United States Department of Agriculture

NRCS

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SUBJECT: MGT – Trip Report, Geophysical Assistance, Illinois November 12, 2008

TO: William J. Gradle
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File Code: 330-7

Purpose:
In south-central Illinois, sodium-affect soils (SAS) are associated with distinct tonal patterns on aerial photographs. These patterns have suggested relict permafrost and periglacial features (e.g., thaw lakes, pattern ground, ice-wedges). In this study, EMI and GPR were respectively used to map the distribution of SAS soils and to help characterize the internal structure and geometry of features associated with these tonal patterns. In addition, in cooperation with Dr Robert Dunker of the University of Illinois, high-intensity EMI surveys were completed on two research fields located in Savoy, Champaign County.

Participants:
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Activities:
All activities were completed during the period of October 27 to 30, 2008.

Summary:

1. Nettleton et al. (1994) demonstrated the use of EMI as a rapid and accurate method to characterize the spatial distribution of sodium-affected soils (SAS) formed on moderately thick to thin loess over Illinoian till in south-central Illinois. This study expands on the work of Nettleton et al. (1994) through the synergistic use of cutting edge EMI and GPS technologies to improve data collection and interpretations.

2. Following EMI surveys in Washington and Montgomery Counties, soil scientists were guided to sampling sites by data displayed on the screen of an Allegro CX field computer using the TrackmakerEM38MK2 program. With this program, the current location of the operator and the collected apparent conductivity (EC_a) data are displayed as a color-scaled pseudo-grid image, in real time on the field computer. This allows soil scientists to immediately observe and analyze the results of EMI surveys and to move directly to sites of different EC_a for sampling and verifications of the factors influencing EC_a. The soils identified

at the core sites displayed increasing soil pH (associated with increasing sodium contents) with increasing EC_a. These results support the use of EMI to map variations in the concentrations of sodium in the SAS of central Illinois.

3. The affects of SAS on GPR was explored at sites in Washington and Montgomery Counties. While the performance of GPR was poor, depths of penetration were more favorable than anticipated. It was expected that penetration depths would be restricted to the surface layer and that the Btn horizon would not be detected with GPR. In areas of Darmstadt soil, penetration depths of 50 to 60 cm were obtained and the contact of the surface layers with the subsoil was identified. In SAS of Illinois, the responses of the 200 and 400 MHz antennas, while undeniably depth restricted, are comparable to those of similarly textured, non-sodium affected, medium and fine textured soils. Based on the results of this survey and others conducted in North Dakota, the affects of sodium on GPR needs to be reexamined.

4. Periglacial features (ice-wedge pseudomorphs, relict polygonal pattern ground), if present at the sites visited in Washington and Montgomery Counties, were too poorly expressed or ill-defined to be identified with either GPR or EMI. If present, it is suspected that infilled materials in wedges lack sufficient contrast with the enclosing soil matrix to be detected with either of these two geophysical techniques. Soils are generally too attenuating for the successful pursuit of these features with GPR. These features may lack sufficient sizes or dimensions to be distinguished with EMI.

It was my pleasure to work in Illinois and to be of assistance to your fine staff.

With kind regards,

JAMES A. DOOLITTLE
Research Soil Scientist
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Background:
Sodium-affected soils (SAS) have high concentrations of exchangeable sodium (Na) or have more exchangeable sodium and magnesium than calcium and hydrogen within the subsoil. Sodic soils have a sodium adsorption ratio (SAR) greater than 13 and an exchangeable sodium percentage (ESP) greater than 15 %. In Illinois, SAS (Natrudalfs) are intermingled with non-sodium affected soils (Hapludalfs, Albaqualfs, Endoaqualfs, Argiudolls, and Argiudolls). These soils developed predominantly in 1 to 2 m of Wisconsinan loess on the Illinoian drift plain. The accumulation of Na in SAS is hypothesized to result from the lateral movement of groundwater along relatively impervious substratum. Sodium rises in soil profiles and accumulates in the Btn horizon through evapotranspiration and/or impeded leaching.

