THE EXPERIMENTAL WARNING PROGRAM

2016 Experiment Summary

NOAA Hazardous Weather Testbed, Norman, OK

28 November 2016

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1. INTRODUCTION

The Hazardous Weather Testbed (HWT) is a joint project of the National Weather Service (NWS) and the National Severe Storms Laboratory (NSSL). The HWT provides a conceptual framework and a physical space to foster collaboration between research and operations to test and evaluate emerging technologies and science for NWS operations. The HWT was borne from the “Spring Program” which, for the last decade, has been used to test and evaluate new forecast models, techniques, and products to support NWS Storm Prediction Center (SPC) forecast operations. Now, the HWT consists of two primary programs. The original NSSL/SPC “Spring Program” is now known as the Experimental Forecast Program (EFP).

Image 1: EWP forecasters interrogate a developing storm.

The other activity in the HWT, and the subject of this summary, is the **Experimental Warning Program (EWP),** which is designed to test and evaluate new applications, techniques, and products to support Weather Forecast Office (WFO) severe convective weather warning operations. This was the tenth year for warning activities in the testbed. Feedback was gathered from NWS operational meteorologists and broadcast meteorologists. User comments were collected during shifts, forecasters participated in live blogging, electronic surveys were given at the end of shifts, and discussions occurred during post-mortem de-briefings. Input from NWS operational meteorologists is vital to the improvement of the NWS warning process, which ultimately saves public lives and property.

2. OVERVIEW

The National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (HWT) Experimental Warning Program (EWP) at the National Weather Center (NWC) in Norman, Oklahoma hosted the 2016 EWP Spring Program (EWP2016). Several experiments to improve National Weather Service severe weather warnings were conducted this spring in the NOAA Hazardous Weather Testbed (HWT) as part of the annual Experimental Warning Program, a joint project of the National Weather Service and NSSL/CIMMS to support NOAA's goal to evolve the National Weather Service and build a Weather-Ready Nation. This year, the 2016 EWP Spring Program featured 4 projects, which operated for 12 calendar weeks.

EWP Project	Operation Dates	Operational Weeks	Number of Forecasters
[1]GOES-R / JPSS Spring Experiment	18 April – 13 May	4 weeks	16
[2]Hazard Services PHI Experiment	2 May – 3 June	3 weeks	6
Prototype PHI Experiment	9 May – 10 June	3 weeks	9
Hydrology Experiment	20 June – 15 July	3 weeks	16

Table 1: Details for the 2016 Experimental Warning Program.

[1] "GOES-R / JPSS" is Geostationary Operational Environmental Satellite – R-series / Joint Polar Satellite System

[2] "PHI" is "Probabilistic Hazards Information"

3. PROJECT DETAILS AND RESULTS

GOES-R / JPSS Spring Experiment

Summary by Bill Line

Overview

The Hazardous Weather Testbed (HWT) provides the GOES-R and JPSS Proving Ground with an opportunity to conduct pre-launch demonstrations of Baseline, Future Capabilities and experimental products associated with the next generation GOES-R geostationary and JPSS polar satellite systems. Many of these products have the potential to improve short-range hazardous weather nowcasting and forecasting. Feedback received from participants in the HWT has led to the continued modification and development of GOES-R and JPSS algorithms.

Experiment Design

During the HWT 2016 GOES-R/JPSS Spring Experiment, GOES-R and JPSS products were demonstrated within the real-time, simulated warning operations environment of the Experimental Warning Program using AWIPS-II. This experiment was conducted Monday-Friday during the weeks of April 18, April 25, May 2, and May 9, and participants included a new group of 3 visiting NWS forecasters and 1 broadcast meteorologist each week. Product developers from various institutions were also in attendance to observe the activities and interact with the forecasters. Mon-Thurs included eight hour forecast/warning shifts, while Friday was a half-day dedicated to final feedback collection. During the forecast shifts, the four forecasters utilized the experimental satellite products – in conjunction with operationally available meteorological data – to issue short-term mesoscale forecast updates and severe thunderstorm and tornado warnings.

Forecaster feedback was collected through the completion of daily and weekly surveys, daily and weekly debriefs, and blog posts. The GOES-R HWT Blog allows participants to record their thoughts on the products during experimental operations (www. goesrhwt.blogspot.com). During the 2016 GOES-R/JPSS Spring Experiment, over 400 posts were made to the blog by participants with a variety of topics including mesoscale forecast updates, reasoning behind forecast/warning decisions, best practices, and ideas for product improvement. Feedback from the experiment was reviewed and organized into a final report.

