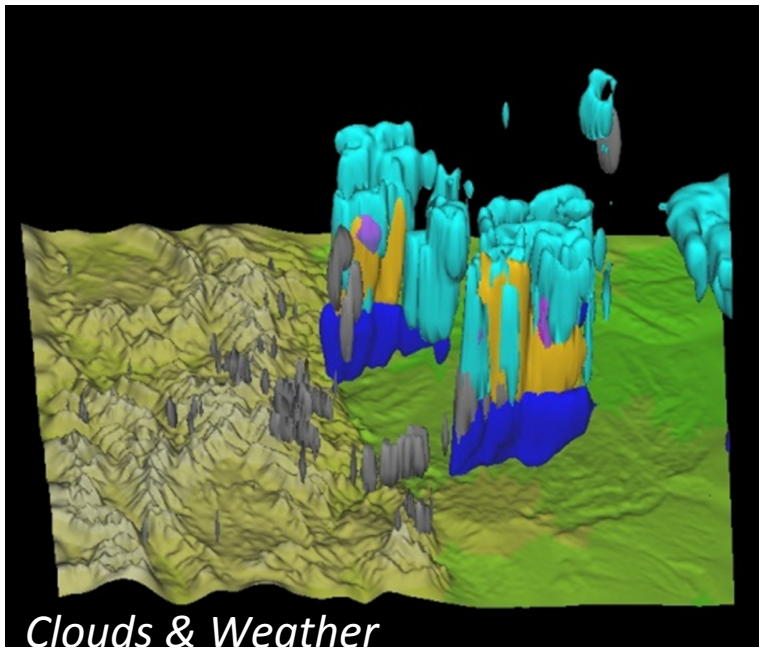
WRF-Hydro: Description and Status Update

WRF-Hydro Development Team:

D. Gochis, W. Yu, A. Dugger, J. McCreight, L. Pan, Y. Zhang, L. Karsten, K. Sampson, D. Yates, L. Read, A. RafieeiNasab



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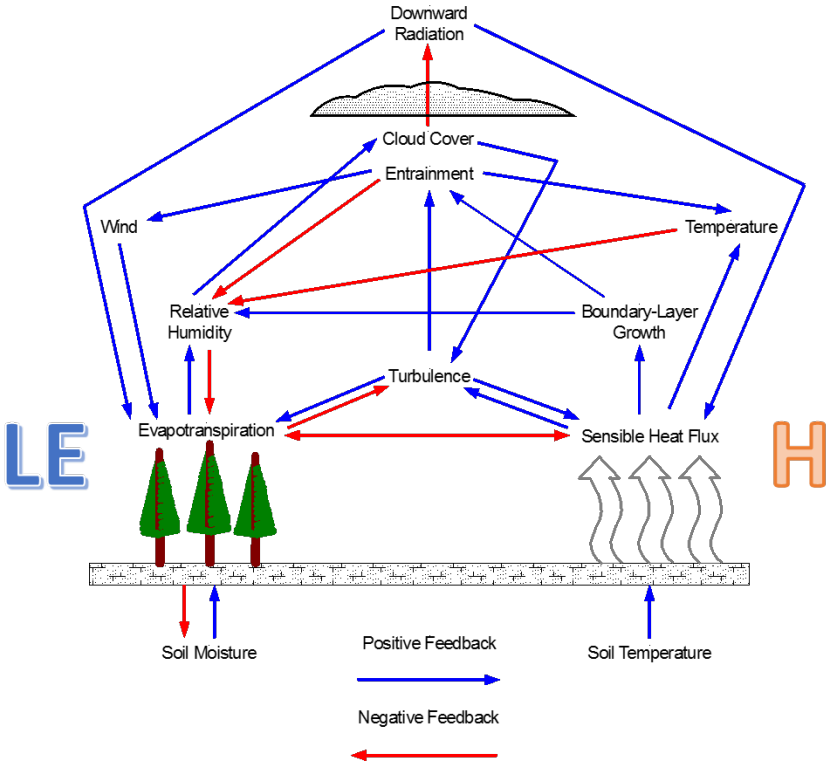
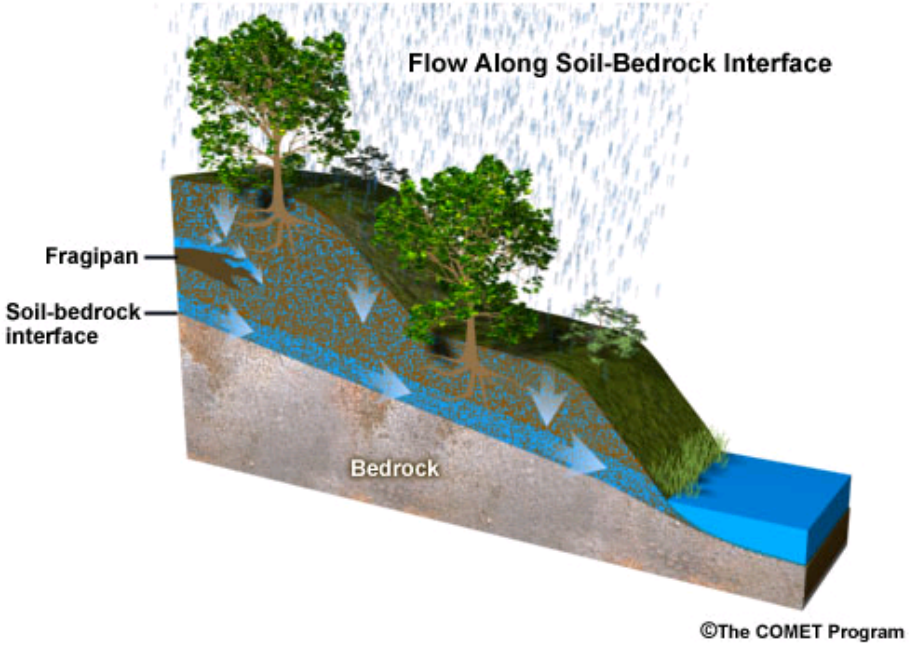
Outline

- Motivation
- Conceptualization: WRF-Hydro System Description
- Application

Motivation:

- Surface Energy Flux Partitioning…

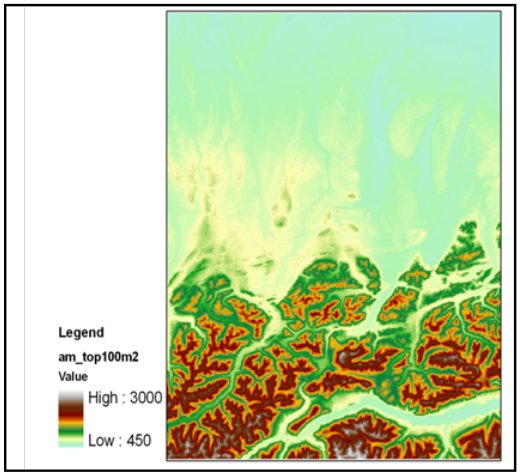




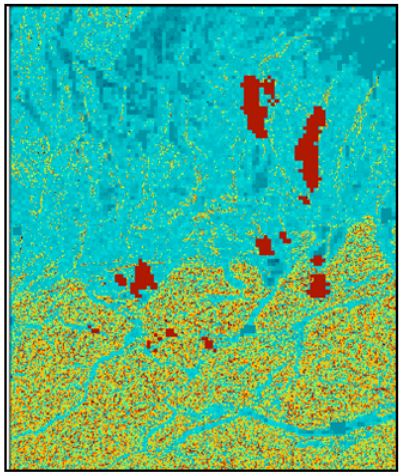
Motivation

- Terrain-driven organization of spatial variability

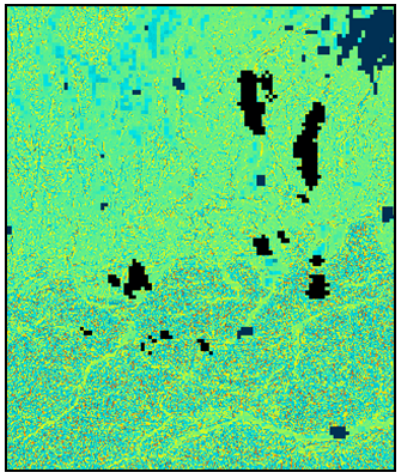
DEM: 100 m



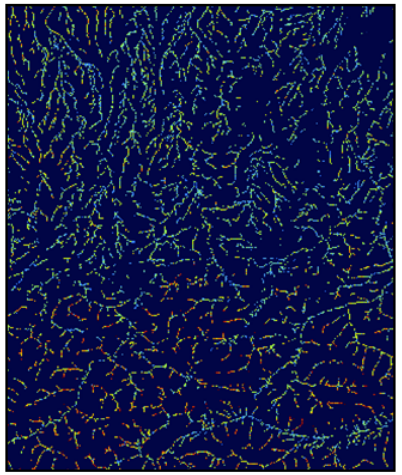
Water table depth (m)



Soil moisture



Stream channel inflows

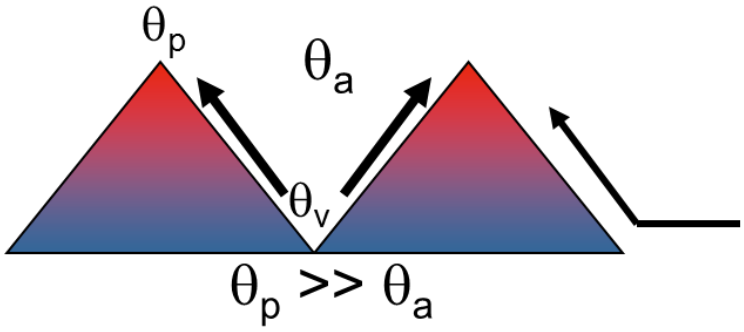


Northern Alps : Germany
Domain: ~140x220 km

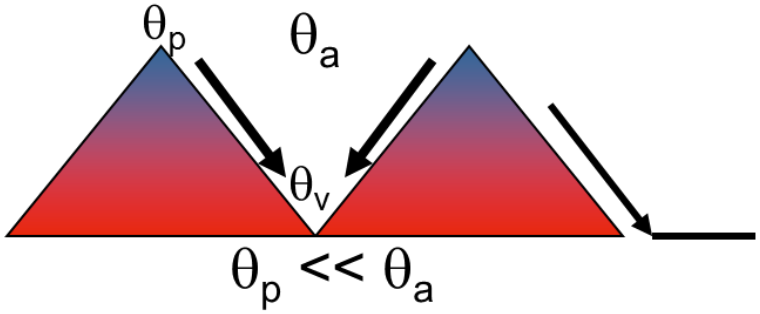
Motivation

Foundational questions…

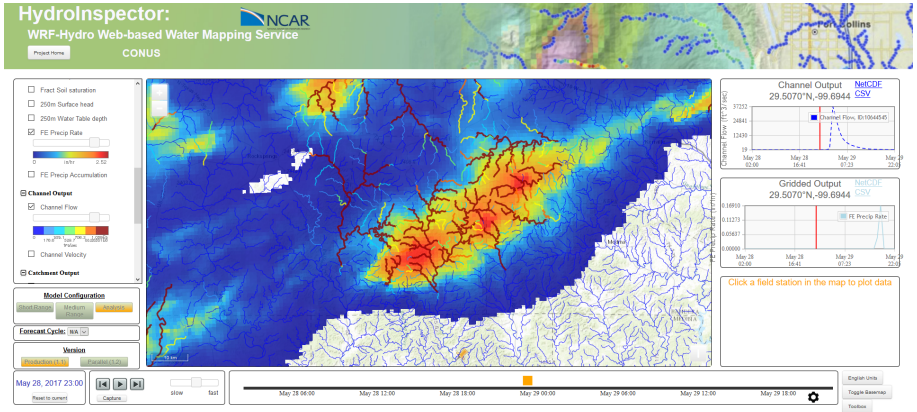
- How do hydrologic routing processes influence background mesoscale circulations?



- At what spatial and temporal scales do routing processes become significant?



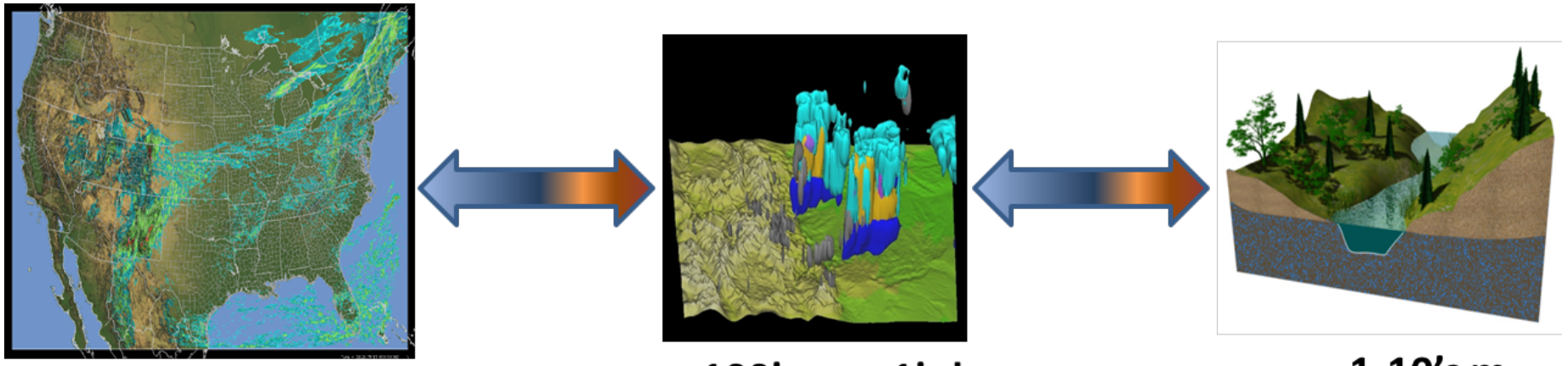
- What are the sources of error and limits on predictability of extreme hydrologic events?



