# GOES-R and JPSS Proving Ground Demonstration at the Hazardous Weather Testbed 2016 Spring Experiment Final Evaluation

**Project Title:** GOES-R and JPSS Proving Ground Demonstration at the 2016 Spring Experiment - Experimental Warning Program (EWP) and Experimental Forecast Program (EFP)

**Organization:** NOAA Hazardous Weather Testbed (HWT)

**Evaluator(s):** National Weather Service (NWS) Forecasters, Broadcast Meteorologists, Storm Prediction Center (SPC), National Severe Storms Laboratory (NSSL)

**Duration of Evaluation:** 18 April 2016 – 13 May 2016

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# 1. Executive Summary

This report summarizes the activities and results from the Geostationary Operational Environmental Satellite R-Series (GOES-R) and Joint Polar Satellite System (JPSS) Proving Ground demonstration at the 2016 Spring Experiment, which took place at the National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (HWT) in Norman, OK from 18 April to 13 May 2016. The Satellite Proving Ground activities were focused in the Experimental Warning Program (EWP). A total of 12 National Weather Service (NWS) forecasters representing four NWS regions and an additional four broadcast meteorologists participated in the EWP experiment. They evaluated eight (Table 1) baseline, future capability, and experimental GOES-R and JPSS products in the real-time simulated short-term forecast and warning environment of the EWP using the second generation Advanced Weather Interactive Processing System (AWIPS-II).

Most of the products demonstrated in 2016 were involved in previous HWT experiments and have received updates based on feedback received from the HWT and other demonstrations. Products evaluated in 2016 included GOES-R All-Sky Legacy Atmospheric Profile (LAP) algorithm atmospheric moisture and stability fields using GOES Sounder data, GOES-R Convective Initiation (CI) algorithms, ProbSevere statistical model, Geostationary Lightning Mapper (GLM) Lightning Detection, and Lightning Jump algorithm (LJA). Additionally, GOES-14 Super Rapid Scan Operations for GOES-R (SRSOR) 1-min visible (VIS), infrared (IR), and water vapor (WV) imagery was available from 18 April to 14 May. Participants viewed the 1-min imagery in near real-time in AWIPS-II in the EWP and in National Centers for Environmental Prediction (NCEP) AWIPS (NAWIPS) in the Experimental Forecast Program (EFP). Parallax-corrected 1-min imagery was also available in AWIPS-II, as were 10-min updating Derived Motion Winds computed from the 1-min satellite data. Finally, the NOAA Unique Combined Atmospheric Processing System (NUCAPS) from the JPSS Suomi NPP and MetOp A/B satellites was also demonstrated in AWIPS-II. Several visiting scientists attended the EWP over the four weeks to provide additional product expertise and interact directly with operational forecasters. Organizations represented by those individuals included: UW/CIMSS, UAH, OU/CIMMS, NSSL, NASA/SPoRT, Science and Technology Corporation and NWS. The 2016 GOES-R and JPSS Proving Ground User Readiness Meeting took place in Norman during the final week of the experiment, providing meeting participants the opportunity to observe the HWT activities. The SPC and HWT Satellite Liaison, William Line (OU/CIMMS and NOAA/SPC), provided overall project management and subject matter expertise for the GOES-R Proving Ground efforts in the HWT with support from Kristin Calhoun (OU/CIMMS and NOAA/NSSL).

Forecaster feedback during the evaluation was collected using several different methods, including daily surveys, weekly surveys, daily debriefs, weekly debriefs, blog posts, informal conversations in the HWT and a weekly “Tales from the Testbed” webinar. Typical feedback included: suggestions for improving the algorithms, ideas for making the displays more effective for information transfer to forecasters, best practices for product use, suggestions for training, and situations in which the tools worked well and not so well. Forecasters favorite aspect of the GOES-R All-sky LAP product was the multi-layer PW fields, which depicted differential moisture advection throughout the atmosphere. The severe CI product was a welcomed addition to the CI suite, albeit sometimes too conservative with its probabilities. The ProbSevere model continues to impress forecasters, though improvements to performance need to be made in the presence of multicellular/linear convective modes and when wind and tornados are the hazard. The 1-min satellite imagery is a capability forecasters are most excited for, finding it to have exceptional value over current imagery throughout the full duration of a severe weather day. Participants appreciated the high density of wind data made available from the high frequency satellite imagery, and found many ways in which it improved their environmental analysis. Forecasters were able to effectively use the lightning products to determine where thunderstorms were developing and where significant increases and decreased in activity were occurring. They look forward to the GLM capability, and anticipate benefits to local Decision Support Services (DSS) activities as well. Finally, participants found the NUCAPS information to be helpful in filling spatial and temporal gaps that exist in vertical moisture information, and liked that the plan view displays provided a quick look at a specific level in a NUCAPS swath.

## 2. Introduction

GOES-R Proving Ground (Goodman et al. 2012) demonstrations in the HWT provide users with a glimpse into the capabilities, products and algorithms that will be available with the future geostationary satellite series, beginning with GOES-R which is scheduled to launch in late 2016. The education and training received by participants in the HWT fosters excitement for satellite data and helps to ensure readiness for the use of GOES-R data. Additional demonstration of JPSS products introduces and familiarizes users with advanced satellite data that are already available. The HWT provides a unique opportunity to enhance research-to-operations and operations-to-research (R2O2R) by enabling product developers to interact directly with operational forecasters, and to observe the satellite-based algorithms being used alongside standard observational and forecast products in a simulated operational forecast and warning environment. This interaction helps the developer to understand how forecasters use the product, and what improvements might increase the product utility in an operational environment. Feedback received from participants in the HWT has proven invaluable to the continued development and refinement of GOES-R and JPSS algorithms. Furthermore, the EWP facilitates the testing of satellite-based products in the AWIPS-II data processing and visualization system.

In 2016, the EWP was conducted during the weeks of April 18, April 25, May 2, and May 9 with three NWS forecasters and one broadcast meteorologist participating each week. In an effort to extend the satellite knowledge and participation to the broader meteorological community, and to recognize the critical role played by the private sector in communicating warnings to the public, broadcast meteorologists sponsored by the GOES-R Program participated in the Spring Experiment for the third year in a row, working alongside NWS forecasters. Training modules in the form of an Articulate Power Point presentation for each product demonstrated were sent to and completed by participants prior to their arrival in Norman. Each week, participants arrived in Norman on Sunday, worked eight hour experimental forecast shifts Monday-Thursday and a half-day on Friday before traveling home Friday afternoon.

Much of Monday was a spin-up day that included a one hour orientation, familiarization with the AWIPS-II system, and one-on-one hands-on training between participants, product developers, and the Satellite Liaison. The shifts on Tuesday, Wednesday and Thursday were "flex shifts", meaning the start time was anywhere between 9 am and 3 pm, depending on when the most active convective weather across the CONUS was expected to occur. The next day start time was determined the previous evening by the Satellite Liaison. The Friday half-day involved a weekly debrief and preparation and delivery of the "Tales from the Testbed" webinar.

Shifts typically began a couple of hours before convective initiation was expected to occur as many of the products demonstrated this year have their greatest utility in the pre-convective environment. At the start of each Mon-Thurs experimental warning shift, the Satellite Liaison and forecasters interrogated the large scale weather pattern across the CONUS and determined where to operate for the day. Forecasters, working in pairs, provided experimental short-term forecasts for their assigned CWA via a blog. Early in the shift, these were primarily mesoscale forecasts discussing the environment, where convection was expected to occur, and what the applicable demonstration products were showing. Once convection began to grow upscale, one forecaster in the pair would switch to issuing experimental warnings for their CWA while the other forecaster would continue to monitor the mesoscale environment and compose blog posts. Blog posts regarding the use of demonstration products in the warning decision-making process were written during this period along with continued updates on the mesoscale environment. If severe convective activity in a CWA ceased or was no longer expected to occur, the Satellite Liaison would transition the pair of forecasters to focus on a more convectively active CWA.

At the end of each week, the three NWS forecasters and one broadcast meteorologist participated in the "Tales from the Testbed" webinar, broadcast by the Warning Decision Training Division (WDTD) via GoToMeeting. These 22 minute presentations gave participants an opportunity to share their experience in the HWT with over 30 offices each week, including NWS Headquarters, NWS WFOs and scientists nationwide, providing widespread exposure for the GOES-R and JPSS Proving Ground products. Topics for each of the four webinars were chosen based off the particular week's weather. Sixteen minutes were allowed afterward for questions and comments from folks on the call.

Feedback from participants came in several forms. During the short-term experimental forecast and warning shifts, participants were encouraged to blog their decisions along with any thoughts and feedback they had regarding the products under evaluation. Over 400 GOES-R and JPSS related blog posts were written during the four weeks of the Spring Experiment by forecasters, product developers, and the Satellite Liaison. At the end of each shift (Monday-Thursday), participants filled out a survey of questions for each product under evaluation. The Tuesday-Thursday shifts began with a "daily debrief" during which participants discussed their use of the demonstration products during the previous day's activities. Friday morning, a "weekly debrief" allowed product developers an opportunity to ask the forecasters any final questions, and for the forecasters to share their final thoughts and suggestions for product improvement. Additionally on Friday morning, forecasters completed one last "end of the week" survey of questions. Feedback from the GOES-R and JPSS demonstrations during the 2016 Spring Experiment is summarized in this report.

# 3. Products Evaluated

**Table 1.** List of GOES-R and JPSS products demonstrated within the HWT/EWP 2016 Spring Experiment

| Demonstrated Product | Category |
|---|---|
| GOES-R All-Sky Legacy Atmospheric Profile Products | GOES-R Baseline and Risk Reduction |
| GOES-R Convective Initiation | GOES-R Future Capabilities |
| ProbSevere Model | GOES-R Risk Reduction |
| GOES-14 SRSOR 1-min imagery | GOES-R Baseline |
| Derived Motion Winds | GOES-R Baseline |
| GLM Lightning Detection | GOES-R Baseline |
| Lightning Jump Algorithm | GOES-R Risk Reduction |
| NUCAPS Temperature and Moisture Profiles | JPSS Baseline |
| **Category Definitions:**<br>**GOES-R Baseline Products** – GOES-R products that are funded for operational implementation<br>**GOES-R Future Capabilities Products** – GOES-R funded products that may be made available as new capabilities<br>**GOES-R Risk Reduction** – New or enhanced GOES-R applications that explore possibilities for improving AWG products. These products may use the individual GOES-R sensors alone, or combine data from other in-situ and satellite observing systems or models with GOES-R<br>**JPSS** – Products funded through the JPSS program | |

## 3.1 GOES-R All-Sky Legacy Atmospheric Profile Products

Cooperative Institute for Meteorological Satellite Studies (CIMSS)

For the second year, blended all-sky moisture and stability fields were demonstrated in the HWT. These fields are derived via a fusion of GOES Sounder radiance observations and Numerical Weather Prediction (NWP) forecast data. This GOES-R Risk Reduction (GOES-R3) project has three components. The first component is the GOES-R Advanced Baseline Imager (ABI) Legacy Atmospheric Profile (LAP) retrieval algorithm, a Baseline GOES-R product. The LAP algorithm generates retrievals in the clear-sky using information from the GOES Sounder as a proxy for the ABI and using Global Forecast System (GFS) NWP model forecasts as a first guess. The second component computes retrievals in some cloudy regions (thin/low clouds), also using information from the GOES Sounder and a GFS first guess. Finally, the GFS NWP model “fills in” the areas where no retrievals are available from the previous two algorithms due to sufficient cloud cover. The combination of these three components allows for one, blended all-sky product. Fields derived from the GOES-R3 all-sky LAP algorithm and available to forecasters during the experiment included Total Precipitable Water (TPW), Layer Precipitable Water (LPW) in the SFC-.9, .9-.7, and .7-.3 atmospheric layers in sigma coordinates, Convective Available Potential Energy (CAPE; surface-based), Lifted Index ( LI), K-Index (KI), Total Totals (TT), and Showalter Index (SI). The LAP products were available every hour shortly after the GOES Sounder observations were made, and combined data from GOES-East and West to provide full-CONUS coverage. New for 2016 was a field that identifies the source of the data (clear retrieval, cloudy retrieval, GFS) at any given point. The purpose of this evaluation was to discover any technical issues with this product and to gather feedback for how the algorithm could be improved to better suit forecaster needs.

*Use of LAP products in the HWT*

Similar to in last year's experiment, the LAP fields were utilized primarily at the beginning of the shift each day to aid in pre-convective mesoscale analysis. The PW fields were helpful in assessing moisture trends and return into the region of interest, while CAPE and LI helped forecasters understand where the greatest instability was setting up. The LAP products were re-evaluated later in the shift each day as well, often to gauge the environment in the vicinity of ongoing convection. Participants found it useful to overlay the satellite-derived winds on the layer PW imagery in order to get an idea of just how quickly the moisture was moving within a given layer. Participants mentioned that the KI, SI, and TT fields are dated and are very rarely used in operations anymore.

> "These products were used to assess the severe weather potential for the day. They were also used to re-evaluate severe set-up after initial round of storms moved through."
> *Forecaster, End-of-Day Survey*

> "Exceeded my expectations for usefulness in an operational environment. It really made the pre-storm analysis more complete and helped with trends during the events as well."
> *Forecaster, End-of-Week Survey*

> "These fields are useful for situational awareness, especially for getting a quick look at the environment when you are just sitting down."
> *Forecaster,* "Week 2 (25-29 April 2016) Summary and Feedback", *GOES-R HWT Blog*

Participants found it especially beneficial to take note of trends in the hourly updating fields, as rapidly increasing moisture and destabilization often represented regions of future convective development. Furthermore, forecasters commented that the LAP products appeared to accurately detect the location and movement of boundaries and local maxima/minima, features which served as foci for convective initiation. Even though absolute LAP values were sometimes underdone (see below), the locations of the gradients and maxima/minima typically appeared accurate based on where convection developed.

> "The LAP CAPE gradient was right through our CWA. It was helpful to focus on the location and movement of this gradient, as convection developed right along it.
> *Forecaster,* "Daily Summary: Week 4, Day 2 (10 May 2016)", *GOES-R HWT Blog*

> "CAPE was helpful in giving an estimate that storms were moving into a more unstable environment. Storms did develop along a strong CAPE gradient."
> *Forecaster,* "Daily Summary: Week 3, Day 1 (2 May 2016)", *GOES-R HWT Blog*

The favorite, and most unique, aspect of GOES-R LAP was the layer PW fields. In fact, 16/16 forecasters answered that they would utilize the Layer PW products in operations if available from GOES-R. While not currently available operationally from other datasets, participants were quick to grasp the forecasting benefits of having PW split up into layers. For convective forecasting in general, layer PW provides better definition for approaching elevated mixed layers and moisture gradients, along which convection tends to be tied. For identifying severe convection, potential flash flooding and major winter storm scenarios in particular, forecasters commented that differential moisture advection is a key component. Forecasters unanimously recommend layer PW be made available operationally from GOES-R.

> "Layered PW products are a highly useful and under-utilized dataset for operational NWS personnel. Seeing differential moisture advection adds significant context to the forecast process."
> *Forecaster, End-of-Week Survey*

> "The TPW and layer PW was alerted us to the fact that we were dealing with a very moist airmass today. Immediately, we identified heavy rain and flash flooding as a primary threat based on this data."
> *Forecaster, End-of-Day Survey*

> "Layer PW was my favorite LAP product as it was most unique, and added value to my analysis. It was particularly useful on days when we had strong low-level moisture advection, tracking the movement of moisture, and dry air aloft."
> *Forecaster,* "Week 4 (9-13 May 2016) Summary and Feedback", *GOES-R HWT Blog*

> "I like looking at the LPW, especially in the lowest level, because you could see where the moisture transport was. It gives you more information than just TPW. I see this being useful for seeing moisture return from the GoM, as different flow regimes often bring moisture up into a region."
> *Forecaster,* "Daily Summary: Week 4, Day 1 (9 May 2016)", *GOES-R HWT Blog*

The Layer PW fields proved to be especially useful in the Norman, OK CWA on 09 May 2016. During the early afternoon mesoscale analysis, forecasters analyzed significantly dry air aloft overrunning moist air at the low levels (Fig. 1). They noted that this drying aloft would contribute to airmass destabilization as the afternoon progressed. Additionally, the low layer PW field depicted the southerly return of moisture along a sharp dry line in western OK. Convection eventually developed ahead of the dryline under the dry airmass, strengthening as it moved east into a region of greater moisture (Fig. 1 inset).

