Multi-variate evaluation of the NOAA National Water Model

NCAR Research Applications Lab

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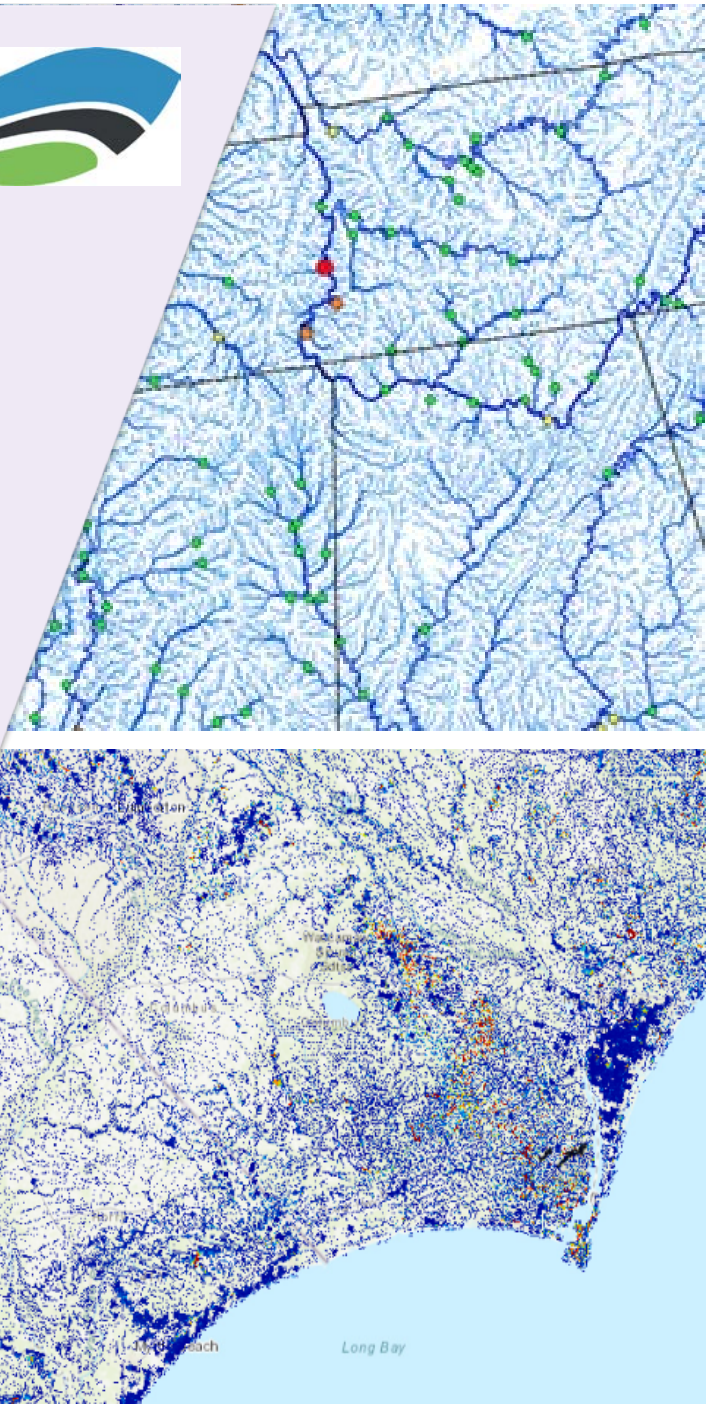


The National Water Model:

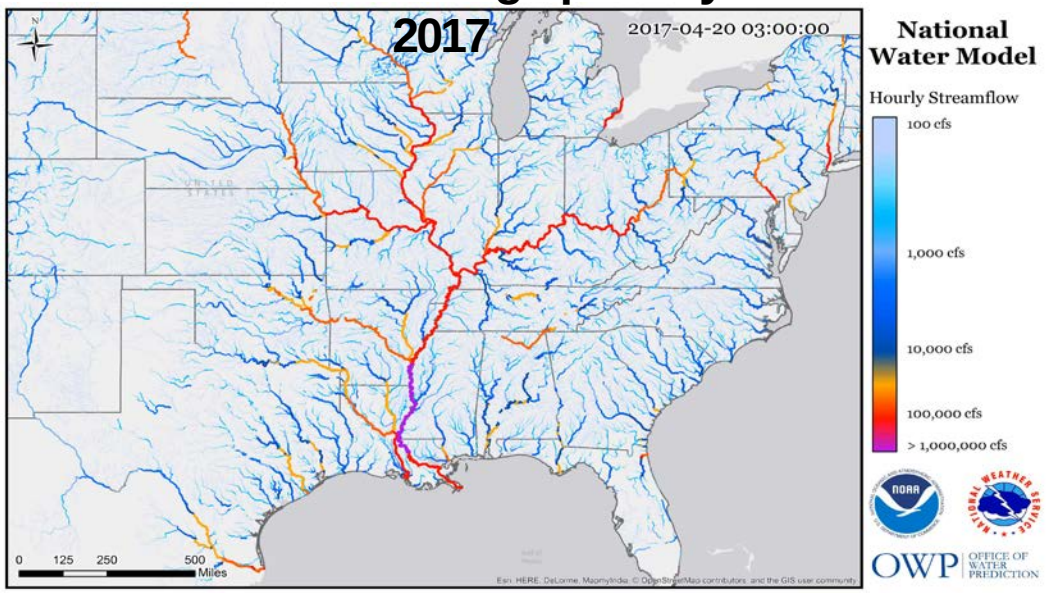
- Brief system overview
- V2.0 developments
- Model assessment
- Summary

National Water Model (NWM)

- NWM implemented in August 2016 and upgraded in May 2017 by OWP, NCEP and NCAR
- Hydrologic core is WRF-Hydro, a community-based hydrologic modeling *framework* supported by NCAR
- Chief Goal: Provide foundation for sustained growth in nationally consistent operational hydro forecasting
- Full spectrum hydrologic model, providing guidance for underserved locations
- Hourly analyses and short-range forecasts along with 4 x day medium-range and daily long-range forecasts

- **Hydrologic Output**
  - River channel discharge and velocity at 2.7 million river reaches
  - Reservoir inflow, outflow, elevation
  - Ponded water depth and depth to soil saturation on 250 m CONUS+ grid
- **Land Surface Output**
  - 1km CONUS+ grid
  - Soil and snow pack states
  - Energy and water fluxes

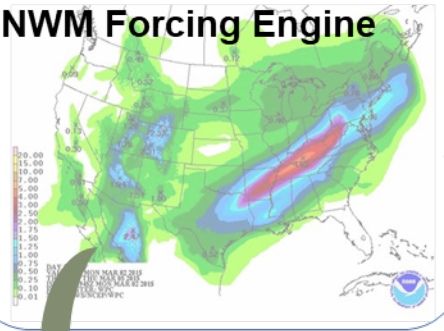
NWM Analysis Animation: Midwest Flooding April-May 2017



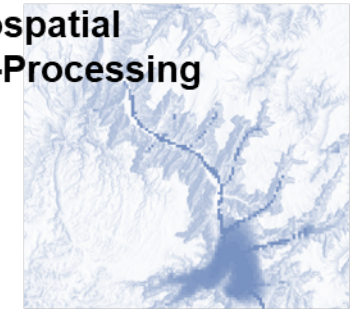
v1.2 Hydro model code: *https://github.com/NCAR/wrf_hydro_nwm_public/releases/tag/nwm-v1.2*