GOES-R Products

GOES-R algorithms demonstrated during the HWT 2016 GOES-R/JPSS Spring Experiment included: GOES-Sounder derived all-sky TPW, LPW, and Derived Atmospheric Stability Indices using the GOES-R Legacy Atmospheric Profile (LAP) algorithm from UW/CIMSS, UAH GOES-R Convective Initiation algorithm, UW/CIMSS ProbSevere Model, PGLM Total Lightning products from NASA/SPoRT and the Lightning Jump Algorithm from UAH and CIMMS/NSSL. Forecasters found the GOES-R LAP instability and moisture fields to be useful guidance for monitoring environmental trends leading up to the development of convection. They appreciated that the product blends retrieval data with GFS model data in order to create an all-sky product. By the end of each week, every forecaster answered that they would utilize layer PW fields from GOES in operations. The GOES-R CI products proved to be effective in drawing the forecaster's attention to areas of future convective development, and had a positive impact on the nowcast/forecast process in most situations. The Severe CI component was a welcomed addition, helping forecasters determine where the strongest storms would develop. Forecasters are excited about the ProbSevere Model, commenting that, at the very least, it increased their confidence in issuing tornado and severe thunderstorm warnings. In many cases, forecasters mentioned that the ProbSevere data helped to increase the lead-time in which they were able to issues warnings. Forecasters primarily used the PGLM data to monitor convective trends, and look forward to using total lightning information from the GOES-R Geostationary Lightning Mapper. The Lightning Jump algorithm was typically used in conjunction with the ProbSevere Model, and indicated to forecasters which storms were experiencing rapid updraft intensification.

In addition to the aforementioned algorithms, GOES-14 1-min Super Rapid Scan Operations for GOES-R (SRSOR) imagery was available in the HWT for the full duration of the experiment, illustrating the very high frequency scanning capability of GOES-R. Parallax-corrected 1-min imagery and 10-min-updating atmospheric motion vectors were derived from the SRSOR data and also made available for forecasters to use in AWIPS-II. The 1-min satellite imagery is one of the GOES-R capabilities forecasters most look forward to. In most cases, it was the first indication that convective initiation had taken place. Forecasters continued to view the 1-min data after convective initiation, finding it useful for identifying new development and for monitoring updraft trends between radar scans. Participants see the value in having parallax-corrected satellite imagery in AWIPS-II as well, especially when viewing the 1-min imagery with lightning and/or radar data. The 10-min satellite-derived winds allowed forecasters to diagnose fields relevant to severe weather analysis such as layer shear, local speed maximum, divergence/convergence, and storm motion. They commented that this information at such high temporal resolution is a unique and valuable resource to have during warning operations.

JPSS Products

From the JPSS program, the NOAA Unique Combined Atmospheric Processing System (NUCAPS) temperature and moisture profiles from Suomi-NPP were demonstrated in AWIPS-II NSHARP. In most situations, forecasters commented that NUCAPS provided an effective update on the current state of the thermodynamic environment. The early afternoon availability fills a temporal gap in observed vertical temperature and moisture information, while the high spatial density fills a spatial gap. The plan view displays allowed for a quick look at NUCAPS at any given level, while forecasters used the cross section displays for more detailed interrogation of important features.

2017 Plans

Satellite Proving Ground activities at the HWT 2017 Spring Experiment will include an early demonstration of actual GOES-R imagery and baseline products. The effectiveness of the GOES-R training will be assessed, and best practices for using the GOES-R data in operations will be learned. Additionally, some of the algorithms demonstrated in 2017 will return with updates based on past forecaster feedback. An updated NUCAPS algorithm from JPSS is also expected to be available.

