SMOS Soil Moisture Validation with Dense and Sparse Networks in the U.S.

T. J. Jackson, R. Bindlish, M. Cosh, and T. Zhao
USDA ARS Hydrology and Remote Sensing Lab
Beltsville, MD 20705 USA
Tom.jackson@ars.usda.gov

November 29, 2010
Overview

- *Contribution to the validation of the SMOS soil moisture product.*
- In situ based observations should be a component of validation; however, we have to deal with the disparity of spatial scales
  - In situ measurements of soil moisture are made at a point (a few square cm in size) whereas satellite sensors provide an integrated area/volume value for a much larger spatial extent (~40 km).
- Robust validation of a global product requires diverse conditions.
- These issues are common to SMOS and most other passive microwave sensors (AMSR-E, WindSat, SMAP).
- **Approach:** combination of a limited set of dense in situ soil moisture observing networks, a sparse network spanning the U.S., and soil moisture products from AMSR-E.
- *The SMOS soil moisture products are not final and will likely change.*
Validation Approach

• Combination of
  – In situ data sources
    • Limited set of dense networks
      – USDA ARS research watersheds
      – Higher quality information
      – Scaling is addressed by integrating multiple sites and additional intensive sampling
    • A sparse network
      – Soil Climate Analysis Network (SCAN)
      – Single points distributed throughout the U.S.
      – Scaling: TBD
  – Soil moisture products from AMSR-E.
Dense Watershed Networks

- Four soil moisture networks (AZ-WG, GA-LR, ID-RC, OK-LW) were developed and used as part of the AMSR-E validation program.
- Each network is located in a different climatic region of the U.S., and each provides estimates of the average soil moisture over highly instrumented experimental watersheds and surrounding areas that approximate the size a SMOS footprint.
- Soil moisture measurements at 5 cm have been made at these validation sites on a continuous basis since 2002 (*eight year period of record*).
- Sites have been calibrated and verified through field campaigns and used in the validation of other satellite products.
Dense Watershed Networks

- Photos of Land Cover Conditions

AZ-WG  OK-LW  GA-LR  ID-RC
Dense Watershed Networks

- Four soil moisture networks (AZ-WG, GA-LR, ID-RC, OK-LW) were developed and used as part of the AMSR-E validation program.
- Each network is located in a different climatic region of the U.S., and each provides estimates of the average soil moisture over highly instrumented experimental watersheds and surrounding areas that approximate the size a SMOS footprint.
- Soil moisture measurements at 5 cm have been made at these validation sites on a continuous basis since 2002 (*eight year period of record*).
- Sites have been calibrated and verified through field campaigns and used in the validation of other satellite products (AMSR-E, WindSat).
Soil Climate Analysis Network (SCAN)

- Operated by the USDA NRCS (1991- )
- Provides hourly meteorological observations including 5 cm and full profile soil moisture
- Currently the network has 151 stations throughout the U.S.
- Very limited quality control is applied.
- Effort underway to evaluate calibration quality.
- Still need to address the point scaling issue!
Role of Alternative Satellite Soil Moisture Products in SMOS Validation

• Soil moisture products are provided by AMSR-E, WindSat, and ASCAT. We will focus on AMSR-E.

• Differences in soil moisture estimates might be due to:
  – Improved contributing depth and reduced canopy attenuation of SMOS
  – Diurnal variations in soil moisture associated with overpass times: SMOS (6 am/6 pm), AMSR-E (1:30 am/1:30 pm), WindSat (6 am/6 pm)

• This is not a direct comparison of SMOS vs. AMSR-E retrievals. It is a performance comparison with the in situ data.

• These other satellite products have been validated (in particular AMSR-E for the dense watersheds) and provide a benchmark on retrieval performance.
Example: AMSR-E Validation Using the Dense Watershed Networks

- Comparison of four algorithms over a 7-year period
- Revealed quite different behavior (bias, range, and accuracy) for each algorithm.
- Results established the performance of these algorithms at these sites.
- Conclusion: it is possible to retrieve soil moisture within mission specified accuracies and bias.
Example: AMSR-E Validation

- The target accuracy for AMSR-E was 0.06 m³/m³ (JAXA had indicated 0.10 m³/m³ as its minimum requirement). Results show that some algorithms can meet this requirement.
- These results establish the performance of these algorithms at these sites for this satellite instrument. They also provide a benchmark for other approaches.
- Since SMOS is a better soil moisture sensor, it is expected that its performance will meet or exceed that of the AMSR-E products.

