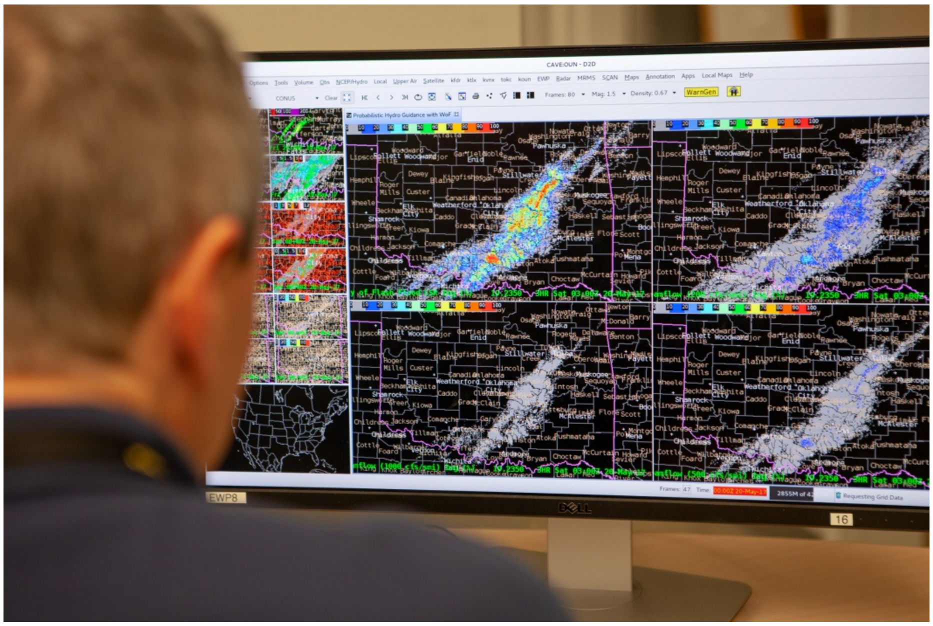
NOAA U.S. Weather Research Program (USWRP)

Hydrometeorology Testbed (HMT)
Multi-Radar Multi-Sensor (MRMS) Hydro Experiment

In Coordination with the HMT Flash Flood and Intense Rainfall (FFaIR) Experiment



-- 2019 HMT-Hydro Operations Plan --

June 24 – July 19, 2019

Hazardous Weather Testbed Facilities
National Weather Center
Norman, OK

Updated June 10, 2019
Version 1.1

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I. Introduction

The National Oceanic and Atmospheric Administration (NOAA) Hydrometeorology Testbed Program (HMT) is administered by the Office of Water and Air Quality (OWAQ). The HMT promotes hydrometeorological research that will have quick and direct impact on operations within the National Weather Service (NWS), especially in regards to flash flood forecasting. The HMT provides a conceptual framework to foster collaboration between researchers and operational forecasters to test and evaluate emerging technologies and science for NWS operations. The project described herein is unique in that it addresses objectives of the HMT program while leveraging the physical facilities of the Hazardous Weather Testbed (HWT) at the National Weather Center (NWC) located in Norman, OK.

The fifth edition of the Multi-Radar Multi-Sensor (MRMS) Hydro Experiment (hereinafter denoted as "HMT-Hydro Experiment") will focus on the issuance of experimental flash flood warnings for hydrologic extremes, including flash flooding, during a select period of the warm season. The 2019 HMT-Hydro Experiment will contain a blend of experiments with real-time data, archived case playback, and experimental data review using prototype products and techniques. The experiment will be conducted in close coordination with the seventh annual Flash Flood and Intense Rainfall (FFaIR) Experiment at the NOAA/NWS Weather Prediction Center (WPC) located in College Park, MD.

We are seeking feedback from NWS operational forecasters. User comments will be collected during testbed operations, electronic surveys will be given at the end of the experiment, and discussions will occur during de-briefings. Inputs from NWS operational meteorologists and hydrologists are vital to the improvement of tools used in the NWS warning process, which ultimately saves lives and property. Feedback from NWS personnel during the HMT-Hydro Experiment is also important for the development of new applications, displays, and product concepts in AWIPS-2.

The participating NWS forecasters are part of a unique team of NOAA scientists, comprised of researchers, technology developers, and trainers, working together to test new and experimental severe weather warning decision making technology for the NWS. This operations plan includes basic information about the new technologies and products that we are testing during the 2019 warm season, as well as logistical information about the three-week program for all participants.

II. Objectives

Past HMT-Hydro Experiments focused on deterministic products, including high-resolution distributed hydrologic model forecasts that operated on the flash flood time scale. The hydrologic models examined in the past experiments were forced by MRMS radar-only quantitative precipitation estimates (QPEs). One model was also evaluated using different deterministic quantitative precipitation forecasts (QPFs) in combination with the QPE forcing.

The next evolution of hydrologic modeling and flash flood prediction will integrate probabilistic information and uncertainty into the warning decision making process. Primary activities within the HMT-Hydro Experiment are split between real-time operations and archived case playback. For real-time operations, forecasters will focus on the decision to issue experimental flash flood warnings using probabilistic gridded information. Archived case playback will analyze a variety of flash flood events that include hydrologic prediction tools that utilize forcing by QPE combined with ensemble QPFs from the National Severe Storms Laboratory (NSSL) Warn-on-Forecast (WoF) system. The 2019 HMT-Hydro Experiment will also introduce the concept of probabilistic QPE (PQPE) as a methodology to generate and provide uncertainty information about precipitation being remotely sensed by radar.

The HMT-Hydro Experiment will be conducted in collaboration with the FFaIR Experiment to simulate the real-time workflow from forecast and guidance products in the 6–24 h timeframe from WPC to experimental flash flood warnings issued in the 0–6 h timeframe. For the days utilizing real-time experimental warning operations, the HMT-Hydro Experiment team will act as a "virtual, floating forecast office" to shift its area of responsibility to where heavy precipitation events and subsequent flash flooding is anticipated to occur. The participating forecasters will have the ability to issue products for any NWS county warning area (CWA) in the CONUS.

The primary scientific goals of the 2019 HMT-Hydro Experiment are as follows:

- Evaluate the relative skill of experimental probabilistic flash flood monitoring and short-term predictive tools.
- Determine the potential benefits/limitations of utilizing precipitation forecasts for flash flood prediction and warning decision making.
- Assess the utility and perceived skill of experimental flash flood warnings that communicate the uncertainty and magnitude of the flash flood threat.
- Evaluate the skill of PQPE precipitation accumulations and the associated probabilistic and uncertainty products
- Enhance cross-testbed collaboration and coordination as well as the collaboration between the operational forecasting, research, and academic communities on the forecast challenges associated with short-term flash flood forecasting.
- Identify how the use of probabilistic information can advance the science and societal impacts of conveying the threat of flash flooding within the Forecasting a Continuum of Environmental Threats (FACETs) paradigm.

The 2019 HMT-Hydro Experiment will operate in a manner that allows participants from across the weather enterprise to work together to explore the utility of emerging flash flood monitoring and short-term prediction tools for improving flash flood prediction and flash flood warnings. An overarching theme amongst the testbeds is the examination of the latest observational and modeling capabilities so that they may be improved for future use.

III. Operations

The HMT-Hydro Experiment will run Monday through Friday for three weeks from 24 June to 19 July 2019 with a break taken during the week of 1 July. The physical location of the experiment will be in the Hazardous Weather Testbed (HWT) on the second floor of the National Weather Center (NWC) in Norman, OK.

The mix of real-time experiment warning operations, archived case studies, and experimental data review allows for variations in the day-to-day running of the HMT-Hydro Experiment. The period from Monday through Thursday will contain two days of real-time operations and two days of case studies. Current weather analysis and forecasts along with daily briefings from the FFaIR Experiment will dictate what activities will be conducted on each day. The anticipated variations in the daily schedule are provided in Appendix A. Detailed descriptions of each activity are provided in the next section.

While we anticipate following the schedule design due to the coordination with the FFaIR Experiment, the HMT-Hydro Experiment officers may modify the daily activities and operating times due to changes in weather and to maximize data collection.

IV. Activity Descriptions

Visitor Welcome – Participating forecasters will meet with HMT-Hydro Experiment officers at the first floor entrance of the National Weather Center prior to the 11:30AM start on Monday morning. Visitor parking is available in the first row of parking spaces closest to the NWC. Participants who are NWS employees are reminded to bring their NOAA CAC cards in order to pass through security. Foreign Nationals need to contact J.J. Gourley (jj.gourley@noaa.gov) well in advance in order to get the required clearance.

The National Weather Center (NWC) is a University of Oklahoma building that houses several NOAA facilities. The HMT-Hydro Experiment operations will be held in the Hazardous Weather Testbed (HWT) on the second floor and is considered a secure NOAA location. Therefore, certain NOAA security requirements are in effect for visitors to the HMT-Hydro Experiment. All NOAA employees are required to visibly wear their NOAA identification badges at all times. Non-NOAA visitors must check-in daily with the security desk on the first floor using a state-issued identification in order to obtain a visitor pass.

NOAA participants will be issued one white magnetic key card which will allow entrance into certain secure locations in the NWC. These locations include the NOAA main hallway (with access to a kitchenette) and the HMT-Hydro Experiment operations area in the HWT. The key cards will be issued to each NOAA participant Monday morning by one of the PIs. Each door card has an associated four-digit PIN that would need to be keyed into the lock pad in order to gain entry. Participants must return their key cards and visitor badges to the PIs before they leave the NWC on Friday to return home, as these will be recycled each week for the next set of participants.

Experiment Introduction – The HMT-Hydro Experiment principal investigators (PIs) and officers will use the Monday time period from 11:30AM to 12:30PM to describe the experiment goals and design. The products that will be featured throughout the testbed week will also be discussed during this introduction period; however, to help familiarize you with them, a description of the various products and forcings are provided in Appendix B at the end of this document.

FFaIR Daily Briefing – The daily weather briefing will be primarily directed by the FFaIR Experiment. HMT-Hydro Experiment participants and officers will join the briefing in the HWT using screen-sharing software. These briefings will occur daily at 12:30PM CDT. The primary goals of the briefing are to: 1) provide present synopsis of rainfall and flooding for situational awareness, 2) summarize model-based forecasts of heavy rainfall and guidance for probabilistic flash flooding for the day, and 3) conduct a post-mortem on experimental products issued the prior day (time dependent). The details from these briefings, along with a beginning-of-the-week forecast, will help determine what days will feature real-time experimental warning operations and what days will focus on archived case studies.

