Hydrological Modeling and Data Assimilation Activities at NASA SPoRT

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Tuscaloosa, AL
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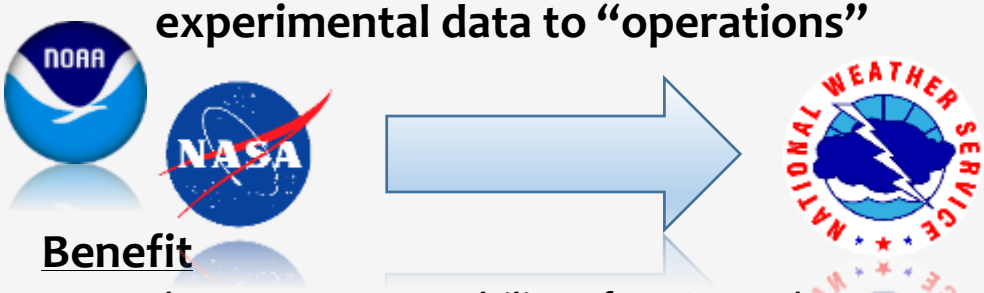
Outline

- NASA SPoRT Introduction
- NASA Land Information System
  - Operational SPoRT-LIS
  - Soil Moisture Data Assimilation
- National Water Model (NWM)
  - Evaluating LIS fields in NWM
  - Assimilation of NASA datasets
  - Inundation
- Development of Tools for WRF-Hydro Community

Short-term Prediction Research and Transition (SPoRT) Center

- **SPoRT is focused on transitioning unique NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale.**
  - Close collaboration with numerous WFOs and National Centers across the country
  - complementary to JCSDA
  - use experimental modeling systems that are modeled after operational systems
- **Proven paradigm for transition of research and experimental data to "operations"**



Benefit

- demonstrate capability of NASA and NOAA experimental products to weather applications and societal benefit
- prepares forecasters and modeling systems for use of data from next generation of operational satellites (JPSS, GOES-R)

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Partnerships with NOAA

Over 30 NWS WFOs and All Regional Headquarters

National Centers for Environmental Prediction

- Environmental Modeling Center
- National Hurricane Center
- Weather Prediction Center
- Ocean Prediction Center
- Aviation Weather Center
- Storm Prediction Center

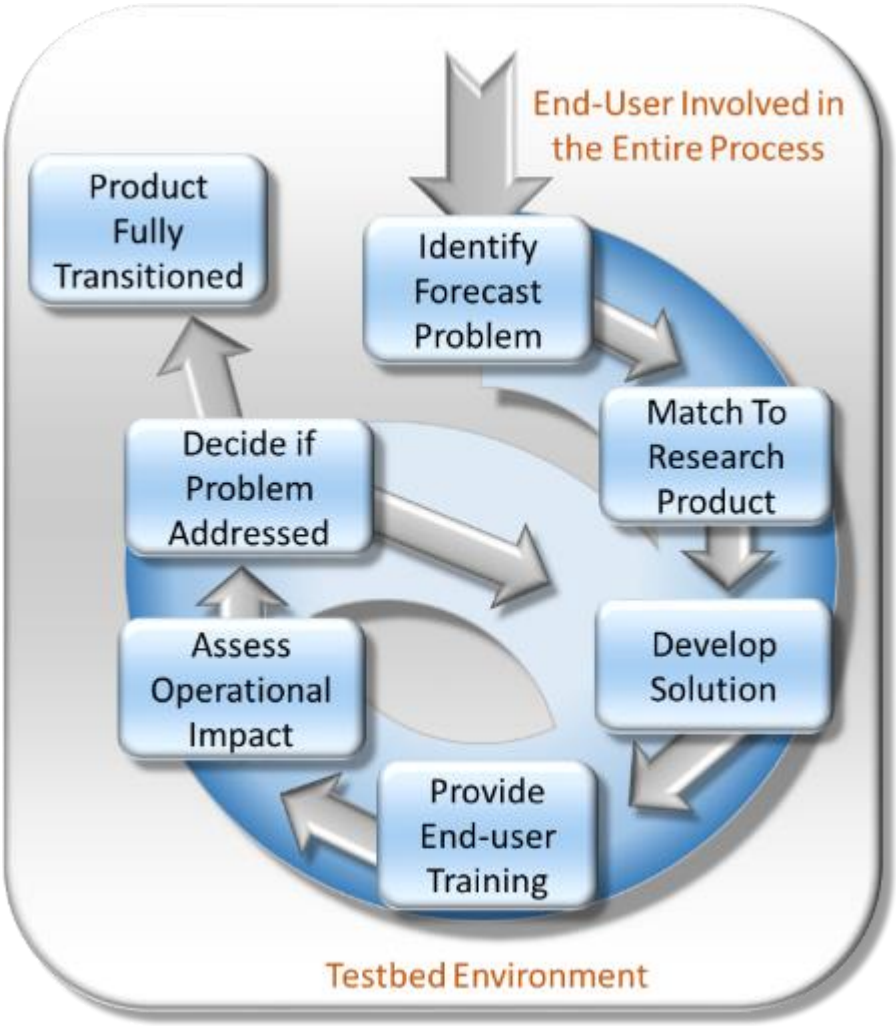
NOAA Cooperative Institutes as Data Delivery and Product Development Partners

Legend
- Product Development Partner
- National Center Evaluation Partner
- NWS Regional Headquarters
- WFO Collaborative Partner

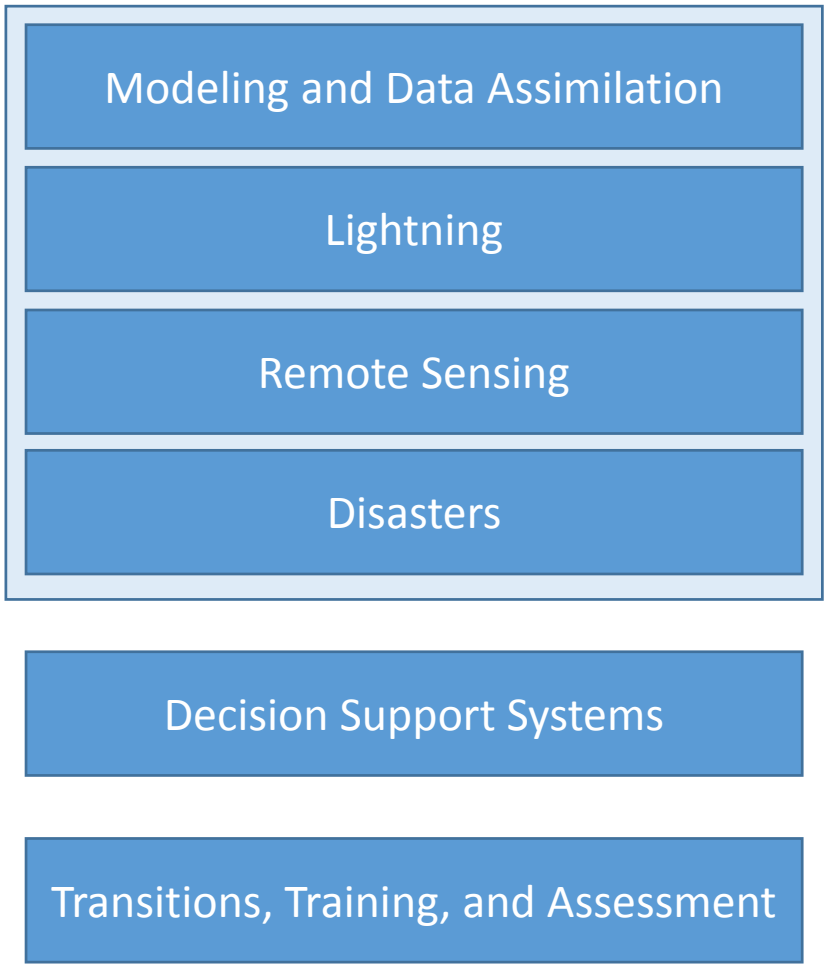
SPoRT collaborates with NOAA Cooperative Institutes to develop and distribute products to partnering NWS WFOs and National Centers, providing unique observation and modeling capabilities to support their daily forecasting operations.

SPoRT R2O/O2R Paradigm

- **Bridge the "Valley of Death"**
- **Can't just "throw data over the fence"**
  - maintain interactive partnerships with help of specific advocates
  - integrate into user decision support tools
  - Create product training
  - Perform targeted product assessments
- **Use experimental datasets and proxies in advance of operational use to demonstrate utility and impact**
- **Concept has used to successfully transition a variety of satellite datasets to operational users for more than 10 years**
- **Other groups in the community have adopted this paradigm**



SPoRT Areas of Expertise



- **Perform targeted research activities to exploit unique capabilities of NASA satellites and technologies to solve specific weather forecasting challenges**
- **Support for product dissemination to AWIPS, AWIPS II, N-AWIPS, WMS, etc.**
- **Apply unique R2O/O2R paradigm for transitioning data and obtaining valuable feedback from NWS forecasters**

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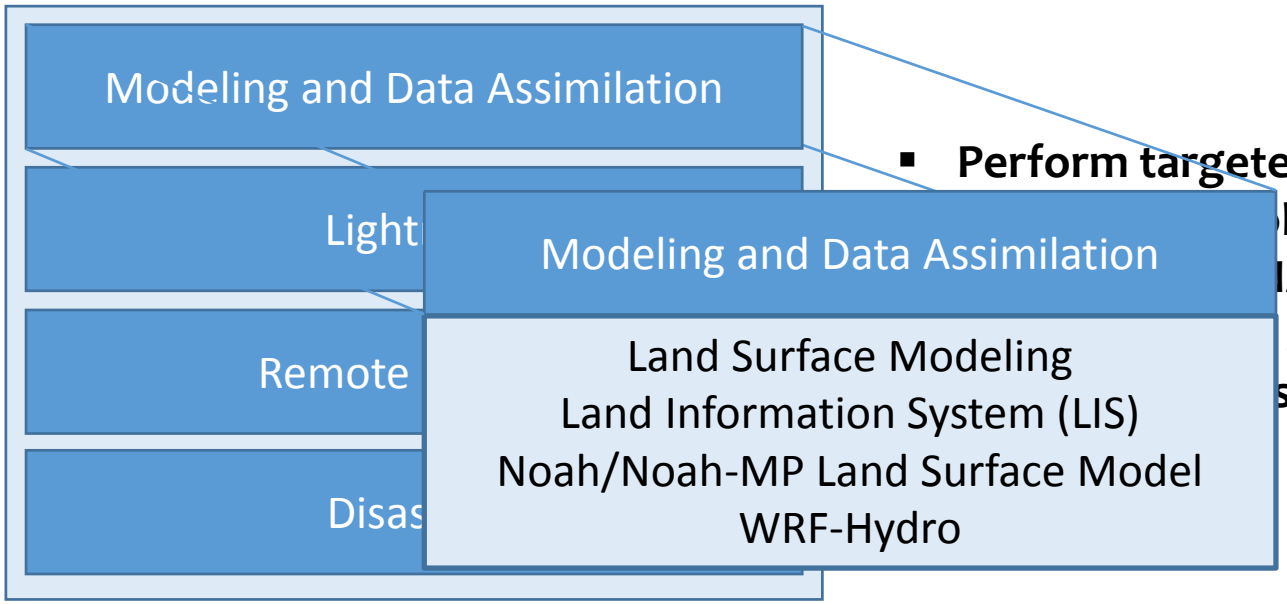
SPoRT Areas of Expertise



- **Perform targeted research**
  loit unique
  IASA satellites and
  solve specific
  sting challenges

Decision Support Systems

Transitions, Training, and Assessment

- **Support for product dissemination to AWIPS, AWIPS II, N-AWIPS, WMS, etc.**
- **Apply unique R2O/O2R paradigm for transitioning data and obtaining valuable feedback from NWS forecasters**

