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

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Operational SPoRT LIS

1st LIS restart from years-long spin up

Use hourly NLDAS-2 + GDAS

2nd LIS restart

Use 3-hourly GDAS + MRMS

- GVF from VIIRS
- Assimilation of SMOS and SMAP soil moisture

3rd LIS restart

Use 3-hourly GFS forecasts

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

SMOS observes irrigated fields.

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

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

NASA LIS

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

2-way coupling

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

Terrain Routing Models:
- Overland, subsurface flow

One-way coupling or 2-way coupling

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

(NCAR 2017)
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)

Elmer et al. (2017), Monday afternoon poster session, 19.
• 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

(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.
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

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References