Full WRF-Hydro / NWM Ecosystem

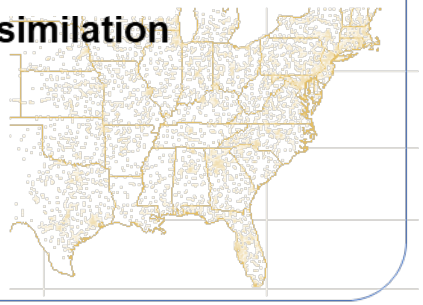
NWM Forcing Engine



Geospatial Pre-Processing

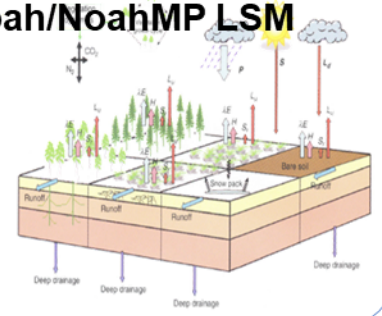


Data Assimilation

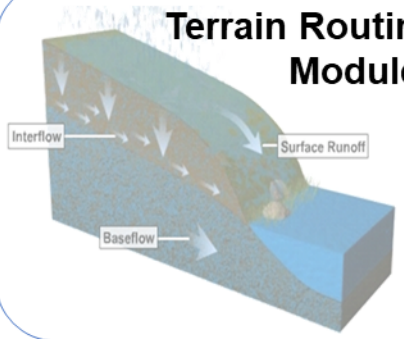


MODEL PHYSICS

Noah/NoahMP LSM

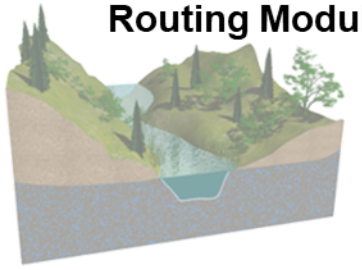


Terrain Routing Modules

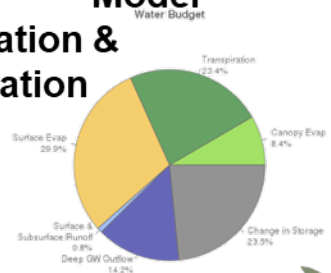


NHDPlus Catchment Aggregation

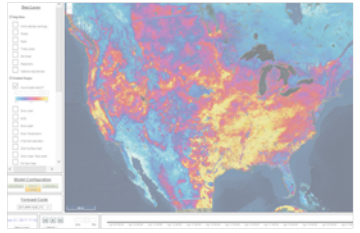
Channel & Reservoir Routing Modules



Model Evaluation & Calibration

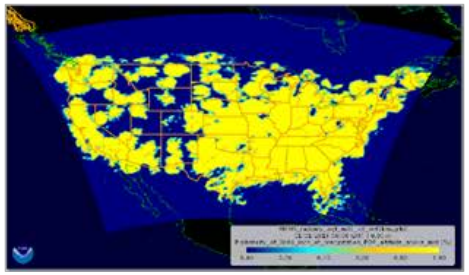


Forecast Display Services

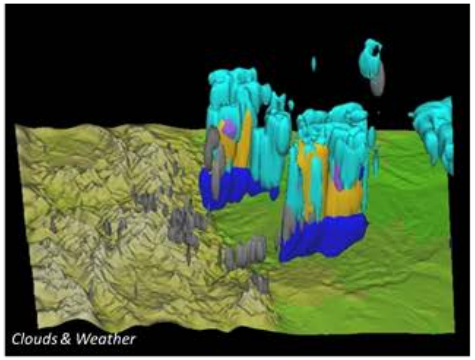


Meteorological Forcing Engine - NWM: Examples

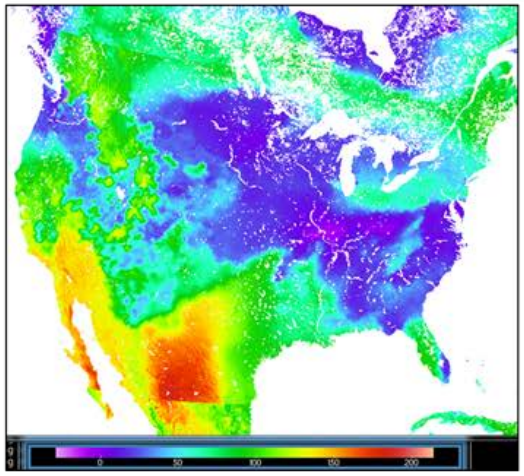
Seasonally-varying MRMS RQI



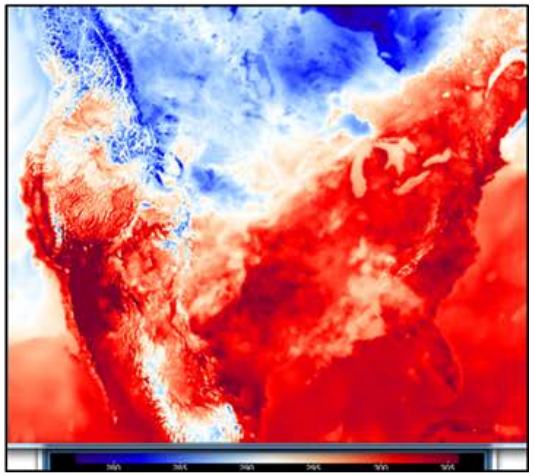
Blended MRMS-HRRR Precipitation



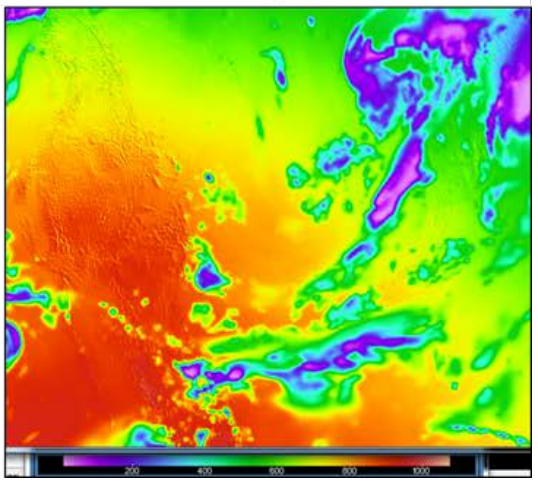
HRRR-RAP incoming longwave radiation



HRRR-RAP 2m Air Temperature



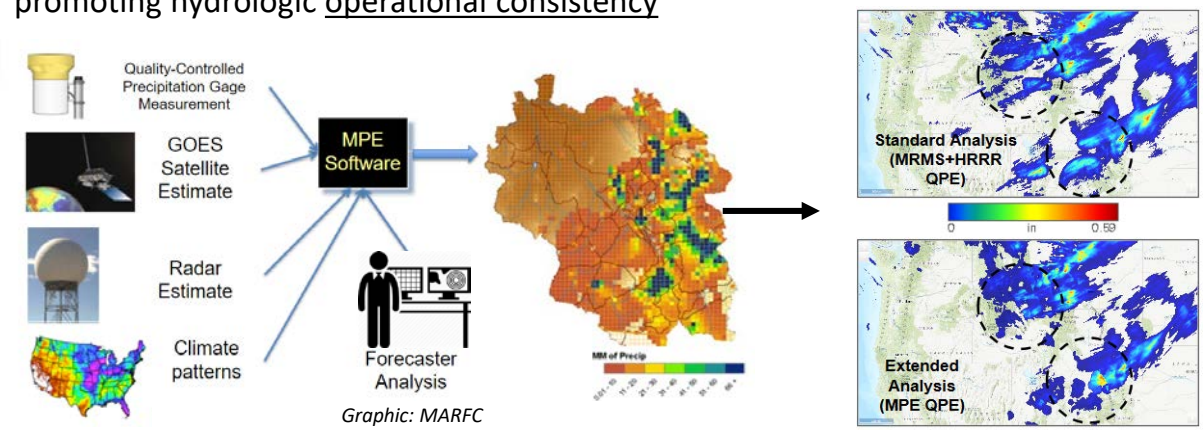
GFS – derived incoming shortwave radiation



- Goal: Create a unified set of high quality met. forcing data for NWM ingest
- Employs regridding, downscaling, bias correction and layering tools

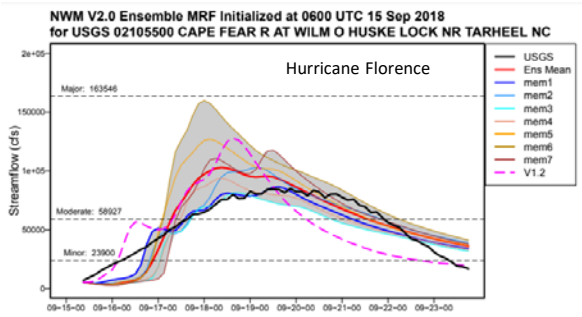
NWM V2.0: Four New Configurations

Key Link to Field: New NWM Extended Analysis Cycle (28-hr lookback)
Daily run, anchors NWM states to RFC MPE observed precipitation product, promoting hydrologic operational consistency

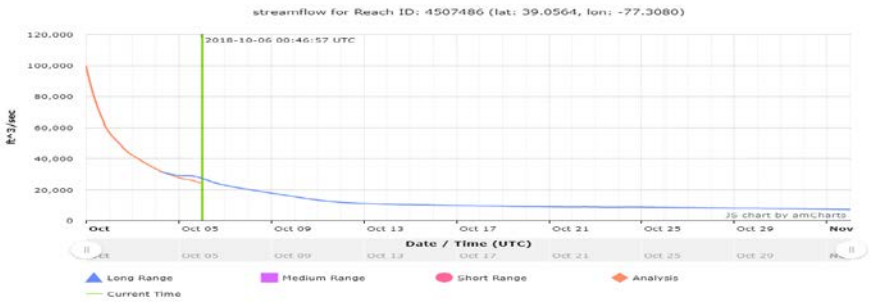


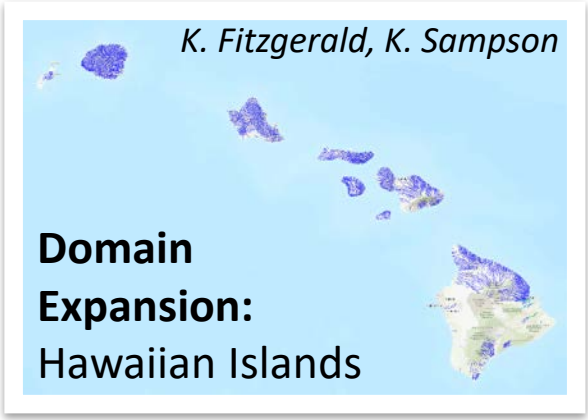
Graphic: MARFC

New Ensembles: New Medium-Range ensemble forecast cycle with time-lagged FV3/GFS to capture forcing uncertainty



Improved Initialization: New NWM Long-Range Analysis Cycle Supplies better-matched initial conditions to Long-Range Forecasts





NWM Version 2.0 Enhancements

Model Configuration

-**Addition of Hawaii** to NWM (3-hr Analysis and 60-hr Short-Range forecast, both forced by NAM-Nest NWP model)
-**Addition of Extended Analysis** (daily 28-hour look-back using RFC-based MPE precipitation from Stage IV)
-Addition of separate **Long-Range Analysis** configuration to initialize LR forecast
-Addition of **Medium Range ensemble** forecast configuration (7 members 4 x day) (mem1=uses current GFS to 10 days, mem2-7=use time lagged GFS out to 8.5 days)

Forcing

-**Use of 13km GFS forcing** (versus 0.25 degree in NWM V1.2)
-Improved downscaling of GFS and CFS forcing via a **Mountain Mapper**-based approach

Physics

-Out-of-bank parameterization via **compound channel** and new empirically based channel parameters
-Improved snow albedo formulation, new soil evaporation parameter and relaxation of ponded water threshold
-Bug fix in the units in one of the groundwater bucket calculations and a fix in reservoir module.

Calibration

-Improved calibration of parameters by using hourly streamflow data, **expanding calibration from ~1100 to ~1400 calibration basins** and improving parameter regionalization process. Also, utilized Mountain Mapper-downscaled NLDAS2 forcing in calibration so as to more closely match the forcing used in the new Extended Analysis cycle.

