P33 THE UTILITY OF THE REAL-TIME NASA LAND INFORMATION SYSTEM FOR DROUGHT MONITORING APPLICATIONS

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1. INTRODUCTION

The NASA Short-term Prediction Research and Transition (SPoRT) Center in Huntsville, AL 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”).

The SPoRT-LIS, which is run with 3-km grid spacing over the eastern United States, has demonstrated utility for monitoring drought and the potential for flooding over northern Alabama (Carcione et al. 2011). The more useful output fields for these applications are volumetric soil moisture (%) in the 0-10 cm and 40-100 cm layers, relative soil moisture (%) in the 0-10 cm and column-integrated (0-200 cm) layers (Figure 1), column integrated relative soil moisture weekly difference, and the real-time green vegetation fraction derived from MODIS (Moderate Resolution Imaging Spectroradiometer). The latter are satellite-derived swath data, which are run within the LIS in place of the monthly climatological vegetation fraction. While these and other variables have primarily been used in local weather models (e.g. Weather Research and Forecasting Model) and other operational forecasting applications at National Weather Service (NWS) offices, the use of the SPoRT-LIS has demonstrated utility as a situational awareness tool for input to the United States Drought Monitor (USDM) by the NWS Huntsville office.

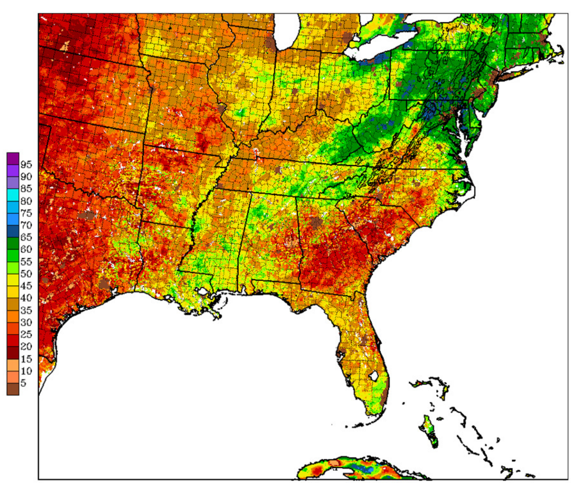

Figure 1. Sample SPoRT-LIS image of relative column integrated (0-200 cm) soil moisture illustrating the geographical extent of the real-time 3-km SPoRT-LIS Noah LSM domain.

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The remainder of this paper is organized as follows. Section 2 gives background information on the NASA LIS and the current real-time SPoRT-LIS configuration. Section 3 describes the drought monitoring methodology while Section 4 provides specific examples on the use of the SPoRT-LIS as a decision support tool. A summary and future work is given in Section 5.

2. NASA LAND INFORMATION SYSTEM AND SPORT-LIS CONFIGURATION

2.1 LIS software 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 to characterize land surface states and fluxes. LIS has also been coupled to the Advanced Research Weather Research and Forecasting dynamical core (Kumar et al. 2007) for numerical weather prediction (NWP) applications.

2.2 SPoRT-LIS Description

In the SPoRT-LIS, version 3.2 of the Noah LSM (Ek et al. 2003; Chen and Dudhia 2001) is run offline (i.e., uncoupled from an NWP model) over a Southeast Continental U.S. (CONUS) domain at 3-km grid spacing for a continuous long simulation, which was initialized at 0000 UTC 1 June 2010. The primary atmospheric forcings (i.e., drivers that serve as input/upper boundary conditions to the Noah LSM integration in the SPoRT-LIS) are hourly atmospheric analyses from the North American Land Data Assimilation System phase 2 (Xia et al. 2012), and hourly precipitation grids from the National Centers for Environmental Prediction (NCEP) Stage IV product (Lin and Mitchell 2005; Lin et al. 2005). The Noah LSM reaches a "modeled equilibrium state" with the atmospheric input acting on the physical equations in Noah.

