US NATIONAL CROPLAND SOIL MOISTURE MONITORING USING SMAP

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ABSTRACT

This paper investigates at the pre-launch stage the feasibility of using NASA SMAP mission results for US national operational crop soil moisture monitoring. The purpose of using remote sensed SMAP data for crop soil moisture monitoring is to eliminate data collection subjectivity, reduce cost, increase cropland soil moisture monitoring data consistency, and operational efficiency. In this paper, the SMAP simulated data product time series, such as L2_SM_A, L3_SM_A/P, L4_SM, L1C-S0_HiRes are first evaluated for their suitability for NASS operational cropland soil moisture monitoring by comparing SMAP results with the NASS' survey based weekly soil moisture observation data for their consistency and robustness. The preliminary results illustrate that SMAP products have the potential for NASS operational use at least for county level soil moisture statistics. This paper also explores a technical route to build a Web-service based interactive soil moisture monitoring system for map visualization, dissemination, and analysis based on SMAP results.

***Index Terms*—** SMAP, soil moisture monitoring, crop condition monitoring, VegScape

1. INTRODUCTION

Crop condition information is critical to decision making in both public and private sectors that concern agricultural policy, production, food security, and food prices. Crop conditions change quickly due to various growing condition changes, such as temperature, soil moisture, fertilization, or disease, etc. Therefore, timely, frequent, fully geospatial covered and sufficiently high resolution observation throughout the season is necessary to monitor crop conditions. The National Agriculture Statistics Services (NASS) of the United States Department of Agricultural (USDA) publishes weekly crop progress and condition report; soil moisture condition is part of crop condition report. NASS currently monitors crop soil moisture condition by weekly field observations for counties in 45 states. State-level estimates are based on subjective field observations not on objective measurements. The surveyed topsoil and subsoil moisture are published weekly during the growing season. It is useful in reflecting some major events in US crop production such as massive flood, drought and long last dry cold winter, which result in drops in corn and soybean acreages and in yields. However, the soil moisture reports are subjective and qualitative assessment. Field observations are from volunteers. They are not precise, not consistent, unreliable and inefficient, and not fully geospatially covered as shown in Fig. 1. The survey operation is a burden to farmers and NASS field officers. Its operational cost is very expensive. To improve NASS cropland soil moisture monitoring, this paper proposes to use the remote sensed soil moisture data for US national cropland soil moisture monitoring. Specifically, the remote sensing results from NASA Soil Moisture Active and Passive (SMAP) mission [1] is proposed to be adapted. This paper will (1) study at the pre-launch stage the feasibility of using SMAP mission results to support US national crop condition monitoring and other NASS operational data needs, such as crop yield modeling needs; (2) explore a technical route to build a remote sensing based soil moisture monitoring system prototype based on the feasibility of application of SMAP data products.

2. DATA AND STUDY AREA

The SMAP mission is currently planned for launch in late 2014. This paper study early adapting of SMAP products at pre-launch phase during which only simulated SMAP data products (no actual SMAP observational data) are available. The SMAP applications to be prototyped are to be completed based on the pre-launch simulated data. For better crop condition monitoring, the soil moisture data resolution should match the field size. Therefore, this application system utilizes high resolution SMAP data products, such as L3SM_A/P, L4_SM, or L1C-S0_HiRes. To derive weekly high spatial resolution soil moisture data products, other remote sensing data such as MODIS products are to be fused or assimilated with SMAP data. For cropland-specific monitoring, a crop mask derived from NASS Cropland Data Layer [2][3][4]. It is idea for USDA NASS to monitor agriculture of every county in all 48 conterminous states in the U.S. Therefore the study area will cover all conterminous states in the U.S.

