2014 Experimental Warning Program (EWP2014)
NOAA Hazardous Weather Testbed, Norman, OK

Multi-Radar/Multi-Sensor (MRMS) Hydro Experiment
In coordination with HMT/Flash Flood and Intense Rainfall (FFaIR) experiment

- DRAFT OPERATIONS PLAN -

July 7 – August 1, 2014
National Weather Center
Norman, OK

Updated 15 June 2014

1. INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (HWT) Experimental Warning Program (EWP) at the National Weather Center (NWC) in Norman, Oklahoma, is hosting the 2014 EWP Spring Program (EWP2014). The HWT is 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). The other activity in the HWT, and the subject of this Operations Plan, 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.

The **Multi-Radar/Multi-Sensor (MRMS) Hydro Experiment ("HWT-hydro" hereafter)** will extend the EWP in Norman, OK to focus on experimental watches and warnings for hydrologic extremes including flash floods during the warm season. The experiment will be conducted in real time in close coordination with the 2nd annual **Flash Flood and Intense Rainfall experiment (FFaIR)** at the Weather Prediction Center (WPC).

We are seeking feedback from NWS operational forecasters. User comments will be collected during shifts, forecasters will participate in live blogging, electronic surveys will be given at the end of the experiment, and discussions will occur during de-briefings. Remember, inputs from NWS operational meteorologists and hydrologists are vital to the improvement of the NWS warning process, which ultimately saves public lives and property. The NWS feedback on this test is most important for future development for the NWS and eventual implementation of new applications, display, and product concepts into AWIPS2 and other operational systems.

You are part of a unique team of NOAA scientists, comprised of researchers, technology developers, and operational forecasters, working together to test new and experimental severe weather warning decision making technology for the NWS. In this operations plan you will find basic information about the various new technologies and products that we are testing during the 2014 warm season, as well as logistical information about the four-week program for all participants.

2. OBJECTIVES

The HWT-hydro experiment will be conducted in collaboration with FFaIR to simulate the real-time workflow from forecast and guidance products in the 6-24 hr timeframe from WPC to experimental flash flood watches and warnings issued in the 0-6 hr period. The HWT-hydro team will act as a "virtual, floating forecast office" to shift its area of responsibility on a daily basis to where heavy precipitation events and concomitant flash flooding is anticipated to occur. The primary scientific goals of the 2014 HWT-hydro experiment are the following:

- Evaluate the operational utility of experimental observations of flash flooding (i.e., local storm reports from the NWS, mPING citizen scientist reports, SHAVE targeted observations from the public, and USGS streamflow observations) for product validation
- Evaluate the relative skill of experimental flash flood monitoring and short-term prediction tools from MRMS QPE, QPE recurrence intervals, QPE-to-flash flood guidance ratios, and simulated surface runoff recurrence intervals from the Flooded Locations And Simulated Hydrographs (FLASH) hydrologic modeling framework
- Determine the benefit of increasing lead time (vs. potential loss in spatial accuracy and magnitude) through the use of HRRR 0-6 hr precipitation forecasts as forcing to FLASH
- Explore the utility of experimental flash flood watches and warnings that communicate both uncertainty (i.e., probability of occurrence) and magnitude (nuisance vs. major flooding events)
- Employ human factors research methods to determine "best practices" for using flash flood prediction tools in experimental watches/warnings and optimizing their displays in AWIPS2
- Enhance cross-testbed collaboration as well as collaboration between the operational forecasting, research, and academic communities on the forecast challenges associated with short-term flash flood forecasting

HWT-hydro 2014 will operate in a real-time environment in which participants from across the weather enterprise can work together to explore the utility of emerging flash flood monitoring and short-term prediction tools for improving flash flood watches and warnings. An overarching theme amongst the testbeds is the rapid testing of the latest observational and modeling capabilities so that they may be improved and optimized for transition to operational decision-making within the NWS. Another unique aspect of HWT-hydro is its bridging with FFaIR in order to simulate the collaboration that occurs between the national centers, river forecast centers, and local forecast offices during flash flood events.

3. OPERATIONS

The HWT-hydro experiment will run Monday-Friday for 4 weeks from July 7 to August 1, 2014. The physical location of the testbed will be in Studio 2 of the NWS Warning Decision and Training Branch (WDTB) on the 2nd floor of the National Weather Center building. Below is the estimated daily schedule for operations. While we anticipate following the schedule to a certain degree due to coordination with FFaIR and fixed-time reservation of conference rooms, we will also adapt the times due to changes in the weather and to the experiment itself.

a. Daily Schedule (all times are in CDT and are subject to change based on the weather)

Monday:

11:00am – 12:00am	Visitor welcome at NWC 1st floor entrance and orientation (Tour of NWC)
12:00pm – 1:00pm	Lunch at the Flying Cow Café
1:00pm – 1:45pm	Weather briefing with FFaIR
1:45pm – 4:00pm	Introduction to experimental flash flood products, Anticipated outcomes, AWIPS2 familiarization and procedure loading, Evaluation methodology, Human factors observational study and consent)
??pm	Dinner break (time chosen based on weather)
4:00pm – 6:45pm	Experimental issuance of flash flood watches and warnings (watches will be valid from 2100 UTC to 0600 UTC, warnings valid from 2100 UTC to 0300 UTC)
6:45pm – 7:00pm	Collection and archiving of materials and notes

Tuesday-Thursday:

12:00pm – 1:00pm	Lunch at the Flying Cow Café
1:00pm – 1:45pm	Weather briefing with FFaIR

1:45pm – 4:00pm	Evaluation and discussion of prior day's tools and watches/warnings
??pm	Dinner break (time chosen based on weather)
4:00pm – 7:45pm	Experimental issuance of flash flood watches and warnings (watches will be valid from 2100 UTC to 0700 UTC, warnings valid from 2100 UTC to 0400 UTC)
7:45pm – 8:00pm	Collection and archiving of materials and notes, seminar prep

Friday:

8:00am – 10:00am	Evaluation and discussion of prior day's tools and watches/warnings
10:00am – 11:00pm	"Tales from the Testbed" seminar preparation
11:00pm – 12:00pm	Working Lunch ("Best practices" questionnaire)
12:00pm – 1:00pm	"Tales from the Testbed" weekly webinar
1:00pm – 1:15pm	Feedback survey
1:15pm – 1:30pm	Group photo
1:30pm	Adjourn

b. Activity Descriptions

Visitor welcome – Participants who are NWS employees are reminded to bring their NOAA CAC cards in order to pass through security. Foreign Nationals need to contact the project PI, JJ Gourley (jj.gourley@noaa.gov) well in advance in order to get the required clearance.

The NWC is a University of Oklahoma building that houses several NOAA facilities. The HWT-hydro Operations Area will be held in the WDTB and is considered a secure NOAA location. Therefore, certain NOAA security requirements are in effect for visitors to the HWT-hydro experiment. All NOAA employees are required to visibly wear, at all times, their NOAA identification badges, in addition to special "HWT Spring Experiment" badges they will receive upon Monday check-in. Non-NOAA visitors must check in each day with the security desk using their state-issued IDs at the 1st floor entrance to obtain a daily visitor pass.

The NOAA participants will be issued one white magnetic key card which will allow entrance into certain secure locations in the NWC. These include the NOAA main hallway (with access to a kitchenette) and the HWT-hydro operations area in WDTB Studio 2. Each door card has an associated 4-number PIN that is keyed into the lock pad in order to gain entry. Participants must return their door key cards and visitor badges to the Operations Coordinator before they leave the NWC on Friday to return home, as these will be recycled each week for the next set of participants.

Weather briefing – The weather briefing will be primarily directed by FFaIR. HWT-hydro participants will join the briefing (via GotoMeeting and conf call) in the WDTB conference room. The primary goals of the briefing are to: 1) provide feedbacks to the FFaIR participants regarding the selection of the prior day's domain and guidance products, 2) summarize the day's model-based forecasts of heavy rainfall, and 3) provide the day's outlook for probabilistic flash flooding.

Introduction – Description of the FLASH experimental products are provided in Appendix 2 at the end of this document. Participants are encouraged to familiarize themselves with the products in advance of the experiment. The experiment coordinators will use the Monday 1:45 time slot to describe the products in more detail and be able to answer participants' questions. We will solicit participant feedbacks at this point because the materials provided in Appendix 2 (and also on the Vlab Wiki) and the powerpoints will eventually be used to develop official WDTB training materials. We will also cover the anticipated outcomes the researchers expect with the experiment. While we hope to use AWIPS2 to display experimental FLASH products as well as operational model and observational products to issue experimental watches/warnings, and to evaluate the products using experimental observations and operation watches/warnings, we are also prepared to use the http://flash.ou.edu website. Thus, we ask the participants to familiarize themselves with the real-time display of products and observations through the website. All evaluations during the HWT-hydro experiment will have a subjective component. We will present to the participants our strategies for evaluating the experimental flash flood observations, forecast tools, watches and warnings. The latter two will also include information about uncertainty and magnitude. Lastly, a PhD student has received authorization from the University of Oklahoma's Institutional Review Board to conduct an observational study on forecaster's best practices in using the FLASH products and communicating uncertainty in the experimental products. We will describe this human factors study and request consent from the potential participants.

Experimental Watches/Warnings – We plan on using AWIPS2 to issue the experimental products beginning at approximately 2100 UTC, depending on the day's weather. The focus region will initially correspond to the FFaIR guidance, but is expected to change based on the observations. The experimental watches and warnings are intended to approximate the responsibilities of a local forecast office, but with the ability to adapt its county warning area. In the event of multiple flash flooding events occurring in separate regions of the US, the experimental domain should prioritize its single domain based on anticipated impacts and perhaps population density (in order to obtain dense reports). It is understood that operational procedures differ from office-to-office in regard to the issuance of flash flood watches. The HWT-hydro experiment will adopt a nationally consistent approach that will be based on observed precipitable water values, short-term QPFs from the HRRR, radar trends, observed river states from available USGS stations (http://waterwatch.usgs.gov/?id=ww_flood) and FLASH products, rather than model guidance of heavy rainfall. Thus, it will more closely mimic the lead-times and space-time scales typically seen with severe weather watches. The experimental watches/warnings will differ from those issued in operations in that they will include estimates of probability of occurrence (low, medium, high) corresponding to two flash flooding magnitudes (nuisance, major).

Subjective Evaluation – Because the evaluations performed in HWT-hydro involve subjectivity, we have devoted at least two hours each day for this important activity. We expect a great deal of information to be inserted into the comments section following each evaluation. First, participants will examine the observations of flash flooding coming from NWS LSRs, mPING citizen-scientist reports, USGS streamflow, and SHAVE targeted public observations with respect to their capability of capturing 1) areal extent, 2) magnitude, and 3) specific impacts. Next, the observations will be used together to rank the MRMS QPE, QPE recurrence intervals, QPE-to-flash flood guidance ratios, and FLASH runoff recurrence intervals in terms of 1) detection of the event (hit, miss, false alarm), 2) spatial accuracy, and 3) magnitude. The HRRR-forced FLASH products will be evaluated to determine 1) their accuracy in comparison to the MRMS-forced FLASH products and 2) amount of lead time provided. The experimental watches are warnings will be evaluated in terms of their communication of uncertainty and magnitude. Watches/warnings associated to low, medium, and high probabilities are meant to correspond to an observation occurring 25%, 50%, and 75% of the time, respectively. All flash flooding observations will be employed to assess whether an event falls into the nuisance or major category. Note that both SHAVE and mPING reports subdivide the flash flooding reports as: 1) river/creek overflowing, 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. Reports of 1 and greater will be used to validate a nuisance flood, while 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. Experimental watches/warnings will be compared and contrasted to operationally issued products.

"Tales from the Testbed" Webinar – Participants will be given time throughout the forecast process Monday-Thursday to conduct live blogging and to collect and archive products and notes. The logistics facilitator will work with the forecasters each day during the week of operations to help them capture images and develop their contribution to the end-of-week webinars. It is encouraged that many images are captured, and used as Blog entries, as this will make the collation of the images for the webinar that much easier. The final 15 minutes of the Monday through Wednesday and 30 minutes of the Thursday shifts will be devoted to gathering all the images for the week and coming up with a strategy for an initial draft of the presentation. Forecasters will be given an hour on Friday morning from 10am to 11am to finalize their presentation and practice. After lunch, from 12-1 pm CDT, we will regroup and present the forecasters' experience throughout the experiment in a webinar setting. The WDTB will facilitate the webinars. The forecasters will have approximately 22 minutes to discuss their key takeaways that week. 15 minutes will remain for audience feedback and questions. The audience is anyone with an interest in what we are doing to improve flash flood monitoring and prediction observations/tools and NWS flash flood watch and warning products. Anticipated audience included NWS field personnel, regional and national headquarters folks, and our other stakeholders in NOAA and elsewhere.

Feedback Survey – During operations, feedback will be obtained via the EWP Blog entries, as well as real-time discussions with the project investigators. At the end of the week, project participants will fill out an online feedback survey. This is an inaugural experiment so we fully anticipate that the comments from participants will be frank and forthcoming. Participant feedbacks will be used immediately to improve the experimental design for coming days, weeks and next year.

