Assimilating Satellite-derived Soil Moisture and Ingesting Real-time Vegetation into WRF-Hydro using the NASA LIS

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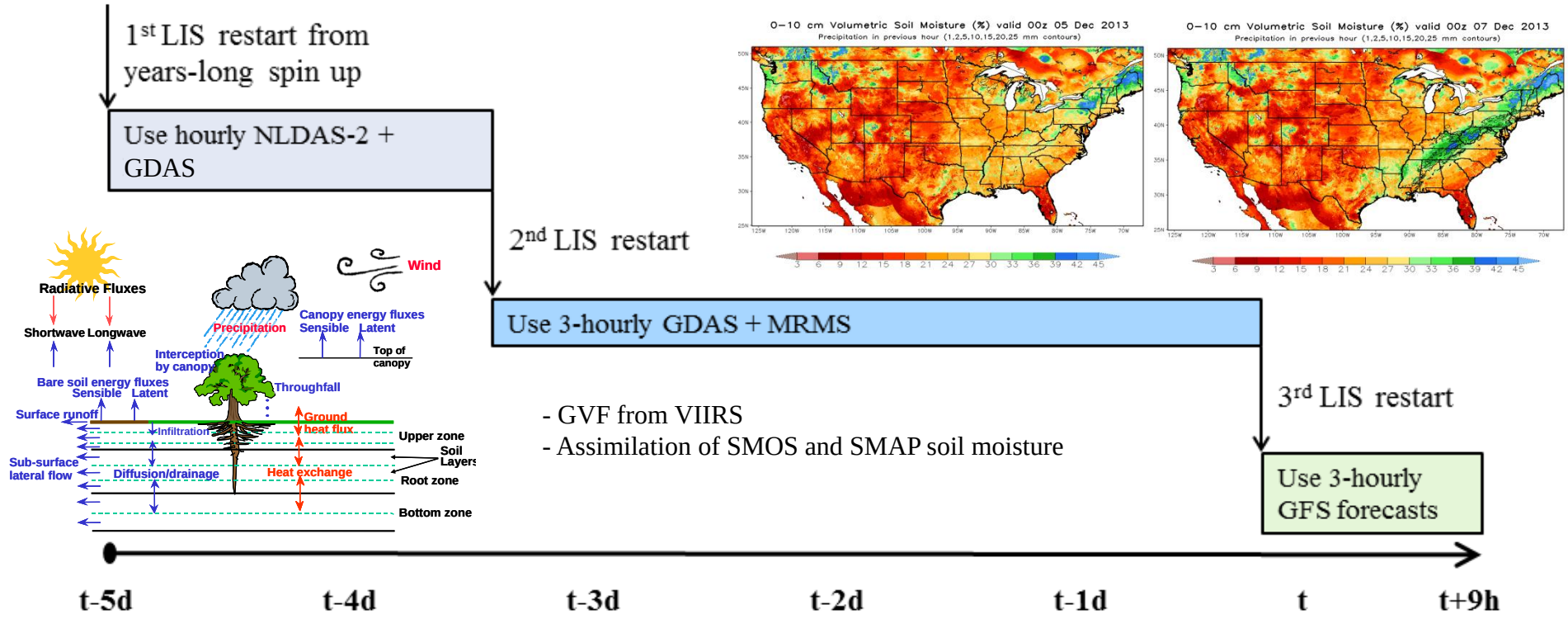
Operational SPoRT LIS

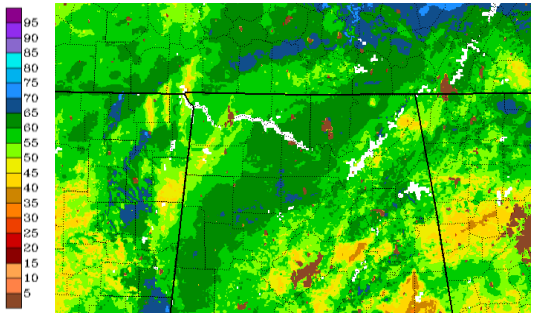


- **CONUS, 3-km resolution**
- **NASA LIS (Kumar et al. 2006; Peters-Lidard et al. 2007) used to perform long-term integration of Noah Land Surface Model (LSM) updated in real-time**
- **Assimilation of soil moisture gives even more accurate LSM soil moisture fields**
  - **Currently undergoing operational assessment**
- **Output used for situational awareness and local modeling by forecasters at select NWS offices and international forecasting agencies**