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Table 1. Sample NASS survey based soil moisture report

Days Suitable & Soil Moisture Condition as of September 25, 2011

Item	Districts									State
	NW	NC	NE	WC	C	EC	SW	SC	SE	
	(Days)	(Days)	(Days)	(Days)	(Days)	(Days)	(Days)	(Days)	(Days)	(Days)
Days suitable	6.2	5.7	5.4	6.7	6.5	6.0	5.9	6.5	6.9	6.2
	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)
Topsoil moisture										
Very short	23	13	12	8	23	5	0	21	42	16
Short	42	40	24	39	31	26	7	49	42	34
Adequate	35	46	59	52	44	69	87	29	16	48
Surplus	0	1	5	1	2	0	6	1	0	2
Subsoil moisture										
Very short	16	16	15	6	24	5	1	17	30	14
Short	43	34	20	29	38	34	9	49	45	34
Adequate	41	49	61	64	37	61	84	34	25	51
Surplus	0	1	4	1	1	0	6	0	0	1

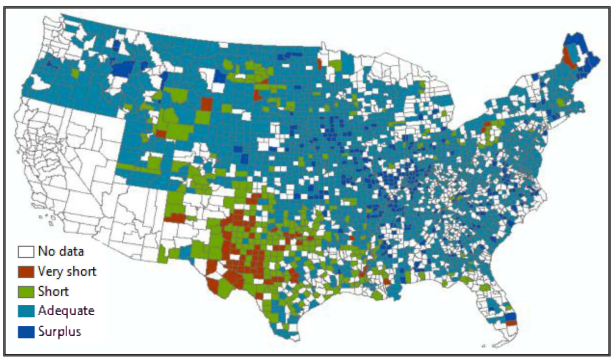

Figure 1. NASS Survey Based Soil Moisture (Week of May 4, 2003).

3. METHODOLOGY

The goal for the US cropland soil moisture monitoring application system based on SMAP data is to provide objective and quantitative soil moisture measurement and assessment. It requires US national geospatial coverage with high resolution of at least sub-county resolution monitoring. To down-scale the SMAP data, data fusion and assimilation are performed. The monitoring system will have the capabilities of automatic data collection, processing and publishing, and online visualization, analysis and dissemination. The calibrated and validated SMAP soil moisture products as well as derived products will be published and disseminated to end users via web service based application system for NASS operations.

3.1. Validation and Calibration

The SMAP data products and their derived down-scale products have to be validated and calibrated before being used for cropland soil moisture monitoring. This proposed two validation methods. The first method is to validate the SMAP data and their derivative products using existing NASS soil moisture survey data. The sample NASS soil moisture survey data are shown as in Table 1. The data categorized in 4 qualitative levels. For a given area, the surveys provide percentages for each level. As shown in Fig. 1, the CONUS county level average soil moisture map was derived by weighting the percentages of every soil moisture level. The purpose of this manipulation is to simplify the comparison between the survey data and SMAP results. As shown in Fig. 2, SMAP L3-AP soil moisture data are presented in numeric number while NASS soil moisture survey data are presented in qualitative categories. Therefore, it is necessary to quantify the NASS soil moisture survey data categories in SMAP soil moisture data scale. This quantification will be performed using Delphi method [5][6]. The quantification will result in a quantitative range of each NASS surveyed soil moisture level. The cropland soil moisture ground truth data is critical for SMAP data to be validated and calibrated for cropland soil moisture monitoring. The second method is based on the controlled ground truth measurement with soil moisture sensors. A large scale sensor network is proposed to continuously collect ground truth data crop land. With SMAP data and ground truth measurement data at hand, an empirical look-up table or mapping equation will be derived.

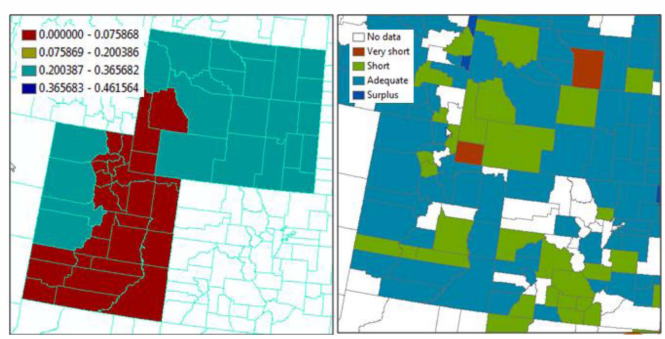

Figure 2. SMAP L3-AP soil moisture(left) vs. NASS Surveyed topsoil moisture(right) – different metrics.

