Multi-scale hydrologic prediction using the community WRF-Hydro modeling system

NCAR Development Team:

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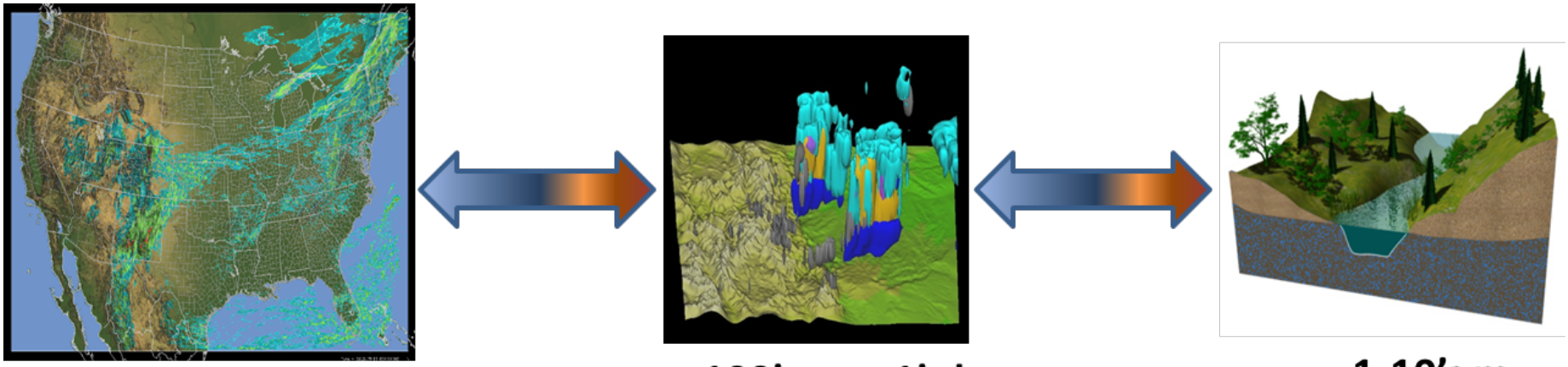
WRF-Hydro System Description

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



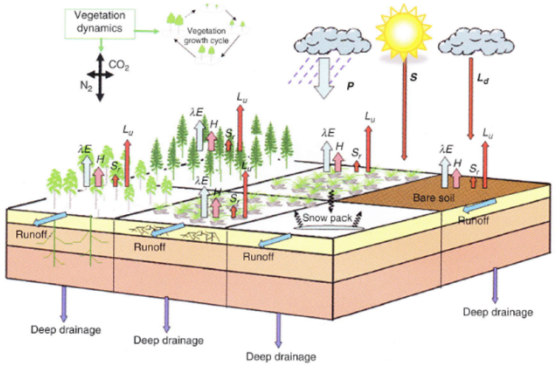
1-10's km

100's m - 1's km

1-10's m

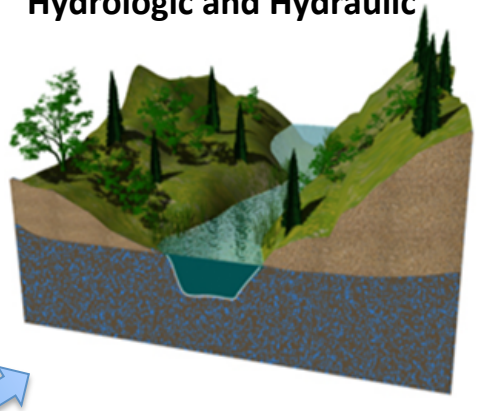
WRF-HYDRO SYSTEM DESCRIPTION

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

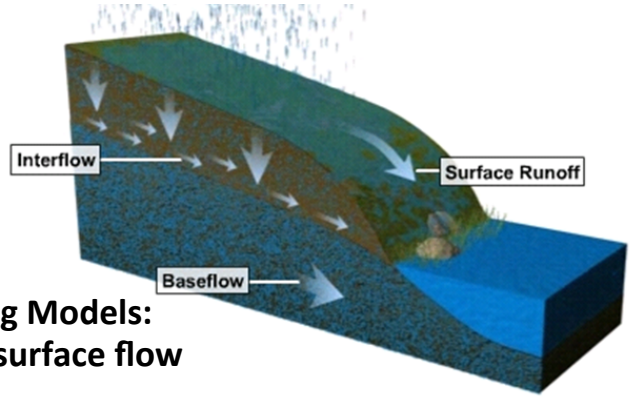


Output Variables:
Evapotranspiration
Soil moisture/Soil Ice
Snowpack/snowmelt
Runoff
Radiation Exchange
Energy Fluxes
Plant Water Stress

Channel & Reservoir Routing Models:
Hydrologic and Hydraulic



2-way coupling

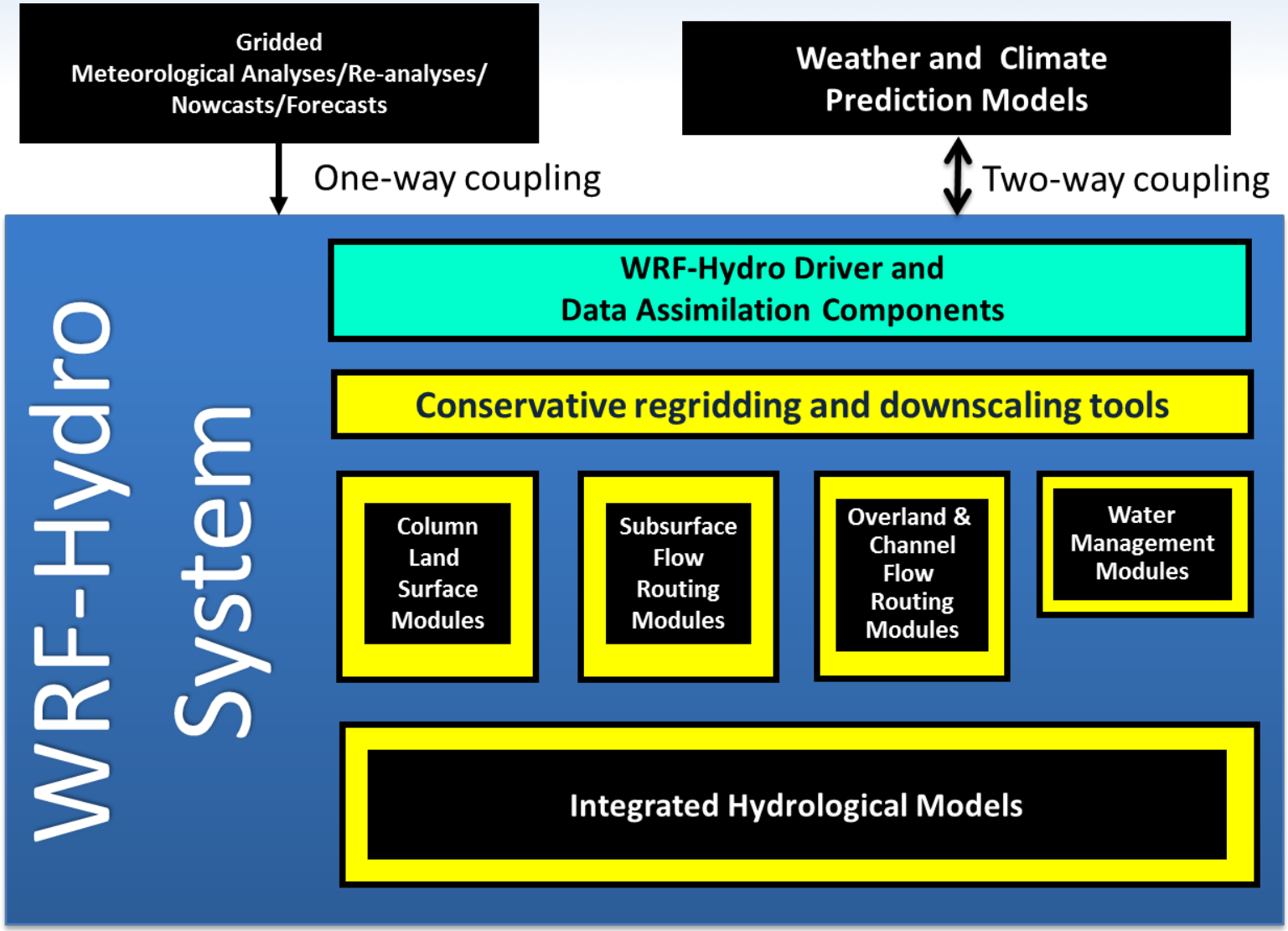


1-way coupling or 2-way coupling

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

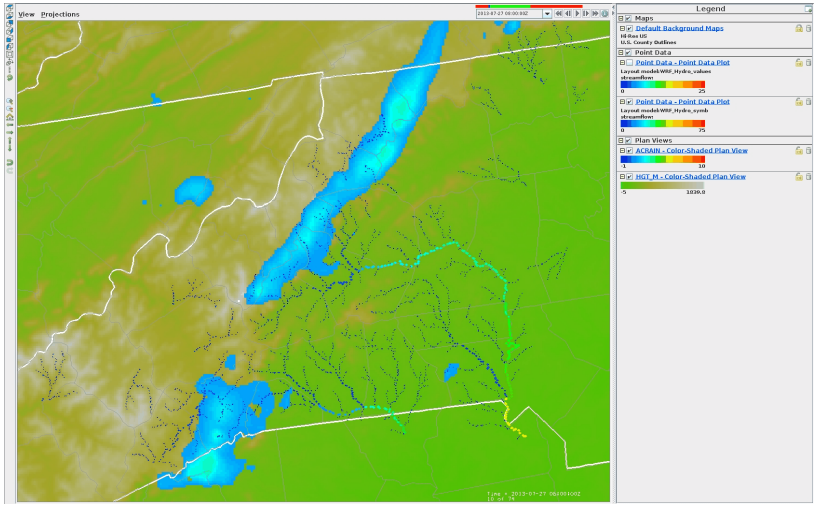
Terrain Routing Models:
Overland, subsurface flow

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


Gridded
Meteorological Analyses/Re-analyses/
Nowcasts/Forecasts
Weather and Climate
Prediction Models
One-way coupling
Two-way coupling
WRF-Hydro
System
WRF-Hydro Driver and
Data Assimilation Components
Conservative regridding and downscaling tools
Column
Land
Surface
Modules
Subsurface
Flow
Routing
Modules
Overland &
Channel
Flow
Routing
Modules
Water
Management
Modules
Integrated Hydrological Models

