National Water Model Version 1.0

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Large integrated OWP and NCAR team

OWP | OFFICE OF WATER PREDICTION

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Presentation Outline

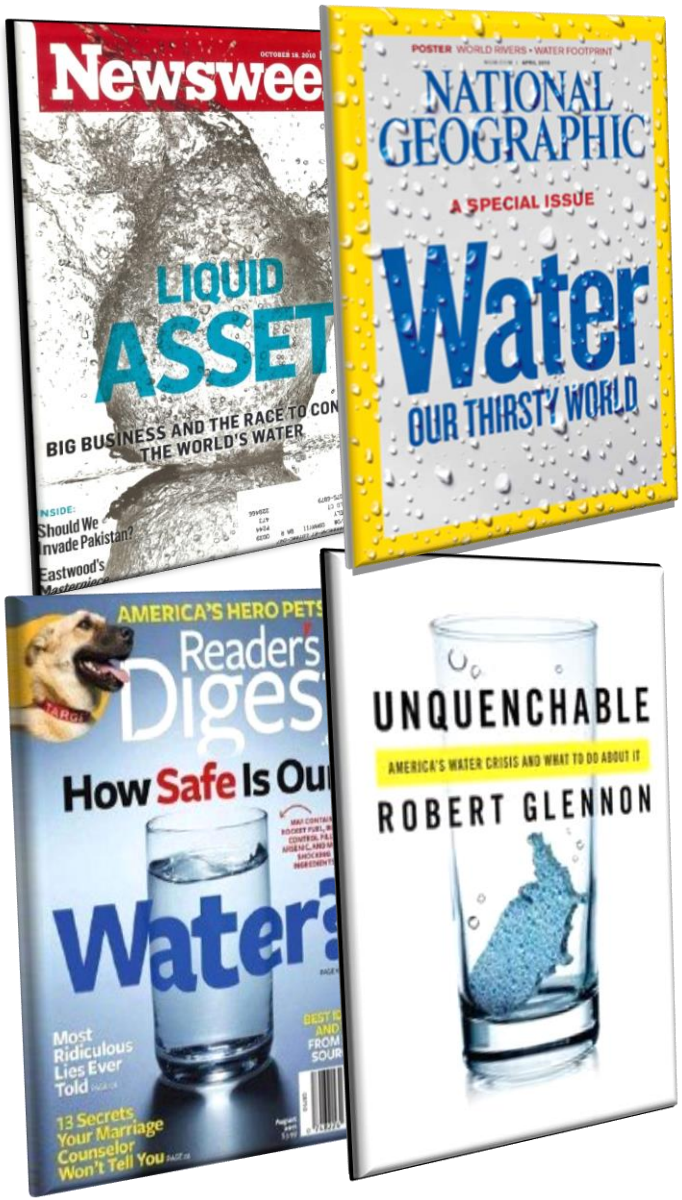
- **Impetus for Change in the NWS Hydrology Program**
- **New Prediction Capabilities: The National Water Model (NWM)**
- **Future Use of Satellite Data in NWM**
- **Summary**

TOO MUCH

TOO LITTLE

POOR QUALITY

Impetus for Change
Growing Water Challenges



Multiple Threats

- Population growth and economic development are stressing water supplies and increasing vulnerability
- A changing climate is impacting water availability and quality, increasing uncertainty
- An aging water infrastructure is forcing critical, expensive decisions
- Socio-economic risks of floods and droughts are escalating

Impetus for Change: National Academy of Sciences Report

Weather Services for the Nation: Becoming Second to None

Findings	Recommendations
NWS Modernization and Restructuring (MAR) did not directly address hydrologic prediction services	Prioritize core capabilities - a MAR-like effort is needed to address long-standing and deep-seated issues in hydrology
A significant gap exists between the state of hydrologic science today and current NWS hydrologic operations	Improve pathways for collaboration & accelerate R2O Establish a hydrologic prediction testbed as part of the National Water Center Implement a consistent framework for hydrologic prediction skill assessment
The level of sophistication, representation of processes, and characterization of uncertainties in external research and operational communities outpace those used in NWS hydrology operations	
NWS Hydrologic Forecasters are extensively *"in the forecast loop"*	Transition RFC forecasters to "over the loop" enabling a shift in focus to model and product development, forecast interpretation, and decision support
Qualifications for hydrologist positions were not updated in the MAR to require degreed hydrologists	Hydrologist staff require re-education and continual retraining to enable adoption of state-of-the-art prediction methodologies Instill evolutionary culture
Lack of skill in modern computational programming, construction and use of new Earth System Models, current hydrologic data assimilation methodologies, and preparation and interpretation of meaningful ensemble predictions	Add value to hydrologic forecasts through the use of more advanced models, data assimilation and employment of more sophisticated ensemble techniques

Impetus for Change: Initial Stakeholder Priorities

Flooding

Water Quality

Water Availability

Drought

Climate Change

Need integrated understanding of near- and long-term outlook and risks

- Provide consistent, high resolution, integrated water analyses, predictions and data to address critical unmet information and service gaps
- Transform information into intelligence by linking hydrologic, infrastructural, economic, demographic, environmental, and political data
- Integrate Social Science to create Actionable Water Intelligence

Response: Integrated Water Prediction

Setting the Stage for Transformation (Parallel Five Year Plans)

Centralized Water Forecasting Demonstration (2015)	Enhanced Water Prediction Capability (2016)	Integrated Water Prediction (2017 Proposed)
• National Water Model (NWM) Development and Demonstration • Centralized Water Resources Data Services • Water Resources Test and Evaluation Service	• Hyper-Resolution Modeling • Real-Time Flood Forecast Inundation Mapping • Enhance Impact-Based Water Resources Decision Support Services	• Stand up the National Water Center Operations Center • Couple terrestrial freshwater and coastal estuary models for total water predictions in the coastal zone • New service delivery model for coastal and inland communities

National Water Model Version 1.0

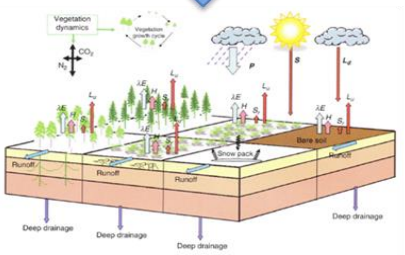
- **NWM Implementation on WCOSS supercomputer**
  - Implemented into operations on WCOSS Cray August 16th
  - Strong OWP/NCAR/NCEP partnership, based on NCAR-supported community WRF-Hydro framework
  - Leverages NWP and NLDAS capabilities of NCEP/EMC
- **Product of a multi-year series of stakeholder meetings**
- **Provides foundation for sustained growth in nationally consistent operational hydrologic forecasting capability**
- **Goals for NWM V1.0**
  - Focus on full range of water resources, from droughts to floods
  - Provide forecast streamflow guidance for underserved locations
  - Produce spatially continuous national estimates and forecasts of hydrologic states (soil moisture, snow pack, etc.)
  - Implement a modeling architecture that permits rapid infusion of new data and science, and supports cross-NOAA water initiative

National Water Model Core: WRF-Hydro

- WRF-Hydro forms the foundation of the National Water Model
- A community-based, ESMF compatible hydrologic modeling *framework* supported by NCAR put into operations by an OWP, NCAR and NCEP partnership
- *Not dependent* on a particular forcing data source or choice of LSM
- Able to operate over multiple scales and with multiple physics options

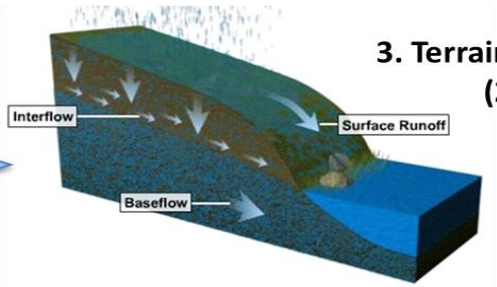
IOC System Flow

1. NWM Forcings Engine (NWS numerical weather models and observations)



2. NoahMP LSM (1 km grid)

2-way coupling

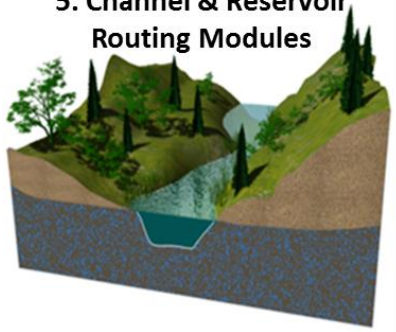


3. Terrain Routing Module (250 m grid)

4. NHDPlus Catchment Aggregation

(avg. size ~1mi^2)

5. Channel & Reservoir Routing Modules



Forecasts

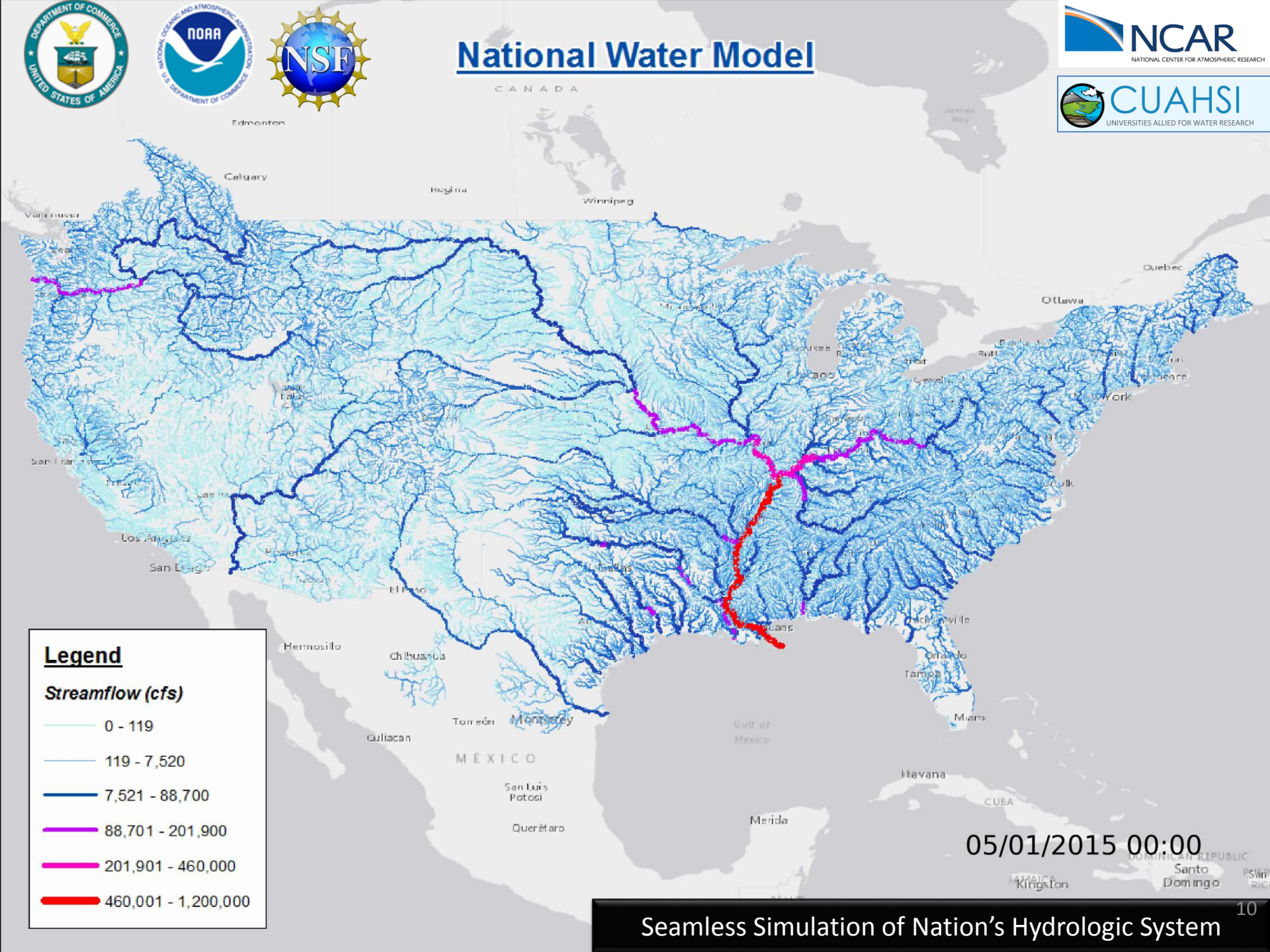
NWM Operational Configuration

Analysis & Assimilation	Short-Range	Medium-Range	Long-Range
Cycling Frequency			
Hourly	Hourly	Daily at 06Z	Daily Ens (16 mem)
Forecast Duration			
- 3 hrs	0-15 hours	0-10 days	0-30 days
Forecast Latency (latency of external forcing data accounts for most of delay)			
1 hour	1 hour 45 mins	6 hours	19 hours
Meteorological Forcing			
MRMS blend/ HRRR/RAP bkgnd.	Downscaled HRRR/RAP blend	Downscaled GFS	Downscaled & bias-corrected CFS
Spatial Discretization & Routing			
1km/250m/NHDPlus Reach	1km/250m/NHDPlus Reach	1km/250m/NHDPlus Reach	1 km/NHDPlus Reach

