Applications of WRF-Hydro

NCAR Research Applications Lab

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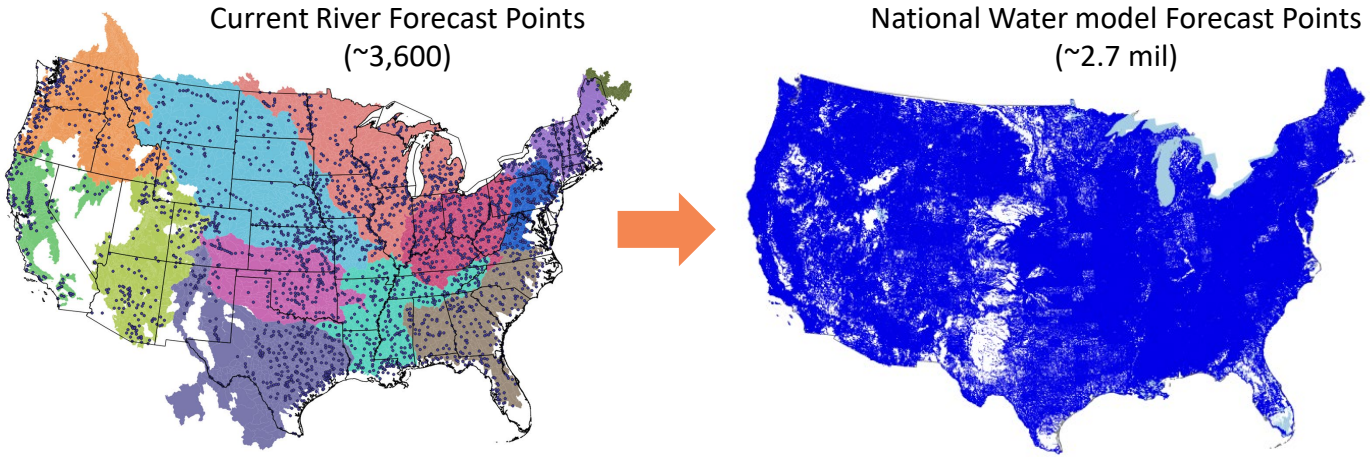
Outline

- WRF-Hydro research areas:
  - NOAA National Water Model
  - Downscaled flood inundation products
  - Hyper-resolution modeling
  - Constituent transport/tracer modeling
  - Seasonal water Supply forecasting
  - USGS Water Census and coupled Hydroclimate Modeling

Goals of the NOAA National Water Model

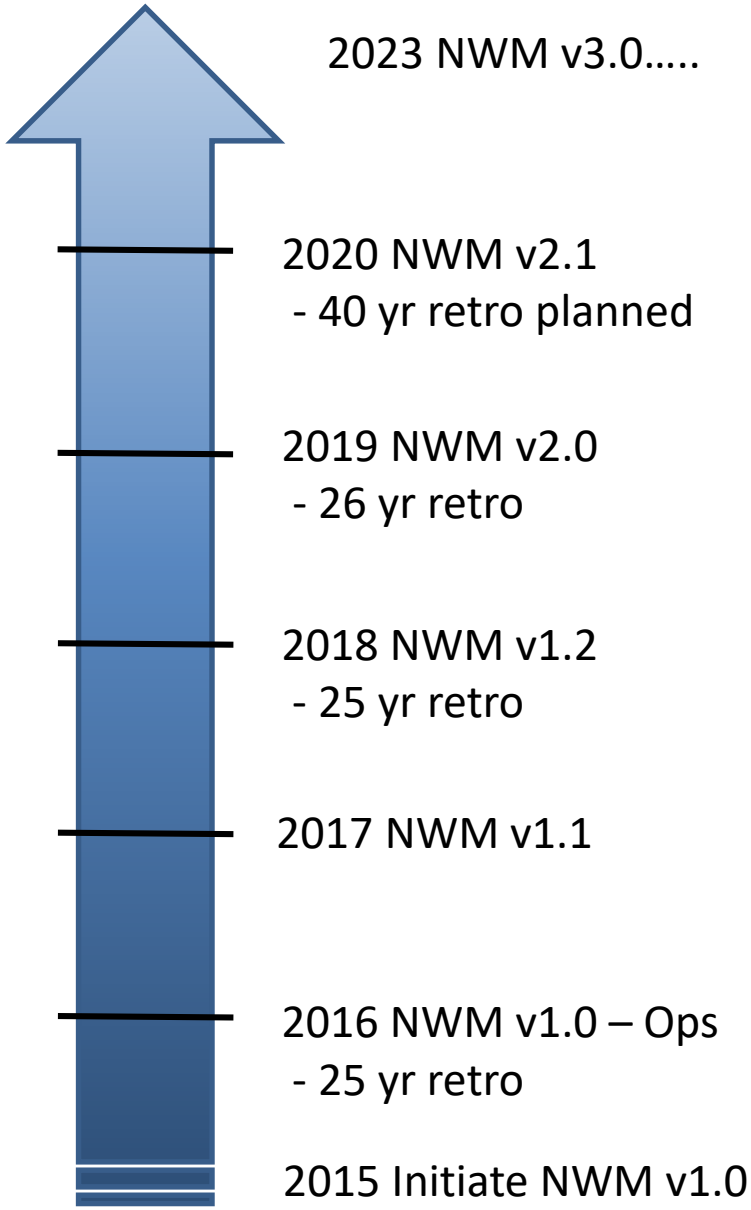
- Operational forecast streamflow guidance for currently *underserved locations*
- Fully *continuous, 24/7/365 analyses and forecasts* of the nation's surface water
- Seamlessly interface real-time hydrologic products into an advanced *geospatial intelligence* framework
- Rapidly *infuse critical observation data*



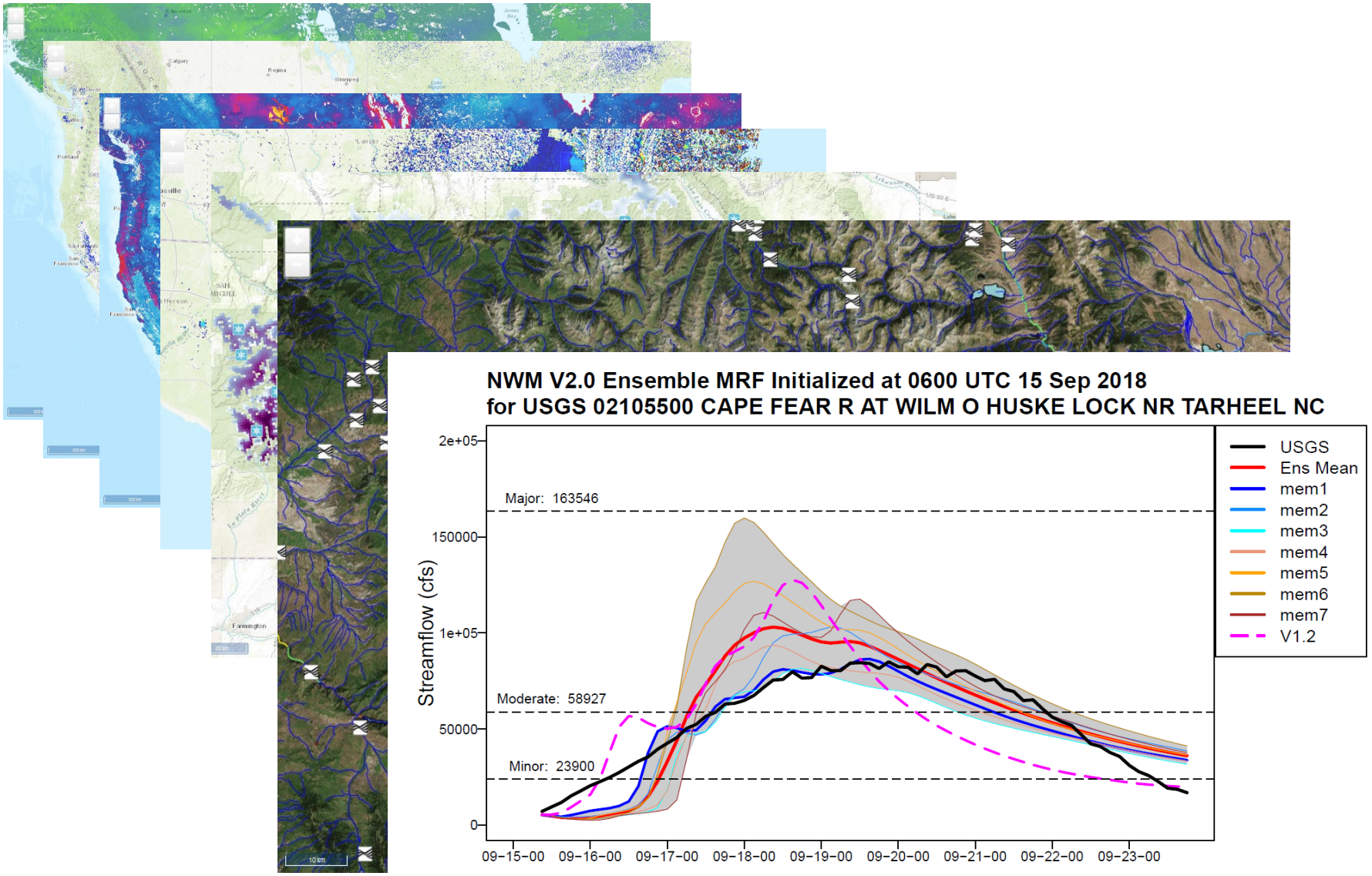
Supporting the NOAA National Water Model

- NCAR Role:
  - Build and maintain underlying WRF-Hydro modeling architecture
  - Enhance physics options and input data into NWM
  - Conduct training and capacity building services
  - Perform version-over-version evaluation and assessment
  - Execute long-term retrospective model integrations for statistical benchmarking

- 25- and 40-year retrospective runs aligned with v2.0 and v2.1 of the NWM respectively. Available on AWS.

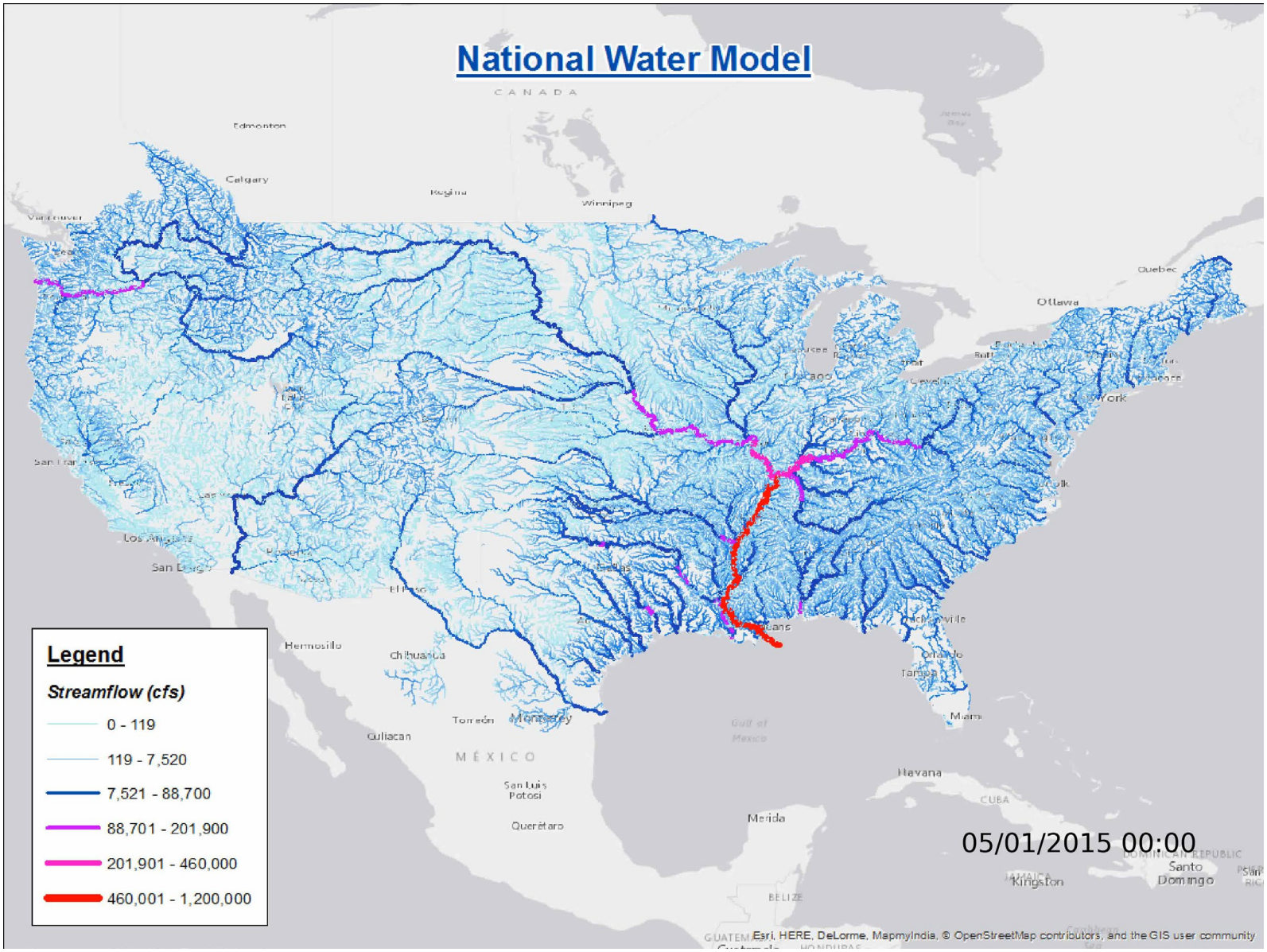


Model Outputs



Ensemble streamflow predictions

The NOAA National Water Model



The NOAA National Water Model: Operational Version Upgrades

v1.0
August 2016
Inaugural water forecasting model, 1-km/ 250-m CONUS coverage, 2.7 mil reaches, stream DA