A limitation of the atmospheric input to the SPoRT-LIS is that NLDAS2 currently has a 4-day lag when data become available on the NCEP server in near-real time. Thus, to ensure that the output are always available in real time, the SPoRT-LIS incorporates a restart configuration strategy using atmospheric forcing from the NCEP Global Data Assimilation System (Parrish and Derber 1992; NCEP EMS 2004) and short-term forecasts from the NCEP Global Forecast System model in place of NLDAS2 from the last NLDAS2 analysis time through the current time, and slightly into the future. NCEP Stage IV is typically available within about an hour of real time, so it is always used as precipitation forcing except for the hours with a slight "future-cast" using GFS forecast data only. The restart strategy begins 5 days prior to the current time, thereby overwriting the recent LIS output driven by GDAS/Stage IV/GFS with that driven by NLDAS2/Stage IV. This process ensures that the long-term Noah LSM soil-state equilibrium always converges to an NLDAS2 + Stage IV precipitation solution. Additional details on the static and dynamic input fields, and how the integration cycle runs in real time within the SPoRT-LIS are presented in a companion poster/paper in this same conference (Case et al. 2013).

3. DROUGHT MONITORING METHODOLOGY

The quantitative assessment of drought conditions involves the synthesis of a plethora of data sets and types of information, including precipitation, hydrologic (i.e., streamflow, groundwater, lake levels) soil moisture, agricultural, and ecological, as well as media and other anecdotal reports of drought-related impacts. Thus, although not an entirely objective exercise, the ability to objectively quantify the process as much as possible is desirous. While meteorologists are generally confident about the various precipitation measurements and data sets available (e.g., Stage III, IV) and thus the inputs to the hydrologic system, information about soil moisture and agricultural responses to these inputs are traditionally less available and often subjective. Since measurements of soil moisture are a crucial component for the proper monitoring of drought conditions, reliable quantitative data are sought for input to the USDM. The rather large spatial and temporal variability of soil moisture complicates the problem, however. Unfortunately, *in situ* soil moisture networks (such as the Soil Climate Analysis Network [SCAN; Schaefer et al. 2007] shown in Figure 2 and Figure 3), while necessary for validation purposes of model and remotely-sensed data, typically consist of sparse point observations.

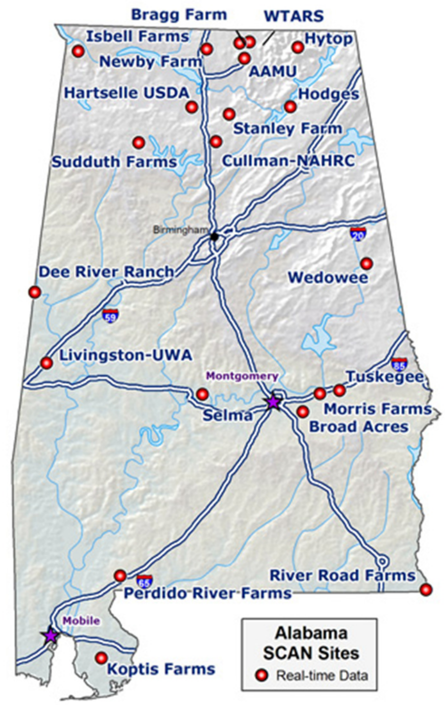

Figure 2. The Soil Climate Analysis Network (SCAN) over the state of Alabama from the Natural Resources Conservation Service (graphic available at http://www.wcc.nrcs.usda.gov/scan/).

While conventional numerical model analyses of soil moisture used to diagnose drought contain useful parameters such as anomalies and percentages of normal based on climatology, the resulting imagery is of relatively coarse spatial resolution (Figure 4). Decision support systems such as the USDM contain drought designations on sub-county scales, which may not be supported by these soil moisture networks or analyses. Therefore, analyses produced by the SPoRT-LIS, which are of relatively high spatial and temporal resolution, offer useful supplemental evidence about current soil moisture conditions.

