GOES-R and JPSS Proving Ground Demonstration at the Hazardous Weather Testbed 2015 Spring Experiment Final Evaluation

Project Title: GOES-R and JPSS Proving Ground Demonstration at the 2015 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: 04 May 2015 – 12 June 2015

Prepared By: William Line (OU/CIMMS and NOAA/SPC) and Kristin Calhoun (OU/CIMMS and NSSL)

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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 2015 Spring Experiment, which took place at the National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (HWT) in Norman, OK from May 4 to June 12, 2015. The Satellite Proving Ground activities were focused in the Experimental Warning Program (EWP; five weeks, off week of Memorial Day), with informal demonstrations taking place in the Experimental Forecast Program (EFP; five weeks ending June 5). A total of 25 National Weather Service (NWS) forecasters representing five NWS regions and an additional five broadcast meteorologists participated in the EWP experiment. They evaluated up to seven experimental satellite-based products, capabilities and algorithms (Table 1) 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). Products included GOES-R All-Sky Legacy Atmospheric Profile (LAP) algorithm atmospheric moisture and stability fields using GOES Sounder data, GOES-R Convective Initiation (CI) algorithm, 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 imagery was available from May 18-June 11 for participants to view in near-real time in AWIPS-II for the EWP and in National Centers for Environmental Prediction (NCEP) AWIPS (NAWIPS) for the EFP. Finally, the NOAA Unique Cross-track Infrared Sounder (CrIS) Advanced Technology Microwave Sounder (ATMS) Processing System (NUCAPS) from the JPSS Suomi NPP satellite was also demonstrated in AWIPS-II. Earth Networks total lightning products now available to NWS for assessment were evaluated in the EWP alongside the GOES-R and JPSS products. Results from the Earth Networks demonstration are documented in a separate report. Many visiting scientists also attended the EWP over the five 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, and NWS. 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 abundant and came in a number of forms, including daily surveys, weekly surveys, daily debriefs, weekly debriefs, over 500 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. Participants appreciated the full-CONUS view provided by the all-sky LAP Sounder products, and found them to be most useful for assessing overall trends and tracking gradients in atmospheric moisture and stability. Throughout the experiment, the CI product was an effective tool for drawing forecaster attention to areas where deep convection was becoming more probable. Participants found that the ProbSevere model improved their situational awareness during severe weather operations by highlighting the most threatening storms in the near-term, sometimes influencing their warning decisions. The 1-min satellite imagery from GOES-14 was coveted by all users as they successfully and creatively incorporated it into their convective warning decision-making, emphasizing specific processes and features made clearer by the very high temporal resolution satellite data. The GLM Lightning Detection products and Lightning Jump algorithm proved valuable for the real-time detection of rapid updraft fluctuations that often preceded the occurrence of severe weather at the surface. Finally, forecasters recognized the value of the NUCAPS soundings in filling the spatiotemporal gap that exists in observed vertical temperature and moisture information.

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 forecasters, and to observe the baseline and experimental GOES-R and JPSS 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 their 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 algorithms. Furthermore, the EWP facilitates the testing of satellite-based products in the AWIPS-II data processing and visualization system.

In 2015, the EWP was conducted during the weeks of May 4, May 11, May 18, June 1, and June 8 with five NWS forecasters and one broadcast meteorologist participating each week. One of the 25 NWS participants was a Center Weather Service Unit (CWSU) aviation forecaster. 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 second year in a row, working alongside NWS forecasters. Training modules in the form of an Articulate Power Point presentation for each demonstration product were sent to and completed by participants prior to their arrival in Norman. Each week, participants arrived in Norman on Sunday, worked 8 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. Based on past feedback, the EFP provided a shorter, more focused weather briefing to the EWP at the start of each Mon-Thu shift. The Friday half-day involved a weekly debrief and preparation and delivery of the “Tales from the Testbed" webinar. Each week, a different weekly coordinator was tasked with: choosing the start time for the Tuesday, Wednesday and Thursday "flex shifts", selecting the three Weather Forecast Office (WFO) County Warning Areas (CWAs) for the days' operations, providing operations status updates, and overseeing EWP activities. The decision on when and where to operate each day was partially based off input from the daily EFP weather briefing and EFP probabilistic severe forecasts.

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. 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 created during this period along with continued posts about the mesoscale environment. If severe convective activity in a CWA ceased or was no longer expected to occur, the weekly coordinator would transition the pair of forecasters to focus on a more convectively active CWA.

At the end of each week, the five 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 five webinars were chosen based off the particular week's weather. Sixteen minutes were allowed afterward for questions and comments from anyone 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 500 GOES-R and JPSS related blog posts were written during the five weeks of the Spring Experiment by forecasters, developers, weekly coordinators 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 2015 Spring Experiment is summarized in this document.

3. Products Evaluated

Table 1. List of products demonstrated within the HWT 2015 Spring Experiment

Demonstrated Product	Category
GOES-R All-Sky Legacy Atmospheric Profile Products	Baseline and Risk Reduction
GOES-R Convective Initiation	Future Capabilities
ProbSevere Model	GOES-R Risk Reduction
GOES-14 SRSOR 1-min imagery	Baseline
GLM Lightning Detection	Baseline
Lightning Jump Algorithm	GOES-R Risk Reduction
NUCAPS Temperature and Moisture Profiles	JPSS

Category Definitions:
Baseline Products – GOES-R products that are funded for operational implementation
Future Capabilities Products – GOES-R funded products that may be made available as new capabilities
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
JPSS – Products funded through the JPSS program

3.1 GOES-R All-Sky Legacy Atmospheric Profile Products

University of Wisconsin/Cooperative Institute for Meteorological Satellite Studies (CIMSS)

New to the HWT this year were all-sky moisture and stability fields generated 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 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 are currently available every hour shortly after the GOES Sounder observations are made, and combine data from GOES-East and West to provide full-CONUS coverage. The purpose of this evaluation was to discover any technical issues with this new product and to gather feedback for how the algorithm could be improved to better suit forecaster needs.

Use of LAP products in the HWT

The GOES Sounder LAP products were viewed most often by forecasters at the beginning of the shift as they conducted their initial environmental analysis. Additionally, forecasters viewed the products throughout the shift as an update on how moisture and instability were evolving, and as a check on the models. Participants liked the full-CONUS coverage of these environmental fields. Past product demonstrations have revealed that a portion of forecasters prefer fields with little-to-no data gaps, even if that means filling in the gaps with NWP data. In addition to the complete spatial coverage, the hourly availability and low-latency of the LAP products were appreciated, keeping forecasters aware of significant environmental trends as they occurred.

> "I used these products as a part of my mesoscale analysis when I was becoming familiar with the environment at the beginning of the radar shift. I also checked these parameters at various times during the shift to stay aware of how the environment was evolving."
> *Forecaster, End-of-Day Survey*

> "For the first part of the day in particular, the LAP CAPE (and LI to an extent) gave an idea of where storms might intensify or weaken. The way the storms evolved suggests that the LAP data was quite reasonable - it helped with having an idea of which storms were most likely to survive for longer periods."
> *Forecaster, End-of-Day Survey*

The LAP products aided a forecaster in her mesoscale analysis at the beginning of the shift on 03 June 2015 in the Jacksonville CWA. Interrogating the 1600 UTC LAP products, she wrote: "looking at the CAPE, LI, PWAT and SI, it's pretty evident that the most favorable area for convection in the Jacksonville FA is the northern part." She noted this portion of the CWA had adequate instability with CAPE values over 2000 j/kg and LI to -6 and an abundance of moisture with TPW up to 1.75" (Fig. 1, left). With relatively weak 0-6 km shear, convection was expected to be disorganized with locally damaging winds and hail the primary threats. This forecast verified as the strongest convection developed and remained in the northern part of the CWA, generating wind damage and 1-2" hail (Fig. 1, right).

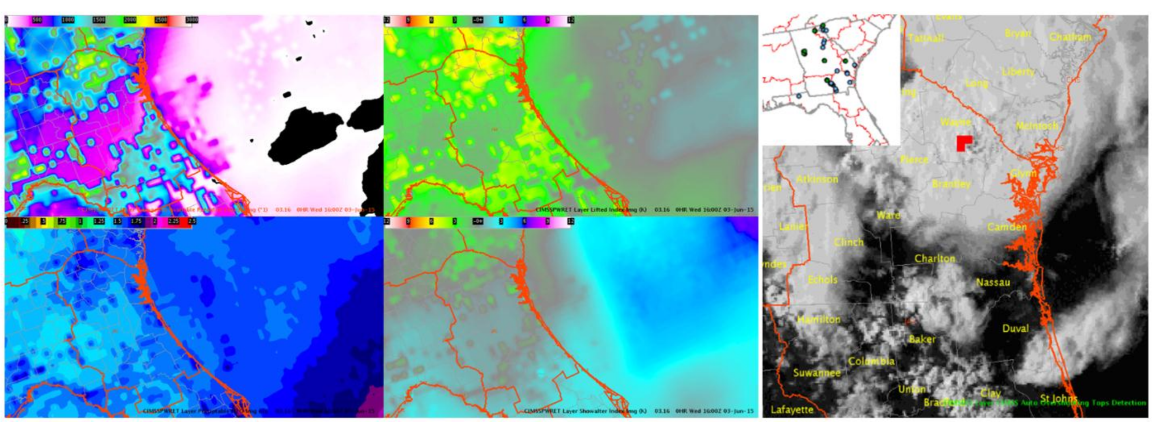

Figure 1: 1600 UTC 03 June 2015 GOES LAP CAPE (upper left), LI (top middle), TPW (lower left), Showalter Index (lower middle). 2330 UTC 03 June 2015 GOES-East visible satellite imagery, Overshooting Top Detection algorithm (overlay; right), SPC local storm reports (inset). From blog posts, "Jacksonville Mesoscale Discussion" and "Multiple Overshooting Top Examples."

Participants consistently commented that gradients, maxima/minima, and trends in the LAP fields provided them with the most unique and accurate information, rather than the absolute values themselves. It was along the moisture/instability gradients and within the areas of increasing moisture/instability that convection most often developed. Alternatively, decreasing moisture/instability trends were often a sign that convective activity would cease. Forecasters would look back at the fields at the end of the day and see that convection had indeed developed along the gradients and in areas of increasing moisture/instability. Observing this early in the week gave forecasters confidence when using the tools as the week progressed. Additional forecast situations in which the LAP products aided participants included: dryline progression, depth of moisture in the atmosphere, progression of moisture return, elevated or surface-based storms, severe vs. non-severe storms, and convection in data sparse regions.

> "CAPE gradients again were an excellent indication of where storms would focus. LAP PW corresponded very closely to observed sounding PW and gave forecaster confidence in trends."
> *Forecaster, End-of-Day Survey*

> "It was most useful to pay attention to the gradients and trends in the fields. Most often, convection developed along these boundaries and in areas of increasing instability/moisture."
> *Forecaster,* "EWP Week 2 Summary (May 11-14, 2015)", *GOES-R HWT Blog*

For example, on 20 May 2015 a strong gradient in CAPE and PW spanned from southwest Texas into northern Mexico. Forecasters operating in the Midland, TX CWA overlaid a radar mosaic on the LAP CAPE field to see how convection was evolving with respect to the satellite-derived product (Fig. 2, left). The forecaster wrote, "It really shows how convection is focused along the tightest gradients of CAPE. A look at other LAP data shows a similar idea." In South Dakota on 09 June 2015, convection initiated along the leading edge of a moisture maximum evidenced by a visible imagery overlay on the LAP PW field (Fig. 2, right). The forecaster wrote, "While looking at the CAPE and PWAT trends, we noticed the storm development in SD matches almost exactly with the leading edge of the gradient ahead of the approaching cold front."

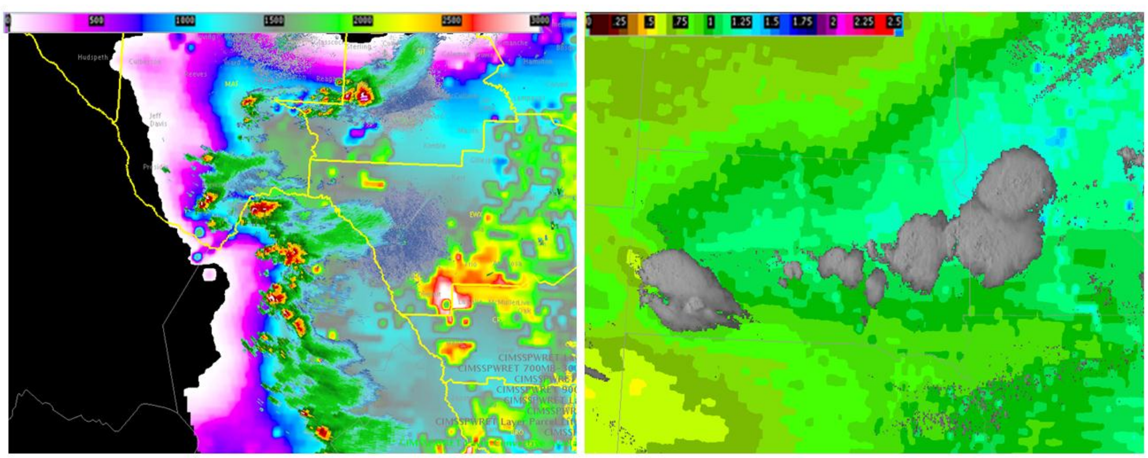

Figure 2: 2200 UTC 20 May 2015 GOES LAP CAPE and radar base reflectivity (left). 2200 UTC 09 June 2015 GOES LAP TPW and 2245 UTC GOES-East visible satellite imagery (right). From blog posts, "Convection focused along CAPE Gradient" and "Interesting Observation."

Limitations of LAP products

While the PW values appeared to be reasonably consistent with that from other data sources (e.g., Rapid Refresh Model, SPC meso-analysis, radiosondes), the LAP CAPE absolute values were often substantially different. This led participants to lose trust in the absolute values of the LAP CAPE field, which is the instability field of choice for most operational forecasters. The other major issue with the LAP products was the apparent "blotchiness" and unrealistic spatial variations that oftentimes appeared in the fields. This anomaly was addressed and mostly resolved by the developers after week 3, but deficiencies in the Sounder instrument cause some striping to remain (Fig. 3).

