United States Department of Agriculture | **Natural Resources Conservation Service** | **11 Campus Boulevard, Suite 200 Newtown Square, PA 19073**

Subject: SOI – Geophysical Field Assistance **Date:** 6 June 2008

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Purpose:
A high-intensity electromagnetic induction (EMI) survey was completed at Pennsylvania State University's Klepler Farm in Centre County. A small permanent grid was established within the Shale Hills Catchment (Huntingdon County) to further evaluate the use of *GPR-SLICE*, a ground-penetrating radar (GPR) processing and imaging software program. In addition, preliminary GPR tree root and water infiltration studies were completed within the Shale Hills Catchment.

Activities:
Field activities were completed on 4 and 5 June 2008.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
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Recommendations:
1. A third, bi-monthly EMI survey was completed over selected research fields at Klepler Farm. The purpose of these surveys is to assess broad (small scale) spatiotemporal variations in spatial EC_a patterns, define hydropedological functional units, and correlate EC_a with soil properties.

2. In order for Jun Zhang to further experiment and evaluate the processing techniques contained in *GPR-SLICE*, a small, permanent, detailed grid site was established on the lower portion of a swale located within the Shale Hills Catchment. Two GPR surveys were completed across this grid site: one with a 400 MHz antenna, the other with a 500 MHz antenna.

3. An infiltration experiment was completed with a 400 MHz antenna in an area of Weikert soils within the Shale Hills Catchment. This brief study is a prelude to more intensive investigations scheduled latter this year with PSU's Geophysical Department.

4. A radar traverse was completed within the Shale Hills Catchment for the purpose of evaluating the impact of tree roots on radar interpretations.

It was my pleasure to participate in these studies and to work with the graduate students at Pennsylvania State University.

With kind regards,

James A. Doolittle
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1. Electromagnetic Induction Survey:
Materials and Methods:
An EM38DD meters, manufactured by Geonics limited (Mississauga, Ontario), was used in the high-intensity EMI survey of Klepler Farm. [1] The EM38DD meter consists of two, coupled EM38 meters. This instrument weighs about 2.8 kg (6.2 lbs). Each meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. Operating procedures for the EM38DD meter are described by Geonics Limited (2000). When placed on the soil surface, the EM38DD meter provides theoretical penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively. The EM38DD meter measures the apparent conductivity (EC_a) of earthen materials, which is expressed in milliSiemens/meter (mS/m).

The EM38DD was placed in a plastic sled and towed behind a Gator utility vehicle. An Allegro CX field computer (Juniper Systems, North Logan, UT) was used to record and store both EMI and position data. The coordinates of each EC_a measurement were recorded with a Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[1] TheTrackmaker38DD software program, developed by Geomar Software Inc. (Mississauga, Ontario), was used to record, store, and process EC_a and GPS data. [1]

In order to make temporal comparisons of EC_a measurements, it is recommended that all data be corrected to a standard temperature. Apparent conductivity increases with soil temperature. As the soil temperature rises, the soil water become less viscous and dissolved ions become more mobile. This results in higher EC_a values (McNeill, 1980). As it is impractical to account for variations at each point and at different soil depths, the correction factor is often based on a single measurement. At Klepler Farm, the soil temperature at a depth of 50 cm was 33 ^{o} F. Based on this temperature, all EC_a data were corrected to a standard temperature of 24^{o} C (75^{o} F) using equation [1] from USDA Handbook 60 (U.S. Salinity Laboratory Staff, 1954):

$$EC_{25} = f_t EC_t \qquad [1]$$

Where, f_t is a temperature conversion factor.

To help summarize the results of the EMI survey, SURFER for Windows (version 8.0), developed by Golden Software, Inc. (Golden, CO), was used to construct the simulations shown in this report.[1] Grids of EC_a data were created using kriging methods with an octant search.

