The U.S. Department of Agriculture's Natural Resources Conservation Service Soil Climate Analysis Network

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Abstract

There is a need for a national network that provides 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. In 1991, a 10-year pilot project was started to test the feasibility of such a network. Initially, 21 stations were established in the pilot project. Over the span of the project, an array of above ground and below ground sensors were tested along with a unique meteor burst communication system. This pilot led to the development of the Soil Climate Analysis Network (SCAN). The network now has 115 stations, of which most have been installed since 1999, located in 39 states. The stations are remotely located and collect hourly atmospheric and soil moisture and temperature data that is made available to the public via the Internet. Future plans for the network include locating new stations on benchmark soils, increasing the number of stations, making data summaries more user-friendly, and increasing data quality.

Introduction

The SCAN is a network of soil climate monitoring stations located across the United States. The network was first initiated in 1991 as a pilot project (USDA-NRCS, 2004). The goal of the project was 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. Soil water status, soil temperature, and associated atmospheric measurements were identified as critical parameters for many applications such as continental-scale climate models, soil classification, and drought and flood assessments. In the first year, 21 soil moisture and temperature (SM/ST) stations were installed and, later, 9 stations were added in watersheds around the country in cooperation with USDA's Agricultural Research Service (ARS). In 1999, SCAN was officially started with support and financial assistance from the USDA's ARS and the USDA's World Agricultural Outlook Board, Joint Agricultural Weather Facility. The network was designed to be a cooperative nationwide effort, with the Natural Resources Conservation Service (NRCS) as the leader. The main focus of SCAN was on agricultural areas of the United States.

The current network is comprised of 113 stations, which are located in 39 states (Figure 1). Under the proposed full implementation of SCAN, more than 1,000 new remote sites would be added (USDA-NRCS, 2004). This would be accomplished by (1) integrating information from existing soil-climate data networks and (2) establishing new data collection points through partnerships with Federal, state, local, and tribal entities. This design will support natural resource assessments and conservation activities well into the 21st century; however, the full implementation of SCAN is dependant upon additional funding.

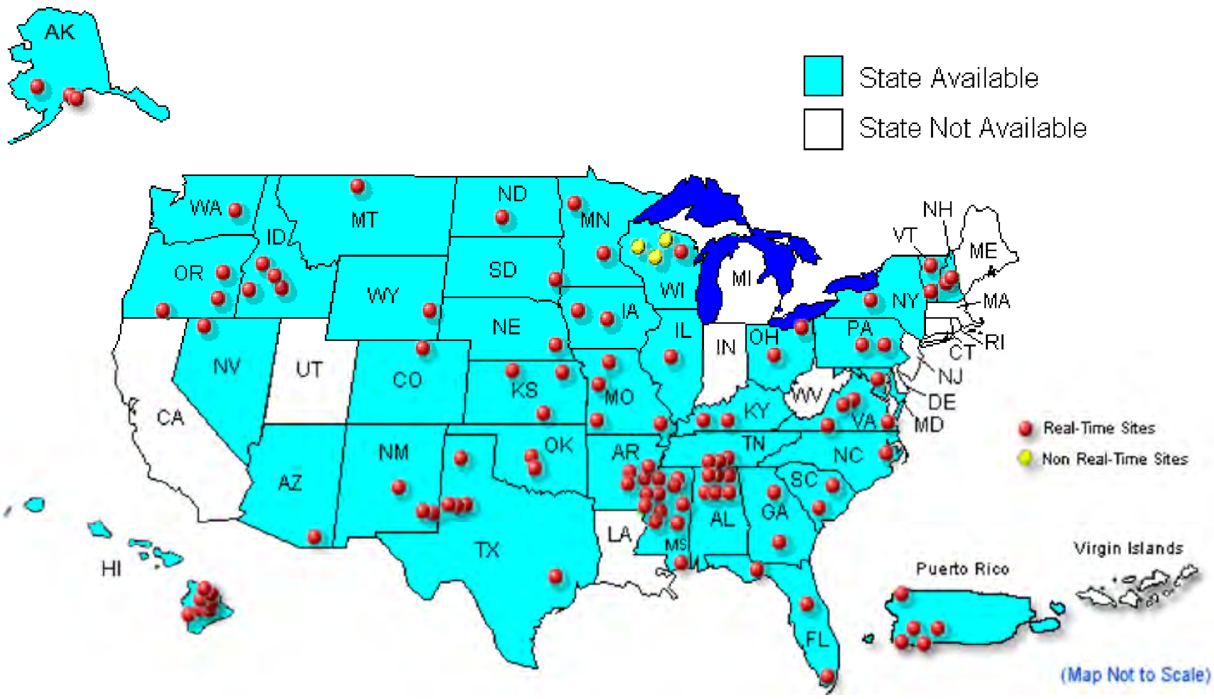

Figure 1. Location of soil climate analysis network stations.