> "Lower than expected (CAPE) values have reduced my confidence in the product despite knowing the gradients have been a good proxy for knowing where storms can develop."
> *Forecaster, End-of-Day Survey*
>
> "Many of these products seem to be blotchy with unrealistic gradients and stripes. This makes the data seem untrustworthy." (Week 2, before fix)
> *Forecaster, End-of-Day Survey*

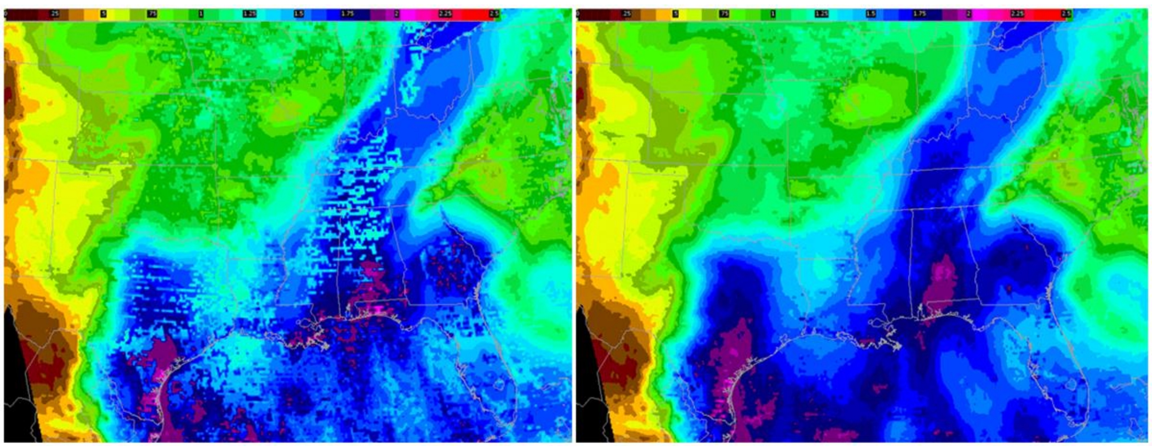

Figure 3: 1800 UTC (left) and 1900 UTC (right) 25 May 2015 GOES LAP TPW before and after a fix was implemented to reduce the degree of unrealistic artifacts in the imagery.

Comments on product display

Forecasters viewed the LAP products in single panel and 4-panel displays, often overlaying satellite imagery, lightning data and surface observations. The overlays allowed forecasters to see how convective activity was evolving with respect to the LAP fields, which gave them an idea of how convection might continue to progress in the future. While most forecasters viewed the LAP products as a fill display, some forecasters preferred to view them as a contour display for overlaying on other datasets such as radar and satellite imagery. Minor adjustments made to the LAP product display early in the experiment included: establishing preferred color tables and data ranges, displaying temperature fields in C instead of K, and displaying PW fields in inches instead of millimeters.

> "I created a four panel with the total PW, LI, CAPE, and Showalter. The trends in these products were of the most interest...showing increasing moisture/instability advecting into CWA."
> *Forecaster, End-of-Day Survey*

> "Overlayed total lightning plots with CAPE images and contoured LI. This was to see how the satellite derived products lined up with where the storms developed."
> *Forecaster, End-of-Day Survey*

> "I found overlaying the Visible Satellite with the GOES-R LAP CAPE product (transparency of 50%) to be useful in situational awareness."
> *Forecaster,* "Visible Satellite with Overlay of GOES-R LAP CAPE", *GOES-R HWT Blog*

Additional suggestions for improvement

Participants offered suggestions for how the LAP products may be improved to better serve their forecast needs. Of course, more accurate values (e.g., CAPE) would give the forecasters greater confidence in the fields and increase their usability. Many felt that the GFS first guess was often the reason values were off, and suggested using other models (e.g., Rapid Refresh) as the first guess over the CONUS. The apparent "blotchiness" and unrealistic gradients in the fields were an issue as well, but this was improved during the experiment. Still, further improvements to provide realistic continuity in the fields will be appreciated. Many forecasters look forward to the higher temporal resolution that will also be available from the ABI (Schmit et al. 2005), with most agreeing 30 minute updates would probably be optimal. Since these particular products combine three algorithms, participants would like to have a simple method of knowing where the data is coming from at each grid point (i.e., clear-sky retrieval, cloudy-sky retrieval, or NWP). This could be added to the data readout of the product in AWIPS-II, or as a separate field the forecaster could overlay. Additionally, it was suggested that a product indicating change in a field over time and horizontally in space (quantifying tendencies and gradients) might be beneficial to see in operations. Finally, participants felt that the training was too technical and would like to have seen more use examples.

The TPW, CAPE and LI were the most heavily used LAP fields during the experiment, and were also found to be most useful. These are three of the thermodynamic fields with which forecasters have the most experience. By comparison, the KI, SI, and TT fields were viewed much less and were found to be less useful as forecasters rarely analyze these fields anymore in operations. The Layer PW field was also not utilized extensively during the experiment, mainly because forecasters do not have as much experience or training viewing PW in atmospheric layers. Enhanced training on Layer PW and examples of it being applied during various operational situations would likely increase its use. Suggestions for additional fields to be added, whether or not possible, included: downdraft CAPE, mixed-layer CAPE, most-unstable CAPE, convective inhibition (CIN), Lifted Condensation Level (LCL) height, and lapse rates (0-3 km, 3-6 km, 850-500 mb, 700-500 mb).

Other comments

When forecasters were asked if they view currently available GOES Sounder derived products at their office, only 9/23 respondents answered “yes”. Those who answered “yes” primarily utilize the TPW field. The reasons forecasters do not view these products varied from not knowing they are available, to preferring SPC meso-analysis and model data, to being unaware of the strengths and weaknesses of the satellite-derived fields. After evaluating the LAP products, however, many respondents said they would start viewing these data in AWIPS, especially if future, blended products are available similar to the GOES-R3 LAP products.

> “Having seen this at the HWT and their utility to interrogate the near term environment and using them here, I will be incorporating these into my situational awareness spin up especially on short term forecast shifts or severe weather operations.”
> *Forecaster, End-of-Week Survey*

> “We tend to lean more towards the models, but my experience here will prompt me to look at those more to see how they do in my Western Region CWA.”
> *Forecaster, End-of-Week Survey*

3.2 GOES-R Convective Initiation

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

The GOES-R Convective Initiation (CI) algorithm returned to the Spring Experiment this year as it continues to be updated and refined, based in part on forecaster feedback from activities within the HWT. The CI algorithm fuses local environmental information from the Rapid Refresh NWP model with satellite fields and uses a logistic regression framework to produce 0-2 hour probabilistic forecasts of convective initiation (Mecikalski et al. 2015). Convective initiation here is defined as a 35 dBz reflectivity echo at the -10C level. Using objective validation techniques, a training database of over 500,000 objects has been developed, representing convective regimes much better when compared to earlier iterations of the algorithm. Additionally, GOES-R proxy cloud products are now utilized within the algorithm to diagnose CI under thin cirrus and to improve CI detection at night. Finally, the development of a quasi-discriminant analysis has reduced some of the noise associated with the lower probabilities. The purpose of this demonstration was to evaluate the ability of the algorithm to increase forecaster confidence in and extend lead time to initial convective development.

> “I remember looking at it a few years ago, and it’s a lot better now than it was then. It provided useful information before event.”
> *Forecaster,* “Daily Summary: Week 5, Day 4 (June 11, 2015)”, *GOES-R HWT Blog*

Use of CI in the HWT

When asked whether the GOES-R CI algorithm provided useful short-term guidance outside of information from hourly update models such as the RAP and HRRR, forecasters answered “yes” 94% of the time. Because the algorithm updates with satellite imagery, it provides forecasters with new high frequency information about the convective potential in-between NWP updates, complimenting model output. Additionally, the approximately 10 minute product latency ensures that the forecasters are getting the latest convective information very shortly after the observations were made. Finally, forecasters have increased confidence in the CI probabilities knowing that they are based largely on observational data.

> "Since the CI product updates more frequently than the rapid refresh models, it certainly has value. In addition, when used in conjunction with those rapid refresh models, there could be higher confidence in initiation (or lack thereof)."
> *Forecaster, End-of-Day Survey*

> "It provides great situational awareness about initial convective development and helps focus in on which areas to watch. This can help verify the accuracy of rapid refresh data and perhaps cause one to modify expectations for further development."
> *Forecaster, End-of-Day Survey*

The CI product was utilized most heavily before deep convection had developed, providing forecasters with the first indications of imminent initiation. However, most forecasters kept the product loaded on one of their displays during warning operations to help maintain their situational awareness to areas of new growth. Forecasters found the product to be quite effective in drawing their focus to areas where initiation would soon occur and away from where it was less probable in the near future. In particular, paying attention to relative maxima in the probability field proved to be a useful strategy as those were the areas that more often resulted in initiation. Additionally, increasing probabilities over time (trends) in a particular area increased forecaster confidence that development was imminent there, while areas of continued low to no probabilities left their attention elsewhere. In fact, forecasters answered that on 81% of the days, probabilities increased in regions where convection initiated. The participant's confidence in the tool was aided by the training, answering that the algorithm performed as expected from the provided training 86% of the time.

> "I do think its biggest strength is in helping to maintain situational awareness about developing convection…especially during the early stages of a convective event."
> *Forecaster,* "Deep thoughts on CI product", *GOES-R HWT Blog*

> "Sometimes it is tedious looking at all the Cu and wondering which will develop. Having this display up helps me quickly see what Cu is developing more than others."
> *Forecaster,* "Watching Cu Field", *GOES-R HWT Blog*

> "CI was 81 at 1830z in northern Jeff Davis County (first image). By 1901z 0.5 deg reflectivity (image 2) showed the first greater than 35 dBZ returns… Severe hail, 1.75 inches, was reported at 2008z."
> *Forecaster,* "CI before severe thunderstorm", *GOES-R HWT Blog*

> "What looked visually like a potential source of a future storm in the south-central BYZ CWA was pegged by CI at 17% at 2000z. It never went on to develop and totally lost a CI value by 2036z."
> *Forecaster,* "Low CI verifies", *GOES-R HWT Blog*

A forecaster operating in the Lubbock CWA observed increasing CI probabilities prior to initiation on 05 May 2015. A line of Cu was first highlighted by the algorithm at 2000 UTC with 10% probabilities (Fig. 4). Fifteen minutes later, probabilities increased to 51%, before capping out at 60% at 2030 UTC. At that time, there were little to no radar returns associated with the area of high probabilities. The first 35+ dBz echo was observed at 2048Z, 33 minutes after the first 50%+ CI probability. The forecaster noted that this event exhibited the value of the CI product to enhance situational awareness.

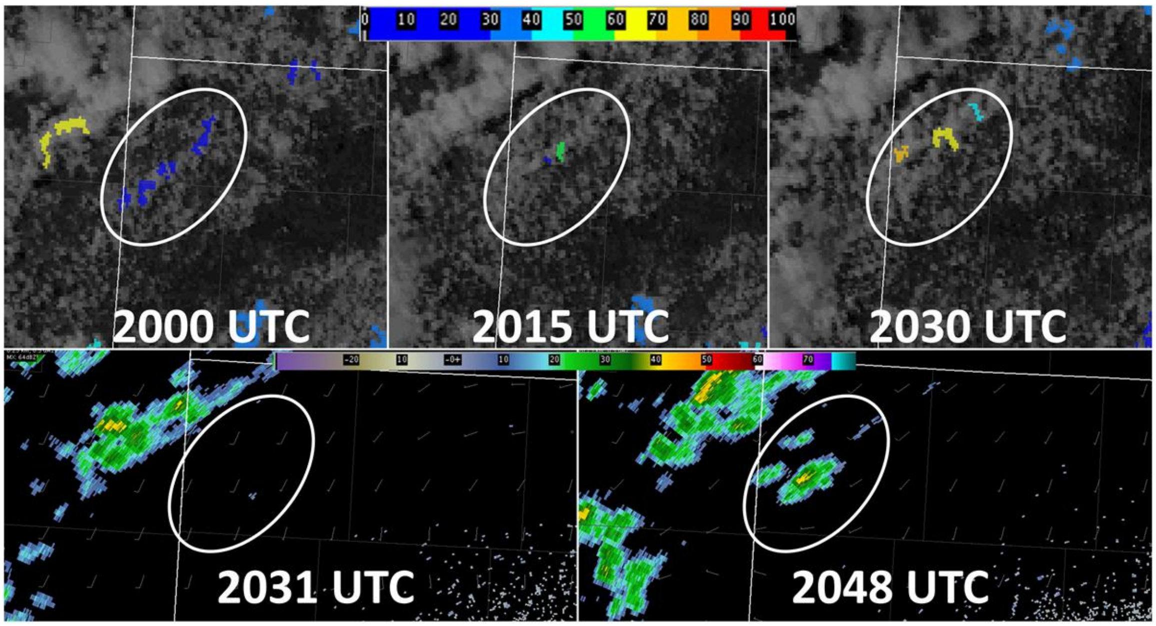

Figure 4: 2000 UTC, 2015 UTC, and 2030 UTC 05 May 2015 GOES-R CI probabilities and GOES-East visible satellite imagery (top row). 2031 UTC and 2048 UTC Lubbock radar base reflectivity (bottom row). From blog post, "Convective Initiation 30+ min lead time."

As the experiment progressed, specific situations in which the CI product proved most valuable became apparent. The tool performed best and forecaster confidence was at its highest in situations where upper-level cloud cover was absent. Forecasters felt that the CI product did quite well in correctly highlighting the future location of initiation along various types of boundaries including sea breezes, cold/warm fronts, dry lines, and outflows. This was especially important in situations where many boundaries and boundary interactions were present and influencing convective activity. Forecasters also found the CI tool to be helpful in busy nowcast situations of widespread convective activity as it successfully kept them alert to impending development. Especially rapid convective growth could often be predicted when the first CI value associated with a cloud element exceeded 80%. The CWSU forecaster surmised that this product would be especially useful in his forecast environment where all convection is relevant.

> "This is a good tool to get an idea to where sea breeze t-storms would initiate. It is often difficult to figure out where storms will initiate along a sea breeze."
> *Forecaster*, "Daily Summary: Week 2, Day 2 (May 12, 2015)", *GOES-R HWT Blog*

> "In Albuquerque, convection was already ongoing in the northern part of the CWA. CI was indicating 60+ probabilities southward along a N-S oriented boundary, indicating

that convection would continue to form southward along the line. Convection did form a little later and would eventually develop into strong storms."
Forecaster, "Daily Summary: Week 1 Day 2 (May 5, 2015)", *GOES-R HWT Blog*

The CI product was utilized by a pair of forecasters as their shift spun-up, focusing in S Florida on 21 May 2015. The environment was characterized by strong instability but very weak shear, with pulse thunderstorms appearing to be the primary threat. With a broad Cu field already in place by late morning, the CI product helped to draw attention to locations where convection was more likely to develop in the near future throughout south Florida. The three areas along a sea breeze front that had probabilities increase to above 70% by 1715 UTC all initiated by 1830 UTC (Fig. 5, yellow circles). Also at 1830 UTC, three new areas of Cu had probabilities steadily increase to over 70% west of the earlier development (white circles). Fifteen minutes later, it was apparent from radar that convective initiation had occurred in all six regions. Forecasters appreciated having the CI product in this pulse thunderstorm situation, noting that it correctly highlighted regions of new convection with useful lead time.

