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Southeast United States Agriculture

Incorporating NASA Earth Observations into the USDA Southeast Regional Climate Hub Lately Identified Geospecific Heightened Threat System (SERCH LIGHTS) to Assist Farmers in Making Informed Decisions on Water and Crop Management

 **Technical Report**

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# 1. Abstract

Regional climate variability in the southeastern United States is a concern for agricultural and forestry management. Droughts are an important consequence of this variability, affecting both the agricultural and forestry sectors’ ability to manage their water resources. The United States Department of Agriculture (USDA) Southeast Regional Climate Hub (SERCH) has thus developed a tool called Lately Identified Geospecific Heightened Threat System (LIGHTS) in order to provide information for its users that would increase water management efficiency. It identifies and alerts users to changes in drought, temperature, and precipitation patterns. However, LIGHTS lacks soil moisture information, which also affects drought patterns. This project therefore aims to update the current drought monitoring system by incorporating Soil Moisture Active Passive (SMAP) level 3 data as a support layer, by retrieving Standardized Soil Moisture Index (SSI) as a measure, and by using Python as the programming language. Ground truth soil moisture data from Soil Climate Analysis Network (SCAN) were collected for validation. As a result, this integration of SMAP data into SERCH LIGHTS will increase the end-user’s water management capabilities in response to drought conditions.

**Keywords**

Remote Sensing, SMAP, NLDAS, Drought, Soil Moisture, Standardized Soil Moisture Index, Python

# 2. Introduction

* 1. ***Background Information***

Climate variability in the Southeastern United States is a major concern. According to the National Climate Assessment for the Southeast, extreme heat and decreased water availability are two of the four identified major stressors on the region (Carter et al., 2014). Drought is a particular climate variability concern for the region’s development as a large part of the Southeast’s landscape is occupied by agricultural, forested, and range land (McNulty et al., 2015). The Southeast’s susceptibility to experiencing extensive droughts is increased by the impact of anthropogenic influences. These demographic dynamics, such as increasing population, expanding urbanization, and other land-use change, result in an increase in water demand, which further intensifies the impact of a water shortage on the region (McNulty et al., 2015).

Water shortage is especially concerning for agricultural and forestry management as droughts affect these sectors’ ability to manage their water resources. For the agricultural sector, water management issues caused by drought lead to vulnerability in crop production and livestock ([IPCC, 2007](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4258067/#b36)). Such vulnerability hurts both the production and profit of many individuals involved in the sector. For the forestry sector, water shortage caused by drought increases the risk of wildfires ([IPCC, 2012](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4258067/#b37)). In order to manage these risks and vulnerabilities, better irrigation practices and distribution of forestland fire-management resources are essential. Given the significant role these industries play in the region, and their increasing vulnerability to agricultural drought, an effective services system and drought index must be developed.

* 1. ***Project Partners & Objectives***

The US Department of Agriculture (USDA) Southeast Regional Climate Hub (SERCH) partnered with the Southeast United States Agriculture DEVELOP Team. SERCH is a climate hub created by the USDA to deliver science-based knowledge on climate change to farmers, ranchers, and forest land managers (USDA, 2015). SERCH provides regional-specific information to farmers to influence technical support and strategies to deal with climate variability issues, such as drought, in the Southeast United States (USDA, 2015). SERCH developed the Lately Identified Geospecific Heightened Threat System (LIGHTS), a drought mitigations tool to assist farmers with making informed decisions on water and crop management (EFETAC, 2015). LIGHTS identifies and alerts users at risk of drought by looking at changes in temperature and precipitation. The SERCH LIGHTS services are available in eleven States: Alabama, Arkansas, Georgia, Florida, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia.

While LIGHTS allows users to view NOAA monthly drought predictions, it lacks soil moisture information, an essential variable when considering drought patterns. According to NOAA, there are four types of droughts: meteorological drought, agricultural drought, hydrological drought, and socioeconomic drought. Agricultural drought occurs when soil moisture is insufficient to sustain average crop or grass production (Wilhite & Glantz, 1985). Since soil moisture is an important factor for determining agricultural droughts, incorporating this factor into the LIGHTS tool was fundamental for developing the tool’s utility towards its subscribers.