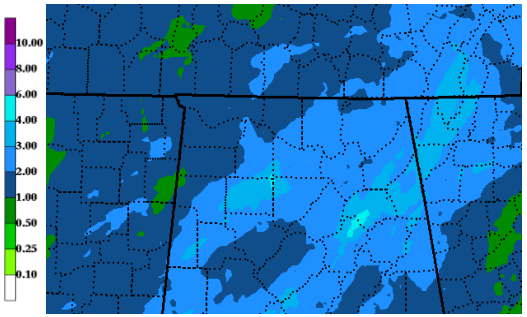
Application: Areal Flood Potential

March

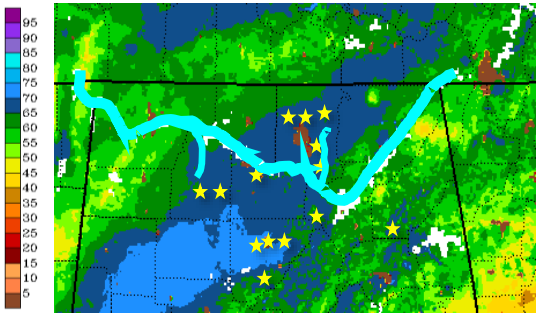
Moderate antecedent soil moisture



Moderate-heavy precipitation

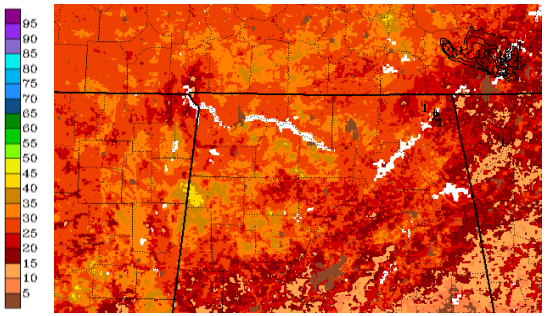


Moderate river flooding and numerous flooding reports

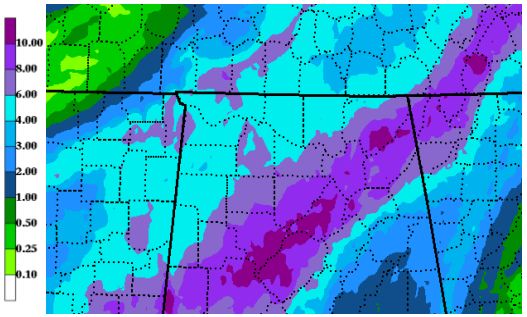


September

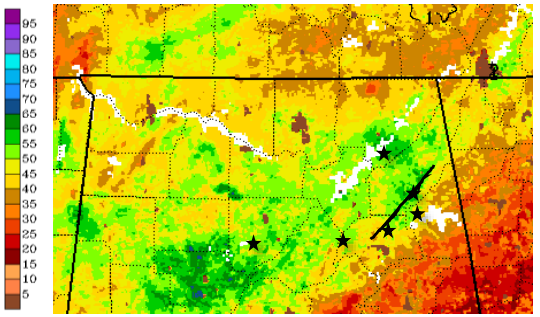
Low antecedent soil moisture



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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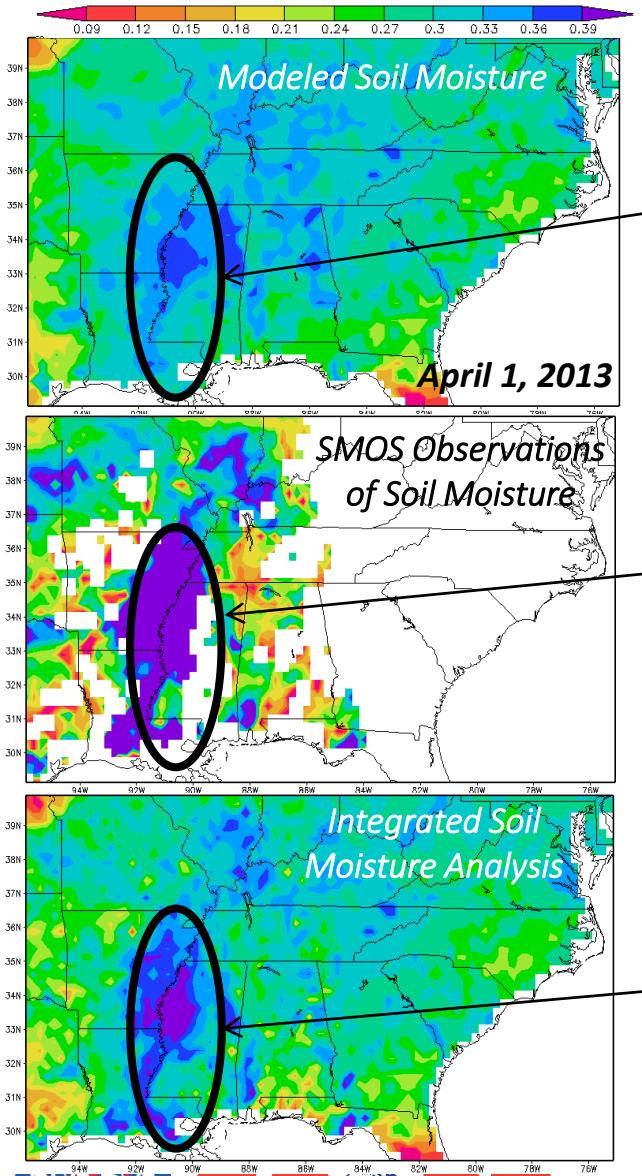