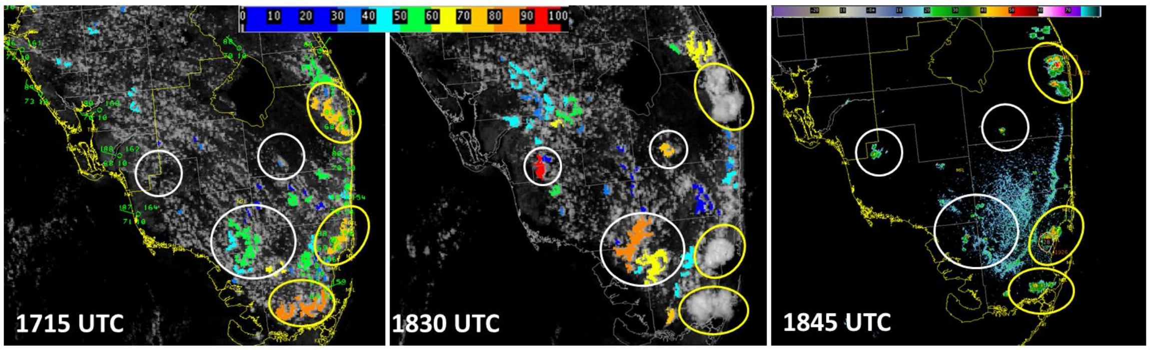

Figure 5: 1715 UTC and 1830 UTC 21 May 2015 GOES-R CI probabilities and GOES-East visible satellite imagery and 1845 UTC radar base reflectivity. Yellow (white) circles indicate over 70% CI probabilities from 1715 UTC (1830 UTC). From blog posts, "CI in South Florida" and "CI Continues to do well in south FL."

Limitations of CI product

Forecasters noted a few deficiencies that plagued the CI algorithm. Although developers have worked to improve this issue, forecasters noted that probabilities were scarce or unrepresentative within upper-level cloudy/cirrus regions. Confidence in the tool was at its lowest when upper level clouds were present, and forecasters were often left questioning what impact, if any, high clouds were having on the CI probabilities. The algorithm also struggled to pick out individual convective elements in areas of congested cumulus, many times grouping multiple clouds together as one larger object. Since experimental forecast activities never extended too far after dark, there was little opportunity to evaluate the product performance at night. However, the transition from day to night did appear to be less dramatic than was noted in previous years. The only nighttime issue mentioned was the existence of low probabilities along cloud edges.

"On a day with congested Cu...it was difficult for the CI algorithm to pick out individual convective elements. Instead the signal was washed out...identifying multiple Cu elements as one."
Forecaster, End-of-Day Survey

While the CI product was quite successful in providing guidance to *where* convection would soon initiate, forecasters were unsure precisely *when* in the future this would occur given the probability. Lead time typically varied from over one hour with low-to-mid probabilities to sometimes one satellite scan when probabilities exceeded 90% with the most rapid convective development. Finally, forecaster confidence in the tool decreased when probabilities jumped around erratically for a given cloud element. When this did occur, it was typically in the presence of upper-level cloud cover and in regions of weak forcing for ascent.

> "There was still inconsistent CI (30%, 60%, 30% in 3 scans) and this is tough for a forecaster to interpret. Usually there was echo by the 60-70% value if it persisted into a second 15 min window."
> *Forecaster, End-of-Day Survey*

Comments on product display

There were only a few concerns expressed about the visual display of the CI product this year. As mentioned earlier, updates to the algorithm have decreased the noise considerably, making it easier for the user to observe trends in the fields and identify local maxima. In situations with abundant Cu where many probabilities did still clutter the display, forecasters recommended monitoring trends in the probabilities over a broader area as opposed to an individual Cu element. Most forecasters preferred to overlay the CI field on satellite imagery, and some made the objects transparent so they could still see the Cu underneath. Similar to last year, some forecasters experimented further with the CI display; either blocking out the lowest probabilities or increasing the probability ranges within each color bin of the display. Some forecasters recommended a color scheme that has shades of gray at the bottom, transitioning to color at the top, putting less emphasis on the lower part of the scale and drawing out the higher probabilities.

> "We like the display, as the higher probabilities draw my attention to the areas where convection would eventually go. Not overwhelming at all."
> *Forecaster,* "Daily Summary: Week 1 Day 2 (May 5, 2015)", *GOES-R HWT Blog*

Additional suggestions for improvement

Forecasters had additional recommendations to potentially make the CI product more useful, especially during severe weather operations. As mentioned, the CI product provides probabilities for the development of a 35 dBz echo at -10C level. Although forecasters understand the need for such a product for other forecasting applications (e.g., aviation), they would like to see an additional algorithm that computes probabilities for severe convective initiation for use during severe weather events, using higher radar thresholds. A few forecasters also requested some sort of indicator, if possible, as to why the probability completely disappeared from a given cloud element. Possible reasons would include: cirrus contamination, probability of initiation has lowered, change in cloud type being detected, algorithm indicated convective initiation has occurred. Many participants asked to have readout of the significant fields influencing the CI probabilities, similar to what is available from the ProbSevere Model. As for the training, forecasters would have liked to have seen more application examples prior to their time in the

HWT. Lastly and for future years, participants would like more opportunity to evaluate the CI product at night.

> "The problem with CI at least for this end user is that a 35dbz storm is minimally impactful. I am more concerned about severe limits that would trigger an increased response and require communicating more urgently to the public."
> *Forecaster, End-of-Day Survey*

Other comments

Forecasters look forward to using the CI product in the GOES-R era when the higher temporal, spatial, and spectral resolution ABI data are expected to have a substantial positive impact on the algorithm. Some forecasters were fortunate enough to evaluate the algorithm when GOES-East was in Rapid Scan mode, experiencing the value of the higher temporal resolution satellite data. Large changes that occur between 15 and 30 minute scans currently are much more likely to be captured in the 5-min CONUS scanning of the ABI. Additionally, more frequent updates of the product in AWIPS will better keep the forecasters aware of the potential for convective initiation. The increased spatial and spectral resolutions of the ABI are also anticipated to have a positive influence on the CI probabilities.

> "The algorithm certainly suffers from the 15 min updates, as it is unable to "see" trends that are occurring between scans."
> *Forecaster,* "Daily Summary: Week 2, Day 1 (May 11, 2015)", *GOES-R HWT Blog*

3.3 ProbSevere Model

University of Wisconsin/Cooperative Institute for Meteorological Satellite Studies (CIMSS)

The NOAA/CIMSS ProbSevere model was evaluated in the HWT for the second consecutive year, with minor 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, and radar derived maximum expected size of hail (MESH). A developing storm is tracked in both satellite and radar imagery using an object-oriented approach. As the storm matures, the NWP information 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

All forecasters recognized the ProbSevere Model as a very useful situational awareness tool, providing them with a quick and easy means of identifying and tracking developing and strengthening storms. This was especially true during busy warning situations when there were many storms that needed to be monitored for the potential to produce severe weather. A high ProbSevere probability value would lead a forecaster to interrogate a storm in more detail, while a low value indicated occurrence of severe was not imminent allowing attention to be focused elsewhere, thus saving the forecaster valuable time. Additionally, rapidly increasing probabilities alerted forecasters to the storm and prompted further interrogation. When operations began after convection had developed, ProbSevere was often the first tool forecasters looked at as it provided them with a quick overview of where the strongest storms were located and where experimental warnings might be necessary. While most forecasters overlayed the ProbSevere data on radar imagery, some preferred to instead load it with satellite imagery in their situational awareness display.

> "In Amarillo, everything was sub-severe, and ProbSevere had very few probabilities over 30% on the day. This information was helpful in telling us that the storms would continue to be sub-severe."
> *Forecaster,* "Daily Summary: Week 1 Day 2 (May 5, 2015)", *GOES-R HWT Blog*

> "It did provide an opportunity to assess the situation quickly and figure out which of the ongoing storms need our attention first."
> *Forecaster, End-of-Day Survey*

> "When you have 30+ storms in your CWA, probsevere will highlight which storm you need to actually watch closer. Great situational awareness tool."
> *Forecaster,* "Daily Summary: Week 2, Day 1 (May 11, 2015)", *GOES-R HWT Blog*

> "Rapidly increasing probability of severe gives the warning forecaster insight that the storm is rapidly intensifying aloft. At this point, a forecaster can do further interrogation on the storm of interest."
> *Forecaster,* "Best Practices for the use of the NOAA/CIMSS ProbSevere Model", *GOES-R HWT Blog*

In most cases, forecasters did not issue warnings based solely off of ProbSevere. Instead, significant values or trends would lead a forecaster to interrogate the storm further, using ProbSevere as a supplement to their decision and confirmation for what other data sources were implying. Oftentimes, it would sway the warning decision when the forecaster was still on the fence after appropriate examination. On 95% of days, forecasters answered that the ProbSevere model output helped to increase their confidence in issuing (or not issuing) severe thunderstorm or tornado warnings. For most, it was important to see at least a couple scans of sustained high probabilities for greatest confidence. Importantly, there were many situations where ProbSevere led to quicker warnings, with forecasters answering that the output helped increase lead time to severe thunderstorm and tornado warning issuance on 76% of days. They noticed that lead time was most apparent when the satellite fields were available, and when the satellite was in rapid scan mode. By the final day of each week, all 25 NWS participants answered that they would use the ProbSevere model output if available during warning operations at their WFO.

"When we spun up MSP, cells were already on the radar, severe probs were 90. It gave me enough confidence to load up Warngen and issue after a cursory look at the radar base data."
Forecaster, End-of-Day Survey

"Satellite input field's added lead time when we had the satellite information previous days. Lead time was lessened when we didn't have the satellite information because of cirrus yesterday."
Forecaster, "EWP Week 2 Summary (May 11-14, 2015)", *GOES-R HWT Blog*

"While working on another monitor, the ProbSevere jumped back to ~90% which grabbed our attention and ended up leading to a warning being issued."
Forecaster, "Cell in SD", *GOES-R HWT Blog*

As an example, the ProbSevere Model aided a forecaster's warning decision with a storm split in the Bismarck CWA on 02 June 2015. A developing storm was first noted by ProbSevere at 2334 UTC with <10% probabilities, increasing to around 35% by 2346 UTC (Fig. 6). Signs of storm splitting had already become apparent in radar reflectivity when ProbSevere first separated it into two cells with similar probabilities of around 35% at 0000 UTC. The forecaster noted that the southern cell quickly became the stronger of the two per ProbSevere, reaching a 72% probability at 0006 UTC compared to 42% for the northern cell. With the southern cell increasing to 90% at 0008 UTC and the northern cell staying constant, the forecaster decided to issue a warning at that time on just the southern cell (warning not showed). The warning verified with a report of 1.25" hail at 0025 UTC, followed by numerous >2" hail reports after 0030 UTC. The forecaster wrote: "Knowing that the prob severe was much lower on the northern cell increased my confidence that I should only include the southern cell in my warning polygon."

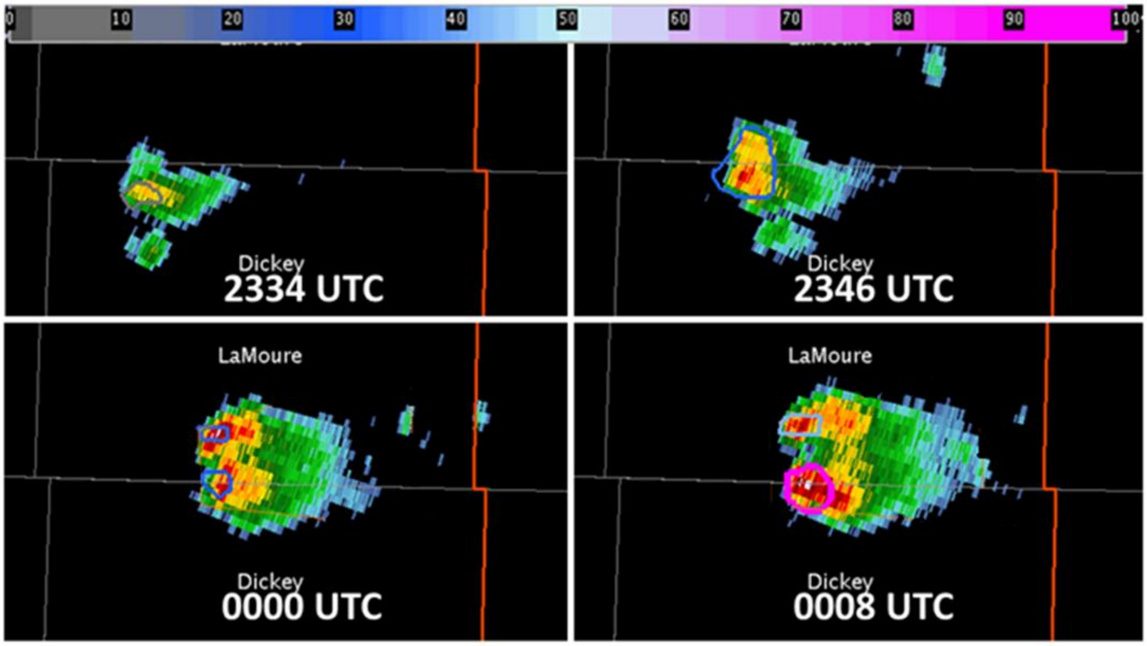

Figure 6: 2334 UTC and 2346 UTC 02 June 2015 and 0000 UTC and 0008 UTC 03 June 2015 radar reflectivity and ProbSevere probabilities (contours). From blog post: "ENI Data with Storm Split."

Although forecasters understood that the model was developed to provide probability guidance during the early stages of storm development, they still found utility after maturation. Persistent high probabilities for a storm with a history of producing severe weather indicated that the storm would likely continue to produce severe and necessitate continued warning issuance. Similarly, a storm with decreasing probabilities was likely weakening and would often lead a forecaster to let associated warnings expire with no reissuance.