The Southeast United States Agriculture team aims to include soil moisture data into the LIGHTS tool by developing a drought index. The objective is to update the current drought monitoring system, LIGHTS, by incorporating SMAP Level 3 data throughout the Southeastern states. As a result, this integration of SMAP data into SERCH LIGHTS will increase the end-user’s water management capabilities in response to drought conditions.

# 3. Methodology

***3.1 Data Acquisition***

The primary data component was acquired from the NASA satellite Soil Moisture Active Passive (SMAP). The data products were Level 3 Soil Moisture data from L-Band Radiometer (SMAP L3-SM-P). The Level 3 data were a daily global composite of the Level 2 surface soil moisture (SMAP L2-SM-P). Level 2 data were a soil moisture product based on brightness temperature measurements that were sensitive to soil moisture. The Level 2 accuracy was equal to or better than 0.04 cm3 (NASA, 2014). SMAP Level 3 products were downloaded from the NASA’s Earth Observing System Data and Information System (EOSDIS) Reverb Echo portal on EARTHDATA as GeoTIFFs in WGS 1984 Geographic Coordinate System.

Ancillary datasets were utilized for model building and verification. Soil moisture data from NASA North American Land Data Assimilation System (NLDAS) was used as a historical reference in models. The NLDAS Noah Land Surface Model L4 Hourly 0.125 x 0.125 degree V002 data was downloaded from Goddard Earth Sciences (GES) Data and Information Center data portal, Mirador. Thirty six years of the hourly data files were downloaded in NetCDF format and in the WGS 1984 Geographic Coordinate System. The files were processed to extract the 1200 UTC data for each day over the 36 years (Xia et al., 2012).

The second ancillary dataset used was the Soil Climate Analysis Network (SCAN). Data retrieved from testing stations in the study area were downloaded from the USDA National Resources Conservation Service (NRCS) as csv files. The sensor was a dielectric constant measuring device, at a depth of 5.08 cm (USDA, 2016).

***3.2 Data Processing***

The SMAP Level 3 data were originally provided as HDF-EOS5 products at 40-km resolution on a fixed 36 km EASE2 grid. The SMAP Level 3 data were acquired from Reverb Echo because it is capable of pre-processing the data. The SMAP Level 3 data was converted to a GeoTiff and reprojected into WGS 1984 Geographic Coordinate System.

In order to avoid invalid values in SMAP data, additional pre-processing was necessary. The conditional, or Con, tool in ArGIS was used to evaluate each point to change any -9999 values to No Data raster values. This step insured that all of the SMAP values were decimal values from 0 to 1.

SMAP and NLDAS soil moisture units do not match. SMAP measures volume of water per unit volume of soil. NLDAS datasets currently provide soil moisture values in units of kilogram per square meter of soil over variable thicknesses. In order to utilize SMAP and NLDAS values in the same models, Equation 1 was used to convert NLDAS to SMAP units.

 $\frac{NLDAS SM (kg/m^{2})}{W(0.1 m)}$ Eq. 1

Equation 1 shows how NLDAS was converted to volumetric units where NLDAS SM represents the original soil moisture value and W is the density of water, or 1,000 kilograms per square meter.

The individual SCAN station data files were combined into one Excel table. A separate Excel table with coordinates was created for daily measurement, and then imported to ArcGIS.

***3.3 Data Analysis***

Setting the norm was an essential procedure for this methodology. Since SMAP was launched in January of 2015, only two years of data were recorded. The focus of this method was to obtain the mean and standard deviation values based on historical NLDAS records for each day of the year. For this study, February 29th was excluded. Approximately 36 years of hourly NLDAS data were used to create the mean and standard deviation for each day at 1200 UTC**.** The NLDAS data were fed through an ArcGIS model that gathered each day from the 36 years. Then the 36 values of each day were used to calculate the mean and standard deviation of that day with the cell statistics spatial analyst tool.

A Standardized Soil Moisture Index (SSI) was used to simplify the national analysis. Using a relative measurement by calculating the normal conditions, or norm, would efficiently compare current soil conditions to historical averages. The SSI was calculated with Equation 2 for the first two years that SMAP data was available.