Assimilation of USGS Obs

Reservoirs (1260 water bodies parameterized with level pool scheme, **focus of active development**)

National Water Model



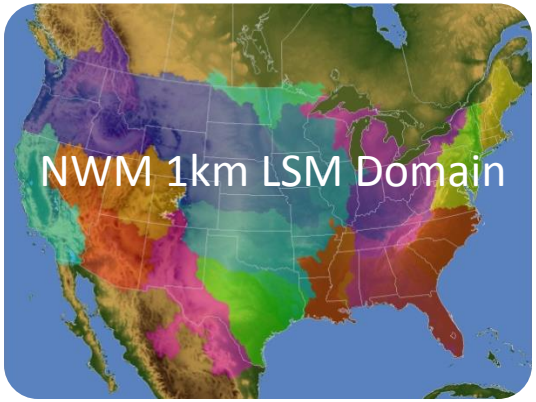
Seamless Simulation of Nation's Hydrologic System

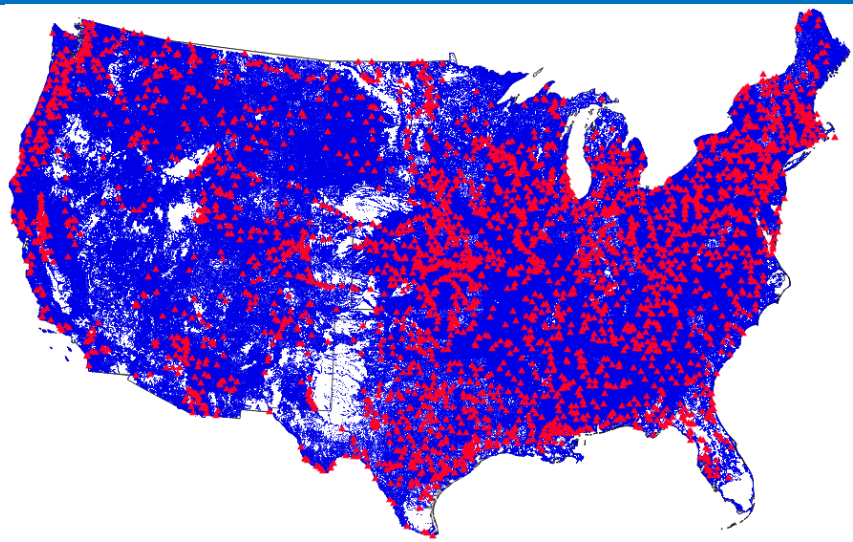
NWM V1.0 Output

- **Hydrologic Output**
  - River channel discharge and velocity at 2.7 million river reaches
  - Reservoir inflow, outflow, elevation
  - Ponded water depth and depth to saturation (250m CONUS+ grid)

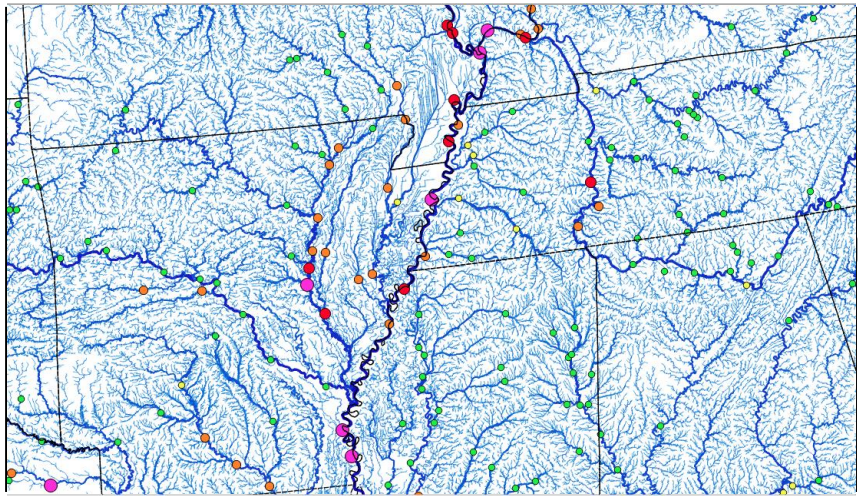
- **Land Surface Output**
  - 1km CONUS+ grid
  - Soil and snow pack states
  - Energy and water fluxes

- **Direct-output and derived products** (e.g. stream flow anomalies)





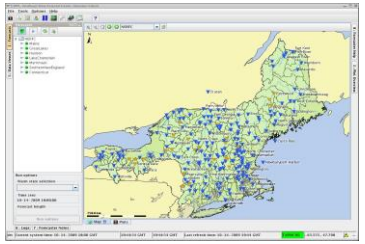
Current NWS AHPS points (red)
NWM output points (blue)

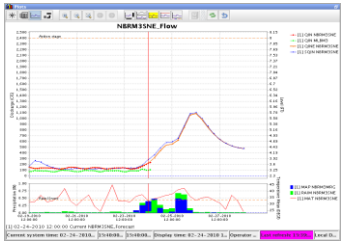


Current NWS River Forecast Points (circles) Overlaid with NWM Stream Reaches

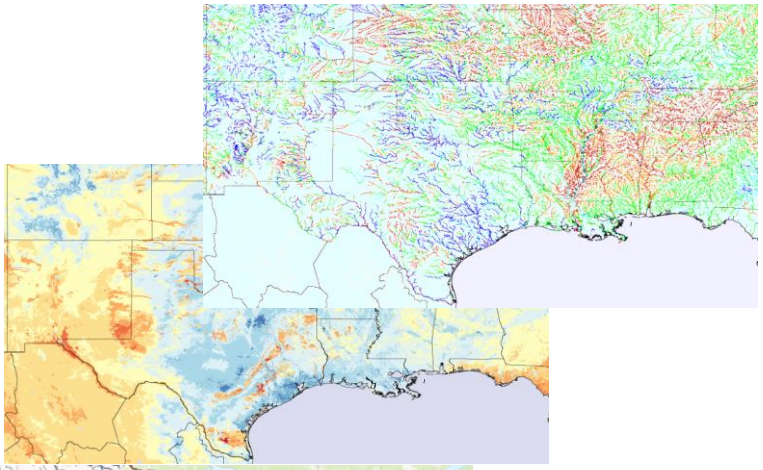
NWM V1.0 Output Dissemination

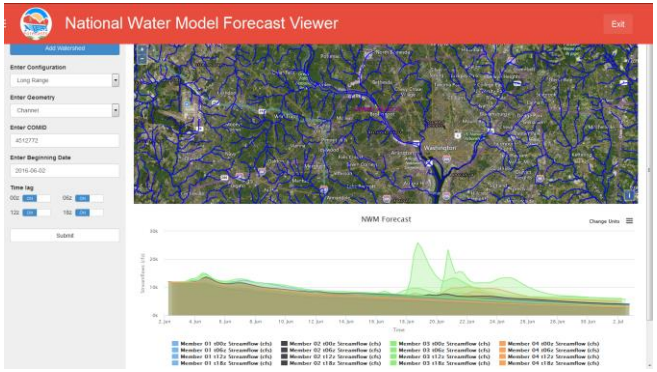
- Visualization and data dissemination key to success, area of active development
- Multi-pronged output dissemination strategy
  - OWP IDP-hosted website-based viewers (water.noaa.gov/map water.noaa.gov/tools/nwm-image-viewer)
  - Subsetted data feed to River Forecast Centers
  - NOAA NOMADS server (full set of NetCDF output)
  - Community tools and viewers via CUAHSI



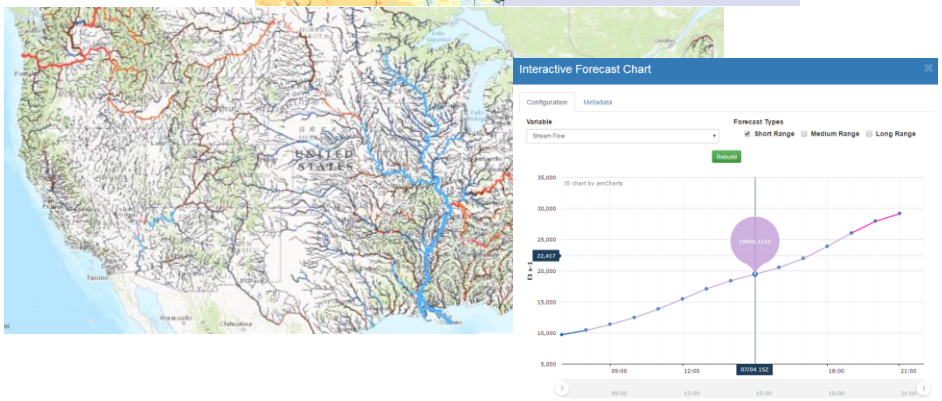


NWS RFC CHPS





Community Web Tools



NWS Web Tools

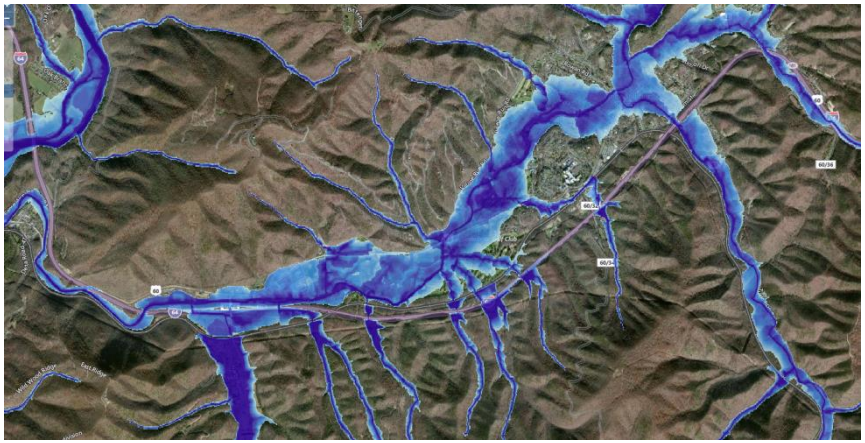
NWM Evaluation

- **Several groups are currently involved in initial NWM evaluation**
  - River Forecast Centers (RFCs)
    - 12-RFC NWM Output Assessment Team (NOAT), using VLAB feedback loop
  - NCEP Weather Prediction Center (FFAIR experiment)
  - Private companies (Worldwinds Inc., CE Hydro)
  - Office of Water Prediction
    - CUAHSI via ongoing Innovator's Program
    - NWM Implementation Project
    - NWM Initial Operational Evaluation Project
  - NCAR NWM Implementation Team