> "With ProbSevere continuing to show 89% and recent reports of hen to tennis ball sized hail with the storm, have reissued for that storm as it nears the edge of the CWA."
> *Forecaster,* "New SVR for Northern OUN Storm", *GOES-R HWT Blog*

> "When warning was almost expiring, we weren't sure exactly what we wanted to do. Probsevere started to come down, plus not looking good on radar, used this to expire warning."
> *Forecaster,* "Daily Summary: Week 2, Day 3 (May 13, 2015)", *GOES-R HWT Blog*

In another example, rapidly increasing ProbSevere probabilities and jumps in lightning data led a forecaster to issue and then reissue a severe thunderstorm warning in the Midland CWA on 20 May 2015. Strong Normalized Growth and Glaciation Rates within a favorable environment and increasing MESH values resulted in a 99% ProbSevere probability at 2000 UTC (Fig. 7). The forecaster issued his first warning on the storm at 2006 UTC. By 2030 UTC, ProbSevere values remained at 99% with even higher MESH, aiding in the forecasters decision to reissue the warning. A trained spotter reported 1.75" hail with this storm at 2040 UTC. After the event, the forecaster noted that the ProbSevere Model did a great job of separating the severe cells from non-severe cells, as the storms associated with lowest probabilities generally remained sub-severe throughout the day.

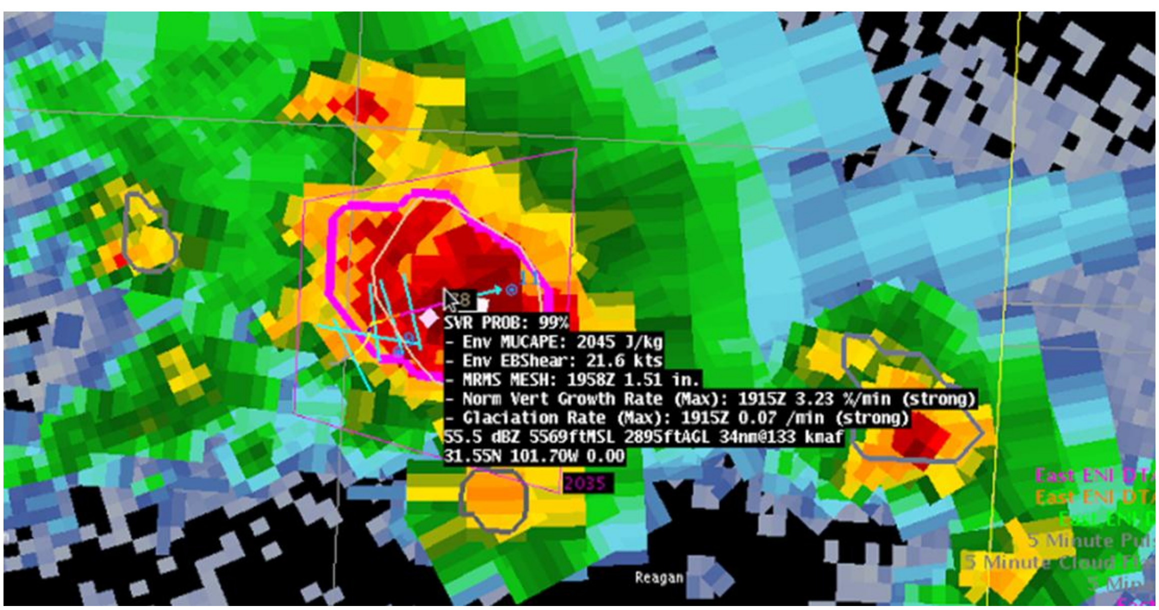

Figure 7: 2000 UTC 20 May, 2015 base radar reflectivity and ProbSevere probabilities (contour) with ProbSevere readout. Also shown are Earth Networks Dangerous Thunderstorm Alerts and Lightning Time Series (not discussed in text). From blog post, "SVR at 2006UTC and 2032UTC in MAF."

Limitations of ProbSevere

Forecasters found ProbSevere to be more useful in some situations than others. Similar to last year, they noted that the ProbSevere Model provided the greatest benefit for deep, discrete storms and when hail was the main threat, while probabilities were underdone with low-topped convection when severe wind was the main threat. Forecasters would like to see the ProbSevere model better handle upscale growth into line segments and multicellular systems. In such situations, storm cores were often lumped together into one larger object, causing the data to become less useful. On obvious days when the severe threat was considerable and storm development was most rapid, participants saw ProbSevere more as a confidence booster. In such situations, warnings were often necessitated based on radar data before or as the ProbSevere probabilities increased to over 80%. Forecasters quickly learned this and subsequently began the warning process after the first signs of rapid probability increase and significant growth in the satellite predictors. The increased temporal resolution of the GOES-R ABI (5-min vs. 15-min over CONUS) is expected to help increase lead time when storm development is most intense. Forecasters did find that ProbSevere provided more of an impact on days where the severe threat was more uncertain and when there were many storms to monitor.

> "Supercell storms were developing and producing tornadoes quickly, sometime before any signal in the MESH. Thus, probsevere percentages were quite low."
> *Forecaster, End-of-Day Survey*

> "More of a confidence booster yesterday, which was an obvious day. On the more marginal days, it was more useful."
> *Forecaster,* Daily Summary: Week 1 Day 3 (May 6, 2015), *GOES-R HWT Blog*

> "Our storms were so explosive, once it got close to 50, we would warn from radar because it was going so fast."
> *Forecaster,* Daily Summary: Week 5, Day 3 (June 10, 2015), *GOES-R HWT Blog*

Comments on product display

In general, participants found the ProbSevere contour display to be unobtrusive and intuitive 85% of the time during experimental warning operations. They appreciated its simplicity, commenting that the probability contours compliment radar imagery well and successfully grabbed their attention to the notable storms without adding too much clutter. However, there were instances where small developing storms in radar were obscured by the ProbSevere contour, especially near reflectivity gradients and when zoomed out in D2D. To get past this issue, several participants chose to decrease the opacity of the contours. Some forecasters did not like the default colormap and chose to create their own, finding that lower values appeared too similar to mid-range values and that the 50% threshold did not stand out enough. Color tables for any product will be a matter of individual preference, and can easily be changed by the user in AWIPS-II. Finally, some participants mentioned it might be helpful if the contour display could indicate when a storm has transitioned from developing stages to mature.

> "I liked the color change and polygon/contour line thickness changes as the probabilities increased."
> *Forecaster, End-of-Day Survey*

> "The higher probability areas stood out nicely. However, due to the small cell sizes the lines covered up quite a bit of the radar data. I decreased the opacity to get around this."
> *Forecaster, End-of-Day Survey*

Forecasters also valued the product readout, saying that it provided a quick and easy means for viewing relevant information about the storm and near-storm environment, while also augmenting their understanding of the probabilities, resulting in less of a black box system. The qualitative descriptors for the satellite values were a crucial component, and many did not see it necessary to display MESH values to hundredths of an inch. Forecasters wouldn't mind seeing the text output highlighted when values reach a certain threshold, including differentiating satellite descriptors that are N/A. Another suggestion made by participants from multiple weeks was to add a time series or trend line of ProbSevere values such that the user can quickly see how the values have changed over time for a particular cell. On a similar note, an indicator/flag of a substantial increase or decrease in probabilities would help to further differentiate cells that were undergoing the most rapid changes.

> "Having a time series would be helpful to see changes in probabilities through time. It is pretty easy to follow as is, but a times series would just add to it as an alternative method of visualizing past tendencies."
> *Forecaster,* EWP Week 2 Summary (May 11-14, 2015), *GOES-R HWT Blog*

> "I would like to see the text information output to be color coded based on thresholds for severity. For example if the glaciation is strong have that line show up as red and if moderate then yellow. The same for MESH, maybe yellow above 0.75 inches and red above 1.0 inch and purple above 2 inches."
> *Forecaster, End-of-Day Survey*

> "While at the lower probs, the satellite fields helped me to identify which storms were growing fast. The increasing trends, even low, told me to keep monitoring. The descriptors were helpful, especially the sat growth, qualitative ones."
> *Forecaster,* Daily Summary: Week 2, Day 2 (May 12, 2015), *GOES-R HWT Blog*

Additional suggestions for improvement

Forecasters suggested that training the algorithm to smaller geographic regions instead of nationwide could potentially make for more representative probabilities in any given location. Additionally, improved training on the thresholds and trends a forecaster should see before considering a warning would be helpful. Forecasters suggested that the issue of storm organization and merging of probabilities could potentially be regulated by incorporating higher dBz requirements once storms reach a certain level of maturity. Finally, some forecasters thought it might be appropriate in particular situations to issue longer-duration warnings when using ProbSevere given that they are likely issuing the warning sooner than they would have without the tool. Over time, a forecaster will develop best practices in his/her home WFO for using the tool in various forecast situations.

> "Wondering if best practice is to lengthen duration of warning in cases when using ProbSevere, since there is some extra lead time compared to when one might issue a warning without it. In our case, we issued at a 30 minute warning (fairly typical) when a 45 minute warning may have been more appropriate given how much sooner ProbSvr can flag a severe potential."
> *Forecaster*, "KPDT ProbSvr followup", *GOES-R HWT Blog*

> "I would like the Severe Probability product to follow the stronger cells embedded in the line, thus breaking up the numbers some."
> *Forecaster*, "Severe Probability along a line", *GOES-R HWT Blog*

Every participant answered that probabilistic output by specific severe threat (e.g., wind, hail, and tornado), would be useful. This work is planned by the algorithm developers, and will necessitate the inclusion of additional observational and NWP parameters. Suggestions from participants included: helicity fields, composite indices (e.g., SigTor for tornadoes), velocity data (e.g., radial velocity, radial shear, radial divergence), descending reflectivity core, dual-pol radar fields, DCAPE gradient, climatological data, reflectivity at certain temperature level, and storm motion. Additionally, information such as reflectivity structure (e.g., bowing segment) could potentially aid in determining severe threat and better detecting severe wind threats. Participants also supported the incorporation of lightning information into the algorithm, as lightning products and ProbSevere were often used in tandem during experimental operations, complementing each other quite well.

> "I had been noticing a gradual increase in ProbSvr and at 2134Z, it reached 79%. At the exact same time, I got a 2 sigma lightning jump. This increased my confidence that the storm was intensifying and that a severe thunderstorm warning was needed. I went ahead and issued the warning based on ProbSvr and Lightning Jump alone."
> *Forecaster*, Lightning Jump and ProbSvr Used in Warning Decision, *GOES-R HWT Blog*

Other comments

ProbSevere was incorporated into the prototype Probabilistic Hazard Information (PHI) Tool for the first time during this year's PHI experiment in the HWT. The PHI tool is part of a broad effort known as Forecasting a Continuum of Environmental Threats (FACETs) that looks to refresh the NWS watch and warning paradigm. Probabilistic output from the ProbSevere Model served as initial guidance for the very short-term PHI probability fields. The PHI output was made available in AWIPS-II for forecasters to view in the GOES-R experiment.

As an example, the PHI probabilities were viewed in conjunction with ProbSevere to aid in issuing an experimental warning in the Topeka CWA on 04 May 2015 (Fig. 8). In addition to favorable radar and lightning signatures, ProbSevere/PHI probabilities increased to over 80% by 2002 UTC, when the forecaster decided to issue the warning. 60 mph winds were reported in association with this storm at 2032 UTC.

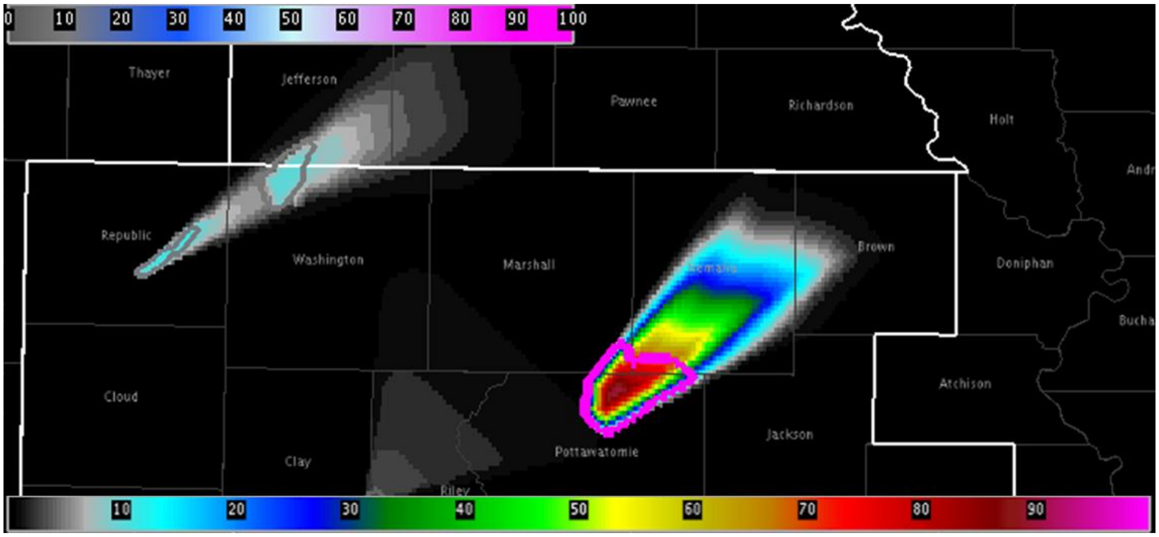

Figure 8: 2000 UTC 04 May 2015 PHI probabilities (fill; lower colorbar) and ProbSevere probabilities (contour; upper colorbar). From blog post, "First Severe TOP."

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

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 May 18 to June 11. 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. The imagery was available in AWIPS-II for EWP participants to view during the final three weeks of the 2015 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 second 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 at the satellite sub-point. An automated Overshooting Top Detection product previously evaluated in the HWT was generated from the 1-min data and also made available to forecasters in AWIPS-II. Finally, a 10-min updating atmospheric motion vector product was generated from the 1-min imagery and made available to some forecasters via a webpage. 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

The most obvious benefit of the 1-min satellite imagery from GOES-14 to the forecasters was the new ability to observe cloud fields as they evolved in near real-time instead after they had changed. Not only was the forecaster receiving new images more often, but the images were available with decreased latency (3-4 min) compared to current routine imagery. This created substantial lead time to the identification of processes and features that are vital to convective nowcasting. The 1-min imagery aided the warning forecaster across the entire convective cycle, including: environmental analysis pre-CI, identification of CI, mature convective monitoring, warning issuance, and storm weakening. Additionally, forecasters were creative in utilizing the 1-min imagery in concert with other very high temporal resolution data sources. Participants answered that the 1-min satellite imagery provided them with significant information not captured in the routine satellite imagery on 93% of the days when it was available.

While some forecasters preferred to load shorter, 20-50 frame loops, others found it more useful to load 100+ frames in AWIPS-II. Additionally, most forecasters experienced the greatest benefit from the imagery when it was "hyperlooped", increasing dwell rates to greater than what the AWIPS-II default menu permits. This allowed for a fluid visualization of atmospheric phenomena. There were no major AWIP-II performance issues noted in association with the 1-min satellite imagery, even as over 100 frames were loaded and various data combinations were used.