4. PRODUCTS

HWT-Hydro experiment participants will have access to the full suite of operational observations and forecast model products available from the AWIPS2 real-time data feed. The subjective evaluations will focus on NSSL's MRMS and FLASH products that are being developed and improved for rapid transition to operational use in the NWS. Specifically, participants will subjectively evaluate observations of flash flooding from NWS local storm reports, citizen-scientist reports from the meteorological Phenomena Indication Near the Ground (mPING) project, targeted reports from the public in the Severe Hazards And Verification Experiment (SHAVE), and USGS streamflow observations. The primary flash flood monitoring and prediction tools to be evaluated include MRMS QPEs, QPE recurrence intervals, QPE-to-FFG ratios, and FLASH runoff recurrence intervals. Table 1 summarizes the experimental and operational flash flood observations and tools that will be the focus of the HWT-hydro experiment.

Table 1. Summary of flash flood observations and tools to be evaluated during HWT-hydro for a four-week experimental period in July 2014.

Provider	Product	Description
Flash Flood Observations		
NWS	Local Storm Reports	Operational reports of flash flooding used to validate warnings
NSSL	mPING	Citizen-scientist reports of flash flooding at 4 levels of severity
NSSL	SHAVE	Targeted reports from the public on details of flash flooding at high resolution
USGS/NWS/NSSL	Streamflow	Reports of streamflow that has exceeded flood stage or a nominal return period flow (e.g., 5-yr return) in small, gauged basins
Flash Flood Monitoring and Prediction Tools (primarily for issuance of warnings)		
NSSL	MRMS QPE	Quantitative precipitation estimates from radar-only algorithms at multiple accumulation periods (1-6 hr)
NSSL	QPE recurrence interval	Compares MRMS QPE to 1-, 3-, and 6-hr precipitation frequencies from NOAA Atlas 14*. The product indicates when a particular return period threshold is exceeded by estimated rainfall. (available every 5 minutes)
RFCs/WPC/NSSL	QPE-to-FFG ratio	Compares a 1-, 3-, and 6-hr rolling sum of MRMS QPE to the most recent issuance of 1-, 3-, and 6-hr FFG** (available every 5 minutes)
NSSL	Max Return Period	Maximum flooding return period forecast by FLASH during an interval spanning 30 min prior to valid time to 6 hrs after valid time (available at 0, 15, 30, and 45 minutes after every hour)
Short-term Forecasting Tools (primarily for issuance of watches)		
NSSL/GSD	Precipitable Water Analysis	RAP analysis of precipitable water (available hourly)
NSSL/GSD	Precipitable Water Anomaly Analysis	Comparison of above produce to sounding-observed values from 1948 to 2010. Values are provided as a percentile.
GSD	HRRR forecasts	QPFs provided to FLASH on 3 km/hourly basis for a lead time of 0-6 hrs

*NOAA Atlas 14 does not yet include precipitation frequency estimates for the Northwestern US, New England, New York, or Texas.

**RFCs typically update FFG at synoptic (00 UTC and 12 UTC) and sub-synoptic (06 UTC and 18 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 flash flood potential index) and so discontinuities in FFG values across RFC boundaries may exist.

5. PERSONNEL

a. Officers

Jonathan J. Gourley
Principal Investigator — jj.gourley@noaa.gov

Lans Rothfusz
NSSL HWT Liaison — lans.rothfusz@noaa.gov

Steve Martinaitis
Operations Coordinator — steven.martinaitis@noaa.gov

Zachary L. Flamig
Information Technology Coordinator — zac.flamig@noaa.gov

Race Clark
Logistics Coordinator — Robert.a.clark@noaa.gov

Jim Ladue
WDTB Liaison — james.g.ladue@noaa.gov

b. Weekly Coordinators

There will be one primary weekly coordinator and a secondary coordinator each operations week. The secondary weekly coordinator will be present at most activities throughout the week to assist the primary coordinator as necessary. The secondary weekly coordinators are also used as a "backup" in case the primary weekly coordinator becomes unavailable to fulfill their duties.

The weekly coordinator will be responsible for facilitating the operational activities of the week, including:

- Welcoming the participants and giving a tour of the building
- Facilitating the daily weather briefing with FFaIR
- Coordinating daily forecast operations
- Directing the daily subjective evaluations and filling out the questionnaire
- Helping forecasters in preparation of materials for the Tales from the Testbed Webinars
- Disseminating the exit survey

During operational periods of the experiment the weekly coordinator will be in charge of:

- Ensuring that the principle scientists are interacting with the forecasters
- Ensuring the smooth running of the technology and alerting various IT personnel when there are problems
- Coordinating dinner time
- Ensuring "crowd and noise control"
- Making sure the ops area is clean and all computers logged off at end of shift

The following are the primary and secondary weekly coordinators:

July 7-11
Elizabeth Mintmire Elizabeth.mintmire@ou.edu
Jess Erlingis j.m.erlingis@gmail.com

July 14-18
Brandon Smith Brandon.r.smith@noaa.gov
Maria Moreno maria@ou.edu

July 21-25
Brandon Smith Brandon.r.smith@noaa.gov
Ami Arthur ami.arthur@noaa.gov

July 28 - August 1
Jess Erlingis j.m.erlingis@gmail.com
Elizabeth Mintmire Elizabeth.mintmire@ou.edu

Cell phone numbers for experiment officers and weekly coordinators will be provided to participants in hard copy form upon their arrival at the National Weather Center.

c. Forecaster Participants

These participants will be the invited NWS WFO/RFC forecasters. The forecasters will be available full-time for the entire weekly shift schedule. There will be 2 forecaster participants per day. They will be helping to evaluate each experiment and providing feedback in real-time and during the debriefings as per the experiment objectives. They will be issuing watches and warnings using WarnGen on AWIPS2, live blogging, and evaluating the observations, tools, and forecast products. They will be working alongside Principle Scientists at any of the experiment stations during the week.

d. Observers/Additional Participants

The budget did not provide for broader participation beyond the two operational forecasters per week. But, we foresee voluntary participation from NWS and RFC forecasters at nearby offices (e.g., ABRFC, WGRFC). Moreover, we anticipate participation 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.

APPENDIX 1: Product Descriptions of Experimental MRMS-FLASH Products

CREST Maximum Return Period (CREST Max RP)

Short Description: Forecast of maximum return period from -30 min to +6 hrs, based on modeled stream flows from the Coupled Routing and Excess STorage (CREST) distributed hydrologic model

Alternate Names: CREST Max RP, Max RP, FLASH RP

Keywords: distributed hydrologic model, return period, flash flood, FLASH, Flooded Locations and Simulated Hydrographs

Spatial Resolution: 1 km X 1 km (4828 x 3179 pixels)

Temporal Resolution: 10 minutes

Input Sources: MRMS quality-controlled radar-only Precipitation Rate, RAP temperature analysis

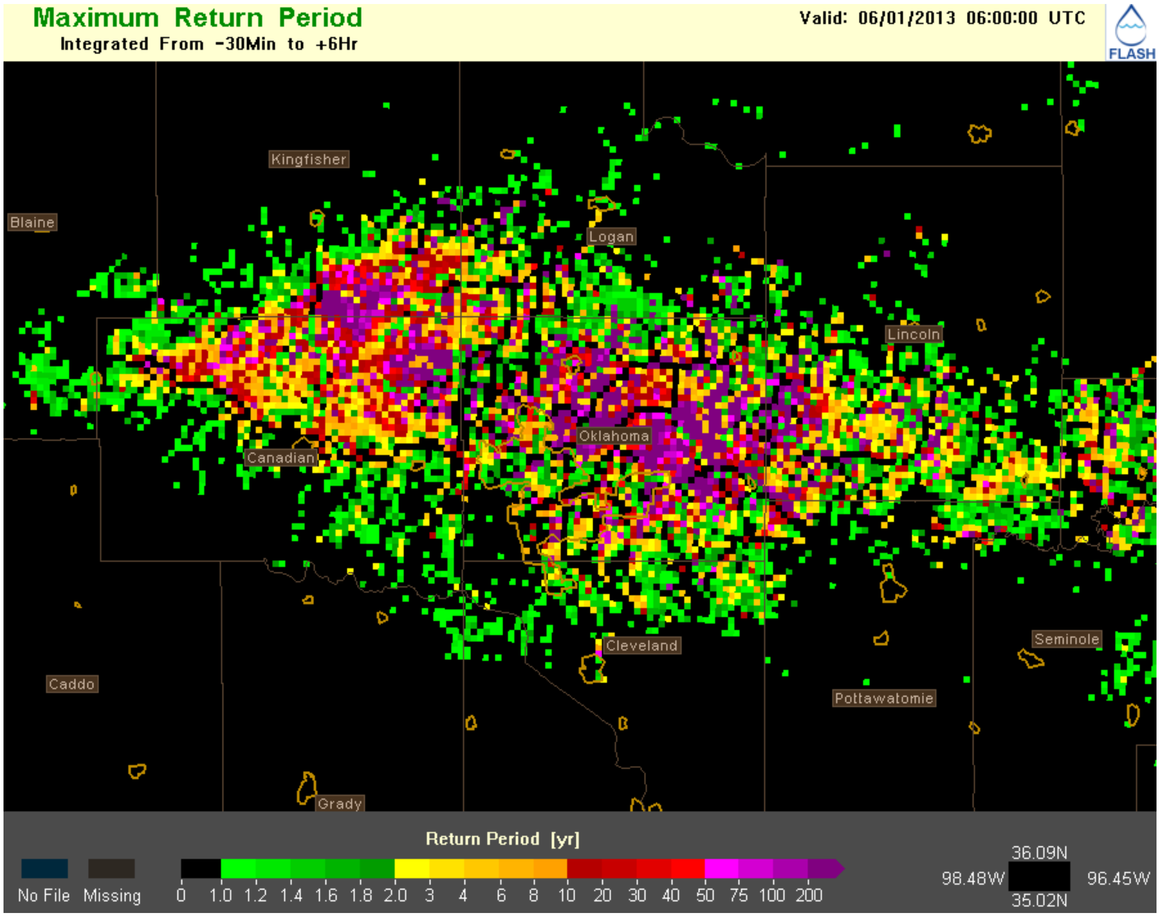
Availability: MOC/FOC

Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

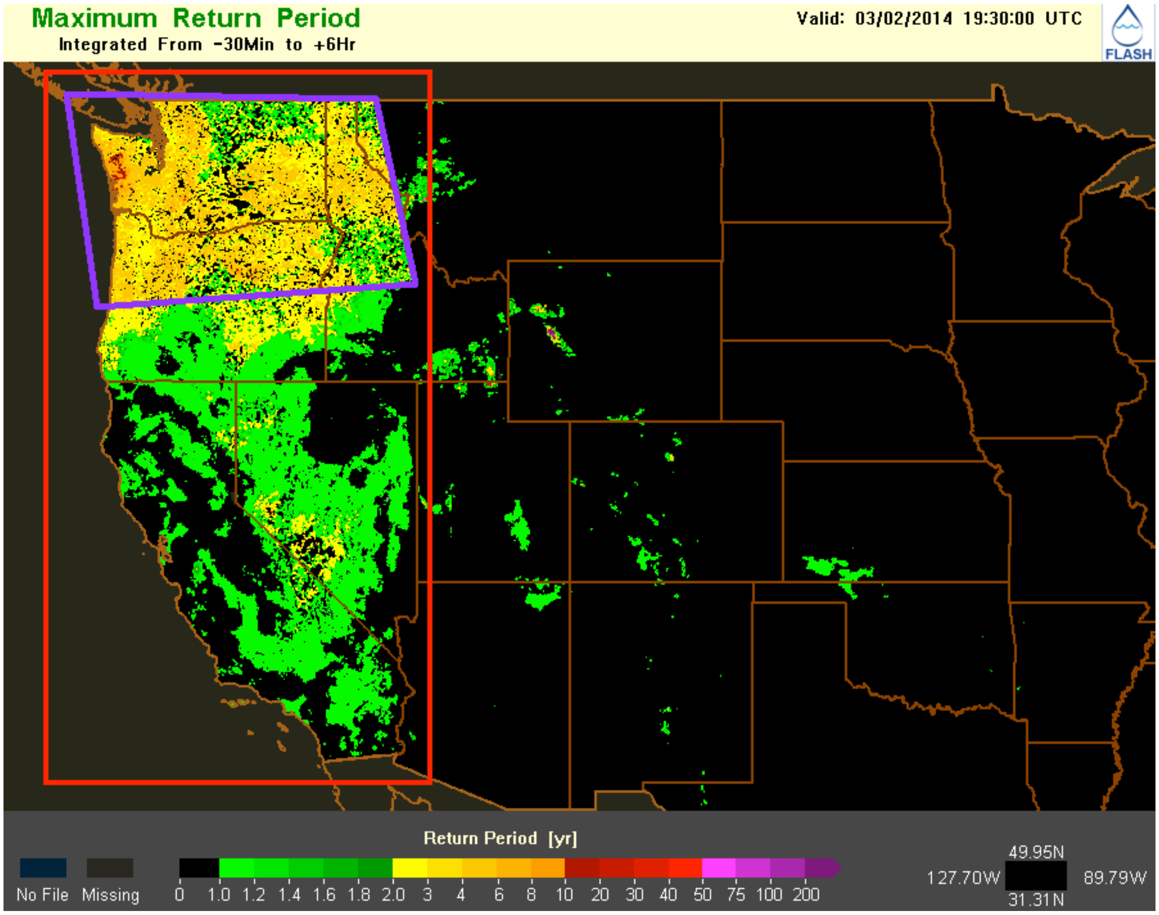
Long Description: Reed et al. (2007) outlined a paradigm for forward simulation of flash floods using distributed hydrologic models. This methodology, DHM-TF (distributed hydrologic model-threshold frequency), consists of historical and forward simulations. The historical simulation is obtained by running a DHM forced with the entire archive of available precipitation observations. Then the forward simulation comes from feeding near real-time precipitation data to the same DHM and allowing the model to run forward over a given time period. Currently, the model assumes that all rainfall stops at the model initialization time. Topographical, land cover, land use, and soil type information is used by the model to infiltrate and route precipitation downstream once it reaches the land surface. Additionally, temperature analyses from the RAP model are used to calculate potential evapotranspiration for forcing to the model. Thus the output from the DHM is a flow rate/discharge at every grid cell. The maximum flow rate within the forward simulation time window is compared to the distribution of flow rates at that same location from the historical simulation. Then the relative severity of the forecast flow rate at each grid cell can be determined. The CREST model serves as the DHM for this product (Wang et al. 2011). The severity of the predicted flow is expressed as a return period. Gourley et al. (2014) have found that this methodology exceeds the skill of flash flood guidance over portions of the U.S. where they conducted the comparison. The advantage of this method is that the model must only properly diagnose the historical rank of the event. The actual values of the simulated flow rates are thus of lesser importance.

