Land Surface Model Assimilation of SMOS Soil Moisture Retrievals

Clay Blankenship (USRA)
Jonathan Case (ENSCO Inc.)
Bradley Zavodsky (NASA)

NASA-Marshall Space Flight Center (Huntsville, Alabama USA)
Short-Term Prediction Research and Transition (SPoRT) Center
Goal: Assimilate SMAP satellite retrievals of soil moisture into a regional land surface model.

• Demonstrate impact on: LSM soil moisture field coupled NWP forecasts

• Transition a real-time version of LIS output to end users.

Using SMOS assimilation to prepare for SMAP.
Motivation

– Improve model depiction of soil moisture and related variables
  (Direct Applications)
  drought monitoring, flood forecasting, agriculture

– Better numerical weather forecasts using coupled NWP/LSM
  Available moisture affects humidity, sensible/latent heating, diurnal heating rate, and convection.
Mission: Transition 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
- SPoRT activities began in 2002, first products to AWIPS in 2003
- Co-funded by NOAA since 2009 through Proving Ground activities
- 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
- Take satellite instruments with climate missions and apply data to solve shorter-term weather problems
Framework for running LSMs incorporating a wide variety of meteorological forcing data and land surface parameters

- Developed at NASA-GSFC
- Includes data assimilation capability.
- Can be run coupled with WRF.

Experiments done in Noah 3.2 Land Surface Model (LSM) within LIS

NASA SPoRT maintains near-real-time and experimental LIS runs

- SE US (3-km), shared with WFO’s
- East Africa, shared with Kenya Meteorological Service (KMS)
**Applications: Flood Potential**

March – *moderate antecedent soil moisture, moderate rain*

- Moderate river flooding and numerous flooding reports

September – *low antecedent soil moisture case*

- Heavy precipitation
- Isolated minor flooding

Contrasting antecedent soil moisture likely played a strong role in the different outcomes

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.

SMOS and SMAP

• L-band radiometers (and radars) can be used to estimate soil moisture near the surface
  – Compared to higher frequency instruments:
    o Sees deeper in the soil (~5 cm)
    o Better vegetation penetration
    o Higher sensitivity (accuracy)
• SMAP radar gives improved horizontal resolution
• Assimilating retrievals from Soil Moisture and Ocean Salinity (SMOS) satellite
• Preparing for assimilation of NASA Soil Moisture Active/Passive (SMAP) retrievals

<table>
<thead>
<tr>
<th>Name</th>
<th>AMSR-E</th>
<th>SMOS</th>
<th>SMAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency</td>
<td>NASA/JAXA</td>
<td>ESA</td>
<td>NASA</td>
</tr>
<tr>
<td>Launch</td>
<td>2002</td>
<td>2009</td>
<td>Jan. 2015</td>
</tr>
<tr>
<td>Orbit</td>
<td>Polar</td>
<td>Polar</td>
<td>Polar</td>
</tr>
<tr>
<td>Sensor Type</td>
<td>Passive</td>
<td>Passive</td>
<td>Passive</td>
</tr>
<tr>
<td></td>
<td>Passive</td>
<td>Active (Failed July 2015)</td>
<td>Combined</td>
</tr>
<tr>
<td>Frequency</td>
<td>6.9 GHz (C-band)</td>
<td>1.4 GHz (L-band)</td>
<td>1.41 GHz</td>
</tr>
<tr>
<td>Resolution</td>
<td>56 km</td>
<td>35-50 km</td>
<td>36 km</td>
</tr>
<tr>
<td>Accuracy</td>
<td>6 cm³/cm³</td>
<td>4 cm³/cm³</td>
<td>4 cm³/cm³</td>
</tr>
</tbody>
</table>

The SMAP Active/Passive product maintains the high accuracy of SMOS with better spatial resolution, enabling reduced representativeness error due to inhomogeneities.
Data Assimilation in LIS

- Uses Ensemble Kalman Filter in LIS
- Combines Background (Model) and Observations (Satellite Retrievals), weighted by their uncertainties, to provide a new analysis
- Observation operator relates the top model layer of soil moisture (0-10 cm) to the bias-corrected observations (~5 cm).
- Better depiction of top layer can improve deeper layers through drainage and diffusion.

