J2.7 U.S. CLIMATE REFERENCE NETWORK SOIL MOISTURE/TEMPERATURE MONITORING

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1. INTRODUCTION

In response to the climate needs purposed at the 1997 World Climate Research Programme conference, climate researchers at NOAA's National Climatic Data Center decided it was important to deploy monitoring stations that were designed for climate science. In 2001, the first stations of the U.S. Climate Reference Network (USCRN) were installed in the continental United States to detect national climate change signals. The primary goal of the network is to create homogenous *in situ* temperature and precipitation records for the detection of climate change. In order to maintain this goal, each station is equipped with triplicate configuration temperature and precipitation measurements. This arrangement allows for consistency and redundancy in the measurements. Thus, each station has repeating measurements for a self-checking verification of equipment error and continuous measurements in the event of a faulty sensor. Sensors and equipment are also calibrated to National Institute of Standards and Technology standards. These state-of-the-art stations are designed to be operational for the next 50-100 years.

In conjunction with the U.S. Cooperative Observer Program (COOP) Network and newly formed U.S. Regional Climate Reference Network (USRCRN), USCRN serves as a reference to accurately assess the variance of the other networks and determine the most precise climate record. The evenly dispersed deployment of the 114 stations in the contiguous U.S (with ongoing development of Alaska USCRN) allows accurate assessment of the current historical stations used for climate monitoring. Data obtained as a result of the configuration of USCRN will allow researchers to understand the historical perspective of climate anomalies without concern for site changes or land use changes.

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One particular climate anomaly, drought, cannot be completely assessed with traditional USCRN aboveground instrumentation. As drought and other climate anomalies could potentially increase in frequency and/or magnitude in the future (Easterling et al. 2001), it is important to have instrumentation to track these changes across the US. Based on the realization that droughts are events that integrate above and below surface processes, precise monitoring of drought events requires observations of soil moisture and soil temperature.

In the spring of 2009, NOAA researchers determined that soil observations should be added to the USCRN network configuration. This will allow for *in situ* measurements of soil moisture and soil temperature for the purpose of drought monitoring, and to build a high quality long-term record of soil climate. In the summer of 2011, installation of the new instrumentation was completed. Like temperature and precipitation, soil observations are performed in triplicate at each USCRN station. In locations that have suitable soil depths, soil probes were installed at five depths: 5, 10, 20, 50 and 100 cm. Stations where soil depth is not suitable for supporting five probe depths had only the 5 and 10 cm depths instrumented; and in one case of a station on solid rock, no probes were installed. In addition to the primary measurements, USCRN has sensors recording wind speed at 1.5 m height, surface IR temperature, solar radiation, and miscellaneous measurements of station health. All measurements are transmitted in near real-time via the GOES satellite.

The purpose of this article is to discuss some of the preliminary work on soil moisture quality control and in developing drought-monitoring products.

2. USCRN SOIL OBSERVATION HISTORY

The National Integrated Drought Information System (NIDIS) and USCRN held a joint workshop on improving the network for drought monitoring purposes. Twenty-five national experts on soil climate measurements met in Oak Ridge, TN, at the offices of NOAA's Atmospheric Turbulence and Diffusion Division (ATDD), the USCRN engineering partner. After considering the input, the decision was made to install soil probes at each station in the network, along with a relative humidity sensor. Following the lead of the temperature and precipitation measurement systems at USCRN stations, soil sensors were to be added in triplicate configuration for purposes of redundancy and consistency at each station. One month later, ATDD installed the first set of probes at the Crossville, Tennessee, USCRN location. By the summer of 2011, the installations of the new measurements were completed for all stations in the contiguous United States (Figure 1).