Survey Procedures:
At Klepler Farm, the EM38DD meter was towed behind a Gator utility vehicle in a plastic sled at speeds of 2 to 4 m/sec. The EM38DD meter was operated in the continuous mode with a sampling rate of 2 samples/sec. The EMI survey of Klepler Farm was completed by driving the Gator utility vehicle at a uniform pace along crop rows, in a back and forth manner. The southwest corner of the study site contained a field of small grains. These grains were about knee high and very wet from recent rains. During the course of the survey it began to rain and the meters became wet. While, the electronics were sealed, the presence of films of water on the meter's exteriors would have a detrimental affect on the results of this survey.

Results:
Table 1 summarizes the results of the three EMI surveys that were completed this year at Klepler Farm. The relatively low EC_a recorded across these fields reflect the electrically resistive nature of soils and underlying limestone bedrock. For the April 2008 survey, EC_a ranged from about 1.6 to 208.0 mS/m in the shallower-sensing (0 to 75 cm), horizontal dipole orientation (HDO). The large range in EC_a values reflects the presence of buried utility lines and artifacts within these fields. In the HDO, EC_a averaged 15.3 mS/m with a standard deviation of 5.3 mS/m. One-half of the EC_a measurements recorded in the HDO were between 12.7 and 17.7 mS/m. For the deeper-sensing (0 to 150 cm), vertical dipole orientation (VDO), EC_a ranged from about 2.8 to 78.0 mS/m. Once again, the large range in EC_a reflects the presence of buried artifacts. In the VDO, EC_a averaged 19.1 mS/m with a standard deviation of 4.7 mS/m. One-half of the EC_a measurements recorded in the VDO were between 16.5 and 22.0 mS/m.

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[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

Table 1
Basic EMI Statistics for the EMI surveys conducted at the Klepler Farm Research Site on 16 January, 11 March, and 4 June 2008.
(Other than the number of observations, all values are expressed in mS/m)

	JAN	JAN	MAR	MAR	APR	APR	JUN	JUN
	HDO	**VDO**	**HDO**	**VDO**	**HDO**	**VDO**	**HDO**	**VDO**
Number	8274	8274	7344	7344	7571	7571	15415	15415
Minimum	8.5	-203.6	-13.2	-96.3	1.6	2.8	1.2	-114.3
25%-tile	21.6	22.4	1.7	8.5	12.7	16.5	18.0	21.0
75%-tile	26.7	27.1	9.2	14.5	17.7	22.0	25.7	26.2
Maximum	266.4	105.6	509.7	68.3	207.5	77.9	338.6	161.4
Average	24.7	25.4	5.4	11.5	15.3	19.1	24.9	25.6
Standard. Deviation	8.4	8.3	8.0	4.6	5.3	4.7	16.4	5.26

As previously experienced, the range in EC_a was affected by the presence of buried utility lines. Buried power cables entered the south-central portion of the study site along a farm road. These utilities produced electromagnetic interference resulting in anomalous EMI responses. In addition, some anomalous EC_a values are attributed to metallic artifacts that were discarded or buried in the field and crossed or closely approached with the meters during the survey.