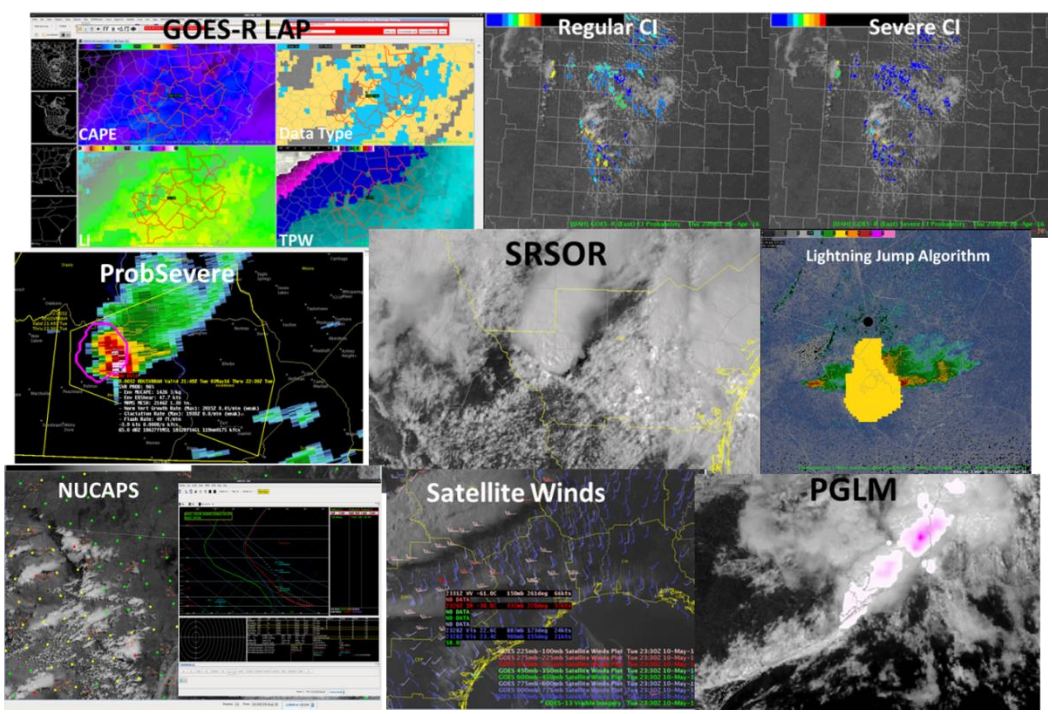

Image 2: Examples of all the products demonstrated in the HWT 2016 Spring Experiment.

GOES-R / JPSS Spring Experiment

Web Presence

GOES-R HWT Blog	http://goesrhwt.blogspot.com/
EWP Blog	http://hwt.nssl.noaa.gov/ewp/internal/blog/
Forecaster Training	http://hwt.nssl.noaa.gov/ewp/internal/2016/ *

*(LDAP user name / password required)

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Hazard Services – Probabilistic Hazards Information Experiment

Summary by Greg Stumpf

Overview

NSSL has been developing a prototype tool for testing the early concepts of [4]FACETs known as Probabilistic Hazard Information (PHI). The PHI Tool has been evaluated by NWS forecasters and human factor experts in the HWT the past two years. Recently, a USRWP grant was awarded which includes the initial effort to transfer the capabilities of the prototype into AWIPS2 Hazard Services (HS). Basic PHI capability in HS was developed during the Fall-Winter 2015-2016 timeframe. The first version of HS-PHI was evaluated in the HWT during the spring of 2016. This evaluation included NWS forecasters and human factor experts. We evaluated the software design using archive and real-time data. We also evaluated the concept of PHI as it relates to hazardous weather warning operations.

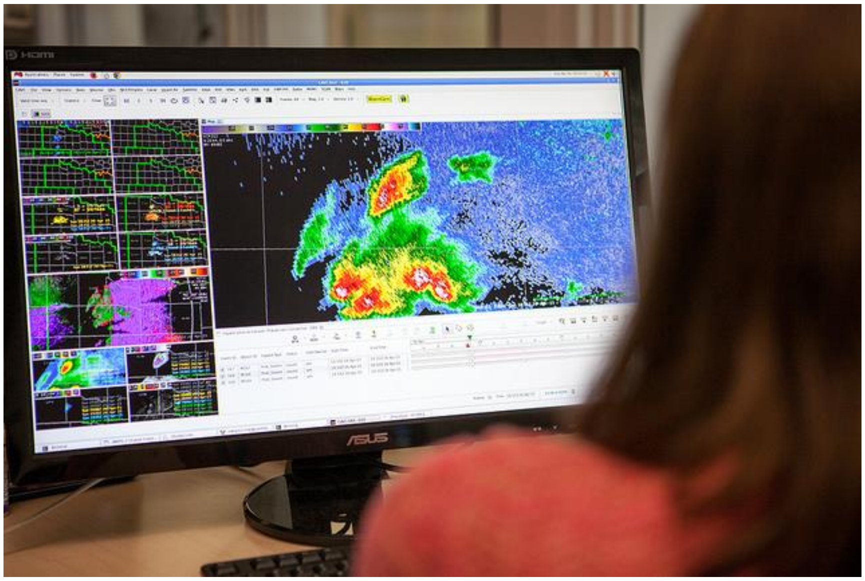

Image 3: Forecaster uses Hazard Services - PHI application within AWIPS-2 platform during the experiment.

We hope to collect the data necessary to make improvements to the HS-PHI software in anticipation of experiments in 2017 and 2018, prior to a decision for operational implementation. In addition, we hope to extend the dialog on FACETs and PHI as the concepts become closer to possible operational reality.

[4]For more on FACETs, please visit http://www.nssl.noaa.gov/projects/facets/

Accomplishments

The following is a list of accomplishments from the 2016 Hazard Services PHI Experiment.