Experimental Warning Operations – The start of experimental warning operations will depend on the daily schedule. The focus region(s) for product issuance will initially correspond to the FFaIR Experiment guidance, but is expected to change based on the observations. Participating forecasters will primarily use products with the Flooded Locations and Simulated Hydrographs (FLASH) system with radar reflectivity and QPEs provided by MRMS. One main objective from the real-time operations is the use of gridded flash flood probabilities versus the deterministic model outputs.

The experimental warning operations are intended to mimic the responsibilities of a local forecast office, but with the ability to change to any county warning area in the testbed. In the event of multiple flash flooding events occurring in separate regions of the CONUS, the HMT-Hydro Experiment officers can prioritize the operations to a single domain based on anticipated impacts and perhaps population density (in order to obtain dense reports). Alternatively, participating forecasters can work the separate regions. The experimental warnings will differ from those issued in operations in that they will include estimates of probability of occurrence corresponding to flash flooding magnitudes. The WarnGen GUI will be tailored to solicit information from the forecaster regarding the decision-making process and the products used for the issuance of each experimental warning.

Archived Case Studies – Two days during the testbed week will be dedicated to the evaluation of three past flash flood events and the potential impacts of including Warn-on-Forecast QPFs into the flash flood prediction process. Forecasters will evaluate a series of products throughout the running of the displaced real-time (DRT) simulations. The baseline products will consist of QPE comparison tools and QPE-forced deterministic hydrologic model output from the FLASH system, and the evaluations will focus on the flash flood probabilities from hydrologic model output that is forced by Warn-on-Forecast QPFs. The evaluation and feedback process will be conducted via simple questionnaires at regular intervals and through flash flood warning issuance and flash flood warning updates. Debriefs will occur with HMT-Hydro Experiment officers at the end of each simulation.

Subjective Evaluations – The evaluations performed in the HMT-Hydro Experiment involve subjectivity; thus, up to 90 minutes are devoted to subjective evaluations for each day following real-time experimental warning operations. First, all available flash flooding observations from NWS local storm reports, citizen-scientist reports from the meteorological Phenomena Indication Near the Ground (mPING) project, and USGS streamflow observations will be used together to rate the various experimental products in how they cover the spatial extent of flooding and the flooding magnitude. Comparisons will also be conducted between the deterministic and various probabilistic hydrologic model outputs. The experimental warnings will be evaluated in terms of their communication of uncertainty and magnitude. Probabilities associated with the warnings are meant to correspond to an observation occurring within them at the same frequency. Note that mPING reports subdivide the flash flooding reports as follows:

1) River/creek overflowing or cropland/yard/basement flooding
2) Street/road flooding or closure; vehicles stranded
3) Homes/buildings with water in them
4) Homes/buildings/vehicles swept away

NWS local storm reports will be rated in a similar fashion by HMT-Hydro Experiment officers. Any report will be used to validate a minor flood, while a report rated as a 3 or 4 is required for a major flood. The major flood category also includes personal impacts such as rescues, evacuations, injuries, and fatalities. If a flood is captured by a USGS stream gauge, then the reported flood stage can be used to validate the magnitude associated with the warning. The experimental coordinators will also examine social media and local news stations for reports that are informative to the validation process. Experimental warnings will be compared and contrasted to operationally issued products.

PQPE Evaluation – The evaluation of PQPE will be formally conducted during a dedicated period on Friday morning. Data will be presented for a one-month period with a variety of accumulations, uncertainty, and probabilistic products. These data sets will be viewable through an internal web-interface. Evaluations of the PQPE product suite will be collected through a web-based questionnaire and survey tool. To maximize the evaluation of PQPE, the products can also be evaluated during inactive periods within real-time experimental warning operations.

Group Discussion – A group discussion will be held on Friday morning to garner feedback on the activities that occurred during the week. HMT-Hydro Experiment officers and PIs will help guide the discussion but the primary objective is to gain insight and feedback on the probabilistic grids and the use of short-term QPFs in the flash flood prediction and warning process.

Feedback Survey – At the end of the week, participants will fill out an online feedback survey. The feedback received within this survey is particularly useful to us because it will be used to improve the experimental design for the coming days, weeks, and years.

Other Activities – Given the variability in the day-to-day schedule, participants can coordinate with HMT-Hydro Experiment officers regarding lunch/dinner plans. While not explicitly stated in the schedule, time will be made for meals during operating hours as well as breaks. A group photo of all participants and officers will be conducted at some point during the week depending on experiment activities and schedules. Public affairs personnel with NSSL will also be in the lab documenting daily activities. For those who have not been to the National Weather Center before, a tour of the building can be given upon request.

V. Products

Subjective evaluations of the real-time operations will focus on the gridded flash flood probabilities and experimental warning issued. Archived cases will utilize the same products but focus on the addition of Warn-on-Forecast QPFs to the situational awareness aspects of the warning decision making process. The table below summarizes the products and observations that will be available for both the archived cases (AC) and the real-time operations (RT) in 2018. The full details of each product are provided in Appendix B.

Product	Provider	Basic Description	AC	RT
Flash Flood Observations				
Local Storm Reports	NWS	Operational reports of flash flooding used to validate warnings		X
mPING	NSSL	Citizen-scientist reports of flash flooding defined by four levels of severity		X
Streamflow vs. Flood Stage	USGS/NWS/NSSL	Measurement of streamflow that have exceeded flood stage or a nominal return period flow (e.g., 5-yr return) in small, gauged basins		X
Quantitative Precipitation Estimations and QPE Comparison Products				
MRMS QPE (Dual-Pol Synthetic w/ Evaporation Correction)	NSSL	Precipitation estimates from radar-only algorithm using various dual-polarization variables and accounts for evaporation; Derives instantaneous rates and multiple accumulations	X	X
QPE-to-FFG Ratio	RFCs/WPC/NSSL	Compares a 1, 3, and 6-h rolling sum of MRMS QPE to most recently issued 1, 3, and 6 h FFG*	X	X
QPE Average Recurrence Interval	NWS/NSSL	Compares various MRMS QPE accumulations from 30-min to 24-h to precipitation frequencies from NOAA Atlas 14**	X	X
Quantitative Precipitation Forecasts				
Warn-on-Forecast	NSSL	Ensemble QPFs provided to FLASH on a 3-km resolution, 900x900 km domain every hour for a lead time of 0–3 h or 0–6 h (case depending)	X	
Hydrologic Modeling Products				
Max Streamflow	NSSL	Maximum streamflow forecast during an interval spanning up to 12 hours after valid time		X
Max Unit Streamflow	NSSL	Maximum unit streamflow forecast during an interval spanning up to 12 hours after valid time	X	X
Soil Moisture	NSSL	Analysis of soil saturation		X
Probability of Flash Flood LSR	NSSL	Gridded probabilities of receiving a local storm report of flash flooding (on a scale of 0.00 to 1.00)	X	X
Probability of Minor/Moderate/ Major Flash Flooding	NSSL	Gridded probabilities to determine the significance (minor/moderate/major) of the flash flood hazard (on a scale of 0.00 to 1.00)	X	X

* RFCs typically update FFG at synoptic (0000, 1200 UTC) and sub-synoptic (0600, 1800 UTC) times, but the FLASH server queries all RFCs once an hour for FFG updates. During heavy rainfall events, some RFCs produce intermediate FFG products and hourly queries ensure that FLASH catches these intermediate FFG issuances. The FFG product displayed in FLASH is a national mosaic. There are different methodologies used to produce FFG across the country (including gridded and lumped FFG as well as the flash flood potential index), so discontinuities in FFG values across RFC boundaries may exist. Since the FFG values are being obtained from the RFCs, no locally forced FFG values from NWS forecast offices are included in this national FFG mosaic.

** NOAA Atlas 14 does not yet include precipitation frequency estimates for the Northwestern United States. Precipitation frequency values were derived by NSSL for use in this product until the official grids are published.

For the MRMS and FLASH products already operational within the NWS, online training modules and detailed product descriptions are provided by the NWS Warning Decision Training Division. If you are unfamiliar with the MRMS and FLASH products, we encourage you to review this material prior to arriving in Norman, OK.

MRMS Training from WDTD:
https://training.weather.gov/wdtd/courses/MRMS/index.php

MRMS Product Guide:
https://vlab.ncep.noaa.gov/web/wdtd/mrms-products-guide

For the PQPE analysis, an internal web interface will display a series of products based on the PQPE algorithm with comparisons to basic MRMS QPE-based products. The data will cover a one-month period with a variety of heavy rainfall and flash flood events. The full details of each PQPE product are provided in Appendix B.

Product	Provider	Basic Description
Probabilistic QPE		
Expected QPE	OU/NSSL	Expected or mean value of the distribution of possible precipitation rates given the radar observations
PQPE Uncertainty	OU/NSSL	Uncertainty in quantifying precipitation rates is associated with the spread of the distribution of possible precipitation rates given the radar observations
Probability of Exceeding QPE Value	OU/NSSL	The probability of exceeding a predefined precipitation rate threshold compares the distribution of possible precipitation rate values to the threshold
Hourly Count of Probability Exceedance	OU/NSSL	Hourly count of probability exceedance counts the number of times a predefined precipitation rate threshold was exceeded by more than 50% during the last hour.

VI. Personnel

a. Officers

The officers of the HMT-Hydro Experiment are responsible for the facilitating all operational activities during the week. The duties of the officers are as follows:

- Welcoming the participants and giving a tour of the building (upon request)
- Facilitating the daily weather briefing with the FFaIR Experiment
- Determining the activities of the day (real-time experimental warning operations or archived case review)
- Coordinating real-time warning operations and identifying forecast domain(s)
- Set-up and delivery of the archived cases for forecaster evaluations
- Ensuring the smooth running of the technology and alerting various IT personnel when problems occur
- Answering any questions participants may have about the products
- Coordinating meals during HMT-Hydro Experiment hours
- Directing post-event evaluations, end-of-week discussions, and the exit survey
- Making sure the operations area is clean and all computers are logged off at the end of the day

At least one or two HMT-Hydro Experiment officers will be in attendance through all daily activities, while other officers will focus on the technical aspects of the experiment or the evaluations of specific products.

