National Soil Moisture Network Workshop 2016

Progress made, future directions

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Authors

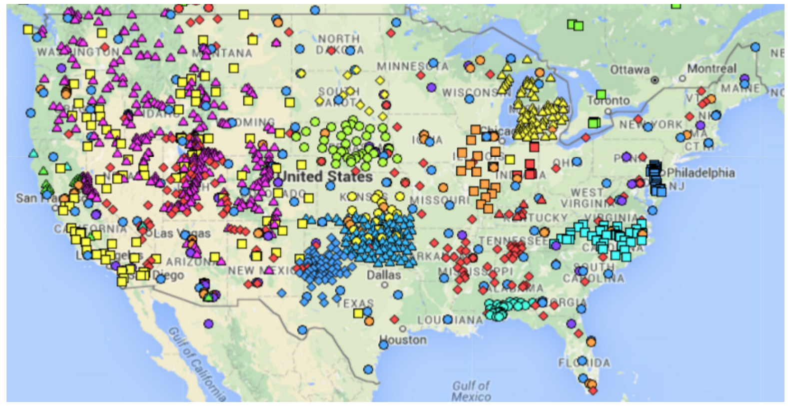
Chad McNutt, National Integrated Drought Information System

Michael Strobel, USDA Natural Resources Conservation Service

Jessica Lucido, USGS

Steve Quiring, Texas A&M University and Ohio State University

INTRODUCTION



This map shows soil moisture monitoring networks in the contiguous U.S., built from the database of networks maintained by Texas A&M University. http://soilmoisture.tamu.edu/

Soil moisture is an important component of the water budget, yet an accurate depiction of this variable has been a serious challenge over the past several decades. Although the U.S. has many platforms on which we can measure it, integrating those systems in a way that improves our knowledge of soil moisture and its status across multiple spatial and temporal scales and over multiple soil depths has only added to this challenge.

In November 2013, the National Integrated Drought Information System (NIDIS) and the National Drought Resilience Partnership (NDRP) held a workshop in Kansas City, MO to discuss the development of a National Soil Moisture Network (NSMN). The motivation for this idea originated from President Obama's Climate Action Plan. The purpose of the 2013 workshop was to identify an approach for the development of a national network that could integrate the multitude of soil moisture data sources across federal and state in-situ monitoring networks, satellite remote sensing missions, and numerical modeling capabilities.

The meeting was the first discussion of its kind on how to integrate such disparate data networks and sources. It brought together experts from the USDA Natural Resources Conservation Service's Soil Climate Analysis Network (SCAN) and Snow Telemetry (SNOTEL) in situ instrument networks; the NOAA Climate Reference Network; state in-situ networks; remote sensing and modeling experts from NASA, NOAA, USDA; and soil moisture database managers from academia and federal and state governments. A summary of the workshop can be found at **https://www.drought.gov/drought/documents/developing-coordinated-national-soil-moisture-network**.

As a result of the 2013 workshop, NIDIS funded a series of workshops and a pilot project to advance this goal. The pilot has served as a potential framework for a coordinated national soil moisture network by demonstrating in-situ soil moisture sensor data could be integrated in real time from a variety of sources, and made accessible both a web service and a web page (http://cida.usgs.gov/nsmn_pilot/) at a common location. The pilot provides the most recent soil moisture percentile for all sites in order to normalize the effect of differing sensors and soil types.

From May 24-26, 2016, many of the same experts who attended the 2013 meeting met in Boulder, CO at NOAA's Earth System Research Laboratory to continue the discussion on how to better communicate and coordinate soil moisture monitoring and assimilation activities across the federal landscape with states and other interests, including the private sector. Two new perspectives were featured at this meeting: the private sector and citizen scientist initiatives to collect soil moisture data. Both have valuable contributions to make in the development of an integrated soil moisture system. The following summary of the workshop will highlight the discussion and identify concrete steps on the future direction and approach for a coordinated NSMN.