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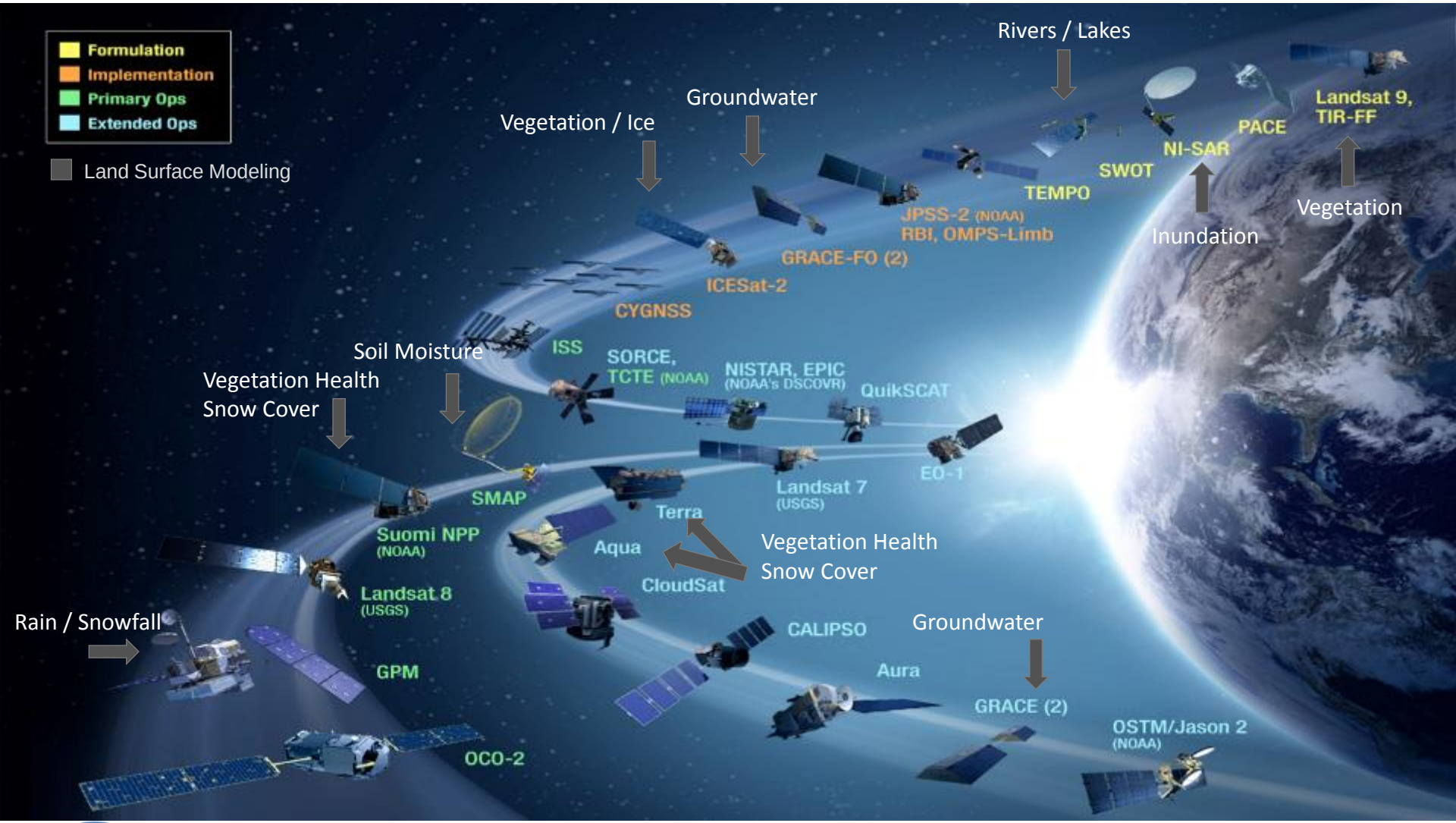
Current and Future NASA Missions



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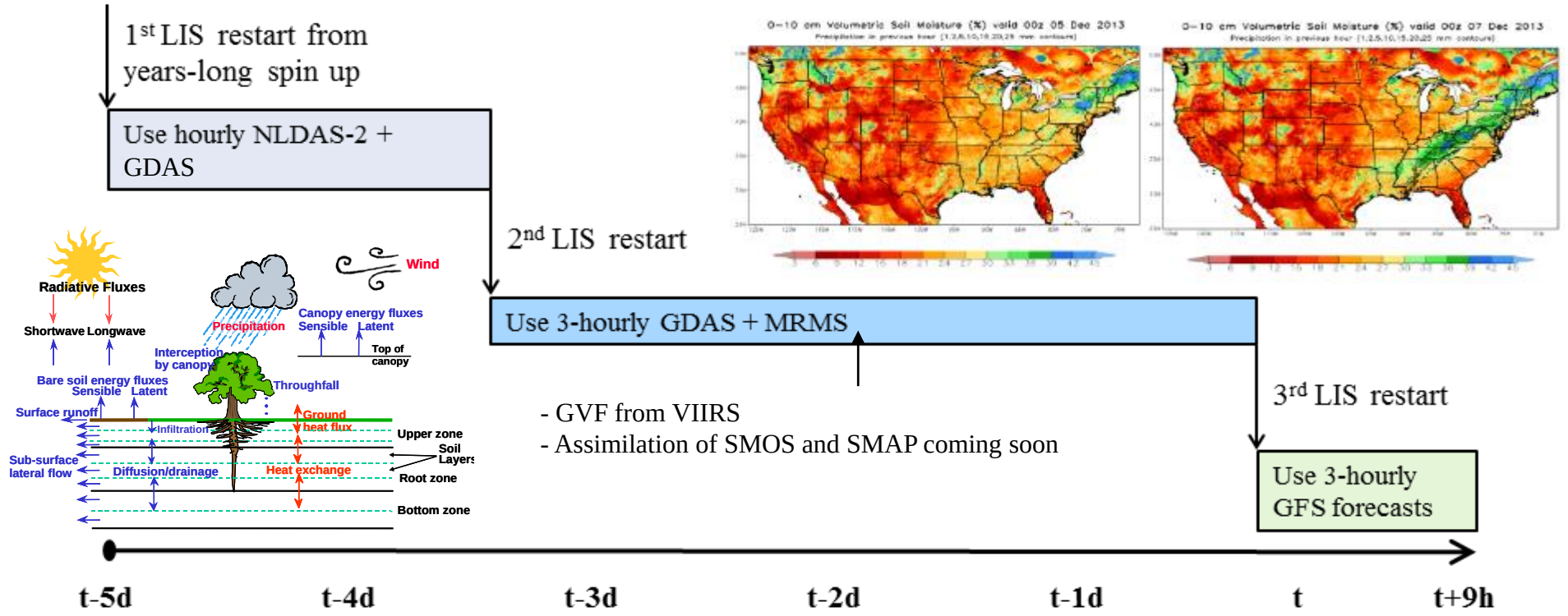
Operational SPoRT LIS

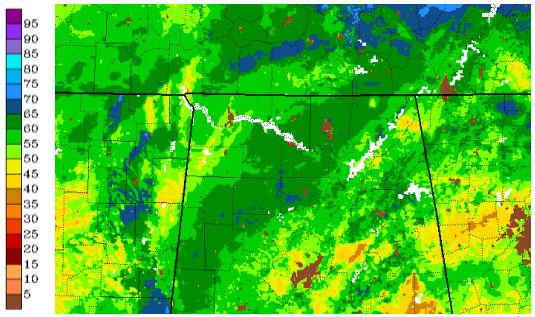


- **CONUS, 3-km resolution**
- **NASA LIS used to perform long-term integration of Noah Land Surface Model (LSM) updated in real-time**
- **Assimilation of soil moisture during 2nd LIS restart should give even more accurate LSM soil moisture fields**
- **Output used for situational awareness and local modeling by forecasters at select NWS offices and international forecasting agencies**

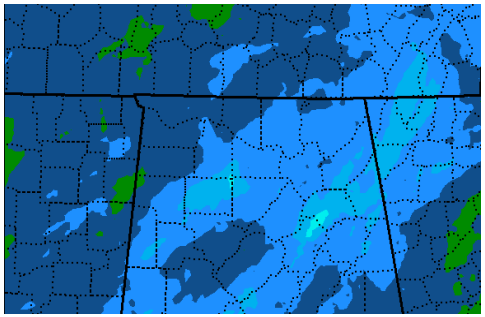
Application: Areal Flood Potential

March

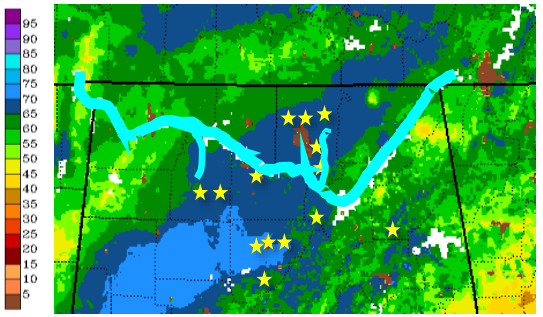
Moderate antecedent soil moisture



Moderate-heavy precipitation

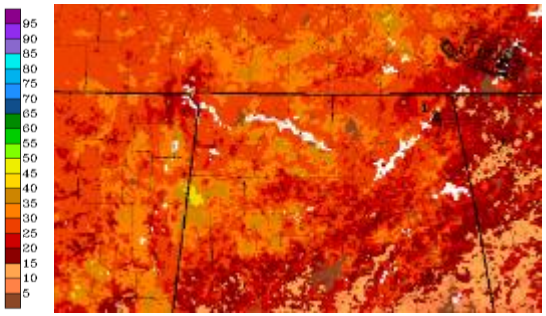


Moderate river flooding and numerous flooding reports

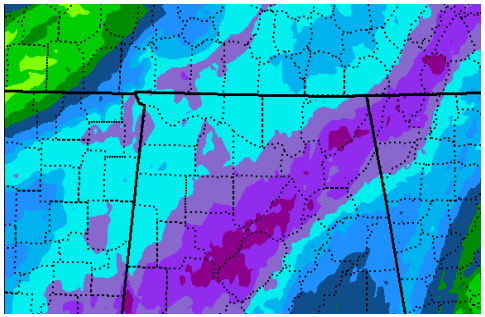


September

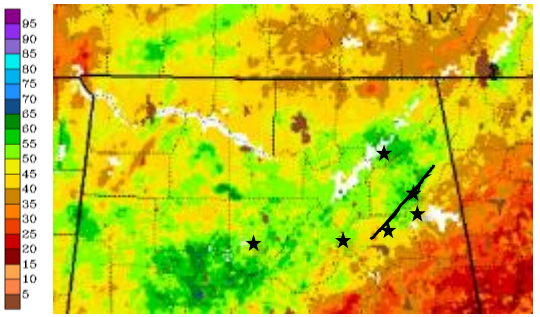
Low antecedent soil moisture



Heavy precipitation



Isolated minor flooding



- **Contrasting antecedent soil moisture likely played a strong role in the different outcomes**
- **Local, subjective analysis of several events suggests typical moderate-heavy synoptic rainfall events over deep-layer relative soil moisture values exceeding 55-60% will lead to more substantial moderate or heavier flooding events**

