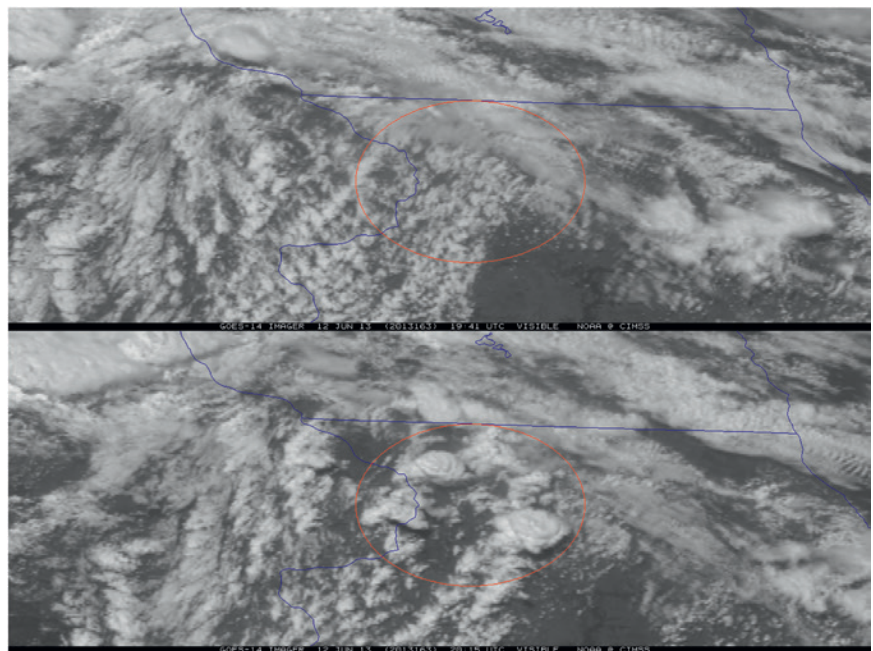
- Aerosol detection (including smoke and dust)
- Aerosol optical depth (AOD)
- Clear sky mask (cloud mask)
- Cloud and moisture imagery
- Cloud optical depth
- Cloud particle size distribution
- Cloud-top height
- Cloud-top phase
- Cloud-top pressure
- Cloud-top temperature
- Derived motion winds
- Derived stability indices
- Downward shortwave radiation: surface
- Fire/hot spot characterization
- Hurricane intensity estimation
- Land surface temperature (skin)
- Legacy vertical moisture profile
- Legacy vertical temperature profile
- Radiances
- Rainfall rate/QPE
- Reflected shortwave radiation: top of atmosphere (TOA)
- Sea surface temperature (skin)
- Snow cover
- Total precipitable water
- Volcanic ash: detection and height

**TABLE 1. Comparison of GOES-East imager schedules, including routine, RSO, SRSO, SRSOR, and GOES-R ABI. The approximate number of images over 3 hours is also listed. The sectors scanned are as follows: full disk (FD), Northern Hemisphere extended (NHE), Northern Hemisphere (NH), contiguous United States (CONUS), Southern Hemisphere (SH), South America (SA), and a mesoscale-sized image (MESO).**

	Routine	RSO	SRSO	SRSOR	SRSOR (no FD)	GOES-R ABI
No. of images (in 3 h)	16	26	56	129	157	~400
No. of images covering part of CONUS (in 3 h)	11	21	56	129	157	~400
Finest refresh time (min)	15	5	1	1	1	0.5
Second slowest refresh rate (min)	15	10	10	4	4	5
Slowest refresh rate (min)	30	30	30	30	15	15
Sectors scanned (listed by size)	FD, NHE, CONUS, SH	FD, NH, CONUS, SA	FD, NH, CONUS, MESO	FD, MESO	FD, MESO	FD, CONUS, MESO

super rapid scan operations (SRSO), SRSOR, and that expected from the ABI on the GOES-R series—are summarized in Table 1. Note that there are two versions of the SRSOR schedule, one with full disk imaging every 3 h and one without. The SRSOR data from August 2013 ran the latter schedule. The area near the middle of the image over northwestern Illinois in Fig. 1 demonstrates how much convection can change over only 34 min, underscoring the need for the geostationary vantage point to observe rapidly changing phenomena.

In 2012 the *GOES-14* instrument scanned images to collect data needed for the imager stray light correction, which allowed the experimental SRSOR imagery to be acquired during other times of the day (away from satellite midnight). The SRSOR campaign of 2012 included approximately 38 days of SRSOR data. In fact, over six days of SRSOR data of Hurricane Sandy were acquired in late October (Schmit et al. 2013). The SRSOR experimental data were used in a number of NOAA test beds and operational centers, including at NOAA’s Storm Prediction Center (SPC), Aviation Weather Center (AWC), Weather Prediction Center (WPC), Ocean



**FIG. 1. GOES-14 visible image on 12 Jun 2013 showing rapid convective development forming over approximately 30 min in northwest Illinois. Note the three convective storms within the circle that developed during this short time frame.**

Prediction Center (OPC), and National Hurricane Center (NHC). Many operational uses for these data were noted: “Examples from the SRSOR data included better determining the cyclone center early in the daylight hours by the NHC, improved monitoring of cumulus cloud fields prior to convective initiation by the SPC, utilizing the imagery animations and derived Atmospheric Motion Vectors (AMV) by the OPC, to better assess the rainfall potential by the WPC, monitoring smoke plumes by the Satellite Analysis Branch, and overshooting tops (OT) detection by the

forecast offices” (Schmit et al. 2013, p. 16). Schmit et al. (2013) summarized the daily schedule during 2012, while this paper summarizes the data collected during parts of 2013. The cases highlighted from 2013 include convection, biomass burning, and hurricanes (including Hurricane Sandy), whereas this paper includes 1-min imagery of a derecho, fog, convection, and the California Rim Fire.

The SRSOR campaign of 2013 included approximately 14 days of SRSOR data. See Table 2 for schedule and daily image center point information; the *GOES-14* subpoint was 105°W. Daily center point decisions were based on a number of factors, including SPC and NHC outlooks, regions with other observations to compare to, and whether the region had been recently scanned. On several days, the location was chosen in part to coincide with other observations from a National Aeronautics and Space Administration (NASA) field experiment called Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC4RS) and ground-based lightning mapping networks providing GLM total lightning proxy data. In June 2013, the first two days of SRSOR observed

a mid-Atlantic derecho, defined by the American Meteorological Society (2014) as “a widespread convectively induced straight-line windstorm...any family of downburst clusters produced by an extratropical mesoscale convective system.” This event occurred just days after the 11-day period when *GOES-14* had operated as the *GOES-East*. *GOES-13* had experienced a major anomaly, possibly because of a collision with a micrometeoroid (Butler 2013). The data from August 2013 were unique since the GOES imager operated in nearly continuous 1-min mode. For the first time, 30-min outages were eliminated and 1-min data collection continued during periods of previous full disk scans every 3 h.

The SRSOR data provided enhanced situational awareness of an “outflow boundary and nearby frontal zone which was not readily apparent in the scant surface data” (WPC Met Watch forecaster 2013, personal communication). Forecasters reported the 1-min imagery “helped to increase lead-time for convective development” and “more easily determine whether convection was elevated or rooted in the boundary layer” (SPC forecasters 2013, personal communication). They also stated that it “could be

**TABLE 2. Starting day (with ordinal day number), schedules, start times, and location with SRSOR from GOES-14 during 2013.**

Starting date (year/day)	Schedule	Starting time	Center point	Comments
12 Jun (163)	SRSOR	1614:30 UTC	37°N, 85°W	Moderate risk over IL, IN, OH
13 Jun (164)	SRSOR	1144:30 UTC	36°N, 84°W	Moderate risk over MD, DE, etc.
13 Aug (225)	SRSOR (no FD)	1114:30 UTC	39°N, 115°W	Pacific NW fires, etc.
14 Aug (226)	SRSOR (no FD)	1114:30 UTC	37°N, 85°W	Southeast U.S. E/W maneuver ~1220–1230 UTC
15 Aug (227)	SRSOR (no FD)	1114:30 UTC	32°N, 85°W	Global Hawk (GH) ferry flight and Gulf of Mexico convection
19 Aug (231)	SRSOR (no FD)	1114:30 UTC	39°N, 115°W	West Coast, northwest fires, etc.
20 Aug (232)	SRSOR (no FD)	1114:30 UTC	37°N, 84°W	Southeast United States, GH takeoff, AWC support, etc.
21 Aug (233)	SRSOR (no FD)	1114:30 UTC	39°N, 93°W	Slight risk over MN
22 Aug (234)	SRSOR (no FD)	1114:30 UTC	39°N, 115°W	Western United States, fires, etc.
23 Aug (235)	SRSOR (no FD)	1114:30 UTC	35°N, 91°W	SEAC4RS field experiment
24 Aug (236)	SRSOR (no FD)	1114:30 UTC	39°N, 98°W	Northern plains, slight risk
25 Aug (237)	SRSOR (no FD)	1114:30 UTC	37°N, 113°W	Monsoon convection over southwest United States
26 Aug (238)	SRSOR (no FD)	1114:30 UTC	40°N, 96°W	Convection over upper Midwest
27 Aug (239)	SRSOR (no FD)	1114:30 UTC	39°N, 115°W	West Coast: Monsoon, SEAC4RS flights, etc.
28 Aug (240)	Schedule tests	1114:30 UTC	39°N, 115°W	Optimized super rapid scan
28 Aug (240)	Schedule tests	1414:30 UTC	—	Optimized rapid scan

