1.2 THE CHARACTERISTICS AND PRELIMINARY QUALITY CONTROL OF SOIL MOISTURE AND TEMPERATURE OBSERVATIONS AT U.S. CLIMATE REFERENCE NETWORK SITES

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1. INTRODUCTION

Soil moisture and temperature probes were installed at USCRN sites, beginning in May 2009. At present, they are installed at 39 sites. The sensors are placed in a radial pattern about 3 m from the tower at each site in three holes, at the depths of 5, 10, 20, 50, and 100 cm when soil conditions permit. The moisture (dielectric) and temperature are available in the normal data stream at a one-hour interval.

The availability of moisture and temperature measurements from three separate, but nearby locations, is unique to the design for the USCRN sites. This design gives a sample of measurement from possibly different soil conditions at the site. With this arrangement of sensors, the average of the three measurements would be expected to be more representative than any one single measurement. However, this poses a dilemma for the design of a quality control program for the data since the measurements are expected to differ in some amount but also largely agree. This paper will describe a preliminary quality control program, along with characteristics of the measurements. The nature of some measurement problems will also be presented.

This investigation was done in close collaboration with personnel at ATDD in Knoxville, TN and NCDC/CRN in Asheville, TN, particularly Bruce Baker, Michael Palecki, and Egg Davis. Their input and access to the data was invaluable.

2. MOISTURE SENSOR INSTALLATION

The moisture and temperature sensors are installed at the 39 USCRN sites shown in Fig. 1. Most of the central part of the U.S. is covered, along with a few in the far west. Installation at many of the mountain sites would be difficult or impractical.

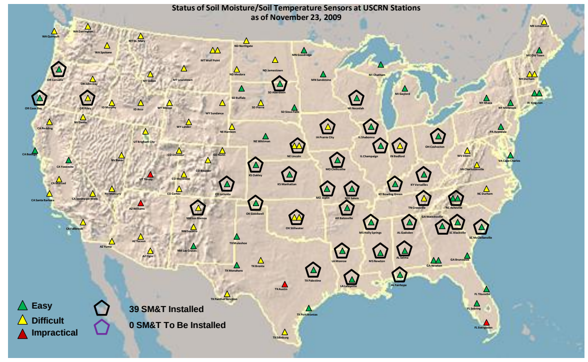

Figure 1. USCRN sites where soil moisture sensors are installed (shown as pentagons).

At each site, the moisture and temperature sensors are installed in three individual holes in a radial pattern at about 3 m (10 ft.) distance around the tower. A typical site, AL Gadsden 19 N, is shown in Fig. 2. The air temperature and other measurements are made from the tower. And precipitation measurements are made from within the wind shelter at the left in the figure. The placement of the sensors, relative to the tower, at AL Gadsden 19 N, is shown in Fig, 3. The sensors are placed horizontally within each hole at 5, 10, 20, and 50 cm depths and vertically at 100 cm depth, as shown in Fig. 4. A typical installation of sensors, before filling the hole, is shown in Fig. 5.

Figure 2. Photo of AL Gadsden 19 N USCRN site.

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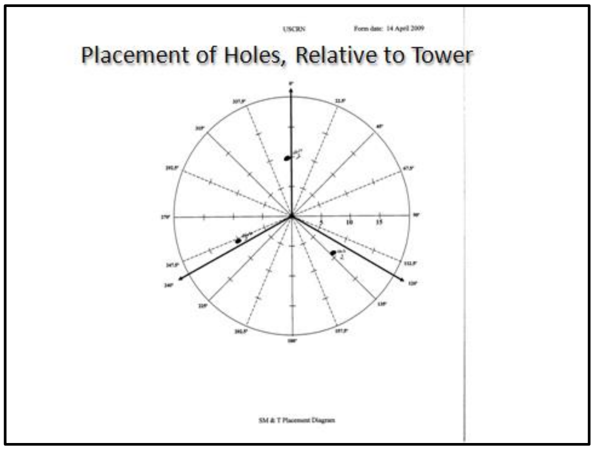

Figure 3. Placement of moisture and temperature sensors, relative to the tower at AL Gadsden 19 N.