These data have been used by the NWS Huntsville office for feedback to the USDM since summer 2011. These data, output in Grib2 format, were ported into the NWS Huntsville Advanced Weather Interactive Processing System (AWIPS I) platform before the transition to AWIPS II in summer 2012. Since then, data output are viewed online in .gif format through a web link at the following address: http://weather.msfc.nasa.gov/sport/case_studies/lis_AL.html. This imagery, zoomed to Alabama and portions of surrounding states, contains the same 3-km gridded output of the larger Southeast CONUS domain (Figure 1), and enables analysis of data on sub-county scales. Since input to the USDM takes place on a weekly basis, weekly difference plots of column-integrated relative soil moisture are being produced by SPoRT to facilitate the process. In addition to the

USDM, these data are being used to assess drought conditions for monthly feedback to the Alabama Drought Monitoring and Impact Group and the Tennessee Drought Task Force, which are comprised of federal, state, and local agencies and other water resources professionals. The following case examples will illustrate how these data are being used for input to the USDM.

4. PRELIMINARY RESULTS

4.1 Mid-summer 2011

Hot and relatively dry conditions in mid-summer 2011 lead to the rapid degradation of soil moisture conditions in portions of northern Alabama. Daily high temperatures were in the 90s to low 100s during the period, while the area experienced very little rainfall (Table 1). In response, per SPoRT-LIS data, volumetric soil moisture in the 0-10 cm layer decreased about 10% from 26 July to 2 August in portions of northwest Alabama and central Alabama (Figure 5). Corresponding stress to agriculture was noted in the weekly USDA Crop Progress and Condition report for the state of Alabama (not shown). Correspondence from Doyle Dutton, Farm Service Agency County Executive Director indicated only spotty rainfall in Lawrence County during the period, with remarks that the cotton crop was in "desperate need of rain" (USDA/National Agricultural Statistics Service Alabama Field Office Crop Progress and Condition, 1 August 2011). Further communications with representatives of the Alabama Cooperative Extension System (ACES) at the Belle Mina, Alabama office affirmed the presence of dry soils for agricultural purposes in portions of northwestern Alabama (ACES representatives, personal communication, 2 August, 2011). A synthesis of these reports combined with precipitation, hydrologic, and SPoRT-LIS soil moisture data led to a suggestion for the introduction of abnormally dry (D0) conditions to the USDM for 2 August 2011. While still experimental, the SPoRT-LIS data nevertheless provided more of a quantitative estimate of soil moisture conditions and a geographical focus for assessing agricultural responses to hot, dry weather conditions. Importantly, this helped to create a more efficient process for drought monitoring in this case.

4.2 Early May 2012

Temperatures averaging around five to ten degrees above normal from late April into early May led to the development of low relative soil moisture in southern DeKalb County, AL by 8 May 2012 (Figure 6, left). Stage-III precipitation amounts indicated a similar lack of rainfall during the previous week (Figure 7). However, one of the primary questions when assessing drought impacts and designations is: "How do relatively high temperatures and the lack of rainfall input affect soil moisture and agriculture?" As shown in the previous example, the SPoRT-LIS enables a more narrow focus to drought analyses. In particular, the SPoRT-LIS difference plots of 0-200 cm relative soil moisture permit the efficient analysis of soil moisture changes over the appropriate weekly period. For the week ending 8 May 2012, the 0-200 cm relative soil moisture difference plot (Figure 6, right) indicated that soil moisture had likely degraded in southern portions of DeKalb County despite weekly rainfall amounts around 0.50 inch, while the 0-200 cm relative soil moisture analysis indicated values at a local minimum for the area (Figure 6, left). Communications with USDA agricultural extension agents verified dry soils and impacts to corn crops in southern portions of DeKalb County (ACES representatives, personal communication, 8 May, 2012), resulting in an expansion of moderate drought (D1) into this area for the 8 May 2012 USDM (Figure 8).

4.3 November 2012

Portions of the lower Ohio Valley region experienced severe (D2) and even extreme (D3) drought during summer and fall 2012. A series of rain-bearing systems began to decrease the effects of the drought during the months of September and October, but meaningful assessments to responses in the hydrologic and soil systems are preferred for input to the USDM. During early November, the SPoRT-LIS was used by technicians at the Kentucky Division of Water Management to help quantify soil moisture responses in drought-stricken areas of western Kentucky. After a period of heavy rain, the SPoRT-LIS indicated that soil moisture was slow to replenish, with relatively low values across much of western Kentucky, including the area with existing severe (D2) drought (Figure 9). A synthesis of *in situ* observations from SCAN sites in western Kentucky, anecdotal reports from agricultural producers in the field, and SPoRT-LIS soil moisture analyses suggested that a continuation of severe drought was warranted despite two-inch rainfall amounts in early November (Figure 10). Although some increases in soil moisture had occurred, they were not sufficient to prompt removal of the severe drought status by the USDM.

