SMAP DATA FOR CROPLAND SOIL MOISTURE ASSESSMENT – A CASE STUDY

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ABSTRACT

Timely, frequent, and complete cropland soil moisture information, acquired throughout the growing season is critical for agricultural policy, production, food security, and food prices. The NASA Soil Moisture Active and Passive (SMAP) mission provides a reliable data source for cropland soil moisture assessment. This paper presents a case study of using SMAP soil moisture data products for agriculture land soil moisture assessment. A prototype application of interactive Web service based SMAP soil moisture data visualization, dissemination and analytics based on VegScape is used. In the study, we propose to temporally aggregate SMAP data for a better crop soil moisture assessment. The case study assesses Iowa's soil moisture status using SMAP data and compares it with the NOAA precipitation record and NASS published soil moisture survey results for a late September period in Iowa. The high correlation between the SMAP and NOAA observations is found. Moreover, we find that the SMAP results are generally consistent with NASS published survey results. The preliminary results of the study indicate the SMAP data have great potential for agricultural soil moisture assessment applications.

Index Terms— SMAP, soil moisture assessment, VegScape, cropland

1. INTRODUCTION

Crop conditions change quickly due to changes in temperature, soil moisture, fertilization, or disease, etc. Therefore, timely, frequent, sufficiently high resolution and full geospatial coverage growing season observation data are necessary to monitor crop conditions. Therefore, the National Agricultural Statistics Services (NASS) of the United States Department of Agriculture (USDA) developed and implemented operationally a Web service based online vegetation condition monitoring system, known as VegScape, based on National Aeronautics Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) data [1]. VegScape has proved to be very helpful in identifying and quantifying major disaster events in US crop production such as massive flood, drought and hail storm damage. However, one major component, soil moisture, is still missing in the system. NASS currently monitors US crop soil moisture condition using weekly field observations for counties in 45 states. State-level estimates reported are based on subjective and qualitative field observations rather than objective measurements. The surveyed topsoil and subsoil moisture information are published weekly during the growing season via the Crop Progress report. Field observations are conducted by approximately 4000 respondents. The observations are not always precise, and they are sometimes inconsistent, unreliable, and do not provide full national scale geospatial coverage. Operational costs are high. The NASA Soil Moisture Active Passive (SMAP) mission [2] provides another potential option for improving NASS cropland soil moisture monitoring operations. Yang, et al. [3] proposed, as an early adopter, to explore the potential of using SMAP data for NASS soil moisture monitoring since the remotely sensed SMAP soil moisture data are quantitative, objective and inexpensive (the data are free), have full geospatial coverage and a sufficiently high temporal frequency for US national cropland soil moisture monitoring. Yang, et al. [5] recently further prototyped an interactive Web-based, SMAP-based soil moisture monitoring system, which was implemented using the VegScape framework. The prototype automatically retrieves and processes the SMAP soil moisture data products from the NASA data archive and publishes the processed soil moisture data for mapping, visualization, dissemination, and online analytics geospatially through standard geospatial Web services in a publicly accessible online environment. This paper presents a case study of using SMAP data, published on the prototype application, to assess soil moisture change dynamics during a disastrous rain event which occurred during the harvest period in the fall of 2016 in Iowa, United States.

2. MATERIALS AND METHODS

2.1. Study Area

In this study, the State of Iowa, is selected as the study area. Iowa is a major agricultural state with major crops including corn and soybeans. Iowa is in the Midwestern United States,

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bordered by the Mississippi River on the east and the Missouri River and the Big Sioux River on the west. This study attempts to examine how well the SMAP data responds to an excessive rainfall event.

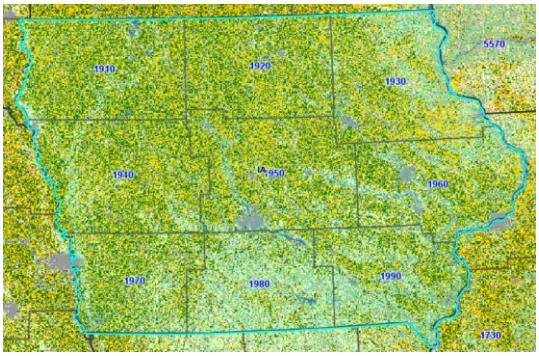

Figure 1. Study area: the State of Iowa, United States, segmented into nine Agricultural Statistical Districts (ASDs).