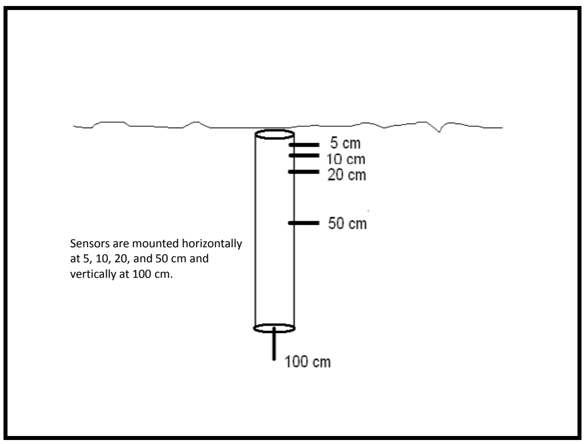

Figure 4. Placement of temperature and moisture sensors within each hole.

Figure 5. Sensors installed at 5, 10, and 20 cm.

Samples are taken of the soil as the sensors are installed. The samples are analyzed by the USDA-NRCS National Soil Survey Center Soil Survey Laboratory. The samples are analyzed for:

1) Total nitrogen, carbon, and sulfur
2) PSDA, air-dry, < 2 mm particles
3) Cation Exchange Capacity (CEC) and cations, routine – Ca, Mg, Na, K
4) Bulk density (from which porosity is estimated)
5) Water retention, field state
6) Water retention, pressure-plate, < 2 mm, (0.33 and 15 bars)

3. SOIL MOISTURE AND TEMPERATURE MEASUREMENTS

The moisture sensor's raw measurement is the dielectric of the soil. This is converted to moisture (m^3 water/m^3 soil) by the following equation:

$$m = 100(.109\sqrt{d} - .179),$$

where *d* is the dielectric and *m* is the moisture. The bulk density is determined from the soil samples, as mentioned above. An approximate value of the porosity of the soil can be obtained from the bulk density. And this porosity can be used to estimate the maximum amount of moisture that the soil can hold. The approximate value of the porosity is:

$$p = 100\left(1 - \frac{b}{2.65}\right),$$

where *b* is the bulk density (g/m^3) and *p* is the porosity (%). The temperature is measured (C) for each hole and depth.

4. PRELIMINARY QUALITY CONTROL PROGRAM

A preliminary version of a quality control program was written to assess the quality of the soil moisture and temperature data. This program makes several checks, including:
1) check for missing data
2) check for data out of range
3) Check for persistently constant, missing, or noisy data
4) check for isolated spikes or jumps in the data
5) check for frozen soil
6) check for saturated soil
Finally, the program calculates a 'representative' value of moisture and temperature from the three holes.

Some of the checks are patterned after those of Shafer, et al (2000) and Illston, et al (2008). The complex quality control used by Hu, et al (2002) must await longer period records of soil moisture and temperature from the USCRN sites before it could be applied.

4.1 Check for Missing Data

Data may be missing for several reasons, including communication problems and sensor failure. If data are missing, they do not participate in further testing and their quality is set to 'bad'. Temperature and moisture (and dielectric) are checked separately.

4.2 Check for Data out of Range

The check for gross errors checks for temperature out of the range, -30 to +55 C. The moisture check looks for dielectric measurements out of the range 3 to 70 (which corresponds to moisture out of the range 0.98 to 73.3). When bad values are found, the quality is set to 'bad' and the data are not used in further testing.

4.3 Check for Persistently Constant, Missing, or Noisy Data

For each temperature and moisture sensor, a record is kept of the number of times that it has failed previous tests or has had a 1-hour change near zero. A QC specialist can be notified if the percent of these times exceeds a specified ratio. The counters can be reset as required.

4.4 Check for Isolated Spikes or Jumps in the Data

The check for jumps in the data uses depth-dependent limits on the absolute value of 1-hour change for temperature and moisture. The limits for an increase or decrease of moisture have different limits as physical increases are related to precipitation and other causes, while decreases are from percolation, evaporation, etc.

The check for isolated spikes uses depth-dependent limits for both temperature and moisture. It checks the value of the 1-hour change, both from before and after the hour. For a spike to be found, both changes must be independently large and in opposite directions.

4.5 Check for Frozen Soil

Note that moisture measurements are not useful in frozen soil. This check sets the moisture measurement to' bad' if the temperature is < 1 C. The temperature measurements remain valid.