Applications: CREST Max RP is used to diagnose areas of flash flooding potential over a 6.5-hr forecast window. CREST Max RP can also identify the relative severity of potential flash flooding impacts. Areas of contiguous pixels with high return periods are usually a cause for concern; a single pixel or a handful of isolated pixels with high return periods and no surrounding moderate return periods are not indicative of a flash flooding threat. Significant flash flooding can be expected when a return period of at least 10 years is exceeded.

Example Images:



This is output from the FLASH web interface showing the forecast maximum return period over central Oklahoma from 5:30 UTC to 12:00 UTC on 1 Jun 2013. This flooding event killed 14 people. Note the core area of 50-yr+ return periods that are surrounded by contiguous areas of progressively lower return periods. Large river systems are visible coursing through the middle of the high-return period area. These channels can experience very high flow rates without adverse effects and so the return periods in the channels themselves are negligible in this example.



This example illustrates western U.S. issues with this product (outlined in red and purple; see below).

Issues: This product relies heavily on precipitation estimates from weather radar. Areas with complex topography, beam blockage, wind farms, and other difficulties that contaminate QPE will be adversely affected. In arid regions this product should be used with extreme caution. Return periods of less than 20 years will appear at most time steps in the area outlined in the red box above, for two different reasons.

1) The historical archive of simulations is produced using 1-hr Stage IV QPE, which is not available from the Northwest River Forecast Center for the area outlined in purple.

2) Over the Intermountain West (i.e., southern Oregon, Idaho, Nevada and eastern California) these spurious return periods are due to a truncation error. In the historical simulation, not enough rain occurs in these areas for the model to simulate significant flows over these grid cells. In the forward simulation, the model sees very small flow rates (on the order of 0.00000001 cfs) in these areas. When these tiny flow rates are compared to 0 cfs from the historical simulation, the model determines that the grid cells have a non-zero return period.

In the literature, return periods of 2 years have been associated with bankfull (i.e., flooding) conditions on small natural streams (Sweeney 1992). This product usually finds that higher return periods are required for flooding impacts to commence.

References:

Gourley, J.J., Z. Flamig, Y. Hong, and K. Howard, 2014: Evaluation of past, present, and future tools for radar-based flash flood prediction in the USA. *Hydro. Sci. J.*, in press.

Reed, S., J. Schaake, and Z. Zhang, 2007: A distributed hydrologic model and threshold frequency-based method for flash flood forecasting at ungauged locations. *J. Hydrol.*, **337**, 402-420.

Sweeney, T., 1992: Modernized areal flash flood guidance. NOAA Tech. Rep. NWS HYDRO 44, Hydrologic Research Laboratory, National Weather Service, NOAA, Silver Spring, MD, 21 pp. and an appendix.

Wang, J., Y. Hong, L. Li, J. J. Gourley, S. Khan, K. Yilmaz, R. Adler, F. Policelli, S. Habib, D. Irwn, A. Limaye, T. Korme, and L. Okello, 2011: The coupled routing and excess storage (CREST) distributed hydrological model. *Hydrolog. Sci. J.*, **56**, 84-98.

CREST Maximum Streamflow (CREST Max Streamflow)

Short Description: Forecast of maximum streamflow from -30 min to +6 hrs, based on modeled stream flows from the Coupled Routing and Excess STorage (CREST) distributed hydrologic model

Alternate Names: CREST Max Streamflow, FLASH Streamflow

Keywords: distributed hydrologic model, streamflow, flash flood, FLASH, Flooded Locations and Simulated Hydrographs

Spatial Resolution: 1 km X 1 km (4828 x 3179 pixels)

Temporal Resolution: 10 minutes

Input Sources: MRMS quality-controlled radar-only Precipitation Rate, RAP temperature analysis

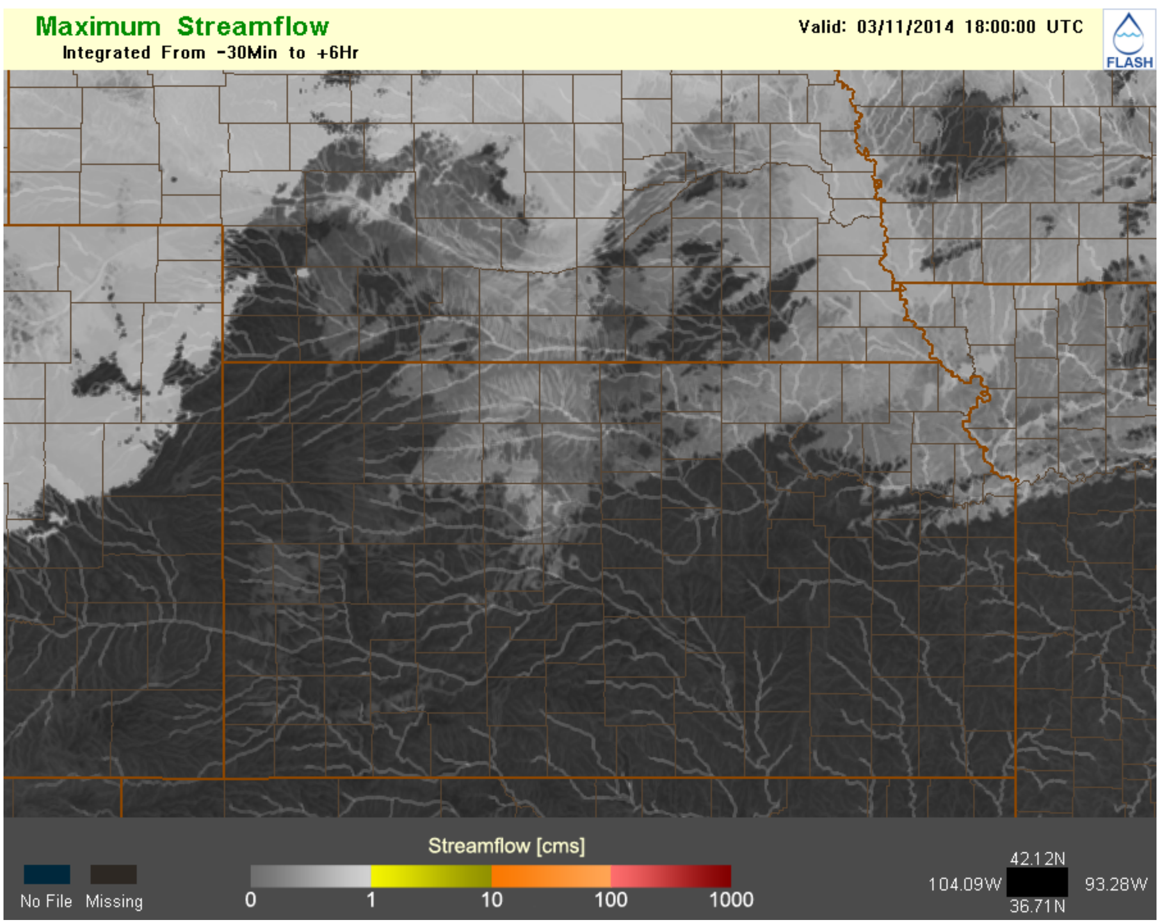
Availability: MOC/FOC

Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

Long Description: Distributed hydrologic models (DHMs) are used to simulated river or stream flow based on rainfall, evapotranspiration, topography, soil characteristics, and other land properties. CREST (Coupled Routing and Excess STorage) is the DHM used to make this product (Wang et al. 2011). A digital elevation model (DEM) and flow accumulation map (FAC) are used by the model to route water from precipitation downstream once it has reached and infiltrated into the land surface. Soil and land use information are used in the model to determine how much of the surface water will run off and how fast it will do so. Temperature analyses from the RAP model are used to calculate potential evapotranspiration for forcing to the model. Currently, the model assumes that all rainfall stops at the model initialization time. The output from the DHM is a flow rate/discharge at every grid cell.

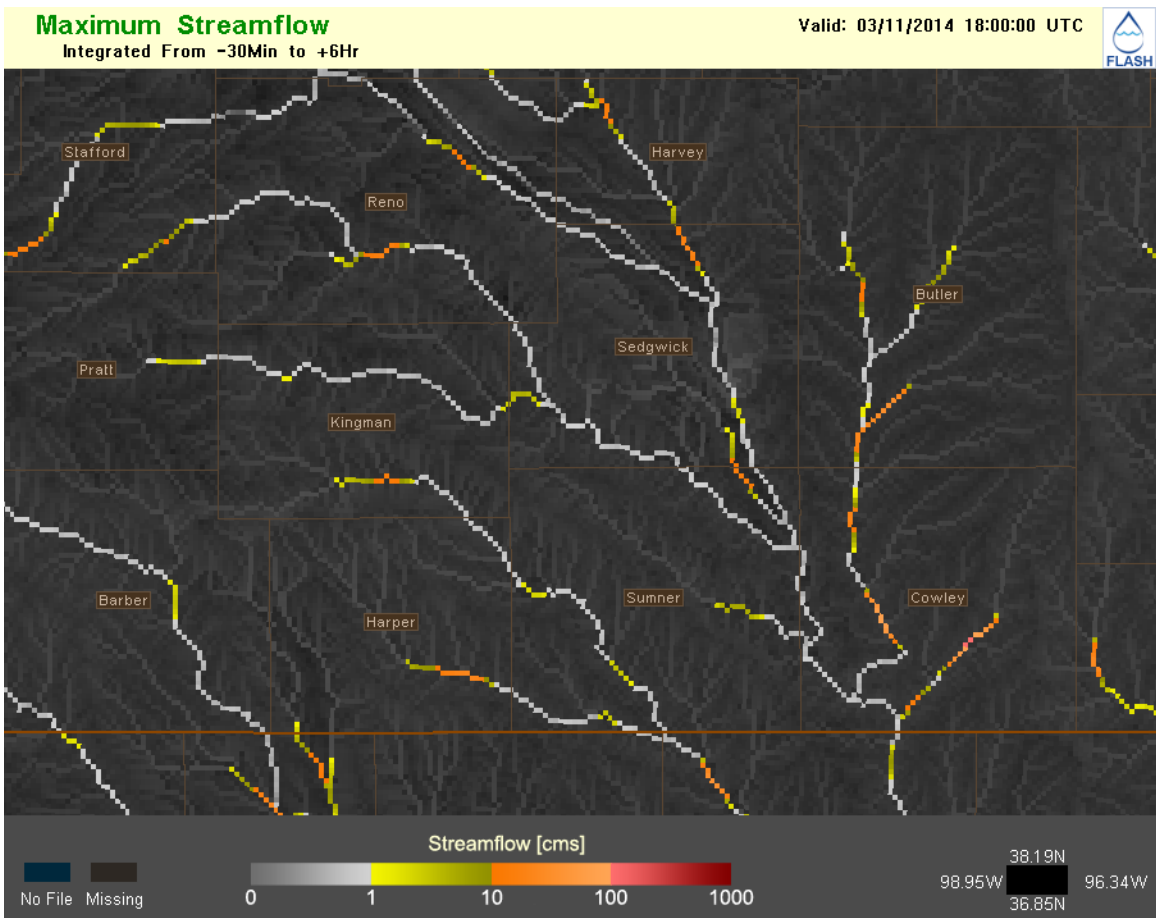
Applications: CREST Maximum Streamflow can be used to visualize stream and river networks and to identify broad areas where relatively high flows are occurring. This product can be used to further interrogate the CREST Maximum Return Period product.

Example Images:



This is output from the FLASH web interface showing the maximum streamflow over Kansas and southern Nebraska from 17:30 UTC 11 Mar 2014 to 00:00 UTC on 12 Mar 2014.

Note the preponderance of gray and white colors that appear from the top of the image south into northern Kansas. This is due to below-freezing surface temperatures appearing in the RAP model analysis. Because of this, the evapotranspiration (ET) forcing for the hydrologic model cannot be calculated. In southern Kansas, pixels in dark gray are forecast to have zero or very near zero stream flow. Pixels in lighter gray to near white are larger river networks containing some non-zero amount of water.



This is output from the FLASH web interface showing the maximum streamflow over south-central Kansas and the Wichita, KS metropolitan area from 17:30 UTC 11 Mar 2014 to 00:00 UTC on 12 Mar 2014. Pixels in dark gray are still those forecast by the model to be experiencing very low or no flows. Those appearing in lighter gray, white, yellow, or orange contain some non-zero amount of water. Without historical context or knowledge of the amount of water required to cause bankfull conditions on the channels in this area, this output cannot easily be used to forecast a flash flooding event.