WRF-Hydro Process Permutations and System Features

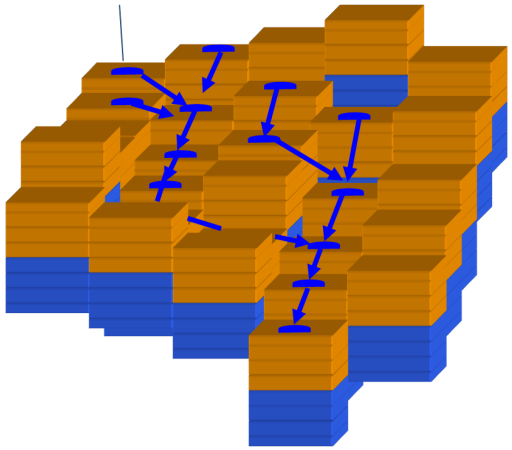
- ~180 possible 'physics' component configurations for streamflow prediction:
  - 3 up-to-date column physics land models (Noah, NoahMP, CLM)
  - 3 overland flow schemes (diffusive wave, kinematic wave, direct basin aggregation)
  - 4 lateral/baseflow groundwater schemes (Boussinesq shallow-saturated flow, 2d aquifer model, direct aggregation storage-release: pass-through or exponential model)
  - 5 channel flow schemes: diffusive wave, kinematic wave, RAPID-Muskingum for NHDPlus, custom network Muskingum/ Muskingum Cunge
- Simple level-pool reservoir with management
- Data assimilation: ensemble (DART) and nudging



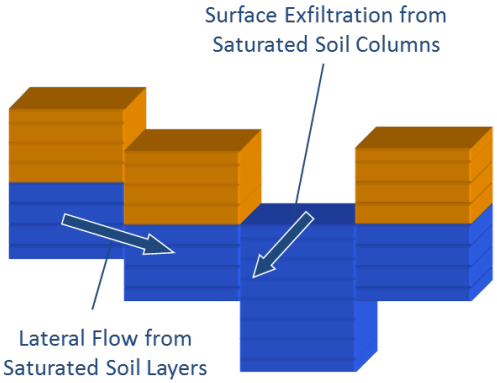
Ensemble Flood Forecasting in the Southeast U.S. with WRF-Hydro
***2014 WRF User's Workshop*, K. Mahoney (NOAA-ESRL)**

WRF-Hydro v2.2 Physics Components

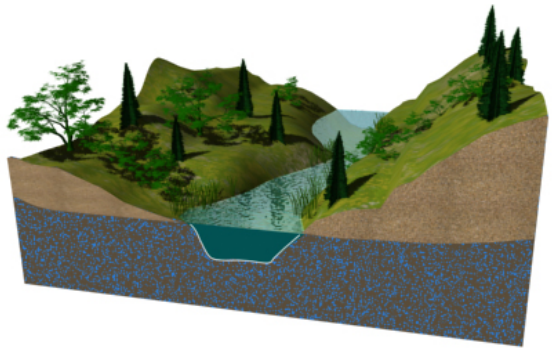
Physics-based runoff processes:



Overland Flow -
Diffusive wave
Kinematic wave
Catchment aggregation



Groundwater Flow –
Boussinesq flow
Catchment aggregation

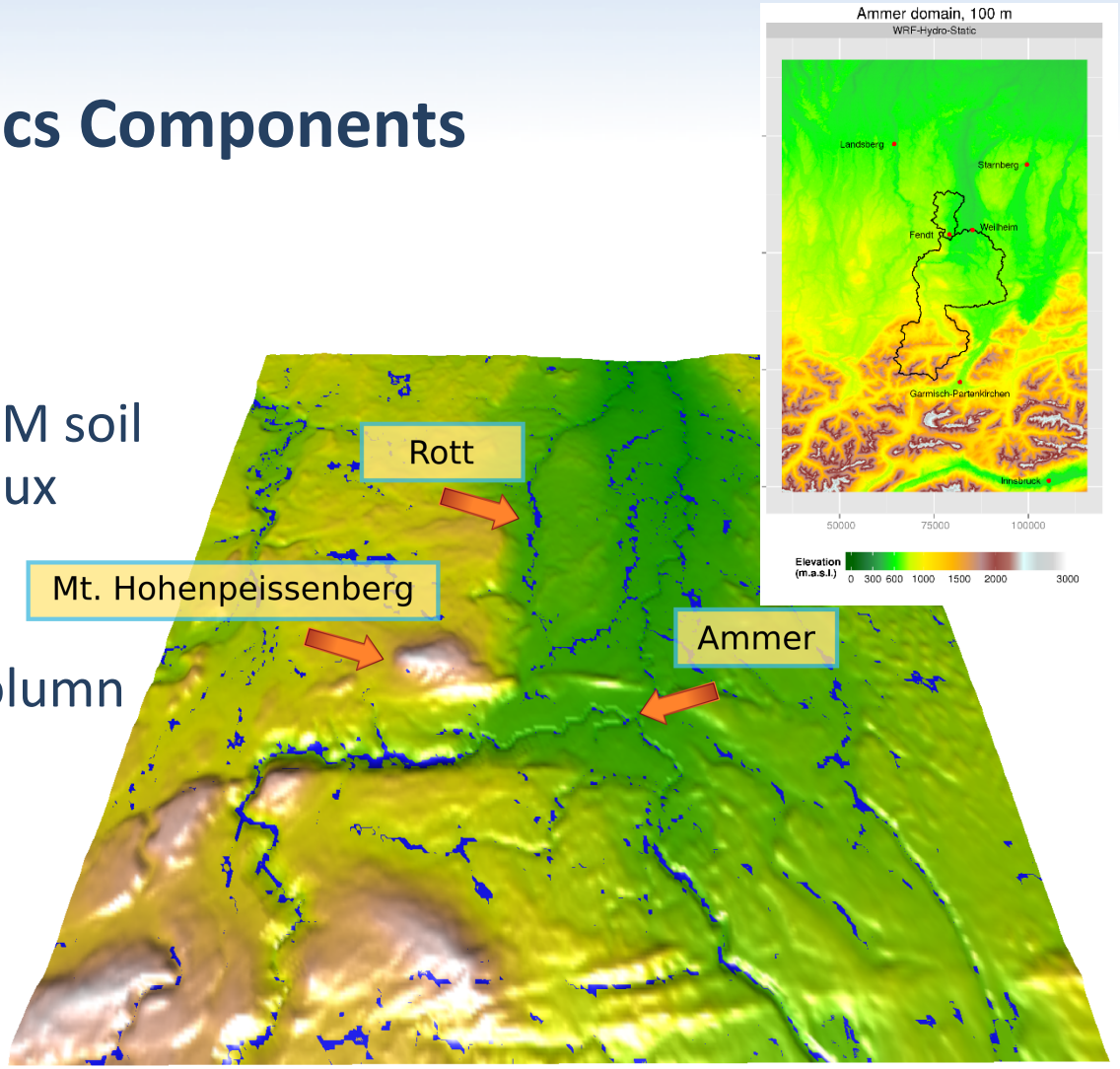


Channel Flow –
Diffusive wave
Kinematic wave
Reach-based Muskingum and Muskingum-Cunge

WRF-Hydro v2.2 Physics Components

Subsurface routing:

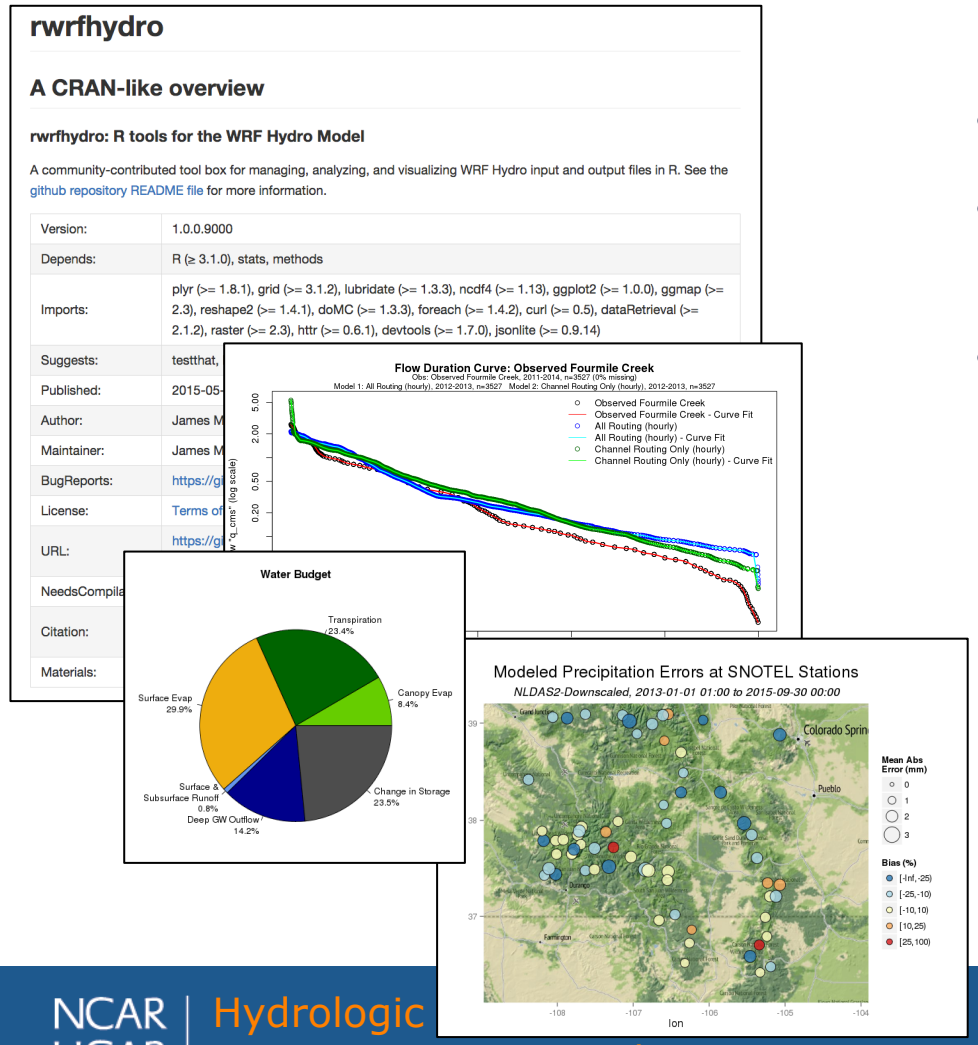
- 2d groundwater model
- Coupled to bottom of LSM soil column through Darcy-flux parameterization
- Independent hydraulic characteristics vs. soil column
- Full coupling to gridded channel model through assumed channel depth and channel head
- Detailed representation of wetlands