Collaboration and Funding

Monitoring soil moisture is a difficult undertaking and requires sufficient resources and coordination over a diverse range of networks. Networks often vary spatially, by sensor type, data collection methods, and with differing end user requirements. A coordinated national soil moisture system, therefore, will only be successful if it is beneficial to a broad range of end users; encourages consistent calibration and validation practices and metadata characterization; and effectively incorporates the diverse existing networks and modeling efforts. With these ideas in mind, participants at the workshop suggested several approaches to improve collaboration, leverage multiple programs and access different sources of funding.

The main topic during the workshop was discussion of how a national network could be developed out of existing programs and activities. This would require assessing existing data assimilation systems -- such as the Meteorological Assimilation Data Ingestion System (MADIS) and the National Mesonet Program or the North American Land Data Assimilation System (NLDAS) -- to understand how diverse data types and providers could be integrated and made accessible to scientists, resource managers and the general public. The framework should also have sufficient buy-in from the community of data providers. This community would include both citizen scientists and private sector groups along with state Mesonet programs, regional climate centers, and federal agencies, among others.

The discussion focused on approaches for collaboration and noted that success would only be achieved if the benefits for participating are understood and the proper incentives are in place to assure robust participation (i.e. sharing data and methodology) in the network. This is particularly important for the citizen scientist and private sector groups. Benefits could be assessed through a series of case studies highlighted in Table 1, at right.

Gaps in funding are another consideration. An effective soil moisture network may not require additional funding for initiation; however, funding will be critical to growing and sustaining the network. The developers of the framework must consider the funding landscape and how it could assist or facilitate growing the network.

Table 1: Collaboration and funding approaches for building a National Soil Moisture Network

- ✦ Assess the value of an integrated network through a series of case studies:
  - -- Integrating a multi-sourced national-gridded soil moisture product into U.S. Drought Monitor
  - -- Improve flood forecasts for reservoir management in the Upper Missouri River Basin
  - -- Improve understanding of tropical cyclones that intensify over land, i.e. the Brown Ocean Effect
- ✦ Improve drought early warning by understanding antecedent soil moisture conditions
- ✦ Use decision theory methodology to quantify economic benefits of soil moisture data
- ✦ Assess approaches to support states in their delivery of soil moisture data to an integrated network
- ✦ Exchange tools and information for private, state, regional soil moisture data. This could include different visualization schemes or complimentary data that would help contextualize soil moisture information.
- ✦ Work with the private sector to assess the feasibility of an opt-in program where private data users would have the option of sharing data
- ✦ Overcome data ownership issues by developing data sharing MOUs

Soil Moisture Data Collection and Integration of Networks

One of the largest obstacles for integrating soil moisture data across networks is the lack of standardization when it comes to collecting in-situ data. This ranges from how the data are collected and synthesized to how we install the sensors, calibrate and validate the measurements, and what metadata are collected as part of this process. This section highlights these issues and the discussion that occurred at the workshop.

In-situ probe installation and data collection

Participants noted a set of consistent standards is needed across networks for soil moisture data collection, such as standards for acceptable error ranges, sensor installation procedures, probe manufacturer, and maintenance of data. Similar standards are needed for soil temperature data as well.

The discussion emphasized the importance of installation of soil moisture probes, their depths, types, and metadata. For sensor installation, participants identified key depths (e.g. 2, 5, 10, 20, 50, 100cm) and their potential application. For example, measurements at 2cm could assist in satellite calibration and verification; measurements at 2cm, 5cm, and 10cm could show available water at the root zone; those at 20cm and 50cm might correspond to streamflow; and those at 100cm and 200cm could indicate drought intensity, as well as drainage and recharge capability.

The standards could vary by region; however, one or two consistent depths should be a minimum requirement across all regions.

For installation of probes, participants noted that, regardless of manufacturer, probes should be calibrated after they have been installed, based on a gravimetric soil analysis for each site. Monitoring sites with probes installed but lacking a soil description could be characterized using the National

SELECTED IN SITU SOIL MOISTURE NETWORKS IN THE U.S.