WRF-Hydro Modeling System

A community-based, supported coupling architecture designed to provide:

1. An extensible *multi-scale & multi-physics* land-atmosphere modeling capability for conservative, coupled and uncoupled *assimilation & prediction* of major water cycle components such as precipitation, soil moisture, snowpack, groundwater, streamflow, inundation
2. 'Accurate' and 'reliable' streamflow prediction across scales (from 0-order headwater catchments to continental river basins & minutes to seasons)
3. Research modeling testbed for evaluating and improving physical process and coupling representations

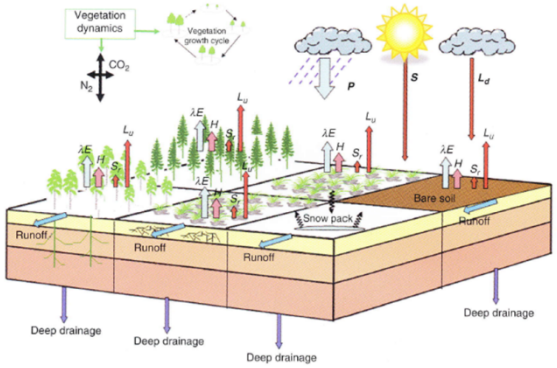


Can be run fully-coupled with WRF or in an offline mode, driven by prescribed meteorological data

Website: https://www.ral.ucar.edu/projects/wrf_hydro

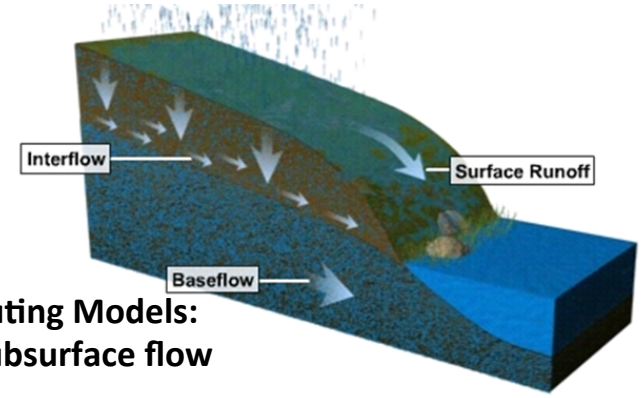
WRF-Hydro system description

Column Land Surface Models:
Noah/NoahMP/SAC-HTET*



Output Variables:
Evapotranspiration
Soil moisture/Soil Ice
Snowpack/snowmelt
Runoff
Radiation Exchange
Energy Fluxes
Plant Water Stress

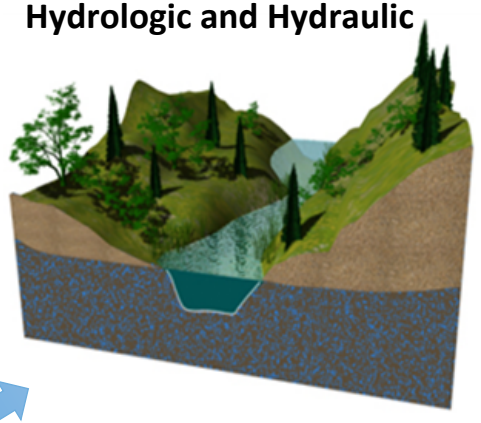
2-way coupling



Terrain Routing Models:
Overland, subsurface flow

1-way coupling or 2-way coupling

Channel & Reservoir Routing Models:
Hydrologic and Hydraulic

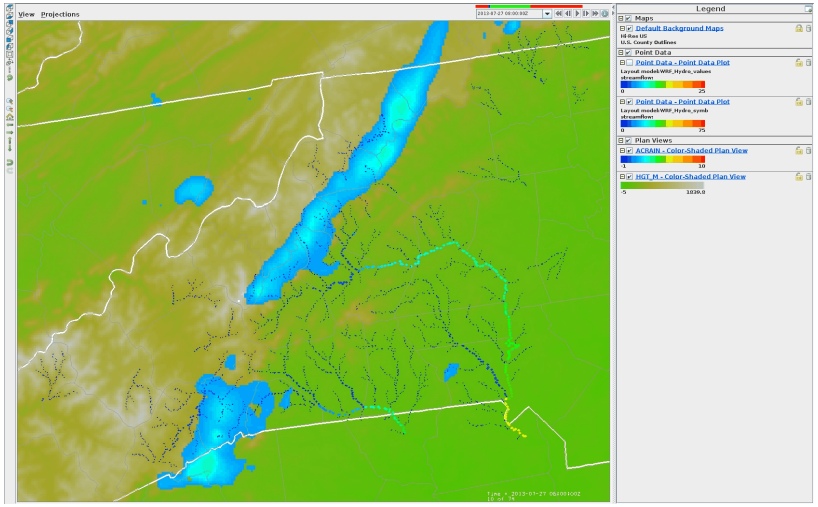


Output Variables:
Streamflow
River Stage
Flow Velocity
Reservoir Storage & Discharge

Output Variables:
Stream Inflow, Surface Water Depth, Groundwater Depth, Soil Moisture

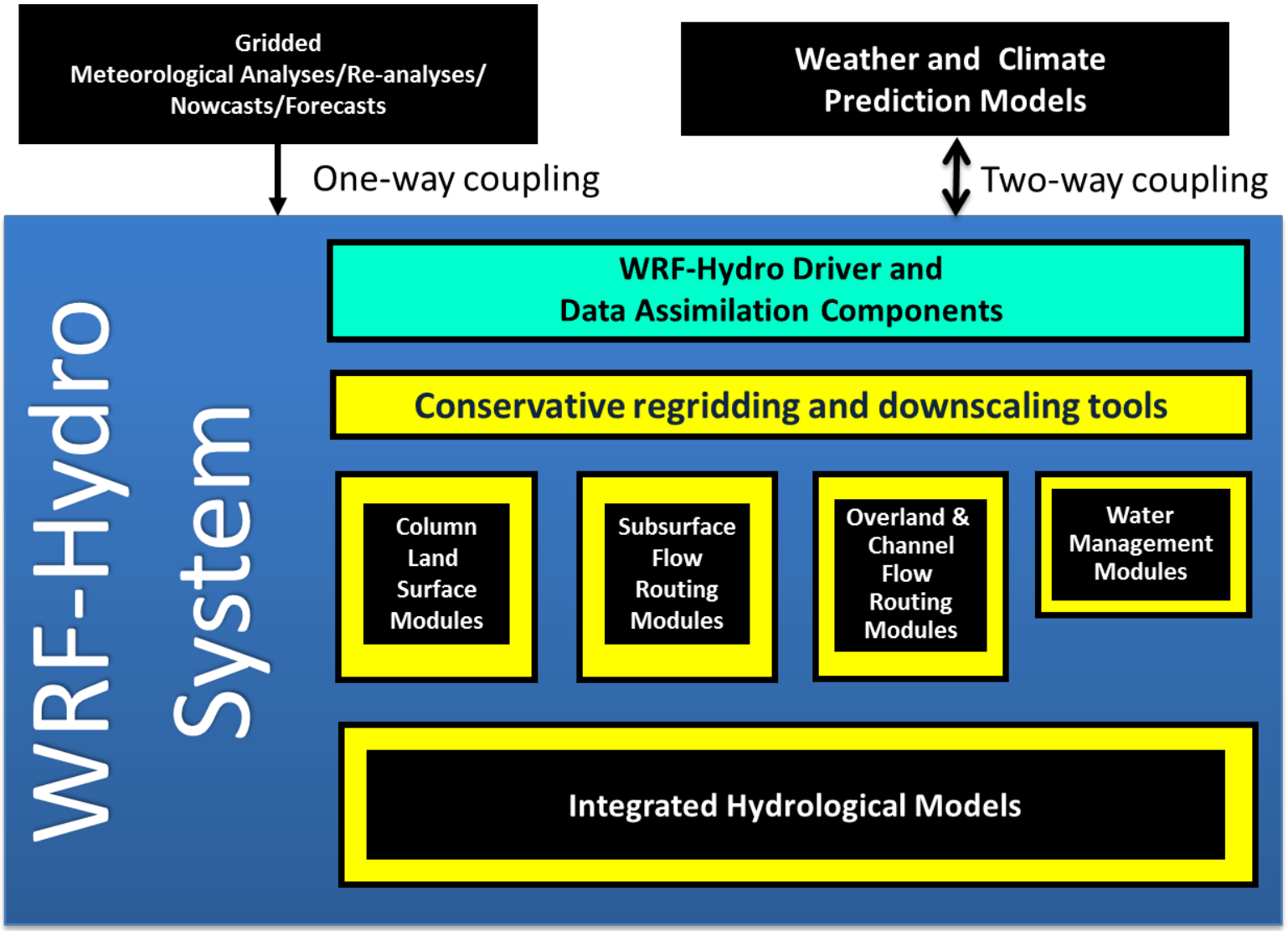
WRF-Hydro system description

- As of v3.0: ~180 possible 'physics' component configurations for streamflow prediction:
  - 3 column physics land models (Noah, NoahMP, SAC-HTET*)
  - 3 overland flow schemes (Diffusive Wave, Kinematic Wave, Direct basin aggregation)
  - 4 lateral/baseflow groundwater schemes (Boussinesq shallow-saturated flow, 2d aquifer model, Direct Aggregation Storage-Release: pass-through or exponential model)
  - 5 channel flow schemes: Diffusive wave, Kinematic Wave, RAPID-Muskingam for NHDPlus, Custom Network Muskingam/ Muskingam Cunge
- Simple level-pool reservoir with management
- DART, filter-based hydrologic data assimilation



Ensemble Flood Forecasting in the Southeast U.S. with WRF-Hydro
***2014 WRF User's Workshop*, K. Mahoney (NOAA-ESRL)**

WRF-Hydro system description



WRF-Hydro system description

Model System and Components:

- GIS Pre-processor – Physiographic data processing
- Meteorological Forcing Engine (MFE) – Met. Pre-processing
- Core WRF-Hydro Model – Model physics
- Hydro-DART – DART-based data assimilation
- Rwrfhydro – Analysis, verification, visualization

WRF-Hydro:
https://www.ral.ucar.edu/projects/wrf_hydro
Rwrfhydro Evaluation Tools:
https://github.com/mccreigh/rwrfhydro

WRF-Hydro system description

What's new in v4.0 (upcoming in summer 2017):

- Improved snowpack ablation formulation in NoahMP
- Improved soil moisture transport in NoahMP
- Spatially distributed land surface hydrology parameter specification
- Enhanced multi-scale mesh-mapping support
- Improved terrain-hydrography harmonization tools
- Updated channel routing options for vector networks
- Updated nudging methods for streamflow data assimilation
- Full integration of WRF-lake and WRF-hydro hydrology
- Expanded meteorological forcing data support
- Hyper-resolution (10-100m) domain specification
- Automated model calibration tools
- Expanded model analysis suite (Rwrfhydro)
- Support for ensemble seasonal water supply forecasting

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

Rwrfhydro Evaluation Tools:
https://github.com/mccreigh/rwrfhydro

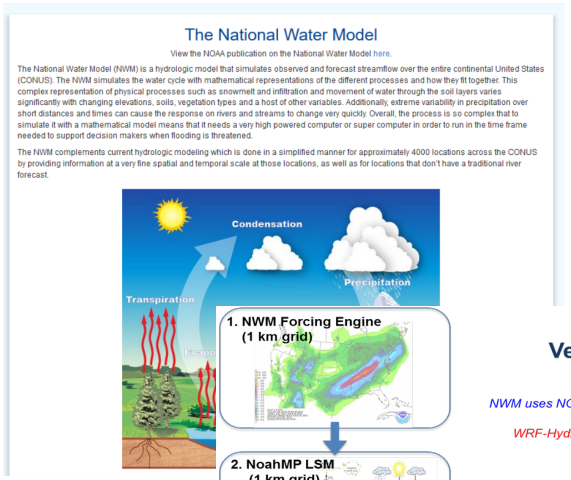
WRF-Hydro Community Research & Applications:

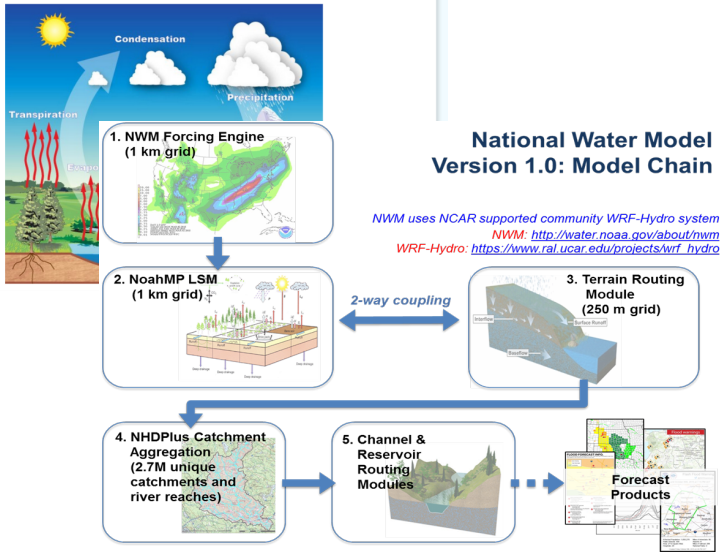
1. **Operational Streamflow Forecasting:**
   - U.S. National Weather Service, National Water Center
     - Hawaii implementation now in retrospective evaluation & calibration
   - Israeli Hydrological Service (4th-yr, Givati et al., 2016 - Hydrology)
   - State of Colorado-Upper Rio Grande River Basin…moving to Statewide for WY 2017 (State of Col., CU, NASA)
   - NCAR-STEP Hydrometeorological Prediction Group, real-time summer forecasting
   - Phillippines (USAID ParaAgua, Navy)
2. **Diagnosing climate change impacts on water resources**
   - Himalayan Mountain Front (Uni-Bjerknes, Lu et al., accepted)
   - CONUS 4km (NCAR, Stevens Institute, Col. School of Mines)
   - Bureau of Reclamation dam safety group (collaborative with ESRL and BoR)
3. **Diagnosing land-atmosphere coupling behavior in mountain-front regions** (Arizona State U., Xiang et al. 2 manuscripts submitted, KIT_Garmisch Alps Rummler et al., submitted)
4. **Assessing role of winter orographic cloud seeding on water resources** (NCAR, Boise State)
5. **Coastal coupling:**
   - U.S. Gulf Coast (Louisiana State U., Xue et al, accepted with revisions)
   - Mediterranean (U. Lecce, Italy, Verri et al., submitted)
6. **Diagnosing the impacts of disturbed landscapes on coupled hydrometeorlogical predictions**
   - Western U.S. Fires (NCAR)
   - West African Monsoon (KIT-Garmisch-Partkenkirchen)
7. **Hydrologic Data Assimilation/Hydro-DART:** Boise State, U. Alabama-Hunstville, U. Texas-Arlington, NASA-ASO

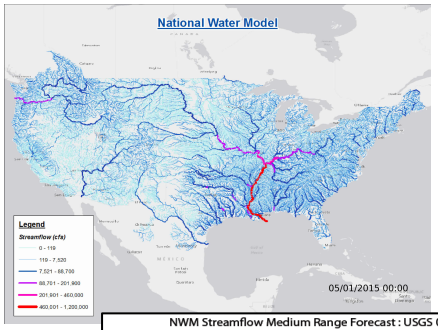
The NOAA National Water Model…(uncoupled WRF-Hydro)