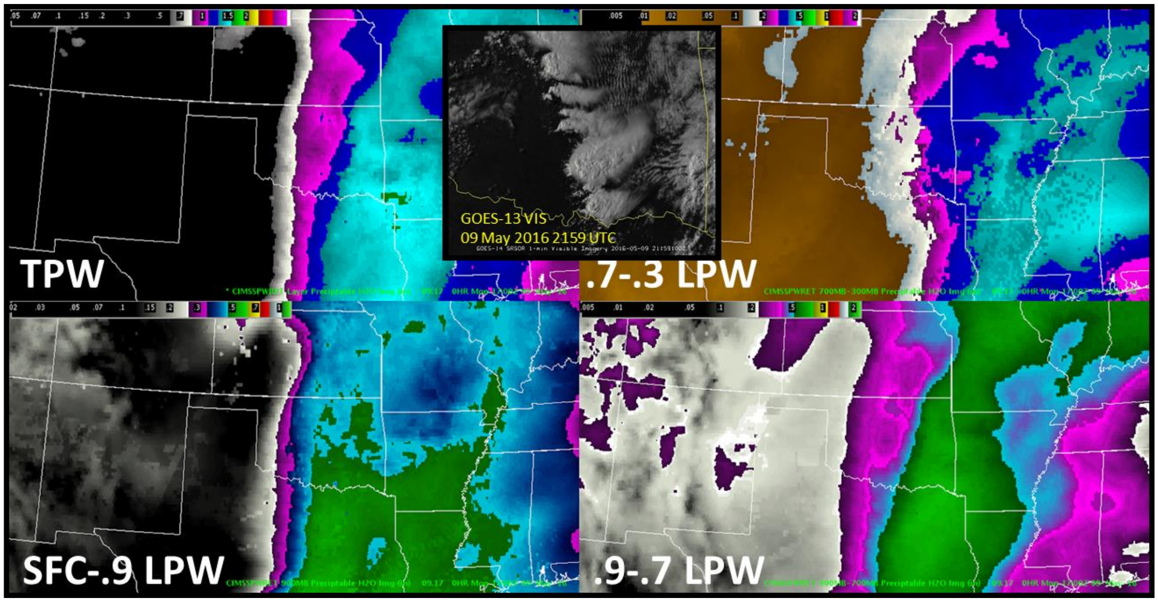

Figure 1: 09 May 2016 LAP precipitable water fields. Total Precipitable Water (upper left), Layer Precipitable Water in the .7-.3 sigma level (upper right), .9-.7 level (lower right), and surface-.9 level (lower left). 2159 UTC GOES-13 VIS satellite image (inset).

Participants appreciated the availability of the "retrieval type" field that allowed them to quickly identify from which source the LAP data were derived at any given point. After analyzing the retrieval type field in conjunction with the thermodynamic fields, participants from each week noted that instability fields (e.g., CAPE, LI) from the GFS model were often underdone when compared to collocated radiosonde data. However, when nearby clear-sky or cloudy sky retrievals were available, instability and moisture values were much closer to those from the radiosonde and other data sources. Since the retrievals use a GFS model first guess, this observation suggested to participants that, when GFS instability was underdone, the retrieval algorithms made a correction in the right direction. The retrieval type field helped to instill confidence in the LAP fields, specifically in areas where clear and cloudy sky retrievals could be computed.

> "We spent some time with the analysis of LAP CAPE and found poor correlation with meso-models/mesoscale analyses when [data] types were anything other than 'Clear Sky'."
> *Forecaster, End-of-Day Survey*

> "[LAP retrievals] correctly increased CAPE... GFS has been underdone for CAPE each day this week, so it was nice to see LAP correctly increase the values."
> *Forecaster, "*Daily Summary: Week 3, Day 3 (4 May 2016)", *GOES-R HWT Blog*

When analyzing the LAP fields at the start of the shift on 03 May 2016, forecasters noted significant differences in values spatially within the instability fields (Fig. 2). In the LAP CAPE fields, values less than 1000 j/kg (point A) were adjacent to values greater than 2000 j/kg (point B). When viewing the LAP retrieval type field, it was obvious that the lower values were in a location where no retrievals were made due to sufficient cloud cover, while the higher values were under clear skies where clear-sky retrievals could be computed. An analysis of other data sources revealed that the higher instability values where retrievals were computed were more in line with the actual present conditions, while the GFS-only values were underdone. Given the presence of high instability computed from the LAP clear-sky retrieval algorithm, forecasters were confident that convection developing in this region would be capable of producing large hail and strong winds. Storms did indeed go on to produce severe hail and wind.

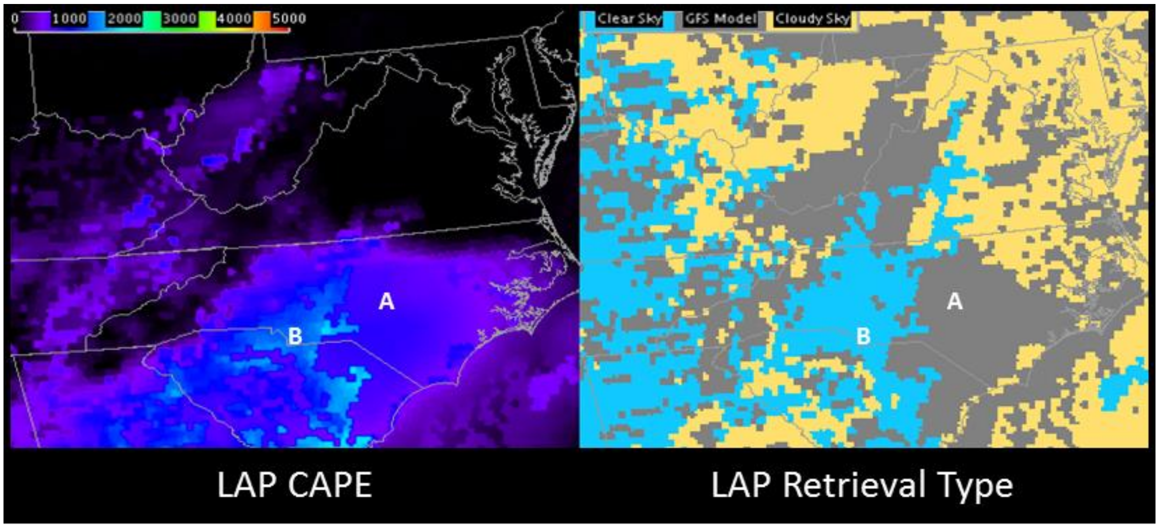


Figure 2: 1600 UTC 03 May 2016 LAP CAPE (left) and LAP Retrieval Type (right). Point A is in an area of GFS-only data, while point B is where clear-sky retrievals were computed.

The LAP fields were often used in concert with and compared against other datasets, including radiosondes, model data (e.g., RAP, GFS), SPC mesoanlysis, and NUCAPS. Forecasters identified advantages of using the LAP fields when these other data sources were also available. LAP has an advantage over radiosondes and NUCAPS in its relatively high (hourly) refresh rate, filling temporal and spatial data gaps. It was already discussed that the retrievals appeared to correct GFS model errors in the right direction when compared to radiosondes, leading forecasters to trust the LAP retrievals over GFS model data. RAP and SPC mesoanalysis also provide hourly updates, but LAP data has less latency (<30 minutes). Additionally, LAP retrieval values appeared comparable to RAP and SPC mesoanlysis in accuracy (when all were compared to radiosonde data). Both LAP and SPC mesosanlysis have disadvantages in that they are tied to the biases of their underlying NWP model. Gradients and trends in the LAP fields usually compared well with the SPC mesoanlysis, however absolute values sometimes appeared too low, likely due to a GFS bias. Several forecasters commented they would like to see forecasts from an NWP model other than GFS (e.g., RAP) used as a first guess in the LAP retrievals over the CONUS.

> "GFS based guidance lags considerably compared to clear sky retrieval areas...RAP guidance would be a better alternative within the CONUS domain."
> *Forecaster, End-of-Day Survey*

> "I compared the LAP stability indices to the SPC mesoanalysis. It seemed like this product closely matched the mesoanalysis in terms of trends and location, but the

magnitude was somewhat underdone when compared to the mesoanalysis, especially in the way of CAPE."
*Forecaster, End-of-Day Survey*

"[Comparing LAP to model] analyses and morning/early afternoon soundings would help the forecaster gain better awareness of how the atmosphere has been changing in the short term, and while an event is ongoing."
*Forecaster, End-of-Week Survey*

Despite the perceived inaccuracies of the GFS, forecasters liked the blended, all-sky nature of the LAP product. Furthermore, by filling in data gaps with the model used in the retrieval first guess, participants were able to use the "retrieval type" field to visualize areas where the retrieval algorithms made the most significant correction. Compared to last year, there were very few comments regarding unrealistic spatial gradients in the LAP fields. The artifacts that were present were due to a transition between retrieval type (clear sky retrieval, cloudy sky retrieval, GFS). These transitions could be identified using the new "retrieval type" field. Forecasters sometimes noted unrealistic changes in LAP values from one timestep to the next. These were likely due to LAP using forecast data from a different GFS model run.

"I liked seeing the model data where retrievals were unavailable. In addition to having a continuous field, it often allowed for quick comparisons of retrievals with nearby GFS."
*Forecaster,* "Week 4 (9-13 May 2016) Summary and Feedback", *GOES-R HWT Blog*

Temporally, while a 1-hour refresh is better or similar to that of other datasets, participants would prefer updates from the LAP fields slightly more often. When asked at the end of each week what the ideal temporal refresh would be for these products, 7/16 (4/16) participants answered 30-minutes (15-minutes), with the 5 other participants were split between 5, 10, and 60 minutes.

"30-min is a good temporal update frequency. Too frequent of updates would not be that useful, as such fields do not change so rapidly."
*Forecaster,* "Week 4 (9-13 May 2016) Summary and Feedback", *GOES-R HWT Blog*

## 3.2 GOES-R Convective Initiation

University of Alabama in Huntsville (UAH) and
NASA Short-term Prediction Research and Transition Center (SPoRT)

For the HWT 2016 Spring Experiment, a newly developed "Severe CI" product was added to the evaluation in addition to the traditional CI product. While the CI product provides the probability of any convective initiation (30 dBz echo) in the next 0-2 hours, Severe CI yields 0-2 hour probabilities that a given cloud object will develop into severe convection. The probabilistic products are produced using a logistic regression framework and a training database of over 500,000 objects. A separate training database of more than ten severe convective days was used to delineate severe CI from non-severe CI. Severe storm reports were used as verification for the severe CI product. The CI products use GOES cloud properties and fields from the Rapid Refresh model to generate the forecasts (Mecikalski et al. 2015). Continued feedback on GOES-

R CI performance and best practices in operations was desired, along with comments on the operational utility of the separate, Severe CI component.

*Use of CI in the HWT*

As in previous years, forecasters viewed the CI product throughout the entire forecast shift each day as an overlay on satellite imagery. Early on in the shift and prior to convective initiation, forecasters monitored the CI product for areas in the cumulus field that would be the first to initiate. Participants found that rather than focusing on the probability of an individual cloud element, more benefit was gained when viewing general trends in a broader group of probabilities. That information alerts the forecaster that the general area is close to supporting deep convective initiation. Just as important as knowing where convection would develop was knowing where convection would not develop, and low to no probabilities in the CI field enhanced forecaster confidence in areas that would remain free of deep convection.

> "It can help forecasters to focus attention on higher risk for development areas, and to pay less attention to lower risk for development areas"
> *Forecaster, End-of-Day Survey*

> "If it highlights the general area of future CI, that is good enough for me. I don't need to know exact cloud."
> *Forecaster,* "Week 2 (25-29 April 2016) Summary and Feedback", *GOES-R HWT Blog*

> "Compared to a fleeting higher CI value, a cluster of high CI and Severe CI values seemed to lend more confidence to the product."
> *Forecaster,* "DFW Mesoscale Discussion May 9", *GOES-R HWT Blog*

> "This image from 18:37Z showed CI values of 80-90%.One hour later at 19:37Z, significant development is apparent with cloud tops approaching -50C."
> *Forecaster,* "GOES CI Useful in Predicting Convective Development on Dryline", *GOES-R HWT Blog*

During the early afternoon hours of 20 April 2016, forecasters were monitoring a cumulus field in San Antonio for sign of convective initiation. Prior to 1815, probabilities across the area remained below 50% (Fig. 3). Thereafter, probabilities began to ramp up, with a small cluster of cloud elements increasing into the 50s at 1815 UTC. By 1845 UTC, probabilities were into the 70s with another nearby cluster. Based on radar reflectivity, the forecaster was confident that convective initiation had occurred in the area by 1906 UTC. Although convection did not develop from the exact location of highest probabilities, and high probabilities fluctuated from cluster to cluster, forecasters were alerted to the general area of increasing values.

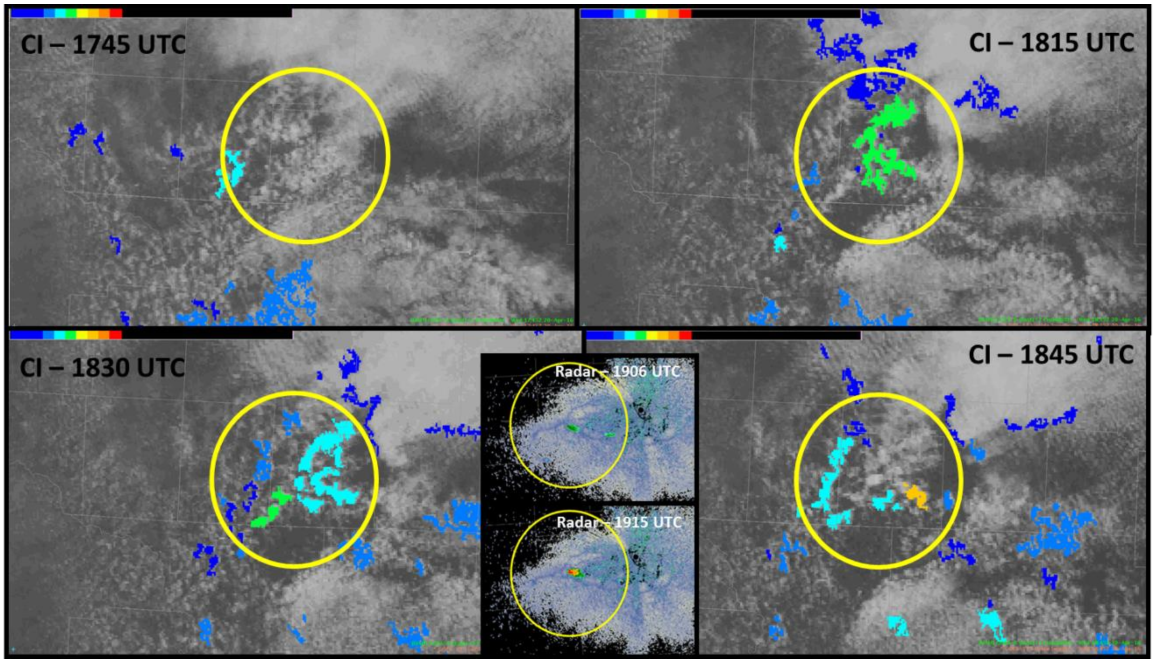

Figure 3: 1745, 1815, 1830, 1845 UTC 20 April 2016 GOES-R Convection Initiation (overlay) and GOES-East VIS. 1906 and 1915 UTC radar reflectivity (inset).

At the end of each week, 10 out of 16 forecasters answered that the CI products added "some" (3/5) impact/value to the operational nowcast/forecast process, while five answered "large" (4/5) or "very large" (5/5), and one answered "very small" (1/5). At the very least, most forecasters agreed that it enhanced their situational awareness during shift to the most likely areas of imminent initiation. In fact, forecasters answered that that on 77% of days, the CI products were useful in short-term situational awareness. In situations where convection did develop, forecasters responded that probabilities increased in the region prior to initiation 88% of the days. Lead-time from CI probabilities over 50% to convective initiation most often ranged anywhere from zero minutes to one hour.