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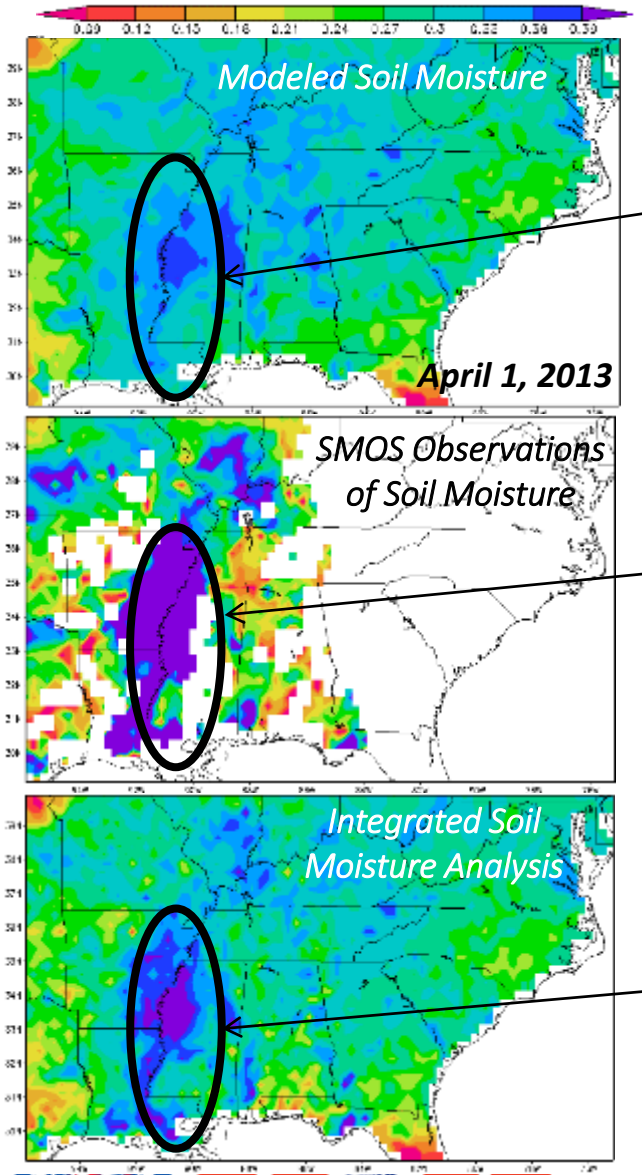
Assimilation of Soil Moisture Data

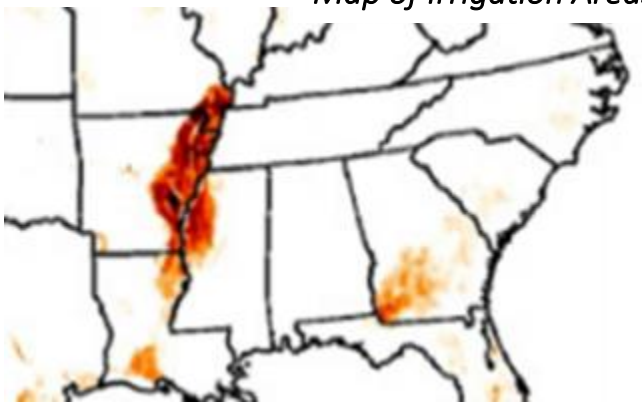


Model soil moisture concentration forced only by precipitation and misses magnitude of irrigation-saturated MS Valley

SMOS observes irrigated fields

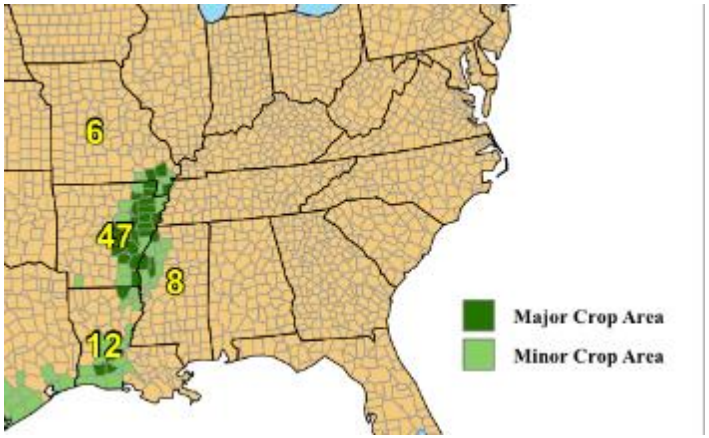
Blended analysis of model and observations better represent irrigated area and should result in improved weather and hydrologic modeling

Map of Irrigation Areas



From U. of Frankfurt-FAO (Ozdogan 2001)

Rice growing areas



Yellow numbers indicate percentage of national crop yield due to each state.

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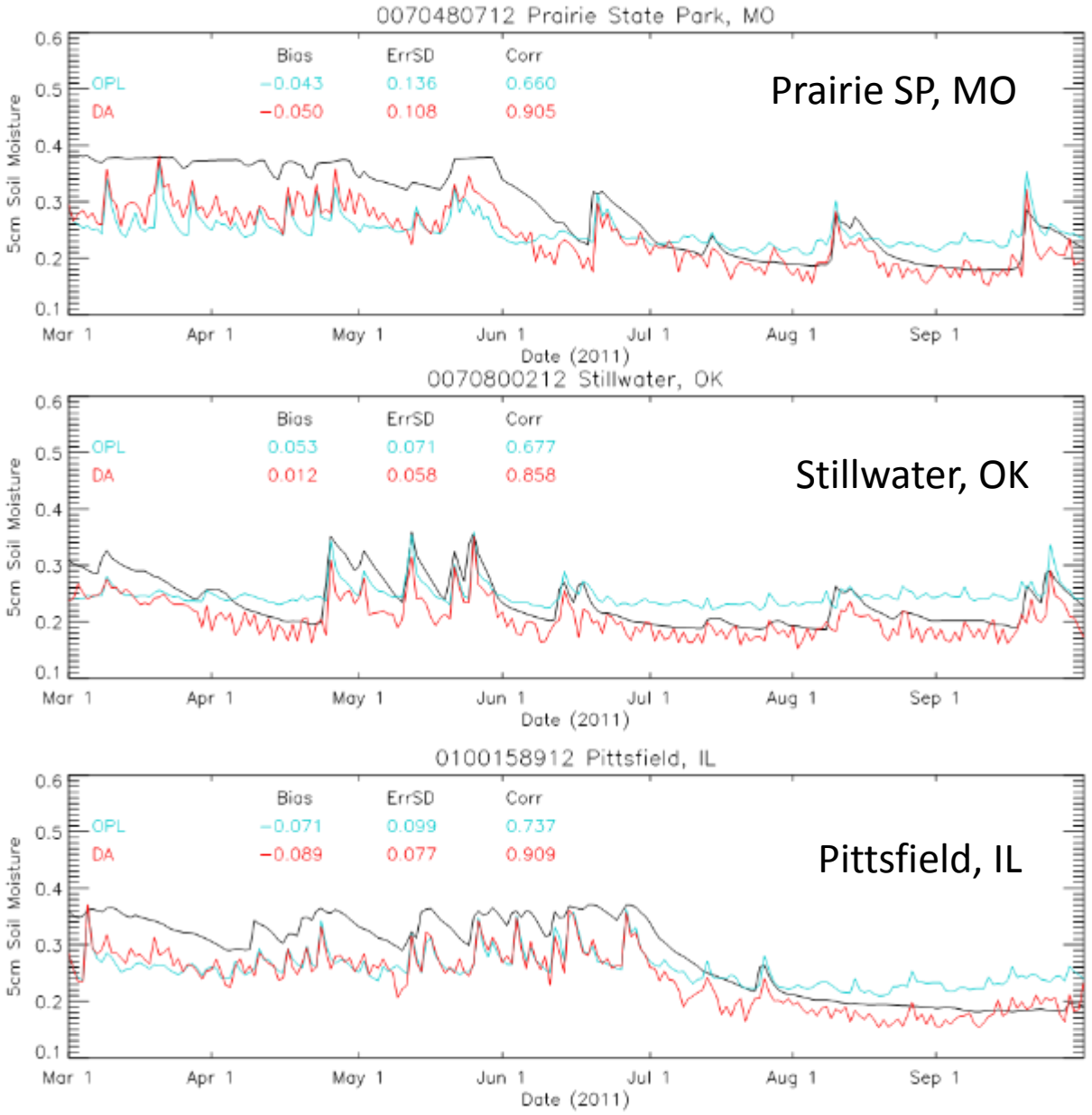
SMOS DA Validation

- **0-10 cm model soil moisture**
- **Results from validation against soil moisture networks in US (North American Soil Moisture Database)**
  - Better correlations
  - Improved dynamic range



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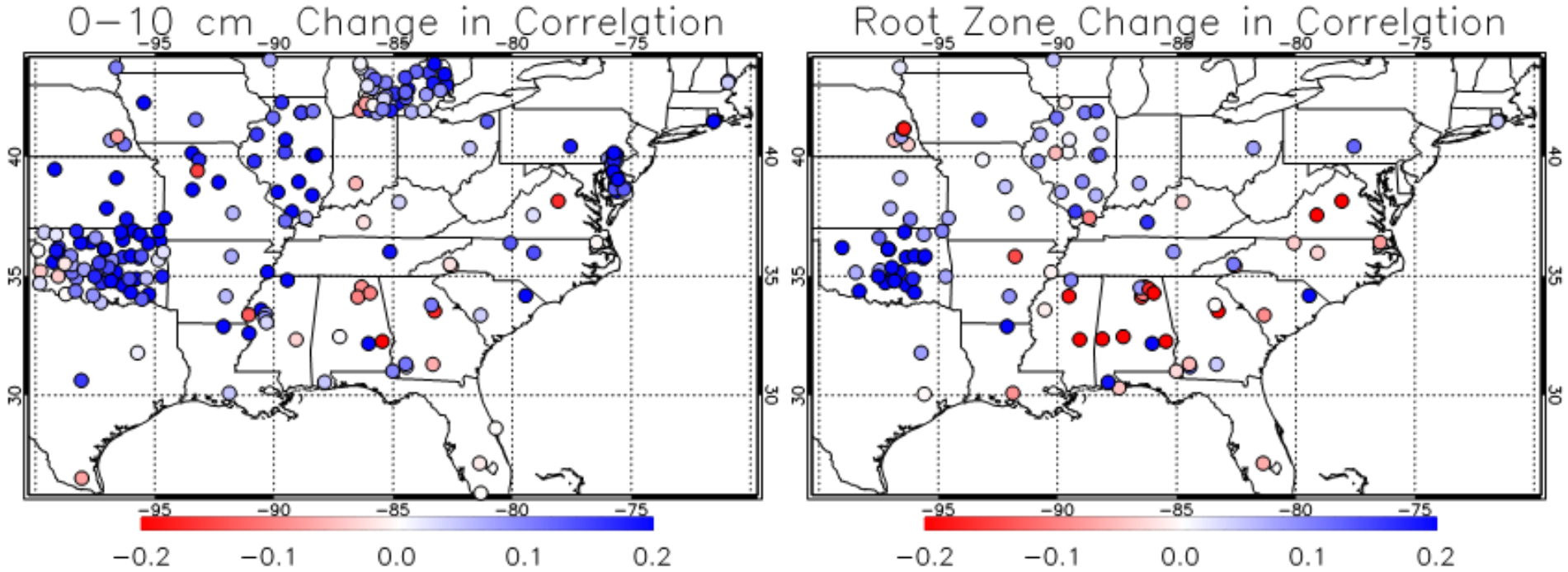
SMOS DA Validation



Degraded w/ DA Improved w/DA

Variable	0-10 cm Soil Moisture				
# Stations	194				
Experiment	**OPL**	**NOBC**	**BC1**	**BCS**	**BCV**
Bias	**-0.000** ± 0.011	-0.026 ± 0.011	-0.023 ± 0.011	-0.005 ± 0.011	-0.025 ± 0.011
RMSE	**0.082** ± 0.005	0.087 ± 0.006	0.086 ± 0.005	**0.082** ± 0.005	0.087 ± 0.006
Unbiased RMSE	0.046 ± 0.003	**0.043** ± 0.002	**0.043** ± 0.002	0.044 ± 0.003	**0.043** ± 0.002
Correlation	0.451 ± 0.023	**0.573** ± 0.027	0.569 ± 0.026	0.539 ± 0.025	0.561 ± 0.026

Assimilation of SMOS using soil classification bias correction results in best overall configuration for bias, RMSE, and r^2

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National Water Model (NWM)

- Instantiation of WRF-Hydro
- Noah-MP land surface model
- Vector routing over nearly 3 million NHD reaches
- Streamflow, soil moisture, reservoir storage, etc.

