GOES-R and JPSS Proving Ground Demonstration at the Hazardous Weather Testbed 2023 Spring Experiment Final Evaluation

Project Title: GOES-R and JPSS Proving Ground Demonstration at the 2023 Spring Experiment – Experimental Warning Program (EWP)

Organization: NOAA Hazardous Weather Testbed (HWT)

Evaluators: National Weather Service (NWS) Forecasters, Storm Prediction Center (SPC), National Severe Storms Laboratory (NSSL), University of Oklahoma (OU), Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO)

Duration of Evaluation: 22 May 2023 – 16 June 2023

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Submitted Date: 12 October 2023

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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 2023 Spring Experiment, which took place in-person and virtually at the National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (HWT) in Norman, Oklahoma from 22 May to 16 June 2023. This year featured 22 participants in the EWP experiment. 21 of the participants were National Weather Service (NWS) forecasters from Weather Forecast Offices (WFOs) in four NWS regions, and one participant was from a Center Weather Service Unit. This group evaluated five major baseline, future capability, and experimental GOES-R and JPSS products in the real-time simulated short-term forecasting, decision support service (DSS), and warning environment of the Experimental Warning Program (EWP). Additionally, they used cloud-based instances of the second-generation Advanced Weather Interactive Processing System (AWIPS-II) and web-based interfaces to interact with the products.

Forecaster feedback during the evaluation was collected through daily and weekly surveys, daily and weekly debriefs, blog posts, a warning and DSS reporting form, public forecast graphics, and informal conversations during the testbed. Typical feedback included suggestions for improving the algorithms, display techniques, training, and awareness of product applications or limitations. Most of the products evaluated in 2023 were advancements of previous product iterations from the 2022 GOES-R/JPSS Proving Ground (Thiel 2022). This included data from the NOAA Unique Combined Atmospheric Processing Systems (NUCAPS), the Polar Hyperspectral Sounder and Microwave Imagery in the Advanced Baseline Imager (PHS) model, the Probability of Severe (ProbSevere) LightningCast model, and the ProbSevere all-hazards model – Version 3. The Optical flow Code for Tracking, Atmospheric motion vectors, and Nowcasting Experiments (OCTANE) Speed and Direction Sandwich products were evaluated in the HWT for the first time. Additionally, experimental RGBs composite imagery products were created and demonstrated within the testbed to expand upon forecaster needs since the launch of the GOES-R program.

Over 20 visiting scientists attended the EWP over the three weeks to provide additional product expertise and interact directly with operational forecasters. Organizations represented by those individuals included three NOAA Cooperative Institutes, five federal partners, and two external partners. The Storm Prediction Center (SPC) and HWT Satellite Liaison Kevin Thiel (OU/CIWRO and NOAA/SPC) provided overall project management and subject matter expertise for the HWT Satellite Proving Ground efforts in the HWT. Technical support for AWIPS-II were provided by Jonathan Madden and Justin Monroe (OU/CIWRO and NOAA/NSSL).

2. Introduction

GOES-R Proving Ground demonstrations in the HWT have provided users with a glimpse into the capabilities, products, and algorithms available since the launch of the GOES-R satellite series in November 2016. The education and training received by participants in the HWT fosters interest and engagement with new satellite data and promotes the continued readiness of GOES-R data and products. Additional demonstration of JPSS products introduces and familiarizes users with advanced satellite data that are already available. The HWT provides a unique opportunity to enhance research-to-operations and operations-to-research (R2O2R) by enabling product developers to interact directly with operational forecasters, and to observe the satellite-based algorithms being used alongside standard observational and forecast products in a simulated operational forecast and warning environment. This interaction helps developers understand how forecasters use these products and what improvements might increase product utility in NWS operations. Feedback received from participants in the HWT has proven invaluable to the continued development and refinement of GOES-R and JPSS algorithms since its inception in 2009. Furthermore, the EWP (Calhoun et al. 2021) facilitates the testing of satellite-based products in the AWIPS-II data processing and visualization system currently used at NWS Weather Forecast Offices (WFOs).

Building upon lessons learned from previous virtual GOES-R/JPSS Proving Grounds and the subsiding COVID-19 Pandemic, activities for the 2023 experiment were conducted in-person for the first time since 2019, as well as virtually. The first week of the testbed (22-26 May) was conducted in-person at the National Weather Center in Norman, Oklahoma in the HWT's Development Lab. The second and third weeks of the experiment (5-9 June and 12-16 June) were conducted virtually using Google Meet and Slack. Seven to eight NWS forecasters volunteered each week to evaluate this year's products. Before the testbed forecasters were provided user guides, PowerPoint presentations, and online learning modules through Google Drive for each of the products demonstrated. The Monday of each week began with introductions, an orientation session, and product summaries from developers, followed by familiarizing forecasters with their cloud-based AWIPS instances. Tuesday, Wednesday, and Thursday began with a discussion between the developers and forecasters of the previous day's operations. After a brief forecast discussion each day by the Satellite Liaison, forecasters were placed into three groups localized to various NWS WFOs (hereafter simulated WFOs) across the United States to begin operations.

The simulated WFOs were selected to maximize the probability of severe thunderstorm activity each day, and to provide adequate evaluation of all demonstrated products. Mock-Decision Support Service (DSS) events were created for a majority of simulated WFOs to investigate how the experimental products could also be utilized in communicating hazards to NWS partners. At the end of each operations period, forecasters were given a daily survey regarding product performance and utility during the day's events. Forecasters were also encouraged to fill out an online form after submitting a convective warning, along with any forecaster who wished to provide DSS messaging for their assigned event. Responses from this form were then examined to identify how the experimental products were incorporated into the communication of convective hazards by the participants. Additionally, forecasters had the option to create social media graphics using the experimental products, further showcasing their ability to be interpreted and transmitted to the public.

Forecasters viewed NUCAPS, OCTANE, PHS, ProbSevere LightningCast, and ProbSevere Version 3 data in the cloud-based instances of AWIPS for the in-person and virtual demonstrations. Prior to the testbed, AWIPS procedures were built by the Satellite Liaison for each product in AWIPS, so forecasters could quickly access the products and leverage best display practices as described in their training. Within operations forecasters had several tasks, such as building procedures of their own to integrate experimental products with the ones they currently use, having discussions with the subject matter experts, writing blog posts, and issuing warnings and DSS information. Discussions between forecasters and developers often involved questions from both groups concerning best display practices and applications, along with feedback from forecasters of what they were observing in real-time. Forecasters also had the opportunity to create blog posts which were published online to the HWT EWP Blog (https://inside.nssl.noaa.gov/ewp/) and the GOES-R HWT Satellite Proving Ground Blog (http://goesrhwt.blogspot.com/)

The first day of the in-person testbed began at 11am CDT (16 Z) and ended at 7 pm CDT (0 Z). Tuesday through Thursday also followed this schedule, but these days could have begun any time between 10am CDT (15 Z) and 1 pm CDT (18 Z) based on the convective environment and was decided on the previous day by the Satellite Liaison. No operations occurred Friday, as forecasters filled out the weekly survey and held their weekly debrief with the developers. To end the week, forecasters were encouraged to participate in the Tales from the Testbed webinar hosted by the NWS Warning Decision Training Division (WDTD). During the two virtual weeks, activities Monday through Thursday began at 1 pm CDT (18 Z) and ended at 6pm CDT (23 Z), approximately following the schedule outlined in Figure 2. On Friday, an end of week survey was sent to the participants in the morning, followed by a two-hour final discussion with developers, observers, and SMEs to summarize the week's events and encapsulate key product themes.

On-Site Demonstration Schedule

Hour (From start)	0:00	0:30	1:00	1:30	2:00	2:30	3:00	3:30	4:00	4:30	5:00	5:30	6:00	6:30	7:00	7:30
Monday	Orientation				Product Training				Operations							Daily Survey
Tuesday	Discussion/ Forecast		Operations													Daily Survey
Wednesday	Discussion/ Forecast		Operations													Daily Survey
Thursday	Discussion/ Forecast		Operations											Webinar Prep		Daily Survey
Friday	Weekly Survey	Weekly Debrief		Webinar												

Figure 1: An approximate schedule of the in-person GOES-R/JPSS Proving Ground HWT Experiment, outlining the major activities from each day.

Virtrual Demonstartion Schedule										
Time (CDT)	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30
Monday	Orientation			Product Training/Operations						Daily Survey
Tuesday	Discussion/ Forecast		Operations							Daily Survey
Wednesday	Discussion/ Forecast		Operations							Daily Survey
Thursday	Discussion/ Forecast		Operations							Daily Survey
Friday	Weekly Survey	Weekly Debrief								

Figure 2: An approximate schedule of the virtual GOES-R/JPSS Proving Ground HWT Experiment, outlining the major activities from each day.

The collective feedback from the 2023 GOES-R/JPSS Proving Ground (daily surveys, weekly surveys, blog posts, and daily debrief discussions) are summarized in this report. Each of products evaluated in the following subsections begin with a summary of the product and its intended applications, followed by science questions from each product developer group. Next, applications and feedback from the forecasters are summarized across all three weeks of the experiment. These are supported by forecaster questions from the surveys, forms, and blog posts throughout each section. Product recommendations are listed at the end of each section as ‘recommended’, ‘strongly recommended’, and ‘highly recommended’ in an ascending order of apparent significance from the forecasters.

3. Products Evaluated

3.1 NUCAPS Temperature and Moisture Profiles

The NOAA Unique Combined Atmospheric Processing System (NUCAPS; Barnet et al. 2021) was evaluated in the 2023 Satellite Proving Ground. Temperature and moisture profiles from NUCAPS were used to evaluate two plan-view displays – Gridded NUCAPS (Berndt et al. 2020) and NUCAPS-Forecast (Kahn et al. 2023) – for their potential to increase situational awareness of developing convection. Vertical profiles from NUCAPS are derived from the infrared and microwave sounders onboard the NOAA-20 satellite, with an approximate local overpass time of 1:30 AM/PM. NUCAPS from NOAA-20 is operationally available on the SBN but was delivered over to the HWT via LDM and had a latency under 60 minutes. Specific parameters and indices are then made available on constant surfaces or layers for the Gridded NUCAPS product fields. NUCAPS-Forecast advects the initial vertical profiles forward in time using the NOAA HYSPLIT trajectory model, allowing for plan-view output available in hourly increments up to six hours ahead in time.

Since the last time NUCAPS-Forecast was evaluated in 2021, improvements to the product have been made to reduce spatial gaps, provide more realistic values, and include a confidence map (parcel count) for assessing data quality. Prior to the testbed forecasters were provided with JPSS QuickGuides for each product and a video on NUCAPS soundings from the 2021 HWT. During the first week of the experiment NUCAPS-Forecast was adjusted to provide data out to 12 hours ahead of each overpass for increased temporal coverage between the NOAA-20 overpasses in the same regions.

NUCAPS Science Questions

- Do additional observations in time allow you to further anticipate convection compared to only having a single time period to analyze?
- What is the optimal spacing and duration of observations?
- What fields from NUCAPS-Forecast are most valuable in your analysis?
- Are you able to assess potential storm mode by using NUCAPS-Forecast?

Use of NUCAPS in the HWT

Overall, participants used Gridded NUCAPS and NUCAPS-Forecast to assess the thermodynamic environment before convection initiated and as it evolved throughout the forecast period. Throughout the experiment, forecasters most often leveraged vertically integrated parameters from Gridded NUCAPS and NUCAPS Forecast to assess the ambient convective environment. Lapse rates, convective available potential energy (CAPE), and precipitable water (PWAT) were the most frequently mentioned products within the daily surveys and group discussions with forecasters. Often forecasters compared these parameters against SPC mesoanalysis, nearby radiosonde profiles, operational models, or the PHS model to assess the quality of the observations and forecast information. Among the lapse rate products, forecasters most often used mid-level lapse rate fields (e.g. 850-700 mb and 700-500 mb) at the suggestion of the NUCAPS developers since NUCAPS has limited sensitivity in the boundary layer. Lastly, some forecasters did mention using the parcel count value when analyzing NUCAPS-Forecast fields. As a new type of data forecasters appeared to struggle when interpreting the parcel values, however in group discussions forecasters generally agreed a data quality product was necessary and could be beneficial when assessing thermodynamic fields from NUCAPS-Forecast.

> ‘The 19Z NUCAPS sounding pass went over Florida as convection was ongoing across much of the state. The 850mb to 700mb lapse rate product picked up on some of the convective overturning in southern Florida where lapse rates were far less steep than other portions of the state (indicative of cooler low levels), as well as where low level lapse rates were a bit lower over the western coast. This lines up well with where the RAP was showing lower surface to 3 km lapse rates. Though these two levels are not completely analogous, they represent similar processes post-convection.’ [Figure 3]
> 25 May 2023, Blog Post: *NUCAPS Low Level Lapse Rates Compared to RAP in Convection*
> https://inside.nssl.noaa.gov/ewp/2023/05/25/nucaps-low-level-lapse-rates-compared-to-rap-in-convection/

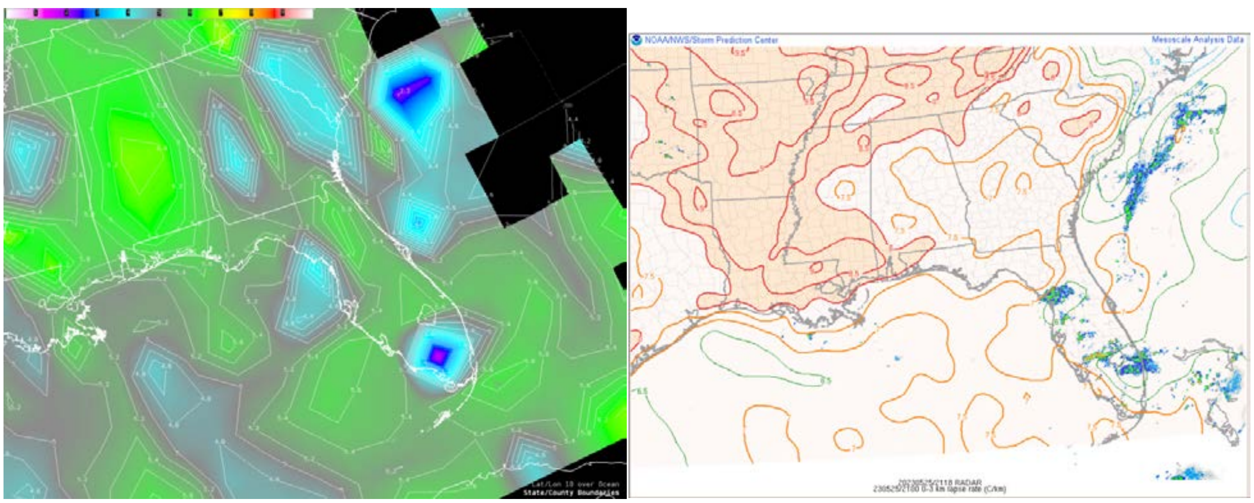

Figure 3: The NUCAPS-Forecast 850 mb to 700 mb lapse rate product (left) when compared to the SPC mesoanalysis low-level lapse rate (0 to 3 km) product (right) at 2100 Z on 25 May 2023.

> ‘The NUCAPS forecast was largely different than the RAP analysis. Due to early day convection the NUCAPS forecast was seen as not representative and I did not explore it further today.’
> *Forecaster – End of Day Survey*

> ‘MUCAPE values seem a bit higher than they should be when compared with the MLCAPE values at the same times over New Mexico. I’m not exactly sure why the values are so high, but the forecast RAP values for the same time frame appear to be notably more displaced to the east and lower.’ [Figure 4]
> 7 June 2023, Blog Post: *Albuquerque HWT*
> https://inside.nssl.noaa.gov/ewp/2023/06/07/albuquerque-hwt/

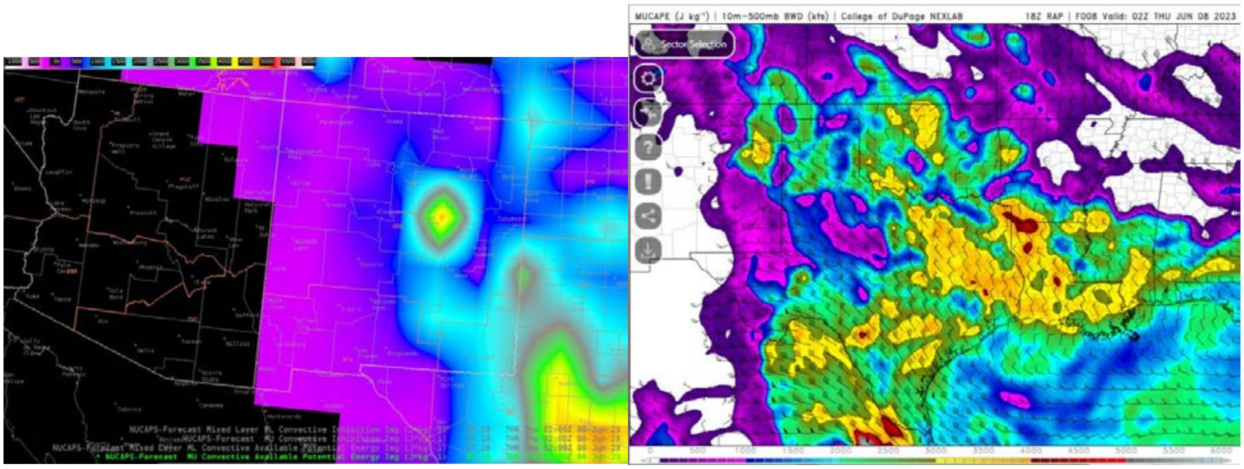

Figure 4: MU-CAPE values from NUCAPS-Forecast (left) when compared to MU-CAPE values from the RAP model (right) at 0200 Z on 8 June 2023.