Most other networks have been severely limited by the lack of quality for historic and real-time soil-climate information. Also, existing data from other networks are essentially inadequate for most purposes since they tend to be application specific, short-term, incomplete, or limited in area of coverage; often include nonstandard sensor arrays; and typically are difficult to obtain. SCAN has overcome many of those problems, ensuring standard sets of sensors and making the data available to users via the Internet in near real-time. Since the inception of the pilot project in 1991, significant knowledge and experience have been gained in the type of sensors used, maintenance, station network operation, quality control, product analysis, and dissemination of information to users. This experience has been used to build, operate, maintain, and develop products that our customers require in order to make sound resource management decisions. The objectives of this paper are to describe the current network and its future.

Soil Climate Analysis Network

Siting Criteria

The location of monitoring sites varied from place to place, depending on the objectives or purpose of the station. For example, in the eastern United States, 10 sites were established to test the communication range of the meteor burst master station. In the western United States, sites were established to collect additional information to accurately characterize soil moisture and temperature regimes in drought susceptible soils.

The local NRCS state office staff provided valuable information required to implement SCAN in their state. It is envisioned that the NRCS 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 can provide key information on critical areas of the state that require monitoring. They can help guide the selection process to ensure that a site represents a predominate climate regime. The following criteria were established for the location of all sites:

1) First priority is given to federally managed land, second priority to state managed land, and third priority to private land. Ideally, stations should be located on federal, state, county, or university land. This will ensure long-term use of the land for monitoring purposes. When it is not possible to locate stations on this type of land, consideration should be given to locating the station on property of Soil and Water District landowners that are cooperators with NRCS.
2) Sites should be approved by a qualified Cultural Resources Specialist.
3) Sites should be accessible by vehicle, and fencing of the site should be allowed.
4) When selecting a suitable location, some consideration of station security must be included. Generally, stations should not be located near public roads and should be located away from public view.
5) Consideration should be given to co-location with Long-Term Ecological Research Sites or other long-term monitoring projects, such as Forest Service Remote Automated Weather Station sites and Agricultural Research Service (ARS) Agricultural Experiment Stations.
6) Consideration must be given to ensure that all Major Land Resource Areas are represented in a given climatic region.
7) Benchmark soils are given priority as sites, and the soil type should be of significant acreage in the area where the station is located. Using the NRCS Benchmark Soils list will ensure that this is accomplished.
8) Soils should be very deep (>60 in), well drained, and, preferably, medium textured.
9) The landscape position of the site should be typical for the soil map unit.
10) The station should represent an agricultural area. The management status should be stable; e.g., in grass vegetation. All stations should be located in nonirrigated areas.
11) Consideration should be given to the World Meteorological Organization's requirements for weather station siting criteria (WMO, 1996). Using these requirements will ensure that proper distances are maintained from objects that could interfere with sensor performance.

For the stations involved in research, the siting requirements can be different depending on objectives. This may result in locating a station in an area that would fail one or more of the preceding criteria.

Soil Characterization

The soil at each SCAN site is fully characterized by documenting site properties, including vegetation, slope, aspect, and other important properties. A pit is opened with a backhoe, and the soil profile is described to a depth of 2 meters (when possible). Soil depth, texture, the content of rock fragments, structure, rupture resistance, color, and the quantity and size of roots are described for each horizon using standard soil description techniques (Schoeneberger, et al., 2002). Soil samples are collected from each horizon and sent to the National Soil Survey Laboratory in Lincoln, Nebraska, for standard characterization analyses. Standard properties measured include particle size separates (pipette method); bulk density (clod method); water content at 10, 33, and 1,500 kPa; cation-exchange capacity (CEC) (buffered ammonium acetate); total C; and pH (1:1 soil:water). The procedures for sampling and properties characterized are described in SSIR No. 1 (Soil Survey Staff, 1972). The current laboratory methods are described in SSIR No. 42, version 4.0 (Burt, 2004). Local NRCS soil scientists describe the soils and assist with the sampling.