Issues: FLASH is an uncalibrated hydrologic model. Therefore, streamflow values at any particular grid cell may not bear much resemblance to observed river conditions, because the FLASH system is designed to correctly place flooding events in a historical ranking, not to correctly forecast streamflow values at all pixels and time steps. This product should not be used in isolation to forecast floods or flash floods. Instead, this, the raw streamflow output from the model, should be used to investigate and confirm output from the CREST Maximum Return Period product.

References:

Wang, J., Y. Hong, L. Li, J. J. Gourley, S. Khan, K. Yilmaz, R. Adler, F. Policelli, S. Habib, D. Irwn, A. Limaye, T. Korme, and L. Okello, 2011: The coupled routing and excess storage (CREST) distributed hydrological model. *Hydrolog. Sci. J.*, **56**, 84-98.

CREST Soil Moisture

Short Description: Analysis of the soil saturation (%) from the Coupled Routing and Excess STorage (CREST) hydrologic model

Alternate Names: CREST SM, FLASH soil moisture

Keywords: distributed hydrologic model, soil moisture, soil saturation, FLASH, Flooded Locations and Simulated Hydrographs

Spatial Resolution: 1 km X 1 km (4828 x 3179 pixels)

Temporal Resolution: 10 minutes

Input Sources: MRMS quality-controlled radar-only Precipitation Rate, RAP temperature analysis

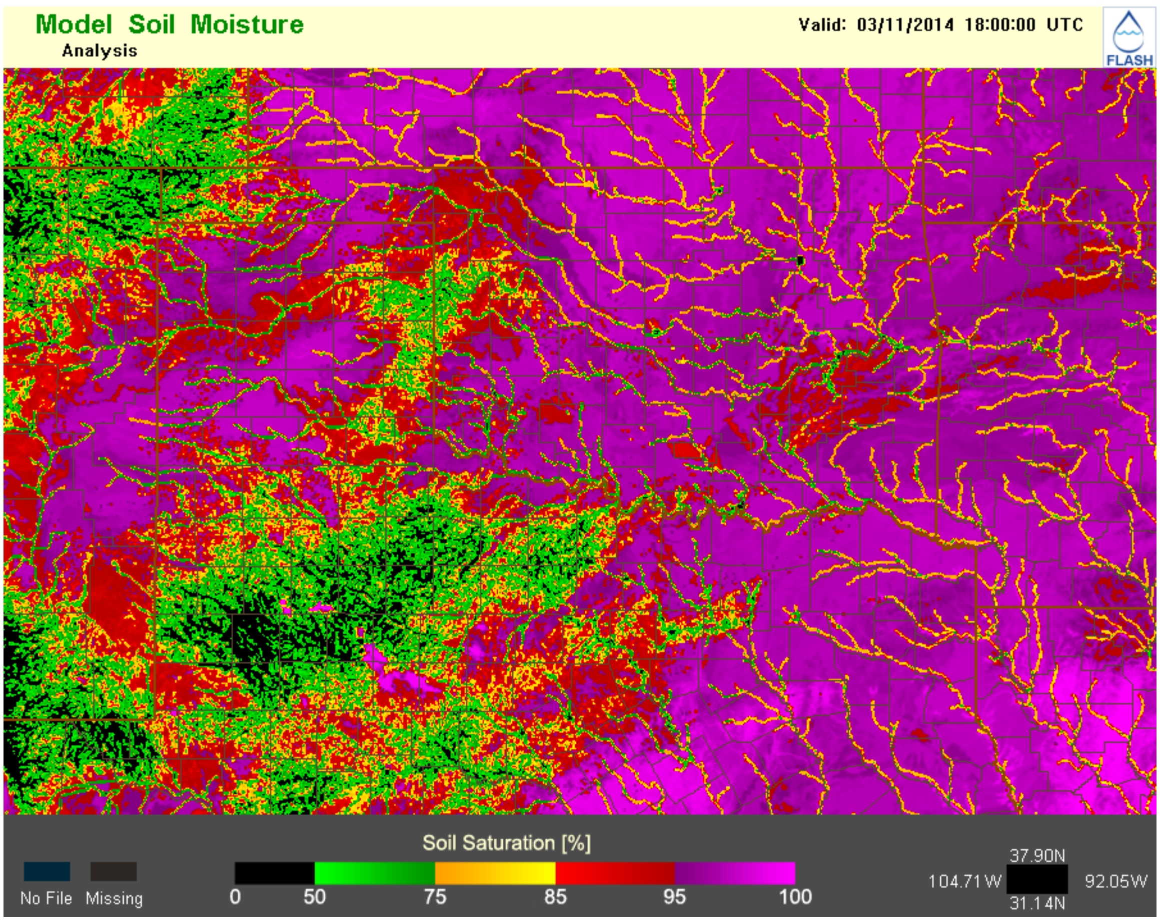
Availability: MOC/FOC

Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

Long Description: One of the key tasks in hydrologic modeling is quantifying the amount of moisture present in the soil within the model domain. This product expresses top-layer soil moisture as a percentage of saturation. Low soil moisture values imply that more water storage space is available in the soil layer; therefore a greater fraction of precipitation will infiltrate into the soil and be unavailable to cause surface runoff. High soil moisture values typically result in greater surface runoff and thus greater flash flood potential. In this product, the output is from the CREST model (Wang et al. 2011).

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

Example Images:



This is an analysis of soil saturation over Oklahoma and northern Texas from the CREST hydrologic model valid at 18 UTC on 11 Mar 2014. Values are expressed as a percentage of saturation. Large river channels appear as relative minima in the soil moisture field.

Issues: This product is a raw model field and has not been post-processed so it may bear little resemblance to *in situ* or remotely sensed soil moisture observations. This field should primarily be used to for diagnosing issues with or further investigating outputs from the CREST maximum return period product.

References:

Wang, J., Y. Hong, L. Li, J. J. Gourley, S. Khan, K. Yilmaz, R. Adler, F. Policelli, S. Habib, D. Irwn, A. Limaye, T. Korme, and L. Okello, 2011: The coupled routing and excess storage (CREST) distributed hydrological model. *Hydrolog. Sci. J.*, **56**, 84-98.

SAC Maximum Return Period (SAC Max RP)

Short Description: Forecast of maximum return period from -30 min to +6 hrs, based on modeled stream flows from the SACramento family (SAC)of hydrologic models

Alternate Names: SAC Max RP

Keywords: distributed hydrologic model, return period, flash flood, SAC

Spatial Resolution: 1 km X 1 km (4828 x 3179 pixels)

Temporal Resolution: 10 minutes

Input Sources: MRMS quality-controlled radar-only

Precipitation Rate, RAP temperature analysis

Availability: MOC/FOC

Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

Long Description: Reed et al. (2007) outlined a paradigm for forward simulation of flash floods using distributed hydrologic models. This methodology, DHM-TF (distributed hydrologic model-threshold frequency), consists of historical and forward simulations. The historical simulation is obtained by running a DHM forced with the entire archive of available precipitation observations. Then the forward simulation comes from feeding near real-time precipitation data to the same DHM and allowing the model to run forward over a given time period. Currently, the model assumes that all rainfall stops at the model initialization time.

Topographical, land cover, land use, and soil type information is used by the model to infiltrate and route precipitation downstream once it reaches the land surface. Additionally, temperature analyses from the RAP model are used to calculate potential evapotranspiration for forcing to the model. Thus the output from the DHM is a flow rate/discharge at every grid cell. The maximum flow rate within the forward simulation time window is compared to the distribution of flow rates at that same location from the historical simulation. Then the relative severity of the predicted flow rate at each grid cell can be determined. Any distributed hydrologic model can be used in this methodology. In this case a model from the Sacramento family is used (Burnash et al. 1973). The severity of the predicted flow is expressed as a return period. Gourley et al. (2014) have found that this methodology exceeds the skill of flash flood guidance in portions of the U.S. where they performed the comparison. The advantage of this method is that the model must only properly diagnose the historical rank of the event. The actual values of the simulated flow rates are thus of lesser importance.

Applications: SAC Max RP is used to diagnose areas of flash flooding potential over a 6.5-hr forecast window. SAC Max RP can also identify the relative severity of potential flash flooding impacts. Areas of contiguous pixels with high return periods are usually a cause for concern; a single pixel or a handful of isolated pixels with high return periods and no surrounding moderate return periods are not indicative of a flash flooding threat. Significant flash flooding can be expected when a return period of at least 10 years is exceeded.

Issues: This product relies heavily on precipitation estimates from weather radar. Areas with complex topography, beam blockage, wind farms, and other difficulties that contaminate QPE will be adversely affected. In arid regions this product should be used with extreme caution. Return periods of less than 20 years will appear at most times in the far northwest CONUS, because historical archive of simulations is produced using 1-hr Stage IV QPE, which is not available from the Northwest River Forecast Center for this area. In the literature, return periods of 2 years have been associated with bankfull (i.e., flooding) conditions on small natural streams (Sweeney 1992). This product usually finds that higher return periods are required for flooding impacts to commence.

References:

Burnash, R. J. C., R. Ferral, R. McGuide, 1973: A generalized streamflow simulation system – conceptual modeling for digital computers. US Department of Commerce, National Weather Service and State of California, Department of Water Resources.

Gourley, J. J., Z. Flamig, Y. Hong, and K. Howard, 2014: Evaluation of past, present, and future tools for radar-based flash flood prediction in the USA. *Hydro. Sci. J.*, in press.

Reed, S., J. Schaake, and Z. Zhang, 2007: A distributed hydrologic model and threshold frequency-based method for flash flood forecasting at ungauged locations. *J. Hydrol.*, **337**, 402-420.

Sweeney, T., 1992: Modernized areal flash flood guidance. NOAA Tech. Rep. NWS HYDRO 44, Hydrologic

Research Laboratory, National Weather Service,
NOAA, Silver Spring, MD, 21 pp. and an appendix.

SAC Maximum Streamflow (SAC Max Streamflow)

Short Description: Forecast of maximum streamflow from -30 min to +6 hrs, based on modeled stream flows from the SACramento (SAC) family of hydrologic models

Alternate Names: SAC Max Streamflow

Keywords: distributed hydrologic model, streamflow, flash flood, SAC

Spatial Resolution: 1 km X 1 km (4828 x 3179 pixels)

Temporal Resolution: 10 minutes

Input Sources: MRMS quality-controlled radar-only Precipitation Rate, RAP temperature analysis

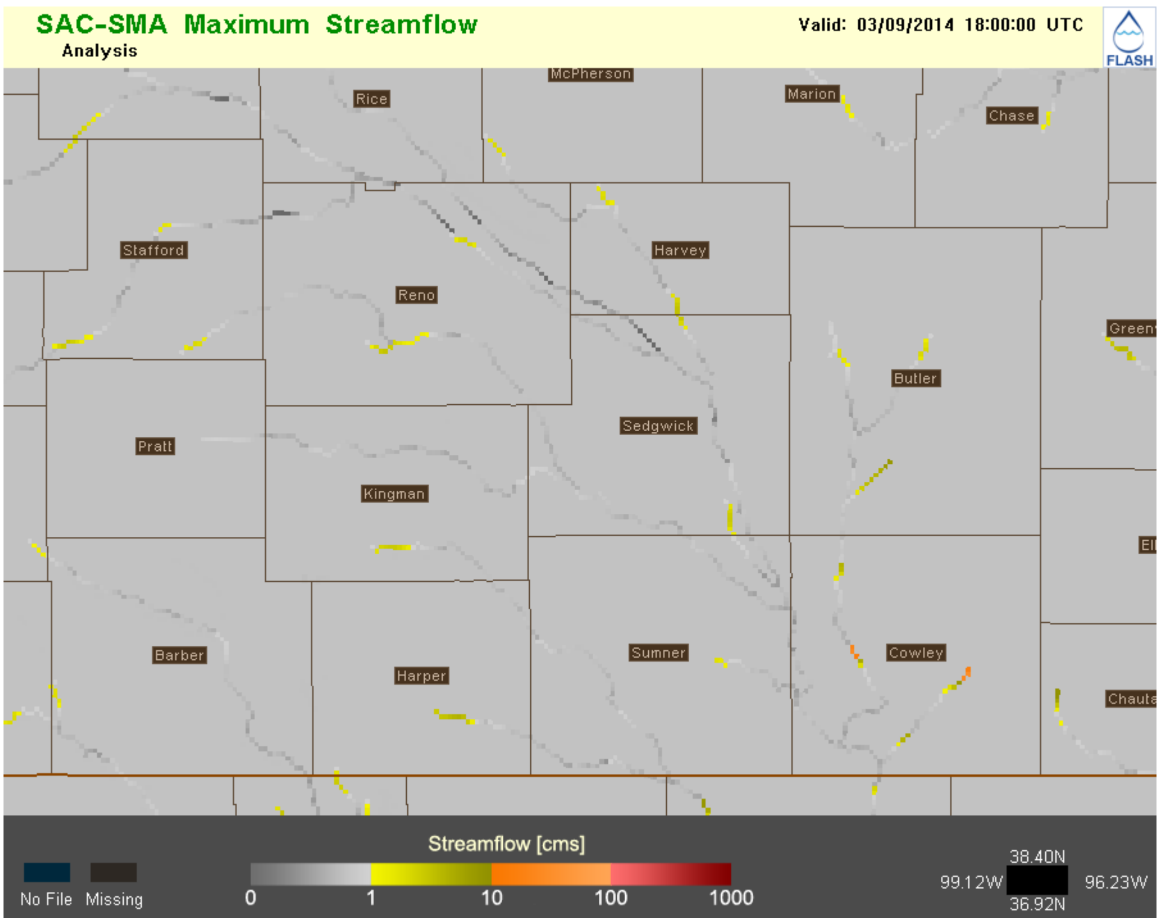
Availability: MOC/FOC

Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

Long Description: Distributed hydrologic models (DHMs) are used to simulated river or stream flow based on rainfall, evapotranspiration, topography, soil characteristics, and other land properties. SACramento (SAC) is the DHM used to make this product (Burnash et al. 1973). A digital elevation model (DEM) and flow accumulation map (FAC) are used by the model to route water from precipitation downstream once it has reached the land surface ad infiltrated. Soil and land use information are used in the model to determine how much of the surface water will run off and how fast it will do so. Temperature analyses from the RAP model are used to calculate potential evapotranspiration for forcing to the model. Currently, the model assumes that all rainfall stops at the model initialization time. The output from the DHM is a flow rate/discharge at every grid cell.

