3.3 REAL-TIME LAND INFORMATION SYSTEM OVER THE CONTINENTAL U.S. FOR SITUATIONAL AWARENESS AND LOCAL NUMERICAL WEATHER PREDICTION APPLICATIONS

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1. INTRODUCTION

The NASA Short-term Prediction Research and Transition (SPoRT; Jedlovec 2013) Center recently upgraded its real-time Land Information System (LIS) simulations to version 7 of the LIS software, increasing its coverage to a full Continental U.S. (CONUS) domain. The real-time LIS (hereafter, SPoRT-LIS) runs the Noah land surface model at ~3-km resolution. Simulations are driven by atmospheric analyses from the National Centers for Environmental Prediction (NCEP) / Environmental Modeling Center (EMC) operational North American Land Data Assimilation System – version 2 (NLDAS-2). Also, short-term hourly quantitative precipitation estimates (QPE) are input from the Multi-Radar Multi-Sensor (MRMS; Zhang et al. 2011; 2014) hourly operational product, and real-time green vegetation fraction (GVF) input comes from the NOAA/NESDIS global, 4-km daily product derived from the Suomi-NPP VIIRS instrument. The objective of the SPoRT-LIS is to provide land surface fields (e.g., soil moisture, soil moisture change maps, etc.) to SPoRT's operational partners for increased situational awareness and local numerical weather prediction (NWP) applications. Updated SPoRT-LIS output are generated in six-hourly cycles and transmitted to SPoRT-partnering NOAA/NWS forecast offices via the Local Data Manager (LDM) software for display in the second generation Advanced Weather Interactive Processing System (AWIPS II), and via ftp for initializing regional NWP models.

The upgraded SPoRT-LIS is based off a climatology run of LIS-Noah spanning 1981 to 2013 that serves as the basis for an experimental real-time soil moisture percentile product (Zavodsky et al. 2016; *this Conf.*). With the SPoRT-LIS, near real-time soil moisture and soil moisture change maps are generated at a higher resolution than currently available national- and global-scale products. In this way, the SPoRT-LIS complements the larger-scale operational products by providing unique, customized land surface grids within the end-user's decision support system to enhance situational awareness (e.g., drought monitoring decisions) and improve land surface initialization in NWP applications.

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This extended abstract and accompanying recorded presentation illustrates examples of how the SPoRT-LIS data are used in an evaluation period during summer 2015. Examples of enhanced situational awareness during the Southwest summer monsoon are shown from this evaluation, as well as an example from the South Carolina flooding event in early October 2015. Section 2 gives background information on successful SPoRT paradigm of transitioning experimental products into NOAA/NWS operations, and conducting product assessments and evaluations. Section 3 describes the LIS framework and real-time SPoRT-LIS configuration details. Results and examples from the Summer 2015 evaluation with the NOAA/NWS forecast offices in Huntsville, AL (HSV), Albuquerque, NM (ABQ) and Tucson, AZ (TWC) are presented in Section 4, along with highlights from the October 2015 flooding event in South Carolina. A summary and future work is given in Section 5, followed by acknowledgements and references.

2. SUCCESSFUL SPORT PARADIGM

As part NASA's Marshall Space Flight Center in Huntsville, AL, the SPoRT Center has been transitioning unique NASA Earth Observing observations and conducting modeling and data assimilation research since 2002. Beginning in 2009, SPoRT has also been conducting unique Proving Ground activities within NOAA for the next generation geostationary (GOES-R) and polar-orbiting (Suomi-NPP/JPSS) suite of satellites. Among the remote sensing and modeling products transitioned to select NWS forecast offices by SPoRT include high-resolution single-channel satellite products from the MODIS and VIIRS instruments; red-green-blue multi-spectral products to highlight specific phenomena such as dust, air mass characteristics, and snow cover; modeling products for the land surface; and sea surface temperatures.