<u>Principal Investigators</u>:
Jonathan J. Gourley jj.gourley@noaa.gov
Steven Martinaitis steven.martinaitis@noaa.gov

<u>Warn-on-Forecast Coordinators</u>:
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Nusrat Yussouf nusrat.yussouf@noaa.gov

<u>Real-Time Operations Coordinators</u>:
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<u>NSSL HWT Information Technology Coordinators</u>:
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Justin Monroe justin.monroe@noaa.gov

<u>Executive Officer – HWT</u>:
Kodi Berry kodi.berry@noaa.gov

<u>Daily Coordinator</u>:
Ami Arthur ami.arthur@noaa.gov

b. Participants

The forecasters, representing a geographically diverse set of NWS Weather Forecast Offices (WFOs), River Forecast Centers (RFCs), NWS training division, will be available full-time for the entire weekly schedule. During archived case examinations, forecasters will work independently from each other. Forecasters can coordinate and work together during real-time experimental warning operations, similar to that of an NWS WFO. Forecasters can also collaborate during their analysis of the PQPE product suite. The participating forecasters will focus on the evaluation of the experimental flash flood and precipitation forecast products during their week in the HMT-Hydro Experiment. A group discussion regarding the probability grids and the addition of Warn-on-Forecast QPFs will be conducted at the end of the week.

<u>HMT-Hydro Experiment -- Week 1 (24-28 June 2019)</u>

Mike Dutter	NWS WFO Wakefield, VA
Amanda Schroeder	NWS West Gulf RFC (Fort Worth, TX)
Jane Marie Wix	NWS WFO Jackson, KY

<u>HMT-Hydro Experiment -- Week 2 (8-12 July 2019)</u>

Linda Cheng	NWS WFO Salt Lake City, UT
Justin Gibbs	NWS Warning Decision Training Division (Norman, OK)
Brian Schoettmer	NWS WFO Louisville, KY
Jimmy Taeger	NWS WFO San Diego, CA

<u>HMT-Hydro Experiment -- Week 3 (15-9 July 2019)</u>

Bridget De Rosa	NWS Ohio RFC (Wilmington, OH)
Emilie Nipper	NWS Lower Mississippi RFC (Slidell, LA)
Jeremy Wesely	NWS WFO Hastings, NE
Alexander Zwink	NWS WFO Norman, OK

Each forecaster should bring his/her CAC card for access into the building. Security access cards and cell phone numbers for the principal investigators will be provided to participants upon their arrival at the National Weather Center.

c. Observers/Additional Participants

We anticipate participation or observations from "participants of opportunity" who may be in town for other meetings. We have enough space to accommodate additional participants and welcome those from NOAA headquarters, academia, private sector, and beyond to take part in the experiment; however, please contact the Principal Investigators prior to arriving.

APPENDIX A

The evaluation of experimental products and techniques will be conducted over a four-day period from Monday through Thursday. Given the various goal and objectives of the 2019 HMT-Hydro Experiment, the real-time operations and the archived case studies will have two days each. This is to ensure that both sets of objectives get ample evaluations and feedback from the participating forecasters. The precipitation forecasts will dictate which days will feature real-time operations versus archived case studies. Due to this uncertainty, multiple variations of the weekly schedule have been developed based on the following combinations:

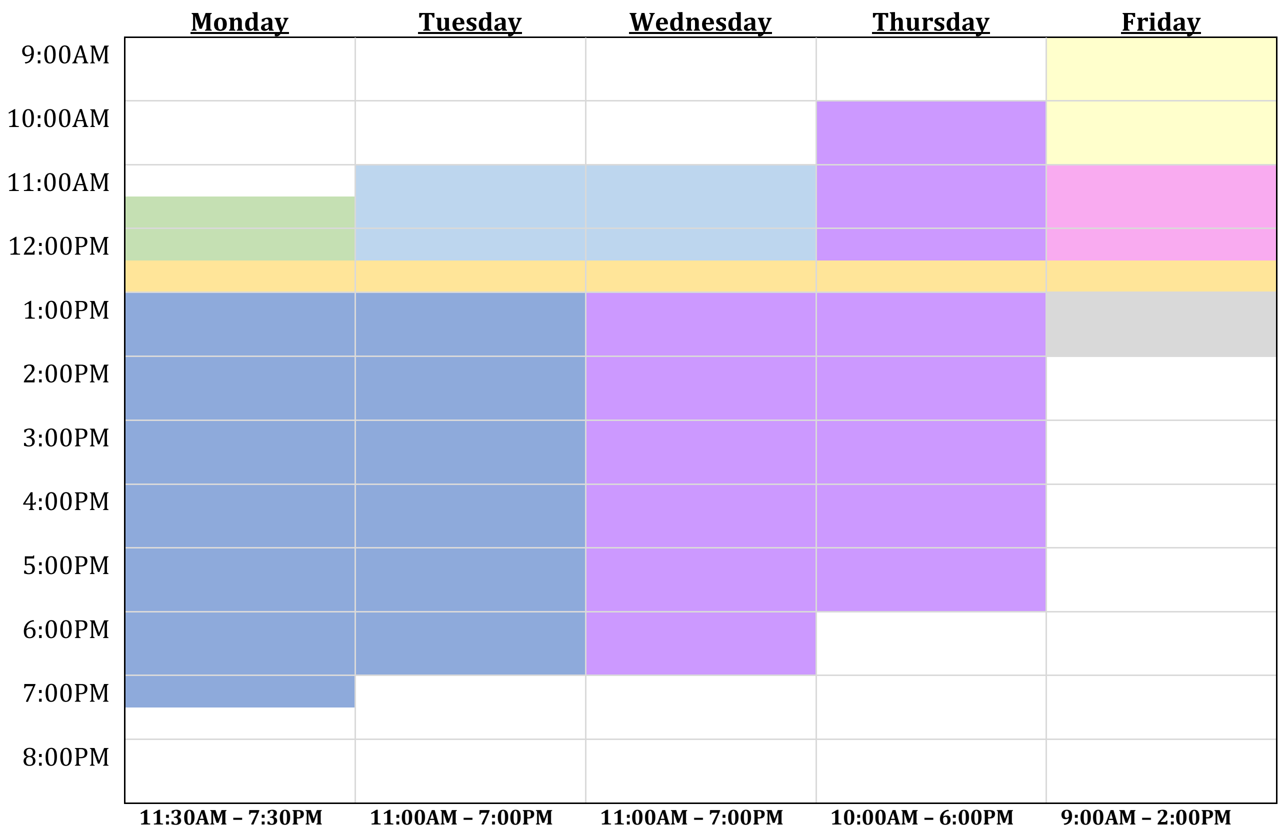
	Monday	Tuesday	Wednesday	Thursday
A.	Real-Time	Real-Time	Archived Cases	Archived Cases
B.	Real-Time	Archived Cases	Real-Time	Archived Cases
C.	Real-Time	Archived Cases	Archived Cases	Real-Time
D.	Archived Cases	Archived Cases	Real-Time	Real-Time
E.	Archived Cases	Real-Time	Archived Cases	Real-Time
F.	Archived Cases	Real-Time	Real-Time	Archived Cases

This appendix will display the six different schedule variations that could be followed over the course of the week. The HMT-Hydro Experiment officers will determine which scheduling framework will be followed throughout the week.

While not explicitly stated in the schedules, time will be made available for lunch and dinner during the HMT-Hydro Experiment hours. The HMT-Hydro Experiment officers can coordinate with you on the timing of meals. Participants can coordinate on getting carry-out meals with the experiment officers. Participants can also bring in their own food. A refrigerator and microwave are available in the NWS space.

As stated earlier, the HMT-Hydro Experiment officers reserve the right to modify the daily activities and operating times due to changes in weather and to the experiment itself to maximize data collection.

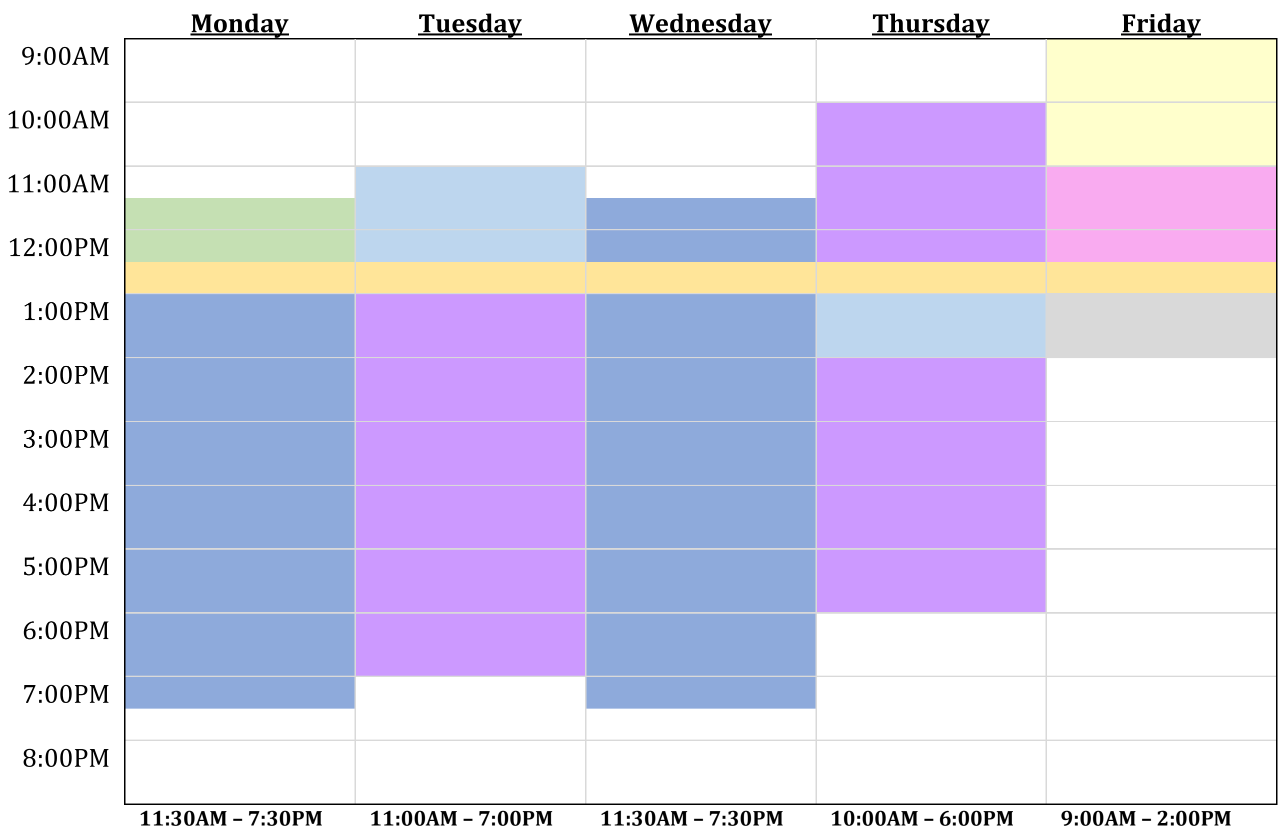
Weekly Schedule - Version A. Real-Time Operations: Monday, Tuesday
Archived Case Studies: Wednesday, Thursday