Applications: SAC Maximum Streamflow can be used to visualize stream and river networks and to identify broad areas where relatively high flows are occurring. This product can be used to further interrogate the SAC Maximum Return Period product.

Example Images:



This is the maximum streamflow forecast from the SAC model over south-central Kansas and the Wichita metropolitan area from 17:30 UTC 11 Mar 2014 to 00:00 UTC on 12 Mar 2014. Pixels in light gray are those forecast by the model to be experiencing very low or no flows. Those appearing in darker gray, white, yellow, or orange contain some non-zero amount of water. Without historical context or knowledge of the amount of water required to cause bankfull conditions on the channels in this area, this output cannot easily be used to forecast a flash flooding event.

Issues: SAC is an uncalibrated hydrologic model. Therefore, streamflow values at any particular grid cell may not bear much resemblance to observed river conditions, because the FLASH system is designed to correctly place flooding events in a historical ranking, not to correctly forecast streamflow values at all pixels and time steps. This product should not be used in isolation to forecast floods or flash floods. Instead, this, the raw streamflow output from the model, should be used to investigate and confirm output from the SAC Maximum Return Period product.

References:

Burnash, R. J. C., R. Ferral, R. McGuide, 1973: A generalized streamflow simulation system – conceptual modeling for digital computers. US Department of Commerce, National Weather Service and State of California, Department of Water Resources.

SAC Soil Moisture

Short Description: Analysis of the soil saturation (%) from the SACramento (SAC) family of hydrologic models

Alternate Names: SAC SM

Keywords: distributed hydrologic model, soil moisture, soil saturation, SAC

Spatial Resolution: 1 km X 1 km (4828 x 3179 pixels)

Temporal Resolution: 10 minutes

Input Sources: MRMS quality-controlled radar-only Precipitation Rate, RAP temperature analysis

Availability: MOC/FOC

Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

Long Description: One of the key tasks in hydrologic modeling is quantifying the amount of moisture present in the soil within the model domain. This product expresses top-layer soil moisture as a percentage of saturation. Low soil moisture values imply that more water storage space is available in the soil layer; therefore a greater fraction of precipitation will infiltrate into the soil and be unavailable to cause surface runoff. High soil moisture values typically result in greater surface runoff and thus greater flash flood potential. In this product, the output is from the SAC model with distributed parameters (Burnash et al. 1973).

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

Issues: This product is a raw model field and has not been post-processed so it may bear little resemblance to *in situ* or remotely sensed soil moisture observations. This field should primarily be used to for diagnosing issues with or further investigating outputs from the SAC maximum return period product.

References:

Burnash, R. J. C., R. Ferral, R. McGuide, 1973: A generalized streamflow simulation system – conceptual modeling for digital computers. US Department of Commerce, National Weather Service and State of California, Department of Water Resources.

Precipitation Return Period (Precip RP)

Short Description: Return period of estimated rainfall in a 1-, 3-, 6-, 12-, or 24-hr period based on historical rainfall information from NOAA Atlas 14

Alternate Names:

1-hour Precipitation RP

3-hour Precipitation RP

6-hour Precipitation RP

12-hour Precipitation RP

24-hour Precipitation RP

Precip RP

Rain RP

PRP

Keywords: rainfall, return period, precipitation, NOAA Atlas 14

Spatial Resolution: 1 km X 1 km (4828 x 3179 pixels)

Temporal Resolution: 2 minutes

Input Sources: MRMS quality-controlled radar-only QPE, RAP temperature analysis

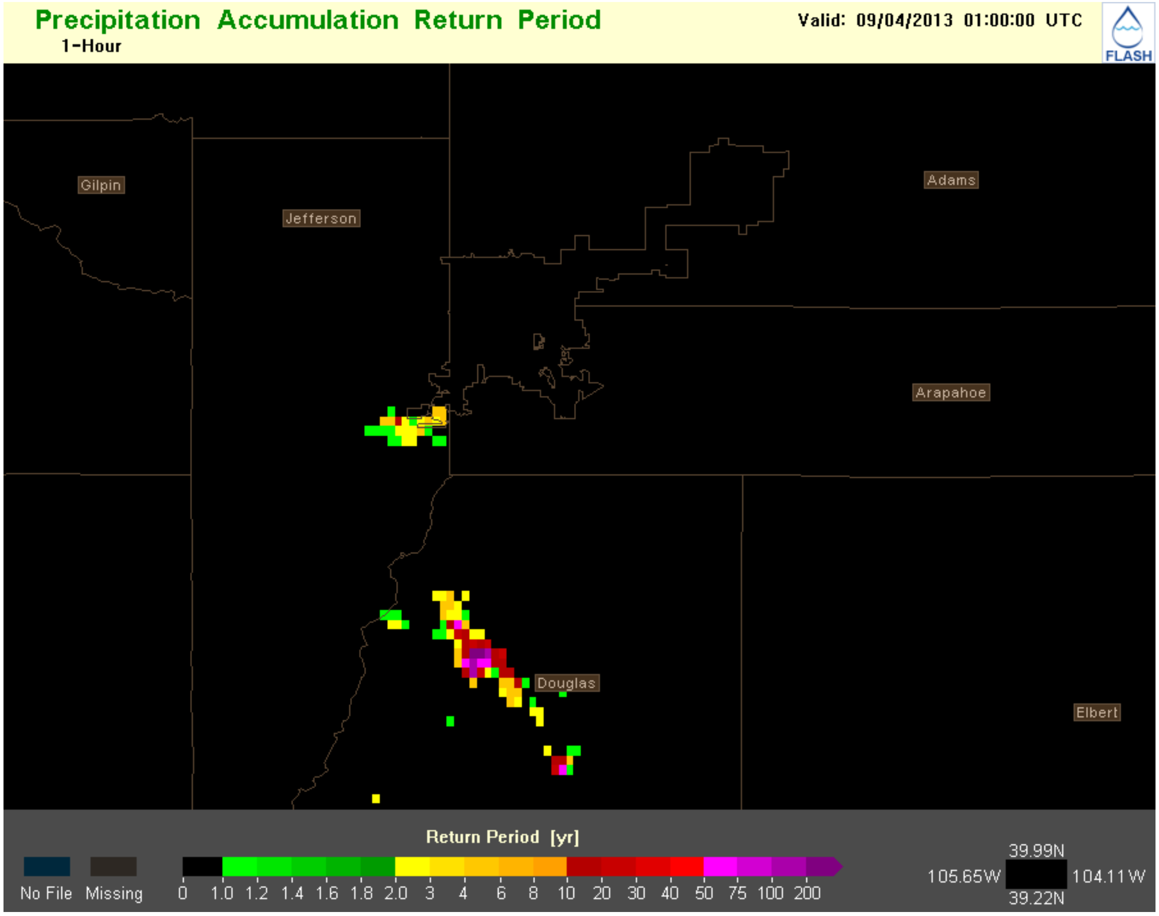
Availability: MOC/FOC

Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

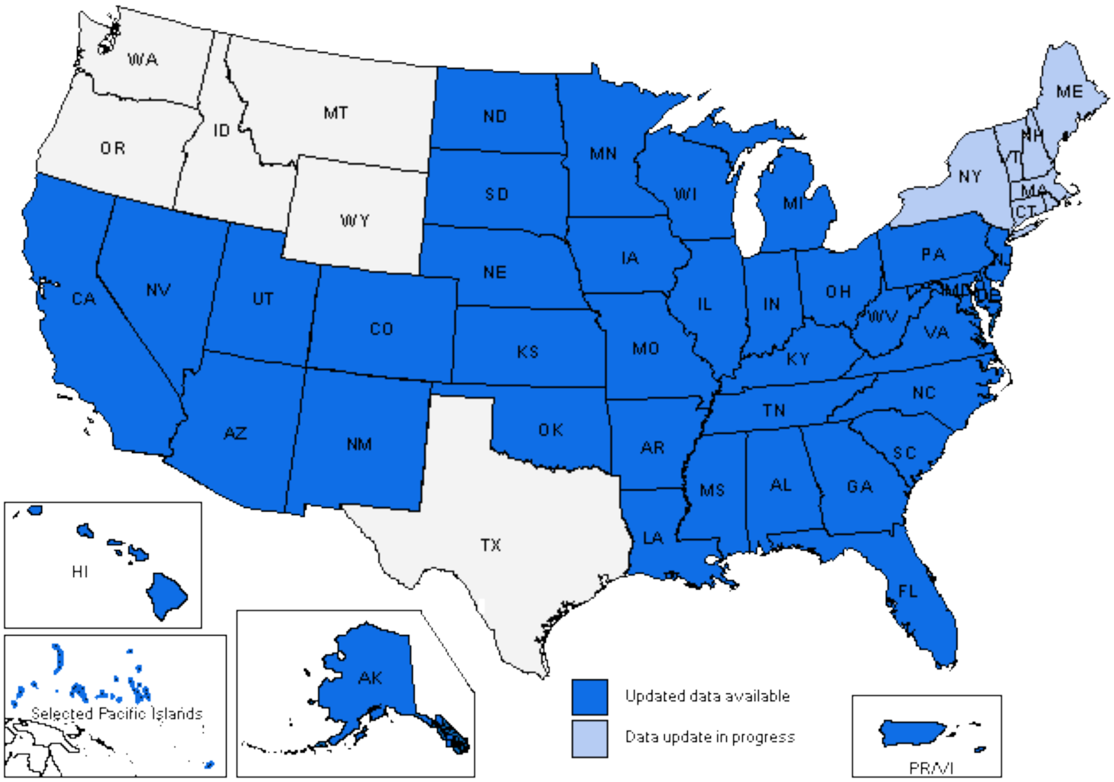
Long Description: NOAA's Hydrometeorological Design Studies Center provides digital access to estimates of point precipitation frequency values for stations across the United States. These values are based on data from the various volumes of NOAA Atlas 14. Detailed documentation regarding this atlas data is available in Perica, et al. (2013), but the general process requires historical rainfall distributions at weather stations across the U.S. From this historical data, rainfall amounts corresponding to various time intervals and return periods are determined. Then regional groups of stations are used to create gridded rainfall return period estimates. In the FLASH system, the NOAA Atlas 14 data exists as grids of precipitation values corresponding to a specific recurrence interval or return period. Then quality-controlled radar-only 1-hr precipitation estimate grids from the MRMS system (updated every 2 minutes) are compared to the Atlas 14 grids and the appropriate return period is returned.

Applications: This product can be used to identify how unusual a particular amount of rainfall for a given location and duration (1-, 3-, 6-, 12-, or 24-hrs). The longer the return period, the rarer the rainfall is.

Example Images:



This is output from the FLASH web interface showing the 1-hr Precipitation Accumulation Return Period between 00 UTC and 01 UTC 4 Sept 2013 on the west and south sides of the Denver, Colorado metropolitan area. The maximum return period is outlined in the dark purple pixels and corresponds to a one-hour rainfall return period of 100 years or more.



This product is currently only available for those parts of the Lower 48 colored in dark blue.

Issues: This product is not available for the entire FLASH domain. Additionally, this product consists entirely of rainfall information and does not include any land surface or soil factors that can contribute to flash flooding impacts.

References:

Perica, S., D. Martin, S. Pavlovic, I. Roy, M. St. Laurent, C. Trypaluk, D. Unruh, M. Yekta, and G. Bonnin, 2013: Precipitation-Frequency Atlas of the United States, Volume 9, Version 2.0. US Department of Commerce, NOAA, NWS. Available online at http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume9.pdf.

1-Hour Probability of Exceeding Precipitation Return Period

(1-hr POE)

Short Description: Probability of exceeding a 2-, 10-, or 50-yr rainfall return period in a span of 1-hr.

