Soil Moisture Data Sets Become Fertile Ground for Applications

An integrated data platform harmonizes many disparate soil moisture data sets to better inform disaster response planners, climate scientists and meteorologists, farmers, and others.

Installation and maintenance of in situ soil moisture sensors require extensive fieldwork. Here Ruzbeh Akbar installs sensors at a SoilSCAPE site in California. A new data platform helps users visualize and work with soil moisture data from a wide variety of ground-based and remote sensing sources. Credit: University of Southern California's SoilSCAPE project

By Rupesh Shrestha and Alison G. Boyer 2 hours ago

When you think about the latest scientific instruments aboard satellites and in networks on the ground, collecting data on how wet (or dry) the soil is probably isn't the first thing that springs to mind. However, soil moisture measurements can alert farmers to crop stress, pinpoint saturated areas where rainfall could trigger landslides, and contribute to a host of other applications.

Accurate and timely information on soil moisture is critical for research in agriculture, flooding, forest health (https://eos.org/meeting-reports/mapping-and-monitoring-soil-moisture-in-forested-landscapes), water quality, and modeling of the global carbon and water cycles. Recently, the availability of soil moisture data has grown considerably. The development of new soil moisture sensing capabilities, wider installation of in situ soil moisture monitoring networks, improved data assimilation, and the launch of the Soil Moisture Active Passive (SMAP) and other satellites have all contributed to this increase in availability.

Investments in improved soil moisture data management and delivery systems are also on the rise. Managing the volume and variety of soil moisture data exemplifies the challenge associated with big data and the increasing need for tools to help users find, explore, and access the data they need.

We developed the Soil Moisture Visualizer (https://daac.ornl.gov/soilmoisture/) (SMV), an integrated visualization and data distribution platform, to harmonize and organize the wide variety of soil moisture data available for North America (Figure 1). Bringing these disparate data into a single system not only adds value to the existing data but also facilitates exploratory analysis and data discovery for different groups of users. The SMV is provided as an open and free data access tool from NASA's Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC (https://daac.ornl.gov/)).

