EVALUATION OF ASSIMILATED SMOS SOIL MOISTURE DATA FOR US CROPLAND SOIL MOISTURE MONITORING

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ABSTRACT

Remotely sensed soil moisture data can provide timely, objective and quantitative crop soil moisture information with broad geospatial coverage and sufficiently high resolution observations collected throughout the growing season. This paper evaluates the feasibility of using the assimilated ESA Soil Moisture Ocean Salinity (SMOS) Mission L-band passive microwave data for operational US cropland soil surface moisture monitoring. The assimilated SMOS soil moisture data are first categorized to match with the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) survey-based weekly soil moisture observation data, which are ordinal. The categorized assimilated SMOS soil moisture data are compared with NASS's survey-based weekly soil moisture data for consistency and robustness using visual assessment and rank correlation. Preliminary results indicate that the assimilated SMOS soil moisture data highly co-vary with NASS field observations across a large geographic area. Therefore, SMOS data have great potential for US operational cropland soil moisture monitoring.

***Index Terms*—** SMOS, cropland soil moisture, assimilation, US soil moisture monitoring, Spearman rank correlation

1. INTRODUCTION

Crop condition information is critical to public and private sector decision making related to agricultural policy, production, food security, and food prices. Crop condition can change rapidly in response to changes in temperature, soil moisture, fertilization, or disease, etc. Cropland soil moisture is critical for healthy crop growth for crop condition monitoring, crop yield estimation, water resource planning, and drought assessment. The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) currently monitors crop soil moisture using weekly field observations for counties in 45 states. State-level estimates of observed topsoil and subsoil moisture are published weekly in the NASS Crop Progress and Condition Report during the growing season. However, the field soil moisture observations are subjective, qualitative, costly, unreliable, inefficient and lack geospatial coverage. Therefore, a source for cost effective, objective and quantitative crop soil moisture information with wide geospatial coverage is actively sought. Remotely sensed soil moisture data meet all these requirements [2]. Remote sensing technology can provide timely data with sufficiently high resolution observations collected throughout the growing season. This paper evaluates the feasibility of using the assimilated ESA Soil Moisture Ocean Salinity (SMOS) Mission L-band passive microwave remote sensing data for operational US cropland soil surface moisture monitoring. The purpose of this study is to examine the consistency between the assimilated SMOS soil moisture measurements and the field observation results from USDA NASS operational program. In this assessment, the assimilated SMOS soil moisture data at 0.25° resolution are compared with NASS's survey-based weekly soil moisture observation data for consistency and robustness. The assimilated SMOS soil moisture data are first categorized in accordance with NASS observation data. The NASS survey-based weekly soil moisture observation data, which are ordinal, are quantified and summarized as weighted averages at the county level. The summarized observation data are then rasterized to 0.25 degree resolution to match the SMOS data spatially. The processed NASS observation data and the assimilated SMOS soil moisture data are then compared for consistency with visual assessment and Spearman rank correlation.

2. STUDY AREA AND DATA

2.1. Study Area

The study area for this research is the NASS Northern Plains region, which includes the states of North Dakota, South Dakota, Nebraska, and Kansas, as shown in Fig. 1 (purple states). This region is selected to have large enough geospatial coverage to include a sufficient variety of crops, and assimilated SMOS data (large pixel size) samples to conduct the data comparison. In this preliminary study, one weekly snapshot of Northern Plains data are used for comparison.

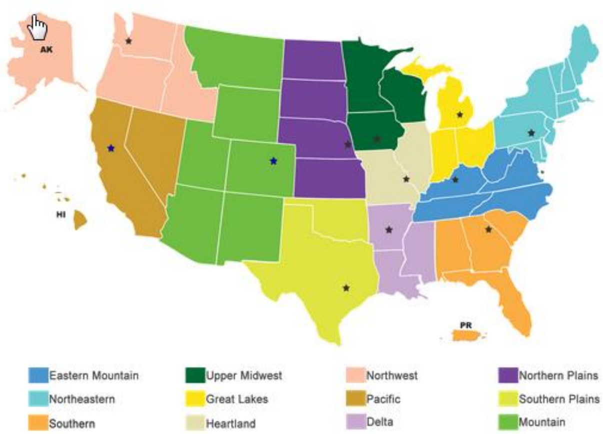

Figure 1. Study area Northern Plains Region in purple color (courtesy of NASS web site)

2.2. NASS Survey Based Soil Moisture Data

This paper focuses on the consistency of the assimilated SMOS soil moisture data and NASS's weekly surveyed top soil moisture and subsoil moisture data. Currently NASS collects cropland soil moisture information by weekly field observation for counties in 45 states. Soil moisture conditions are observed in one or two locations in each county. State level estimates of the observed topsoil and subsoil moisture are conducted weekly from the collected samples during the growing season. The NASS top soil and subsoil moisture condition has four qualitative categories including: very short, short, adequate, and surplus. The observation values for each county are the land percentages of each soil moisture categories for both top and sub soils. However, the NASS soil moisture survey is a volunteer program. The data may not be available for every county for a given week. In this study, the week of July 1, 2013 soil moisture observation data of NASS Northern Plains Region are selected for comparison. This period is selected for its data completeness.