> "CI was helpful in identifying areas of future convective development. Good for situational awareness. When CI severe showed high probabilities it acted as an alert."
> *Forecaster, End-of-Week Survey*

> "It drew my attention to cumulus fields that could be ready to convect. At the very least, it triggered me to more closely look at the mesoscale environment in these regions."
> *Forecaster, End-of-Week Survey*

> "While storms have been developing across southern OK and near the OK/TX border...A jump in CI much closer to Dallas has shifted my attention southward."
> *Forecaster,* "CI good for situational awareness", *GOES-R HWT Blog*

Post convective initiation, at least one person in each pair would continue to monitor the CI product. In busy situations where both forecasters were issuing warnings, CI provided a quick and easy means of identifying areas of new development. In situations of strong forcing along a boundary, CI proved to be an excellent decision aid for continued thunderstorm development down a line.  Such was the case on 19 April 2016, when CI signaled continued development southwest along a flanking line of convention (Fig. 4).

> "CI did well with flanking line development, I was impressed with this."
> *Forecaster,* "Daily Summary: Week 1, Day 2 (April 19, 2016)", *GOES-R HWT Blog*

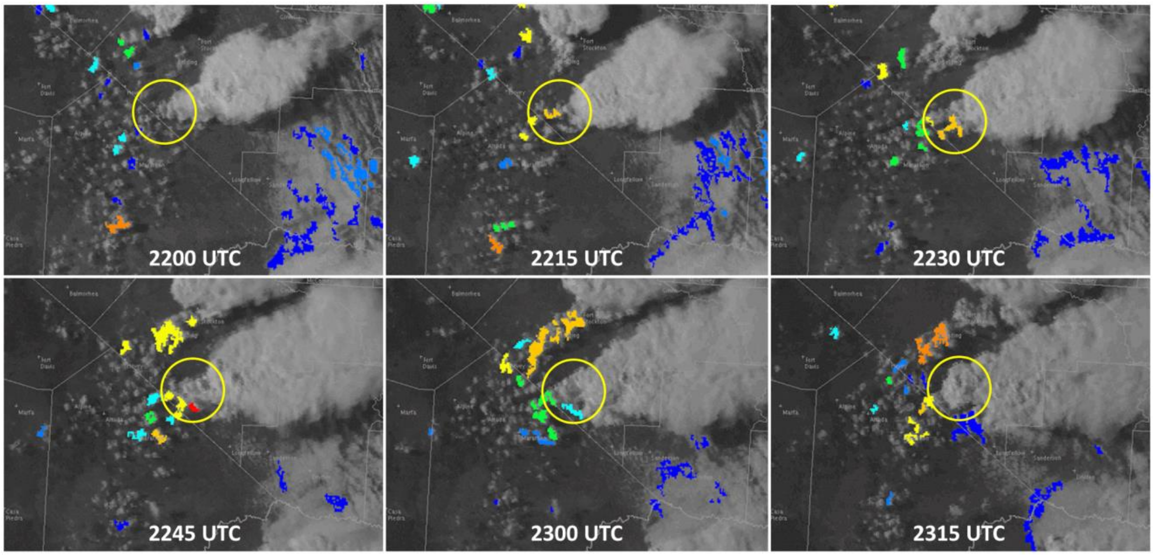


Figure 4: 2200, 2215, 2230, 2245, 2300, 2315 UTC 19 April 2016 GOES-East VIS, GOES-R CI. Yellow circle indicates region of flanking line development.

By the end of the experiment, all but one participant acknowledged a benefit in having a separate Severe CI product in addition to the regular CI. This component was added based on feedback from previous HWT experiments. Although CI is certainly useful in many forecast situations, on severe weather days, forecasters are most concerned with where severe convection will develop. In situations where the severe CI component worked well, forecasters were able to further hone in on regions of potential convective initiation that were most likely to develop into severe convection. There were many situations where regular CI was hitting on a very broad area, but severe CI focused in on local regions of more vigorous future convective development, allowing forecasters to focus their attention. Severe CI did not appear to perform differently based on the threat (i.e. wind, hail, tornado.)

> "I think the better value in an expected severe weather situation is the severe CI. The CI kind of gets things started, but then a shift to Severe CI is what I typically focused on. In situations where non-severe weather or general thunderstorms are likely, then I would focus more on CI."
> *Forecaster, End-of-Week Survey*

> "CI picked up on a broad area where convection developed, and severe CI focused in on where the best storms ended up developing."
> *Forecaster,* "Week 2 (25-29 April 2016) Summary and Feedback", *GOES-R HWT Blog*

“We noticed a strong cluster of CI severe values around 90 percent in the Southern portion of our CWA around 20:45z. About an hour later these clouds had developed into likely severe thunderstorms, with dbz values of 60+.”
*Forecaster,* “CI Severe comparison & verification with Prob Severe”, *GOES-R HWT Blog*

Severe CI correctly highlighted future areas of Severe Convection within a broader field of elevated CI probabilities in the Lubbock, TX CWA on 28 April 2016 (Fig. 5). Regular CI probabilities increased from less than 30% at 1845 UTC, to over 50% at 1900 UTC, and over 75% at 1930 UTC. At this time, forecaster confidence was high that convection would develop within this region of elevated regular CI probabilities, but severity was uncertain given severe CI remained less than 30%. At 1945 UTC, regular CI continued to increase to over 80%, and Severe CI rose dramatically to over 70% within a smaller region of the cu field. The high values persisted over the next hour, resulting in high forecaster confidence that convection developing from these high severe CI values would become severe. Deep convection continued to strengthen beyond 2030 UTC, and the first report of hail (1 inch) came in at 2124 UTC. These storms would go one to produce at least 2 inch sized hail in addition to damaging winds.

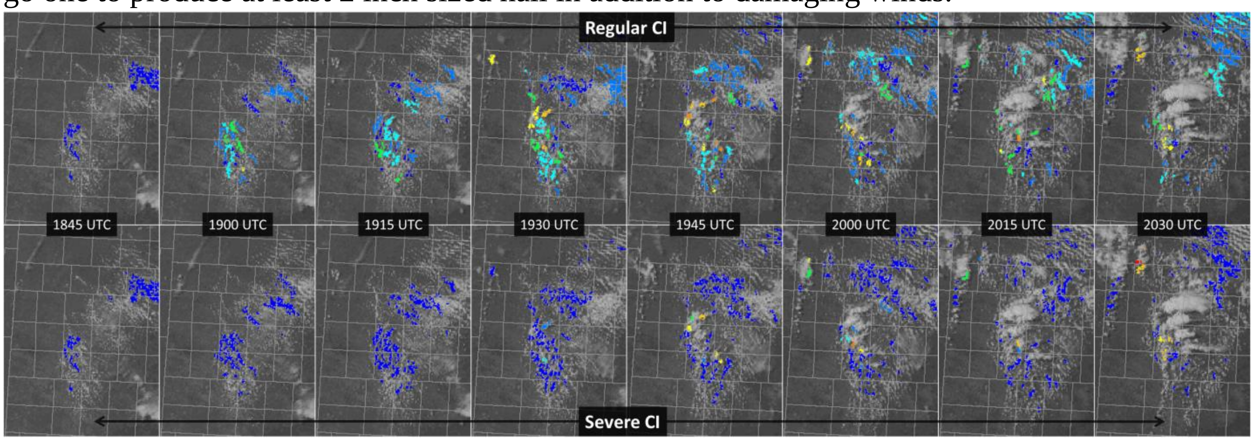


Figure 5: 1845 – 2030 UTC 28 April 2016 GOES-East VIS, regular CI (top), and severe CI (bottom).

*Limitations of CI product*

As with previous years, forecasters noted deficiencies in the CI product. Performance under all but the thinnest cirrus clouds suffered significantly with underrepresented to missing values due to the opaqueness of the high clouds in IR imagery. With rapidly developing convection, high/increasing CI probabilities were sometimes available too late to provide benefit to the forecaster, especially when the satellite was in routine, 15-30 minute scan mode. Furthermore, the availability of 1-min satellite imagery allowed forecasters to identify the early onset of rapidly developing storms prior to increases in CI probabilities. Forecasters foresee the CI algorithm benefiting considerably from the higher temporal (and spatial/spectral) resolution imagery that will be available in the GOES-R era. Finally, some forecasters noted a significant amount of false alarm in the product, making it difficult to use reliably on some days.

> “Regular CI generally did a good job of identifying agitated cumulus and probable CI. However, there were times when false alarms were high (high probabilities were indicated and CI failed to occur).”
> *Forecaster, End-of-Week Survey*

> “With the 1 minute imagery, I could tell on my own which cells were going to go up fairly quickly and by the time CI caught on there really wasn't too much added value.”
> *Forecaster, End-of-Week Survey*

> “There were several instances where the CI values remained low, due to middle to high clouds blocking the view of the cumulus development below. There was CI with a few of the cells with low CI probabilities in these situations.”
> *Forecaster, End-of-Day Survey*

A majority of forecasters commented that significant performance improvements will need to be made in order to make Severe CI useable in an operational environment. The most common issue noted by participants was that Severe CI probabilities were often too conservative, never moving above 10% on some days, despite the later development of severe storms. Given the conservative performance, false alarms were not as common as what was seen with the regular CI algorithm. Some forecasters acknowledged that severe CI provided the best guidance on days when a strong capping inversion was in place. On such days, the product indicated increasing probabilities just prior to the cap breaking and deep convection developing. A few forecasters commented that Severe CI was not necessary for them as it did not provide significant benefit over regular CI. Finally, on multiple occasions Severe CI probabilities exceeded those of regular CI for the same cloud object, which did not make sense conceptually to the forecasters.

> “I'm not sure if the severe CI product would help much, as we already know the environment in which these cells are developing.”
> *Forecaster, End-of-Week Survey*

> “Severe CI rarely 30%, and never exceeded 40%, despite the fact that we did have several severe reports.”
> *Forecaster, End-of-Day Survey*

*Comments on product display*

Generally, forecasters had few negative comments about the display. The one common complaint was associated with the color table, which is editable in AWIPS by the user. The color blue on the color table, which represents values less than 30%, stood out versus higher probabilities, particularly the lighter blues used up to 50%. Some forecasters changed the colors, while others made values less than 30% transparent, commenting that the lowest range did not add much value. Also, forecasters would appreciate an indication that convective initiation has occurred for a given cloud element and therefore is no longer being sampled by the algorithm.

> “Shades of gray might be better for lower probs. Dark blue stands out too much, especially against clouds.”

*Forecaster,* "Daily Summary: Week 2, Day 3 (27 April 2016)", *GOES-R HWT Blog*

*Other comments*

"As a broadcaster, I would love to have this in my office. Often I don't have as much time to analyze the weather before my broadcast. This is something I could have up when I begin my day."
*Forecaster,* "Week 2 (25-29 April 2016) Summary and Feedback", *GOES-R HWT Blog*

"This would be more useful for the shift coordinator, and for DSS, over the warning forecaster."
*Forecaster,* "Week 2 (25-29 April 2016) Summary and Feedback", *GOES-R HWT Blog*

## 3.3 ProbSevere Model

Cooperative Institute for Meteorological Satellite Studies (CIMSS)

The NOAA/CIMSS ProbSevere model was evaluated in the HWT for the third consecutive year, with updates made since last year's experiment. The statistical model produces a probability that a developing storm will first produce any severe weather in the next 60 minutes (Cintineo et al. 2014). The data fusion product merges NWP-based instability and shear parameters, satellite vertical growth and glaciation rates, radar derived maximum expected size of hail (MESH), and total lightning information. The addition of the total lightning component was new for 2016, and used data from the Earth Networks Total Lightning Network. A developing storm is tracked in both satellite and radar imagery using an object-oriented approach. As the storm matures, the NWP information, lightning data, and satellite growth trends are passed to the overlapping radar objects. The product updates approximately every two minutes and is displayed as contours that change color and thickness with probability to be overlaid on radar imagery. Data readout is available by mousing over the probability contour, revealing the probability of severe along with the model predictor values. The product was evaluated on its ability to increase forecaster confidence and skillfully extend lead time to severe hazards for NWS warnings during potential severe weather situations. Additionally, feedback regarding the product display and readout was desired.

*Use of ProbSevere in the HWT*

Forecasters loaded the ProbSevere contour as an overlay on either their base radar imagery, or MRMS products (e.g., Composite Reflectivity, MESH) at the beginning of each shift. Early in the shift, it alerted forecasters to the first significant storms of the day. Forecasters consistently commented that ProbSevere provided great situational awareness, alerting them to storms that needed further interrogation. This was especially important in busy warning situations where many storms were present, as ProbSevere helped the forecaster to quickly rank the storms (Fig. 6). In situations where justification for warning issuance was borderline based on standard data, ProbSevere was sometimes the deciding factor. Of course, forecasters did not use ProbSevere alone to issue warnings, but instead based their decisions on what ProbSevere was showing in context with other observational datasets

"There were several occasions when I was very busy across the CWA with multiple warnings going out at one time. In these situations, I used ProbSevere to highlight which storms needed the most attention."
*Forecaster, End-of-Week Survey*

"Our one hail-maker in St Louis made it into the 90s. ProbSevere did well on that cell. Otherwise, we didn't see many storms go over 10, which was good since we didn't have any other severe."
*Forecaster,* "Daily Summary: Week 4, Day 3 (11 May 2016)", *GOES-R HWT Blog*

"I think it is especially helpful for the first cells of the day. It was helpful for marginal cells at the beginning of the shift that were on the edge of becoming severe."
*Forecaster,* "Daily Summary: Week 4, Day 1 (9 May 2016)", *GOES-R HWT Blog*

"Especially on marginal days with a lot of subsevere wind and hail and trying to decide to warn or not, seeing a jump in ProbSevere gave me confidence to warn, and not seeing it also gave me confidence not to warn."
*Forecaster,* "Daily Summary: Week 3, Day 1 (2 May 2016)", *GOES-R HWT Blog*

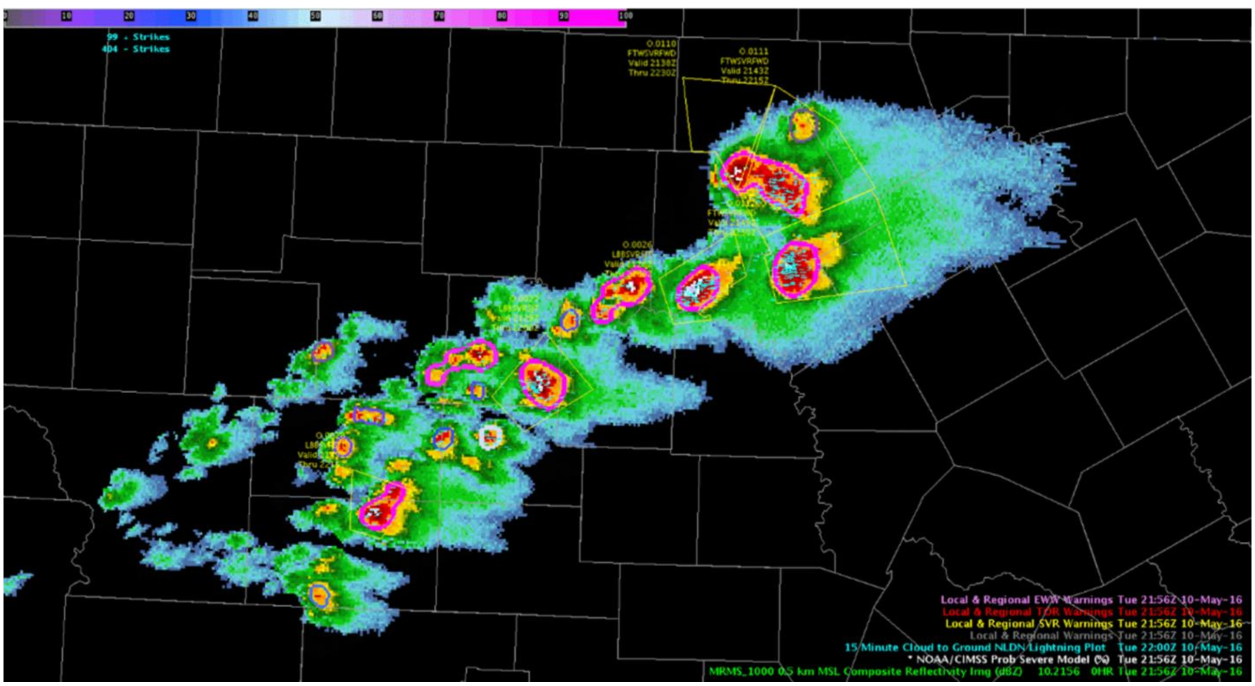

Figure 6: 2156 UTC 10 May 2016 MRMS Composite Reflectivity, ProbSevere Model contours, warning polygons, NLDN 15-min cloud-to-ground lightning. During this busy warning situation, the ProbSevere Model helped forecasters rank storms in order of most imminent need for further interrogation.