5. SUMMARY AND FUTURE WORK

This paper and poster presented some applications of the real-time SPoRT-LIS at NWS Huntsville, AL and with state environmental technicians at the Kentucky Division of Water Management. The level of horizontal detail that the SPoRT-LIS provides can help those with responsibility for weekly input to the USDM improve the delineation of drought categories on finer scales than can be achieved with the current suite of operational datasets.

Future modifications are planned to the SPoRT-LIS to improve the quality of soil moisture output, and expand the domain beyond the Southeast CONUS. The companion paper/poster in this conference (Case et al. 2013) described work being done to expand the SPoRT-LIS to a full CONUS domain. In addition, future improvements planned to the SPoRT-LIS include the assimilation of retrieved soil moisture from the future NASA Soil Moisture Active Passive mission as data become available by ~2014-2015.

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REFERENCES

Carcione, B., K. D. White, 2011: New Operational Applications for the NASA Land Information System. Abstracts, *36th Annual National Weather Association Meeting,* Birmingham, AL, National Weather Association, P2.20.

Case, J. L., S. V. Kumar, R. J. Kuligowski, and C. Langston, 2013: Comparison of four precipitation forcing datasets in Land Information System simulations over the Continental U.S. Preprints, *27th Conf. on Hydrology,* Austin, TX, Amer. Meteor. Soc., P69. [Available online at https://ams.confex.com/ams/93Annual/webprogram/Paper214457.html]

Chen, F., and J. Dudhia, 2001: Coupling an advanced land-surface/hydrology model with the Penn State/NCAR MM5 modeling system. Part I: Model description and implementation. *Mon. Wea. Rev.,* **129,** 569-585.

Ek, M. B., K. E. Mitchell, Y. Lin, E. Rogers, P. Grunmann, V. Koren, G. Gayno, and J. D. Tarpley, 2003: Implementation of Noah land surface model advances in the National Centers for Environmental Prediction operational mesoscale Eta model. *J. Geophys. Res.,* **108 (D22),** 8851, doi:10.1029/2002JD003296.

Kumar, S. V., and Coauthors, 2006. Land Information System – An Interoperable Framework for High Resolution Land Surface Modeling. *Environmental Modeling & Software,* **21 (10),** 1402-1415, doi:10.1016/j.envsoft.2005.07.004.

______, C. D. Peters-Lidard, J. L. Eastman, and W.-K. Tao, 2007: An integrated high-resolution hydrometeorological modeling testbed using LIS and WRF. *Environmental Modeling & Software,* **23 (2),** 169-181, doi: 10.1016/j.envsoft.2007.05.012.

Lin, Y., and K. E. Mitchell, 2005: The NCEP Stage II/IV hourly precipitation analyses: Development and applications. Preprints, *19th Conf. on Hydrology,* San Diego, CA, Amer. Meteor. Soc., 1.2. [Available online at http://ams.confex.com/ams/pdfpapers/83847.pdf]

______, ______, E. Rogers, and G. J. DiMego, 2005: Using hourly and daily precipitation analyses to improve model water budget. Preprints, *Ninth Symp. on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, San Diego, CA, Amer. Meteor. Soc., 3.3. [Available online at http://ams.confex.com/ams/pdfpapers/84484.pdf]

NCEP Environmental Modeling Center, 2004: SSI Analysis System 2004. NOAA/NCEP/Environmental Modeling Center Office Note 443, 11 pp., April, 2004. [Available online at http://www.emc.ncep.noaa.gov/officenotes/newernotes/on443.pdf]

Parrish, D. F., and J. C. Derber, 1992: The National Meteorological Center's spectral statistical-interpolation analysis system. *Mon. Wea. Rev.,* **120,** 1747-1763.