Alternate Names:

1-hour POE 2-year Precipitation RP

1-hour POE 10-year Precipitation RP

1-hour POE 50-year Precipitation RP

1-hr POE 2-yr RP

1-hr POE 10-yr RP

1-hr POE 50-yr RP

Keywords: rainfall, return period, precipitation, NOAA Atlas 14, probability of exceedance

Spatial Resolution: 1 km X 1 km (4828 x 3179 pixels)

Temporal Resolution: 2 minutes

Input Sources: MRMS quality-controlled radar-only 1-hr Precipitation Accumulation, NOAA Atlas 14

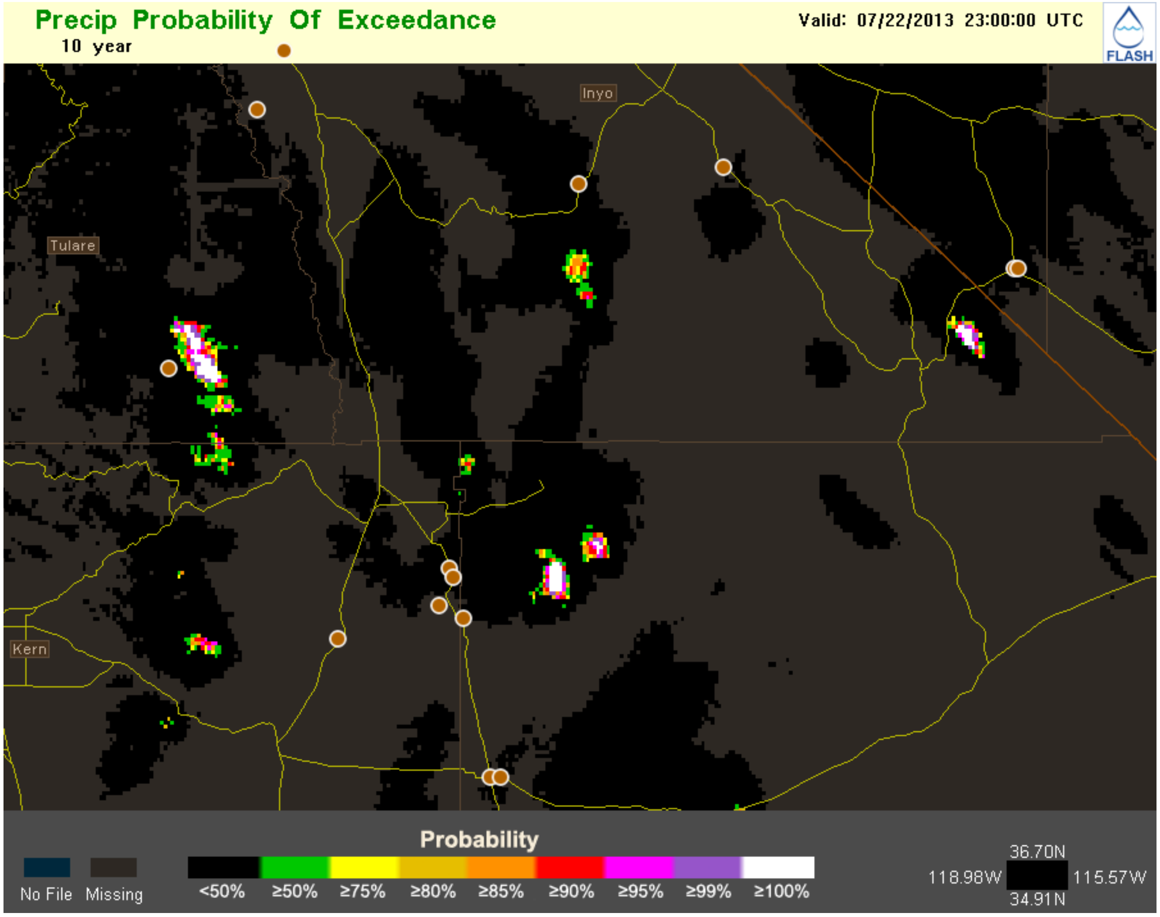
Availability: MOC/FOC

Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

Long Description: NOAA Atlas 14 includes gridded estimates of the amount of rainfall required in 1 hour to reach the 2-, 10-, or 50-yr return period threshold across many areas of the United States (Perica et al. 2013). The uncertainty in radar-only 1-hr precipitation estimate grids from the MRMS system (updated every 2 minutes) is derived as a probability density function (PDF) of rates in place of deterministic values. Then the PDFs are compared to the Atlas 14 grids and the probability of exceeding appropriate return periods is returned.

Applications: Given the uncertainty in radar 1-hr precipitation estimate, the higher the probability of exceeding a given return period, the higher the risk the rainfall to be rare. This product can be used to identify the risk of a particular amount of rainfall to be unusual at various levels.

Example Images:



This is output from the FLASH web interface showing the 1-hr Probability Of Exceeding a 10-year Precipitation Accumulation Return Period between 22 UTC and 23 UTC 22 Jul 2013 on the east side of the San Diego, California metropolitan area. The maximum return period is outlined in the white pixels and corresponds to a 100% probability of exceeding one-hour rainfall return period of 10 years or more.

Issues: This product is not available for the entire FLASH domain, but only in regions where there are precipitation frequency estimates from NOAA Atlas 14. Additionally, this product consists entirely of rainfall information and does not include any land surface or soil factors that can contribute to flash flooding impacts.

References:

Kirstetter, P.E., J.J. Gourley, Y. Hong, S. Moazamigoodarzi, E. Mintmire : Probabilistic Quantitative Precipitation Estimates with NOAA/NSSL Ground Radar-Based National Mosaic and QPE System. *Poster presentation at the 36th Conference on Radar Meteorology*, Breckenridge, CO, U.S., September 16-20, 2013.

Precipitation-to-Flash Flood Guidance Ratio (QPE-to-FFG Ratio)

Short Description: Ratio of 1-, 3-, or 6-hr radar precipitation estimate to the corresponding 1-, 3-, or 6-hr flash flood guidance grid

Alternate Names:

1-Hour QPE-to-FFG ratio

3-Hour QPE-to-FFG ratio

6-Hour QPE-to-FFG ratio

Keywords: flash flood guidance, FFG ratio, flash flood, FFG precipitation ratio, FFG/QPE ratio

Spatial Resolution: 1 km X 1 km (4828 x 3179 pixels)

Temporal Resolution: 2 minutes

Input Sources: MRMS quality-controlled radar-only QPE, national mosaicked flash flood guidance grid

Availability: MOC/FOC

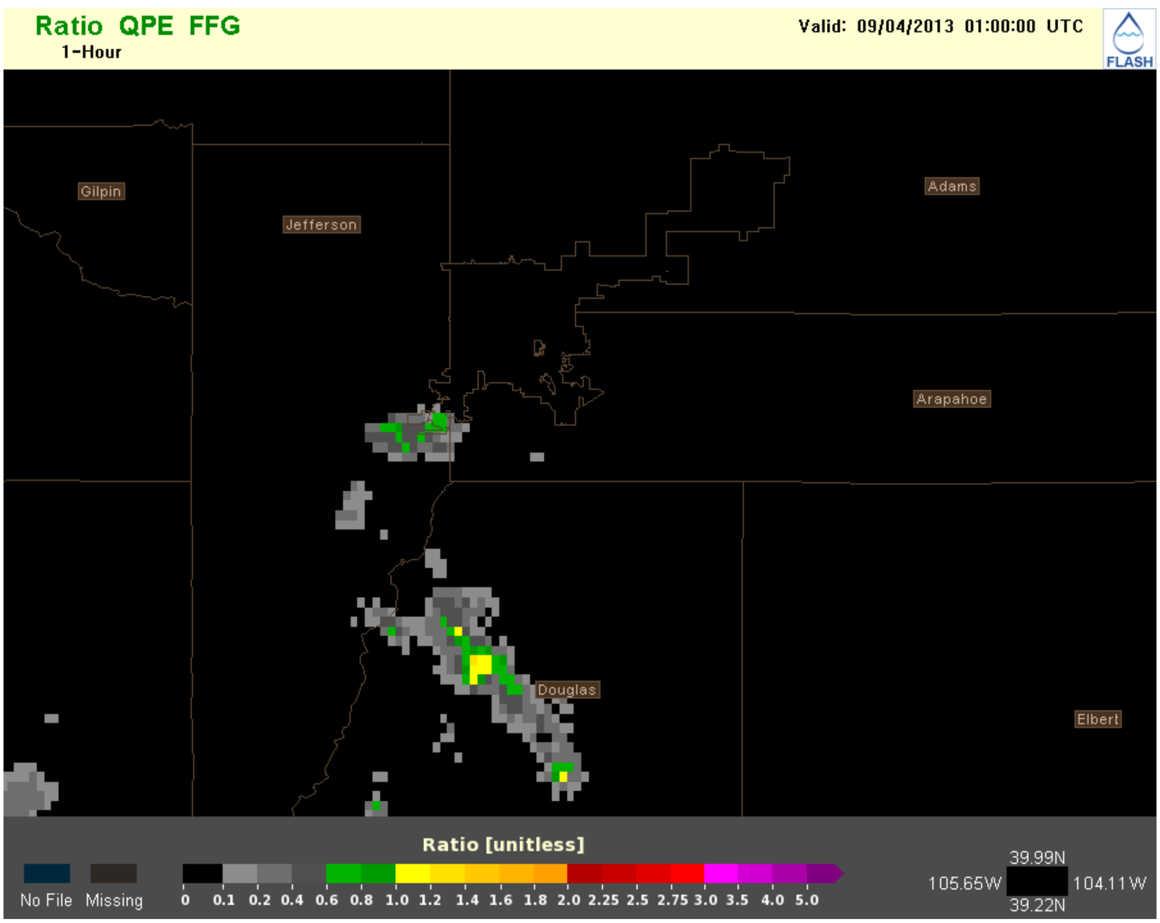
Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

Long Description: Clark et al. (2014) describe the state of the NWS flash flood guidance program across the United States. Several methods for producing FFG have been developed at the regional River Forecast Center level. This product relies on the standard FFG grids produced by the RFCs and issued every 6-, 12-, or

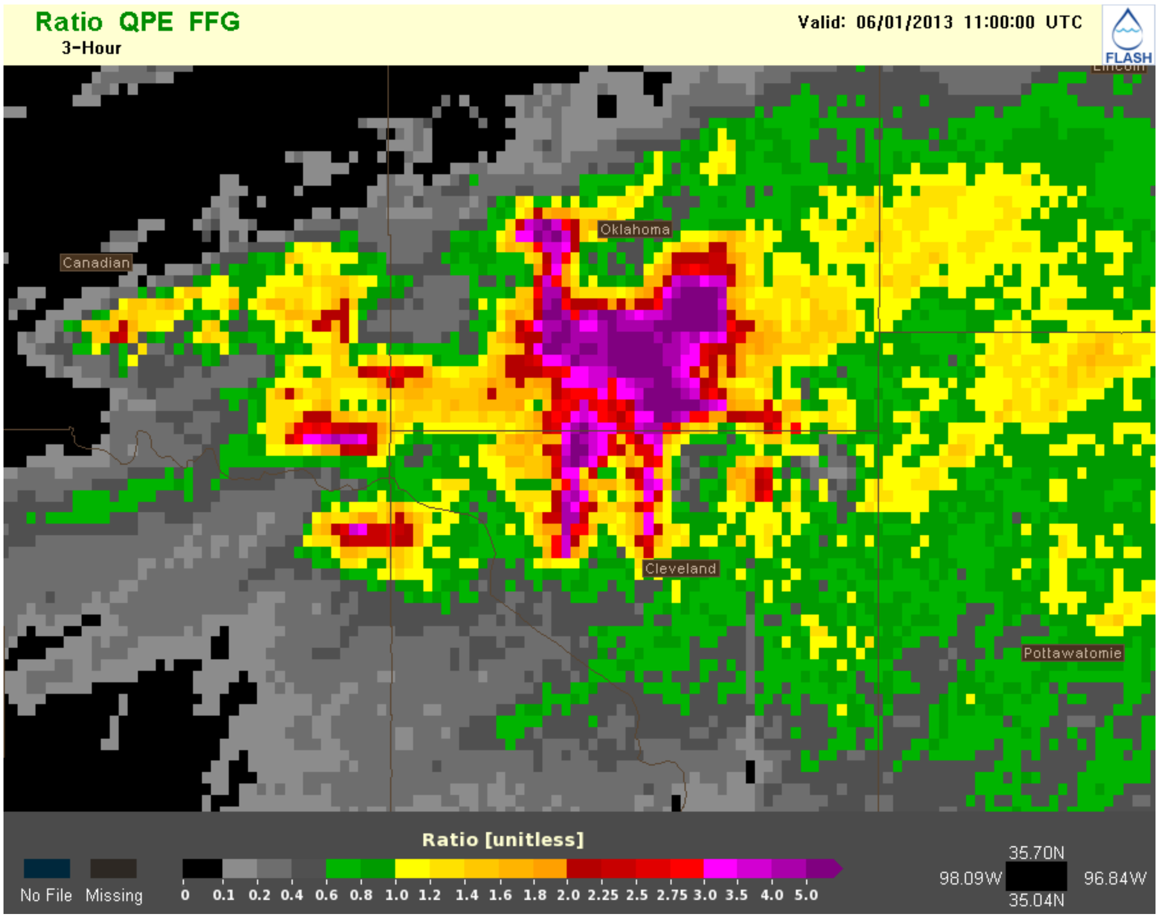
24-hours. Intermediate FFG updates requested by WFOs or individual FFG modifications made at the WFO level will not be reflected in this product. The NCEP Weather Prediction Center mosaics the various RFC grids together to create a national grid. This national grid, updated at most every 6 hours, is compared to radar-only precipitation estimate grids from the MRMS system. Updates to the precipitation grids are available every 2 minutes and so updates to the ratio product are available every 2 minutes, as well.

Applications: QPE-to-FFG ratio can be used to identify specific areas where flash flood guidance is suggesting bankfull conditions on small natural stream networks.