Later in the day, forecasters continued to utilize ProbSevere to check for newly strengthening storms, as well as for monitoring the evolution of storms that had already produced severe. Sustained high probabilities led forecasters to continue warnings for a storm, while decreasing trends increased forecaster confidence in letting a warning expire or in not issuing a new warning.

> "It's excellent confirmation of ongoing severe weather, a great overview tool for the warning coordinator to use, and works well when making continuation decisions."
> *Forecaster, End-of-Day Survey*

> "Reverse trend helped. The storm went up, produced severe, then ProbSevere values dropped. At that point I knew I could let the storm go."
> *Forecaster,* "Daily Summary: Week 3, Day 1 (2 May 2016)", *GOES-R HWT Blog*

At the very least, ProbSevere enhanced forecaster confidence when issuing convective warnings. In fact, on days when using ProbSevere was used in warning decisions, forecasters felt that it increased their confidence in issuing those warnings 100% of the time (44 answers). Rapid or large jumps in probabilities captured the forecaster's attention and led to more confident warnings. The quick jump in probabilities was a key indicator that a storm would soon become severe. Forecasters suggested, however, one wait for at least two scans of high or increasing probabilities before making a decision. There were many days (50%) in which forecasters felt ProbSevere increased lead-time to warning issuance. Forecasters commented that lead-time was most often in the 0-10 minute range ahead of when they would likely have issued based off of radar alone. When asked after each shift if they would use ProbSevere in operations, only one out of 62 responses was "no" (see first comment below).

> "Every other day I said yes [to using ProbSevere in operations], but based on the poor performance of the product today in the SE, I would be hesitant to rely on this product."
> *Forecaster, End-of-Day Survey*

> "For the most part, ProbSevere provided 5-10+ minute lead times for severe storm development, over and above just using the radar."
> *Forecaster, End-of-Week Survey*

> "Without ProbSevere I would have waited to warn. It definitely added lead time in that situation."
> *Forecaster,* "Daily Summary: Week 4, Day 2 (10 May 2016)", *GOES-R HWT Blog*

> "The next storm had a rapid increase in probabilities early in its development, but since the previous one did not produce right away, I did not warn based on my previous experience, which was the correct decision."
> *Forecaster,* "Daily Summary: Week 3, Day 2 (3 May 2016)", *GOES-R HWT Blog*

The impact of the satellite predictors on the ProbSevere probabilities was evident to participants throughout the experiment. One particular example of strong satellite growth rates impacting probabilities occurred during operations in the Blacksburg CWA on 28 April 2016. From 1844 UTC to 1850 UTC, probabilities rose from 20% to 51% due primarily to a rise in MESH and lightning (Fig. 7). ProbSevere saw a rapid increase in probabilities over the next 2 minutes solely due to an increase in both satellite fields from weak to strong and moderate. The rapid increase attracted forecaster focus to this particular storm. Probabilities proceeded to slowly increase to 88% by 1908 UTC, when a severe thunderstorm warning was issued by the forecaster. Severe hail was first reported with this storm at 1936 UTC.

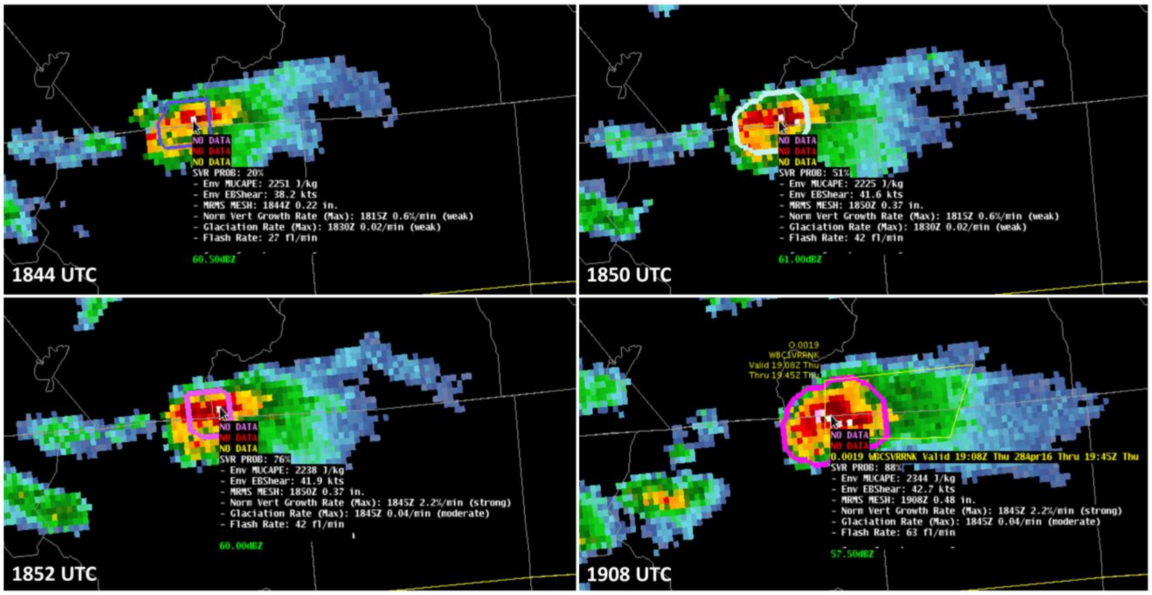


Figure 7: 1844, 1850, 1852, 1908 UTC 28 April 2016 ProbSevere probability contour (overlay), ProbSevere readout (text), and radar reflectivity.

ProbSevere was a key component in a severe thunderstorm warning decision for a rapidly developing thunderstorm on 03 May 2016 in the Raleigh, NC CWA. ProbSevere probabilities increased from 46% at 2144 UTC to 95% at 2146 UTC (Fig. 8). Despite weak satellite growth rates, high MESH combined with a high lightning flash rate in a favorable environment allowed for the significant probabilities. The rapid increase in probabilities to high values, combined with the appearance of a three-body scatter spike in radar reflectivity imagery, prompted the issuance of a severe thunderstorm warning at 2149 UTC. Severe hail of 1” was first reported with this storm at 2225 UTC.

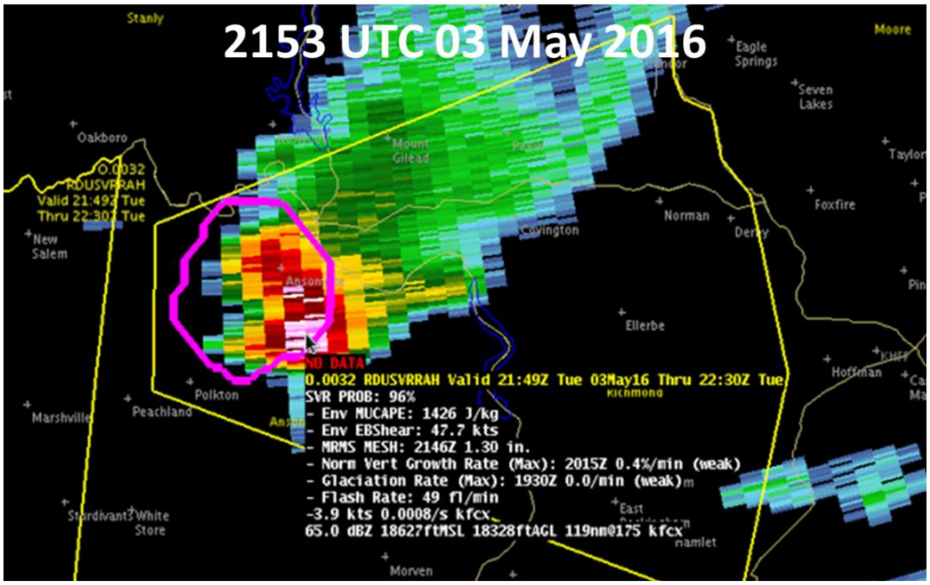

Figure 8: 2153 UTC 03 May 2016 ProbSevere probability contour (overlay), ProbSevere readout (text), severe thunderstorm warning polygon, and radar reflectivity.

ProbSevere is also currently being tested within NWS forecast offices. Forecasters from such offices were able to provide the group with additional insight based on their longer-term use of the product.

> "We have been using Prob Severe for several years at our WFO, and it is very helpful with evaluating storms and maintaining situational awareness."
> *Forecaster, End-of-Day Survey*

> "In my office, the threshold to warn depends on the day, but I've found with most of our events, especially with severe wind, we can get severe with a threshold of ~60%. Definitely not using it as a yes/no."
> *Forecaster*, "Week 4 (9-13 May 2016) Summary and Feedback", *GOES-R HWT Blog*

*Limitations of ProbSevere and suggestions for improvement*

There were instances commonly pointed out where ProbSevere was not as effective. With rapidly developing thunderstorms, forecasters often found that high ProbSevere probabilities lagged slightly behind the strengthening seen in radar products. When storms developed in close proximity to each other (or split), ProbSevere sometimes grouped them into one contour. In such situations, forecasters did not put much trust into the probabilities. An idea for improvement was to track mature storm objects using a higher reflectivity threshold or track using a threshold at a higher radar scan elevation.

> "We had some clusters of cells that were grouped into a single contour. It was difficult to trust the ProbSevere in these situations."
> *Forecaster, End-of-Day Survey*

"Some caution needs to be exercised with ProbSevere. Due to the lag that comes from using MRMS data, there were some occasions in which ProbSevere indicated the threat was diminishing, the raw radar data was showing an increasing severe threat."
*Forecaster, End-of-Day Survey*

"Using the composite MRMS washes out individual cores along a line. We knew there was a severe core on one end of the line… but the whole line was one big ProbSevere contour."
*Forecaster, End-of-Day Survey*

"With the storm on the west side of DC, we had a storm split, but ProbSevere grouped the storms together, so it was unclear from which cell the information was coming."
*Forecaster,* "Week 3 (2-6 May 2016) Summary and Feedback", *GOES-R HWT Blog*

As was experienced in previous years, the ProbSevere probabilities seemed to be most useful when hail was the primary severe threat and discrete thunderstorms the primary mode. Given this, forecasters would like to see probabilities improved for wind and tornado threats. Ideas for fields that may improve threat-specific probabilities were provided by participants. Users would also like to have a separate product display for each specific threat (i.e. wind, hail, tornado), in addition to the current all severe product display. Forecasters agreed that they would load the four components in a 4-panel display. Participants suggested that ProbSevere could benefit from being further trained to specific regions and seasons.

"The algorithm seemed to perform best when convection was first developing and strengthening and on cells that were more isolated/not clustered."
*Forecaster,* "Day 2 Wrapup: Tue, May 10", *GOES-R HWT Blog*

"ProbSevere did not respond very well to a wind threat from a storm today. I don't think it even reached 30%."
*Forecaster, End-of-Day Survey*

*Comments on product display*

In general, forecasters liked the ProbSevere contour display and readout, and agreed that it was unobtrusive in most situations. Only rarely did forecasters comment that the contour masked important information below. There were also a few instances where forecasters would prefer an alternative color scheme. Given the importance of the trends in probabilities, forecasters would like a method of easily viewing the rate-of-change of ProbSevere probabilities, perhaps in the form of a graphical readout (e.g., meteogram). With the addition of total lightning to the algorithm, forecasters would appreciate seeing the "sigma lightning jump" value in the readout, ideally with a graph depicting the total lightning trend. Participants were fine with the amount of information currently in the cursor readout, but warned that as new predictors are added, the readout could get too cluttered. Allowing the user to select which readout to be displayed would help with this.

> "I like the read-out, where you can see what parameters are likely driving the increase or decrease in ProbSevere values."
> *Forecaster, End-of-Week Survey*

> "I found that while the probabilities are helpful, the rate of change of probabilities is also helpful. I wonder if a product could be made that simply shows the rate of change of probabilities."
> *Forecaster, End-of-Day Survey*

## 3.4 GOES-14 Super Rapid Scan Operations for GOES-R 1-min imagery

Cooperative Institute for Research in the Atmosphere (CIRA), Cooperative Institute for Meteorological Satellite Studies (CIMSS), and National Severe Storms Laboratory (NSSL)

GOES-14 was out of storage mode and operating in Super Rapid Scan Operations for GOES-R (SRSOR; Schmit et al. 2013 and 2014) mode from 18 April to 15 May. The location of the approximately 1500 km x 2000 km sector of 1-min satellite imagery was adjusted daily based on the expected area of most active hazardous weather. 1-min VIS, IR, and WV imagery was available in AWIPS-II for EWP participants to view for the entirety of the 2016 GOES-R/JPSS Spring Experiment. Additionally, the EFP side of the HWT utilized the imagery in NAWIPS during daily experimental operations. Finally, SPC forecasters evaluated the imagery in NAWIPS in SPC operations (Line et al. 2016). This report will focus on feedback received during the HWT EWP experiment.

GOES-14 SRSOR demonstrates a capability of the GOES-R ABI when in Mode 3 "flex mode" scan strategy, which will include 30-sec imagery over one 1000 km x 1000 km sector, or two 1000 km x 1000 km sectors of 1-min imagery. The 1000 km x 1000 km refers to the size of the sector at the satellite sub-point. In addition to the regular imagery, parallax-corrected 1-min VIS and IR imagery was available for forecasters to view in AWIPS-II. In addition to familiarizing users with a future ABI capability with respect to its temporal resolution, the EWP evaluation sought to learn how the forecaster can incorporate very high resolution satellite imagery into his/her convective warning process.

*Use of 1-min satellite imagery in the HWT*

As in past experiments, the 1-min imagery was one of the highest favored, operationally useful, and most anticipated GOES-R capabilities evaluated by participants. At the end of each day, when asked to rate the overall impact of the 1-min satellite imagery for that day, 71% (out of 63 total answers) of forecasters responded very high positive impact (5/5), 21% answered a 4/5, and 8% answered moderate positive impact (3/5). No forecaster ever answered below a 3/5. After using the imagery for a whole week, forecasters (16 total) were asked to rate the impact of 1-min imagery on improving convective nowcasting and warning operations on a scale of 1-5, five being the greatest positive impact. Fourteen forecasters answered five, one forecaster answered four, and one forecaster answered three. Forecasters acknowledged the many benefits of 1-min satellite imagery beyond convective cases (e.g., aviation, fire weather), and look forward to taking advantage of it in those instances as well.

> “1-minute satellite imagery is a ‘home-run’ for the operational community.”
> *Forecaster, End-of-Week Survey*

> “Huge for severe weather operations and just day-to-day forecasting as well. This is a must and the quicker operational forecasters have access to this the better.”
> *Forecaster, End-of-Week Survey*

Forecasters have commented that there are many significant features and processes that occur within a 15- and 5-min period that are missed in current GOES imagery. They quickly learned that 1-min imagery effectively fills the gap and allows forecasters to observe features and processes important to convective development and evolution earlier than is currently possible from current satellite data. Forecasters can see processes occur in real-time, instead of waiting to see what has happened in the past “x” minutes. Simply put, imagery at 1-min intervals appears smooth and continuous, becoming choppy as the gap between scans increases. In the daily survey, all but one (61/62) forecasters responded that the 1-min imagery provided them with significant information not captured in the routine satellite imagery. The benefit was realized in all stages of convective evolution, including the pre-convective environment, post-convective initiation, and in null events.

> “It cannot be overstated how helpful it is to have satellite information flowing every minute compared to having to wait 15 minutes or more without knowing what is going on.”
> *Forecaster, End-of-Week Survey*

> “Such a high temporal refresh allows forecasters to see trends and signatures not easily discernable with 15+ minute refresh times.”
> *Forecaster, End-of-Week Survey*

> “I didn't realize how much information is lost with only a snapshot every 15 minutes. It's analogous to driving a car and only looking up briefly a few times per minute. You might make it some distance down the road before running into trouble, but eventually you'll miss something important and end up crashing”
> *Forecaster, End-of-Week Survey*

> “I have heard a lot of talk about the 1 minute vs. 5 minute imagery and which is necessary. I really feel like to add a lot of value to the warning process, 1-minute data is necessary. We already get radar data about every 5 minutes and sometimes more often with SAILS and AVSET. Therefore while 5 minute data would certainly be better than what we have now, 1 minute data could really fill in the gaps between radar scans and provide that extra information a forecaster may need to warn on a storm between radar scans.”
> *Forecaster, End-of-Week Survey*

Perhaps the greatest benefit of the very high temporal resolution satellite imagery came in the period leading up to convective initiation. In particular, the 1-min data greatly enhanced the forecaster’s ability to identify and track boundaries and possible boundary interactions that were relevant to future convective development. Additionally, forecasters continually appreciated their improved ability to track trends in the cu field, identifying areas where cumulus clouds were appearing more likely than others to develop into deep convection in the near future. Cumulus cloud trends at 1-min resolution provided real-time information on how close the capping inversion was to breaking and where, as well as where the greatest forcing was present. Finally and as expected, forecasters observed deep convective initiation earlier than was possible in GOES-East or -West routine or rapid scan data.