2.2. SMAP DATA

The SMAP mission (launched on 31 January 2015) measures passive land surface microwave emission and active radar backscatter. It is designed to measure surface soil moisture (the amount of water in the top 5 cm (2 inches) of soil everywhere on the Earth's surface). It repeatedly measures soil moisture every 2-3 days. However, the active Radar sensor failed on July 7, 2015. For improved crop condition assessment, the soil moisture data resolution should be as high as possible. Therefore, NASA SMAP Level 4 Surface and Root Zone Soil Moisture (SPL4SMGP) data products were selected for the NASS agricultural soil moisture monitoring system prototype. This data product, an assimilated result of SMAP data, ground precipitation observations, and NASA modeled results, provides both top and root zone soil moisture estimates, which are required for NASS operational reports. For a cropland-specific assessment, a crop mask derived from the NASS Cropland Data Layer [4] is also used. Therefore the cropland in the study area can be easily identified.

2.3. VegScape Based SMAP Implementation Prototype

The SMAP soil moisture data products need to be published, visualized, accessed, and disseminated to end users so that they can be analyzed for applications. Yang, et al. added a component on the VegScape application to perform SMAP soil moisture data interactive mapping, visualization, online analytics, and dissemination [3], [5]. VegScape adopts a 3-layer service oriented architecture (SOA) to process, share and disseminate geospatial remote sensing data. The maximum scalability of SOA makes adding a SMAP soil moisture component to the VegScape system possible with minimum engineering cost.

Similarly, the new soil moisture component includes the same three layers: application, service and data. The Application Layer implements various geospatial applied functionalities. The Service Layer contains OGC standard compliant Web Feature Service (WFS), Web Map Service (WMS), Web Coverage Service (WCS) and Web geoprocessing services (WPS), of which the WCS is for raster data storage and service, WPS for processing algorithms and their managements, WFS for storing and serving vector geographical features, and WMS for web-based geospatial presentation. The Data Layer includes original VegScape data sets and new SMAP soil moisture data products, as well as geospatial feature data. Similarly, the soil moisture data in the Data Layer are processed and or served by Web services of the Service Layer. The processed results or data retrieved from the Data Layer are sent back to clients in the Application Layer. The SMAP data processing tasks, such as data retrieving, clipping, reformatting, re-projection, and map generation are implemented following the interfaces of Web Processing Service (WPS) for interoperation.

VegScape has a thin client, as shown in Fig. 2, for users to interact with the back-end server and different web services. The prototype for SMAP soil moisture reuses the existing functionalities and tools of the VegScape system. The new soil moisture data layers and associated legends, and product selection interface are to be added to include SMAP data products.

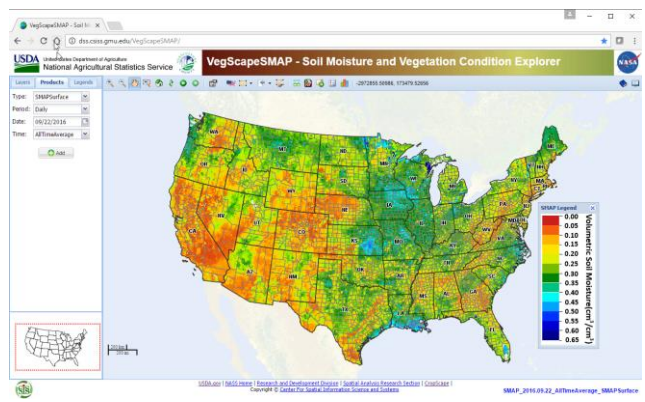

Figure 2. Client interface of prototyped VegScape with SMAP component (https://dss.csiss.gmu.edu/VegScapeSMAP/)

3. SMAP DATA TEMPORAL AGGREGATION

The NASA officially released SMAP level 4 data to provide both surface soil moisture (top 5cm) and root-zone soil moisture (defined nominally as soil moisture in the top 1 m of the soil column). Both soil moisture data products are spatially and temporally complete with 9km resolution. For U.S. agricultural statistics reporting purposes, 36km resolution SMAP level 3 data is sufficient for either state level or Agricultural Statistics District (ASD) (consisting of multiple counties) level reports. However, for more detailed county level report, minimum 9km or better resolution is required. The 9km SMAP level 4 data meets the minimum requirement for county level soil moisture assessment.