2.3. Assimilated SMOS Soil Moisture Data Products

The ESA SMOS Mission was launched in October 2009 [3]. The SMOS soil moisture data are freely available via an existing ESA/USDA Agricultural Research Service (ARS) data agreement. In this study, the assimilated SMOS soil moisture data are assessed for their consistency with USDA NASS soil moisture survey data. The assimilated SMOS soil moisture data are derived by assimilating SMOS L01 product into the modified two-Layer Palmer water balance model at 0.25° resolution [4]. In assimilation, a composite product L01is first produced from three consecutive days of SMOS Level 2 soil moisture retrievals by gridding to quarter-degree, combining ascending/descending orbits, and re-scaling to match the USDA Foreign Agricultural Service (FAS) surface soil moisture climatology (2-Layer Palmer Model). The L01 product is then assimilated into the FSA's 2-Layer Palmer model using a 30-member EnKF to create a daily data assimilation product L03. The 30-member Ensemble Kalman Filters (EnKF) are used to update the output surface and root-zone soil moisture data. The level L03 product includes: Layer 1 soil moisture product (i.e., enmm1.qtr) and Layer 2 soil moisture product (i.e., enmm2.qtr). The data are formatted to match the original FAS soil moisture data product layers. In this study, we use Layer 1 soil moisture data. The final L03 data product is a 3-day composite. It is delivered at ~4-day latency. Fig. 2 illustrates the assimilated SMOS top and root zone soil Moisture. It covers CONUS nicely and provides fair variation details.

All data are provided in GRIB format. The horizontal grid spacing is 0.25 degrees (roughly 25km) and the i/j dimensions are 1440x600, lower left point is at 59.875 South 179.875 West and the upper right point is at 89.875 North 179.875 East. Grids with missing data over land (i.e. no data available to be processed) are coded with a value of -999.000. All data products are in units of depth (mm).

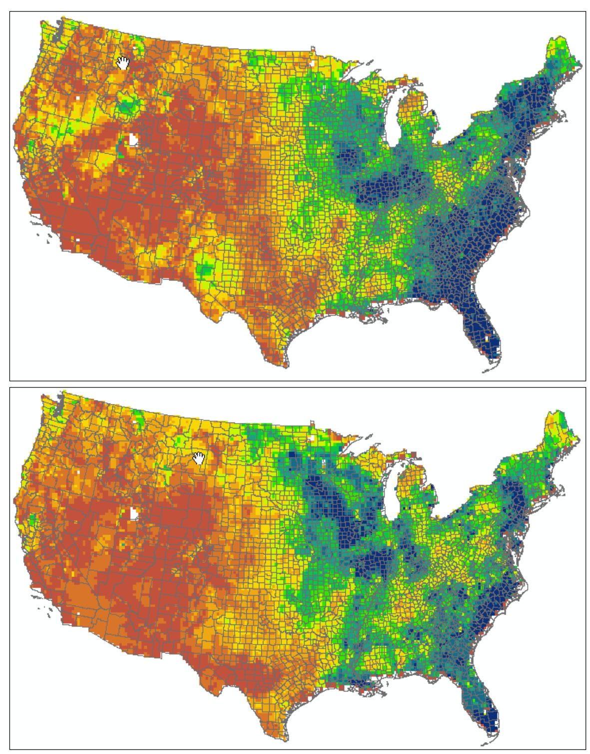

Fig. 2. Assimilated SMOS Soil Moisture on July 2-4, 2013, (a) top soil; (b) subsoil.

3. METHODLOGY

3.1. Data Processing

The assimilated SMOS soil moisture data have approximately 25km resolution, which is about the size of a county. It is difficult to compare SMOS data with the NASS county level survey-based weekly soil moisture observation data. Therefore, the data comparison level is set to the NASS Agricultural Statistics District (ASD) level, which usually covers several counties (around 10 or over 10 counties for big agricultural states). Every ASD covers multiple SMOS pixels. All county level survey data are aggregated to ASD level by summarizing the quantified (by category code) soil moisture category by category of all counties within the ASD. The final ASD level soil moisture category is derived by rounding the weighted (by category percentage) average of all soil moisture categories. The aggregated field observation data are then rasterized to 0.25 degree resolution. Fig. 3 illustrates the aggregated ASD level NASS surveyed soil moisture condition data.