Hydrofabric

-**Increased CONUS reservoirs from ~1500 to ~5500** (impact mostly on non-calibration basins)
-Fixed 37 stream breaks
-For Hawaii, added 58 USGS gauges for DA, 13,637 new flowlines, 10 reservoirs and 16,625 km^2 of basins

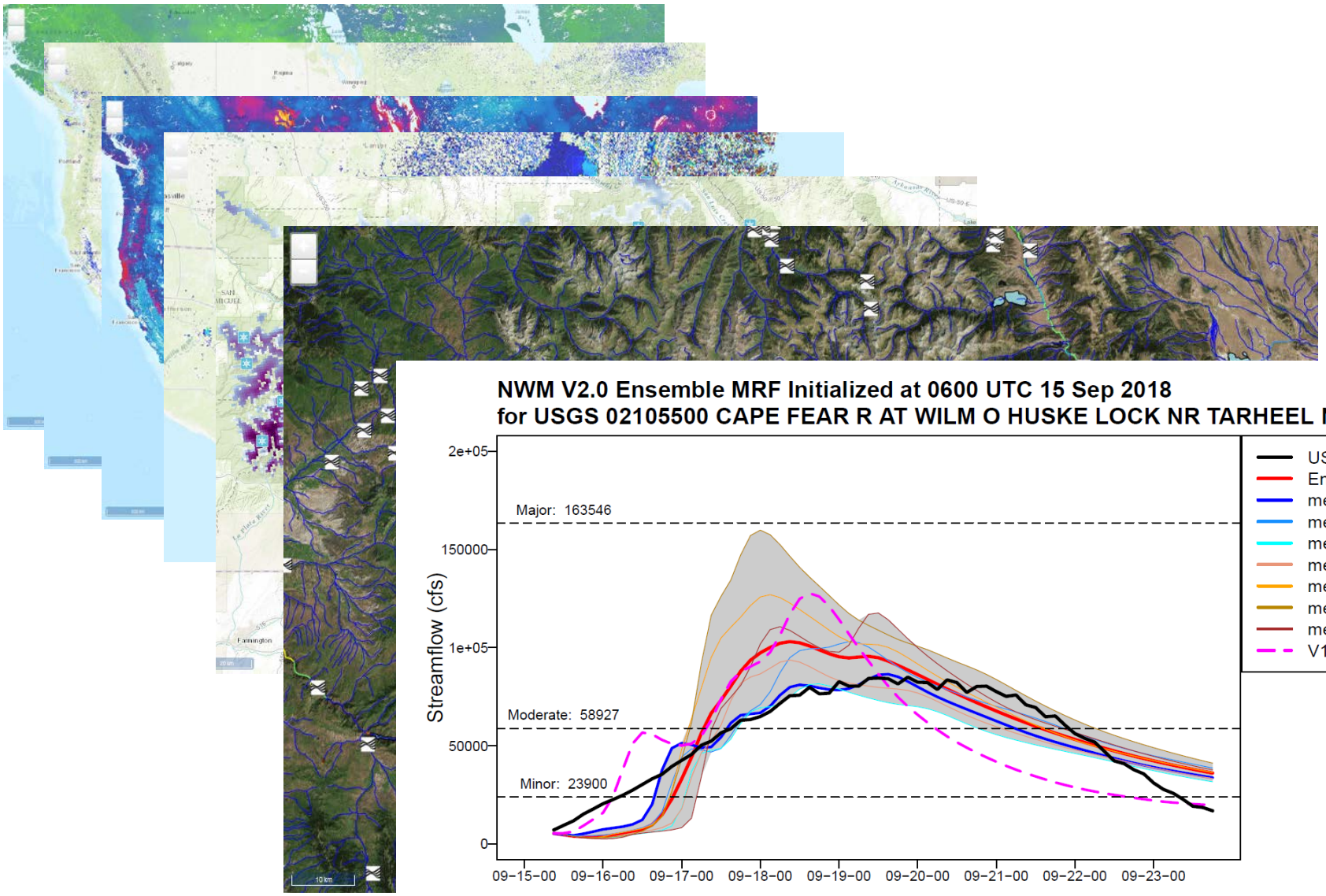
The National Water Model: Operational Cycling - CONUS

National Water Model V1.2/V2.0

CONUS Analysis and Forecast Cycling Configurations

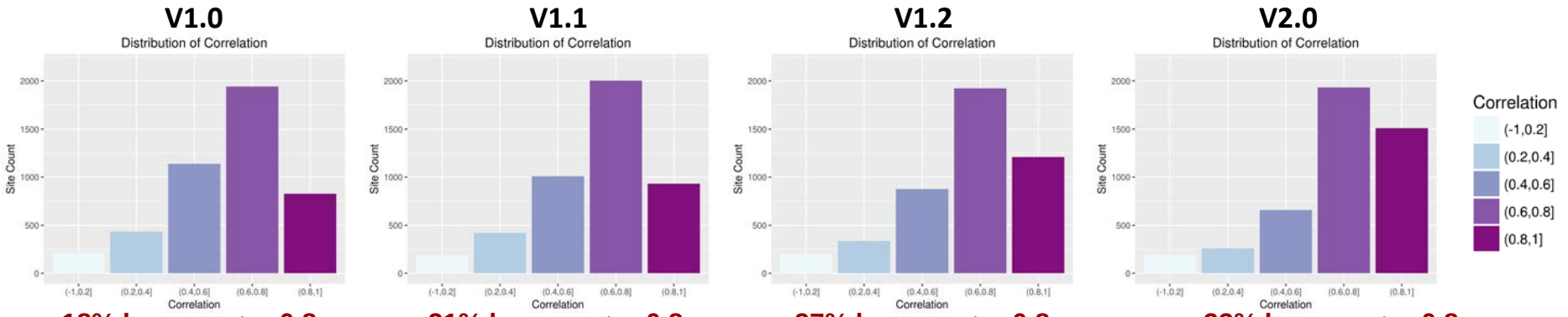
	Cycling	Forecast	Forcing	Outputs
Analysis 	Std: Hourly Ext: Daily Long-Range: 4 x day	Std: -3 Hour Ext: -28 Hour Long-Range: -12 hours	Std/Long: MRMS Ext: RFC MPE All: Downscaled HRRR/RAP	All: 1km Land States, NHDPlus Streamflow Std and Ext: 250m Sfc Routed Water
Short-Range 	Hourly	18 hours	Downscaled HRRR/RAP Blend	1km Land States, 250m Sfc Routed Water, NHDPlus Streamflow
Medium-Range 	4 x Day (7 members)	Member 1: 10 days Members 2-7: 8.5 days	Downscaled 13km GFS	All: NHDPlus Streamflow Member 1: 1km Land States, 250m Sfc Routed Water
Long-Range 	Daily Ensemble (16 members)	30 days	Downscaled and Bias-Corrected CFS	1km Land States, NHDPlus Streamflow

Operational outputs:



Ensemble streamflow predictions

NWM v2.0 Improvement: All USGS Gauges (Validation Retrospective)



18% have cor >= 0.8

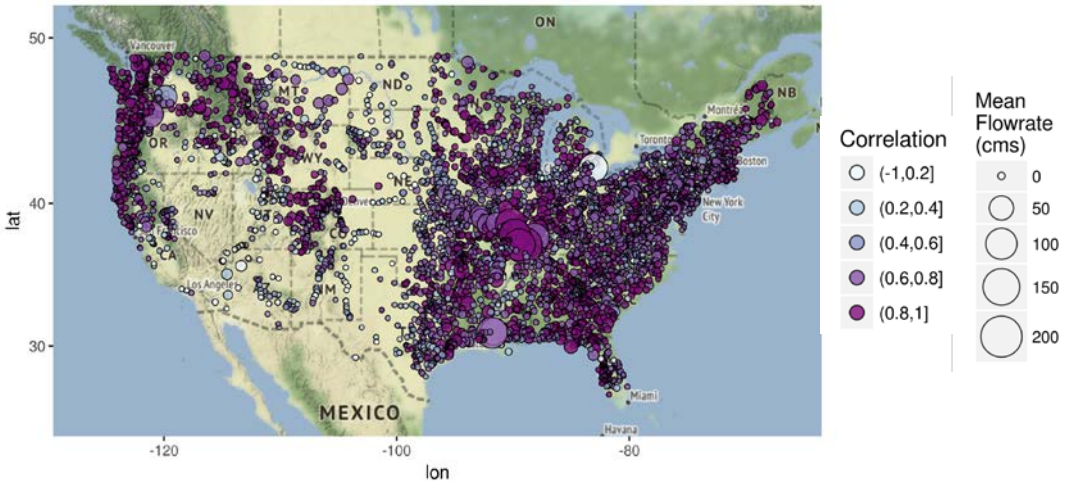
21% have cor >= 0.8

27% have cor >= 0.8

33% have cor >= 0.8

> 70% have hourly cor >= 0.6

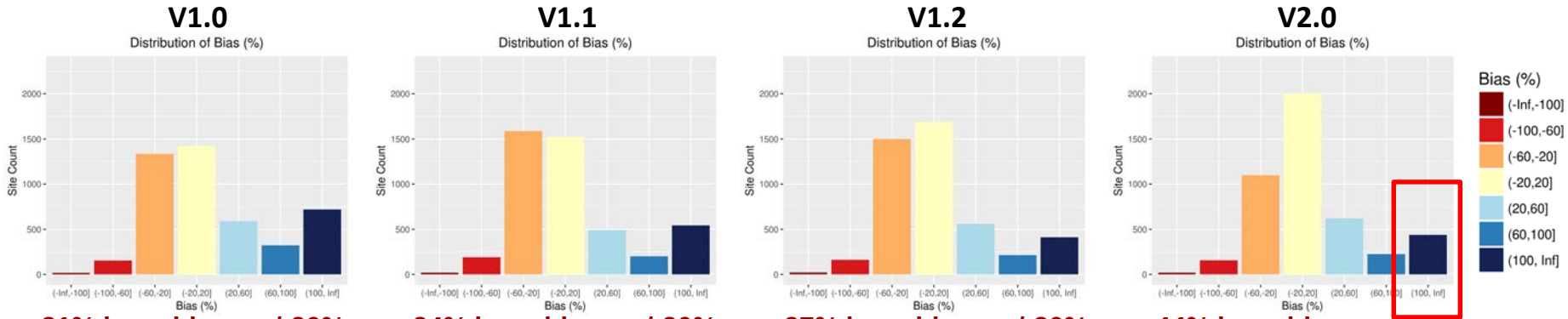
NWM v2.0 Streamflow Hourly Correlation at USGS Gauges (WY 2014-2016)