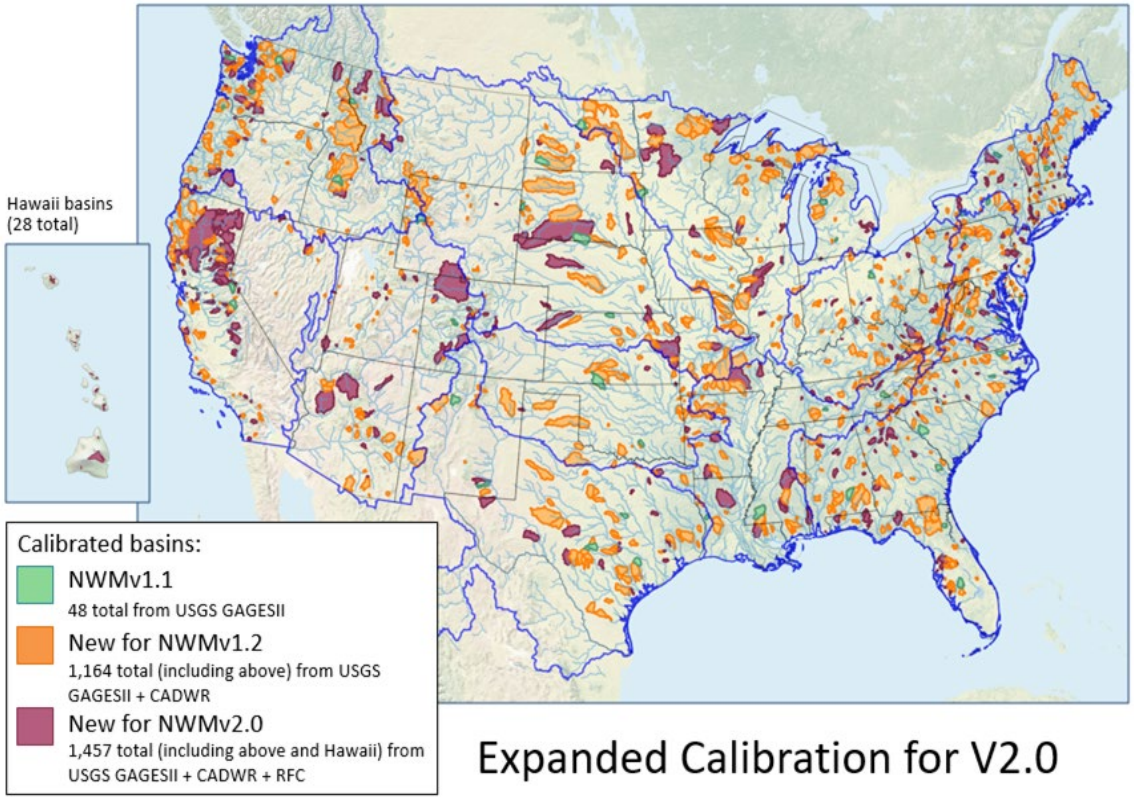
v1.1
May 2017
Extended forecasts, parameter calibration

v1.2
March 2018
Expanded parameter calibration, improved DA

v2.0
June 2019
Hawaii expansion, new ensembles, compound channel, extended analysis

v2.1
In transition to ops: March 2021
Expansion to Great Lakes & PR/VI, new reservoir management modules

v3.0
Future upgrade: 2023
Expansion to Alaska, improved runoff, improved derived parameters, dynamic land cover, multi-variate calibration



Expanded Calibration for V2.0

National Water Model V2.1: Cycling Overview

Lookback Range 3-28 hrs

New for V2.1…open loop (non-DA) members

18 Hour Forecast

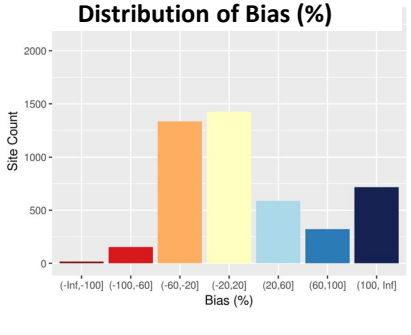
~10 Day Ensemble Forecast

New for V2.1…open loop (non-DA) member

30 Day Ensemble Forecast

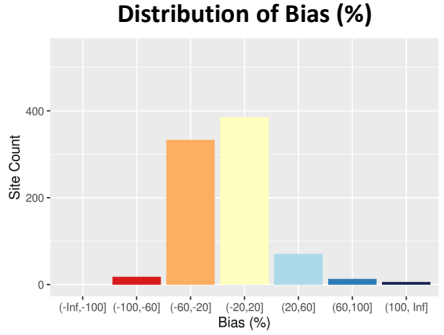
NWM v2.1 Retrospective Improvement: USGS Reference Gauges

V1.0



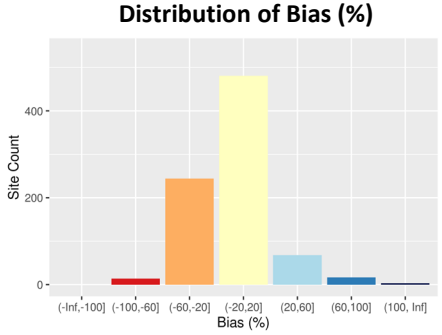
31% have bias < +/-20%

V1.2



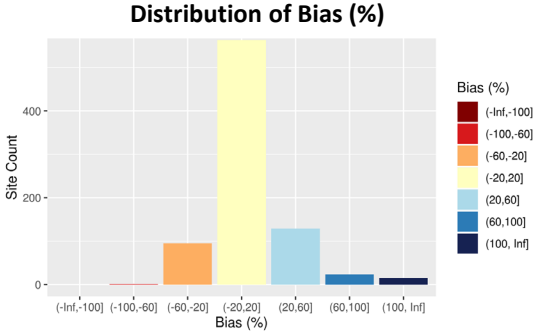
46% have bias < +/-20%

V2.0



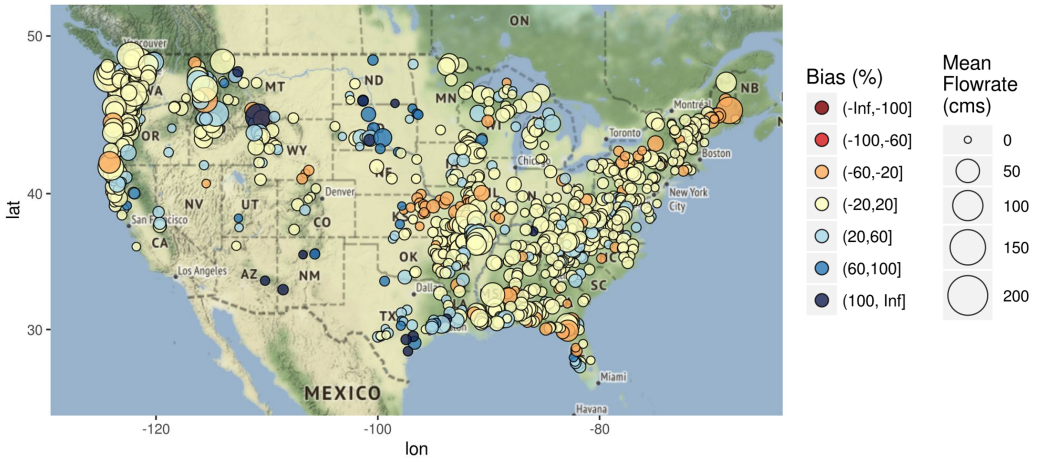
58% have bias < +/-20%

V2.1



68% have bias < +/-20%

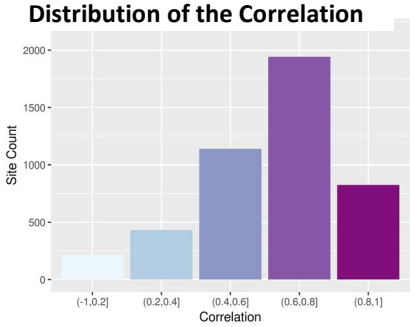
NWM v2.1 Hourly Streamflow Bias at USGS Gauges (WY 2014-2016, AORC Forcing)



- **Streamflow bias continues to improve at unregulated USGS gauged basins**
- **Simulation is for WY2014-2016 (validation period) and uses AORC forcing data**
- **No assimilation of streamflow or reservoir observations**

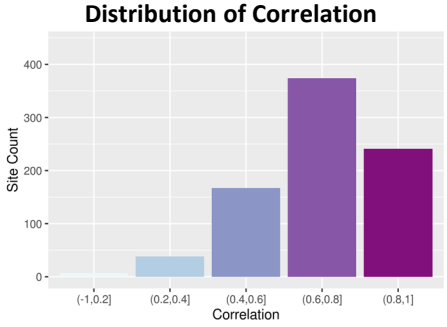
NWM v2.1 Retrospective Improvement: USGS Reference Gauges

V1.0



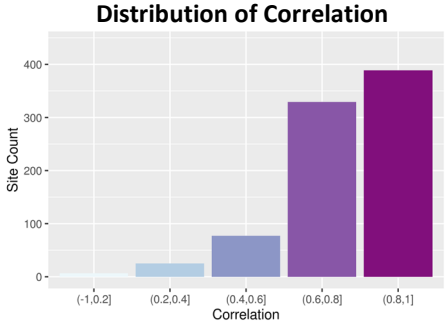
18% have cor >= 0.8

V1.2



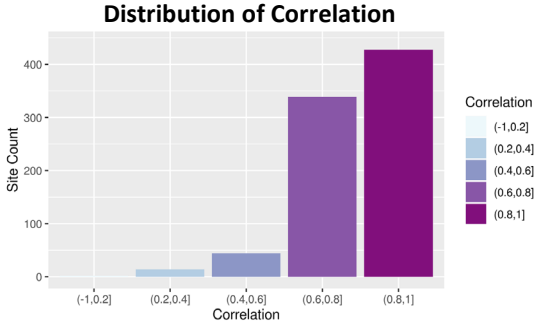
29% have cor >= 0.8

V2.0



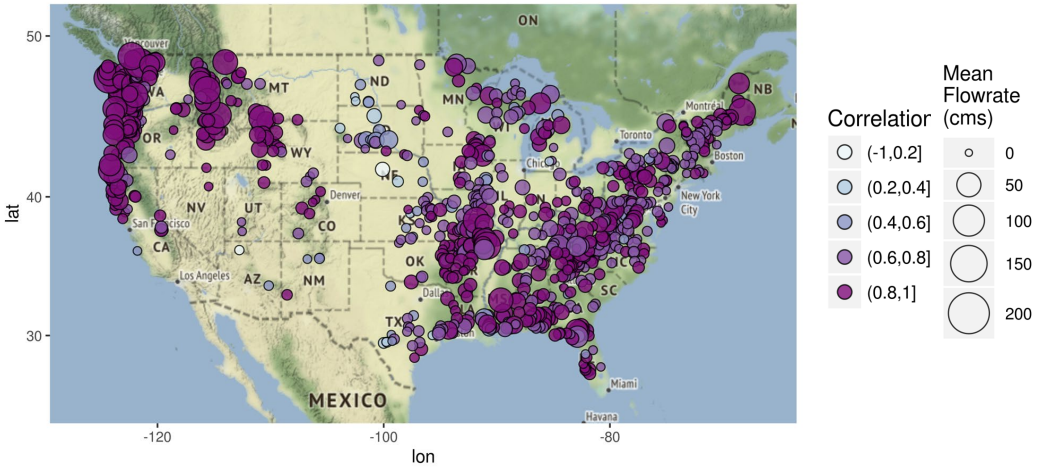
47% have cor >= 0.8

V2.1



52% have cor >= 0.8

NWM v2.1 Streamflow Correlation at USGS Gauges (WY 2014-2016, AORC Forcing)



- **Streamflow correlation continues to improve at unregulated USGS gauged basins**
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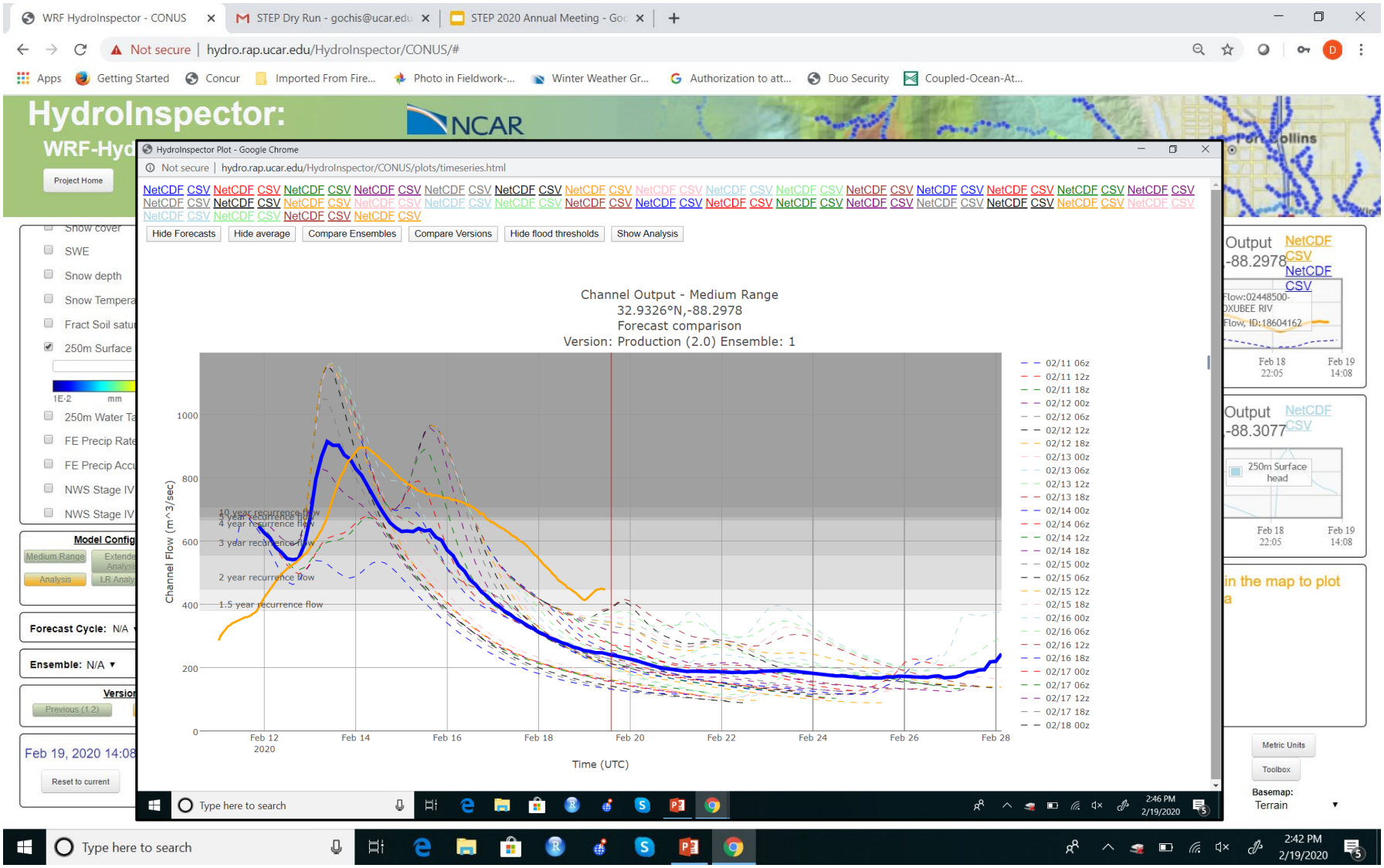
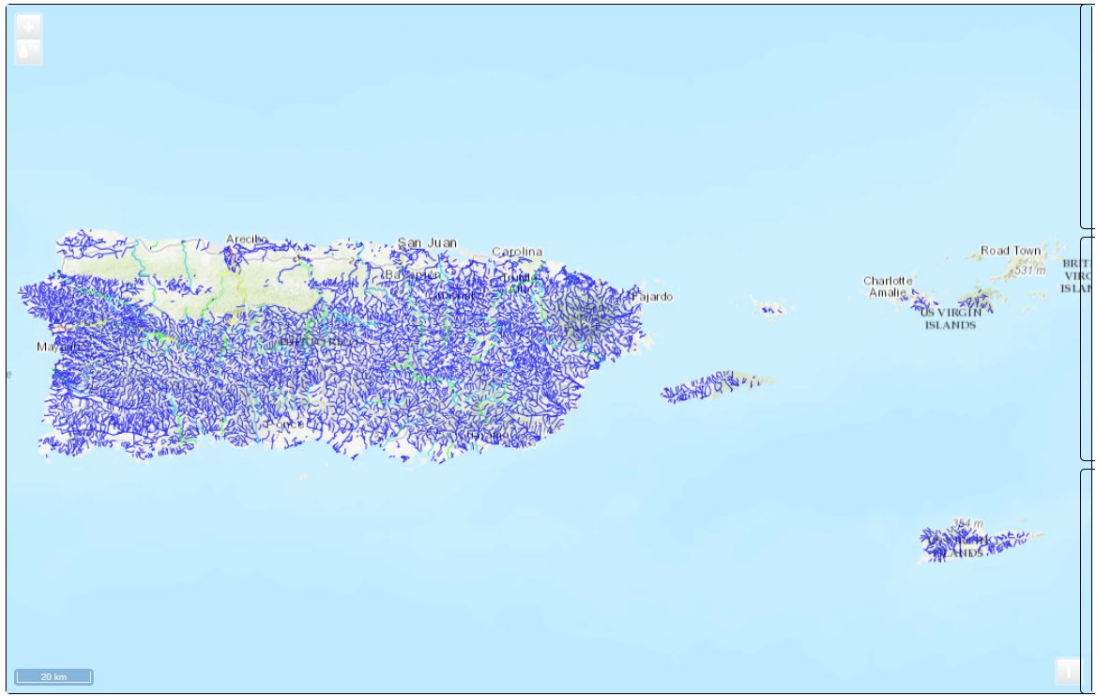
WRF-Hydro Research: Flood Frequency Exceedance Products