4.6 Check for Saturated Soil

A comparison is made between the estimated porosity of the soil and the moisture. If the ratio

(moisture/porosity) > 1.1,

then the soil is likely saturated and the quality of the moisture measurement is set to 'bad'. It was found that many saturated measurements lead to very noisy moisture data.

4.7 Calculation of a Representative Value

The temperature and moisture measurements are taken from three separated holes, thus providing an aerial sample of these measurements. The most appropriate representative, single, value from these measurements is their average. The difficulty comes when one or more of the measurements are missing or bad, possibly leading to a discontinuity in the average of the remaining values (particularly for moisture, as the spatial variation of soil moisture is generally much greater than the temperature variation).

5. EXAMPLE OF GOOD MEASUREMENTS

The temperature measurements are most always good, and the moisture measurements for most stations are also good. This section shows an example of good measurements from KS Oakley 19 SSW for the month of September 2009. Fig. 6 shows the precipitation and three sensor measurements of moisture at 5 cm depth. There is a good correspondence between the precipitation and these near-surface moisture measurements.

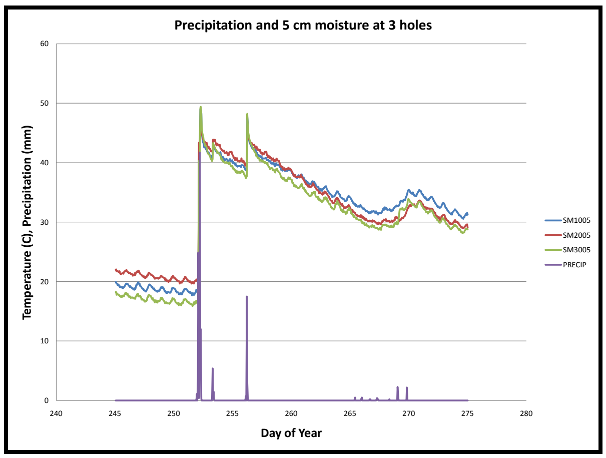

Figure 6. Precipitation and 5 cm moisture for KS Oakley 19 SSW for September 2009

The following Figs. 7-11 show the moisture and temperature measurements at the 5, 10, 20, 50, and 100 cm depths for KS Oakley 19 SSW for September 2009. Also included in these figures is a curve of the average of the three measurements (purple curve). Most notable is the decrease in the amplitude of the temperature daily variation with depth. The moisture penetrates to significant depths for this station with sandy, loamy soil.