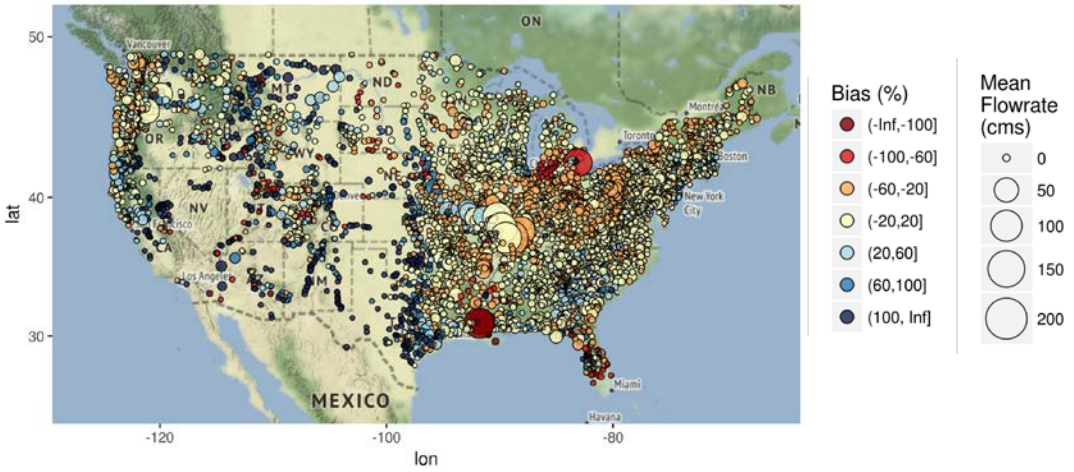
- **Streamflow correlation improves at USGS gauged basins with each version**
- **Improvements more pronounced at directly calibrated sites**
- **Model now calibrated/validated against hourly (previously daily) streamflow obs**
- **Daily metrics also improve**
- **Simulation is for WY2014-2016 (validation period) and uses NLDAS-2 forcing data (with Mountain Mapper downscaling in v2.0)**
- **No assimilation of USGS obs**

A. Dugger, J. Mills, E. Towler, A. RafieeiNasab

NWM v2.0 Improvement: All USGS Gauges (Validation Retrospective)



NWM v2.0 Streamflow Bias at USGS Gauges (WY 2014-2016)



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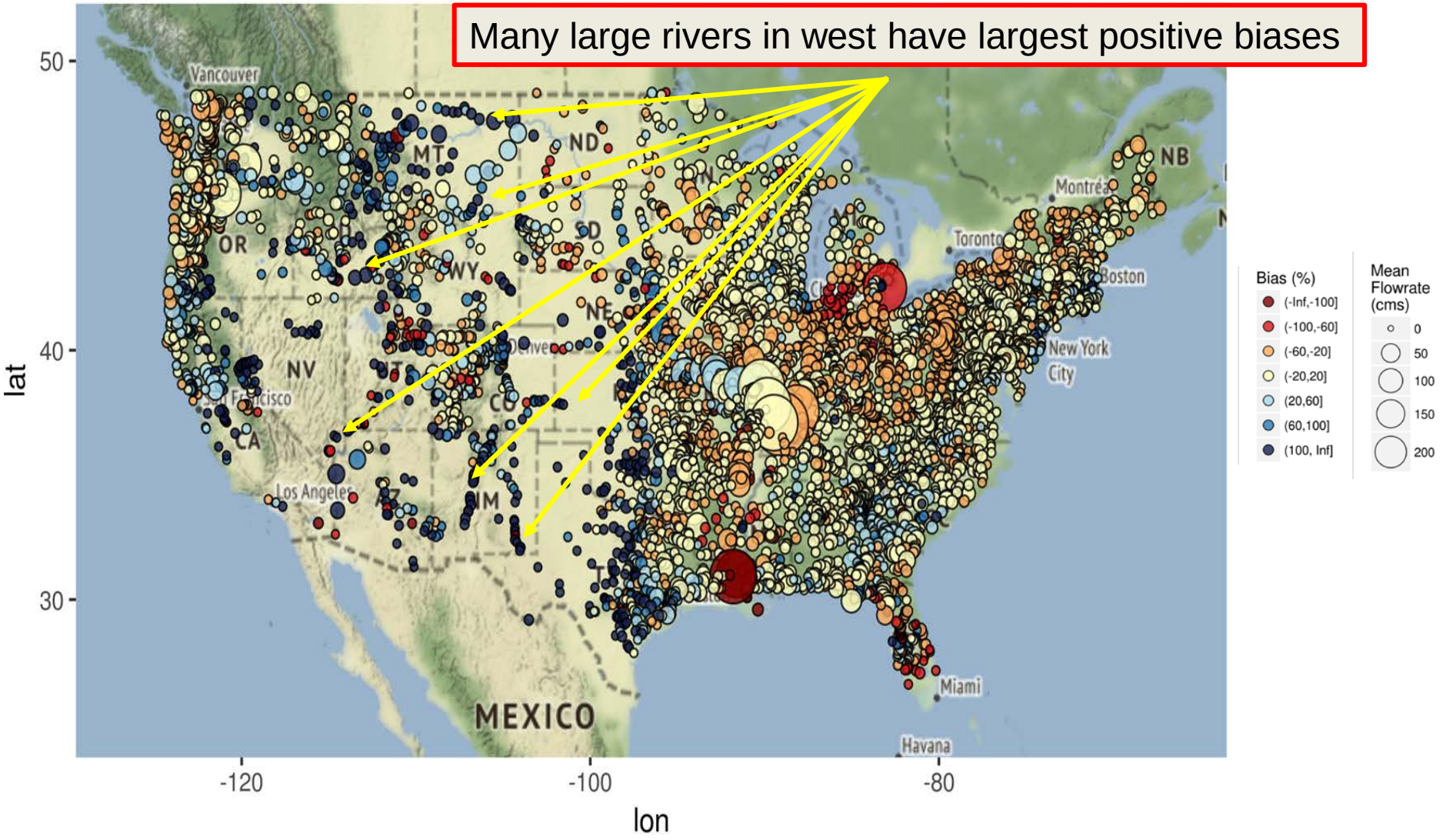
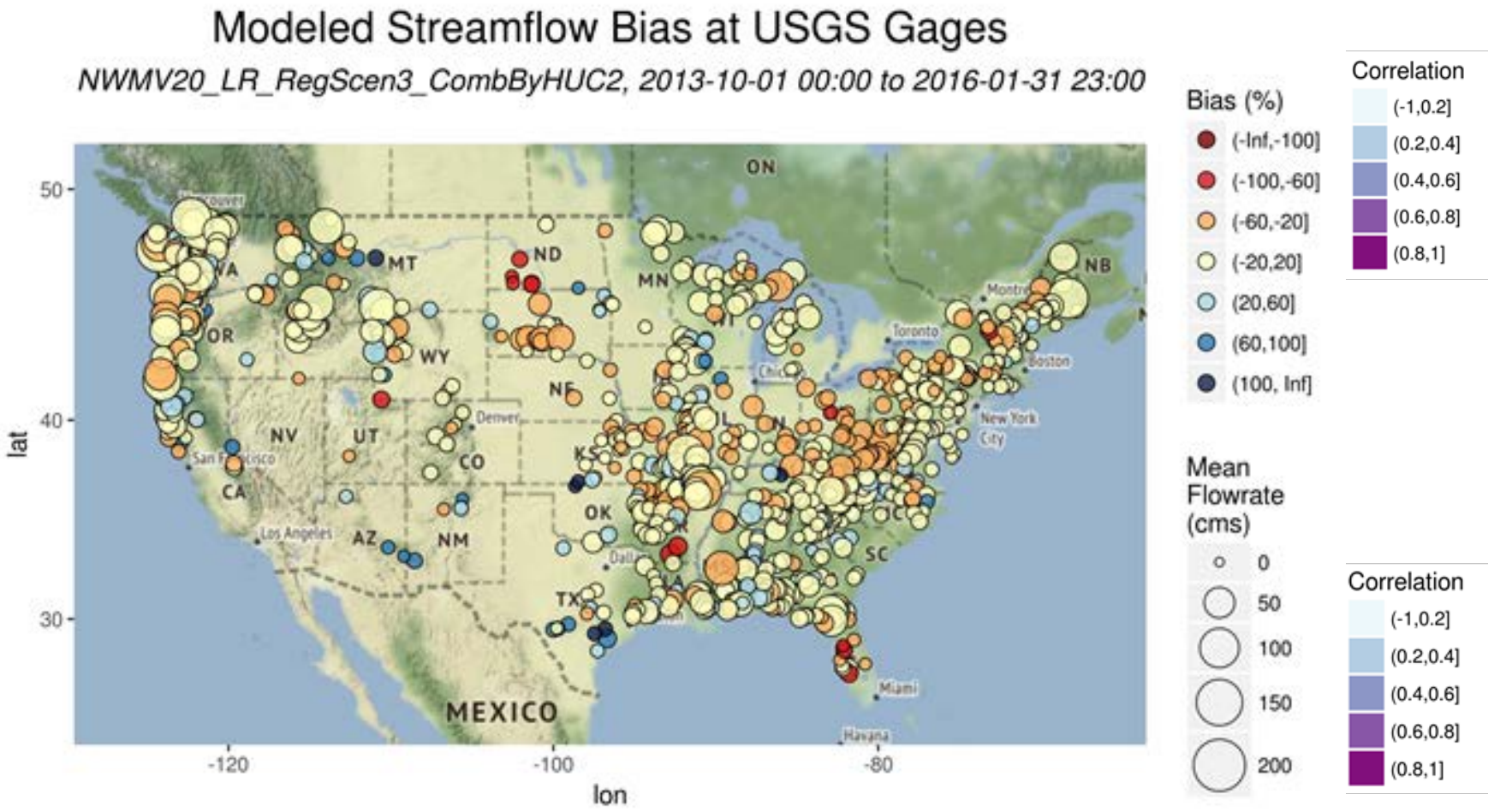
Shortcomings in water management/diversion producing large positive biases