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The SMAP level 4 assimilated data has 8 acquisitions daily (every 3 hours), which is too frequent for crop condition monitoring since it is difficult to detect crop changes in three hours. Therefore, appropriate daily or weekly data temporal aggregation has to be performed to make the data useful for crop soil moisture monitoring. In the prototype, we proposed following temporal aggregations: 1) daily average; 2) daily maximum; 3) weekly average; 4) weekly maximum; 5) biweekly average; and 6) biweekly maximum. As shown in Fig. 3, the original top soil moisture data acquired every three hours clearly demonstrated the soil moisture change dynamics. Fig. 4 illustrates the daily average top soil moisture on September 17 – 25, 2016. As shown in the center of Fig. 4, the average value is a balanced representation of top soil of September 21, 2016. The root-zone soil moisture (not shown here due to limited space) in general follows the same pattern as the top soil moisture in this case study.

Fig. 7 and Fig. 8 illustrate the weekly average top and root-zone soil moisture for September 2015 and September 2016. As shown in Fig. 7 and 8, the top and root-zone soil moisture were consistent for both 2015 and 2016 respectively. Iowa was much wetter in September 2016 than in September 2015. In Fig. 7 and 8, the fourth picture of second row shows the peak average soil moisture of the week of (9/20/16 – 9/26/16), which covers the repeated heavy rain storms in north east Iowa as shown in Fig. 5. In general, soil moisture in north east Iowa gradually increased from the beginning of September. As observed, the root-zone soil moisture was lower than the top soil moisture for both 2015 and 2016, which was expected.

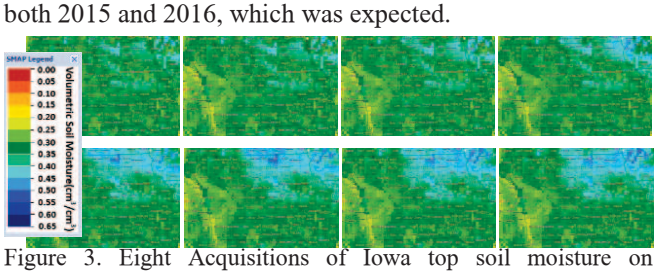


Figure 3. Eight Acquisitions of Iowa top soil moisture on September 21, 2016.

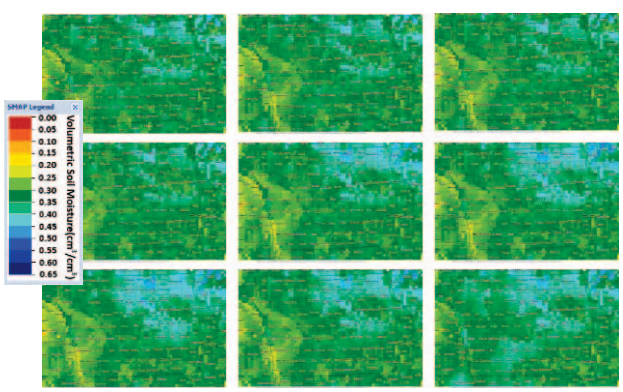


Figure 4. Daily aggregation – Daily average top soil moisture (9/17/16 ~ 9/25/16).

4. IOWA CASE STUDY

In late September 2016, the fall crop harvest period in Iowa, numerous rounds of storms hit north east Iowa. The storms had heavy rainfall rates of 1-3 inches per hour which were repeated over the same locations in some areas over many days. Rainfall totals of 3-7 inches were reported across the entire area from the 20th through 23rd. However, some locations had much higher amounts of 9-11 inches as shown in Fig. 5. When comparing Fig. 5 with Fig. 4 daily top soil moisture for the same period or with Fig. 7 peak weekly average soil moisture, we found that the soil moisture geospatial distribution pattern was the same as the rainfall distribution. This implies high correlation between SMAP soil moisture and rainfall.