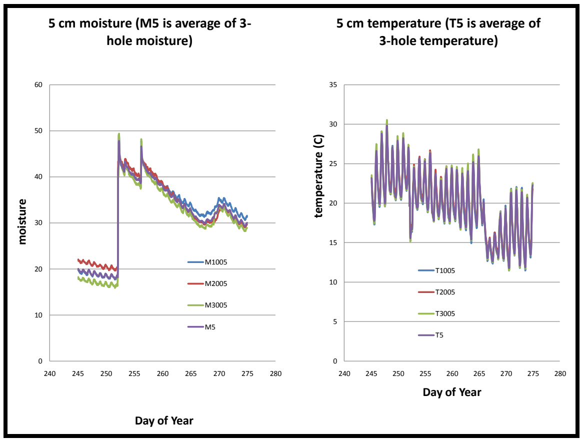

Figure 7. 5 cm moisture and temperature for KS Oakley 19 SSW for September 2009

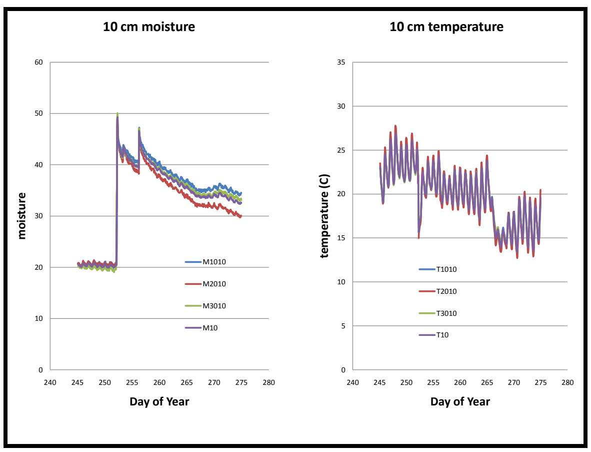

Figure 8. 10 cm moisture and temperature for KS Oakley 19 SSW for September 2009

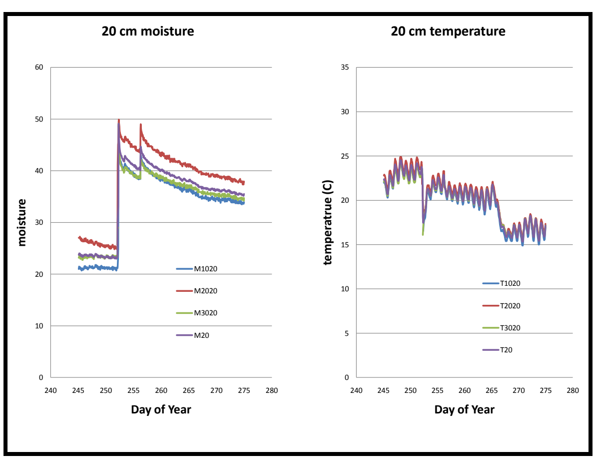

Figure 9. 20 cm moisture and temperature for KS Oakley 19 SSW for September 2009

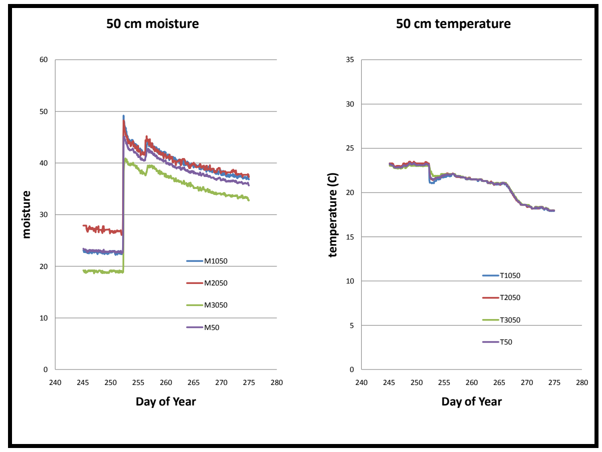

Figure 10. 50 cm moisture and temperature for KS Oakley 19 SSW for September 2009

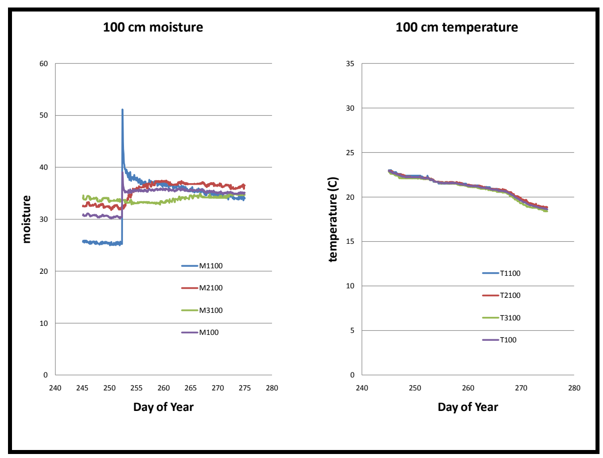

Figure 11. 100 cm moisture and temperature for KS Oakley 19 SSW for September 2009

6. EXAMPLE OF STATION WITH NOISY MOISTURE MEASUREMENTS AT LOWER DEPTHS

Some stations exhibit a noisy signal from the moisture sensors, particularly at 50 and 100 cm depths. In most cases, this appears to be associated with moisture near the maximum that the soil can hold. The following Figs. 12-16 show the measured moisture at the depths between 5 and 100 cm. (Fig. 12 also includes the precipitation for comparison.) It is seen that the noise only shows at the lower depths and for high levels of moisture. As described earlier, the bulk density measurements made from soil samples are used to estimate the soil porosity. As this is an estimate of the maximum moisture that the soil can hold, the quantity (moisture - porosity) is expected to be negative. The Figs. 17-19 show the (moisture - porosity) for the 5 depths at each of the three holes. These figures clearly show that the noise occurs only for moisture near or above the maximum that should be possible. Automated use (moisture/porosity) is now made in the quality control of moisture.