 SSI $=\frac{x\_{SMAP}-μ\_{NLDAS}}{σ\_{NLDAS}}$ Eq. 2

Where $x\_{SMAP}$ is the soil moisture content from SMAP Level 3 data for a single day, $μ\_{NLDAS}$ is the mean value of soil moisture content for the, and $σ\_{NLDAS}$ the standard deviation of soil moisture content for corresponding day.

The raster calculation tool from ArcGIS was used to calculate the SSI for each day. The SSI indicates how many standard deviations a daily input soil moisture is from the mean, and therefore is an ideal relative measure of the soil moisture content.

***3.4 Accuracy Assessment***

The final step in the methodology was to perform an accuracy assessment. The process determined the accuracy of SMAP and NLDAS data, verifying the methodology and the results. The validation was performed by comparing the soil moisture daily data from SMAP and NLDAS to daily soil moisture data retrieved from USDA Soil Climate Analysis Network (SCAN) stations. SCAN stations contain measuring sensors that provide soil moisture data from ground-based stations located across the United States (USDA, 2016).

The point validation process had two parts. The first was selecting SCAN locations as the testing stations for the validation. The second part was comparing the daily data retrieved from stations with the SMAP and NLDAS daily data in the matching locations. The comparison was done by compiling SMAP and the georeferenced SCAN data into Excel, and then performing a regression analysis to test the correlations between the data. This same process was applied to validate NLDAS data. Throughout this accuracy assessment, data latency and accuracy were taken into account. The SMAP Level 3 soil moisture product has a 50-hour latency, which met the required latency threshold of 72 hours.

*3.4.1 Ground Station Selection*

Ground station selection was the first part of the validation process. While validating and processing data for the continental United States was optimal, only four ground stations across the U.S. were selected (see Table 1). The criteria for this selection process consisted of identifying the stations with the most accurate and longest collection of data based in locations that were agricultural lands, plains, or grasslands. The stations selected together were expected to be representative of diverse weather conditions, from wet to dry areas. Some of the areas considered for the preferred ground stations included: the Midwest plains, plains in the central valley of Nebraska, the farther east of Georgia, California, Northern Mississippi, and Alabama. The validation was on a daily level, from March 31 2015, since SMAP was available.

**Table 1. SCAN Stations Used for Validation**

|  |  |  |
| --- | --- | --- |
| **Station ID** | **State Code** | **Station Name** |
| 2013 | GA | Watkinsville #1 |
| 2024 | MS | Goodwin Ck Pasture |
| 2053 | AL | Wtars |
| 2006 | TX | Bushland #1 |

*3.4.2 SMAP and NLDAS data Validation*

Point validation process was done by comparing SMAP and SCAN daily data values in all four selected SCAN stations for a period of 16 months, starting on January 2015. Daily data retrieved from the four SCAN stations were also compared with NLDAS daily values for 12 months, starting on January 2015. The data value period for NLDAS and SMAP does not match in length, but this period was selected for consistency since both SMAP and NLDAS have data values in 2015. The 12-month period of 2015 was the longest period with data values for all three sources – SCAN, NLDAS, and SMAP.

The validation process for both SMAP and NLDAS data were based on first compiling the retrieved point values into the same excel sheet consisting of values from a SCAN station. This resulted in the creation of a total of eight excel sheets for the SMAP validation, two sheets for each of the four stations, one for the year 2015, and another for the year 2016. Given that NLDAS values were only based on 12 months, the validation resulted in four excel sheets only, one for each station from the year 2015.

However, before comparing the values from a selected SCAN station with SMAP values in Excel, one more step was required. Because SMAP data was provided in raster format, it was necessary to retrieve the SMAP data values from a *point* location matching the station’s location. The tool *extract values to table* in ArcGIS was used for the point extraction process. These pixel values were then exported and inserted into the Excel sheet it belonged to – matching date and SCAN station.

The next step for the comparison consisted of matching up the SMAP and SCAN daily data on the Excel sheet. This step was particularly significant as the SMAP data had several missing values due to its three-day coverage. Days with missing values were dropped, and dates between the two sources were re-arranged.