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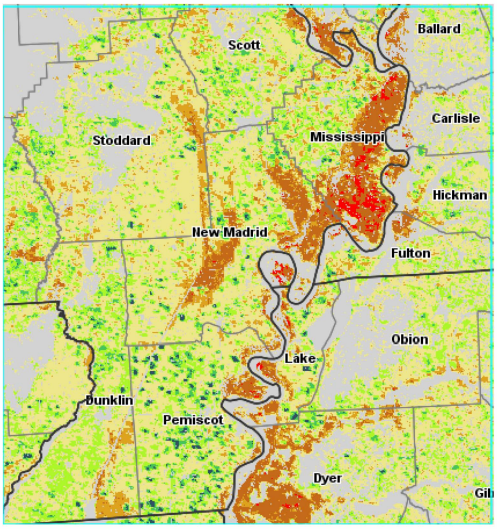

Figure 3. SMAP soil moisture assessment using NDVI Ratio to Historical Median by their correlation.

3.2. SMAP Data Downscaling

The spatial resolutions of SMAP products usually lower than the most crop field sizes. It is necessary to downscale the SMAP data to the field level size so that crop specific soil moisture monitoring using SMAP became possible. Piles, et al. proposed an approach to improve the spatial resolution of Soil Moisture and Ocean Salinity (SMOS) soil moisture estimates with the use of higher resolution visible/infrared (VIS/IR) satellite data [7]. The algorithm is based on the so-called "universal triangle" concept that relates VIS/IR parameters, such as the Normalized Difference Vegetation Index (NDVI), and Land Surface Temperature (Ts), to the soil moisture status. This method combines the accuracy of SMOS observations with the high spatial resolution of VIS/IR satellite data into accurate soil moisture estimates at high spatial resolution. They reported that results were fairly agreed with ground-based soil moisture measurements, and that the soil moisture variability was effectively captured at 10 and 1 km spatial scales without a significant degradation of the root mean square error. The specification of the SMAP is similar to that of SMOS. Therefore, it is proposed to apply this downscaling method to SMAP data to derive high resolution SMAP derivative products.

3.3. SMAP Data Assessment

The calibrated SMAP soil moisture products as well as derived products to be used for crop soil moisture monitoring need to be to be evaluated to see if these data are consistent with the existing soil moisture data from SMOS or evapotranspiration data products derived from other sensors, such as LanSat [8]. Moreover, the correlation between the SMAP soil moisture data and crop vegetation condition data derived from MODIS [9] also needs to be examined since the crop condition is strongly correlated with water supply, which is indicated by soil moisture.

4. SYSTEM DESIGN

The calibrated and validated SMAP soil moisture products as well as derived products need to be published, visualized, accessed, analyzed, and disseminated to end users via online application. The online geospatial application system will reuse the existing crop vegetation condition monitoring system-VegScape [10]. The application system has a service-oriented architecture (SOA) with which the MapServer [11] is configured as the server of WCS, WFS, and WMS to support retrieval and rendering of soil moisture data. The W3C Web service is adopted in implementing the Web geoprocessing service and Web processing services for SMAP data reformatting, reprojection, downscaling and quantification while web map services is implemented for data visualization, publishing and dissemination. In the implementation, open source JavaScript libraries and OpenLayers [12], are used to develop a rich Internet application which can be accessed through most common browsers, such as Internet Explorer, Firefox, Safari, Opera, and Chrome, without installing any additional software or plug-in. The VegScape SOA architecture is scalable. A SMOP component can be added to the VegScape framework directly as shown in Fig. 4. Moreover, most of the VegScape browser based client user interface components including data layers, legends, product selection, overview window, map window, and a toolbar can be reused. Only data layers, legends, product selection components need to be modified to include SMAP data products. The new additions will include SMAP data layers, map legends, and product selection options.

5. CONCLUSION

This paper proposes to use SMAP data products for US national cropland soil moisture monitoring. It is expected that using SMAP data in cropland soil moisture monitoring will be consistent, reliable, efficient and low cost. It will substantially reduce the survey burden. The SMAP data products provide objective and quantitative assessment and fully geospatial coverage. The preliminary study demonstrates that it is possible to use SMAP L3 AP soil moisture product for sub-county topsoil survey monitoring. This paper also presents the application system design and technical route to build a soil moisture monitoring system prototype. The future research includes (i) find the vegetation impact on SMAP data results since; (ii) assess errors caused by low 9km resolution; (iii) establish the mapping relation between different SMAP's soil moisture measurement and the qualitative assessment of NASS soil moisture survey result once the real SMAP data are available.