The strength and success of SPoRT's transition activities lie in its close involvement with the end user throughout the entire transition process, as illustrated by Figure 1. First, a specific forecast challenge is identified by a partnering NWS weather forecast office (WFO) and matched to a unique remote sensing or research product that SPoRT can produce or disseminate. The second step is to develop a prototype solution along with appropriate training customized for the forecast challenge and end-user needs. A formal assessment or less formal evaluation is then conducted by the participating forecasters to determine the utility of the experimental product(s) in operations. The product evaluation is an important step in determining product utility, and/or identifying areas of improvement for the algorithm or display. Weaknesses identified by the assessment are used to improve the algorithm or display characteristics, if necessary. It is important to note that for a successful transition to operations, it is critical to ensure that the product is seamlessly ingested and displayed in the end-users decision support system with minimal latency, typically within AWIPS II. It is through this process that the SPoRT-LIS was first evaluated by the NWS WFOs in HSV, Houston, TX, and Raleigh, NC during summer-fall 2014, followed by the more recent evaluation during summer 2015 with the NWS ABQ, HSV, and TWC WFOs.

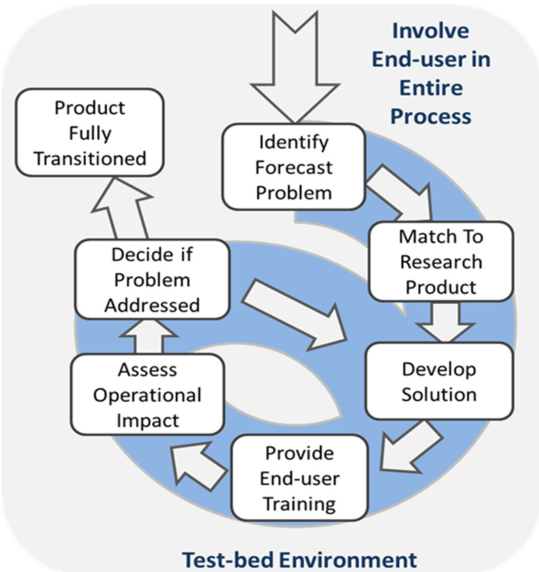

Figure 1. Illustration of the SPoRT paradigm for successful product transitions to operations.

3. NASA LIS AND SPORT-LIS CONFIGURATIONS

3.1 LIS framework

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 (or finer) to characterize land surface states and fluxes. LIS has also been coupled to the Advanced Research Weather Research and Forecasting (WRF) dynamical core (Kumar et al. 2007) for NWP applications using the NASA Unified-WRF modeling framework (Peters-Lidard et al. 2015). The various modes of operation for LIS include offline and coupled LSM simulation, land data assimilation via an Ensemble Kalman Filter algorithm, and an optimization and uncertainty analysis for calibrating land surface parameters (Figure 2). The real-time SPoRT-LIS configuration (described below) currently runs LIS in an offline mode, but will include data assimilation of satellite-retrieved soil moisture in the near future.

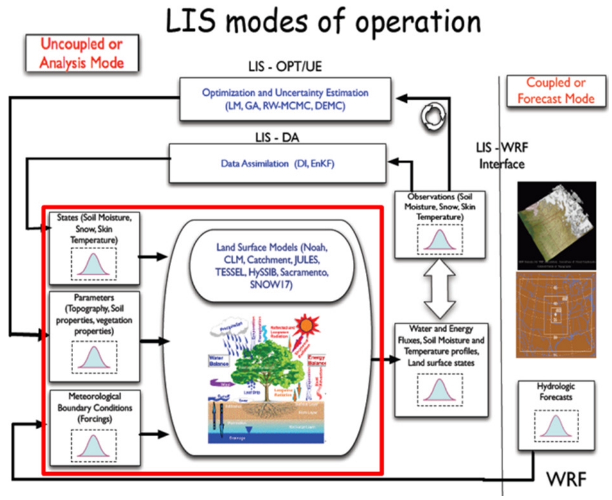

Figure 2. NASA LIS software framework and capabilities. The red box indicates the mode of operation of the real-time SPoRT-LIS.

3.2 SPoRT-LIS Description

In the SPoRT-LIS evaluation during summer 2015, version 3.3 of the Noah LSM (Ek et al. 2003; Chen and Dudhia 2001) is run in analysis mode (i.e., uncoupled from an NWP model) over a full CONUS domain (Figure 3) at 0.03-degree grid spacing 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 Jan 1979, followed by an integration using a 30-minute timestep through 2013. The entire period was then re-started from 1979 to present, forming a soil moisture climatology spanning 1981-2013 that forms the basis for a near real-time soil moisture percentile product (presented in Zavodsky et al. 2016). In essence, the real-time SPoRT-LIS is an extension of the long-term climatology run.