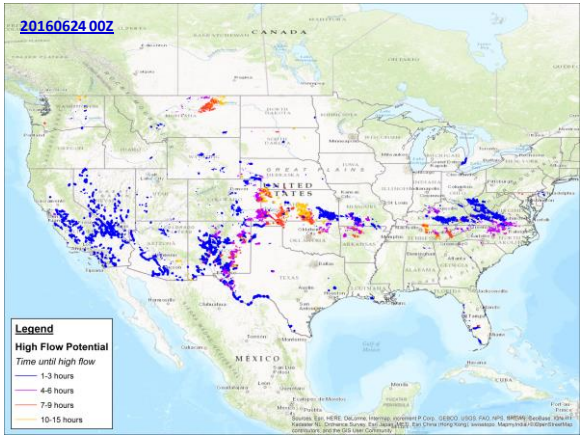
- **Groups evaluating NWM output will expand over time**
  - OWP Water Resource Evaluation Service (WRES)
  - NWS Weather Forecast Offices (WFOs)
  - NCEP Environmental Modeling Center

Leveraging Feedback: Enhancements to NWM V1.0 Output Visualization

- **Work underway to provide more context to NWM output**
  - **Spatial Context**…what are surrounding streams showing? New web viewer allows for full zoom and plotting of all stream forecasts.
  - **Forcing Context**…how might errors in QPF impact streamflow? How does NWM QPF compare to other QPF? Adding ability to view NWM precipitation.
  - **Historical Context**…how does NWM streamflow relate to historical streamflow? Refining streamflow anomaly product and investigating overlay of USGS obs.
  - **Coverage Context**…how does NWM streamflow translate to flooding? Prototype flood inundation mapping, use of USGS/NWS rating curves for stage
- **New products will distill information and increase accessibility**



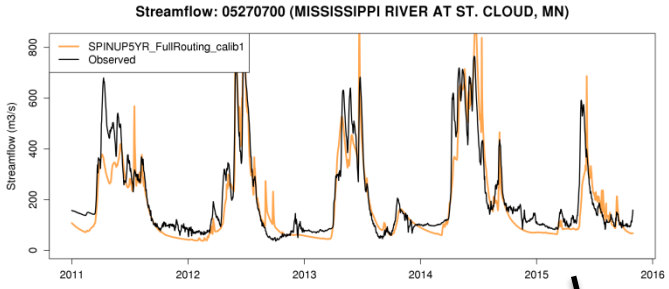
Experimental Flood Inundation Map

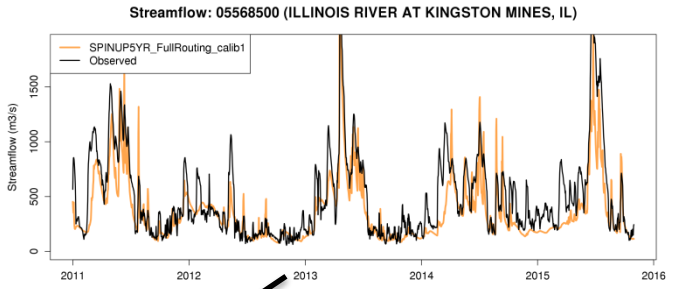


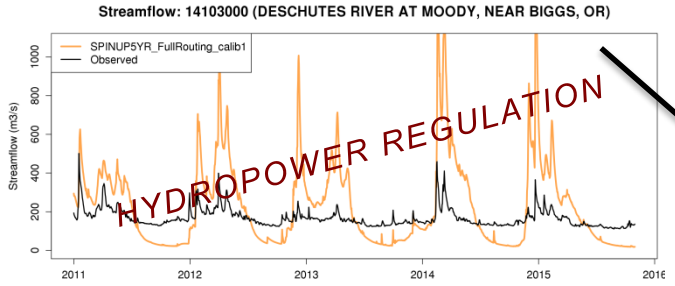
Experimental Threshold Alert Map

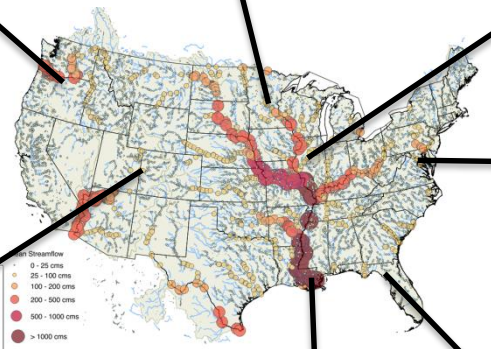
Initial Retrospective NWM CONUS Evaluations: Streamflow

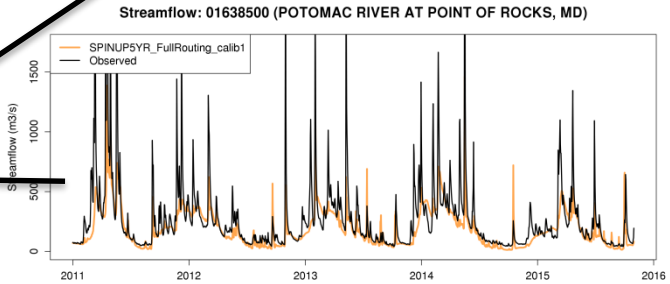
Regional Breakouts of Big River Flows:

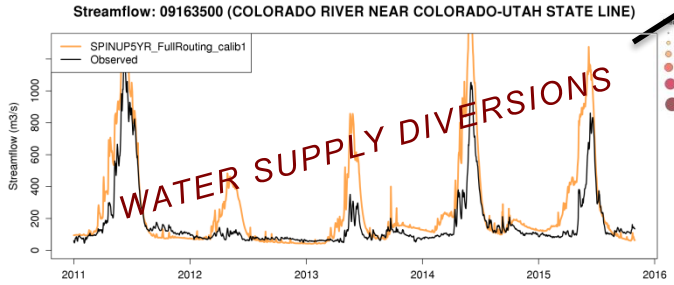


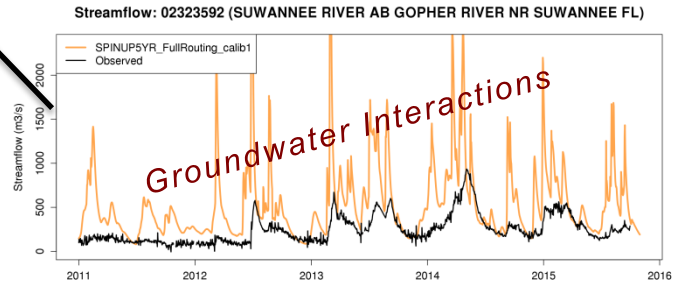


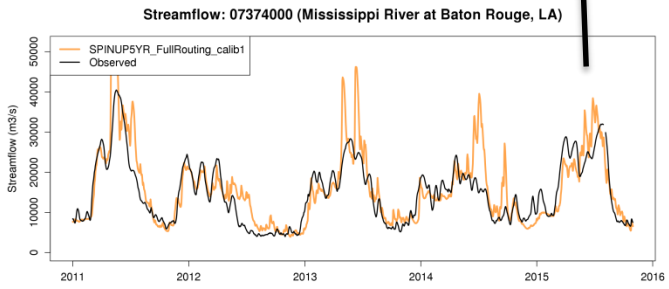






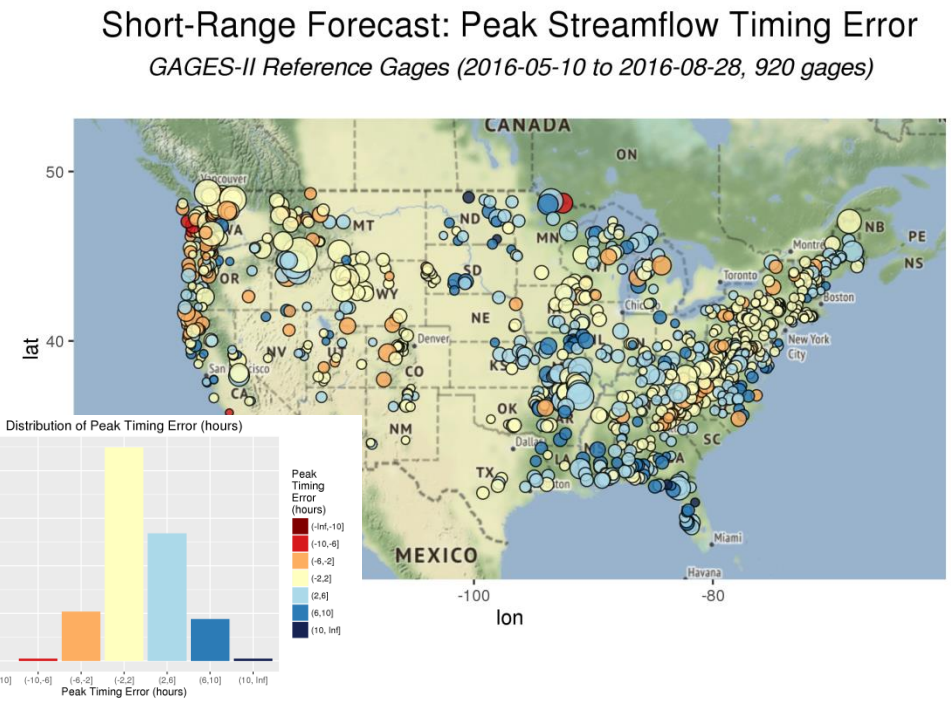




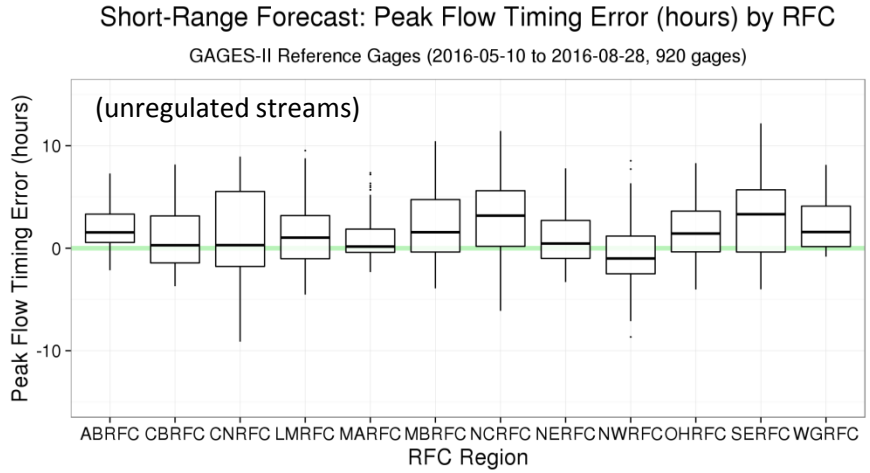


Promising initial results: Simulated flows closely resemble actual flow where flow is unregulated

