The USDA Natural Resources Conservation Service Soil Climate Analysis Network (SCAN)

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ABSTRACT

Surface soil moisture plays an important role in the dynamics of land–atmosphere interactions and many current and upcoming models and satellite sensors. In situ data will be required to provide calibration and validation datasets. Therefore, there is a need for sensor networks at a variety of scales that provide near-real-time soil moisture and temperature data combined with other climate information for use in natural resource planning, drought assessment, water resource management, and resource inventory. The U.S. Department of Agriculture (USDA)–Natural Resources Conservation Service (NRCS)–National Water and Climate Center has established a continental-scale network to address this need, called the Soil Climate Analysis Network (SCAN). This ever-growing network has more than 116 stations located in 39 states, most of which have been installed since 1999. The stations are remotely located and collect hourly atmospheric, soil moisture, and soil temperature data that are available to the public online in near–real time. New stations are located on benchmark soils when possible. Future plans for the network include increasing the number of stations, improving on user-friendly data summaries, increasing data quality, and scaling the stations to the surrounding region.

1. Introduction

Soil moisture, soil temperature, and associated atmospheric measurements are critical parameters for many applications, including continental-scale climate models, soil classification, and drought and flood assessments. The Soil Moisture/Soil Temperature (SM/ST) Pilot Project was proposed in 1990 to test the feasibility of establishing a national soil–climate monitoring program that meets the growing demands of the global climate change community, modelers, resource managers, soil scientists, ecologists, and others.

The U.S. Department of Agriculture (USDA)–Natural Resources Conservation Service (NRCS) is the leader of a cooperative nationwide, comprehensive soil moisture and climate information system designed to support natural resource assessments and conservation activities into the future. The Soil Climate Analysis Network (SCAN) focuses on the agricultural areas of the United States. The system currently comprises 129 stations located in 39 states and Puerto Rico. These data and analysis note serve as an introduction to the SCAN data products and to encourage their use in research and decision-making.

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2. Network summary

a. Network description

The ability of NRCS and its partners to make sound resource assessments and watershed decisions has been severely limited by the lack of high quality, historic, and real-time soil–climate information. Existing data from other networks are essentially inadequate for most purposes because they tend to be application specific, short-term, incomplete, or limited in area of coverage; include nonstandard sensor arrays; or are difficult to obtain. The NRCS has operated the national SM/ST Pilot Project since 1991. Significant experience has

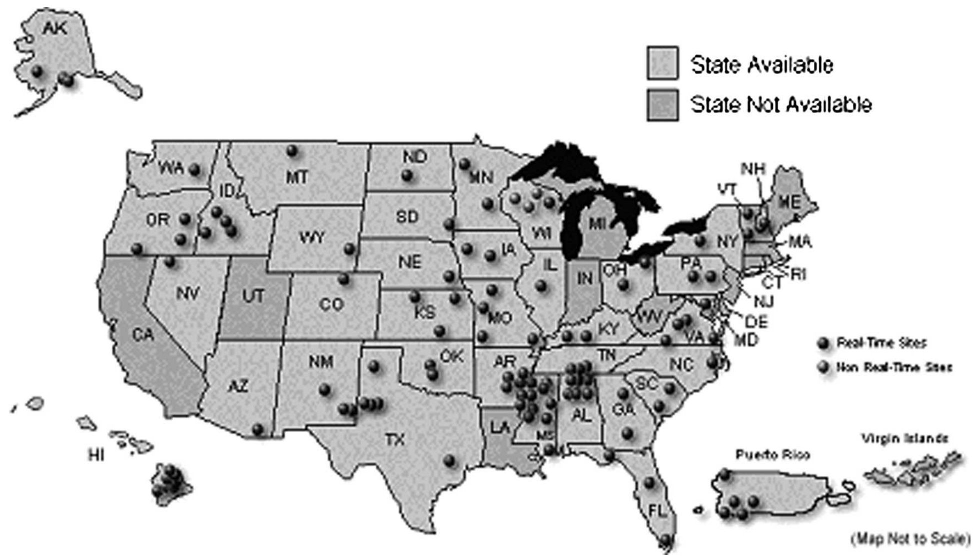

FIG. 1. Current map of 129 SCAN stations in the United States. States that do not have SCAN stations at this time are denoted by the dark gray shading.

been gained in the management of SCAN, including sensor selection, network operation, quality control, product analysis, and technology transfer of information to the user community. SCAN used this experience to build, operate, maintain, and develop products that its customers require in order to make sound resource management decisions. SCAN has overcome many of the above-mentioned problems, ensuring standard sets of sensors and making the data available to users via the Internet in near–real time.