Overall, forecasters used NUCAPS-Forecast more frequently in operations than Gridded NUCAPS. In the daily surveys 56% (42/75) of forecasters stated they used NUCAPS-Forecast in their severe weather analysis compared to 35% (25/72) using Gridded NUCAPS. When asked how well features from NUCAPS-Forecast were complimentary to other data sources, participants responded 'Moderate' and 'High' most often for 'Spatial Patterns' (33/45, 75%), 'Trends' (32/43, 75%), and 'Gradients' (31/43, 72%). The 'Magnitudes' option was deemed least complimentary with a majority of forecasters responding 'Low' and 'Moderate'.

Forecasters were also asked to subjectively rate the value of NUCAPS-Forecast in determining the location of convection initiation and storm mode. The 'Location' option received the most favorable responses, with 43% (18/42) selecting 'Moderate' and 24% (10/42) selecting 'Small'. In comparison, 30% (11/37) of forecasters selected 'Moderate' and 35% (13/37) selected 'Small' for the 'Storm Mode' option. The parameters most frequently used from NUCAPS-Forecast (CAPE, lapse rates, and PWAT) provided information regarding the initiation of convection, however kinematic fields were often used to further determine storm mode. The lack of wind information in the Gridded NUCAPS and NUCAPS-Forecast data was noted by the forecasters in group discussions, however the idea of including modeled winds in an observational product was met with mixed support among the participants.

> 'There was a noticeable instability gradient across the MAF CWA today where NUCAPS Forecast showed better low level moisture (via LCLs) and instability in the east-northeast portions of the CWA. This coincided with a higher SPC risk for severe weather in today's outlook.'
> *Forecaster – End of Day Survey*

> 'I was able to use NUCAPS-Forecast to analyze moisture and instability gradients, once providing better placement and accuracy than the SPC Mesoscale analysis page (in a situation where the instability gradient was through the middle of my forecast area). Gridded NUCAPS didn't have quite this capability due to both the lack of instability fields and lack of temporal component. I would have used Gridded NUCAPS if there was

more time between data availability and convective initiation, but most convection occurred earlier on in the afternoon compared to the NUCAPS pass.'
Forecaster – End of Week Survey

As reflected in the first NUCAPS science question, the added value of NUCAPS information forward in time from NUCAPS-Forecast when compared to information at a single time from Gridded NUCAPS was another consistent point of emphasis throughout the experiment. Forecasters cited in blog posts and group discussions the value of temporal trends within the mesoscale environment as convection initiated and evolved. Participants were asked to rank the importance of the temporal information from NUCAPS-Forecast on a subjective scale from 'Very Low' to 'Very High' in the daily surveys. The most common response was 'Moderate' with 34% (16/47), followed by 'High' with 30% (14/47). While forecasters were provided with forecasts out to 12 hours to fill temporal gaps, they noted less confidence in convective products later in the forecast period (greater than approximately 6 hours) when realizing NUCAPS-Forecast does not dynamically evolve the environment regarding convection, insolation, and boundary layer processes. In the weekly surveys forecasters were asked to choose the optimal combination of NUCAPS-Forecast temporal resolutions and were provided with several combinations of temporal resolutions (every half hour/one hour/three hours) and durations (3/6/12 hours) to chose. Half-hourly forecasts out to 6 hours were the most frequent response at 43% (9/21), followed by half-hourly forecasts out to 3 hours at 24% (5/21).

'Looking at the NUCAPS-Forecast initialization at 19z, the mid-level lapse rates are lower in areas NE of the higher terrain, where convection has been a bit slower to strengthen, as compared to the storms to our SW over Mexico, where MLLRs [mid-level lapse rates] are higher…The new TPW imagery from [Gridded] NUCAPS shows well the delineation of the moist air to the East and drier air to the West.' [Figure 5]
7 June 2023, Blog Post: *MAF Convection*
https://inside.nssl.noaa.gov/ewp/2023/06/07/maf-convection/

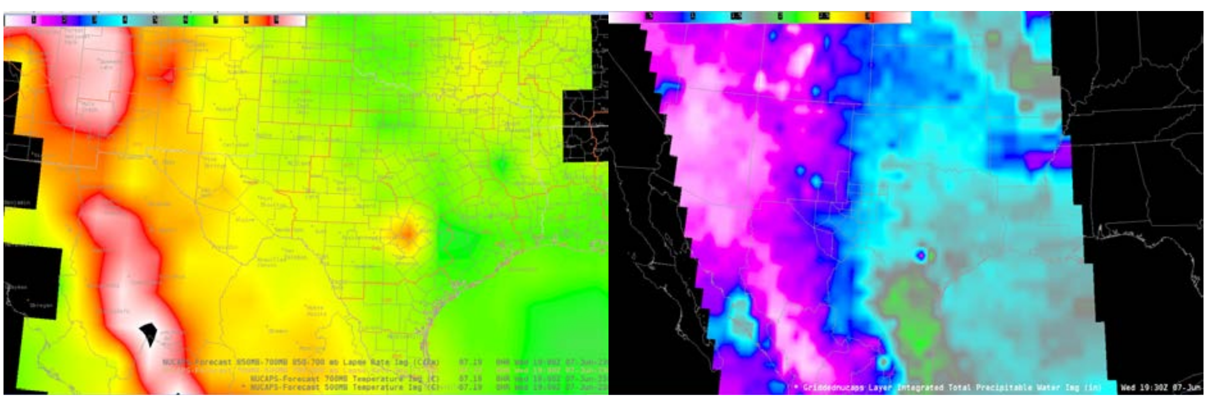

Figure 5: NUCAPS-Forecast values of 700 to 500 mb lapse rates (left) and Gridded NUCAPS values of Total Precipitable Water (right) at 1900 Z on 7 June 2023.

'The 08Z Pass of NUCAPS-Forecast shows a rather impressive PWAT/Moisture gradient this morning, which would likely lead to increased storm chances along the theta gradient over the Hill Country and stretching eastward into the I-35 Corridor. The gradient ranged

from 1.25” over the Coastal Plains to .50” over the Edwards Plateau and western EWX CWA.’ [Figure 6]
8 June 2023, Blog Post: *Severe Storms Over Central Texas*
https://inside.nssl.noaa.gov/ewp/2023/06/08/severe-storms-over-central-texas/

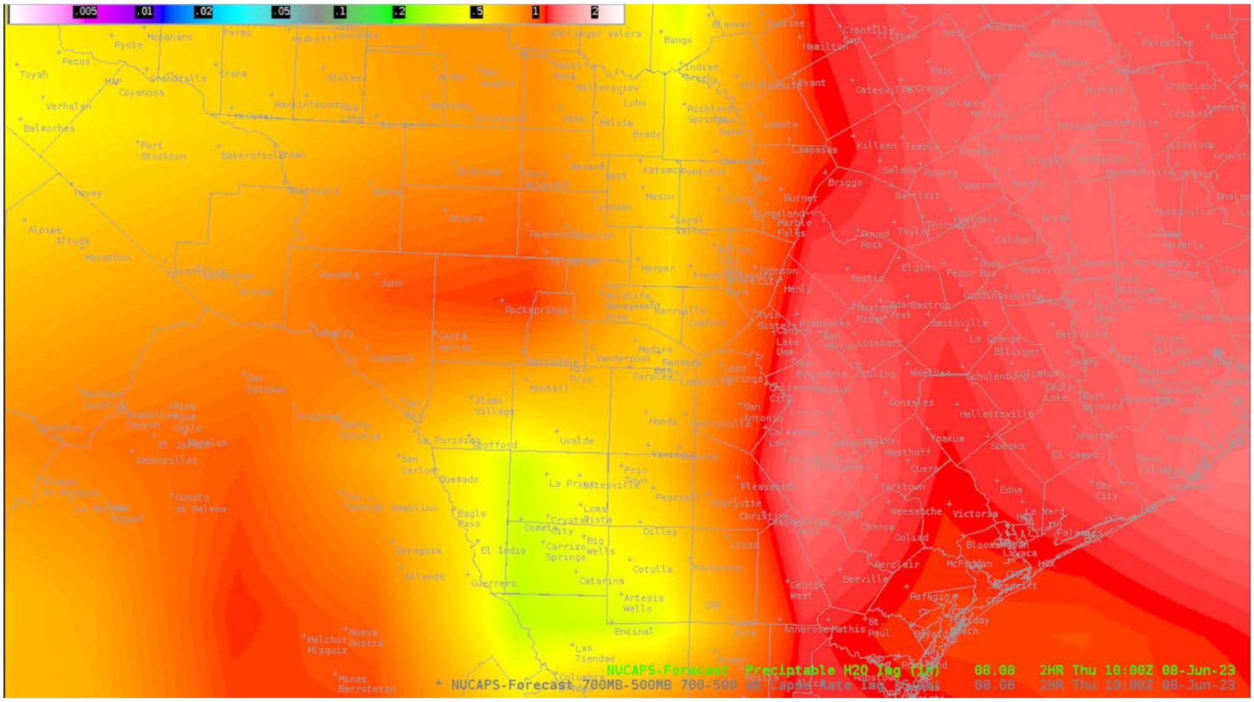

Figure 6: Precipitable water (PWAT) values from NUCAPS-Forecast at 10 Z on 8 June 2023.

Akin to previous NUCAPS-related testbed demonstrations, data latency and availability continued to be an issue with Gridded NUCAPS and NUCAPS-Forecast. While some issues were due to upstream data providers (e.g. outages or latency from NESDIS and direct broadcast sources), forecasters frequently noted that the timing of the 1:30 PM afternoon overpasses and subsequent product latency relative to convection initiating or entering their forecast area inhibited the use of Gridded NUCAPS and NUCAPS-Forecast. The timing of convection and its relative NOAA-20 overpass often determined how much time forecasters had to use the NUCAPS products, as environments with convective inhibition and entrainment of dry air often delayed initiation and provided more time for mesoanalysis. Additionally, overpasses in the eastern United States were earlier in the day and increased the likelihood of receiving NUCAPS products prior to convective initiation. These issues are noted in the following quotes from forecasters:

‘Convection had already initiated when NUCAPS became available, so we were unable to utilize it in our determination of CI.’
Forecaster – End of Day Survey

‘Today's issue was that the edges of two NUCAPS passes fell over the ABQ CWA, making analysis a bit more difficult.’
Forecaster – End of Day Survey

‘I think it was most unusable to due to timing and sometimes being on the edge of the scans. When you got a good scan at a good time it was very useful.’
Forecaster – End of Week Survey

Recommendations for Operational Implementation

Based upon the evaluation of NUCAPS products in the 2023 HWT Satellite Proving Ground, the following items have been recommended:

- **It is strongly recommended that Gridded NUCAPS and NUCAPS-Forecast datasets be evaluated against commonly used datasets and fields by NWS forecasters to increase confidence in the products.** These may include radiosonde profiles, SPC mesoanalysis data, and model fields such as the HRRR or RAP. Convective products such as CAPE (mixed layer or most unstable) values, mid-level lapse rates, and PWAT values should be included in these evaluations.
- **It is strongly recommended that exploration of a NUCAPS-Forecast product with half-hourly output out to six hours be evaluated in future testbeds.** Alternative approaches to increasing the temporal availability of all NUCAPS data for forecasters are also recommended.
- **It is recommended that data quality parameters for Gridded NUCAPS and NUCAPS-Forecast continue to be explored to increase forecaster confidence in the available thermodynamic information from NUCAPS.**
- **It is recommended that the integration of wind information into NUCAPS-Forecast fields be explored to increase the utility of these data when interpreting storm mode.** Potential avenues of development may include the use of wind data from models (e.g. RAP, HRRR, GFS, etc.) or adjacent RAOBs to create additional convective indices.

3.2 OCTANE Speed and Direction Sandwiches

The Optical flow Code for Tracking, Atmospheric motion vectors, and Nowcasting Experiments (OCTANE) Speed and Direction Sandwich products (Apke et al. 2022) were demonstrated for the first time in the 2023 Satellite Proving Ground HWT. Near-pixel level changes in cloud textures from the ABI visible band (0.64 μm) during the day and the clean-infrared band (13.3 μm) at night are calculated using the 1-minute and 30-second mesoscale scenes available from the GOES-R series ABI. Magnitudes are calculated in m s^{-1}, a 5-minute median filter is applied to mitigate jitter signals, and new outputs are available with a latency of 2.5 to 5 minutes. OCTANE speeds are calculated by the visible (infrared) band when the solar zenith angle is less than (greater than) 80 degrees. The OCTANE Speed and Direction Sandwich products provide wind information at cloud top within each mesoscale scene, highlighting environmental shear and cloud-top divergence from developing and mature convection. The sandwich is a combination of the OCTANE speed and direction fields overlaid on visible imagery using a Hue Saturation Value (HSV) display method, which was adapted for use in AWIPS-II for the testbed. Derived speeds and directions fields were made available in AWIPS-II, while a wind barbs product was available through the CIRA SLIDER web page.

These products were assessed in the 2023 Satellite Proving Ground HWT for their ability to complement existing information such as GOES atmospheric motion vectors (AMVs), cloud top heights, radar data, and lightning information. Monitoring the pre-storm, initial convective development, intensification, and decay stages using the OCTANE Speed and Direction Sandwich products were all potential areas of focus. Within the testbed, forecasters used OCTANE in all phases of convection, and in tandem with satellite, radar, and mesoanalysis data, to identify thunderstorm features and attributes related to the mesoscale environment.

OCTANE Science Questions

- Does this product raise your situational awareness on the state of the wind profile in convective environments (compared to Derived Motion Winds)?
- Does this product help you identify stronger versus weaker updrafts for developing and mature convection?
- Are there any modifications you would make to the display to better highlight relevant features for convection?

Use of OCTANE in the HWT

Forecasters readily identified updraft trends, convection initiation, and the wind profiles of convective environments throughout the experiment, in line with the provided training materials. When asked in the daily surveys how they used the OCTANE products, approximately 80% of participants (66/83) marked that they identified updraft trends from mature convection, and 61% marked that they identified sheared convection initiation profiles. Strong gradients in the OCTANE speed product coincident with a storm's updraft, which signaled robust cloud top divergence, were most frequently used by forecasters to monitor convective trends. Several forecasters noted in blog posts, surveys, and ground discussions that cloud top divergence trends observed from OCTANE occurred up to several minutes before corresponding features were observed from radar. This occurred not only during updraft intensification and dissipation, but also was noted as a thunderstorm's parent updraft began to split.

> 'The top image is Octane Speed with DMW overlayed. The bottom image is MRMS 0.5 km MSL Composite Refl [Figure 7]. Notice an intense updraft develop in the center of the screen. The blue indicates lower winds while green/yellow are higher. Winds get as low as 2 kt in the anvil, while just downstream of it they are 30-40 kt!!! The DMW confirm this as they are generally within 5 kt of the Octane speed. Shortly after this happens, reflectivities rapidly increase.'
> 24 May 2023, Blog Post: *OCTANE Captures Intense Updraft Over NV*
> https://inside.nssl.noaa.gov/ewp/2023/05/24/octane-captures-intense-updraft-over-nv/

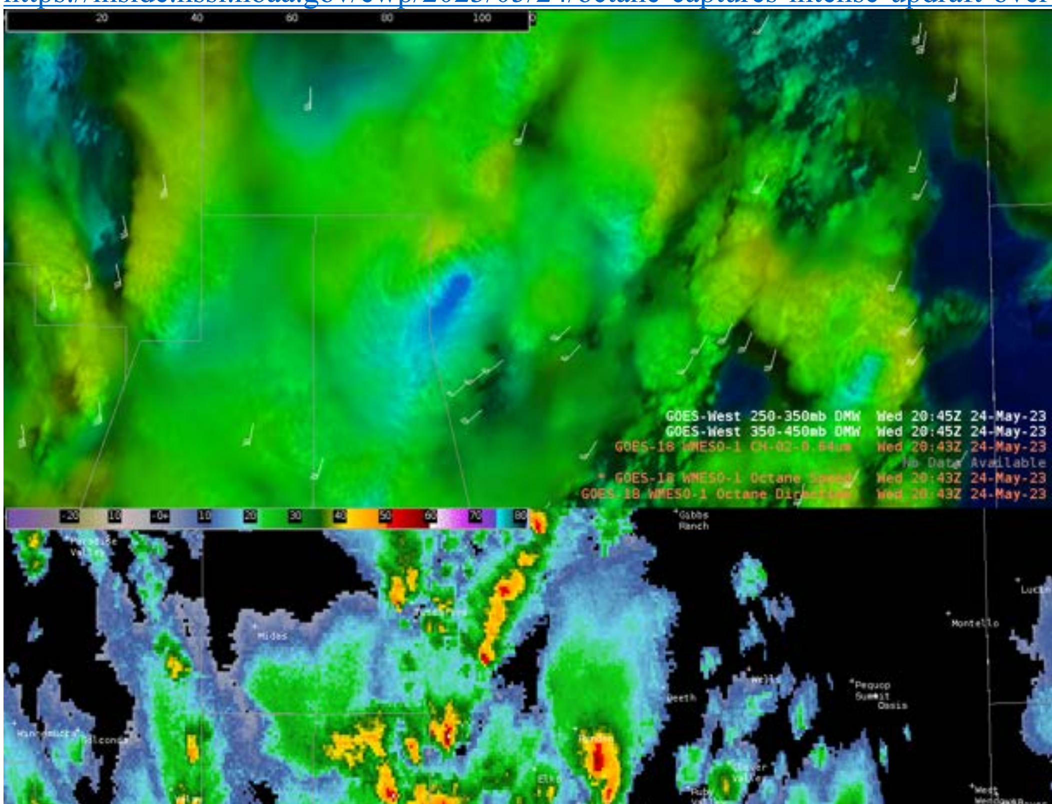

Figure 7: (Top) OCTANE motions over Nevada on 24 May 2023 at 2043 Z. (Bottom) MRMS Composite Reflectivity at 2042 Z.