In order to compare SMAP/SCAN dates, the *Mid string* function in Excel was used to retrieve the day, month, and year from each SMAP data value. The re-arranged data, corresponding SCAN and SMAP data retrieval dates, were then inputted in a table using the ArcGIS *attribute join* tool. Any outliers, such as -99.9 or No Data values, were then deleted. The same process was carried out for validating NLDAS values.

After the data compilation and organization were completed, a regression analysis was performed to test the correlations between the data. This step was carried out in each of the 12 excel sheets (8 SMAP, and 4 NLDAS). The regression analysis provided a scatter plot between the compared data in each sheet, and included the regression line and R-squared.

#  4. Results & Discussion

***4.1 Analysis of Results***

Soil moisture is an output of the water balance. Several methods for soil moisture retrieval were proposed in past research (Thornthwaite, 1955; Ritchie, 1998). Various variables were suggested to retrieve soil moisture data such as climate, plant, and soil characteristics. These three variables expand to rainfall rates, potential evapotranspiration, soil water capacity, soil proximity to the water table, vegetation type, leaf area, management practices, crop sensitivity to water stress, and crop water requirement for each phenological phase (Sivakumar et al., 2010). One of the most used indexes, the relative soil moisture index (RSMI) was designed to measure and simulate how much water was available in soil for crops (Sivakumar et al., 2010).

This model requires soil water holding capacity, which is a variable depending on soil type information.

Obtaining soil moisture from SMAP was straightforward because the Level 3 product was a daily global Radiometer-Only Soil Moisture Product, which provides direct sensing of soil moisture in the top 5 cm of the soil column in units of cm3/cm3 (NASA, 2014). SMAP data of GeoTiff format with a geographic projection were directly supported by ArcGIS.

SSI reference layers were created on order to incorporate SMAP and NLDAS into the SERCH LIGHT system. Soil type and characteristics varied greatly throughout such a broad study area. SSI would simplify the national analysis and eliminate the need to account for mapping soil types. Figure 1 shows how three days of SMAP Level 3 data would cover the US. The simplified SSI is a z-score, thus indicating how many standard deviations a SMAP value is from the historic mean. The yellow values indicate a low z-score, which means that the values are lower than the historic soil moisture average. The blue values indicate a high z-score, which means that the values are higher than the historic soil moisture average.



-01

-00.5

-00

SSI Score

**Figure 1. Three consecutive SSI calculation from June 2015. The values reflect how the current SMAP soil moisture deviates from the NLDAS records. Areas in yellow represent areas that are experiencing very dry conditions, indicating drought.**

This results in SMAP classification as a value from 0 to 1. SMAP values greater than 0.5 are uncommon. Some clay rich-soils can reach SMAP values of 0.5 under normal conditions. For sandy soils, the practical upper limit is even less, but it does occur in tropical and coastal cases as seen by observation (Cepuder et al., 2008). Figure 2 shows how the SSI values changes from different seasons.



-01

-00.5

-00

SSI Score

**Figure 2. SSI calculations from three consecutive days in June 2015 on the bottom, October 2015 in the center, and February 2016 on the top. The values reflect how the soil moisture changes slowly over time.**

SSI calculations are ineffective in winter months due to permafrost. Figure 2 shows that a large portion of data is lost in the northern states during the winter season.

*4.1.1 Validation Result*

The correlation between SMAP soil moisture data and the SCAN data is between 0.4612 and 0.9177. As for NLDAS validation result with the four selected SCAN stations, the correlations found throughout the stations range from about 0.376 to 0.7742. Table 2 shows the validation root mean squared error, R2, values for NLDAS in 2015, and SMAP in 2015 and 2016. Figure 4 in the appendix shows a graph of the station 2053 in Alabama having a strong correlation between SMAP and SCAN in 2016. Figure 5 in the appendix shows the same station in 2015, the correlation between SMAP and SCAN is significantly lower.