National Water Model Forecast Evaluation: Short Range Forecasts



- **Short Range Prediction Goal: Provide effective guidance for floods and flash floods**
- **Assess skill of forecast peak flow amount and timing**
- **Based on 3.5 months of NWM forecasts from WCOSS versus 920 USGS Gauges II unregulated stations, May-August 2016**

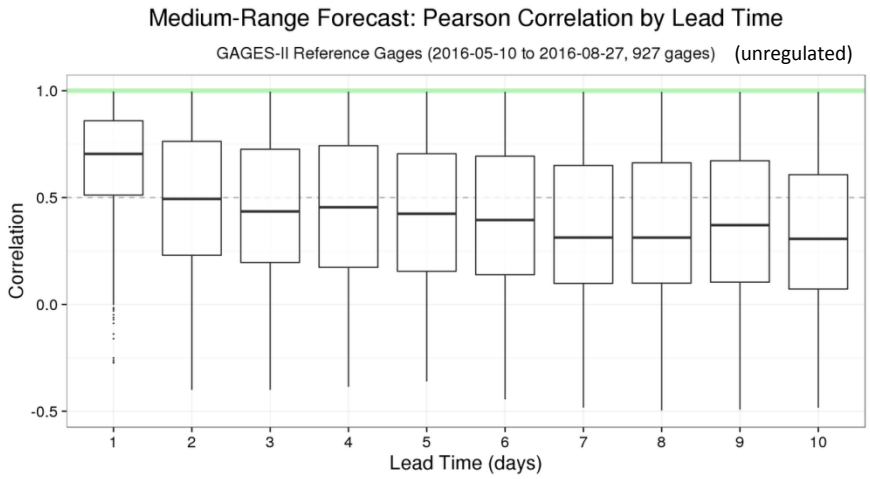


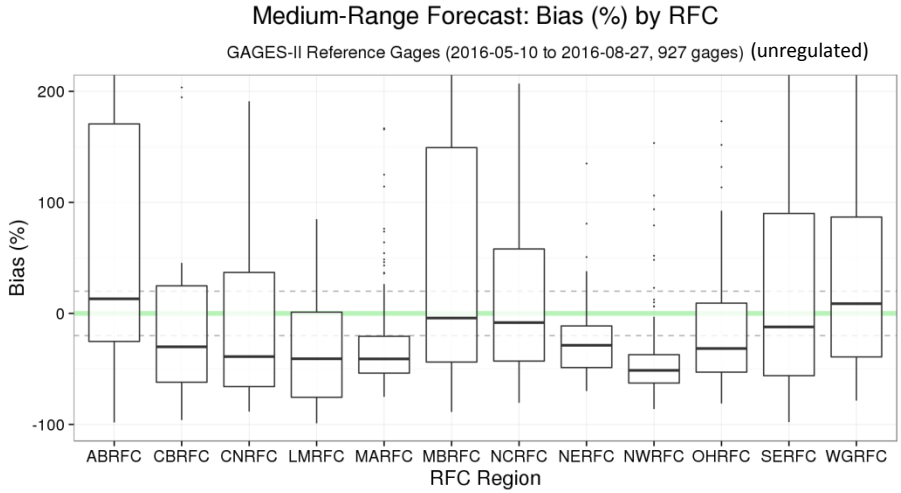
Preliminary Findings

- **Errors in peak flow amount center around 0, and are relatively small (i.e., ≤4 cms)**
- **Median errors in peak flow timing are generally under ~2 hours**

Pre- and Post-operational Short Range (0-15 hrs) Verification

National Water Model Forecast Evaluation: Medium Range Forecasts





- **Medium Range Prediction Goal: Provide advanced lead-time guidance for flood and river flow**
- **Assess forecast daily flow correlation and percent bias**
- **Based on 3.5 months of NWM forecasts from WCOSS versus 927 USGS Gauges II unregulated stations, May-August 2016**

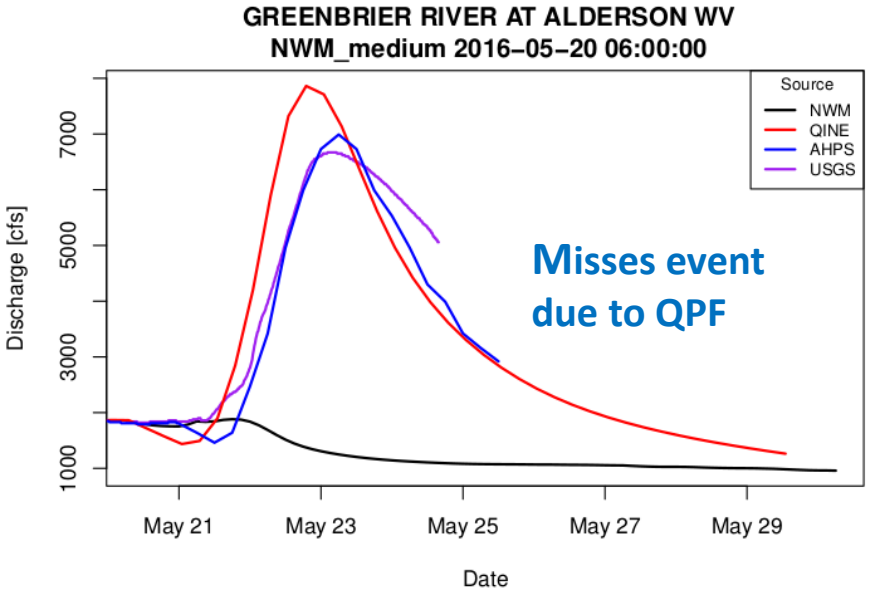
Preliminary Findings

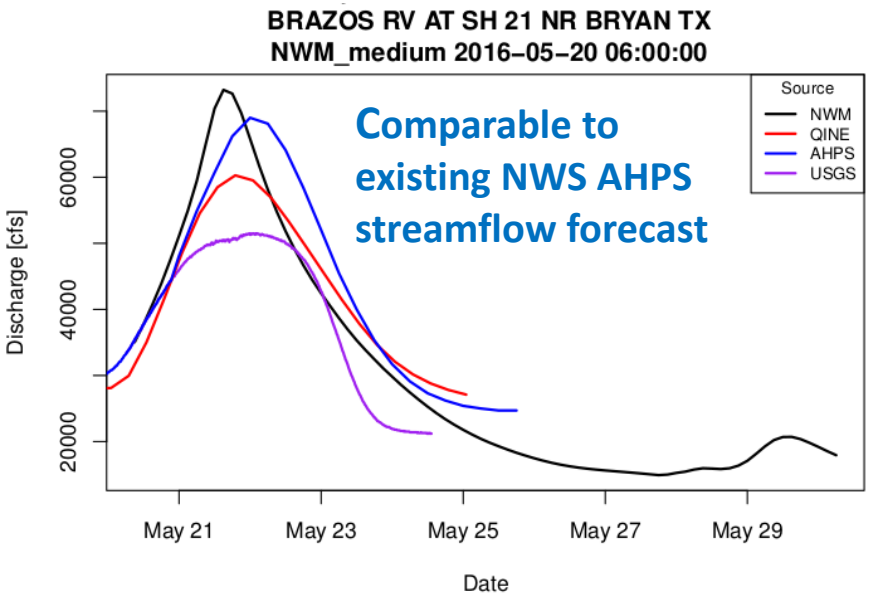
- **Though trailing off with time, daily streamflow correlation values are skillful through 10 days**
- **Median streamflow bias over all 10 days in most RFCs is less than 25%**

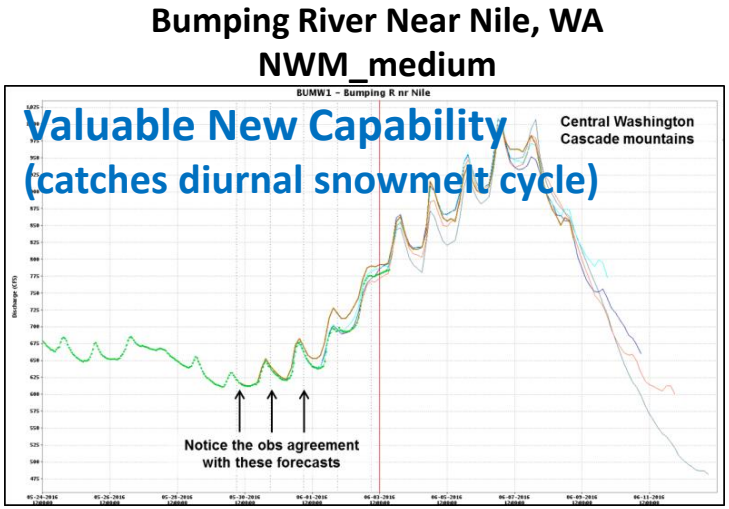
Pre- and Post-operational Medium Range (0-10 days) Verification

National Water Model Forecast Evaluation: Medium Range Forecasts

- Individual hydrographs assessed
- As expected, NWM version 1.0 exhibits areas of varying streamflow forecast performance
- Strength in hydro-blind areas and physical process representation

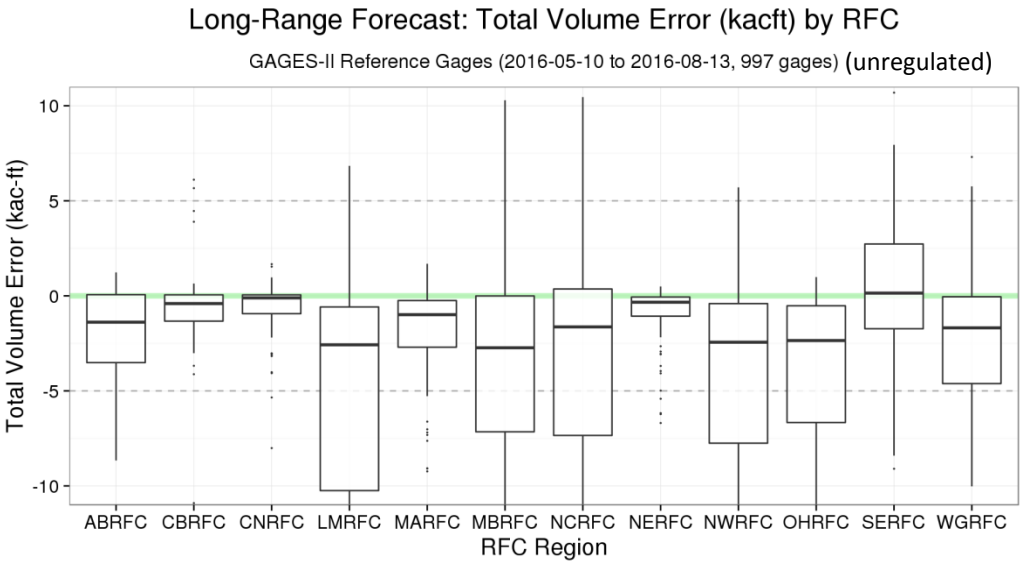




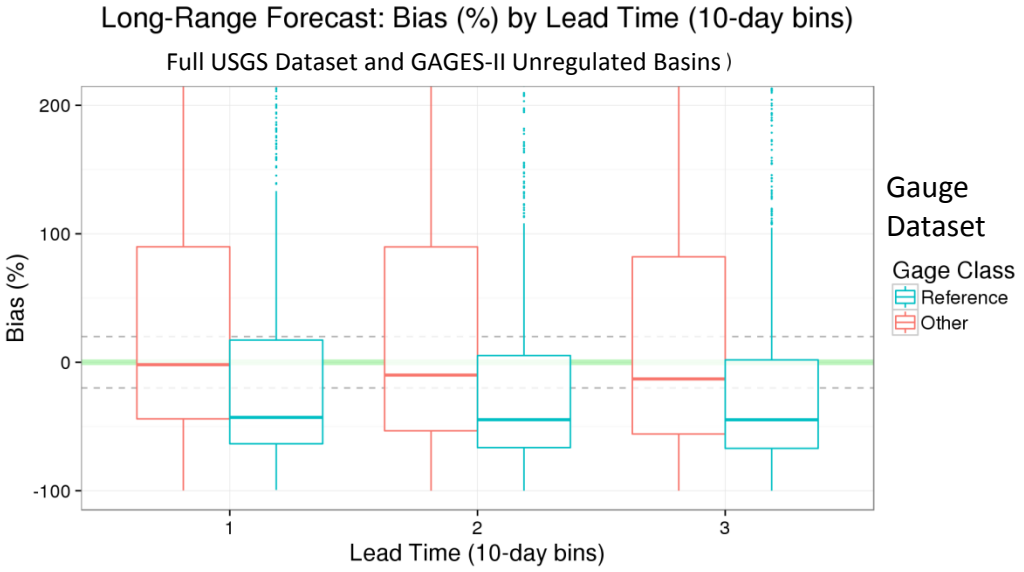


Pre- and Post-operational Medium Range (0-10 days) Verification

National Water Model Forecast Evaluation: Long Range Forecasts



- **Long Range Prediction Goal: Provide long-lead guidance for water resource management**
- **Assess accumulated flow error**
- **Based on ~3 months of NWM forecasts from WCOSS versus 997 USGS Gauges II unregulated stations and ~4,000 full set of USGS data, May-August 2016**