Assimilation of Soil Moisture Data

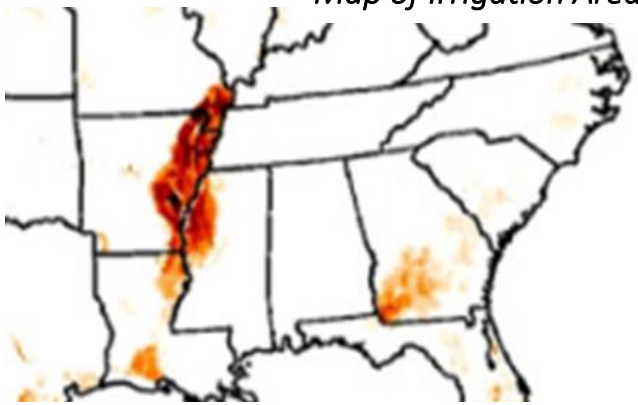


Model soil moisture concentration forced only by precipitation and misses magnitude of irrigation-saturated MS Valley

SMOS observes irrigated fields

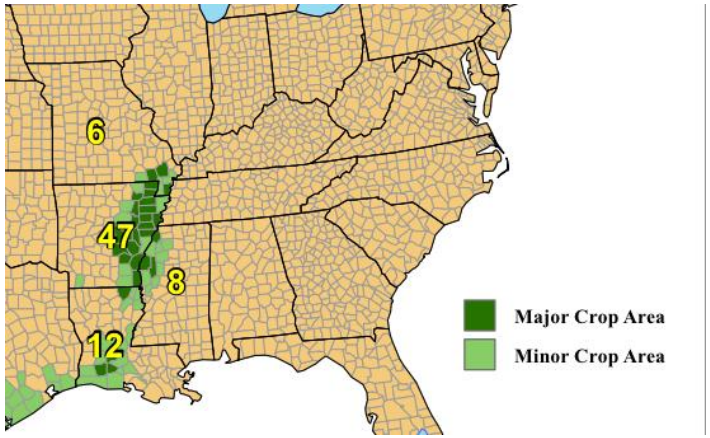
Blended analysis of model and observations better represent irrigated area and should result in improved weather and hydrologic modeling

Map of Irrigation Areas



From U. of Frankfurt-FAO (Ozdogan 2001)