**Table 2. SCAN Stations validation with SMAP.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Station ID** | **NLDAS R2 in 2015** | **R2 in 2015** | **R2 in 2016** |
| 2013 | 0.5758 | 0.6802 | 0.9124 |
| 2024 | 0.6935 | 0.7634 | 0.6817 |
| 2053 | 0.3376 | 0.4612 | 0.9177 |
| 2006 | 0.7742 | 0.6526 | 0.245 |

*4.1.2 Accuracy analysis*

Although most of the accuracy results were close to the desired value set at 0.7, the value at the Texas station for the year 2015 was exceptionally low at 0.24497 in Figures 10-11. This extraordinarily low value indicated a discrepancy between the two data sources. In order to discover what caused the significantly low accuracy in the Texas station for the year 2016, a data analysis between SMAP and SCAN was performed in depth. This was achieved through creating a time plot comparison to identify the anomaly shown in Figure 3.

**Figure 3. Texas Station 2006 for 2016**

When analyzing Figure 3, the relationship between SMAP and SCAN looks correlated, but the relationship changes drastically on around April 31st, breaking the correlation pattern. The discrepancy in their relationship continues until July.

Given this time plot analysis, a few speculations have been made to shed light on the cause of this inconsistency. It is possible that the break in the correlation may have been a reaction to the summer Texas flood of 2016.

Another potential cause may have been an outcome of the disparities caused by collecting data at slightly different times between NLDAS and SMAP. SMAP data was collected at 6 AM local solar time. Since NLDAS data time zone was Coordinated Universal Time (UTC), the ideal procedure to ensure matching NLDAS time with SMAP 6 AM, would have required combining five time zone layers, 1000 to 1400 UTC. Since this manual procedure for 36 years of data is extensive, 1200 NLDAS data were selected instead. 1200 UTC does not perfectly match the SMAP 6 AM time, and may as a result have impacted thE accuracy assessment.

Another speculation was based on the extensiveness of the data processing procedure. The manual process of NLDAS data was time consuming as well as labor intensive which lead to concern in regards to the likelihood of error during the process. An error during the manual process of data downloading or processing could explain an unusual trend between the data, hence a low accuracy.

The final speculation emphasized the role of the simplified SSI, and its potential impact on accuracy. The SSI developed throughout this project assumed normal distribution for the historic records of the soil moisture instead of non-normal distribution. Such an assumption may be non-representative of reality, thus decreasing the accuracy.

Throughout the accuracy analysis, it was considered that the assessment was only determined on four SCAN stations for point validation. This emphasized the importance of performing more point validation by expanding the number of test stations used. Further assessment would provide better understanding of the SMAP and NLDAS accuracy.

*4.2 Future Work*

This project can be expanded on in future study in four areas. As stated earlier, we selected 1200 UTC NLDAS data, which does not perfectly match the SMAP 6 AM time. Future research could collect and reprocess NLDAS corrected to SMAP overpass time. Another addition to the project could be to revisit the simplified SSI, or Z-score, and change our assumption to gamma distribution. This may create a more accurate SSI.

SERCH expressed interest in the investigation of long-term climatic events, such as El Niño, and how these could alter the accuracy of the soil moisture measurements. A future project could examine climate records from other NASA Earth observation satellites to explore possible correlations. SERCH also expressed interest in incorporating soil temperature data using NASA Earth observations into their tool.

# 5. Conclusions

The SERCH LIGHTS system is currently driven by NOAA’s Climate Prediction Center’s Monthly Drought Outlook, Monthly Temperature and Precipitation Outlook, and Risk of Seasonal Climate Extremes in the U.S. related to the El Niño Southern Oscillation (ENSO). Subscribers, who are typically in the sectors of forestry or agriculture, receive a notification when their location is predicted to experience changing conditions related to drought. This system allows users to address drought and water management issues efficiently and directly. While this tool allows users to address water management more efficiently, it lacked information regarding soil moisture, which also affects drought patterns.

The project therefore adopted the past 36 years of NLDAS data to obtain the historical mean value and standard deviation, in order to get a relative measurement of soil moisture, the SSI. Integrating the NLDAS and SMAP data into SERCH LIGHTS will therefore help with the end-user’s water management capabilities in response to drought conditions. This will help farmers, foresters, extension, consultants, and field staffs make timely, informed decisions on water and crop management based on the best available and most current climate observations.