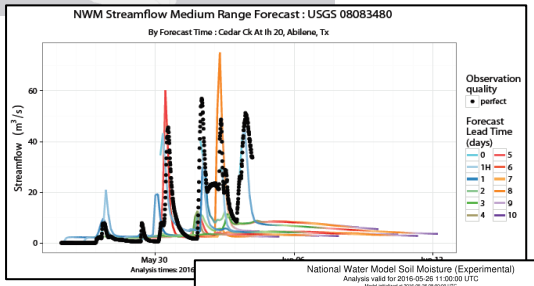
Development Team: NCAR/RAL, NOAA/OWP/NWC, USGS, CUAHSI, Universities

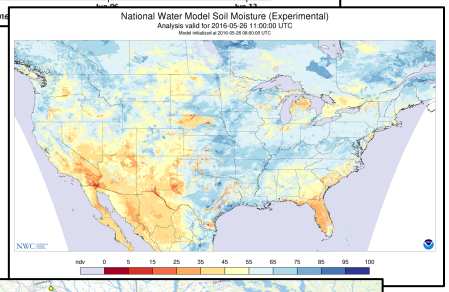
Sponsor: NOAA Office of Water Prediction

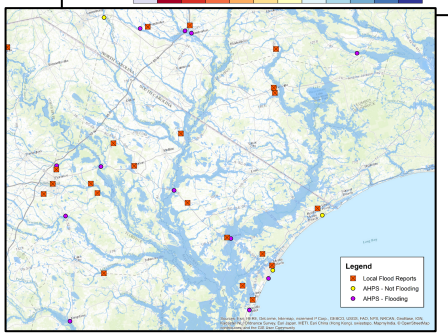












http://water.noaa.gov/about/nwm

System become fully operational beginning Aug. 16, 2016

- Utilizes the community WRF-Hydro Modeling System as underlying hydrologic modeling system
- Real-time verification since June 2016 (Rwrfhydro)
- Multiple operational products created by NOAA, academia, private sector

The National Water Model Version 1: Technical Specs

Development Team: NCAR/RAL, NOAA/OWP/NWC, USGS, CUAHSI, Universities
Sponsor: NOAA Office of Water Prediction

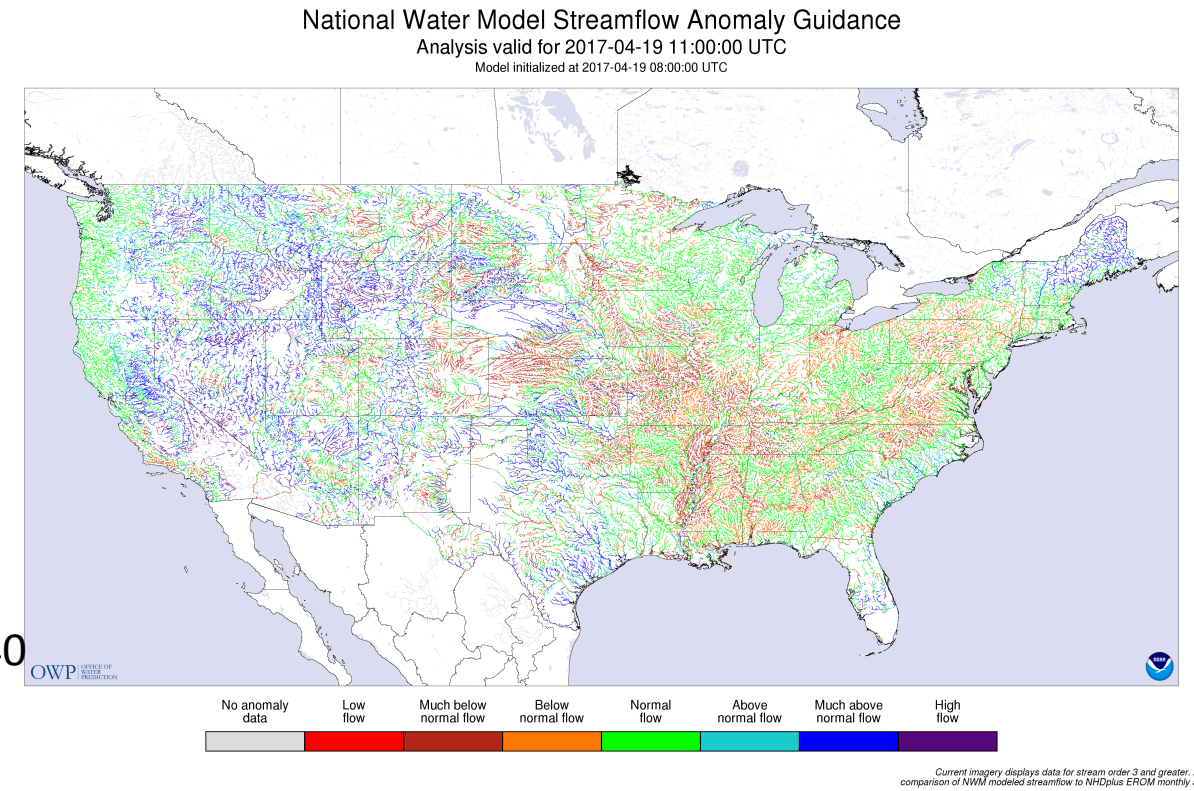
Data Throughput:

- Input data per day: 4.45 Terabytes
- Output data per day: 3 Terabytes
- # of river channels: 2.7 million
- # of reservoirs: 1,260
- Total # of computational elements: ~360,000,000

Model Details:

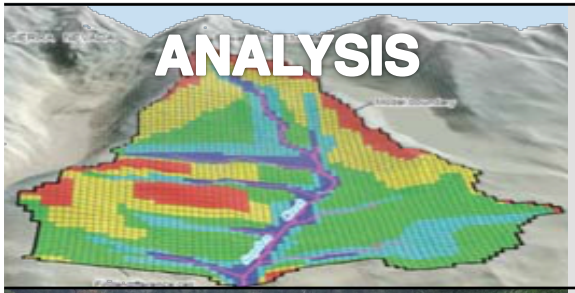
- Number of lines of code: 74,740
- Computer usage: > 100,000 cpu-hours per day

National Streamflow Anomaly Map

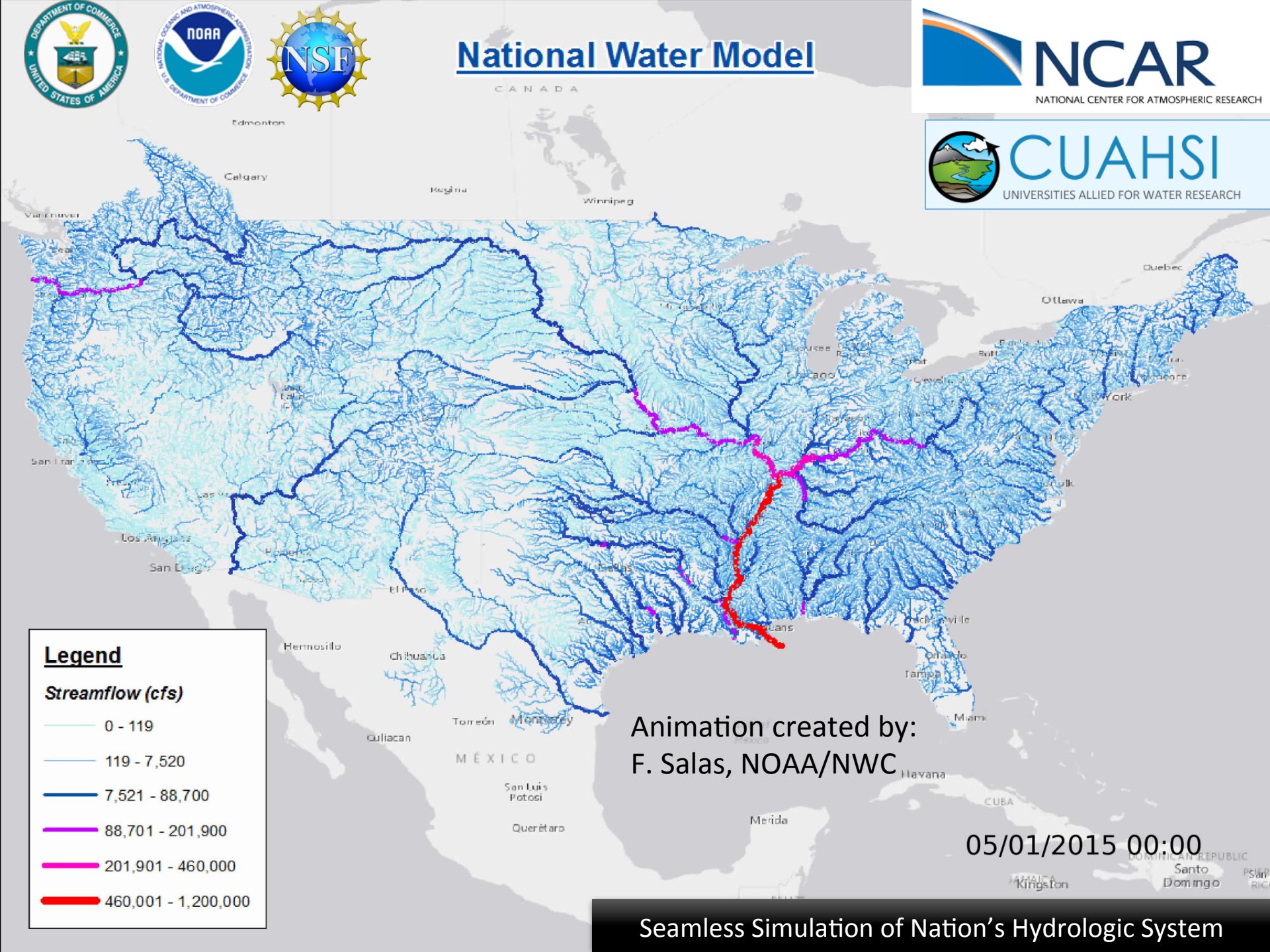


Available online at: *http://water.noaa.gov/tools/nwm-image-viewer*

NWM Operational Cycles:

	Cycling	Forecast	Met Forcing	Outputs
	Hourly	-3 - 0 hrs	MRMS/HRRR Blend QPE	1-km spatial fluxes (water & energy); 250-m routed fluxes (water); NHDPlus channel routing
	Hourly	1 – 18 hrs	Downscaled HRRR/RAP Blend	1-km spatial fluxes (water & energy); 250-m routed fluxes (water); NHDPlus channel routing
	4x Daily	to 10 days	Downscaled GFS	1-km spatial fluxes (water & energy); 250-m routed fluxes (water); NHDPlus channel routing
	Daily x 16 ensembles	to 30 days	Downscaled & NLDAS2 Bias-Corrected CFS	1-km spatial fluxes (water & energy); NHDPlus channel routing

National Water Model



Animation created by:
F. Salas, NOAA/NWC

05/01/2015 00:00

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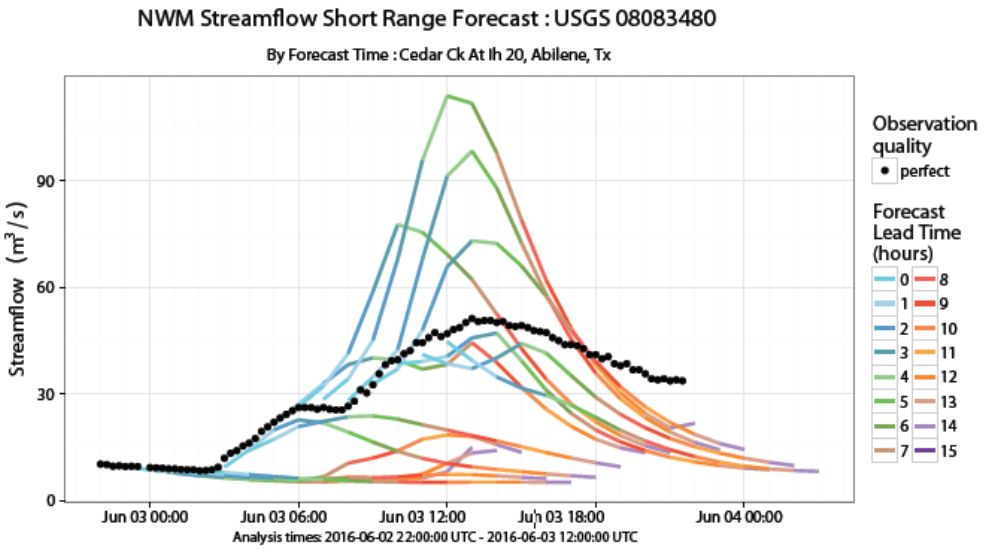
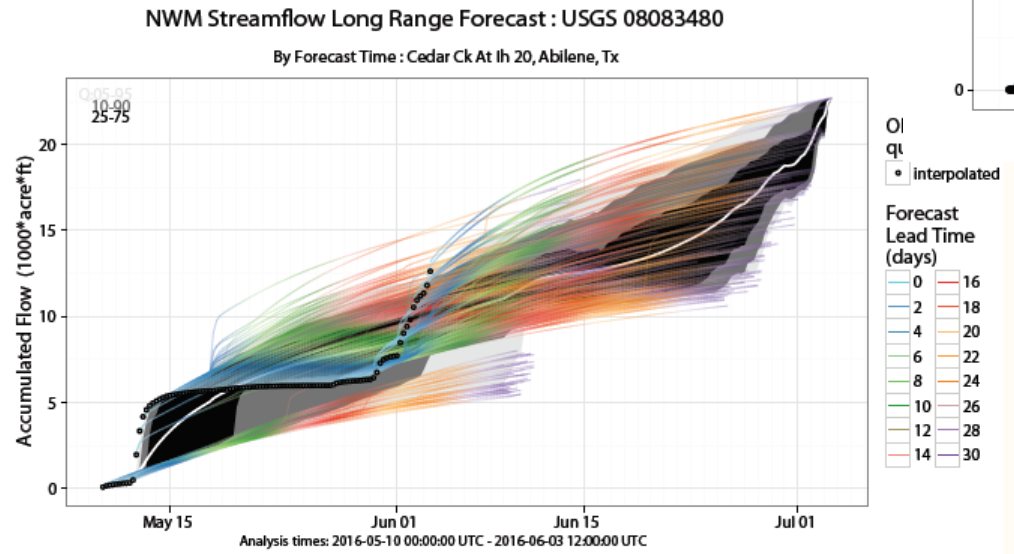
UNIVERSITIES ALLIED FOR WATER RESEARCH