Legend:

- Introductory Remarks and Testbed/Product Training
- FFaIR Experiment Daily Weather Briefing
- Real-Time Experimental Warning Operations
- Group Evaluation of Previous Day Real-Time Operations
- Archived Case Studies
- Group Discussion on Flash Flood Probabilities and WoF QPFs
- PQPE Analysis
- End-of-Week Survey and Closing Remarks

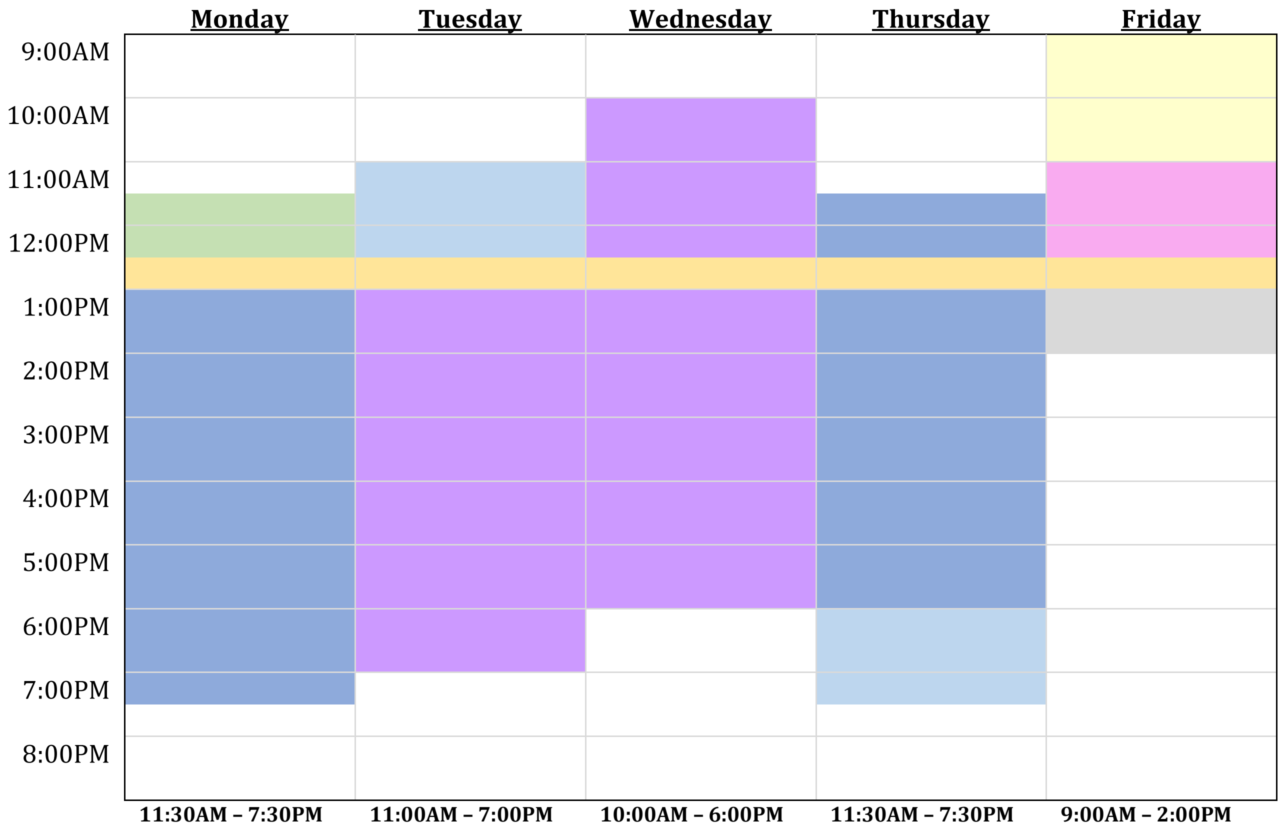
Weekly Schedule - Version B. Real-Time Operations: Monday, Wednesday
Archived Case Studies: Tuesday, Thursday



Legend:

Introductory Remarks and Testbed/Product Training
FFaIR Experiment Daily Weather Briefing
Real-Time Experimental Warning Operations
Group Evaluation of Previous Day Real-Time Operations
Archived Case Studies
Group Discussion on Flash Flood Probabilities and WoF QPFs
PQPE Analysis
End-of-Week Survey and Closing Remarks

Weekly Schedule - Version C. Real-Time Operations: Monday, Thursday
Archived Case Studies: Tuesday, Wednesday

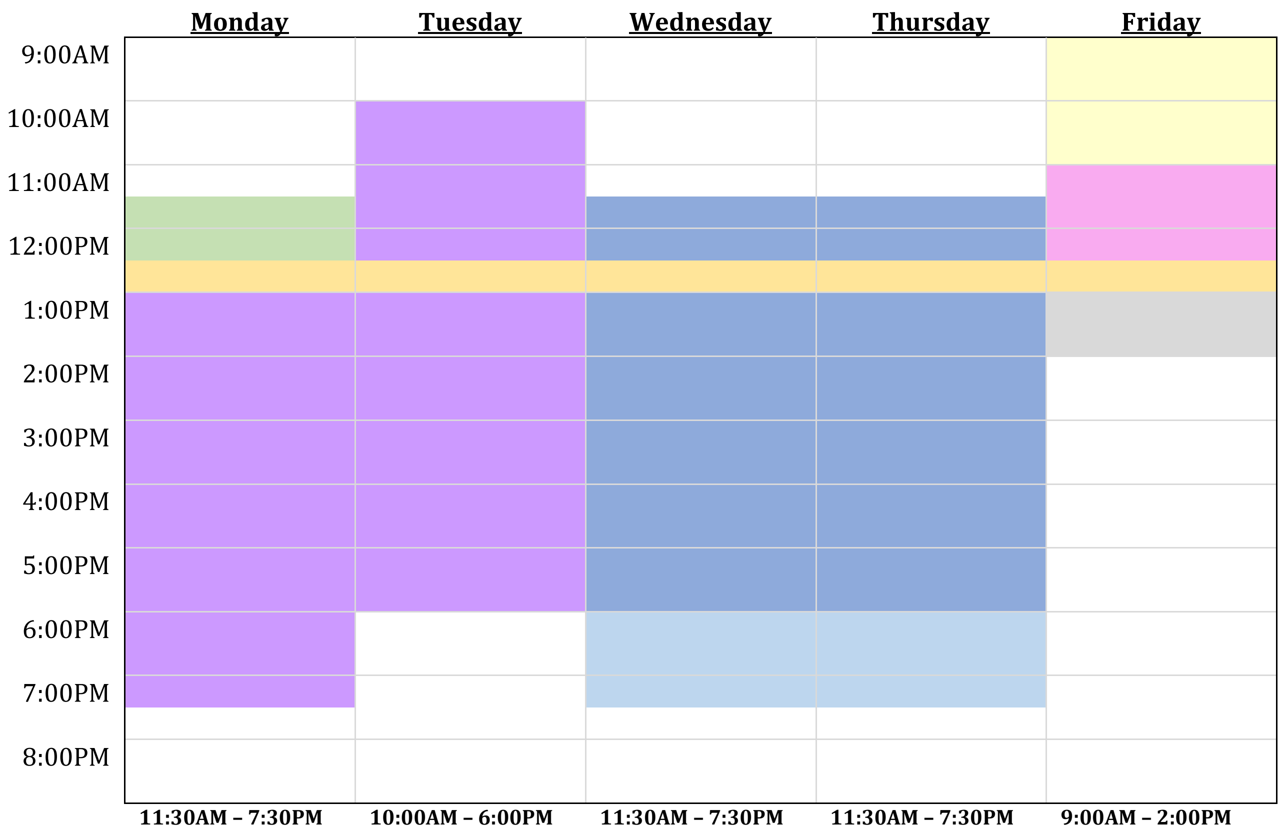


Legend:

Introductory Remarks and Testbed/Product Training
FFaIR Experiment Daily Weather Briefing
Real-Time Experimental Warning Operations
Group Evaluation of Previous Day Real-Time Operations
Archived Case Studies
Group Discussion on Flash Flood Probabilities and WoF QPFs
PQPE Analysis
End-of-Week Survey and Closing Remarks

Weekly Schedule - Version D.

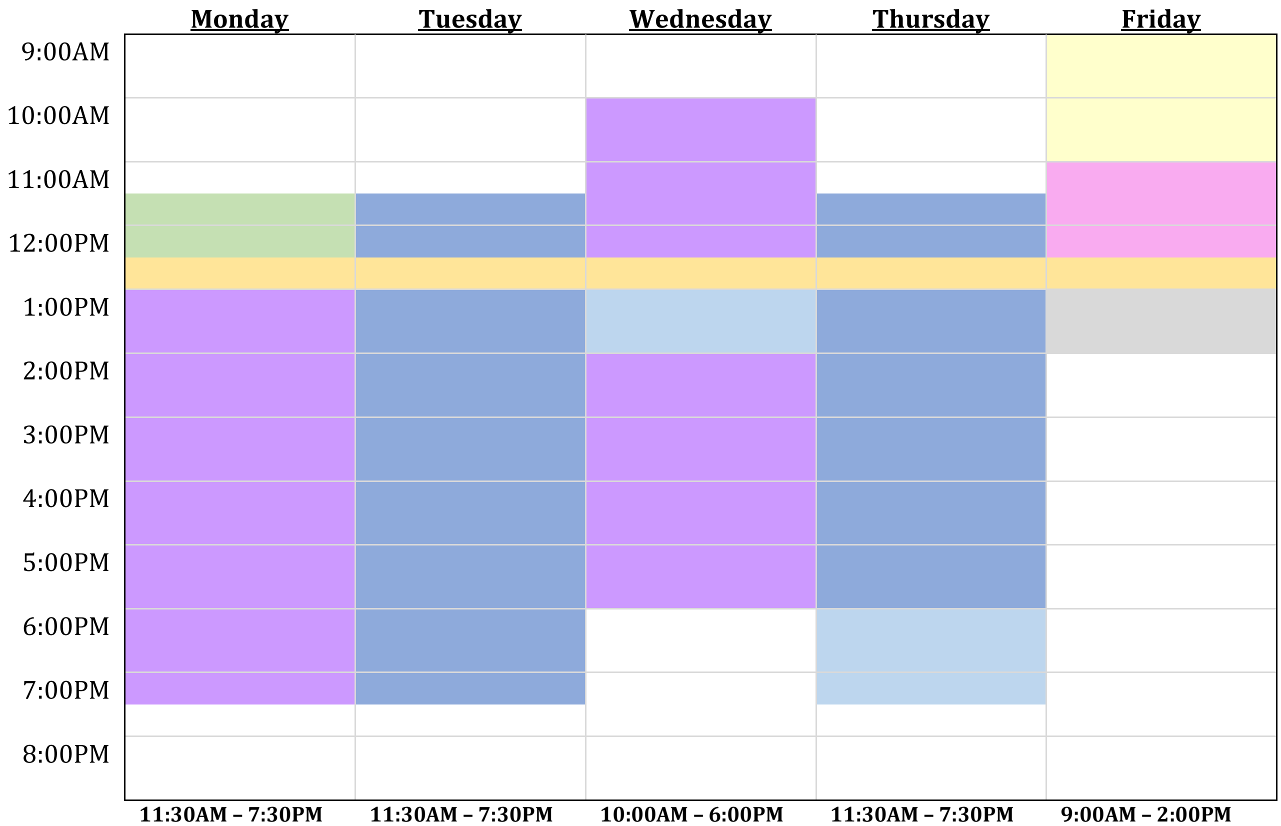
Real-Time Operations: Wednesday, Thursday
Archived Case Studies: Monday, Tuesday