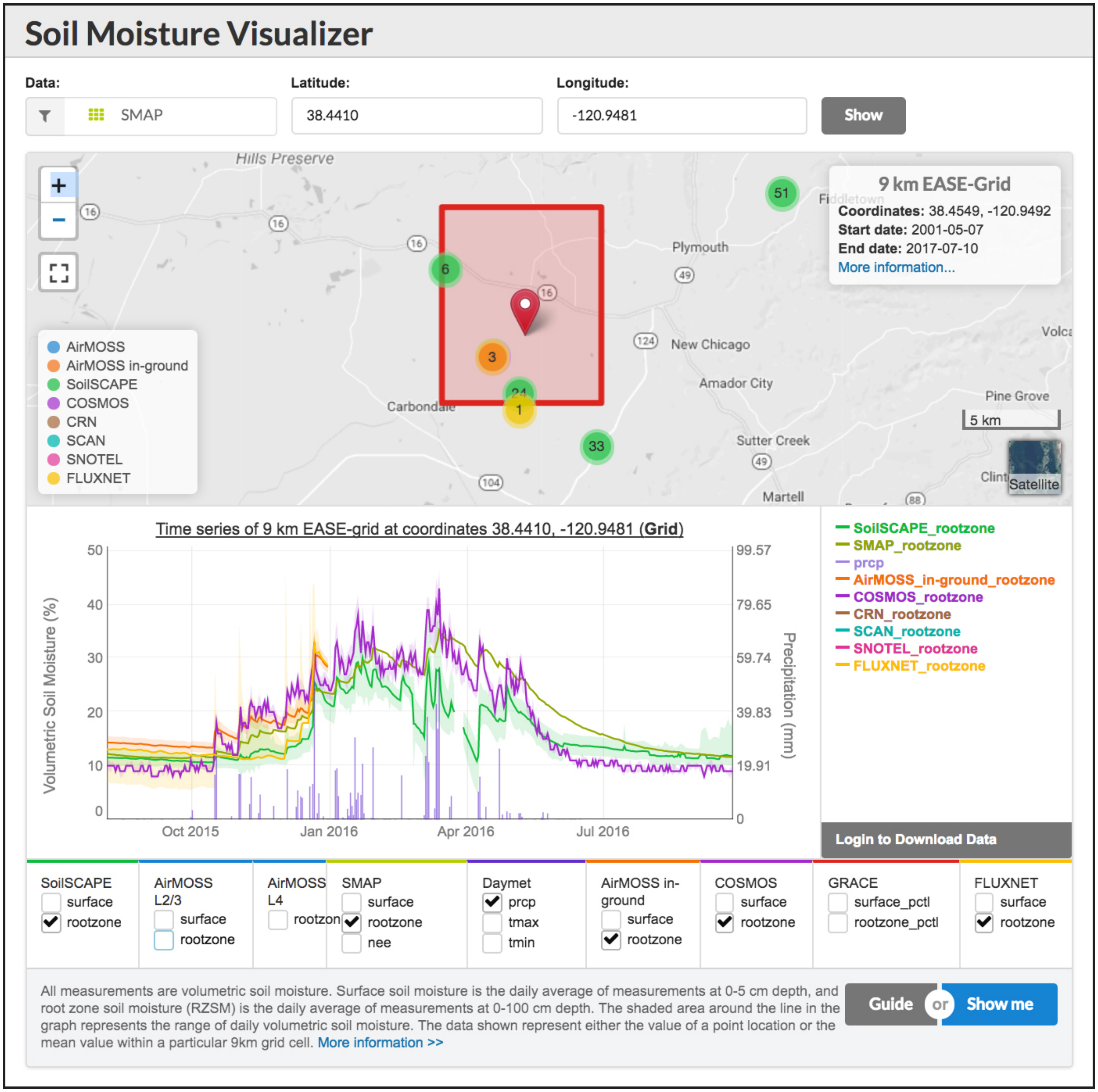

Fig. 1. The Soil Moisture Visualizer allows users to compare soil moisture measurements from multiple sources (figure legends, top left and bottom right) at the same location. In this screenshot, Level 4 Root Zone Soil Moisture (L4 RZSM) data from NASA's Soil Moisture Active Passive (SMAP) Observatory are shown with data from in situ sensors across the 9-kilometer Equal-Area Scalable Earth (EASE) grid cell encompassing the Tonzi Ranch Fluxnet site in the Sierra Nevada foothills of California. Daily precipitation values for the site (purple spikes) are also provided for reference.

Challenges of Heterogeneous Data Sets

The amount of soil moisture, especially the moisture at deeper layers where vegetation roots grow (root zone soil moisture (RZSM)), has significant effects on flows of carbon and nutrients into and out of the soil [*Baldocchi*, 2008]. RZSM information is also critical to applications in many other fields, including meteorology, hydrology, flood forecasting, drought monitoring (https://eos.org/articles/assessing-u-s-fire-risks-using-soil-moisture-satellite-data), and crop decision support systems [*Brown et al.*, 2013; *Legates et al.*, 2011].

Traditionally, soil moisture data have been collected at specific sites using dielectric sensors placed at various depths below the soil surface and recording at specified time intervals. Soil moisture information at regional to global scales is estimated through airborne or satellite remote sensing, often coupled with data assimilation. Remote sensing efforts include NASA's SMAP (launched in 2015), the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS; launched in 2009), and NASA's Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) campaign (2012–2015) [*Moghaddam et al.*, 2016].