- Developed initial capability for PHI in HS. This included most everything in the National Severe Storms Laboratory web browser-based PHI Prototype, except the CIMSS ProbSevere Guidance.
- Developed archive case scenarios / use cases to test the software on a variety of severe weather conditions.
- Tested HS-PHI in the NOAA Hazardous Weather Testbed for three alternating weeks from April-June 2016 with 6 National Weather Service forecaster participants using archived and real-time severe weather cases. The objectives of the test included:
  - Gathering feedback on software performance and design, with bug-fixes and improvements developed and tested during the off-weeks of the test.
  - Collecting forecaster workload data in collaboration with human factors scientists from the University of Akron. Analysis is still pending.
  - Capturing discussions on the FACETs and PHI concepts in NWS severe weather warning operations, including how adjacent forecast offices would collaborate and share severe storm objects to provide seamless service across forecast area boundaries.

Software Development Takeaways

The following is a list of takeaways from the 2016 Hazard Services PHI Experiment.

- Need to start sooner on detailed collaboration between the NSSL, the Meteorological Development Lab (MDL), and the Global Systems Division (GSD)
- Need “frozen” version of PHI Tool and access to code and developer for information
- Need more steady development throughout the process, rather than focused on the end
- Need more software engineering resources to work in AWIPS 2 / Hazard Services

2016-2017 Plans

The following is a list of goals for the next iterations of the Hazard Services PHI experiments.

- Establish a test process for GSD and MDL.
- Establish process for NSSL to manage software within software repositories, to ensure that GSD has access to stable working versions of the PHI Prototype.
- Develop two new archive case scenarios (e.g., QLCS, low-shear) and use cases for each.
- Complete development of Year 2 version of HS-PHI by January 1. Testing of performance and stability will take place at the HWT from January 1 – February 15.
- HWT operational test with NWS forecasters on three weeks: 15 February – 31 March.
- Seek funding to study how WFOs would collaborate in the FACETs world, with object handoff to allow seamless transitions across CWA boundaries, etc. The study would require meteorologists working with psychologists.

Hazard Services – Probabilistic Hazards Information Experiment

Web Presence

PHI – Hazard Services	https://vlab.ncep.noaa.gov/group/facets/ewp2016-hs-phi-experiment

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Prototype Probabilistic Hazard Information Experiment

Summary by Chris Karstens

The 2016 HWT Probabilistic Hazard Information (PHI) Experiment was conducted during the weeks of May 9-13, May 23-27, and June 6-10. During this experiment, participants worked in an integrated warning team: forecasters were tasked with issuing experimental probabilistic forecasts for real-time and displaced real-time severe convective events, and emergency managers and broadcasters used this experimental information to make simulated decisions. After each event, researchers brought the three groups together for discussions focused on particular elements of the forecast information (e.g., tools, probabilities, visualization, communication) and how each element could be improved.

Image 4: Forecaster assesses the storm threat with the PHI Tool during Prototype PHI Experiment.

In 2014, when NWS forecasters were the only participants, it was learned that manual generation and maintenance of object-based probabilistic forecasts becomes problematic when there are 4-5 or more hazard areas to manage simultaneously, presenting a potential limitation to the amount of information that can be updated and passed along to users. In an ideal framework, information would be passed along to users without obstructive workload constraints. In 2015, automated, object-based guidance was introduced to combat this workload issue for the forecasters while striving to understand and optimize elements of forecast information for the EMs. Initially, the

goals were to identify various levels of forecaster-automation and to sense whether or not an optimal human-machine mix exists. Additionally, Emergency Managers (EMs) were added in 2015 to explore key decision-maker needs through the usage of PHI, and to begin a co-creation process among researchers, developers, forecasters, and users.
In 2015 it was learned that the optimal human-machine mix is one in which the automated system maintains and updates geographic hazard areas (i.e., objects) while forecasters override various attributes (e.g., storm motion, forecast duration, probabilities, communication) of the forecast. This strategy gives forecasters more time to analyze radar and other observations while communicating more quality forecast information. In addition, no warning decisions were made by forecasters; they only provided probabilistic information regarding the tornado and wind/hail hazards to the EMs. The presence of emergency managers provided forecasters an audience for their communication, as well as feedback as to what kinds of information about storms were helpful for decision-making. Through testing and evaluation of this strategy, a few critical limitations were identified with this work strategy for forecasters. In particular, automated object identification and tracking is not a steady process. Hazard areas are not always immediately identified and maintained, and thus, the tracking is sometimes unjustifiably (and sometimes justifiably) discontinuous. When presented with these situational impasses, forecasters preferentially assumed control of the object as a way to eliminate the error, but the reversion to manual usage resurfaces the aforementioned workload issues, thus limiting information flow. The challenge for 2016 was to develop and test tools that get forecasters through these impasses to maintain operating in the optimal human-machine mix mode. Additionally, EMs and forecasters independently realized the potential of a short forecast discussion to provide critical information needed by the EMs for sense-making, and thus, decision-making. The meaning the forecasters could add by typing a short discussion was critical. Identification of this critical communication element led to an expansion of efforts focusing on the communication (e.g., formatting, colors, wording) of hazardous weather information to key decision-makers in 2016.