NWM v2.0 Streamflow Bias at
USGS Gauges (WY 2014-2016)



Shortcomings in water management/diversion producing large positive biases

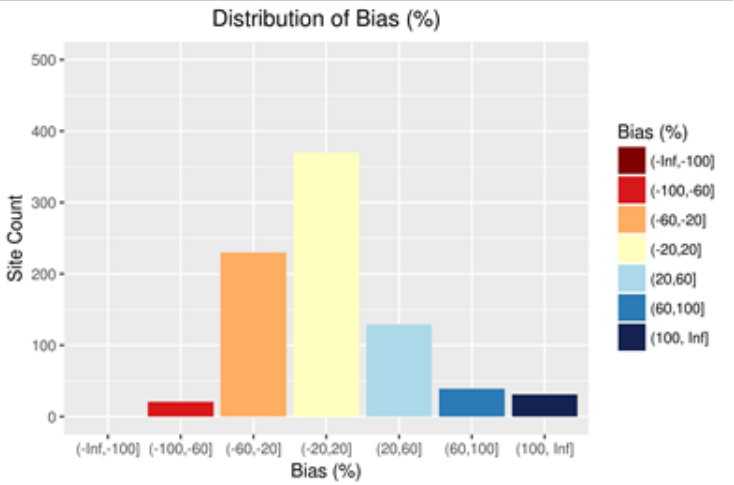
Validati
All USG



Validati
Gauge-

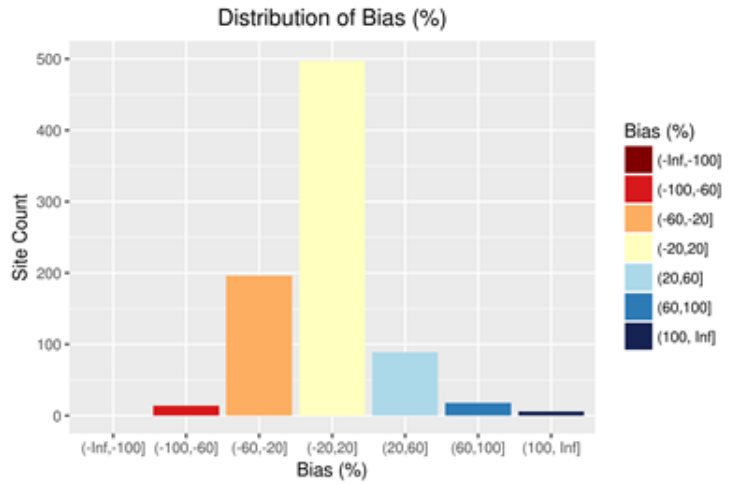
Long-Range Evaluation:

V1.2



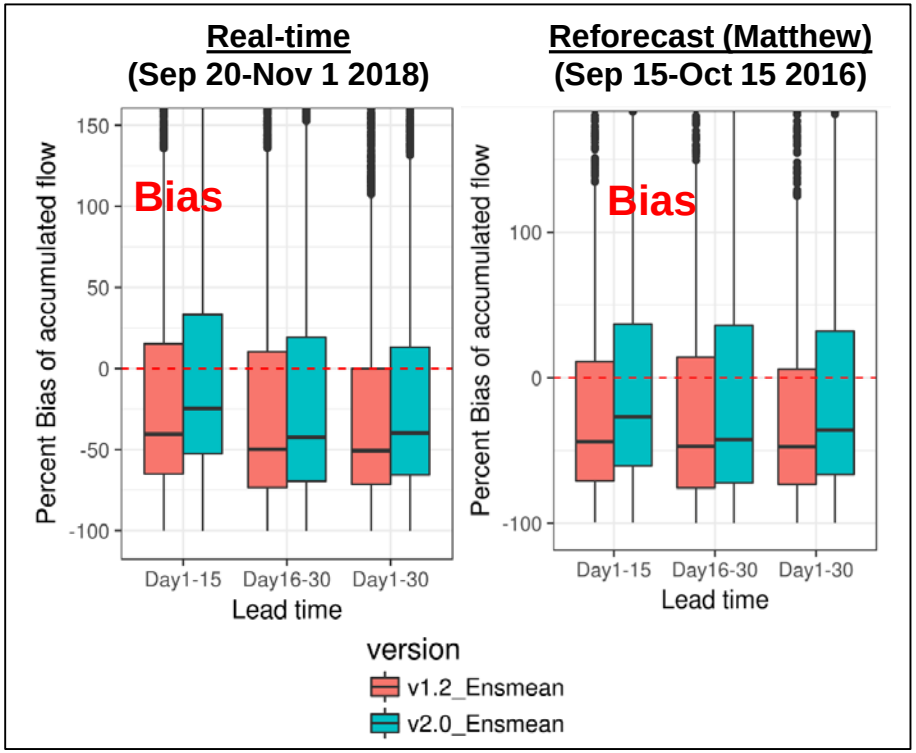
All USGS Gauges 45% have bias < +/-20%

V2.0



USGS Gauges-II: 61% have bias < +/-20%

Accumulated flow of long range ensemble mean during Days 1-15, Days 16-30, and Days 1-30



NWM 2.0 shows improved bias at all lead times

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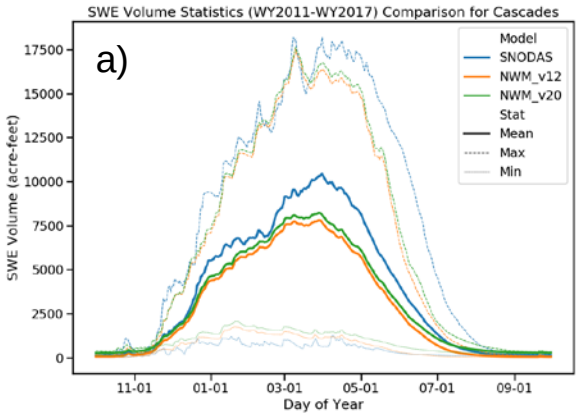
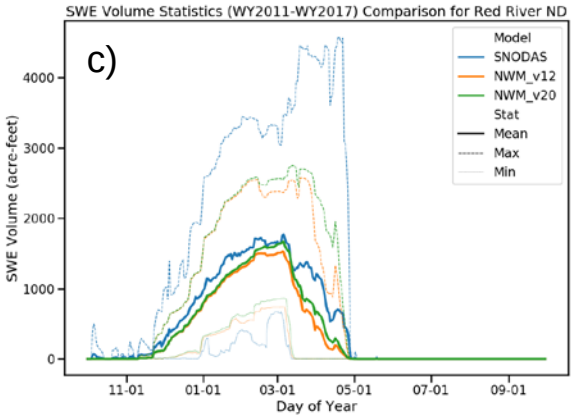
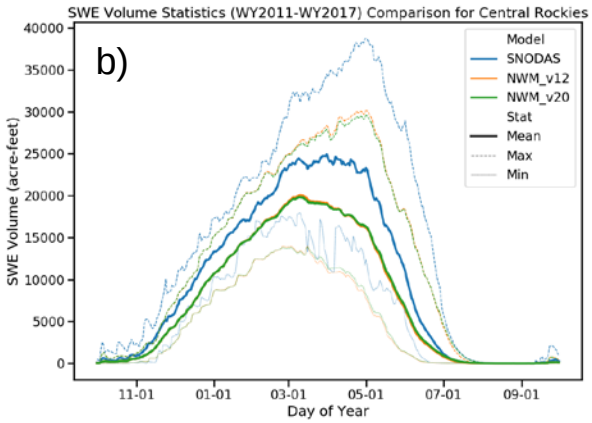
NWM V2.0 Snowpack Improvement (Retrospective)

- v2.0 enhancement: 2-band albedo formulation (VIZ/NIR) uncalibrated
  - ➢ Albedo now being evaluated using tower data and ASO imaging spectrometer

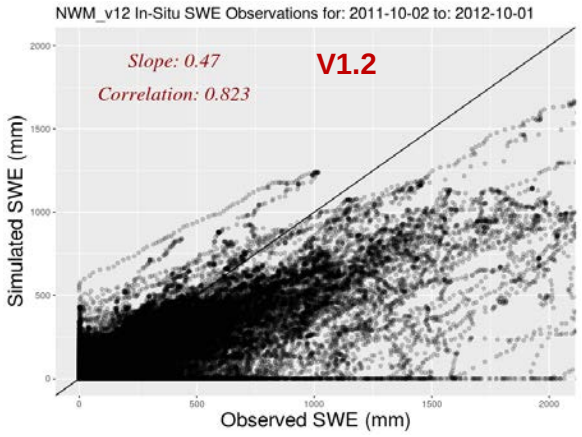


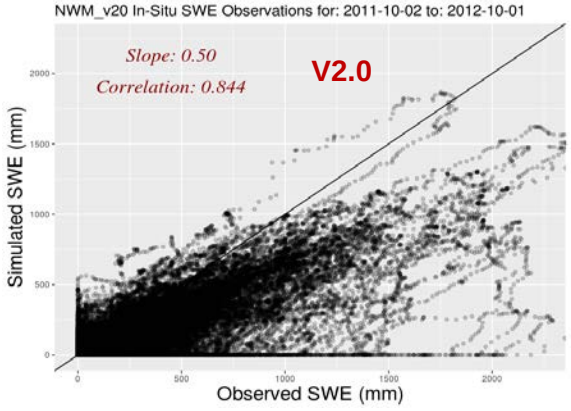




- **Validated against SNODAS, v2.0 shows slight improvement across the Pacific Northwest (a), slight degradation across the Sierra and Central Rockies (b), and mixed minor changes east of Rockies (c)**
- **SNOTEL in situ analysis shows slight improvement overall**