> "Watching the cloud streets and any agitated cumulus within those cloud streets gave me more confidence that certain areas would develop more than others."
> *Forecaster, End-of-Day Survey*

> "It was easy to see the moderate to towering cumulus as they were on the brink of breaking the cap."
> *Forecaster, End-of-Day Survey*

> "1-min data greatly improves a forecaster's ability to track low-level boundaries in real-time. Outflow boundaries, fronts, differential heating boundaries, etc are all better resolved with a higher temporal resolution."
> *Forecaster, End-of-Day Survey*

> "For initial development along the dryline, convection went up very fast. Without 1-min data, we wouldn't have been able to recognize so soon that convective initiation was occurring."
> *Forecaster,* "Daily Summary: Week 4, Day 1 (9 May 2016)", *GOES-R HWT Blog*

After convective initiation, forecasters continued to realize the benefits of increased temporal resolution satellite imagery. During initial deep convective development, forecasters were able to easily identify the most rapidly developing storms, and therefore most imminent areas of severe potential. Forecasters commonly commented on their improved ability to track overshooting tops as an assessment of updraft trends and strength. Forecasters could quickly asses which storms had persistent strong updrafts and therefore greatest severe potential. When vast anvils began to fill the scene, the 1-min imagery often picked out new development just prior to being masked by the cirrus clouds, between routine GOES scans. Because forecasters could more easily track boundary movement, they could better anticipate boundary-storm interactions. Signs of splitting cells were sometimes first identified with confidence in the 1-min satellite imagery before being confirmed in radar imagery. The 1-min imagery was used in conjunction with radar data during warning operations, acting to fill the gap between routine 5-min radar scans. When radar was in SAILS (~2.5 min low-level scans) or meso-SAILS (~1-min low-level scans) mode, the 1-min imagery was vital in showing storm trends aloft, as upper-level radar scans become less frequent.

> "Seeing the overshooting tops was useful in identifying which storms had the strongest updrafts."
> *Forecaster, End-of-Day Survey*

"High temporal and spatial resolution allows for direct comparison with radar imagery, which is helpful when monitoring trends with storms. It can give higher confidence to issue (or not issue) warnings."
*Forecaster, End-of-Day Survey*

"Overshooting tops were detected quicker this way. Radar techniques may delay detection as much as 8-9 minutes over 1 minute vis satellite given longer volume scan times now with meso-SAILS. 19.5 cuts come less frequently for example. This is where satellite techniques can significantly help warning operations."
*Forecaster, End-of-Day Survey*

"There were a few occasions that 1-min imagery influenced my warning decisions in a positive way. I noticed that in some well-established thunderstorms, the 1-min imagery showed explosive growth in the storm that really stood out when compared to what the storm previously looked like, and severe weather usually followed within 30 minutes. On one occasion, this explosive growth only evident in the 1-min imagery was enough to convince me to issue a warning, which did verify."
*Forecaster, End-of-Week Survey*

Early identification of null convective events and a decreasing severe threat were also better visualized in the 1-min imagery. The stable character of a cu field was telling to a forecaster that convective activity was not imminent. The effect a boundary or gravity wave had on atmospheric stability was readily apparent in 1-min imagery, helping forecasters to rule out areas of future development. The evolution of boundaries and their effect on the environment becomes more difficult to discern in less frequent imagery. For a developed storm, the lack of overshooting tops or texture at the storm top indicated that updrafts were not particularly robust. Downward trends in overshooting top abundance and strength were indicators that storm intensity and coverage may be waning. Similarly, the slowing spread and decreasing sharpness of storm anvil edge were also indicators of convective decay captured nicely in the 1-min imagery.

"Once again, flat/stable looking cumulus elements were identified, which were able to rule out robust/severe convection."
*Forecaster, End-of-Day Survey*

"1-min SRSOR visible imagery confirmed the weak and shallow nature of the convection that developed"
*Forecaster, End-of-Day Survey*

"It aided with helping me determine that some cells were slowly weakening, or just not getting any stronger. This gave me more confidence to not issue warnings."
*Forecaster, End-of-Day Survey*

"On a marginal day, like yesterday, 1-min imagery was very helpful to differentiate the rapid vertical development from all the "noise" of surrounding non-severe storms."
*Forecaster, End-of-Week Survey*

The 1-min VIS imagery played an important role in forecast decision-making on 18 April 2016 in southern Texas (Fig. 9). A supercell thunderstorm had developed along the intersection of two boundaries in an atmosphere conducive to tornadic storms. Prior to issuing a warning, the forecaster noticed in the 1-min imagery that the storm was beginning to lag behind the boundaries into a region of low-level cool, stable air. Given this, the forecaster was confident that the storm would become elevated and pose little tornado risk, and therefore issued a severe thunderstorm warning. No tornado was reported with this storm.

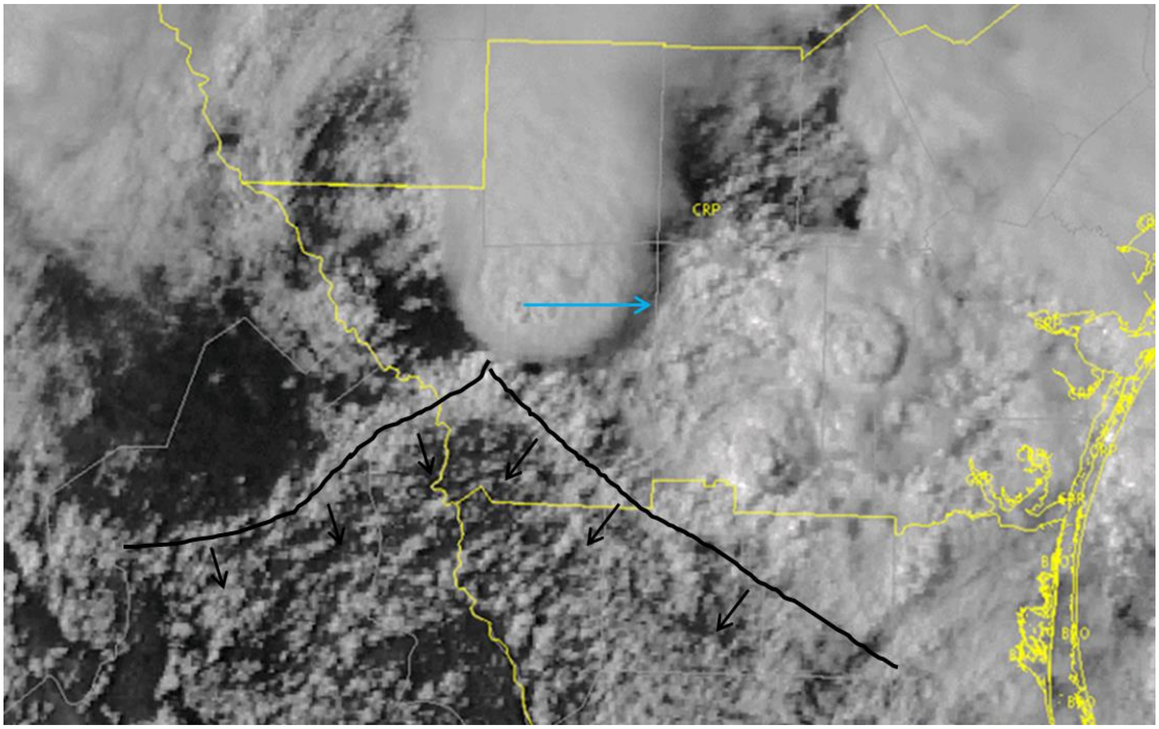


Figure 9: 2138 UTC 18 April 2016 GOES-14 1-min VIS imagery. Black lines indicate locations of boundaries, black arrows indicate general direction of boundary movement, and blue arrow indicates general direction of supercell movement.

When operating in geographic regions of poor radar coverage, forecasters commented on the enhanced utility of the 1-min imagery in filling radar gaps.

> "The 1-minute imagery really helped me key in on areas to watch for convective development especially since there was radar beam blockage going on. It showed me which storms were strengthening with overshooting tops and it also help me identify low level circulations that convection was firing off of."
> *Forecaster, End-of-Day Survey*

> "There was one occasion in a radar sparse area that the 1-min imagery showed explosive growth in the thunderstorm. Despite little in the way of traditional severe weather signatures, this explosive growth only shown in the 1-min imagery gave me the confidence to issue a warning. About 20 minutes after warning issuance, thunderstorm winds at 60 mph were reported out of this line."
> *Forecaster, End-of-Day Survey*

Forecasters also found value, albeit to a lesser extent, in the 1-min IR imagery. There were instances during the day when forecasters utilized IR 1-min imagery in addition to or in combination with the VIS imagery. By overlaying partially transparent IR imagery on the VIS imagery, forecasters could view a quantitative measure of storm growth/decay (brightness temperature from IR imagery) along with the texture (VIS imagery) all in one image (Fig. 10). The IR imagery allowed forecasters to get a rough estimate of clout top growth and decay rates by computing IR temperature trends. Viewing IR temperatures in the context of proximity soundings helped forecasters determine whether cloud tops were reaching critical thresholds related to storm initiation or hail development.

> "Overlaying the IR with the visible imagery was helpful, to get cloud top temperatures and note trends with them. I can also compare this with radar imagery directly, to see how storms are developing and monitor trends."
> *Forecaster, End-of-Day Survey*

> "I was able to use IR and see cloud top temperatures that were well into the convective layer according to proximity soundings. That was useful as storms were developing."
> *Forecaster, End-of-Day Survey*

> "I like the idea of comparing IR temperatures to the atmospheric profile. This could be a flag to cloud tops reaching a critical threshold like the -20C layer or a layer above a mid-level cap."
> *Forecaster, End-of-Week Survey*

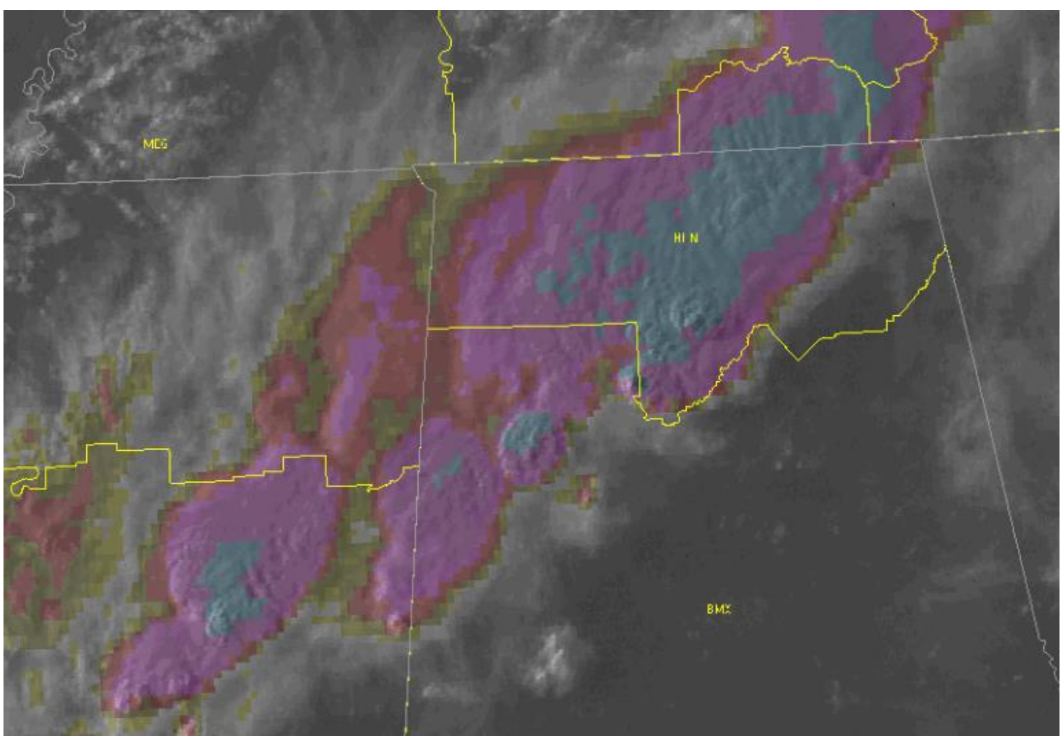


Figure 10: 2347 UTC 12 May 2016 GOES-14 1-min imagery VIS (underlay) and IR (transparent overlay) imagery.

*Use of parallax-corrected 1-min satellite imagery in the HWT*

New to the HWT this year was the availability of parallax-corrected 1-min VIS and IR imagery in AWIPS-II. In real-time, the imagery corrects the parallax error present in satellite data, placing elevated features (e.g., convection) into a more accurate geographic position. By overlaying other datasets such as total lightning on un-corrected and parallax-corrected imagery, forecasters immediately got a feel for how significant the error could be (especially at high latitudes), and that the algorithm makes a proper adjustment to the imagery (Fig. 11).

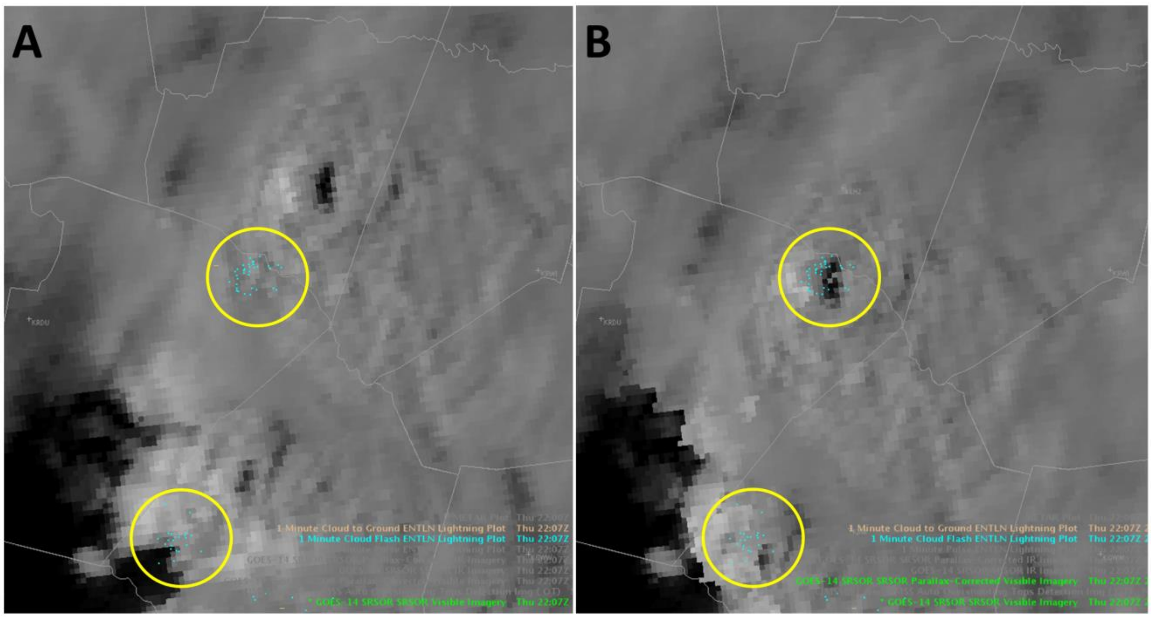


Figure 11: 2207 UTC 28 April 2016 GOES-14 1-min VIS imagery A) un-corrected and B) parallax-corrected, and ENTLN cloud-to-ground (tan dash) and in-cloud (blue dot) lightning data. Yellow circles indicate core of lightning activity. Note that the parallax-corrected imagery appropriately places the overshooting top in the location of greatest total lightning activity.

After using the parallax-corrected imagery for a week, forecaster feelings on whether it should be made available operationally in AWIPS were mixed. Most to all forecasters saw the value in the parallax-corrected imagery. Errors of even just a few km can be significant when dealing with convective weather, especially when storms are in the vicinity of large population areas. However, the parallax-correction introduces issues of its own, such as masking important low-level features that appear in the un-corrected imagery. Additionally, unnatural, blocky artifacts are sometimes apparent at the transition from un-corrected to corrected portion of the images. Forecaster consensus was a recommendation that the parallax-corrected imagery be made available in addition to the un-corrected imagery. Training would need to be made available explaining what the parallax error is, what the correction does, and the caveats behind using the corrected imagery.