For 2016, three types of automated guidance were available to forecasters. These included the NOAA/CIMSS ProbSevere model for the occurrence of any severe (tornadoes, wind, and hail), the NSSL Experimental Warn-on-Forecast System for ensembles (NEWS-e) for tornadoes, and early algorithm development occurring at CIMMS/NSSL for lightning. In addition to having EM participants, Broadcast Meteorologists participated by using PHI to decide whether and when to do simulated cut-ins to programming on an internal TV broadcast. Week one of the experiment began with forecaster tools identical to those from 2015 to re-identify challenges associated with automated object identification and tracking, particularly when the tracking breaks. This breakage occurs when the original object cannot be identified on the successive data layer, and will manifest as one of three potential situations:

1. The original object disappears,
2. The original object is replaced with a new object or set of objects,
3. The original object is merged with another previously identified object or set of objects.

To address these three tracking issues, a tactic was developed to reintroduce any forecaster-modified object that undergoes a tracking failure back into the spatial display while automatically masking any overlapping object not being maintained by the forecaster. At this juncture, the forecaster is presented with the power to decide how to proceed, depending on which of the three tracking situations have been incurred. In situation #1, the forecaster can take no action or expire the object. In situations #2 and #3, the forecaster can repair the broken object tracking by transferring attributes from one object (original) to another (new object(s) that automatically replaced the original). Usage with this new tactic quickly revealed new results and additional challenges. In convective events, particularly those with minimal spatial coverage, where tracking issues happen intermittently, the tactic appears to work well. Forecasters are able overcome the three situational impasses quickly and decisively without interrupting the flow of information to users. However, some convective events appear to trigger these tracking situations frequently and randomly, leading to additional workload to maintain a coherent geospatial representation of the hazard areas. It is hypothesized that adjustments to the object identification and tracking algorithm may alleviate a significant portion of these issues. Preparations are underway to investigate how, if at all, such changes can improve upon the robustness of the current object identification and tracking configuration. However, it is clear that tracking discontinuities are an innate predicament of tracking convective hazard areas. It is also apparent that the previously identified optimal human-machine mix mode is likely optimal for most convective modes and evolutions, but clearly not for all. Thus, forecasters need tools that effectively allow them to transfer between various modes of usage with automated object-based guidance. This conditional usage concept is a topic that will be investigated further in the next experiment.

In addition to working through the object identification and tracking challenges, forecasters were presented with first guess probabilistic trends within the automated object-based guidance. These trends were created from probabilistic predictions from machine learning algorithms, extending through an assumed or predicted duration of predictability. It was hypothesized that these automated predictions would help forecasters in making their probabilistic trend predictions. Usage with this information revealed that forecasters find the automated predictions to be helpful in prioritizing which hazards to engage for generating forecasts for users, with the highest priority given to hazard areas associated the highest predicted probabilistic values. Such hazard areas were typically assigned a warning, whereas hazard areas with lower probabilistic predictions were typically assigned a significant weather advisory. EMs and broadcast meteorology participants used both severe and sub-severe information in their decision making. EMs carefully watched the trends in probabilities, and depending upon circumstance, they made decisions based first on time, second on severity. For example, if a dorm at a university requires 18 minutes to get students to safe areas on the lowest floors, that EM might make a decision ahead of a warning because more time is required than a typical warning lead time. Broadcasters could better prepare for cut-in decisions, and while a sub-severe storm generally did not merit a cut-in to programming, the broadcast meteorologists found the information useful to confirm their own assessments of the storms.

Additionally, forecasters were given the ability to adjust the first guess probabilistic predictions. It was found that adjustments were made frequently (greater than 90% of the time) and the probabilistic trends were typically adjusted to higher values that extended through the assigned duration. However, verification efforts performed from the 2014 experiment indicate that such adjustments result in detrimental reliability, drifting into over-forecasting with little or no skill. These adjustments appear motivated by the precautionary principle, and were used as a means to reinforce the communication of a warning and drive desired action. Although these actions appear well intentioned with perhaps some communicative merit (discussed later), the intentional distortion of probabilities implies some level of unjustified mistrust of the guidance, and inevitably leads to misunderstanding and misusage of the probabilistic information. Efforts are underway to help improve forecasters understanding of the automated guidance by assessing its seasonal skill and envisioning new capabilities for visualizing its underlying reasoning and training information. Additionally, the definition of the probabilistic trend will be simplified to reflect forecast confidence in an effort to address the reliability of the combined forecaster-automated probabilistic forecast system.

