Assessment of the 3-km SPoRT-Land Information System for Drought Monitoring and Hydrologic Forecasting

Final Report Prepared by

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Executive Summary

The Short-term Prediction Research and Transition (SPoRT) Center conducted an assessment of selected soil moisture output of the NASA Land Information System (LIS) from August to October 2014 to determine its potential utility in the areas of drought monitoring and estimating the areal/river flooding potential from antecedent soil moisture conditions. SPoRT manages a real-time configuration of the LIS (hereafter "SPoRT-LIS") which runs the Noah land surface model in an offline or analysis mode, uncoupled to a numerical weather prediction model. Unique characteristics of the SPoRT-LIS and its dissemination include (1) Higher-resolution grid (~3 km) than most operational land surface modeling systems, (2) Input real-time green vegetation fraction (GVF) from the Moderate Resolution Imaging Spectroradiometer (MODIS) produced in-house at SPoRT in place of climatological GVF, and (3) Dissemination of data to select National Weather Service (NWS) weather forecast offices (WFOs) for display in the next generation Advanced Weather Interactive Processing System.

The SPoRT-LIS has been evaluated in a testbed mode since ~2011 by the NWS WFO in Huntsville, AL (HUN). Given the utility found at WFO HUN, this more formal assessment was conducted to broaden the HUN applications of the SPoRT-LIS to drought and areal flood potential with the NWS Houston, TX and Raleigh, NC WFOs. A subset of the SPoRT-LIS output variables were sent to each WFO consisting of the 0-10 cm volumetric and relative soil moisture, 0-200 cm (total column) relative soil moisture, and the weekly change in the total column relative soil moisture.

Prior to the kick-off of the August to October assessment, SPoRT developed two training modules (*NASA Land Information System: A Primer,* and *NASA Land Information System: Applications Training*; both available from the SPoRT web page at http://weather.msfc.nasa.gov/sport/training/) to help acquaint the participating NWS end-users with the SPoRT-LIS. Throughout the development of the modules, SPoRT personnel worked with NWS forecasters to ensure an appropriate presentation level.

Feedback from the NWS WFOs during the assessment was handled in several ways: (1) blog posts to the Wide World of SPoRT blog, (2) correspondence via email and/or the NWS chat forum, and (3) completion of short, online questionnaires. Two separate surveys for drought and flooding were developed using a Likert-type scale to determine the level of perceived utility of select SPoRT-LIS soil moisture variables on the forecaster's decision-making process. A total of 10 blog posts were made during the course of the assessment along with 27 completed questionnaires (24 for drought and 3 for flooding).

Overall survey results indicated that forecasters had high confidence in applying the SPoRT-LIS soil moisture to drought monitoring and to a lesser extent, areal flooding potential. Survey participants noted that they were comfortable in applying the SPoRT-LIS data based on the training, indicating the success of the training modules developed in advance of the assessment. Forecasters identified the total column relative soil moisture and especially the weekly change in this variable as the most helpful fields in making decisions regarding drought classification. Based on displays of the soil moisture fields in AWIPS II, the NWS RAH forecast office recommended adjustments to the USDM D0 areal coverage, which was accepted by USDM authors. These recommendations were highlighted in cases and blog posts documented by the NWS RAH. Future recommendations for the LIS include an expansion to a full CONUS domain at the same resolution, and the development of a soil moisture climatology to place real-time soil moisture into an historical context for drought and flood applications.

1. Introduction and Background Information

The NASA Short-term Prediction Research and Transition (SPoRT) Center is running a real-time configuration of the Noah land surface model (LSM) within the NASA Land Information System (LIS) framework (hereafter referred to as the "SPoRT-LIS"). Output from the real-time SPoRT-LIS is used at select NOAA/National Weather Service (NWS) partner offices for (1) initializing land surface variables for local modeling applications, and (2) situational awareness of drought and areal flood potential monitoring. This report describes the summer/autumn 2014 assessment of several soil moisture variables output by the SPoRT-LIS. The assessment was conducted from 1 August through 31 October 2014 and included participation from NOAA/NWS Weather Forecast Offices (WFOs) in Houston, TX (HGX), Huntsville, AL (HUN) and Raleigh, NC (RAH).

The NASA LIS is a high performance land surface modeling and data assimilation system that integrates satellite-derived datasets, ground-based observations and model reanalyses to force a variety of LSMs (Kumar et al. 2006; Peters-Lidard et al. 2007). By using scalable, high-performance computing and data management technologies, LIS can run LSMs offline globally with a grid spacing as fine as 1 km to characterize land surface states and fluxes. LIS has also been coupled to the Advanced Research Weather Research and Forecasting (WRF) model (Kumar et al. 2007) for numerical weather prediction (NWP) applications using the NASA Unified-WRF modeling framework (Peters-Lidard et al. 2015).

The LIS has been run in real time since 2010 at NASA/SPoRT over a southeastern Continental U.S. (CONUS) domain. The SPoRT-LIS was initially implemented to support enhanced soil initialization for local modeling applications at WFOs within the Southeast CONUS, although it was also tested as supplemental guidance for a summer convective initiation forecast experiment conducted by the Birmingham WFO (Goggins et al. 2010; Unger et al. 2011). From spring 2011 to 2014, the Applications Integration Meteorologist (AIM) at the Huntsville WFO examined SPoRT-LIS variables in a testbed mode via image files available from the SPoRT website, and used the information to suggest designation of drought classifications for the U.S. Drought Monitor (White and Case 2013). Several soil moisture variables were considered useful for the drought monitoring process, including:

- 0-10 volumetric soil moisture,
- 0-10 cm relative soil moisture,
- 0-200 cm relative soil moisture,
- 0-200 cm relative soil moisture weekly change.

The latter variable was created by the SPoRT modeling team in 2012 due to a request by the AIM to better visualize weekly changes in soil moisture corresponding to the update frequency of the U.S. Drought Monitor (USDM) product. The AIM and other forecasters at the Huntsville WFO also examined several fields to determine thresholds of soil moisture that corresponded to elevated risks for areal/river flooding in their County Warning and Forecast Area (CWFA). While all variables added some value to the process, the 0-200 cm relative soil moisture variable was determined to be the most reliable and operationally useful for assessing the risk for longer-term flooding of several tributaries and basins along the Tennessee River. Transitioning SPoRT-LIS data into the Advanced Weather Interactive Processing System (AWIPS) platform presented challenges initially due to the inability of AWIPS I to ingest and display sub-surface data fields, thus the reason for testbed evaluation of variables via online graphics initially at WFO Huntsville. However, the data-ingest mechanisms within the next generation AWIPS II are more self-describing, thereby enabling the display of sub-surface data more easily.

Given the ability to transition SPoRT-LIS data into AWIPS II and the success of soil moisture variables for drought and areal/river flooding applications at the Huntsville WFO, SPoRT decided to conduct a broader, more formal dissemination and assessment of several SPoRT-LIS variables to interested WFO collaborators already upgraded to AWIPS II. This assessment supports the SPoRT R2O strategy since soil and hydrology applications will have increased visibility with upcoming NASA missions such as the Soil Moisture Active Passive (SMAP; launched in January 2015), and the Global Precipitation Mission (GPM; launched in early 2014). The HGX, HUN, and RAH WFOs were chosen to participate in this assessment for several reasons:

1. Presence of AWIPS II in their operations,
2. Interest in the SPoRT-LIS to address local operational challenges,
3. Existing relationships with respective state climate offices,
4. Presence of robust drought/hydrology programs, and
5. CWFA boundaries lay within the SPoRT-LIS domain.

SPoRT conducted the assessment of the afore-mentioned soil moisture products during August to October 2014 to determine their efficacy to the drought monitoring process and for determining the risk for areal/river flooding across different environments. Further description and example imagery of these soil moisture products is contained herein.

The remainder of this document includes more detailed, specific information regarding the transitioned SPoRT-LIS fields and the assessment results from user feedback. The report is intended primarily for NOAA and NASA program managers and product developers; however, others with interests in this report will include operational forecasters as well as institutions participating NASA LIS development or research-to-operations activities, and the general LSM community.

2. SPoRT-LIS Product Description

The soil moisture variables/products used during this assessment were derived from the SPoRT-LIS, which runs version 3.2 of the Noah land surface model (LSM) in an offline mode, driven by operational analyses and gridded precipitation. The SPoRT-LIS is a continuous integration of the Noah LSM within LIS beginning 1 June 2010 through the present time, continuously restarted as new model analyses and precipitation datasets become available in real time. Below is a brief description of the LIS configuration as run in real-time to support this assessment, including the input data sets, domain, product latency, and variables output to the NWS forecast offices participating in the assessment. Much of the material presented in this section is available in greater detail within the "*NASA Land Information System Primer*" training module, available on the SPoRT web page at http://weather.msfc.nasa.gov/sport/training/.

Domain and Resolution

The SPoRT-LIS is run in real-time on a grid with ~3 km (0.03°) spacing over the southern and eastern half of the Continental U.S. (CONUS; Figure 1). In the SPoRT-LIS, version 3.2 of the Noah LSM (Ek et al. 2003; Chen and Dudhia 2001) is run offline or in analysis mode (i.e., uncoupled from an NWP model) for a continuous long simulation. The soil temperature and volumetric soil moisture fields were initialized at constant values of 290 K and 20 % in all four Noah soil layers (0-10, 10-40, 40-100, and 100-200 cm) on 1 June 2010, followed by an integration using a 30-minute time step to near real-time.

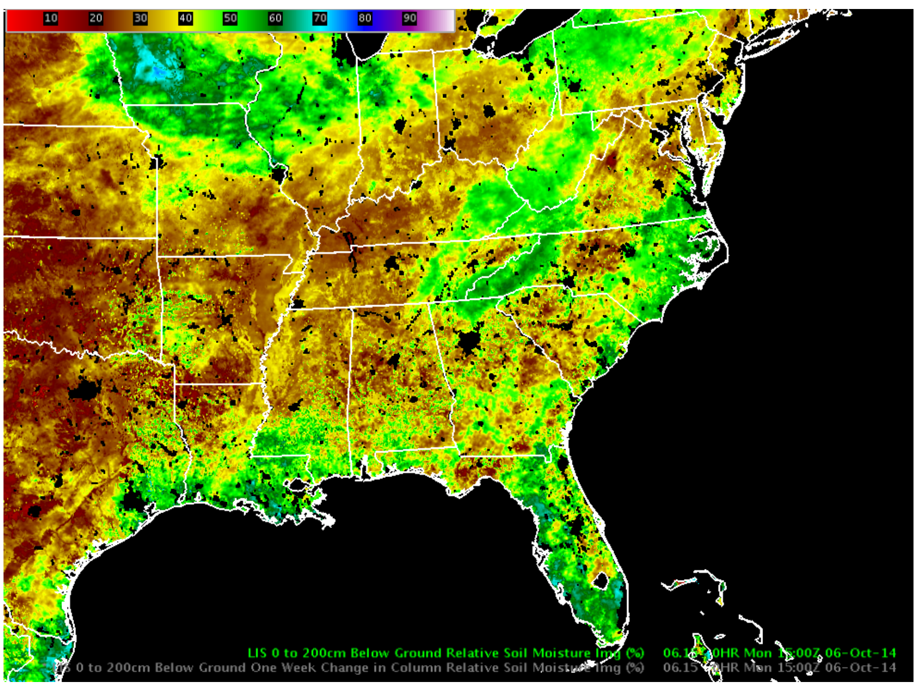


Figure 1. Depiction of the 0-200 cm total column relative soil moisture on the full SPoRT-LIS domain, as displayed in the AWIPS II at NWS Huntsville, AL.