> 'Really was impressed with how I could use it to see "pulses" of strength within my updraft. Usually would be able to tell that a storm would strengthen or weaken several minutes before I would get the radar/MRMS data I would need to confirm it.'
> *NWS Forecaster – End of Day Survey*

‘The image below [Figure 8] shows the Octane Speed product on the left and the Octane Direction product on the right, focusing on a cluster of activity near the Jefferson/Douglas County line in Colorado…The Octane Speed product shows some speed shear present with the lighter speeds (darker blue, ~5 kts) transitioning to brighter green/a bit of yellow (~30 kts). The magnitude of directional shear was higher, showing direction of motion/divergence ranging from ~170 degrees (core of red area) to ~295 degrees (core of green area).’
24 May 2023, Blog Post: *Afternoon High Plains Convection in Southern Colorado*
https://inside.nssl.noaa.gov/ewp/2023/05/24/afternoon-high-plains-convection-in-southern-colorado/

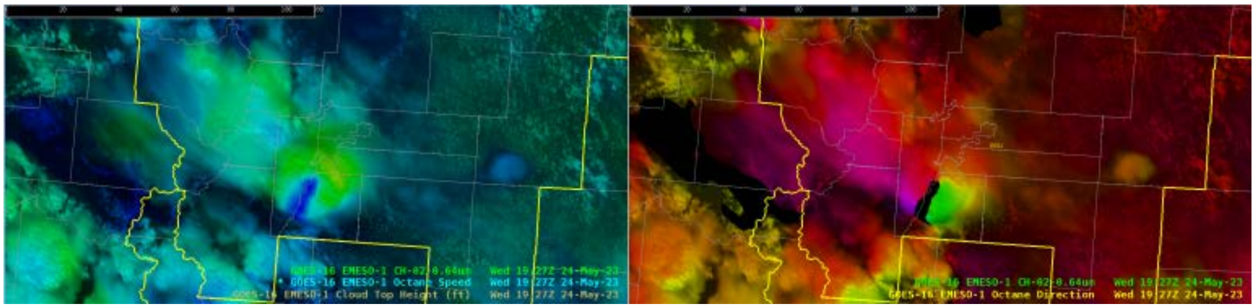

Figure 8: OCTANE speed (left) and direction (right) fields from a storm in Colorado on 24 May 2023 at 1927 Z.

In the daily surveys, forecasters used the OCTANE winds product most often with satellite imagery (88%, 73/83), which coincides with the visible, infrared, and RGB composite imagery used in the premade OCTANE procedures prepared for the forecasters. Radar (reflectivity and radial velocity) and lightning data (ENTLN, GLM, and NLDN) were also mentioned frequently, with 73% (61/83) and 61% (51/83) of responses respectively. OCTANE products were also used with SPC mesoanalysis data in 27% (22/83) of all responses, as forecasters most frequently mentioned CAPE, shear, 500 mb wind, and 300 mb wind fields. When performing mesoanalysis with OCTANE forecasters often leveraged the motions of cumulus clouds, horizontal convective rolls, cirrus, and other cloud features to assess the amount of speed and directional shear within the environment, or to interrogate regions of mesoscale ascent.

‘When looking at the OCTANE Speed Sandwich [Figure 9], a notable gradient in color between darker blue and cyan/green can be seen within widespread stratus over northeastern TX. This delineated agitated stratoCu in cyan/green from flatter, more uniform stratoCu darker blue. This made it easy to find where lift was locally higher (in this case isentropic lift via low level WAA overrunning a surface boundary)… Tracking the delineating line as well as the overall zone of lift itself as it moves over time could help increase a forecaster’s confidence on whether additional convection associated with this forcing mechanism would remain possible or become unlikely, proving OCTANE can be a useful tool in the Mesoanalyst’s tool belt. Comparing OCTANE Speed Sandwich to the popular Day Cloud Phase RGB, OCTANE appeared to highlight the area of lift more easily than Day Cloud Phase RGB, and to a relatively high degree of spatial detail.’

13 June 2023, Blog Post: *OCTANE’s Ability to Assess Areas of Lift in Strongly Sheared Environments*
https://inside.nssl.noaa.gov/ewp/2023/06/13/octanes-ability-to-assess-areas-of-lift-in-strongly-sheared-environments/

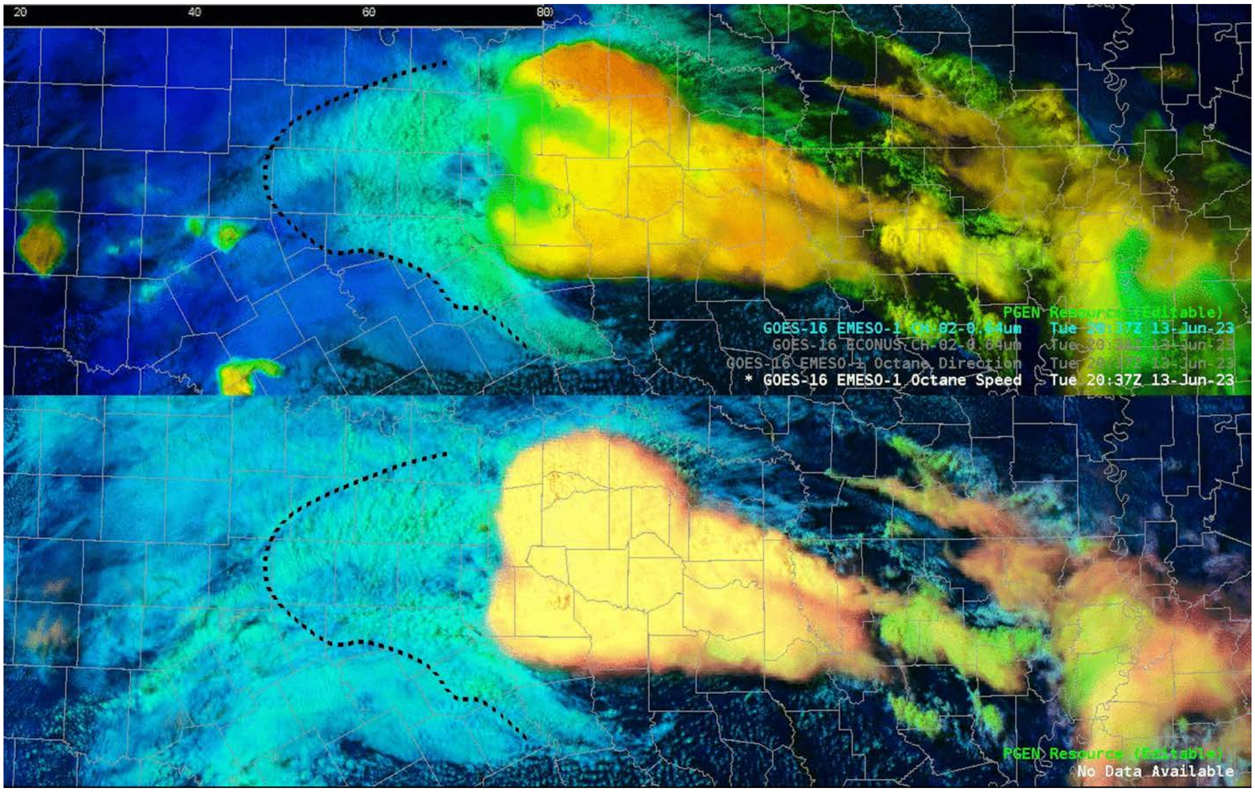

Figure 9: OCTANE Speed (top) and ABI Day Cloud Phase Distinction RGB (bottom) over northeast Texas at 2037 Z on 13 June 2023. The black dotted line was drawn by the forecaster to identify a region of mesoscale ascent.

Intercomparisons with the GOES atmospheric motion vectors (AMVs) product were used to investigate the quality of OCTANE speed and direction data, and in group discussions the forecasters often cited small differences between the two motion calculations. When compared to the operational AMVs, a strong majority of participants noted the added value of OCTANE winds within the daily and weekly surveys due to their increased temporal and spatial frequencies. Additionally, forecasters stated in group discussions they did not routinely use AMVs in convective scenarios at their home office, which made the use of cloud top winds for mesoanalysis and convective nowcasting a novel exercise. Additionally, a few forecasters admitted they entered the testbed speculative of the utility of the OCTANE products for convective monitoring, but that their trust in OCTANE increased throughout the week as they became more aware of how to use cloud top wind signatures from convection.

> ‘The more I learn about this product, the more I see its usefulness and potential in an operational setting. The biggest aspect I learned today was the diagnosis of upper-level divergence and the differences in the wind speeds from the wind product.’
> *NWS Forecaster – End of Day Survey*

‘Octane data from Goes west meso sector was zoomed in along the inflow region across the SW OK supercell [Figure 10]. The upper right panel is the directional component and the color scale was changed to highlight approximately 210 – 150 degree range. The increasingly warm colors represent a backing of flow at approximately 4.5 kFt. This level of storm integration (if appropriate) would be advantageous to warning operations.’
15 June 2023, Blog Post: *6-15-23 HWT AMA*
https://inside.nssl.noaa.gov/ewp/2023/06/15/6-15-23-hwt-ama/

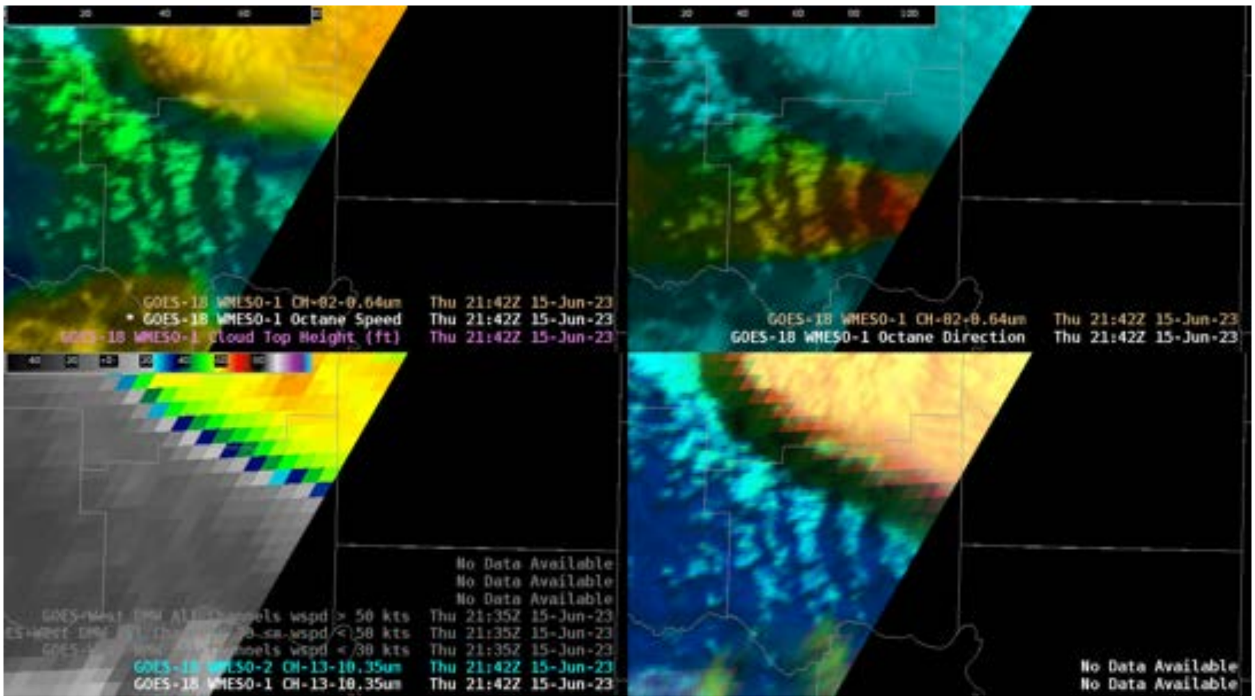

Figure 10: OCTANE speed (top left), OCTANE direction (top right), ABI Clean-IR imagery (bottom left), and ABI Day Cloud Phase Distinction RGB (bottom right) at the edge of the GOES-18 Mesosector in southeast Oklahoma on 15 June 2023 at 2142 Z.

OCTANE Motions and Speed Sandwich were also mentioned as factor when issuing convective warnings, DSS messages, and creating graphics for the public. Of the 96 recorded convective warnings issued, one-third (32) mentioned that the OCTANE products were used in the decision process. Similarly, 29% (18/63) of all DSS messages leveraged OCTANE as part of the communicating severe convective threats. Divergence signatures and their trends were the most frequently used features amongst in both warnings and DSS messages. Warning decisions also cited corresponding trends in radar reflectivity, satellite imagery, lightning, and ProbSevere v3 data. When communicating OCTANE through public graphics the Speed Sandwich product was often used to identify strong or intensifying storms, along with regions of interest for initiating convection.

‘Scattered to widespread thunderstorm activity continues this afternoon across the area, closest storms as of 2224Z are within 5-10 miles of the DSS site. Similar to the previous updates, severe weather is not expected - as far as large hail, damaging winds are

concerned - but storms are on the strong side at times, with lightning, gusty winds, and heavy rain being the primary hazards.'
'Radar-reflectivity trends, LightningCast and LightningCast Time Series, Octane Speed/Direction continue to not show a notable amount of shear in the storms in the immediate area.'
Forecaster – *DSS Messaging Form*

'Our best example today was in convection that was in a radar gap. Octane was able to show the shear and strong development of the cell which helped up to issue a warning which normally we probably wouldn't have without it.'
NWS Forecaster – End of Day Survey

Depending on the amount of environmental wind shear present, a handful of forecasters adjusted the range of values within the OCTANE speed product. Often the maximum speed was reduced in environments with marginal deep layer shear, which made subtle gradients in speeds from diverging cloud tops more visible. In a few cases, the direction product was also altered so diffuse directional gradients could be depicted within the mesoscale environment. Regions with slow wind retrievals (<5 kts) were censored to remove noise from the direction fields. This created 'holes' in the OCTANE direction fields, which could occur at the point of maximum cloud top divergence when the speed of the divergent wind on the upshear side was comparable to the background flow at cloud top. This was suggested as a future OCTANE training opportunity. Additionally, forecasters often mentioned in surveys and group discussions the idea of creating a divergence field from the OCTANE motions to identify cloud top divergence more readily from convection.

'Possibly a colorized image of divergence/convergence like the wind direction images. These would quickly identify location and strength of divergence and convergence.'
NWS Forecaster – End of Week Survey

'I think the color scales just need to be worked on a little bit. The directional shear really needs to eliminate the reds and pinks and I was able to do that by adjusting the color scale (but it also made all color from 270-360 the same).'
NWS Forecaster – End of Week Survey

'Cloud-top divergence would be great, but I definitely would love to see it studied in context with radar. Would be good to know if there is a consistent "rule of thumb", given forecasters already have preset ideas of how strong a storm may be via radar storm top divergence.'
NWS Forecaster – End of Week Survey

Recommendations for Operational Implementation

Based upon the evaluation of the OCTANE Motions and Speed Sandwich product in the 2023 HWT Satellite Proving Ground, the following items have been recommended:

- **It is highly recommended that forecasters leverage OCTANE Motions and Speed Sandwich to assess cloud top divergence trends from convection, convective initiation, and perform mesoanalysis of the ambient kinematic environment.** Additional applications include identifying mesoscale boundaries, splitting or merging storms, and above anvil cirrus plumes.
- **It is strongly recommended that OCTANE training materials include, along with a description of the product and its applications, the physical basis for using cloud top winds with high spatiotemporal resolution in context with radar, lightning, and satellite imagery datasets.** Additional topics may include the use of HSV display methods or the adjustment of color tables to adequately highlight gradients in OCTANE speed and direction fields.
- **It is recommended that a cloud-top divergence field be explored to synthesize the OCTANE speed and direction products.** Additional display methods regarding the OCTANE speed and direction fields – including color tables, gradients, wind barbs, or point-source hodograph retrievals – should also be considered to optimize the interpretation of these data.

3.3 PHS Model

The Polar Hyperspectral Soundings and Microwave Data and ABI (PHS) Model was demonstrated again in the 2023 Satellite Proving Ground HWT. Information from hyperspectral sounders and microwave imagers on the NOAA-20/-21, and MetOp-B/-C satellites in low-Earth orbit are integrated with the GOES-R ABI, and then ingested into a numerical weather model similar to the High-Resolution Rapid Refresh (HRRR) model (Smith et al. 2020). Temperature and moisture information from the NOAA-20/-21 and MetOp-B/-C satellites are associated with/linked to GOES-R ABI data, stepped forward in time, and then used to initialize the numerical model. The PHS model is initialized every two hours, with hourly output available out to nine hours, a horizontal resolution of 4 km, and covering nearly all the continental United States. The numerical model leverages the high spectral resolution of the hyperspectral sounders and microwave imagers in low-Earth orbit with the high spatiotemporal resolution of the ABI to provide more accurate forecasts of the mesoscale environment coincident with deep convection. Numerous model fields were included in AWIPS-II (based on suggestions from the 2022 Satellite Proving Ground HWT) to allow direct comparisons to data from SPC mesoanalysis fields. These included instability parameters, vertical wind shear, composite indices, and thermodynamic variables at 850, 700, and 500 mb.

Prior to the testbed, participants were provided with a training video, a ‘one-pager’ summary document, example applications, and a user’s guide. Forecasters accessed the PHS model products in AWIPS-II, with a larger suite of model output available online in a web display. Procedures were made using the PHS model for common convective parameters (CAPE, CIN, STP, etc.), along with comparing the PHS composite reflectivity output against MRMS composite reflectivity observations. Forecasters used the PHS model throughout the experiment to perform mesoanalysis to anticipate the location, timing, and evolution of convection, and provided feedback on model performance, output characteristics, and display needs.

PHS Science Questions

- Do the PHS forecasts give better, more geographically constrained information with respect to the initiation of convection, and to the development of tornadoes?
- Did you regularly fuse this product with any others? That is, was the efficacy of PHS amplified by any other product in particular, or is the efficacy of that other product amplified by PHS?
- Do the results make you look forward to hyperspectral geostationary sounders during the GeoXo era?