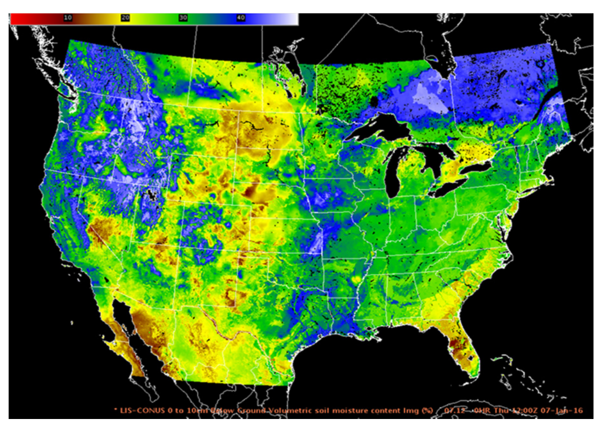

Figure 3. Depiction of the current full CONUS SPoRT-LIS, as displayed in the NWS AWIPS II.

3.2.1 Static input fields

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). Monthly climatological GVF are incorporated in the long-term climatology simulation of LIS from 1979 to 2013 using the 2000-2010 MODIS fraction of photosynthetically active radiation-based dataset available in the community WRF model since the version 3.5 release (NCAR 2014; Barlage, personal communication). Real-time GVF data derived from Suomi-NPP VIIRS (Vargas et al. 2015) are subsequently incorporated into the real-time SPoRT-LIS runs in place of the monthly climatology GVF dataset from Sep 2012 to present.

3.2.2 Simulations and atmospheric forcing

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 climatology simulation, all atmospheric forcing variables are provided by hourly analyses from NLDAS-2 (Xia et al. 2012). However, the NLDAS-2 analyses have ~3-4 day lag in real time, warranting the use of alternative forcing 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 from the NCEP/EMC GDAS (Parrish and Derber 1992; NCEP EMC 2004), along with hourly ~1-km resolution MRMS QPE from the gauge-adjusted radar product. 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/EMC GFS model 3–15 hour forecasts.

The SPoRT-LIS cycle is initiated four times daily at 0400, 1000, 1600, and 2200 UTC with the history re-starts of the simulation as described above. In each cycle, the first re-start simulation begins 5 days before the current time, over-writing previous output files. The long-term LIS/Noah LSM solution ultimately converges to a modeled state based on the NLDAS-2 forcing input. This ensures that real-time soil moisture percentiles and anomalies are derived in a consistent manner with the long-term climatology.

4. SUMMER 2015 LIS EVALUATION

Given the recent expansion to a full CONUS domain and to follow up with the summer-fall 2014 evaluation, the SPoRT-LIS was evaluated by the NWS WFOs at HSV, ABQ, and TWC during summer 2015. The primary forecast challenges that have been addressed by SPoRT-LIS to date have been drought monitoring and assessing areal flooding potential. However, the expansion into the western U.S. introduced potential new applications of SPoRT-LIS soil moisture fields to operations. Experimental applications were encouraged through blog posts made by participating forecasters, as well as completing online evaluation forms to determine product relevancy and utility. The following three examples highlight some of the potential utility that can be gained in WFO operations using the SPoRT-LIS.

4.1 Flooding and blowing dust event at NWS TWC

During the summer wet monsoon in the U.S. Southwest, forecast challenges often include flooding/flash flooding and blowing dust storms associated with strong convective outflows. An example of how the NWS TWC began using the SPoRT-LIS soil moisture data to evaluate these hazards is highlighted in Figures 4 and 5. The SPoRT-LIS soil moisture from 2 Sep 2015 displayed in the NWS TWC AWIPS II (Figure 4) depicts considerably more moist soils over southeastern Arizona near and to the northeast of the TWC label. Much drier soils prevail to the west of TWC and southwest of Phoenix (PHX). This soil moisture distribution gleaned from the SPoRT-LIS suggests an increased threat of flooding in the regions of elevation near-surface and total column soil moisture, should heavy rainfall develop in the areas of high antecedent soil moisture. Similarly, the very dry 0-10 cm relative soil moisture to the west and southwest of PHX (panel b) suggests an elevated risk of blowing dust, contingent on convective development.