Forecaster creation and adjustment toward precautionary probabilistic trends was also partially motivated by interaction with users through the integrated warning team. When the traditional notion of warnings was removed in 2015, users (only EMs that year) struggled with the understanding and intention of probabilities for severe convective events. In pre-week surveys they clearly expressed an understanding that warnings have a range of likelihood of verifying. They've not had to operationalize and use that understanding, however, and were initially unsure they knew how to apply these likelihoods and how to do it well. As they gained some comfort in thinking about how probability might link to action, they pointed out that they might act on a much lower probability when high-end severe weather was expected than on a marginal day, when it was unclear whether storms would reach severe criteria. Ultimately, they strongly expressed the need for the meteorologists to make the meteorological assessment regarding whether a storm merited a warning. EMs need warnings: their standard operating plans have elements (e.g., sounding outdoor warning sirens) based upon those warnings from the NWS. Reinserting traditional warning information into the PHI system in 2016 helped forecasters and users re-establish necessary and (apparently) effective elements of the current warning system (i.e., do no harm). Broadcasters, who first participated in 2016, conveyed that warnings are a lowest-common denominator type of information for the public. In recognition of these needs, the system design will be re-strategized such that generation and consumption of warnings and significant weather advisories are initially prioritized, with probabilistic information initially treated as supplemental information.

The reinsertion of traditional warning information in 2016 was supplemented with a test of prototypes from the Hazard Simplification Project. The tested prototypes changed the overall format to a simple, essentially bulleted form. They included specification of forecaster confidence and severity level in addition to standard information on what, where, and when to expect severe weather. One prototype also changed wording from the current "Advisory" and "Warning" to "Be aware" and "Take action." TV broadcasters found the wording initially difficult to adapt to on air; shifting language to action words and phrases was possible but restricted many of the ways broadcasters currently speak. EMs also found the wording difficult because they talk to their city/county personnel, as well as neighboring EMs (for mutual aid purposes), about warnings. Prototypes also included a color to specify warning level, and all prototypes attempted to use color in some way. Green was universally dismissed as a first hazard level; green should mean "okay."

Additionally, the reinsertion of traditional warning information allowed forecasters and users to focus on new forecast elements associated with the PHI system. Savvy users not only have well-developed plans of action, but, as mentioned earlier, have estimated the amount of time it takes to execute these plans. Thus, time of arrival information, in addition to traditional warning and probabilistic information, meets important needs of this subset of users. However, providing accurate and reliable timing information *requires* a dedication on the part of the forecaster to provide frequent updates to the hazard location, movement, and its various attributes (e.g., severity, intensity, history of reports, forecast information), as well as an increased attention to the geospatial specification of the hazard areas. This critical process of providing frequent updates is a concept we've termed "continuous flow of information," and it is sought out or calculated (if necessary) by our Emergency managers and broadcasters. Because the PHI system completes some tasks for the forecasters, they are able to use their time to focus on meteorological assessment and communication. In other words, frequent updates are possible. Observations of forecasters working high-impact tornado events show evidence that forecasters can naturally identify and utilize the capability of providing continuous flow of information while using geospatially precise objects within the PHI system. Additionally, the optimal human-machine mix mode directly supports these concepts, but as previously noted, more work is needed to better situate the forecaster with the guidance. Emergency managers found the increased precision of PHI objects over traditional warning polygons extremely helpful, and stated they would have tolerance for unexpected changes in the information. The next iteration of this joint experiment will likely give emphasis to the “continuous flow of information” concept, in addition to continuing to challenge forecasters and users to consider the more insightful elements of the PHI system.