Sodium affected soils occur as irregular-shaped areas varying in size from less than one acre (0.5 ha) to 8,686 acres (3518 ha). Areas of SAS produce distinct tonal patterns on aerial photographs. It has been noted that the tonal patterns produced by SAS in Illinois have geometries that are similar to the polygonal pattern grounds observed in periglacial and permafrost environments. In Illinois, Johnson (1990) has described the pattern ground seen on aerial photographs. He noted that these patterns are "commonly circular, but some are distinctly polygonal in outline". Furthermore, these features are apparent on aerial photographs "because the outer boundary zone of an individual element has a darker tone than the interior."

On the Illinoian drift plain, large-scale pattern ground-like features, which are observable on aerial photographs, commonly occurs on flat (less than 50 cm relief), poorly drained, undissected uplands covered by loess deposits (Johnson, 1990). The diameters of these features range from 10 to more than 100 m (Johnson, 1990). In Illinois, these patterns are evident because of differences in micro-topography and soil drainage. Typically, when investigated in the field, these features are high-centered (i.e., they have slightly raised interiors and lower-lying outer areas). The lower-lying, boundary areas are more poorly drained and have thicker A horizons, which accounts for their darker appearance on aerial photographs (Johnson, 1990). However, contradictions exist. The purpose of this investigation was to use electromagnetic induction (EMI) to map differences in apparent conductivity (EC_a), which, based on previous studies, should mimic the distribution of SAS soils (Nettleton et al., 1994). In addition the use of ground-penetrating radar (GPR) to characterize the internal structure and geometry of features associated with these tonal patterns was explored.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] 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 200 and 400 MHz were used in this study.

The RADAN for Windows (version 6.6) software program (GSSI; Salem, NH) was used to process the radar records.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (see Daniels (2004) for a discussion of these techniques). The Super 3D QuickDraw program developed by GSSI was used to construct three-dimensional (3D) pseudo-images of radar records collected at grid sites.

The EM38-MK2-2 and EM38DD meters (Geonics Limited, Mississauga, Ontario) were also used in this investigation.[1] These meters require no ground contact and only one person to operate. These meters measured the EC_a of soils, which is expressed in milliSiemens/meter (mS/m). The EM38-MK2-2 meter was used for the pedestrian EMI surveys that were completed on sites in Washington and Montgomery Counties. The EM38DD meter was used for the high-intensity, mobile EMI survey that was completed across research fields in Champaign County.

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

The EM38-MK2-2 meter weighs about 2.8 kg (6.2 lbs) and operates at a frequency of 14,500 Hz. The meter has one transmitter coil and two receiver coils. The receiver coils are separated from the transmitter coil at distances of either 1.0 or 0.5 m. This configuration provides nominal penetration depths of 1.5 and 0.75 m (for the 1.0 and 0.5 m coil spacings, respectively) in the vertical dipole orientation, and 0.75 and 0.38 m in the horizontal dipole orientation. The EM38-MK2-2 meter can provide simultaneous measurements of both quadrature-phase (conductivity) and in-phase (susceptibility) components within two depth ranges. Operating procedures for the EM38-MK2-2 meter are described by Geonics Limited (2008).

The EM38DD meter consists of two, coupled EM38 meters. Each EM38 meter weighs about 3 kg (6.6 lbs), has a 1-m intercoil spacing, and operates at a frequency of 14,600 Hz. When placed on the soil surface, these meters provide nominal penetration depths of about 0.75 m (meter positioned in the horizontal dipole orientation) and 1.5 m (meter positioned in the vertical dipole orientation). Operating procedures for the EM38DD meter are described by Geonics Limited (2000).