Starting in 1999, with support and financial assistance from the USDA–Agricultural Research Service (ARS) and the USDA–World Agricultural Outlook Board, Joint Agricultural Weather Facility, SCAN was established. It incorporated the existing 21 SM/ST stations the first year and installed an additional 9 stations on ARS watersheds around the country. The network has expanded each year with cooperator and NRCS funding. Figure 1 shows the current SCAN stations.

The standard SCAN station configuration has remained relatively consistent since 1999, with minor changes for station-specific user requests. An example of a standard installation is shown in Fig. 2, which is SCAN site 2049, located in Beltsville, Maryland. The SCAN network is made up of the original 21 SM/ST Pilot Project stations, with many being upgraded to the standard SCAN configuration, and some research stations, which have additional sensors not typically found on SCAN sites. Table 1 identifies the type of sensor packages that are included on most SCAN stations. Figure 3 shows an example of the soil moisture profile data for one location (2049) for the life of the installation. These data are hourly; however, there are several gaps due to instrument failure during 2003 that are associated with a lightning strike.

Additional sensors were added to some of the SCAN stations to support local needs. On seven stations in the north-central and eastern United States, snow pillows and snow-depth sensors have been added to measure snow water content and snow depth. These sensors are critical to assist with the predication of surface water runoff and flood forecasting. Research stations typically have the same sensor suite as a SCAN station and additional sensors used for specific investigations. Table 2 lists most of the major additional sensors used on the research stations. Some or all of the sensors listed may be associated with a station. Another ex-

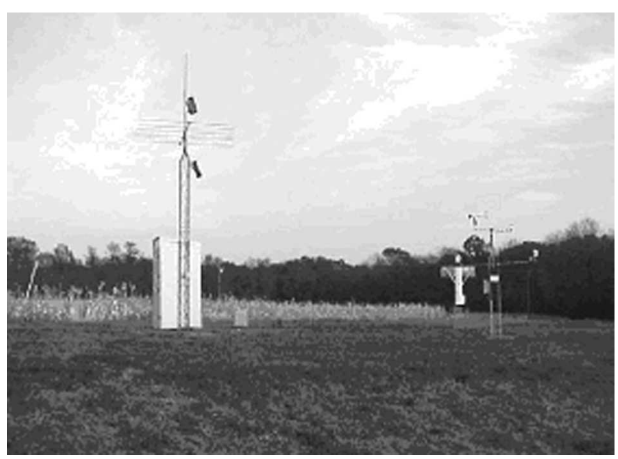

FIG. 2. SCAN station 2049 in Beltsville, MD.

TABLE 1. Parameters measured at many SCAN stations and their descriptions.

Parameter measured	Description	Accuracy and units
Air temperature	Collected by a shielded thermistor	±2°C
Relative humidity	Collected by a thin-film capacitance-type sensor	±2%
Wind speed and direction	Collected by a propeller-type anemometer	±3 mph and 355°
Solar radiation	Collected by a pyranometer	5% of signal (W m^{-2})
Barometric pressure	Measured by a silicon capacitive pressure sensor	Inch of Hg
Dielectric constant	Measured by a dielectric probe	±0.2 (unitless)
Conductivity		±0.002 dS m^{-1}
Soil moisture	Collected by a dielectric constant measuring device; typical measurements are at 2, 4, 8, 20, and 40 in. where possible	±0.03 m^3 m^{-3} volumetric soil moisture
Precipitation	Collected by storage gauge or tipping-bucket	±0.01 in.
Soil temperature	Collected by an encapsulated thermistor; typical measurements are at 2, 4, 8, 20, and 40 in. where possible	±0.6°C

ample of local modifications to the SCAN network is the Alabama Mesonet (Tsegaye et al. 2005). A total of 12 SCAN stations are distributed in northern Alabama and southern Tennessee to complement the mesonet, which consists of 11 additional stations. This configuration was motivated by the 2003 Soil Moisture Experiment (SMEX03) (Jackson et al. 2004).

The SCAN network, when fully deployed, would consist of approximately 2000 stations: 1000 new stations and approximately 1000 existing stations operated by other entities. The cooperator stations would be upgraded to meet SCAN standards in order to provide a full spectrum of climate information to users. Proper siting of the new SCAN stations is critical to ensure representative spatial coverage for the agricultural regions of the United States.