> "You must keep both. In one example, 1-min visible imagery (parallax uncorrected) showed the left split supercell storm well northwest of DC and to the untrained observer, not expected to affect the DC metro area. However, when corrected for parallax error,

> this storm was correctly placed just west of DC and which went on to drop baseball size hail across the northwest suburbs of DC. In another example, with a supercell hail producing storm over southeast NC on May 3rd, 2016, parallax-corrected imagery actually masked otherwise very useful information seen in the non-corrected parallax 1-min visible imagery. In this case, 3 individual strong/deep updraft pulses were observed to develop within the flanking line of this supercell but were masked and hidden in the parallax-corrected imagery. The 3rd pulse yielded significant radar echo aloft of which subsequently resulted in the largest reported hail a short time later."
> *Forecaster, End-of-Week Survey*

## 3.5 10-min Updating Derived Motion Winds

National Severe Storm Laboratory (NSSL) and Cooperative Institute for Meteorological Satellite Studies (CIMSS)

For the first year, 10-minute updating winds derived from the GOES-14 1-min satellite imagery were available as wind barbs in AWIPS-II. The winds are generated from the motion of features in the IR, VIS, and WV channels, and include the pressure level at which they reside. Using the SRSOR satellite data (vs routine data) to compute the winds allows for many more winds to be generated both vertically and horizontally in the atmosphere. The satellite-derived winds provide forecasters with observation-based details that are important to understanding the pre-convective and near-storm environments.

Throughout the 2016 experiment, forecasters found great operational value in the SRSOR-derived winds for severe weather operations. In fact, many forecasters answered that higher density satellite-derived winds is one of the capabilities they are most looking forward to with GOES-R. This should come as no surprise, as observed atmospheric wind data is fairly scarce, both vertically and horizontally, despite its importance in a multitude of meteorological tasks. Forecasters commented that numerical weather models generally do not do very well with winds, particularly at the low-levels. The 10-min interval seemed to be the sweet spot for preferred update frequency, as at the end of each week when asked, three forecasters answered 1-min, four 5-min, three 10-min, four 15-min, and two 30-min. Forecasters managed to exploit the SRSOR-derived winds a multitude of ways throughout the experiment.

> "In FWD, I noticed a difference between the RAP analysis and satellite-derived winds. The RAP had significant LL convergence that was not apparent in the SRSOR winds. Nothing ever developed in that area. My initial discussion mentioned this, and how the satellite-winds made me doubt that convection would develop since I was not seeing convergence."
> *Forecaster,* "Daily Summary: Week 4, Day 1 (9 May 2016)", *GOES-R HWT Blog*

The most common use of the SRSOR-derived winds was to diagnose layer shear in the atmosphere. Prior to convective initiation in the presence of an unstable cu field, many low-level winds were available at the level of the cu. By also viewing surface wind speeds measured from ASOS and AWOS instruments, a quick measure of low-level (surface to ~1 km) wind shear could be derived. Low-level wind shear is an important parameter for aviation, as well as in severe weather situations. Forecasters also used the winds to monitor the approach of upper level jet maxima and the potential for increasing deep layer sheer, which is also vital for determining severe weather potential and storm mode (Fig. 12). The ramping up of a low-level jet was another important feature that was diagnosed from the winds.

> "The GOES winds also helped with estimating the deep layer (700 mb to 250 mb) shear over the area, as the afternoon evolved. This was handy to assess the environment and storm mode."
> *Forecaster,* "Overview of Thursday, May 5, 2016", *GOES-R HWT Blog*

> "I see this being helpful in diagnosing LL shear, and trends in shear, from the surface to cloud base."
> *Forecaster,* "Daily Summary: Week 1, Day 3 (April 20, 2016)" , *GOES-R HWT Blog*

> "This is very good info. We watched a mid-level speed max approach our area, which increased environmental shear as storms developed."
> *Forecaster,* "Daily Summary: Week 3, Day 1 (2 May 2016)", *GOES-R HWT Blog*

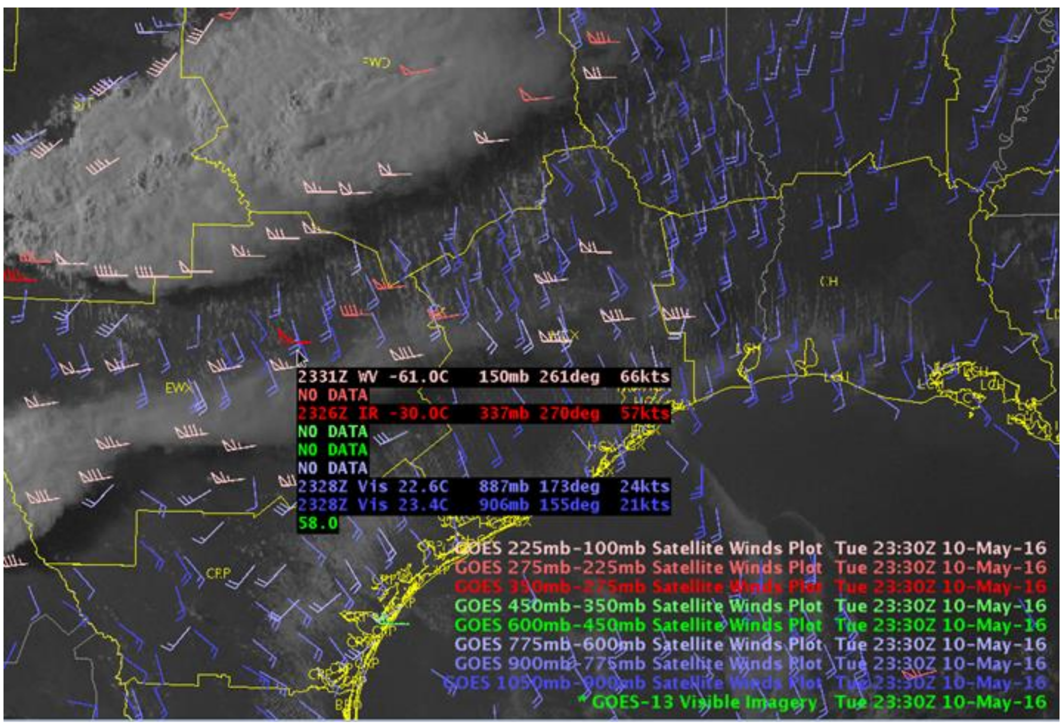


Figure 12: 2330 UTC 10 May 2016 GOES-East VIS imagery, SRSOR-derived winds. Four levels of winds are available within a small area, allowing a forecaster to capture a vertical wind profile. Significant speed and directional shear was present in the vicinity of severe convection.

Boundaries, low-level convergence, and wind shifts, particularly at the low-levels, were other important features that were picked up nicely in the SRSOR-derived winds. By knowing exactly where boundaries and areas of convergence were setting up prior to noticeable enhancement in satellite imagery, forecasters were able to gain an early idea of where deep convection was most likely to set up later. Storm motion could also be diagnosed from the low- to mid-level winds.

> “Atmospheric motion vectors were once again instrumental in identifying boundaries in the convective initiation phase. It was a great situational awareness tool to gauge where the next convection would possibly occur.”
> *Forecaster,* “Final Analysis DFW 5/10/16”, *GOES-R HWT Blog*

> “The winds indicated convergence along a boundary ahead of the dryline. We did get enhanced cu development in this area. The winds alerted us to areas of concern.”
> *Forecaster,* “Daily Summary: Week 4, Day 2 (10 May 2016)”, *GOES-R HWT Blog*

> “Atmospheric vectors did a great job of showing the structure of the pre-frontal trough in the vertical.”
> *Forecaster,* “Final Thoughts 5/12/16 HUN”, *GOES-R HWT Blog*

Forecasters generally viewed the winds with satellite imagery, including VIS, IR, and WV. These combinations allowed forecasters to better anticipate the movement of features, and identify boundaries and wind shifts. Forecasters also found it useful to overlay the winds on their respective layer PW field. This allowed for a more detailed and quantitative visualization of moisture transport in different layers of the atmosphere.

*Limitations of 10-min Updating Derived Motion Winds and suggestions for improvement*

The presence of many winds at multiple levels throughout the atmosphere, though appreciated in a forecast sense, created technical problems for forecasters. The primary issue was that, since winds are quite memory intensive for AWIPS, the presence of many caused the system to freeze and crash. Although one can easily decrease the density of winds shown in AWIPS, forecasters would prefer to see as much of the field as possible. The other issue was that the presence of many winds made it somewhat difficult to visualize the wind profile. One suggestion was that winds within a certain area snap to a central point, making it easy for a user to see the changing winds with height, and sample all of the winds in that column. The immediate solution forecasters used was to color-code the wind barbs by height. A procedure was built for the HWT which used blue for winds in the lowest levels, green in the mid-levels, and red in the upper levels (Fig. 12). Other suggestions that would enhance the value of the SRSOR-derived winds included a gridded analysis of the winds (e.g., wind speed, divergence), and automated computation of layer wind shear in areas of sufficient data.

## 3.6 GLM Lightning Detection

NASA-Short-term Prediction Research and Transition (SPoRT) and
University of Oklahoma (OU) /Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) and NOAA/National Severe Storms Laboratory (NSSL)

To continue to develop forecaster awareness and understanding of total lightning data within severe weather forecasting, psuedo-Geostationary Lightning Mapping (pGLM) products were reviewed as part of the live experiment in 2016.  One of the primary goals of this evaluation was to prepare for the use of GLM (Goodman et al. 2013) data within operations through vetting, training, and development of best practices prior to launch and data access by the NWS. These total lightning products were created using Lightning Mapping Array (LMA) data from regional networks around the CONUS. The very-high frequency (VHF) radiation detected by the LMA networks provided areal extent of lightning that, once sorted into flashes, was gridded and remapped to the spatial resolution matching that of the GLM (set at 8x8 km for the current experiment) to produce a flash extent density.

Similar to previous evaluations, forecasters found the pGLM products useful for situational awareness and building confidence in warning decisions. Multiple forecasters noted in blogs and surveys how "the pGLM performed very well showing higher flash densities as the storm grew", "showed precisely when storms pulsed up and down", and "it certainly helped the warning process in both the decision to warn and the decision to cancel the warning earlier." Additionally, forecasters enjoyed the 1-min rapid update cycle of the product when paired with other super rapid scan data available from GOES-14.

Forecasters also foresaw the data being very helpful for Decision Support Services including public safety at major outdoor events including stadiums, concerts, and festivals. In particular, the 1-minute update and spatial coverage was seen as a major advantage as the spatial extent "can give an idea of how far away from the storm that lightning can travel" (Blog post: 12 May 2016). Forecasters also noted the additional lead time the pGLM provided over cloud-to-ground lightning data alone. Additionally, forecasters voiced the advantage the data could provide in regions of poor radar coverage particularly in the western United States and for fire weather forecasting.

Similar to previous evaluations, forecasters did not show a strong preference for any single colortable beyond the default (see Fig. 13 for colortable options viewed in the 2016 evaluation). The preference was dependent upon the individual and how the forecaster chose to do the product integration (e.g., overlaid on visible satellite or radar or displayed alone). However, multiple forecasters did note that contouring the density might provide more feasibility of use in overlays with both other satellite data as well as radar.

Finally, multiple forecasters each week had concerns regarding proper training on use and understanding of lightning data for the NWS as GLM data formally reaches offices. Most forecasters have little training or background on the creation and use of lightning data and in particular need information not just on integration and best practices within severe weather forecasting but details on differences between different network types, detections, and terminology.

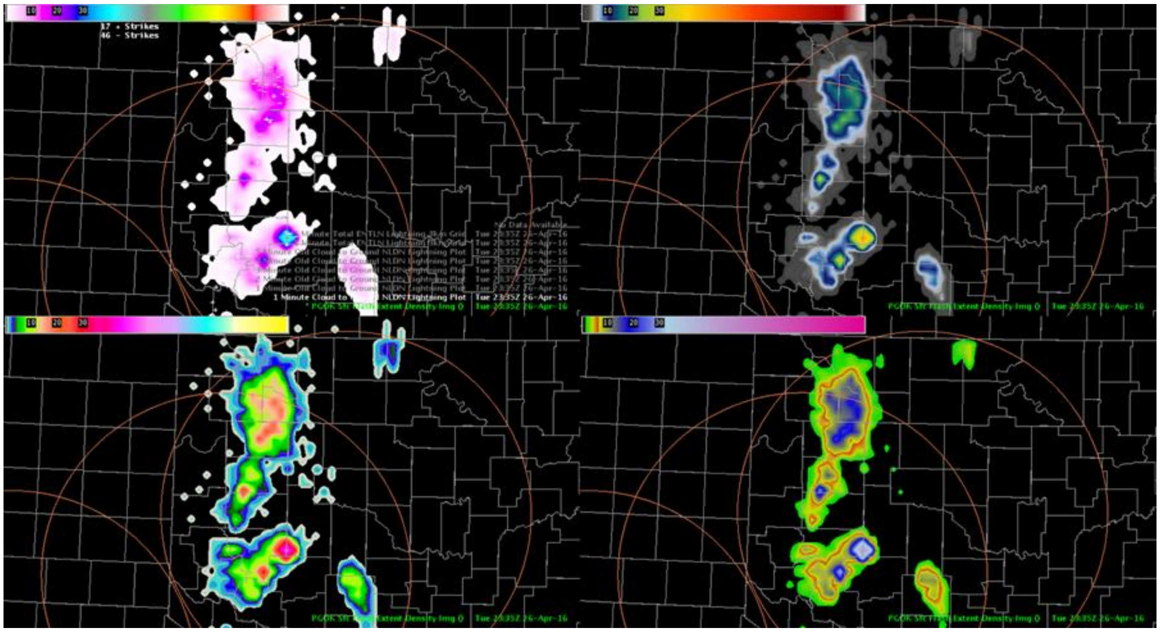

Figure 13: 4-panel display of pGLM colortable options available to forecasters during the 2016 experiment for a storm system in western Oklahoma on 26 Apr 2016. Forecasters noted different preferences throughout the experiment with many defaulting to the base AWIPS-II choice in the top left. Other forecasters preferred the logarithmic scale of the top right, while some preferred how the bottom left quickly picked up on developing convection.

## 3.7 Lightning Jump Algorithm

University of Alabama at Huntsville (UAH) and
University of Oklahoma (OU) /Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) and NOAA/National Severe Storms Laboratory (NSSL)

A fully automated, real-time Lightning Jump Algorithm (LJA) completed the final evaluation as part of the 2016 experiment. The LJA was designed to highlight rapid intensification in thunderstorms preceding severe weather such as tornadoes, hail and straight-line winds at the surface by tens of minutes. While the GOES-R Geostationary Lightning Mapper (GLM) provides a general path to operations for the use of continuous total lightning observations and the lightning jump concept over a hemispheric domain, the operational implementation of the LJA pre-GLM experiment is being produced using data from the Earth Networks Total Lightning Network (ENTLN) and Lightning Mapping Array data on localized domains. Again in 2016 along with ProbSevere, the lightning jump remained one of the most highly utilized products in the warning process for the GOES-R proving ground evaluation.

Forecasters continued to find it useful in severe and hazardous weather monitoring, particularly when used in tandem with the "ProbSevere" product (Figs. 14 and 15). Primary feedback focused on the visualization, and suggestions included either moving the visualization to a transparent display or to an outline as well as providing more details in a "mouseover" regarding the current flash rate and number of flashes in the standard deviation to facilitate quick storm comparisons. Both a 1-min update and a 5-min max product (created based on previous feedback) were evaluated by forecasters; one was not greatly preferred to the other as individual forecasters generally gravitated to one or the other depending on the operational focus of the day. It was suggested that both move forward as operational products.