Input Parameter Data Sets

The SPoRT-LIS uses the International Geosphere-Biosphere Programme (IGBP) land-use classification (Loveland et al. 2000) as applied to the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument (Friedl et al. 2010). All static and dynamic land surface fields are masked based on the

IGBP/MODIS land-use classes. The soil properties are represented by the State Soil Geographic (STATSGO; Miller and White 1998) database.

Additional parameters include a 0.05° resolution maximum snow surface albedo derived from MODIS (Barlage et al. 2005) and a deep soil temperature climatology (serving as a lower boundary condition for the soil layers) at 3 meters below ground, derived from 6 years of Global Data Assimilation System (GDAS) 3-hourly averaged 2-m air temperatures using the method described in Chen and Dudhia (2001). In addition, real-time green vegetation fraction (GVF) data derived from MODIS normalized difference vegetation index (NDVI) data (Case et al. 2014) are incorporated into the LIS runs in place of the default monthly climatology GVF dataset (Gutman and Ignatov 1998) as used in the community WRF NWP model. The real-time MODIS GVF are produced by SPoRT on a CONUS domain with 0.01° (~1 km) grid spacing, and updated daily with new MODIS NDVI swath data from the University of Wisconsin Direct Broadcast feed that the SPoRT Center receives in near real-time.

Simulation and Atmospheric Forcing

The Noah LSM simulation was initialized at 0000 UTC 1 June 2010, coinciding with the first day of availability of the real-time SPoRT-MODIS GVF. The simulations were run for over two years prior to use for real-time applications in order to remove memory of the unrealistic, uniform soil temperature and moisture initial conditions. The atmospheric forcing variables required to drive the LIS/Noah integration consist of surface pressure, 2-m temperature and specific humidity, 10-m winds, downward-directed shortwave and longwave radiation, and precipitation rate. In the long-term simulation, all atmospheric forcing variables are provided by hourly analyses from the North American Land Data Assimilation System-phase 2 (NLDAS-2; Xia et al. 2012), except for precipitation, where hourly precipitation analyses from the NCEP Stage IV radar and gauge blended precipitation product (Lin and Mitchell 2005; Lin et al. 2005) are used. The grid spacing of the NLDAS-2 analyses is one-eighth degree (~14 km) and the Stage IV analyses have 4.8 km grid spacing. The Noah LSM solution ultimately converges to a modeled state based on the NLDAS-2 and Stage IV precipitation input.

The Stage IV precipitation analyses are typically available within an hour or two of the current time. Meanwhile, the NLDAS-2 analyses have ~3-4 day lag in real time, warranting the use of alternative datasets in order to provide timely SPoRT-LIS output each day. To integrate LIS/Noah from the time availability of NLDAS-2 to approximately the current time, the LIS is re-started using atmospheric forcing files from the NCEP GDAS (Wu et al. 2002; NCEP EMC 2004), along with a continuation of the Stage IV hourly precipitation. The GDAS contains 0–9 hour short-range forecasts of the required atmospheric forcing variables at 3-hourly intervals, derived from the data assimilation cycle of the NCEP Global Forecast System (GFS) NWP model. The GDAS files are available about 6–7 hours after the valid GFS forecast cycle. Finally, to ensure continuous availability of SPoRT-LIS output for initializing LSM fields in local NWP modeling applications, an additional LIS re-start is made, driven by atmospheric forcing from the NCEP GFS model 3–15 hour forecasts; however, the SPoRT-LIS output using GFS forecasts is not disseminated to the NWS WFOs for this assessment to ensure the most representative soil analysis derived solely from atmospheric analyses input.

The SPoRT-LIS cycle is initiated four times daily at 0400, 1000, 1600, and 2200 UTC with the history re-starts of the simulations as described above. In each cycle, the first re-start simulation begins 5 days before the current time, over-writing previous output files to ensure a model convergence towards NLDAS-2 + Stage IV precipitation forcing.

Data dissemination and latency

SPoRT-LIS data are output in the gridded binary (GRIB) format and then converted to GRIB-2 format prior to sending the data to NWS Southern Region Headquarters via the local data manager (LDM) software. Gridded output in three-hourly intervals are sent to the LDM server for ingest into AWIPS II. The GDAS files needed to drive the SPoRT-LIS simulation experience slightly more than 6 hours latency, so the SPoRT-LIS latency is constrained by this GDAS latency. The SPoRT-LIS output through the portion of the integration cycle using the GDAS and Stage IV precipitation analyses results in a data latency of ~2-8 hours from the time that the output is valid to the time that the data are displayed within AWIPS II at a local WFO. For the applicability to drought monitoring and assessing longer-term areal flood risk, this latency was deemed acceptable (see Assessment Results section).

Overview of SPoRT-LIS output variables for assessment

Examples of each of the SPoRT-LIS soil moisture variables transitioned to AWIPS II for this assessment are given in Figure 2. The screen captures provide representative visualizations of the fields in AWIPS II and give an overall sense of the dynamic range of each variable and the color bar configured for overall ease of interpretation. Volumetric soil moisture is the volume of water content per total volume of soil, and is expressed as a unitless percentage (%, or $m^3 m^{-3}$). Volumetric soil moisture can be measured directly and is thus better suited for comparison to in-situ networks that measure soil at similar depths. This variable was used for drought monitoring purposes by the Huntsville WFO, mostly for comparison with the regional Soil Climate Analysis Network.

Relative Soil Moisture (RSOIM) is the ratio of volumetric soil moisture between the wilting and saturation points for a given soil type, and is expressed as a percentage. Relative soil moisture values, thus, offer more information about the soil saturation state and the availability of water for evapotranspiration by vegetation. Values at 0% indicate vegetation can no longer extract any moisture from the soil, while values at 100% indicate complete saturation with respect to soil type. This variable has been useful mainly for drought monitoring purposes, especially when determining impacts from dry conditions on short time scales. The RSOIM was output over two layers for this assessment: 0-10 cm and the entire 0-200 cm column.

The 0-200 cm layer RSOIM has demonstrated operational utility for both drought monitoring and assessing flood threat. The total column layer is also generally used for comparison to other soil moisture model analyses, including those from NCEP (Noah LSM and NLDAS-2), the Climate Prediction Center, and the NWS (Sacramento Soil Moisture Accounting Model [SACSMA]). Due to the deeper layer, soil moisture evolves more slowly than in the 0-10 cm layer. Thus, this variable has demonstrated greater utility overall for drought monitoring purposes since drought evolves typically on timescales of weeks to years. This variable has also proven to be operationally useful for assessing the threat for areal/river flooding, particularly in several river basins in the Huntsville CWFA. Subjective analysis of several events in the Huntsville CWFA have shown that the threat for flooding increases substantially when a standard synoptic-scale rainfall event of two to three or more inches of rain occurs over 0-200 cm RSOIM values in excess of 55-60%. Although a more rigorous, objective analysis is preferred (e.g., via a soil moisture climatology and accompanying anomalies), Huntsville WFO forecasters have still used these thresholds to increase situational awareness of the flooding risk since summer 2011.

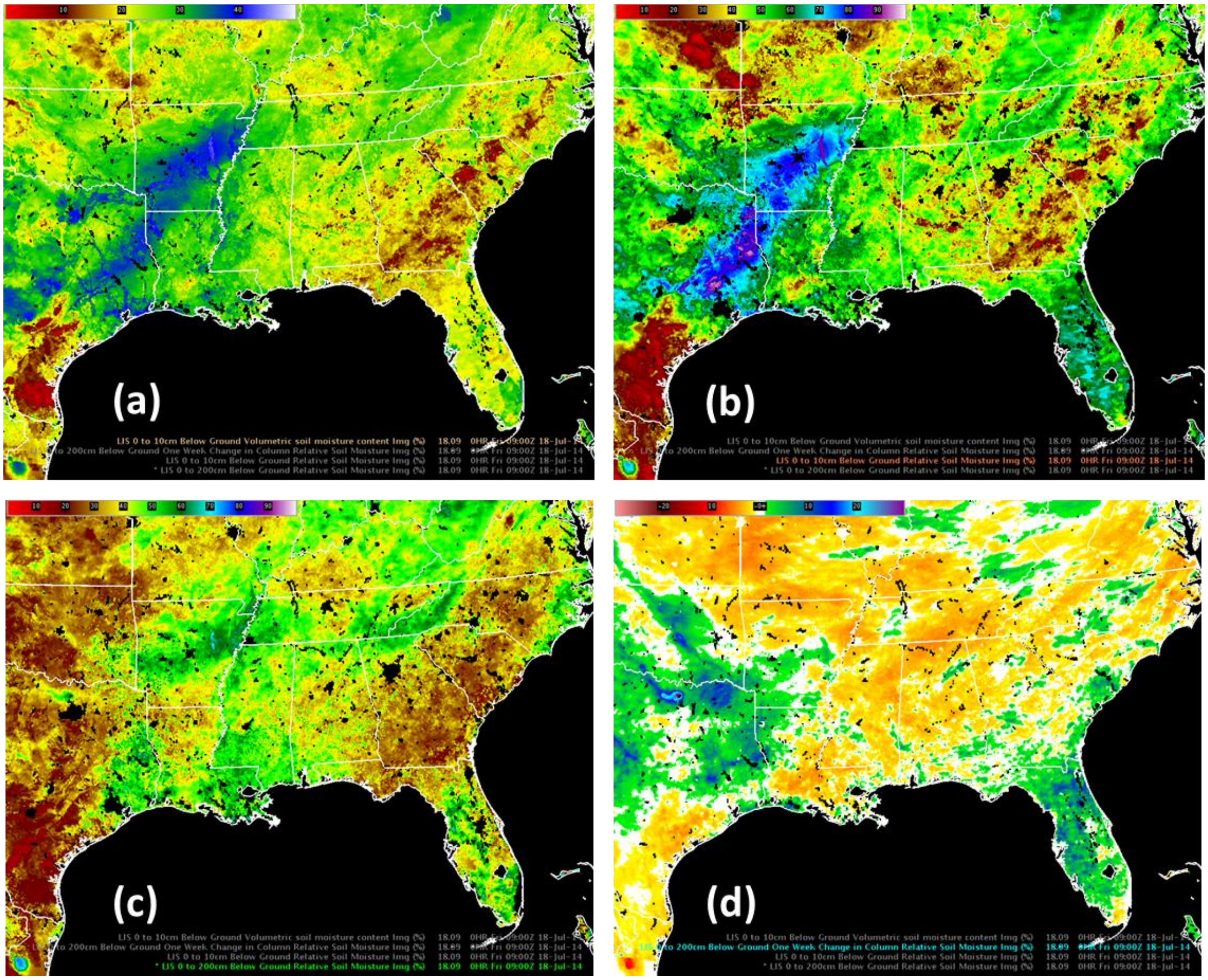


Figure 2. Screen captures within AWIPS II of the four SPoRT-LIS variables used in this assessment.: (a) 0-10 cm volumetric soil moisture (m^3 m^{-3}); (b) 0-10 cm relative soil moisture (%); (c) 0-200 cm relative soil moisture (%); (d) one-week change in 0-200 cm relative soil moisture.