Legend:

- Introductory Remarks and Testbed/Product Training
- FFaIR Experiment Daily Weather Briefing
- Real-Time Experimental Warning Operations
- Group Evaluation of Previous Day Real-Time Operations
- Archived Case Studies
- Group Discussion on Flash Flood Probabilities and WoF QPFs
- PQPE Analysis
- End-of-Week Survey and Closing Remarks

Weekly Schedule - Version E. Real-Time Operations: Tuesday, Thursday
Archived Case Studies: Monday, Wednesday

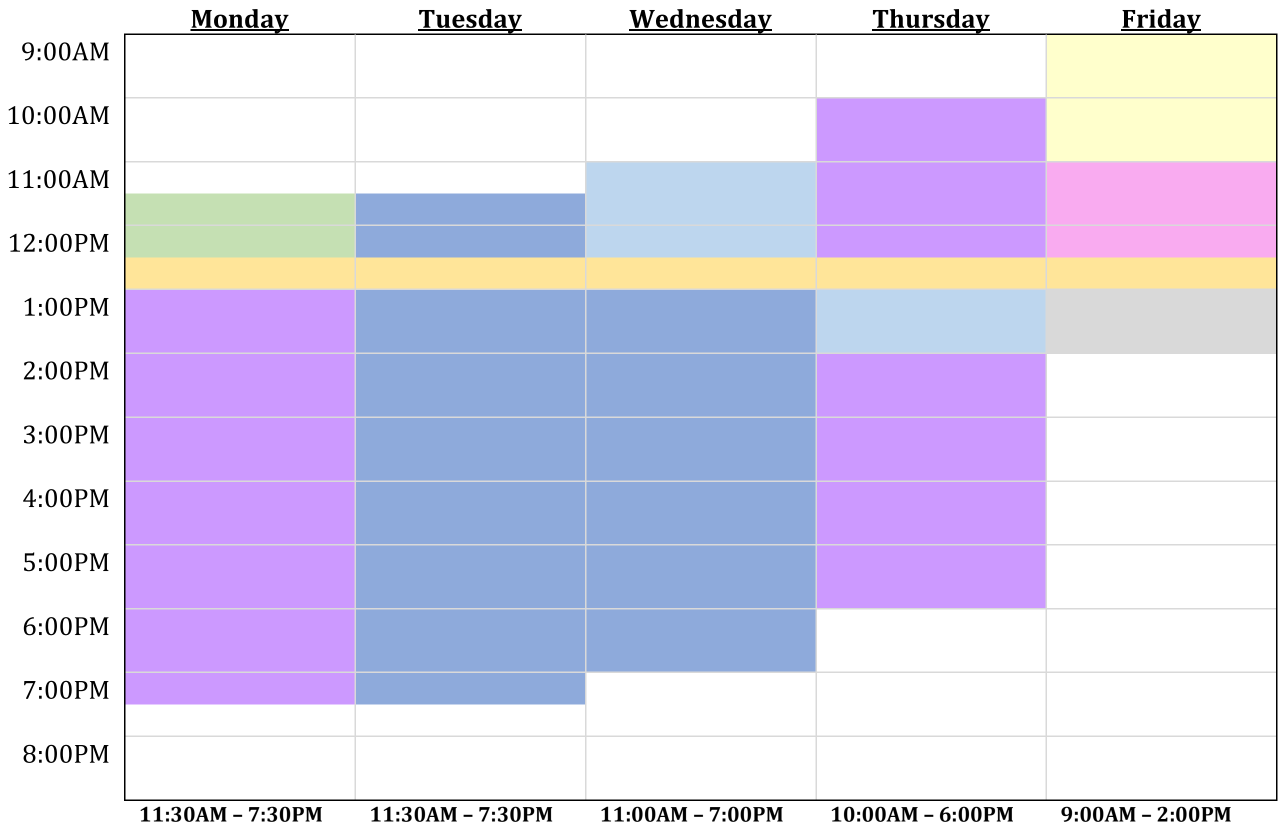


Legend:

- Introductory Remarks and Testbed/Product Training
- FFaIR Experiment Daily Weather Briefing
- Real-Time Experimental Warning Operations
- Group Evaluation of Previous Day Real-Time Operations
- Archived Case Studies
- Group Discussion on Flash Flood Probabilities and WoF QPFs
- PQPE Analysis
- End-of-Week Survey and Closing Remarks

Weekly Schedule - Version F.

Real-Time Operations: Tuesday, Wednesday
Archived Case Studies: Monday, Thursday



Legend:

- Introductory Remarks and Testbed/Product Training
- FFaIR Experiment Daily Weather Briefing
- Real-Time Experimental Warning Operations
- Group Evaluation of Previous Day Real-Time Operations
- Archived Case Studies
- Group Discussion on Flash Flood Probabilities and WoF QPFs
- PQPE Analysis
- End-of-Week Survey and Closing Remarks

APPENDIX B

This appendix highlights the following hydrologic and QPE comparison products that will be featured in the 2019 HMT-Hydro Experiment:

- Maximum Streamflow
- Maximum Unit Streamflow
- Soil Moisture
- Probability of Receiving a Flash Flood LSR
- Probability of Minor/Moderate/Major Flash Flooding
- QPE-to-FFG Ratio
- QPE Average Recurrence Interval

All of the hydrologic modeling products will be derived from the Coupled Routing and Excess Storage (CREST) model, while some of the products will also be generated from the Sacramento – Soil Moisture Accounting (SAC-SMA) and hydrophobic models. Details of each product are provided on each of the product pages in this appendix. Details on the model QPFs forcing the CREST model are provided in Appendix C.

There is also a series of PQPE products that will be available in the 2019 HMT-Hydro Experiment that are also detailed in this section:

- Expected QPE (Instantaneous Rates; 1, 3, and 6-hour accumulations)
- PQPE Uncertainty (Instantaneous Rates)
- Probability of Exceeding QPE Value:
    - 10 mm h^{-1}: (Instantaneous Rates; 1-hour accumulation)
    - 25 mm h^{-1}: (Instantaneous Rates; 1-hour accumulation)
    - 50 mm h^{-1}: (Instantaneous Rates; 1 and 3-hour accumulations)
    - 100 mm h^{-1}: (Instantaneous Rates; 1 and 3-hour accumulations)

Though they are not featured in this document, a select suite of Multi-Radar Multi-Sensor (MRMS) products will be available in both the real-time experimental warning operations and the archived case studies in the 2019 HMT-Hydro Experiment:

- Seamless Hybrid Scan Reflectivity
- Radar Quality Index
- Dual-Pol Synthetic QPE with Evaporation Correction
    - Dual-Pol Synthetic QPE Flag (*real-time only*)
    - Instantaneous Rates
    - Accumulation Periods: 1, 3, 6, 12, 24, 48, and 72 hours

The Dual-Pol Synthetic QPE with the Evaporation Correction algorithm is an experimental MRMS product that will be delivered operationally to the National Weather Service in MRMS v12.0 at a to-be-determined date. Further details on these experimental QPEs can be provided by HMT-Hydro Experiment PIs upon request.

Notes About Hydrologic Modeling Used in HMT-Hydro Experiment:

The three hydrologic models used within the FLASH product suite are the Coupled Routing and Excess Storage (CREST) model, the Sacramento Soil Moisture Accounting (SAC-SMA) model, and a Hydrophobic model, which turns all precipitation into runoff. The models use observed rainfall from a radar- based QPE product within the MRMS system. The archived cases are using the operational MRMS Radar Only QPE, which uses reflectivity to generate instantaneous rates. The real-time operations use the experimental MRMS Dual-Pol Synthetic QPE, which uses various dual-polarization variables to calculate instantaneous rates. The MRMS Dual-Pol Synthetic QPE also uses an experimental evaporation correction module. The CREST model will also use various precipitation forecasts (i.e., QPFs) beyond the valid time to generate forecast model outputs.

Topographical, land cover/land use, and soil type information is used by these distributed hydrologic models (DHMs) to infiltrate and route precipitation downstream once it reaches the land surface. A digital elevation model (DEM) and flow accumulation map (FAC) are used by the models to route water from precipitation downstream once it has reached and infiltrated into the land surface. Soil and land use information are used to determine how much of the surface water will become overland flow, and a kinematic wave solution to the Saint-Venant Equations are used to route the channelized water downstream. Temperature analyses from the Rapid Refresh (RAP) model are used to calculate potential evapotranspiration for forcing to the models. Thus, the outputs from the DHMs are flow rate and discharge at every grid cell.