Model vs. SNOTEL SWE Scatterplots (all CONUS sites)



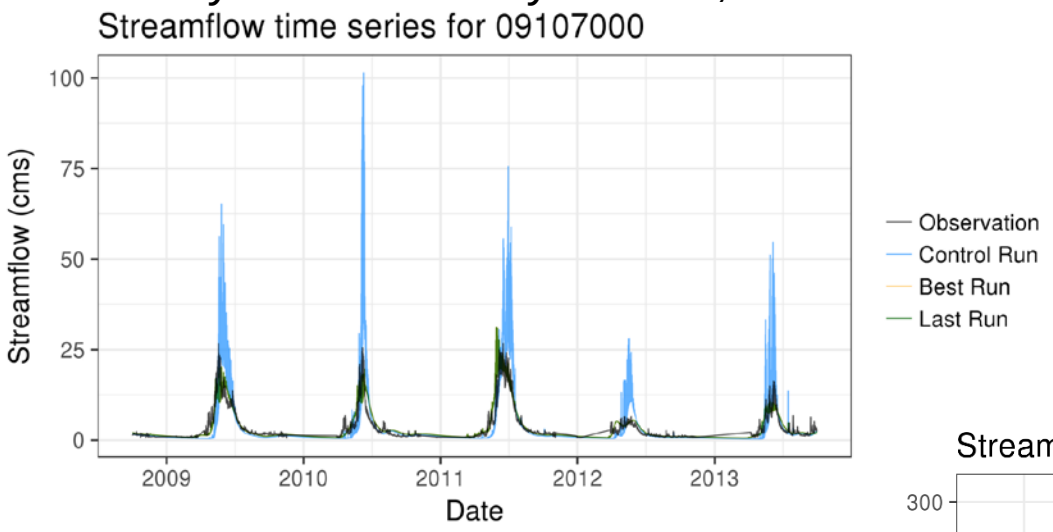


L. Karsten

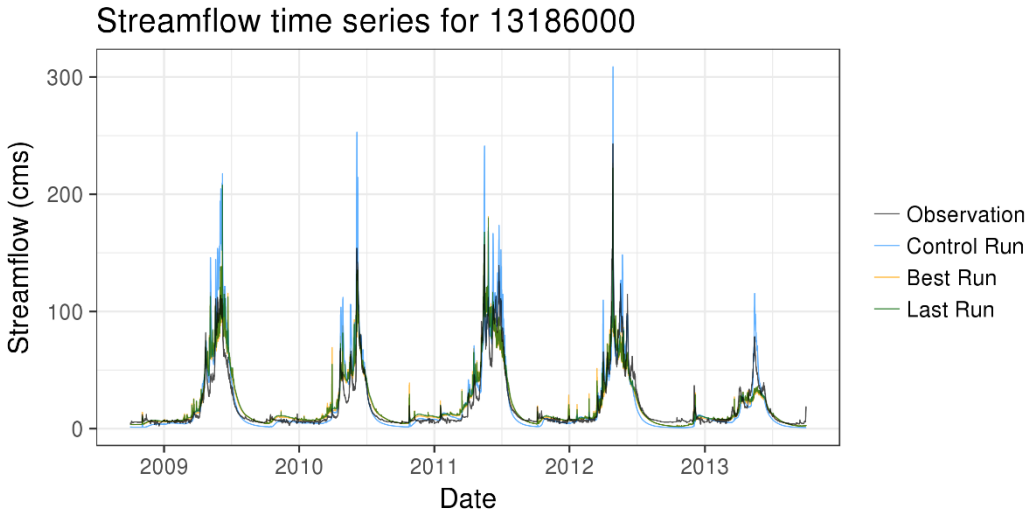
NWM V2.0 Snowpack Improvement (Retrospective)

- Snow model upgrades and use of hourly vs. daily streamflow for calibration improves model performance in snowmelt dominated systems…dampens diurnal maxima
- More work on assessment of albedo and snow ablation rates continuing…

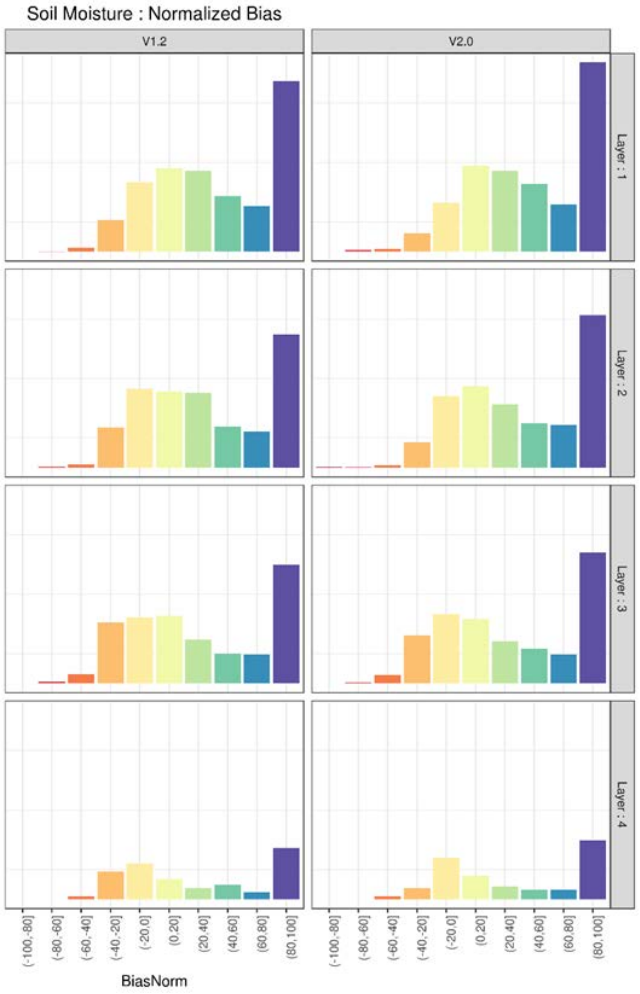
Taylor River at Taylor Park, CO

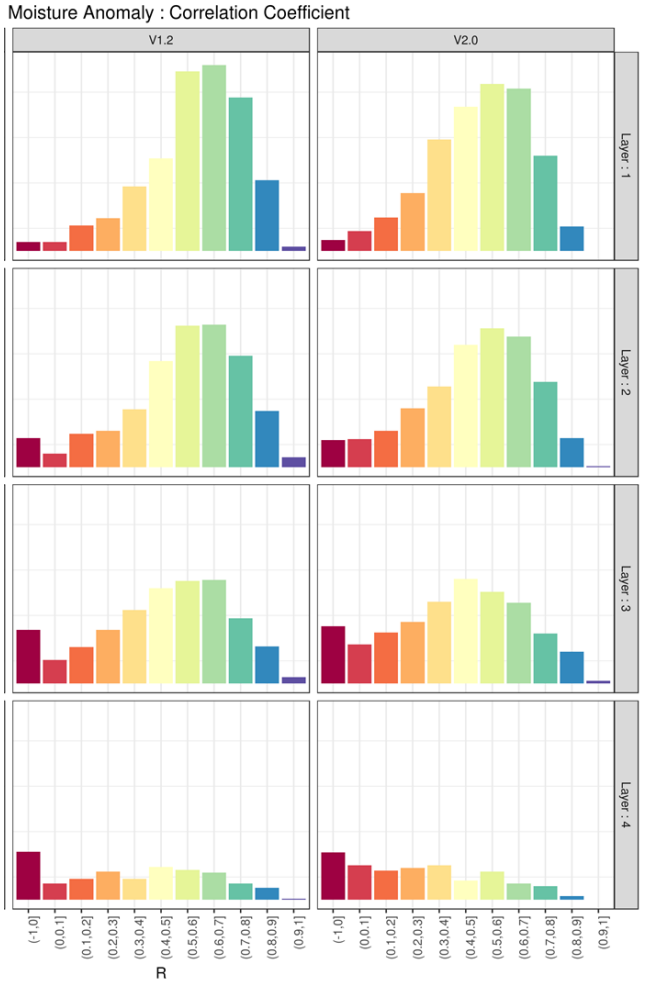


Boise River at Featherville, ID



NWM V2.0 Soil Moisture



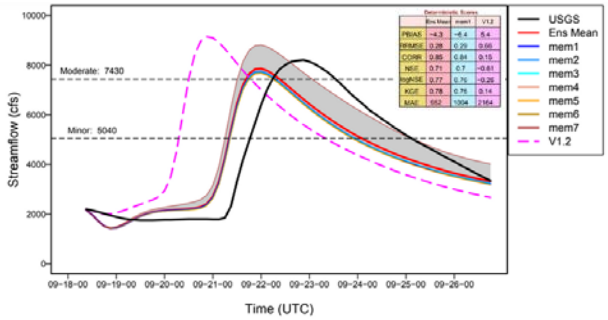


- Soil moisture statistics degraded slightly from v1.2 to 2.0
  - Number of sites with wet bias (RMSE) increased slightly, anomaly correlation decreased slightly
  - Cause is likely due to compensating effects of reducing baseflow error/bias stemming from inadequate groundwater dynamics and unconstrained ET estimates