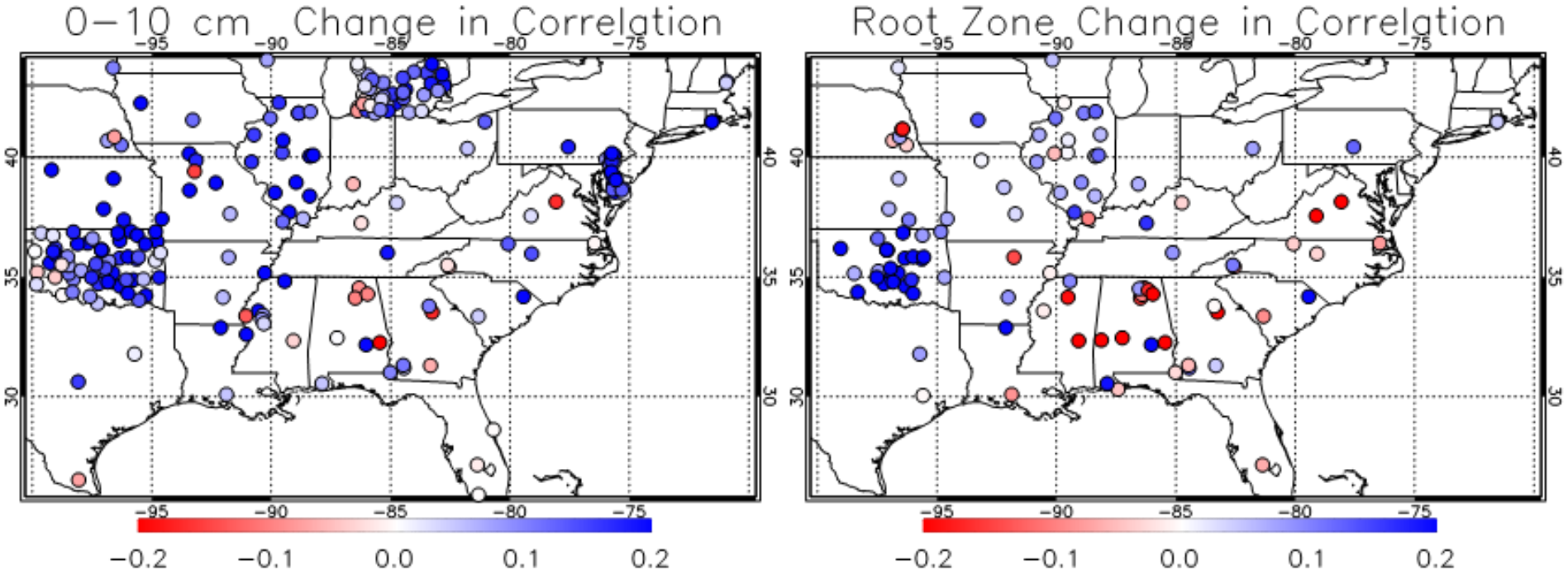
Rice growing areas



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

(Blankenship et al. 2016)

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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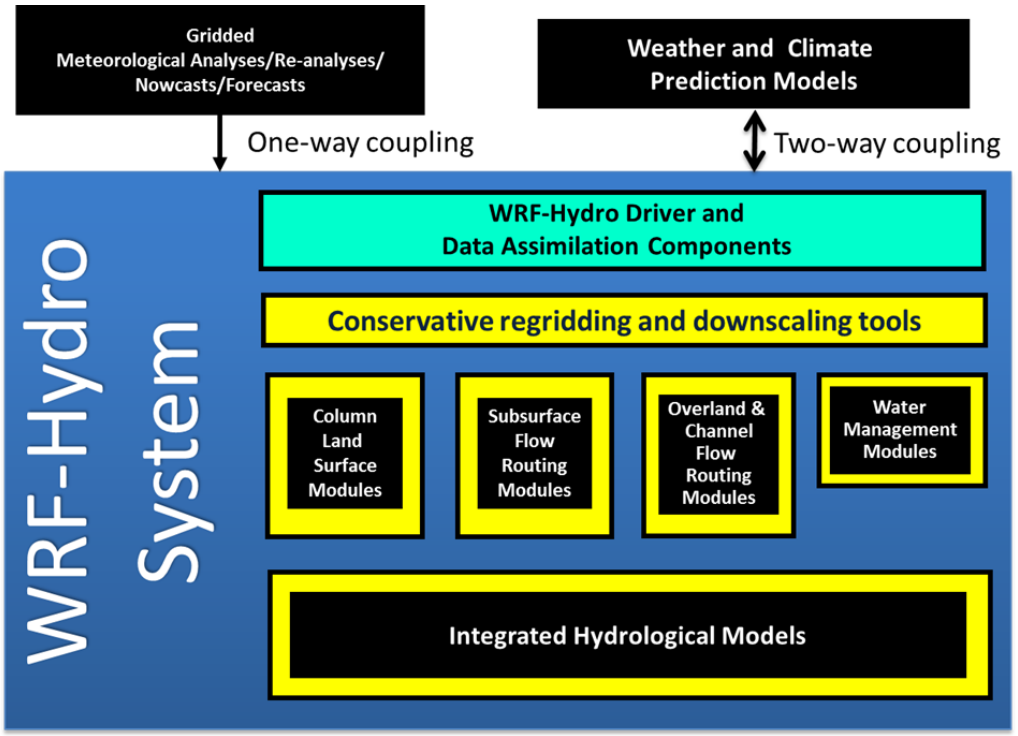
(Blankenship et al. 2016)