The selection process for identifying station locations must involve the states to help ensure that proper areas are represented. The local NRCS State Office staff provide valuable information required to implement SCAN within the state. It is envisioned that the state resource conservationist, state soil scientist, state range specialist, and other local field office staff will be involved in the ultimate selection of station locations. The local state climatologist, drought coordinator, and other state and local government officials provide key information on critical areas of the state that require monitoring. They guide the selection process to ensure that a site represents a predominant climate regime. Station locations are selected based on several criteria, including NRCS National Benchmark Soils, land ownership (federal, state, county, or university land), whether nonirrigated, whether agricultural in nature, and station security. The first stations to be installed were located in areas that were susceptible to drought. When installed, full soil characterization was conducted (soil pedon information is available online at http://www.wcc.nrcs.usda.gov/scan/).

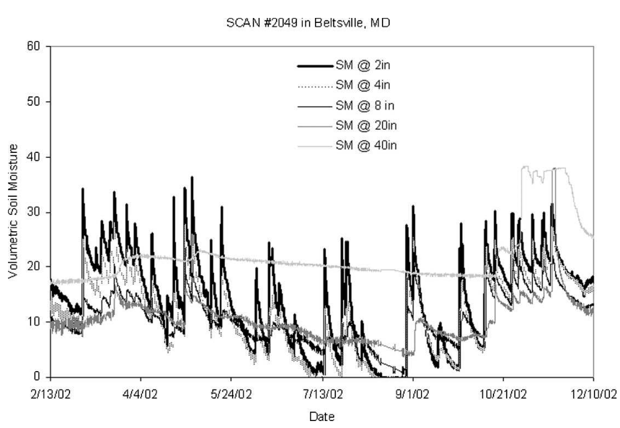

FIG. 3. Time series of SCAN station 2049 in Beltsville, MD.

b. *Station maintenance*

With any network, maintenance is a very critical component to preserve data quality. From the beginning of the Pilot Project, station maintenance was a major concern. Currently, typical station maintenance for SCAN is scheduled annually when possible. The scheduled maintenance includes fixing sensor problems and completing preventive steps. Inadequate funding and the limited number of personnel continue to restrict the implementation of a fully adequate maintenance schedule for all stations. The bulk of the maintenance is performed by National Water and Climate Center (NWCC) or National Soil Survey Center staff.

c. *Data acquisition*

The SCAN system utilizes meteor burst communication technology or a line-of-sight (LOS) system, which

TABLE 2. Additional parameters measured at SCAN research stations.

Parameter measured	Description	Accuracy and units
Pizometer	Water level	±0.1 in.
Redox	Measurement of oxygen reduction potential	Varies
Soil temperature	Additional soil temperature measurements by different devices	±2°C
Water quality	Water temperature, pH, turbidity, biological oxygen demand, and conductivity	Varies
Surface soil temperature	Typically measured by an infrared sensor	±2°C

is connected to a datalogger to acquire remote station data (Schilling 1993; Schaefer and Sytsma 2001). Meteor burst communication was developed by the military in the 1950s, but no effective system was implemented until NRCS and its contractors developed Snowpack Telemetry (SNOTEL) in 1975. Meteor burst communication uses the billions of sand-sized particles (1 g or larger) that burn up in the 50–80-mile-high region of the atmosphere to relay radio signals back to the earth. This technique allows communication to take place between remote sites and a master station as far as 1200 miles away. Upon entering the earth's atmosphere, the particles burn up and leave an ionized gas trail behind them. This gas trail enables very high frequency (VHF) radio signals in the 38–50-MHz range to reflect, or reradiate, signals back to the earth. These signals generate a communications footprint on earth and, if the remote sites located in the footprint hear the master station signal, they will transmit their data back to the master station. At the master station, the remote site data are checked for completeness. If the data are complete, an acknowledgment message is sent back to the remote site, along the same path, telling the remote site not to transmit again until new data are ready to be transmitted. All three transmissions take place in less than a tenth of a second. A datalogger is connected to the meteor burst radio and is responsible for the collection and processing of the sensor data. Data are summarized and transferred hourly to the radio for transmission.