Surface ponded water from coupled groundwater in WRF-Hydro
B. Fersch, KIT, Germany

Rwrfhydro: R package for WRF-Hydro Model Evaluation

https://github.com/mccreigh/rwrfhydro

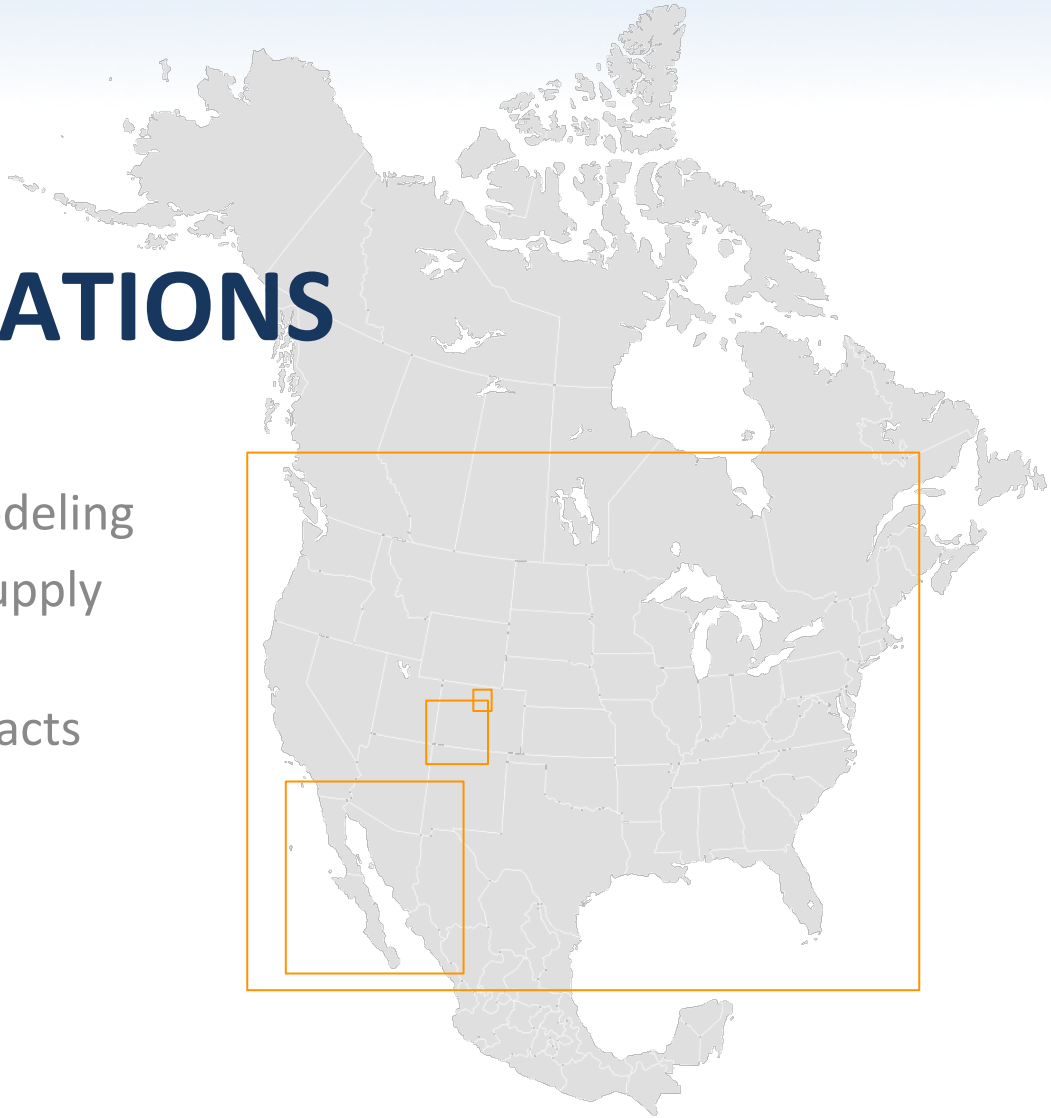


- Set of R tools to support WRF-Hydro pre- and post-processing
- Open source, community tool
- Full documentation and training vignettes
- Major Features:
  - Domain visualization
  - Remote sensing & geospatial data prep
  - Output post-processing
  - Observation data acquisition and processing
  - Model output evaluation and visualization

Current WRF-Hydro Applications around the world:

1. Operational Streamflow Forecasting:
   - U.S. National Weather Service, National Water Center
   - Israeli Hydrological Service
   - State of Colorado-Upper Rio Grande River Basin (CWCB, NSSL)
   - NCAR-STEP Hydrometeorological Prediction Group
   - U. of Calabria reservoir inflow forecasting
2. Streamflow prediction research (U. Ankara, Arizona State U., Karlsruhe Inst. Tech.)
3. Diagnosing climate change impacts on water resources
   - Himalayan Mountain Front (Bjerknes Inst.)
   - Colorado Headwaters (U. Colorado)
   - Bureau of Reclamation Dam Safety Group (USBR,NOAA/CIRES)
4. Diagnosing land-atmosphere coupling behavior in mountain-front regions of the U.S. and Mexico (Arizona State U., U. Arizona)
5. Diagnosing the impacts of disturbed landscapes on coupled hydrometeorlogical predictions
   - Western U.S. Fires (USGS)
   - West African Monsoon (Karlsruhe Inst. Tech)
   - S. America Paraná river (U. Arizona)
   - Texas Dust Emissions (Texas A&M U.)
   - Landslide Hazard Modeling (USGS)

EXAMPLE APPLICATIONS



Boulder, Colorado - 2013 Flood Modeling

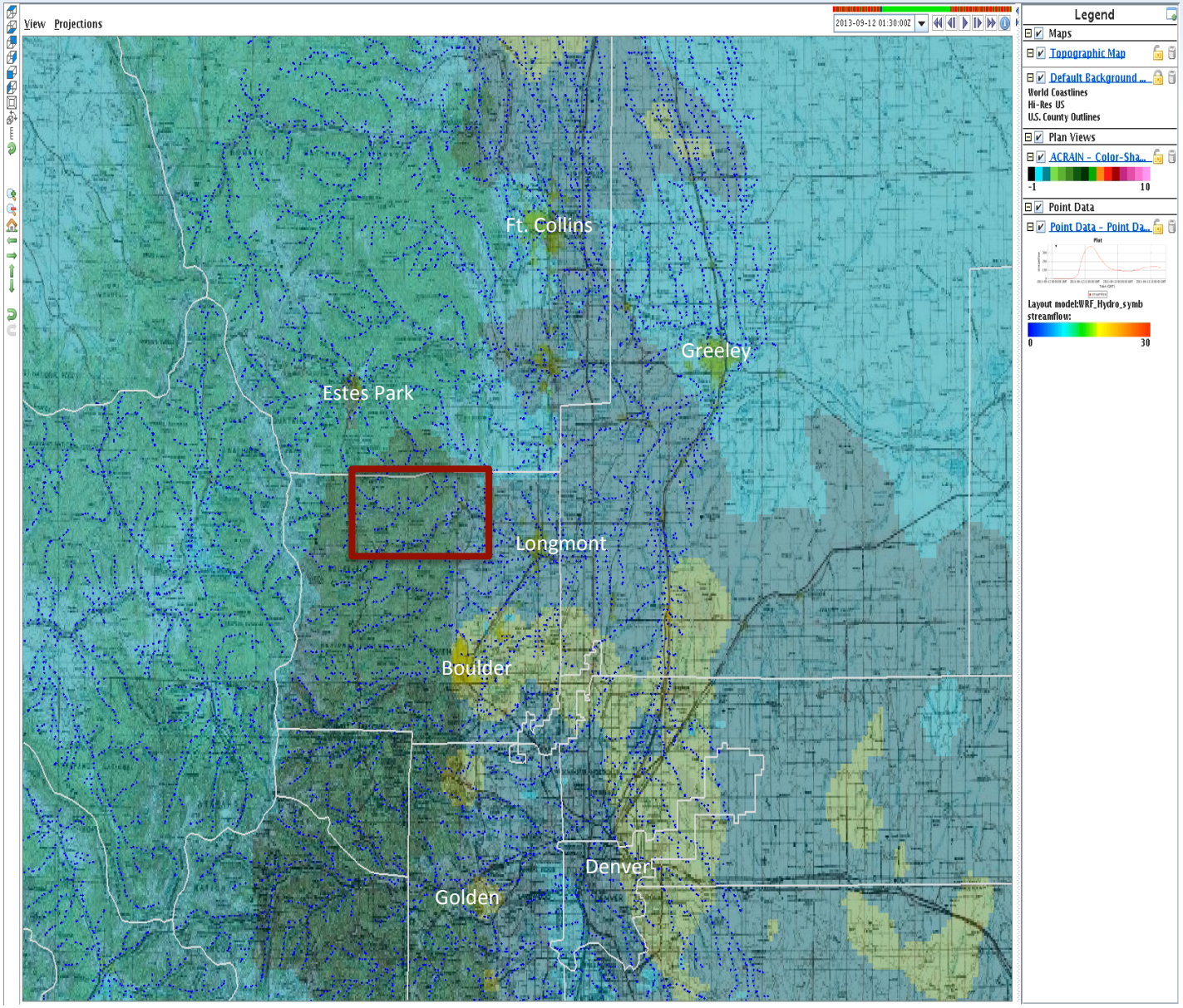
Upper Rio Grande Basin – Water Supply Forecasting