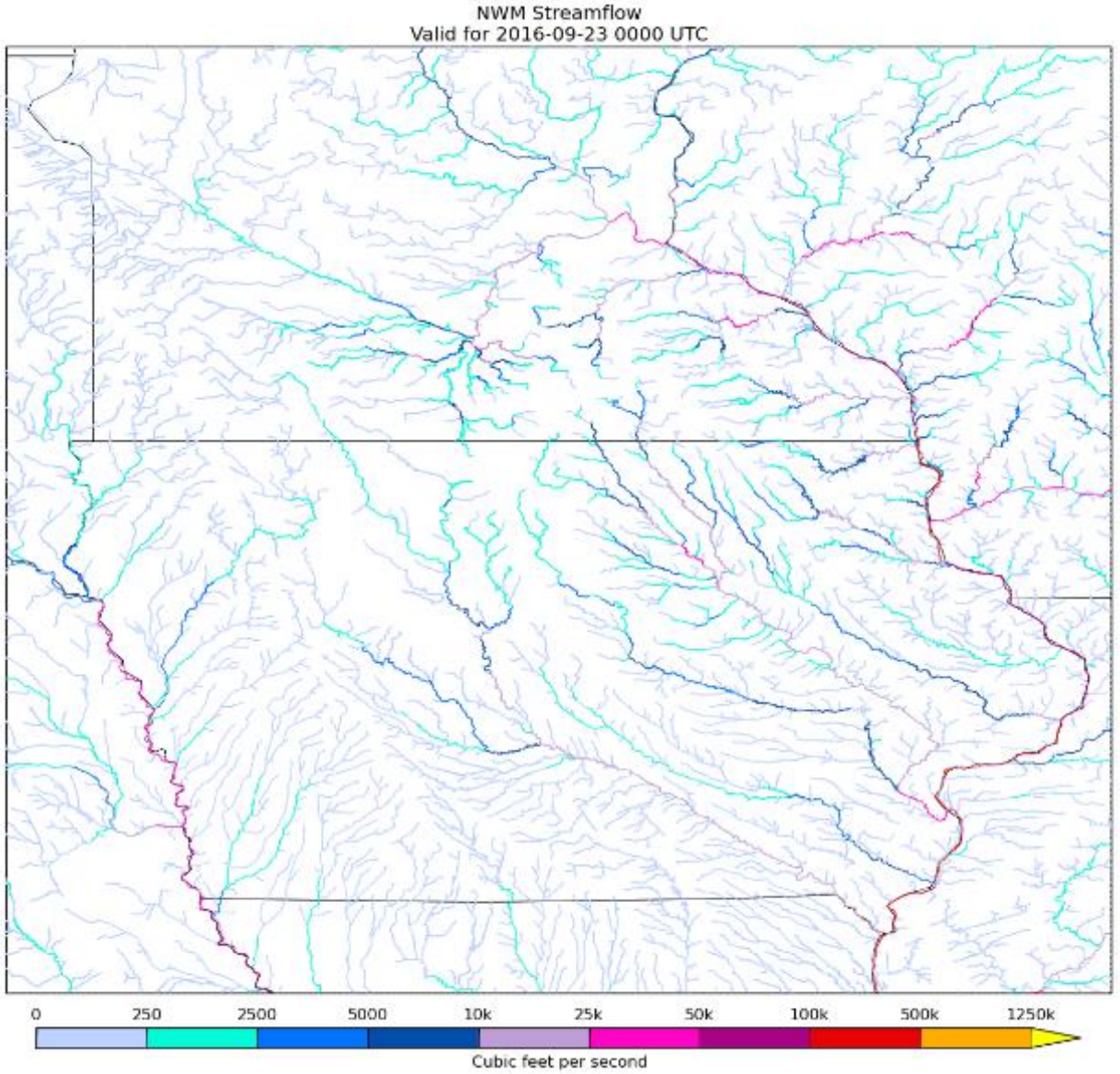
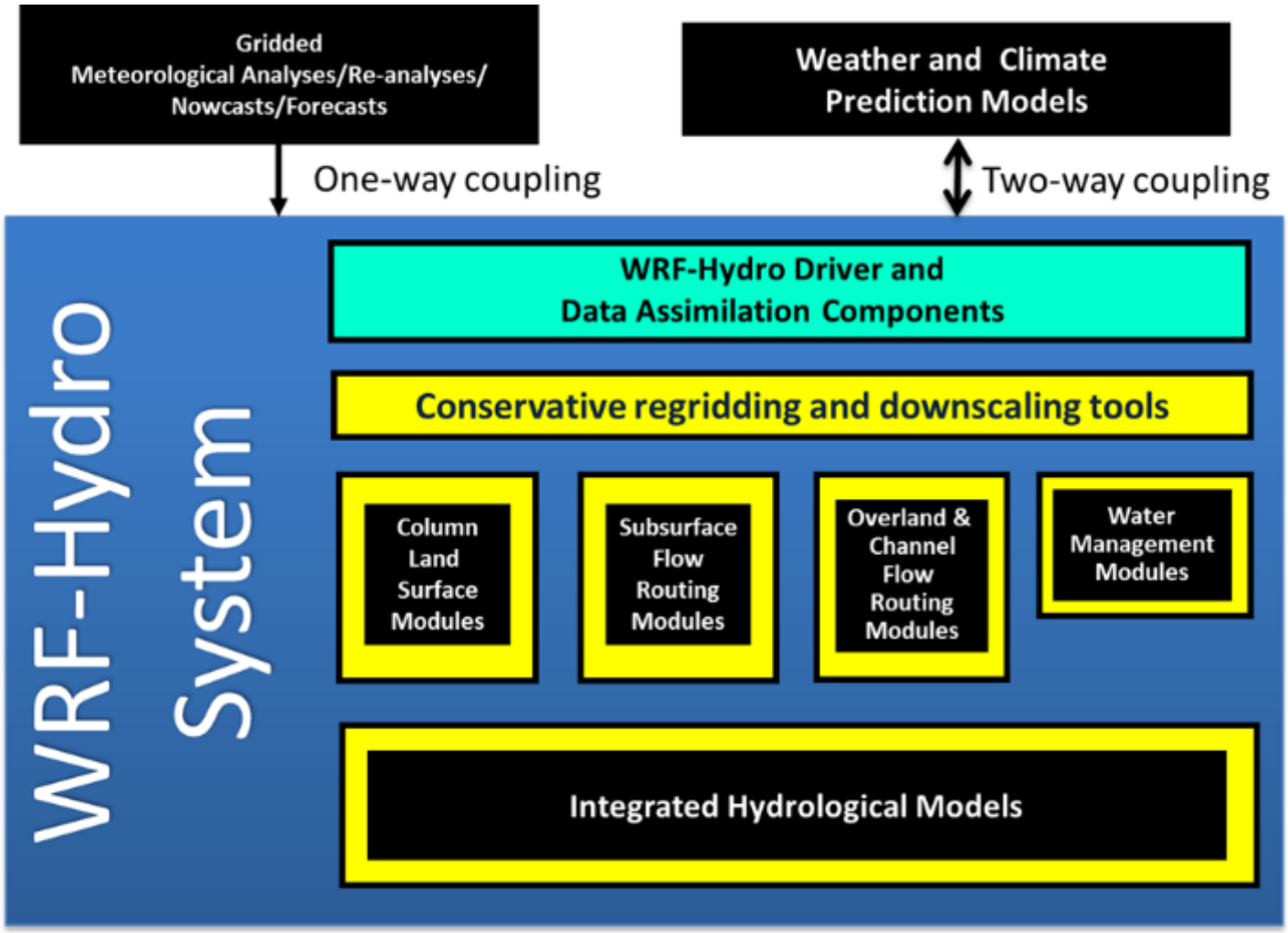


Fig. Streamflow animation for September 2016 Iowa Flood

WRF-Hydro System



https://www.ral.ucar.edu/sites/default/files/public/projects/wrf_hydro/wrf-overview.png

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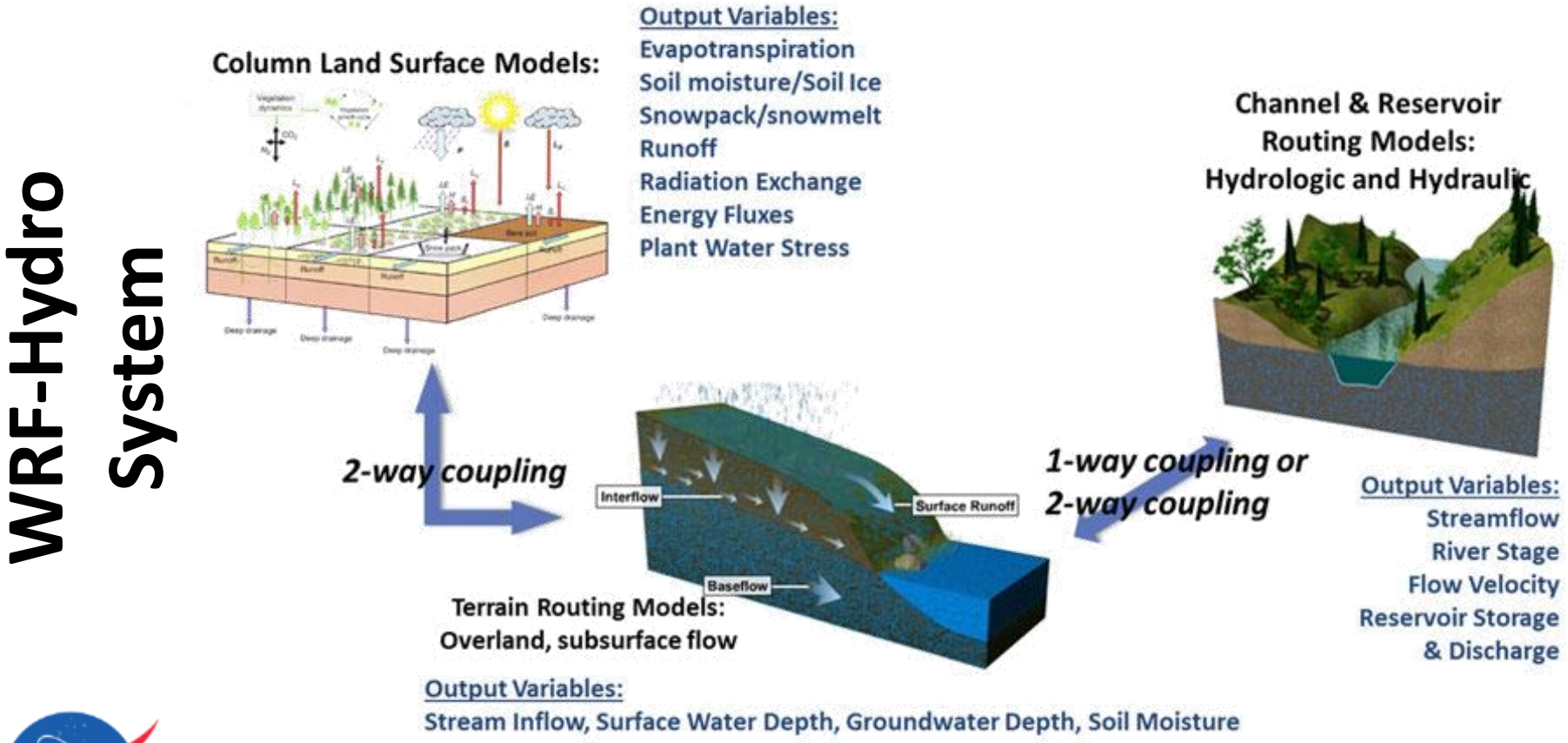
Coupling LIS and WRF-Hydro