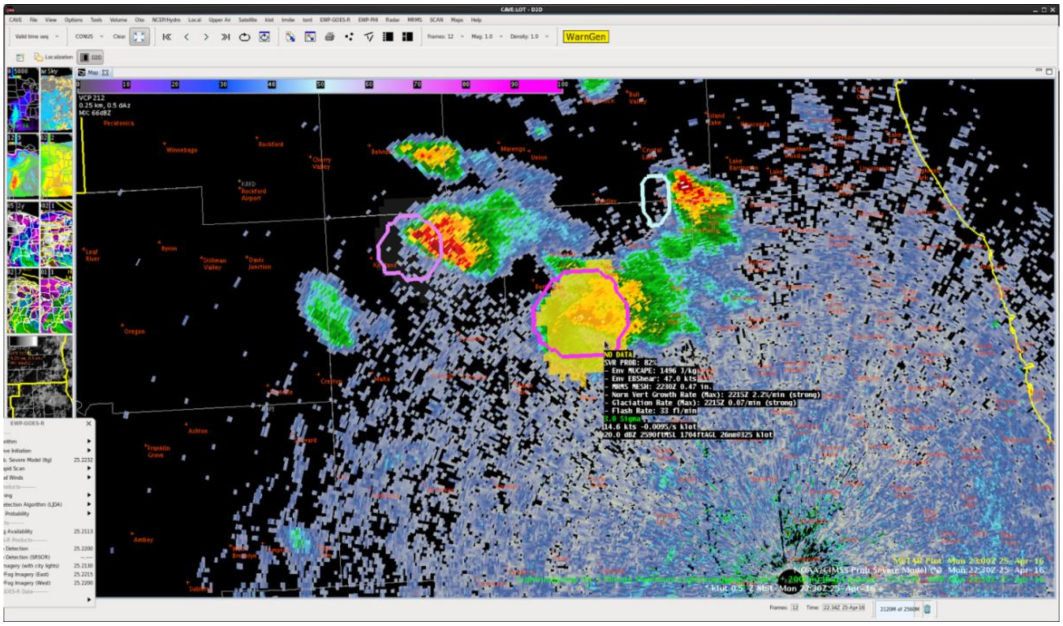

Figure 14: Forecaster screenshot from AWIPS-II during HWT evaluation on 25 Apr 2016. Forecaster chose to issue warning on this storm at 2230 due to increase of ProbSevere (pink outline) to 82% and corresponding lightning jump of 3-sigma (yellow region) at the same time. Shortly after warning issuance, 1" hail was reported west of the Chicago metro region with this storm.

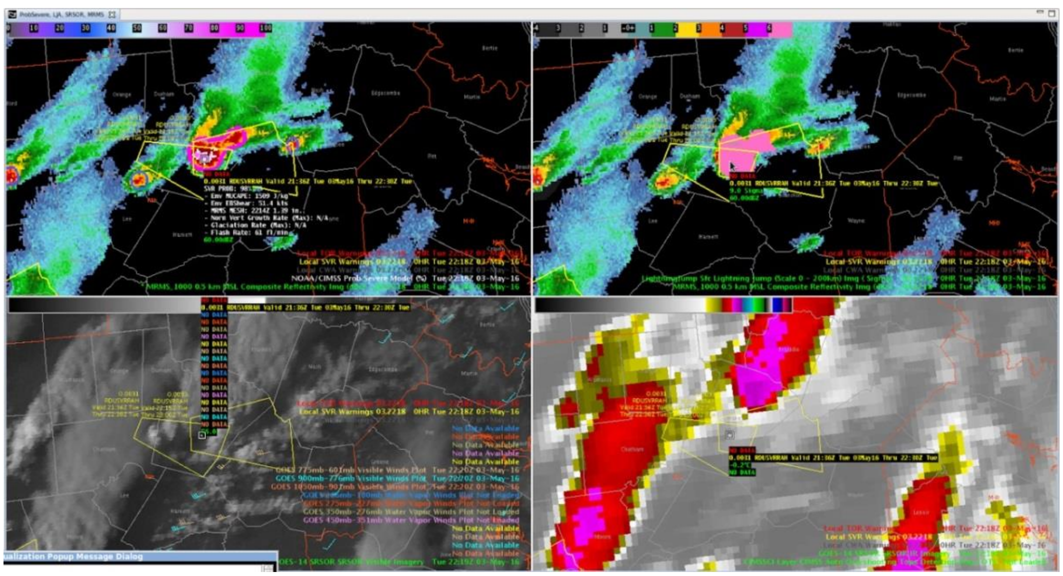

Figure 15: 4-panel configuration of forecaster display from AWIPS-II during HWT evaluation on 3 May 2016 in Wake County, NC. Forecaster had high confidence in extending the warning due to 9-sigma lightning jump.

## 3.8 NUCAPS Temperature and Moisture Profiles

Joint Polar Satellite System (JPSS)

The NOAA Unique Combined Atmospheric Processing System (NUCAPS) was demonstrated in the HWT in 2016 for the second year in a row. The atmospheric temperature and moisture profiles are generated using an algorithm that combines both statistical and physical retrieval methods. NUCAPS combines information from both the CrIS and ATMS instruments aboard the Suomi NPP polar orbiting satellite to provide soundings as close to the surface as possible. These profiles are produced at NESDIS/NDE and delivered over the AWIPS Satellite Broadcast Network (SBN) for display in the National Skew-T and Hodograph Analysis and Research Program (NSHARP) application in AWIPS-II. During the experiment, swaths of NUCAPS profiles from Suomi NPP were available over the east coast around 1800 UTC, central US around 1930 UTC, and western US around 2100 UTC with a typical latency of one hour and fifteen minutes.

There were several additions to the NUCAPS evaluation for 2016. Quality control (QC) flags associated with the NUCAPS profiles were integrated into AWIPS. These flags allow forecasters to quickly and easily identify which profiles within a swath passed (green) or failed (red/yellow) QC. Plan view displays and vertical cross-sections of NUCAPS-derived thermodynamic fields were also available for forecasters to view in AWIPS. Finally, for the fourth and final week of the experiment, NUCAPS temperature and moisture profiles generated using data from instruments aboard the European MetOp-B satellite were made available in AWIPS. Swaths of NUCAPS profiles from MetOp-B were available over the east coast around 1500 UTC, central US around 1630 UTC, and western US around 1800 UTC.

The purpose of the NUCAPS demonstration was to assess the value added of NUCAPS data to the severe weather nowcast and warning process.

*Use of NUCAPS in the HWT*

A key benefit of NUCAPS noted by forecasters was its availability between the morning 1200 UTC and evening 0000 UTC balloon soundings, oftentimes just prior to convective initiation. Given its availability in the early afternoon, NUCAPS was primarily used by forecasters in the HWT to assess the present state of the pre-convective environment. When storms were already ongoing, NUCAPS would be used to analyze the environment ahead of the convection in determining whether they would increase or decrease in intensity. Participants noted exceptional utility of NUCAPS in data sparse regions between radiosonde data. At the very least, NUCAPS was used to confirm that the environment was evolving as expected from the model forecasts and analyses. In addition to the profiles, fields derived from NUCAPS that forecasters noted as being particularly useful included CAPE, lapse rates, freezing level, -20C level, Precipitable water, layer moisture trends, and the shape of the profile.

> "[Today, we use NUCAPS for] tracking trends in mid/upper level drying."
> *Forecaster, End-of-Day Survey*

“I used them to see how the 0C and -20C levels were changing over the afternoon (they decreased in height a few thousand feet each). This was key for warning operations.”
*Forecaster, End-of-Day Survey*

“[We used NUCAPS] to look at instability in a fairly data sparse region in the Pueblo CWA.”
*Forecaster, End-of-Day Survey*

NUCAPS proved to be useful for monitoring sub-severe convective weather on 04 May 2016 in the Memphis, TN CWA. Despite the lack of instability expected in the region, the approach of an upper-low and associated cold mid-level temperatures and strong upper-level flow created the possibility of low-end severe. By the early afternoon hours, forecasters wanted to know the degree of instability ahead of the pre-frontal trough in order to assess whether convection would occur, and if it might reach severe criteria. NUCAPS provided this information, as the adjusted profile indicated just over 400 j/kg of SBCAPE in northern Mississippi (Fig. 16). The low CAPE values suggested to the forecaster that the environment would support the development of convection in the region, but would remain below severe criteria. Low-topped convection did indeed occur, but no severe weather was reported.

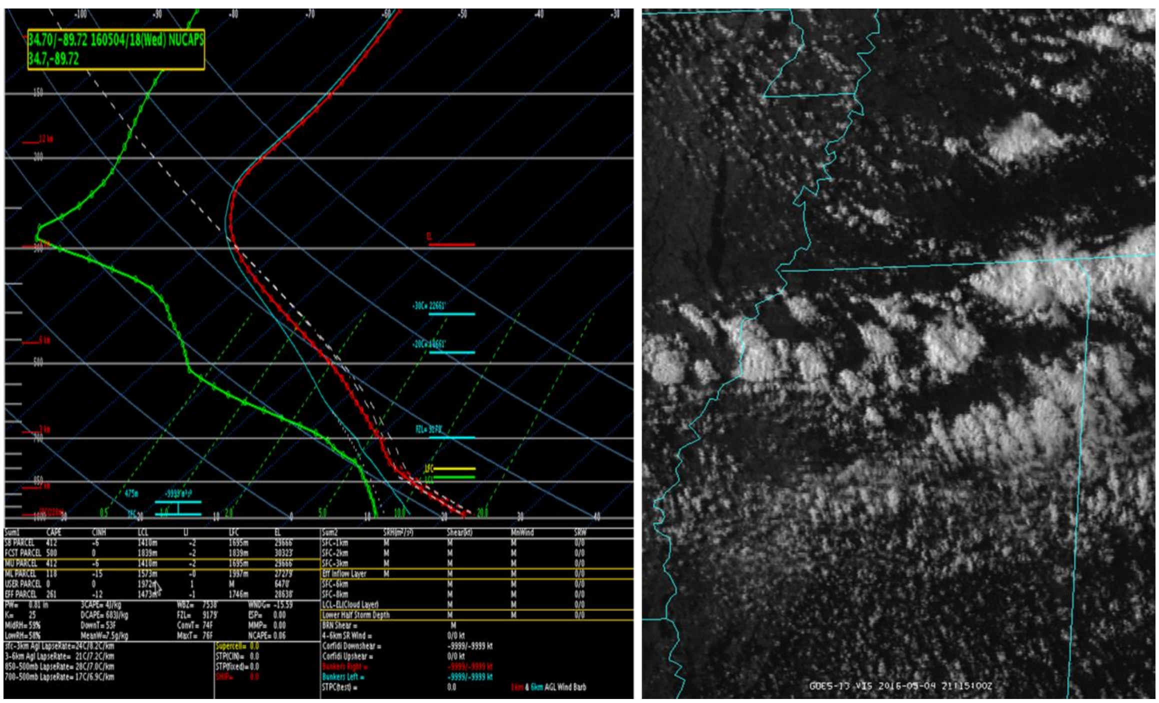

Figure 16: 1800 UTC 04 May 2016 NUCAPS temperature and moisture profile plotted in a skew-t diagram (left), 2115 UTC 04 May 2016 GOES-East visible satellite imagery (right).

Throughout the experiment, forecasters consistently compared the NUCAPS profiles with those from other datasets. Such comparisons allowed them to learn the strengths and weaknesses of the NUCAPS data, identify inaccuracies, and visualize environmental trends. In situations where a special afternoon radiosonde sounding was available, forecasters took advantage of the opportunity to learn key differences between point-based and satellite-based sounding profiles. Most obvious was the smoother appearance of the satellite-based soundings, lacking the vertical detail one gets from a radiosonde. The availability of a temporally and spatially collocated radiosonde also allowed them to gauge the accuracy of the NUCAPS data. When the proper low-level modifications (see below) were made to the NUCAPS profile, values of fields like CAPE and lapse rates typically match up well with those from a radiosonde. Forecasters also interrogated variations between the NUCAPS profiles and NWP-derived soundings, primarily from the Rapid Refresh Model (RAP). This allowed them to assess model accuracy, primarily in the upper levels where NUCAPS has been shown to be most skillful. Finally, forecasters compared NUCAPS derived fields with those from the SPC mesoanalysis webpage and GOES-R LAP algorithm.

> "IASI soundings were able to confirm the very low levels of CAPE values that RAP and GFS analysis are showing."
> *Forecaster*, "Mesoscale setup for Pueblo 5/11/16", *GOES-R HWT Blog*

Many participants noted the benefit in interrogating short-term environmental trends using NUCAPS. Contrasting NUCAPS profiles with modified 1200 UTC radiosonde profiles revealed how the environment had evolved from the early morning to the early afternoon. Even shorter-term trends could be analyzed when a special radiosonde sounding was available but displaced in time from NUCAPS by 1-3 hours. Comparisons between NUCAPS soundings could be made along the edges of consecutive swaths, and between profiles from MetOp in the morning and Suomi in the afternoon. A few examples of important trend information analyzed through these comparisons that increased forecaster confidence in imminent convective activity included drying and cooling aloft, moistening and warming of the low levels, lowering of the freezing and -20C levels, increasing instability, and approach of a frontal boundary.

> "There were two soundings in close proximity to each other (within KLWX) only 1 hour apart. These soundings showed the warming and moistening of the lower layers as well as the increase in instability."
> *Forecaster, End-of-Day Survey*

> "I used [NUCAPS] to look at how instability was evolving during the day. We had an 18Z OUN supplemental sounding, with a 20Z NUCAPS sounding showing how much instability had increased a couple of hours later."
> *Forecaster, End-of-Day Survey*

The new additions to this year's NUCAPS evaluation were appreciated by participants. The QC flags saved valuable time by indicating on which profiles a forecaster should focus their attention. A few instances were noted, however, of NUCAPS profiles passing QC that appeared unrealistic, and vice versa. Forecasters took advantage of NUCAPS in the late morning via MetOp, and would welcome the application of NUCAPS to other satellites where possible. These extra soundings earlier in the day increased the likelihood of NUCAPS availability prior to convective initiation, and allowed for trend analysis from the early morning (radiosonde) to the late morning (MetOp) to the early afternoon (Suomi). Finally, forecasters found operational utility in the NUCAPS plan view and cross section displays. The plan view displays allowed for an overview of the swath at a given level, which forecasters primarily used to identify local maximum in low-level moisture, and cool, dry air moving in aloft. Fields available included temperature, moisture, and those derived from temperature and moisture at the sounding levels of the NUCAPS profile. Forecasters would like to see the addition of layer-derived fields such as CAPE and lapse rates, and other fields including the heights of the -20C and freezing levels. Forecasters primarily made cross-section displays in AWIPS to analyze known and suspected fronts.

> "We also used a cross-sectional view of Theta-E in the afternoon to determine the location of our cold front (Fig. 17)."
> *Forecaster, End-of-Day Survey*

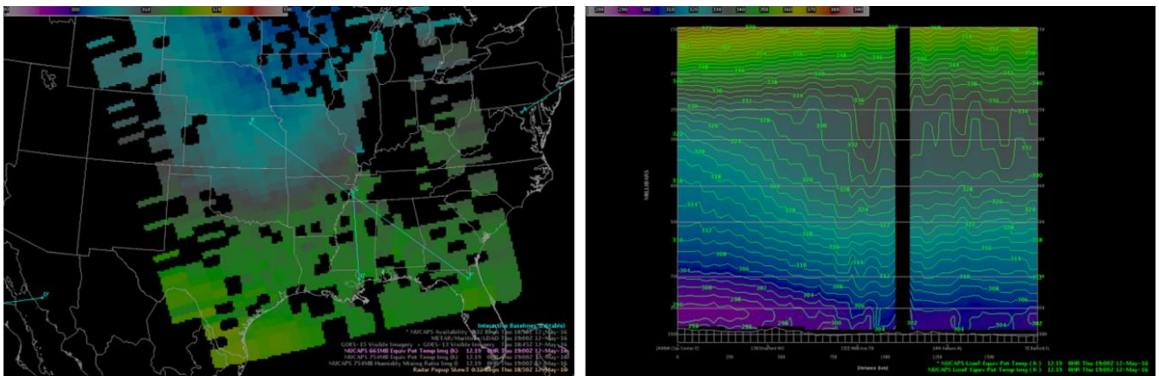

Figure 17: 1900 UTC 12 May 2016 NUCAPS plan view of equivalent potential temperature and location of cross section (left), NUCAPS cross section of equivalent potential temperature (right).