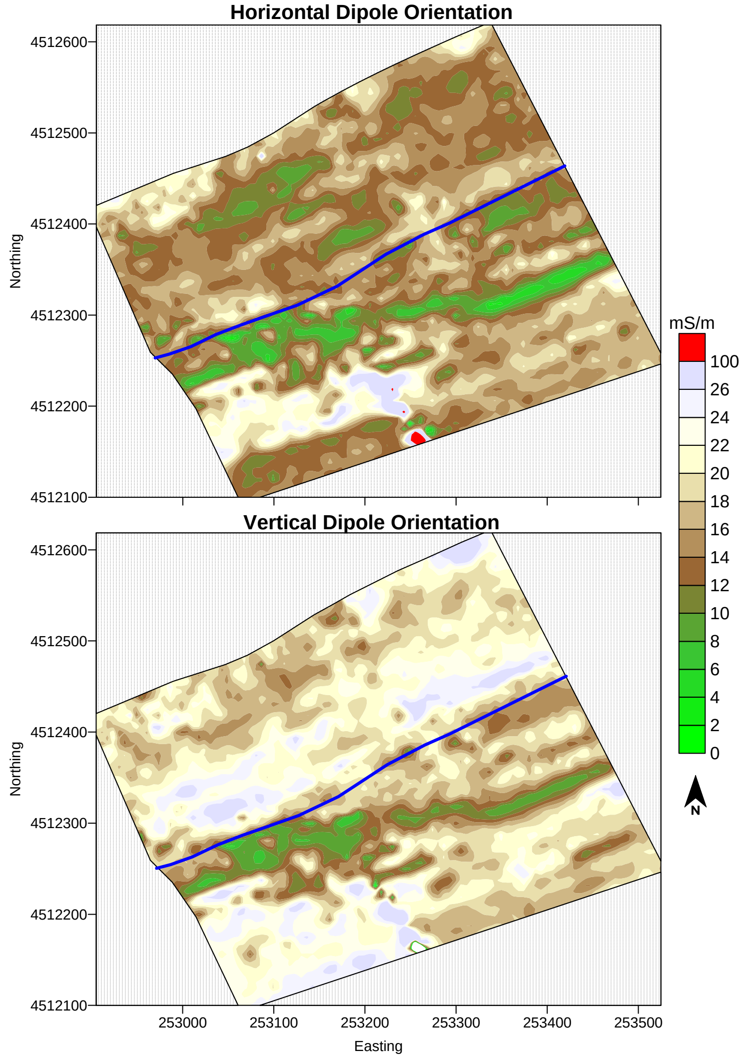
The EM38DD meter had recently been recalibrated at Geonics Limited in Canada. To improve confidence in measurement obtained over these fairly resistive grounds, a known "calibration site" was established near the top of a low ridge at a point located immediately upslope from the farm road and in an area with exposed bedrock. The EMI response was very low at the calibration site (favorable for calibration). This site will help to insure consistency among the EMI surveys that will be completed this year at Klepler Farm. As greater care and attention to detail have been exercised in the calibration of the EM38DD meter, greater confidence can be reported in the measured responses.

While measurements obtained in the HDO (shallow) and VDO (deep) often followed similar tends in magnitudes, measurements obtained at the same observation points were not similar (r =-0.21). As the EM38 meter has been recently calibrated and tested by its manufacturer, the lack of association between the HDO and VDO measurements are assumed to be real and reflect the two tiered nature of the soils (fairly resistive soils over very resistive bedrock) and spatial and vertical variations in soil moisture.

Figure 1 contains two, two-dimensional plots of the EC_a data that were measured with the EM38DD meter in the horizontal (upper plots) and vertical (lower plots) dipole orientations. In each plot, the isoline interval is 2 mS/m and the same color ramp is used. Spatial EC_a patterns appearing in Figure 1 are assumed to be principally related to differences in soil depth and wetness. Areas with lower EC_a are on higher-lying, more sloping, better drained landscape positions. In general, these areas have thinner caps of residuum and shallower depths to limestone bedrock. Areas with higher EC_a are on lower-lying, more imperfectly drained plane and concave slopes. In general, these areas are wetter, and have thicker caps of residuum and deeper depths to bedrock. In Figure 1, a prominent, east-to-west trending, linear band of lower EC_a can be identified in the lower center of each plot. This pattern closely conforms to the crest of a prominent ridgeline, where the depth to bedrock is mostly shallow. The extreme northeast and southwestern portions of the study area were noticeably wetter at the time of the survey. Higher levels of soil moisture were assumed to be responsible for the higher EC_a in these areas. In addition, some higher-lying, more nearly level to gently sloping areas displayed higher EC_a than adjoining, more sloping, shallower to bedrock, side slopes areas.

In the plots shown in Figure 1, the approximate locations of buried utility lines can be identified by anomalous EC_a values plotted in the extreme south central portion (most evident in the upper plots) of the research fields. The northern portion of the research site also contains buried utility lines, but this area was avoided. In Figure 1, in order to evaluate the effects of management, a blue line indicates the location of a major field boundary.

The spatial EC_a patterns evident in the plots of Figure 1, while varying in actual values are closely similar to those obtained during pervious EMI surveys that were conducted this year. Because of these spatial similarities, temporally stable hydropedologic functional units appear to have been defined with EMI.