Peters-Lidard, C. D., and Coauthors, 2007: High-performance Earth system modeling with NASA/GSFC's Land Information System. *Innovations Syst. Softw. Eng.,* **3,** 157-165.

Schaefer, G. L., M. H. Cosh, and T. J. Jackson, 2007: The USDA Natural Resources Conservation Service Soil Climate Analysis Network (SCAN). *J. Atmos. Oceanic Technol.,* **24,** 2073-2077.

USDA/National Agricultural Statistics Service Alabama Field Office. *Crop Progress And Condition*. Montgomery, AL: National Agricultural Statistics Service, August 1, 2011. Print.

Xia, Y., and Coauthors, 2012: Continental-scale water and energy flux analysis and validation for the North American Land Data Assimilation System project phase 2 (NLDAS-2): 1. Intercomparison and application of model products. *J. Geophys. Res.*, **117,** 27 pp. doi:10.1029/2011JD016048.

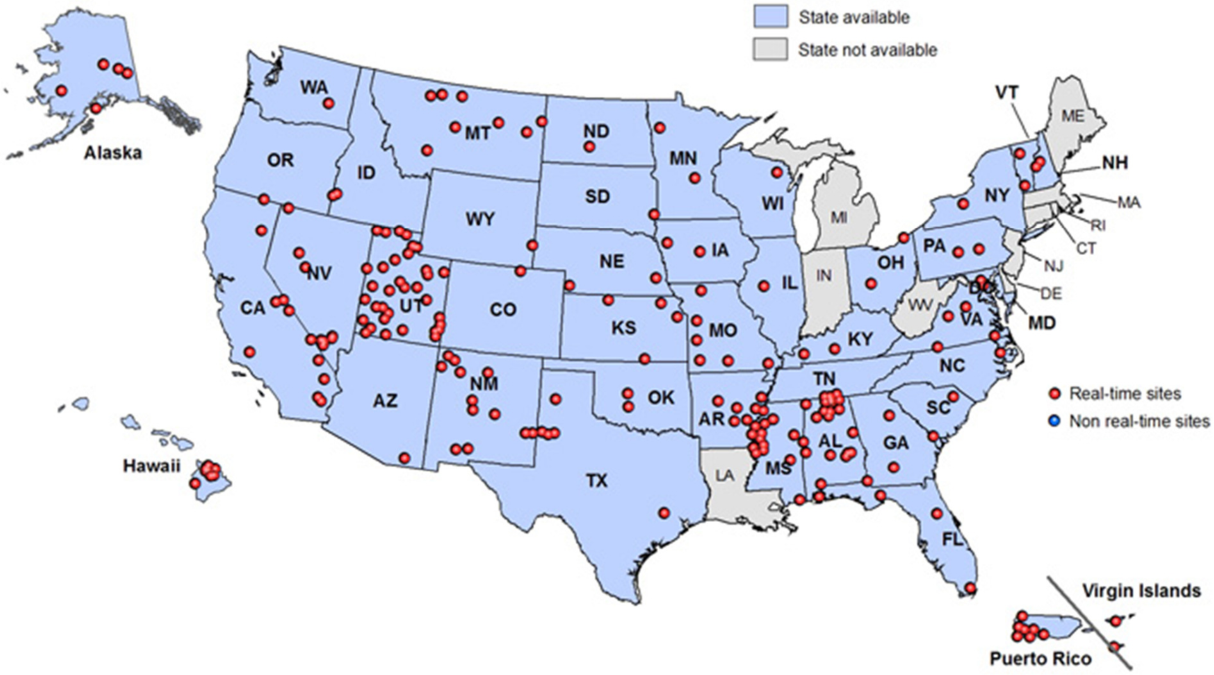

Figure 3. The Soil Climate Analysis Network (SCAN) from the Natural Resources Conservation Service (graphic available at http://www.wcc.nrcs.usda.gov/scan/).