Network Name	Geographic Region	# of Stations	Period of Record	Observing Depths (cm)
Agricultural Research Service (ARS)	Oklahoma	44	2005-present	5, 25, 45
AmeriFlux	United States	39	1997-present	Variable
Atmospheric Radiation Measurement (ARM)	Kansas, Oklahoma	17	1996-present	5, 15, 25, 35, 60, 85, 125, 175
Automated Weather Data Network (AWDN)	Nebraska	52	2006-present	10, 25, 50, 100
Climate Reference Network (CRN)	United States	114	2009-present	5, 10, 20, 50, 100
Cosmic Ray Soil moisture Observing Station (COSMOS)	United States	54	2008-present	Variable
Delaware Environmental Observing System (DEOS)	Delaware	29	2004-present	5
**Georgia Automated Environmental Monitoring Network (GAEMN)	Georgia	79	1992-present	Variable
Illinois Climate Network (ICN)	Illinois	19	1988-present	5, 10, 20, 50, 100, 150
Kansas Mesonet	Kansas	15	2008-present	5, 10, 20, 50, 100
Michigan Enviro-weather (Automated Weather Network, MAWN)	Michigan, Wisconsin	80	2000-present	5, 10
Missouri Agriculture Weather Network (MAW)	Missouri	8	2002-present	5, 10
**New Jersey Mesonet	New Jersey	10	2003-present	5
NOAA Hydrometeorological Testbed	Western U.S.	25	2004-present	Variable
North Carolina EcoNet	North Carolina	36	1999-present	20
Oklahoma Mesonet	Oklahoma	113	1998-present	5, 25, 60, 75
**Remote Automated Weather Stations (RAWS)	Western U.S.	50	1983-present	Variable
Snowpack Telemetry (SNOTEL)	Western U.S.	414	2000-present	Variable
Soil Climate Analysis Network (SCAN)	United States	203	1996-present	5, 10, 20, 50, 100
South Dakota Automated Weather Network (SDAWN)	South Dakota	11	2000-present	5, 10, 20, 50, 100
UA Fairbanks Water and Environmental Research Center (WERC)	Alaska	24	2000-present	Variable
West Texas Mesonet	Texas, New Mexico	64	2000-present	5, 20, 60, 75

Data from Mike Strobel presentation, https://www.drought.gov/drought/sites/drought.gov.drought/files/media/calendar/pre_SoilMoisture2016_Strobel1.pdf

Cooperative Soil Survey and its Soil Survey Geographic Database (SSURGO).

Siting in-situ monitoring locations should also consider areas that may not be spatially representative locations but instead could improve research in such places as ephemeral snow regions, irrigated areas, energy-limited and water-limited areas or unique transition zones.

Improving metadata standards was also a topic that received much scrutiny. At a minimum, a set of metadata fields should be agreed on and communicated broadly to the soil moisture community. Participants noted site-specific metadata for in-situ monitoring were often lacking in many networks. Examples include soil texture, vegetation type and condition, hydraulic conductivity, organic matter, and soil bulk density, among others. For soil descriptions, the Soil Science Society of America has a set of standards that should be used when describing in-situ sites. The range of metadata reported for each site should also be expanded to include land-use and land-change information such as burn areas or areas with tile drains. Ideally, a plan or process should also be in place for updating the site descriptions, and a detailed description of the calibration and validation procedures for these measurements should be easily accessible. Probe manufacturers at the meeting noted that if a consistent set of metadata standards could be agreed on they could incorporate these requirements in their probe or data logger software.

Finally, whereas the discussion mostly focused on in-situ soil moisture monitoring, having a consistent set of requirements will improve capabilities for intercomparison and informed blending of in-situ observations with modeled and remotely sensed data.

Soil Moisture Data Format, Integration, and Storage

Because there are many existing soil moisture data sources, it can be difficult for a user to determine the best data to use, especially if the data are not integrated through a common system. Integrating networks can be a difficult undertaking given many of the networks were designed with different approaches and for different purposes. The challenge going forward will be to effectively leverage the existing networks and integrate the diverse data sets.