Baja, Mexico - Hurricane Odile Impacts

CONUS – Streamflow Prediction

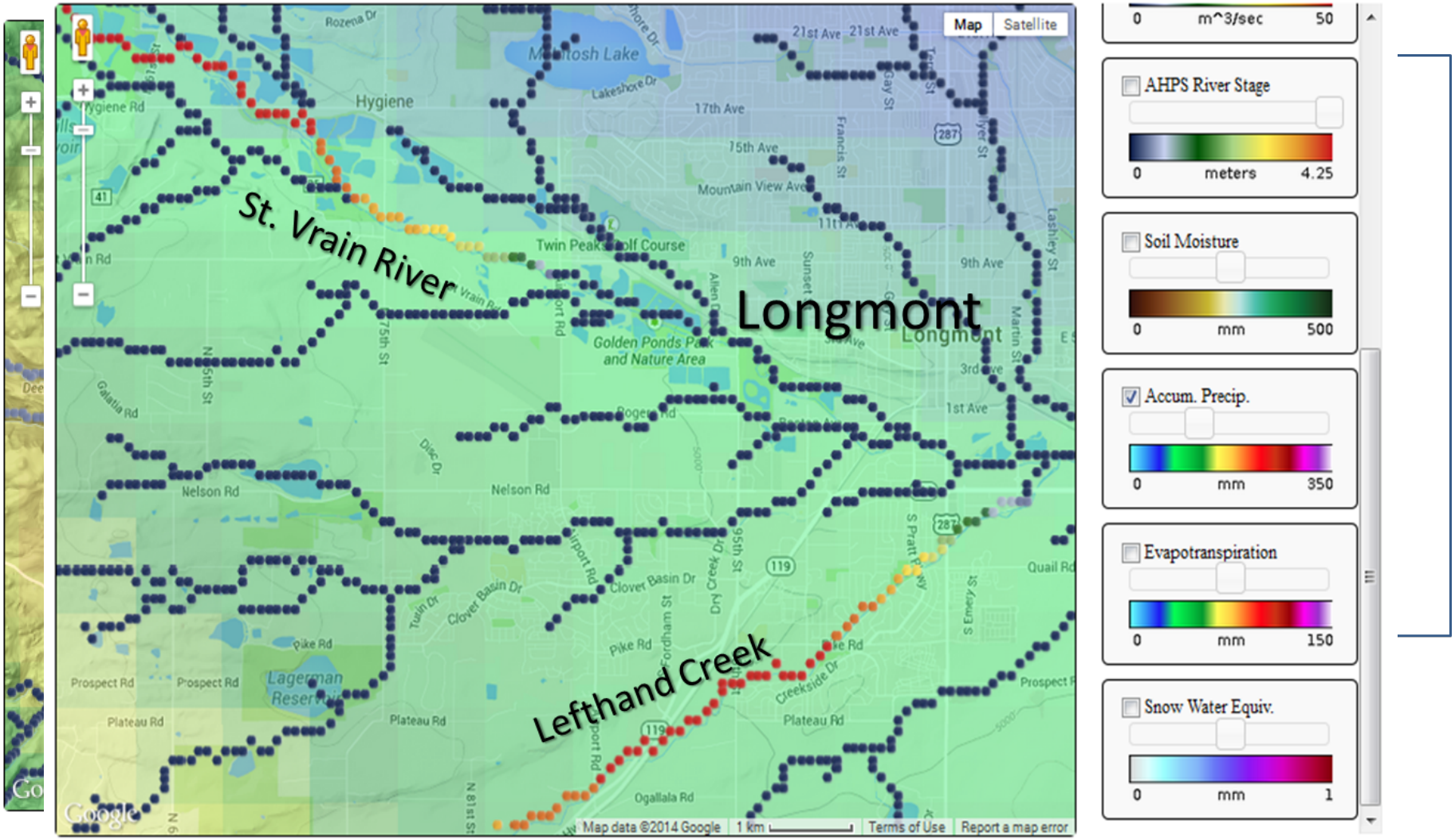
Modeling the Sept. 2013 Floods:

WRF-Hydro simulated streamflow using NOAA radar-gauge observed rainfall



Streamflow in cms

Getting to Street Level Impacts



Rio Grande Basin: Water Supply Forecasting

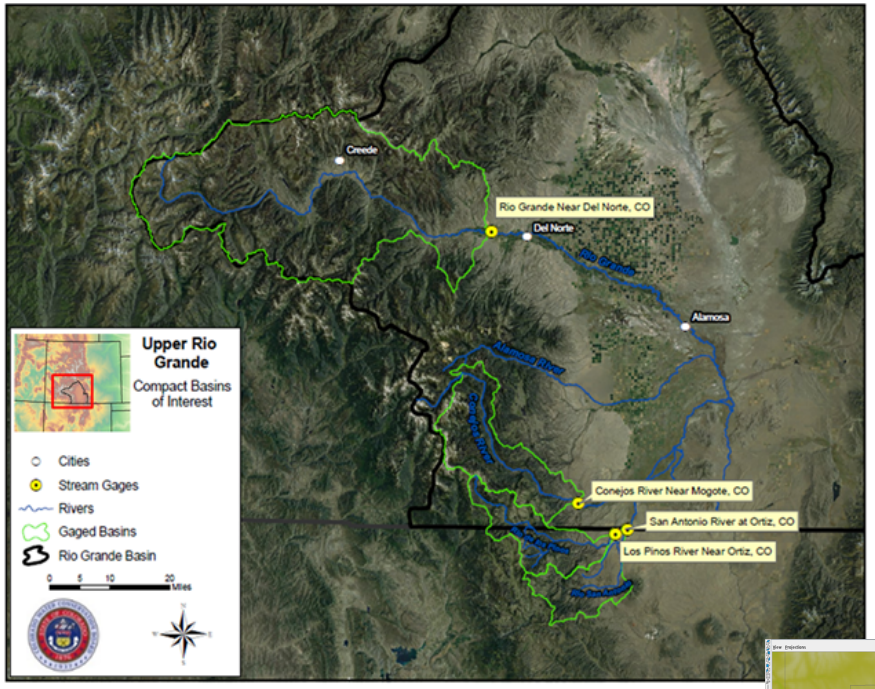
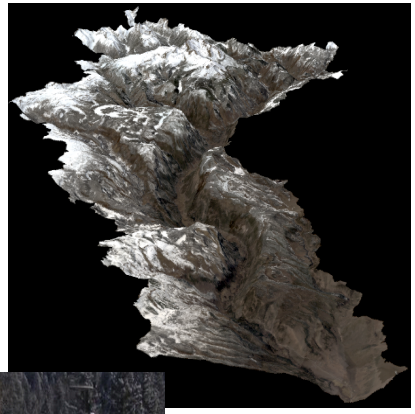


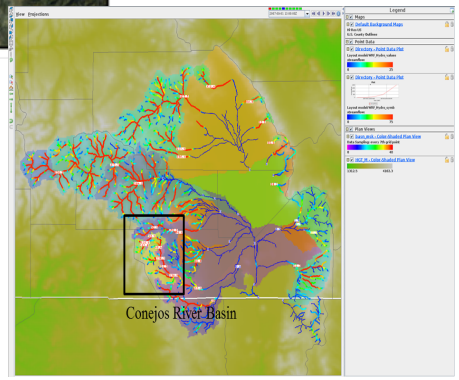
Figure 1. Colorado-New Mexico Water compact basins of the Upper Rio Grande River basin