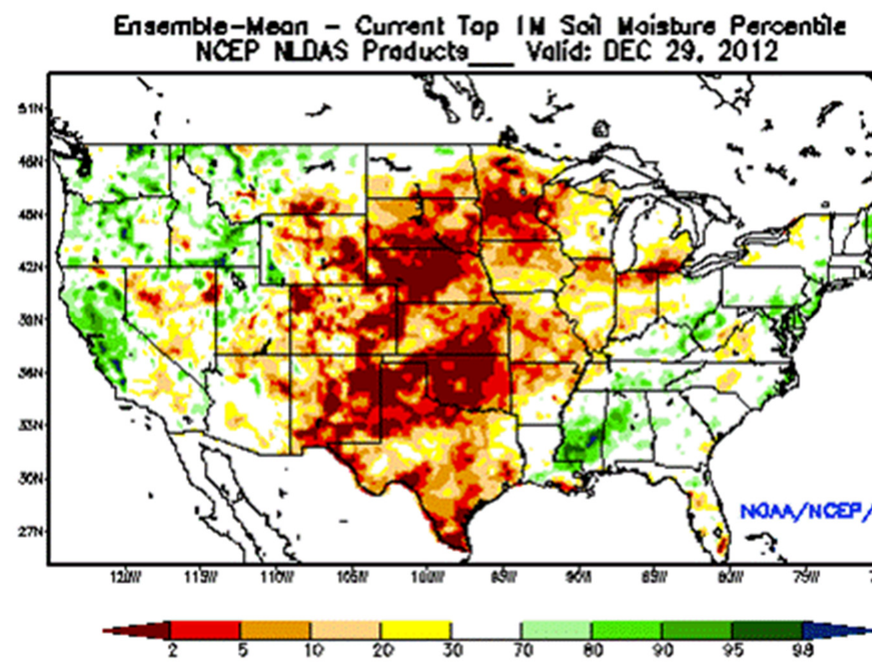

Figure 4. NCEP NLDAS example: Ensemble Mean Top 1-m Soil Moisture Percentile.

Table 1. Daily temperature and precipitation observational data for Muscle Shoals and Russellville, Alabama from 27 July to 2 August 2011.				
	Muscle Shoals		**Russellville**	
Date	High Temperatures	Precip	High Temperatures	Precip
07/27	97	0.00	93	0.00
07/28	92	0.16	91	0.00
07/29	91	0.01	88	0.03
07/30	96	0.01	97	0.00
07/31	98	0.00	98	0.00
08/01	98	0.00	99	0.00
08/02	99	0.00	101	0.22

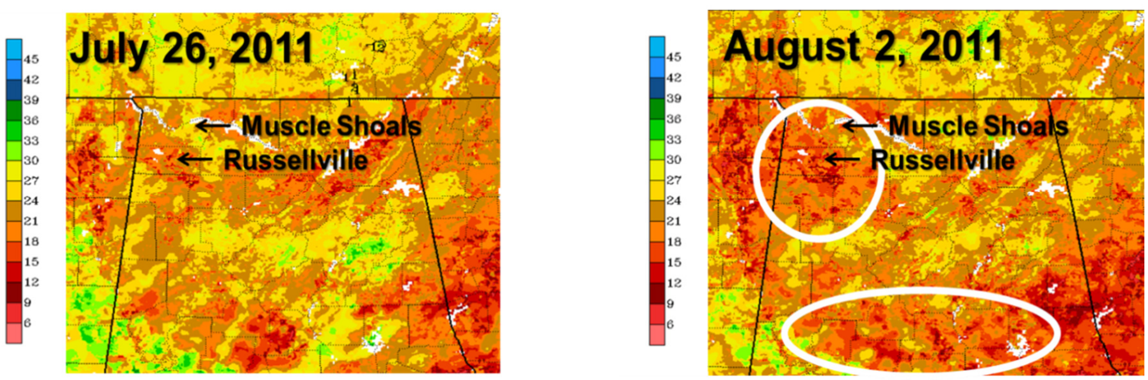

Figure 5. SPoRT LIS 0-10 cm volumetric soil moisture (%), valid at 0900 UTC on the dates indicated. Areas of degraded soil moisture are circled in white.