WRF-Hydro System

- Weather Research and Forecasting model hydrological extension package (WRF-Hydro; Gochis et al. 2013)
- Extensible, high-resolution hydrologic routing and streamflow modeling framework
- Contains column land surface, terrain routing, and channel routing modules
- National Water Model (NWM; Office of Water Prediction 2017) runs instantiation of WRF-Hydro operationally



(NCAR 2017)

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Coupling LIS and WRF-Hydro

- Collaborative project between NASA GSFC and NCAR (Santanello et al. 2015)
  - 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
- Plan to leverage this project to assimilate/integrate NASA mission datasets in WRF-Hydro using the LIS Ensemble Kalman Filter (EnKF)

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Assimilation of SMAP/SMOS into WRF-Hydro

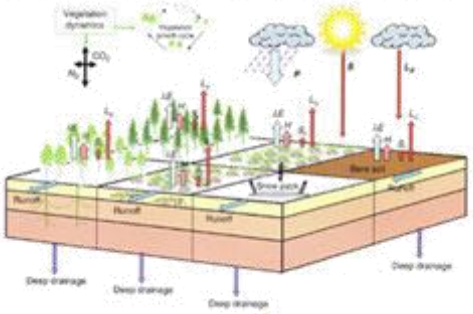
- Soil moisture (SMAP/SMOS)
- Snow cover (MODIS/VIIRS) and snow water equivalent (AMSR2)
- Total terrestrial/ground water (GRACE/GRACE-Follow On)
- Other future NASA missions (ICESat-2, Landsat-9)

- Inundation and Streamflow (NISAR, SWOT)

WRF-Hydro System

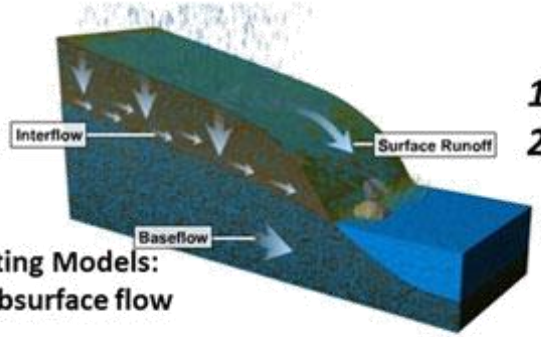
NASA LIS

Column Land Surface Models:



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

2-way coupling

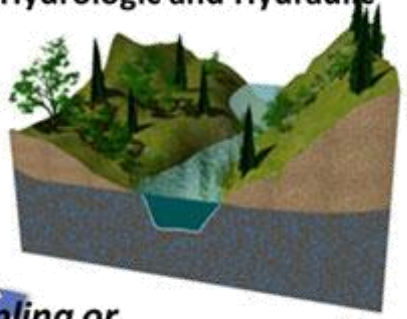


Terrain Routing Models:
Overland, subsurface flow

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

1-way coupling or 2-way coupling

Channel & Reservoir Routing Models: Hydrologic and Hydraulic



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

(NCAR 2017)