NSSL NOXP Experimental Radar

Conejos Basin ASO-SWE

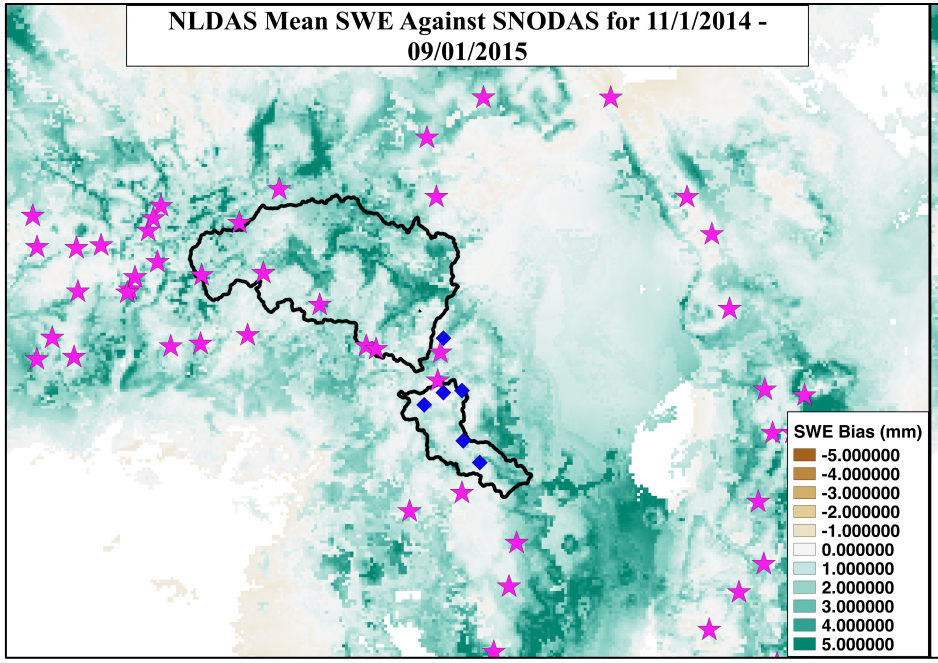


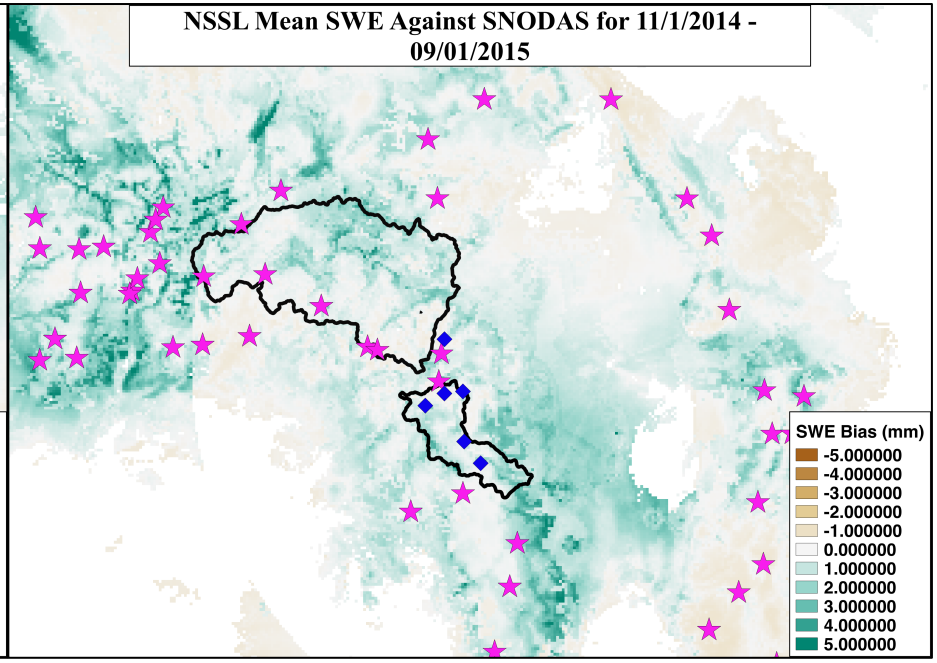
WRF-Hydro Model Domain

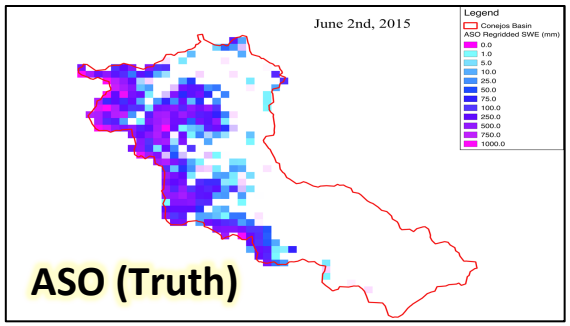


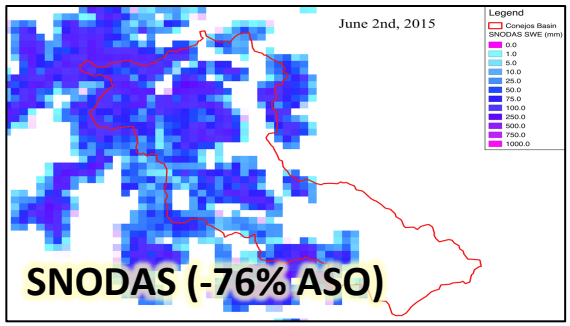
In-situ Stations

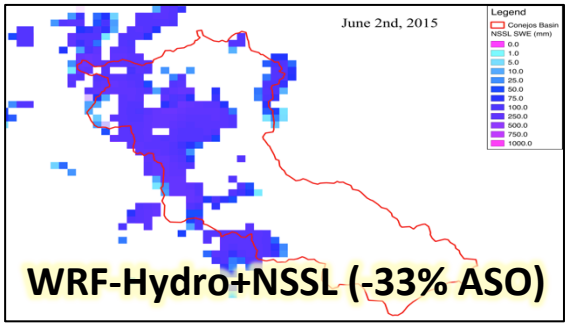
Rio Grande Basin: Model Simulated Snow Water Equivalent