The accuracy of using SMAP to monitor soil moisture content displayed a very high statistical correlation (Table 2) between SCAN data, which indicated that SMAP is a reliable method of soil moisture monitoring. However, an exceptionally low value during the accuracy assessment emphasized the importance of performing further validation. In addition to expanding the validation, exploring the cause of the low value from the Texas station is also very important. It may reveal new points about SCAN, SMAP, and the methodology utilized, help raise new questions, and provide an opportunity to learn more about the SMAP satellite and its data.

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* POC: Jennifer Moore Myers(Project Manager) and John Cobb(Lead Developer)

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# 8. Content Innovation

**Content Innovation #2**

* **Data Latency:** A product’s latency is the measure of time between the observation acquisition of instrument data by the observatory and the time the product is available to the public at the SMAP Data Centers (NASA Jet Propulsion Laboratory). The SMAP Level-3 data has a 50 hour latency. This means that the Level-3 data is available to the public within 50 hours after its acquisition by the observatory.
* **Drought/Agricultural Drought:** A drought occurs when there is a deficiency in precipitation over an extended period of time (NOAA National Weather Service, 2012). There are four types of drought: meteorological, hydrological, socioeconomic and agricultural. Agricultural drought is considered based on the impacts of certain factors to agriculture, such as deficits in the amount of moisture in the soil.
* **EASE2 Grid:** Version 2.0, the newest release of EASE-Grid, is defined with the WGS 84 ellipsoid (NSIDC 2016). Two major NASA-funded projects have adopted EASE-Grid 2.0 as the standard format for gridded data sets, including the Soil Moisture Active Passive (SMAP) project (data are forthcoming), and the MEaSUREs snow and ice project (NSIDC, 2016).
* **EOSDIS:** Earth Observing System Data and Information System is a key core capability in NASA’s Earth Science Data Systems Program.
* **Geographic Coordinate System:** A geographic coordinate system (GCS) uses a three-dimensional spherical surface to define locations on the earth. A GCS includes an angular unit of measure, a prime meridian, and a datum (based on a spheroid).
* **GeoTIFF:** GeoTIFF is a raster data format which allows geo-referencing information to be embedded within a TIFF file. This format allows storage and transfer of digital satellite imagery, as well as establishing map projections, coordinate systems, ellipsoids, datums, and everything else necessary to establish the exact spatial reference for the file (Geospatial World, 2009). SMAP L3 data were provided as GeoTIFF format as requested.
* **Historical statistics:** This term refers to either the *historic average soil moisture* or the *historic standard deviation soil moisture*, or both. Historical statistics refer to the mean values and/or standard deviation values calculated from 36 years of daily soil moisture data (1980-2015).
* **Network Common Data Form (NetCDF):** NetCDF is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data (OGC 2016). NLDAS data was downloaded from Mirador as NetCDF format.
* **NLDAS:** NASA North American Land Data Assimilation System (NLDAS) is a model that creates land surface model datasets with reduced errors. It collects these datasets based on other observations and models. One of these includes a collection of accurate soil moisture data extending back from January 1979 to 2015 in central North America (NASA, 2016). This soil moisture ancillary dataset was utilized as historical record for soil moisture data in the study area.
* **SCAN:** USDA Soil Climate Analysis Network (SCAN) provides soil moisture, soil temperature, precipitation, wind, and solar radiation data (U.S. Climate Resilience Toolkit, 2015). This data is collected from the SCAN sensors in the ground-based stations located across the United States. The SCAN sensor is a dielectric constant measuring device at a depth of 5.08cm (USDA Natural Resources Conservation Service).
* **SERCH:** Southeast Regional Climate Hub (SERCH) is one of the climate hubs created by the US Department of Agriculture (USDA) to deliver science-based knowledge on climate change to farmers, ranchers, and forest land managers (USDA SERCH). SERCH provides the technical support and strategies to help farmers deal with climate variability issues, such as drought, in the Southeast United States (USDA SERCH).
* **SERCH LIGHTS:** Lately Identified Geospecific Heightened Threat System(LIGHTS) is a drought mitigations tool created by SERCH. Its function is to assist farmers with making informed decisions on water and crop management by identifying and alerting users on drought. The tool predicts drought by looking at changes in patterns of temperature and precipitation. SERCH is currently partnering with NASA Develop to augment the LIGHTS system.
* **Southeast United States:** Southeast United States is considered as the region farthest east of the Southern United States. The states considered as part of this region, and represented by the USDA Southeast Regional Climate Hub, include: Alabama, Arkansas, Georgia, Florida, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia (USDA Climate Hubs). The time zone for the region is Eastern Standard Time (EST).
* **SMAP:** Soil Moisture Active Passive (SMAP) is a NASA Earth Observation that makes polar orbits around the Earth at a three day coverage. It measures the amount of water in the top 5cm of soil on Earth’s surface, and can also determine if the ground is frozen or thawed (NASA, 2014). SMAP was launched on the 31st of January 2015 and detects soil moisture patterns on the Earth. We used SMAP soil moisture data collected at the Level-3 Passive, 36 km resolution radiometer.
* **Radiometer:** A radiometer is an instrument that measures the intensity of radiation in a particular band of wavelengths in the electromagnetic spectrum (Esri). The SMAP radiometer detects radio waves emitted by the ground, and determines the temperature of the ground depending on the strength of the emission (NASA Jet Propulsion Laboratory). The Level-3 Soil Moisture data collected from SMAP is a Radiometer-Only Soil Moisture Product, which means it provides direct sensing of soil moisture on the surface.
* **Soil Moisture Content:** Soil moisture content is the amount of water contained in soil. SMAP data estimates the 0-5cm surface of soil moisture in units of cm3/cm3 (NASA Jet Propulsion Laboratory (2014).
* **Standardized Soil Moisture Index (SSI):** This index is an ideal relative measure of the soil moisture content, as it indicates how many standard deviation a daily input soil moisture is from the mean. In order to calculate the SSI, it was imperative to set the soil moisture norm, which was done by obtaining mean and standard deviation values of past records. The SSI is calculated by subtracting the historical mean value of soil moisture content from the current mean value of soil moisture content, and dividing this difference by the historical standard deviation of soil moisture content. This SSI is a simplified version of the z-score.
* **Z-score:** A z-score indicates how many standard deviations an element, in this case, daily input soil moisture, is from the mean (Stat Trek, 2016). The calculated Standardized Soil Moisture Index (SSI) is a simplified version of the Z-score.