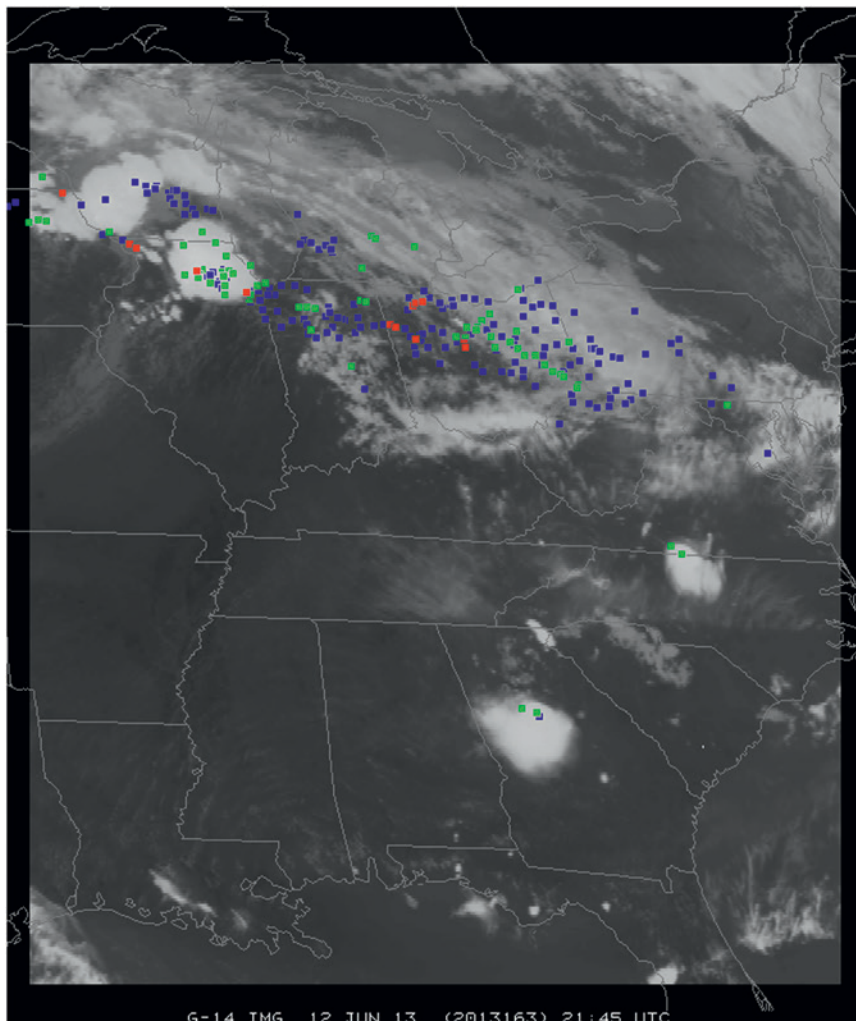


helpful in radar gap areas, and where there is less confidence in radar.” Several animations are included to showcase the rapid change of the many phenomena observed during SRSOR from the *GOES-14* imager.

The recent SRSOR imagery continues the long legacy of rapid scan imagery from GOES, as stated by Davis (2007, p. 10): “Rapid interval imaging has been an important component of the GOES research program since 1975. In 1979 during the Severe Environmental Storm and Mesoscale Experiment (SESAME) two GOES satellites were synchronized to produce three minute interval rapid scan imagery to study storm development.” Previously, T. Fujita and others demonstrated the many uses of these data (Purdum 1976).

### DERECHO EVENTS OF 12 AND 13 JUNE 2013

The *GOES-14* satellite was placed into SRSOR mode to monitor the development of severe weather over a SPC high risk region on 12 June 2013. In SRSOR mode, images were available at approximately 1-min intervals (compared to the routine 15-min image interval). The development of numerous large thunderstorms can be seen on *GOES-14* SRSOR 0.63- $\mu\text{m}$  visible channel images. These storms produced tornadoes, large hail, and damaging winds across parts of Minnesota, Iowa, Wisconsin, and Illinois according to NOAA SPC storm reports. One item of interest revealed by the 1-min imagery was the appearance of “inflow feeder band” clouds (Weaver and Lindsey 2004) that developed along the western edge of a large thunderstorm which was located over northeastern Iowa from 2015 to 2058 UTC; the 1-min temporal resolution allows for improved detection of subtle mesoscale features, compared with conventional 15-min imagery.



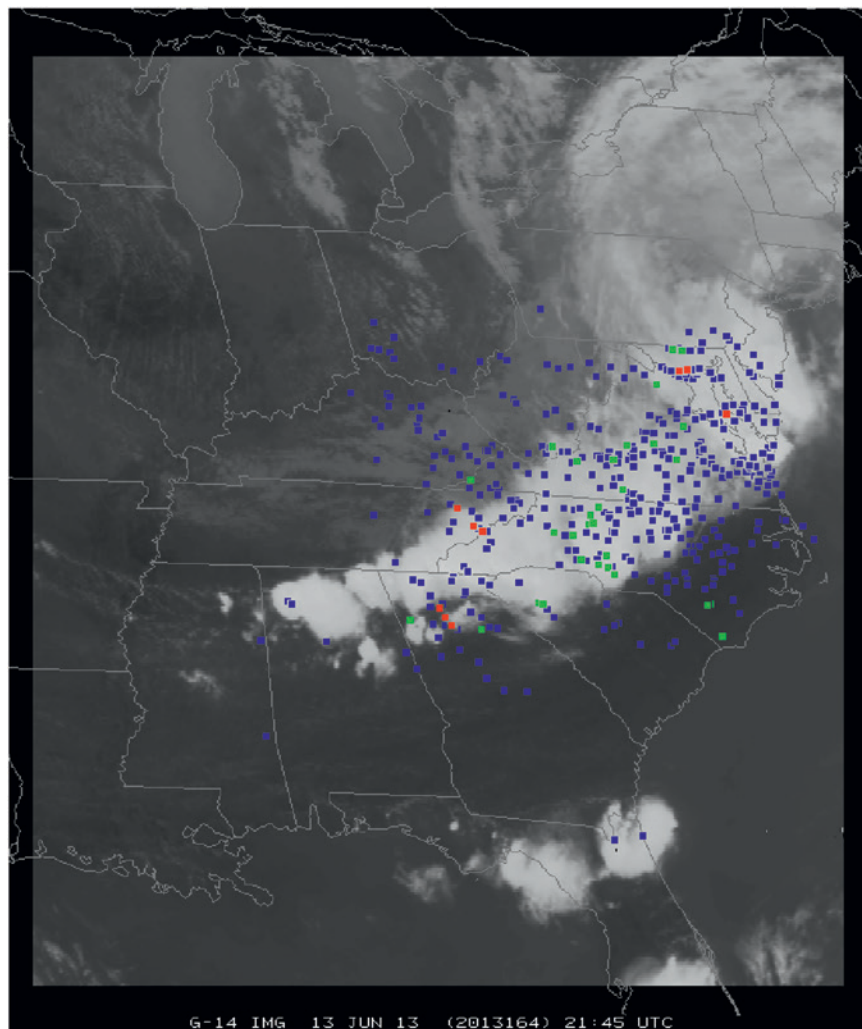
**FIG. 2.** A demonstration of the *GOES-14* SRSOR coverage (12 Jun 2013) in 1-min mode, with the day’s (1200–1200 UTC) severe weather reports plotted (the colors indicate the type, where tornado reports are plotted in red, hail is in green, and winds are in blue). The satellite image is of the 10.7- $\mu\text{m}$  longwave window (*GOES* imager band 4).

Numerous overshooting tops could also be seen on some larger storms. The plotted (preliminary) reports follow the SPC time range convention of 1200 UTC on the preceding day to 1200 UTC on the given day (Figs. 2 and 3 for 12 and 13 June, respectively). The severe weather reports from NOAA’s SPC are overplotted, showing the active weather associated with a derecho. Tornado reports are plotted in red, hail is in green, and winds [greater or equal to 50 kt (25.8  $\text{m s}^{-1}$ ) or wind damage] are in blue; note that these reports have been parallax corrected to be consistent with the satellite view (Davenport and Kuligowski 2008). These figures also show the coverage each minute from the current *GOES* imager in SRSOR mode.

To simulate the future GLM, the Washington D.C. Lightning Mapping Array (DCLMA), which is one of

the few regional multistation [very high frequency (VHF)] total lightning mapping networks and provides detailed 3D lightning observations, was used. Knowledge of rapidly changing lightning patterns in developing storms enhances the situational awareness of forecasters and helps inform decision makers regarding severe weather and lightning threats. These lightning channel VHF source data have been resampled to the GLM nadir pixel resolution of 8 km to produce a pseudo-GLM flash extent density grid updated every minute (Goodman et al. 2012; Stano et al. 2014). The flash extent density product is then combined with *GOES-14* visible SRSOR information to illustrate a potential new blended product that could be provided to weather forecasters and broadcast meteorologists in the GOES-R era (Fig. 4). Recent studies have shown that rapidly increasing lightning flash rates (colloquially known as “lightning jumps”) often precede severe winds, hail, and tornadoes (Schultz et al. 2009, 2011). Lightning jumps are evident ~20 min prior to each of the tornadoes shown in Fig. 4, and frequent lightning flashes persist throughout the duration of both tornadoes. The *GOES-14* and DCLMA image is complemented by an animation (Video1) in the online supplement for this article and a larger *GOES-14* visible satellite-only view (Video2) is also available in the online supplement (available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>).