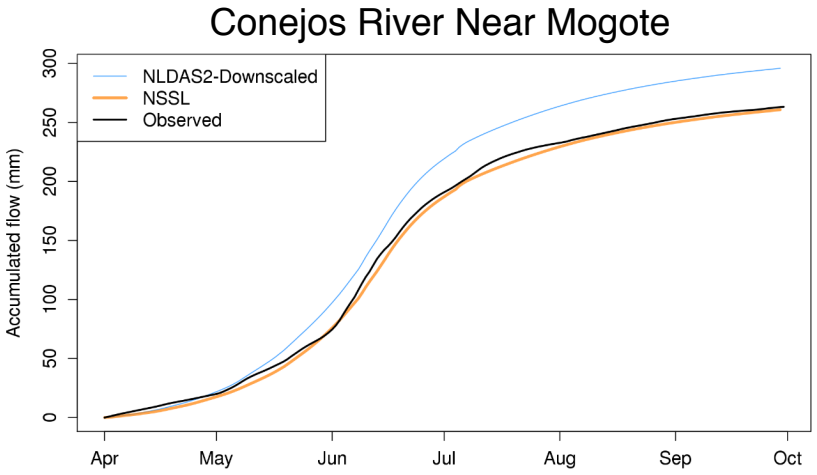


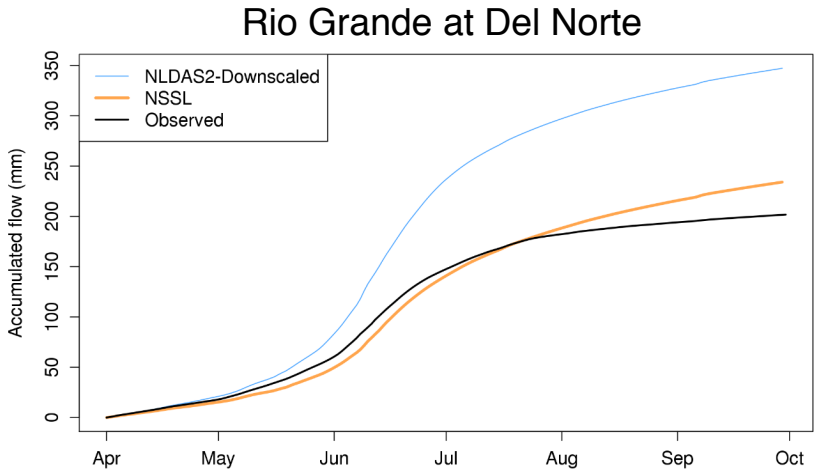


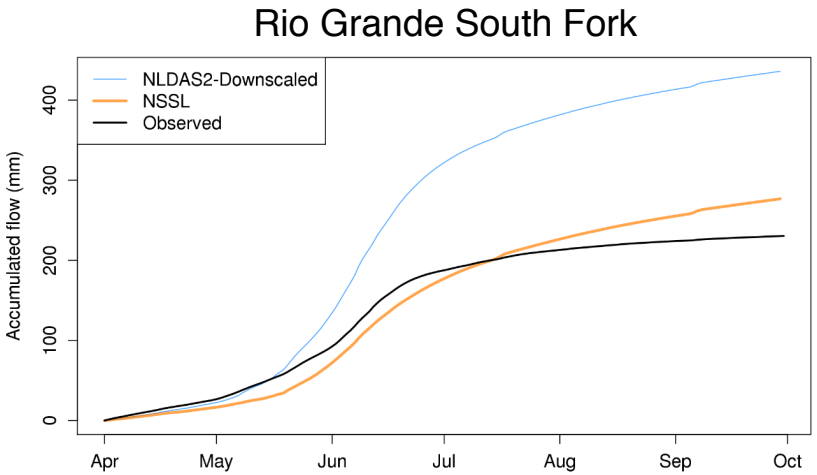


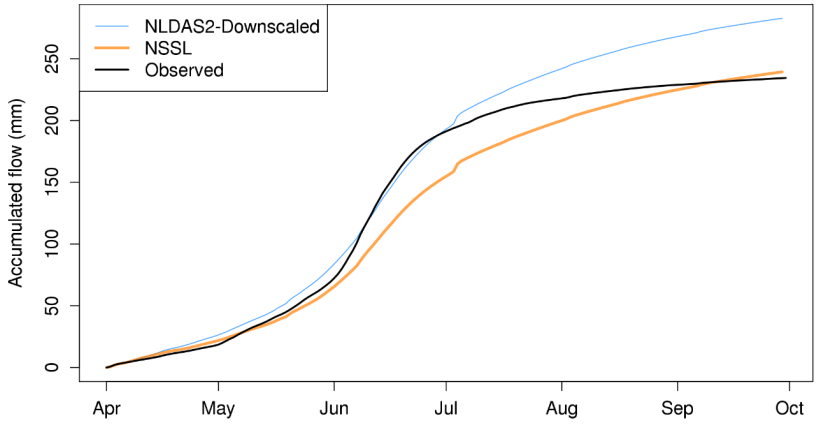


Rio Grande Basin: Model Simulated Accumulated Streamflow



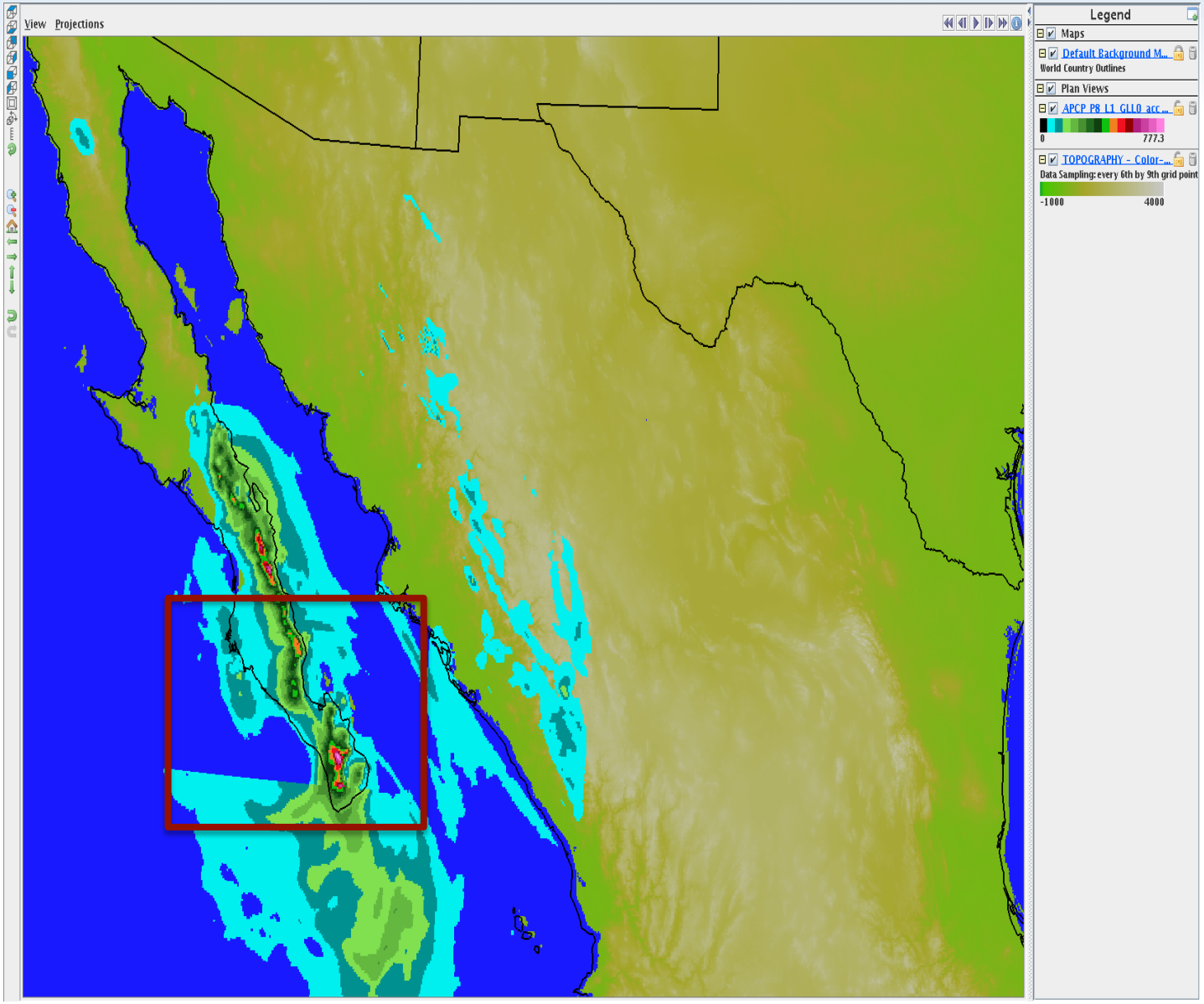






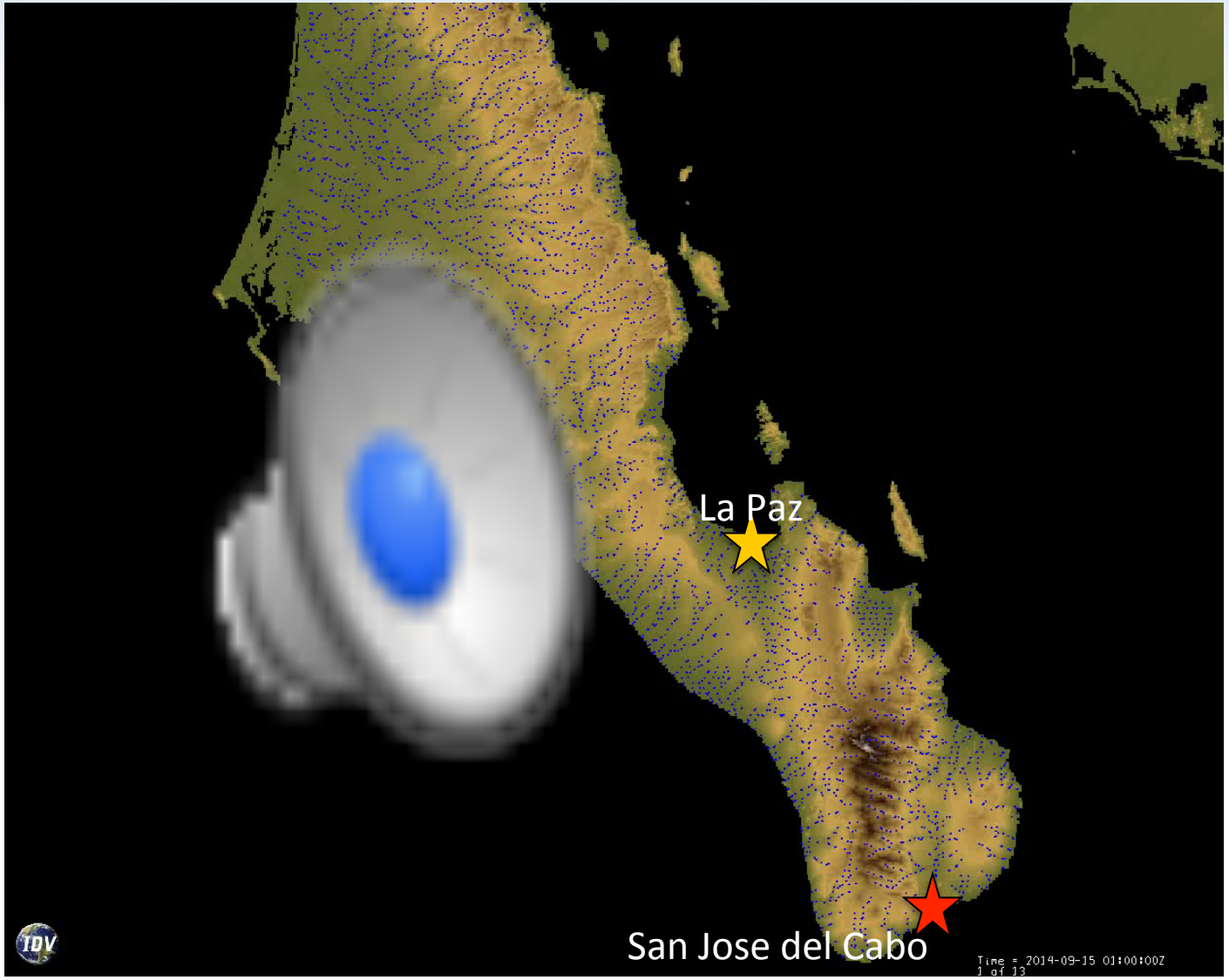
Hydrologic impacts of hurricane landfall

HWRF/WRF-Hydro



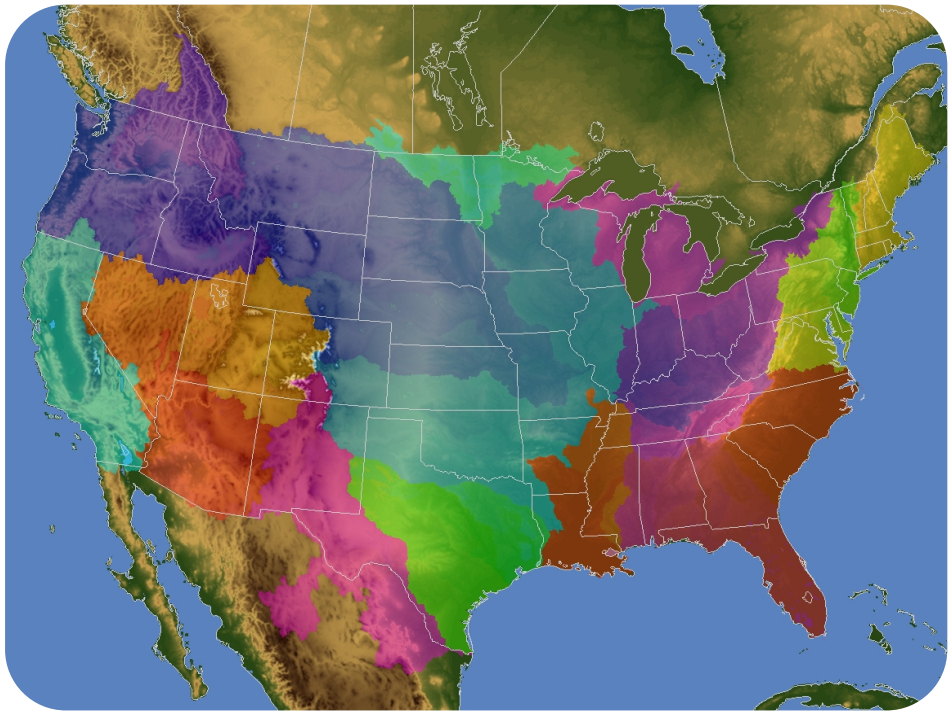
Hydrologic impacts of hurricane landfall

HWRF/WRF-Hydro



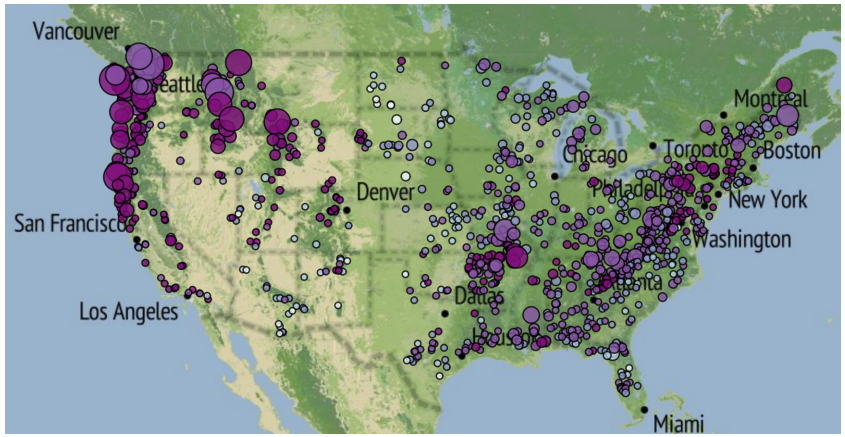
National Water Modeling Initial Operating Capability (IOC):

- Operational forecast streamflow guidance for currently underserved locations
  - ~ 4,000 ➔ 2.7 million river reaches
- Spatially continuous estimates of hydrologic states for the nation through enhanced physical accounting of major water cycle components
  - snowpack, soil moisture, ET, channel flow, flood inundation

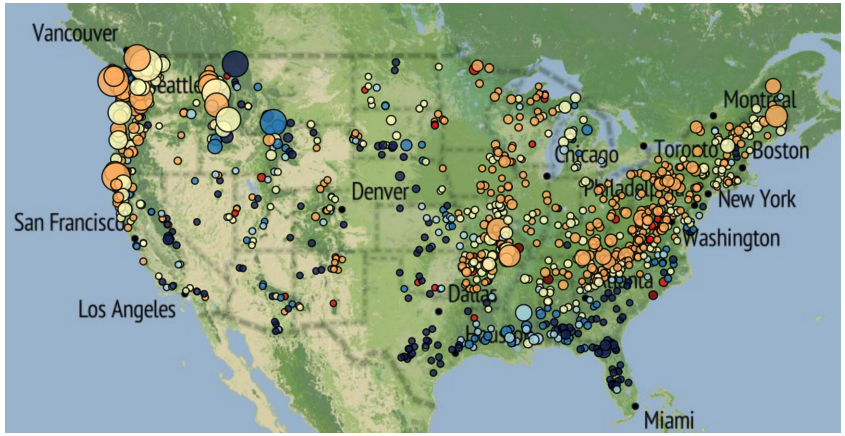


IOC Model Benchmark Evaluation: Streamflow

Correlation:



Bias:



Mean Flowrate (cms)

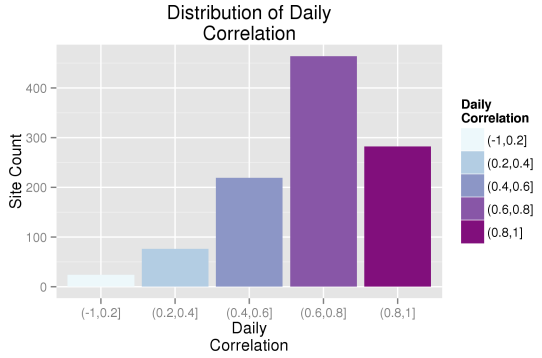
- 0
- 50
- 100
- 150
- 200

Daily Correlation

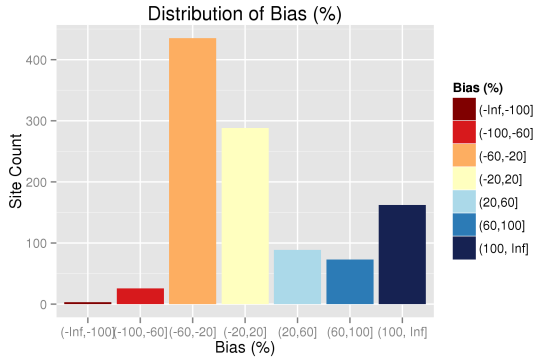
- (-1,0.2]
- (0.2,0.4]
- (0.4,0.6]
- (0.6,0.8]
- (0.8,1]

Bias (%)

- (-Inf,-100]
- (-100,-60]
- (-60,-20]
- (-20,20]
- (20,60]
- (60,100]
- (100, Inf]

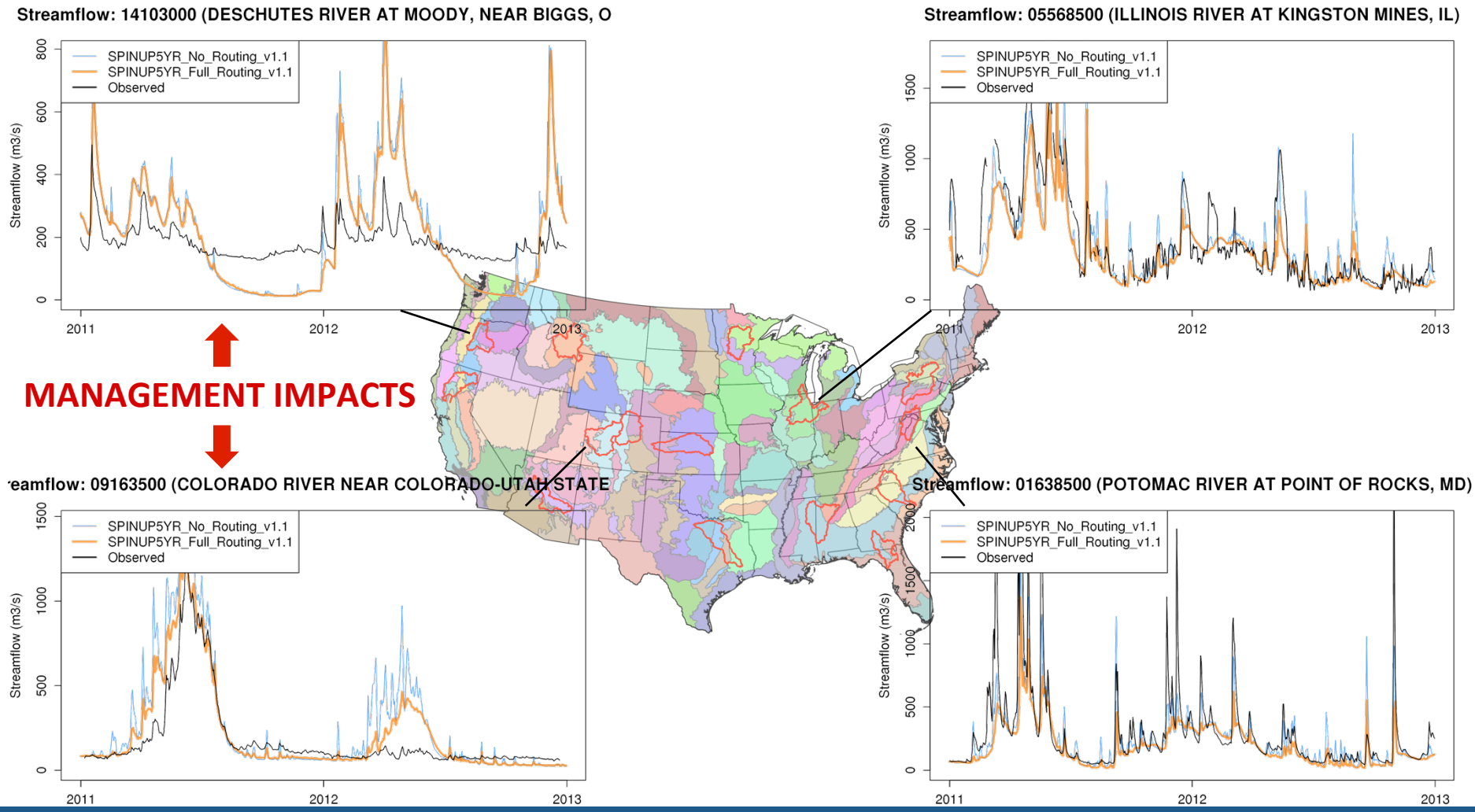


71% of basins had correlation > 0.6



27% of basins had bias < 20%

IOC Model Benchmark Evaluation: Big Rivers



Data Assimilation with WRF-Hydro

1. HydroDART: ensemble DA

2. Nudging: operational streamflow forecasting

"HydroDART" =

WRF-Hydro
(offline)

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

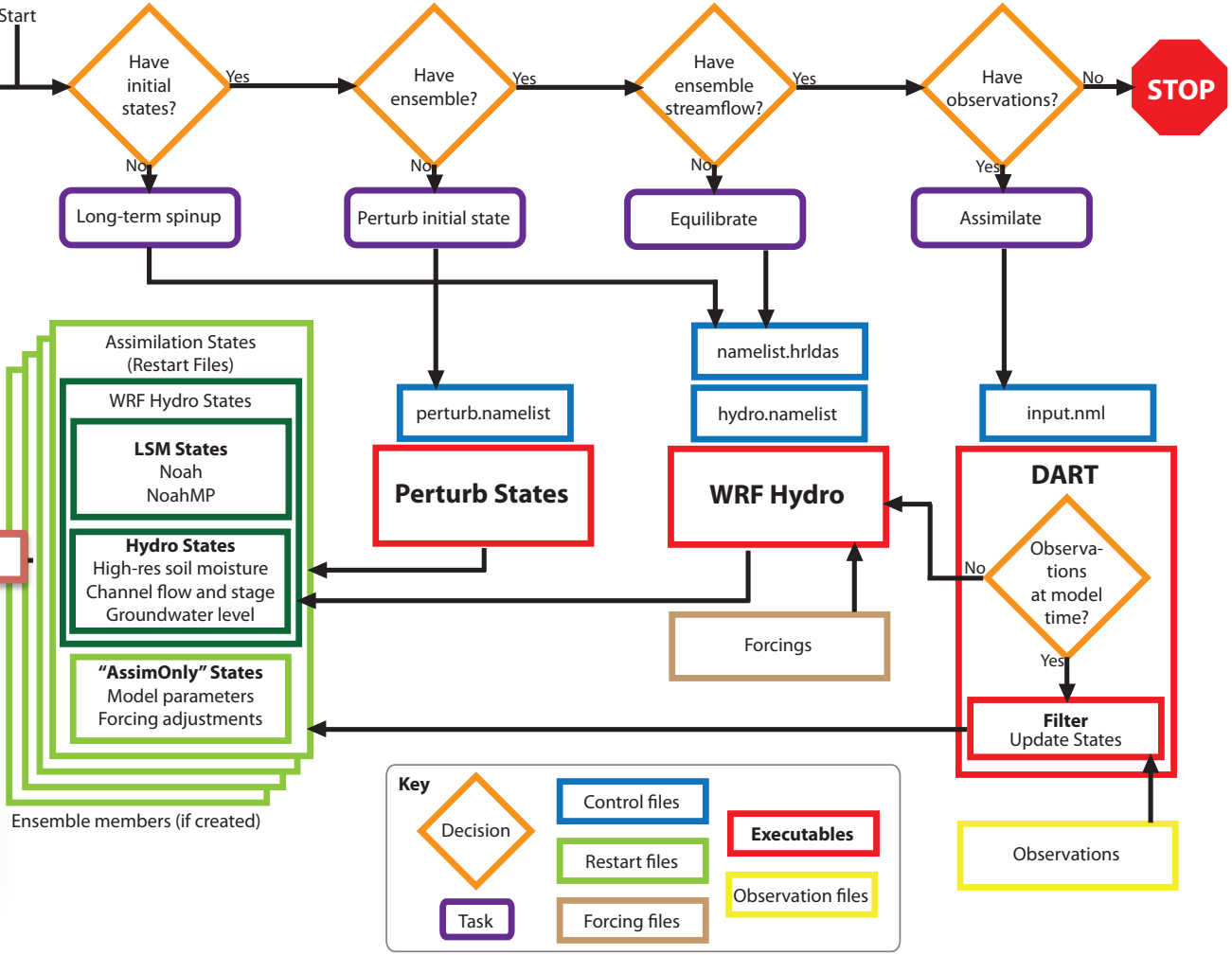
- Multi-model
  - NoahMP & Noah
- Uncertainty specification
- rwrfhydro
- Parallelization
- Observation retrieval

+

http://www.image.ucar.edu/DAReS/DART/

- Filters
- Inflation
- Localization
- Parallelization
- Observation handling
- OSSE
- Diagnostics
- Etc…