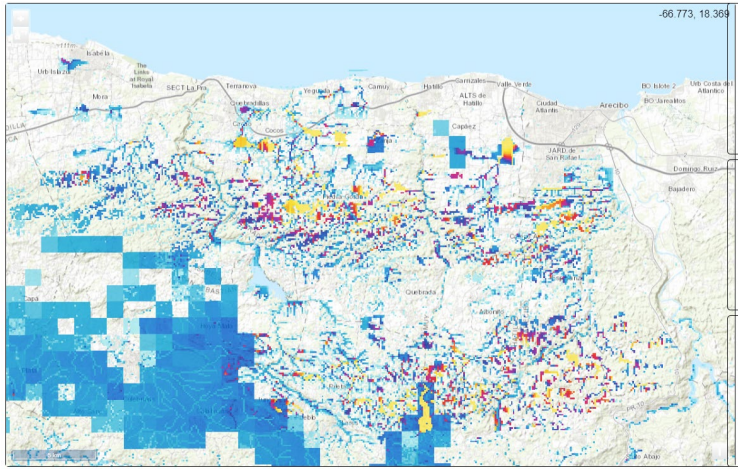

WRF HydroInspector - CONUS
STEP Dry Run - gochis@ucar.edu
STEP 2020 Annual Meeting - Goo
Not secure | hydro.rap.ucar.edu/HydroInspector/CONUS/#
Apps
Getting Started
Concur
Imported From Fire...
Photo in Fieldwork-...
Winter Weather Gr...
Authorization to att...
Duo Security
Coupled-Ocean-At...
HydroInspector:
WRF-Hyd
NCAR
Project Home
HydroInspector Plot - Google Chrome
Not secure | hydro.rap.ucar.edu/HydroInspector/CONUS/plots/timeseries.html
NetCDF CSV NetCDF CSV NetCDF CSV

WRF-Hydro/NWM Implementation over Puerto Rico & V.I.

Puerto Rico & Virgin Island Hydrography

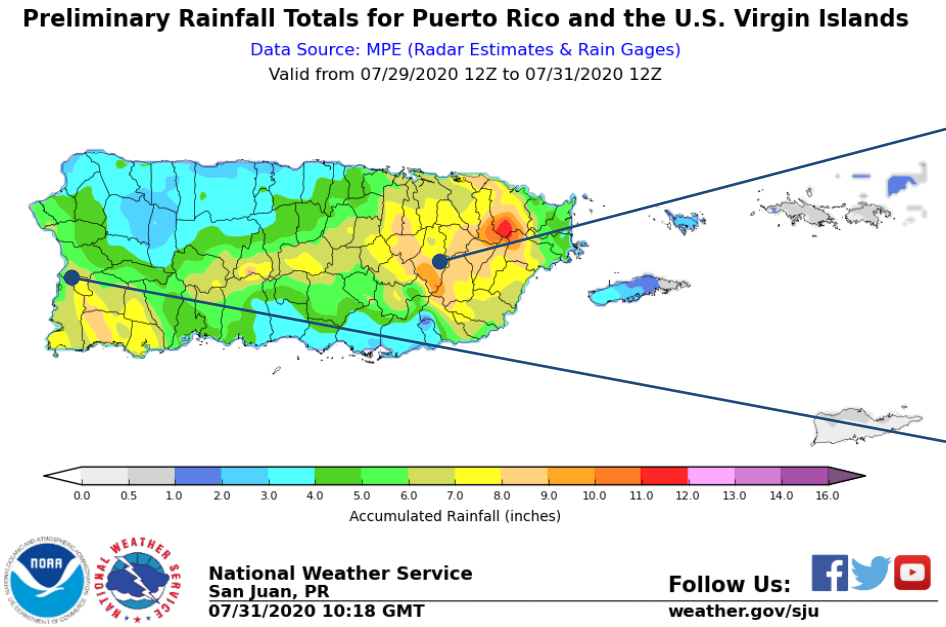


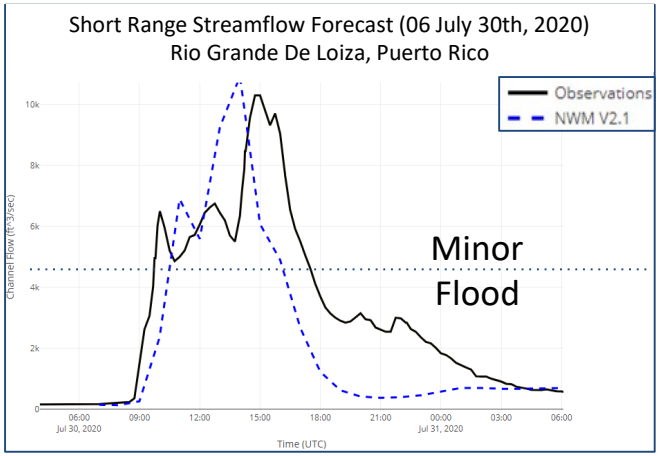
Overland Flow Depth 9/30/2020

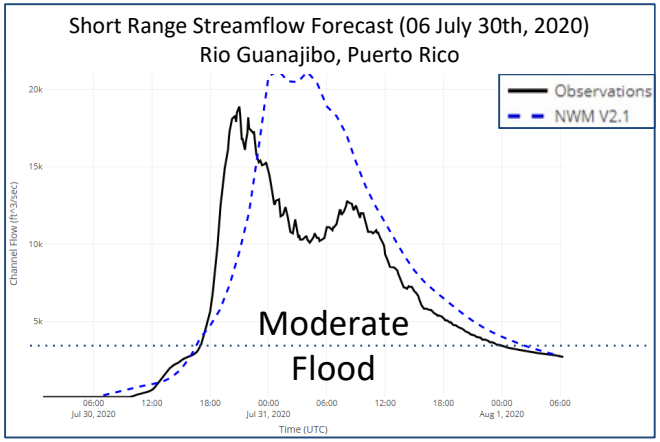


- **As with Hawaii there is significant heterogeneity in landforms, precipitation regimes, channel structures and hydrologic behavior**
- **Multiple forms of hydrologic guidance from different model outputs**