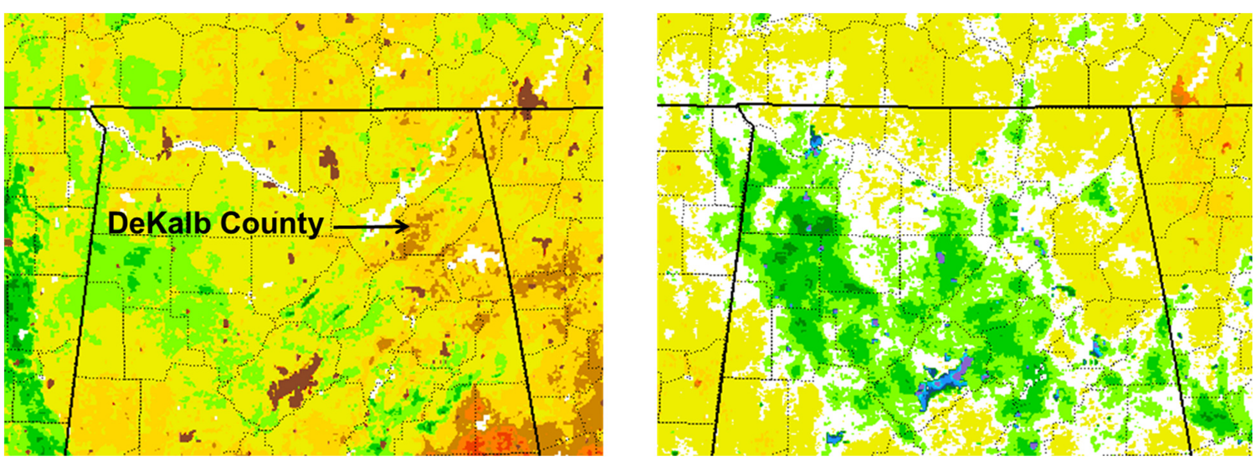

Figure 6. SPoRT LIS 0-200 cm relative soil moisture (%, left) and 0-200 cm relative soil moisture weekly difference (%, right), valid 0900 UTC 8 May 2012.

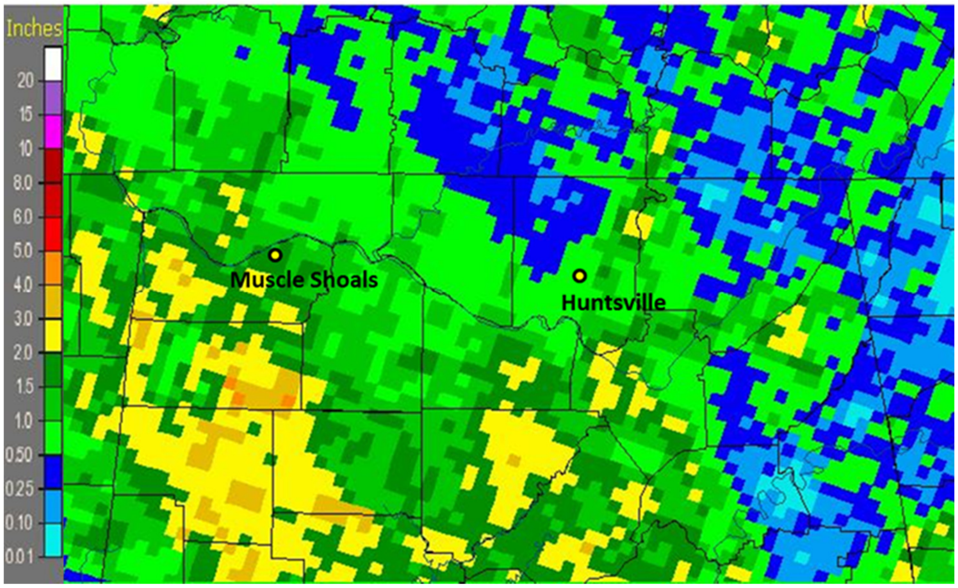

Figure 7. Stage III precipitation for the week ending 1200 UTC 8 May 2012.