### Summary Algorithm Performance Statistics (All Watersheds)

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>RMSE</th>
<th>Bias</th>
<th>SEE (Watershed Bias)</th>
<th>SEE (Watershed Regression)</th>
<th>SEE (Global Bias)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAXA</td>
<td>0.073</td>
<td>0.040</td>
<td>0.060</td>
<td>0.039</td>
<td>0.061</td>
<td>11075</td>
</tr>
<tr>
<td>NASA</td>
<td>0.059</td>
<td>0.040</td>
<td>0.037</td>
<td>0.037</td>
<td>0.043</td>
<td>11737</td>
</tr>
<tr>
<td>SCA</td>
<td>0.040</td>
<td>-0.002</td>
<td>0.035</td>
<td>0.033</td>
<td>0.040</td>
<td>11429</td>
</tr>
<tr>
<td>LPRM</td>
<td>0.159</td>
<td>0.134</td>
<td>0.077</td>
<td>0.035</td>
<td>0.085</td>
<td>11737</td>
</tr>
</tbody>
</table>

RMSE (Root mean square error), Bias, and SEE (Standard error of estimate) are in m³/m³. N is the number of samples.
AMSР-E Validation: Lessons Learned on Seasonality and Period of Record

• Computed performance statistics from beginning for increasing period of record.
• SCA algorithm for three of the watersheds.
• Conclusions during the first 6 months would have been quite different than those from that point on, which were very stable.
• Seasonality of the test sites is very important. Anomalous conditions (drought or floods) could also impact conclusions.
• TAKE INTO CONSIDERATION WHEN INTERPRETING EARLY SMOS RESULTS!
SMOS Results

• Preliminary watershed networks results
  – Observed vs. estimated soil moisture

• AMSR-E comparisons
  – Does this POR match the previous long-term study results? (Any anomalies?)
  – Statistical comparisons
  – Closer look at sites

• SCAN results
SMOS Validation (Feb. 1-Oct 31, 2010)

First reaction: reasonable results but what should we expect? Look at AMSR-E.
How does this POR Compare to the Long Term AMSR-E Results?

Summary of AMSR-E Soil Moisture Statistics (SCA)

- Long Term: From Jackson et al. (2010): 7 year data set
- Short Term: 9 month 2010 data set

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Algorithm</th>
<th>AMSR-E Dsc. 0130</th>
<th>AMSR-E Asc. 1330</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RMSE</td>
<td>Bias</td>
</tr>
<tr>
<td>Walnut Gulch, AZ</td>
<td>Long Term</td>
<td>0.021</td>
<td>-0.008</td>
</tr>
<tr>
<td></td>
<td>Short Term</td>
<td>0.032</td>
<td>-0.023</td>
</tr>
<tr>
<td>Little Washita, OK</td>
<td>Long Term</td>
<td>0.053</td>
<td>-0.017</td>
</tr>
<tr>
<td></td>
<td>Short Term</td>
<td>0.052</td>
<td>-0.032</td>
</tr>
<tr>
<td>Little River, GA</td>
<td>Long Term</td>
<td>0.051</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td>Short Term</td>
<td>0.050</td>
<td>0.039</td>
</tr>
<tr>
<td>Reynolds Creek, ID</td>
<td>Long Term</td>
<td>0.024</td>
<td>-0.011</td>
</tr>
<tr>
<td></td>
<td>Short Term</td>
<td>0.041</td>
<td>-0.035</td>
</tr>
</tbody>
</table>

RMSE (Root mean square error), Bias, and SEE (Standard error of estimate) are in m³/m³.

- Conclusion: This time period does not appear to be anomalous for AMSR-E/SCA
## Comparison of SMOS and AMSR-E Soil Moisture Statistics (SCA)

- Short Term: 9 month 2010 data set Feb. 1-October 31, 2010

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Algorithm</th>
<th>SMOS Asc. 0600 AMSR-E Dsc 0130</th>
<th>SMOS Dsc. 1800 AMSR-E Asc. 1330</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RMSE</td>
<td>Bias</td>
</tr>
<tr>
<td>Walnut Gulch, AZ</td>
<td>SMOS</td>
<td>0.042</td>
<td>-0.001</td>
</tr>
<tr>
<td></td>
<td>AMSR-E</td>
<td>0.032</td>
<td>-0.023</td>
</tr>
<tr>
<td>Little Washita, OK</td>
<td>SMOS</td>
<td>0.056</td>
<td>-0.018</td>
</tr>
<tr>
<td></td>
<td>AMSR-E</td>
<td>0.052</td>
<td>-0.032</td>
</tr>
<tr>
<td>Little River, GA</td>
<td>SMOS</td>
<td>0.051</td>
<td>0.026</td>
</tr>
<tr>
<td></td>
<td>AMSR-E</td>
<td>0.050</td>
<td>0.039</td>
</tr>
<tr>
<td>Reynolds Creek, ID</td>
<td>SMOS</td>
<td>0.037</td>
<td>-0.027</td>
</tr>
<tr>
<td></td>
<td>AMSR-E</td>
<td>0.041</td>
<td>-0.035</td>
</tr>
</tbody>
</table>

RMSE (Root mean square error), Bias, and SEE (Standard error of estimate) are in m³/m³.