The assimilated SMOS soil moisture data are derived from sensor measurement while the NASS observed soil moisture conditions are ranked categorical data. To compare one measurement variable and one ranked variable, the measurement variable has to be converted to ranks. Thus, the assimilated SMOS soil moisture measurements are converted into ranks. To match with the NASS surveyed soil moisture condition data, the assimilated SMOS soil moisture data are equally divided into the four categories based on data values. Fig. 4 illustrates the categorized assimilated SMOS Soil Moisture.

3.2. Spearman Correlation

Spearman rank correlation coefficient indicates whether two ranked variables co-vary or whether, as one variable increases, the other variable tends to increase or decrease. With assimilated SMOS soil moisture data converted into ranks, Spearman rank correlation can be used on these two sets of ranks. The Spearman correlation coefficient r_s is defined as the Pearson correlation coefficient between the ranked variables [5][6]. For a sample of size n of ranked variables x_i, y_i, the r_s is computed from:

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d^2}{n^3 - n}$$

where $d_i = x_i - y_i$ is the difference between ranks.

The Spearman rank correlation does not tell whether two ranked data sets are consistent, but does indicate whether they co-vary. If the assimilated SMOS soil moisture data co-vary with NASS's observed soil moisture condition data, the assimilated SMOS soil moisture data can be calibrated and converted into ranks, and ultimately be used to replace the in-person field observation.

4. RESULTS AND DISCUSSIONS

When visually comparing Fig. 3 and Fig. 4, it is found that the pair of NASS surveyed topsoil and subsoil moisture conditions have more variations than that of SMOS. The overall distribution patterns of top soil and subsoil moisture are similar in both SMOS and the surveyed results. It is observed that the equal-interval division in assimilated SMOS data causes SMOS data in general to trend one rank lower than NASS surveyed results. This implies inappropriate ranking thresholds in the SMOS data categorization. It is also observed from Figs. 5 and 6 that some ASD soil moisture ranks between the two datasets are not consistent with the overall patterns. This fact may be caused by inappropriate ranking thresholds in SMOS data conversion or by unreliable survey observations. This means that calibration is necessary for determining the thresholds for the SMOS data ranking conversion.

The Spearman rank correlation coefficients for the topsoil moisture data pair and subsoil moisture date pair are 0.99468 and 0.99566 respectively. The high Spearman rank correlation coefficient value indicate that assimilated SMOS data and NASS surveyed soil moisture data (both topsoil and subsoil) are highly co-varied. This means that assimilated SMOS soil moisture data have great potential for using in operational US soil moisture monitoring after appropriate calibration.

5. CONCLUSIONS

This paper assessed assimilated SMOS soil moisture data for potential US soil moisture monitoring by comparing the change trend of SMOS data and NASS field observed soil moisture condition data. The high Spearman rank correlation coefficient value indicate that assimilated SMOS data and NASS surveyed soil moisture data (both topsoil and subsoil) are highly co-varied.

The assimilated SMOS data has full geospatial coverage for CONUS states. The three day composite data meet the time requirement for NASS weekly reports. The 25km resolution assimilated SMOS soil moisture data are sufficient to provide an ASD level statistics in both topsoil and subsoil. This provides a potential improvement in NASS reporting level from state level to ASD level.

The assimilated SMOS data also provide efficient, geo-referenced, objective, consistent, quantitative soil moisture measurements and can reduce the operational cost and survey burden to farmers. In addition, it is possible to use the data in direct measurement without converting them into categorical condition data.

Automated data collection, processing and publishing is foreseeable.