Puerto Rico Performance: Hurricane Isaias

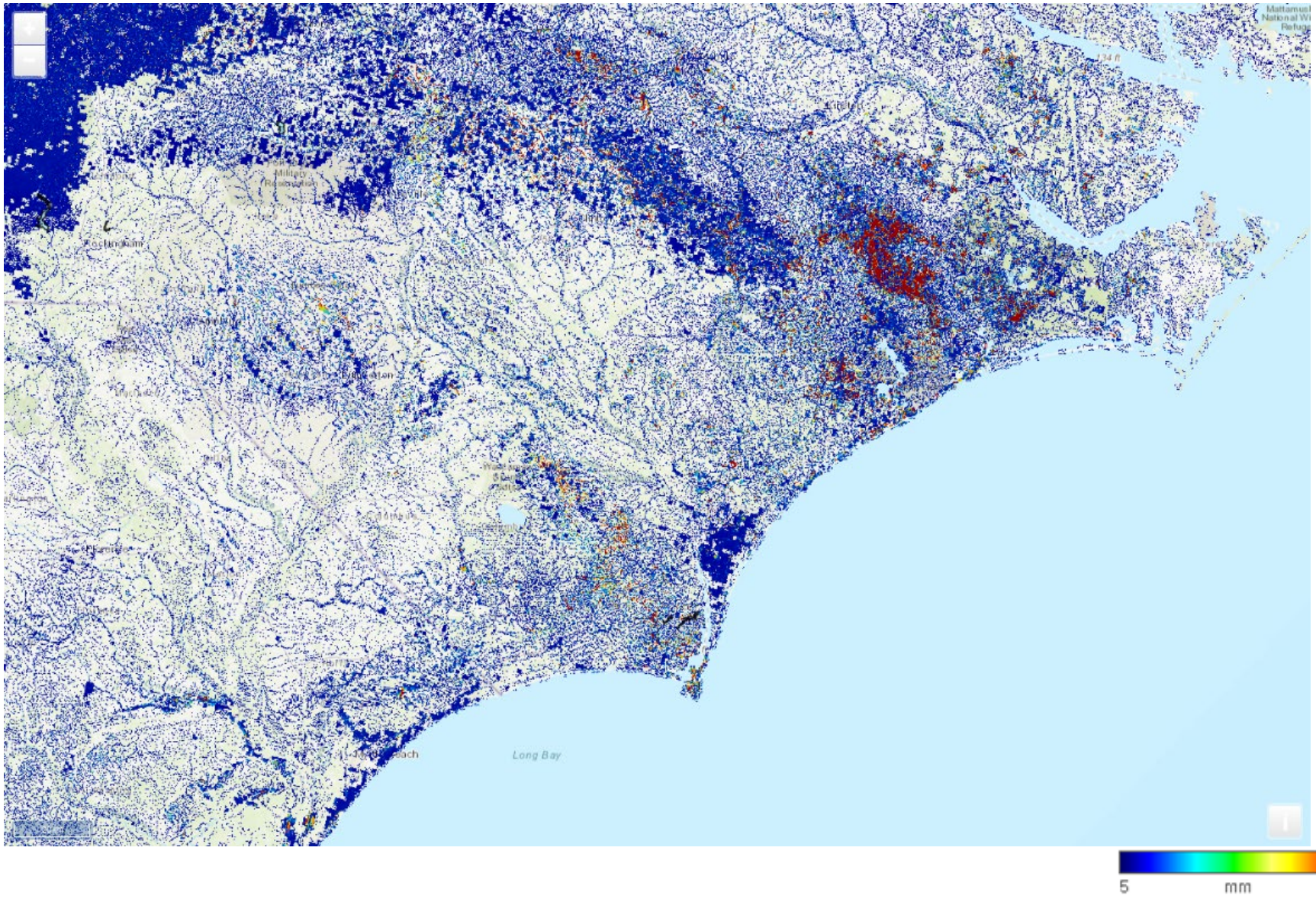




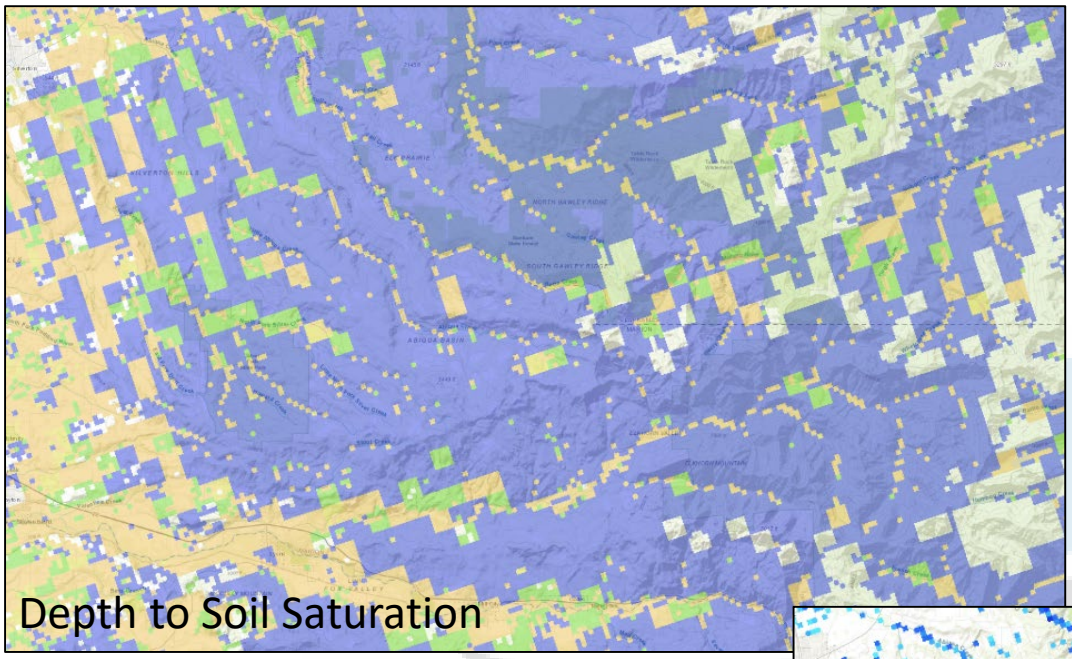


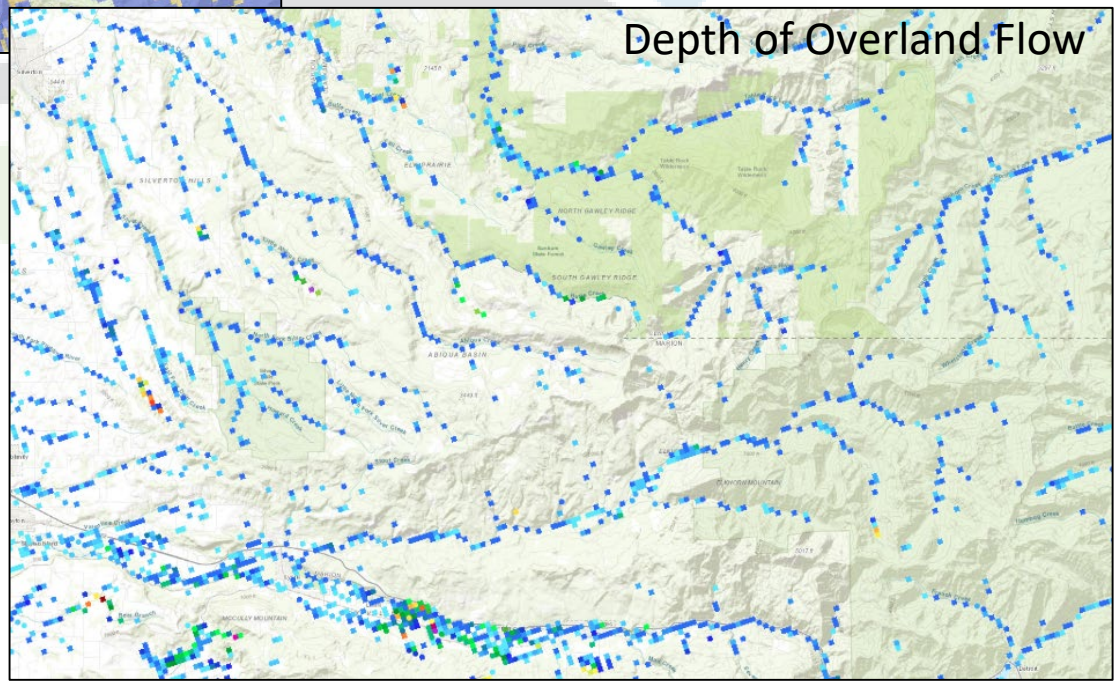
- **First implementation of PR/USVI domain performing well**
- **Good streamflow forecast magnitude and timing during Isaias**

NWM v1.2 Medium Range Forecast Surface Overland Flow Water Depth (mm):
Eastern N. Carolina, Hurricane Florence….Forecast guidance up to 6 days in advance



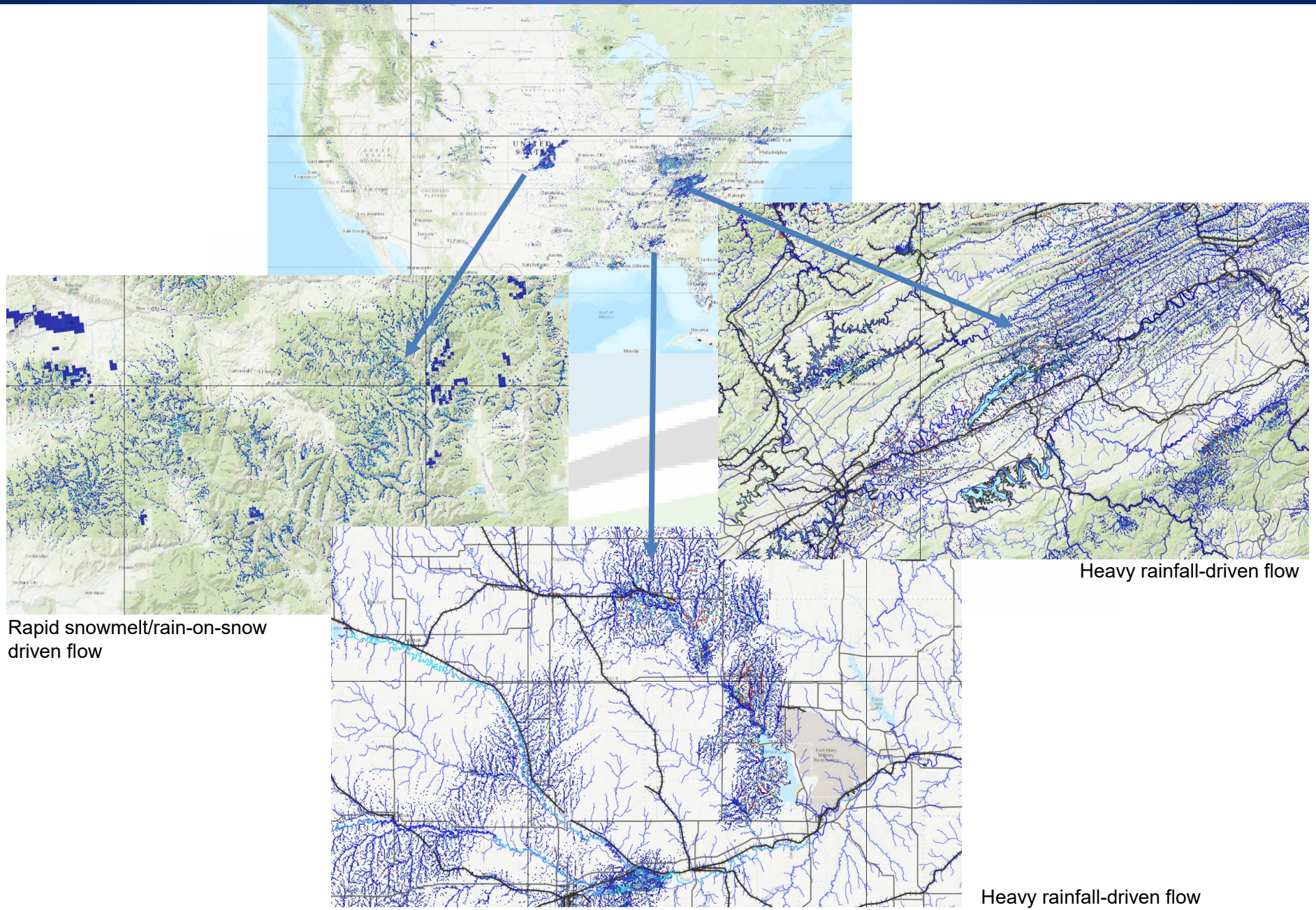
WRF-Hydro Research: Capturing multiple flooding mechanisms





- Soil column saturation
- Exfiltration to surface
- Overland flow production

WRF-Hydro Research: Capturing multiple flooding mechanisms



Rapid snowmelt/rain-on-snow driven flow

Heavy rainfall-driven flow

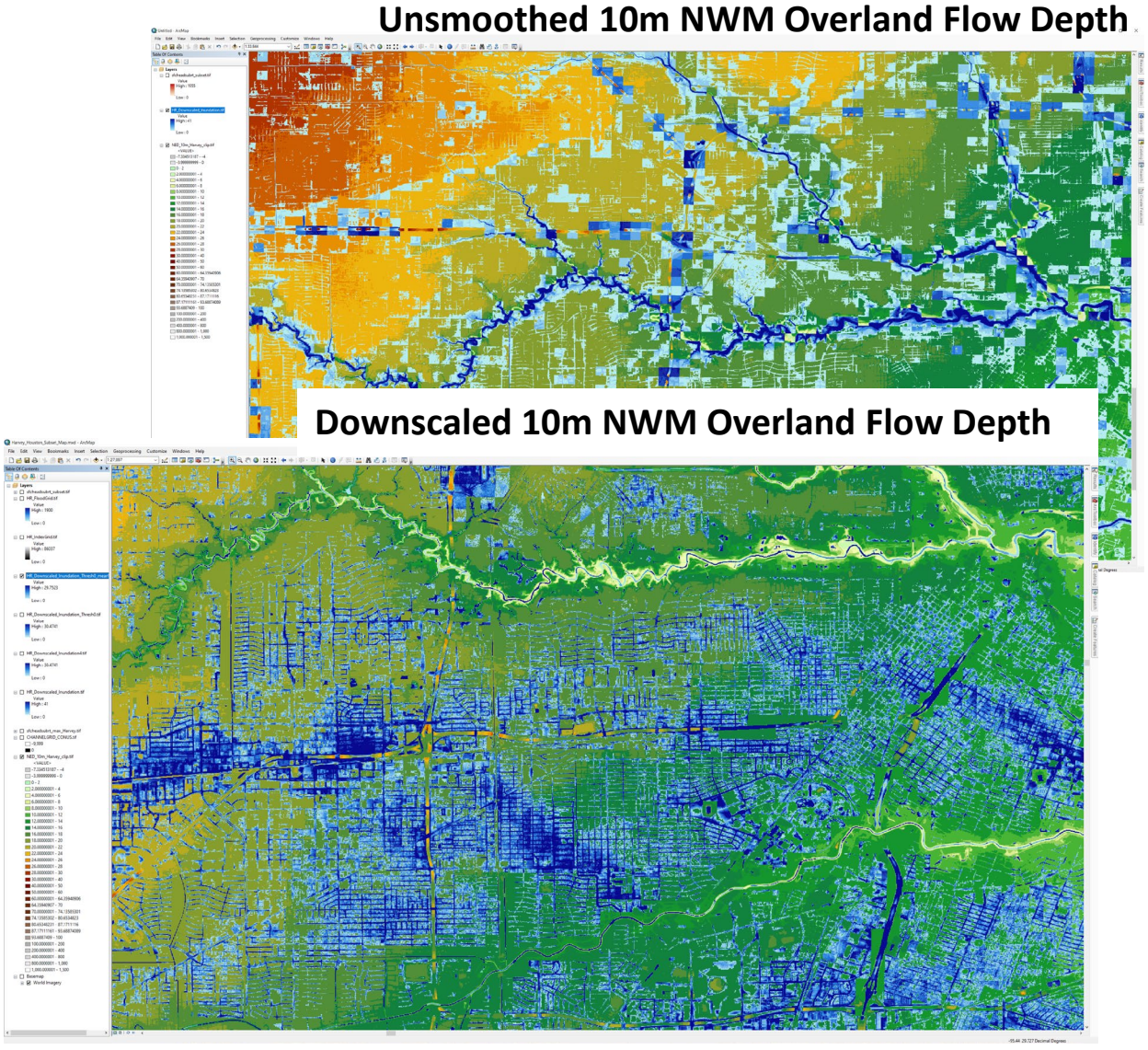
Heavy rainfall-driven flow

WRF-Hydro Research: Flood Inundation Products

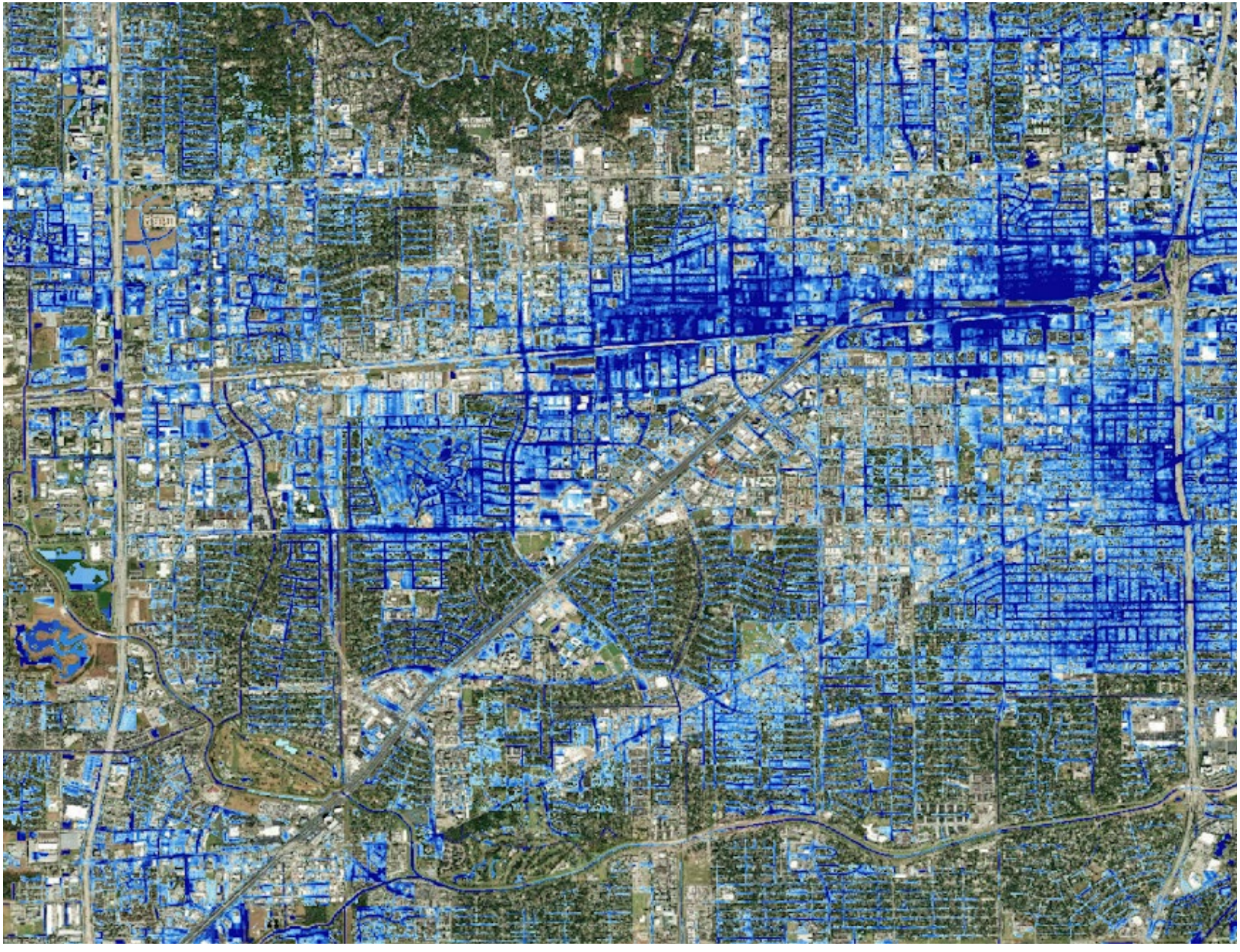
- Terrain-downscaled inundation maps

- 2-step hybrid blended product:
  - Downscaled max. overland flow depth
  - Riverine inundation
  - Utilize ensembles forecasts to make probabilistic product
  - Adopt workflow to ‘on-demand’ service via HydroInspector