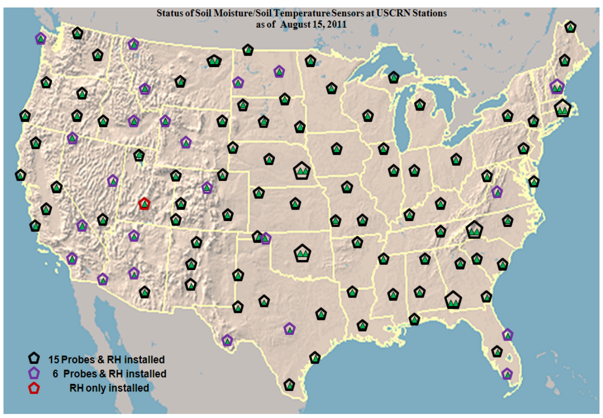

Figure 1. Installation of the soil climate instrumentation was completed for the contiguous US in 2011. Of the 114 stations, 89 stations had all five depths installed, 24 had only the top two depths installed and 1 could not support any soil probes.

3. SOIL OBSERVATIONS APPROACH

The design of the soil probe configuration is targeted to obtain three independent samples for each instrumented soil depth (5, 10, 20, 50, and 100 cm). Observations are produced at three plots in a 5-meter radius around the main instrument tower. Stations with soils that were not conducive to deep installations had only the top 5 and 10 cm probes installed. As the original purpose of USCRN was not for soil monitoring, 24 stations were in the category of only having the top two layers installed. The USCRN station located near Torrey, UT, in Capitol Reef National Park, is on bare rock, and has no soil probes installed.

A typical set of soil moisture values averaged for each depth is show for one of the Asheville, NC, USCRN stations in Figure 2. As can be seen, soil moisture levels gradually decline during the growing season from March to September, with the downward tendency broken only by precipitation events. While the response of soil moisture to precipitation is rapid in the 5, 10, and 20 cm layers, the changes are much more subdued by the time the moisture reaches the 50 and 100 cm layers.

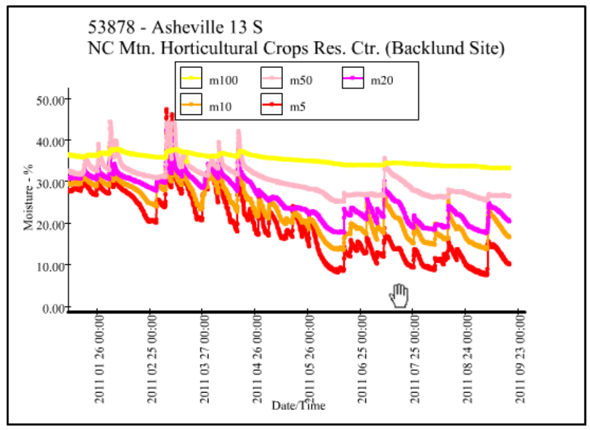

Figure 2. USCRN layer averages of soil moisture from the Asheville 13 S station in North Carolina. This figure was created from the US Drought Portal website (www.drought.gov).

4. DROUGHT MONITORING PRODUCTS

Soil samples are taken at all depths for every installation. The samples are then sent to the USDA soils lab in Lincoln, Nebraska for further evaluation. The samples are analyzed to determine bulk density, field capacity (at -33kpa), wilting point (at -1500kpa), and general soil characteristics. From the soil measurements, soil water content at the permanent wilting point and field capacity is calculated for each probe, allowing for an estimate of plant available water (PAW). The PAW value at each of the probes can vary due to differences in soil characteristics (Figure 3), even if the probes are at the same depth. There may also be some issues with the accuracy of some of the sample measurements that can cause a wider than expected variance between PAWs at the same depths. In some of these cases, soils will be resampled to confirm findings.

In order to fully assess changes in the percentage of plant available water with regards to vegetative health, the onset of the vegetative growing season needs to be determined. Traditional methods of determining growing season are based on air temperature measurements, with the first day that stays above 0^{o}C as the indicator of start of the growing season. However, research in plant physiology suggests that soil temperature is a better indicator of herbaceous plant growth(DeLucia, E. and W. Smith. 1987; Day et al. 1990; Schwarz, P., et al. 1997; Ruess et al. 2003; Alvarez-Uria, P. and C. Korner 2007). In order to determine the onset and end of the growing season, a preliminary analysis of growing season was conducted using satellite derived Normalized Difference Vegetation Index (NDVI) and soil temperatures at a USCRN site in Manhattan, KS. From our preliminary analysis, soil temperature serves as a better indicator of the onset of the growing season than air temperature.