2. Ground-Penetrating Radar work at the Shale Hills Catchment:

GPR Equipment:

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[2] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Daniels (2004) discusses the use and operation of GPR. Antennas with center frequencies of 400 and 500 MHz antenna were used in this investigation.

Radar records contained in this report were processed with the *RADAN* for Windows (version 6.6) software developed by GSSI.[2] Processing included: header editing, setting the initial pulse to time zero, distance normalization, signal stacking, migration, and range gain adjustments. The Super 3D QuickDraw program developed by GSSI was used to construct three-dimensional (3D) pseudo-images of radar records collected at the grid site.

[2] Manufacturer's names are provided for specific information; use does not constitute endorsement.

Field Methods:
To collect the data required for studying time-lapsed, 3D GPR pseudo-images, a permanent survey grid was established on the lower portion of a swale within the Shale Hills Catchment. Two GPR surveys were conducted across this grid site: one survey with 400 MHz antenna, the other with a 500 MHz antenna. For both surveys, traverse lines parallel to the X-axis (cross swale profiles). The grid site had overall dimensions of 12 by 15 ft. Plastic stakes have been inserted in the ground at the four grid corners and a rope grid-lattice has been fabricated for attachment to these stakes and overlaid across the grid area. The rope lines extend across the grid (parallel with X axis) at intervals of about 13 inches and provide ground control. Each rope line should be distance-graduated. Distance marks should be affixed to each rope line at intervals of 2 to 3 feet to provide a greater measure of ground-control along each radar traverse.

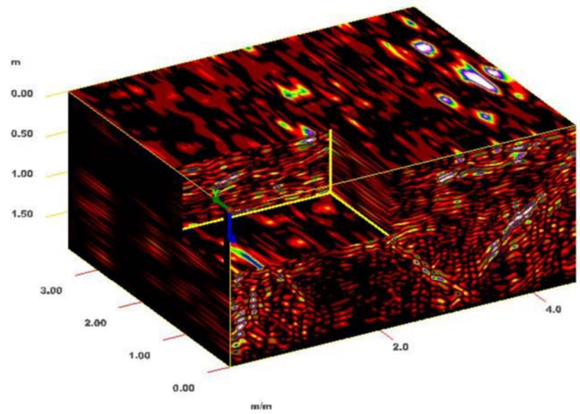
Surveys were completed with both the 400 and 500 MHz antennas pulled along the rope lines. Following data collection along a traverse line, the antenna was sequentially displaced about 13 inches across the grid to the next rope line, and the process was repeated. A total of 12 traverses were required to complete each GPR grid survey. Based on the depth to a known reflector (buried at a depth of 19 inches), the velocity of propagation (v) and relative dielectric permittivity (E_r) through the upper part of the soil profile were estimated. An E_r of 14.03 (v of 0.079 m/ns) was used to depth scale the radar imagery. Soils were considered exceedingly moist at the time of this investigation.

Results:
Grid Site:
Two 3D GPR pseudo-images are shown in Figure 2. In Figure 2, the upper and lower images were constructed from data recorded with the 400 MHz antenna on two separate days. It was raining and the soil surface was wet at the time of the June 4th survey. About twenty-four hours had elapsed and the surface was moist at the time of the June 5th survey. Both 3D GPR pseudo-images were submitted to the same processing (signal stacking, migration, and horizontal high pass filtration). The same display gain adjustments were used to enhance subsurface reflections. The 3D GPR pseudo-images were not subjected to terrain correction.

Compared with the imagery collected on 1 May, subsurface reflection were noticeably weaker. Broad hyperbolic patterns are evident in the 3D pseudo images shown in Figure 3. These are believed to represent reflection off of overhang foliage on tree limbs. The wetter surface conditions reflected a greater amount of energy, some of which bounced upward and of the tree limbs and foliage and returned to the antenna producing the broad hyperbolic patterns. Though still evident, these patterns are more weakly expressed on the data collected on the second day.

In the 3D pseudo-images shown in Figure 2, a sequence of stratigraphic layers is evident within the column of colluvium that fills the swale. These 3D pseudo-images provide a means of visualizing and interpreting the 3D continuity of these layers. As radar scans are continuously collected in the direction of the radar traverse (along the X axis; right foreground), subsurface features are better resolved along the direction of radar travel. In the orthogonal direction to the radar traverse (along the Y axis), images are interpolated between successive GPR traverses. These images are therefore more poorly resolved and appear smudged.