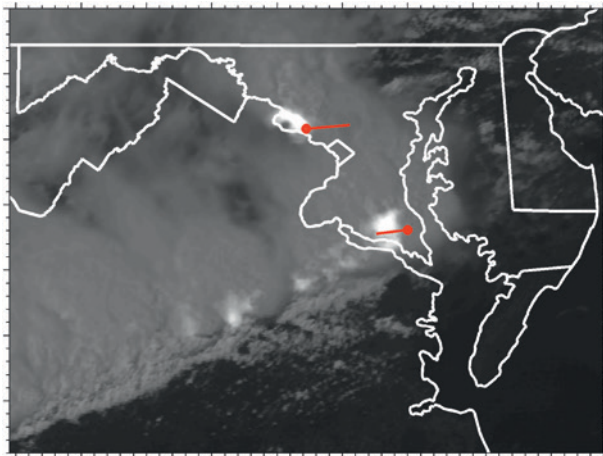
**FOG OVER PENNSYLVANIA ON 20 AUGUST 2013.** While fog may not change rapidly, finer-time-resolution imagery may provide faster, more accurate detection or a better understanding



**FIG. 3. A demonstration of the *GOES-14* SRSOR coverage (13 Jun 2013) in 1-min mode, with the day’s (1200–1200 UTC) severe weather reports plotted (the colors indicate the type, where tornado reports are plotted in red, hail is in green, and winds are in blue). The satellite image is of the 10.7- $\mu\text{m}$  longwave window (*GOES* imager band 4).**

of fog formation and dissipation. More frequent images increase confidence in the products by better capturing changes. Time delays can be critical when detecting fog that may affect surface transportation, such as fog in river valleys or at airports. A combination of the infrared bands (along with other data) can be used to detect fog and low stratus at night. From the 2013 SRSOR data, valley fog was clearly evident in the *GOES* imager visible band over Pennsylvania on 20 August 2013 (Fig. 5). The *GOES-14* image of low cloud and fog referenced in the text is complemented by an animation (Video3) in the online supplement for this article (available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>). This animation shows the improved temporal resolution possible from the ABI on *GOES-R*.





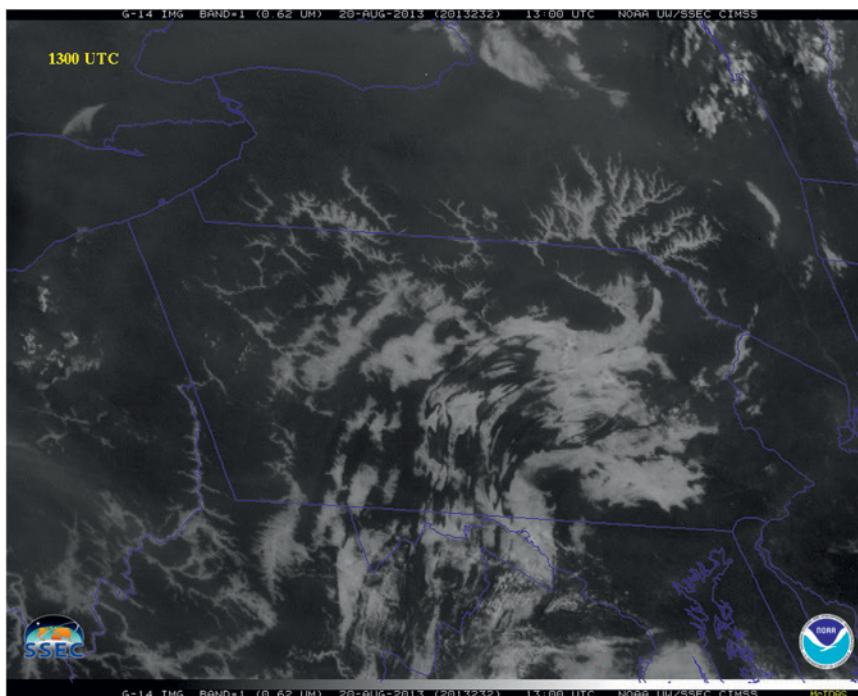
**FIG. 4. Visible GOES-14 SRSOR imagery blended with DCLMA lightning observations to illustrate a potential new GOES-R product. Red lines indicate the paths of two F-0 tornadoes, and the red circles illustrate their estimated locations at 1941 UTC 13 Jun 2013 (animation available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>).**

### SEVERE CONVECTION OVER THE MIDWEST ON 21 AUGUST 2013.

A cold front moving through Wisconsin triggered severe convection (NOAA SPC storm reports of wind and hail) on 21 August 2013. *GOES-14* SRSOR data provided a compelling look at the convective development at 1-min intervals. The cloud-top cooling (CTC) product developed for GOES/GOES-R at the University of Wisconsin (UW) provides an estimate of the cooling rate of the cloud tops to give better situational awareness (Dworak et al. 2012; Sieglaff et al. 2013, 2014; Cintineo et al. 2013). Figure 6 shows the *GOES-14* visible band and CTC product on 21 August 2013. The figure illustrates the importance of timing in detecting rapidly cooling (vertically growing) convection with both the SRSOR and routine GOES imager operations. The *GOES-14* image of CTC complemented by an animation (Video4) is in the online supplement for this article. An animation (Video5)

of the *GOES-14* visible images with SPC (parallax corrected) storm reports is also available in the online supplement (<http://dx.doi.org/10.1175/BAMS-D-13-00210.2>). This animation over northwestern Wisconsin is shown with imagery spaced approximately 1, 5, and 15 min apart. Additionally, the ability to scan in intervals as small as 1 min may be necessary to more accurately diagnose physical processes within deep convection. Cintineo et al. (2013) demonstrated using *GOES-14* SRSOR data that infrared cloud-top brightness temperatures can cool substantially within minutes and even 5-min scanning intervals can underrepresent the actual vertical growth and associated cloud-top cooling.

These data were a valuable resource as they also coincided with the third annual Summer Experiment at the Aviation Weather Testbed (AWT) in Kansas City, Missouri, which took place 12–23 August 2013. The AWT had a twofold purpose: 1) provide a preoperational environment in which to test and evaluate new GOES-R proxy products and 2) aid in familiarizing forecasters with the capabilities of the next-generation GOES series. The goal with the SRSOR information was to familiarize forecasters with the temporal latency expected with the GOES-R ABI in its mesoscale mode and how it will benefit operations. Participation included 14 operational forecasters from the AWC, as well as 44 visitors. These visitors represented various organizations throughout the aviation community

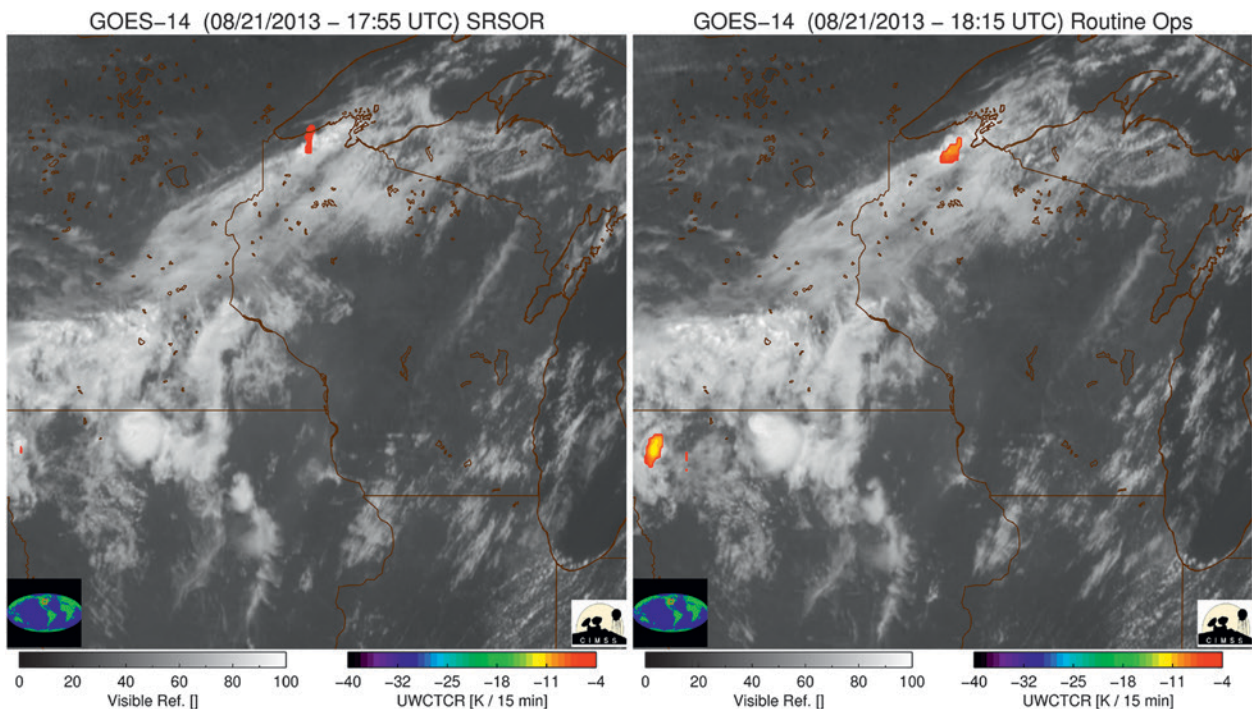


**FIG. 5. Enhanced GOES-14 visible image of fog and low stratus at 1300 UTC 20 Aug 2013 (animation available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>).**