Combining data from multiple sources helps fill spatial and temporal gaps in soil moisture measurements.
Each type of data collection has its own strengths and limitations. The data from in situ sensor networks have high temporal and spatial resolution, but they cover limited areas. Remote sensing (https://eos.org/editors-vox/seeing-soil-moisture-from-the-sky) and data assimilation methods provide information across broad spatial scales, but with higher uncertainty. Dense vegetation reduces the accuracy of satellite-based soil moisture estimates but not ground measurements [e.g., *Small et al.*, 2016]. Thus, combining data from multiple sources not only helps to calibrate and validate the data and reduce uncertainty but also helps fill spatial and temporal gaps in soil moisture measurements.

The SMV concept builds on previous efforts [*Dorigo et al.*, 2011; *Robock et al.*, 2000] to bring together soil moisture data sets, such as the North American National Soil Moisture Network (http://nationalsoilmoisture.com/) [*Quiring et al.*, 2016] and ESA's Soil Moisture Climate Change Initiative (https://www.esa-soilmoisture-cci.org/). However, none of these existing efforts provide data harmonization between the in situ soil moisture data and larger-scale remote sensing and data assimilation data sets.

Data Platform Provides Harmony

The goal of the ORNL DAAC Soil Moisture Visualizer is to bring together a wide variety of in situ and remotely sensed soil moisture data in a single platform for visualization and for creating data subsets across various spatial and temporal spans. The tool harmonizes surface and root zone soil moisture data sets from multiple sources and file formats and presents the data and visualizations in a simple Web application, providing seamless access to multiple NASA and non-NASA soil moisture data sets.

The SMV relies on a set of custom Python (https://www.python.org/) language scripts that aggregate and harmonize the incoming soil moisture data into standardized comma-separated value (CSV) files for download. This framework can be leveraged to harmonize other diverse Earth observation data.

A variety of complementary data sets allows users to explore potential relationships between soil moisture and other relevant parameters (such as temperature (https://eos.org/editor-highlights/wet-soils-elevate-nighttime-temperatures), vegetation, and drought) within the Web application. A complete list of available data products is provided in the online user guide (https://daac.ornl.gov/soilmoisture/guide.html).

The SMV currently includes data from major in situ networks, including the Soil Moisture Sensing Controller and Optimal Estimator (SoilSCAPE), the Cosmic-ray Soil Moisture Observing System (COSMOS), the National Oceanic and Atmospheric Administration's U.S. Climate Reference Network, the U.S. Department of Agriculture's Soil Climate Analysis Network and Snow Telemetry (SNOTEL) network, and Fluxnet/AmeriFlux sites (Figure 2). Airborne and spaceborne data include AirMOSS airborne L2/3 and 4 products, SMAP Level 4 RZSM data, and the Gravity Recovery and Climate Experiment (GRACE) Data Assimilation for Drought Monitoring (GRACE-DA-DM) product, version 2.0. Additional environmental data include the SMAP L4 daily Carbon Net Ecosystem Exchange; Moderate Resolution Imaging Spectroradiometer (MODIS) evapotranspiration, enhanced vegetation index, and daytime land surface temperature; and Daymet daily maximum and minimum air temperature and daily precipitation (version 3.0) [*Thornton et al.*, 2017].