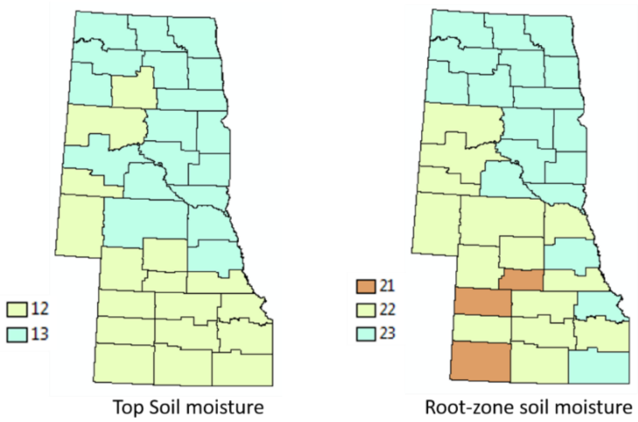

*Figure 3. Agregated NASS survey soil moisture conditions

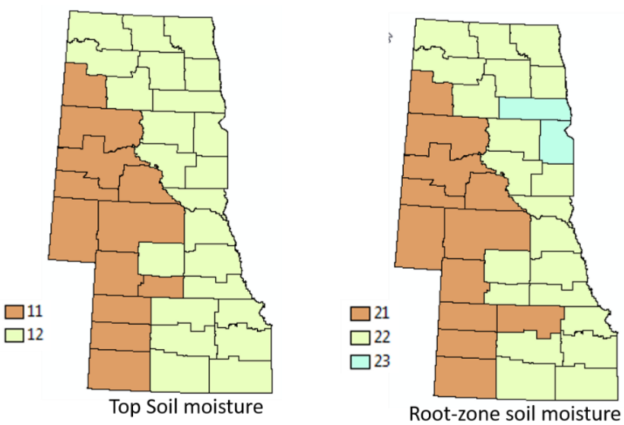

Figure 4. Categorized assimilated SMOS soil moisture

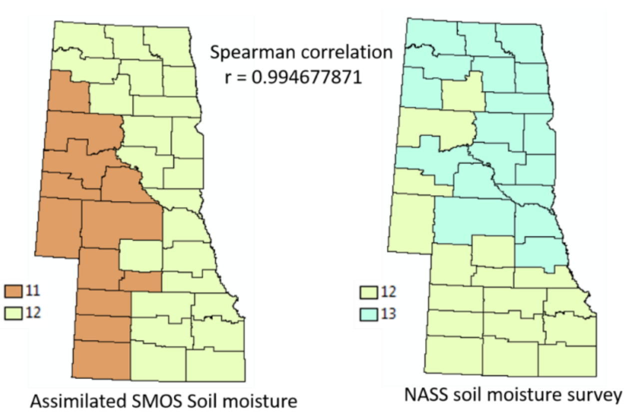

Figure 5. Assimilated SMOS topsoil vs. NASS survey topsoil moisture

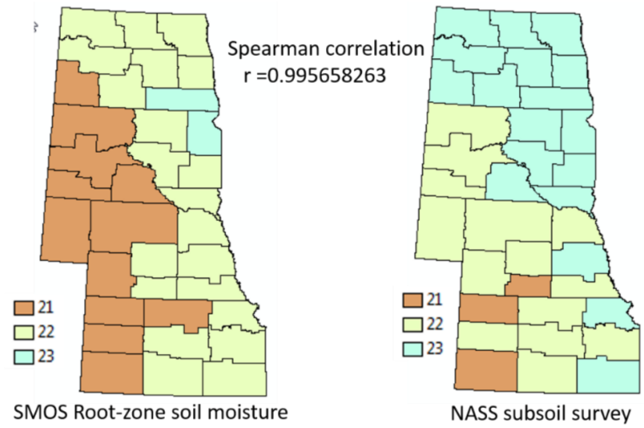

Figure 6. Assimilated SMOS vs. NASS surveyed root-zone soil moisture.

* In Figs. 3 ~ 6, the top soil and subsoil moisture conditions are classified into four qualitative categories: very short, short, adequate, and surplus. They are coded with (11, 12, 13, 14) and (21, 22, 23, 24) for top and sub soil respectively.

6. REFERENCES

[1] Yang, Z., Mueller, R., and Crow, W., "Us National Cropland Soil Moisture Monitoring Using SMAP," Proc. of IEEE IGARSS 2013, Melbourne, Australia, July 2013.

[2] Bolten, J. D., W. T. Crow, T. J. Jackson, X. Zhan, and C. A. Reynolds (2010), "Evaluating the utility of remotely-sensed soil moisture retrievals for operational agricultural drought monitoring," *IEEE J. Sel. Topics Appl. Earth Obs*., 3(1), 57–66.

[3] Yann H. Kerr, Philippe Waldteufel, Jean-Pierre Wigneron, Jean-Michel Martinuzzi, Jordi Font, and Michael Berger, "Soil Moisture Retrieval from Space: The Soil Moisture and Ocean Salinity (SMOS) Mission," *IEEE Trans. on Geoscience and Remote Sensing*, VOL. 39, NO. 8, AUGUST 2001'

[4] Bolten, J. D., W. T. Crow, X. Zhan, C. Reynolds, and T. J. Jackson (2009), "Assimilation of a satellite-based soil moisture product in a two-layer water balance model for a global crop production decision support system," in Data Assimilation for Atmospheric, Oceanic, and Hydrologic Applications, pp. 449–463, Springer, Berlin.

[5] McDonald, J.H. Handbook of Biological Statistics (Sparky House, Baltimore, 2008).

[6] Myers, Jerome L.; Well, Arnold D. (2003). *Research Design and Statistical Analysis* (2nd Ed.). Lawrence Erlbaum. p. 508. ISBN 0-8058-4037-0.