which included government personnel, commercial entities, and aviation research interests. For example, participants came from the Federal Aviation Administration (FAA), Lockheed Martin, United Parcel Service (UPS), the Air Force Weather Agency (AFWA), the GOES-R program, Earth Networks, various research entities within NOAA, and numerous universities. Operational forecasting desks with real-time nowcasting responsibilities such as the Convective Significant Meteorological Information (CSIG) and National Aviation Meteorologist (NAM) desks consistently used the 1-min imagery as a situational awareness tool. These forecasters were able to identify details missed in the typical 15-min latency of current GOES. An excellent example of this was noted in association with convective development around the area known as the Minneapolis Air Route Traffic Control Center (identified by the circle in Fig. 7). Participants used the 1-min imagery to monitor the convective development to the northeast. In particular, the growth of the southwestern-most cell closest to Minneapolis was evident in the SRSOR information, especially the rapid expansion of the anvil as it began to impede the airspace above the center. This additional detail will provide air traffic managers and aviation forecasters a more accurate picture of the growth rate or dissipation of convection and thus allow for more efficient and

safer air traffic control. Forecasters were very pleased with the SRSOR imagery overall and eagerly anticipate it in operations on a permanent basis come the launch and operation of GOES-R.

For the same case Fig. 8 shows an analysis performed using the GOES-R Algorithm Working Group (AWG) cloud height algorithm (ACHA) products (Heidinger and Pavolonis 2009) generated from 1-min GOES-14 SRSOR data. The top panels show a broad view of the ACHA cloud-top temperature product at 2000, 2100, and 2200 UTC. The bottom panel shows times series from both the satellite (dashed line) and radar (solid line) for the region defined by the black boxes in the top panels. The dashed line shows the maximum cloud-top height for clouds with opaque cloud types. The restriction to opaque cloud types removes the nonconvective signal offered by cirrus clouds. The time series captures the vertical velocity of the growing convective cells early in development of this line and the tallest clouds increased by 3 km in the 30-min period from 1930 to 2000 UTC. Of course these velocities are not the individual storm cores, rather, they are observations within an infrared (IR) pixel (Adler and Fenn 1979); the availability of 1-min data provides a much more accurate ability to estimate these vertical velocities than 15-min-resolution data. After 2200 UTC, the undulation in the maximum



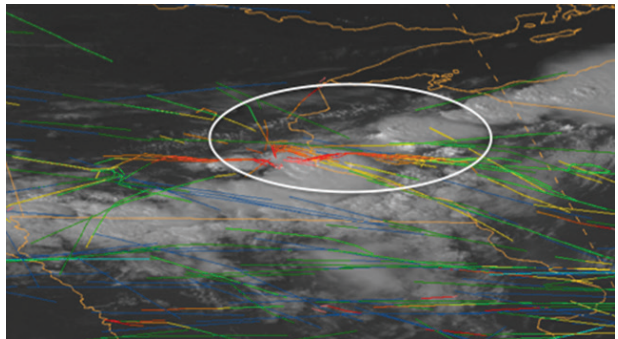
**FIG. 6.** The SRSOR imagery shows GOES-14 visible band on 21 Aug 2013 with (left) the CTC product for the SRSOR timing and (right) the timing of routine GOES operations. The SRSOR shows the convective cloud-top cooling over far northern Wisconsin well before that from routine operations (animation available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>).



cloud height values likely represent gravity waves which are poorly sampled by the 15-min-resolution data. Also shown (solid line) are a time series of the radar data that were obtained from a national (CONUS) 3D radar mosaic grid with a 1-km horizontal resolution over 31 vertical levels. The numbers of points are plotted in the defined box with heights greater than 10 km. The National Mosaic and Multi-Sensor Quantitative Precipitation Estimation (QPE) system (Zhang et al. 2011) takes base-level data from all available radars [Next Generation Weather Radar (NEXRAD), Canadian, terminal Doppler weather radar, etc.], performs quality control, and combines reflectivity observations onto a 3D Cartesian grid. The plot shows the areal coverage of the 18-dBZ reflectivity at heights of at least 10 km above ground level.

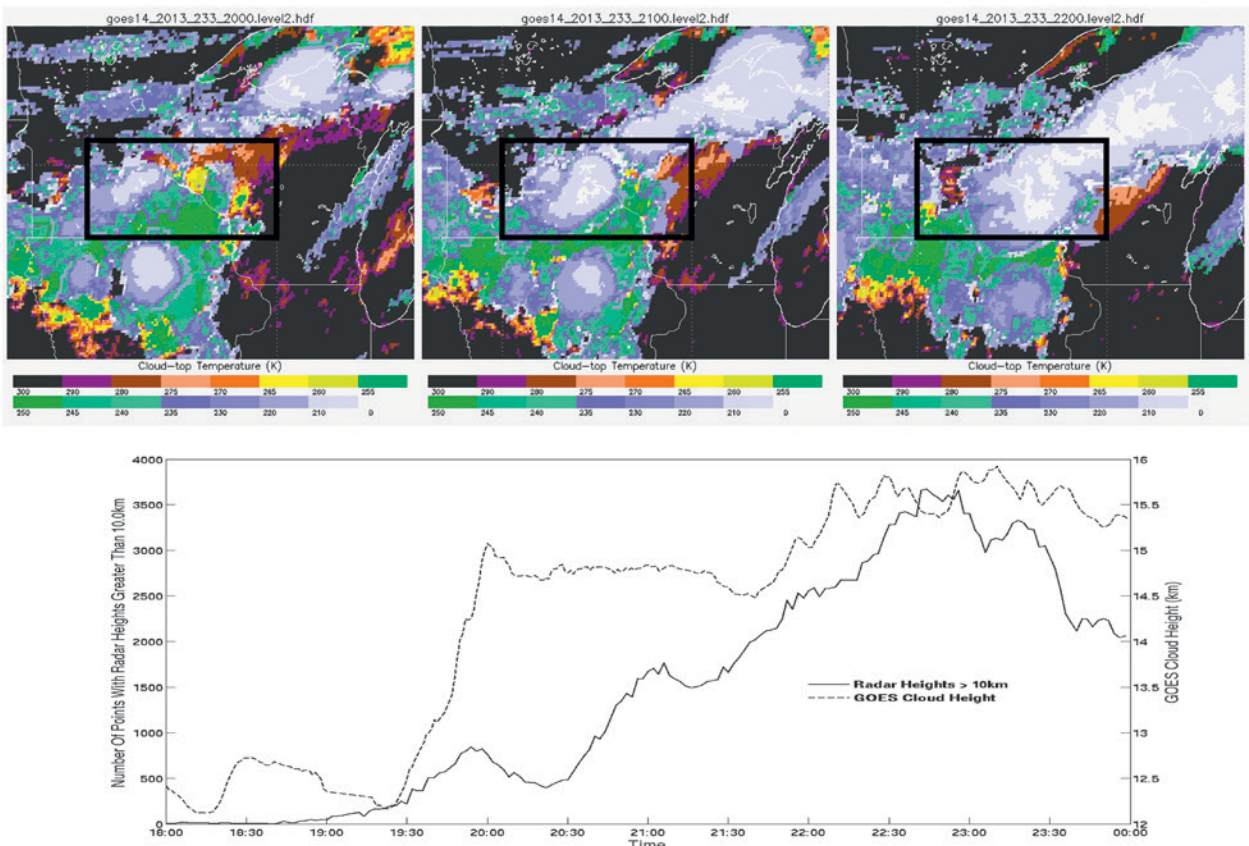
THE PAST HR PER 1-MIN SUPER RAPID SCAN VISIBLE SATELLITE IMAGERY.”

One method of combining the views of the visible and longwave window imagery is known as the “sandwich” product (M. Setvák 2013, personal

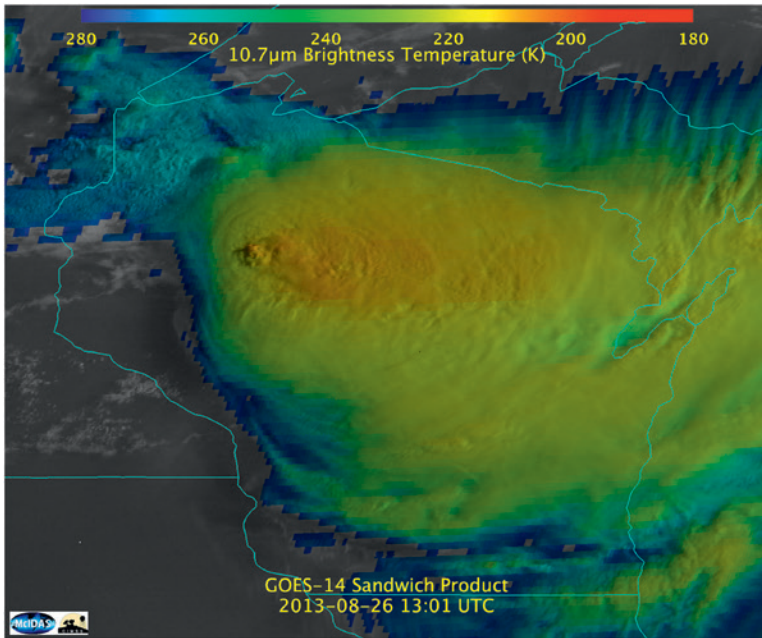


**FIG. 7.** One-minute visible imagery and aircraft situation display to industry (ASDI) flight routes over the Minneapolis Air Route Traffic Control Center at 2100 UTC 21 Aug 2013. The colors denote the height of the aircraft, with warm colors being lower. The white circle denotes the region of interest associated with the flights into or out of Minneapolis.