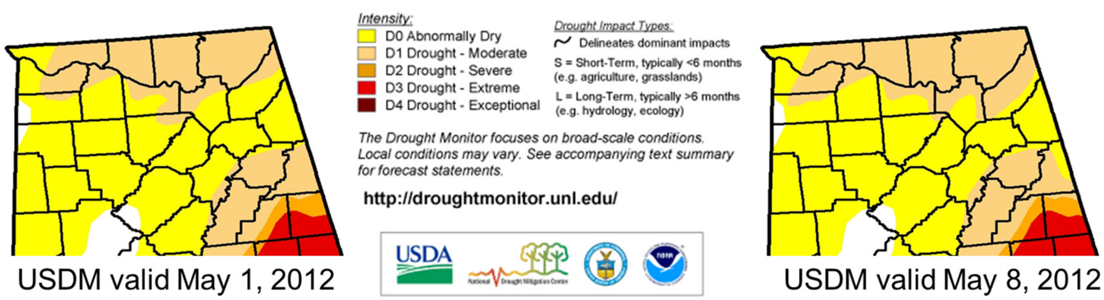

Figure 8. USDM product valid for the dates indicated. Notice the expansion of D1 conditions into southwestern portions of DeKalb County, AL for the 8 May 2012 USDM map.

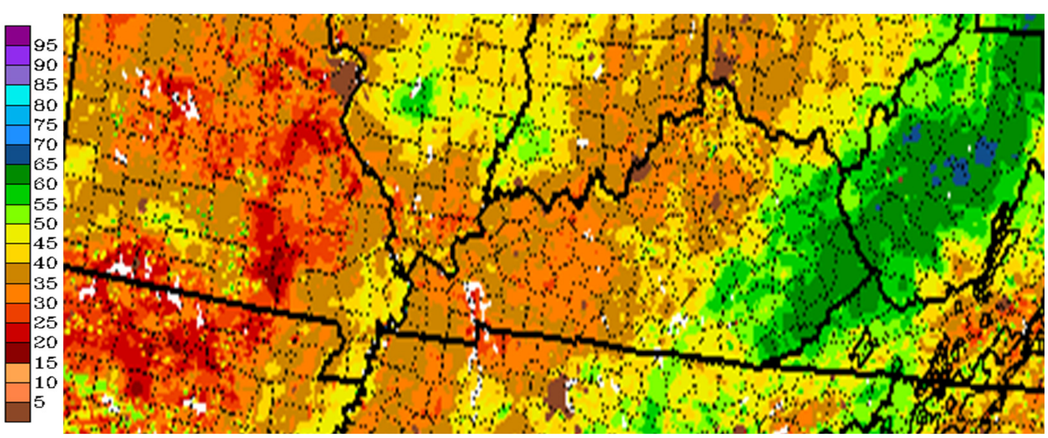

Figure 9. SPoRT-LIS 0-200 cm relative soil moisture (%), valid 13 November 2012.

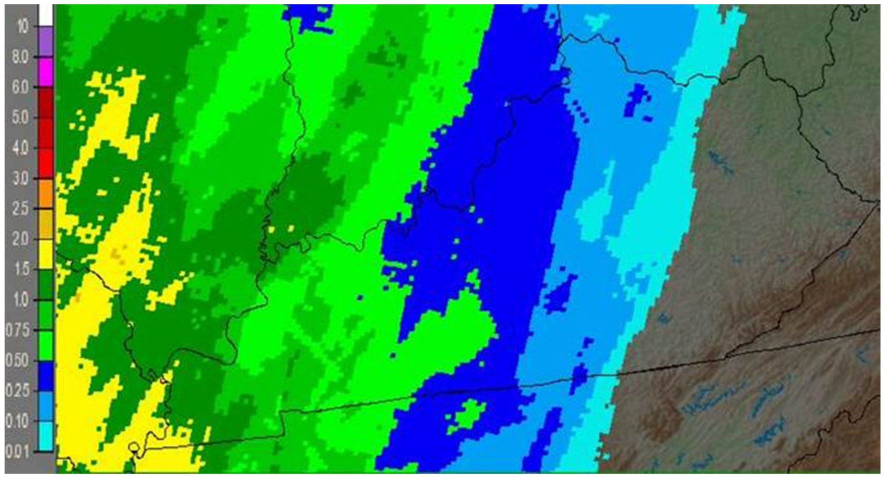

Figure 10. Stage III precipitation totals for the 24-hour period ending 1200 UTC 8 November 2012.