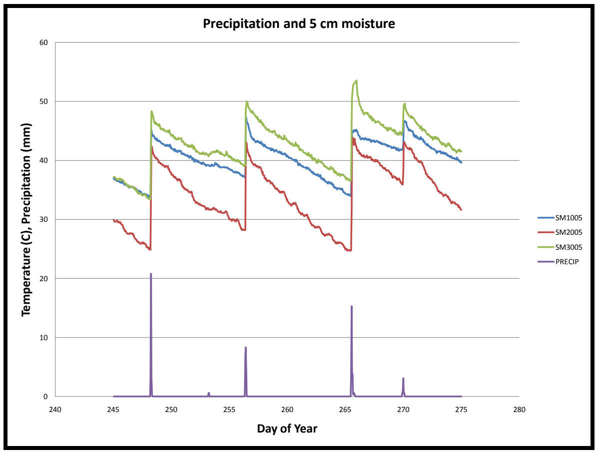

Figure 12. Precipitation and 5 cm moisture for
KS Manhattan 6 SSW for September 2009

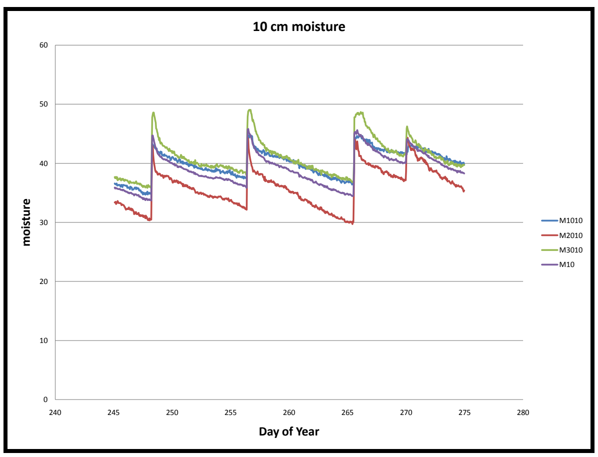

Figure 13. 10 cm moisture for KS Manhattan 6
SSW for September 2009

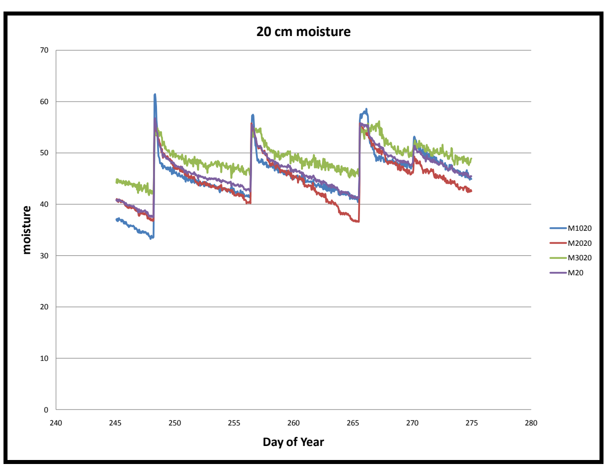

Figure 14. 20 cm moisture for KS Manhattan 6
SSW for September 2009

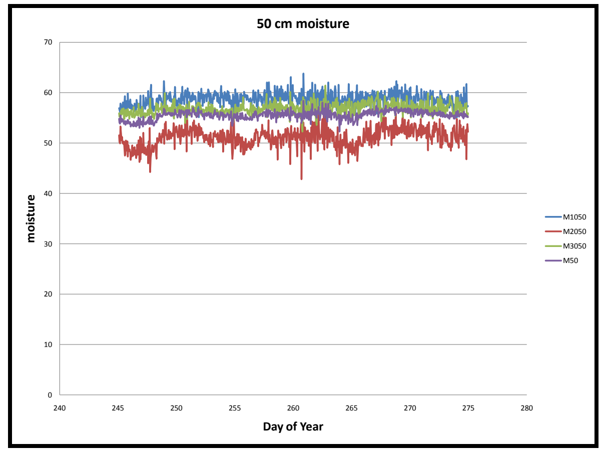

Figure 15. 50 cm moisture for KS Manhattan 6
SSW for September 2009

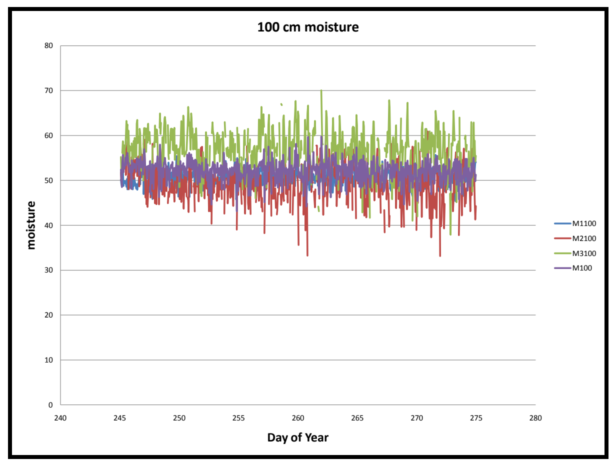

Figure 16. 100 cm moisture for KS Manhattan 6
SSW for September 2009

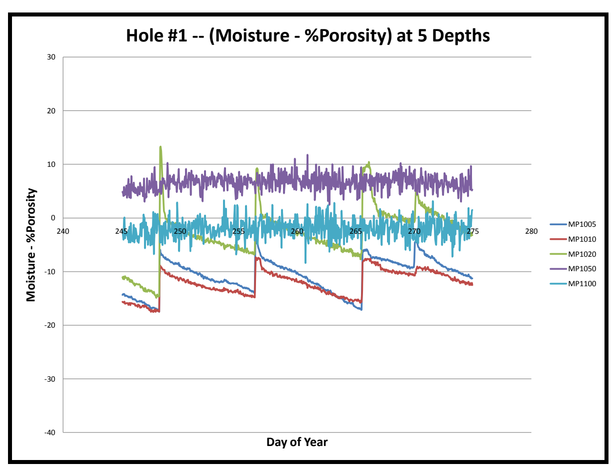

Figure 17. (Moisture-porosity) for hole 1 for