- Applications in:
  - Operational prediction
  - Long term risk analysis

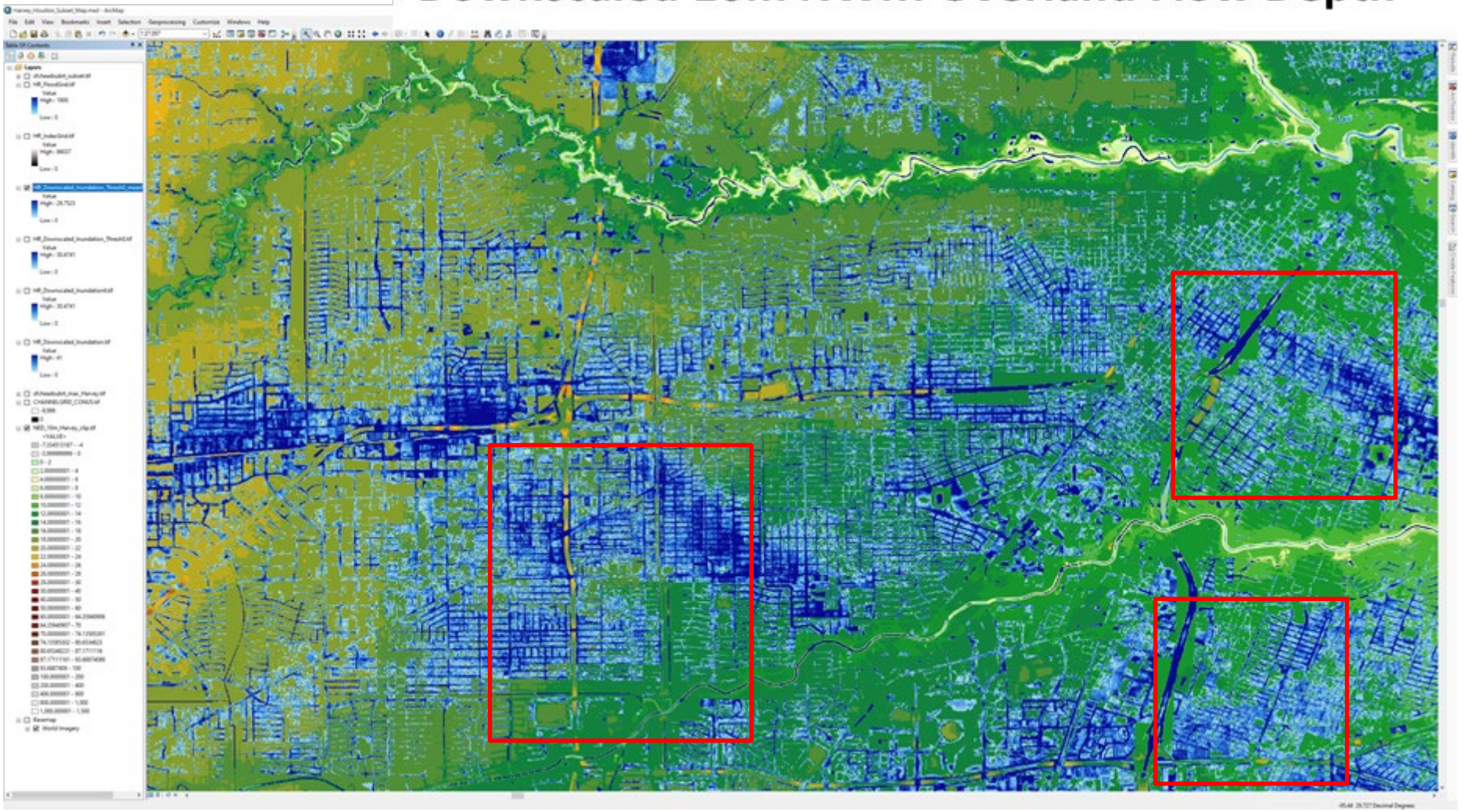


WRF-Hydro Research: Flood Inundation Products



WRF-Hydro Research: Flood Inundation Products

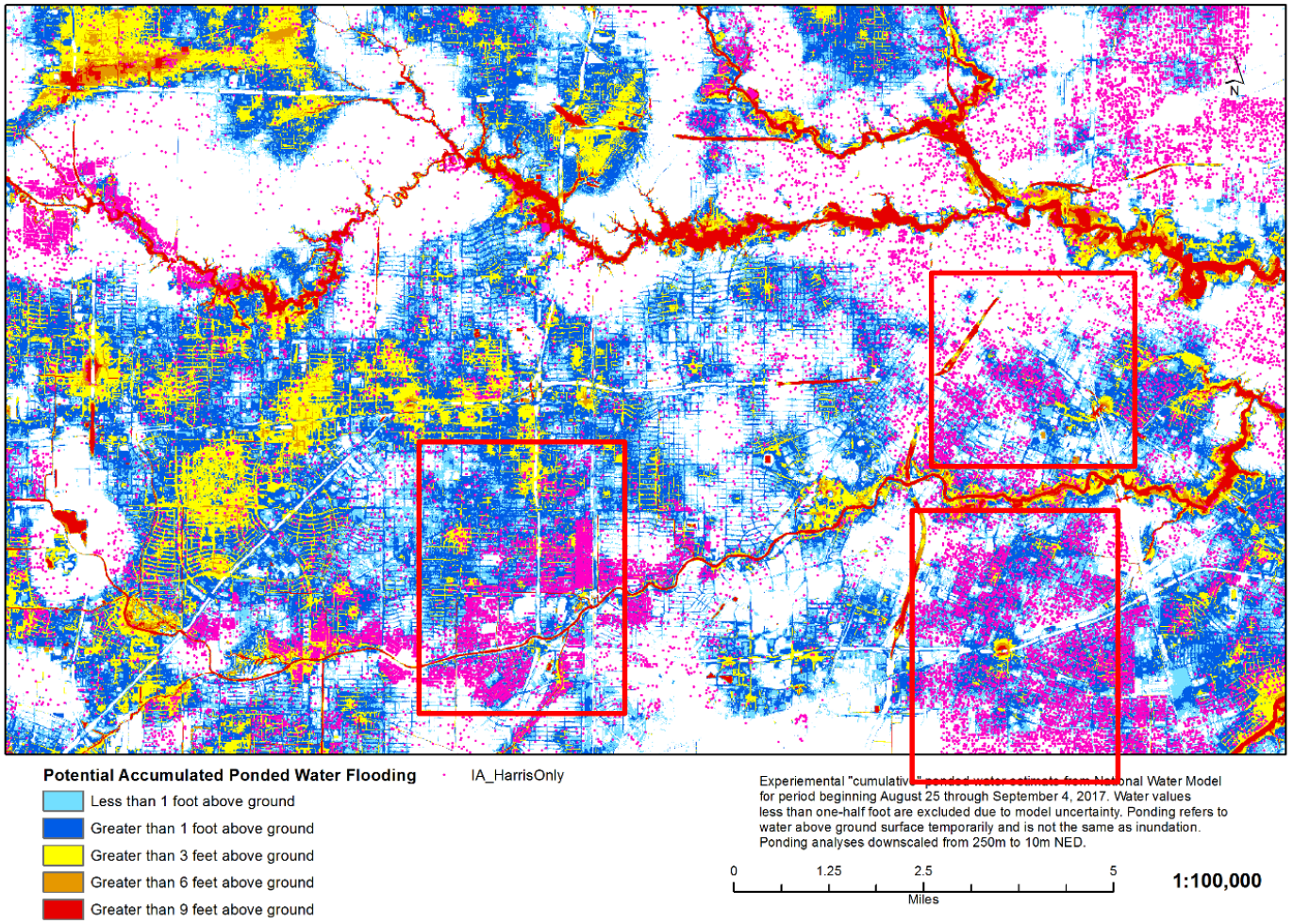
Downscaled 10m NWM Overland Flow Depth



- Work to blend overland flow with riverine flood inundation products is ongoing

WRF-Hydro Research: Flood Inundation Products

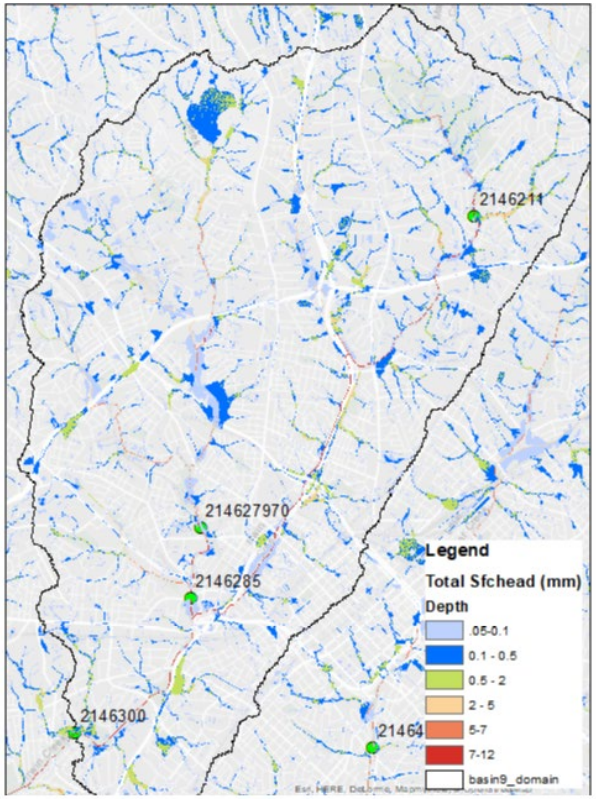
- Guidance for validating FEMA damage claims
- Building capability for cloud-based, on-demand production



WRF-Hydro Hyper-Resolution Modeling:

- Explicit characterization of landscape-constrained inundation modeling
  - Spatial scale of 1's to 10s' of meters explicit modeling
  - Akin to Large Eddy Simulation for atmosphere (not CFD though…)

10m model of Charlotte, NC

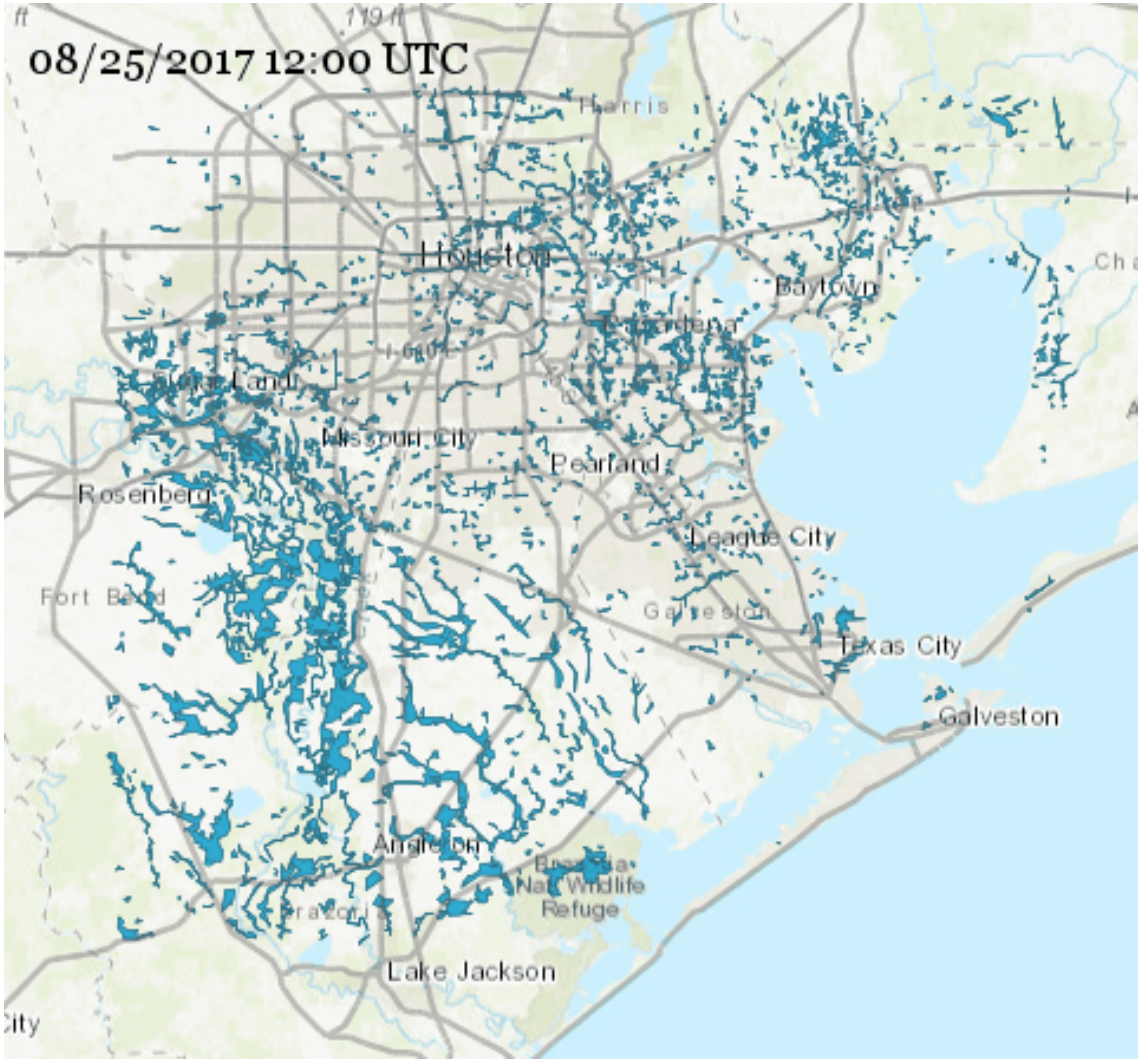


30m model of 2013 Colorado Floods

Hurricane Harvey Inundation Area Hyper-Resolution Modeling:

2D Grid Evaluation (example: hyper-resolution inundation):

