Inter-comparison and Validation of Soil Moisture Estimates from Microwave/Thermal Infrared Remote Sensing and Land Surface Model

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ABSTRACT

Significant advances have been achieved in generating soil moisture (SM) data products from satellite remote sensing and/or land surface modeling with reasonably good accuracy in recent years. However, the discrepancies among the different SM data products can be considerably large, which hampers their usage in various applications. Understanding the characteristics of each of these SM data products is required for many applications where the most accurate data products are desirable.
This study inter-compares five SM data products from three different sources over 14-year period from 2000 to 2013. Specifically, three microwave (MW) satellite based data sets (ECV, ECV active and passive products), one thermal infrared (TIR) satellite based product (ALEXI), and the Noah land surface model (LSM) simulations. The in-situ SM measurements from the North American Soil Moisture Database (NASMD), which involves more than 600 ground sites from a variety of networks, are used to evaluate the accuracies of these five SM data products.

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Introduction

The impact of **Soil Moisture (SM)** on precipitation forecasts of numerical weather prediction models is well known. The demand for consistent SM observations has been steadily growing over the past few years. In the past decade, a variety of methodologies have been studied to retrieve SM using satellite observations from different kinds of channels, including:

- ❖ **Active/Passive microwave (MW)**
- ❖ **Thermal Infrared (TIR)**
- ❖ **Land Surface Model (LSM)**

A number of studies have been focusing on the comparison of the various existing SM products from different sources (Al-Yaari et al. 2006, 2014, Reichle et al. 2004, Leroux et al.,2004, Wagner et al., 2003, Draper et al. 2009, Hain, 2011). However, the comparisons in the current literature were mainly based on no more than two data sources, either inter-comparisons of MW products within each other, or comparisons with model based simulations, or MW versus TIR. Furthermore, in the effort of in-situ validation, the comparison results were based on very limited number of ground sites.

This study attempts to conduct a **comprehensive** comparison of SM products from **four different sources**, including (1) Noah offline simulations as representative of SM predictions LSMs; (2) ECV, ECV active and passive SM products as representative of satellite based MW SM retrievals; (3) ALEXI SM proxy as representative of satellite based TIR SM retrievals; (4) ground based SM observations from the North American Soil Moisture Database (NASMD).

Data and Model

Data source	Archive	Resolution	Spatial coverage
Noah off-line	2000 – date	0.125 Deg./daily	CONUS
ALEXI	2000 - date	0.0899Deg./daily	CONUS
ECV Merged	1978 – 2013	0.25Deg./daily	Global
ECV Active	1991 – 2013	0.25Deg./daily	Global
ECV passive	1978 - 2013	0.25Deg./daily	Global
NASMD	1990s - date	-- / Hourly	>600 sites U.S.

- ❖ **Noah Land Surface Model**
  - ✓ Four-layer soil moisture (0-0.1m, 0.1-0.4m, 0.4-1m and 1m-2m)
  - ✓ NLDAS-2 Forcing
  - ✓ CONUS domain, 0.125 Deg. Resolution
- ❖ **NASA Land Information System**
  - ✓ Version 6.1; LIS

Original SM retrievals/predictions Validated with ground observations

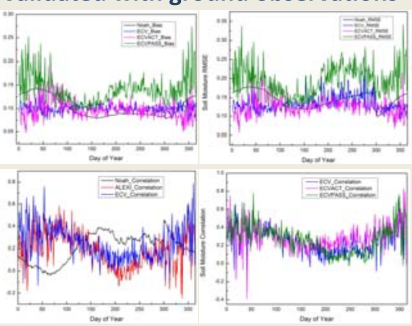


Figure 1 Bias (a), RMSE (b) and correlation (c and d) on each day of year between SM products and ground observations from NASMD

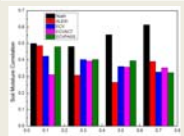
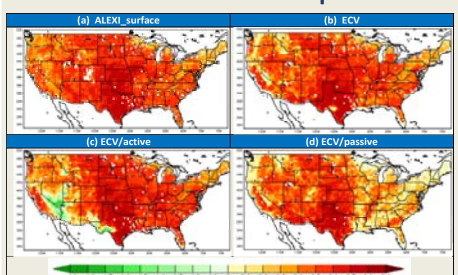


Figure 2 Frequency histogram of time series correlation as a function of vegetation fraction cover for Noah estimates, ECV and ALEXI products

Table 1 Average bias, RMSE and correlation between SM products and NASMD observation

Products	Bias	RMSE	Correlation
Noah	0.109	0.127	0.454
ECV	0.104	0.120	0.379
ECV/active	0.101	0.120	0.331
ECV/passive	0.153	0.176	0.369
ALEXI	--	--	0.356

Inter-comparison of time series anomaly correlation between satellite based products