KS Manhattan 6 SSW for September

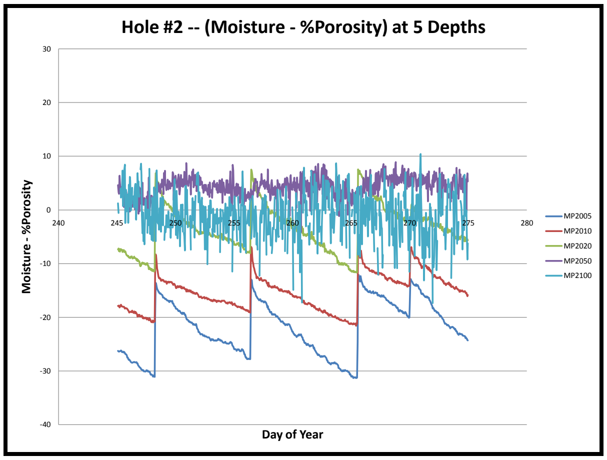

Figure 18. (Moisture-porosity) for hole 2 for KS Manhattan 6 SSW for September

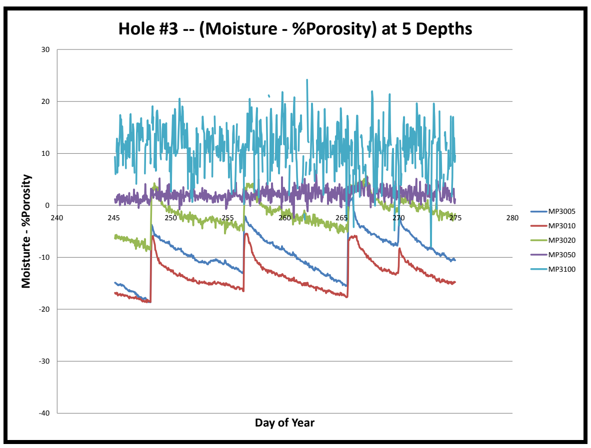

Figure 19. (Moisture-porosity) for hole3 for KS Manhattan 6 SSW for September

7. FURTHER EXAMPLES

The next example shows a station with spikes in the data and periods of missing reports. It comes from MS Newton 5 ENE for October 2009. Fig. 20 shows the moisture measurements at 5 cm, accompanied by the precipitation that was observed. The negative spikes in the moisture happen at odd times, and without any known explanation. Sensor #2 also has periods of missing data.