Finally, a simple difference between the current 0-200 cm RSOIM and the value from one week ago at the same UTC time is given in panel d. These data offer a quick, effective evaluation of soil moisture changes during the previous week, which can be especially useful for the drought monitoring process since the USDM product is updated on a weekly basis. These data were created by the SPoRT modeling team specifically due to a request from the AIM.

It is important to note that in the display of RSOIM variables within AWIPS II (and on the SPoRT web page), urban pixels are masked due to the inherent handling of urban points by the Noah LSM. The Noah LSM "hard-wires" the wilting and saturation points of volumetric soil moisture to a very narrow range for urban land-use points. This introduces an artifact of the RSOIM quickly saturating during rain events, and rapidly drying during precipitation-free episodes (especially for the shallow, top-layer 0-10 cm RSOIM). Consequently, SPoRT opted to mask out urban points in the RSOIM variables to prevent these artifacts from being manifested in the display.

3. Transition and Training

In the months leading up to the assessment, SPoRT personnel developed two Articulate© training modules specific to the SPoRT-LIS data. The first of these, "*NASA Land Information System: A Primer*" (Figure 3), was created as an introductory lesson for the operational forecaster. The module includes information about the NASA LIS framework and SPoRT's real-time configuration of the Noah land surface model within LIS. Input static fields and atmospheric forcing datasets are described, including the use of real-time MODIS GVF in place of climatological GVF. The second module, "*NASA Land Information System: Applications Training*" provides operational examples and potential benefits of the SPoRT-LIS for NWS forecast/analysis operations. Specifically, the module covers the applications of SPoRT-LIS soil moisture variables for drought monitoring decisions, and enhancing situational awareness for determining areal/river flood risk. Only soil moisture variables transitioned for the summer LIS assessment are covered in the training module. The "primer" module is designated as a prerequisite to taking the second, more operationally-relevant module. These modules were made available to the Houston and Raleigh NWS offices for viewing/download on 16 July 2014, and are available at the following URL: http://weather.msfc.nasa.gov/sport/training/. In addition, the modules were later placed in the NOAA Learning Management System to enable forecasters to take a quiz to earn credit for continuing education within their professional development.

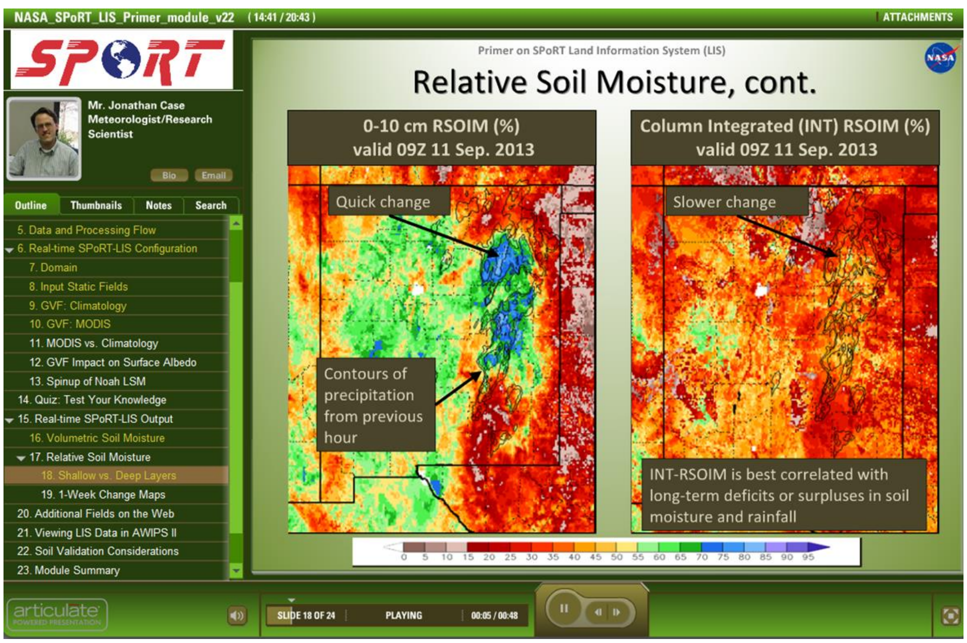


Figure 3. Example Slide from SPoRT training module, "NASA Land Information System: A Primer".

In addition to the Articulate© training modules, a two-sided, one-page SPoRT "Quick-Guide" was created and delivered to participating NWS offices prior to the assessment. A hard copy was also mailed to each office and digital copies were available at the URL linked above for easy access at forecast workstations. These Quick Guides are a summary of the main points from the training modules and contain a product example with basic interpretation. They are meant to serve as a quick reference with pertinent information about each of the soil moisture variables, including strengths, weaknesses and proper operational usage.

SPoRT personnel who created the training modules and conducted the assessment also coordinated and delivered a 45-minute teletraining session to the Houston and Raleigh NWS offices on the afternoon of the first day of the assessment, 1 August 2014. At least two participants were present from each office, in addition to a representative from NWS Eastern Region Headquarters. This training session covered material from the training modules in greater detail, and importantly, allowed for interaction between product developers and forecasters from each office who would be helping to evaluate the soil moisture products.

4. Assessment Feedback Methodology

User Feedback Questionnaires

For a SPoRT assessment to be successful, it is crucial that our partners provide feedback on their experiences with the products. To strike a proper balance between the needs of the assessment and the often busy operational forecast environment, SPoRT developed an online, 2-minute feedback form to obtain user input regarding the application of LIS soil moisture fields for drought and flood risk monitoring. The feedback form and corresponding questionnaire uses a Likert-type scale to determine the level of perceived impact of the product on the forecaster's decision-making process for the given forecast challenge. Accordingly, since this assessment involved the use of the data for two distinct purposes (i.e., evaluation of drought conditions and/or flood risk), two separate surveys were created pertaining to the specific application of the data. Forecaster respondents answered questions using clickable radio buttons corresponding to their choice of 3-6 predetermined answers (Appendix A). Comment boxes were also provided to allow for follow-up clarification and further description to certain questions, if needed. At the end of each survey, an optional comment box was provided for any additional information the forecaster respondent felt pertinent to the event where LIS fields were being assessed. All of the answers were tallied at the end of the assessment and analyzed to gain a better understanding of the utility of the soil moisture products.

Wide World of SPoRT blog posts

In addition to the evaluation form, SPoRT also hosts The Wide World of SPoRT, a blog on the Wordpress website. Forecasters and developers were encouraged to highlight examples of specific product use. These examples work to educate others in the community by providing examples and lessons learned. There were a total of 10 posts to the Wide World of SPoRT blog during the assessment period, some of which were authored by SPoRT personnel.

NWS Chat and Email Communication

The SPoRT NWS chat room (address: nasa_sport) was also provided for participants at each NWS office as a forum for communication and feedback during the assessment. The chat room was created to enable more efficient communication between SPoRT and assessment participants in an open forum setting. In addition, the chat room has proven to be valuable for communicating information about specific products and any related technical issues. For example, information pertaining to a temporary outage of the SPoRT-LIS data during the 16-17 August weekend was shared with the assessment participants. SPoRT provided an estimated time for the return of product availability along with confirmation of receipt of the data in AWIPS on 18 August.

Communication was also conducted via email with survey respondents during the process. Comments and other aspects of feedback submitted via the online form were addressed during e-mail conversations. These conversations led to improved understanding of the SPoRT-LIS soil moisture products and their uses at the respective WFOs.

5. Application Examples

NWS Raleigh WFO Drought Application

On 28 October 2014, the NWS WFO at Raleigh, NC again referred to SPoRT-LIS soil moisture data when the forecast office participated in the weekly conference call with NCDMAC to discuss possible adjustments to the USDM drought classification over North Carolina. Figure 4 summarizes the 30-, 60-, and 90-day rainfall deficits, as well as the 0-200 cm RSOIM from NASA/SPoRT. The circled area in each image corresponds to the area designated as “abnormally dry” (D0) for the previous week. The RSOIM (using a subjective 25% threshold) showed a strong correlation to rainfall deficits in the longer time frames (60 and 90 days), which are the fields typically used to help delineate low base flow in areas where reliable streamflow data are more sparse. The high resolution of the RSOIM enabled sub-basin and sub-county scale delineation of drought classification in the areas of concern, as depicted by the county dissections of the USDM D0 expansion on 28 Oct (left side of Figure 5). There were also other examples of the SPoRT-LIS being used by NWS RAH to recommend adjustments to the USDM product during the course of the assessment.