The 1-min imagery aided participants well before convection even began to initiate as they analyzed the environment and eventual growth of the Cu field. Morning and early afternoon cloud clearing trends were analyzed promptly and with ease, allowing for the straightforward identification of areas that were likely to destabilize and initiate first or where differential heating boundaries may set up. The subsequent development of boundary layer Cu seen in the SRSOR imagery led the forecaster to more precisely monitor destabilization trends, classify regions of relatively high moisture, and track the movement of moisture in space and time. In the presence of multiple cloud layers, forecasters said that they could visualize shear in the atmosphere important to the development of organized severe storms. Finally, boundaries (e.g., outflow, warm/cold front, sea breeze) were more easily identified and tracked in the continuous imagery, including the diagnosis of merging boundaries.

> "An area of higher moisture as indicated by low level surface based Cu development was poised just east of the mountains."
> *Forecaster, End-of-Day Survey*

> "Two boundaries were evident over southern TX that had direct effects on the cumulus field, suppressing it, as it passed through. No evidence of a wind shift occurred with these boundaries."
> *Forecaster,* "Trackable Boundaries Better Seen in GOES 1min Imagery", *GOES-R HWT Blog*

> "The 1-min SRSOR nicely shows the sea breeze along the NC/SC border. Looping the satellite imagery shows the cumulus along that boundary towering and I would expect some convection to develop along that soon."
> *Forecaster,* "1-min Super Rapid Scan imagery shows sea breeze boundary", *GOES-R HWT Blog*

> "The GOES SRSO imagery from 1848-2015 UTC shows the influence of the cool onshore flow with marine stratus holding on the southeast coast of New England from

Groton, CT (KGON) to Providence, RI (KPVD) to Marshfield, MA. Just to the north of that region the smooth texture of the marine stratus changes to rolls/streets showing us where it might be possible for convection to develop."
Forecaster, "SRSO showing marine stratus over SE coast of New England", *GOES-R HWT Blog*

The 1-min imagery most often provided the first sign that convective initiation was imminent or occurring during experimental warning operations. Forecasters were able to track the evolution of individual cloud elements, observing trends that become disconnected with longer time between scans. The processes of Cu developing into towering Cu or groups of Cu clumping together were visualized in near real-time, drawing forecaster attention to the areas of most imminent convective initiation. Failed attempts of convective initiation were important to visualize in the 1-min imagery, as it signaled to the forecaster that the capping inversion was still in place but weakening. The first signal of convective initiation was diagnosed from the 1-min imagery as it occurred (instead of after), with areas of rapid development standing out against the background Cu field. The 1-min IR imagery was also helpful during initial development for the identification of rapid cooling and implicit most rapid convective development.

> "The 1 minute temporal resolution allows for visual tracking of individual small convective cell development. This detail in not as easily detected in the 15 min typical visible satellite imagery…because the vertical development gets disconnected from the low-level features in that time span."
> *Forecaster,* "Utility of GOES Superscan to visualize vertical wind shear and individual cell development", *GOES-R HWT Blog*

> "Tremendously useful to monitor developing cu and help focus SA into what to monitor. Felt it kept me ahead of the game and able to plan for the next piece of data to look at."
> *Forecaster, End-of-Day Survey*

> "We were able to easily identify clouds that were getting sheared off before they had a chance to grow enough to overcome that issue…. Was very helpful in seeing "dud" updrafts basically in realtime so that we knew storms were not imminent."
> *Forecaster, End-of-Day Survey*

> "Having such fine time resolution really helps to pick out which clouds might have the most promise of going up, and being able to see them begin to get sheared almost as it's happening is valuable in assessing not just the individual cell's situation, but the environmental conditions as a whole."
> *Forecaster,* "Thoughts on 1-min vis imagery", *GOES-R HWT Blog*

For example, the 1-min satellite imagery aided forecasters during the early stages of Cu development and convective initiation in the Chicago CWA on 10 June 2015. A broken mid-level cloud deck partially obscured the surface-based Cu below, making it difficult to monitor organization using the routine satellite imagery. With the 1-min imagery, however, forecasters were able to track individual cloud elements as they quickly grew and became organized along a boundary draped across N Illinois (Fig. 9). It became apparent that this boundary would serve as the focus for convective development with Cu clumping together and rapidly growing into towering Cu. Convection first initiated along the boundary near the Lake Michigan shoreline, and continued its development westward through the evening. The forecaster commented: “When hyper-looping it was easy to see where cumuli were developing on the boundary, even with a mid-deck of clouds moving across the developing cumulus.”

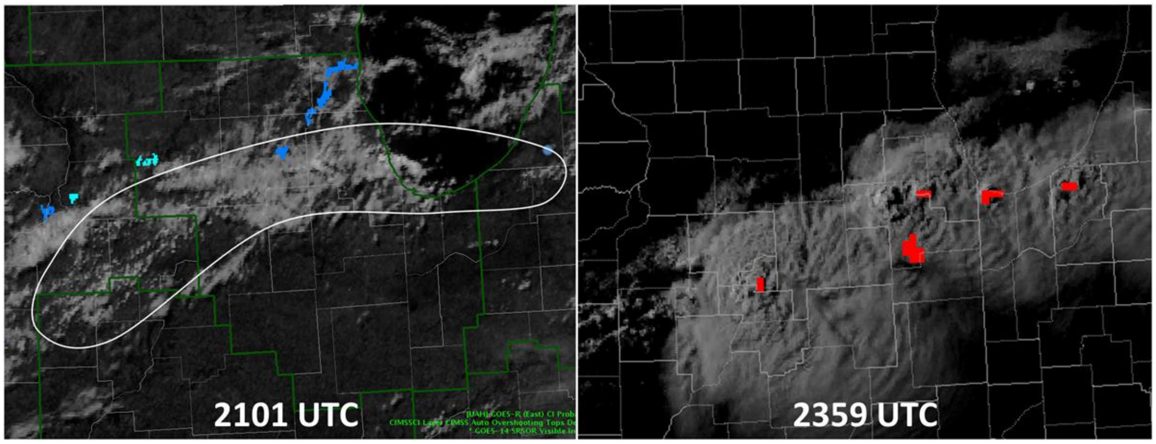

Figure 9: 2101 UTC 10 June 2015 GOES-14 SRSOR 1-min visible imagery and 2045 UTC GOES-R CI product overlay (left) with concentration of cu along boundary circled in white. 2359 UTC GOES-14 SRSOR 1-min visible imagery and Overshooting Top Detection algorithm overlay (right). From blog posts, “One-minute clearly showing boundaries over LOT” and “Overshooting tops in IL.”

The 1-min satellite imagery continued to aid the warning forecaster after initiation and when convection had matured. Improved monitoring of boundaries remained beneficial during this period, especially the analysis of boundary interaction with ongoing convection. The flux of upstream boundary layer Cu into mature convection implied the storms were being fed with low-level moisture and had the potential to be long-lived. Participants continually noted their improved ability to identify and track gravity waves and observe their impact on convective activity. Analyzing cloud top features such as overshooting tops and above anvil cirrus plumes in the 1-min imagery kept forecasters aware to the locations of the strongest updrafts at all times, noting particularly long-lived cells and where weakening trends (collapsing tops) were just starting to become apparent. Especially in pulse thunderstorm situations, forecasters noted the importance of observing collapsing tops in real-time as such a process is often a precursor to strong winds at the surface. Warming of cloud tops in the 1-min IR imagery also clued forecasters into areas of convection that were starting to show signs of weakening. Several forecasters remarked that as convection continued to grow upscale, they could more easily and quickly identify the convective mode. This included early signs of thunderstorm growth into a supercellular storms and the transition of single cellular storms into multicellular and linear systems.

> “Seeing the overshooting tops, rather than seeing them in 15-minute jumps, gave a much better idea of which specific parts of a storm were the most intense.”
> *Forecaster, End-of-Day Survey*
>
> “I min visible imagery shows a developed inflow region marked by low level cu field streaming into the southeast flank of the cell.”
> *Forecaster,* “Supercell west of Limon, CO matures”, *GOES-R HWT Blog*

> "If I had near real time one minute satellite data, I could find the strongest updraft in the line. This could have a huge impact on these warnings, the FAR and POD for these storms… This could lead to lead time with QLCS and HSLC storms."
> *Forecaster,* "Thoughts on Overshooting Tops and 1 min imagery", *GOES-R HWT Blog*

Although radar imagery continued to serve as the primary warning tool, forecasters found it useful to incorporate the 1-min satellite imagery into their warning decision-making process. 1-min satellite imagery allowed the forecaster to monitor updraft health in-between radar volumes, which was especially important in situations where storms were growing and changing rapidly. Continued updraft strengthening before the first warning issuance acted to increase forecaster confidence that a warning would be needed upon seeing the next radar scan. Decreasing updraft strength of ongoing storms as seen in the 1-min imagery oftentimes influenced a forecaster's decision to discontinue a warning. First signs of continued development along a boundary or redevelopment away from the previously primary updraft were observed in the 1-min imagery, indicated new warnings may be necessary in the near future. When the radar was operating in Supplemental Adaptive Intra-Volume Low-Level Scans (SAILS) or meso-SAILS scan mode, the 1-min imagery supplemented the extra base scans by continuing to provide information through the depth of the storm. Finally, in situations where radar coverage is lacking or non-existent, the 1-min satellite imagery had even more weight in the warning decisions, especially when used in conjunction with total lightning data.

> "Were able to see where the strong updrafts were and continued a warning in one case based on seeing that updraft and expecting the radar data to match soon after."
> *Forecaster, End-of-Day Survey*

> "Decided not to issue a third warning for a left moving SC in ICT based on less of an updraft in that imagery."
> *Forecaster, End-of-Day Survey*

> "Seeing updrafts reorganize themselves within storms. Repositioning itself into more favorable part of storm, gives you confidence that that storm may thrive. In near real time that is big."
> *Forecaster,* "Daily Summary: Week 4, Day 3 (June 3, 2015)", *GOES-R HWT Blog*

Throughout the experiment, forecasters found it beneficial to view the 1-min satellite imagery concurrently with other very high temporal resolution observational datasets. Total lightning data were commonly used as an overlay on the SRSOR imagery, including 1-min Earth Networks point data and 1-or 2-min gridded pGLM flash extent density. Lightning data supplemented the SRSOR imagery by providing an alternative depiction of rapid fluctuations in updraft strength within a storm. Forecasters also found it useful to view SRSOR and radar image combinations, especially when the radar was in SAILS or meso-SAILS scan mode. They valued the ability to monitor the evolution of near-storm features from satellite and storm structure from radar in a single display. Forecasters commented that the various data combinations improved their understanding of how convective activity was evolving in real-time by providing a more complete and continuous view of the phenomena at hand. Some participants noted that, at the very least, it would be useful to incorporate such displays onto the situational awareness monitors present in forecast offices. Examples of various data combinations used during this experiment are shown in Fig. 10.

> "I would love to have a Super Rapid Scan Satellite loop with reflectivity, and lightning somewhere on my D2D as a way to stay grounded with what is happening in real time during severe weather operations."
> *Forecaster, End-of-Week Survey*

> "The 1-min satellite imagery was invaluable in seeing how convection (or lack thereof) was occurring and evolving. Working that in with total lightning really helped with confidence in warning vs. not warning. NWP has its place, but real, actual data to compare against NWP is helpful in having an idea of storm evolution."
> *Forecaster, End-of-Week Survey*

> "The high frequency satellite imagery enables the ability to better match the frequency of radar data and combine them to give a unique view in this case of the radar data near the ground and the top of the storm via satellite… Evident are storm structure, outflow boundary, inflow, and anvil development and storm top outflow all in the same image. This helps verify the conceptual model of supercells."
> *Forecaster,* "Combining SRSO and Radar Data", *GOES-R HWT Blog*

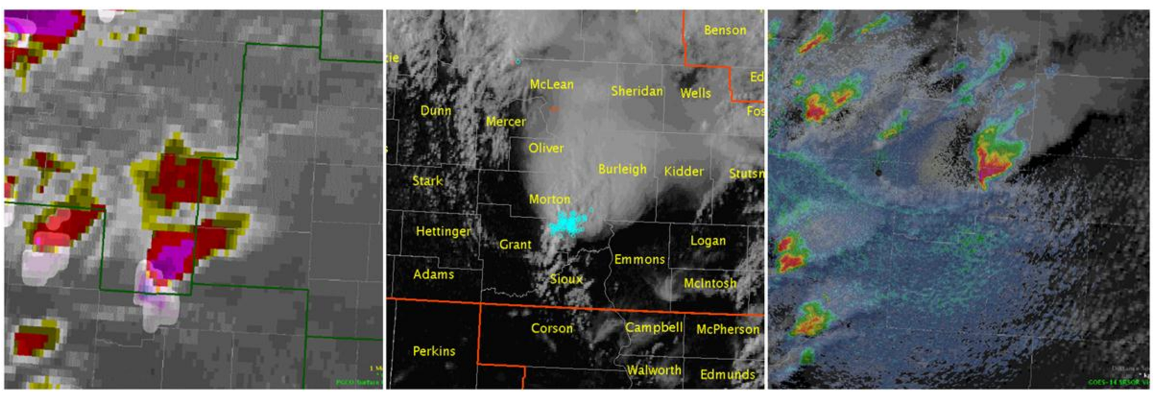

Figure 10: 11 June 2015 GOES-14 SRSOR 1-min IR imagery and pGLM total lightning flash extent density (left), 02 June 2015 GOES-14 SRSOR 1-min visible imagery and Earth Networks Total Lightning flashes (middle), and 11 June 2015 GOES-14 SRSOR 1-min visible imagery and KPUX base radar reflectivity (right). From blog posts, "Integrating SRSO Visible imagery with 1 minute total lightning data", "Utilizing 1 min GOES Visible Satellite Imagery", and "Combining SRSO and Radar Data."

Algorithms using SRSOR data

Various algorithms are being developed to further take advantage of the 1-min satellite data and complement the imagery, some of which were demonstrated in the HWT. The automated Overshooting Top (OT) Detection algorithm is one such product that was generated from the 1-min data and made available to the HWT participants in AWIPS-II (Bedka et al. 2010). Forecasters felt that the algorithm made it easier to identify and track strong, persistent updrafts, and identify cells that were showing weakening trends via collapsing storm tops. With the 1-min imagery, these trends were easier to monitor and significant changes were not missed as is often the case in routine imagery. Many commented, however, that overshooting tops were especially easy to identify manually in the 1-min visible imagery and were often apparent prior to the algorithm picking it up. This is due to the fact that the current algorithm has set brightness temperature thresholds, so weaker overshoots are missed.