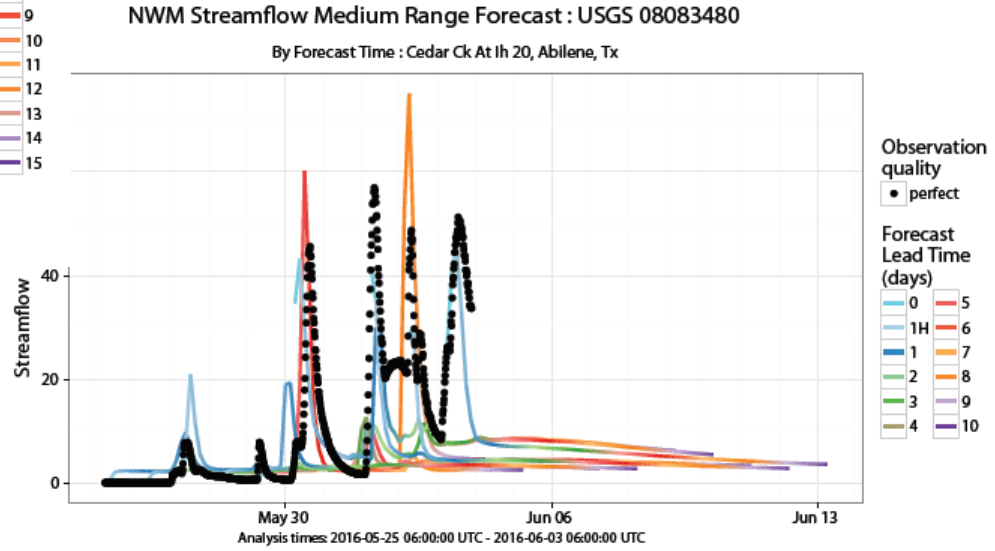
Seamless Simulation of Nation's Hydrologic System

NWM WRF-Hydro System: Hydro Model Outputs





- Forecasts from Short, Medium and Long Range configuration
- De facto time-lagged ensembles

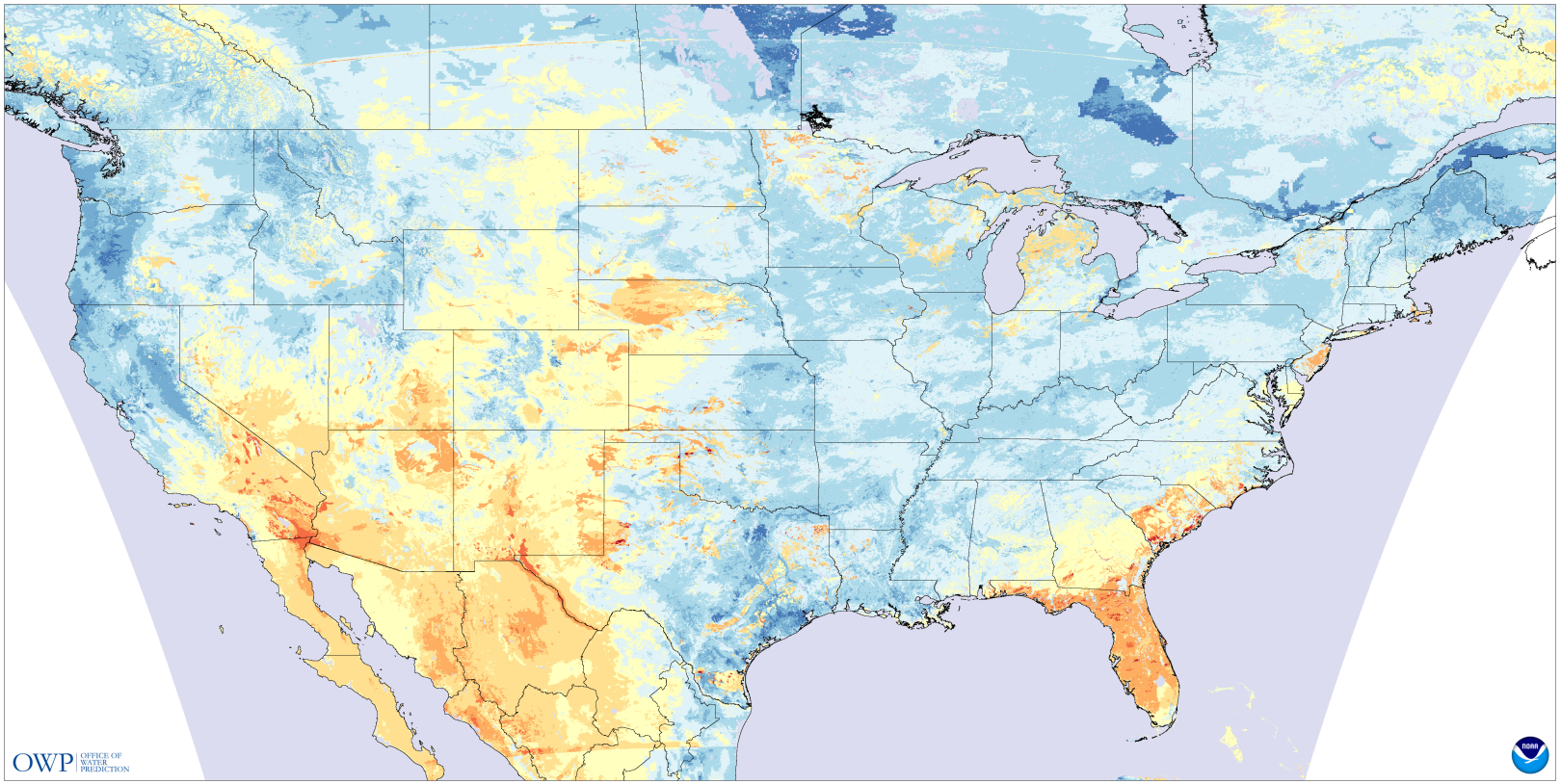


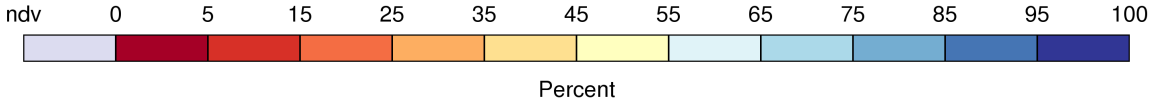
Hydrologic Forecasts:

National Water Model Soil Moisture Guidance

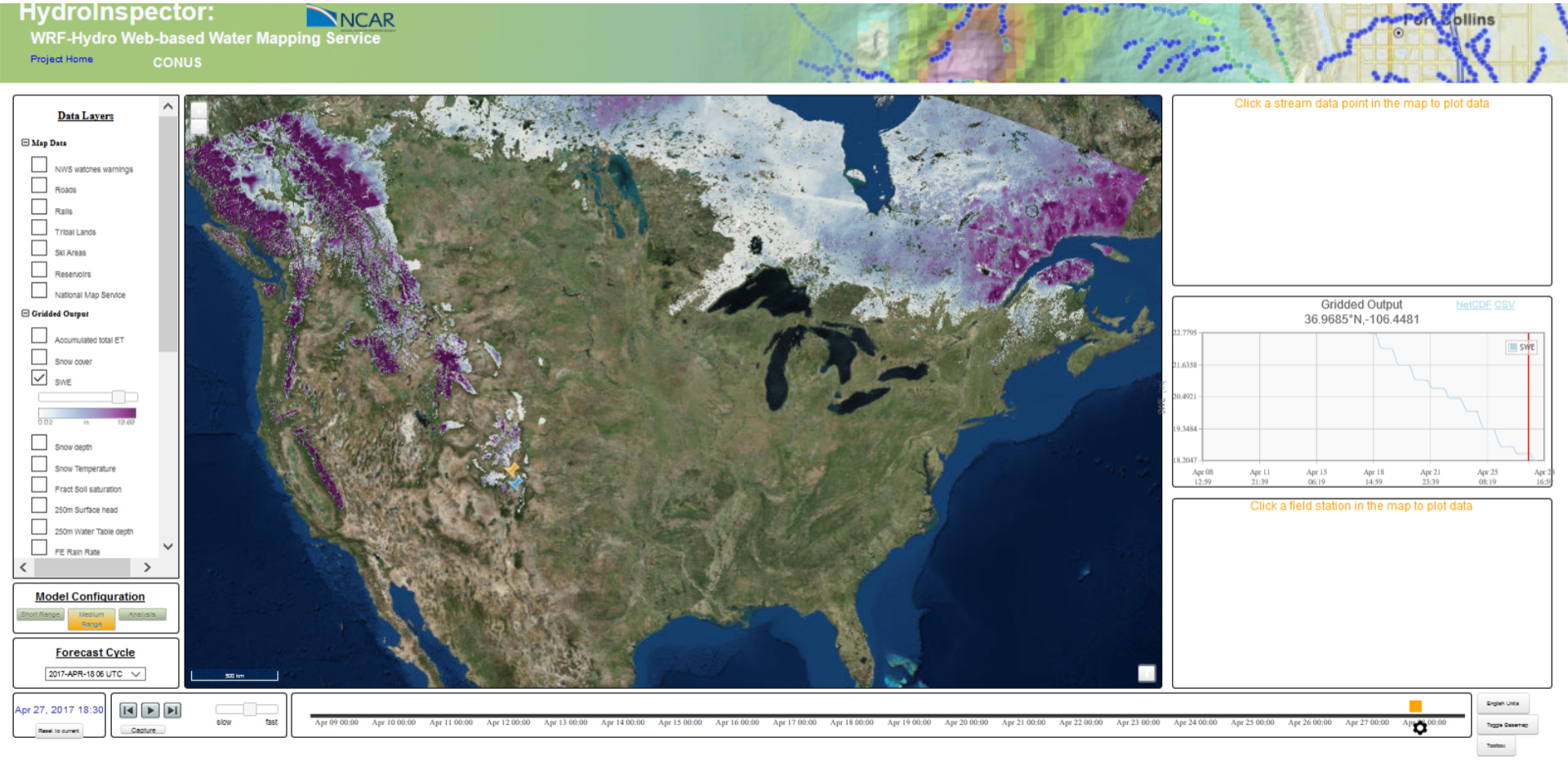
Analysis valid for 2017-04-18 13:00:00 UTC

Model initialized at 2017-04-18 10:00:00 UTC



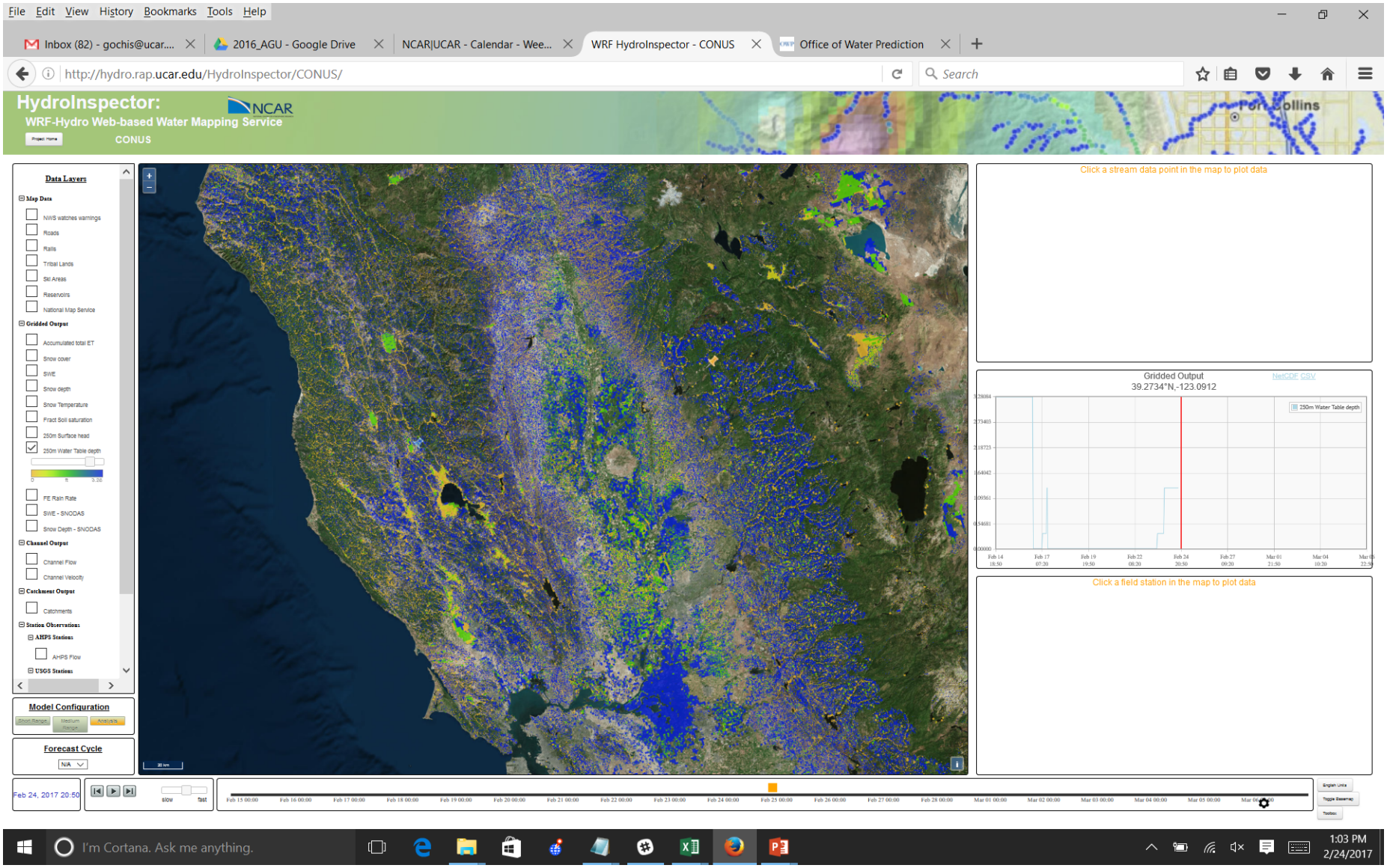


Hydrologic Forecasts:



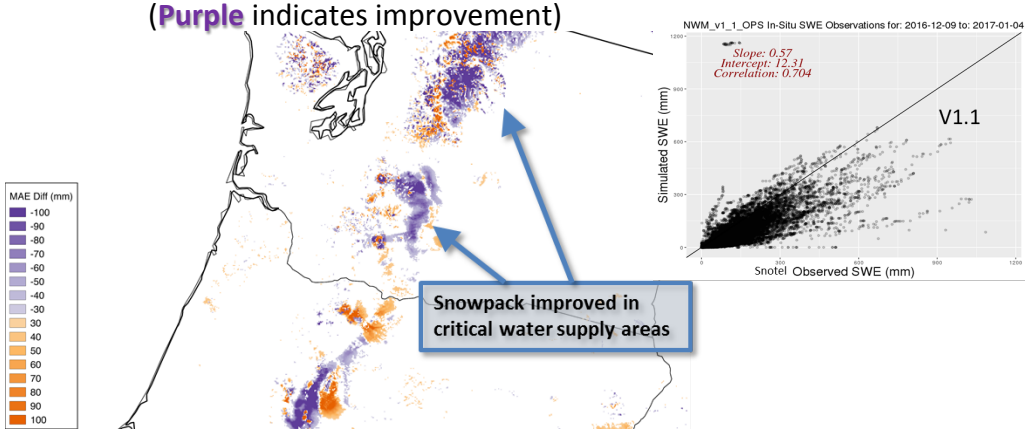
- Validated against SNODAS, NRCS SNOTEL and NASA ASO/MODSCAG products

Hydrologic Forecasts:



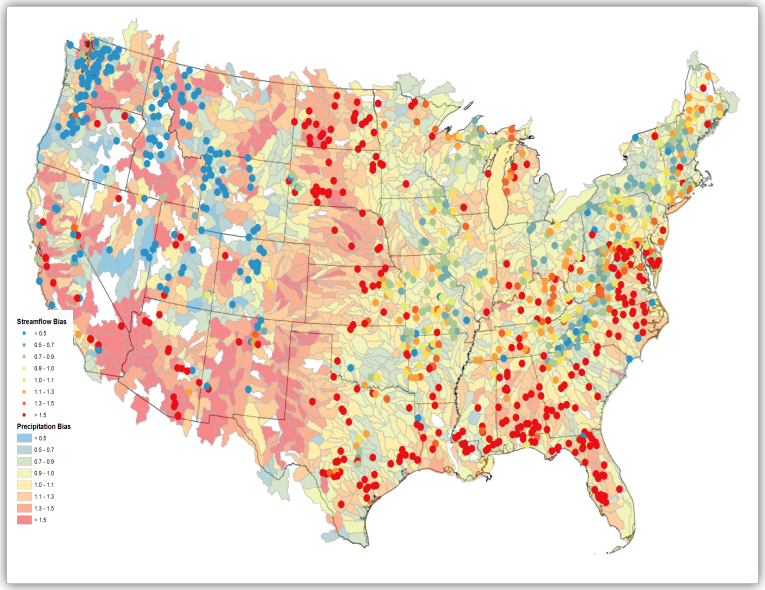
National Multivariate Assessment: Rwrfhydro evaluation package

Difference in MAE Between NWM V1.1 and V1.0 SWE
NWM 10-day Forecasts, SNODAS Baseline
(**Purple** indicates improvement)



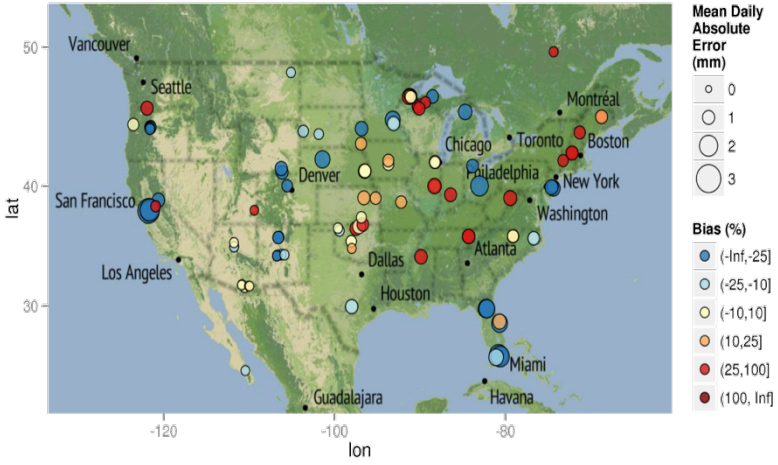
Snow Water Equivalent Comparison

Key to assess the full range of water budget variables



Precipitation-Streamflow Bias Comparison

NWM V1.0 Modeled ET Errors at Ameriflux Stations Driven by NLDAS Forcing

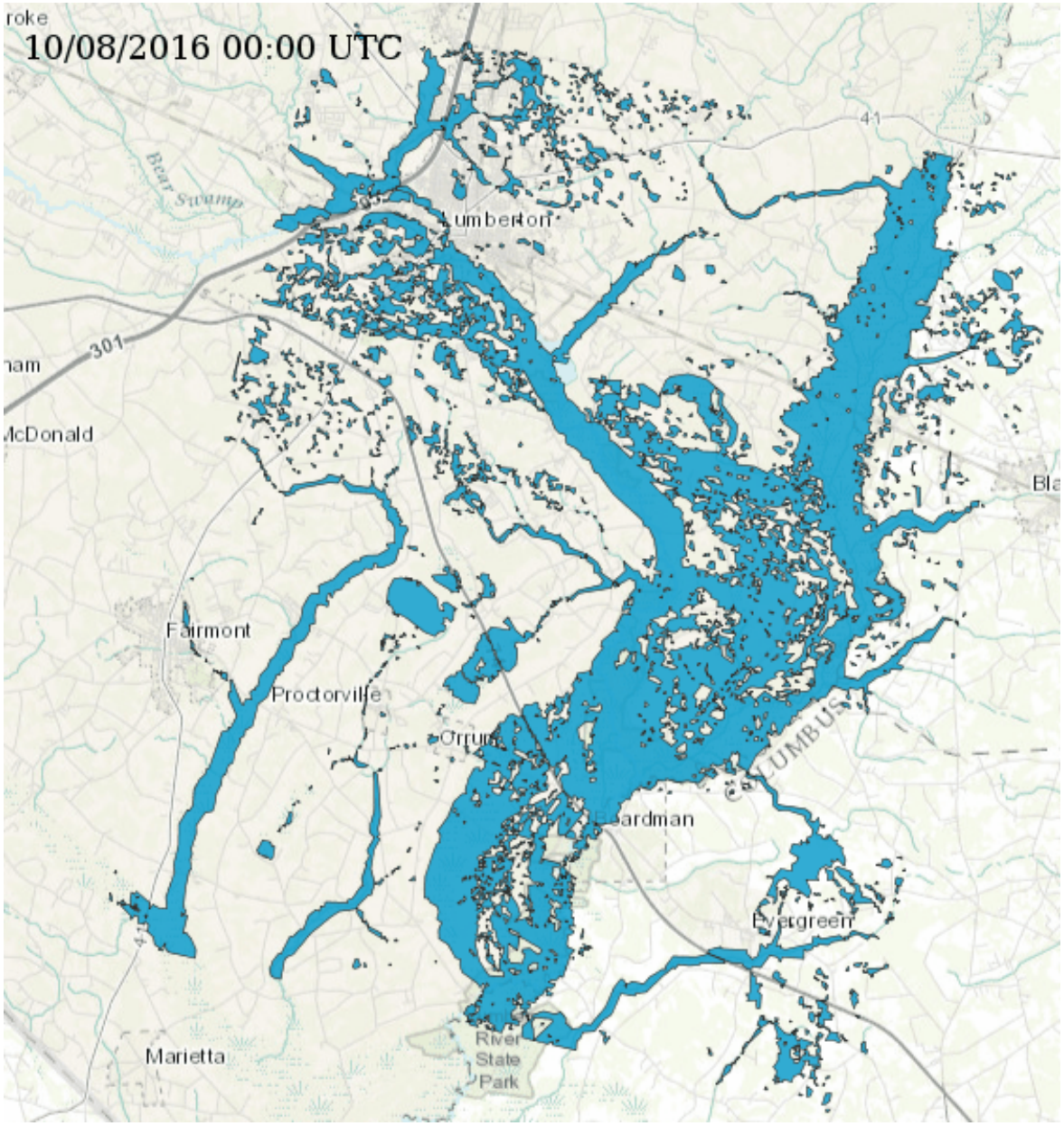


Ameriflux ET comparison

NWM Hyper-resolution Nests: Goals

- Urban hyper-resolution nests
  - –Experiment with levels of imperviousness in landuse
  - –Test sensitivity to NoahMP and soil params
    - SMCMAX, SMCREF, SMCWLT, RETDP, OVRGH
  - –Experiment with burning in detention features, streets (10m)
  - –Experiment with LIDAR terrain data

- Develop methods for describing boundary conditions (in space and time) for nested runs



Thanks!

NWM:

http://water.noaa.gov/about/nwm

WRF-Hydro:

https://www.ral.ucar.edu/projects/wrf_hydro

Rwrfhydro Evaluation Tools:

https://github.com/mccreigh/rwrfhydro

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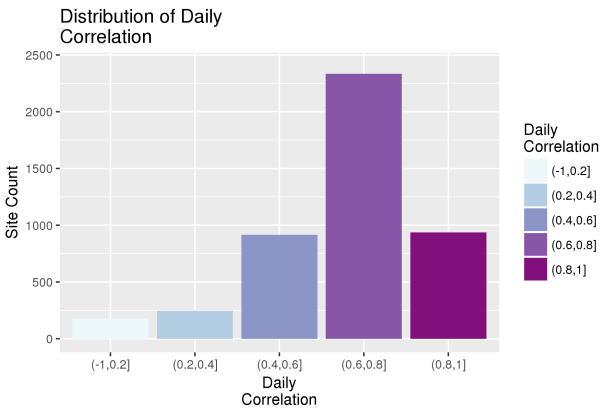
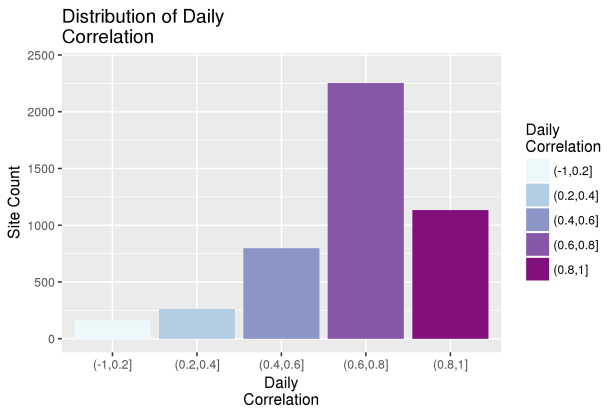
NWM Updates: Performance Changes

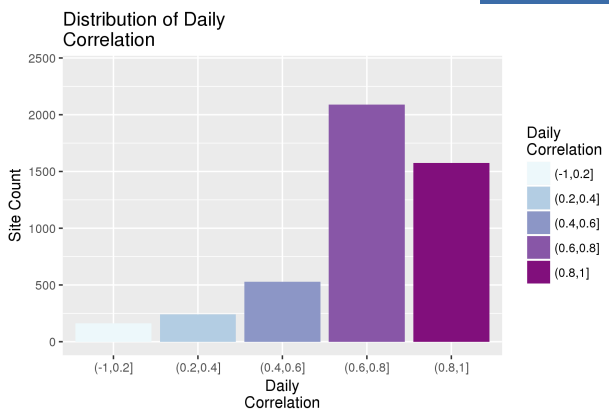
V1.0



V1.1



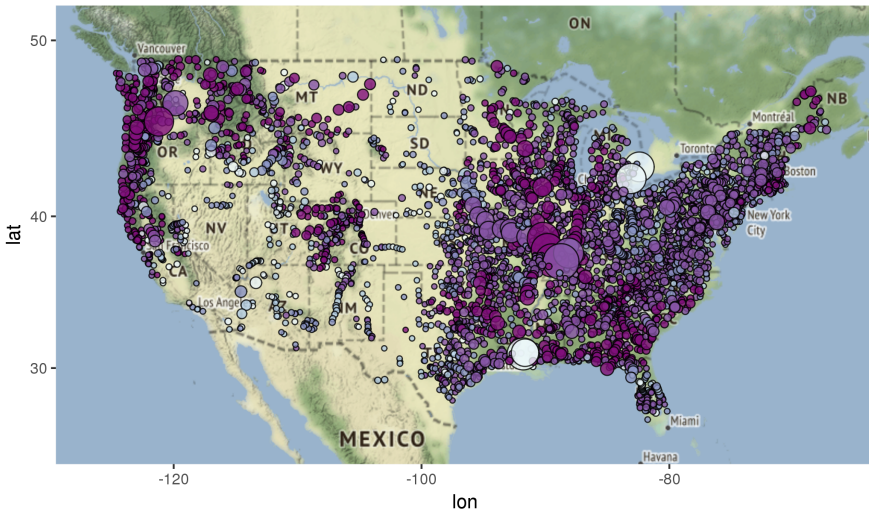
V1.2



V1.0:

Modeled Streamflow Correlation at USGS Gages

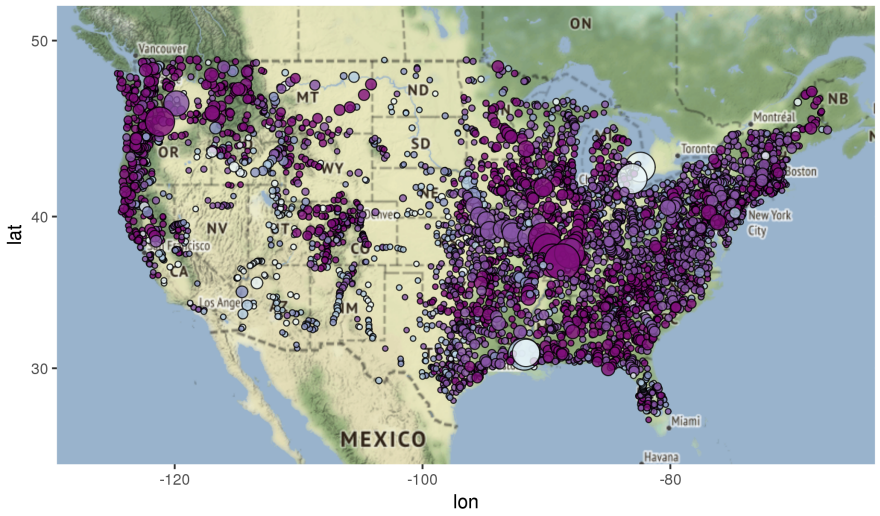
NWMV10_FULLRT_FINAL, 2011-10-01 00:00 to 2016-11-30 23:59