The coordinates of each EC_a measurement were recorded with a Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[2] An Allegro CX field computer (Juniper Systems, North Logan, UT) was used to record and store both EMI and position data.[2] The TrackmakerEM38MK2 and the TrackmakerEM38DD software programs (Geomar Software Inc., Mississauga, Ontario) were used to record, store, and process EMI and GPS data.[2]

Field Methods:

For the EMI surveys that were completed in Washington and Montgomery Counties, the EM38-MK2-2 meter was operated in the deeper-sensing vertical dipole orientation (VDO). Apparent conductivity data were recorded for both the 50 and 100 cm intercoil spacings. For the high-intensity EMI survey that was completed in Champaign County, an EM38DD meter was used. Both the EM38-MK2-2 and EM38DD meters were operated in the continuous (measurements recorded at a rate of 2/sec) mode. Using the TrackmakerEM38MK2 or the TrackmakerEM38DD programs, both GPS and EC_a data were simultaneously recorded in an Allegro CX field computer. While surveying, the EM38-MK2-2 meter was held about 5 cm (about 2 inch) above the ground surface; the EM38DD meter was placed in a plastic sled. Both meters were orientated with their long axes parallel to the direction of traverse. Surveys were completed by walking or driving (ATV) at a fairly uniform pace, in a back and forth pattern across each field (generally along crop rows). The EC_a data discussed in this report were not temperature corrected.

To collect the data required for the construction of 3D GPR pseudo-images, a survey grid was established at two sites located in Washington and Montgomery Counties. At the Washington County Site, two parallel, 30-m lines were spaced 42 m apart. Along each of these parallel lines, survey flags were inserted into the ground at a spacing of 100 cm. At the Montgomery County Site, two parallel, 10-m lines were spaced 12 m apart. Along each of these parallel lines, survey flags were inserted into the ground at a spacing of 50 cm. At both sites, a reference line was extended between matching survey flags on opposing sides of the grid using a distance-graduated rope. At each site, GPR traverses were conducted along the distance-graduated rope. A 400 and 200 MHz antenna were used at the Washington and Montgomery County sites, respectively. At each site, the antenna was towed along the graduated rope, and as it passed each 100-cm graduations, a mark was impressed on the radar record. Following data collection, the reference line was sequentially moved to the next pair of survey flags to repeat the process. A total of 31 and 21 traverses were conducted at the Washington and Montgomery County sites, respectively. Traverses were 40 and 10 m long at the Washington and the Montgomery County sites, respectively.

Calibration of GPR:

Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer, bedrock) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must

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be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (*v*) are described in equation [1] (after Daniels, 2004):

$$v = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to equation [2] (after Daniels, 2004):

$$E_r = (C/v)^2 \qquad [2]$$

Where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and *v*. At the time of this investigation, soils were moist.

Based on the measured depth and the two-way pulse travel time to a known subsurface reflector (a 25-cm diameter, metal plate buried at a depth of 50 cm), the velocity of propagation and the relative dielectric permittivity through the upper part of soil profiles were estimated using equations [1] and [2]. In areas of Darmstadt soils, using a 200 MHz antenna, the estimated E_r was 12.6 and the estimated *v* was 0.08396 m/ns. Also in areas of Darmstadt soils, using a 400 MHz antenna, the estimated E_r was 13.6 and the estimated *v* was 0.08066 m/ns.

Study Sites:

Washington County:

The site is located in a field of harvested soybeans just north of Nashville, Illinois, in the NE ¼ of Section 1, T. 2 S., R. 3 W. The site is situated in an area Hoyleton-Darmstadt silt loams, 0 to 2% (912A); and Darmstadt-Coulterville silt loams, 2 to 5 % slopes, eroded (880B2). The very deep, somewhat poorly drained Coulterville, Darmstadt, and Hoyleton soils formed in loess on uplands. All of these soils are considered to be affected by sodium, but to different extents. The sodium is associated with in situ weathering of sodium feldspars contained in the loess. Coulterville and Darmstadt contain noticeable concentrations of exchangeable sodium in their subsoil, but only Darmstadt soils have natric horizons. Table 1 lists the taxonomic classifications of the soils recognized at the Washington County site.

Table 1. Taxonomic Classification of Soils recognized at the Washington County site.