- Collaborative project between Joe Santanello (NASA/GSFC) and David Gochis (NCAR)
  - Funded by NASA's Modeling, Analysis, and Prediction (MAP) program
  - Couple LIS and WRF-Hydro in the Earth Science Modeling Framework (ESMF), which will enable operational linking of these two systems
  - SPoRT plans to leverage this project to assimilate/integrate NASA mission datasets in WRF-Hydro using the LIS Ensemble Kalman Filter (EnKF)

Assimilation of NASA Data in NWM

- Soil moisture (SMAP/SMOS)
- Snow cover (MODIS/VIIRS) and snow water equivalent (AMSR2)
- Total terrestrial/ground water (GRACE/GRACE-Follow On)
- Other future NASA missions (ICESat-2, NISAR, Landsat-9, SWOT)



https://www.ral.ucar.edu/sites/default/files/public/projects/wrf_hydro/WRF_Hydro_conceptualization_figure.jpg

LIS as Assimilation Framework for NWM

- Currently, the NWM does not have a system for assimilating land surface satellite observations
- The LIS system is a strong candidate given both the long history of the LIS and its linkage through the ESMF
- LIS has a built-in Ensemble Kalman Filter (EnKF) that enables assimilation of satellite-based observations (e.g., SMOS, SMAP, MODIS, VIIRS, AMSR-2, ICESat-2, etc.)
- SPoRT-LIS being upgraded to run Noah-MP LSM using NWM configurations

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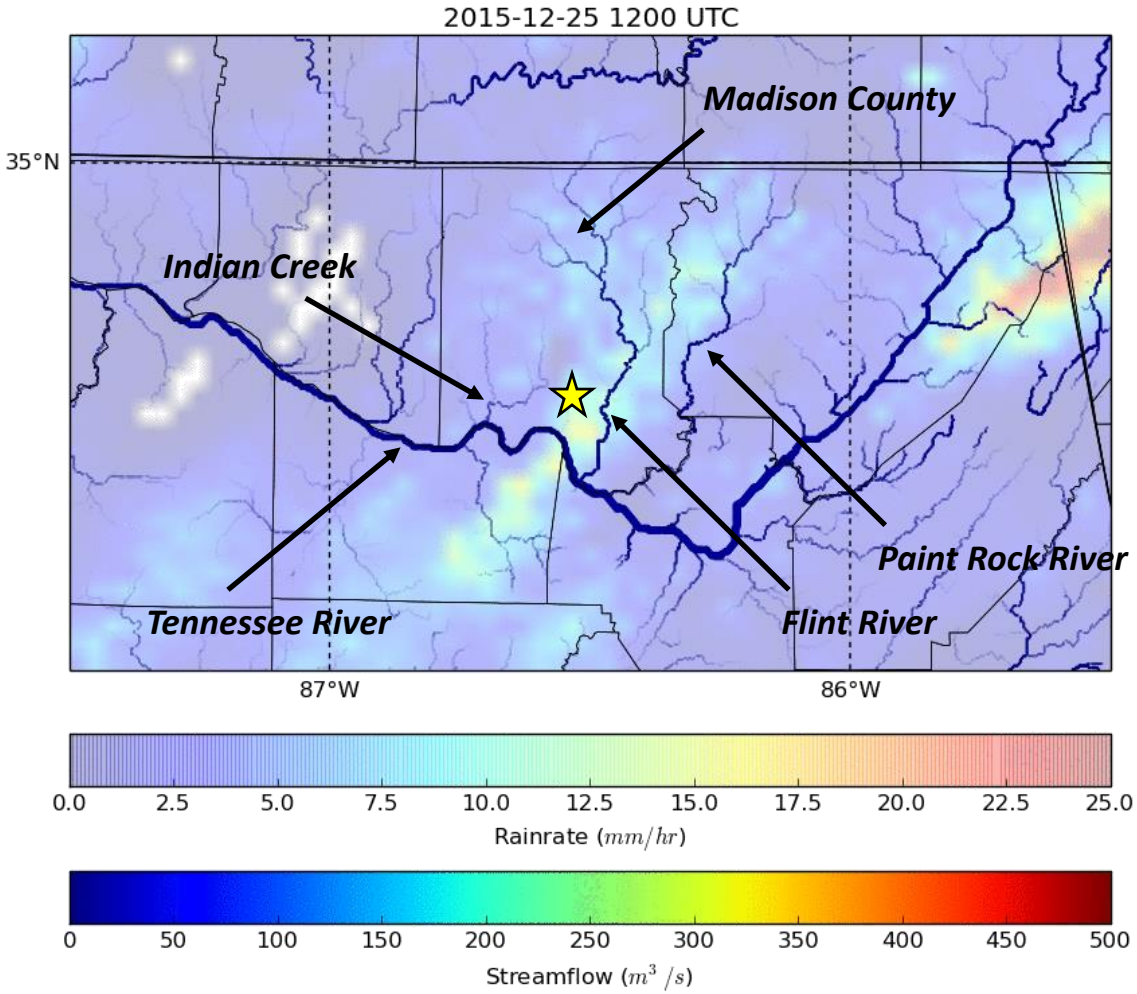
Experimental NWM

- Through collaborations with NWC, SPoRT has implemented a version of WRF-Hydro mimicking the NWM (experimental NWM)
- Plan to perform offline simulations to:
  - Evaluate NASA mission data impacts
  - Determine optimal assimilation strategies for NASA data
  - Support NWC operations in collaboration with the model implementers at the NWC, model developers at NCAR, and collaborators at GSFC

Evaluating LIS fields in NWM

December 2015 Alabama Flood



- Noah-MP initialized with LIS soil moisture, soil temperature, surface skin temperature, and vegetation fraction
- Multi-Radar Multi-Sensor (MRMS) 1-hr gauge corrected accumulated precipitation (background field; mm hr^{-1})
- "Cold start" of hydrological model (i.e., streambeds initially dry)

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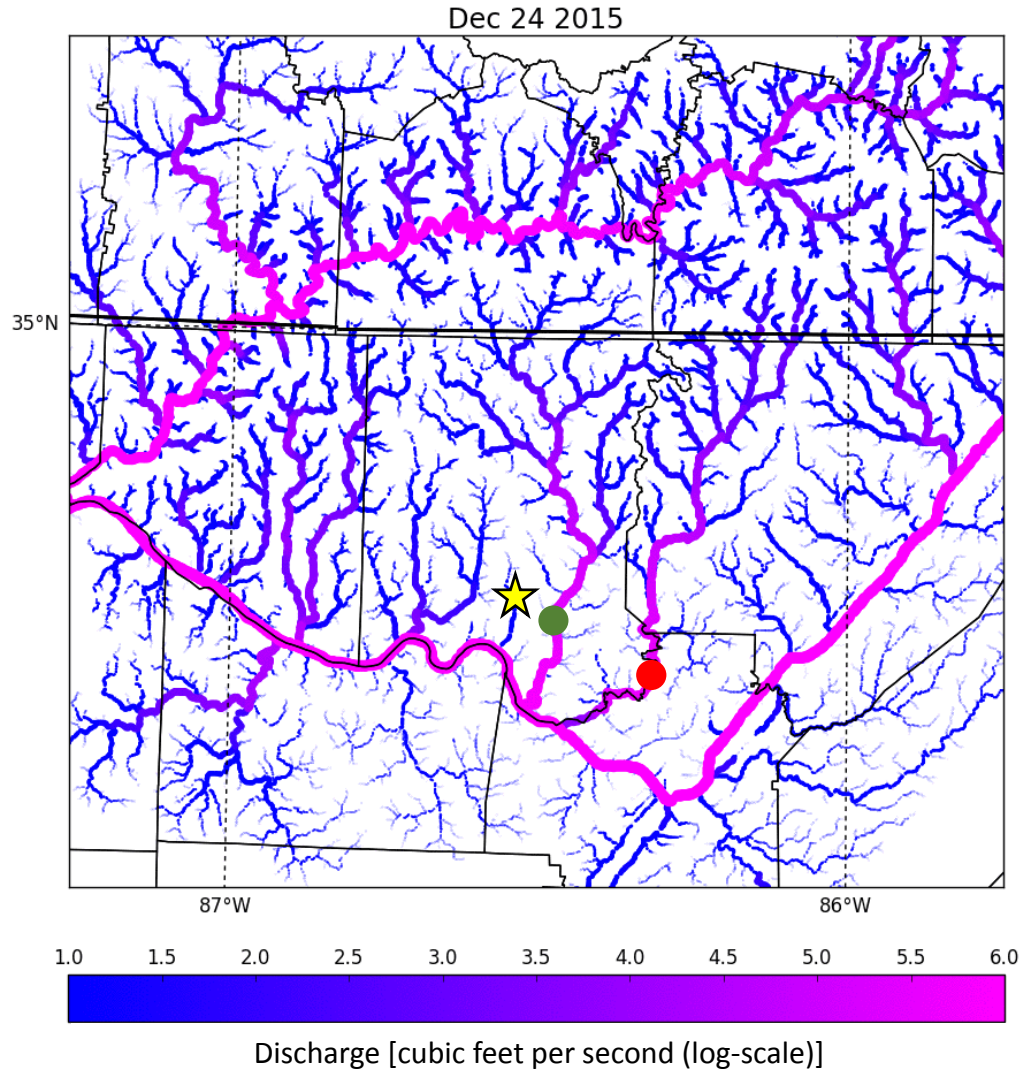
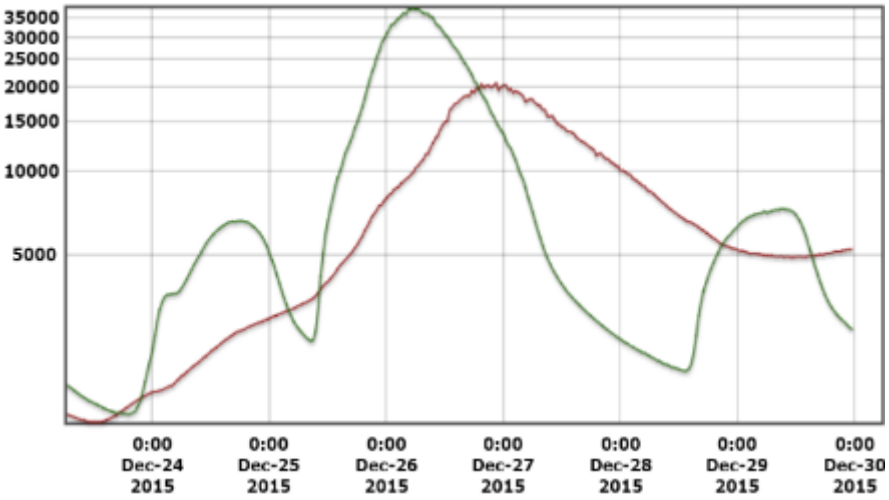
Calibration and Spin-up



- Spin-up with minimal calibration
- Infiltration and retention parameters are too low, leading to streamflow order of magnitude larger than observed
- Calibrating these parameters using the PEST parameter estimation tool (http://www.pesthomepage.org/)