Preliminary Findings

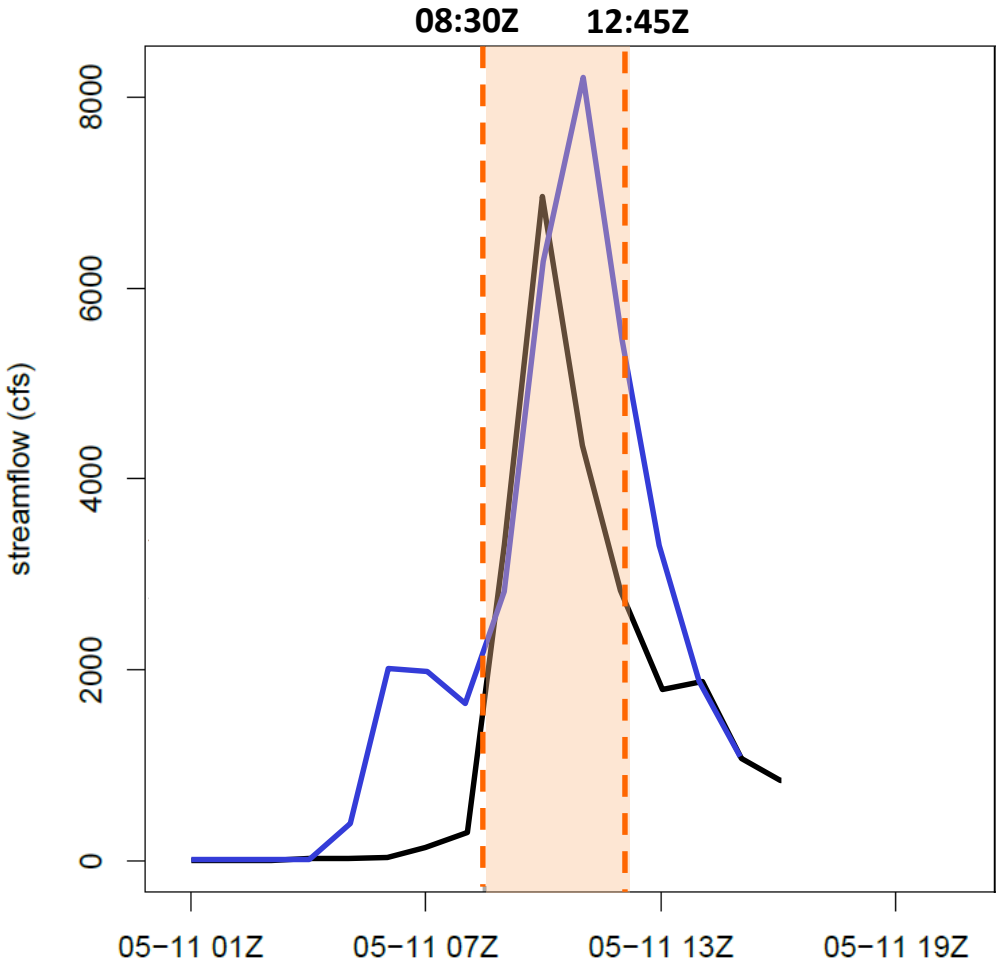
- **Regional breakout by RFC reveals an underlying dry bias for <u>unregulated</u> basins**
- **Median flow bias near 0% using <u>full</u> set of USGS data, temporally stable**

Pre- and Post-operational <u>Long</u> Range Ensemble (0-30 days) Verification

National Water Model Forecast: Hydro-Blind Example
Little goose Creek, May 11, 2016

"I can only remember a couple times in my history when Highway 25 was broached by Little Goose Creek and it happened last night. Little Goose is actually what runs into downtown Hartsville."

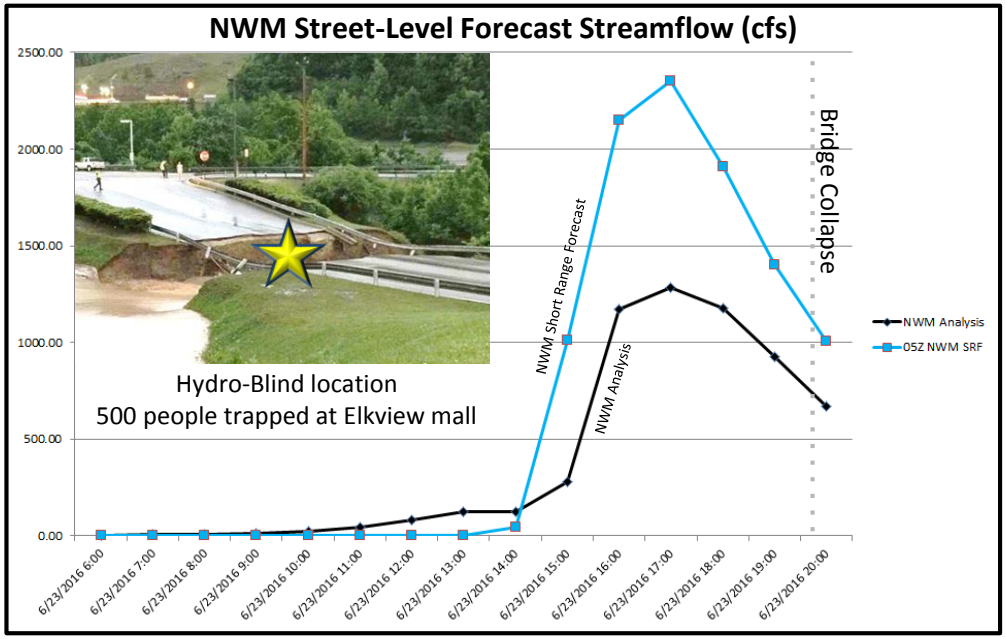
--County Mayor Carroll Carman via *NBC Channel 4 WSMV*

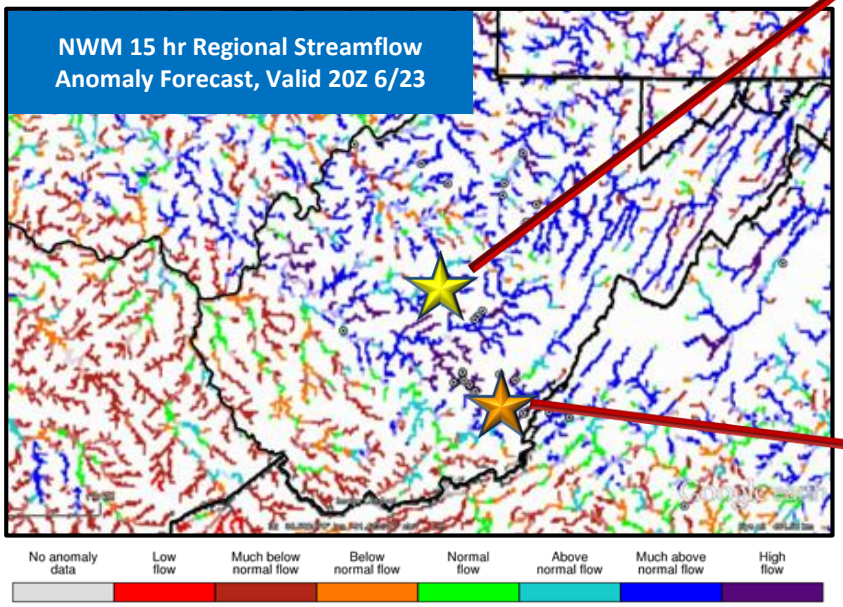


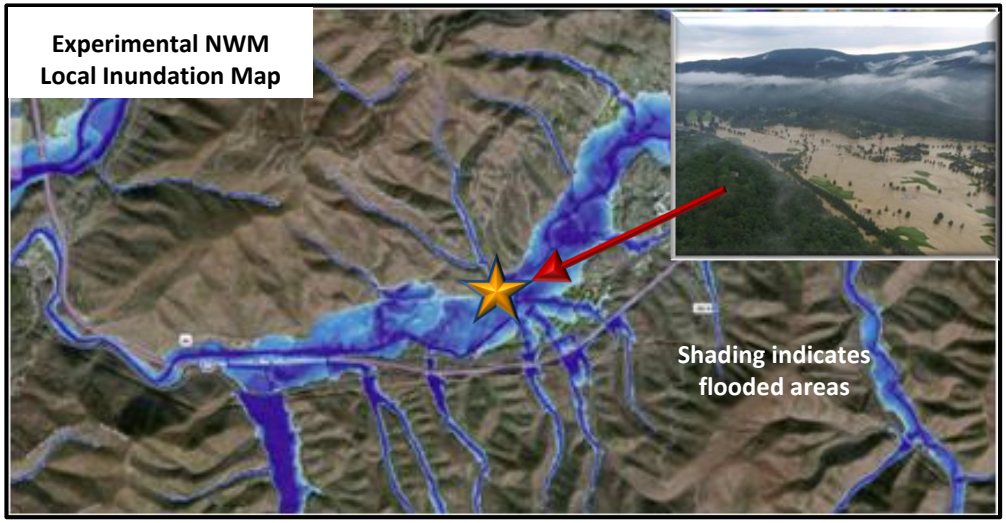
- **"NWS flash flood warnings not issued until 09:03Z. No watches issued.**
- **Eight hours before flood reports, short range NWM forecasts indicate sharp streamflow rises**

NWM-Based Street Level Hydrologic Prediction
Record Setting West Virginia Flood Event, June 23rd 2016

- Thousands of homes damaged or destroyed, $111+ million in FEMA aid
- NWM allows users to drill down from regional to local to street scale
- Information complements hydrologic guidance at existing forecast locations and provides new insight at millions of hydro-blind locations