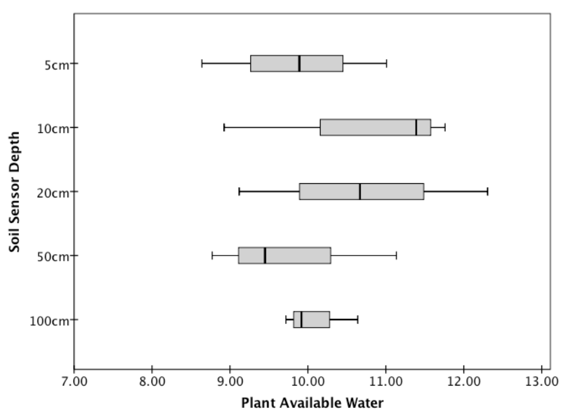

Figure 3. Box plot of the plant available water (PAW) for the USCRN Los Alamos, NM station. PAW was determined by subtracting wilting point from field capacity. The distribution results from differences in soil characteristics of the three plots at each of the five soil depths.

A preliminary study of growing season air and soil temperatures to NDVI was conducted for the year 2010 at a number of locations in the conterminous U.S.. The air temperature defined growing season at USCRN stations was based on the 1.5 m above ground air temperature measurements, with the start of the growing season when the temperature remains above 0°C and the end of the growing season when the temperature drops below 0°C for the first time in the fall. Soil temperature growing season was determined with the same methodology; however, the cutoff temperature was set to a threshold of 5°C, the biologically determined limit for root activity. Using the four closest satellite images to the USCRN station, the change of NDVI was recorded at each time step for 2010 and plotted to identify change. Consistently, soil temperature at the top four depths (5, 10, 20, and 50cm) was closer to the onset of the NDVI derived growing season than air temperature (Figure 4).

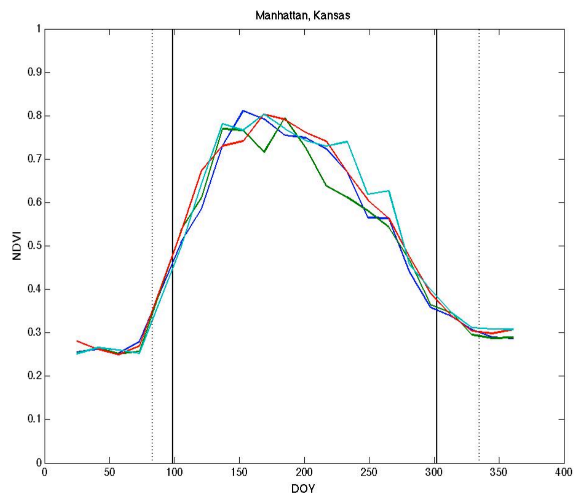

Figure 4. Preliminary comparison of air and soil temperature growing seasons. Colored lines are four MODIS satellite NDVI measurements near the USCRN Manhattan, KS. station during 2010. Solid black vertical lines indicate the onset and end of the growing season using the traditional 0°C air temperature method. Dotted vertical black lines indicate the onset and end of the growing season with 5°C soil temperature at 20 cm. As all soil temperatures are closer to the onset of the NDVI growing season, only the soil temperature at 20cm depth was used to increase the ability to identify the change.

5. SUMMARY

USCRN has completed the installation of soil climate monitoring probes in the contiguous United States. Stations have triplicate measurements of soil moisture and soil temperature at five depths (5, 10, 20, 50, and 100cm). Stations that cannot support the five depths have installations in the top two depths and one station, because the installation is on bare rock, does not have soil observations. In addition to making quality controlled soil moisture data available, the USCRN program is developing derived products that will be useful for the analysis of growing seasons and drought. USCRN soil observations have a wide-variety of uses, including drought monitoring, satellite calibration, agriculture, hydrology, and weather monitoring.

6. ACKNOWLEDGEMENTS

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