> "Algorithms such as the Overshooting Top Detection will first give a quick snapshot of current conditions, then will give persistence of the overshooting top over time, which could mean possible warnings."
> *Forecaster, End-of-Week Survey*

> "OT detection algorithm is nice because it is capturing the strongest OTs. It is nice to be able to quantify the OTs, something you can't do quickly without an algorithm."
> *Forecaster,* "Daily Summary: Week 4, Day 2 (June 2, 2015)", *GOES-R HWT Blog*

Another algorithm that utilizes the 1-min data and was evaluated by a few forecasters in the HWT this year was the 10-min updating satellite-derived winds product. This product was available to forecasters via a webpage, and provided wind barbs in 5 layers, including: 1000-800, 800-600, 600-400, 400-200, and 200-50 mb. Forecasters who viewed this product overwhelmingly found it to be useful and look forward to viewing it in AWIPS-II, especially considering observations of wind vertically through the atmosphere are scarce both temporally and spatially. As an example, the wind data were found to be especially useful when assessing the severe threat with developing convection in the Cheyenne CWA on 02 June 2015. See comments below and related blog posts for details.

> "[1-min srso wind data] shows that there is a weak 50kt + jetlet moving across the cwa. This suggests that deep layer shear is larger than previous suggested by the RAP. As storms move to the east across the cwa, I'm expecting the storms to become more organized."
> *Forecaster,* "SRSO data vs. RAP", *GOES-R HWT Blog*

> "I thought that the jetlet would cause the storms to become stronger and more supercell in nature until it moved out of the area. This in fact happened. This lead to a small window ~2 hours of supercells with large hail."
> *Forecaster,* "Thoughts on 1min SSRO Data and Severe Weather Forecasting and Ops", *GOES-R HWT Blog*

Other comments

Participants went on to speculate other situations in which they foresee the very high temporal resolution satellite imagery aiding their WFO. Improved real-time fire weather monitoring was mentioned numerous times, especially the earlier identification of wind shifts as indicated from the smoke plume. Forecasters in coastal offices see the imagery helping to more efficiently track the evolution of marine stratus, and differentiating such cloud types from cloud roles and streets. Forecasters in offices with desert terrain look forward to using the 1-min imagery to identify the first signs of developing dust storms and closely track there evolution. Finally, forecasters see the imagery aiding in the monitoring winter snow bands and volcanic ash plumes.

> "[The 1-min data will be helpful] with fires, when providing DSS. If you have a plume and you think it is going to change based on winds in sat imagery, that gives you lead time to make the call and say the plume will be changing direction. Would want to warn of impending wind shift, as any heads up would be great."
> *Forecaster,* "Daily Summary: Week 4, Day 3 (June 3, 2015)", *GOES-R HWT Blog*

> "In San Francisco with stratus, it would help with aviation, timing of amendments and knowing exactly where the edge of stratus is ASAP is important."
> *Forecaster,* "Daily Summary: Week 5, Day 4 (June 11, 2015)", *GOES-R HWT Blog*

Across the three weeks of super rapid scan availability in the HWT, none of the 18 forecasters expressed any concerns related to "data overload" when applying the 1-min satellite imagery in experimental warning operations. It was obvious that the 1-min imagery greatly enhanced forecaster awareness to the current atmospheric situation, pre- and post- convective initiation, revealing what was happening in near real-time. The imagery now matches and even surpasses the temporal resolution of other significant observational data sources such as radar and lightning, allowing all three sources to serve as complements to each other. Participants stressed that an important aspect for GOES-R 1-min/30-sec imagery training will be to see examples of how the super rapid scan imagery has already been utilized in various operational situations. Participants offered ideas for how the mesoscale sectors might be requested once GOES-R is operational: 1) have pre-defined mesoscale sectors from which a user can request, and 2) make a webpage available that allows a forecaster to select and submit a pre-defined region or a custom region. Forecasters foresee the 1-min imagery likely having forecast utility in multiple regions every day as there are many situations in which it has already proven to be operationally significant.

3.5 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)

The psuedo-Geostationary Lightning Mapping (pGLM) products were reviewed as part of the experiment in 2015. These total lightning products were created using Lightning Mapping Array (LMA) data from regional networks around the CONUS to make a proxy accumulated product for the GLM (Goodman et al. 2013). The very-high frequency (VHF) radiation detected by the LMA networks provides areal extent of lightning. Once sorted into flashes, these data are gridded and remapped to the spatial resolution matching that of the GLM (8 km x 8 km) and displayed as a flash extent density product. For the 2015 evaluation, forecasters were specifically asked to evaluate multiple time updates (i.e., 6-min matching that of radar frequency and 1-2 min matching the native LMA network update frequency). Additionally, forecasters were asked to provide a preference on multiple color tables for the pGLM data.

Forecasters were able to view and evaluate the pGLM data during 14 of the 20 operational days of the experiment, covering northern and central Colorado, West Texas (Lubbock), South Texas (Houston), Washington D.C., and northern Alabama/southern Tennessee. New for the 2015 experiment, the forecasters were also provided shape files of the range rings of the various LMA networks within the AWIPS-II display; this helped forecasters focus on the central LMA areas and discount decreases in storm lightning activity as storms moved beyond 150 km (Fig. 11).

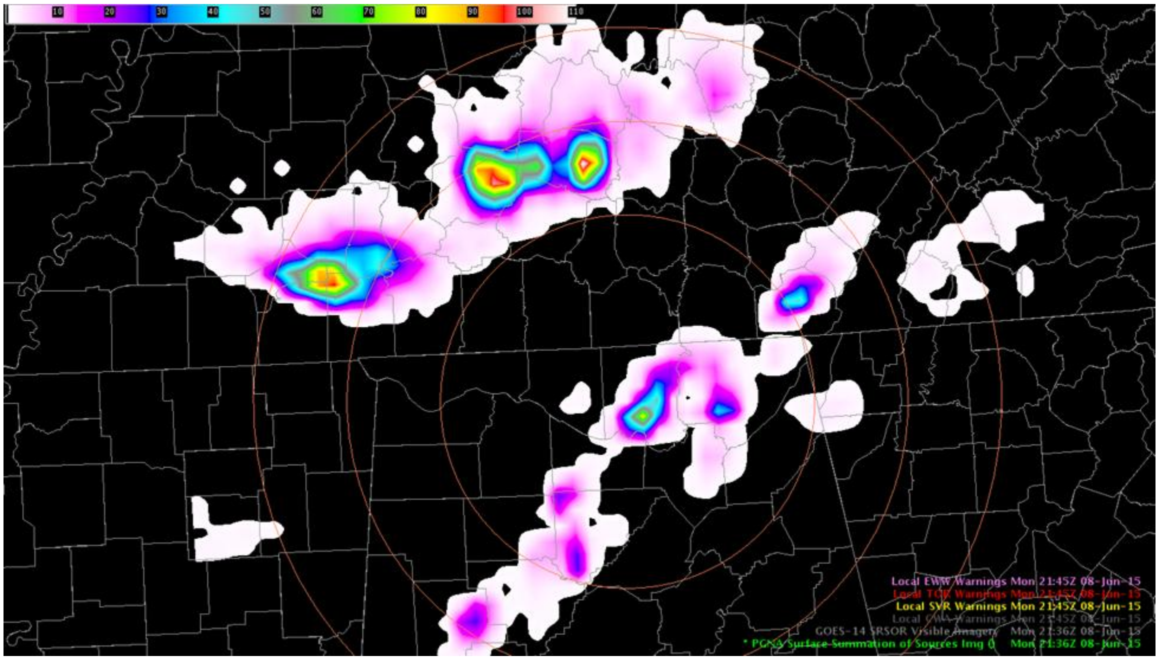

Figure 11: Interpolated pGLM 6-min flash extent summation for northern Alabama on 8 June 2015. Range rings for northern Alabama LMA shown in orange. From blog post, "PGNA/lightning data on warned storm in Williamson Co."

Use of pGLM total lightning products in the HWT

The forecasters in the HWT primarily utilized the multiple pGLM products for situational awareness (85% of survey respondents) and to monitor convective growth (68% of survey respondents). When super-rapid-scan imagery was available over the same domain, forecasters created visualizations that incorporated both datasets – looping (or hyper-looping) the frames in order to isolate intensifying storms (e.g., 11 June 2015 blog: "Integrating SRSO Visible imagery with 1 minute total lightning data"). Additionally, many forecasters integrated the pGLM data with other products such as the lightning jump algorithm and ProbSevere to create "ideal" situational displays. The use of the pGLM for situational awareness and monitoring storms was a theme repeated within the forecaster blog posts and the daily surveys.

> "It provided more data in an area that didn't have much ground truth to begin with."
> *Forecaster, End-of-Day Survey*

> "It was one of the primary ways used to monitor convective growth and changes in storm intensity."
> *Forecaster, End-of-Day Survey*

> "I felt the pGLM data did provide me with improved situational awareness and help focus my attention to this area as these storms had been quite weak in the several scans leading up to this event."

Forecaster, "pGLM/Prob Severe associated with Storm Merger", *GOES-R HWT Blog*

The gridded pGLM products were easily integrated into the warning decision process by some forecasters and were often the deciding factor in choosing to warn or not-to-warn when in a marginally severe environment (Fig. 12). The forecasters that utilized the data in the warning-decision process appeared to have a better understanding of the link between storm intensity and electrification, using statements such as "compact clusters [of lightning] help[ed] to identify updraft locations", the "storm had new growth that occurred coincident with an increase in the total lightning on the pGLM" and the lightning data "keyed in on the stronger more dominant right mover" as part of the warning-decision discussion.

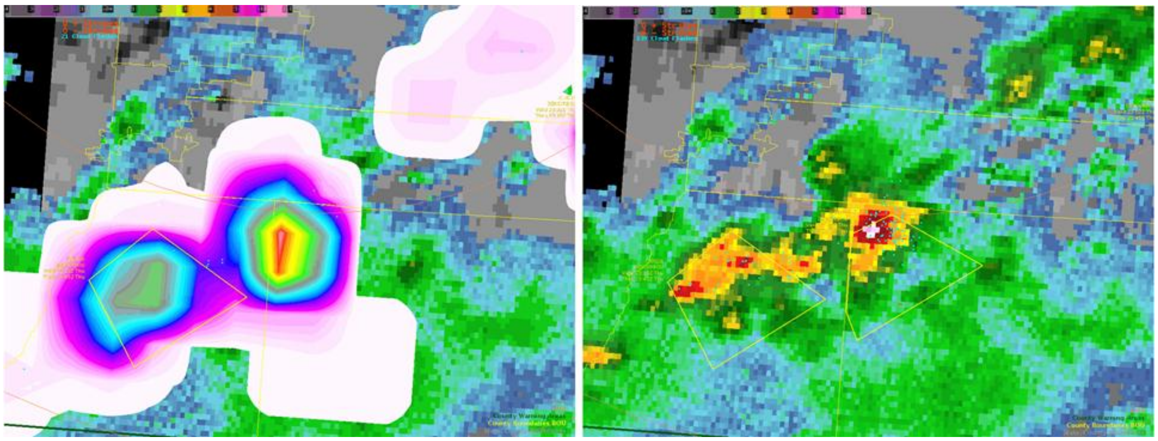

Figure 12: Interpolated pGLM flash extent density grid (default color map) just prior to forecaster warning issuance (left panel) and KFTG reflectivity following warning (right panel). Forecaster issued warning on eastern cell following rapid increase in flash rate when storm interacted with outflow from the western cell. Lightning increase was the primary influence on the warning decision. From blog post, "Strong pGLM surge leads to warning."

However, multiple forecasters mentioned that they did not understand how the lightning data could be incorporated into the warning-decision process. This points to a necessity for in depth training modules and courses before and as the GLM data are made available to forecast offices. One visiting NWS Science and Operations Officer (SOO) suggested this training should be set up as a multiple hour package that reviews foundations of the various lightning detection networks and scientific research for severe, winter, and safety uses. The training should also incorporate a "best practices" for operational displays and product integration and an overview of future algorithms and tools.

"Trying to figure out what the values mean and how it might be useful."
Forecaster, End-of-Day Survey

"As a warning forecaster, trying to weigh a large total flash rate increase with the near-storm environment and radar data can be a challenge."
Forecaster, "Flash Increase, To Warn or Not To Warn?", *GOES-R HWT Blog*

Despite the need for additional training regarding total lightning data and use, nearly all forecasters mentioned at some point during their visit (either in the blogs, discussion, or the surveys) the value of the pGLM products for Decision Support Services (DSS) for locations such as outdoor venues as well as for marine and fire weather forecasting. Multiple forecasters commented on the additional lead time and areal extent information over cloud-to-ground lightning data. A few discussed with surprise the extent of lightning relative to the storm core and main updraft. Finally, as more than one forecaster noted, a storm does not need to be severe to be a threat to someone outdoors and “any lightning is hazardous.”

Comments on product display

Three separate color maps were provided to the forecasters for evaluation this year (Fig. 13). In general, most forecasters (41%) used the default color map (note: this color map is the default for all gridded data within the AWIPS2 operational system) as it was the best for clearly highlighting the high flash rates. Though many forecasters noted they could see how one (“LMA1”) may be more useful than another for low flash rate storms. None of the forecasters liked the third option (“LMA2”) as the breaks from one side of the color wheel to another did not appear to fall at logical or important flash density values. Discussion and survey responses suggest there is room for continued improvement regarding the color maps. One suggestion included moving to a monocolor visualization (e.g., Gray-to-white scale, though this could prove difficult for visible satellite overlays). Additionally, multiple forecasters specifically stated not to duplicate a radar reflectivity color map (since the products are also often overlaid). Forecasters also suggested using the sampling tool as a best practice with any of the color curves to ensure finding the highest rates, as it was difficult to pick out the highest rates at a glance with any of the current color maps.