Prototype Probabilistic Hazard Information Experiment

Web Presence

FACETS Program	http://www.nssl.noaa.gov/projects/facets/

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HMT-Hydro Experiment

Summary by Steven Martinaitis

Overview

The Hydrometeorology Testbed Multi-Radar Multi-Sensor (MRMS) Hydro Experiment (hereinafter denoted as the HMT-Hydro Experiment) was a part of the 2016 United States Weather Research Program (USWRP) Hydrometeorology Testbed (HMT). The HMT-Hydro Experiment was conducted in the Hazardous Weather Testbed (HWT) and was conducted in conjunction with the Flash Flood and Intense Rainfall (FFaIR) Experiment at the Weather Prediction Center (WPC) in College Park, MD. The HMT-Hydro Experiment operated for three weeks during the period from 20 June to 15 July 2016 with a one-week break during the 4th of July holiday. Forecasters from National Weather Service (NWS) Weather Forecast Offices (WFOs) and River Forecast Centers (RFCs) worked with research scientists to assess emerging hydrometeorological technologies and products to improve the prediction, detection, and warning of flash flooding. The primary focus of the experiment in 2016 was the forecaster evaluation of short-term predictive tools derived from the MRMS radar-only quantitative precipitation estimates (QPE) and the Flooded Locations and Simulated Hydrographs (FLASH) hydrologic modeling framework. The decision-making process for each experimental flash flood watch and warning that was issued was also evaluated through the Hazard Services platform. The HMT-Hydro Experiment also explored the utility of experimental flash flood watches and warnings conveying uncertainty and magnitude. Lastly, we evaluated a statistical approach using a random forest based on GFS model products to forecast flash flooding out to several hours. Results from the HMT-Hydro Experiment will help in determining operationally relevant best practices.

Experiment Details and Results

The 2016 HMT-Hydro Experiment placed a particular emphasis on the forecaster evaluation of the rainfall estimated by the Multi-Radar Multi-Sensor (MRMS) radar-only quantitative precipitation estimation (QPE) products as well as the short-term predictive tools from the Flooded Locations and Simulated Hydrographs (FLASH) product suite. This included hydrologic modeling output from the Coupled Routing and Excess Storage (CREST) model. The goals of the HMT-Hydro Experiment are as follows:

- Evaluate the relative skill of experimental flash flood monitoring and short-term prediction tools from the FLASH suite of products: MRMS QPE average recurrence intervals, MRMS QPE-to-flash flood guidance (FFG) ratios, and CREST forecast unit streamflow from the hydrologic modeling framework.

- Assess the utility in using Hazard Services for issuing flash flood watches and warnings that communicate both uncertainty and magnitude of impacts.
- Determine the benefit of increasing lead time (vs. potential loss in spatial accuracy and magnitude) through the use of HRRRX 0-6 h precipitation forecasts as forcing to FLASH.
- Evaluate a new statistical approach to flash flood forecasting using a random forest model that operates on GFS model forecast products.
- Enhance cross-testbed collaboration as well as collaboration between operational forecasting, research, and academic communities on the forecast challenges associated with short-term flash flood forecasting.
- Identify forecast best practices using the suite of FLASH products that will ultimately be used in the development of training materials and a concept of operations (CONOPS) document.

Operations within the HMT-Hydro Experiment were conducted in collaboration with the Flash Flood and Intense Rainfall (FFaIR) Experiment at the Weather Prediction Center (WPC) in College Park, MD. The FFaIR Experiment simulated a national center by providing a daily briefing that contained analysis of experimental probabilistic and ensemble model output as well as probabilistic rainfall and flash flood products. This information was used to establish the potential flash flood threat areas of that particular day. The HMT-Hydro Experiment then simulated a National Weather Service (NWS) Weather Forecast Office (WFO) environment with the ability to issue experimental flash flood watches and warnings without any geopolitical constraints (i.e., forecasters had the ability to issue products anywhere across the CONUS).

Forecasters would consider all of the MRMS and FLASH products in their decision-making process, which helped increased their confidence with issuing (or not issuing) a flash flood warning. The products were also shown to quickly highlight areas with greater potential for flash flooding. Subjective rankings did place greater emphasis on the MRMS QPE and the CREST forecast unit streamflow product as better capturing the spatial coverage and magnitude of evaluated flash flood events. This was more noticeable with flash flooding over urban areas, where the CREST hydrologic model can account for impermeable surfaces while the QPE analysis products, such as QPE-to-FFG ratio or QPE average recurrence intervals, would not necessarily show a signal for potential flash flooding (Figure 1). Forecasters had reduced confidence in using the average recurrence interval product in their warning decision making, but stated it could provide context of the potential magnitude of the event.