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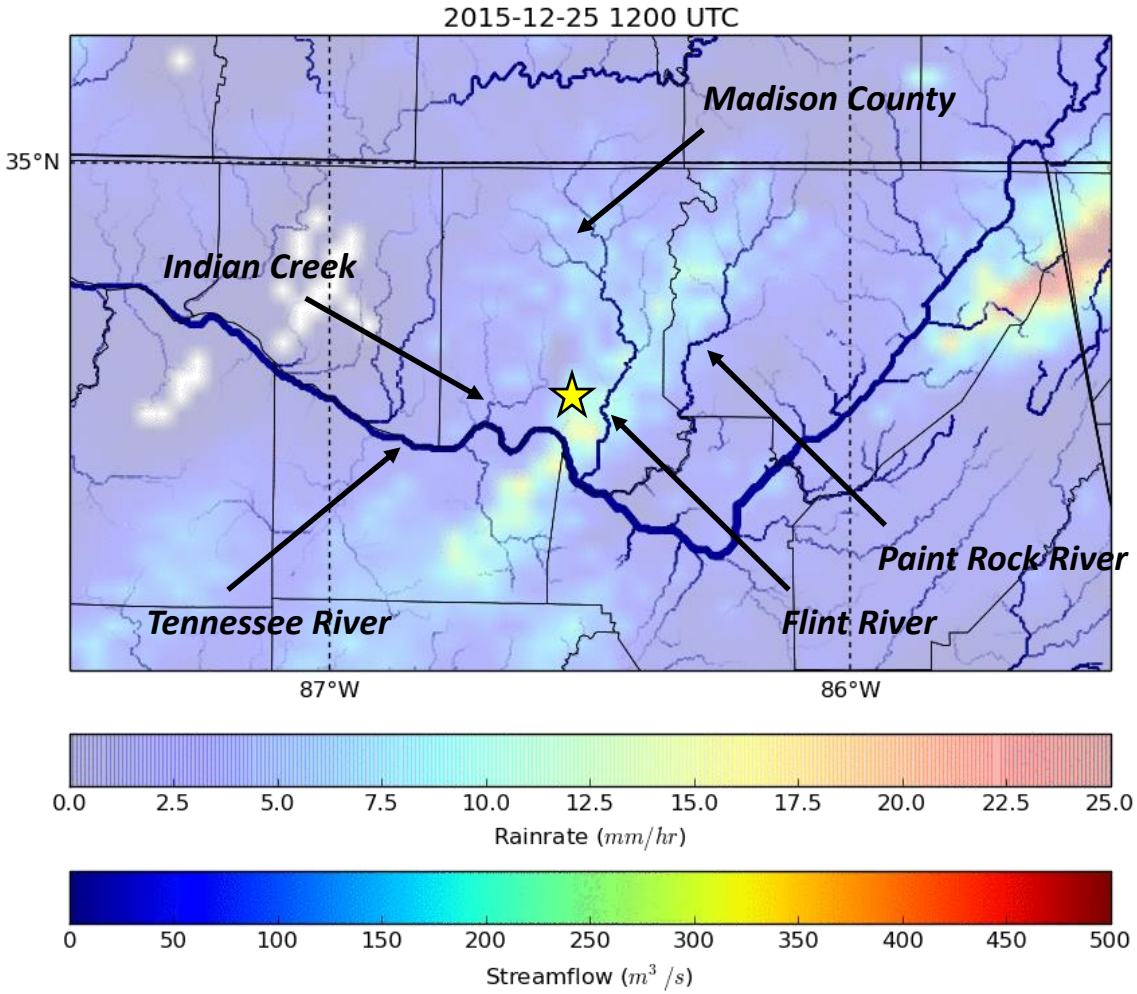
Evaluating LIS fields in WRF-Hydro