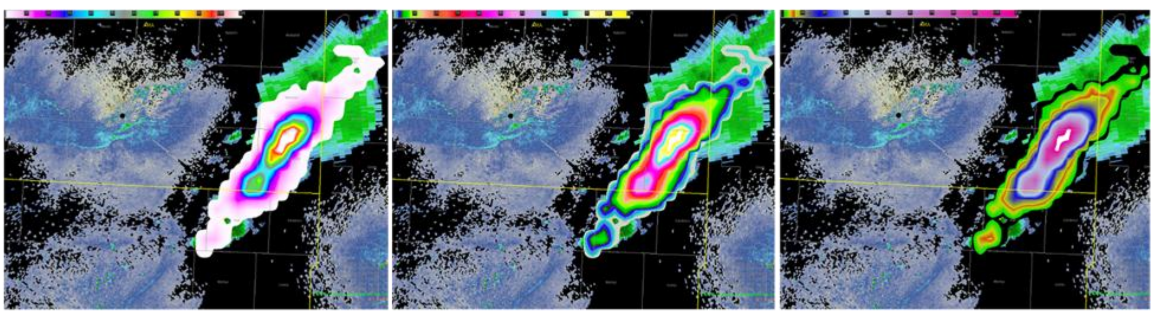

Figure 13: The three color maps available to forecasters for the HWT evaluation: “LMA default” (left), “LMA1” (middle), and “LMA2” (right). For this event on 19 May 2015, the forecaster preferred the default color map, but noted the possible value of LMA1 for low flash rate storms.

Finally, while forecasters did incorporate the 6-min accumulation products into their analysis, the overwhelming preference was for the one or two-min native LMA temporal resolution. In a couple cases, forecasters liked the accumulation product because of the higher counts, but overall the utility in the 6-min product was only rated “medium” to “high” by a majority of the forecasters in the post event surveys. Meanwhile, the utility of the 1 or 2-min flash extent density product was rated “high” to “very high” by most forecasters. The main reasoning for the 1-min preference was the additional information provided between radar volume scans and the ability to match it with other 1-min products such as the super rapid scan satellite data.

> “I much preferred the 2-minute density rather than 6-minute summation, although it's possible further use might change my mind. But I thought the 2-minute product helped me identify shorter increases more easily. “

Forecaster, End-of-Day Survey

"I like the one-minute flash density plot and it did provide some usefulness in highlighting developing storms in between radar scans and other traditional lightning datasets."
Forecaster, End-of-Day Survey

"Updates to the flash every 2 minutes gave more lead time versus waiting for radar data to update."
Forecaster, End-of-Day Survey

3.6 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) was evaluated for the second time in the experimental operational environment of the HWT. 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 (e.g., Schultz et al. 2009). While the GOES-R 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 implementation of the LJA pre-GLM in the 2015 HWT experiment was produced using data from the Earth Networks Total Lightning Network (ENTLN). The switch to ENTLN data allowed for the evaluation of the LJA by forecasters on a daily basis throughout the experiment; this was possible due to the CONUS coverage of the ENTLN as opposed to the limited range the LMAs that were utilized in the 2014 evaluation period. While the detection efficiency of the ENTLN is less than that of the LMA, this change ultimately led to more feedback regarding the algorithm display, integration within the warning-decision process, and best practices for future implementation.

The LJA was provided to forecasters through a gridded display of tracked storm objects that highlighted the degree of jump (or sigma-level, Fig. 14). Storm tracking and jumps were completed in the background while the LJA grid was updated every minute within the AWIPS-II display for the forecasters. The jump was calculated using the 2-min storm flash rate and the standard deviation over the previous 10-min period of activity (not including the period of interest). At the request of multiple forecasters during week one of the experiment, the display was expanded to include the visualization of negative jumps (or rapid decreases) in the storm-based flash rate. This addition of negative-sigma levels needs further evaluation before it is transitioned to operations.

Use of LJA in the HWT

Forecasters utilized the LJA for both situational awareness and during the warning-decision process throughout the five week experiment. Forecasters did not typically issue warnings on LJA signals alone, but often commented that the LJA added confidence in a warning decision.

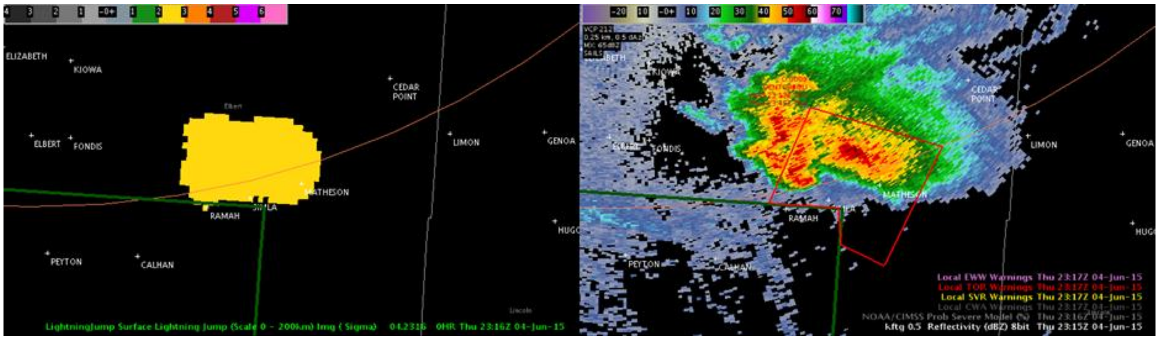

Figure 14: The storm-based lightning Jump Grid (left) and 0.5 deg Reflectivity from KFTG on 04 Jun 2015.

> "The LJA really helped with both warning operations and situational awareness. It was one of the first products to identify rapid intensification of one of the cells in our [County Warning Area]. We used it along with a Zdr column well above the freezing level to issue a warning."
> *Forecaster, End-of-Day Survey*
>
> "It caught upward trends better than the other lightning products."
> *Forecaster, End-of-Day Survey*
>
> "I found it to be very useful for a quick visualization... With all of the other data to look at during the warning decision process, having a product that was a easy 0-6 scale made for fast analysis."
> *Forecaster, End-of-Day Survey*

For this evaluation using ENTLN data, there was an overall increase in sigma-levels in the LJA product above the previous evaluation using LMA data. Forecasters noted daily LJA grid values above 6-sigma. However, many of these increased sigma-levels occurred in storms undergoing explosive growth prior to severe weather. One example is the 7-sigma jump prior to tornadic development for a supercell storm on 04 June 2015 near Simla, CO (Fig. 14). However, other examples of these increased sigma levels were a result of storm mergers with an increased storm size. While previous research (e.g., Chronis et al. 2015) does not show significant differences in the number of tracked clusters with jump levels of at least 2-sigma between the LMA and ENTLN, it did not compare how the two networks differed on maximum sigma levels. It is clear that another verification analysis should be completed for this dataset collected during the 2015 EWP.

Additionally, forecasters also pointed out cases where lightning increases were more gradual (a series of 1-sigma jumps as opposed to a large increase) and often viewed these as "misses" by the algorithm when they were followed by severe weather. Particularly, with experience of seeing the larger sigma values in previous cases, many forecasters used only "4 or higher sigma jump[s]" for warning decisions, thus 1- and 2-sigma jumps were often batched into the "miss" category. Forecasters also noted misses during severe storm interrogation when lightning data were near max at time of update or new warning issuance. Thus, the flash rate varied very little in value, not producing a jump. During these periods, the LJA grid was of little to no use. Finally, several forecasters noted what appeared to be false alarms in the algorithm when the flash rates were low and/or the standard deviation in the flash rate was low. To address these issues, training and best practices for using the jump in context with environmental and radar information should be established in addition to the development of metadata information (details below) for the LJA display.

> "I would need to understand what a sigma represents (quantity) for it to be more useful. However, understanding that higher sigma values mean larger jumps in flash rate is enough for situational awareness."
> *Forecaster, End-of-Day Survey*

> "I was not so sure if a 1 or 2 sigma jump was significant, or if I should wait for a 5 or 6 jump."
> *Forecaster*, "Week 1 (May 4-7 2015) Summary and Feedback", *GOES-R HWT Blog*

> "I do think the data needs to be used in conjunction with the flash extent density. There were multiple cases of large jumps in storms which start with little or no lightning (initial development). In the atmosphere of [Lubbock, TX] these storms tended to pulse back down after the jump. This is different from a storm which has a lot of lightning and sees a significant jump."
> *Forecaster, End-of-Day Survey*

Suggestions for improvement

Feedback regarding improvement of the product repeatedly included adding metadata to the LJA grid, such as mouse-over read-out that includes current flash rate and number increase (e.g., 7 flashes, 27 flashes). Forecasters also desired corresponding cell-based time series information to put the jump in context of the storm flash history. This could be displayed as a pop-up window similar to the radar pop-up Skew-T display currently available in AWIPS-II (Fig. 15). While many forecasters thought the rainbow-color scale was appropriate and grabbed the attention of higher-sigma jump storms, one suggestion was to move towards a monocolor scale (e.g., light-red to dark-red – positive jumps and blue-gray –negative jumps). Additionally, by default there is no transparency built into the LJA grid. Since forecasters frequently overlay the grid on radar data, such a capability should be added with lower values of the grid receiving greater transparency.

While almost all the forecasters liked the rapid update of the product, a few highlighted that the 1-min update means forecasters can miss significant jumps if they don't look back in time. An idea for future implementation and testing is to incorporate "biggest jump over past 5-min" metadata for mouse-over read outs (as discussed above) or development of an additional max-LJA product that only displays the peak jump over past five minutes.

> "It's nice having this information update every minute to capture trends. However… Forecasters can easily miss these fast changes given all of the data they need to look at. It would be better for the data to update every minute, but leave the strongest Sigma in place longer."
> *Forecaster*, "Lightning Jump Detection Algorithm Suggestion", *GOES-R HWT Blog*

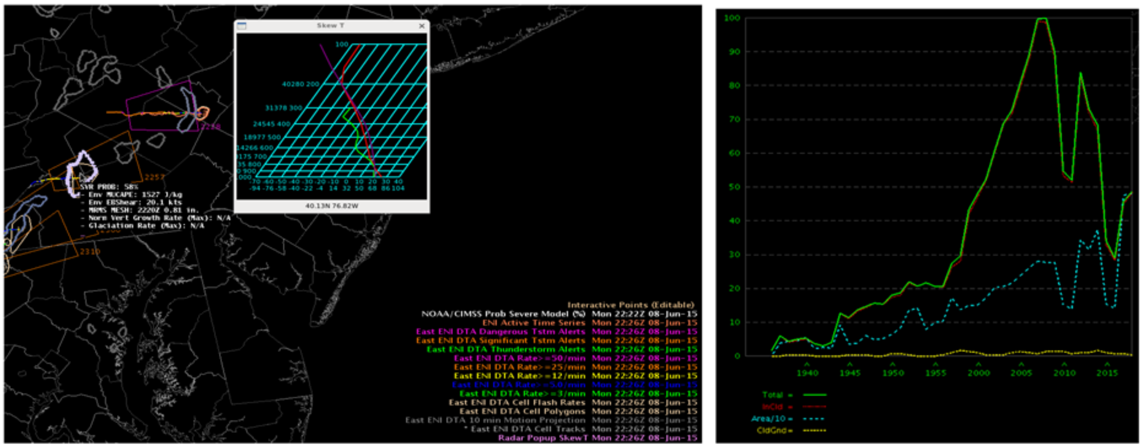

Figure 15: Idea for possible configuration for future lightning jump display as suggested by a forecaster in the HWT. Metadata for jump could be provided via mouse-over (similar to ProbSevere product) and pop-up for lightning time series (similar to right panel) could be displayed via right mouse click on storm cell of interest (as illustrated in left panel for "Radar Popup SkewT" product).

3.7 NUCAPS Temperature and Moisture Profiles

Joint Polar Satellite System (JPSS)

For the first time, an algorithm from the Joint Polar Satellite System (JPSS) program was demonstrated in the HWT during the 2015 Spring Experiment. The NOAA Unique Cross-track Infrared Sounder (CrIS) Advanced Technology Microwave Sounder (ATMS) Processing System (NUCAPS) 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 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. Since most forecasters were unfamiliar with space-based soundings coming into the HWT, the NUCAPS training addressed important concepts surrounding how these profiles are created. The purpose of this demonstration was to assess if NUCAPS added value to the severe weather nowcast and warning process and enlighten participants to the existence of NUCAPS profiles in AWIPS-II.

Use of NUCAPS in the HWT

As is often the case with new forecast tools and observations, forecasters spent time comparing the NUCAPS profiles with other available sounding data sources. Other sources included modified 1200 UTC radiosonde soundings, special afternoon radiosonde soundings, NWP-based soundings, and SPC meso-analysis. These comparisons allowed forecasters to assess the accuracy of the NUCAPS profiles and learn their strengths and weaknesses.

One of the most important aspects of the NUCAPS soundings expressed by forecasters during the experimental severe weather operations was time of availability: roughly centralized between the 1200 UTC and 0000 UTC radiosonde balloon launches. The NUCAPS data were usually available shortly before convective initiation, providing forecasters with an observation-based update on how the thermodynamic environment has evolved since the morning radiosonde soundings. Other times, convection was already ongoing when NUCAPS became available, allowing forecasters to gauge the thermodynamic environment into which storms were moving and determine whether or not the environment was favorable for storm maintenance. In fact, 74% of the time participants responded that the NUCAPS soundings provided an effective update on the current state of the thermodynamic environment.

> "The NUCAPS soundings are a good way to see changes in the airmass since the RAOB soundings have been taken."
> *Forecaster, End-of-Week Survey*

> "Presence of a cold pocket aloft and relatively low precipitable water values around a half an inch confirm elevated convection."
> *Forecaster,* "NUCAPS shows environment favorable for elevated convection", *GOES-R HWT Blog*

> "The drying of the air at 600-800 mb since 1200 UTC is reflected by intermediate NUCAPS soundings."
> *Forecaster,* "West Texas Soundings", *GOES-R HWT Blog*

Another key advantage of the NUCAPS soundings was spatial availability. With only approximately 70 NWS sites launching daily 1200 UTC and 0000 UTC radiosondes in the CONUS, large gaps exist from coast to coast in observed vertical sounding information. Approximately 25 miles separates each NUCAPS retrieval resulting in improved spatial coverage and continuity, allowing for more precise analysis of the environment at any given location within a swath. This was especially helpful for forecasters working in offices with no balloon launch and in regions where geographic features (e.g., mountain, ocean, lake, valley) lead to significant variations in environmental conditions within relatively small distances. Furthermore, the availability of NUCAPS retrievals over ocean areas - where even fewer observations are available - allowed forecasters to assess approaching air masses. Finally, the high density of profiles provided confidence to the existence of boundaries, including outflow and upper-level, especially those that were suspected but difficult to discern from other observing methods.