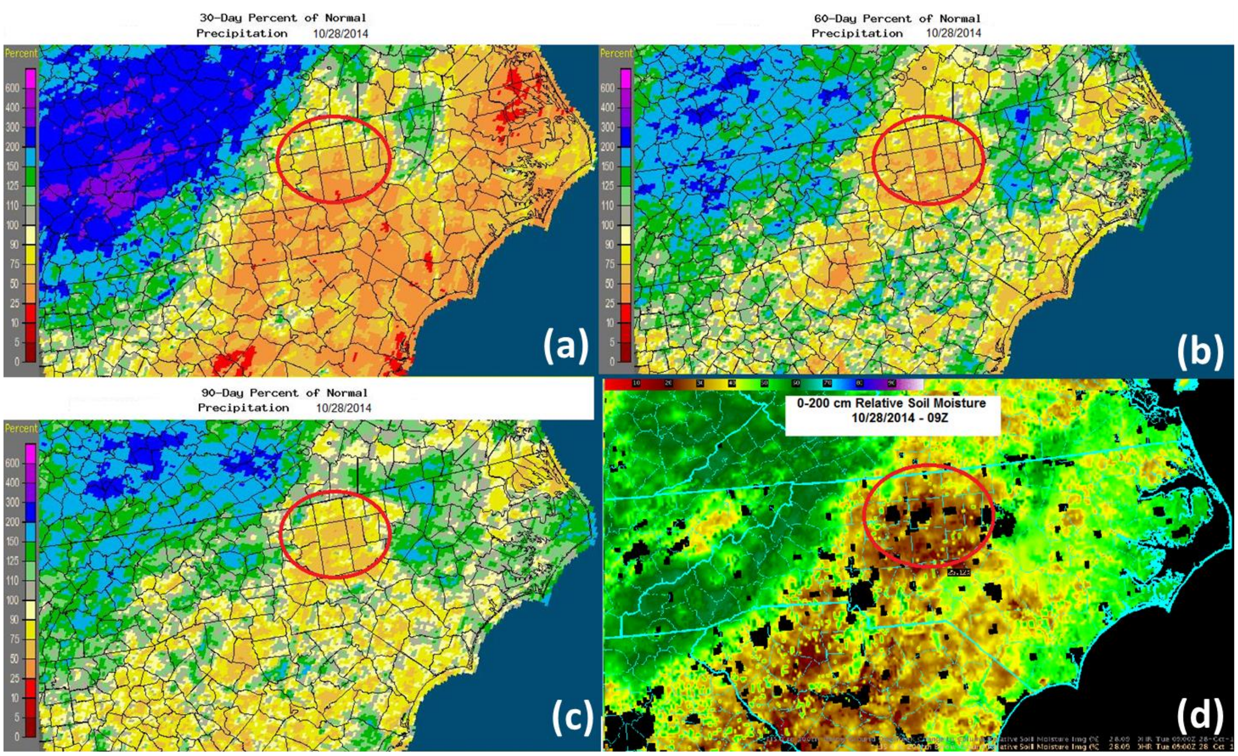
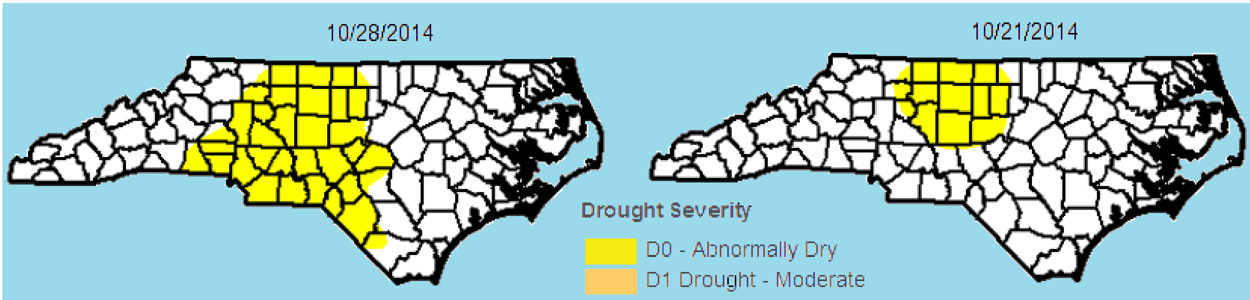


Figure 4. Comparison between AHPS/Stage IV (a) 30-day, (b) 60-day, (c) 90-day rainfall deficits, and (d) the 0-200 cm LIS relative soil moisture on 28 October 2014.

Southerly expansion of D0 conditions were recommended (Figure 5), with the SPoRT-LIS RSOIM weighing heavily on the recommendation. The U.S. Drought Monitor author for the week was on the call and requested information concerning the SPoRT-LIS product suite. He was subsequently provided with the SPoRT-LIS links and information.



Week	None	D0-D4
2014-10-28	67.55	32.45
2014-10-21	87.7	12.3

Figure 5. Adjustment to the USDM from 21 October (right) to 28 October (left), based on recommendations from NWS RAH according to the analysis of rainfall deficits and LIS column-integrated relative soil moisture. The table inset indicates the percent area coverage of no drought (i.e., "None") and D0 in the state of North Carolina.

NWS Houston WFO Drought Application

The NWS Houston/Galveston (HGX) WFO provides weekly feedback to the state climatologist in support of the preparation of the USDM product. In late August 2014, portions of southeast Texas began to experience drying conditions due to the lack of rainfall and above normal temperatures.

The NWS HGX climate focal point utilized the SPoRT LIS soil moisture products (0-10 cm RSOIM, 0-200 cm RSOIM, and 0-200 cm RSOIM weekly change; Figure 6a-c, respectively) to highlight an area of concern for increasing drought levels to abnormally dry (D0) and moderate drought (D1) from the previous week's (19 August) drought monitor product. Worth noting were locations where less than 20% 0-10 cm RSOIM (Figure 6a) had developed. Since forecasters were not expecting much rainfall and temperatures were expected to remain in the mid and upper 90s Fahrenheit, the suggestion to expand the D0 and D1 areas was largely accepted by the USDM. Note the expansion within the highlighted area from the 19 August to the 26 August USDM products (Figure 7).

This case highlights how the SPoRT LIS soil moisture products help identify the gradient of soil moisture conditions across a given region. In late August, there were substantially different near surface (0-10 cm) soil moisture conditions across eastern/northeastern areas (40-60%) of the HGX CWFA compared to southwestern areas (< 30%).

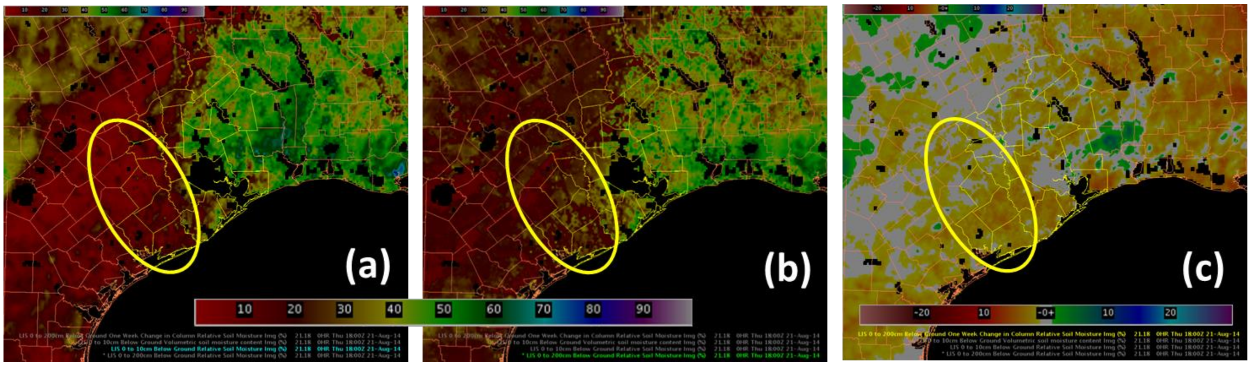


Figure 6. SPoRT-LIS variables within the NWS HGX AWIPS II valid 1800 UTC 21 August 2014, showing (a) 0-10 cm RSOIM, (b) 0-200 cm RSOIM, and (c) weekly change in 0-200 cm RSOIM. The yellow circles denote the area where the U.S. Drought Monitor D0 and D1 classifications were adjusted based on NWS HGX recommendations.

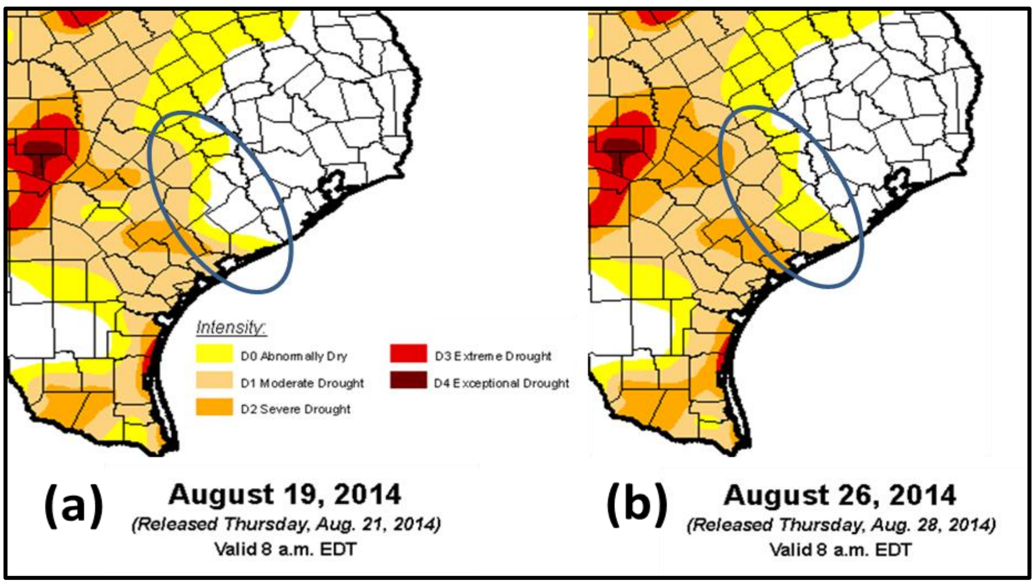


Figure 7. Adjustments to the U.S. Drought Monitor D0 and D1 drought classifications over southeastern Texas from (a) 19 August USDM product to (b) the 26 August USDM product.

NWS Huntsville WFO Areal Flooding Application

A heavy rainfall event affected the Tennessee Valley in early-mid October 2014, with antecedent soil moisture values highest in parts of northeastern Alabama. Heavy rainfall occurred across the region in the seven day period from 6 to 13 October, with between three and five inches of rainfall having occurred in the Paint Rock River basin (Figure 8). By 1200 UTC 13 October, SPoRT-LIS 0-200 cm RSOIM had increased to around 50-55% in portions of the Paint Rock River basin (Figure 9a), and in the subsequent 24-h period, additional heavy rainfall totaling around two to three inches fell (Figure 9b). The Paint Rock River stream height as measured at the Woodville, AL USGS station reached a maximum stage of 14.88 ft at 2330 UTC, just shy of minor flood stage (15 ft as defined by NWS; Figure 10). River stage forecasts from the Lower Mississippi River Forecast Center (LMRFC) did not indicate that the river would reach Action Stage until the 1332 UTC 15 October model forecast output. However, by 1100 UTC on 15 October the river had already reached Action Stage at Woodville. Subjective analyses by Huntsville WFO forecast staff during numerous flooding events have determined that rises to Action or Flood Stage occur in several rivers within the Huntsville CWFA during a typical synoptic rainfall event totaling around two inches or more, when 0-200 cm relative soil moisture surpasses ~55-60% threshold. An objective, quantitative analysis is desired by Huntsville WFO staff, however, to help refine these subjective thresholds for the assessment of flood risk.

While the data for this particular event were not used in real-time to enhance the forecast process, this case was evaluated in hindsight by the AIM and other staff at the Huntsville WFO, and serves as reinforcement for subjectively-determined soil moisture thresholds that significantly increase the risk for river flooding. Partnering with River Forecast Centers (RFCs) to incorporate SPoRT LIS soil moisture into experimental hydraulic/hydrologic model forecast runs may serve as an important initial step. Additionally, the development of climatological "normals" and associated soil moisture anomalies would greatly aid in interpreting the historical context of soil moisture on a given day and region.