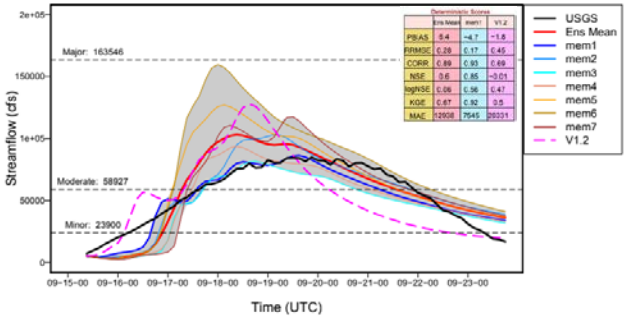
NWM V2.0 Medium-Range Real-time Ensemble Forecast Examples

Hurricane Florence

NWM Medium-Range Forecast (06Z 9/18)
Lynches River at Effingham, SC

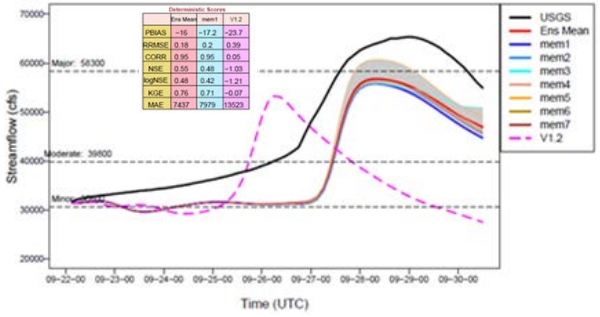


NWM Medium-Range Forecast (06Z 9/15)
Cape Fear River at William O. Huske Lock near Tar Heel, NC

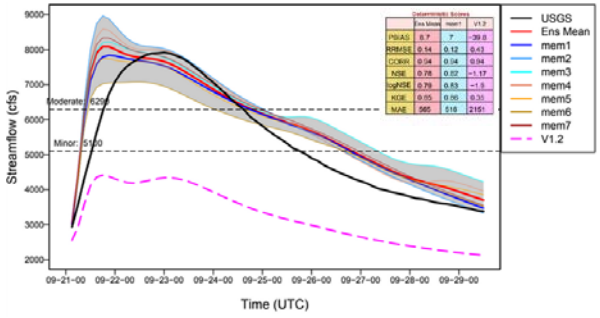


Iowa Flooding

NWM Medium-Range Forecast (00Z 9/22)
Iowa River at Wapello, IA

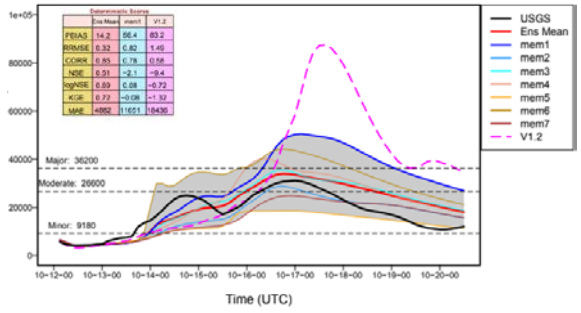


NWM Medium-Range Forecast (00Z 9/21)
East Fork Des Moines River, Near Algona IA

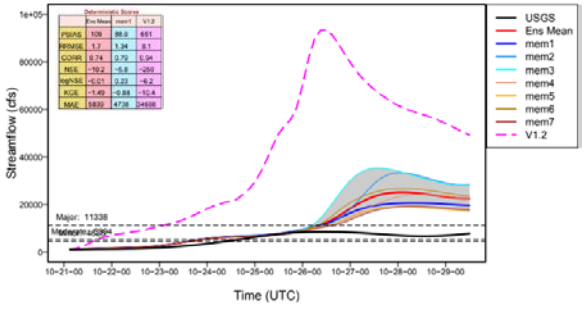


Texas Flooding

NWM Medium-Range Forecast (12Z 10/12)
Trinity River at Dallas, TX



NWM Medium-Range Forecast (00Z 10/21)
Nueces River near Three Rivers, TX

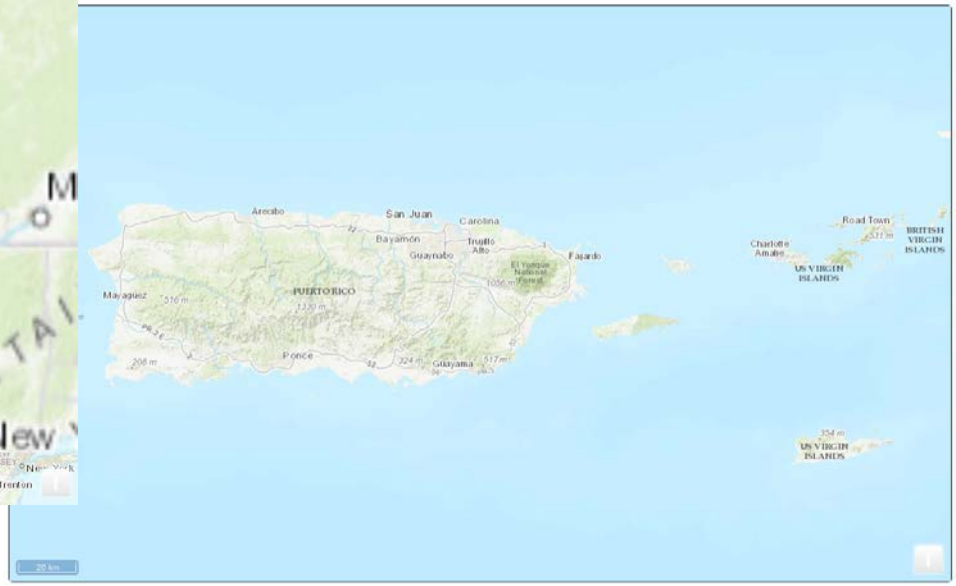


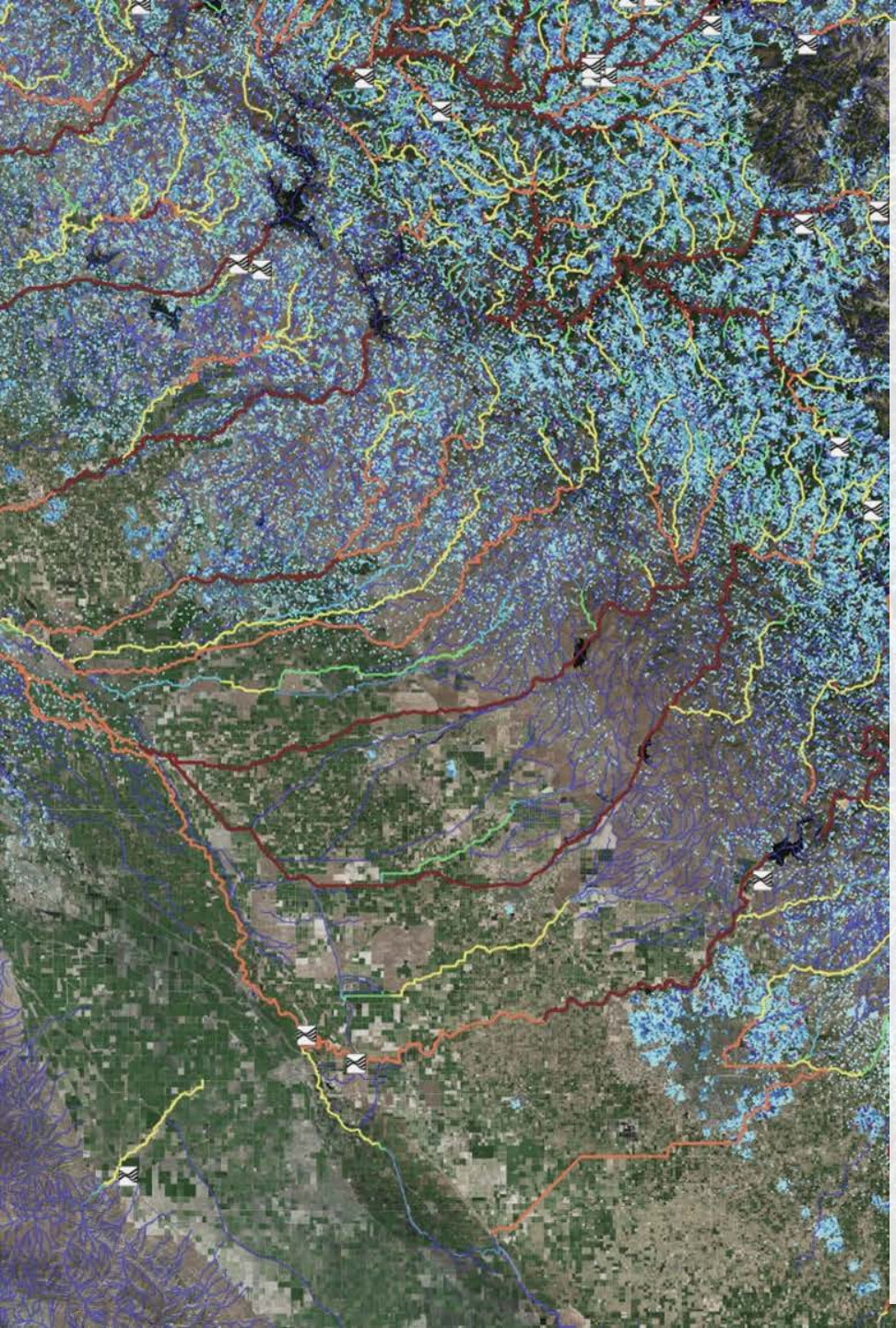
NWM V2.0 displayed good performance for Hurricane Florence flooding, and in Iowa and Texas flood events, new ensemble begins to capture forecast uncertainty

A. Dugger, J. Mills, E. Towler, A. RafieeiNasab

The National Water Model:

- **What is around the next corner…v2.1**
  Version 2.1 targeted for March 2020
  - Expanded domain (Great Lakes and Puerto Rico/Virgin Islands)
  - Enhanced treatment of reservoirs (supporting data streams, parameters needed)
  - Improved forcing over Hawaii





Thank you!