**SEVERE CONVECTION OVER WISCONSIN 26 AUGUST 2013.** The GOES-14 SRSOR information proved valuable to NOAA’s SPC as noted in a forecast discussion on 26 August 2013: “TOWERING CU ROOTED IN THE BOUNDARY LAYER IS INCREASING IN AREAL COVERAGE OVER



**FIG. 8.** Time series of the cloud height on 21 Aug 2013. (bottom) Time series of ACHA results between 1800 and 0000 UTC 21 Aug 2013. (top) Images show ACHA cloud-top temperature at 2000, 2100, and 2200 UTC. The dashed line is the maximum satellite cloud-top height for opaque cloud types over the box drawn in (top). The time series from the radar (solid line) also shows rapid changes.



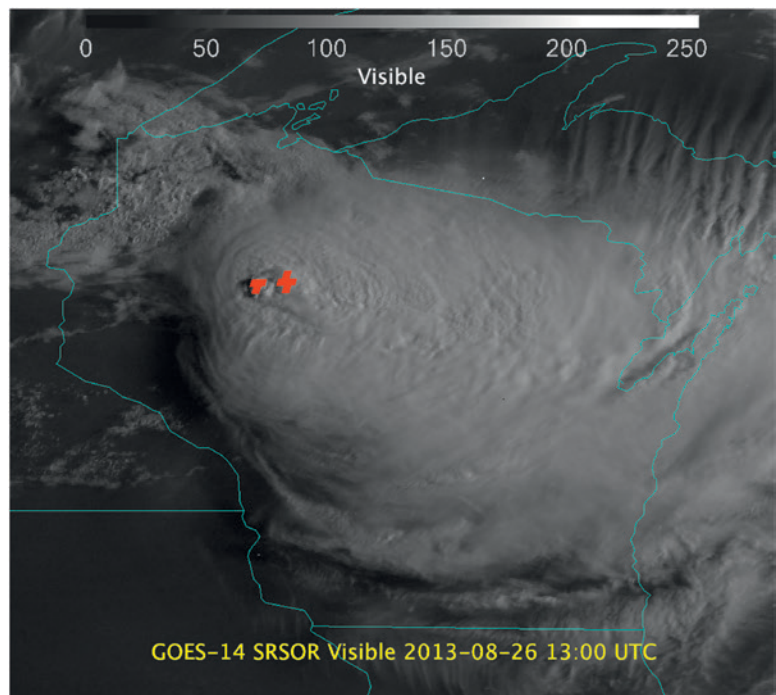
**FIG. 9.** Combined visible and infrared sandwich product from at 1300 UTC 26 Aug 2013 (animation available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>). This product shows both the visible imagery as well as the infrared window band. The image is centered on the state of Wisconsin.

communication; Miller et al. 2012; Setvák et al. 2012). This allows information from two spectral bands to be shown at the same time. The two layers of this blended product are the full-resolution visible imagery and a color-enhanced longwave window band that is shown with a partial transparency (Fig. 9). Note that only clouds colder than 280 K in the infrared window are color coded. While detecting and observing rapid developing convection is important, so is the rapid dissipation that was evident on this day. The *GOES-14* sandwich product referenced in the text is complemented by an animation (Video6) in the online supplement for this article (available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>). SRSOR data showed rapid dissipation but also an undular bore (Martin and Johnson 2008) over southern Wisconsin on the morning of 26 August 2013. The presence of two OST at 1300 UTC was evident (Fig. 10); an OST is derived from the infrared window band (Bedka et al. 2010). However, parallel lines of low

clouds marked the leading edge of the bore, later in the day (after 1600 UTC, northwest of Madison, Wisconsin). The *GOES-14* animation (Video7) in the online supplement for this article (available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>) also shows the transformation of the atmosphere from convectively unstable, with transverse bands in the cirrus outflow suggestive of turbulence, to an atmosphere with midlevel cumuliform clouds (over northwest Wisconsin) in the wake of a departing mesoscale system. (Note that the images do contain some “salt and pepper” noise artifacts, most likely during the local ingest of the data from the satellite.)

### CALIFORNIA RIM FIRE ON 19 AND 22 AUGUST 2013.

On 19 August 2013, the Rim Fire complex in Groveland, California, spawned a pyrocumulonimbus cloud (pyroCb; Fromm et al. 2010) as it burned through the Stanislaus National Forest. The *GOES-14* SRSOR visible imagery showed a white plume (our



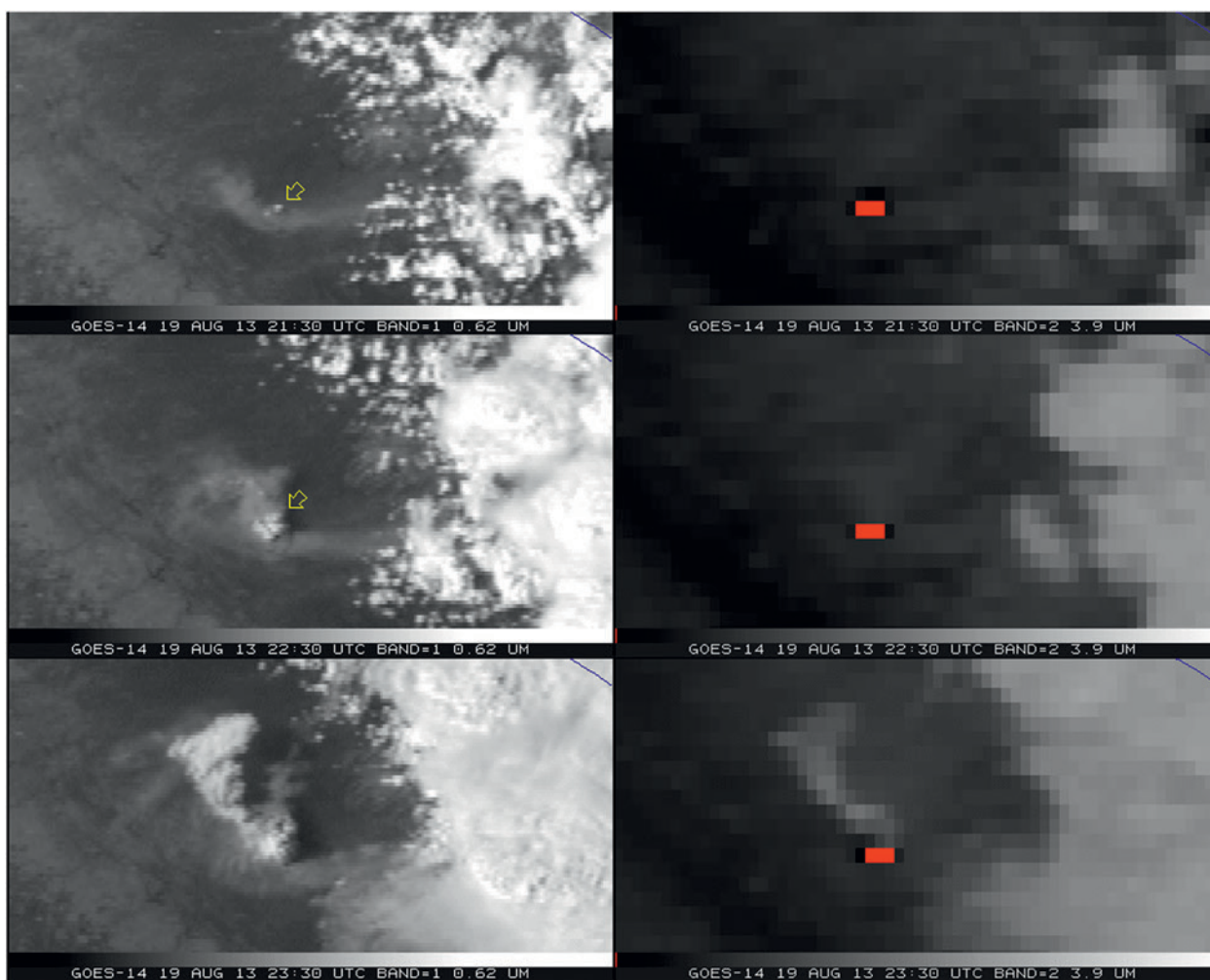
**FIG. 10.** *GOES-14* visible image and derived overshooting tops (in red) at 1300 UTC 26 Aug 2013 (animation available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>). The OSTs are derived from IR window information. The image is centered on the state of Wisconsin.



soon-to-be pyroCb) erupting from the fire complex in the center of the image at approximately 2300 UTC (Fig. 11). The fire complex was enveloped by convection from the east as the evening progressed, but the path of the initial pyroCb was seen throughout. As this plume drifted to the northwest, it developed into a pyroCb, casting a shadow over some lower-level clouds. The *GOES-14* shortwave IR imagery showed the pyroCb (lighter pixels), which emanated from the fire complex (red pixels). The *GOES-14* imagery referenced in the text is complemented by an animation (Video8) in the online supplement for this article (available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>).