This information was used in combination with the local high-resolution WRF NWP model output for this day, as generated by the University of Arizona (Figure 5). The model output of 10-m wind speeds valid at 2100 UTC 2 Sep (panel a) suggests that the initial concern would be flooding over southeastern Arizona, given by the string outflows emanating from simulated convection in that region, coincident with the area of high soil moisture. Later on at 0300 UTC 3 Sep, the strong simulated convective outflows shift to south-central Arizona to the south and southwest of PHX (panel b), beginning to impinge on the area of drier soil moisture indicated by SPoRT-LIS. Thus, if the local WRF model had a good handle on the convective evolution, then the blowing dust threat might be higher after dark. This case provides an example of how the SPoRT-LIS can be used to increase situational awareness in U.S. Southwest during the summer monsoon.

4.2 Wildfire application at NWS ABQ

Another application of real-time SPoRT-LIS was the correspondence between soil moisture fields and a wildfire, identified by forecasters at the NWS ABQ WFO. They examined the annual soil moisture change output (left panel of Figure 6) alongside the current shallow soil moisture (right panel of Figure 6) to subjectively correlate these fields with a wildfire event south of ABQ. In general, the total column soil moistened considerably across New Mexico and West Texas between 27 July 2014 and 27 July 2015 (panel a). A few exceptions include a local area to the south of ABQ within the red box in panel a. Upon expanding the red box in panel b, we see that a patch of very dry 0-10 cm soil moisture coincides with the area of little annual improvement in total column soil moisture. In fact, the label "Home" in panel b denotes the location of a 700-acre wildfire the occurred at Ft. Craig, NM on 27-28 Jul. So despite the overall regional improvements to the soil moisture over New Mexico, this local pocket of very dry soil moisture proved conducive to the development of a wildfire. Of course, other factors such as vegetation coverage/health, wind speeds, and relative humidity also need to be considered when assessing a wildfire threat.

4.3 SPoRT-LIS associated with SC flooding event

In early October 2015, a prolific 10-20"+ rainfall event occurred over central South Carolina when an upper-level trough interacted with a deep moisture feed connected with Hurricane Joaquin over the Bahamas. The flooding could have been considerably worse had there not been a prevailing moderate to severe drought prior to the heavy rainfall event. The experimental percentile product (described further in Zavodsky et al. 2016; *this Conf.*) is shown prior to and following the event in Figure 7a-b. Historically dry soil moisture percentiles in the 5^{th} to 30^{th} range were widespread on 27 Sep, especially across North Carolina. However, following the prodigious rainfall, soil moisture on 4 Oct exceeded the 98^{th} percentile across much of central South Carolina and portions of coastal North Carolina. The soils remained at or above the 98^{th} percentile for several weeks following the event (not shown), indicating the extreme nature of the rainfall event relative to the 1981-2013 climatology used to derive the percentiles.

These high soil moisture percentiles corresponded very well with the occurrences of minor to major flooding as indicated by the highlighted USGS stream gauges in Figure 7c. Another SPoRT-LIS soil moisture product available in AWIPS II is shown in panel d: the one-week change in total column relative soil moisture. The purple shading shows the exceptionally large increases in relative soil moisture that occurred in just one week, representing a 100-200% change in available water in just a week time span.

5. SUMMARY AND FUTURE WORK

This paper described the SPoRT real-time configuration of LIS and how these data can be used for enhancing situational awareness at NWS WFOs. The summer 2015 evaluation featured forecaster participation at the NWS WFOs in HSV, ABQ, and TWC. New potential applications in assessing blowing dust and wildfire risks were highlighted by the participating Western Region WFOs. The product also continued to be utilized by SPoRT partners from the previous year's assessment, which proved beneficial during the major flooding event in the Carolinas during Oct 2015.

Future efforts to improve the SPoRT-LIS shall include assimilating satellite-retrieved soil moisture in near real time. SPoRT is a recognized early adopter for the NASA Soil Moisture Active-Passive (SMAP) mission, which offers L-band radiometer retrievals of soil moisture. The SMAP mission provides superior accuracy of global soil moisture estimates, which will be assimilated into the SPoRT-LIS using the Ensemble Kalman Filter in LIS (Kumar et al. 2008, 2009). [Unfortunately, the truly unprecedented high-resolution soil moisture retrievals from SMAP were only available for the first few months of the mission before the radar failed in July 2015.] The enhanced LIS output using assimilated SMAP data will have the potential to further improve the initialization of soil variables in local and regional real-time NWP modeling applications, and enhance situational awareness.