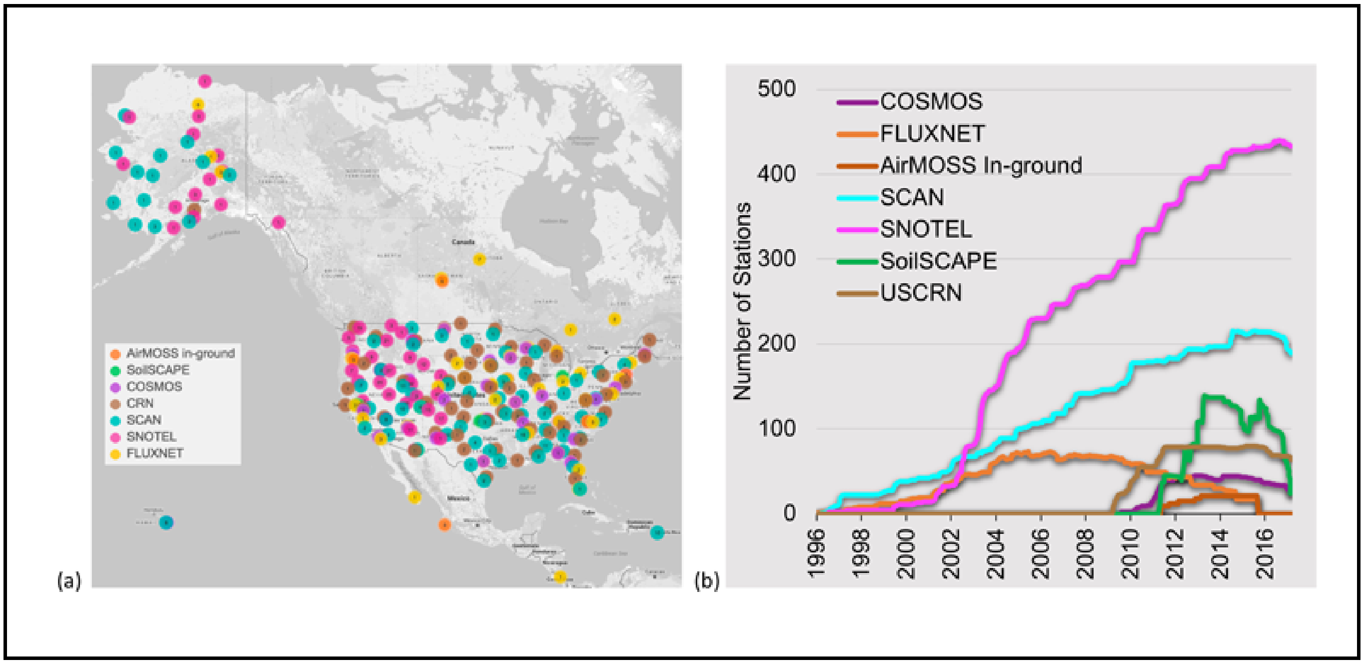

Fig. 2. (a) Locations of in situ soil moisture networks from North America. The included networks are listed in the text. (b) Numbers of operational in situ stations in these networks from 1996 to 2017.

Data included in the SMV span a variety of spatial footprints (point versus gridded representation), frequencies (subhourly to daily), subsurface measurement depths, and methods of measurement (in situ versus remote sensing). To harmonize these disparate data, we aggregate data across three different dimensions: space, time, and subsurface depth (Figure 3). Information on the aggregation methods is provided in the online user's guide (https://daac.ornl.gov/soilmoisture/guide.html). We expect to update the data included in the SMV system weekly, but some data sets might have a longer latency period set by the provider.