December 2015 Alabama Flood



- Noah-MP initialized with SPORT-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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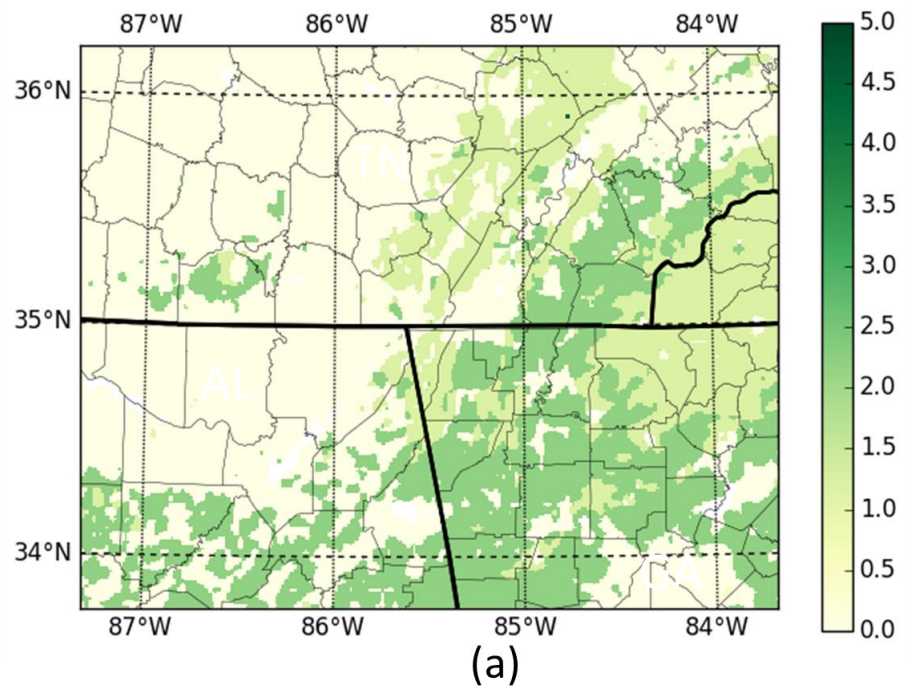
Elmer et al. (2017), Monday afternoon poster session, 19.

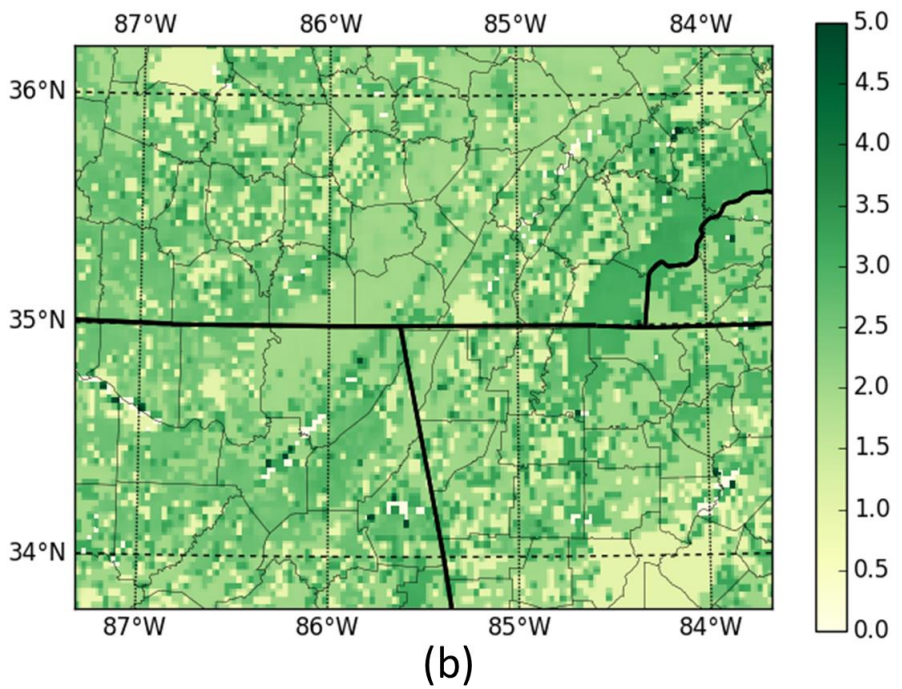
Impacts of Real-time Vegetation

Monthly Mean LAI - December



(a)

Real-time LAI (VIIRS/LIS) - 20151223



(b)

- Ongoing project to quantify impact of VIIRS real-time vegetation on simulated soil moisture and streamflow
- Larger deviations from climatology also likely in early spring and late fall