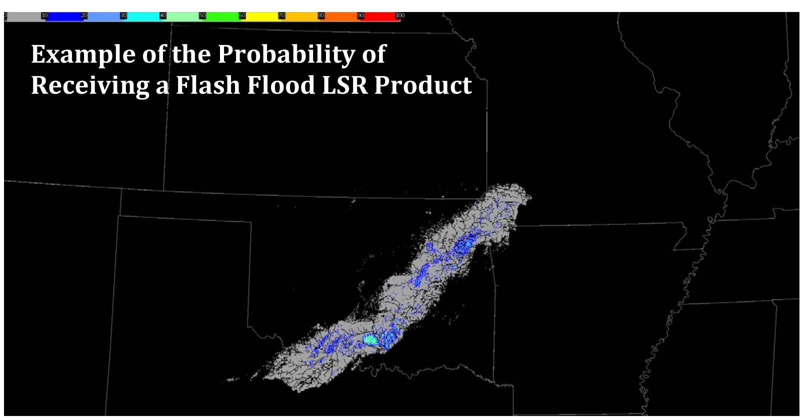
The outputs from the hydrologic models rely heavily on the precipitation estimates from weather radars. Areas with complex topography, beam blockage, wind farms, and other difficulties that contaminate the QPE will be adversely affected. Further, the models do not presently simulate snowmelt and assumes that all rivers remain free from diversions, dams, withdrawals, dikes, and any other anthropogenic influences.

The water balance parameters of the models are based on a-priori physiographic maps and are not optimized using streamflow observations. The kinematic wave parameters have been derived at USGS gauge stations and are modeled for all channel pixels. In any case, as with any uncalibrated model, streamflow values at a particular grid cell may differ from the observed river conditions. The models have primarily been designed to forecast peakflows, so large model-observation discrepancies can occur, especially when examining details such as baseflow or recession limb of the hydrograph. The maximum streamflow should not be used in isolation to forecast floods or flash floods. Instead, it should be used to investigate and confirm model based errors that will propagate to the maximum unit streamflow products, which are more relevant to flash flood prediction.

Notes About Probabilistic Hydrologic Model Guidance:

Using the CREST model, two different types of probabilistic guidance totaling four products will be evaluated in the HMT-Hydro Experiment. The first product is a probability of receiving a flash flood local storm report (LSR). The probability level corresponds to a range of unit streamflow values that have been associated with flash flood LSRs. The probability values depicted in this product indicates how frequent the corresponding values of simulated unit streamflow have been associated with flash flood LSRs. A value of 100% means that the corresponding simulated unit streamflow value has always been associated with flash flood LSRs, while a value of 0% means that the corresponding simulated unit streamflow value has never been associated with flash flood LSRs. These probabilities are generated in a post-processing algorithm using probabilistic models that have been trained on historical data. This means that the hydrologic model is integrated in a deterministic way and the resulting output (unit streamflow) is used as input to the probabilistic model. For this product, the flash flood LSR probabilistic model is based on reports from 2005–2011, and uses a logistic regression algorithm.

The second product is a probability of minor/moderate/major flash flood as based on exceeding a maximum unit streamflow value. Each level represents a different potential magnitude of the flash flood hazard. The definitions of the different magnitudes were based on past studies and observations from previous events and HMT-Hydro Experiments. The probabilities are generated in a post-processing algorithm using probabilistic models that have been trained on historical data. This means that the hydrologic model is integrated in a deterministic way and the resulting output (unit streamflow) is used as input to the probabilistic model. The probabilistic model is based on probabilities of observed USGS unit streamflow values conditional to values of simulated unit streamflow. This probabilistic model was trained on archived data from 2002–2011.



Maximum Streamflow

<u>Basic Description</u>: Forecast of maximum streamflow at each grid cell based on the routing and infiltration of water using precipitation as forcing. The maximum value is calculated from -30 min to +12 hrs from valid time for real-time operations (from 0 min to +12 hrs from valid time for archived case studies).

<u>Spatial Resolution</u>: 0.01 × 0.01 degrees (approximately 1 × 1 km)

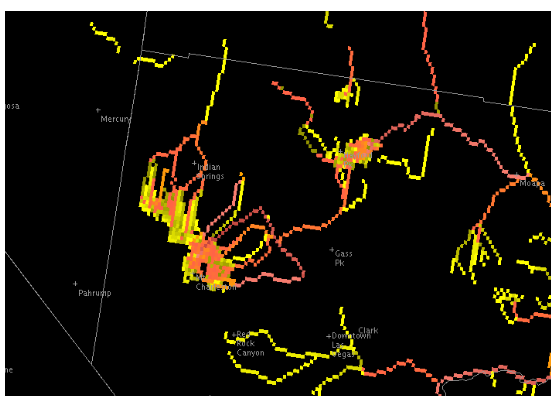
<u>Temporal Resolution</u>: 10 minutes

<u>Units</u>: $m^3\ s^{-1}$ (conversion is ~35 $ft^3\ s^{-1}$ for 1 $m^3\ s^{-1}$ in AWIPS)

<u>Hydrologic Models</u>:
CREST (real-time operations and archived case studies)
SAC-SMA (real-time operations only)
Hydrophobic (real-time operations only)

<u>Input Sources (QPE)</u>:
MRMS Dual-Pol Synthetic QPE with Evaporation Correction
RAP model temperature

<u>Applications</u>: Maximum streamflow can be used to visualize stream and river networks and to identify broad areas where relatively high flow is occurring. This product can be directly compared to streamflow measured at USGS gauge sites.



Maximum Unit Streamflow

Basic Description: Forecast of maximum streamflow at each grid cell based on the routing and infiltration of water using precipitation as forcing that is normalized to the upstream basin area. The maximum value is calculated from -30 min to +12 hrs from valid time for real-time operations (from 0 min to +12 hrs from valid time for archived case studies).

Spatial Resolution: 0.01 × 0.01 degrees (approximately 1 × 1 km)

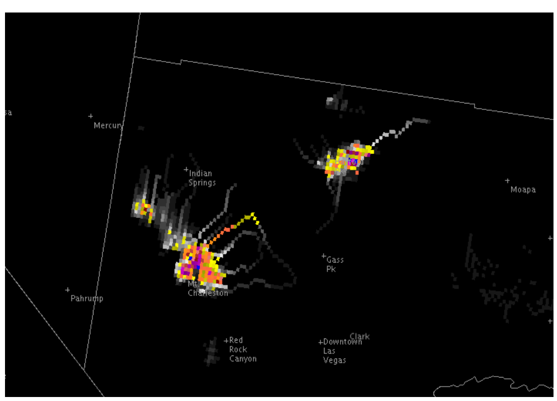
Temporal Resolution: 10 minutes

Units: $m^3\ s^{-1}\ km^{-2}$ (conversion is ~91.5 $ft^3\ s^{-1}\ mi^{-2}$ for 1 $m^3\ s^{-1}\ km^{-2}$ in AWIPS)

Hydrologic Models: CREST (real-time operations and archived case studies)
SAC-SMA (real-time operations only)
Hydrophobic (real-time operations only)

Input Sources (QPE): MRMS Dual-Pol Synthetic QPE with Evaporation Correction
RAP model temperature

Applications: Maximum unit streamflow can be used to diagnose areas of flash flooding potential, as well as identify the relative severity of the potential flash flooding impacts. Areas of contiguous pixels with high values are usually a cause for concern; a single pixel or a handful of isolated pixels with higher values may not be indicative of the flash flooding threat.



Soil Moisture

Basic Description: Analysis of the soil saturation percentage from the hydrologic model. The values represent a percent of saturation of the top-layer soil moisture. High soil moisture values typically results in greater surface runoff.

Spatial Resolution: 0.01 × 0.01 degrees (approximately 1 × 1 km)

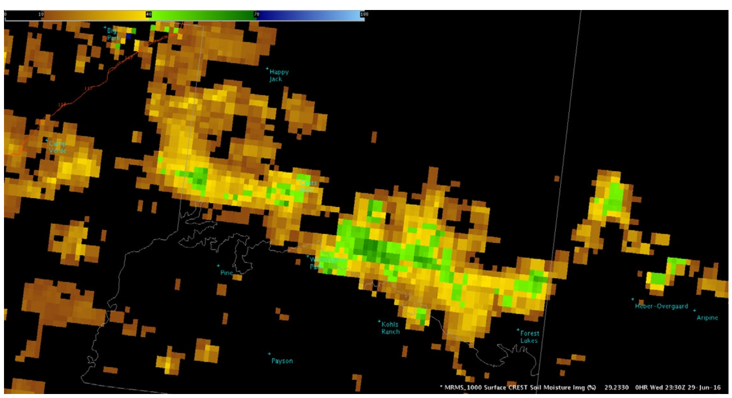
Temporal Resolution: 10 minutes

Units: Percent

Hydrologic Models: CREST (real-time operations and archived case studies)

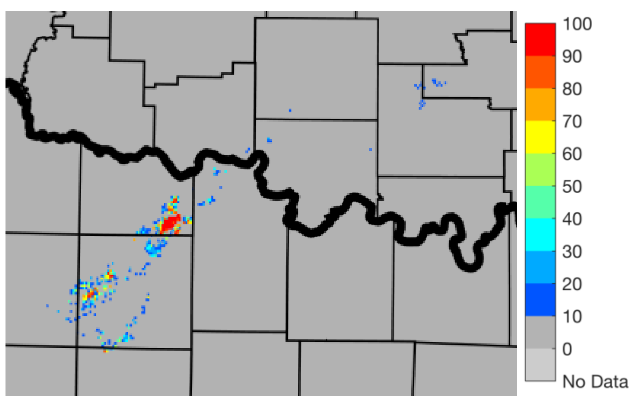
Input Sources (QPE): MRMS Dual-Pol Synthetic QPE with Evaporation Correction
RAP model temperature

Applications: The Soil Moisture product can be used to distinguish between broad areas of wetter or drier soil conditions. This will allow a forecaster to identify areas that have recently received rainfall and are at an increased risk of flash flooding due to moist soil conditions.



Probability of Receiving a Flash Flood LSR

Basic Description:	Gridded probabilities of receiving a flash flood local storm report (LSR) based on statistical analysis of flash flood reports from NWS *Storm Data* and CREST maximum unit streamflow.
Spatial Resolution:	0.01 × 0.01 degrees (approximately 1 × 1 km)
Temporal Resolution:	10 minutes
Units:	Percent
Hydrologic Models:	CREST (real-time operations and archived case studies)
Input Sources (QPE):	MRMS Dual-Pol Synthetic QPE with Evaporation Correction
Input Sources (QPF):	Warn-on-Forecast Ensemble QPF (for archived case studies)
Applications:	The probability of receiving a LSR gridded product can be used to diagnose areas of flash flooding potential. Areas of contiguous pixels with high values are usually a cause for concern; a single pixel or a handful of isolated pixels with higher values may not be indicative of the flash flooding threat.