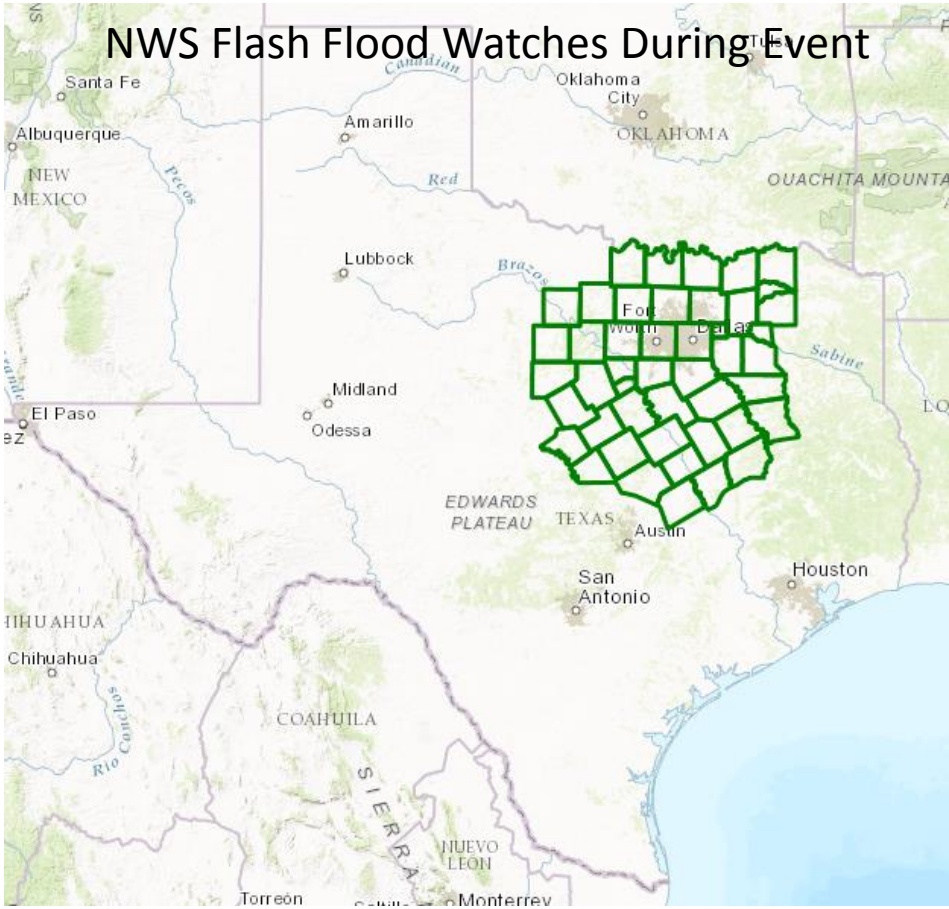






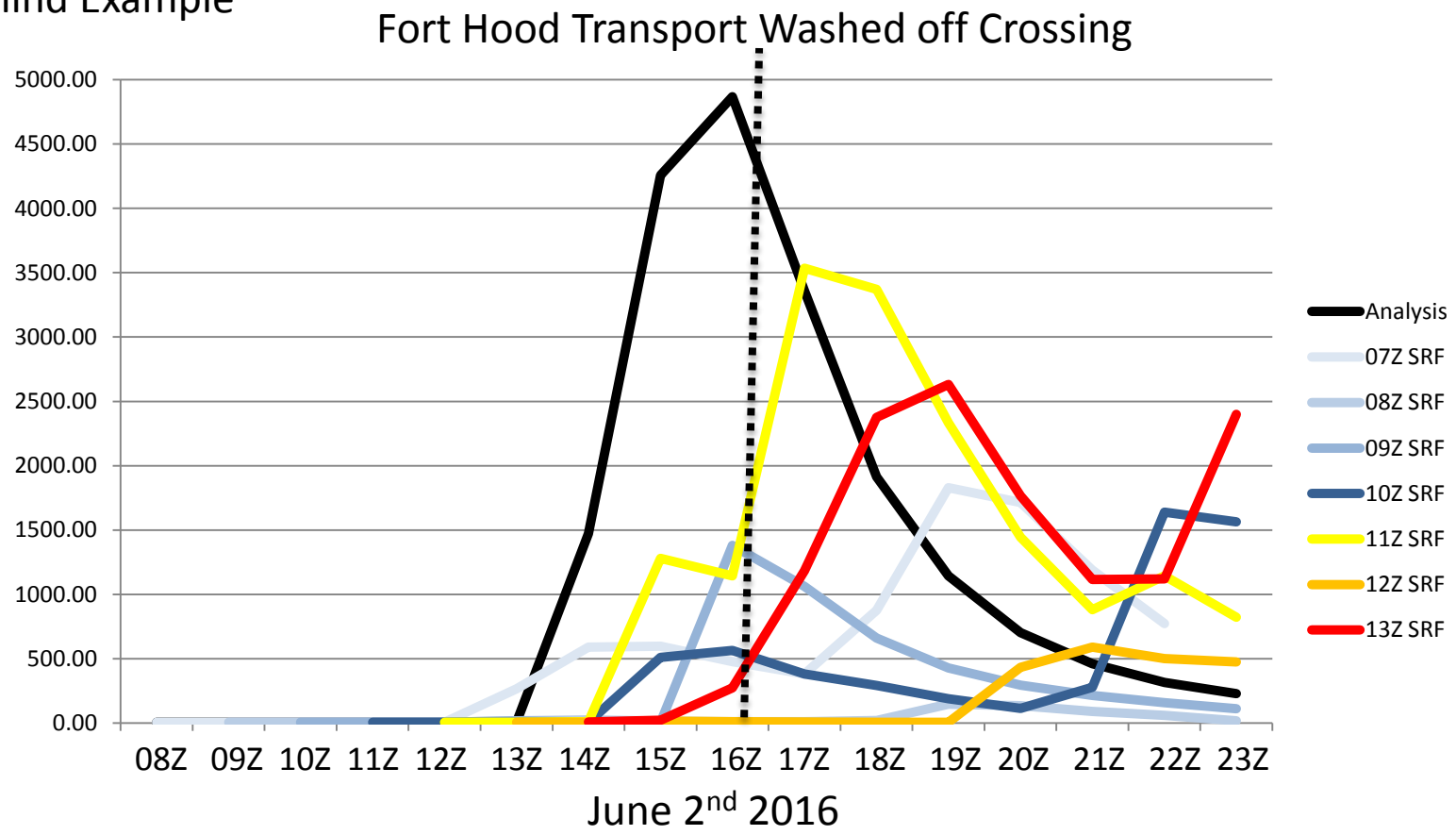
Fort Hood Flash Flooding: NWS Services

- Heavy rain led to flash flooding of small Owl Creek the morning of June 2nd, 2016.
- Nine soldiers drowned after their 2.5 ton truck was swept off a low water crossing on base
- Underserved/Hydro-blind area
- Nearest NWS river forecast point and USGS gauge 25km from where flooding occurred
- Flash flood watch active for broad area
  - "FLASH FLOOD WATCH CONTINUES FOR A PORTION OF NORTH CENTRAL TEXAS… MANY AREAS HAVE ALREADY RECEIVED HEAVY RAINFALL OVER THE LAST WEEK AND ADDITIONAL RAINFALL IS LIKELY TO CAUSE FLOODING"



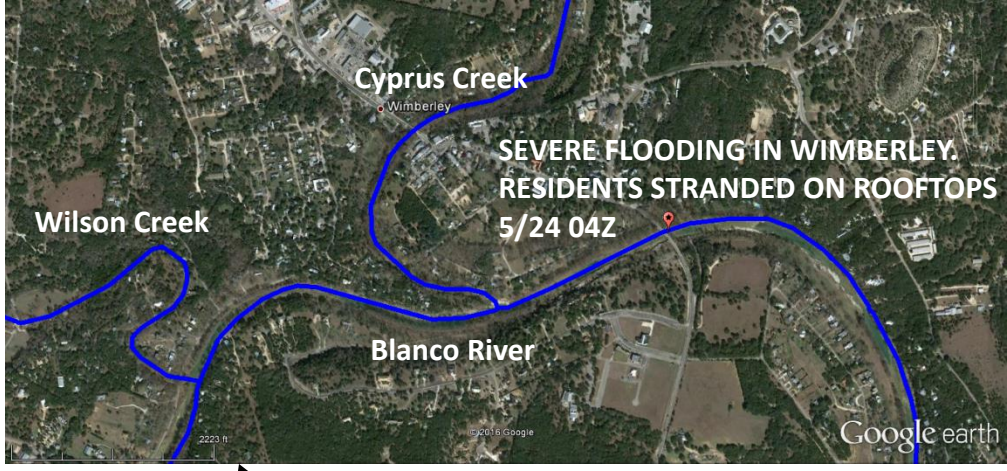
Fort Hood Flash Flooding: NWM Short-Range Forecasts

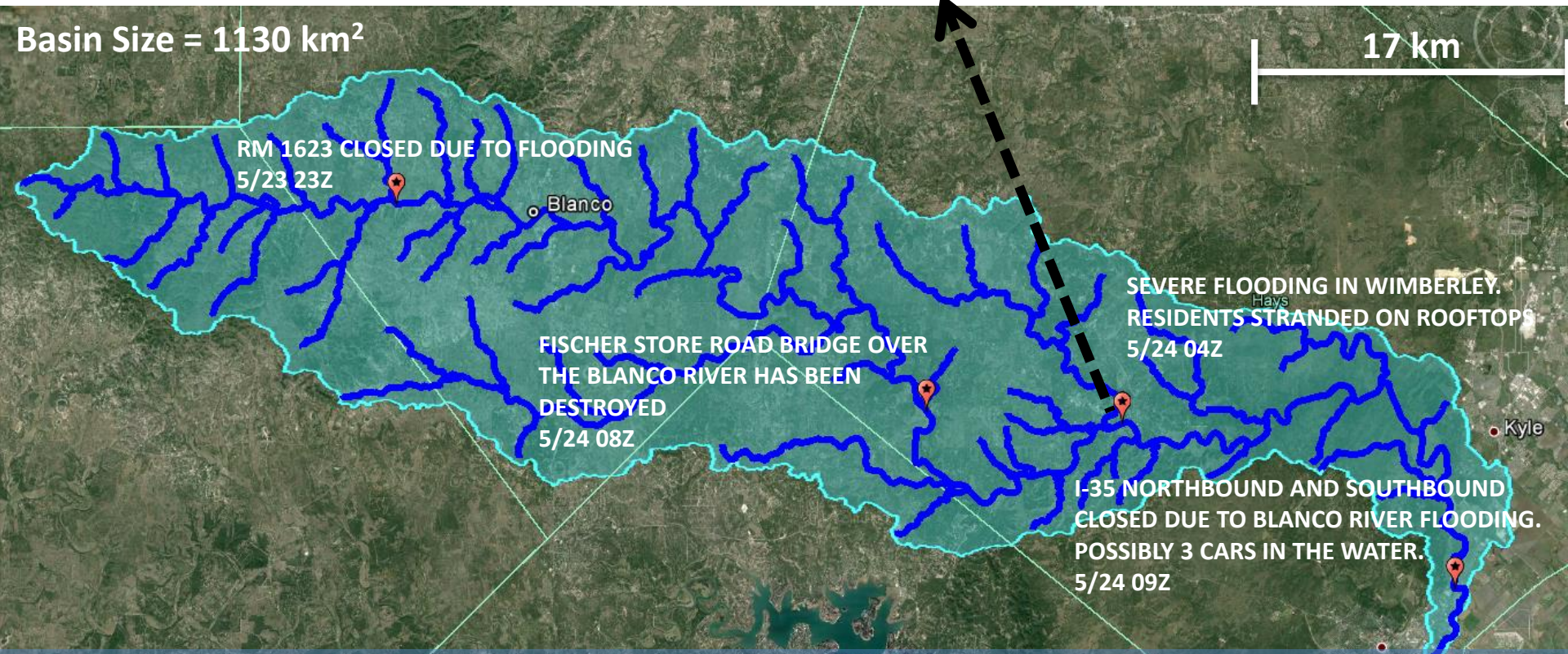
Hydro-Blind Example



- The NWM short range forecast detects the basic event signal 9 hours in advance
- Seven hours in advance, the model captures the timing extremely well
- Taken together, they give a forecaster useful insight into this severe, localized event
- Could enable specific, localized actions to prevent loss of life and property
- Timing varied at medium range (not shown), but basic signal appeared 4-5 days out