V1.2:

Modeled Streamflow Correlation at USGS Gages

NWMV12_FULLRT_CALIB2, 2011-10-01 00:00 to 2016-11-30 23:59



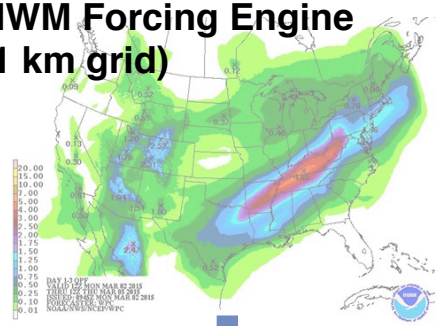
National Water Model
Initial Operating Capability: Model Chain

NWM uses NCAR supported community WRF-Hydro system

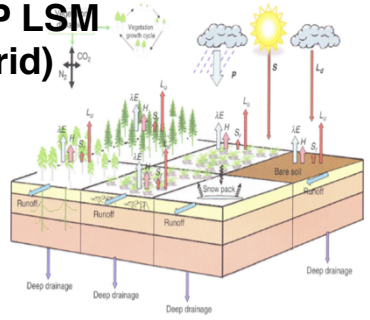
NWM: http://water.noaa.gov/about/nwm

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

1. NWM Forcing Engine (1 km grid)

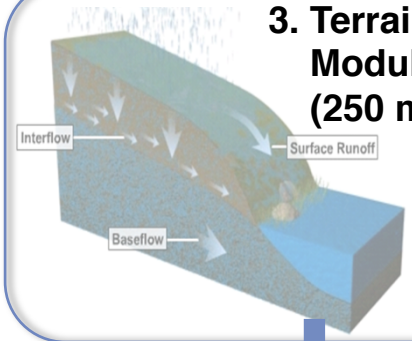


2. NoahMP LSM (1 km grid)

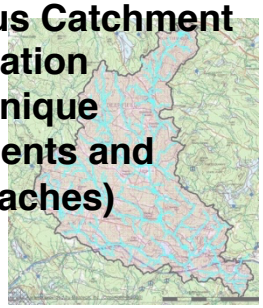


2-way coupling

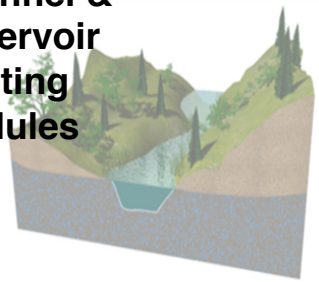
3. Terrain Routing Module (250 m grid)



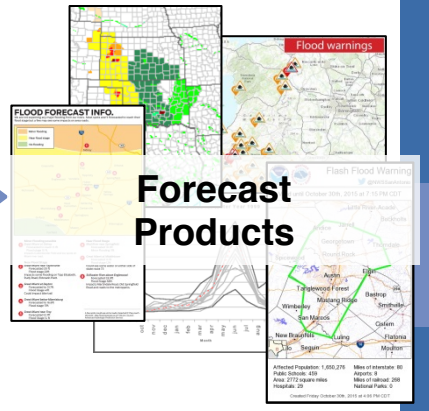
4. NHDPlus Catchment Aggregation (2.6M unique catchments and river reaches)



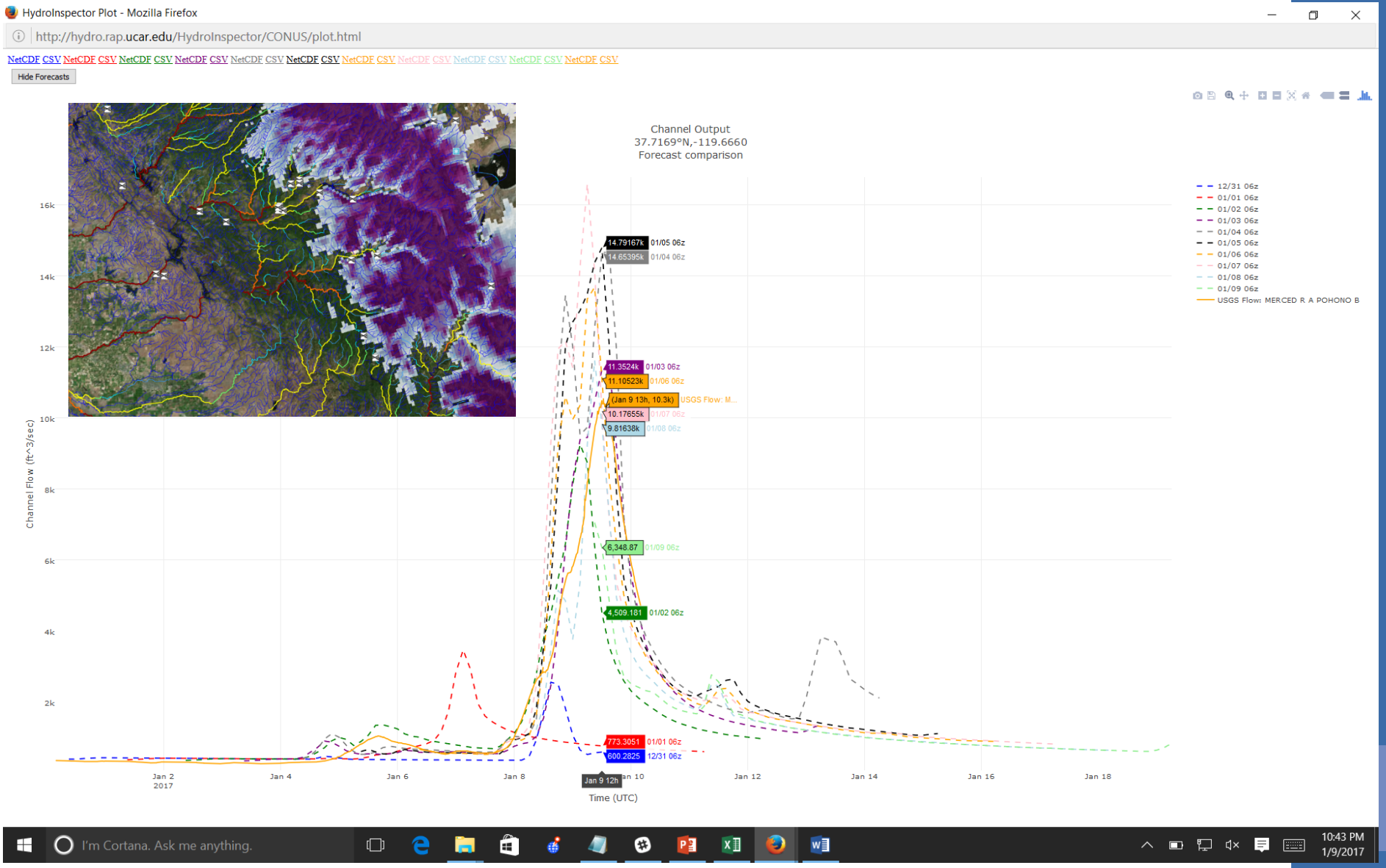
5. Channel & Reservoir Routing Modules



Forecast Products



NWM v1.0 Jan. 3-7 Atmospheric River in California

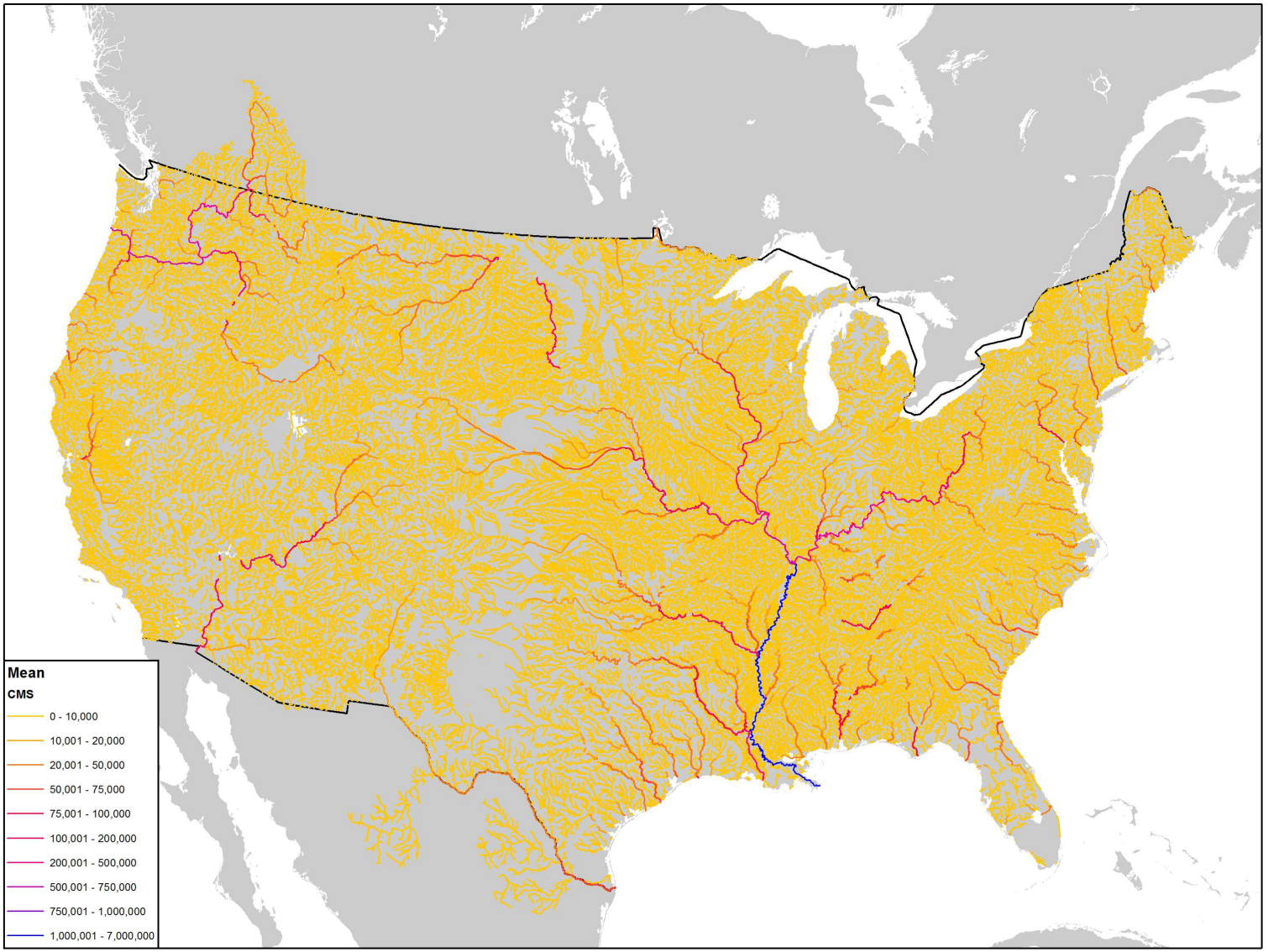


- Merced River streamflow forecasts, with snow depth

NWM v1.0: April 19 Snowmelt forecast

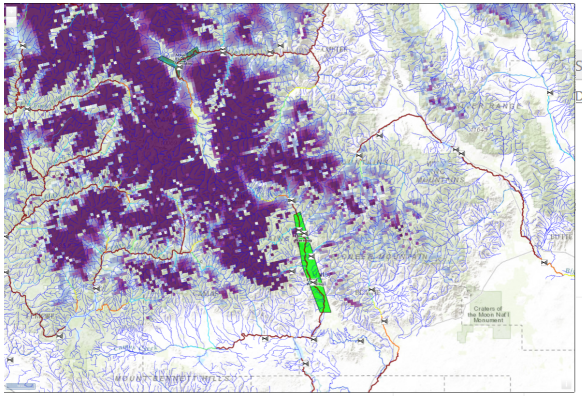
- Animas River at Durango medium range forecast

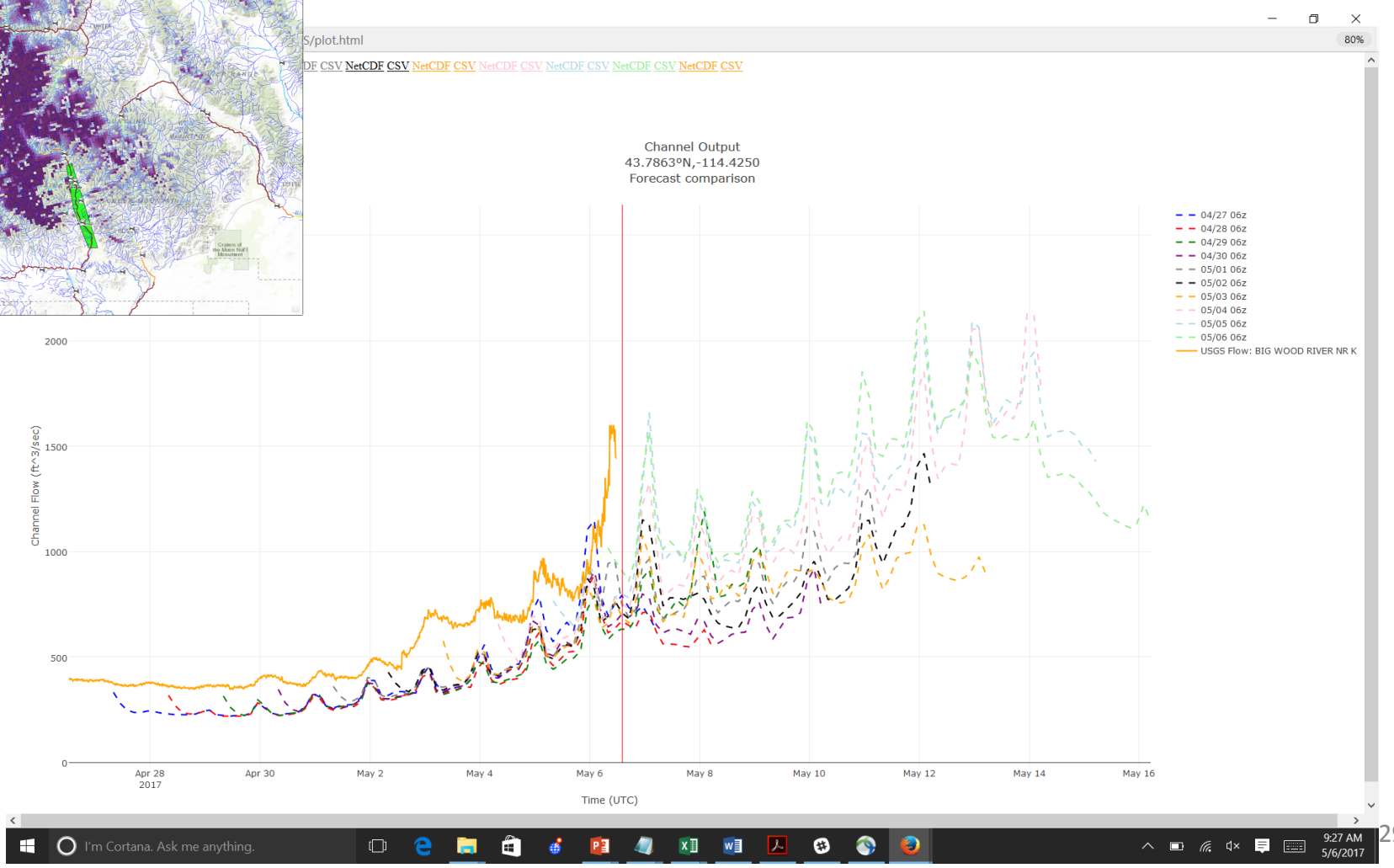
25yr retrospective for statistical post-processing