One of the points discussed at the meeting was whether an inventory of available soil moisture data should be completed. The inventory would include what data are being collected, how they are being stored, and how people are using the data. Currently the most extensive inventory of available data is the North American Soil Moisture Database (NASMD). The NASMD identifies several sources of in-situ soil moisture data for the U.S., Mexico and Canada, collects station metadata from all sites, quality controls the data, and generates gridded soil moisture products. The NASMD includes national, regional, state and local networks. It also includes in-situ soil moisture data collected during field campaigns and research projects. An inventory would utilize the NASMD but would also assess private and citizen science data, along with other data types such as modeling and remotely sensed data, and incorporate information on how the data are being used for research and decision-making.

Hydrologist Tom Jackson and student Parmecia Jones use different methods to test soil moisture. USDA photo

Table 2: Soil moisture products

Possible requirements and examples of products discussed during the 2016 workshop.

Requirements:

- Temporal scales: Weekly, monthly, daily
- Spatial scales: Hydrologic Unit Code, census, state/county
- In situ Depths (cm): 2,5,10, 20,50,100
- Contextual data: SSURGO points, land cover, bench mark soils, National Hydrography Dataset, state, county
- All raw data behind maps should be available: time series, water year, etc.
- Data search features: state, basin, station, time periods, network, format

Monitoring and Forecast Products:

- Volumetric water content
- Percent saturation
- Soil temperature daily average max, min
- Station map using U.S. Drought Monitor color scheme (e.g. weekly averaged percentiles)
- Percent of normal gridded and point product
- Probabilistic gridded product (e.g. non-exceedance probability)

Assimilating soil moisture data and the data formats needed for both input and output will need to be considered in any strategic framework. Ideally, data providers could take a standardized approach, including common data formats such as CSV and tab-delimited formats. Output formats would be more diverse and could serve a variety of platforms such as ArcGIS, NetCDF, or WaterML 2.0. Archiving the raw data is another area the strategic framework would need to incorporate.

Soil Moisture-Related Products

The discussion of potential soil moisture products was expansive and covered general CONUS-wide products down to specific tools that could improve decision-making for specific sectors such as agricultural producers. Most participants agreed a high-resolution gridded product that leverages multiple networks and platforms is needed. That product could serve

Appendix 1: National Soil Moisture Network Workshop Agenda

The meeting took place May 24 - 26, 2016 at the David Skaggs Research Center, 325 Broadway, Boulder, CO 80305. Presentations from the meeting can be viewed at https://www.drought.gov/drought/calendar/events/national-soil-moisture-network-workshop.

GOALS AND OBJECTIVES

- ✦ Communicating and coordinating soil moisture monitoring and assimilation activities across the federal landscape with states and other interests, including the private sector.
- ✦ Providing an update on the progress made thus far on a Coordinated National Soil Moisture Network. Reporting on the findings from the NSMN pilot work.
- ✦ Crafting a future direction and approach for a coordinated NSMN. Identifying the next steps, addressing who will be involved, and how and what needs to be accomplished. Identifying short-term, medium- term, and long-term goals of coordinating a NSMN.

DAY 1: TUESDAY, MAY 24, 1:00 PM

Welcome & Introduce Meeting Objectives

Session 1: Background & Update

- November 2013 workshop and framework for a National Soil Moisture Network
- National Drought Resiliency Partnership and goals of NIDIS
- NSMN Pilot Study design and outcomes
- Pre-Workshop Survey Results Review

Session 2: Public sources of information and their application

- In situ networks: SCAN, CRN, NASMD, National Mesonet
- Remote sensing: SMAP, SMOS, GRACE
- Modeling: NLDAS, NASA SPoRT

Session 3: Private and grass root sources of information

- Private industry
- Citizen science: GLOBE, CoCoRaHs, SciStarter

DAY 2: WEDNESDAY, MAY 25

Session 4: Panel - Users of soil moisture information, part 1

- U.S. Drought Monitor
- Climate science
- Drought assessment
- Climate Hubs

Session 4: Panel - Users of soil moisture information, Part 2

- Water Census
- River forecasting
- Human Health
- Industry
- Others

Session 5: Small Group Facilitated Discussion: Identifying gaps & needs

- Identifying gaps in available data and information products
- Identifying temporal and spatial
- Brainstorm how existing data sets could be leveraged or integrated to fill gaps and meet needs
- Vote & prioritize information products