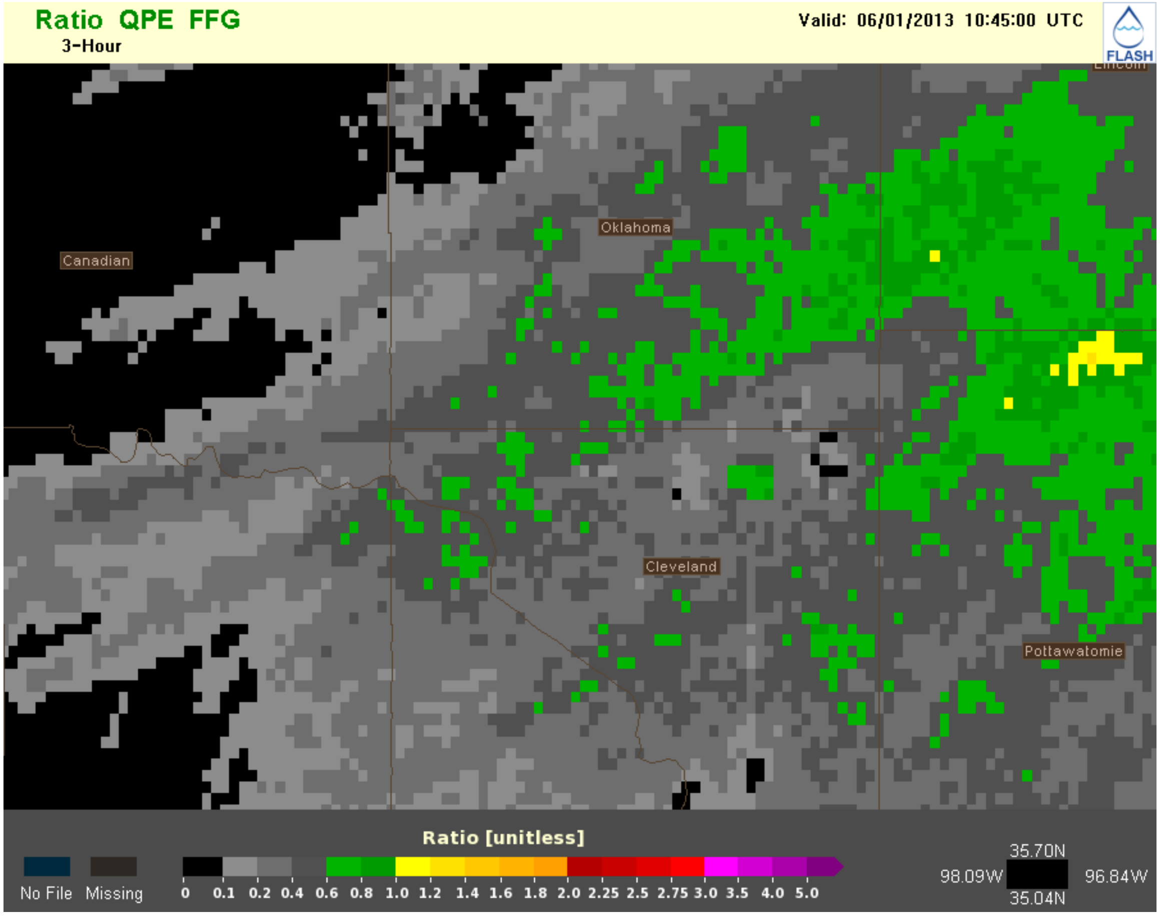
Example Images:



This is an image from the FLASH web interface showing the 1-hour QPE to FFG ratio for the Denver metropolitan area at 01 UTC on 4 Sept 2013. Pixels in yellow indicate those areas where the 1-hr QPE is exceeding the 1-hr FFG.



This is the 3-hr precipitation to FFG ratio for the Oklahoma City area valid at 11 UTC on 1 Jun 2013. This example illustrates the difficulties in using this product immediately after a new FFG product has been issued by an RFC. In the center of this image, the darkest purple pixels represent areas where precipitation is exceeding FFG by over 800%. Below is another image showing the same product valid 15 minutes earlier.



Here, the highest values reported by the product are only around 120% of FFG. A new FFG grid with very low values (due to a large amount of antecedent rainfall) is ingested into the system at 11 UTC. These very low FFG values are being compared to high amounts of precipitation and erroneously large ratios are the result.

Issues: Flash flood guidance is updated at different times and different frequencies depending on the RFC responsible for issuing the product. Therefore it is important when using this product to determine how "fresh" the FFG values in the area of interest are. Although a ratio of 1.0 (i.e., precipitation just matching or exceeding FFG) is traditionally used to identify flash floods, Gourley et al. (2012) and Clark et al. (2014) determined that the product is nominally more skillful at a ratio of 1.5. Different methods are used to produce FFG, depending on the RFC. Therefore, in WFOs that have territory within two RFCs, FFG may be produced using different formulae. Use of the product immediately after updated FFG values are available can result in erroneously high QPE-to-FFG ratios.

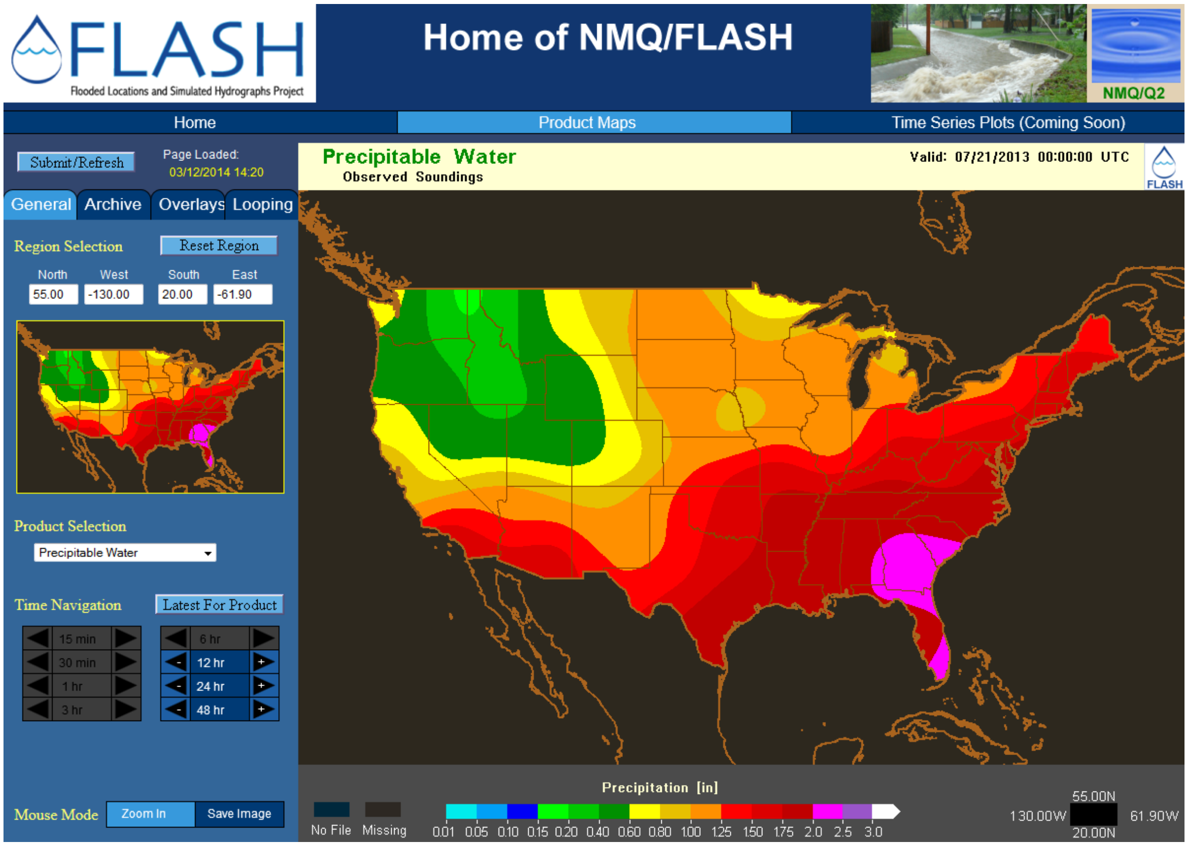
References:

Clark III, R., J. J. Gourley, Z. Flamig, Y. Hong, and E. Clark, 2014: CONUS-wide evaluation of National Weather Service flash flood guidance products, *Wea. Forecasting* doi: 10.1175/10.1175/WAF-D-12-00124.1 (in press)

Gourley, J. J., J. Erlingis, Y. Hong, and E. Wells, 2012: Evaluation of tools used for monitoring and forecasting flash floods in the United States. *Wea. Forecasting*, **27**, 158-173.

Observed Precipitable Water (PW)

Short Description: Precipitable water (PW) analysis over the continental United States (CONUS) derived from observed PW from atmospheric soundings (available at 00- and 12-UTC)
Alternate Names: PW, precipitable water vapor
Keywords: hydrometeorology, flash flood, FLASH
Spatial Resolution: 0.01 x 0.01 degrees
Temporal Resolution: 12 hours
Input Sources: observed soundings
Availability: MOC/FOC
Users: NWS WFOs, NWS RFCs, NWS NCEP WPC
Long Description: As defined in the American Meteorological Society's Glossary of Meteorology (2013), PW is "the total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified levels." This metric is usually measured in terms of the height that the water would reach if it were completely condensed in a vessel the same shape as the column. PW is measured between the earth's surface and 500 mb. In a study exploring the relationship between precipitable water, saturation thickness, and precipitation, Lowry (1972) pointed out that precipitable water decreases as station elevation increases. Equations used to calculate precipitable water can be found in Bolton (1980).
Applications: PW can be used to determine heavy rainfall potential. Heavy rainfall and subsequent flooding may be more likely to occur when PW is greater than twice the climatological value for a geographic region.
Example Images:



This image shows FLASH's visualization of precipitable water (PW) based on observed soundings at 00:00 UTC on 21 July 2013. Each color band represents a certain amount of precipitable water, measured in inches. The higher the PW values, the greater the potential for heavy rainfall and flash flooding.

Issues: It would be incorrect to use PW to predict heavy precipitation alone; while it is a measure of potential, it is only correctly interpreted when viewed in combination with regional climatology. In addition, as suggested by the NWS WFO in Rapid City, SD (2013), users of this plot should take care when interpreting these values due to uncertainty in interpolated data.

References:

American Meteorological Society, cited 2013: "Precipitable Water." Glossary of Meteorology. [Available online at http://glossary.ametsoc.org/wiki/Precipitable_water]

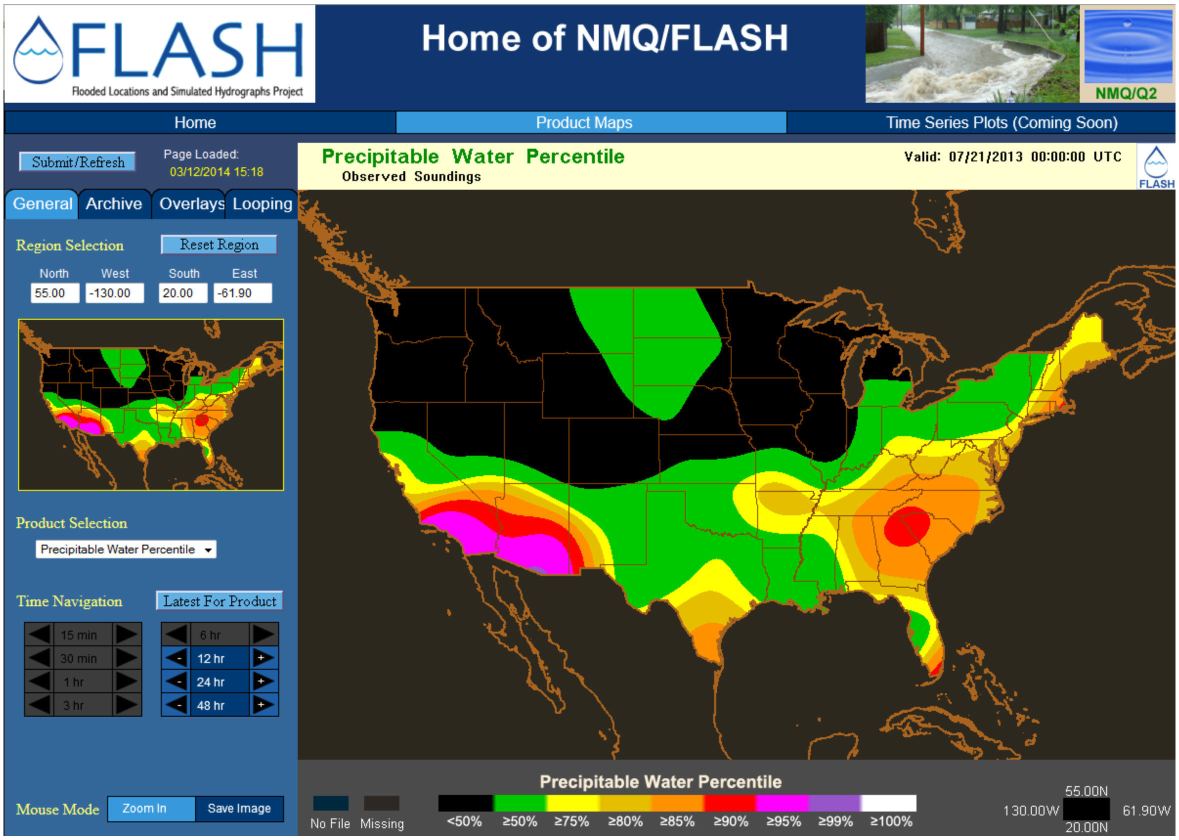
Bolton, D. 1980: The computation of equivalent potential temperature. *Monthly Weather Review*, **108**, 1046-1053.

Lowry, D. A. 1972: Climatological relationships among precipitable water, thickness and precipitation. *J. Appl. Meteor.*, **11**, 1326-1333.