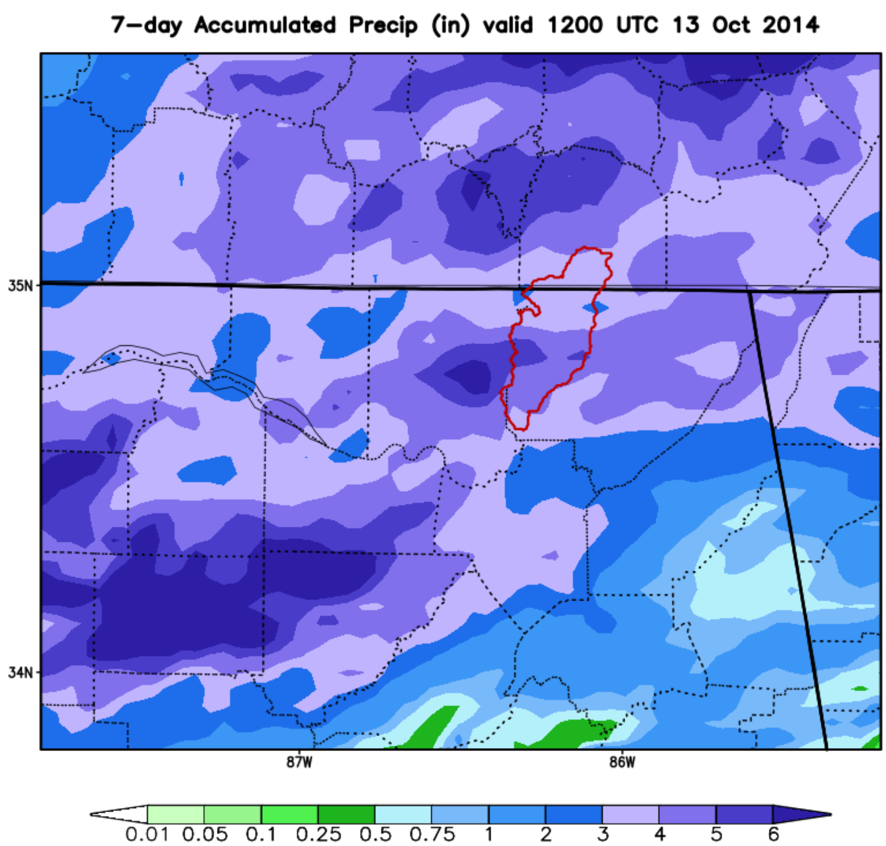


Figure 8. Seven-day accumulated precipitation (inches) between 1200 UTC 6 October and 1200 UTC 13 October 2014, derived from hourly Stage IV precipitation analyses. The location of the Paint Rock river basin is denoted by the red outline (see text).

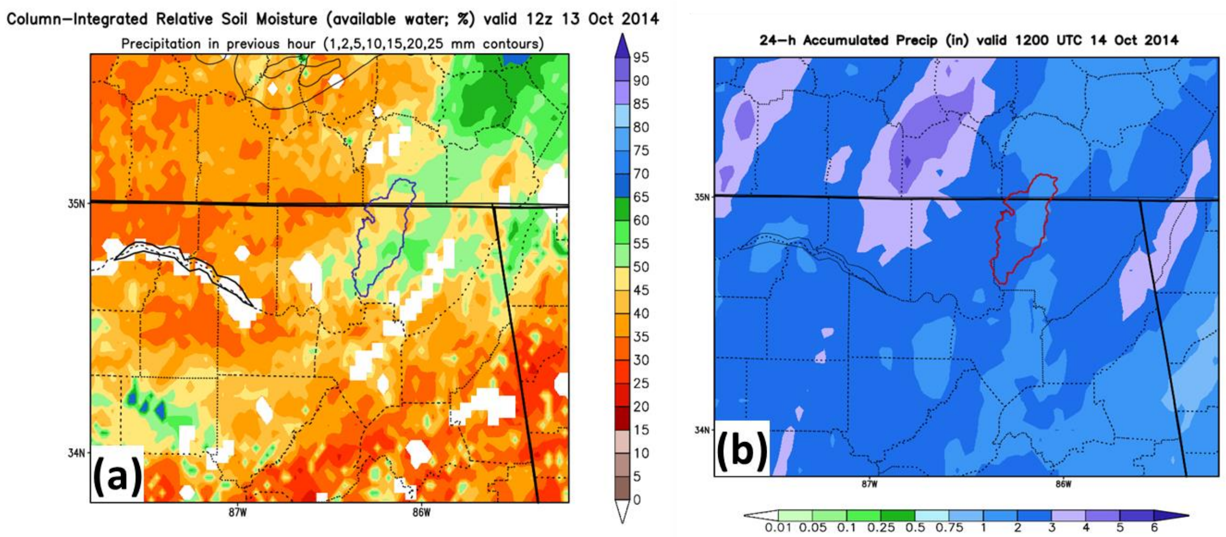


Figure 9. (a) SPoRT-LIS 0-200 cm relative soil moisture valid 1200 UTC 13 October 2014, and (b) Stage IV 24-h accumulated precipitation ending 1200 UTC 14 October 2014. The outline of the Paint Rock River basin is denoted in each image.

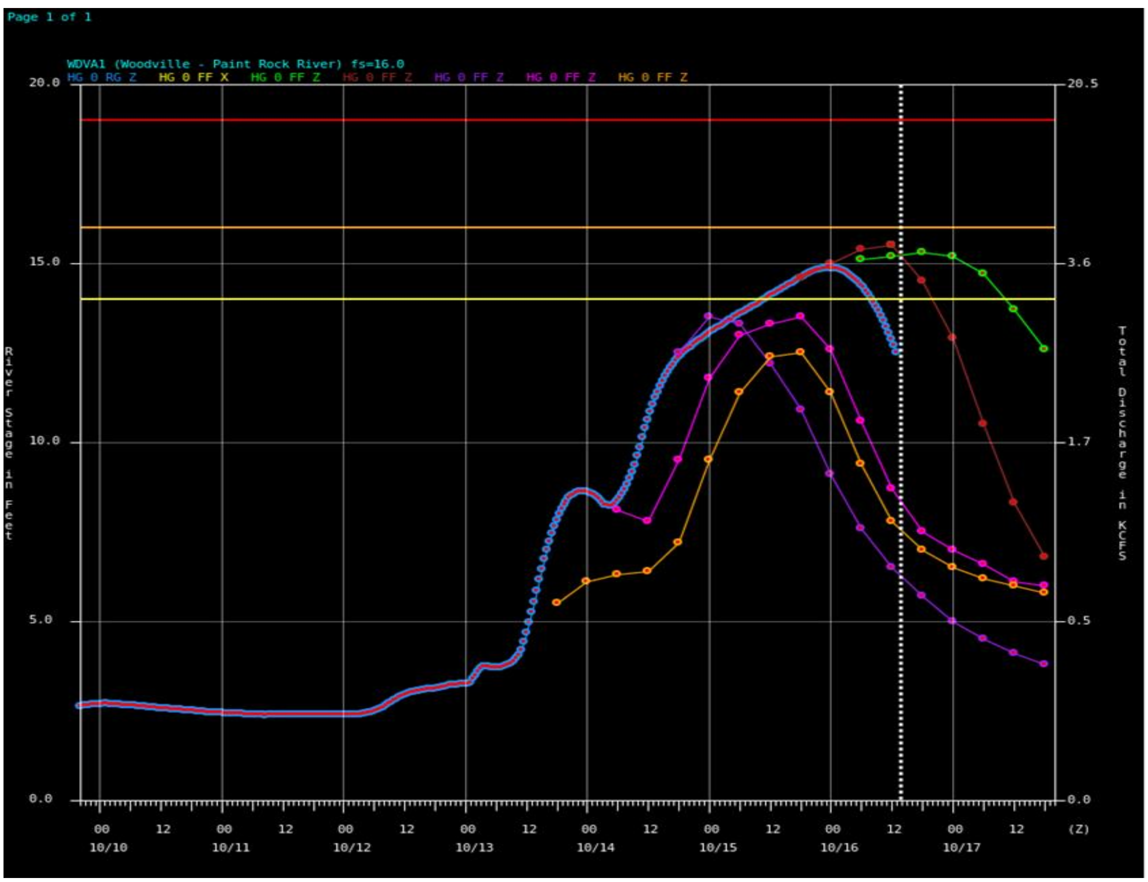


Figure 10. Paint Rock River Stage (purple dotted line) from approximately 0000 UTC 10 October through 1200 UTC 16 October 2014. River stage forecasts from the LMRFC also shown: 1306 UTC 13 October (orange line), 0203 UTC 14 October (pink line), 1415 UTC 14 October (purple line), 1332 UTC 15 October (red line), and 0047 UTC 16 October (green line). Notice that initial forecasts did not indicate the river would reach Action Stage (14 ft, yellow horizontal line). However, antecedent soil moisture values and forecast rainfall would have suggested this likelihood.

6. Assessment Results

The overall results of the August to October assessment indicate that the participating forecasters were able to understand the SPoRT-LIS soil moisture products and incorporate the data into operations, especially pertaining to drought monitoring. The LIS data proved reliable, and timeliness was not a concern during the assessment according to user feedback. Forecasters had a high degree of confidence in applying the LIS soil moisture data, as the soil moisture output corroborated with other datasets typically utilized by forecasters. Forecasters found the most utility in the total column relative soil moisture (0-200 cm RSOIM) and weekly change in 0-200 RSOIM variables.

Due to the prevailing climatological conditions of the Southern U.S. during the late summer and early fall 2014, the vast majority (89%) of feedback forms submitted involved application of drought monitoring rather than assessing areal flood potential. Very few opportunities arose that enabled forecasters to establish or modify thresholds of soil moisture and precipitation that correlated with flooding events. Nevertheless, the example included from the Huntsville WFO serves to reinforce previously determined significant thresholds for soil moisture that lead to increased flood risk. Additionally, no areas with drought designation exceeding D1 (moderate drought) occurred during the August to October 2014 timeframe in the CWFAs of the three participating offices. However, numerous recommendations were made during the assessment on adjusting the lower-end drought categories based on SPoRT-LIS provided soil moisture output. Selected survey assessments results are highlighted in the sub-sections below; all assessment questions are listed in Appendix A for reference purposes.

It is worth mentioning that comparing the SPoRT-LIS output with other model analyses can be problematic. Other soil moisture analyses commonly referenced during the assessment (such as that from the Climate Prediction Center [CPC] or Noah/SACSMA within NLDAS-2) provide values in terms of anomalies or percentages of normal, while the SPoRT-LIS output contains soil moisture magnitudes only. Thus, participants had to compare areas of relative dryness in the SPoRT-LIS output with disparate soil moisture variables. Additional significant differences between the SPoRT-LIS and other models include data latency and spatial resolution, which lead to other complications in making direct comparisons. For example, data latency with the previously-mentioned Noah/SACSMA in NLDAS-2 is about four days, while latency with the SPoRT-LIS in AWIPS II is just two to eight hours. Changes in shallow layer soil moisture can be particularly large during heavy precipitation events and would be reflected in the near real-time output of the SPoRT-LIS, but not captured in the other more latent analyses if they fell within the most recent four day period.