Use of PHS in the HWT

When available in the testbed, forecasters performed mesoanalysis duties with PHS model data and compared its data to other commonly available fields for short term forecasts. SPC Mesoanalysis data were used as a point of comparison with the PHS modeled fields, and often included instability, shear, composite indices, and composite reflectivity data. The developers also warned forecasters that the composite reflectivity data had not been quality controlled, so numerical artifacts and unrealistic values may be present in these data. This was observed primarily in the first two hours of the forecast period. PHS data were most often viewed in the 0-4 forecast hours, as two thirds of participants in the daily surveys noted they used either the 0-2 hr (20/63, 32%) or the 2-4 hr (22/63, 35%) PHS outputs. One-quarter (16/63, 25%) of forecasters also selected the 4-6 hr model output. Variability in the length of each day, 8 hours for the in-person demonstration and 5 hours for the virtual demonstration, may have influenced the forecaster's decision to more frequently use the earlier forecaster hours. Within AWIPS-II, forecasters mentioned in daily surveys the desire for more shear-related products, as they were not included in the procedures provided at the beginning of the week. Lastly, a few participants expressed in group discussions and weekly surveys the desire for products that conveyed how the integration of the satellite information had changed the base state of the model and subsequent forecast hours.

Within warning and DSS scenarios, forecasters used PHS data to perform mesoanalysis of the environments containing convection along with establishing the timing of convective initiation or when storms could impact an area. PHS was mentioned as a contributing factor in 6% (6/96) of all warnings reported throughout the experiment. Forecasters noted in blog posts and group discussions that the kinematic, thermodynamic, and composite index fields were often use to assess thunderstorm evolution, maximum intensity, and potential hazards to look for in radar and satellite imagery. With respect to the 63 DSS messages sent, PHS was listed as contributing factor in 14% (9/63) of all cases. While the fields previously described where also used in DSS scenarios, the composite reflectivity field was more heavily used to provide timing and intensity guidance for the simulated DSS event. This was observed frequently with DSS messages, along with a few of the public graphics that were created for the simulated event.

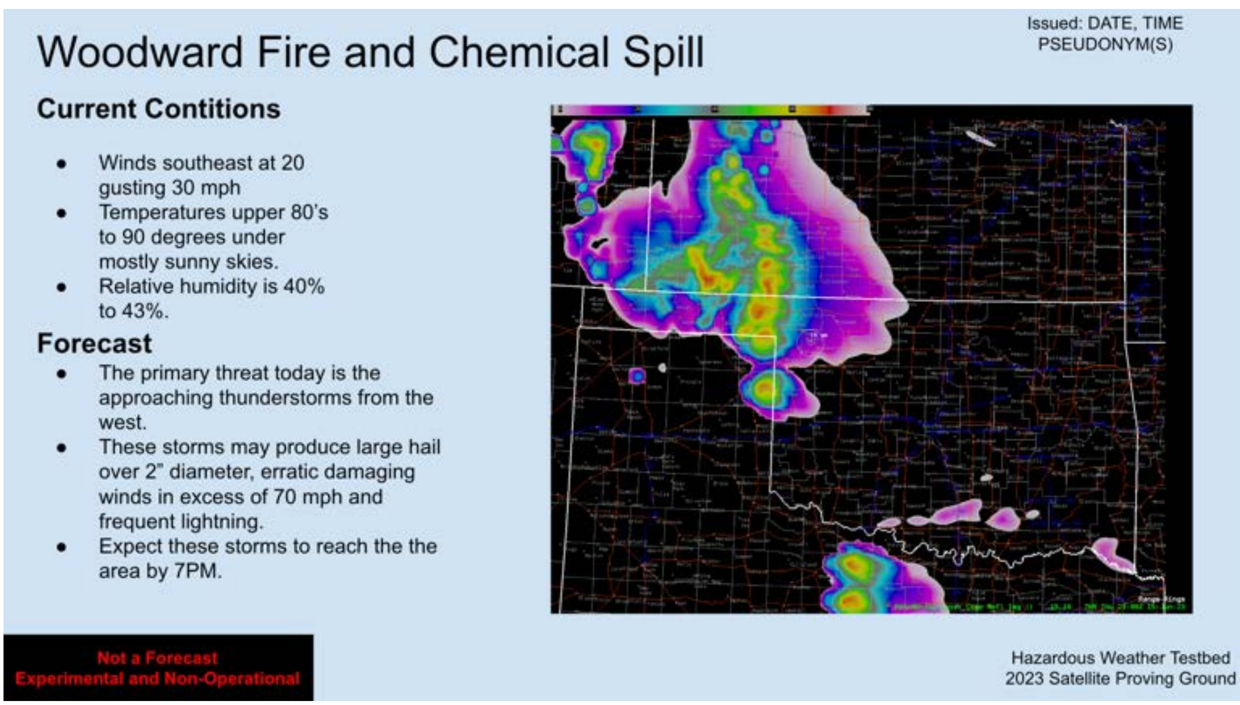

Figure 11: A public graphic for a simulated DSS event near Woodward, Oklahoma on 15 June 2023. PHS forecast composite reflectivity fields were shown in an animation (snapshot at forecast hour 7, 2300 Z). The event location is centered on the two white circles.

> 'Strong to severe storms were forecast throughout the afternoon and evening hours and the event coordinator requested DSS for lightning and any severe weather with as much lead time as possible. Using the 14.16z initialization of the PHS reflectivity was useful in

providing some timing details to the event coordinator [Figure 12]. It suggested a fairly robust storm to roll through the Jackson area by around 00z with the forecast reflectivity ranging from 50-65 dBz directly over the event site… Overall, the product was very useful in boosting the forecaster's confidence in the convection timing to impact the event.'
14 June 2023, Blog Post: *PHS Reflectivity Forecast Helping Out with DSS*
https://inside.nssl.noaa.gov/ewp/2023/06/14/phs-reflectivity-forecast-helping-out-with-dss/

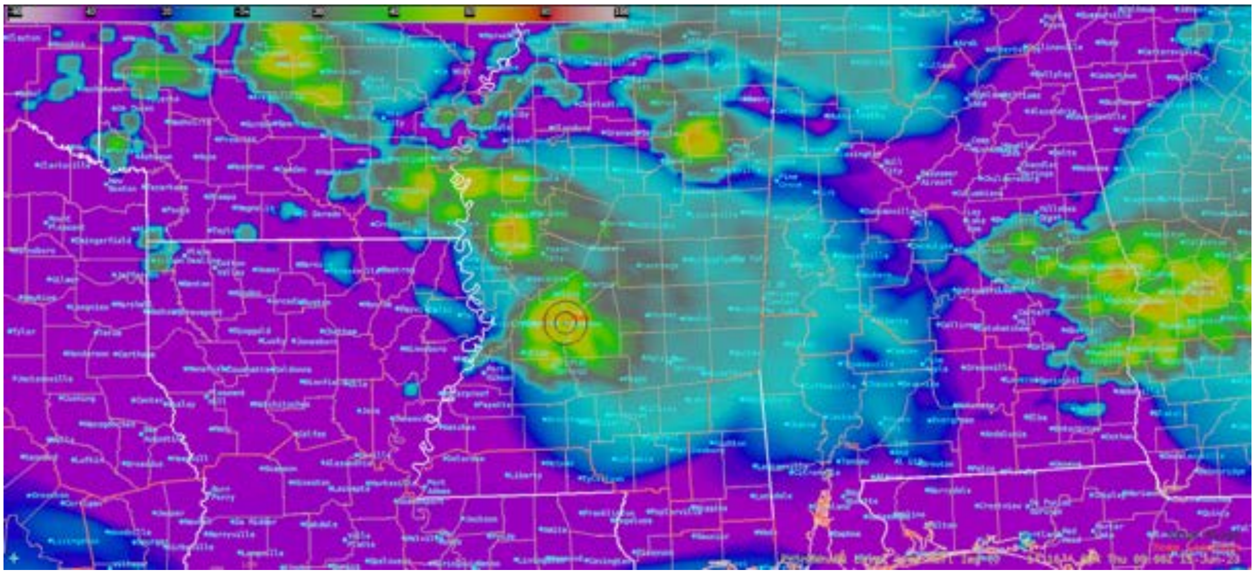

Figure 12: PHS forecast composite reflectivity (8 hours) from 0000 Z on 15 June 2023 with respect to a simulated DSS event in western Mississippi (see black circles).

'Leaned on MESH for hail.. cell merger and quasi-linear structure lowering hail threat, but PHS SHIP still indicating favorable environment just south of rain cool/diff heating boundary, perhaps showing better than SPC Mesoanalysis.'
Forecaster – Warning Submission Form

When comparing stability fields from PHS model against other data sources, 73% (11/15) of participants in the weekly survey stated they thought there was generally good agreement. From the daily surveys, a strong majority (49/62, 79%) of forecasters felt the model gave them a more accurate view of where strong convection was more likely. These results were further supported by blog posts and discussions with forecasters where they compared PHS data to the SPC mesoanalysis and other high-resolution models (HRRR, RAP, etc.). One limitation to these comparisons was the ability to directly observe these data within one platform, as all SPC mesoanalysis and model data were viewed online for this experiment.

'Convection has been slow to initiate in W TX, but we're finally seeing some vertical extension and greater texture in the CU field on the NE side of the mountains… We are seeing good destabilization. The PHS MUCAPE compares quite well to the SPC mesoanalysis.'
7 June 2023: *MAF Convection*

https://inside.nssl.noaa.gov/ewp/2023/06/07/maf-convection/

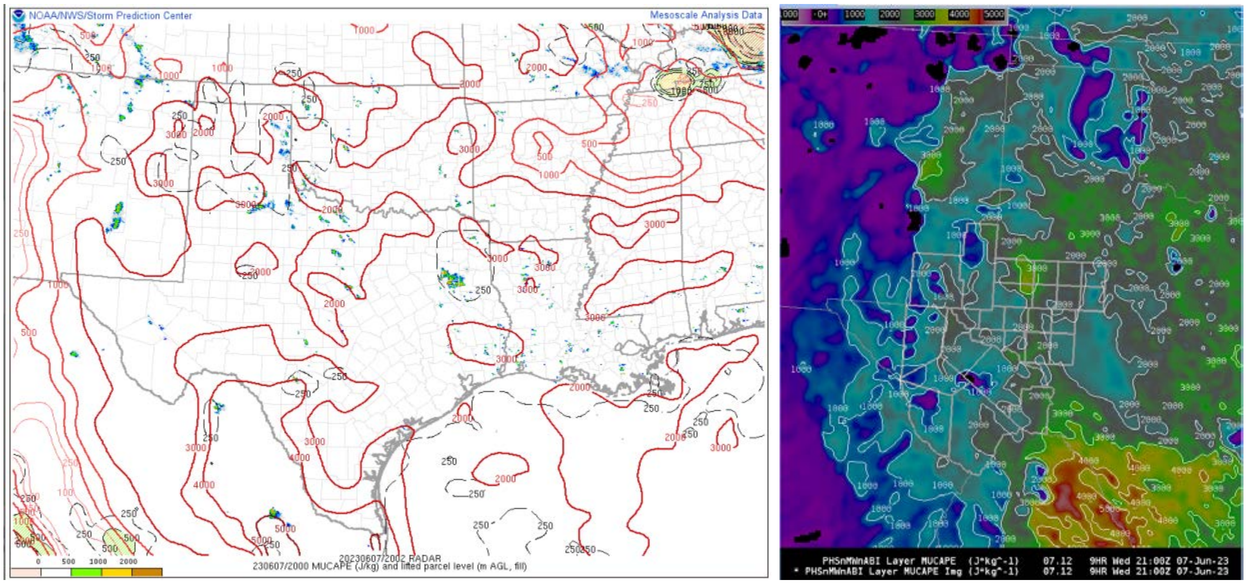

Figure 13: SPC Mesoanalysis (left) and PHS (right) MUCAPE from 2100 Z on 7 June 2023.

'PHS captured the initial convection just east of AMA well, even though the convection started an hour earlier than PHS indicated… Toward the end of the exercise, the storm coverage was well captured by the PHS 16z run. Should have taken this into account for my public graphics when describing the storm evolution.'
15 June 2023, Blog Post: *6/15 Feedback for AMA*
https://inside.nssl.noaa.gov/ewp/2023/06/15/6-15-feedback-for-ama/

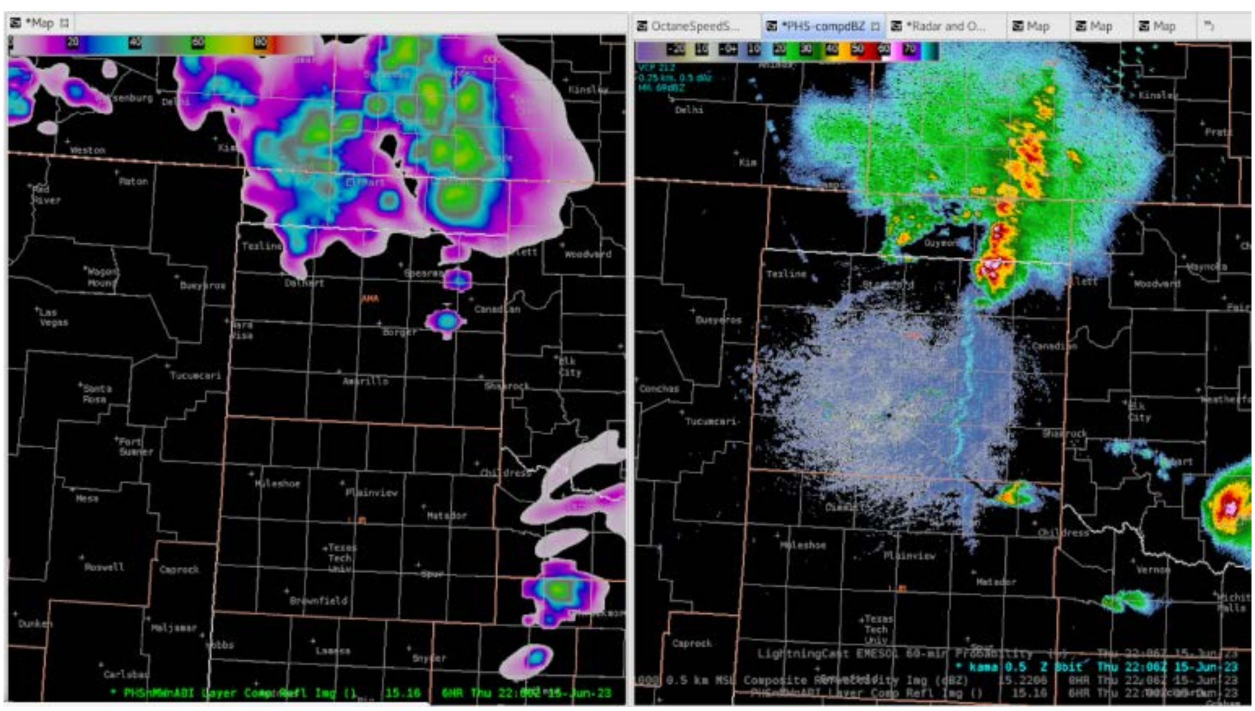

Figure 14: PHS forecast composite reflectivity (hour 6) at 2200 Z on 15 June 2023 (left), and KAMA 0.5° base reflectivity at 2206 Z on 15 June 2023 (right).

From the daily surveys, two thirds of the time (47/71, 66%) forecasters only viewed the PHS data within AWIPS-II while all others viewed the data in both AWIPS-II and online. Additionally PHS faced several issues, especially during the first week of the experiment, regarding the flow of data into AWIPS-II and the latency of the model. In some cases, this may have led to more forecasters viewing the data through the web display rather than though AWIPS-II. When forecasters used the web display to view the PHS model data, several issues were raised regarding the display and its impact on their applications. A few forecasters found the website difficult to navigate and find their desired fields. Timestamps and the values listed on color bars were also difficult to read in several variables. Some products (CAPE, CIN, etc.) used sequential color tables with differing shades of one color, which forecasters found difficult to use when discriminating magnitudes spatially. Forecasters therefore recommended that the color tables change to more discrete colors like those shown in AWIPS-II, along with enlarging the size of the plots or displaying smaller regions to observe spatial gradients and magnitudes more easily.

> ‘The color bars are not great on most of the online products. An example is the red contours for SBCAPE. You can hardly tell the difference in specific values. Often the time stamp was on top of the lat/lon so it was impossible to read the time stamp on some images.’
> *Forecaster – End of Week Survey*

> ‘If the data cannot be ingested into AWIPS, the website needs to be more user friendly. The products were not easy to read, the legends were overlaid by other content, the data was not accurate in comparison to other sources, and the color scheme was not ideal.’
> *Forecaster – End of Week Survey*

> ‘The PHS idea of better utilizing sampled profiles seems good to me. I would prefer it not be solely validated by WRF model output. I like the idea of showing where the fusion data senses departure from model initial conditions similar to shown on this website: cas.hamptonu.edu/~adinorscia/InteractiveMap/FusionMap.html’
> 13 June 2023, Blog Post: *6/13/23 EWP Blog Post SHV*
> https://inside.nssl.noaa.gov/ewp/2023/06/13/6-13-23-ewp-blog-post-shv/

> ‘The idea of PHS data ingest seems like a great application of high resolution satellite imagery. I struggle with the idea that the modeling output will become just another model to monitor. My hope is that this system can become more of a real time analysis tool and/or it becomes the standard for all model initialization schemes.’
> *Forecaster – End of Week Survey*

Recommendations for Operational Implementation

Based upon the evaluation of the PHS model in the 2023 HWT Satellite Proving Ground, the following items have been recommended:

- **It is strongly recommended that product fields be developed which show how the data assimilation technique employed by the PHS model adds value when compared to a control or similar model run.** Potential data sets of comparison may be the SPC mesoanalysis, HRRR model, RRFS model, or models of a similar resolution and architecture.
- **It is strongly recommended that improvements to the PHS model be made such that data are more readily available in AWIPS-II with decreased latency, in addition to an improved web display for this experimental model.** Web display improvements may include the number or size of sectors used, their color tables, and the readability of each product field.
- **It is recommended that PHS model data be used to perform mesoanalysis regarding convection initiation timing and location, storm mode, and potential convective hazards based upon the environmental and reflectivity fields provided.** Additionally, a quality-controlled composite reflectivity product is recommended.