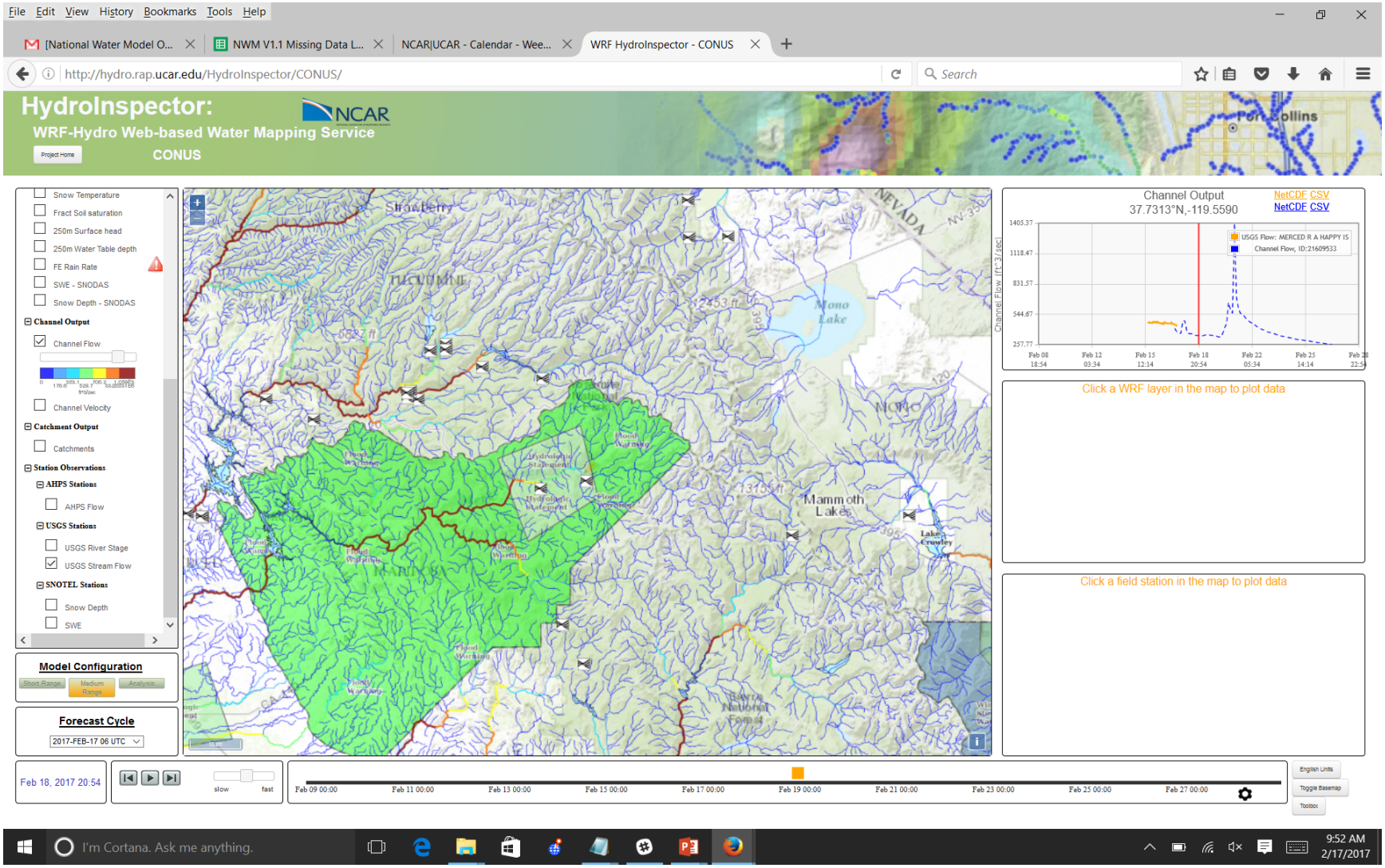
Summary:

- **NWM Medium range streamflow forecast for Big Woods R. at Ketchum**
- **Model flows have low bias but appear well correlated, excessive diurnal cycling**
- **Peak flows forecasted to be above 2,000 cfs in May 12-14 period**



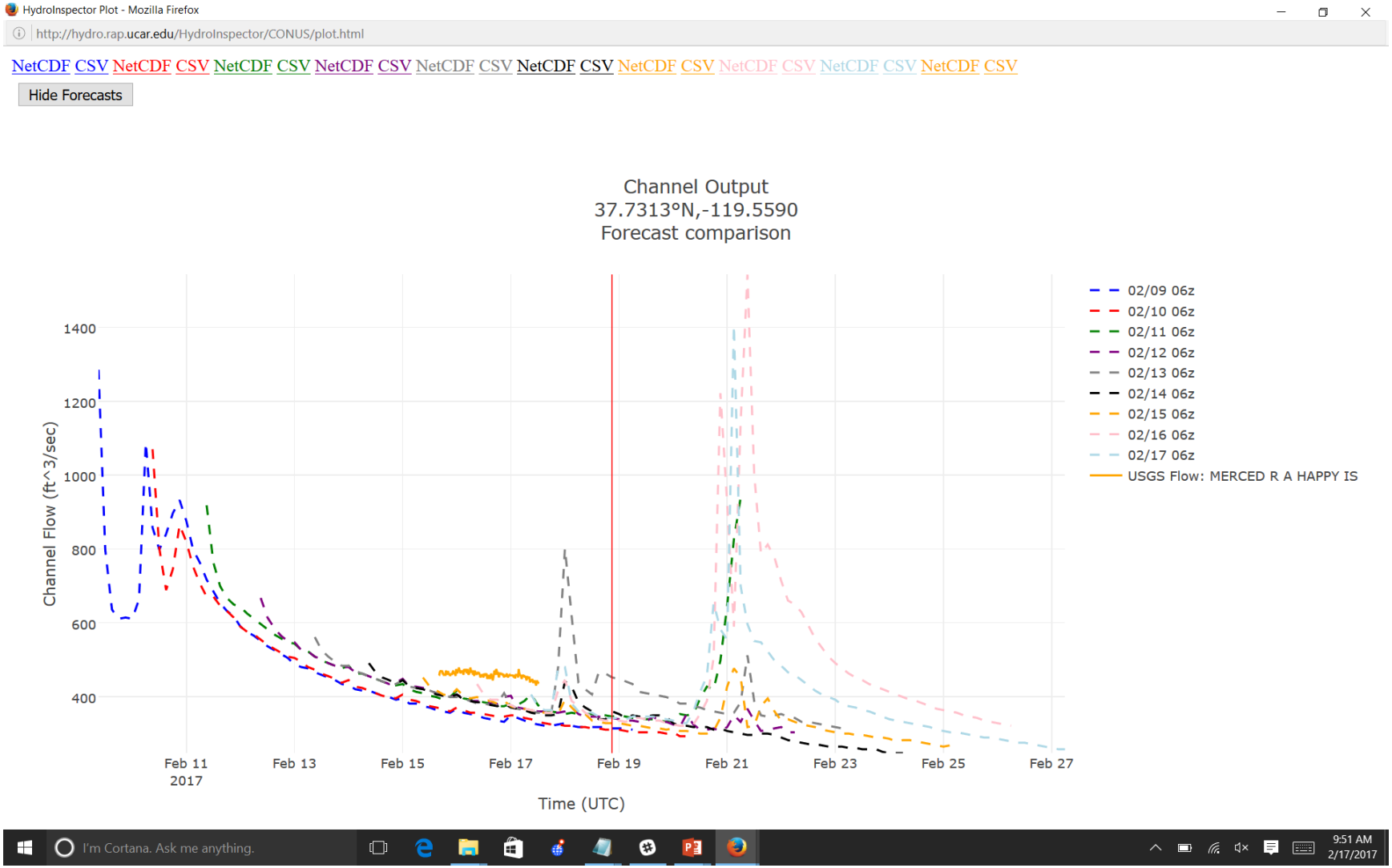


NWM Feb. 9-25 Lake Oroville/Feather R in California



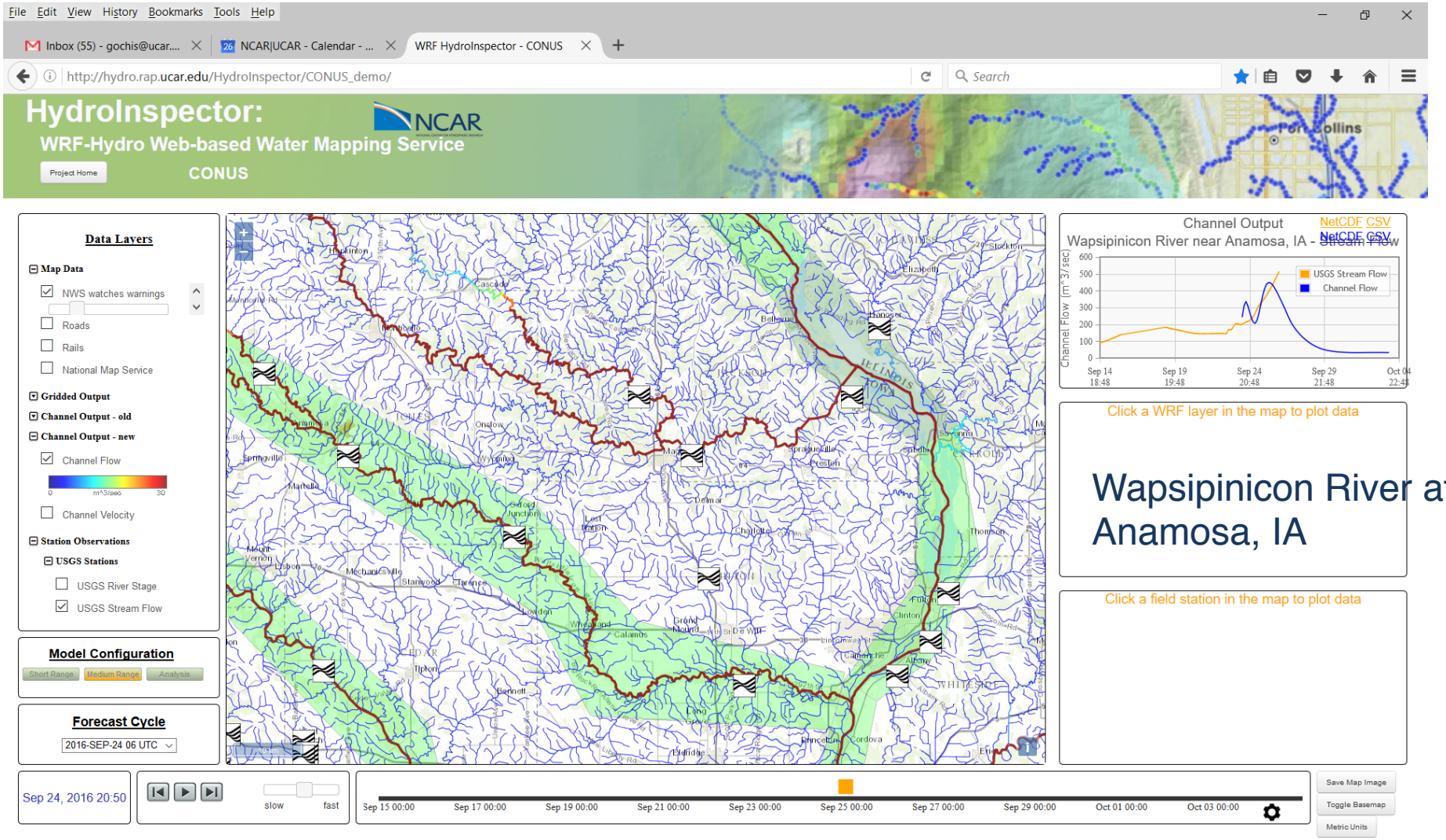
- Feather River, medium range forecast init 16 Feb 06UTC