**Content Innovation #3**

Inline Supplementary Material

* Table 1. SCAN Stations Used for Validation
* Figure 1. Three consecutive SSI calculation from June 2015. The values reflect how the current SMAP soil moisture deviates from the NLDAS records. Areas in yellow represent areas that are experiencing very dry conditions, indicating drought.
* Figure 2. SSI calculations from three consecutive days in June 2015 on the bottom, October 2015 in the center, and February 2016 on the top. The values reflect how the soil moisture changes slowly over time.
* Table 2. SCAN Stations validation with SMAP.
* Figure 3. Texas Station 2006 for 2016

# 9. Appendices

**Figure 4. Station 2053 in 2016.**

**Figure 5. Station 2053 in 2015.**

**Figure 6. Station 2024 in 2016.**

**Figure 7. Station 2024 in 2015.**

**Figure 8. Station 2013 in 2016.**

**Figure 9. Station 2013 in 2015.**

 **Figure 10. Station 2006 in 2016.**

**Figure 11. Station 2006 in 2015.**

Table 3. SCAN Stations Used for Validation

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Station Id** | **State Code** | **Network Code** | **Station Name** | **Elevation** | **Latitude** | **Longitude** | **County Name** | **HUC** | **HUC Name** |
| 2013 | GA | SCAN | Watkinsville #1 | 770 | 33.88333 | -83.43333 | Oconee | 30701010305 | Lower Barber Creek |
| 2024 | MS | SCAN | Goodwin Ck Pasture | 320 | 34.25 | -89.86667 | Panola | 80302030403 | Johnson Creek-Long Creek |
| 2053 | AL | SCAN | Wtars | 625 | 34.9 | -86.53333 | Madison | 60300020306 | Lower Brier Fork |
| 2006 | TX | SCAN | Bushland #1 | 3820 | 35.16667 | -102.1 | Randall | 111201020301 | Negro Arroyo |