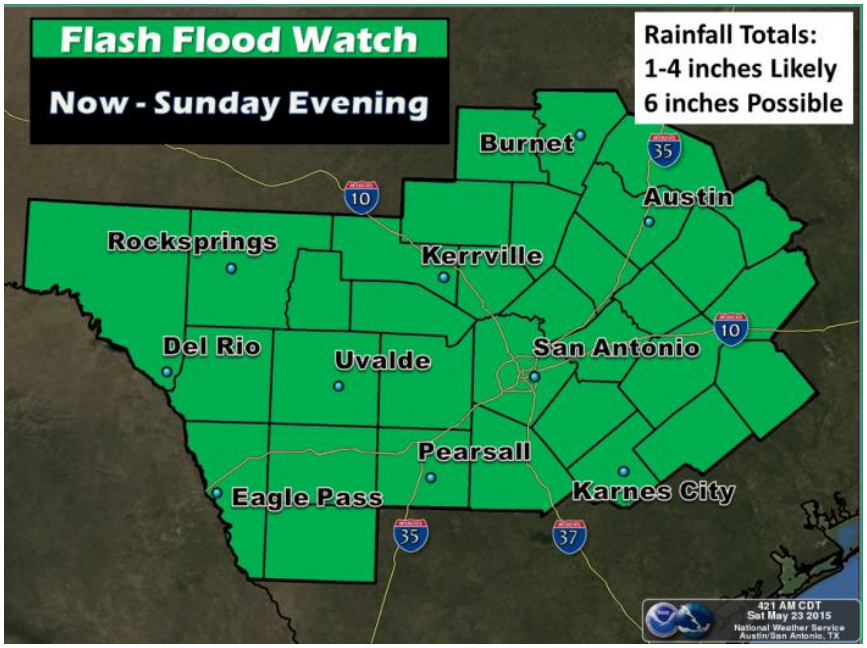
Event Overview
Blanco River Flooding
May 23-24 2015
Hydro-Rich area
(gauged with AHPS point)





- **Heavy rain fell in the headwaters of the Texas Blanco River Basin over 4-6 hours**
- **Blanco River at Wimberley rose from *near 5 feet at 9pm to near 41 feet by 1am*, rising 5 ft every 15 minutes from 10:45pm to 11:45pm.**

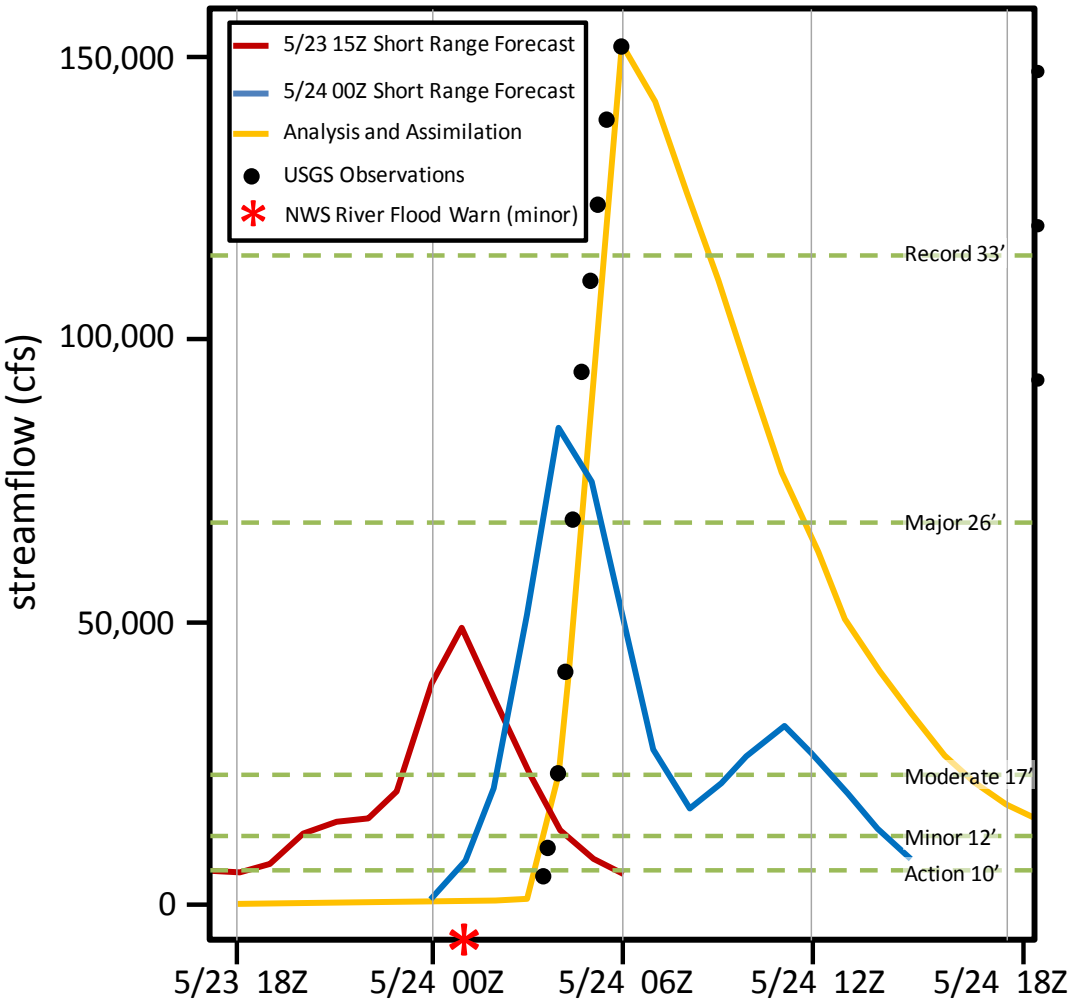
Blanco River Flash Flooding: NWS Services



- **NWS did a good job highlighting general threat of flooding**
  - **Products included flash flood watches, warnings and emergencies along with river flood warnings**
  - **Several hours of lead time were granted by warnings**
- **Increase in geographic specificity of watches and warnings would have been beneficial**

Blanco River Flash Flooding: National Water Model Forecast Evaluation

Blanco River at Wimberley Texas (08171000)
Short-Range NWM Forecasts, May 2015

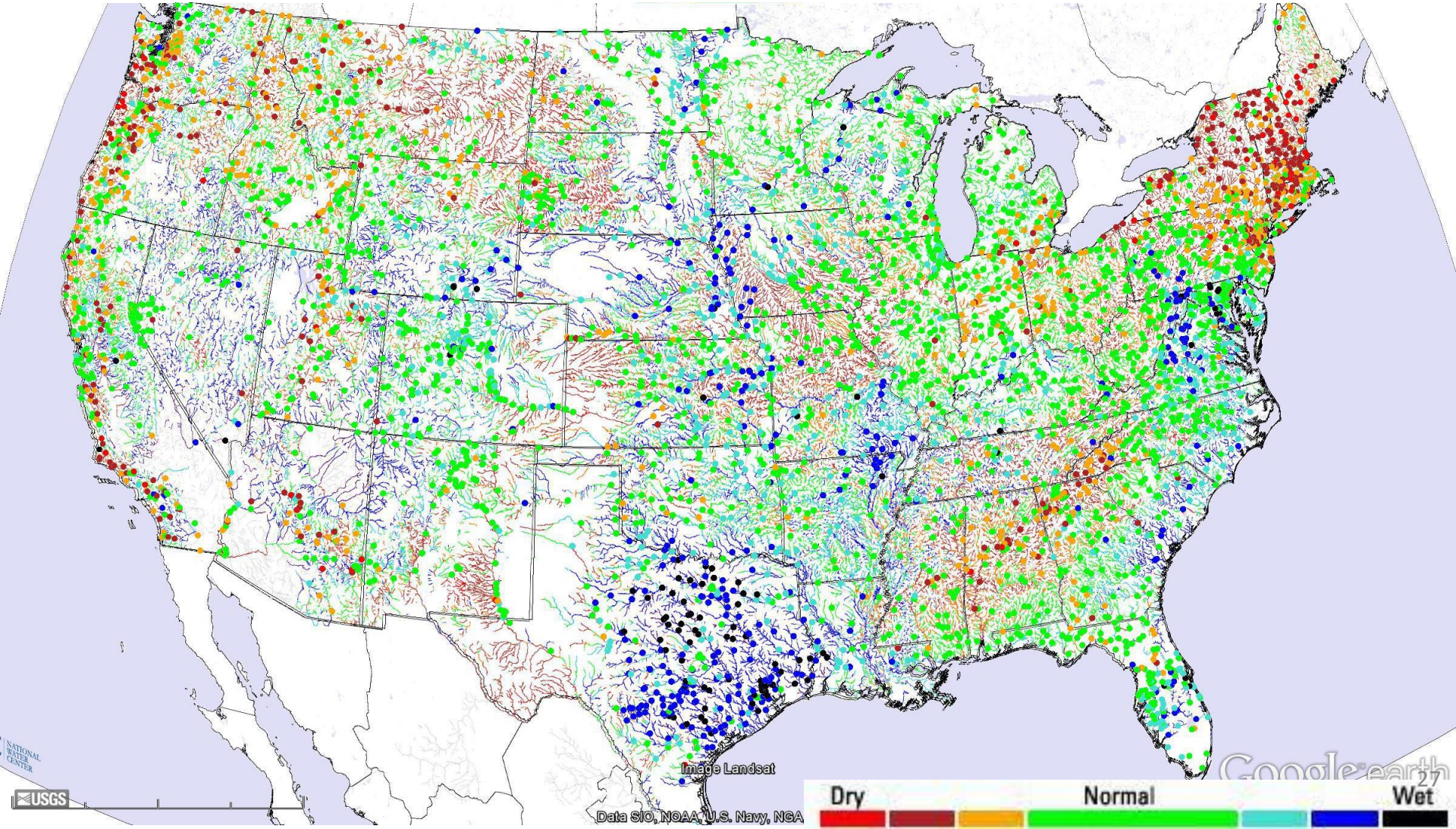


- Challenging, localized event
- Flooding reported at 04Z, residents on rooftops
- NWM forced with HRRR forecasts and MRMS observations
- Key highlights of NWM output
  - Analysis w/DA tracks flood peak timing and magnitude very well
  - NWM forecasts, used to complement existing guidance, would have provided several hours of lead time, indicating potential for significant flooding at local level