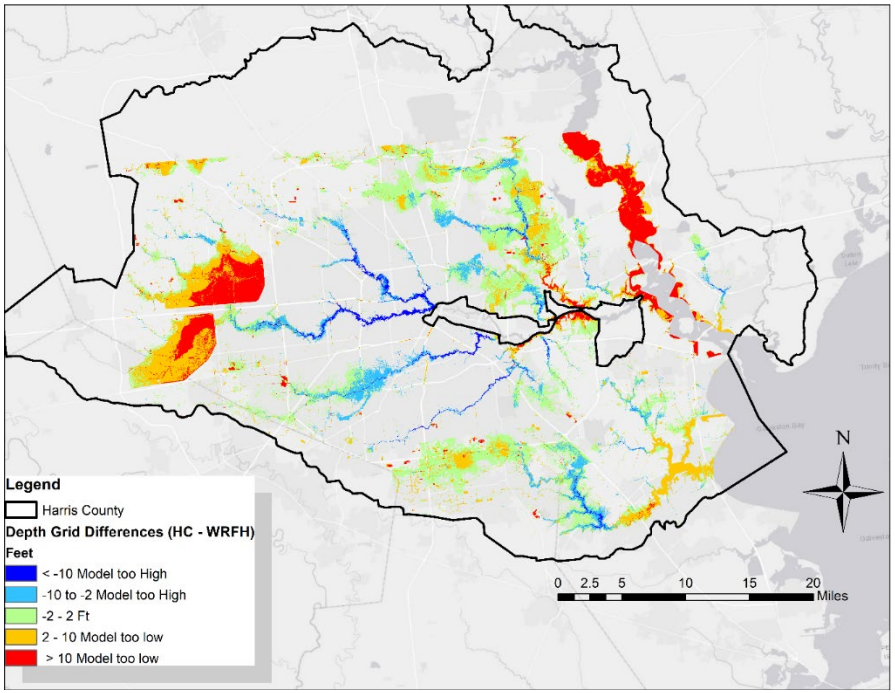
Inundation now being evaluated using CYGNSS retrievals via UCAR President's Fund project

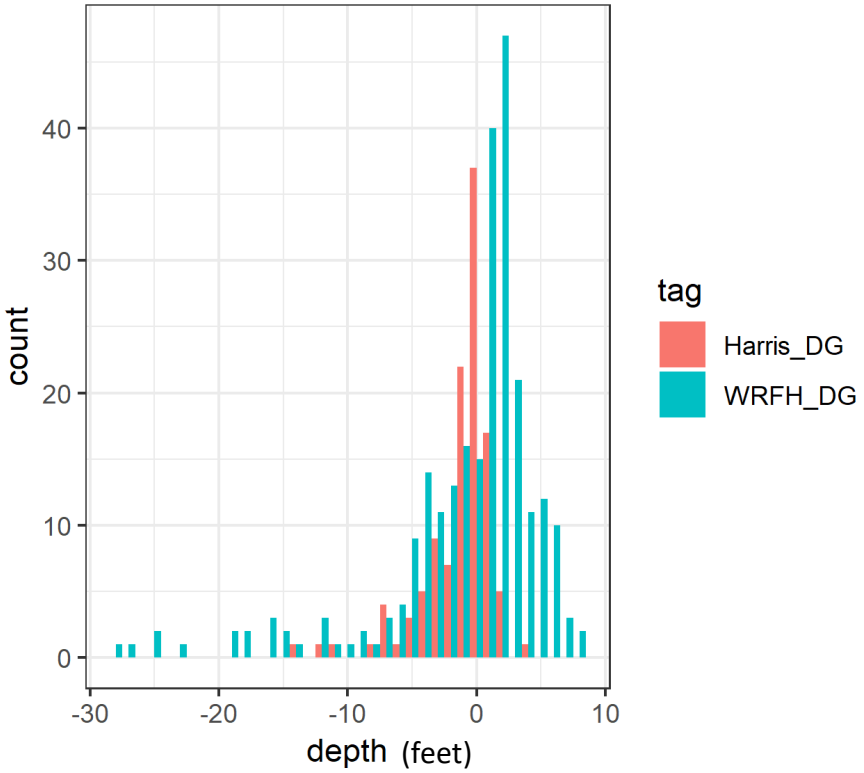


Hurricane Harvey hyper-resolution simulation

WRF-Hydro Research: Evaluating depths in Hurricane Harvey

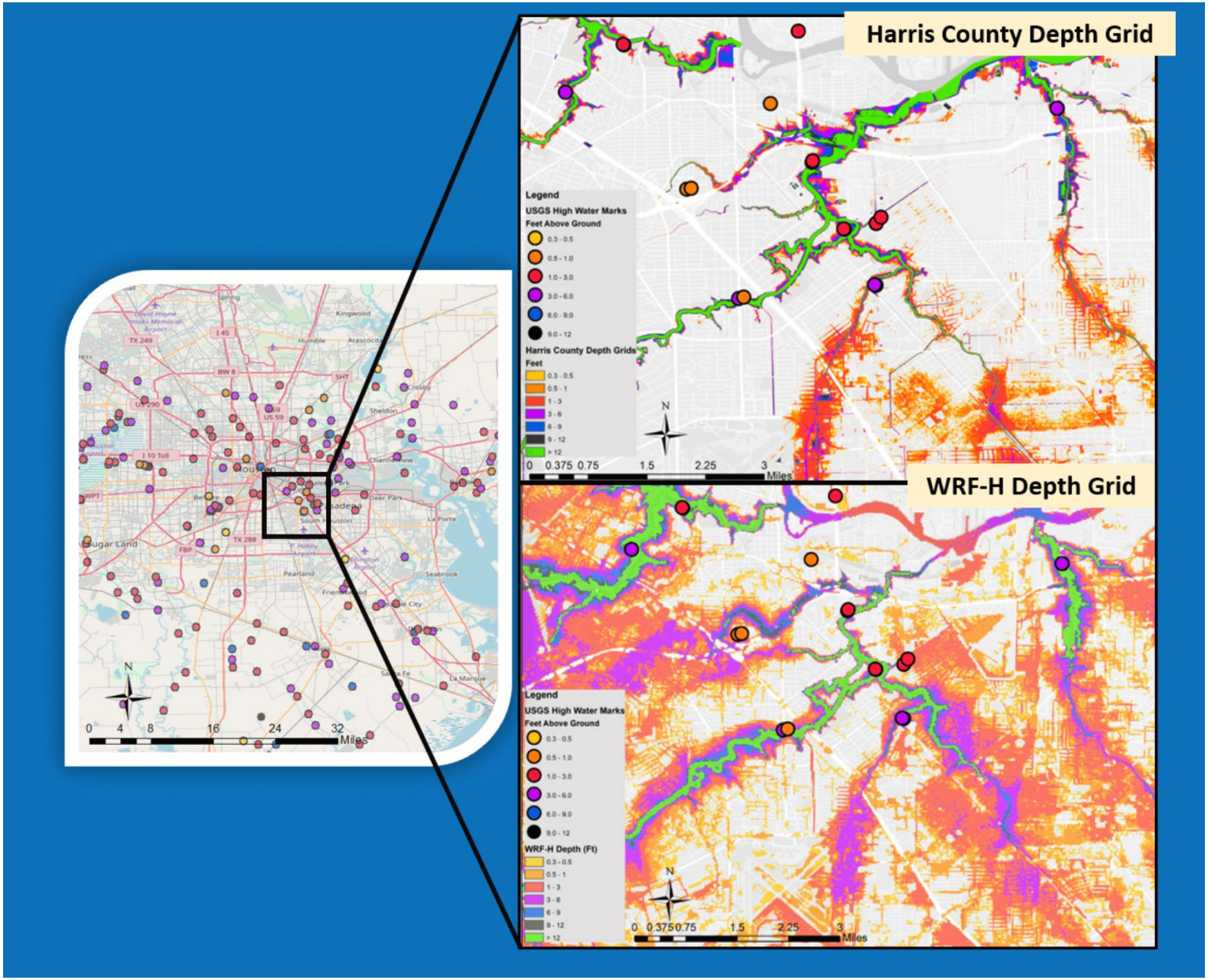
Maximum inundation in Harris County. WRF-Hydro simulation compared with Harris Co. depth grids.



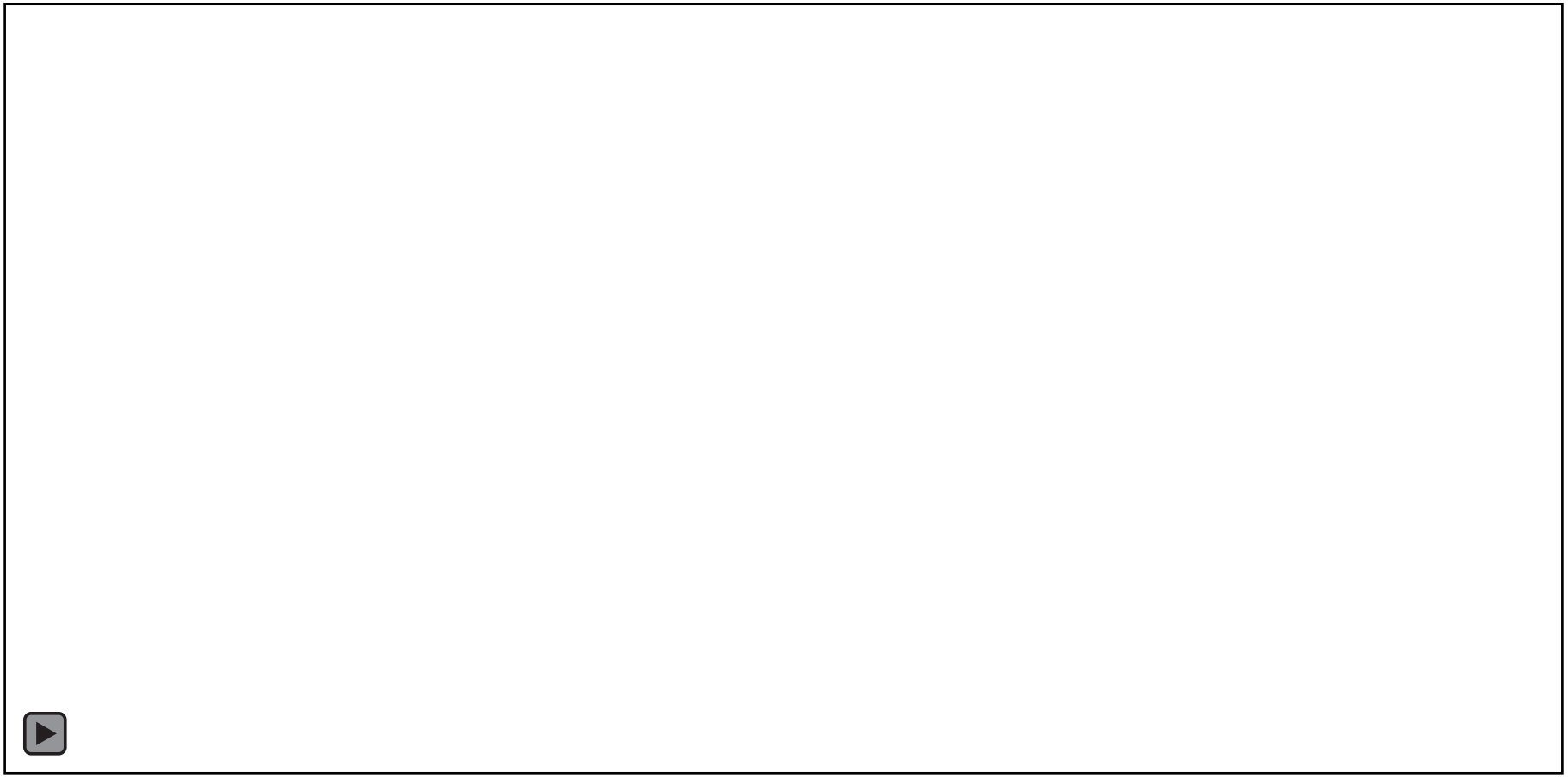


WRF-Hydro shows some areas of under prediction, mainly in detention ponds that were not initialized properly.

WRF-Hydro Research: Capturing multiple flooding mechanisms



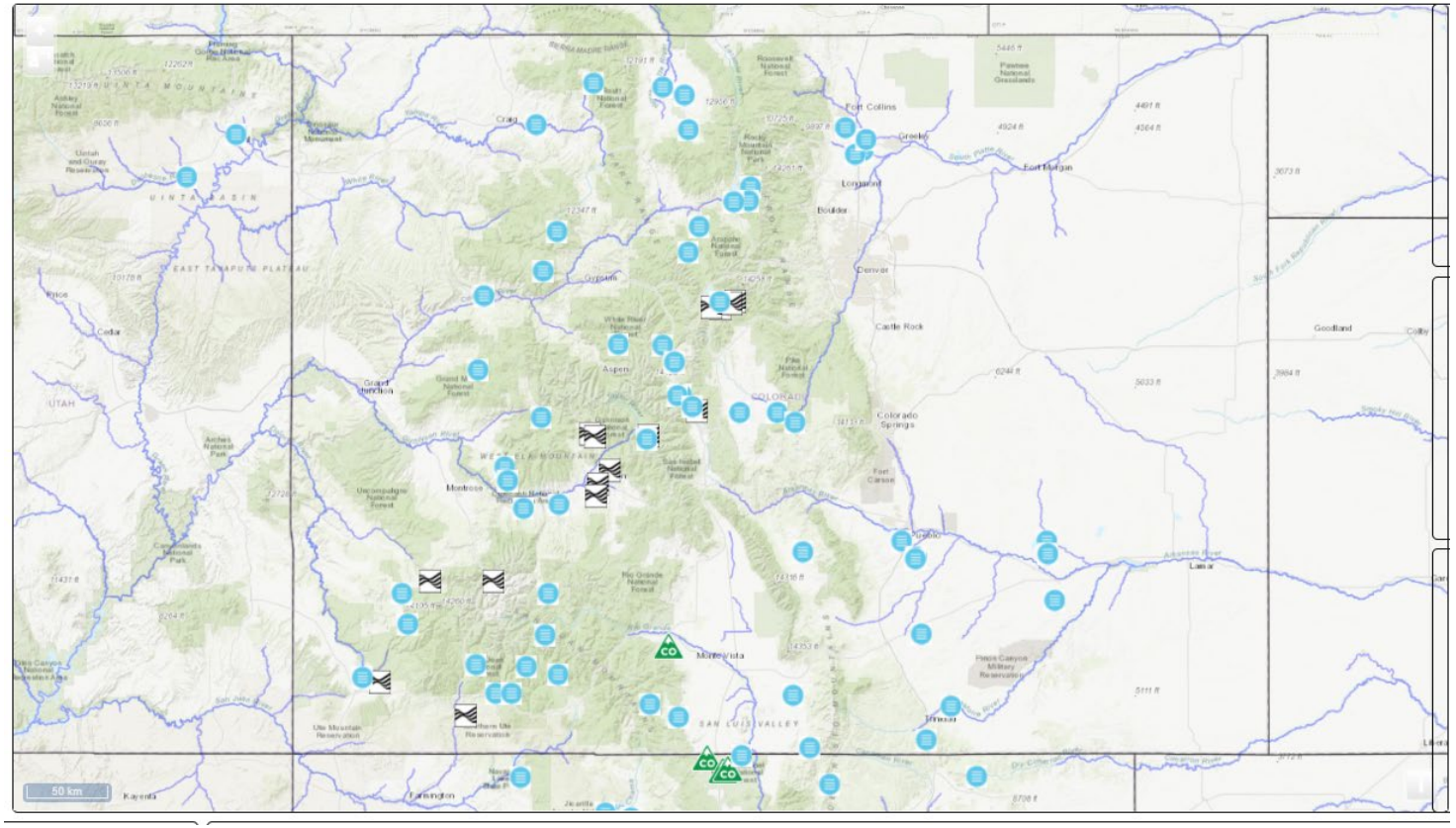
Real-time, on-demand flow path tracing:



- Environmental tracers for transport timing prediction
- On-demand capability using existing operational NWM
- Nearly instantaneous response
- Amenable to stochastic perturbation of flows to generate probabilisitc guidance
- Example of the Gold King Mine Spill

Colorado Forecasting Model Domain

- **Forecast Process:**
- Keep a continuous cycling WRF-Hydro analysis driven by current observed conditions
- Run WRF-Hydro water supply forecasts from present through Sep 30 using 15 past years of observed data
- Bias correct water supply volume (kac-ft) forecasts based on long term simulation verification
- Create bias corrected mean/median/quantile water supply forecasts



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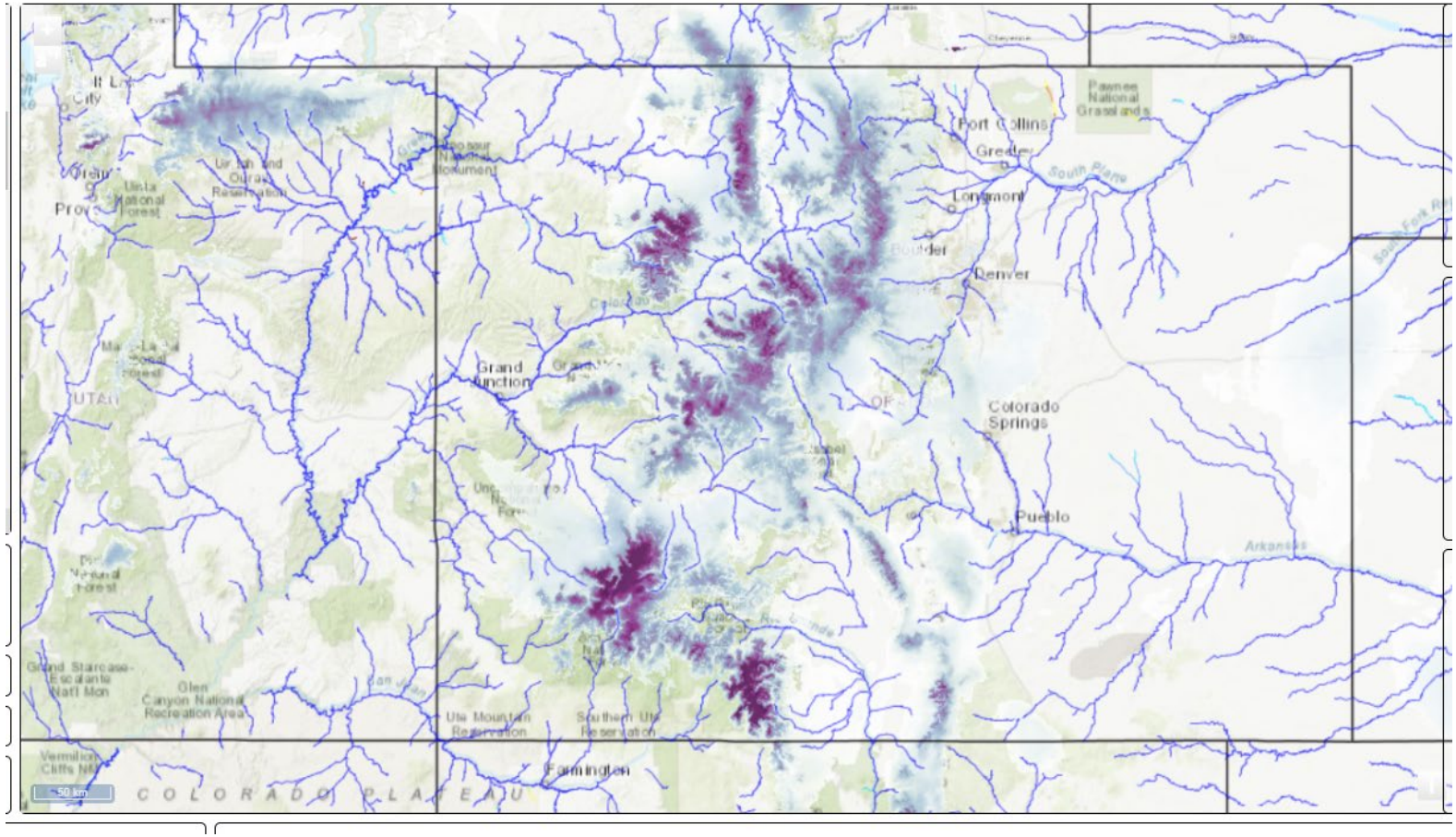
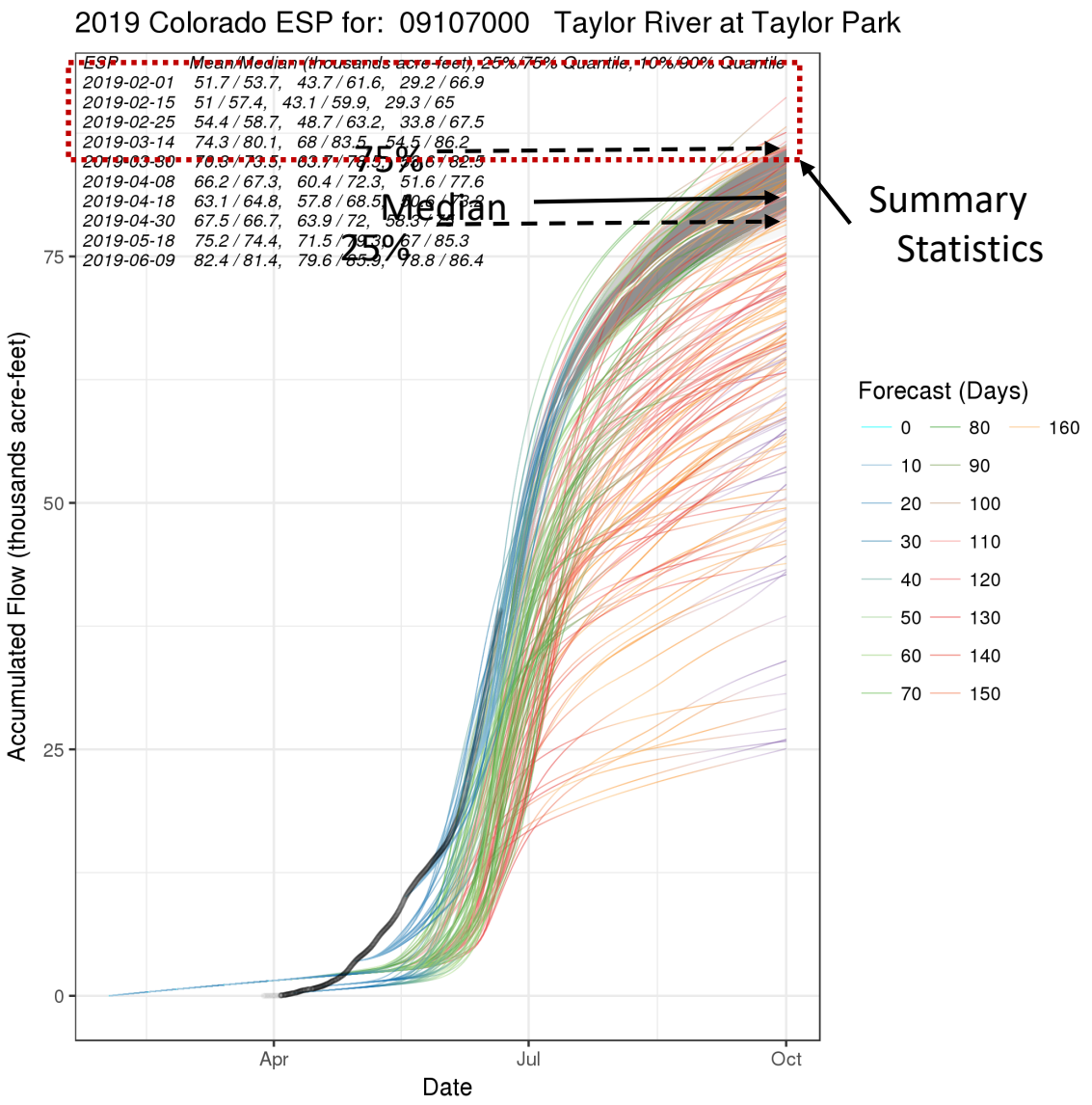


Plots and summary statistics

- Ensemble plot shows all forecast traces in accumulate runoff volume (kac-ft)
- Color shading on traces indicate forecast lead time
- Ensemble statistics provided in inset table
- Ensemble quantiles shown with grey bands
- *Ensemble quantile ranges will shrink with time and reduced forecast uncertainty*

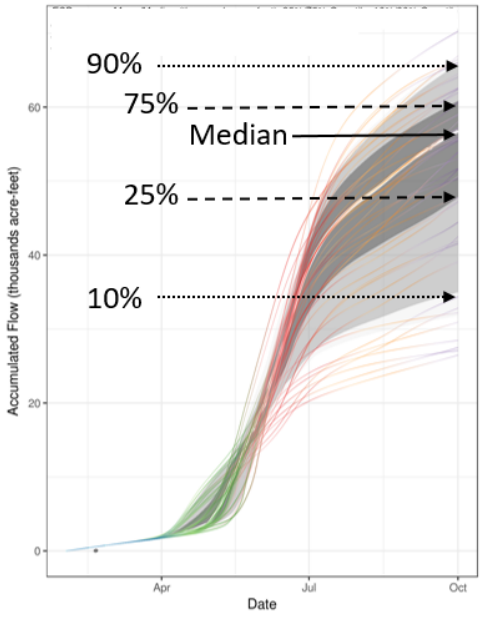


V2.0 Hydro model code: *https://github.com/NCAR/wrf_hydro_nwm_public/releases/tag/nwm-v2.0*

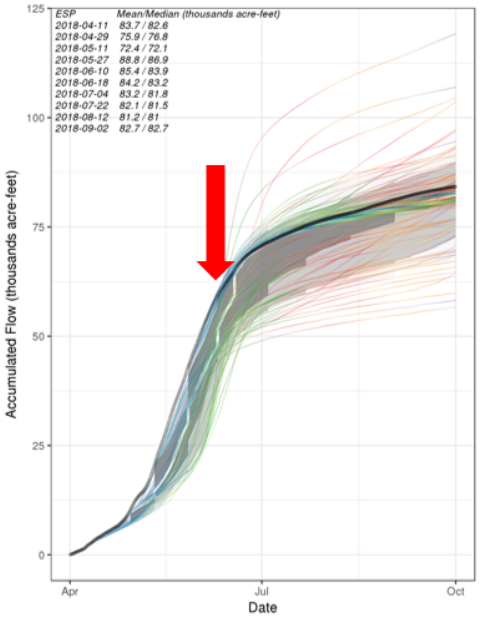
East River at Almont

Adding accuracy to water supply forecasts

Ensemble Streamflow Prediction (ESP)



East River @ Almont



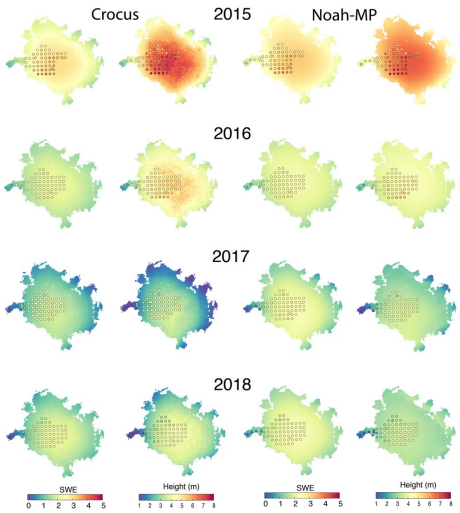
National Water Model support

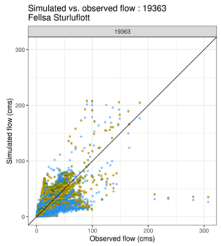
- April-July water supply forecast
- 24 May use of ASO data reduces low forecast bias
  - Due to late season high elevation snowpack data

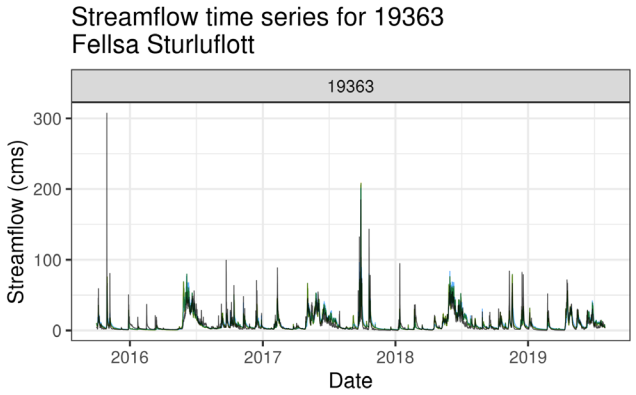
courtesy Dave Gochis, NCAR

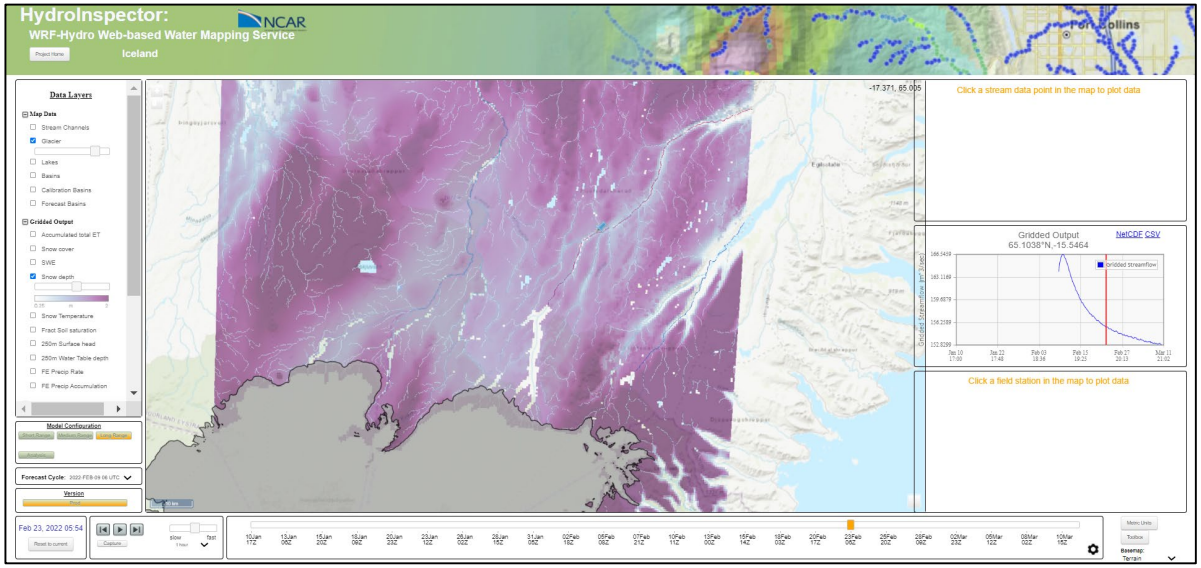
WRF-Hydro Research Highlight: Glacier Melt Modeling in Norway & Iceland