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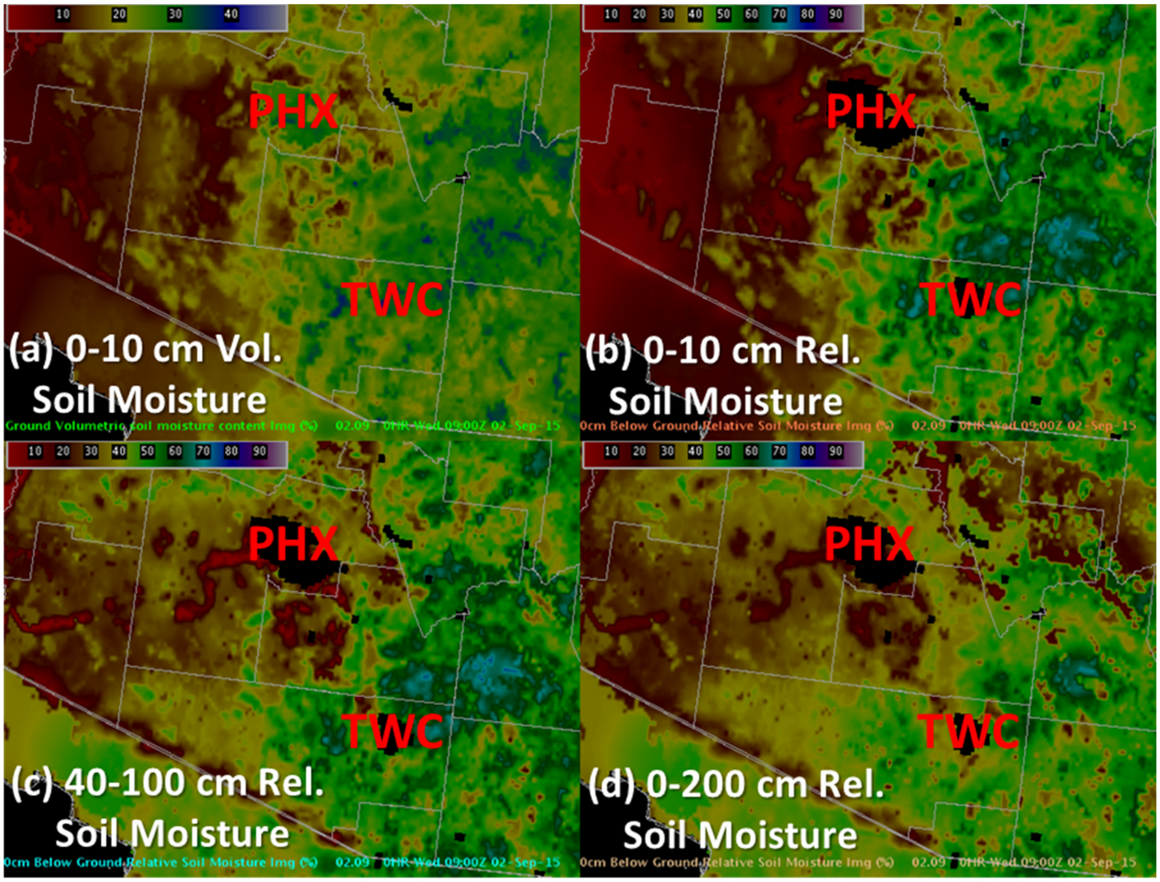

Figure 4. Display of four different SPoRT-LIS Noah soil moisture fields within AWIPS II at the NWS TWC forecast office from 2 Sep 2015: (a) 0-10 cm volumetric soil moisture, (b) 0-10 cm relative soil moisture, (c) 40-100 cm relative soil moisture, and (d) 0-200 cm (total column) relative soil moisture.