Probability of Minor/Moderate/Major Flash Flooding

Basic Description: Gridded probabilities of minor/moderate/major flash flooding are defined from exceeding various CREST maximum unit streamflow values based on statistical analysis and derived probability distribution functions created from CREST maximum unit streamflow data. Three threshold values are used to create grids representing probabilities of the different flash flood severities.

Spatial Resolution: 0.01 × 0.01 degrees (approximately 1 × 1 km)

Temporal Resolution: 10 minutes

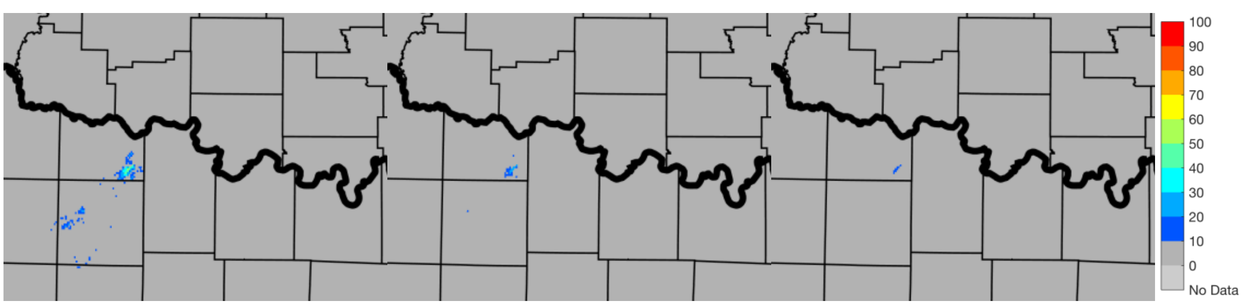
Units: Percent

Hydrologic Models: CREST (real-time operations and archived case studies)

Input Sources (QPE): MRMS Dual-Pol Synthetic QPE with Evaporation Correction

Input Sources (QPF): Warn-on-Forecast Ensemble QPF (for archived case studies)

Applications: The probability of minor/moderate/major flash flooding can be used to diagnose the areas of potential flash flooding as well as the relative severity of the potential flash flooding impacts. Areas of contiguous pixels with high values are usually a cause for concern; a single pixel or a handful of isolated pixels with higher values may not be indicative of the flash flooding threat.



Minor Moderate Major

QPE-to-FFG Ratio

Basic Description: Ratio of MRMS radar-based precipitation estimates compared to corresponding flash flood guidance (FFG) values. Comparisons are conducted on the 1, 3, and 6 hour accumulations, and a maximum QPE-to-FFG ratio product shows the maximum value over all accumulation periods.

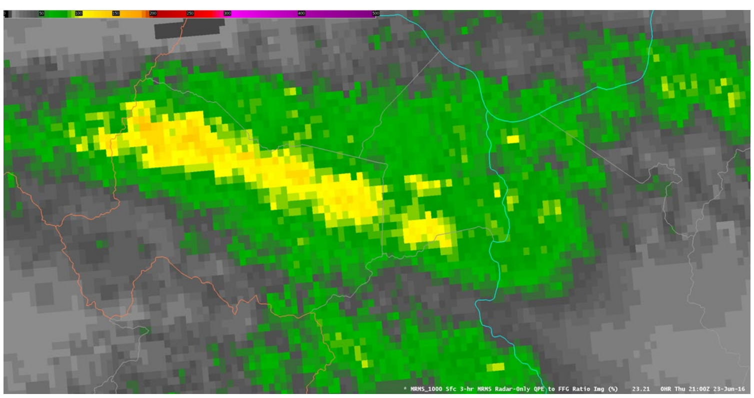
Spatial Resolution: 0.01 × 0.01 degrees (approximately 1 × 1 km)

Temporal Resolution: 2 minutes

Units: Unitless (ratio)

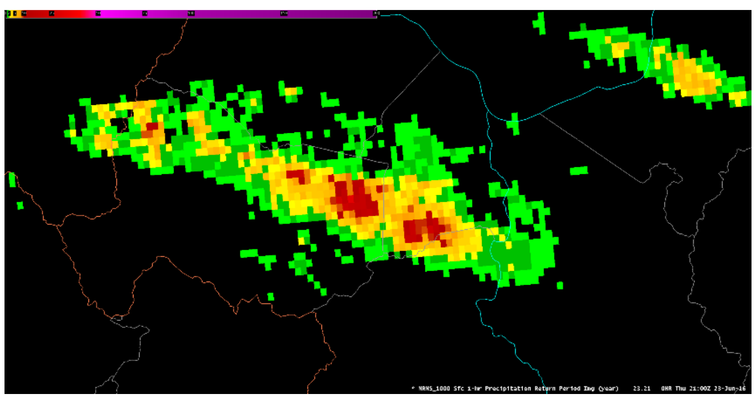
Input Sources: MRMS Dual-Pol Synthetic QPE with Evaporation Correction
FFG Grids (from RFCs nationally mosaicked by WPC)

Applications: The QPE-to-FFG ratio product can be used to identify specific areas where FFG is being met or exceeded, signifying the potential for bankfull conditions on small natural stream networks. This is similar to the FFG analysis done in FFMP, but on the MRMS grid space.



QPE Average Recurrence Interval

Basic Description:	The return period, or average recurrence interval (ARI), of estimated rainfall when compared to the NOAA Atlas 14 data. Comparisons are conducted on the 30-min, 1, 3, 6, 12, and 24 hour accumulations, and a maximum QPE ARI product shows the maximum value over all accumulation periods.
Spatial Resolution:	0.01 × 0.01 degrees (approximately 1 × 1 km)
Temporal Resolution:	2 minutes
Units:	Years
Input Sources:	MRMS Dual-Pol Synthetic QPE with Evaporation Correction NOAA Atlas 14
Applications:	The QPE ARI product can be used to identify the potential rarity of precipitation in a given location. The greater the return period, the more extraordinary the event is. This does not have a direct relationship with flash flood prediction but can provide situational awareness and context of the precipitation event.



PQPE – Probabilistic QPE

Basic Description: The expected or mean value of the distribution of possible precipitation rates given the radar observations. Rates are generated for PQPE as well as accumulations for 1, 3, and 6 hourly periods.

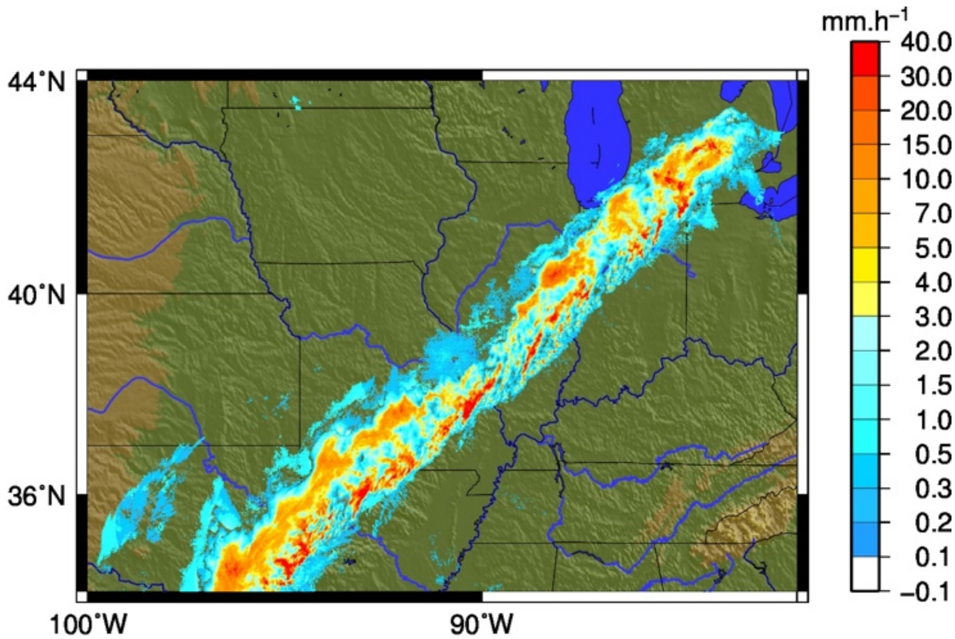
Spatial Resolution: 0.01 × 0.01 degrees (approximately 1 × 1 km)

Temporal Resolution: 2 minutes

Units: mm h^{-1} (Rates)
mm (Accumulations)

Input Sources: MRMS Seamless Hybrid Scan Reflectivity
MRMS Precipitation Type

Applications: The expected value can be used as any deterministic QPE product to monitor the expected magnitude of precipitation at a given location and time and given the radar observations.



PQPE – Uncertainty of QPE

Basic Description: The uncertainty in quantifying precipitation rates is associated with the spread of the distribution of possible precipitation rates given the radar observations. It strongly depends on the type and the magnitude of the measured reflectivity, and can be attributed to error factors in the precipitation estimation process. It is computed as the inter-quantile range [25%–75%] of the distribution normalized by the expected value.

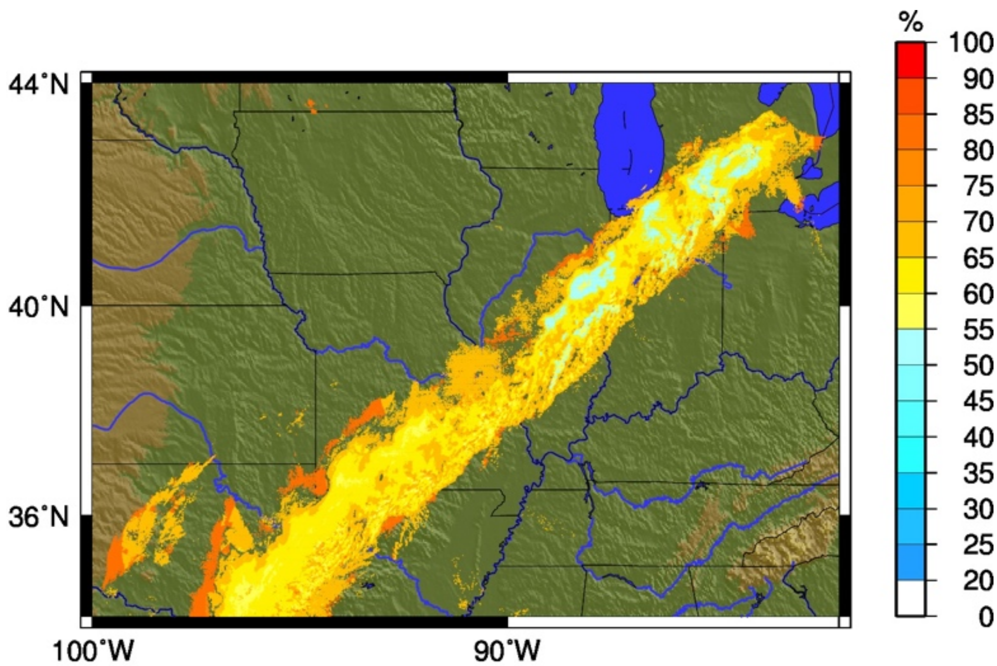
Spatial Resolution: 0.01 × 0.01 degrees (approximately 1 × 1 km)

Temporal Resolution: 2 minutes

Units: Percent

Input Sources: MRMS Seamless Hybrid Scan Reflectivity
MRMS Precipitation Type

Applications: The PQPE uncertainty indicates the robustness of PQPE precipitation rate estimates. The lower the uncertainty, the more robust the precipitation rate estimate is.