National Weather Service Weather Forecast Rapid City SD, cited 2014: "Upper-Air Climatology Plots." [Available online at http://www.crh.noaa.gov/unr/?n=pw]

Observed Precipitable Water Percentile(PW Percentile)

Short Description: Precipitable water percentile (PW Percentile) analysis over the continental United States (CONUS) derived from observed PW from atmospheric soundings and regional climatology (available at 00- and 12-UTC)
Alternate Names: PW Anomaly, total precipitable water anomaly, PW Percentile
Keywords: hydrometeorology, flash flood, FLASH, precipitable water, PW
Spatial Resolution: 0.01 x 0.01 degrees
Temporal Resolution: 12 hours
Input Sources: observed soundings
Availability: MOC/FOC
Users: NWS WFOs, NWS RFCs, NWS NCEP WPC
Long Description: Precipitable water percentile refers to the magnitude of precipitable water measurements in comparison to climatological values for a given region. Across the CONUS, climatology data is sourced from a base map containing data from 1948-2013 (National Weather Service Weather Forecast Office Rapid City SD, 2014). PW percentile can be used in flash flood forecasting to indicate anomalies in levels of precipitable water, which may be connected to the potential for heavy rainfall and subsequent flash flooding.
Applications: PW percentile is used in flash flood forecasting to identify regions that may have anomalous levels of atmospheric precipitable water. Heavy rainfall and subsequent flooding may be more likely to occur when PW percentile is greater than twice the climatological value for a geographic region.
Example Images:



This image depicts a map of precipitable water percentiles across the CONUS on 21 July 2013 at 00:00 UTC.

Issues: It would be incorrect to use PW Percentile to predict heavy precipitation alone; it is a measure of the *potential* for heavy precipitation. In the case shown above, there is great potential for heavy rainfall, but other ingredients (lift and instability) are lacking to initiate storms. In addition, users of this plot should take care when interpreting these values due to uncertainty in interpolated data (National Weather Service Weather Forecast Office Rapid City SD, 2014).

References:

American Meteorological Society, cited 2013: "Precipitable Water." Glossary of Meteorology. [Available online at http://glossary.ametsoc.org/wiki/Precipitable_water]

Bolton, D. 1980: The computation of equivalent potential temperature. *Monthly Weather Review*, **108**, 1046-1053.

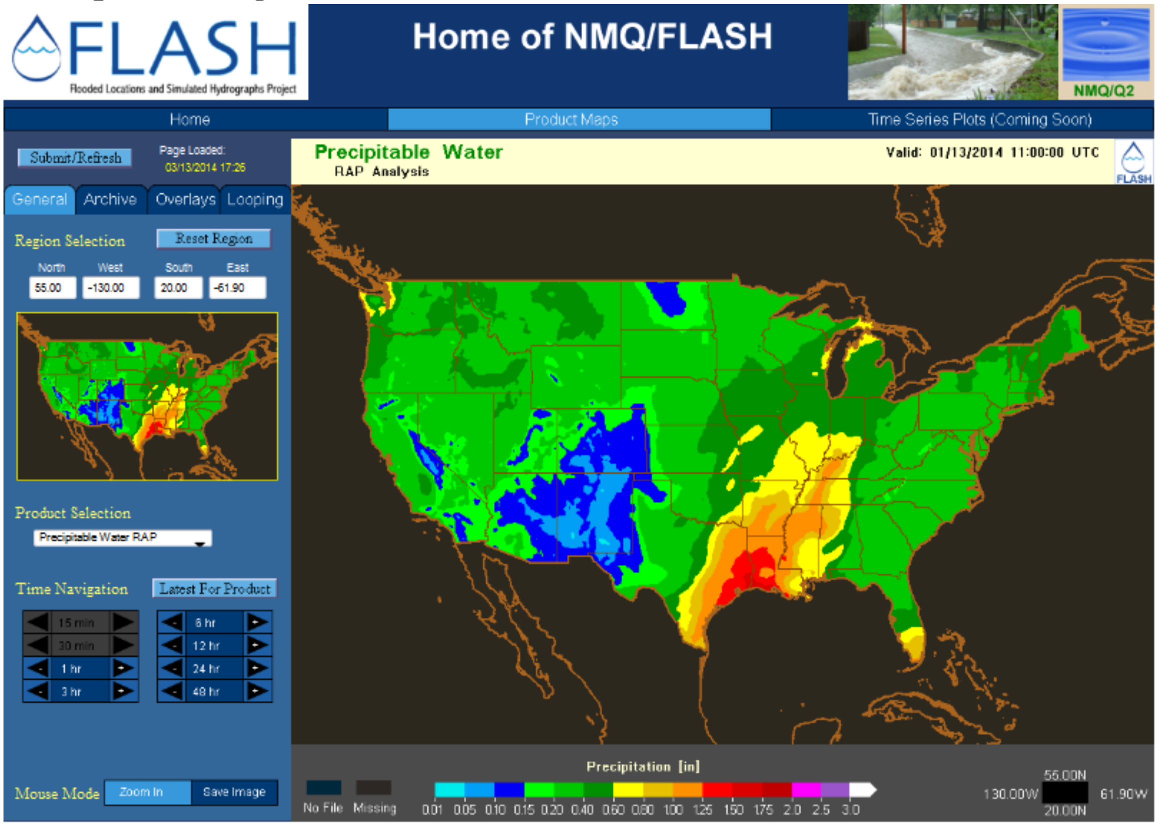
Forsythe, J. M., J. B. Dodson, P. T. Partain, S. Q. Kidder, and T. H. Vonder Haar, 2011: How total precipitable water vapor anomalies relate to cloud vertical structure. *J. Hydrometeor.*, **13**, 709-721.

National Weather Service Weather Forecast Rapid City SD, cited 2014: "Upper-Air Climatology Plots." [Available online at http://www.crh.noaa.gov/unr/?n=pw]

Rapid Refresh Precipitable Water(Precipitable Water RAP)

Short Description: Precipitable water (PW) analysis over the continental United States (CONUS) derived from the Rapid Refresh (RAP) modeling system
Alternate Names: PW, total precipitable water, PW RAP
Keywords: hydrometeorology, flash flood, FLASH, precipitable water, PW, Rapid Refresh, RAP
Spatial Resolution: 0.01 x 0.01 degrees
Temporal Resolution: 1 hour
Input Sources: RAP
Availability: MOC/FOC
Users: NWS WFOs, NWS RFCs, NWS NCEP WPC
Long Description: As defined in the American Meteorological Society's Glossary of Meteorology (2013), PW is "the total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified levels." This metric is usually measured in terms of the height that the water would reach if it were completely condensed in a vessel the same shape as the column. PW is measured between the earth's surface and 500 mb. In a study exploring the relationship between precipitable water, saturation thickness, and precipitation, Lowry (1972) pointed out that precipitable water decreases as station elevation increases. Equations used to calculate precipitable water can be found in Bolton (1980). Instead of using observed soundings to calculate PW, the PW RAP employs data from the Rapid Refresh (RAP) modeling system, which supports hourly short-range model forecasts out to 18-hours.
Applications: PW can be used to determine the potential for heavy rainfall. Heavy rainfall and subsequent flooding may be more likely to occur when PW is greater than twice the climatological value for a geographic region.

Example Images:



This image depicts a map of PW derived from RAP data across the CONUS on 13 Jan 2014 at 11:00 UTC. PW is measured in inches.

Issues: It would be incorrect to use PW to predict heavy precipitation alone; it is a measure of the *potential* for heavy precipitation. There may be great potential for heavy rainfall, but other ingredients (lift and instability) are needed to initiate storms. In addition, users of this plot should take care when interpreting these values due to uncertainty in interpolated data (National Weather Service Weather Forecast Office Rapid City SD, 2014).

References:

American Meteorological Society, cited 2013: "Precipitable Water." Glossary of Meteorology. [Available online at http://glossary.ametsoc.org/wiki/Precipitable_water]

Bolton, D. 1980: The computation of equivalent potential temperature. *Monthly Weather Review*, **108**, 1046-1053.

National Weather Service Weather Forecast Rapid City SD, cited 2014: "Upper-Air Climatology Plots." [Available online at http://www.crh.noaa.gov/unr/?n=pw]

Rapid Refresh Precipitable Water Percentile (PW Percentile RAP)

Short Description: Precipitable water percentile (PW Percentile) analysis over the continental United States (CONUS) derived from the Rapid Refresh (RAP) modeling system

Alternate Names: RAP PW Anomaly, PW Percentile RAP

Keywords: hydrometeorology, flash flood, FLASH, precipitable water, precipitable water percentile, PW percentile, Rapid Refresh, RAP

Spatial Resolution: 0.01 x 0.01 degrees

Temporal Resolution: 1-hour

Input Sources: RAP

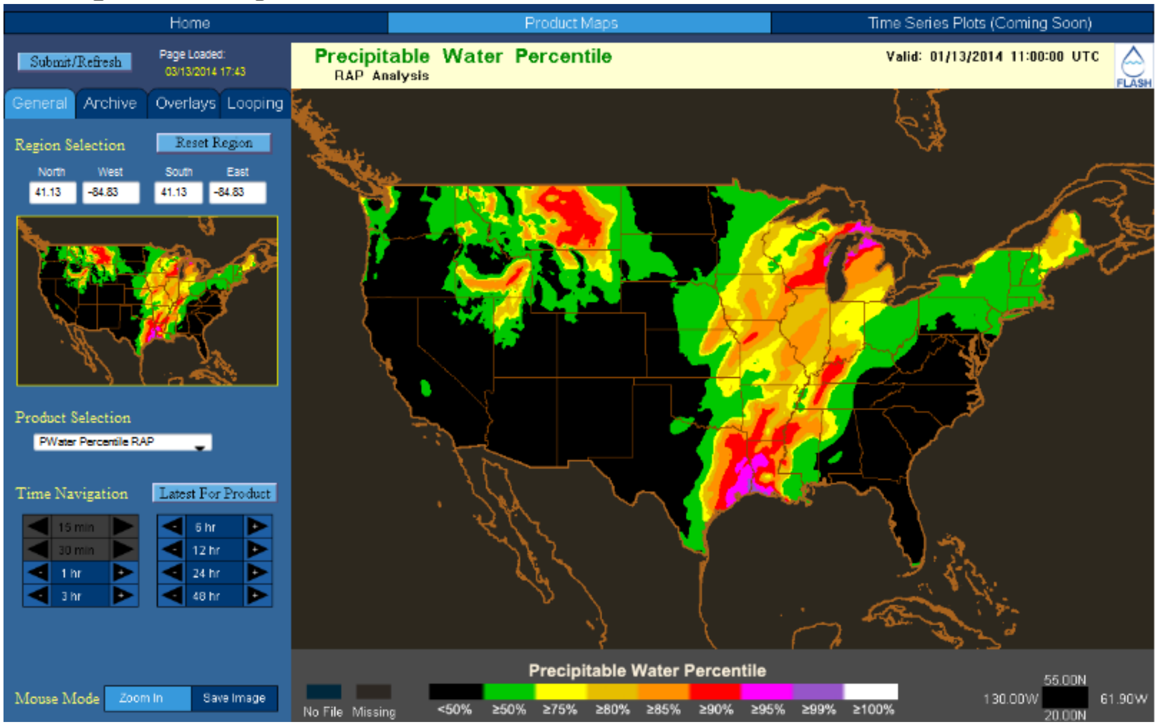
Availability: MOC/FOC

Users: NWS WFOs, NWS RFCs, NWS NCEP WPC

Long Description: Precipitable water percentile refers to the magnitude of precipitable water measurements in comparison to climatological values for a given region. Across the CONUS, climatology data is sourced from a base map containing data from 1948-2013 (National Weather Service Weather Forecast Office Rapid City SD, 2014). PW percentile can be used in flash flood forecasting to indicate anomalies in levels of precipitable water, which may be connected to heavy rainfall and subsequent flash flooding. Instead of using observed soundings to calculate PW, the PW RAP employs data from the Rapid Refresh (RAP) modeling system, which supports hourly short-range model forecasts out to 18-hours.

Applications: PW percentile is used in flash flood forecasting to identify regions that may have anomalous levels of precipitable water. Heavy rainfall and subsequent flooding may be more likely to occur when PW percentile is greater than twice the climatological value for a geographic region.

Example Images:



This image depicts a map of precipitable water percentiles derived from RAP model data across the CONUS on 13 Jan 2014 at 11:00 UTC.

Issues: It would be incorrect to use PW Percentile to heavy precipitation alone; it is a measure of the *potential* for heavy precipitation. In the case shown above, there is great potential for heavy rainfall, but other ingredients (lift and instability) are lacking to initiate storms. In addition, users of this plot should take care when interpreting these values due to uncertainty in interpolated data (National Weather Service Weather Forecast Office Rapid City SD, 2014).

References:

American Meteorological Society, cited 2013: "Precipitable Water." Glossary of Meteorology. [Available online at http://glossary.ametsoc.org/wiki/Precipitable_water]

Bolton, D. 1980: The computation of equivalent potential temperature. *Monthly Weather Review*, **108**, 1046-1053.

Forsythe, J. M., J. B. Dodson, P. T. Partain, S. Q. Kidder, and T. H. Vonder Haar, 2011: How total precipitable water vapor anomalies relate to cloud vertical structure. *J. Hydrometeor.,* **13**, 709-721.

National Weather Service Weather Forecast Rapid City SD, cited 2014: "Upper-Air Climatology Plots." [Available online at http://www.crh.noaa.gov/unr/?n=pw]