Observed hydrographs

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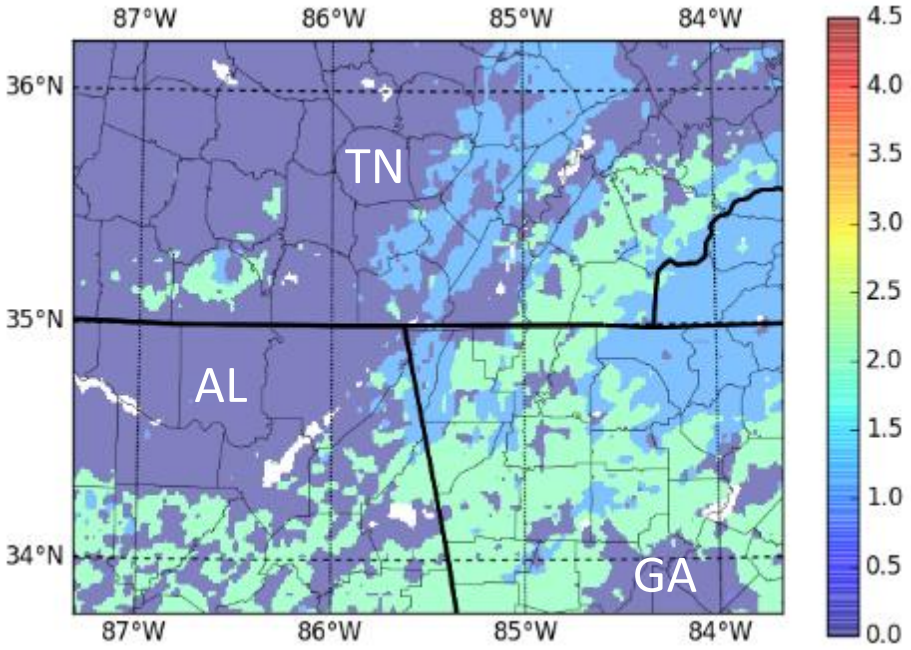
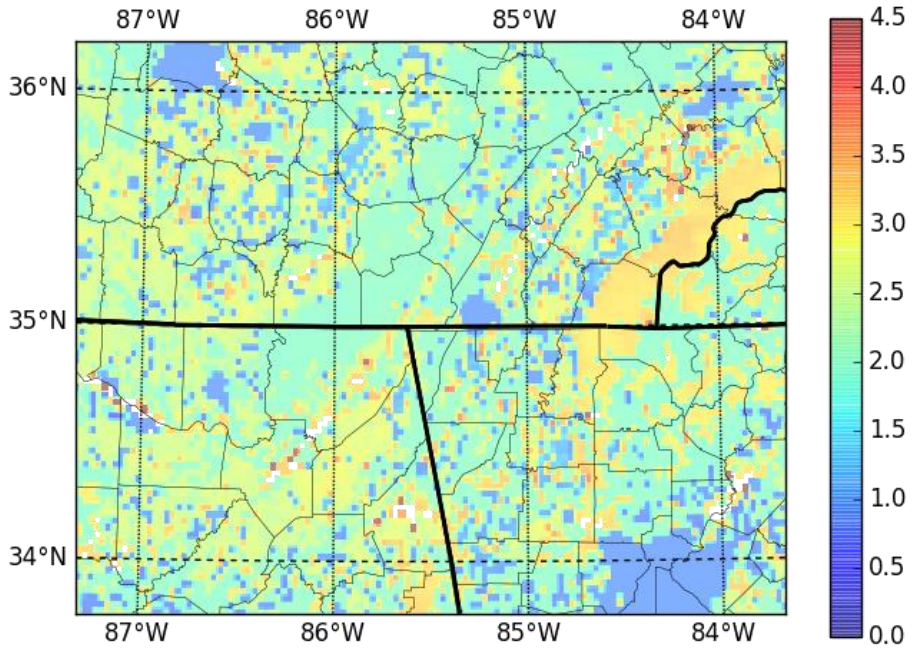
Impacts of Real-time Vegetation

Noah-MP Monthly Mean LAI - December



Real-time LAI (VIIRS/LIS) - 20151223



- Ongoing project to quantify impact of VIIRS real-time vegetation on simulated soil moisture and streamflow
- Larger differences between real-time and monthly mean LAI more likely in early spring and fall

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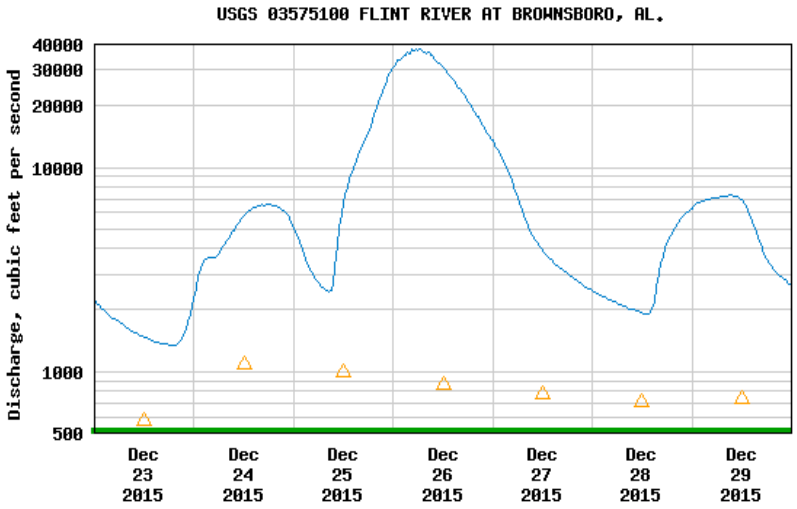
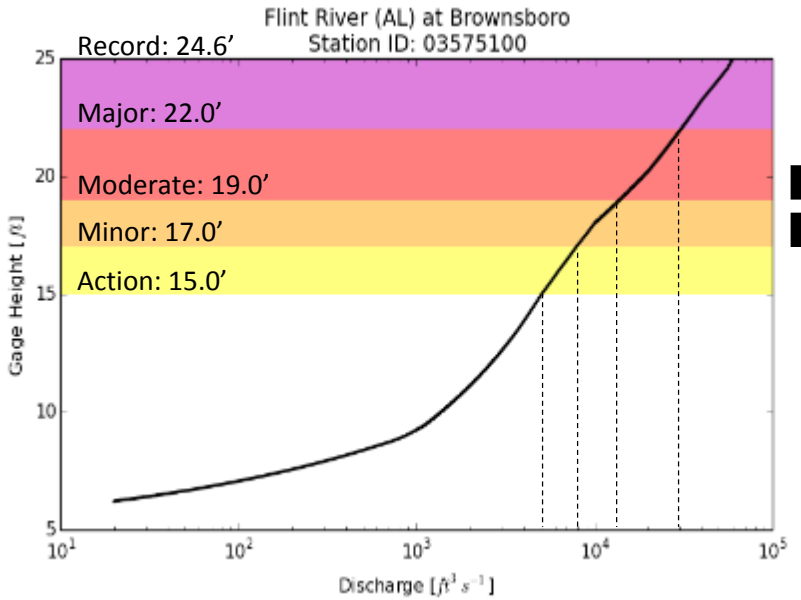
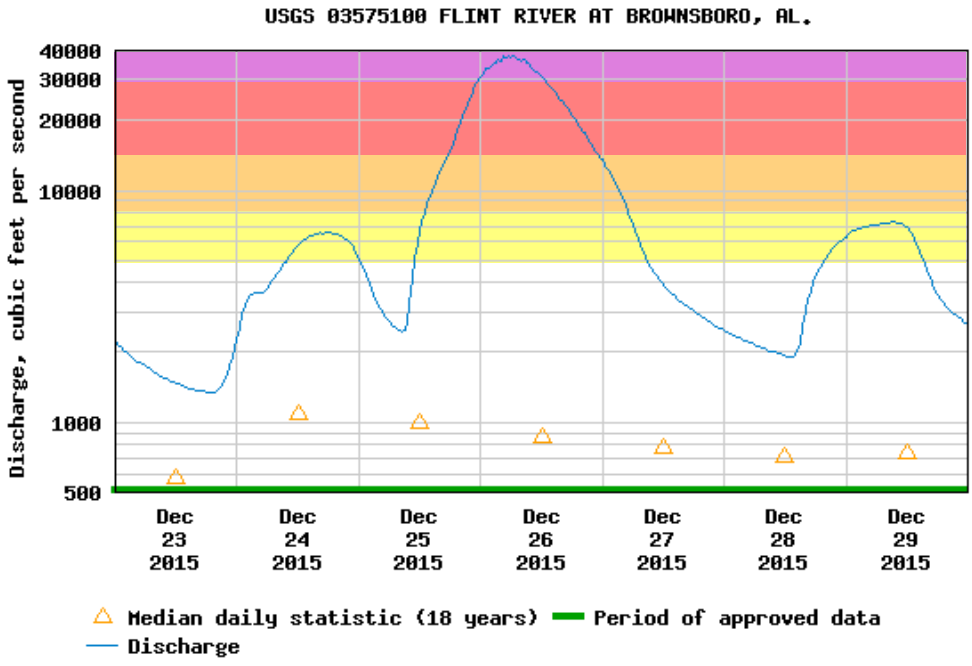
Rating Curves: Streamflow to Inundation Depth



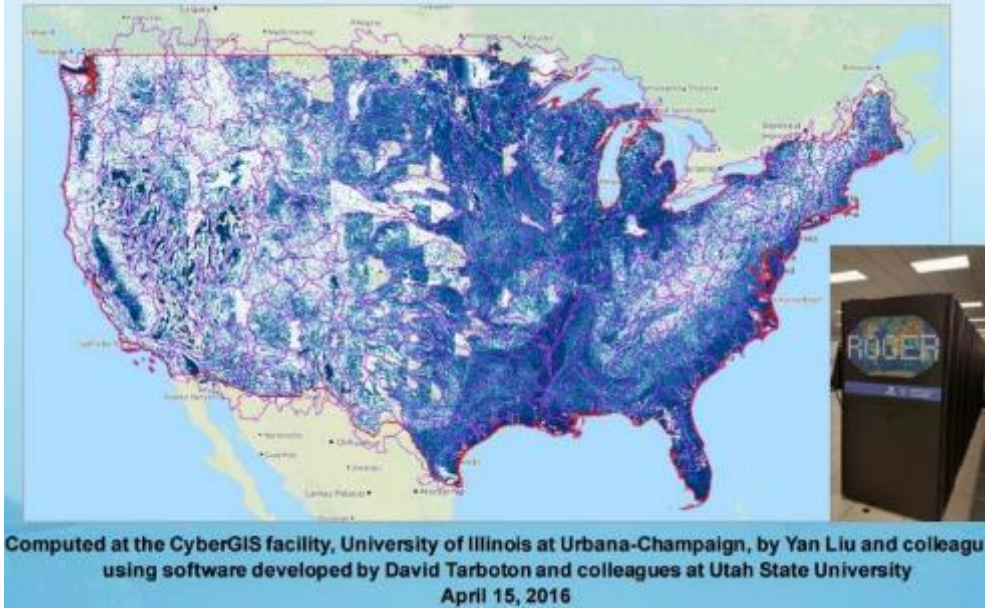




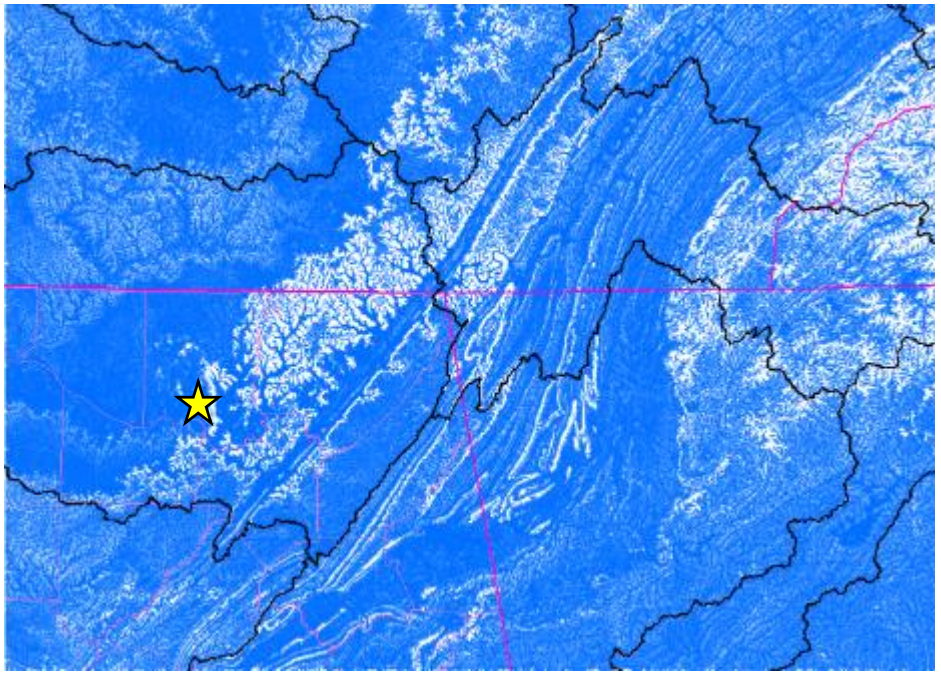
- Rating curves link WRF-Hydro simulated discharge to gage height, which in turn is linked to inundation depth