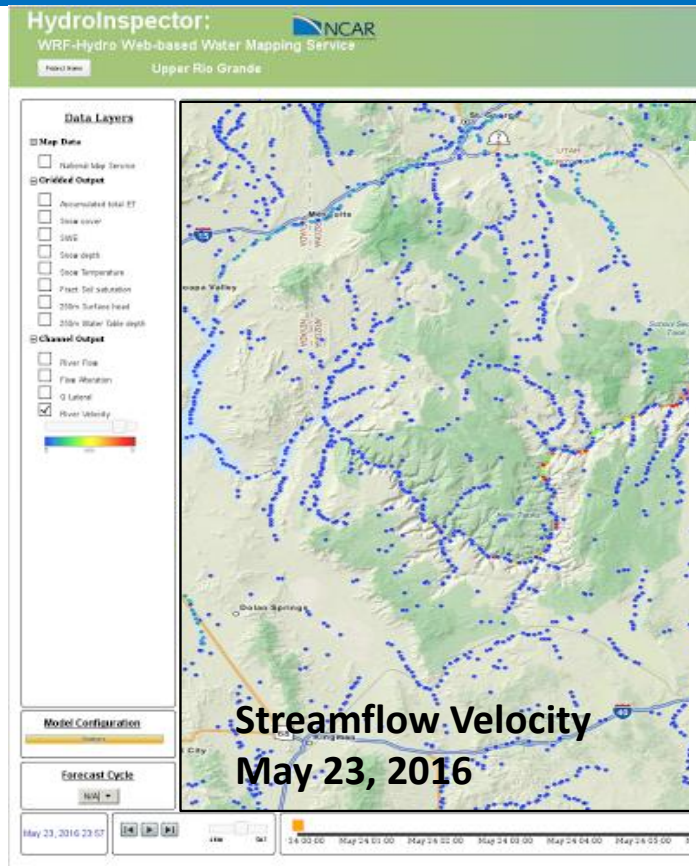
HRRR-driven NWM provided 12 hour lead time for this event

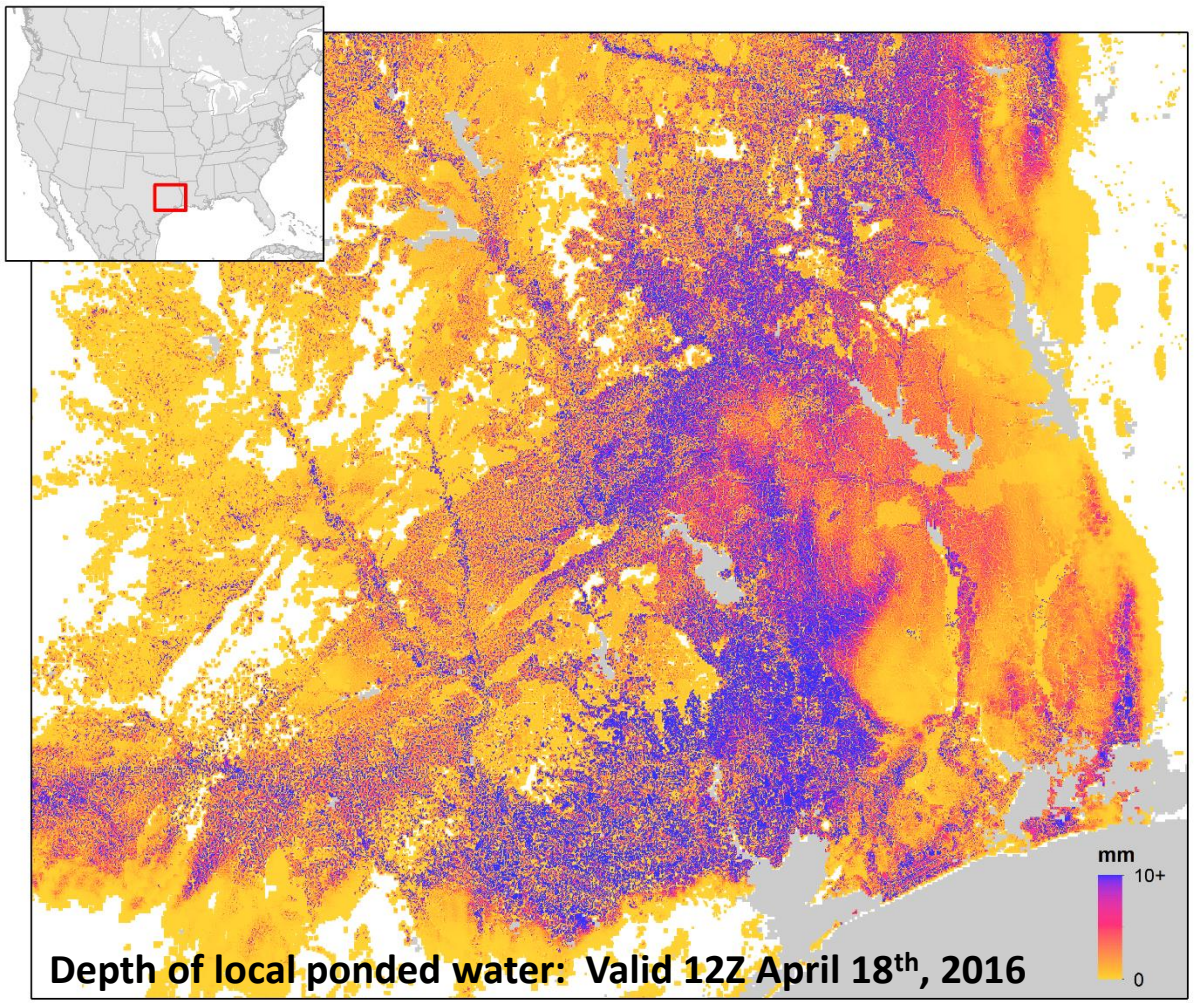
NWM: Beyond Forecasts, Improved Hydrologic Situational Awareness

USGS Observed Streamflow Anomalies (dots)
and NWM Analysis Streamflow Anomalies (lines)



NWM V1.0: Forward-Looking Non-Traditional Output

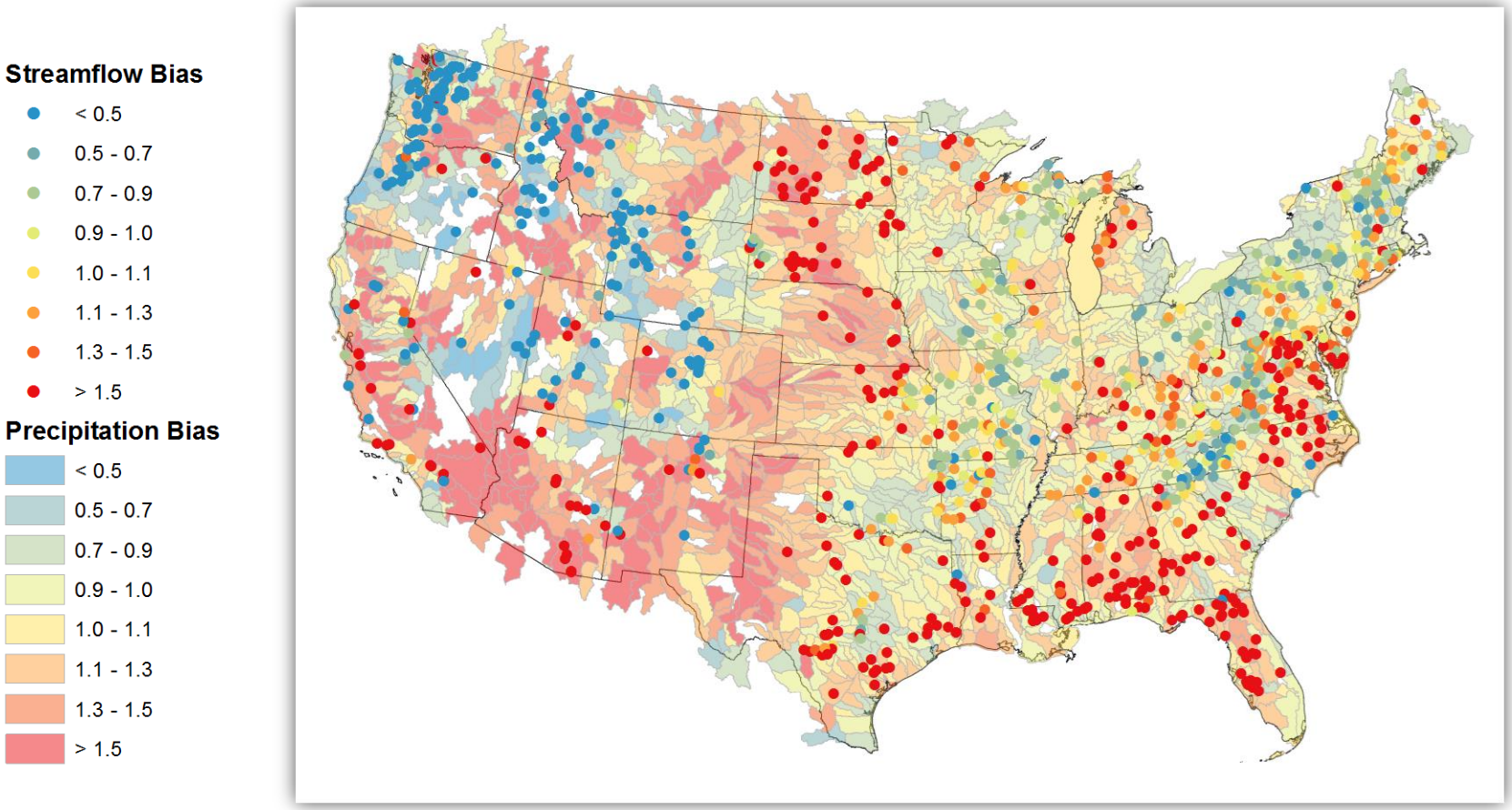




- Depth of ponded water analyses and forecasts, insight into non-channelized flash flooding (right)
- Streamflow Velocity analyses and forecasts, public safety and engineering applications (left)

NWM: Feedback to Atmospheric NWP Community

Ongoing Work:
Assessment of how much errors in QPF contribute to errors in NWM streamflow



- Sample type of plot that will be used to examine key relationship between precipitation forcing and NWM streamflow forecast accuracy
- Constructive feedback loop to assist in improvement of QPF from atmospheric models

NWM: Potential Uses of Satellite Data

- **Currently, only in situ streamflow observations are assimilated**
- **Bias correction of hydrologic states via assimilation**
  - Snowpack (Recently funded NOAA/NCAR JPSS Risk Reduction proposal)
    - VIIRS snow cover fraction
    - ATMS and AMSR2 snow depth and snow water equivalent
  - Flood inundation, river ice and lake level products
  - Soil moisture
- **Gap-filling areas of poor radar coverage via blending with terrestrial data**
  - IR and passive microwave precipitation products
  - Lightning data
  - Satellite snowfall rates
- **Dynamic model parameter updates**
  - Vegetation green fraction
  - Burn scar mapping
- **Validation of model output**
  - Evapotranspiration
  - Snowpack
  - Soil Moisture
  - Flood Inundation

Summary

National Water Model V1.0 in operations on NOAA WCOSS Cray

- NWM designed to address NAS recommendations, and meet the growing need for enhanced water resources information
- NWM will provide complementary hydrologic guidance at current forecast locations and significantly expand guidance coverage and type
- Strong evaluation effort underway
  - Assessing performance of version 1.0, informing use of model output
  - Moving beyond evaluation to error attribution with linked streamflow-QPF analysis
  - Provides an objective set of measures upon which to base future model upgrades
- Future enhancements tied to OWP strategic plan and the broader NOAA Water Initiative
- Work will occur with EMC to move forward on areas of collaboration
- NWM V1.0 establishes foundation for sustained improvement in water prediction and first ever nationally consistent operational hydrologic forecasting capability