Session 6: Lessons learned from other programs and networks

Session 7: Small Group Facilitated Discussion: Collaboration, funding & data integration

- Collaboration models
- Funding models
- Data integration strategies

Group reports

Session 8: Data format

- Standards and specifications for networks
- Telemetry
- Web services
- Spatial and temporal frequency
- Soil science

Group reports

DAY 3: THURSDAY, MAY 26

Session 8: Small Group Facilitated Discussion: Gathering requirements for the Network

- Describing preferred data access formats and method
- Describing preferred data access frequency & access methods
- Brainstorming ways of presenting and visualizing soil moisture data
- Vote & prioritize network requirements

Group reports

Session 9: Next steps

- Identifying goals for the network
- Forming work group(s) to develop a framework for the network

as a foundation and give a CONUS-wide picture of soil moisture. Other suggestions included a map of all applicable soil moisture-monitoring stations in percentiles that correspond to the U.S. Drought Monitor categories. Agriculture and range managers could use estimates of plant-available water, which could be based on stations or a gridded estimate. A model currently exists with the Oklahoma Mesonet (e.g. 1-day average 16 in. Plant Available Water). In addition to new data products there are existing information sources such as remotely sensed and modeled data that could help contextualize soil moisture data. Table 2 shows the larger list of potential products discussed.

Two ideas were put forward for follow-up: developing a community of practice or clearinghouse of who is working on soil moisture data and products; and conducting workshops with users of soil moisture data such as range and crop producers, university extension agents, reservoir operators, fire managers, etc. Building a community of practice would involve organizing the institutions focused on conducting research around soil moisture, monitoring soil moisture conditions, and building information products for decision-makers. Much of this information is already contained in the North American Soil Moisture Database that is administered by Texas A&M University and supplementing this existing database could be accomplished fairly quickly. Finally, a set of workshops focused on individuals or institutions that rely on soil moisture data would help focus the discussion around what data products are useful and effective for decision-making. Ideally these discussions would incorporate research program managers, which could inform subsequent grant solicitations.

Conclusions and Next Steps

The discussion at the conclusion of the workshop focused on three elements of a coordinated and integrated National Soil Moisture Monitoring System. These elements are: 1. Improve collaboration through incentives and partnerships; 2. Develop a consistent methodology for data collection and installation of in-situ probes including metadata standards; and 3. Develop a national multi-platform soil moisture gridded product that could serve as a first-order data and information source as well as a platform for the development of derivative or secondary soil moisture products.

More specifically, activities to address these three themes could include:

- **Develop a soil moisture community of practice (CoP) that includes soil moisture data providers, groups that are developing products and tools, and users of the data and information.** The CoP would include citizen science initiatives and the private sector. Specific activities could include a "sensor challenge" for developing low-cost soil moisture/soil temperature probe alternatives, and developing case studies that highlight different approaches for integrating multiple sources of soil moisture data for specific issues and sectors.
- **Establish a working group to begin the process of developing a strategic framework for building an integrated national network.** The framework would consider issues around standardizing soil moisture measurements and metadata requirements, scale and spatial distribution for monitoring in observing networks, remote sensing platforms, and modeling efforts.
- **Develop a nationwide product from existing soil moisture data to demonstrate the potential usefulness of a coordinated effort.** The product and the investment of time by individuals who collect, process and store these data would guide how the process could be integrated on a broad spatial and temporal scale.