Station Configuration

The standard SCAN station configuration has remained fairly consistent since 1999, with minor changes for station specific user requests. Dataloggers are 2MB units that are programmed to record sensor data every 20 minutes and to store data hourly. The data is then transferred to a radio and sent out to a master station. Table 1 lists the standard set of sensors that are included on all SCAN stations. Additional sensors are added to some SCAN stations to support local needs. For example, on seven stations in the north-central and eastern United States, snow pillows and depth sensors have been added to measure snow weight and thickness. These sensors are critical to assist with the prediction of surface water runoff and flood forecasting. Stations developed for specific research typically have the same standard suite of sensors with the addition of sensors used for specific investigations. Table 2 lists most of the additional sensors used on the research stations. Some or all of the sensors listed may be associated with a station.

Table 1. List of standard sensors used in the SCAN.

Parameter Measured	Description
Air temperature	Collected by a shielded thermistor
Relative humidity	Collected by a thin film capacitance-type sensor
Wind speed and direction	Collected by a propeller-type anemometer
Solar radiation	Collected by a pyranometer
Barometric pressure	Measured by a silicon capacitive pressure sensor
Soil moisture	Collected by a dielectric constant measuring device. Typical measurements are at 2, 4, 8, 20, and 40 inches where possible.
Soil temperature	Collected by an encapsulated thermistor. Typical measurements are at 2, 4, 8, 20, and 40 inches where possible.

The SCAN stations are designed to be located remotely. The entire station is powered by solar panels and batteries. Proper determination of station power requirements is critical to maintain system performance and ensure good sensor data. The sensors chosen for SCAN require very little power, and solar panel and battery technologies have improved over the years. The larger, more efficient solar panels that have been developed are better at charging batteries.

Table 2. List of additional sensors used in research.

Parameter Measured	**Description**
Piezometer	Water level
Redox	Measurement of oxygen reduction potential
Soil temperature	Additional soil temperature measurements by different devices
Water quality	Water temperature, pH, turbidity, DOB, and conductivity
Surface soil temperature	Typically measured by an IR sensor

Good grounding is critical for the equipment to operate properly. The radio and antenna make up a ground-based system that requires a proper ground to maintain communications between the remote station and the master station. Over the years, several stations have gone down due to lightening damage. Improved grounding and static dissipaters have decreased downtime of these lightening prone stations.

The average cost for a standard SCAN station is about $18,000 for the sensors, radio, and datalogger. USDA’s NRCS estimates that a SCAN station and sensors are good for a minimum of 10 years.

Station Data Acquisition

The SCAN system utilizes meteor burst communication technology or Line-of-Sight (LOS), to remotely acquire station data. The communication system is connected to a datalogger. 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 (USDA-NRCS, 2003). Meteor burst communication uses the billions of sand-sized particles (1 gram or larger) that burn up in the 50- to 80-mile-high region of the atmosphere to relay radio signals back to the Earth (MeteorComm, 2004). This technique allows communication to take place between remote sites and a master station as far as 1,200 miles away. Upon entering the Earth’s atmosphere, the particles burn up and leave an ionized gas trail behind. This gas trail enables VHF radio signals in the 38MHz to 50MHz 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 is checked for completeness. If the data is 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. The LOS system, which uses the same radio that is used for meteor burst telemetry, 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 equipment at remote sites, maintain the master station, and improve upon the hardware and software used. On the average, more than 98 percent of all remote sites report data at midnight; the less than 2 percent failure rate is generally related to some electronic failure, not to a meteor burst communication failure.