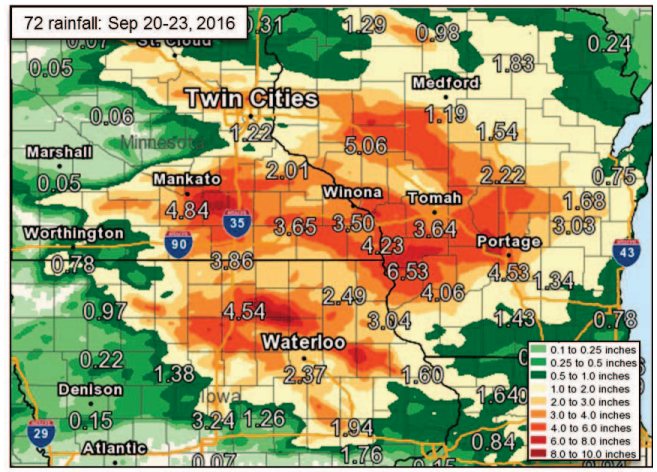
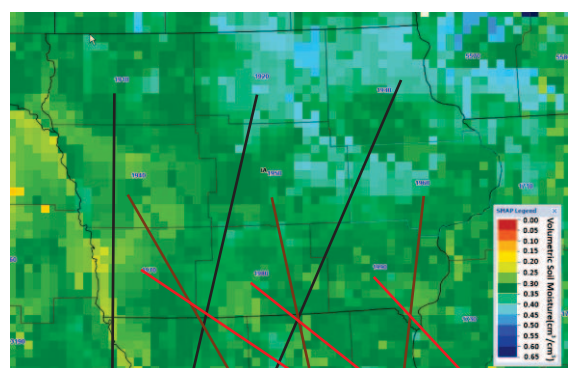


Figure 5. 72 hour rainfall in Iowa on September 20-23, 2016. (Courtesy of NOAA, NWS https://www.weather.gov/arx/sep2116)



Days Suitable & Soil Moisture Condition as of September 25, 2016

Item	Districts								
	NW	NC	NE	WC	C	EC	SW	SC	SE
	(days)	(days)	(days)	(days)	(days)	(days)	(days)	(days)	(days)
Days suitable	4.0	4.7	2.6	4.1	3.1	4.0	4.5	4.3	6.4
	(percent)	(percent)	(percent)	(percent)	(percent)	(percent)	(percent)	(percent)	(percent)
Topsoil moisture									
Very short	0	0	0	0	0	1	0	0	11
Short	4	0	1	0	1	1	0	4	15
Adequate	70	40	42	83	73	68	82	87	72
Surplus	26	60	57	17	26	31	18	9	2
Subsoil moisture									
Very short	0	0	0	0	0	0	0	4	9
Short	5	0	1	5	3	0	0	6	18
Adequate	73	51	55	83	84	73	95	85	71
Surplus	22	49	44	12	13	27	5	5	2

Figure 6. NASS Soil Moisture Report of Iowa on September 19-25, 2016 and SMAP weekly top soil comparison.

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We also compared the SMAP results with NASS' survey results. Fig. 6 illustrates the SMAP weekly average top soil moisture map of Iowa and NASS published Iowa soil moisture results at the ASD level from September 19-25, 2016. As shown in Fig. 6, about 60% of cropland top soil moisture was rated as surplus and about 40% of cropland sufficient in the NC and NE areas. These two ASDs were the wettest areas. The C and EC ASD's were the second wettest areas, which had 26% and 31% cropland soil moisture surplus and 73% and 61% sufficient. As shown in Fig. 6, the report shows that the soil moisture in the SW and SC ASD's were 82% and 87% sufficient and 18% and 9% were surplus, but the SMAP weekly average map does not show as much moisture. However, if we check the daily average map of September 25 in Fig. 4, we find the reported results were consistent with the most recent SMAP results.