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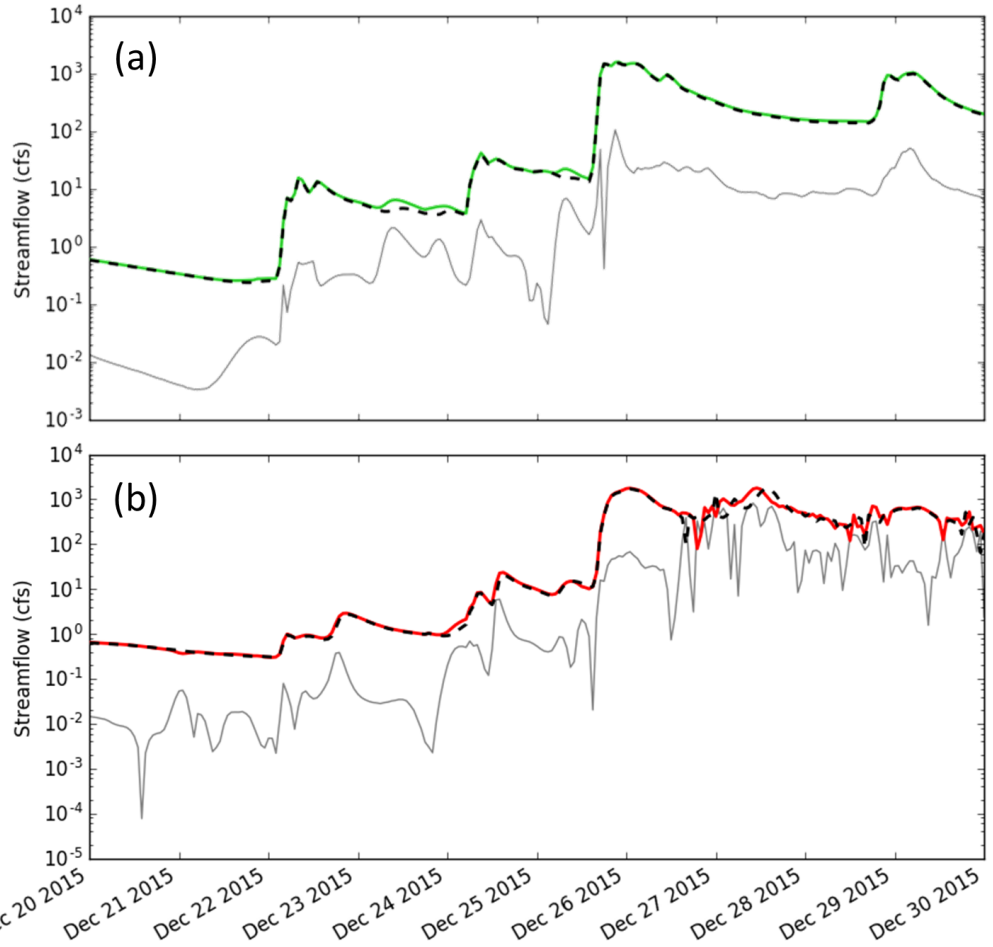
(Elmer et al. 2016)

Impacts of Real-time Vegetation

- 20-29 December 2015 modeled streamflow
- climatological GVF (dashed black line) and real-time VIIRS GVF (solid green/red line)
- Absolute difference (gray solid line)
- Replacing climatological GVF with real-time GVF results in approximately 1% change in streamflow (i.e., minimal impact for high-flow event)
- Greater differences expected for low-flow events



(Elmer et al. 2016)

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 EnKF enables assimilation of satellite-based observations (e.g., SMAP, SMOS, MODIS, VIIRS, AMSR-2, ICESat-2, etc.)
- SPoRT-LIS is being upgraded to include a Noah-MP LSM run using NWM configurations to demonstrate impacts of NASA datasets in NWM

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Summary and Future Work

- SPoRT is assimilating/ingesting satellite soil moisture and vegetation measurements into the operational SPoRT-LIS
- NASA LIS being coupled to WRF-Hydro by GSFC and NCAR
- In collaboration with the National Water Center (NWC), SPoRT is developing an offline, experimental version of the NWM to evaluate the impact of current and future NASA mission datasets (e.g., SMAP soil moisture, VIIRS real-time vegetation, SWOT surface water elevations)

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NASA SPoRT

Webpage: http://weather.msfc.nasa.gov/sport/

Blog: https://nasasport.wordpress.com/

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References

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Peters-Lidard, C. D., et al., 2007: High-performance Earth system modeling with NASA/GSFC's Land Information System. *Innovations Syst. Softw. Eng.*, **3**(3), 157-165, doi:10.1007/s11334-007-0028-x.

Santanello, Jr., J. A., S. V. Kumar, D. Gochis, C. DeLuca, C. D. Peters-Lidard, 2015: An integrated, observation-driven hydrological modeling system using LIS and WRF-Hydro enabled by ESMF. 2015 NASA Research Opportunities in Space and Earth Science Funded Proposal (NNH15ZDA001N-MAP), 21 pp.

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