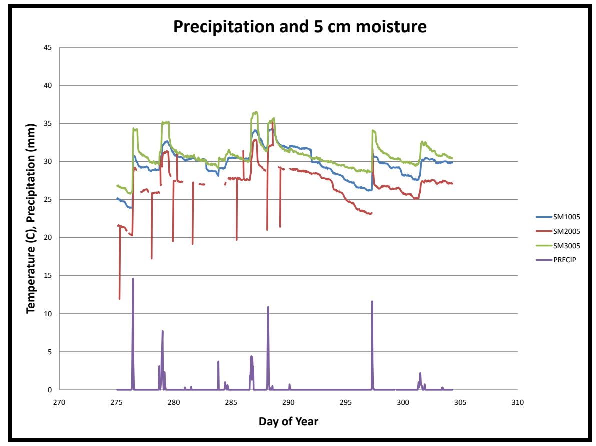

Figure 20. Example of problem moisture measurements from MS Newton 5 ENE for October 2009

Another case of questionable, but possibly correct, measurements is afforded by IL Chamgaign 9 SW for October 2009. At this station, the 5, 10, and 20 cm temperature measurements from the three holes have greatly differing amplitudes, as shown in Figs. 21-23.

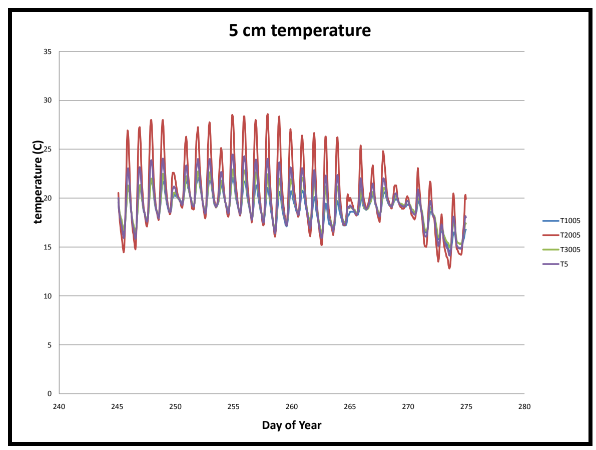

Figure 21. Large temperature range differences for IL Champaign 9 SW for October 2009 at 5 cm.

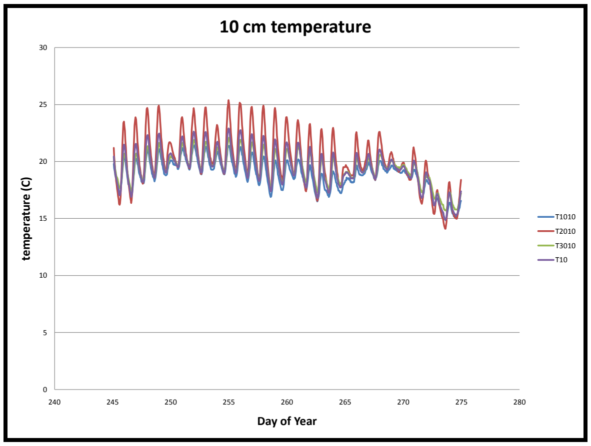

Figure 22. Large temperature range differences for IL Champaign 9 SW for October 2009 at 10 cm.

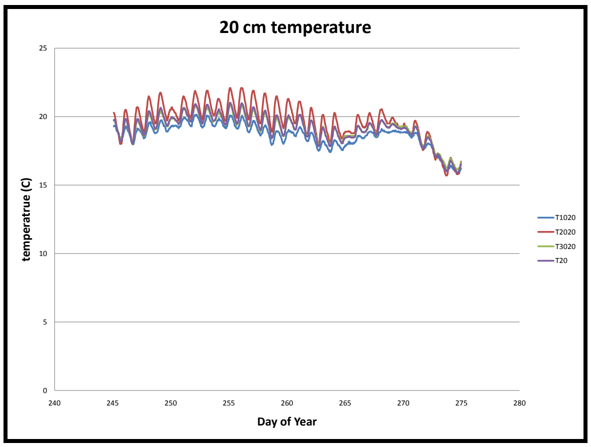

Figure 23. Large temperature range differences for IL Champaign 9 SW for October 2009 at 20 cm.

8. SUMMARY

Soil moisture and temperature sensors are installed at 39 USCRN sites at 5 depths and in three separate holes. A preliminary QA/QC program is used to examine the hourly data to assess the data quality and is able to automatically find many of the typical data problems. Some sample observations, both good and bad, were shown.

9. REFERENCES

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