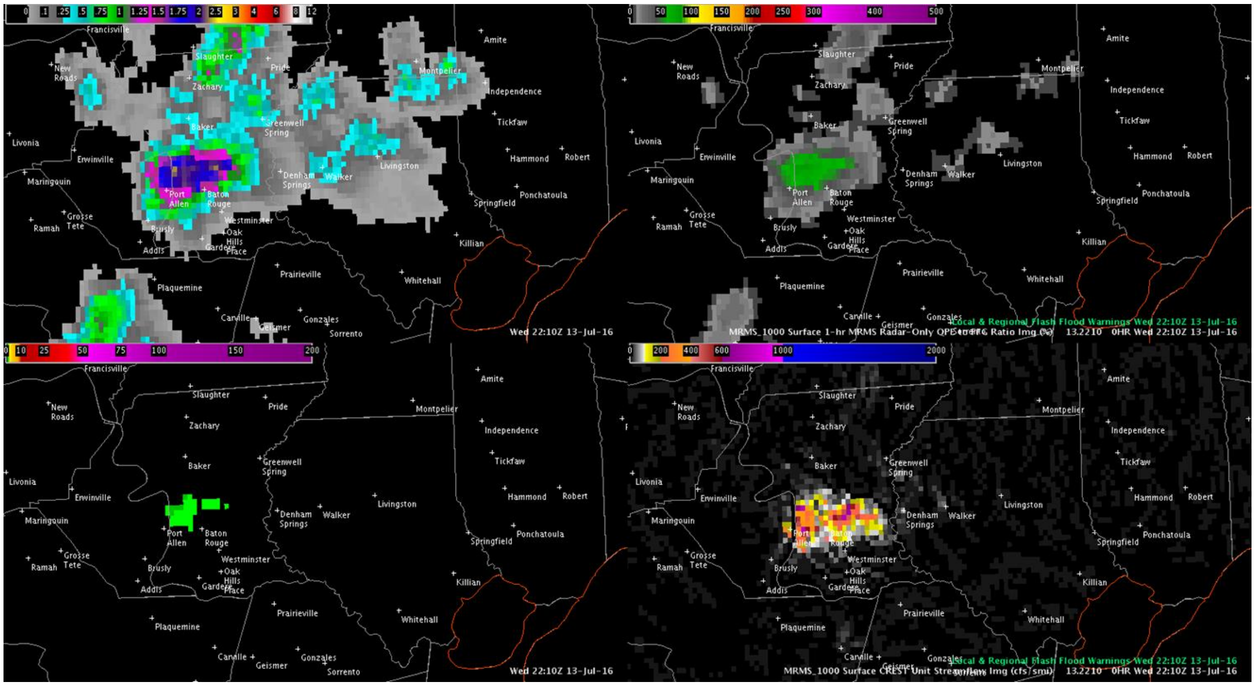

Image 5: MRMS QPE (top left), QPE-to-FFG ratio (top right), QPE average recurrence interval (bottom left), and the CREST forecast unit streamflow (bottom right) over Baton Rouge, LA.

The use of quantitative precipitation forecasts (QPFs) from the HRRRX model presented challenges in providing increased lead time for flash flood warnings consistently. This includes spatio-temporal inconsistencies between model runs and convective initiation; however, there were some instances that forecasters felt the HRRRX QPF could have provided up to and sometimes more than an hour of additional lead time. The random forest model probabilistic output that operated on GFS model forecast products was shown to work well in synoptically-driven events, but would have difficulties in detecting meso-scale and storm-scale events. The FFaIR briefings and experimental guidance products were shown to help in the decision-making process for issuing short-term flash flood watches, as well as increase the situational awareness of enhanced flash flood threats during the operational periods.

HMT-Hydro Experiment

Web Presence

FLASH Data Website	http://flash.ou.edu/
HMT-Hydro Experiment	https://blog.nssl.noaa.gov/flash/hwt-hydro/
MRMS Data Website	http://mrms.ou.edu/

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6. ACKNOWLEDGMENTS

EWP2016 wouldn't have been possible without contributions from a number of individuals and organizations. Those organizations include the Cooperative Institute for Mesoscale Meteorological Studies, the National Severe Storms Laboratory, the GOES-R Program Office, the JPSS Program Office, the Meteorological Development Laboratory, and the National Weather Service Forecast Office in Norman, Oklahoma.

We would like to acknowledge the contributions of the following individuals: Chris Barnet, Alyssa Bates, Michael Bowlan, Kristin Calhoun, John Cintineo, Race Clark, Karen Cooper, Jimmy Correia, Vicki Farmer, Zac Flamig, Aimee Franklin, Antonia Gambacorta, Alan Gerard, J.J. Gourley, Tracy Hansen, Joseph James, Chris Jewett, Darrel Kingfield, Chris Karstens, Bill Line, Chen Ling, Daphne LaDue, Steve Martinaitis, Kevin Manross, John Mecicalksi, Tiffany Meyer, Lans Rothfusz, Justin Sieglaff, Travis Smith, Geoffrey Stano, Sarah Stough, Greg Stumpf and others. And we'd also like to give special thanks to James Murnan and Keli Pirtle, who managed the media associated with the experiment.

This work has been primarily funded via sources from the National Severe Storms Laboratory, the National Weather Service Meteorological Development Laboratory, Earth Networks Incorporated, the U.S. Weather Research Program, Multi-Function Phased Array Radar, the GOES-R Program Office, the JPSS Program Office, and via the NOAA-University of Oklahoma Cooperative Agreement #NA11OAR4320072, U.S. Department of Commerce.