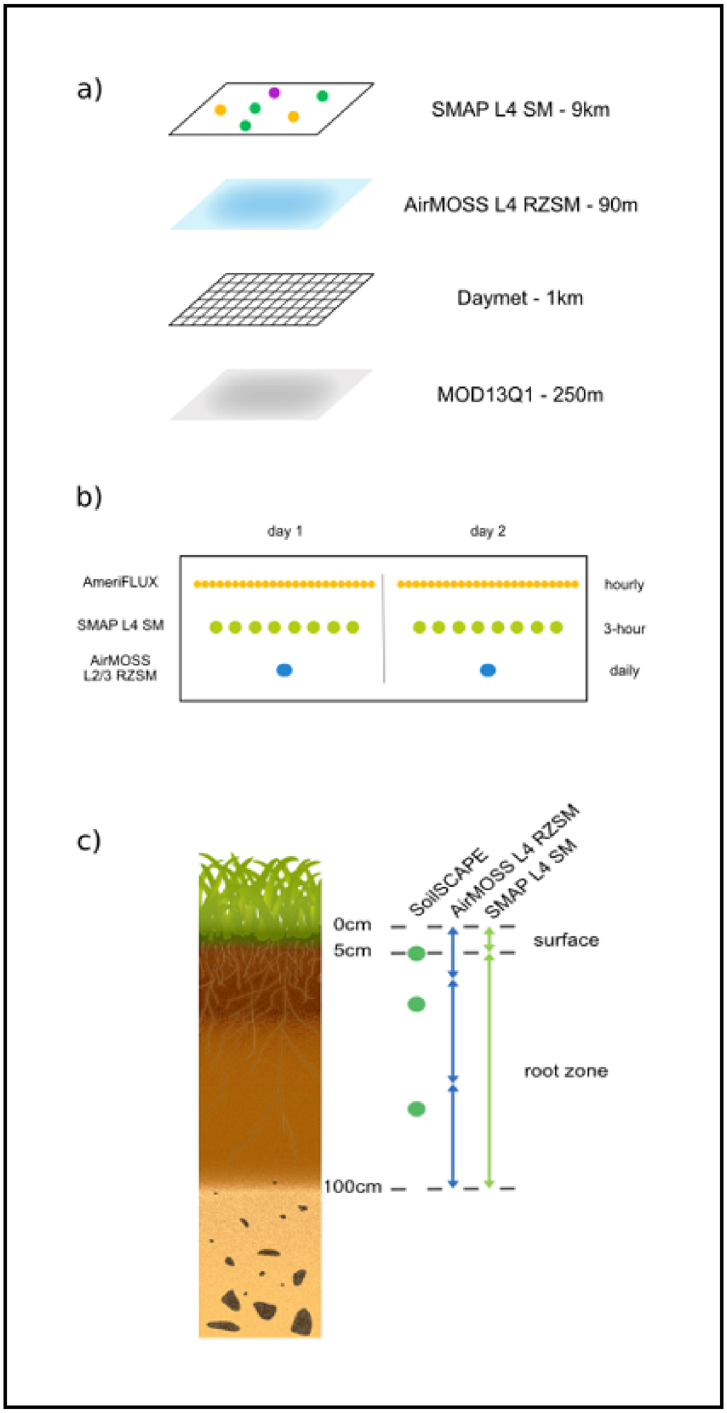

Fig. 3. The Soil Moisture Visualizer uses three levels of data aggregation: (a) spatial aggregation to sampling point locations or the 9-kilometer EASE grid cell, (b) temporal aggregation to a daily time step, and (c) depth aggregation to either the surface or the root zone.

The user interface of the Soil Moisture Visualizer was designed to enable viewing of RZSM time series without having to download and format the data. However, users who want to download the data can sign in via NASA's Earthdata Login (https://urs.earthdata.nasa.gov/) system and click the button labeled "Log in to Download Data" to obtain data from the visualization in a CSV text file. Users are encouraged to acknowledge the use of the SMV tool in publications by including the digital object identifier in a reference [*ORNL DAAC*, 2017].

A Work in Progress

The goal of this system is to reduce the burden on scientists and stakeholders who want to find and use soil moisture data, but accomplishing this goal will require more work. For example, many geographic areas have gaps in the data from in situ networks. Also, data users should pay careful attention to the methods we have employed to harmonize the data in both the spatial and temporal dimensions. This data harmonization approach may not be suitable for all applications and scientific use cases, so users are encouraged to download the raw data through the links provided on the SMV page.

The SMV is currently limited to North America, but expanding it globally would serve more applications. In addition, the system would be enhanced by adding more data products. These products could include remote sensing data (e.g., from ESA's SMOS and Sentinel-1 missions) and data from in situ soil moisture sensors, such as the U.S. Department of Energy's Atmospheric Radiation Measurement Network.

We anticipate that as the volume and variety of soil moisture data sources continue to expand, the user community will need easy-to-use tools like the SMV to preview, select, subset, harmonize, and download data.