NWM Feb. 9-25 Lake Oroville/Feather R in California



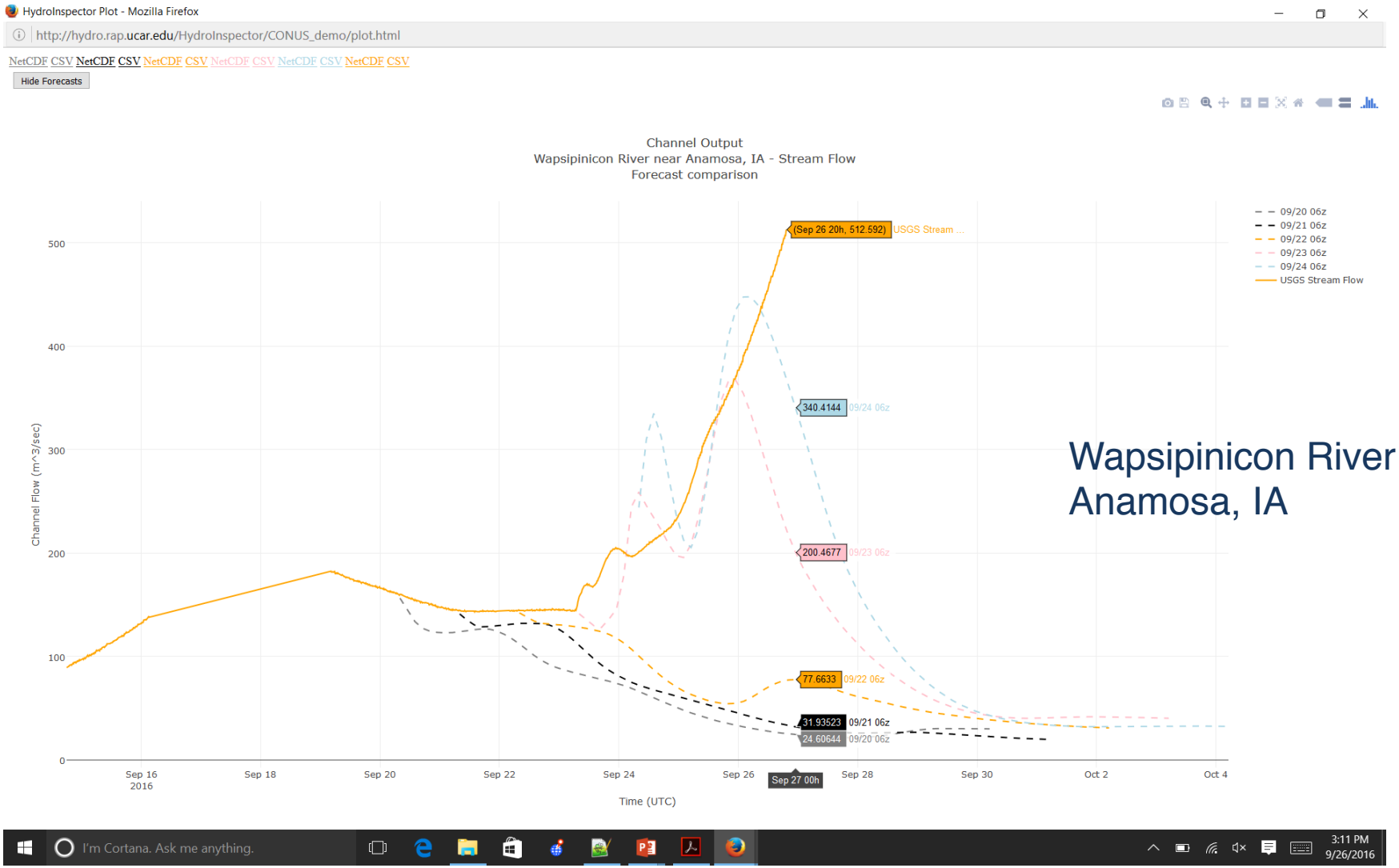
- Feather River, medium range forecast init 16 Feb 06UTC

Additional Visualization Tools: WRF-Hydro 'HydroInspector'



- Sept. 26, 2016 Iowa flooding…

Additional Visualization Tools: WRF-Hydro 'HydroInspector'



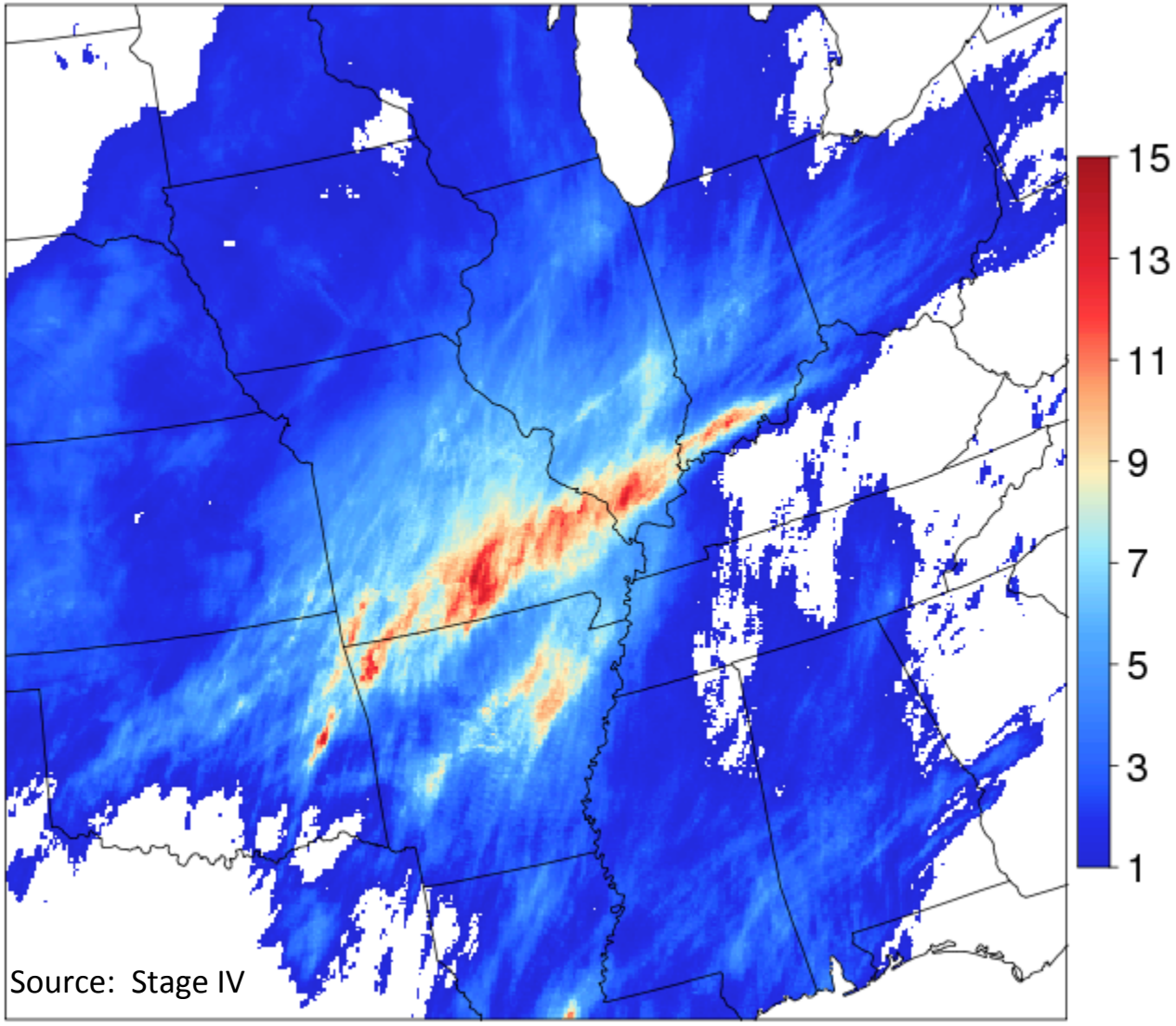
Wapsipinicon River at Anamosa, IA

- Sept. 26, 2016 Iowa flooding…

NWM V1.1 Forecast Assessment: Midwest Flooding April-May 2017

Illustrating the challenges of hydrologic forecasting

Total Rainfall During Flood Period (April 26th-May1st 2017)

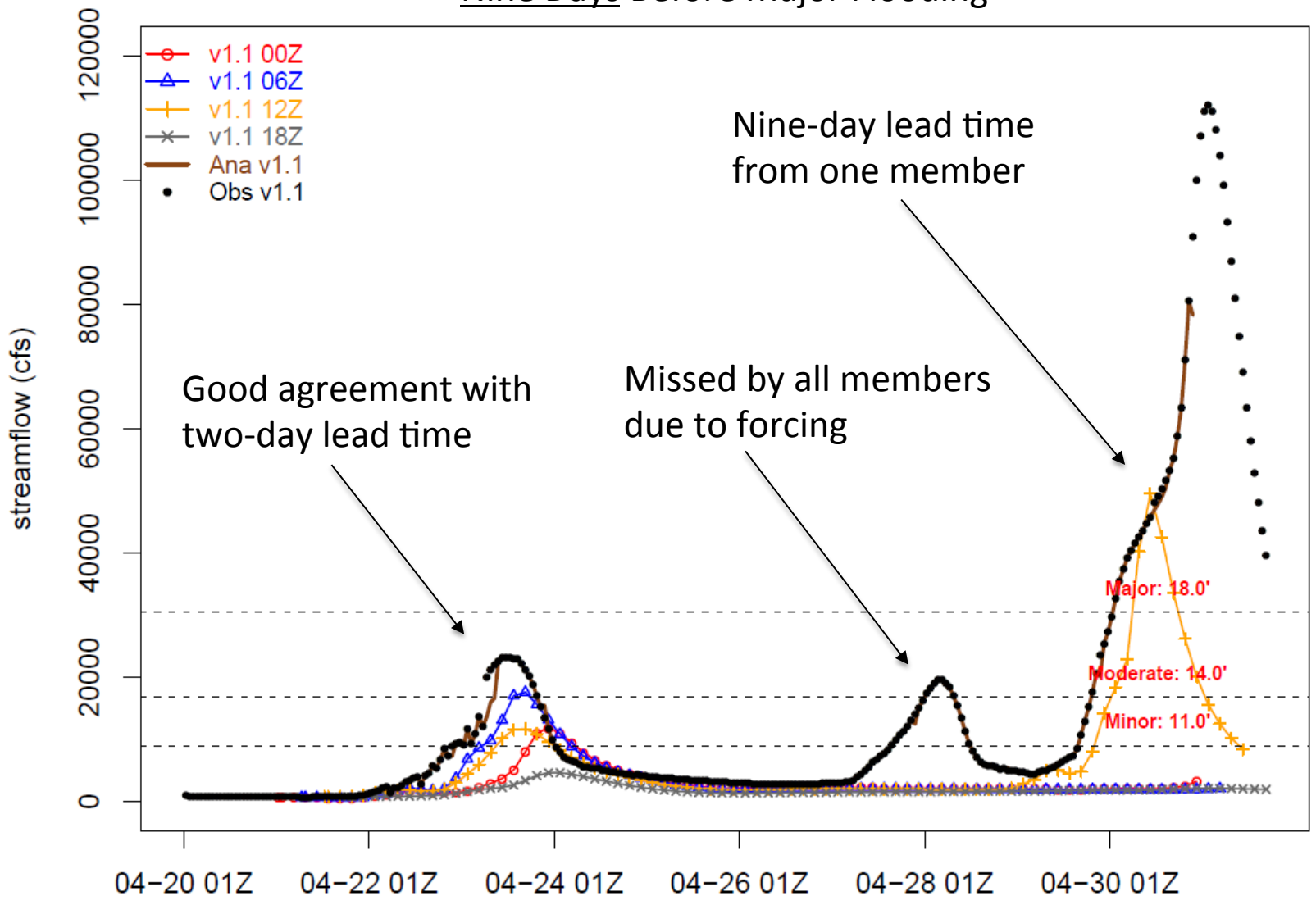


NWM V1.1 Forecast Assessment: Midwest Flooding April-May 2017

Illustrating the challenges of hydrologic forecasting

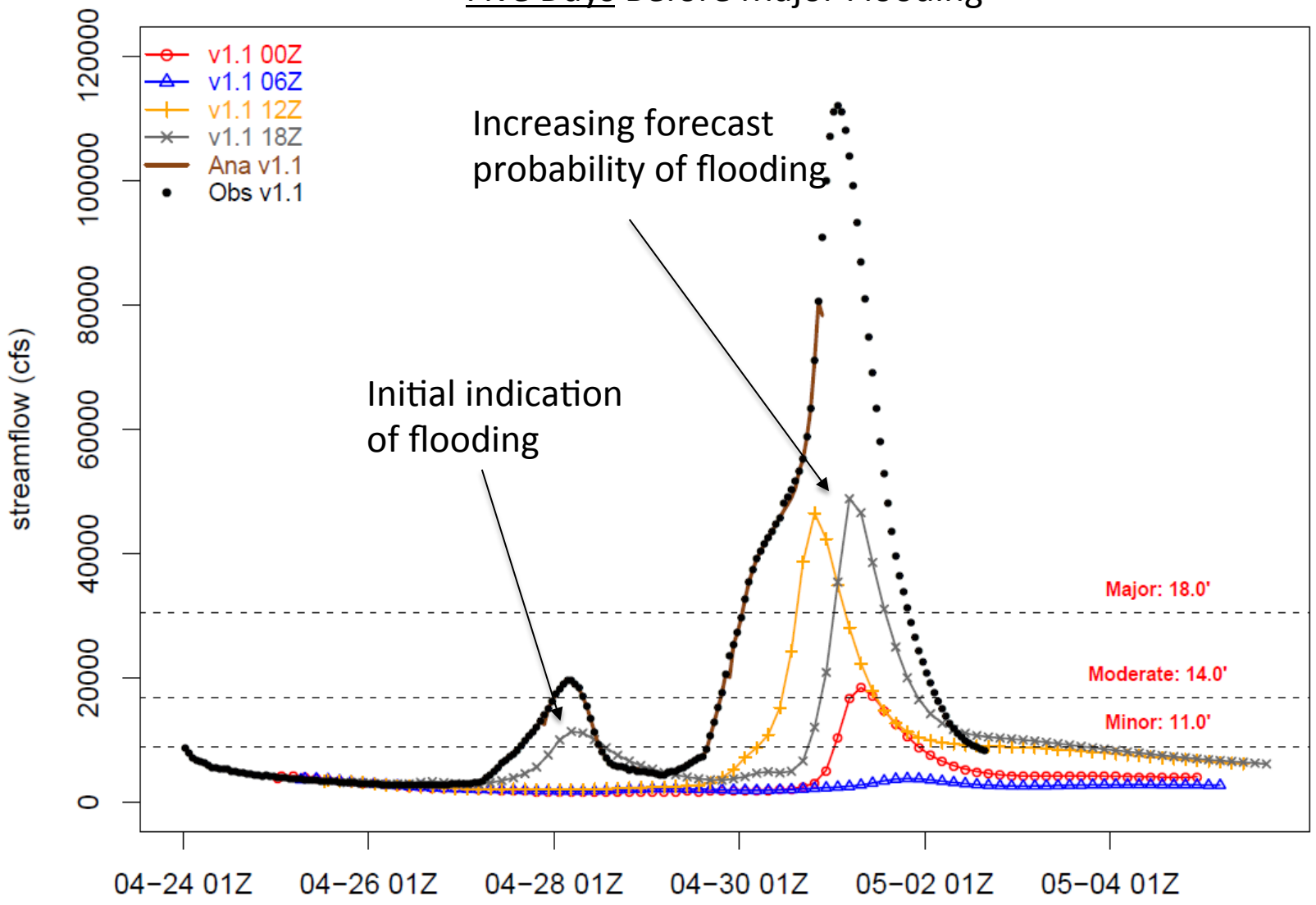
NWM Forecast for Illinois River Near Tahlequah, OK on 4/21/17

Nine Days Before Major Flooding



NWM V1.1 Forecast Assessment: Midwest Flooding April-May 2017

Illustrating the challenges of hydrologic forecasting

NWM Forecast for Illinois River Near Tahlequah, OK on 4/25/17

Five Days Before Major Flooding