Quantitative derived products have the capability to derive multiple pieces of information from the radiances. The wildfire automated biomass burning algorithm (WFABBA) not only reports locations of

detected fires but also derives information about fire characteristics (Prins 1996; Schroeder et al. 2008). For example, it is postulated that a hot spot with greater temporal changes in fire radiative power (FRP) may be more erratic than a hot spot with a more uniform fire radiative power. It is shown for 22 August 2013 that the high-time-resolution *GOES-14* SRSOR allows for sensing these rapid changes in FRP (Fig. 12). This time series represents *GOES-R* ABI-like time resolutions for the mesoscale images. The horizontal line near the top of the image represents a saturated pixel value. A sequence of *GOES-14* SRSOR 0.63- $\mu\text{m}$  visible channel images showed that the initial northward motion of the smoke plume transitioned to a more northeasterly motion after approximately 1700 UTC (Fig. 13). This change was due to a shift in the winds at the plume height as a semistationary cutoff low just west of the



**FIG. 11.** *GOES-14* (left) visible and (right) shortwave infrared window from the California Rim Fire for 19 Aug 2013. Note that warm temperatures in (right) have been color coded to be dark, with the hottest pixels being red and the colder pixels being white. The maximum temperature on the scale is 330 K, while the coldest possible value is 163 K (animation available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>). The spatial coverage of the image is approximately 150 km (east–west) by 120 km (north–south).

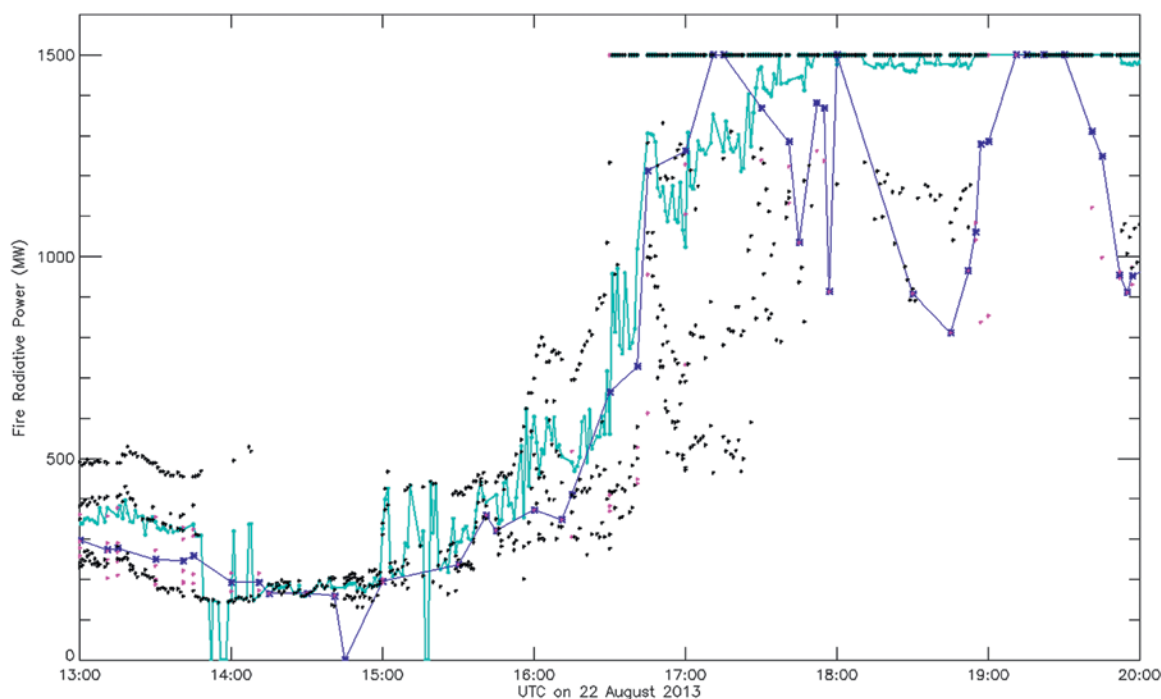


coast of California began to move northward during the day. This shift is best seen in the *GOES-14* animation (Video9) in the online supplement for this article (available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>).

**SUMMARY.** The *GOES-14* imager was operated in an experimental rapid scan 1-min mode during parts of the summer in 2012 and 2013. These special scans, called super rapid scan operations for GOES-R (SRSOR), emulated the high-temporal-resolution sampling possible from the ABI on the next-generation GOES-R series. Many phenomena were observed from *GOES-14*, including fog, clouds, convection, severe storms, fires and smoke (including the California Rim Fire), monsoon moisture, and several tropical cyclones. These data are helping users better prepare for the next-generation GOES-R imager, which will be able to routinely scan mesoscale regions every 30 s (or two separate locations every minute). In addition, these experimental data were used in a number of NOAA test beds, including those at NOAA's Storm Prediction Center (SPC), Aviation Weather Center (AWC), Ocean Prediction Center, and others. The applications included monitoring towering cumulus, rapidly growing convection, heavy precipitation, fires, smoke, overshooting tops, cloud-top cooling, monitoring outflow boundaries, and frontal zones; earlier detec-

tion of convection dissipation; increasing lead time for convective development; and a better understanding of convective processes. Forecasters stated that super rapid scan information could be helpful in radar gap areas. Many animations or derived products are available to showcase the rapid change of the multiple phenomena observed during SRSOR from the *GOES-14* imager. This article provides several examples of actual applications of *GOES-14* 1-min refresh SRSOR datasets collected in the summers of 2012 and 2013 and hints at what will be capable with the ABI on the GOES-R series. In fact, researchers have shown how the GOES rapid scan information could be used to increase lead time before severe weather (Bedka et al. 2015). Of course the most complete information results from combining information provided by geostationary, polar orbiting, and other sources such as from radars (Cintineo et al. 2014). One challenge for the GOES-R era will be to effectively use the rapid scan, multispectral imagery and derived products, along with other measurements, to best monitor the earth-atmosphere system in order to enhance the timeliness of forecasts and warnings for a wide range of environmental phenomena that impact human activities.

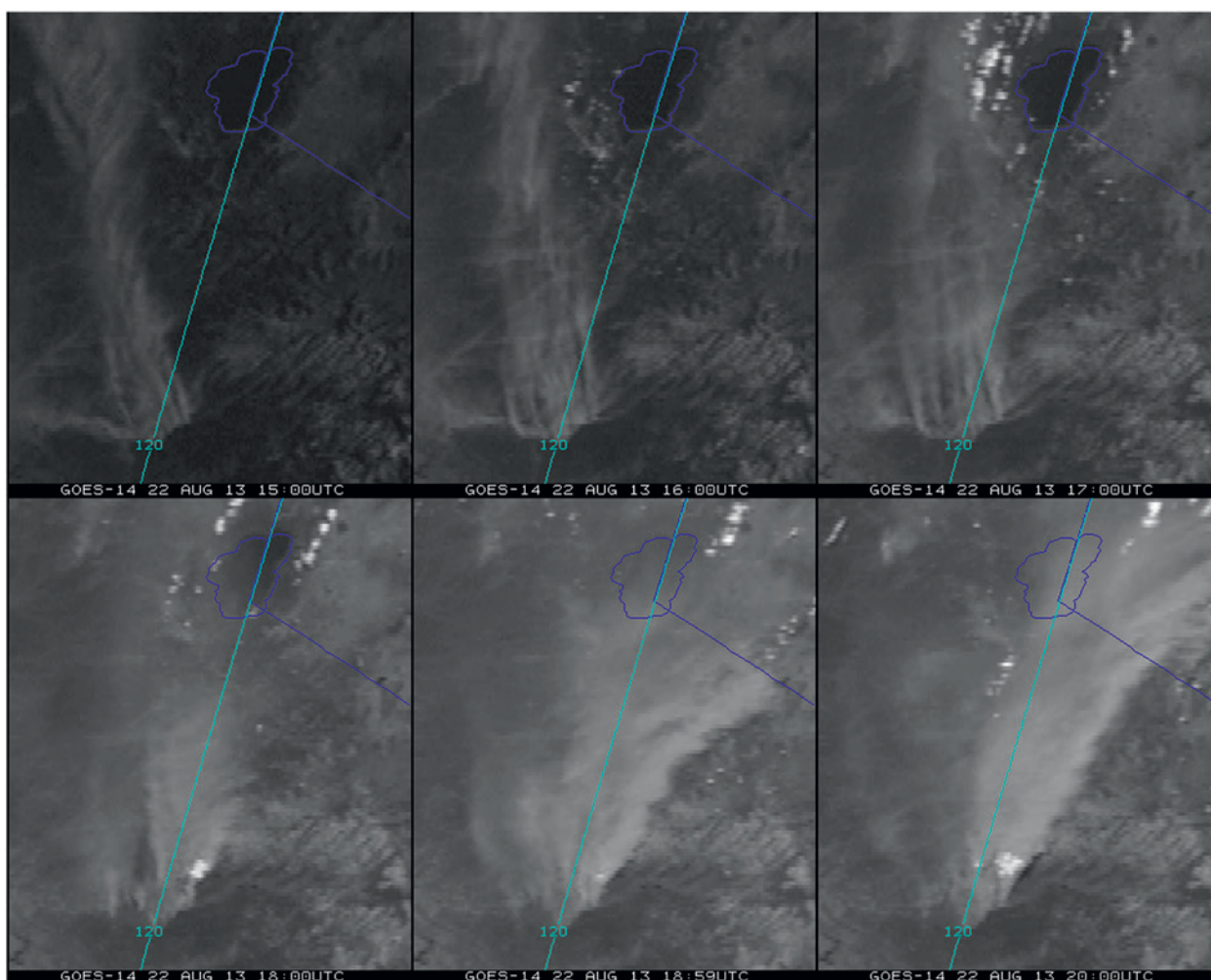
**ACKNOWLEDGMENTS.** More information about the SRSOR in 2012, 2013, and 2014 has been posted online (at



**FIG. 12.** Time series of FRP from WFABBA of *GOES-14* SRSOR and *GOES-15* data from 1300 to 2000 UTC 22 Aug 2013. The dots represent the times, while the lines represent running averages. The (thicker) cyan line is from the higher-time-resolution *GOES-14* SRSOR data, while the (thinner) blue line is derived from less frequent *GOES-15* views.