Resources:

NOAA National Water Model:
http://water.noaa.gov/about/nwm

NOAA National Water Center:
http://www.nws.noaa.gov/oh/nwc/

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

WRF-Hydro GitHub Repository:
https://github.com/NCAR/wrf_hydro_nwm_public

NCAR
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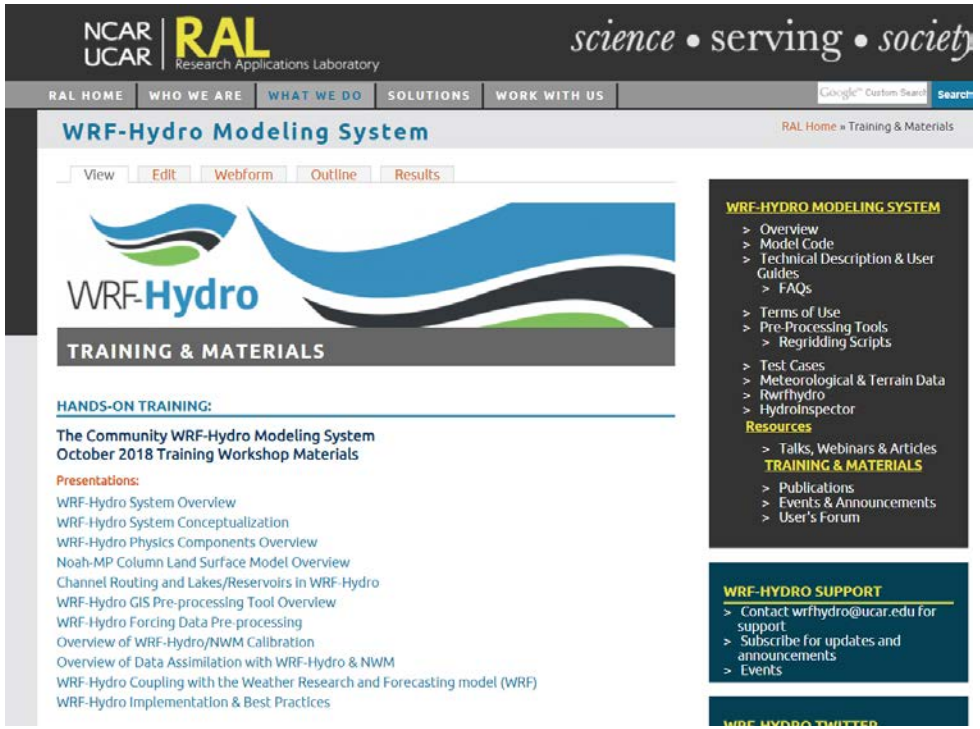
WRF-Hydro/NWM Community Support

- Fully public GitHub repository for model code access and development:

v1.2: https://github.com/NCAR/wrf_hydro_nwm_public/releases/tag/nwm-v1.2

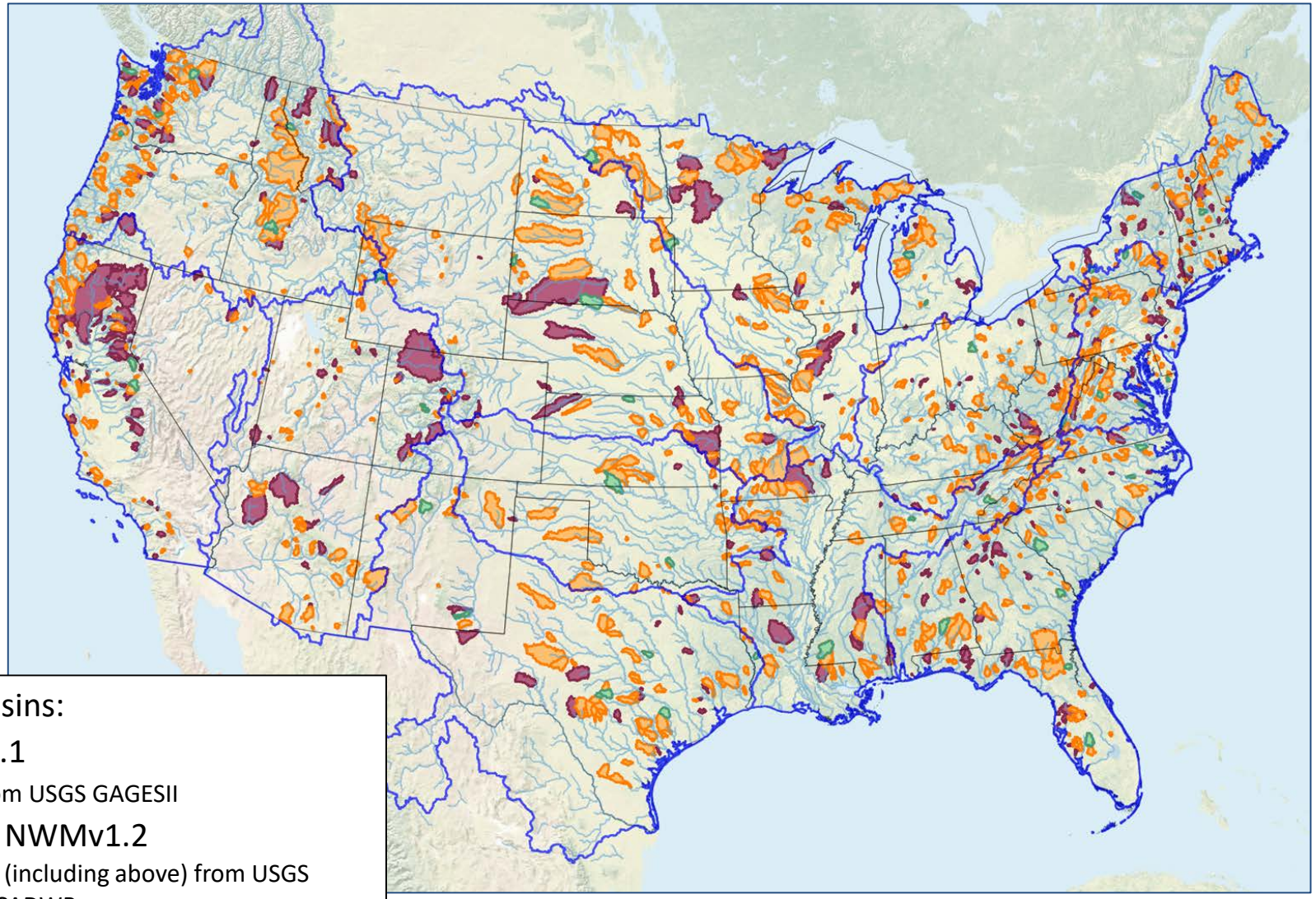
- Online training materials via JupiterHub notebooks (sync'd with CUAHSI-NCAR training)
- Email ticketing system, technical documents, User Forum, test cases, reference lists, FAQs
- Twice per year live training courses at NCAR w/ CUAHSI
- Spanish version technical documents (coming soon!)



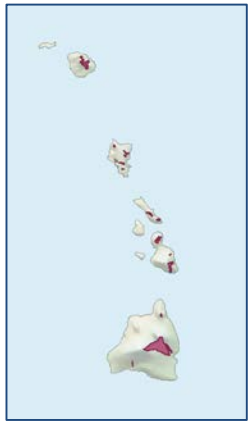
NWM V2.0 Calibration: Methodology

- Expanded calibration coverage:
  - All USGS GAGES-II reference basins
  - Non-reference USGS gages with low Hydrologic Disturbance Index (HDI) values
  - Select CA DWR basins
  - RFC-identified priority basins
    - NOTE: All of the above basins are screened for % completeness in obs and minimal management/disturbance.
- New sensitivity analysis capabilities:
  - Distributed Evaluation of Local Sensitivity Analysis (DELSA) (Rakovec et al, 2013)
- Calibration runs:
  - Dynamically-Dimensioned Search (DDS) method (Tolson & Shoemaker, 2007)
  - 5/3 year calibration/validation periods (2008-2013, 2014-2016)
  - Multiple evaluation criteria with emphasis on bias reduction (NSE, RMSE, % bias, correlation, KGE)
  - New inclusion of categorical statistics
  - Objective function is a weighted Nash-Sutcliffe Efficiency: 1-(NSE+LogNSE)/2
  - Automated workflow using Python and R with a PostgreSQL database
- Regionalize parameter sets based on a cluster analysis:
  - Calculate hydrologic landscape parameters for HUC10s and calibration basins
  - Cluster both together using PCA analysis and K-means clustering
  - Select donor basin for each HUC10 and apply parameters
  - More details on the next slide
- Re-validate full CONUS with 5-yr runs

NWM Calibration: Version-to-Version Changes



Hawaii basins
(28 total)



Calibrated basins:

- NWMv1.1
  48 total from USGS GAGESII
- New for NWMv1.2
  1,164 total (including above) from USGS GAGESII + CADWR
- New for NWMv2.0
  1,457 total (including above and Hawaii) from USGS GAGESII + CADWR + RFC

NCAR team:

A. Dugger – Analysis, ecohydrology

D. Yates - Hydraulics

K. Sampson – Geospatial development

M. Barlage – NoahMP column physics

L. Pan – Meteorological forcing

Y. Zhang – Climate analysis and forcing preparation

J. McCreight – Data Assimilation and software engineering

A. RafieeiNasab – Data assimilation and model calibration

M. McAllister – User support, training and documentation

L. Karsten – Snow analysis, forcing engine, software engineering

K. Fitzgerald – Coupled model development, groundwater modeling, Hawaii domain

J. Mills – Model evaluation, software engineering, water quality

L. Read – Hydraulics, water management, hyper-resolution

A. Gaydos – Software engineering, web mapping services

R. Cabell – Software engineering

J. Grim – Forcing data analysis

E. Towler – Ensemble model analysis and verification

A. Newman – Forcing data preparation

A. Wood – Ensemble system development