> "It would be helpful because the climate within our CWA varies so greatly. Our sounding is not representative of the environment over the deserts, and the nearest soundings are a bit too far and not consistent."
> *Forecaster, End-of-Week Survey*

> "I used NUCAPS to sample the environment ahead of the outflow boundary and behind the dryline, in order to assess the difference in air masses."
> *Forecaster, End-of-Day Survey*

> "They were useful since our closest RAOB site was out of our CWA, so they helped to fill in the gap in coverage."
> *Forecaster, End-of-Day Survey*

As an example, the NUCAPS retrievals proved to be especially valuable in filling a spatial and temporal gap during experimental operations on 12 May 2015 in the Pocatello, Idaho CWA. With no nearby radiosonde location, forecasters relied on model data and distant radiosonde sites for their early-day thermodynamic information. By 2000 UTC, only weak convection existed in the Pocatello CWA area where models indicated weak instability and relatively low moisture levels, leading forecasters to grow skeptical that severe convection would develop (SPC Day 1 Convective Outlook indicated only a Marginal Risk for severe wind and hail). Modified 2000 UTC NUCAPS profiles revealed much greater instability than was thought to have been present (~1500 j/kg surface-based CAPE); indicating to the forecasters that the potential for strong storms did indeed exist (Fig. 16). Convection moving through the region by 2200 UTC did strengthen considerably as indicated by composite reflectivity values in excess of 60 dBz, MESH values around .8", increased total lightning activity, and the development of overshooting tops seen in visible satellite imagery.

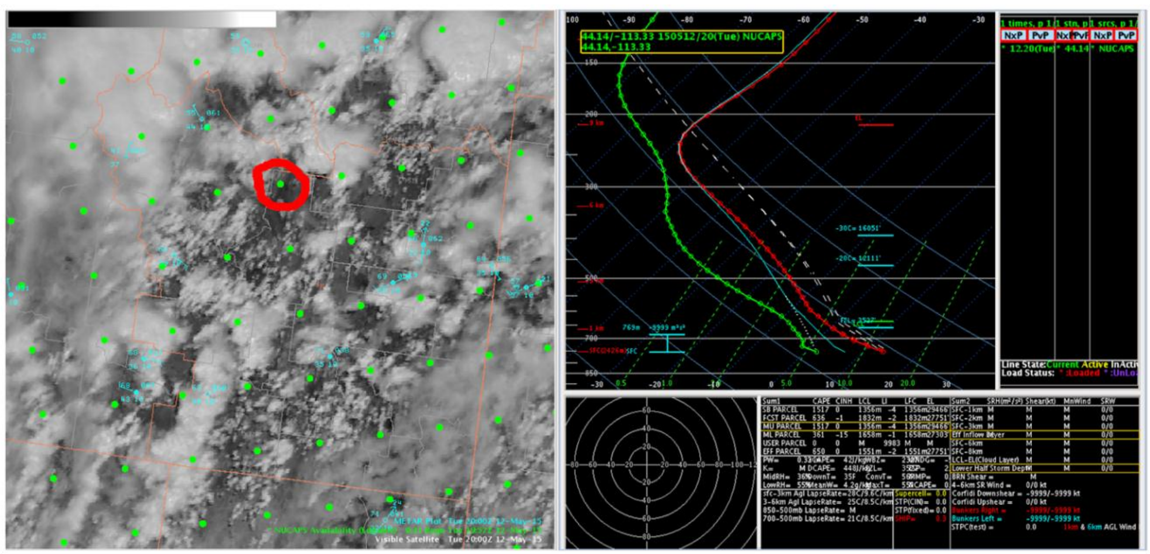

Figure 16: 2000 UTC 12 May 2015 NUCAPS availability and GOES-West visible satellite imagery over Pocatello, ID CWA (left) and modified NUCAPS temperature and moisture profile on skew-T diagram (right). Location of selected profile is circled in red. From blog post, "NUCAPS Sample."

Limitations and suggestions for improvement

Through comparisons with other data sources, it quickly became apparent that most NUCAPS profiles must be manually adjusted by the forecaster at and near the surface due to inaccuracies in the data. This is not a native concept to forecasters, as they have experience making surface modifications to radiosonde and NWP soundings. After selecting a profile to interrogate, forecasters would first compare the surface temperature and dew point values in NUCAPS to a nearby surface observation. If the values differed, the forecaster would simply adjust NUCAPS one of two ways in NSHARP. Many times after modifying the surface values, unrealistic conditions such as extreme superadiabatic lapse rates would exist above the surface. Consequently, forecasters would “mix” the lowest part of the atmosphere to create more realistic looking profiles. Though such modifications were fairly quick and easy, they did take up valuable time the forecaster could have used on other tasks, and were subjective. Accordingly, forecasters recommended the process of modifying the surface and low-level conditions of NUCAPS profiles be automated.

> “In its current state, I would probably not use NUCAPS. It is cumbersome to modify the sounding by hand and try to determine the amount of mixing required…I would probably use it more when it automatically uses surface observations and mixes it for you.”
> *Forecaster, End-of-Week Survey*

> “I selected a sounding from a clear spot on the NE/KS state line and had to modify it at the low levels as it was too dry and cold. The modifications drastically increased the CAPE to around 2000 j/kg, which was a better representation of what I thought the environment was.”
> *Forecaster,* “Daily Summary: Week 1 Day 3 (May 6, 2015)”, *GOES-R HWT Blog*

The adjustment of surface values in a NUCAPS profile was illustrated by a forecaster on 11 May 2015 operating in the Wilmington, Ohio CWA. A special 1800 UTC radiosonde launch revealed 1761 j/kg of surface-based CAPE, with the un-modified NUCAPS profile indicating a stable atmosphere (Fig. 17, left and middle). While the overall structure of the NCUAPS profile appears similar to that of the radiosonde, conditions near the surface were the culprit for the stability discrepancy. A nearby METAR site showed a surface temperature/dew point of 85/61 ^{o}F, significantly warmer and moister than the 77/55 ^{o}F measured in NUCAPS, necessitating adjustments (Fig. 17, right). Upon making these changes, the NUCAPS surface-based CAPE increased to 1688 j/kg, similar to that from the 1800 UTC radiosonde value. Severe convection would later produce damaging winds across the region. This example demonstrates the importance of low-level modifications to NUCAPS while also exhibiting the value of comparisons with other data sources.

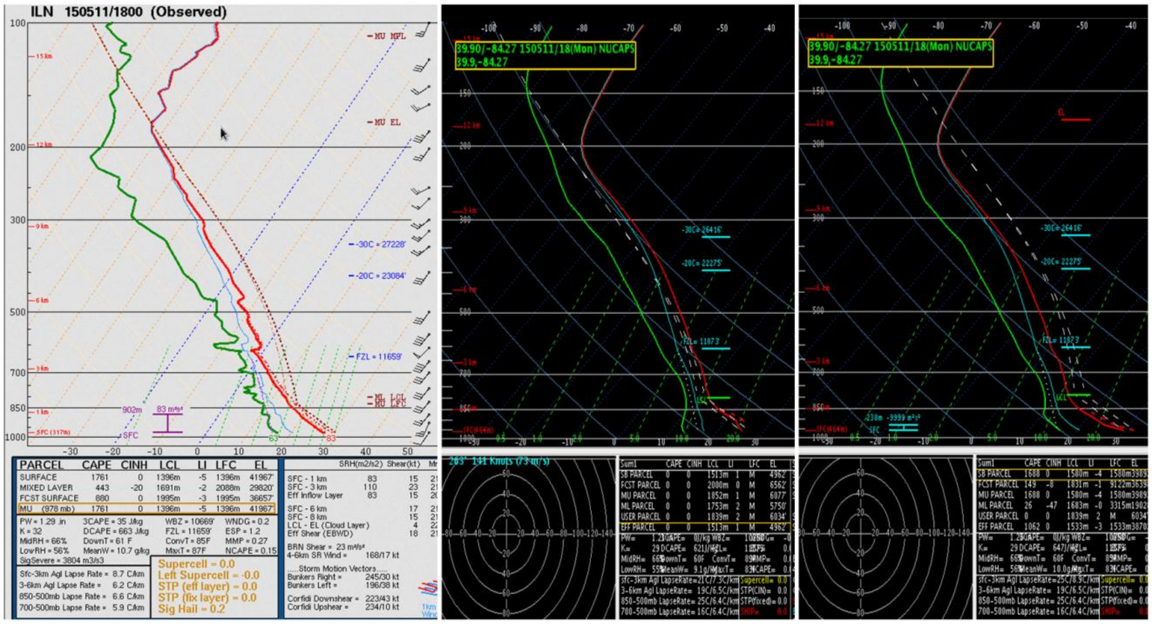

Figure 17: 1800 UTC 11 May 2015 Wilmington, Ohio radiosonde sounding on skew-T diagram (left), nearby un-modified NUCAPS sounding on skew-T diagram (middle), and same NUCAPS sounding after surface modifications (right). From blog post, "Observed Radiosonde Data/NUCAPS Comparison."

Another aspect addressed in the training was the recommendation to select profiles in relatively clear air conditions since clouds (especially deep and upper-level) have a negative influence on the quality of the retrieved profiles. Quality control (QC) flags do exist within the NUCAPS data, but they are not yet able to be displayed in AWIPS-II. The lack of QC flags was unfortunate as it often left the forecaster questioning the quality of the data being viewed, especially when clouds were nearby. Not surprisingly, participants requested that NUCAPS QC flags be included in the AWIPS-II NUCAPS availability display.

> "QC flags would be helpful to have so we know with confidence which profiles to trust."
> *Forecaster*, "EWP Week 2 Summary (May 11-14, 2015)", *GOES-R HWT Blog*

Participants across all weeks mentioned that the overall smoothness of the NUCAPS profiles relative to a radiosonde or NWP profile was a significant deficiency. Although the general shape of the profiles and values of derived fields such as CAPE and PW were usually found to be comparable to that from observed soundings and SPC mesoanlysis (after necessary modifications to low-levels were made), vital features such as capping inversions were not depicted well or at all. Stable layers would sometimes appear as a bump in the profile, but how to interpret this was unknown. Given the importance such features play in convective development, participants suggested merging the NUCAPS information with readily available higher vertical resolution data sources that have more skill in resolving such features. Additional experience and training, including comparisons of NUCAPS soundings with nearby radiosonde profiles, will help users to better interpret the smoother space-based profiles.

> "I'm still a little suspect of the NUCAPS data as it doesn't show the fine scale detail that is so valuable in a standard RAOB."
> *Forecaster, End-of-Week Survey*

> *"*The observed sounding also shows an elevated mixed layer and capping near 825 mb which is not seen in the NUCAPS sounding."
> *Forecaster,* "NUCAPS compared to Observed IAD sounding", *GOES-R HWT Blog*

Aside from those already mentioned, forecasters made additional recommendations that would help make interrogating the NUCAPS data more efficient and useful, many of which are AWIPS-II NSHARP related. Some of the most common suggestions included: undo button when editing a profile in NSHARP, an indicator in the NUCAPS availability window of the profile location that is selected, and a map in the sounding window of selected profile or list nearest city. Additionally, most of the forecasters desired the ability to overlay NUCAPS profiles with those from other sources (e.g., NWP, radiosonde); this could be done if the NUCAPS data were delivered in a more appropriate file format. Some forecasters indicated they would like to see plan view displays of thermodynamic fields derived from NUCAPS added to AWIPS-II. With regard to the training, participants would like to see: more guidance on proper surface/low-level temperature/dew point modification, verification statistics, differences between NUCAPS and GOES soundings, and additional operational use examples. Finally, forecasters would like to see these profiles made available more often, which could be done by applying the algorithm to other appropriate polar-orbiting satellites.

Other comments

Since NUCAPS is already available in AWIPS-II, forecasters were asked if they have viewed the data in their home office. Only one participant answered "yes", while 20/23 of the other NWS forecasters responded that they will load NUCAPS in operations after their experience in the HWT.

> "Now that I know this tool is available in AWIPS II, I plan to make sure my staff are training on its usability once I return to the WFO."
> *Forecaster, End-of-Week Survey*

> "I may not use it every day, but getting additional experience will help me understand the environments and situations where it will provide the most critical value."
> *Forecaster, End-of-Week Survey*

After modifying the surface and near-surface values, participants felt that the NUCAPS profiles provided a reasonable representation of the thermodynamic environment in most situations. This led them to see value in having these space-based soundings to fill the spatiotemporal gap that exists in observed sounding information. However, there are several adjustments that could be made to the NUCAPS products as well as to AWIPS-II that would increase their usability in the severe weather nowcast and warning process. Summarizing, NUCAPS soundings were utilized by forecasters during the experiment to: asses how the environment has changed since the morning RAOB, asses the environment upstream of developing or mature convection, assess the environment ahead of and behind suspected boundaries, compare with NWP to assess model performance, and compare with modified 1200 UTC and special afternoon radiosonde profiles. Forecasters look forward to examining the NUCAPS data in non-severe weather forecast situations as well. Those specifically mentioned include: winter weather (i.e., during lake effect snow events, determining precipitation type), marine layer over ocean, rainfall during summer monsoon season in the southwestern US, and cloud/fog over great lakes.

4. Summary and Conclusions

The GOES-R Proving Ground was a major component of the 2015 HWT/EWP Spring Experiment. Twenty-five NWS forecasters and five broadcast meteorologists evaluated seven GOES-R and JPSS products and capabilities and interacted directly with algorithm developers during the five week experiment. With only one other project under evaluation alongside GOES-R and JPSS, participants agreed that they had ample opportunity to fairly evaluate, identify strengths and weaknesses, and suggest potential improvements for all of the tools. 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 pleasing, 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. They did note that the training should focus on how to use the product in operations via examples, strengths and weaknesses, and verification statistics. Short information sheets for each product covering those points were suggested by some for reference during the experimental activities. Participants also recommended an additional training module that would run through the EWP menu and show where all of the products are located in AWIPS-II as well as highlight pre-built procedures. Finally, forecasters agreed that in addition to the Articulate training, the completion of a WES case including all of the demonstration products would be the ideal method for fully preparing participants before arriving to the experiment.

The start of each week included a brief tutorial of AWIPS-II and overview of each product under demonstration followed by informal one-on-one training between the developers/satellite liaison and participants. Based on feedback from 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. Forecasters really appreciated the pre-built procedures (especially the broadcast meteorologists), and suggested having even more in future years. The condensed and focused EFP weather briefing at the start of each shift received positive reviews from EWP participants, and is recommended for future years.

For the second 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 broadcaster 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, highlighting ProbSevere, 1-min satellite imagery, and lightning data as being the most helpful for them and poised for potential on-air success. Although the broadcasters requested to see the online versions of most of these products where available, ideally the network vendors would provide them for integration into their systems. AWIPS familiarization prior to their arrival in Norman was vital to 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 seeing continued improvements and eventual operational implementation.

More detailed feedback and case examples from the GOES-R and JPSS demonstration at the 2015 EWP Spring Experiment in the HWT 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 2015 SRSOR activities can be found at:
http://cimss.ssec.wisc.edu/goes/srsor2015/GOES-14_SRSOR.html

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