5. CONCLUSION

This paper presents a case study of using SMAP soil moisture data products for agricultural land soil moisture assessment. This study uses an application prototype for interactive SMAP soil moisture data visualization, dissemination and analytics based on VegScape. In this study, temporal aggregation of SMAP data was performed for improved crop soil moisture assessment. This study assessed Iowa's soil moisture status and compared it with the National Oceanic Atmospheric Administration (NOAA) precipitation record. We found high correlations between the SMAP and NOAA observations. Moreover, NASS published soil moisture survey results were compared with SMAP weekly and daily average soil moisture data. It is found that the SMAP results were generally consistent with NASS published survey results. The results indicate that the SMAP data have great potential for agricultural soil moisture assessment applications. It has also proven that the VegScape-based prototype greatly enhanced the user experience and facilitates using SMAP soil moisture data products for crop condition monitoring and decision support.

6. REFERENCES

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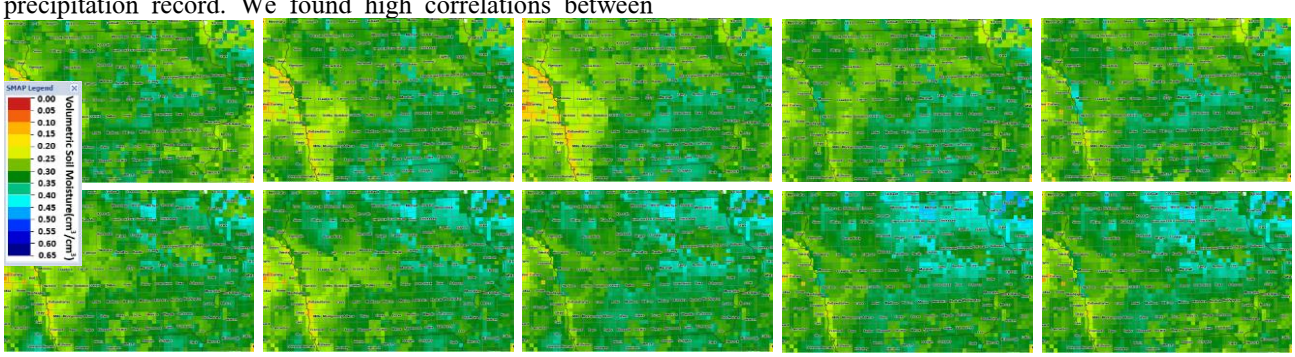

Figure 7. Weekly average top soil moisture (Iowa) – 09/2015 vs 09/2016. The top row is the weekly average data of September 2015 (09/01/15 – 10/05/15). The bottom row is the weekly average data of September 2016 (08/30/16 – 10/03/16).

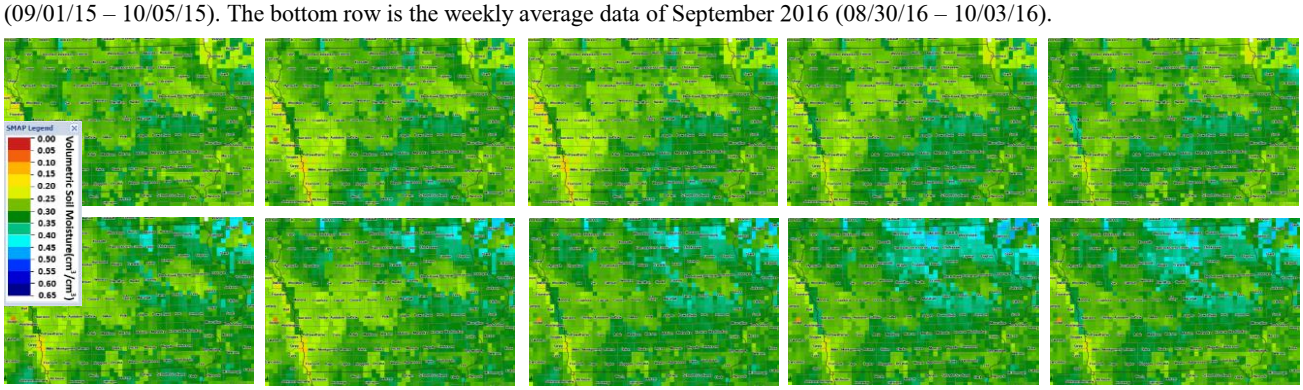

Figure 8. Weekly average root-zone soil moisture (Iowa) – 09/2015 vs 09/2016. The top row is the weekly average data of September 2015(09/01/15 – 10/05/15). The bottom row is the weekly average data of September 2016 (08/30/16 – 10/03/16).

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