June 4 2008



June 5 2008

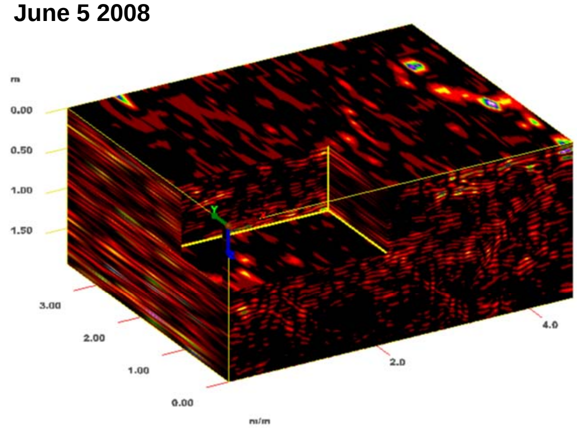


Figure 2. The radar records used to construct these two 3-D pseudo image of the grid site were collected on twenty four hours apart.. This grid was created from GPR traverses run parallel to X axis. In each image, a 213 x 133 x 82 cm inset cube has been removed.

<u>Infiltration Experiment:</u>
The Shale Hills Catchment is underlain by fractured rock. Because of the varied distribution and connectivity of fractures, fractured rocks offer highly complicated flow paths, which are difficult characterize. This study attempts to better understand and characterize ground-water flow paths in shallow soils over fractured bedrock, at scales of one to several meters.

An experiment was conducted to observe differences in subsurface reflection patterns associated with the infiltration of water in an area of Weikert soils. A metallic plate was buried at a depth of 48 cm and rested on the shale bedrock surface. A three-meter traverse line was established across the area containing the buried plate. Survey flags were inserted in the ground at distances of 50 cm along this line for reference. Before wetting, the estimated dielectric permittivity (E_r) and velocity of propagation (*v*) were 16.3 and 0.0738 m/ns, respectively. Radar traverses were completed before wetting, immediately after wetting, and at intervals of 5, 15, 30, and 45 minutes after wetting. Wetting was accomplished by pouring 20 liters of water onto the site. During wetting water flowed across the soil surface to the refilled hole over the buried plate, but did not appear to extend beyond this feature. The results of this study are shown in Figure 4.