Inundation

- Major focus of CUAHSI Summer Institute at NWC
    - Height Above Nearest Drainage (HAND) methodology
- Several current and future NASA missions have data assimilation and mapping applications for inundation (e.g., Landsat, NISAR, SWOT)



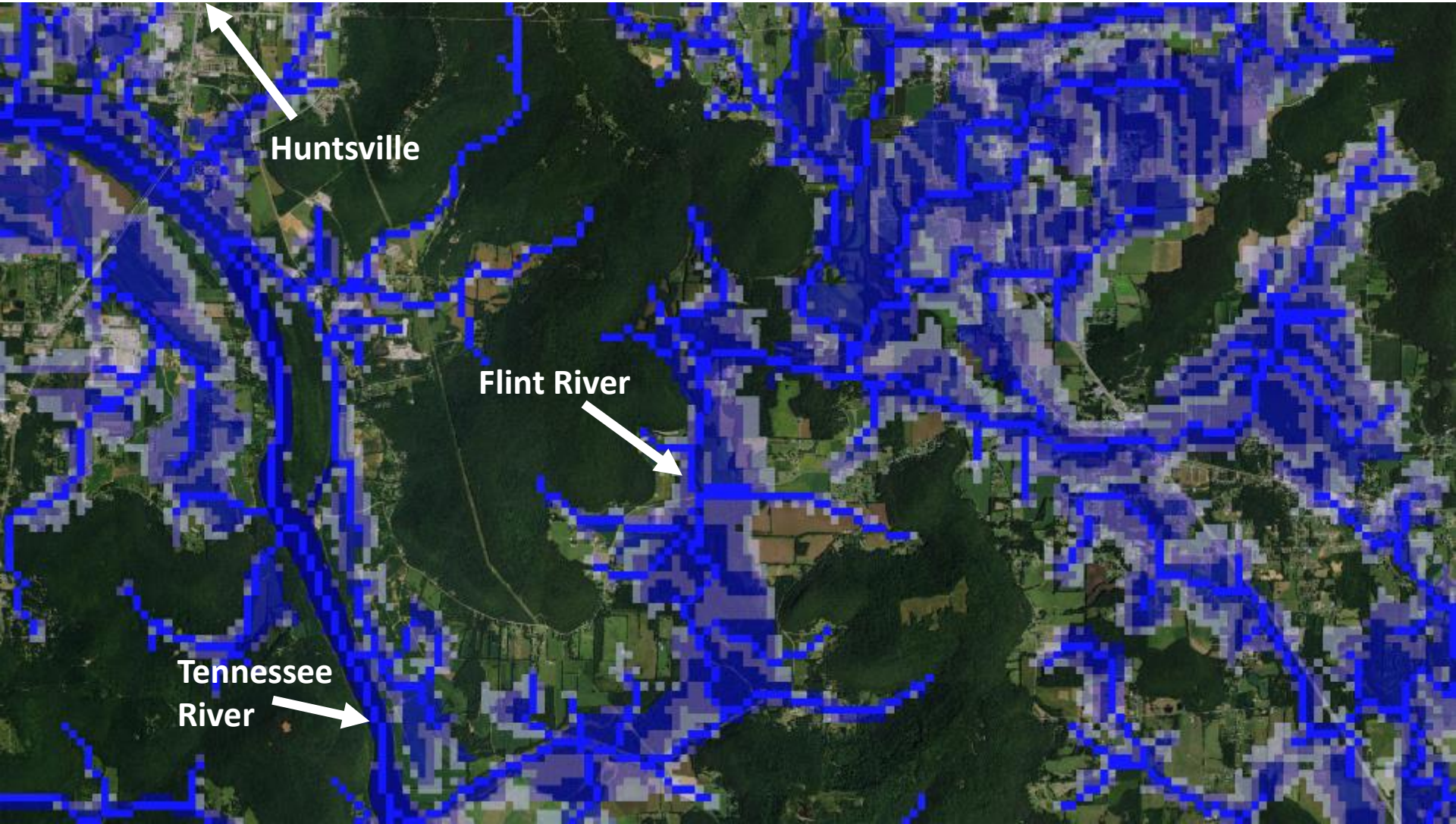
10 meter NHDPlus HAND Raster (Maidment et al. 2016)



Regional HAND raster generated by SPoRT

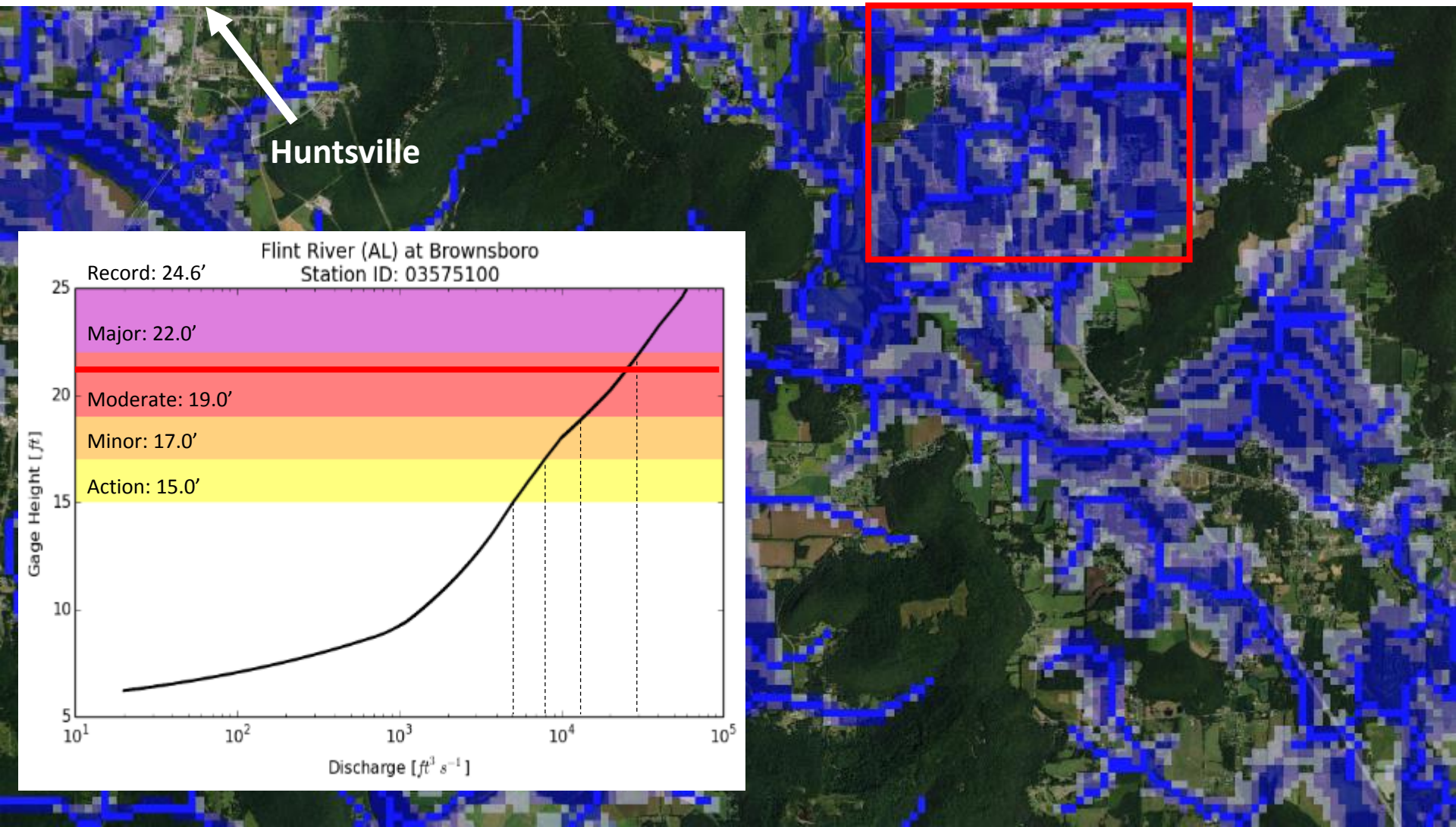
Inundation Depth

- Potential inundation depth as determined by HAND model
  - > 0 meters (white) – 2 meters (navy)



Inundation Depth

- Potential inundation depth as determined by HAND model
  - 0 meters (white) – 2 meters (navy)
  - Corresponds with moderate flooding along Flint River



Inundation Depth

- Dec. 26, 2015, inundation along Flint River (southeast of Huntsville, AL)

Image from: https://www.youtube.com/watch?v=ud1bdVjOZJs

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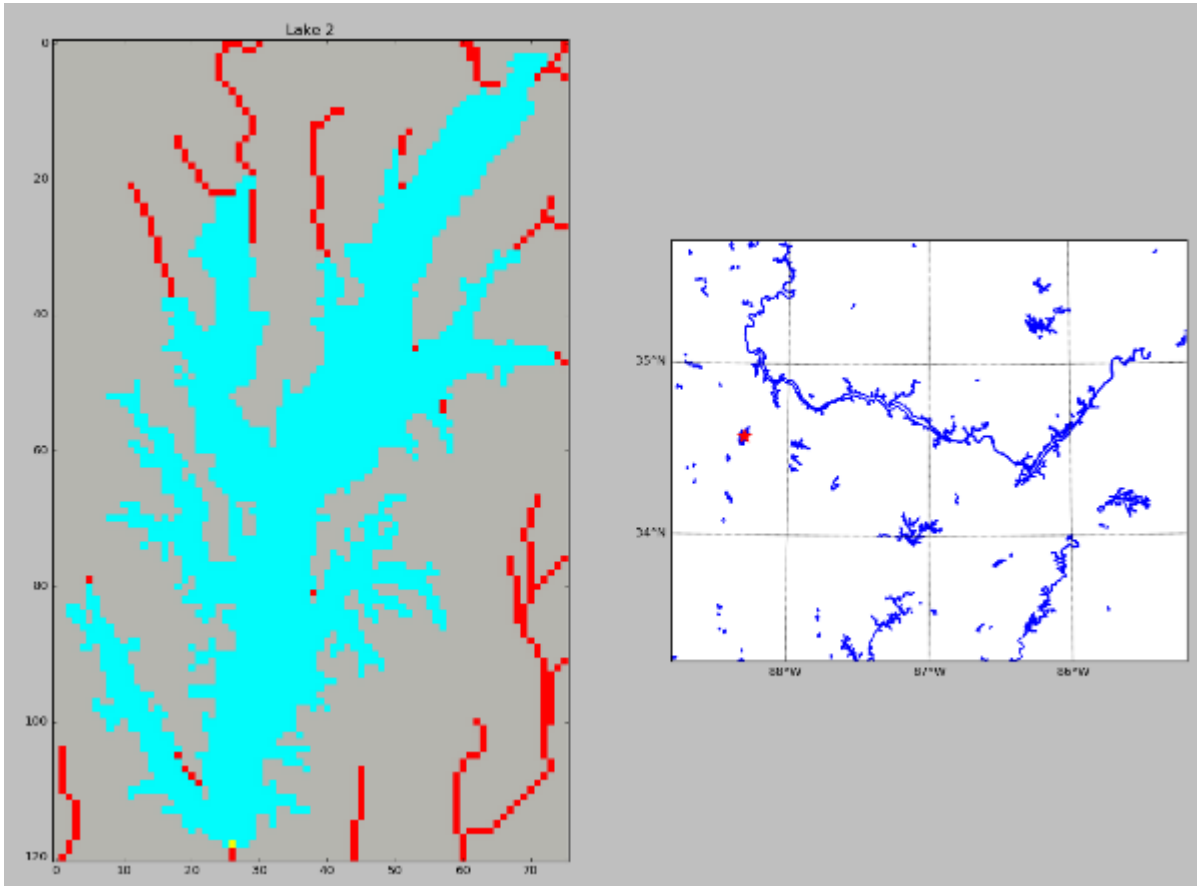
Development of Tools for WRF-Hydro Community