- Conclusion: Not too bad… but should be better.
- Closer look at results for each watershed.
SMOS Validation: AMSR-E Benchmark

The overall similarity of the error behavior is encouraging.
SMOS Validation: AMSR-E Benchmark

Recall that SMOS should be better than AMSR-E. The larger deviations for SMOS that are not apparent in AMSR-E suggest algorithm and/or parameter issues. (RFI?)
Comparison of SMOS and AMSR-E Soil Moisture Statistics (SCA)

- Short Term: 9 month 2010 data set Feb. 1-October 31, 2010

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Algorithm</th>
<th>SMOS Asc. 0600 AMSR-E Dsc 0130</th>
<th>SMOS Dsc. 1800 AMSR-E Asc. 1330</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RMSE</td>
<td>Bias</td>
</tr>
<tr>
<td>Walnut Gulch, AZ</td>
<td>SMOS</td>
<td>0.042</td>
<td>-0.001</td>
</tr>
<tr>
<td></td>
<td>AMSR-E</td>
<td>0.032</td>
<td>-0.023</td>
</tr>
<tr>
<td>Little Washita, OK</td>
<td>SMOS</td>
<td>0.056</td>
<td>-0.018</td>
</tr>
<tr>
<td></td>
<td>AMSR-E</td>
<td>0.052</td>
<td>-0.032</td>
</tr>
<tr>
<td>Little River, GA</td>
<td>SMOS</td>
<td>0.051</td>
<td>0.026</td>
</tr>
<tr>
<td></td>
<td>AMSR-E</td>
<td>0.050</td>
<td>0.039</td>
</tr>
<tr>
<td>Reynolds Creek, ID</td>
<td>SMOS</td>
<td>0.037</td>
<td>-0.027</td>
</tr>
<tr>
<td></td>
<td>AMSR-E</td>
<td>0.041</td>
<td>-0.035</td>
</tr>
</tbody>
</table>

RMSE (Root mean square error), Bias, and SEE (Standard error of estimate) are in m³/m³.

- Conclusion: Not too bad…but should be better.
- Closer look at results for each watershed.
SMOS Validation: LR
Vegetation/Temperature increase?

• Little River Watershed- summer crops
• SMOS and AMSR-E retrievals (SCA) for the same period (Feb. – Oct. 2010)
• Problem is unique to SMOS…something needs fixing?
• Somewhat larger errors for pm retrievals … related to temperature?
SMOS Validation: LR Crop Growth

- SMOS also provides an estimate of tau (vegetation opacity)
- Soil moisture retrieval error is correlated with tau: larger errors as tau increases
- Dsc errors > Asc errors; variability and sensitivity are higher
- More information is needed on source of tau, is it retrieved or estimated using ancillary data?
SMOS Validation: LR Temperature?

- SMOS also provides an estimate of soil temperature
- Soil moisture retrieval error is also correlated with soil temperature (not linear), increased sensitivity with $T$
- Patterns for Asc and Dsc are the same but Dsc covers a larger range of
- Does error result from the $T$ component and is it the nonlinearity and larger range that produces the larger errors for the Dsc?
SMOS Validation: Seasonality/Versions

- Multiple versions
- Seasonal changes are tied with the versions making it difficult to isolate sources of error
- 309 shows the largest errors but this is also peak biomass and temperature in the US
- It would be helpful if reprocessing was performed when a new version is introduced
SMOS Validation: SCAN Network

- When using SCAN data there are two issues to address; data quality and scaling
  - Data quality: SCAN stations that exhibited consistent soil moisture were selected (61 of 151)
  - Scaling: not addressed, much of the variability is the result of the disparity in spatial scale
- However, all things considered the results aren’t that bad
  - Error levels actually meet the minimum requirements specified for AMSR-E
- Further work needed to consider scales.
Summary

• Preliminary evaluation of the SMOS soil moisture products over U.S. sites.

• Approach: Combines in situ networks (dense and sparse) and AMSR-E soil moisture estimates.
  – Confidence in dense networks from previous field campaigns and AMSR-E validation.
  – AMSR-E products should be a benchmark for performance

• Reasonable results, ~ AMSR-E (remember these are preliminary)

• Results for specific sites may indicate specific problems with the retrieval algorithm.

• However; until we see the full reprocessing it is difficult to come to a conclusion.
SMAP Items

• NASA is expected to issue a Request for Information through NSPIRIS on SMAP Core Validation. (~Dec. 15th). This will be open to international participants and will provide access to SMAP data during the C/V phase in return for validation data.

• SMAP will hold a C/V Workshop May 3-5, 2011 in Oxnard, CA. Website is open, registration and accommodation links are supposed to be open later today (?). [http://Smap.jpl.nasa.gov](http://Smap.jpl.nasa.gov)