- Coupled CROCUS/NoahMP/WRF-Hydro modeling system
- CROCUS handling deeper ice layers
- Intended to handle accumulation/melt processes and runoff generation near glacier periphery
- Does not handle glacial iceflow dynamics
- Results indicate fidelity commensurate with improved accounting in seasonal growth/melt processes



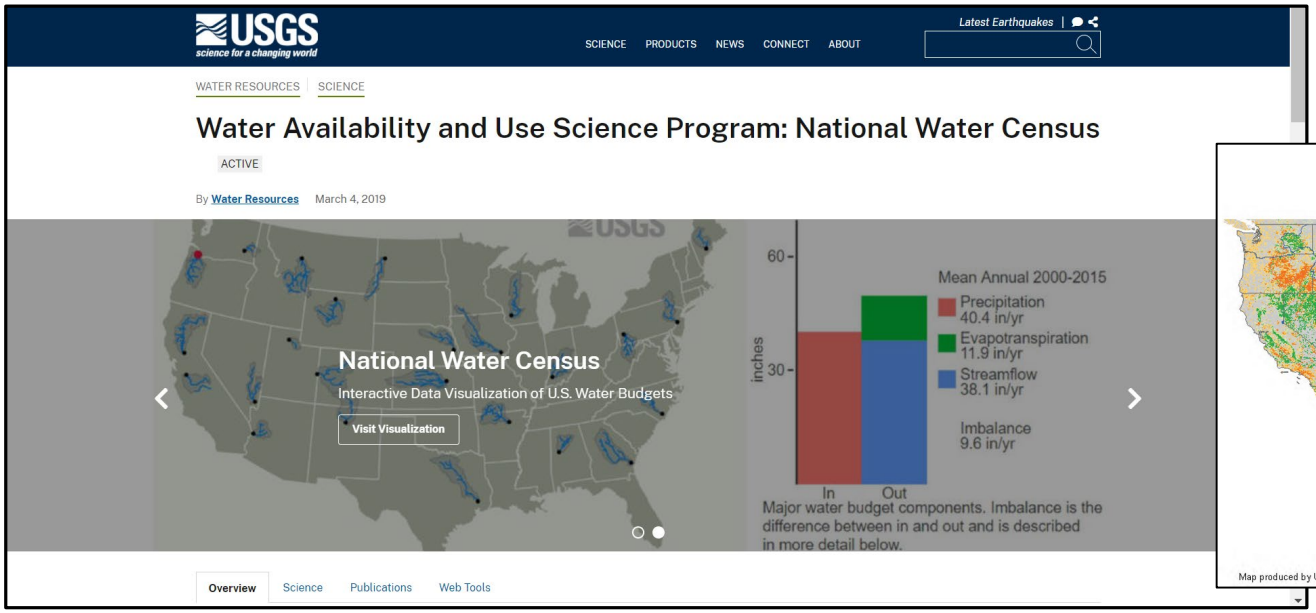


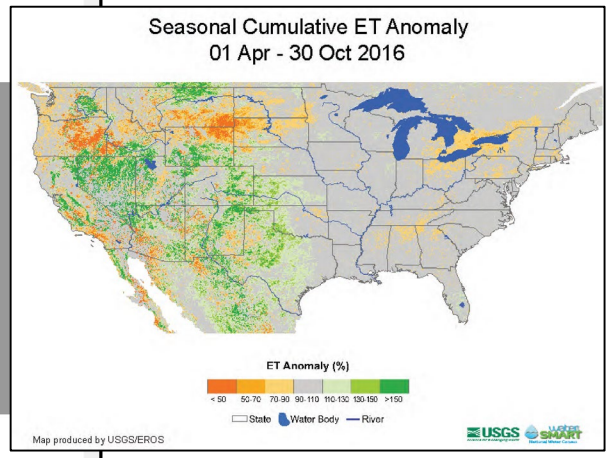




Eidhammer et al., 2021 HESS

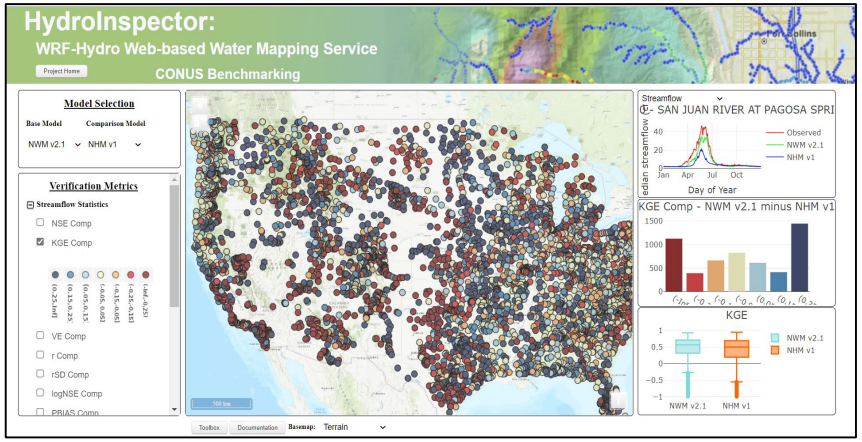
Windshield: USGS Water Census & Coupled Modeling



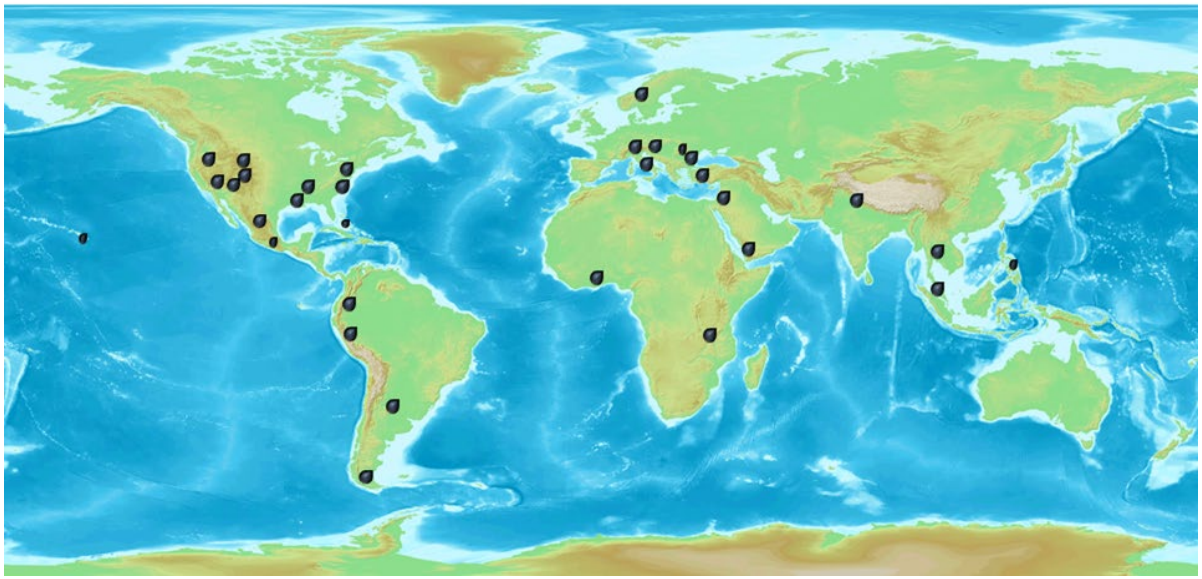


USGS Water Census….

- Current water availability/demand
- Future water availability/demand (downscaled projections)
- Coupled modeling for advanced observing network impacts assessment



WRF-Hydro® Applications Around the Globe



Operational Streamflow Forecasting

- U.S. National Weather Service National Water Model (NOAA/NWS, National Water Center, USGS, CUAHSI)
- Israel National Forecasting System (Israeli Hydrological Service)
- State of Colorado Upper Rio Grande River Basin Water Supply Forecasting (Colorado Water Conservation Board, NOAA/NSSL)
- NCAR-STEP Hydrometeorological Prediction (NCAR)
- Italy reservoir inflow forecasting (Univ. of Calabria)
- Romania National Forecasting System (Baron)

Streamflow Prediction Research

- Flash flooding in Black Sea region of Turkey (Univ. of Ankara)
- Runoff production mechanisms in the North American Monsoon (Ariz State Univ.)
- Streamflow processes in West Africa (Karlsruhe Inst. Tech.)

Coupled Land-Atmosphere Processes

- Diagnosing land-atmosphere coupling behavior in mountain-front regions of the U.S. and Mexico (Arizona State Univ., Univ. of Arizona)
- Quantifying the impacts of winter orographic cloud seeding on water resources (Wyoming Board on Water Resources)
- Predicting weather and flooding in the Philippines, Luzon Region (USAID, PAGASA, AECOM)
- RELAMPAGO in Argentina (Univ. of Illinois Urbana-Champaign, NCAR)

Diagnosing Climate Change Impacts on Water Resources

- Himalayan Mountain Front (Bierknes Inst.)
- Colorado Headwaters (Univ. of Colorado)
- Bureau of Reclamation Dam Safety Group (USBR, NOAA/CIRES)
- Lake Tanganyika, Malawi, Water Supply (World Bank)
- Climate change impacts on water resources in Patagonia, Chile (Univ. of La Frontera)

Coupling WRF-Hydro with Coastal Process Models

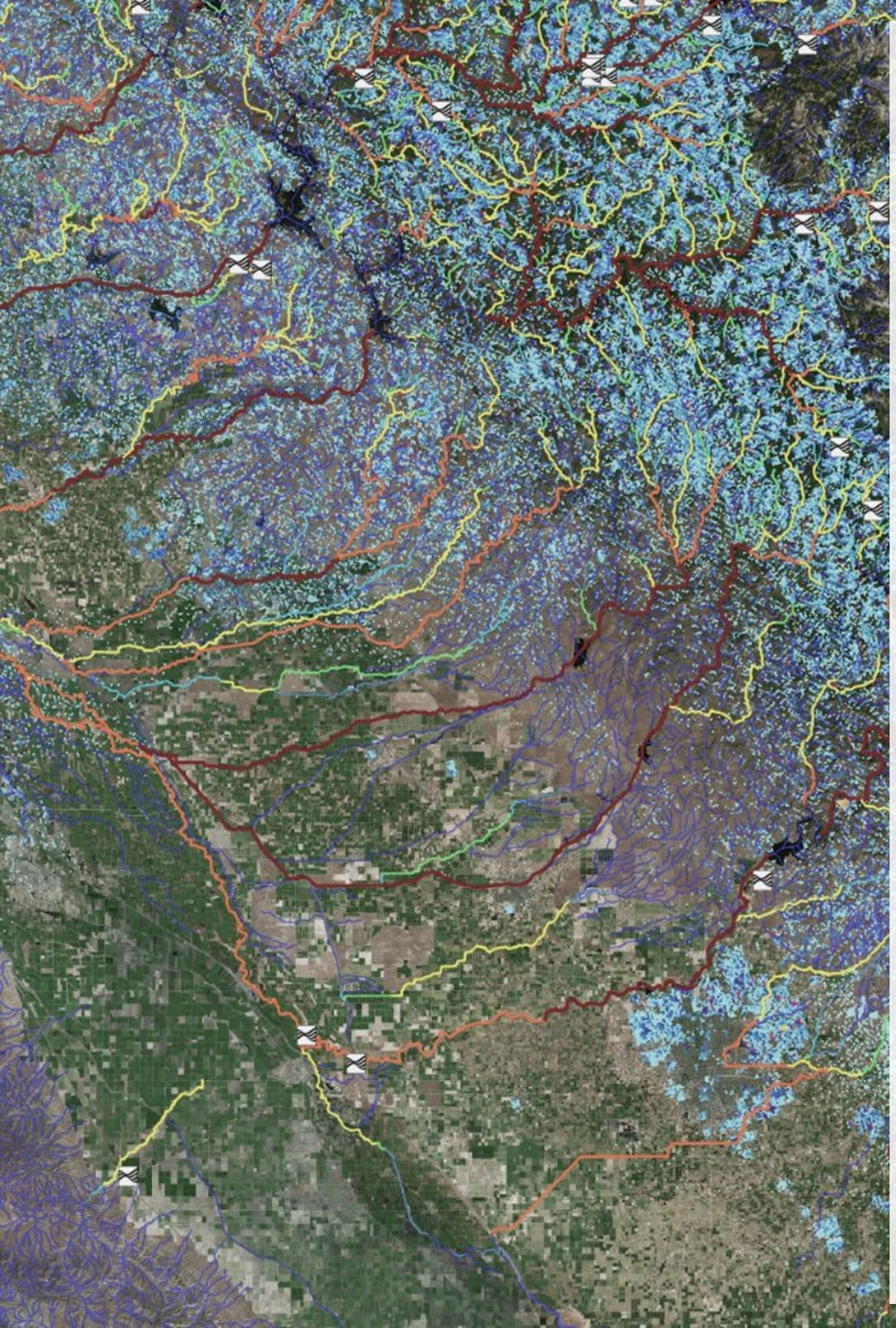
- Italy-Adriatic sea interactions (Univ. of Bologna)
- Lower Mississippi River Valley (Louisiana State University)
- Integrated hydrological modeling system for high-resolution coastal applications (U.S. Navy, NOAA, NASA)

Diagnosing the Impacts of Disturbed Landscapes on Hydrologic Predictions

- Western U.S. Fires (USGS)
- West African Monsoon (Karlsruhe Inst. Tech)
- S. America Parana River (Univ. of Arizona)
- Texas Dust Emissions (Texas A&M Univ.)
- Landslide Hazard Modeling (USGS)

Hydrologic Data Assimilation:

- MODIS snow remote sensing assimilation for water supply prediction in the Western U.S. (Univ. of Colorado, Univ. of California Santa Barbara, NSIDC, NCAR)
- WRF-Hydro/DART application in La Sierra River basins in southeast Mexico (Autonomous National University of Mexico)



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Thank you!

Resources:

WRF-Hydro Community Model:
https://ral.ucar.edu/projects/wrf_hydro