Meteor burst communication has proven to be extremely reliable for data acquisition purposes and supports the SCAN need for hourly data. The LOS system, which uses the identical equipment that is used for meteor burst SNOTEL system performance, has improved over the years. Much of this improvement is the result of agency electronic maintenance technicians and managers becoming knowledgeable on how to optimize the performance of remote sites, maintaining the master station, and improving the hardware and software. Response averages more than 98% for all remote sites reporting data at midnight; the less than 2% failure is generally related to some electronic failure, not to a meteor burst communication failure.

d. Station power and grounding requirements

The SCAN stations are designed to be located where they are needed. The entire station is powered by solar panels and batteries. The sensor package that is chosen for SCAN requires very little power, thus allowing for the stations to be located where they are needed, rather than compromised by having to be located near commercial power facilities. Solar panel and battery technology has changed over the years. Larger solar panels and increased efficiency have helped to overcome most power concerns. Battery technology has also advanced. Batteries are charged by solar cells and are more efficient than batteries manufactured in the past. Proper determination of station power requirements is critical to maintain system performance and ensure good sensor data.

Station grounding has improved over the years. Proper grounding is critical for the datalogger to operate properly and to ensure good sensor data. The radio and antenna make up a ground-based system that requires good grounding to maintain communications between the remote station and the master station. Lightning damage to the remote stations has not been frequent, but there has been occasional interruption in the data stream. Improved grounding has allowed some of the more lightning prone stations to continue operation without any problems with lightning.

3. Data access

SCAN data are available hourly from the NWCC home page (http://www.wcc.nrcs.usda.gov/scan). Each remote station should respond with hourly data at the top of each hour. From the top of the hour to when the data are posted to the Internet archive is typically 30 min. On arriving at the NWCC, the data are screened for the limits of the sensors, and obvious errors are flagged. Additional automated data screening is envisioned in the future to assist with data quality. Some of these automated data-screening techniques will be rate of change for air temperature, rate of change for precipitation, etc.

Specialized reports can be requested for specific stations and period of record via e-mail. New reports that will provide easier retrieval of station data are planned. Station metadata files are currently being worked on for each station. These metadata will include sensor history, calibration, station pictures, and maintenance history.

4. Data quality

The real-time data that are available online are provisional and subject to change. The NWCC recognizes the value of these data but would like users to note that these data should be taken with caution. One data editor examines the data weekly and edits obvious sensor problems. These edits will be in the historical data files, which are also accessible via the Internet. The data editor identifies problems that require maintenance visits, and the NWCC schedules station repairs based upon these identified problems. However, less obvious errors may still remain undetected, and some examination of the datasets needs to be conducted before use.

The NWCC over the years has supported several independent analyses on the SCAN data. The University of Idaho, the ARS, and the NWCC conducted an investigation of the soil moisture sensor used in the network (Stevens Water Hydra Probe) to see how consistent the soil moisture sensors were and how they behaved in known soil-water concentrations (Seyfried et al. 2005). This study demonstrated the reliability of the Hydra Probe sensors. They have been used in SCAN since 1995 and have provided reliable soil moisture and soil temperature information.

5. Future of the network

The SCAN network has grown quickly over the years, and its popularity and usefulness has grown exponentially. The number of data downloads has risen dramatically. In 2005, there were over one million downloads of SCAN data. The number of requests for new stations has exceeded the NWCC ability to fund, install, and maintain the network. The uses of the data continue to grow as well. The main purpose for establishing the network was to assist agriculture with resource decision-making and develop tools to assess crop production, and disease and pest control, and to mitigate drought affects by reducing the risk involved. Additional uses have been found for this type of network as well. The pipeline industry and fiber-optic cable companies are using the information to determine freeze depths and how far they can locate transmission buster stations. The need for reliable and readily available soil moisture and soil temperature information nationally has been demonstrated by the number of users obtaining SCAN data. A larger network with new stations and partnered stations would provide this type of national coverage. To date, half of the funding for SCAN has come from cooperators.

New research has begun on development of a tool that will integrate SCAN data with soils information and spatially distributed soil moisture. The development of the science to accomplish this task is critical to be able to provide information about soil moisture conditions nationally. The work is expected to be complete within three years. If this is successful, with a full implementation of SCAN in the United States, it will be possible to identify potential drought areas and predict where future drought conditions could appear.

While the future of the network is still uncertain, unless a more stable funding source is found, one thing is certain: SCAN has a valid role to play in integrating soil–climate monitoring. No other system exists in the United States that provides this kind of information.

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