Station Maintenance

As with any network, maintenance is a very critical component in maintaining data quality. From the beginning of the pilot project, station maintenance was a major concern. Some stations collected poor information and performed poorly because of the lack of maintenance. Currently, typical station maintenance for SCAN is scheduled to be performed annually. Typical maintenance includes sensor and datalogger calibration, repairs, upgrades, and preventative measures; e.g., replacing desiccant, checking enclosure seals, and removing vegetation. Inadequate funding and the limited number of personnel continue to restrict the adequate maintenance of all stations. During the past 2 years, new stations generally were installed in areas where local staff could help with station maintenance, under the direction of the USDA's NRCS National Water and Climate Center (NWCC) staff. This arrangement has proven to be very effective and has ensured better performance at those stations. The NWCC staff and the National Soil Survey Center (NSSC) staff still perform the bulk of the station maintenance. Additional staff personnel are needed in order to ensure station reliability. While the NWCC and NSSC desire to maintain the stations annually, it is not possible with the current staffing levels.

SCAN Data Access and Reliability

SCAN data are available hourly from the USDA's NRCS-NWCC homepage at http://www.wcc.nrcs.usda.gov/scan. Each remote station should respond with hourly data at the top of each hour. The time interval between when the station reports to when the data is posted on the Internet is typically 30 minutes. Once the data arrives at the NWCC, a computer performs an initial data quality check; this screening ensures that the sensor data are within reasonable, predefined limits. Additional automated data screening, which may include rate of change for air temperature and rate of change for precipitation, is envisioned in the future to assist with data quality.

Users can easily obtain SCAN data from the NWCC homepage. Specialized reports can be requested via e-mail by identifying the specific stations and the period of record. New reports will be developed to provide easier retrieval of station data in the future. Station metadata files, which provide sensor history, calibration, station pictures, and maintenance history, are currently being developed for each station, and they will be linked to the NWCC homepage.

The real-time data provided on the Internet are provisional and subject to change. The NWCC believes that the information is valuable but recommends that people be cautious when they use the data. The data is examined weekly and edited for obvious sensor problems. These edits are in the historical data files, which are also accessible via the Internet. Problems that require maintenance visits to a station are identified during the data examination, and the NWCC tries to schedule station visits based upon the identified problems.

Over the years the NWCC has supported several independent analyses on the SCAN data. In 2001, an initial determination of the quality of the soil moisture sensors (hydra probe) was undertaken. The hydra probe sensors are a capacitance type of device that provides volumetric soil water content, salinity, and soil temperature information (Stevens, 2006). In addition, the University of Idaho, USDA's Agricultural Research Service, and the NWCC were successful in obtaining a U.S. National Oceanic and Atmospheric Administration (NOAA) grant to examine the soil moisture sensor (hydra-probe) data from the SCAN network. ARS provided an evaluation of the Vitel "hydra probe" to see how consistent the soil moisture sensors were and how they behaved in known soil water concentrations (Seyfried and Murdock, 2004). The results demonstrated the reliability of the hydra probe sensors. The hydra probes have been used in SCAN since 1995 and have provided reliable soil moisture information.

A Cooperative States Research proposal has recently been funded between Oregon State University, Alabama A&M University, and NWCC to begin the development of a tool that will integrate SCAN data with soils information and distribute soil moisture spatially. The development of the science to accomplish this task is critical to be able to provide "risk" information about soil moisture conditions nationally. The work has just begun and is envisioned to take at least 3 years to develop and test. If this work is successful and SCAN is fully implemented in the United States, it will be possible to identify potential drought areas and predict where future drought conditions could appear.

Future of SCAN

The SCAN network has grown over the years, and the popularity and usefulness have grown exponentially. The number of data downloads has risen dramatically. In fiscal year 2005, more than 1 million downloads took place. The number of requests for new stations has exceeded the NWCC ability to fund, install, and maintain the network. The main reasons for establishing the network were to assist agriculture with resource decisionmaking, to develop tools to look at crop production and the control of diseases and pests, and to mitigate drought affects by reducing the risk involved. Additional uses of this type of network and uses of the data continue to grow as well. The pipeline industry and fiber-optic cable companies are using the information to determine freeze depths and how far apart transmission buster stations can be located. The nationwide need for reliable, readily available soil moisture and soil temperature information 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 co-operators. These co-operators are excited about the future of the network.

The SCAN, when fully deployed, would consist of approximately 2,000 stations: 1,000 new stations and about 1,000 existing stations operated by other entities. The co-operator stations would be upgraded to meet SCAN standards in order to seamlessly 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. While the future of the network is still uncertain unless a more stable funding source is found, one thing is certain: SCAN has a vital role to play in integrating soil-climate monitoring. No other system that provides this kind of information exists in the United States.

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