> "The plan view fields were more helpful than the actual soundings. I enjoyed looking at the mixing ratio field for this product and can see the utility of having plan view and cross sections available for NUCAPS fields such as LRs, CAPE, RH, Dewpoints, etc."
> *Forecaster, End-of-Day Survey*

> "I would like to say that having the IASI soundings was very helpful and getting them 4 times per day would be great. This could also help with your buy in because getting data in between the synoptic times is always helpful."
> *Forecaster, End-of-Week Survey*

> "Storms formed on the border of the FWD and SJT forecast areas but seemed to die out quickly once entering the FWD area. A shot of mixing ratio helps show that mixing ratios were much better to the southwest. Travelling further southwest into the EWX area, mixing ratios approached 9 g/kg and just over the Mexican border there was the longest lived storm of the day that persisted for a long time. At first I was not convinced of the utility of NUCAPS but these fields show much more promise to me as a forecaster (Fig. 18)."
> *Forecaster,* "NUCAPS Mixing Ratio Plan View", *GOES-R HWT Blog*

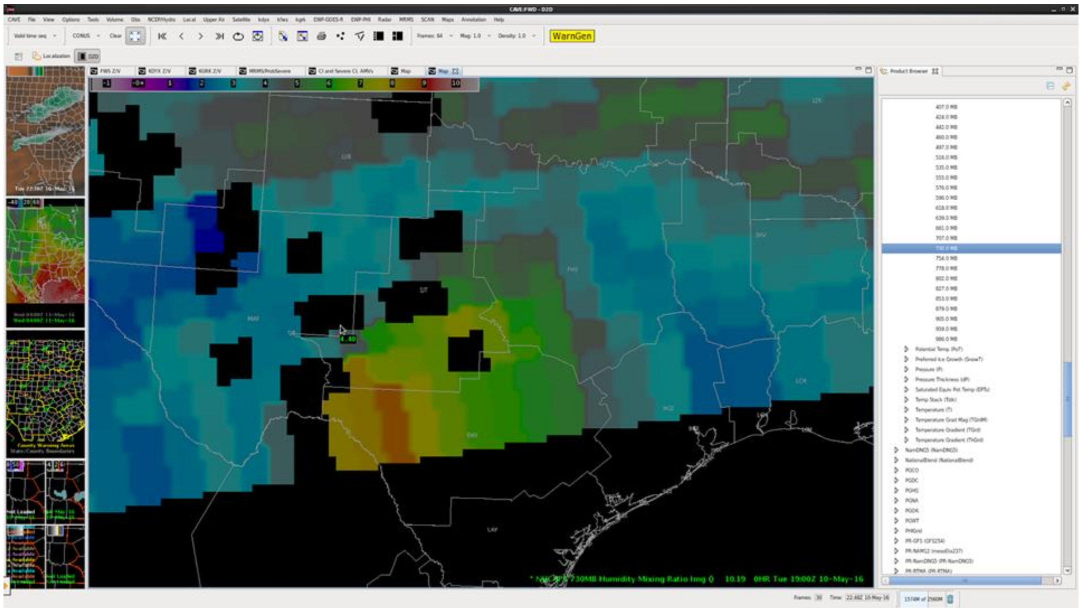


Figure 18: 1900 UTC 10 May 2016 NUCAPS plan view of mixing ratio.

Given the abundance of NUCAPS points available within a swath, participants recommended using the pop-up skew-T feature of AWIPS-II for a simple, initial analysis of the NUCAPS data over a given area (Fig. 19). This feature allows the user to quickly view NUCAPS profiles within a swath, without having to load the data in NSHARP, by simply dragging the cursor over the profile locations. The soundings will change dynamically within a separate window as the cursor moves over different profiles. If the forecaster finds a profile they want to interrogate further, then they simply click and load the profile in NSHARP.

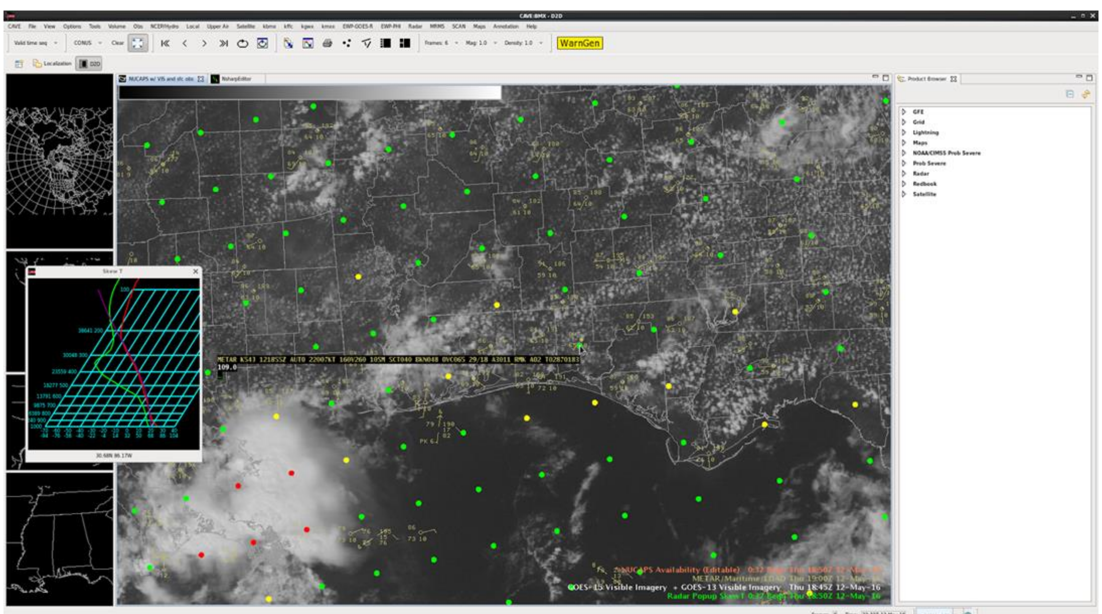


Figure 19: 1845 UTC GOES-East visible satellite imagery, 1850 NUCAPS availability/quality control flags and pop-up skew-t, and 1900 UTC surface observations for 12 May 2016.

*Limitations and Suggestions for Improvement*

As was noted during last year's NUCAPS evaluation, the surface and lowest few levels of the NUCAPS profiles are often inaccurate when compared to surface METAR observations and radiosonde data. As such, when participants loaded a NUCAPS profile, it was necessary for them to adjust the temperature and dew point values at the surface and lowest few levels in most situations. After making such adjustments, participants noted that derived values such as CAPE were on par with what was observed in radiosonde data when available. While some forecasters were content with making these adjustments, most felt that the process was too time-consuming and tedious, especially during warning operations. Additionally, adjusting the low-levels up from the surface was very subjective. It was recommended that during warning operations, the mesoscale analyst be the one to analyze NUCAPS and make adjustments when necessary, passing along this information to the radar operators. Forecasters routinely commented that above the boundary layer (~700 mb), the NUCAPS sounding compared well with nearby radiosondes as was expected from the training, and needed no adjustment.

> "I also noticed that the near surface data was not very accurate. However, after modifying the sounding with surface obs, the sounding seemed pretty reasonable."
> *Forecaster, End-of-Day Survey*

> "In today's case, we had to modify the boundary layer as the NUCAPS soundings were too cold along the surface. Immediately above the surface layer, the soundings were too warm and needed to be cooled. This takes a lot of time and I'm struggling to convince myself that forecasters would activity take the time to adjust them."
> *Forecaster, End-of-Day Survey*

> "Forecasters probably are going to be quick to abandon this product if the data is suspect and they have to do a lot of extra work to make it useful. Not a lot of bang for their buck. That being said, in the absence of observed soundings this can potentially be a great check against short term model soundings."
> *Forecaster, End-of-Day Survey*

Forecasters commented that NUCAPS would be a lot more appealing if the surface and low-level values did not have to be manually corrected. The ideal solution expressed by the participants is to improve the algorithm in the lowest part of the atmosphere while keeping it totally dependent on the satellite observations. The secondary preference would be to automate the surface value correction of NUCAPS using the nearby surface observations, and perhaps a vertical interpolation. Finally, the low-level correction could be made using high-resolution model data such as RAP. The third solution is least desired by forecasters since it would introduce potential model error. If a NUCAPS-NWP blended product is developed, the NUCAPS-only product should still be made available to forecasters in addition.

> "With some improvement to the lower levels, this could be a very useful operational tool to check against model derived fields and the current state of the atmosphere. After careful thought, as a forecaster I would like to keep all data coming from NUCAPS observational, even if this means that the quality of the data is a bit suspect at times. By

introducing model data to the process you could make it look better but you are introducing a second possible source of error into the product."
*Forecaster, End-of-Day Survey*

"I suspect that if I trained my staff on it as is, maybe 1 out of 10 forecasters would use it as is. That being said if it can be delivered in a format that is easy to put into a procedure and that they don't have to modify I think buy in will be a lot higher. There can be extreme value in this product, especially if it is kept entirely observational."
*Forecaster, End-of-Week Survey*

Although the general shape of the profiles appeared accurate in most situations, forecasters recognized that a deficiency of satellite retrievals is lack of detail in the vertical when compared to point-based, radiosonde profiles (Fig. 20). Forecasters continually noticed the inability of NUCAPS to resolve capping inversions and called it a significant deficiency given the importance of such features in severe weather situations. Considering the suggestions outlined earlier, forecasters felt that high resolution model data that can resolve such features should be blended with NUCAPS in that layer of the atmosphere.

"The smoothed nature of the soundings limits the potential usefulness of the soundings. The inability to see capping inversions and saturated layers is a real drawback."
*Forecaster, End-of-Week Survey*

"Automated modification in the 850-500 hPa layer is important as this is the portion of the sounding where the CAP is most prevalent."
*Forecaster, End-of-Week Survey*

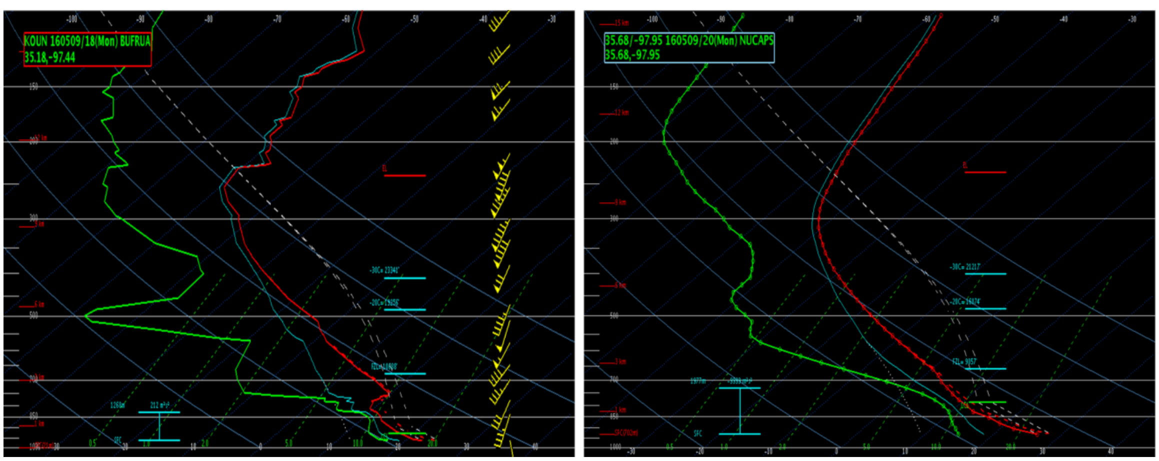


Figure 20: 1800 UTC OUN radiosonde (left) and ~1930 UTC NUCAPS profile near OUN (right) on 09 May 2016. Forecaster compared radiosonde profile with NUCAPS profile just prior to convective initiation in central Oklahoma. Notice the NUCAPS profile, while similar in overall shape, lacks the vertical detail that is present in the radiosonde. Most notable is the absence of the elevated mixed layer just below 700 mb, which had prevented convective initiation up to that point in time. Both profiles revealed significant instability with over 2000 j/kg of CAPE. NUCAPS was slightly more unstable due to heating that occurred at the surface between 1800 and 1930 UTC.

Additional suggestions to make NUCAPS more desirable were noted by participants throughout the experiment. With a typical latency of up to 1.5 hours from timestamp to availability in AWIPS, many forecasters commented that they would prefer to have the NUCAPS data available in AWIPS with less latency. Forecasters would like to have the ability in AWIPS to compare NUCAPS soundings with other soundings (e.g., NWP, RAOB) in the same NSHARP panel. Improved availability of NUCAPS in cloudy-sky situations was also requested be participants, which could be done by including microwave-only soundings in AWIPS. Participants would like to see verification statistics comparing NUCAPS sounding data with that from the RAP, which is the primary source of vertical sounding data in the absence of a radiosonde. After using the morning MetOp soundings, forecasters recommended that they be processed and made available in AWIPS operationally. Finally, forecasters thought it would be convenient to plot nearby surface-observation-based and satellite-derived winds in AWIPS-II NSHARP with the NUCAPS profile.

*Final Comments*

On 49% of days, forecasters answered that the NUCAPS soundings were either extremely useful (5/5) or very useful (4/5) for the particular forecast situation, while it was found to be not useful at all (1/5) only 3.64% of the time. At the end of each week, 12 forecasters commented that they are already or will start using NUCAPS in its current form in their home office, three forecasters said that they would use it only if/when the surface/low-level modification process was automated, and one forecaster answered that they would likely never use NUCAPS in their home office.

> "This data could be highly useful, if there was more confidence in the actual profiles. Taking the time to modify a significant portion of the sounding to more accurately match things like RAP analyses, is not necessarily practical."
> *Forecaster, End-of-Week Survey*

> "We already use NUCAPS [in my office]. The main use so far has been to identify mid-level moisture and the potential for elevated convection."
> *Forecaster, End-of-Week Survey*

# 4. Summary and Conclusions

The GOES-R and JPSS Proving Ground held four weeks of evaluations during the 2016 Spring Experiment in the Hazardous Weather Testbed. Twelve NWS forecasters and four broadcast meteorologists evaluated eight GOES-R and JPSS products and capabilities and interacted directly with algorithm developers during the experiment. With GOES-R and JPSS being the sole focus of the demonstration, participants agreed that they had ample opportunity to fairly evaluate, identify strengths and weaknesses, and suggest potential improvements for all of the products. An abundance of feedback was captured from participants via multiple methods, including daily and weekly surveys, daily and weekly debriefs, real-time blog posts, informal conversations in the HWT and the "Tales from the Testbed" webinars. This feedback included suggestions for improving the algorithms, ideas for making the displays more effective, best practices for product use, and highlighting specific forecast situations in which the tools worked well and not so well.

Training, in the form of Articulate PowerPoint presentations for each product, was generally well received by participants. They did not have issues completing it before arriving in Norman, and felt that it provided them with an adequate basic understanding of each of the products. Based on past feedback, more time was spent at the start of each week as a group going through each of the products in AWIPS. Provided to participants was a brief refresher of each product, a tutorial on where to load the products in AWIPS, recommendations for pre-built procedures, and caveats. Starting the week with this walkthrough was applauded by participants, and contributed to a smooth start to experimental operations. Similar to last year, an information sheet listing each product under evaluation, its location in AWIPS-II, and contents of notable procedures was created for reference during experimental operations. The pre-built procedures were really appreciated (especially by the broadcast meteorologists) as they allowed for a quick start to operations.

For the third year, broadcast meteorologists participated in the EWP Spring Experiment alongside and to the same degree as the NWS forecasters. Once again, the inclusion of broadcast meteorologists in the HWT activities went smoothly and proved to be fruitful for both sides. The broadcasters received a unique glimpse into the life of a NWS forecaster during severe weather operations, noting the massive amount of data a forecaster must sift through and the substantial responsibility and stress one feels in such situations. Similarly, the interaction allowed NWS forecasters to gain insight from the broadcast meteorologists on some of their responsibilities, helping to unify the two groups. Broadcasters found at least some utility in all of the products demonstrated, and especially look forward to the high temporal resolution satellite imagery. AWIPS familiarization prior to their arrival in Norman was vital for their successful participation in HWT activities.

Overall, participants enjoyed their experience in the HWT, and felt that the experiment was very well organized. With the emphasis being on future satellite products and capabilities, this activity helps to reinvigorate the use of satellite data in severe warning operations, fostering excitement and increased preparedness for the use of future satellite technology. Participants found at least some utility in all of the satellite products demonstrated, and look forward to using actual GOES-R data in operations.

More detailed feedback and case examples from the HWT 2016 GOES-R/JPSS Spring Experiment can be found on the GOES-R Proving Ground HWT blog at:
www.goesrhwt.blogspot.com

Archived weekly "Tales from the Testbed" webinars can be found at:
http://hwt.nssl.noaa.gov/ewp/

More information on 2016 SRSOR activities can be found at:
http://cimss.ssec.wisc.edu/goes/srsor2016/GOES-14_SRSOR.html

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