3.4 Probability of Severe (ProbSevere) LightningCast Model

The NOAA/CIMSS Probability of Severe (ProbSevere) LightningCast model (Cintineo et al. 2022) was evaluated again in the 2023 Satellite Proving Ground HWT. LightningCast is a machine learning model trained using the reflectances of four predefined ABI bands as input (Band 2: 0.64 µm, Band 5: 1.6µm, Band 13: 10.3µm, and Band 15: 12.3µm) and 60-minute accumulations of the Geostationary Lightning Mapper (GLM) Flash Extent Density product as truth. The four GOES-R ABI spectral bands are used in a machine-learning model to predict the probability that the GLM will observe lightning in the next 60 minutes. At night the model input is limited to Band 13 and Band 15. Learned spatial and multi-spectral features from the training data, important for short-term lightning forecasting, are then leveraged by the model. Output probabilities are displayed as contours with the option for parallax-corrected data, available for the GOES-16/-18 CONUS and mesoscale scenes, and accessible both day and night. Continued demonstrations of ProbSevere LightningCast in the 2023 SPG were motivated by the need for further operational testing of the models output forecasting the onset and advection lightning activity.

ProbSevere LightningCast contours were available in AWIPS-II and through a web display. New this year forecasters could produce 'lightning meteograms' online, which included time series output of LightningCast probabilities, along with lightning flash rates from the GOES-East/-West GLM and Earth Networks Total Lightning Network, at ASOS stations across the CONUS. Additionally, the developers created special meteograms for each simulated DSS event. Prior to the testbed, forecasters viewed a training video describing how the ProbSevere LightningCast model generates its output, the definition of the lightning related probabilities, and example applications including forecasting the initiation of lightning and decision support services. AWIPS-II procedures overlaying the LightningCast model on the Day Cloud Phase Distinction RGB, GLM Flash Extent Density, and the MRMS Isothermal Reflectivity at -10 °C were provided to forecasters. The default probability contours were set to 10%, 25%, 50%, and 75%.

ProbSevere LightningCast Science Questions

- How well does LightningCast help with lightning initiation forecasts?
- How well does LightningCast help with lightning advection forecasts?
- What kind of lead time do you find with LightningCast?
- How would you like to see LightningCast improved?

Use of ProbSevere LightningCast in the HWT

Throughout the testbed, forecasters frequently used the ProbSevere LightningCast model to monitor initiating or ongoing convection, along with maintaining severe convective situational awareness. Probability contours were often overlaid with the ABI Day Cloud Phase Distinction RGB, GLM gridded products, radar reflectivity, and ground-based lightning networks to provide additional context for storm-based features. During the first week of the experiment, GLM data was unavailable for approximately two days, which led those forecasters to more frequently use ground-based lightning networks to verify LightningCast. Forecasters were asked in the daily surveys for their average actionable lead time when monitoring the two scenarios of lightning initiation and the advection of storms. The 10-19 minute option was selected most often by 39% (19/49) of forecasters when monitoring for lightning initiation, with 25% (12/49) of forecasters selecting 40+ minutes the second most often. When monitoring the advection of storms, the 40+ minute actionable lead time option was selected by 36% (17/47) of the forecasters, the most for this scenario. The second most picked option was 20-29 minutes, by 23% (11/47) of the forecasters.

> 'Lightning Cast (parallax corrected) had a 75% contour for lightning within the next hour (screenshot taken at 21:51Z) for our railroad DSS event. Notified the DSS event about the high lightning potential within the next hour. Went back to look at radar and lightning data for 22:50 to 22:54Z and there were CG and CC strikes just north of the Railroad DSS event in Levelland, TX. This allowed us to give them an hour to make any ground preparations regarding personnel.'[Figure 15]
> 23 May 2023, Blog Post: *LightningCast Gives Advance Notice for DSS Event*
> https://inside.nssl.noaa.gov/ewp/2023/05/23/lightningcast-gives-advance-notice-for-dss-event/

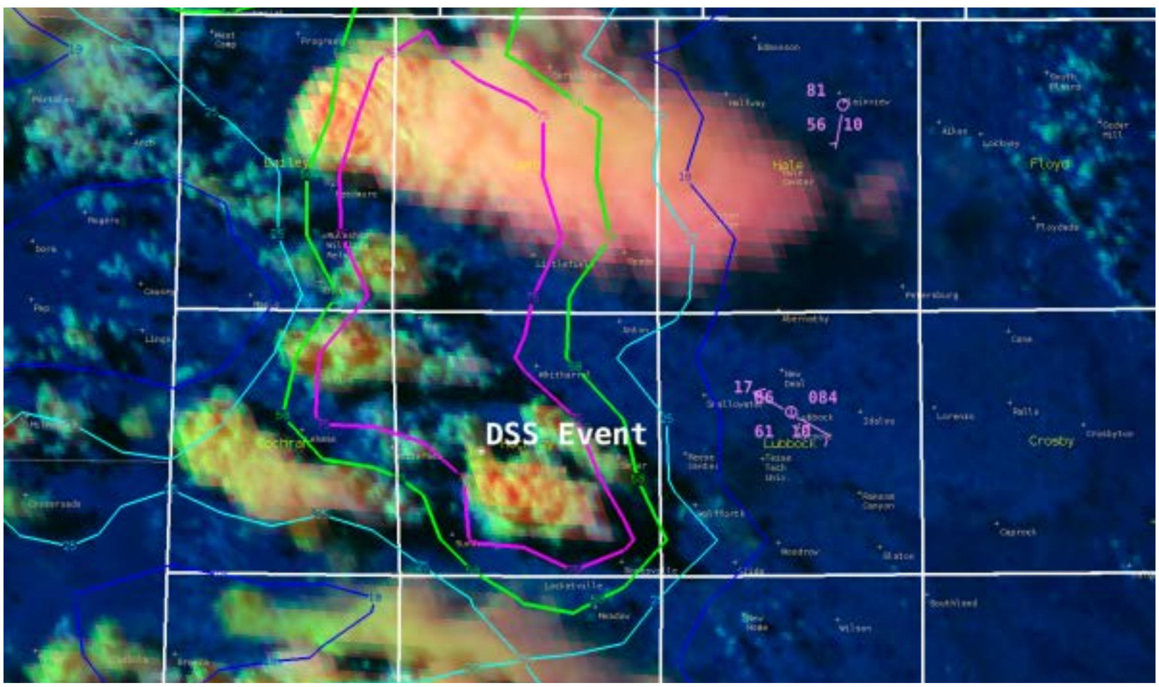

Figure 15: ProbSevere LightningCast overlaid on the GOES-16 Day Cloud Phase Distinction RGB in the Texas panhandle at 2151 Z on 23 May 2023.

LightningCast was used liberally during the simulated DSS events to aid in communicating probabilities of lightning occurrence, maintaining situational awareness, and providing timing guidance to the events. Of the 22 forecasters within the testbed, 21 stated in their end of week survey that they would use LightningCast for DSS support. Of the 63 DSS messages sent over the three weeks within the testbed, 52 (82%) mentioned using the LightningCast model to influence their messaging, with 9 explicitly stating that they used the meteogram tool. Within these DSS messages, forecasters mentioned the location of current lightning activity, direction of the thunderstorms, and expected timing of when lightning would be present at the DSS site. Timing guidance was further supported by some forecasters using the movement of LightningCast probability contours with the AWIPS-II time of arrival tool. On a few occasions forecasters provided LightningCast probabilities within their messaging, reflecting the probability for lightning to occur at the site within the next hour. One third (9/27) of the public graphics made during the testbed included the LightningCast probability contours or meteogram tool to highlight areas of concern for initiating convection or ongoing lightning activity in mature convection.

> *'A couple of showers have developed within 10 miles of the festival to the west and southwest. While there is no indication of lightning currently occurring, there is about a 60% chance of lightning within the next hour.'*
> *Forecaster – DSS Messaging Form*

> 'Utilized LightningCast to highlight the region of concern for new storm development [Figure 16]. The storms did develop but it was a more gradual evolution. The highlighted region did verify as the region of development.'
> 14 June 2023, Blog Post: *6-14-23 HWT SHV*
> https://inside.nssl.noaa.gov/ewp/2023/06/14/6-14-23-hwt-shv/

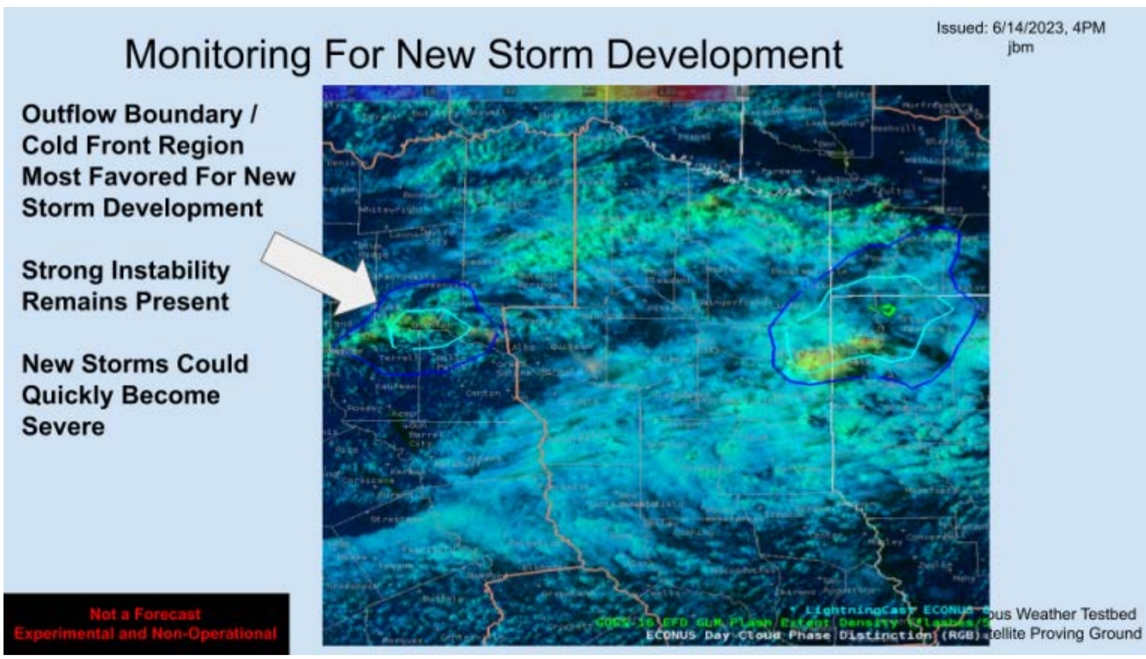

Figure 16: An experimental public graphic featuring ProbSevere LightningCast probabilities overlaid on the GOEW-16 Day Cloud Phase Distinction RGB on 14 June 2023 at 2100 Z.

> '…LightningCast was used to build confidence in where convection was growing and tracking, aiding in defining this area of concern…When comparing this to radar reflectivity, radar was devoid of robust convection in the growing area of concern. Thus satellite proved useful in providing further lead time in defining the area of concern as well as when to start graphic creation. While we opted to not show satellite imagery for public consumption (satellite imagery can be distracting and/or misinterpreted when messaging severe hazards and impacts), it was crucial in the development stage of graphic creation, particularly defining areas of growing concern.'
> 15 June 2023, Blog Post: *Using Satellite to Aid in Defining Areas of Concern for Graphical Messaging*

https://inside.nssl.noaa.gov/ewp/2023/06/15/using-satellite-to-aid-in-defining-areas-of-concern-for-graphical-messaging/

Throughout the experiment, forecasters leveraged the LightningCast online meteogram tool for monitoring trends in model probabilities and local lightning activity during simulated DSS events and received a strongly positive reception from the participants in group discussions. Trends and thresholds in LightningCast probabilities prompted forecasters when to communicate information to the simulated events concerning lightning and thunderstorm related hazards. Forecasters also consistently remarked that the currently available locations for the LightningCast meteogram tool (ASOS stations) made them especially convenient for aviation forecasting such as when issuing Terminal Aerodrome Forecast amendments and Airport Weather Warnings. LightningCast developers also discussed potential ways that forecasters could request temporary meteograms for more specific locations, such as what was implemented manually within the testbed for DSS events. One common request from the forecasters was that the point-based probabilities were parallax-corrected, as regions of sensor overlap between GOES-East and GOES-West could create substantial differences in the probability of lightning occurrence.

> 'I used the LightningCast probabilities in AWIPS overlaid with satellite data to provide multiple updates to Emergency Management, using it to confidently state that probabilities of lightning were increasing as storms approached from the south. Lead time for action would have been within the 45 min to 1 hour range. Was able to confidently say they would see lightning within the 10 mile range a good 15-30 minutes before the first strike occurred within the range per the ENTLN network data [Figure 17]…As a forecaster, having this type of data available to me outside of AWIPS is a game changer. I know it may be challenging, but being able to click on a point like this and get this type of information would be huge for briefings and emails with decision makers.'
> 24 May 2023, Blog Post: *Satellite HWT Day 3 Carl*
> https://inside.nssl.noaa.gov/ewp/2023/05/24/satellite-hwt-day-3-carl/

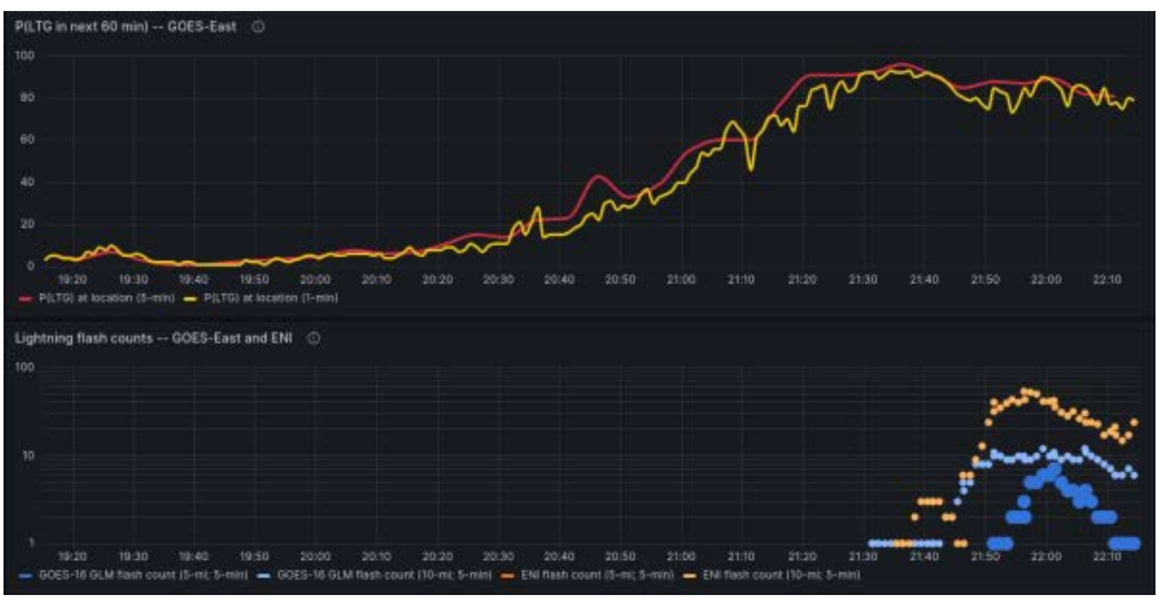

Figure 17: A ProbSevere LightningCast meteogram for the GOES-East CONUS and Mesoscale sectors (top) and the local flash counts (bottom) on 25 May 2023.

‘The data readout of the parallax corrected LightningCast offered within AWIPS (not shown) was favored over the non-parallax corrected time series [Figure 18], giving higher confidence in the true probability of occurrence used within the DSS message. This gave around a 35 minute lead time before the first strike was detected within 10 miles of the DSS site. Had we used the non-parallax corrected readout values, lead time would have been much shorter, around 10 minutes using 1-minute imagery and less than 10 minutes using 5-minute imagery. This clearly demonstrates the value of using parallax corrected data compared to non-parallax corrected data when performing DSS.’
15 June 2023, Blog Post: *Utility of Parallax Corrected LightningCast Versus Non-Corrected Within DDC*
https://inside.nssl.noaa.gov/ewp/2023/06/15/utility-of-parallax-corrected-lightningcast-versus-non-corrected-within-ddc/

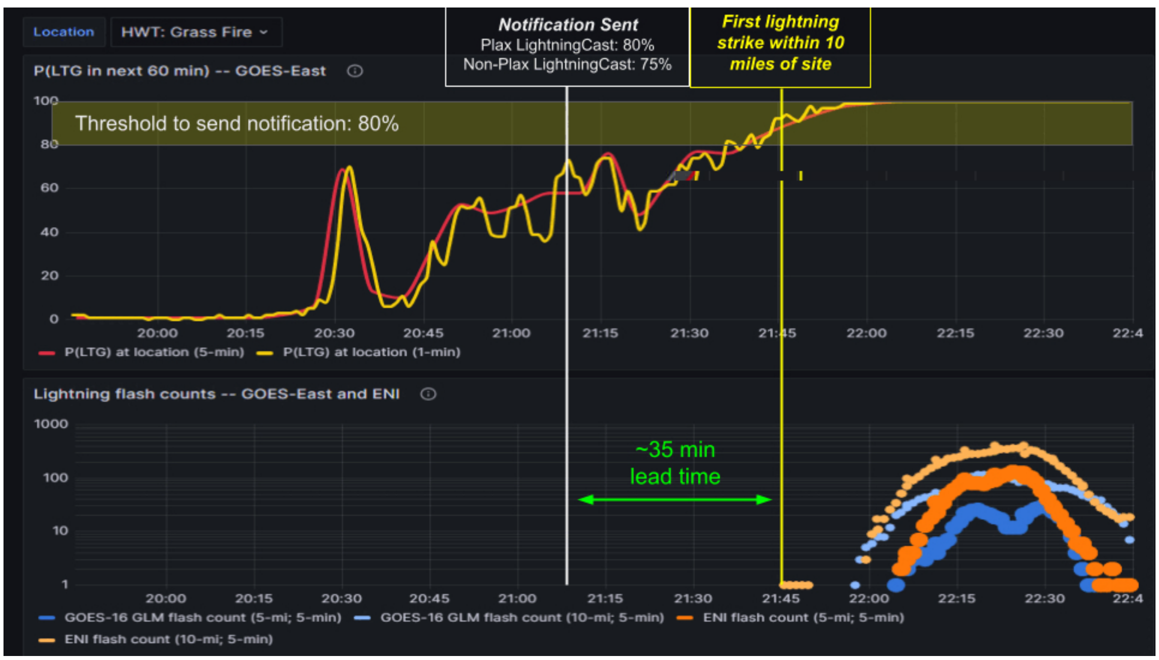

Figure 18: A ProbSevere LightningCast meteogram for the GOES-East CONUS and Mesoscale sectors (top) and the local flash counts (bottom) on15 June 2023.