PQPE – Probability of Exceeding Values

Basic Description: The probability of exceeding a predefined precipitation rate threshold compares the distribution of possible precipitation rate values to the threshold. It is estimated as the proportion of possible rate values in the distribution that are exceeding the threshold. Comparisons are conducted on the 10, 25, 50, and 100 mm h^{-1} rates.

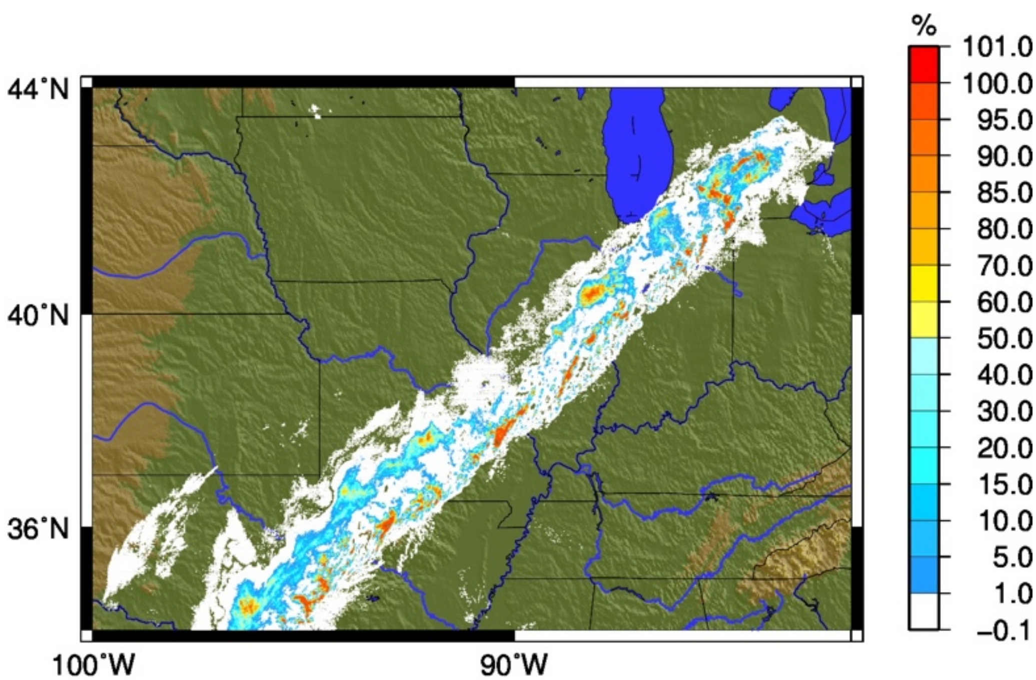
Spatial Resolution: 0.01 × 0.01 degrees (approximately 1 × 1 km)

Temporal Resolution: 2 minutes

Units: Percent

Input Sources: MRMS Seamless Hybrid Scan Reflectivity
MRMS Precipitation Type

Applications: The probability of exceeding a predefined threshold indicates the chances that the threshold is exceeded given the radar observations and the associated uncertainty in estimating precipitation. It is useful for monitoring the occurrence of precipitation extremes that may lead to flooding.



PQPE – Hourly Count of Probability Exceedance

Basic Description: The hourly count of probability exceedance counts the number of times a predefined precipitation rate threshold was exceeded by more than 50% during the last hour. Comparisons are conducted on the 10, 25, 50, and 100 mm h^{-1} rates.

Spatial Resolution: 0.01 × 0.01 degrees (approximately 1 × 1 km)

Temporal Resolution: 2 minutes

Units: Unitless (count)

Input Sources: MRMS Seamless Hybrid Scan Reflectivity
MRMS Precipitation Type

Applications: The hourly count of probability exceedance indicates the number of times there were significant chances that the threshold was exceeded during last hour given the radar observations and the associated uncertainty in estimating precipitation. It is useful for monitoring the time accumulated occurrence of precipitation extremes that may lead to flooding.

[Image Not Available]

APPENDIX C

Three model-derived quantitative precipitation forecasts (QPFs) from the NSSL Experimental Warn-on-Forecast (WoF) model ensemble will be evaluated during the 2019 HMT-Hydro Experiment. The use of the NSSL WoF ensemble QPFs will be the focus of the archived case studies conducted during the week. The table below provides the details of NSSL WoF ensemble during the 2019 HMT-Hydro Experiment.

	NSSL WoF
Native Spatial Resolution*	3 km Lambert Conformal
Update Time	30-minutes
Forecast Period	0–6 h
Forecast Period used in HMT-Hydro	0–3 h
Forecast Time Step	5 minutes**
Domain Area	900 × 900 km floating domain

* The model data are interpolated onto the MRMS grid space (1 km Cartesian) for use in the FLASH system.

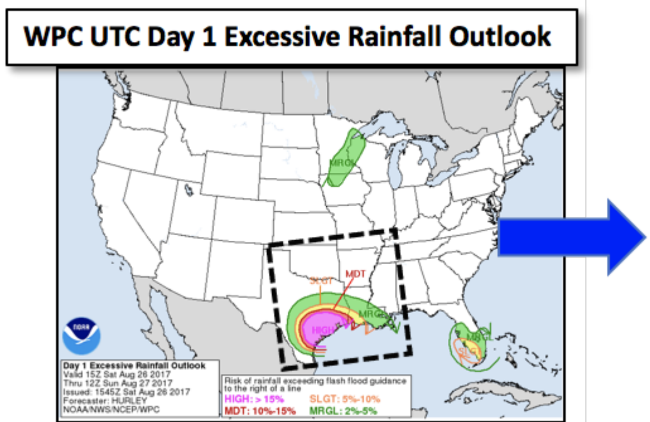
** The NSSL WoF QPFs are accumulated to 10 minutes for ingest into the FLASH system based on the frequency of FLASH hydrologic data output.

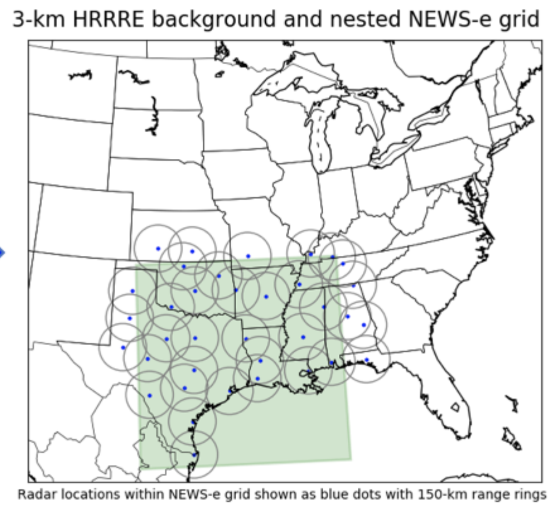
NSSL Experimental Warn-on-Forecast (WoF) System for ensembles (NEWS-e)

The NSSL Experimental Warn-on-Forecast (WoF) System for ensembles (NEWS-e) is an on-demand, regional, numerical weather prediction model based convective-scale ensemble data assimilation and forecast system for very short-range (0–6 h) probabilistic forecasts of severe thunderstorms and associated hazards, such as the rotational characteristics, heavy rainfall, damaging hail and high winds. The placement of the NEWS-e domain of the day is driven by Day 1 outlook from the national centers like the Storm Prediction Center (SPC) and the Weather Prediction Center (WPC). An example of WPC's Day 1 Excessive Rainfall Outlook and the corresponding NEWS-e grid overlaid with WSR-88D radars used for data assimilation is shown here.

The NEWS-e system uses ESRL/GSD Experimental HRRR Ensemble (HRRRE) for initial and boundary conditions. The domain covers a ~900-km wide region and consists of 36-member ensemble. All ensemble members utilize the NSSL 2-moment microphysics parameterization and the RAP land-surface model, but the PBL and radiation physics options are varied amongst the ensemble members to address uncertainties in model physics. MRMS reflectivity, WSR-88D Level II radial velocity data, cloud water path retrievals from the GOES-16 imager, and conventional observations from NCEP are assimilated in the system every 15 minutes using an EnKF data assimilation approach. The NEWS-e provides sub-hourly 0–6 hour ensemble forecasts with WRF history files every 5 minutes for the duration of the event. Differences in model specifications between HRRRE and NEWS-e are shown below.

The Warn-on-Forecast ensemble forecast products are viewable using the web-based NEWS-e Forecast Viewer at https://www.nssl.noaa.gov/projects/wof/news-e/wpc/ and https://www.nssl.noaa.gov/projects/wof/news-e/realtime/





	HRRRE	**NEWS-e**
Model Version	WRF-ARW v3.8+	WRF-ARW v3.8+
Grid Points	1150 × 960 × 50	300 × 300 × 50
Grid Spacing	3 km	3 km
EnKF Cycling	36 mem w/ **GSI-EnKF every 1 h**	36 mem w/ **GSI-EnKF every 15 min**
Observations	**Conventional obs:** T, q_v, u, v, and p from rawinsonde, aircraft, surface (land and marine), profiler; **MRMS reflectivity**	**Conventional obs:** T, q_v, u, v, and p from rawinsonde, aircraft, surface (land and marine), profiler; **WSR-88D radial velocity** **MRMS reflectivity** **Cloud-water path (GOES-16)**
Radiation LW/SW	RRTMG/RRTMG	Dudhia/RRTM or RRTMG/RRTMG
Microphysics	Thompson (aerosol aware)	NSSL 2-moment
Cumulus Parameter	none	none
PBL	MYNN	YSU, MYJ, or MYNN
LSM	RUC (Smirnova)	RUC (Smirnova)

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