Appendix 2: Workshop Participant List

Travis Andersen
The GLOBE Program
andersen@ucar.edu

Andrew Badger
CIRES
andrew.badger@colorado.edu

Jesse Bell
CICS-NC/NOAA
jesse.bell@noaa.gov

Courtney Black
NIDIS
courtney.black@noaa.gov

Clay Blankenship
NASA-MSFC SPoRT (USRA)
clay.blankenship@nasa.gov

Kathy Bogan
NIDIS
kathleen.bogan@noaa.gov

Mark Brusberg
US Department of Agriculture
mbrusberg@oce.usda.gov

Jordan Clayton
NRCS-Snow Survey
jordan.clayton@ut.usda.gov

Doug Cobos
Decagon Devices/Washington
State University
doug@decagon.com

Mindy Conyers
Texas Water Development Board
mindy.conyers@twdb.texas.gov

Nolan Doesken
Colorado Climate Center /
Colorado State
University
nolan@atmos.colostate.edu

Thomas Evans
US Army Corps of Engineers
(HEC)
thomas.a.evans@usace.army.mil

Dave Gochis
NCAR
gochis@ucar.edu

Earl Greene
USGS
eagreene@usgs.gov

Kevin Grode
U.S. Army Corps of Engineers,
Missouri
River Basin Water Management
kevin.r.grode@usace.army.mil

Christopher Hain
University of Maryland / NOAA
chris.hain@noaa.gov

Laura Harding
Geospatial Research Laboratory
/ Penn
State University
laura.e.harding@usace.army.mil

Deborah Harms
USDA-NRCS- National Water and
Climate
Center
deb.harms@por.usda.gov

Adrian Harpold
University of Nevada, Reno
aharpold@cabnr.unr.edu

Paul Heppner
Global Science & Technology
pheppner@gst.com

Eric Hunt
Nebraska State Climate Office
ehunt2@unl.edu

Eric Jones
NOAA/NWS/ABRFC
eric.jones@noaa.gov

Logan Karsten
NCAR
karsten@ucar.edu

Sujay Kumar
NASA GSFC
Sujay.V.Kumar@nasa.gov

Patrick Lambert
WestFAST/USGS
plambert@usgs.gov

Jessica Lucido
U.S. Geological Survey
jlucido@usgs.gov

Alicia Marrs
NOAA/NIDIS
alicia.marrs@noaa.gov

Chad McNutt
NIDIS
chad.mcnutt@noaa.gov

Tilden Meyers
NOAA/ATDD
tilden.meyers@noaa.gov

David Mocko
SAIC at NASA/GSFC
David.Mocko@nasa.gov

Tyson Ochsner
Oklahoma State University
tyson.ochsner@okstate.edu

Ming Pan
Princeton University
mpan@princeton.edu

Andres Patrignani
Kansas State University
andrespatrignani@ksu.edu

Todd Pett
Ball Aerospace & Technologies
Corp
tpett@ball.com

Richard Pouyat
OSTP
rpouyat@ostp.eop.gov

Steven Quiring
Texas A&M University
squiring@tamu.edu

Christopher Redmond
Kansas State University
christopherredmond@ksu.edu

Leonardo Rivera
Decagon Devices, Inc.
leo@decagon.com

Melanie Russ
UCAR/JOSS
melanie@ucar.edu

Lee Schmelzer
MSU Extension
lees@montana.edu

Cathy Seybold
USDA-NRCS
cathy.seybold@lin.usda.gov

Nicholas Silverman
Montana Climate Office
nicholas.silverman@umontana.
edu

Ravi Sripada
The Climate Corporation
Ravi.Sripada@climate.com

Jenna Stewart
University of Colorado
jenna.r.stewart@colorado.edu

Michael Strobel
USDA Natural Resources
Conservation
Service
michael.strobel@por.usda.gov

Kent Sutcliffe
USDA-NRCS
kent.sutcliffe@ut.usda.gov

Mark Svoboda
National Drought Mitigation
Center
msvoboda2@unl.edu

Sterling Elwynn Taylor
Iowa State University
setaylor@iastate.edu

Dennis Todey
State Climate Office/South
Dakota State
University
dennis.todey@sdstate.edu

Michael Wilson
USDA-NRCS
mike.wilson@lin.usda.gov

Youlong Xia
Environmental Modeling Center,
National
Centers for Environmental
Prediction,
NOAA
Youlong.Xia@noaa.gov

Robert Zamora
NOAA/ESRL Physical Sciences
Division
robert.j.zamora@noaa.gov