Through its frequent use within the testbed, a few limitations of the ProbSevere LightningCast model were noted by the forecasters. When dense altostratus and cirrus were present, forecasters pointed out that the LightningCast model often produced probabilities that were too low for initiating convection, as the model struggled to observe the relevant features within the scene. This included after lightning activity within a thunderstorm had already started as well and led suggestions by the forecasters to incorporate radar information into the model. Lower than expected probabilities were also noted by participants where flashes initiated and propagated through stratiform convection, especially within trailing stratiform regions of mesoscale convective systems.

When asked in the daily surveys, 80% (60/75) of forecasters felt that the probabilities generally seemed well calibrated, with the other 19% (14/75) responding that the probabilities were a little too high and one person responding a little low. Deep convection was slow to initiate in a few cases, such as when convection was induced by terrain or in environments with notable convective inhibition, which led to increasing LightningCast probabilities well before the first flash. Slow moving convection also led to probabilities extending well ahead of the storm. In discussions between the ProbSevere developers and the forecasters, the 10 km resolution was also raised in connection to the spread of the probability contours, and the implications of generating finer resolution model output was discussed.

> 'There are new cells developing in far SW FL with lightning noted on GLM, however the cirrus canopy there is too thick to allow LightningCast to detect this convection.' [Figure 19]
> 6 June 2023, Blog Post: *Monitoring South FL Convection for the Miami Open*
> https://inside.nssl.noaa.gov/ewp/2023/06/06/monitoring-south-fl-convection-for-the-miami-open/

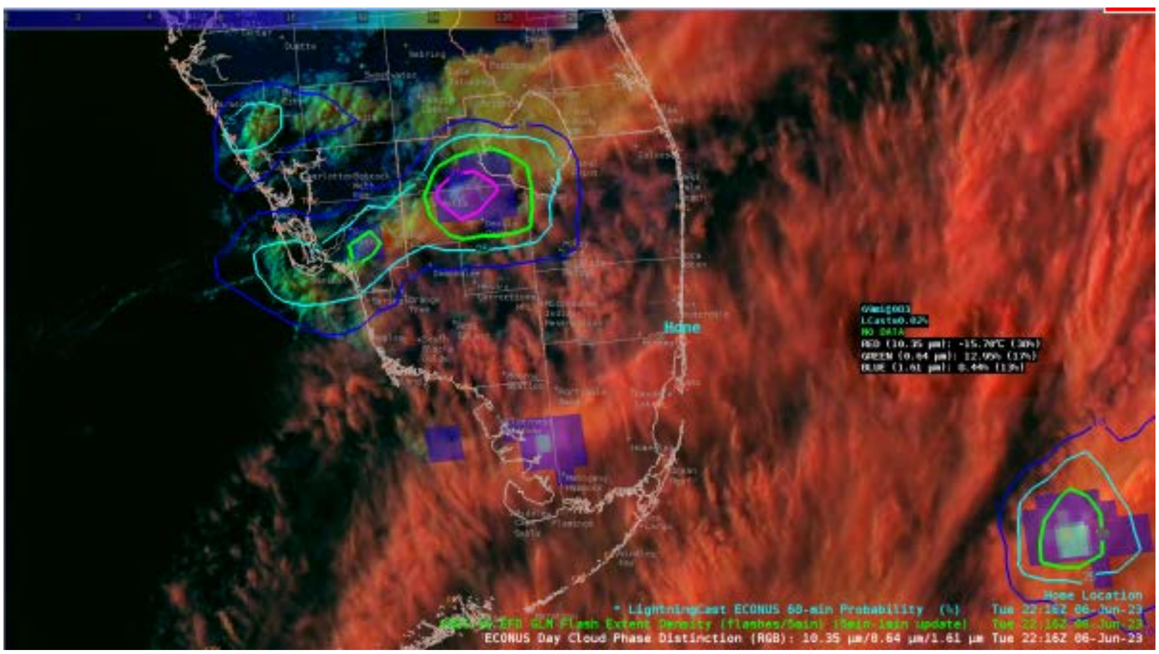

Figure 19: ProbSevere LightningCast overlaid on the GOES-16 Day Cloud Phase Distinction RGB and GLM Flash Extent Density in southern Florida at 2216 Z on 6 June 2023.

> 'LightningCast within the trailing anvil portion of the squall line steadily dropped off within the trailing stratiform region. However, these probabilities decreased when cloud to ground lightning was still being observed, with even some strikes occurring in probabilities less than 10%. This can be seen in [Figure 20] in the far left hand portion of the animation with CG icons occurring within and outside of the lower contours of LightningCast…This significantly lowered confidence in tracking the lower probability contours to give an estimated time of cessation.'
> 15 June 2023, Blog Post: *Low Probabilities of LightningCast Despite Observed Cloud-to-Ground Lightning Within Trailing Anvil Stratiform Region*
> https://inside.nssl.noaa.gov/ewp/2023/06/15/low-probabilities-of-lightningcast-despite-observed-cloud-to-ground-lightning-within-trailing-anvil-stratiform-region/

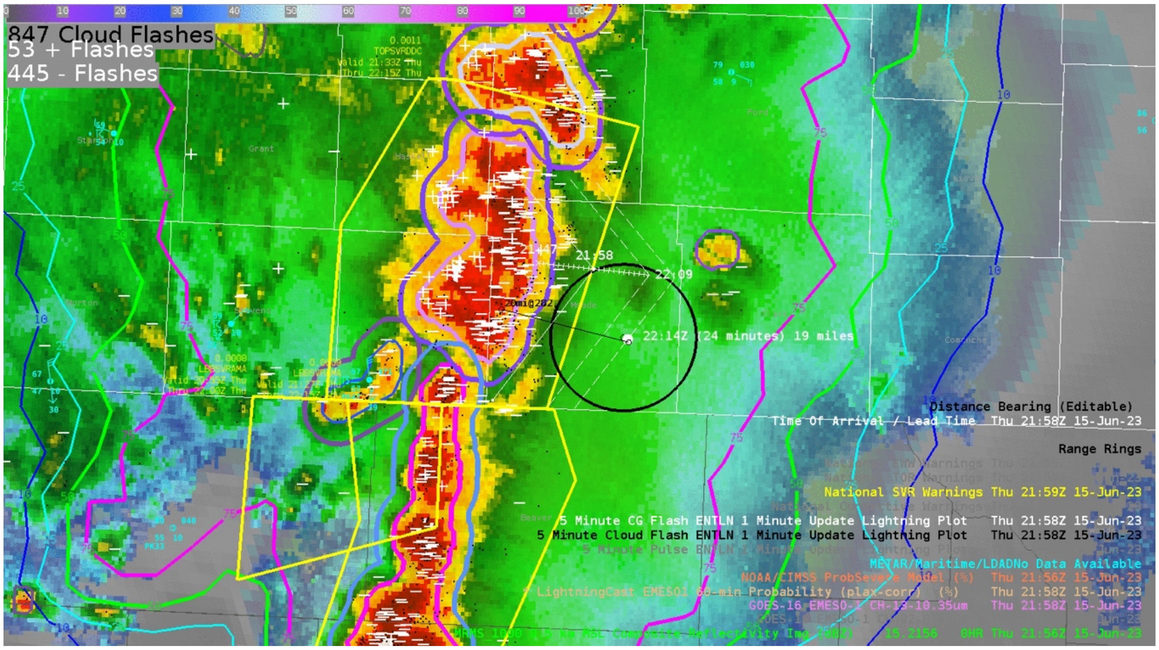

Figure 20: ProbSevere LightningCast contours overlaid on MRMS Composite Reflectivity ENTLN total lightning activity in southwest Kansas at 2156 Z on 15 June 2023. Severe thunderstorm warning polygons are yellow, the time of arrival tool are the white dotted lines, and the DSS event is centered on the black circle.

Recommendations for Operational Implementation

Based upon the evaluation of the ProbSevere LightningCast model in the 2023 HWT Satellite Proving Ground, the following items have been recommended:

- **It is highly recommended that the ProbSevere LightningCast model be integrated into NWS operations for the purposes of situational awareness, anticipating the initiation of convection and associated lightning activity, and monitoring the advection of lightning activity from mature convection.** These applications are especially prudent for impact-based decision support services and include both spatial probability contours and point-based time series tools such as the lightning meteogram tool.
- **It is recommended that ProbSevere LightningCast training incorporate the previously mentioned applications, along with model limitations such as lower than expected probabilities in dense cirrus and stratiform precipitation.** Methods for displaying LightningCast probability contours at certain values, along with recommended values for lightning initiation and convective monitoring, may also be included.
- **It is recommended that the ProbSevere LightningCast meteogram tool use parallax-corrected model output to improve the interpretation of these probabilities and align with corresponding lightning information.** The ability to request event-specific meteograms is an encouraged area of future development.

3.5 Probability of Severe (ProbSevere) Model – Version 3

The NOAA/CIMSS Probability of Severe (ProbSevere) Model (Cintineo et al. 2014) Version 3 (v3) was evaluated again in the 2023 Satellite Proving Ground HWT. ProbSevere v3 is a set of machine-learning models that provide storm-relative probabilistic guidance regarding the occurrence of severe weather within the next 60 minutes, updating every two minutes. Its associated hazard models are trained for severe hail (ProbHail), severe wind (ProbWind), tornadoes (ProbTor), and all hazards (ProbSevere). Version 3 of the model received several fundamental changes compared to ProbSevere Version 2 (v2), including a new machine learning algorithm, new inputs from the GOES-16 ABI and GLM, and environmental fields from the High-Resolution Rapid Refresh (HRRR) model. This year was the first testbed with HRRR model data as a ProbSevere v3 model input, which was the primary motivation for its continued demonstration in the Satellite Proving Ground. Additional model inputs include Earth Networks Total Lightning Network (ENTLN), GOES-16 ABI/GLM, Multi-Radar Multi-Sensor (MRMS) data. ProbSevere data is displayed for each storm-relative contour, and when sampled provides listed probabilities and common parameters used in the model. Additionally, double-clicking the ProbSevere v3 contour in AWIPS-II provides time series information so forecasters can quickly diagnose convective trends. Additional time series information from common input variables are available through a web display along with the ProbSevere v2 and v3 probabilities.

Prior to the testbed, forecasters were provided a training video discussing how ProbSevere v3 differs from ProbSevere v2 in terms of input variables, calibrated probabilities from each model, overall performance, and how to access the time series tool. AWIPS-II display procedures were also made to overlay the ProbSevere v3 storm objects on MRMS variables which frequently are the leading predictands for ProbHail, ProbWind, and ProbTor. This frequently involved MRMS Composite Reflectivity, Maximum Expected Size of Hail (MESH), Vertically Integrated Liquid (VIL), and Low-Level (0-2 km) Azimuthal Shear.

ProbSevere v3 Science Questions

- Does ProbSevere increase your confidence in warning-decision making?
- Does ProbSevere increase the lead time you can achieve to severe weather hazards?
- How would you like to see ProbSevere improve?

Use of ProbSevere v3 in the HWT

Forecasters frequently used the ProbSevere v3 model to monitor convection in all stages, and combined this information with radar, satellite, and mesoanalysis fields. Most often, the ProbSevere v3 all hazards storm objects were overlaid on MRMS fields or information from nearby radar. This provided additional context when sampling the storm objects and the changing probabilities with time. While visible, infrared, and RGB composite satellite imagery were sometimes used with ProbSevere v3, forecasters more frequently referenced the experimental OCTANE Speed Sandwich product when identifying sudden changes in thunderstorm intensity, as observed by satellite. Forecasters overwhelmingly approved of the ProbSevere time series tool when making warning decisions, with all respondents (48/48) stating that the tool was useful. In group discussions, forecasters mentioned the ability to monitor trends in thunderstorm intensity with the time series tool.

‘The strongest cell, pictured below, had a PSv3 of 73%, while PSv2 remained as 56%...We issued a warning for a northern cell moving into the CWA into Madison county, based on a -70C cloud top brightness temp and PSv3 total prob over 70% (had been climbing from the 50s fairly steadily). But the cloud top shear noted by Octane was not strong (~20-25 kts), so the warning was very borderline.’
8 June 2023, Blog Post: *HGX Convection Impacting the Car and Truck Show in Burton, TX*
https://inside.nssl.noaa.gov/ewp/2023/06/08/hgx-convection-impacting-the-car-and-truck-show-in-burton-tx/

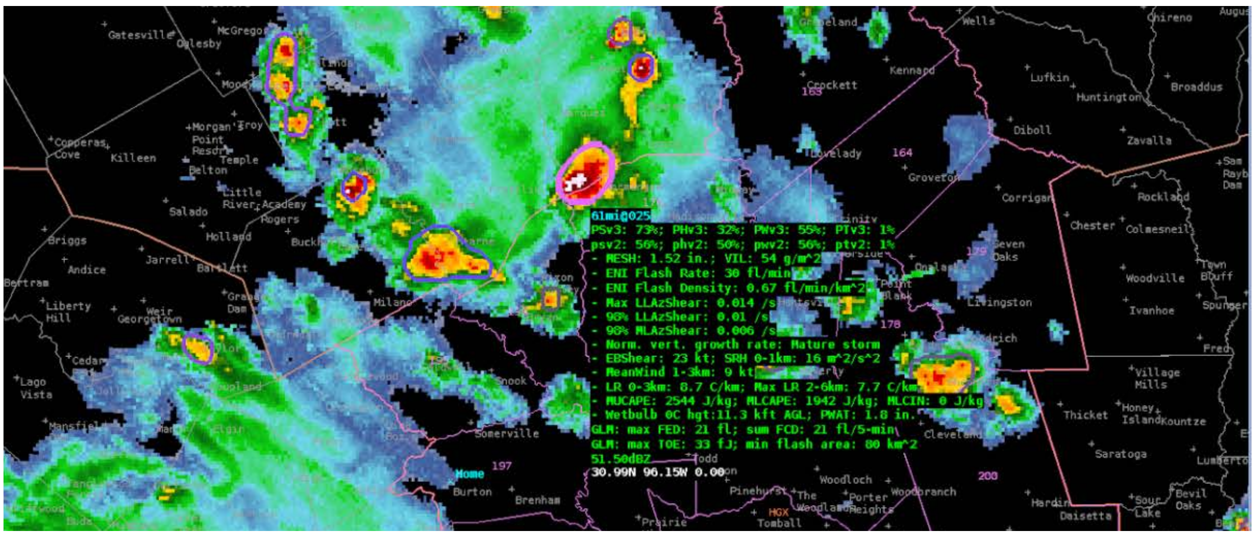

Figure 21: ProbSevere v3 all hazards overlaid on MRMS Composite Reflectivity from 1928 Z on 8 June 2023. The storm object of interest is sampled with the probabilities and model inputs.

‘ProbSevere v3 highlighted the increasing trend in severe probabilities and in tandem with the Octane speed sandwich product, and solidified the decision to keep a severe thunderstorm warning in effect for the central Elko County supercell. Prob severe values were quite a bit higher with v3 compared to v2 (see details below). The decision to not issue a tornado warning was due to the high LCL values in the region (>1,800 m AGL), despite increased ProbTor values maxing out around 17% for this supercell.’
24 May 2023, Blog Post: *OCTANE and ProbSvr Highlight Elko County Supercell*
https://inside.nssl.noaa.gov/ewp/2023/05/24/octane-and-probsvr-highlight-elko-county-supercell/

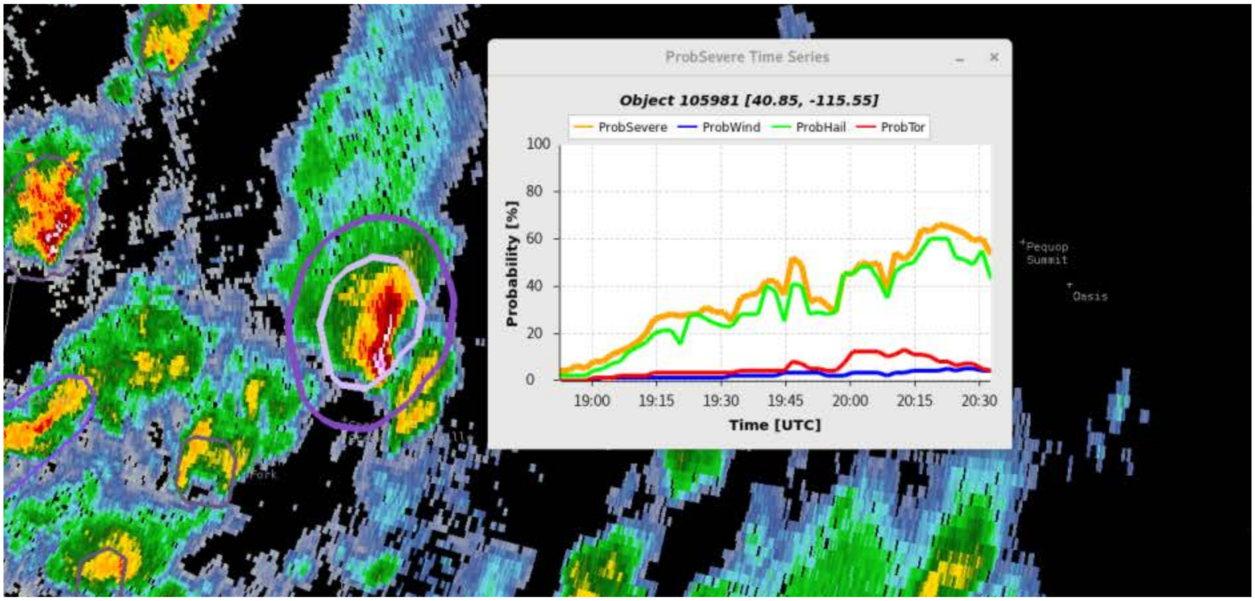

Figure 22: ProbSevere v3 all hazards overlaid on the KLRX base reflectivity from 2028 Z on 24 May 2023. The time series tool is selected from the storm object of interest.

