Developing a Coordinated National Soil Moisture Network

Findings from meeting in Kansas City, Missouri, Nov. 13-14, 2013

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Introduction

Recognizing the long standing need to improve the integration of soil moisture data and information across the United States, a group of federal, state, and academic experts met to discuss approaches for developing a coordinated national soil moisture network. The meeting was hosted by the National Oceanic and Atmospheric Administration (NOAA) in Kansas City, Missouri, November 13-14, 2013. This white paper provides a brief description of the meeting and an account of the discussions that addressed ways to assess federal and state in situ monitoring networks, satellite remote sensing missions, numerical modeling capabilities, and experiences in soil moisture database integration and user access, and how to merge these capacities into a new network of networks providing a comprehensive national view of soil moisture as a terrestrial climate variable.

Background

Nace and Pluhowski (1965) noted in their assessment of the 1950's southern Plains drought that soil moisture is a major factor in the water economy, and its function usually is overlooked in assessments of water use and future water demand. Nearly 50 years since that report, soil moisture observations, while now recognized as being critically important, are still not well integrated into assessments of vulnerability to droughts and floods, nor into monitoring for early warning of these threats.

In the U.S., soil moisture observations are made in two ways, either directly with in situ instruments, or indirectly using terrestrial or space borne remote sensing instruments. Additionally, soil moisture variations in space and time are simulated by numerical modeling of land surface physical processes. Each approach has strengths and weaknesses, and each was designed and has evolved to meet specific purposes and goals.

Observations

In situ Observations

There are numerous in situ instrument networks in the U.S. that continuously measure soil moisture and soil temperature. NOAA operates the Climate Reference Network (CRN) which has 114 stations at 107 locations across the contiguous U.S. and 16 in Alaska, Hawaii and Canada. The Natural Resources Conservation Service (NRCS) has managed the Soil Climate Analysis Network (SCAN) since 1991 and has 200 stations across the U.S. and in Puerto Rico and U.S. Virgin Islands. Many states, including Oklahoma, Nebraska and parts of Texas, operate mesonet systems that provide extensive in situ measurements within their states. A synopsis of most soil moisture networks is available from the North American Soil Moisture Database (NASMD: http://soilmoisture.tamu.edu/) provided by Texas A&M University. In general, in situ networks provide accurate measurements of soil moisture and soil temperature at depths up to 100 cm for specific sites.

Although many local and regional meteorological and hydrological networks routinely measure soil moisture, the lack of standard measurement techniques and protocols complicates the use of network data. As a result, there are many differences between the networks such as measurement depth, units of soil moisture, sampling interval, and precision. Some states have dense coverage, but from a national perspective, there are many gaps in the spatial distribution of observation stations.

Remote Sensing Observations

Remote sensing observations of soil moisture are made by a number of different agencies. NOAA conducts soil moisture remote sensing through both microwave and thermal infrared observations and provides a number of products that show spatial information across the country. In 2014, NASA will launch the Soil Moisture Active/Passive (SMAP) satellite for a 3-year mission to provide global measurements of soil moisture and its freeze/thaw state. SMAP is designed to make measurements of surface emissions and backscatter, with the ability to measure the soil conditions even in the presence of partial vegetation cover. On the ground, the Cosmic-Ray Soil Moisture Observing System (COSMOS) is operated by the University of Arizona and determines average soil water content by measuring the flux of low-energy cosmic-ray neutrons above the land surface.

Modeling

The North American Land Data Assimilation System (NLDAS), developed by the National Aeronautics and Space Administration (NASA) and NOAA provides multi-model simulated soil moisture spatial representations of soil moisture anomalies and percentiles.

Models and remote sensing data provide spatial coverage of soil moisture for the U.S., but have coarse resolution. Typically models only model near-surface soil conditions, and need to be calibrated with in situ measurements. In situ observations will be crucial for improving the products coming out of these efforts and will need to be available for a large number of sites worldwide representing a wide range of climatological conditions and land cover characteristics.

Key findings from the Kansas City Workshop

Conclusions and findings from the workshop have been grouped into two key categories, which reflect the differences among the networks, such as the instrument resources, the purpose of the network, and its ongoing support. While not specifically described below, it is implicit that an increase in the number of monitoring sites would improve the overall depiction of soil moisture.