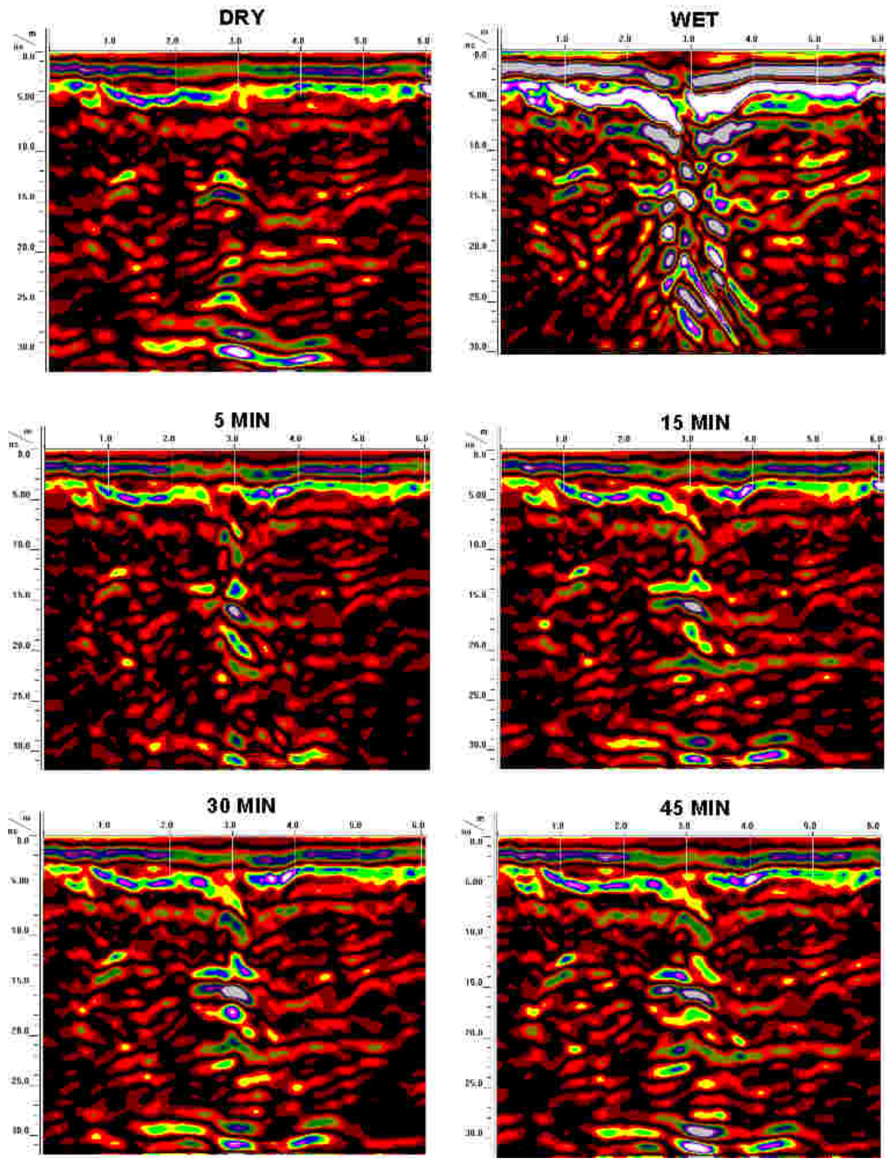


Figure 4. These 2D radar records show the results of a wetting experiment.

A metallic plate was buried at a depth of 48 cm near the fourth (labeled 3 in Figure 4) reference flag. The buried plate is evident in the "dry" radar record (in Figure 4, upper left image) at a time interval of about 13 ns. In the "wet" radar record, which was obtained immediately after wetting with the 20 liters of water, this reflector is difficult to identify, but appears at a time interval of about 15 ns (with the addition of water, *v* has decreased to 0.064 m/ns and E_r has increased to 21.7). The addition of water has increased the dielectric gradient (reflection coefficient) of the air/soil interface resulting in high amplitude reflections (colored grey and white) that cover the presumed area of wetting. This wetted area appears to extend across the entire traverse area. This may be an incorrect inference as the bottom of the antenna was also wetted by its passage over the area. In the "Wet" radar record (in Figure 4, upper right image), high amplitude reflection patterns that bend downwards at the fourth reference flag are inferred to represent the downward flow of water into the refilled hole used to place the metallic plate in. The increased water in the refilled-hole is responsible for reflection "multiples" evident within the hole.

After 5 minutes, water has moved downward into the soil profile noticeably reducing the contrast at the air/soil interface. In the "5 min" record, the refilled hole is more clearly identifiable than in the "Dry" or "Wet" radar records. On the "5 min" record, the buried plate is evident at a scanning time of 15.12 ns. This time interval corresponds to a velocity of 0.0635 m/ns (slight decrease from "Wet" record) and an E_r of 22.0 (slightly higher). In the "5 min" record, compared with the “Dry” record, the most noticeable changes in the radar refection patterns occur over and near the refilled hole. In the “15 min” radar record, the buried plate continues to provide a high-amplitude reflection, which appears more clearly expressed than in the “Dry "radar record. The time window to the buried plate reflection remains constant at 15.12 ns (the same as in the 5 minute radar record). In the “25 min”, the refilled hole remains clearly identifiable and the buried plate is evident at a scanning time of 14.93 ns. The reduction in the time window to the buried plate between the “15 min” and “25 min” radar records could indicate a decrease in soil moisture content as water drains and flows away from the refilled hole. However, this trend is not consistent in the “45 min” radar record where the time window is 15.05 ns. These slight differences are therefore assumed to be artifact from processing and picking errors.

References:

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