[http://cimss.ssec.wisc.edu/goes/srsor/overview\\_training.html](http://cimss.ssec.wisc.edu/goes/srsor/overview_training.html)). This page includes the daily schedule, image center point, coverage area and other information. The authors thank the many contributors to the generation of the *GOES-14* SRSOR imager data streams. The NOAA/National Environmental Satellite, Data, and Information Service (NESDIS)/Office of Satellite and Product Operations (OSPO) is especially thanked for the production of the GVAR data. Thanks to Vanessa Griffin, Kevin Ludlum, GOES shift supervisors and operators, John Tsui, Tom Renkevans, Ralph Petersen, Steve Weiss, Jaime Daniels, Bill Bellon, Pete Pokrandt, Michael J. Folmer, Gregg Gallina, Jordan Gerth, William Straka, Chad Gravelle, Bill Line, Mark Ruminski, Bryan Baum, John L. Cintineo, Lee Cronce, Christopher S. Velden, Kristopher M. Bedka, Mike Hiley, Carrie Langston, Wayne Feltz, Louis Nguyen, Jean Phillips, and Jackie Lang. James P. Nelson III and Gary S. Wade are thanked for Figs.

2 and 3, while Patrick Meyers is thanked for Fig. 4. Martin Setvák is thanked for his work with the “sandwich product” (for more information on this product, see [http://essl.org/cwg/?page\\_id=143](http://essl.org/cwg/?page_id=143)). Special thanks to Jerry Robaidek and the SSEC Data Center staff who acquired the *GOES-14* data in real time and subsequently archived them at the SSEC Data Center. The Man Computer Interactive Data Access System (McIDAS-X or V) was used to create most of the images. Special thanks to Leanne Avila for an internal review of this paper and the anonymous reviewers for their detailed comments. More information on the aviation summer experiment is available online ([http://testbed.aviationweather.gov/page/public?name=2013\\_Summer\\_Experiment](http://testbed.aviationweather.gov/page/public?name=2013_Summer_Experiment)) and on the GOES schedules ([www.ospo.noaa.gov/Operations/GOES/schedules.html](http://www.ospo.noaa.gov/Operations/GOES/schedules.html)) can be found online. The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official



**FIG. 13.** *GOES-14* visible image enhanced to better visualize the smoke from the California Rim Fire on 22 Aug 2013 (animation available at <http://dx.doi.org/10.1175/BAMS-D-13-00210.2>). The fire is near the lower part of the image, while the smoke moves northward, in general, to over Lake Tahoe (outlined, in the northern portion of each image), reducing visibility. The spatial coverage of the image is approximately 100 km (east–west) by 200 km (north–south).

National Oceanic and Atmospheric Administration or U.S. government position, policy, or decision. More information on many of these cases can be found in the CIMSS Satellite Blog, under the *GOES-14* category (<http://cimss.ssec.wisc.edu/goes/blog/archives/category/goes-14>).

## REFERENCES

- Adler, R. F., and D. D. Fenn, 1979: Thunderstorm intensity as determined from satellite data. *J. Appl. Meteor.*, **18**, 502–517, doi:10.1175/1520-0450(1979)018<0502:TIADFS>2.0.CO;2.
- American Meteorological Society, cited 2014: Derecho. Glossary of Meteorology. [Available online at <http://glossary.ametsoc.org/wiki/derecho>.]
- Bedka, K. M., J. Brunner, R. Dworak, W. Feltz, J. Otkin, and T. Greenwald, 2010: Objective satellite-based overshooting top detection using infrared window channel brightness temperature gradients. *J. Appl. Meteor. Climatol.*, **49**, 181–202, doi:10.1175/2009JAMC2286.1.
- , C. Wang, R. Rogers, L. D. Carey, W. Feltz, and J. Kanak, 2015: Examining deep convective cloud evolution using total lightning, WSR-88D, and GOES-14 super rapid scan datasets. *Wea. Forecasting*, doi:10.1175/WAF-D-14-00062.1, in press.
- Butler, A., cited 2013: GOES control problem could be due to micrometeoroid collision. Aviation Week. [Available online at [www.aviationweek.com/Article.aspx?id=/article-xml/asd\\_05\\_30\\_2013\\_p03-01-583298.xml](http://www.aviationweek.com/Article.aspx?id=/article-xml/asd_05_30_2013_p03-01-583298.xml).]
- Cintineo, J. L., M. J. Pavolonis, J. M. Sieglaff, and A. K. Heidinger, 2013: Evolution of severe and nonsevere convection inferred from GOES-derived cloud properties. *J. Appl. Meteor. Climatol.*, **52**, 2009–2023, doi:10.1175/JAMC-D-12-0330.1.
- , —, —, and D. T. Lindsey, 2014: An empirical model for assessing the severe weather potential of developing convection. *Wea. Forecasting*, **29**, 639–653, doi:10.1175/WAF-D-13-00113.1.
- Davenport, J. C., and R. J. Kuligowski, 2008: An improved GOES parallax correction scheme for rainfall estimation. *22nd Conf. on Hydrology*, New Orleans, LA, Amer. Meteor. Soc., 9.4. [Available online at <https://ams.confex.com/ams/pdfpapers/134462.pdf>.]
- Davis, G., 2007: History of the NOAA satellite program. *J. Appl. Remote Sens.*, **1**, 012504, doi:10.1117/1.2642347.
- Dworak, R., K. Bedka, J. Brunner, and W. Feltz, 2012: Comparison between *GOES-12* overshooting-top detections, WSR-88D radar reflectivity, and severe storm reports. *Wea. Forecasting*, **27**, 684–699, doi:10.1175/WAF-D-11-00070.1.
- Fromm, M., D. T. Lindsey, R. Servranckx, G. Yue, T. Trickl, R. Sica, P. Doucet, and S. Godin-Beekmann, 2010: The untold story of pyrocumulonimbus. *Bull. Amer. Meteor. Soc.*, **91**, 1193–1209, doi:10.1175/2010BAMS3004.1.
- Gatlin, P. N., and S. J. Goodman, 2010: A total lightning trending algorithm to identify severe thunderstorms. *J. Atmos. Oceanic Technol.*, **27**, 3–22, doi:10.1175/2009JTECHA1286.1.
- Goodman, S. J., D. E. Buechler, P. D. Wright, and W. D. Rust, 1988: Lightning and precipitation history of a microburst producing storm. *Geophys. Res. Lett.*, **15**, 1185–1188, doi:10.1029/GL015i011p01185.
- , and Coauthors, 2012: The GOES-R proving ground: accelerating user readiness for the next-generation geostationary environmental satellite system. *Bull. Amer. Meteor. Soc.*, **93**, 1029–1040, doi:10.1175/BAMS-D-11-00175.1.
- , and Coauthors, 2013: The GOES-R Geostationary Lightning Mapper (GLM). *Atmos. Res.*, **125–126**, 34–49, doi:10.1016/j.atmosres.2013.01.006.
- Heidinger, A. K., and M. J. Pavolonis, 2009: Gazing at cirrus clouds for 25 years through a split window. Part I: Methodology. *J. Appl. Meteor. Climatol.*, **48**, 1100–1116, doi:10.1175/2008JAMC1882.1.
- Martin, E. R., and R. H. Johnson, 2008: An observational and modeling study of an atmospheric internal bore during NAME 2004. *Mon. Wea. Rev.*, **136**, 4150–4167, doi:10.1175/2008MWR2486.1.
- Miller, S. D., C. C. Schmidt, T. J. Schmit, and D. W. Hillger, 2012: A case for natural colour imagery from geostationary satellites, and an approximation for the GOES-R ABI. *Int. J. Remote Sens.*, **33**, 3999–4028, doi:10.1080/01431161.2011.637529.
- Prins, E. M., 1996: The GOES-8 automated biomass burning algorithm (ABBA) introducing new capabilities for monitoring diurnal fire activity in the Western Hemisphere. *Int. For. Fire News*, **15**, 49–52.
- Purdum, J. F. W., 1976: Some uses of high-resolution GOES imagery in the mesoscale forecasting of convection and its behavior. *Mon. Wea. Rev.*, **104**, 1474–1483, doi:10.1175/1520-0493(1976)1042.0.CO;2.
- Ralph, F. M., and Coauthors, 2013: The emergence of weather-related test beds linking research and forecasting operations. *Bull. Amer. Meteor. Soc.*, **94**, 1187–1211, doi:10.1175/BAMS-D-12-00080.1.
- Schmit, T. J., M. M. Gunshor, W. P. Menzel, J. Li, S. Bachmeier, and J. J. Gurka, 2005: Introducing the next-generation advanced baseline imager on GOES-R. *Bull. Amer. Meteor. Soc.*, **86**, 1079–1096, doi:10.1175/BAMS-86-8-1079.
- , and Coauthors, 2013: Geostationary Operational Environmental Satellite (GOES)-14 super rapid scan operations to prepare for GOES-R. *J. Appl. Remote*