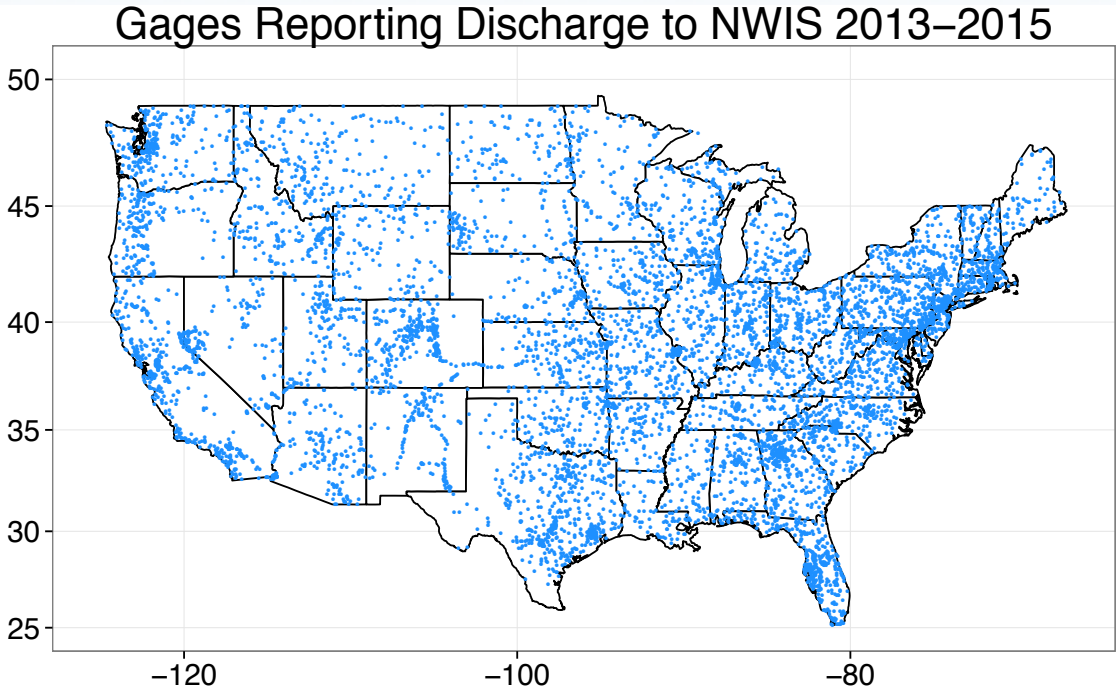
HydroDART Flowchart

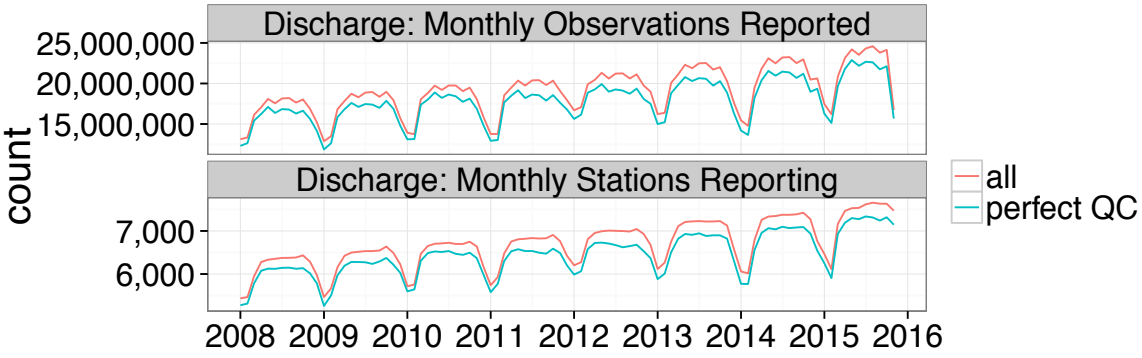


Nudging DA: Motivation

- Operational forecasting: IOC
- Lots of available observations from USGS NWIS
  - 2015:
    - 6,000 – 8,000 available stations (.2-.3% of NHD reaches)
    - 15,000,000 – 25,000,000 observations monthly
- State agency data

- **Why nudging?**
  - Calibration challenges => model biases => improper error covariances
  - (No error covariances => treat symptom not cause)
  - Computationally tractable at national scale
  - Future: hybrid with other DA methods

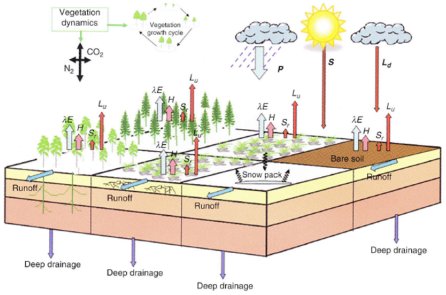




WRF-Hydro Initial Operating Capability (IOC) System: Model Chain with nudging data assimilation

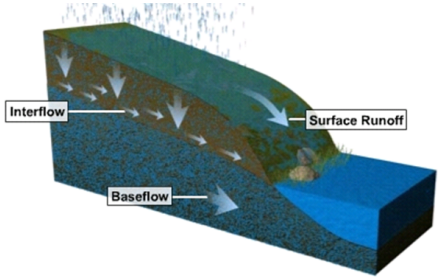
1. WRF-Hydro Forcing Engine (1 km grid)

2. NoahMP LSM (1 km grid)

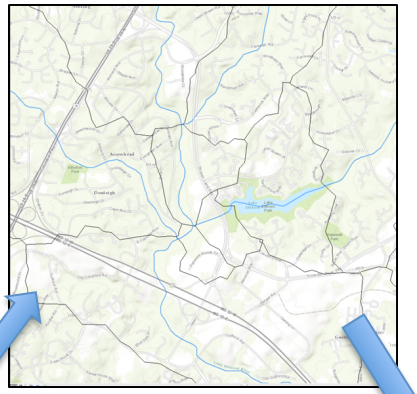


2-way coupling

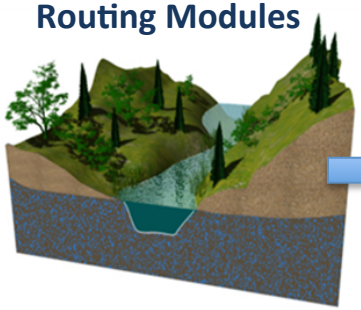
3. Terrain Routing Module (250 m grid)



4. NHDPlus Catchment Aggregation

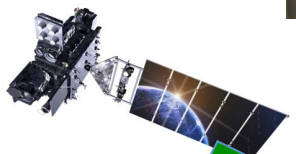


5. Channel & Reservoir Routing Modules



6. USGS stream gages

7. GOES satellites



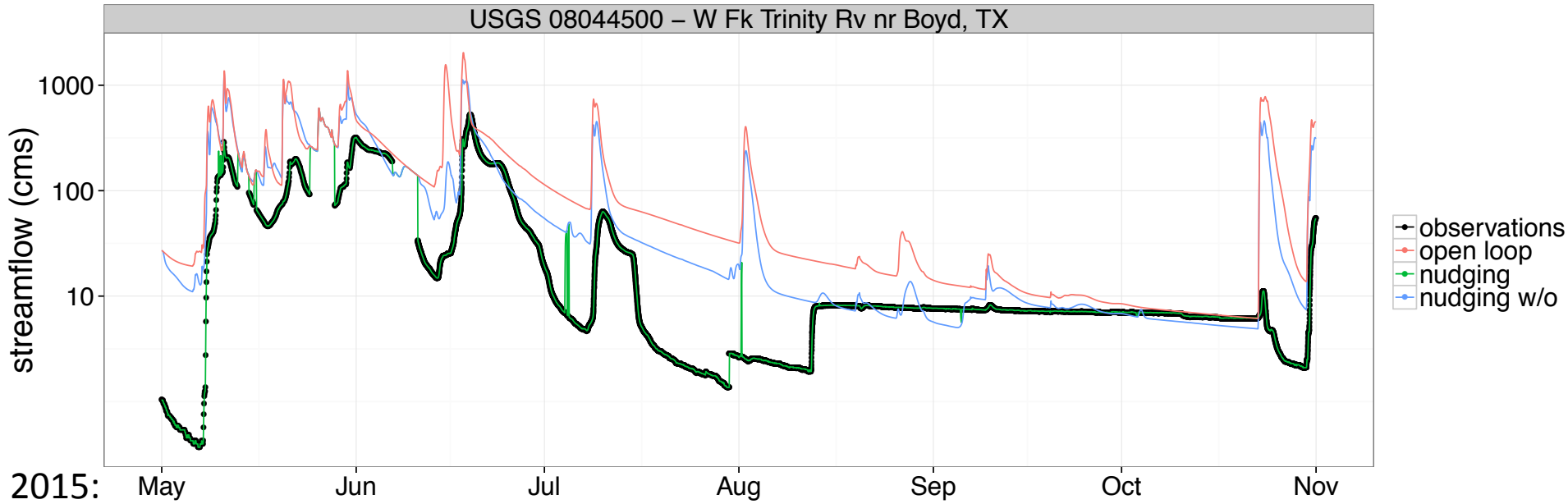
8. USGS National Water Information System (NWIS)

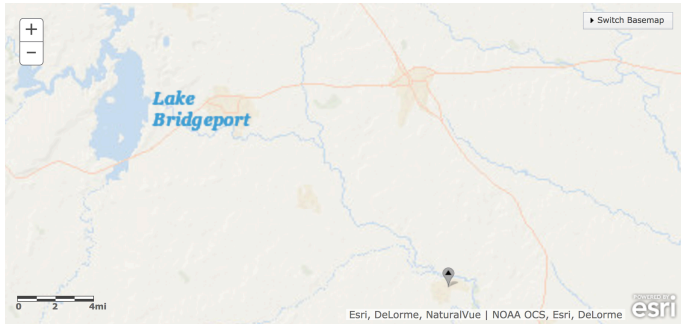
USGS

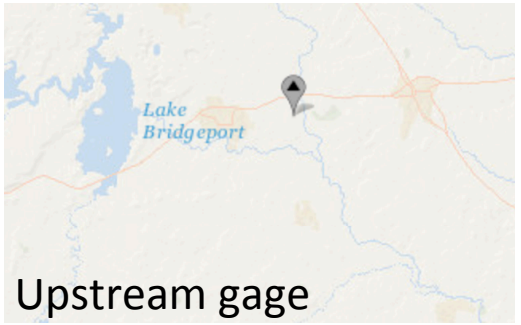
9. Preprocess: Ingest and QC

10. Stream Nudging Module

WRF-Hydro Nudging: Illustration near a reservoir







% Open Loop Bias Reduction : OL –> Nudge Validation: May–Oct, 2015

Thank you.

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