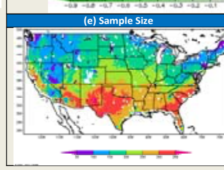


Table 2 Mean correlations

SM product	Mean Correlation over land pixels	Number of pixels with Highest correlation
ECV	0.492	13.62%
ECV/active	0.470	42.56%
ECV/passive	0.394	10.45%
ALEXI	0.519	33.37%

Figure 3 (a-d) Anomaly correlations between satellite-based SM products (ALEXI, ECV, ECV/active, and ECV/passive) and Noah SM predictions over the period of 2000 – 2013; (e) Sample size

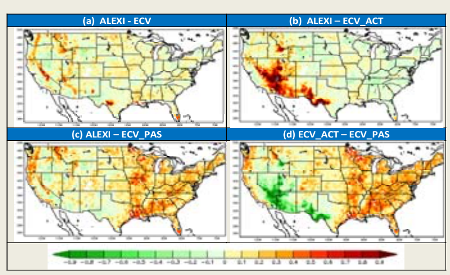


Figure 4 Differences in anomaly correlations between (a) ALEXI and ECV, (b) ALEXI and ECV_ACT, (c) ALEXI and ECV_PAS and (d) ECV_ACT and ECV_PAS

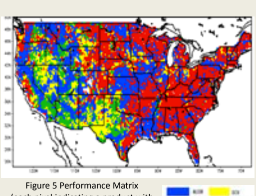


Figure 5 Performance Matrix (each pixel indicating a product with the highest correlation with respect to Noah estimates)

Out of the total 12526 land pixels, **ECV/active** product achieves the largest correlation coefficient over 42.56% of land pixels, followed by **ALEXI** over 33.37% and **ECV merged** product over 13.62%

SM Anomaly Correlation Validated with ground observations

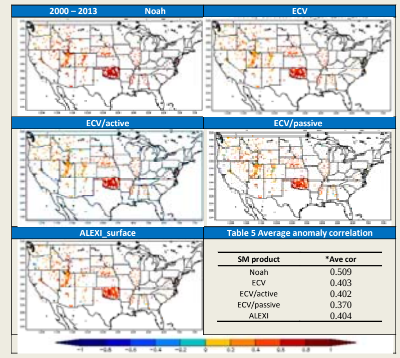


Table 5 Average anomaly correlation

SM product	*Ave cor
Noah	0.509
ECV	0.403
ECV/active	0.402
ECV/passive	0.370
ALEXI	0.404

Figure 6 Time series anomaly correlation coefficients between SM products (Noah, ECV, ECV/active, ECV/passive and ALXIE) and ground observations over the period of 2000 – 2013

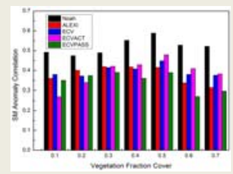


Figure 7 Frequency histogram of anomaly correlations as the function of vegetation fraction cover between SM products (Noah, ECV, ECV/active, ECV/passive and ALEX) and in-situ SM anomaly from NASMD

- ❖ Noah LSM performs well in a wide range of vegetation conditions;
- ❖ ALEXI and ECV merged products are also considerably representative over various levels of vegetation covers;
- ❖ The performance of ECV passive product is limited when vegetation fraction cover goes higher than 0.6, while that of ECV active is poor over low vegetation cover regions

Validation of ALEXI SM retrievals at root zone depth

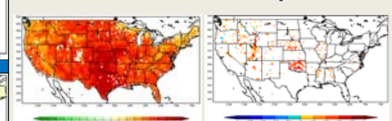


Figure 8 Correlations of ALEXI anomalies with respect to root zone estimates from Noah LSM (left) and in-situ NASMD (right) over the period of 2000- 2013

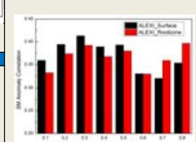


Figure 9 Histogram of correlations as the function of vegetation fraction cover between ALEXI anomalies and in-situ SM anomalies from NASMD for both surface and root zone over the period of 2000- 2013

- ❖ ALEXI SM providing the composite SM information of both surface and root zone, depending on the surface vegetation density condition Noah Land Surface Model
- ❖ The mean anomaly correlation averaged over all valid NASMD site is 0.397

Conclusions

Although the validation results show that each of the five SM products is capable of capturing the dry and wet pattern over the validation period, but the quantitative accuracy varies notably from product to product.

- ❖ **Noah** LSM provides more stable SM predictions over time with the average bias of 0.109 and RMSE of 0.127;
- ❖ Mean correlation coefficient of original **ECV** merged product is 0.379, higher than either individual active or passive product;
- ❖ **ALEXI** anomalies exhibits the best agreement with Noah model predictions with CONUS average correlation of 0.519, followed by ECV product with 0.492;
- ❖ A unique SM data set from satellite TIR observations using **ALEXI** model is proved to be capable of providing high quality composites of both **surface and root zone** SM information.