Acknowledgments

This project was possible because of the open data philosophy of many organizations who shared their soil moisture data with us. The authors gratefully acknowledge all the investigators and data providers who contributed to creating and distributing data in standards-compliant formats. The authors also acknowledge Mahta Moghaddam, Ranjeet Devarakonda, Suresh Vannan, and colleagues at ORNL, whose comments and suggestions helped improve the tool. Jessica Welch provided graphics and editing. The ORNL Distributed Active Archive Center (DAAC) is funded by NASA's Earth Science Data and Information System project NNG14HH39I. Oak Ridge National Laboratory is managed by UT-Battelle, LLC under contract DE-AC05-00OR22725 with the U.S. Department of Energy.

References

Baldocchi, D. (2008), 'Breathing' of the terrestrial biosphere: Lessons learned from a global network of carbon dioxide flux measurement systems, *Aust. J. Bot.*, *56*, 1–26, https://doi.org/10.1071/BT07151 (https://doi.org/10.1071/BT07151).

Brown, M. E., et al. (2013), NASA's Soil Moisture Active Passive (SMAP) mission and opportunities for applications users, *Bull. Am. Meteorol. Soc.*, *94*, 1,125–1,128, https://doi.org/10.1175/bams-d-11-00049.1 (https://doi.org/10.1175/bams-d-11-00049.1).

Dorigo, W. A., et al. (2011), The International Soil Moisture Network: A data hosting facility for global in-situ soil moisture measurements, *Hydrol. Earth Syst. Sci.*, *15*, 1,675–1,698, https://doi.org/10.5194/hess-15-1675-2011 (https://doi.org/10.5194/hess-15-1675-2011).

Legates, D. R., et al. (2011), Soil moisture: A central and unifying theme in physical geography, *Prog. Phys. Geogr.*, *35*, 65–86, https://doi.org/10.1177/0309133310386514 (https://doi.org/10.1177/0309133310386514).

Moghaddam, M., et al. (2016), AirMOSS: L2/3 Volumetric Soil Moisture Profiles Derived from Radar, 2012–2015, Oak Ridge Natl. Lab. Distrib. Active Arch. Cent., Oak Ridge, Tenn., https://doi.org/10.3334/ORNLDAAC/1418 (https://doi.org/10.3334/ORNLDAAC/1418).

Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) (2017), Soil Moisture Visualizer, Oak Ridge, Tenn., https://doi.org/10.3334/ORNLDAAC/1366 (https://doi.org/10.3334/ORNLDAAC/1366).

Quiring, S. M., et al. (2016), The North American soil moisture database: Development and applications, *Bull. Am. Meteorol. Soc.*, *97*, 1,441–1,459, https://doi.org/10.1175/bams-d-13-00263.1 (https://doi.org/10.1175/bams-d-13-00263.1).

Robock, A., et al. (2000), The Global Soil Moisture Data Bank, *Bull. Am. Meteorol. Soc.*, *81*, 1,281–1,299, https://doi.org/10.1175/1520-0477(2000)081<1281:tgsmdb>2.3.co;2 (https://doi.org/10.1175/1520-0477(2000)081%3c1281:tgsmdb%3e2.3.co;2).

Small, E. E., et al. (2016), Validation of GPS-IR soil moisture retrievals: Comparison of different algorithms to remove vegetation effects, *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, *10*, 4,759–4,770, https://doi.org/10.1109/JSTARS.2015.2504527 (https://doi.org/10.1109/JSTARS.2015.2504527).

Thornton, P. E., et al. (2017), Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 3, Oak Ridge Natl. Lab. Distrib. Active Arch. Cent., Oak Ridge, Tenn., https://doi.org/10.3334/ORNLDAAC/1328 (https://doi.org/10.3334/ORNLDAAC/1328).

Author Information

Rupesh Shrestha and Alison G. Boyer (boyerag@ornl.gov (mailto:boyerag@ornl.gov)), Environmental Sciences Division, Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center, ORNL, Oak Ridge, Tenn.

Citation: Shrestha, R., and A. G. Boyer (2019), Soil moisture data sets become fertile ground for applications, *Eos, 100,* https://doi.org/10.1029/2019EO114329. Published on 04 February 2019.