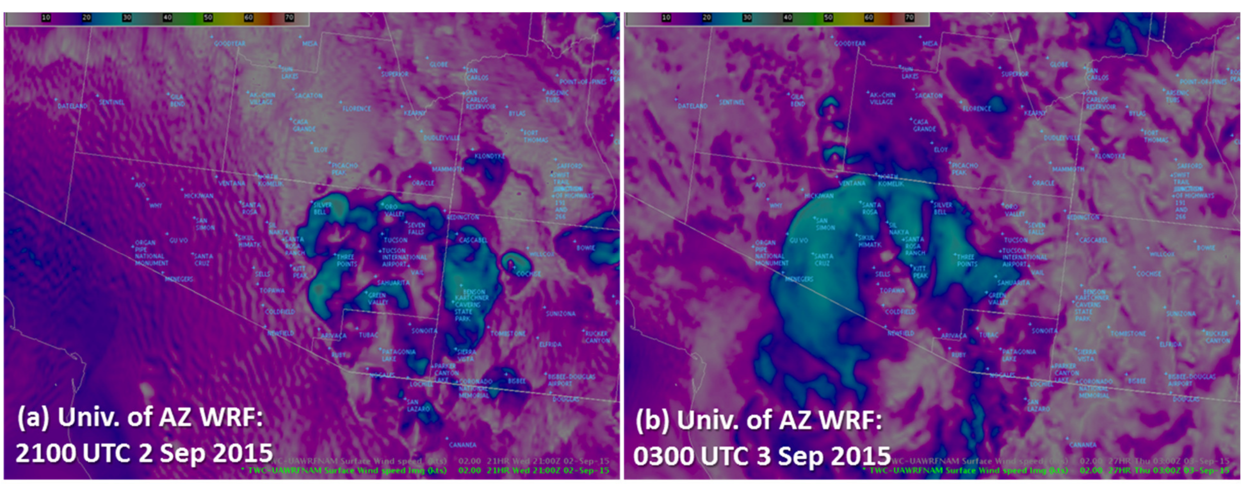

Figure 5. Local WRF NWP model of 10-m wind speeds, initialized at 0000 UTC 2 Sep 2015. The model is run by the University of Arizona, provided to the NWS TWC forecast office, and displayed in AWIPS II: (a) 21-h forecast valid 2100 UTC 2 Sep, and (b) 27-h forecast valid 0300 UTC 3 Sep.

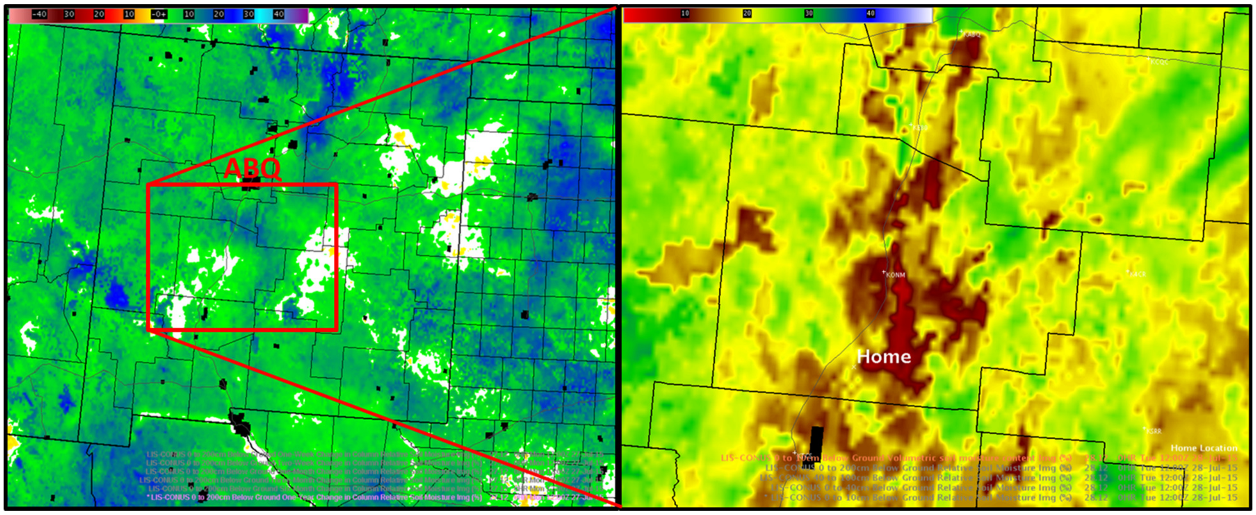

Figure 6. SPoRT-LIS soil moisture maps as displayed in AWIPS II at the NWS ABQ forecast office: (left) one-year change in total column relative soil moisture valid 1200 UTC 27 Jul 2015; (right) 0-10 cm volumetric soil moisture value 1200 UTC 28 Jul 2015. The "Home" label indicates the location of the Ft. Craig 700-acre wildfire.