Summary of completed surveys

Twenty eight surveys were completed during the assessment, with the percentage contributions from each office summarized in Figure 11. Of these, twenty-four detailed the use of the data for drought monitoring application, while three surveys were submitted pertaining to the use of the data for areal/river flood risk analysis. One survey submitted by the HGX WFO involved the use of the data for high temperature forecasting. While a potentially useful application of the soil moisture data, this survey response fell outside the scope of the assessment, and it is not included in the report statistics.

The question pertaining to training indicated that the vast majority of participants were able to interpret the SPoRT-LIS data based on the training already received from the modules produced by SPoRT (26 of 27 responses; Figure 12). This result suggests that prior to the start of the assessment the two LIS training modules successfully conveyed information about the product and operational applications to drought and areal flooding at an appropriate level for the forecast environment.

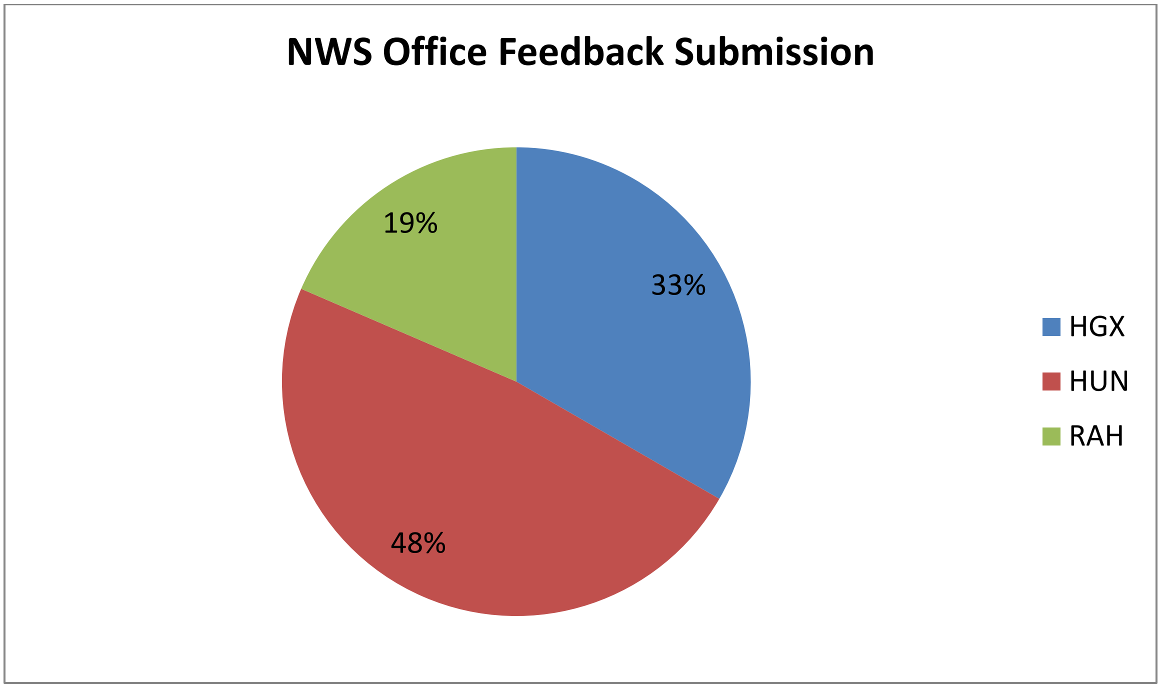


Figure 11. The percentage distribution of completed LIS assessment surveys by NWS WFO.

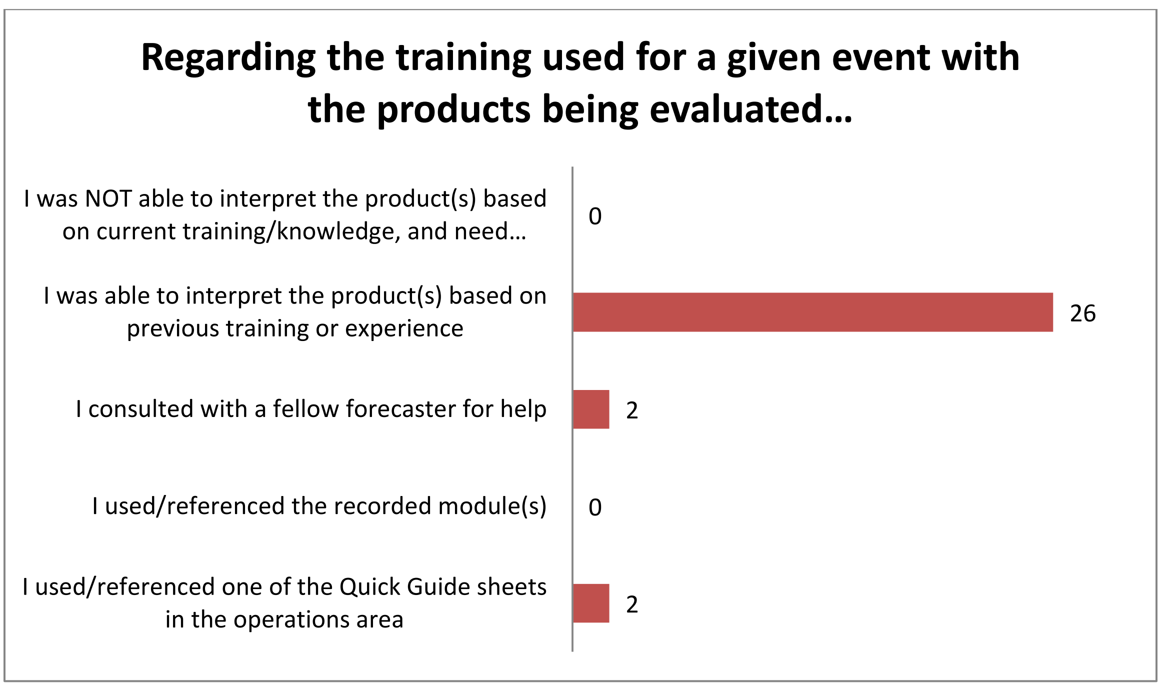


Figure 12. Distribution of survey responses with respect to the training used for the products evaluated. Note that in some instances, more than once choice was selected.

User Responses Specific to Drought Assessment

Results from the first four questions are presented in Figure 13 based on 24 surveys completed in the area of drought monitoring. The confidence level in the SPoRT-LIS soil moisture was largely "High" (80% of responses), with no forecaster having rated his/her confidence less than "Medium" (Figure 13a). The SPoRT-LIS soil moisture data were usually compared to other available data sources for corroboration (92% of responses; Figure 13b), with the SPoRT-LIS soil moisture trends typically similar or only slightly different than the comparison observations. The similar data trends likely contributed to the overall high confidence in the product.

In terms of assessing the USDM classification, the vast majority of responses (96%; Figure 13c) indicated at least "Some" contribution to decisions regarding drought classification. This result suggests that forecasters were actively engaged in the weekly USDM conference calls and occasionally contributed SPoRT-LIS soil moisture information to the drought decision-making process, as highlighted in Section 5. Participants identified the weekly change in 0-200 cm RSOIM as the most valuable field for assessing drought (54%; Figure 13d).

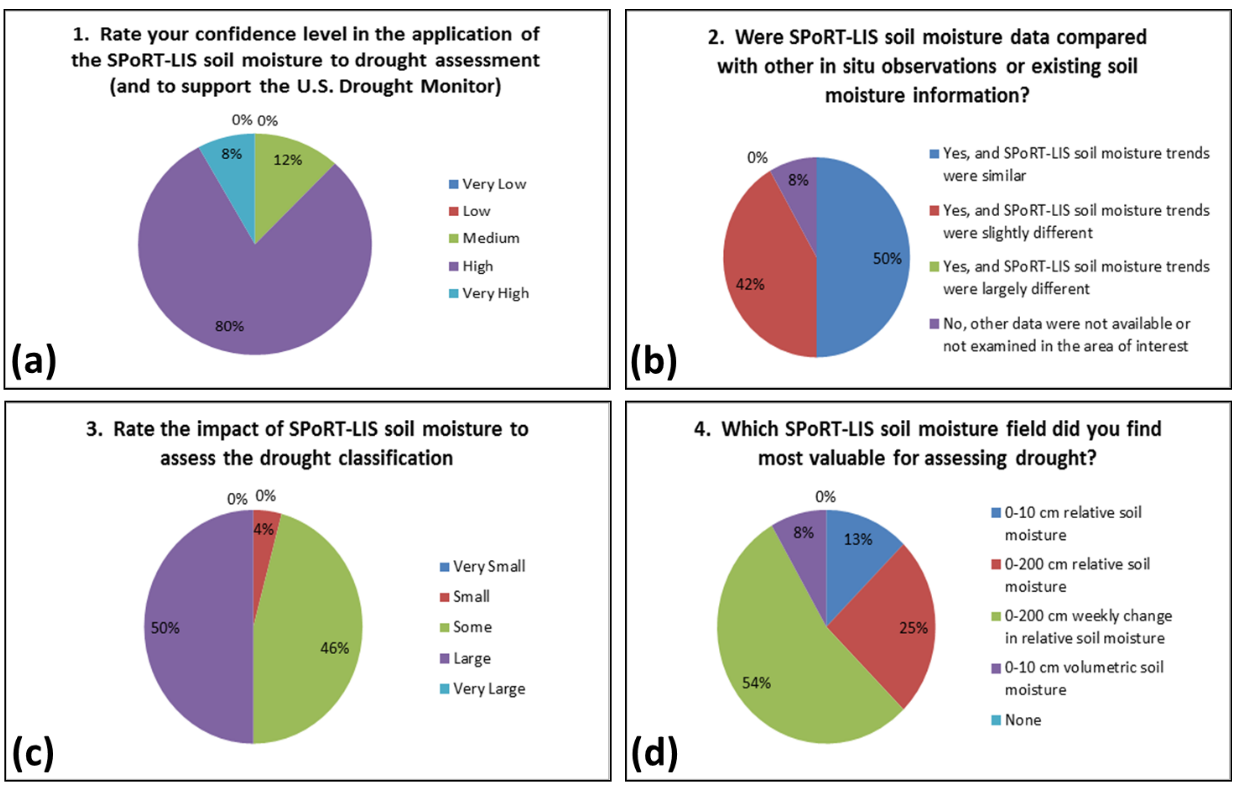


Figure 13. Summary of select SPoRT-LIS assessment survey results pertaining to drought monitoring, including (a) Forecaster confidence in applying soil moisture to drought assessment; (b) How SPoRT-LIS soil moisture were compared to other observations; (c) Perceived impact of soil moisture to assess the USDM classification; and (d) Soil moisture variables found to be most valuable for assessing drought conditions.