When monitoring multiple thunderstorms, forecasters used the ProbSevere v3 model to identify the most intense storms that required more attention. By sampling the probabilities from multiple thunderstorm objects and reviewing the time series tool, forecasters remarked that they could triage the storms in more active environments to help maintain situational awareness. While ProbSevere v3 helped the forecasters triage thunderstorms when convection was widespread within a CWA, adjacent thunderstorm objects could combine themselves into a single object. When multiple storms were combined, the probabilities became less representative of the storm of interest or would suddenly jump. These jumps were observed in the time series tool and sparked discussions between the forecasters and ProbSevere developers regarding how the ProbSevere storm objects are created.

> 'ProbSevere helped considerably in triaging which storms deserved attention, and which storms were trending in such a way that warranted a warning decision and/or adjustment. A combination of several supercells that would merge with other cells and evolve into clusters and bowing quasi-linear structures made it difficult to have a comfortable handle on storm behavior and associated hazards. This was compounded by the fact that radar data from the favored radar site, KBMX, was dropping out at times. While other datasets were referenced (satellite, surface observations, storm reports, objective analysis, etc.), ProbSevere felt like it gave the biggest helping hand in warning decisions during this complex scenario.'
> 14 June 2023, Blog Post: *BMX Warning Met West Sector on June 14 2023*
> https://inside.nssl.noaa.gov/ewp/2023/06/14/bmx-warning-met-west-sector-on-june-14-2023/

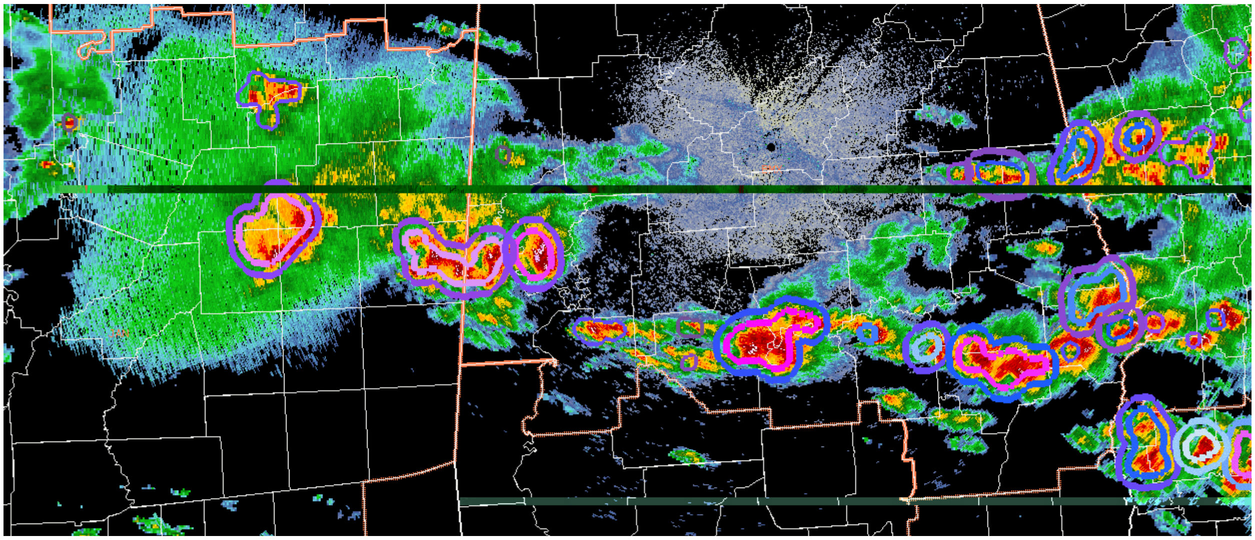

Figure 23: ProbSevere all hazards overlaid on KBMX base reflectivity from 2042 Z on 14 June 2023. Note the numerous storm objects within the Birmingham, MS CWA.

> ‘Noticed an interesting time period where two close updrafts – one fading, one picking up, resulted in some jumping of the ProbSevere product as it would sometimes combine the objects and then sometimes track them separately. I think this shows the importance of pairing the algorithm with analysis – just looking at the time series of the product could lead to misinterpretation of what was happening.
> 22 May 2023, Blog Post: *Satellite HWT Day 1 Analysis Carl*
> https://inside.nssl.noaa.gov/ewp/2023/05/22/satellite-hwt-day-1-analysis-carl/’

After comparing the ProbSevere v2 and v3 model outputs, forecasters overwhelmingly stated in the daily surveys that v3 model was an improvement over the v2 model, and no forecasters stated that the v3 model performed worse than the v2 model. In the end of week survey, 90% (19/21) of participants preferred the v3 model over the v2 model, with the remaining 10% (2/21) stating that they were unsure. Forecasters identified several cases of v3 probabilities steadily increasing before v2 rapidly increased as the thunderstorms intensified and became severe. Additionally, forecasters already familiar with ProbSevere v2 mentioned the need to recalibrate themselves to the new probabilities, and that having output from v2 and v3 within the sampled storm objects made this process easier.

> ‘I think ProvSevere V3 was great. I really liked how it was more "aggressive" as the storm was developing and V2 always lagged behind.’
> *Forecaster – End of Week Survey*

> ‘Looking at ProbSev V3 you can see the values for hail compared to V2 are very similar at the end. However, the bigger thing we noticed is that V3 picked up on the hail much earlier in the event compared to V2. We also noticed the chance of tornadoes in V2 was nearly zero while V3 was almost 20%. Looking at velocity I would agree with V3 as we did see some good rotation in the low to mid levels. As of this writing the storm has produced at least 2 inch hail.’
> 23 May 2023 Blog Post: *Severe Storm Review Looking at PSv3 vs v2 and OCTANE*

https://inside.nssl.noaa.gov/ewp/2023/05/23/severe-storm-review-looking-at-psv3-vs-vs2-and-octane/

Throughout the 2023 experiment, nearly all forecasters surveyed each day found the ProbSevere v3 model increased their confidence when issuing severe thunderstorm warnings (53/53) and tornado warnings (9/10). In terms of lead time, 86% (36/42) of forecasters surveyed felt the model increased their lead time when issuing severe thunderstorm warnings, and nearly all who responded (5/6) felt similar with respect to issuing tornado warnings. While forecasters in the experiment did not issue warnings using only the ProbSevere probabilities, their information were frequently cited to influence their warning decisions. Of the 96 warnings issued 72 (75%) mentioned that ProbSevere v3 probabilities influenced their decisions, with 14 mentioning trends in the probabilities specifically. Group discussions affirmed these data, as forecasters referred the probabilities as a 'nudger' or 'influence' on the warning process. This included not only when issuing warnings, but also when making decisions to reissue, cancel, or let warnings expire. Additionally, when forecasters were tasked with issuing DSS messages within the testbed 32% (20/63) mentioned using ProbSevere v3. Within those DSS messages forecasters referenced the severity of ongoing thunderstorms and their associated hazards but did not mention their specific probabilities.

> 'Screen capture of the ice machine and intense three body scatter spike that persisted for close to an hour at least. Probsevere was very good especially once the tracking element was assigned to just the primary updraft. I issued several warnings during the exercise window and utilized probsevere on each one. The time trend window is great and I hope it gets to the operational version soon.'
> 13 June 2023, Blog Post: *6-13-23 EWP Blog Post SHV*
> https://inside.nssl.noaa.gov/ewp/2023/06/13/6-13-23-ewp-blog-post-shv/

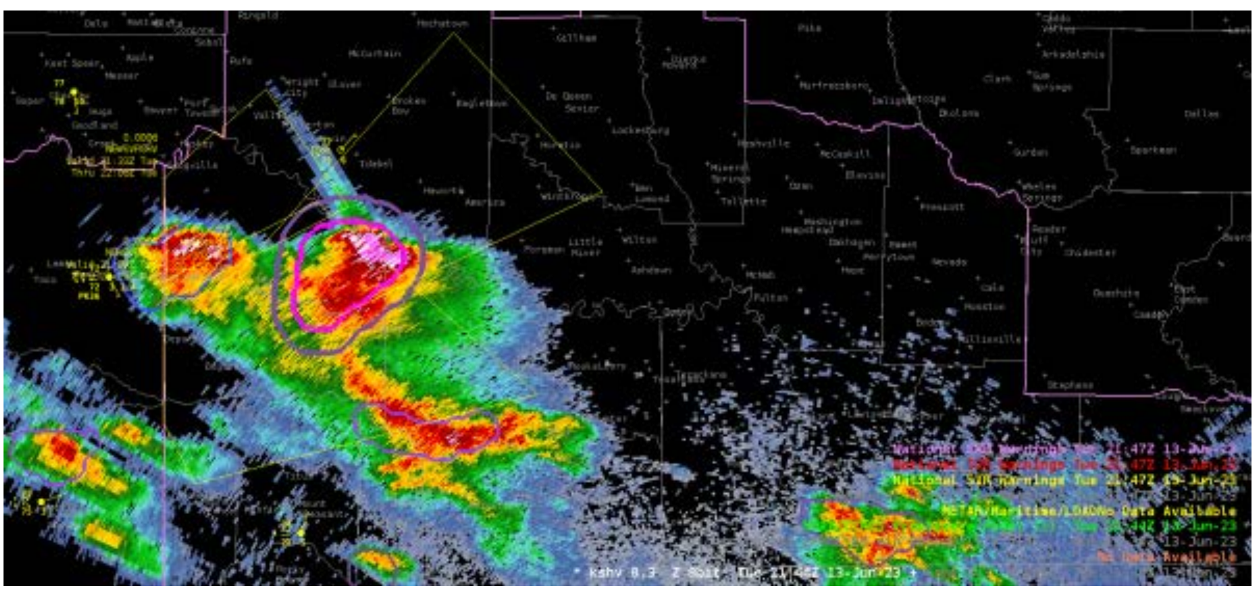

Figure 24: ProbSevere all hazards overlaid on KSHV base reflectivity from 2147 Z on 13 June 2023. Note the severe thunderstorm warning issued for the storm of interest, along with the three-body scatter spike from the reflectivity data.

‘ProbSevere version 3 increases our confidence that storms will remain generally sub-severe as ProbSevere values are below 10% across the Tampa CWA as of 1930Z.’
25 May 2023, Blog Post: *PHS and GLM Data for Tampa, Florida this Afternoon and Evening*
https://inside.nssl.noaa.gov/ewp/2023/05/25/phs-and-glm-data-for-tampa-florida-this-afternoon-and-evening/

‘ProbSevere showing the weakening trend of the storm gave us confidence that the storm was in fact weakening…ProbSevere showing continued weakening trend. We decided not to issue another severe thunderstorm warning on this storm based on the trend.’
24 May 2023, Blog Post: *Afternoon High Plains Convection in Southern Colorado*
https://inside.nssl.noaa.gov/ewp/2023/05/24/afternoon-high-plains-convection-in-southern-colorado/

Figure 25: ProbSevere all hazards overlaid on KPUX base reflectivity from 2042 Z on 14 June 2023.

Data outages from radar and satellite products during the first week of the experiment provided a unique test of the ProbSevere v3 model and its applications. GLM data were missing for one day, and forecasters stated that they noticed little to no change in the hazard probabilities. Additionally, a radar in the eastern portion of the Albuquerque, New Mexico CWA was not operational during the first week of the experiment. Forecasters noted that certain MRMS products struggled to accurately depict convection when compared with satellite information. With this consideration in mind, forecasters closely monitored changes in the satellite derived IntenseStormNet parameter and the subsequent trends in the hazard probabilities from the ProbSevere v3 model. Overall forecasters still found utility in the model’s probabilities but noted that probability trends and magnitudes may be lower when compared to more traditional cases. Additional model considerations were noted in the intermountain west, as in one scenario forecasters noted the ProbWind values appeared too low and not sensitive to the current environment. Forecasters with experience in this region discussed with ProbSevere developers several environmental parameters that could assist ProbWind in these regions.

‘Issued a warning in an area of pretty poor radar coverage (lowest tilt height was around 15kft). MRMS was still capturing a good bit of the freezing level to -20C isothermal levels, so ProbSevere was running pretty strongly with hail probabilities…Given the environment, these products definitely gave me additional confidence and potential lead time, given these cores really grew tremendously about 15 minutes later, including an eventual split and right mover that likely produced some large hail (hard to verify in this area given lack of population).’
25 May 2023, Blog Post: *Satellite HWT Day 4 Carl*
https://inside.nssl.noaa.gov/ewp/2023/05/25/satellite-hwt-day-4-carl/

‘Due to a software error during an update, the GLM data dropped out for a few hours, which is an input into the ProbSevere model. It was good to see that ProbSevere seemed to remain well calibrated despite losing the data. I observed no large spikes or increase in the overall probabilities when the data was added back in – just a few small increases in some places. Data outages are not uncommon, so I think it is good that the model continues to perform well in the absence of a product.’
23 May 2023, Blog Post: *HWT Day 2 Tuesday Thoughts*
https://inside.nssl.noaa.gov/ewp/2023/05/23/hwt-day-2-tuesday-thoughts/

Recommendations for Operational Implementation

Based upon the evaluation of the ProbSevere v3 model in the 2023 HWT Satellite Proving Ground, the following items have been recommended:

- **It is highly recommended that ProbSevere v3 be implemented within NWS operations and replace ProbSevere v2.** Motivation for operational implementation includes further assisting forecasters when making more timely convective warning decisions, quickly identifying trends in thunderstorm intensity, and maintaining situational awareness.
- **It is highly recommended that forecasters leverage the ProbSevere v3 time series tool within convective warning operations to efficiently display trends in thunderstorm intensity and identify convective hazards.**
- **It is recommended that training regarding the ProbSevere v3 model include the calibration of probabilities from the ProbSevere v2 model, the products input into ProbSevere v3, the definition of the individual probabilities, and examples depicting the expected model performance.** Additional examples may include model performance during data outages or cases of limited radar data that impact the model’s input parameters.

4. Summary and Conclusions

The GOES-R and JPSS Satellite Proving Ground conducted one in-person week and two virtual weeks of satellite product evaluations during the 2023 Spring Experiment of the Hazardous Weather Testbed. Twenty-two NWS forecasters evaluated five GOES-R and JPSS products and interacted with multiple algorithm developers and subject matter experts during the experiment. Quantitative feedback was collected through surveys administered at the end of each day and week, along with a warning/decision support service reporting form. Qualitative feedback came from daily discussions with forecasters, blog posts, and public graphics. Along with the standard warning operations, mock decision support service events were created each day to reflect the updated NWS mission. Participants received training materials prior to the testbed for each product through a combination of user guides, PowerPoint presentations, and online learning modules. Products were also summarized at the beginning of each week by their developers, which included product applications, limitations, locations in AWIPS, and recommended display practices. Based on feedback from previous all-virtual experiments, and the subsiding COVID-19 pandemic, in-person demonstrations resumed for the first time since 2019.

2023 Satellite Proving Ground HWT Science Questions

- How does the in-person and virtual settings of the testbed impact the quality of product demonstrations?
- How can the experiment format improve to benefit developers and forecasters?

During the end of week surveys and discussions, forecasters were presented with questions regarding their experience in the virtual testbed, providing feedback that may be helpful for future experiments. Overall forecasters responded positively when asked for their impression during the end of week discussions. Often the forecasters cited the opportunity to learn about new products and forecasting techniques from developers and other forecasters as the most positive outcome, which they wanted to then share with their home offices. This was apparent in both the in-person and virtual settings of the testbed. Forecasters who participated in person had more conversations with other testbed participants and the developers during their additional time in operations, leading to a more thorough evaluation of the products. Within the virtual setting several forecasters expressed that personal commitments and staffing limitations within their home offices made attending in person unattainable. This has been mentioned each year since 2021.

> 'The Satellite Proving Grounds testbed was an exciting whirlwind of a week where we got to test new satellite technologies and techniques in convection applications. It was really neat to have developers there next to you to provide feedback to, to answer your questions, or to ponder new uses of their research.'
> *Forecaster – End of Week Survey*

> 'The testbed was a massive opportunity to become introduced to new products that could potentially be useful in operations. Go into the testbed with an open mind, and understand that you may not understand everything that you are being introduced to. Also, understand that while you are expected to provide feedback to the developers, you may also find yourself learning new things with a wide range of experienced forecasters.'
> *Forecaster – End of Week Survey*

> 'I found the HWT Satellite Testbed to be interesting, beneficial, and somewhat exhausting. At the beginning of the week, there was so much information about the products that it took some time to wrap my head around when they would be useful and/or beneficial. After using them in an operational setting for about a day and a half, their usefulness did become more clear, and look forward to using the products in ops on a regular basis.'
> *Forecaster – End of Week Survey*

While the response was overwhelmingly positive, forecasters did mention opportunities for improvement within future experiments. While designed to keep forecasters engaged without overwhelming them, the first day of the experiment involved quickly learning about several new products and some forecasters stated that they felt inundated with the information provided to them. It was suggested that links to the web displays of the products be made available alongside the training materials before the experiment. Some forecasters also felt that the scope of the evaluations for each product were ambiguous and made it more difficult to provide useful feedback. Both forecasters and developers often approved of using live weather to test data, and found that it provided a sense of realism within the simulated operations. However, the second week of the experiment had an inactive pattern with very few opportunities for severe weather, and during this week forecasters suggested that archived cases be considered to supplement these periods. Lastly, some virtual forecasters on active weather days reported becoming task saturated between monitoring products, issuing warnings via WarnGen, reporting warnings through a form, writing blog posts, and talking with other forecasters and developers. Recommendations concerning this feedback included modifying WarnGen to include the feedback collected within the form, reducing redundant information, along with exploring more efficient ways for forecasters to write blog posts.