For this assessment, however, the discussion focused mostly on current soil moisture networks and data and ways to improve the calibration and validation of soil climate variables, improving metadata and site descriptions associated with each monitoring site, and approaches for integrating data from the diverse range of existing and future networks.

Improving Metadata and Calibration and Validation of Soil Moisture Data

Soil moisture can mean different things depending on the question being asked and the perspective of the user. For example, an agricultural producer might think of soil moisture in terms of the root zone, while a user of satellite derived data might only consider the first few centimeters. It is not possible to develop one definition for all uses of soil moisture data given the diverse communities that currently use soil moisture data. To develop a truly integrated system that can meet a diversity of needs we must recognize the different perspectives and uses for the information while capturing how the data were acquired in the form of site-specific metadata. This would include soil texture, vegetation type and condition, hydraulic conductivity, organic matter, and soil bulk density.

In addition to having good metadata for each site, every monitoring network should have detailed descriptions of the calibration and validation procedures for the soil moisture measurements. Standards are needed across networks for soil moisture monitoring such as acceptable error ranges, how sensors are installed, what probes are used, and how data quality is maintained. Improving standardization will allow for more confident intercomparison and informed blending of in situ observations from different networks.

Data Integration

With so many existing networks and data sources it can be difficult for a user to determine the best data or network to draw on especially if the data are not integrated through a common system. At the same time, integrating data from multiple networks is not a straightforward proposition since many of the networks were designed for different purposes. The challenge going forward will be to leverage (while not duplicating) the existing networks and integrating diverse data sets from networks that were designed with different purposes in mind.

At the workshop examples of other data integration efforts were discussed. Most notable was the North American Soil Moisture Database (NASMD). The NASMD identifies multiple 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. At present, meta-data has been developed for all of the stations including sensor, soil characteristics, surface vegetation, and details on instrument calibration. The goal of the NASMD is to provide an integrated database of historical soil moisture data and has been targeted to the research community. The effort is primarily funded through the National Science Foundation and therefore it lacks a long-term funding stream and was not intended to be a near-real-time operational system.

Two other models for national data integration were also discussed at the workshop. These include the National Ground-Water Monitoring Network (NGWMN) and the Water Quality Portal (WQP) that was developed by the National Water Quality Monitoring Council. The NGWMN and the WQP vary in their approach in that the former is more of a distributed, “grass roots” network, while the latter is more of a “top-down” approach. The purpose of the NGWMN is to create a single accessible data portal that could communicate groundwater levels, groundwater quality data and associated lithology, and well construction information from several database sources in real-time. The advantages of the more distributed NGWMN are that data providers maintain ownership, the data are stable and reliable, and it has advanced querying capabilities, re-usable back end web services, and on-the-fly transformation. However, the NGWMN is network and processing intensive, the data are not integrated in real-time, and there is a significant initial set-up effort for each provider.

The WQP integrates publicly available water-quality data from the USGS National Water Information System (NWIS) and the EPA STORET (STOrage and RETrieval) Data Warehouses from over two million monitoring locations. The advantages of the system are that it has a small number of data providers, it offers single end-point data access, it has advanced querying capabilities, and it has a full service application programming interface. Disadvantages of the WQP are that it is network intensive, data quality control can be difficult, and the data must be provided in a standard format.

Conclusions and recommendations

Being highly variable in space, depth, and time, soil moisture monitoring is a difficult undertaking, in many ways more complicated than monitoring atmospheric variables because there is such a diversity of 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/validation practices and metadata characterization, and effectively leverages the full variety of existing networks and modeling efforts. With these ideas in mind, participants at the workshop suggested several next steps to move forward. They included:

- ♦ Establishing a working group to discuss issues of scale and spatial distribution for monitoring in observing networks, remote sensing platforms, and modeling efforts, and metadata needs at minimal and optimal levels;
- ♦ Developing a nation-wide 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 will guide how the process could be integrated at a broad spatial and temporal level;
- ♦ Piloting a soil moisture monitoring system for a small number of regions that would integrate all available soil moisture data types and assess how the data would be used by researchers, Federal and State agencies, as well as specific sectors (e.g. agricultural producers)

REFERENCES

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