Interactive Python Tool/Widget

- Uses Python Tkinter module (open-source; useful for those without ArcGIS license)
- Compatible with NCAR WRF-Hydro Preprocessing Tool
- Mouse and keyboard controls, pan and zoom capabilities
- Modify channel grid and lake grid elements as needed to remove channel artifacts and fix discontinuities caused by lake masking
- Can be extended for other modifications
- Intended for regional domains



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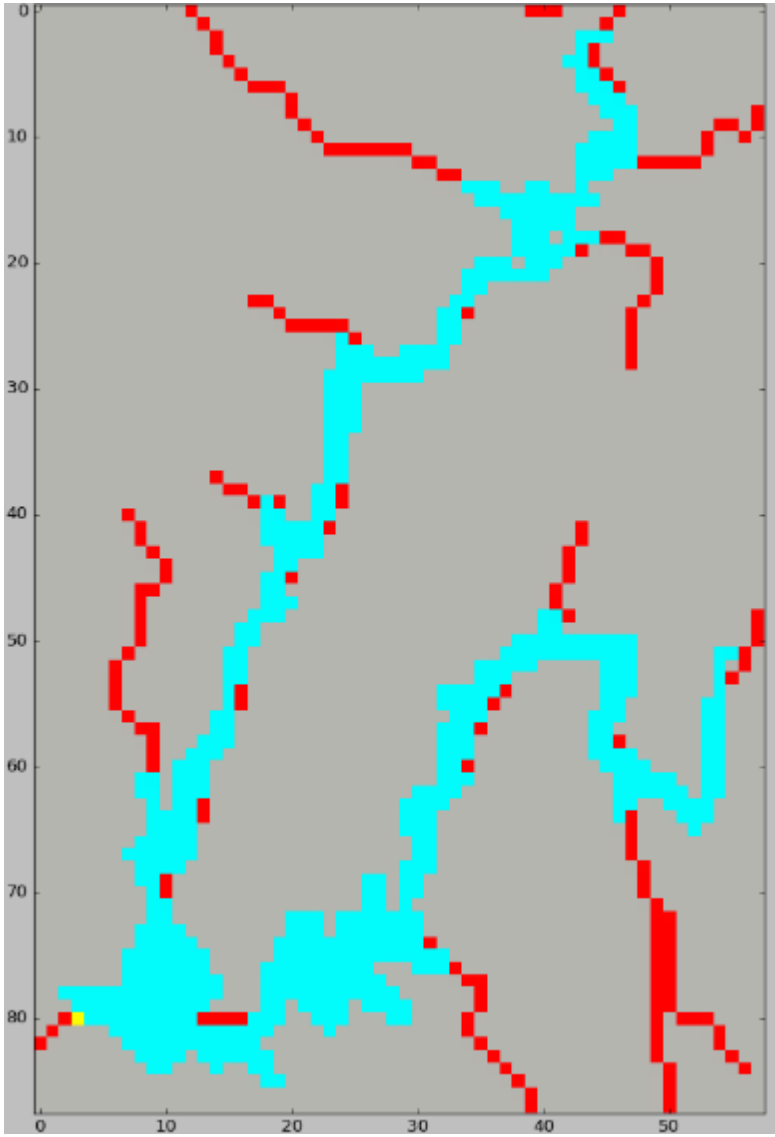
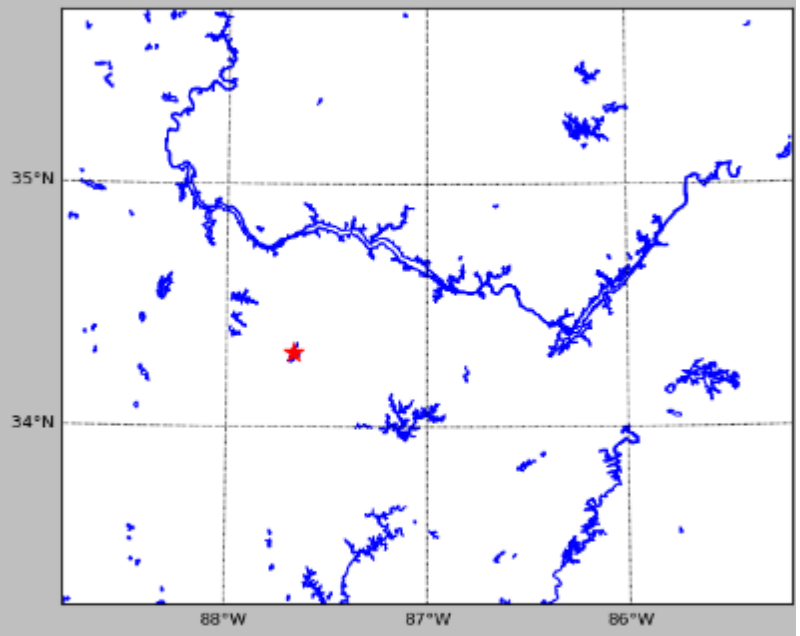
Development of Tools for WRF-Hydro Community

Before:





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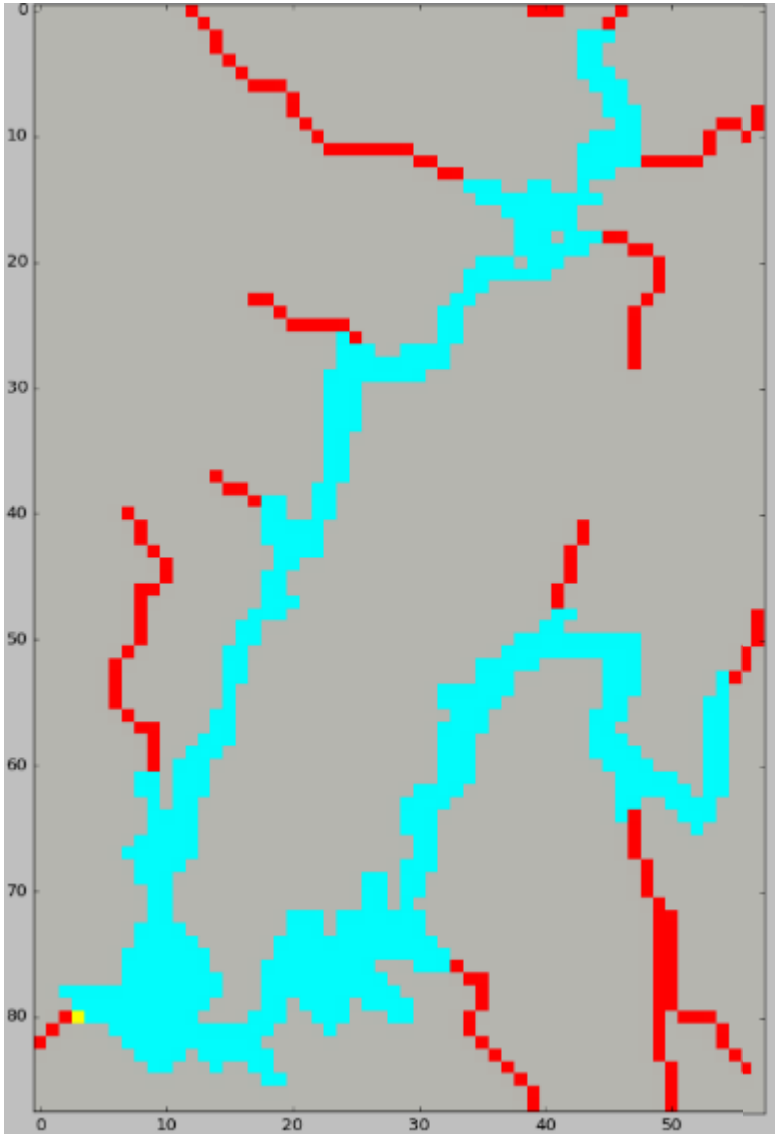
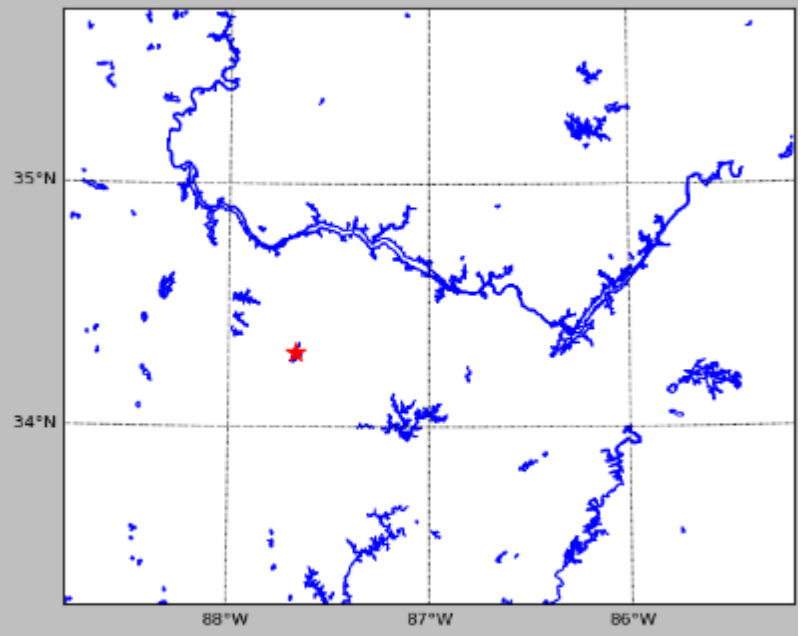
Development of Tools for WRF-Hydro Community

After:





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Summary and Future Work

- NASA SPoRT's mission includes transitioning NASA datasets to operations to address forecast problems
- SPoRT is assimilating/ingesting satellite soil moisture and vegetation measurements into the operational SPoRT-LIS, which is currently being coupled to WRF-Hydro by GSFC and NCAR
- LIS is an ideal candidate for assimilating NOAA and NASA observations of land surface state variables into the NWM
- In collaboration with the NWC, SPoRT is developing an offline, experimental version of the NWM to evaluate the impact of NASA mission datasets (e.g., SMAP soil moisture, VIIRS real-time vegetation)

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Questions/Discussion

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