> 'I felt logging the warnings onto a separate Google form was largely redundant. All but one element on the form is available within the warning text. Efforts to include that missing information within either the WarnGen GUI and/or eventually HazardServices would streamline the data collection.'
> *Forecaster – End of Week Survey*

> 'I think the one thing I was missing was a better description of what the developers could find useful with the feedback mechanisms (such as blog posts). I was unsure the what the length of a post should be and initially spent too much time on a single topic when I could have spent more time posting about other things I was seeing.'
> *Forecaster – End of Week Survey*

New to the experiment this year, developer groups formally applied to the experiment. The application required describing the motivation for demonstrating their product, the science questions they wished to answer, and if they had demonstrated their product previously what improvements or adaptations had been made. This provided additional clarity to all developers, forecasters, and experiment organizers regarding the demonstration of the products, and was well received by the developers. Developers who attended the in-person weeks also found the additional time within operations and in-person setting highly valuable when collecting verbal feedback from the forecasters. During an end of testbed survey, developers were asked to report their level of support or opposition to several potential formats for the experiment. These included ‘All virtual’, ‘2 virtual weeks – 1 in-person week’, ‘1 virtual week – 2 in-person weeks (with fewer forecasters)’, and ‘All in-person’. Overall the developers opposed an all virtual format, and had more support for the options that included in-person demonstrations. Amongst those three options, the developers appeared most supportive of the ‘1 virtual week – 2 in-person weeks (with fewer forecasters)’ option, however the sample size was fairly limited (6 responses).

> ‘Once again I think you all did a stellar job of making the virtual format work easily. One thing I might tinker with for virtual is the start time. If initiation is going to happen earlier/later, maybe start earlier/later in the day.’
> *Developer – End of Testbed Survey*

> ‘I think the ease of interaction and constant interaction (both in the testbed and outside of the testbed during the week) are extremely valuable both to the developer (ease of collecting feedback, and also discussions regarding forecaster life and challenges) and to the forecaster (easier to communicate feedback, ask questions, interact with other forecasters). Being in-person, the forecaster (and developer) are all in, with no personal or professional interruptions.’
> *Developer – End of Testbed Survey*

> ‘I think the in-person format is vital. It's difficult to have multiple simultaneous conversations with the virtual format. Furthermore, rapport and trust with the forecasters is built with in-person interactions. I believe they're more willing to engage during and after the testbed because of the relationship built during the in-person testbed.’
> *Developer – End of Testbed Survey*

Recommendations for Future GOES-R/JPSS HWT Satellite Proving Ground Experiments

Based upon the 2023 GOES-R/JPSS HWT Satellite Proving Ground, the following recommendations for future testbeds are included below:

- **It is strongly recommended that both in-person and virtual weeks of the HWT Satellite Proving Ground experiment continue.** This configuration allows forecasters and developers the flexibility needed to maximize their time in each version. Future experiments may consider holding two in-person weeks and one virtual week
- **It is recommended that, prior to the testbed, online versions of products be made available to the forecasters alongside their training materials when possible, along with sharing the science questions from each developer group.** These efforts may accelerate the product introductions within the experiment and more thorough evaluations.
- **It is recommended that flexible start times and longer operational periods for the virtual weeks, along with archived cases for both formats, be considered to improve the quality of the evaluation.**

4.1 Acknowledgements

Multiple NWS meteorologists participated in this experiment and provided detailed feedback that went into the recommendations fromthis report. It would not be possible to complete research-to-operations without their willingness to work with experimental data, ask questions, and participate in crucial discussions with product developers. The developer teams themselves have continued to leverage the HWT Satellite Proving Ground as a collaborative environment to test emerging technologies and transfer impactful knowledge to NWS operations. Johnathan Madden and Justin Monroe (OU CIWRO) provided exceptional technical support during all phases of the experiment, which allowed forecasters to effectively use the cloud-based AWIPS-II instances for the evaluation. Alyssa Bates (CIWRO/WDTD) organized the renewed WDTD Tales from the Testbed Webinar and Kodi Berry (NSSL) provided logistical and technical oversight for the Experimental Warning Program. The following people participated as product focal points, subject matter experts, and observers for the products demonstrated in the experiment. The Satellite Proving Ground at the HWT thanks them for their contributions.

NUCAPS

Emily Berndt	NASA – Marshall Space Flight Center
Jon Case	ENSCO Incorporated
Rebekah Esmaili	Science and Technology Corporation
Brian Kahn	NASA – Jet Propulsion Laboratory
Peter Kalmus	NASA – Jet Propulsion Laboratory
Bill Sjoberg	NOAA – National Environmental Satellite, Data, and Information Service
Mark Richardson	NASA – Jet Propulsion Laboratory
Kristopher White	NWS / NASA – Short-term Prediction Research and Transition

OCTANE

Jason Apke	Colorado State University – CIRA
Bill Line	NOAA – National Environmental Satellite, Data, and Information Service

PHS

Scott Lindstrom	University of Wisconsin – CIMSS
William Smith	University of Wisconsin – CIMSS

ProbSevere (v3 and LightningCast)

John Cintineo	University of Wisconsin – CIMSS
Lee Cronce	NOAA – National Environmental Satellite, Data, and Information Service
Justin Sieglaff	University of Wisconsin – CIMSS

Observers and Subject Matter Experts

Dan Bikos	Colorado State University – CIRA
Dan Lindsey	NOAA – National Environmental Satellite, Data, and Information Service
Nolan Meister	NWS – Norman, Oklahoma WFO
Jordan Rabinowitz	NWS – Eastern Region Headquarters
Jorel Torres	Colorado State University – CIRA
Brad Vrolijk	Meteorological Service of Canada

5. Appendix: Experimental RGBs

Two experimental RGB composites provided by Bill Line, the Geostationary Lightning Mapper (GLM) RGB and the Moisture Gradient Convective RGB, were viewed intermittently by forecasters during the first week of the testbed. The goal was to receive informal feedback regarding these products, which will help identify convective applications and accelerate future development. Flash Extent Density (FED) and Minimum Flash Area (MFA) products were used in the GLM RGB to identify regions with frequent lightning activity and small (large) flashes. The Moisture Gradient Convective RGB was designed to monitor moisture gradients which may initiate convection, the initiation of convection, and cloud top structure. Three versions of the RGB were introduced, with forecasters gravitating towards the version that uses a combination of four ABI bands (0.64 µm, 1.61 µm, 10.3 µm, and 12.3 µm). More information regarding the RGBs can be found in the recipes and color explanations below.

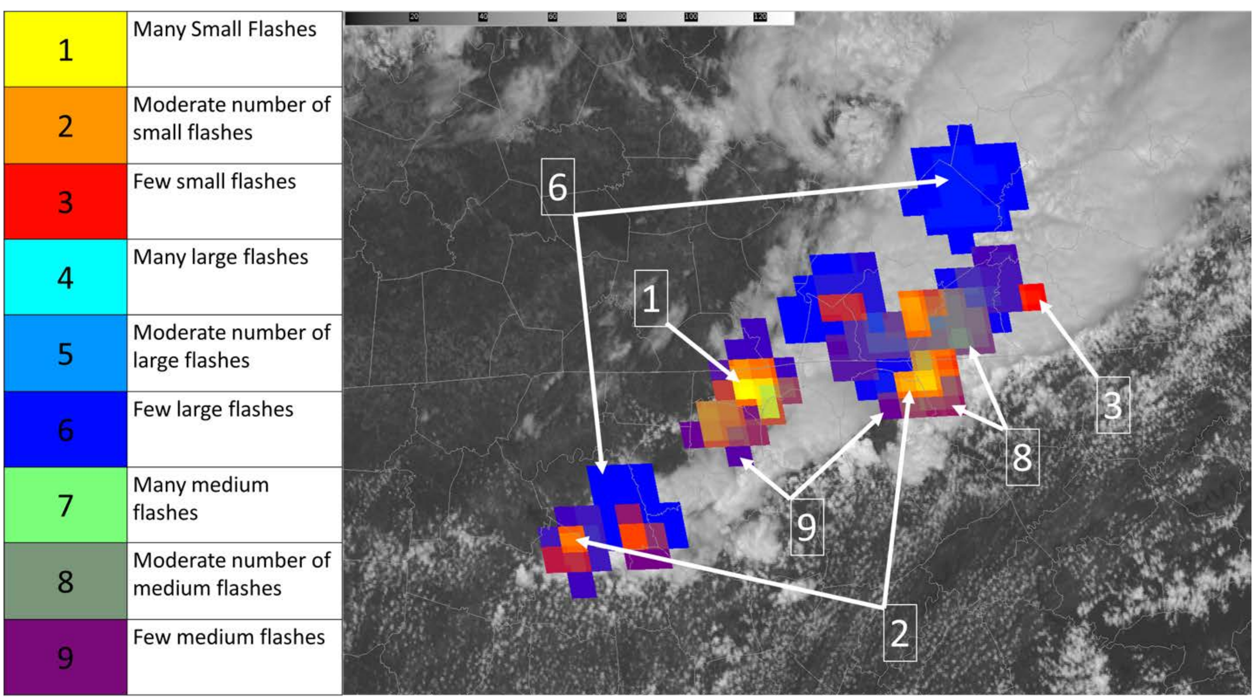

Figure 26: The recipe and color explanation of the GLM RGB (provided by Bill Line).

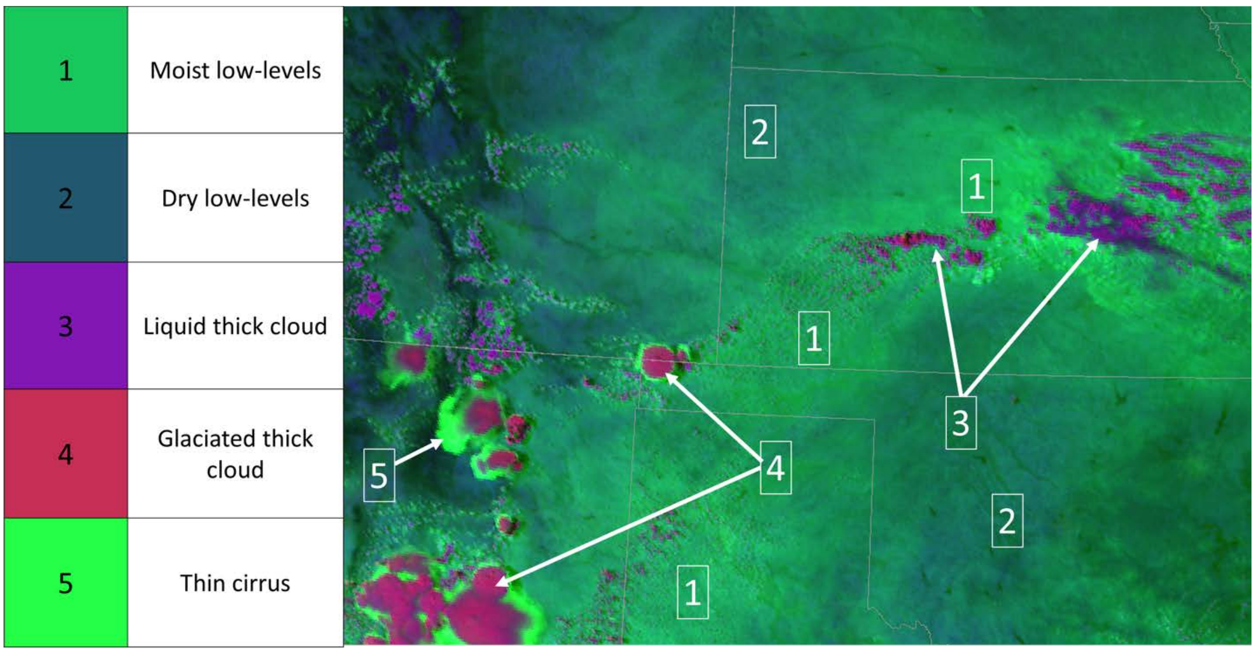

Figure 27: The recipe and color explanation of the Moisture Gradient Convective RGB (provided by Bill Line).

GLM RGB Applications and Feedback

Upstream data issues during the first week of the experiment prevented forecasters from viewing the five-minute composite imagery of the GLM RGB, resulting in a modified RGB suited to the one-minute GLM imagery. Even with this limitation, a few forecasters mentioned that the GLM RGB appeared to be an improvement over displaying FED and MFA individually. Forecasters stated that the transition to the yellow signature as storms intensified was useful and made picking up on periods of intensification straightforward. The ability to save screen space in a composite product was one motivating factor for using the GLM RGB, and forecasters found the concept intuitive after clarifying the signal represented from each color. If used within their offices, forecasters mentioned the need for additional training materials to understand the meaning behind the colors.

‘GLM FED/MFA RGB here shows the rapid thunderstorm life cycles in the weakly sheared but highly unstable Florida atmosphere, as reds to yellows (intensifying convection with lots of short cloud flashes) give way to blues and purples (weakening convection with fewer but longer flashes).’
25 May 2023, Blog Post: *Using GLM to Track Thunderstorm Life Cycles*
https://inside.nssl.noaa.gov/ewp/2023/05/25/using-glm-to-track-thunderstorm-life-cycles/

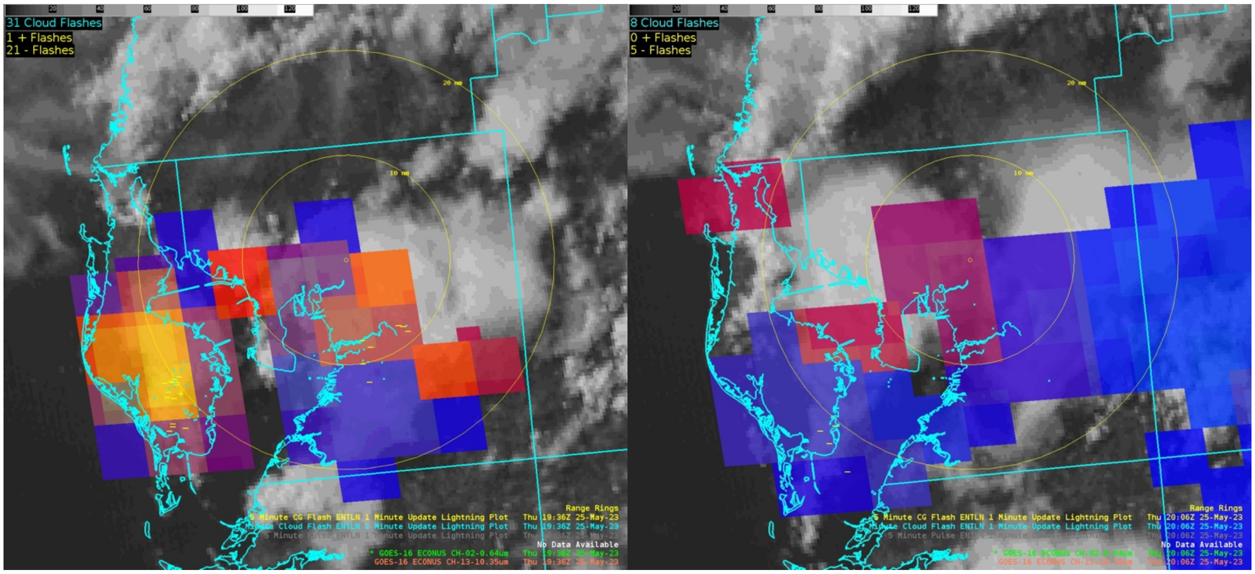

Figure 28: GLM RGB imagery overlaid on ABI channel 2 visible imagery from 1936 (left) and 2006 (right) Z on 25 May 2023.

Moisture Gradient Convective RGB Applications and Feedback

The Moisture Gradient Convective RGB was regarded as a product with specific applications and environmental requirements, and thus had very few ideal cases during its limited exposure within the first week of the experiment. One notable case involved surface moisture pooling prior to the development of a cumulus field, followed by the initiation of convection. The ability to identify low level moisture gradients led some forecasters to wonder if this product could be useful for identifying sea breezes not apparent from radar or visible imagery. The ability to observe the low-level moisture field was noted as a motivating factor for its use by the participants in other regions of the United States. Using a split-window difference field or a near-IR channel was also discussed in comparison to the applications of the Moisture Gradient Convective RGB.

‘Using the late morning split window difference field (within the RGB shown below), the greater moisture field can be found over northeastern portions of the CWA with the subtly greener shade of color. This color shade in the northeast generally overlaps with surface observations showing >60 F dew points. The color shade is more blue in central portions of the CWA where dew points drop into the upper 40s. While dew points are still lower in the southwest, there is a color shade difference where higher terrain exists (as well as greener vegetation). In this area early morning orographic convection had developed. By the mid afternoon, convection had developed near the moisture gradient in

the south central portion of the CWA as well as near the northern moisture gradient along a surface low over the southwest New Mexico border.'
23 May 2023, Blog Post: *Sectorizing Initiation Points and Greatest Severe Threats by Low Level Moisture Content*
https://inside.nssl.noaa.gov/ewp/2023/05/23/sectorizing-initiation-points-and-greatest-severe-threats-by-low-level-moisture-content/

Figure 29: The Moisture Gradient Convective RGB sandwich from 1726 Z on 23 May 2023.

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This report was prepared by Kevin Thiel with funding provided by NOAA/Office of Oceanic and Atmospheric Research under NOAA-University of Oklahoma Cooperative Agreement #NA21OAR4320204, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of NOAA or the U.S. Department of Commerce.