Figure from J. Anderson, NCAR.
LIS can apply point-by-point correction curves. To increase the background dataset size, we are aggregating points by landcover type. We will also explore correction at each point and aggregating by soil type.

In general, observations are drier than the model but have a higher dynamic range.
Bias Correction

- Implemented landcover-based CDF matching correction for SMOS retrievals.
Example DA (rice irrigation)

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

Yellow numbers indicate percentage of national crop yield due to each state.
3-km results (14 May 2011)
Experiment Design

- Southeastern/Central USA 3-km domain
- MODIS/IGBP Vegetation Type
- STATSGO Soil Type
- Daily MODIS GVF
- North American Land Data Assimilation 2 (NLDAS-2) forcing
- Precip: Stage IV (radar+gauge)

- 1-yr spinup, 1 month perturbations, 32 ensemble members
- Experiment run March-October 2011
- SMOS DA
  - State, Observation, and Forcing Perturbations
  - Control (Open loop with perturbations)

- Validation
  - North American Soil Moisture Database
  - Due to scale mismatch, expect correlations to be most useful metric
SMOS DA Validation

0-10 cm model soil moisture
Compared open loop run to
SMOS DA run.

Results from validation against soil moisture networks in US
(North American Soil Moisture Database)
• Better correlations
• Improved dynamic range
SMOS DA Validation

<table>
<thead>
<tr>
<th></th>
<th>Near Surface (0-10 cm)</th>
<th>Root Zone (10-100 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.6%</td>
<td>23.5%</td>
</tr>
<tr>
<td>SMOS DA</td>
<td>-0.5%</td>
<td>21.8%</td>
</tr>
</tbody>
</table>
SMOS DA Validation

<table>
<thead>
<tr>
<th></th>
<th>Near Surface (0-10 cm)</th>
<th>Root Zone (10-100 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.6%</td>
<td>23.5%</td>
</tr>
<tr>
<td>SMOS DA</td>
<td>-0.5%</td>
<td>21.8%</td>
</tr>
</tbody>
</table>
WRF impact tests

- Coupled LIS/WRF runs
  - NWP provides forcing for LSM
  - LSM provides fluxes and surface conditions to NWP model
- Assess impact of SMAP DA on NWP for coupled runs
  - Verify NWP forecasts against surface obs, soundings, and precipitation analyses
  - Examine impact on significant events

<table>
<thead>
<tr>
<th>Validation Datasets</th>
<th>Domain</th>
<th>T, q, wind</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFS Atmospheric Boundary Conditions</td>
<td>CONUS</td>
<td>MADIS</td>
<td>MRMS</td>
</tr>
<tr>
<td></td>
<td>East Africa</td>
<td>WMO network</td>
<td>GPM IMERG</td>
</tr>
</tbody>
</table>
WRF impact tests

- Weather impacts of improved LSM states
  - Moisture
  - Surface fluxes
  - Diurnal heating rates
  - Convection

Impact of using high-res LIS output in WRF rather than NAM fields.
(Case et al. 2008, J. Hydro.)
Open Loop

SMOS DA

WRF Impact

Initial Soil Moisture

CAPE (21-h Fcst)

- Soil moisture and associated surface fields have known impacts on weather
- How much can SMAP retrievals improve weather forecasts?
Summary and Plans

Successful validation of SMOS DA showing improved correlations with ground observations for upper layer (0-10 cm) and root zone (10-100 cm).

Future Plans

• Assimilate SMAP data
  – L2 Active-Passive Retrieval (9 km) product (limited time period)
  – L2 Passive Retrieval (36 km)
  – Awaiting info on other SMAP products
• Coupled LIS-WRF experiments using NU-WRF
  – NWP validation over US and East Africa
• Implement DA in near-real-time LIS runs
  – Transition products to NWS and international partners
• Further investigate bias correction

Predicted Impacts

• Improved resolution of SMAP Active-Passive product will reduce representativeness errors due to heterogeneity while maintaining high accuracy
• Better depiction of gradients and structure for coupling with NWP models at convection-allowing resolution (3 km) for regional forecasting
Extras/scratch space...
Applications: Drought Monitoring

- Soil moisture from SPoRT LIS has been used by NWS forecasters to refine drought indices on the county scale (Huntsville, Houston, Raleigh)
- Soil moisture and GVF output from LIS could also be applied to situational awareness and forecasts of red flag warnings and potential for fires