The weekly change in total column (0-200 cm) RSOIM was found to be the most valuable product in drought decisions for several reasons:

- The variable contains information about long-term drought conditions (e.g., precipitation deficits) due to the deep layer of estimated soil moisture,
- The weekly change coincides with the USDM product update frequency,
- Total column RSOIM evolves more slowly in response to precipitation events, thereby retaining soil moisture deficit conditions despite short-term precipitation, and
- Local and regional soil moisture patterns corresponding to precipitation surpluses and/or deficits are more easily diagnosed than with a single-time product or the 0-10 cm layered products.

Regarding the question, "*Would you like a change in the SPoRT-LIS soil moisture product display or additional output fields/layers*", most responses claimed "no"; however, 25% of responses offered suggested changes in the product. Suggestions included improving the distinction between urban masked pixels and near-zero change in the 0-200 cm RSOIM. In response to this comment, SPoRT revised the color curve to better distinguish between 0-200 cm RSOIM changes around urban corridors. Also, a respondent notice a small positional offset in the 0-200 cm RSOIM display in AWIPS II, which SPoRT was able to correct early in the assessment. Other suggestions for changes included additional time frames for 0-200 cm RSOIM weekly change, such bi-weekly, monthly, multi-month, or since the last substantial rainfall event. HGX users inquired about examining different soil layers or enhancing the grid spacing to better resolve barrier islands along the Texas coast.

Most participants (~79%) responded that the SPoRT-LIS soil moisture values, when used in conjunction with other data, provided sufficient confidence for estimating drought classification. However, five survey responses (~21%) indicated other data were preferred over the SPoRT-LIS for determining the proper drought classification. In each these, the Advanced Hydrologic Prediction Service (AHPS; i.e., Stage IV) data produced by the RFCs were listed among the preferred data. Interestingly, since these data provide the necessary precipitation forcing for the SPoRT-LIS, the two data sets are inextricably linked. Since the AHPS/Stage IV data are a primary dataset commonly used and referenced by USDM authors and participants, respondents likely felt more comfortable basing difficult drought designation decisions on these data rather than SPoRT-LIS soil moisture values, with which they had less familiarity. One user comment noted differences in land surface model resolution between the SPoRT-LIS versus other soil moisture models (~3 km vs. climate division) and data latency (~3 h for SPoRT-LIS vs. ~4 days for other products), which probably resulted in notable differences in the output data. Another survey indicated that the U.S. Geological Survey (USGS) streamflow data were preferred as the primary data for determining the drought designation. Heavy rainfall in northern Alabama a couple of weeks prior to the LIS assessment was still apparent in area streamflows, even though soil moisture had decreased due to recent dry weather. With conflicting evidence from soil moisture and streams, the user noted that the decision was made to go with status-quo for the USDM update due to conflicting information.

The SPoRT-LIS soil moisture fields were most often used to incorporate sub-county scale information into drought decision-making, but users also indicated that the LIS provided increased efficiency over traditional methods of drought categorization (Figure 14). These results indicate that the SPoRT-LIS soil moisture fields were successfully contributing to improved operational decision-making, confidence, and precision in contributing to the USDM weekly product.

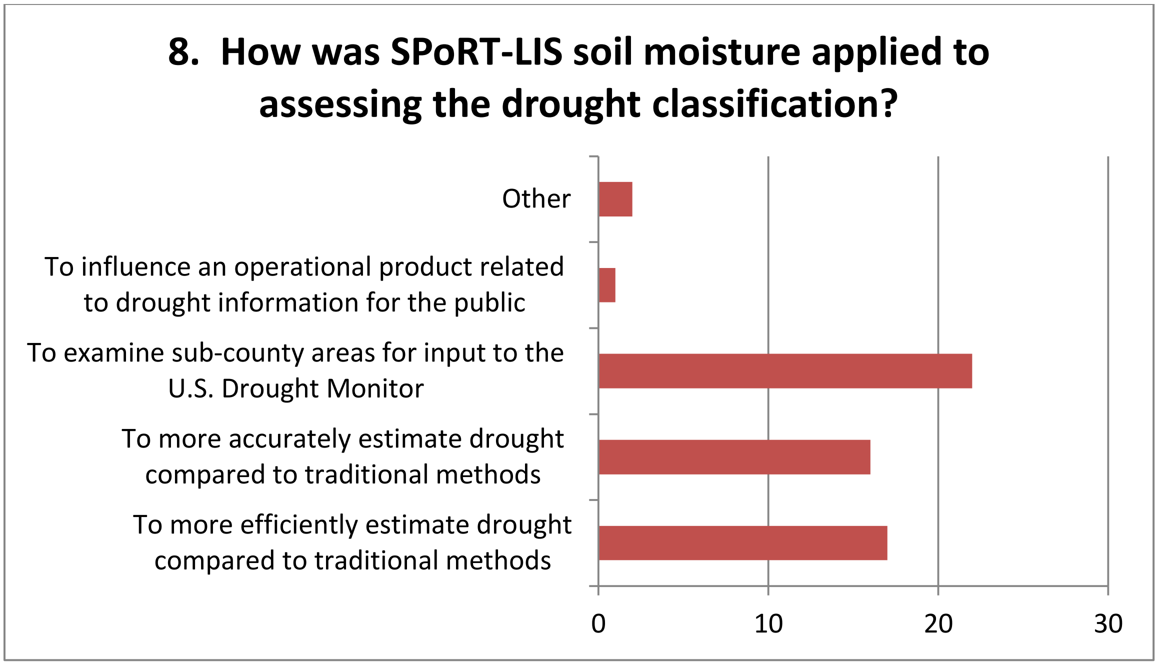


*Figure 14. The distribution of survey responses denoting how the SPoRT-LIS soil moisture was applied to assessing the USDM drought classification. Users were able to choose more than one answer per survey submitted. (*Based on responses, forecasters were then asked to provide a brief event description and any additional comments regarding the application of NASA/LIS for this instance of drought monitoring. (Sample comments below)*

Finally, a subset of specific comments from Question 9 (see Appendix A on drought) are shown below on how the SPoRT-LIS was applied to a given instance of drought monitoring.

- The 0-200 relative soil moisture and weekly change images helped to identify drying conditions over Walker County (TX). The images also helped to extend D-0 conditions into a few counties west of the city of Houston. I'll e-mail the drought monitor images so that you can see the changes.
- We went with status-quo across northern Alabama for this week's USDM. That leaves all of the area in D-nothing...or no drought conditions. We had heavy rains a couple of weeks ago which are still in the hydro system and soils. Streamflows are decreasing, but are still above weekly median statistics. I mainly used the 0-200 cm soil moisture to see the values for our area. They "looked" ok for the end of October, but I really need a climatology to properly assess that. Thus, why I'm very excited about the prospect of the 30-year LIS climo!! One other thing I wanted to point out...a comparison of the LIS vs more "traditional" sources is not possible in all cases, especially with short term precip since the CPC analysis is one day old, and the NLDAS soil moisture anomalies/percentages are more than 4 days old.
- The 0-10 cm Volumetric Soil Moisture yesterday at 12Z showed an area of particularly low soil moisture centered over northern Cullman and Blount Counties and southern Marshall and Morgan Counties. Much of this area was not in any drought designation, although areas to the south were already in D0, where soils were more moist. I then looked at other available LIS variables. The 0-200 cm RSM was fairly homogeneous across the area. I called the ACES ag agent in the Cullman County office to determine if the dry soils were beginning to have an impact on area crops. He affirmed that the recently dry soils were beginning to have adverse effects on vegetable crops and recently planted corn. I presented this evidence to the USDM author who expanded the D0 northward to include some of these areas (but not all).

Survey Responses Specific to Areal/River Flooding

The application of the data to assessing the risk for areal or river flooding proved more challenging, partly due to the lack of synoptic scale systems during the assessment period (August through October). Nevertheless, three surveys were received on the use of the data for this application. In one of these surveys, the respondent noted that the data were not applied operationally, but for post-analysis.

Similar to the use of the data for drought analysis, no survey respondents expressed a lack of confidence in applying the data to forecasting areal/river flooding. Meanwhile, in the question regarding the impact of the SPoRT-LIS soil moisture for help in assessing the threat for areal/river flooding, one response indicated some impact, while the other stated a large impact. For the *large* impact case, the LIS application may have been unsuitable. The forecaster wrote that the "LIS was favored over the FFG (Flash Flood Guidance)" when responding to the list of complimentary products used to assess the flooding threat. However, it was stressed and explicitly stated in both the training module and the SPoRT-LIS "Quick-Guide" that the proper application is only for assessing longer-term, areal and/or river flooding, but not intended for use in flash-flooding events. This is due to the fact that flash flooding is much more dependent on rainfall rates and topography rather than soil moisture.

For the survey where *some* impact was noted, the forecaster used the 0-200 cm RSOIM data to show an emergency manager why flooding was likely not occurring in Grimes County, TX after a relatively heavy rainfall event in the Houston CWFA (rainfall amounts exceeding four inches were noted). The very dry antecedent soil moisture preceding this rainfall event (Figure 15) was able to accommodate much of the rainfall, thereby minimizing the flooding threat. The survey respondent also indicated that this county is "*fairly data-free in real time*", depending largely on radar-derived data for precipitation analysis. This event highlighted operational utility and reliability in the fact that the SPoRT-LIS soil moisture data helped to demonstrate why flooding was not occurring in an area of concern and that the forecaster had sufficient confidence to share the data with the county emergency manager.

Considering the use of the 0-200 cm RSOIM data as outlined in the event above, this LIS output field was cited in two surveys as the most valuable for assessing the flood threat compared to the other LIS output fields provided during the assessment (with the only other layer being 0-10 cm). Additional testing and subjective calibration of other LIS-Noah output layers may be warranted in the future to determine whether the other layers may provide more utility than the total column RSOIM in assessing areal flooding potential.

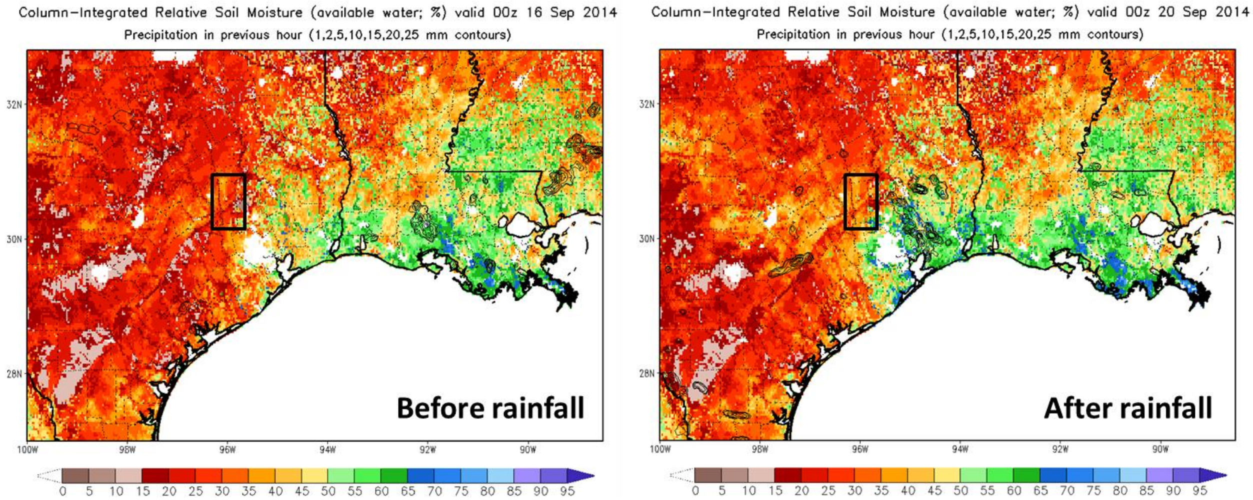


Figure 15. Depiction of 0-200 cm relative soil moisture over southeastern Texas from 0000 UTC 16 Sep (before rainfall event; left) and 0000 UTC 20 Sep 2014 (after rainfall event; right), highlighting the very dry soils over Grimes county, TX (within box inset) that were able to accommodate the heavy rainfall, as noted by the NWS Houston forecaster assessment survey entry.