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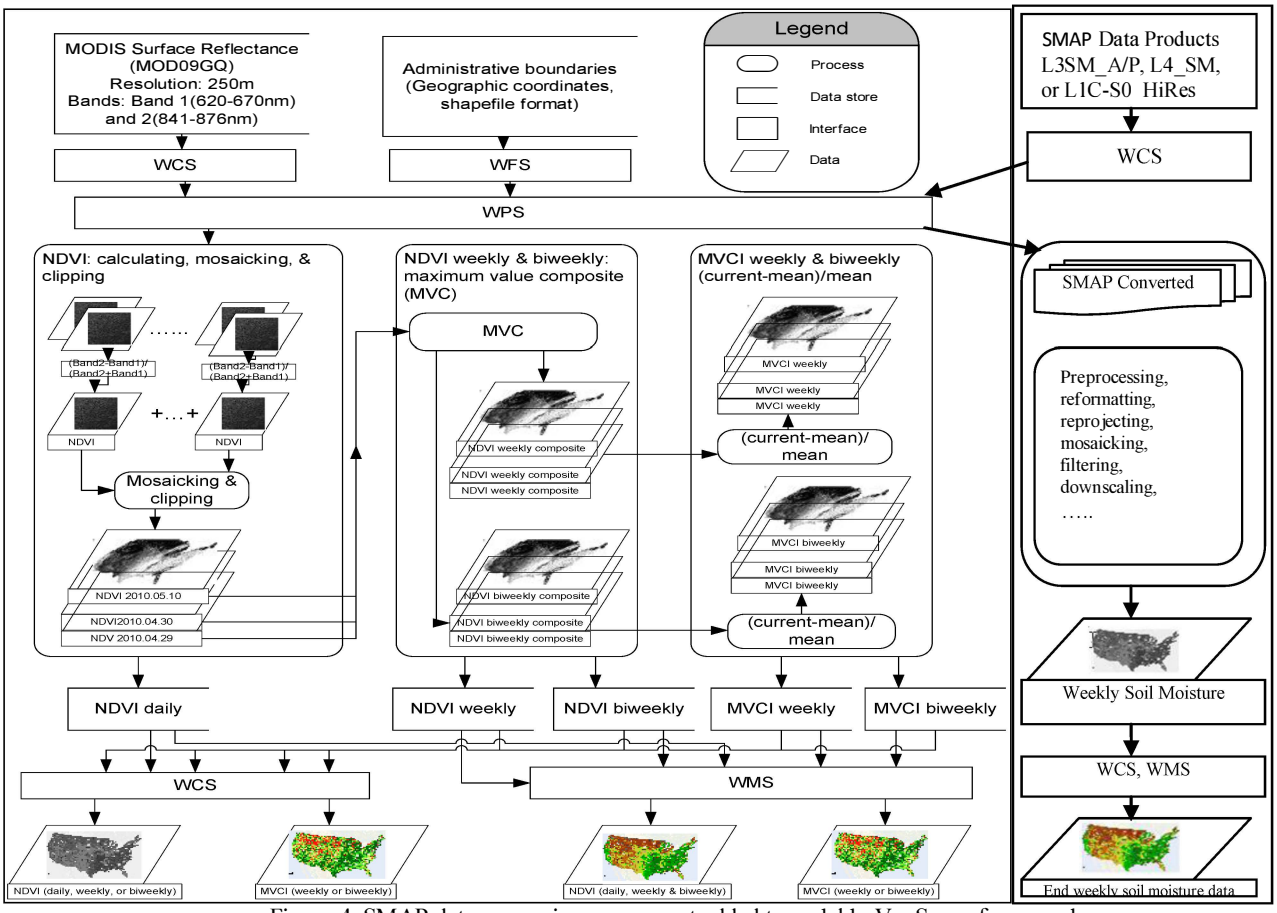

Figure 4. SMAP data processing component added to scalable VegScape framework

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