- Sens.*, 7, 073462, doi:10.1117/1.JRS.7.073462.
- Schroeder, W., M. Ruminski, I. Csiszar, L. Giglio, E. Prins, C. Schmidt, and J. Morissette, 2008: Validation analyses of an operational fire monitoring product: The hazard mapping system. *Int. J. Remote Sens.*, **29**, 6059–6066, doi:10.1080/01431160802235845.
- Schultz, C. J., W. A. Petersen, and L. D. Carey, 2009: Preliminary development and evaluation of lightning jump algorithms for the real-time detection of severe weather. *J. Appl. Meteor. Climatol.*, **48**, 2543–2563, doi:10.1175/2009JAMC2237.1.
- , —, and —, 2011: Lightning and severe weather: A comparison between total and cloud-to-ground lightning trends. *Wea. Forecasting*, **26**, 744–755, doi:10.1175/WAF-D-10-05026.1.
- Setvák, M., K. Bedka, D. T. Lindsey, A. Sokol, Z. Charvát, J. Štástka, and P. K. Wang, 2013: A-Train observations of deep convective storm tops. *Atmos. Res.*, **123**, 229–248, doi:10.1016/j.atmosres.2012.06.020.
- Shapiro, M., and A. Thorpe, 2004: The Observing System Research and Predictability Experiment (THORPEX): International science plan. WMO Tech. Doc. WMO/TD-1246, 57 pp. [Available online at [http://library.wmo.int/pmb\\_ged/WMO\\_TD1246.pdf](http://library.wmo.int/pmb_ged/WMO_TD1246.pdf).]
- Sieglauff, J. M., D. C. Hartung, W. F. Feltz, L. M. Counce, and L. Valliappa, 2013: A satellite-based convective cloud object tracking and multipurpose data fusion tool with application to developing convection. *J. Atmos. Oceanic Technol.*, **30**, 510–525, doi:10.1175/JTECH-D-12-00114.1.
- , L. M. Counce, and W. F. Feltz, 2014: Improving satellite-based convective cloud growth monitoring with visible optical depth retrievals. *J. Appl. Meteor. Climatol.*, **53**, 506–520, doi:10.1175/JAMC-D-13-0139.1.
- Stano, G. T., C. J. Schultz, L. D. Carey, D. R. MacGorman, and K. M. Calhoun, 2014: Total lightning observations and tools for the 20 May 2013 Moore, Oklahoma, tornadic supercell. *J. Oper. Meteor.*, **2**, 71–88, doi:10.15191/nwajom.2014.0207.
- Weaver, J. F., and D. T. Lindsey, 2004: Some frequently overlooked visual severe thunderstorm characteristics observed on GOES imagery: A topic for future research. *Mon. Wea. Rev.*, **132**, 1529–1533, doi:10.1175/1520-0493(2004)1322.0.CO;2.
- Zhang, J., and Coauthors, 2011: National mosaic and multi-sensor QPE (NMQ) system: Description, results, and future plans. *Bull. Amer. Meteor. Soc.*, **92**, 1321–1338, doi:10.1175/2011BAMS-D-11-00047.1.

## NEW FROM AMS BOOKS!

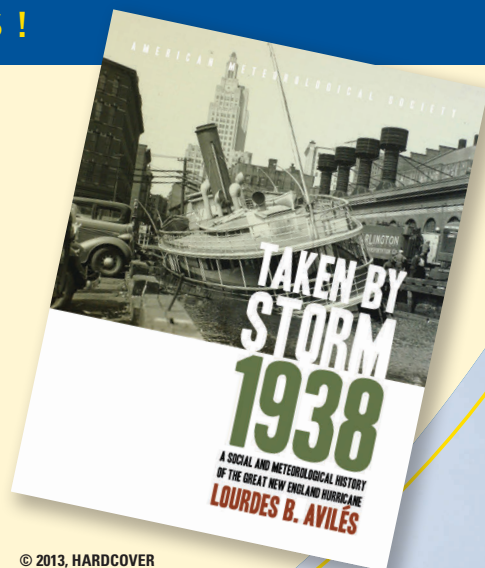
“An engrossing account of New England’s worst natural catastrophe.”

— KERRY EMANUEL, *Professor of Atmospheric Science, MIT*

### **Taken by Storm, 1938:** *A Social and Meteorological History of the Great New England Hurricane*

LOURDES B. AVILÉS

When the Great New England Hurricane of 1938 hit the Northeast unannounced, it changed everything from the landscape, to Red Cross and Weather Bureau protocols, to the measure of Great Depression relief New Englanders would receive, and the resulting pace of regional economic recovery. The science behind this storm is presented here for the first time, with new data that sheds light on the motivations of the Weather Bureau forecasters. This compelling history successfully weaves science, historical accounts, and social analyses to create a comprehensive picture of the most powerful and devastating hurricane to hit New England to date.



© 2013, HARDCOVER  
ISBN: 978-1-878220-37-0  
LIST \$40 MEMBER \$30

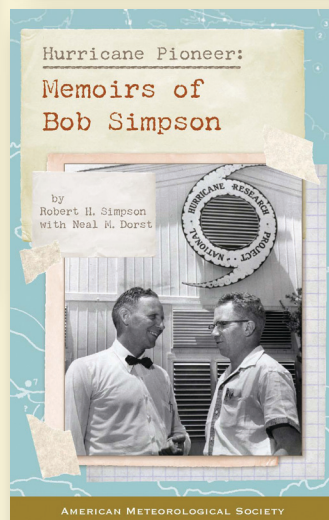
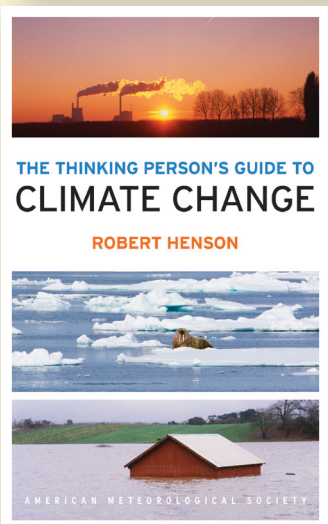
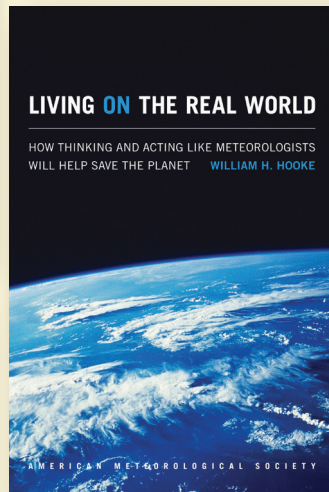
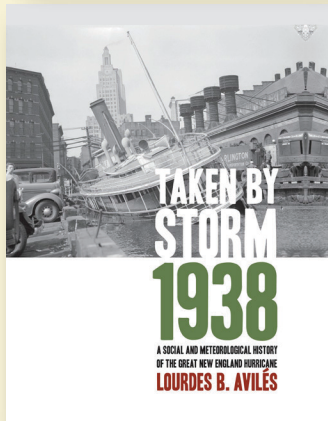
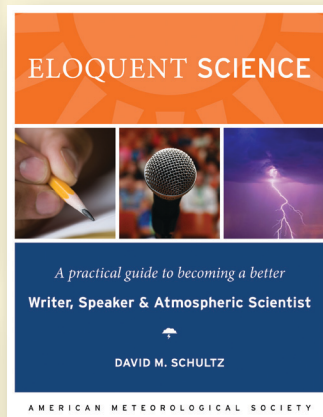
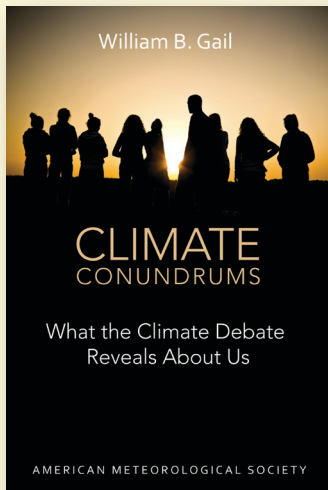
## AMS BOOKS

RESEARCH APPLICATIONS HISTORY

[www.ametsoc.org/amsbookstore](http://www.ametsoc.org/amsbookstore)

# AMS BOOKS: SOMETHING FOR EVERYONE

From enthusiasts,  
to students, to experts



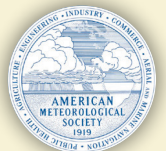
We publish:

- Meteorological reanalysis and storm histories
- Weather, water, and climate coursebooks
- Research monographs for many focused specialties
- Weather and climate images for lecture notes and slides
- References including our bestseller *Eloquent Science*

Members always receive  
discounts and

**FREE SHIPPING**

[www.ametsoc.org/bookstore](http://www.ametsoc.org/bookstore)



**20% OFF** your order  
through 9/1/15 with  
code **BAMS2015**  
(Does not apply to  
undergraduate  
coursebooks.)

**AMS BOOKS**