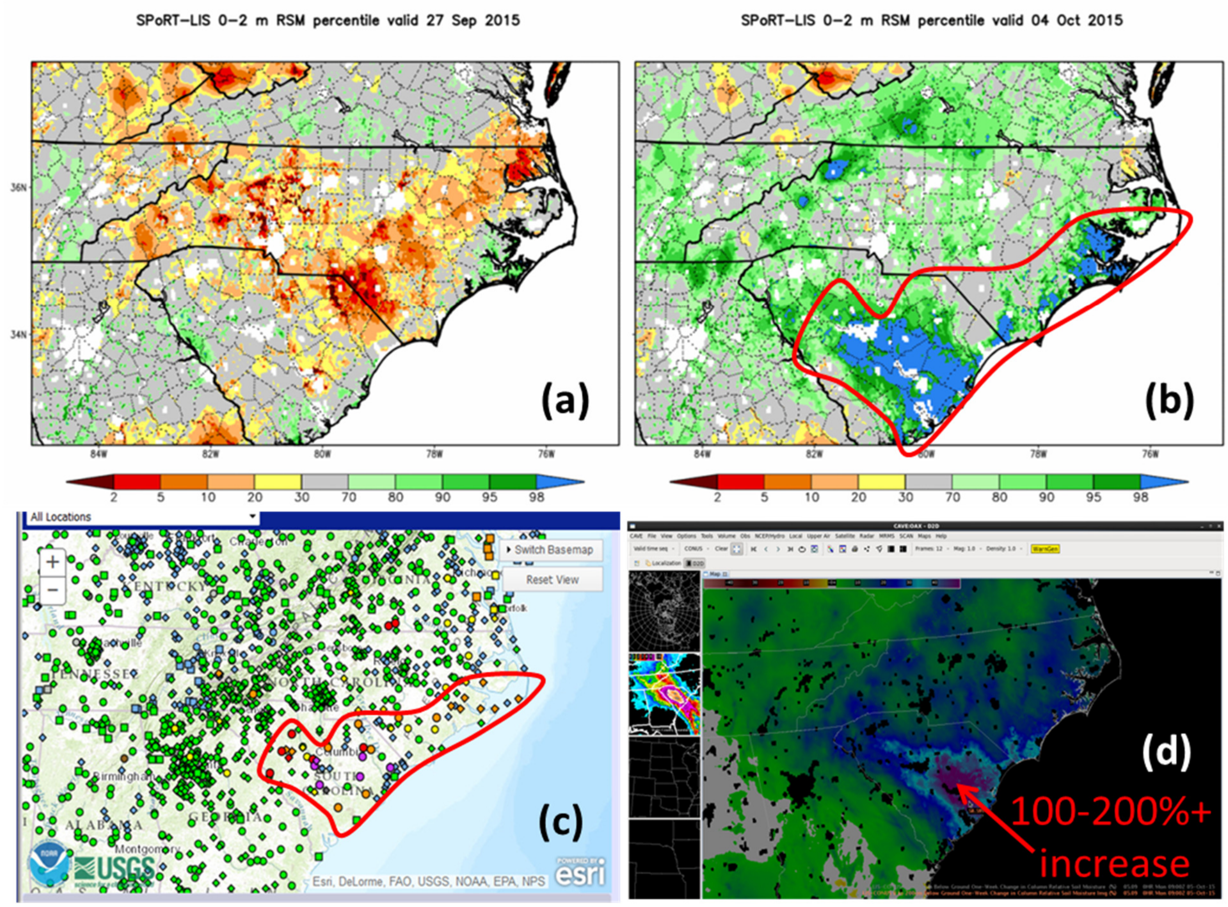

Figure 7. SPoRT-LIS soil moisture products and USGS stream gauges associated with the South Carolina flooding event during early October 2015: (a) Experimental total column relative soil moisture percentile valid 27 Sep; (b) Same as in (a), but valid 4 Oct; (c) USGS stream gauges indicating minor to major flooding within the highlighted region; (d) One-week change in SPoRT-LIS total column relative soil moisture for the week ending 0900 UTC 5 Oct.

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