7. Conclusions and Recommendations

This final report presented highlights and key results of a three-month assessment of the SPoRT real-time configuration of the NASA LIS, held from August to October 2014. The focus of the assessment was on applications of select SPoRT-LIS soil moisture output to assist in drought monitoring and assessing areal flooding potential, with participation from the NWS WFOs at Huntsville, Houston, and Raleigh. SPoRT personnel developed two training modules and a Quick Guide in conjunction with NWS forecasters to ensure that the training was at an appropriate level and that personnel involved in the assessment were adequately familiarized with the SPoRT-LIS product.

Twenty seven online, user-feedback questionnaires and ten blog posts were submitted during the assessment that highlighted primarily drought monitoring applications, since the prevailing weather conditions during the period of record were not conducive to many flooding events. Assessments were submitted in which WFOs applied SPoRT-LIS soil moisture data to make adjustments to the USDM drought classifications within the CWFA of responsibility. Survey results indicated that forecasters had high confidence in applying the SPoRT-LIS soil moisture to drought monitoring. Participants noted that they were comfortable in using the SPoRT-LIS data based on the training, indicating the success of the modules developed in advance of the assessment. Forecasters identified the total column relative soil moisture and especially the weekly change in this variable as the most helpful fields in making decisions regarding drought classification.

While able to provide sub-county details of soil moisture variability, LIS users expressed a need for an historical context to better quantify the relative dryness or moistness of the soils. It is recommended that SPoRT develop a soil moisture climatology and accompanying soil moisture anomalies to promote more quantitative measures of soil moisture conditions. This will also help in comparing the SPoRT-LIS output to existing operational products such as the CPC and NLDAS-2 soil moisture anomalies, thereby ensuring an "apples-to-apples" comparison between common output fields. To help address these recommendations in a preliminary fashion, SPoRT is already undertaking the development of a CONUS-scale soil moisture climatology on a 0.03-deg (~3 km) grid spanning 1981 – present (Case et al. 2015). A daily soil moisture climatology is being developed for every county in the CONUS based on daily output of 0-200 cm RSOIM. From the daily county-by-county climatologies, soil moisture gridded anomalies are being developed, with the option of examining histograms of soil moisture distributions relative to the daily average in a given county. SPoRT is also collaborating with personnel from the NCEP Environmental Modeling Center in order to complement (and not merely duplicate at higher resolution) current operational products already being generated by the NLDAS-2 and Climate Prediction Center.

This climatological run will serve as a backdrop for a future expanded near real-time SPoRT-LIS over a CONUS domain (Case and White 2014) in order to support interests in the NWS Western Region for future LIS assessments. Additionally, in preparation for using data from the upcoming SMAP mission, SPoRT is conducting soil moisture data assimilation experiments within LIS using the European Space Agency's Soil Moisture and Ocean Salinity soil moisture retrievals (Blankenship et al. 2015). Finally, SPoRT plans to incorporate into the CONUS LIS runs the real-time daily global GVF data being produced by the National Environmental Satellite Data and Information Service, derived from the Visible Infrared Imaging Radiometer Suite (Vargas et al. 2013), as well as short-term quantitative precipitation estimates from the Multi Radar Multi Sensor (MRMS; Zhang et al. 2011, 2014), which was recently promoted to operations at NCEP.

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Appendix A: Survey Questions for drought monitoring and assessing areal flood potential

The following three questions were asked for both drought and flood surveys:

Have you completed training materials regarding LIS soil moisture prior to the assessment period? Check all that apply

- *Yes, I have completed the LIS Primer module by SPoRT*
- *Yes, I have completed the LIS Applications training module by SPoRT*
- *Yes, I have participated in or seen a teletraining session (live or recorded)*
- *No, I have not previously completed the training items listed above*

Regarding the training used with products being evaluated?
Check all that apply for this particular event

- *I used/referenced one of the Quick Guide sheets in the operations area*
- *I used/referenced the recorded module*
- *I consulted with a fellow forecaster for help*
- *I was able to interpret the product(s) based on previous training or experience*
- *I was NOT able to interpret the product(s) based on current training/knowledge, and need additional help*

Was the LIS soil moisture output timely for application to the forecast issue?

- *Yes, it was timely*
- *No, it was not timely*
- *No, it was not available at the time*

Questions specific to Drought Assessment:

1. Rate your confidence level in the application of the LIS soil moisture to drought assessment (in particular to support the U.S. Drought Monitor) [*Very low, Low, Medium, High, Very High*]

2. Were LIS soil moisture data compared with other in situ observations or existing soil moisture information?

- *Yes, and LIS soil moisture trends were similar*
- *Yes, but LIS soil moisture trends were slightly different*
- *Yes, but LIS soil moisture trends were largely different*
- *No, other data were not available or not examined in the area of interest*

3. Rate the impact of LIS soil moisture output to assess the drought classification: [Very small, Small, Some, Large, Very Large]

4. Which LIS soil moisture field did you find most valuable for assessing drought?

- *0-10 cm relative soil moisture*
- *0-200 cm relative soil moisture*
- *0-200 weekly change in relative soil moisture*
- *0-10 cm volumetric soil moisture*
- *None*

5. Would you like a change in the LIS soil moisture product display or additional output fields/layers?

- *No, I like the product as is - product displays are good and output fields/layers are easy to interpret and use*
- *Yes, I would like a change - state a sentence or two with suggestions and/or requests*

6. Did you use a product which provided more confidence and/or better utility than the NASA/LIS soil moisture for estimating the drought classification? (*Yes or No*)

7. For both "Yes" or "No" in the previous question, please list either the product(s) that were complemented by LIS or that was/were preferred over LIS. (*e.g., AHPS/Stage IV Precipitation, CPC soil moisture products, agricultural reports, in situ soil moisture observations*)

8. How was NASA/LIS soil moisture applied to assessing the drought classification? Check all that apply

- *To more efficiently estimate drought compared to traditional methods*
- *To more accurately estimate drought compared to traditional methods*
- *To examine sub-county areas for input to the U.S. Drought Monitor*
- *To influence an operational product related to drought information for the public*
- *Other: (explain)*

9. Please provide a brief event description and any additional comments regarding the application of NASA/LIS for this instance of drought monitoring.

Questions specific to Areal/River flooding Assessment:

1. Rate your confidence level in the application of the LIS soil moisture as applied to forecasting the potential for areal/river flooding (excluding flash flood events): [*Very Low, Low, Medium, High, Very High*]

2. Where LIS soil moisture data compared with other in situ observations or existing soil moisture information?

- *Yes, and LIS soil moisture trends were similar*
- *Yes, but LIS soil moisture trends were slightly different*
- *Yes, but LIS soil moisture trends were largely different*
- *No, other data were not available or not examined in the area of interest*

3. Rate the impact of LIS soil moisture output to assist in the process of assessing the threat of areal/river flooding: [*Very Small, Small, Some, Large, Very Large*]

4. Which LIS soil moisture field did you find most valuable for assessing the flood threat?

- *0-10 cm relative soil moisture*
- *0-200 cm relative soil moisture*
- *0-200 weekly change in relative soil moisture*
- *0-10 cm volumetric soil moisture*
- *None*

5. Would you like a change in the LIS soil moisture product display or additional output fields/layers?

- *No, I like the product as is - product displays are good and output fields/layers are easy to interpret and use*
- *Yes, I would like a change - state a sentence or two with suggestions and/or requests*

6. In addition to model/WPC QPE, did you use a product which provided more confidence and/or better utility than the NASA/LIS soil moisture for estimating the flooding threat potential?

- *No - the NASA/LIS was used to complement model and/or WPC QPE products*
- *Yes - there was another product outside of QPF that I preferred for this event (See next question to list product)*

7. For both "*Yes*" or "*No*" in the previous question, please list either the product(s) that were complemented by LIS or that was/were preferred over LIS. (*e.g., RFC river stage guidance, AHPS/Stage IV Precipitation, CPC soil moisture products, in situ soil moisture observations*)

8. How was NASA/LIS soil moisture applied to this potential flooding event?
Excluding flash flood events; Check all that apply

- *To more efficiently estimate flood threat compared to traditional methods*
- *To more accurately estimate flood threat compared to traditional methods*
- *To examine flood risk for sub-county areas*
- *To influence an operational product or the forecast for flood risk for NWS customers*
- *Other: (explain)*

9. Please provide a brief event description and any additional comments regarding the application of NASA/LIS for this instance of flooding. (*why/how; impacts on forecasts; etc.*)

Appendix B: List of Acronyms and Abbreviations

AHPS	Advanced Hydrologic Prediction Service
AIM	Applications Integration Meteorologist
AWIPS II	Next generation Advanced Weather Interactive Processing System
CONUS	Continental United States
CPC	Climate Prediction Center
CWFA	County Warning and Forecast Area
EMC	Environmental Modeling Center
GDAS	Global Data Assimilation System
GFS	Global Forecast System
GPM	Global Precipitation Mission
GRIB	Gridded Binary
GSFC	Goddard Space Flight Center
GVF	Green Vegetation Fraction
HGX	Houston, TX NWS forecast office identifier
HUN	Huntsville, AL NWS forecast office identifier
LIS	Land Information System
LMRFC	Lower Mississippi River Forecast Center
LSM	Land Surface Model
MRMS	Multi Radar Multi Sensor
NCDMAC	North Carolina Drought Management Advisory Council
NCEP	National Centers for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NLDAS	North American Land Data Assimilation System
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
NWS	National Weather Service
QPE	Quantitative Precipitation Estimates
RAH	Raleigh, NC NWS forecast office identifier
RFC	River Forecast Center
RSOIM	Relative Soil Moisture
SMAP	Soil Moisture Active Passive
SPoRT-	Short-term Prediction Research and Transition
USDM	U.S. Drought Monitor
USGS	U.S. Geological Survey
WFO	Weather Forecast Office
WRF	Weather Research and Forecasting