Soil Series	Taxonomic Classification
Coulterville	Fine-silty, mixed, superactive, mesic Aeric Epiaqualfs
Cowden	Fine, smectitic, mesic Mollic Albaqualfs
Darmstadt	Fine-silty, mixed, superactive, mesic Aquic Natrudalfs
Hoyleton	Fine, smectitic, mesic Aquollic Hapludalfs
Oconee	Fine, smectitic, mesic Udollic Endoaqualfs

Montgomery County:

Site 1 is located in a field of harvested soybeans just west of Litchfield, Illinois, in the NW ¼ of Section 31, T. 9 N., R. 5 W. The site is situated in areas of Oconee silt loam, 0 to 2 % slopes (113A); Harrison silt loam, 2 to 5 % slopes (127B); and Herrick-Biddle-Piasa silt loams, 0 to 2 % slopes (894A). All of these named soils are very deep and formed in loess overlying either silty or loamy materials. Biddle, Herrick, and Oconee soils are somewhat poorly drained. Harrison soils are moderately well drained. Piasa soils are poorly drained and contain high concentrations of exchangeable sodium and have natric horizons. The taxonomic classifications of the soils recognized at this site are listed in Table 2.

Table 2. Taxonomic Classification of Soils recognized at the Montgomery County sites.

Soil Series	**Taxonomic Classification**
Biddle	Fine, smectitic, mesic Aquic Argiudolls
Harrison	Fine-silty, mixed, superactive, mesic Oxyaquic Argiudolls
Herrick	Fine, smectitic, mesic Aquic Argiudolls
Oconee	Fine, smectitic, mesic Udollic Endoaqualfs
Piasa	Fine, smectitic, mesic Mollic Natraqualfs
Virden	Fine, smectitic, mesic Vertic Argiaquolls

Site 2 is located in a field of harvested soybeans about 3 miles west of Nokomis, Illinois, in the SW ¼ of Section 17, T. 10 N., R. 2W. The site is situated in areas of Herrick-Biddle-Piasa silt loams, 0 to 2 % slopes (894A); and Virden silty clay loam, 0 to 2 % slopes (50A). All of these named soils are very deep and formed in loess overlying either silty or loamy materials. Virden soils are poorly drained. The taxonomic classifications of the soils recognized at this site are listed in Table 2.

<u>Champaign County:</u>
The site is located on two research fields of corn stubble just east of Savoy, Illinois, in the NW ¼ of Section 31, T. 19 N., R. 9 E. These fields are situated in areas of Drummer silty clay loam, 0 to 2 % slopes (152A); and Flanagan silt loam, 0 to 2 % slopes (154A). The very deep, poorly drained Drummer soils formed in loess or other silty material and in the underlying loamy stratified outwash on till plains. Drummer is a member of the fine-silty, mixed, superactive, mesic Typic Endoaquolls family. The very deep, somewhat poorly drained Flanagan soils formed in loess or other silty material and the underlying loamy calcareous till on till plains. Flanagan is a member of the fine, smectitic, mesic Aquic Argiudolls family.

EMI Results:

<u>Washington County site:</u>
Table 3 provides basic statistics for EMI survey that was completed with the EM38MK2-2 meter at the Washington County site. Within this site, values of EC_a are moderate and relatively invariable (both spatially and with depth). Within the site, EC_a ranged from about 1.4 to 78.0 mS/m. With the shallower-sensing, 50-cm intercoil spacing, EC_a averaged 26.5 mS/m, and one-half of the measurements were between about 20.4 and 31.9 mS/m. With the deeper sensing, 100-cm intercoil spacing, EC_a averaged 44.2 mS/m, and one-half of the measurements were between about 36.9 and 50.4 mS/m. In general, EC_a increases and becomes more variable with increasing measurement depth. This trend in EC_a reflects increases in clay, moisture, and soluble salt contents with depth. However, in areas of SAS, though other factors influence the EMI responses, increases in EC_a are principally associated with increasing concentrations of clays and exchangeable sodium in the lower part of soil profiles.

Table 3. Basic statistics for the EMI survey that was conducted at the Washington County site with the EM38MK1-2 meter operated in the vertical dipole orientation

Intercoil Spacing	**Numb er**	**Minimu m**	**25%-tile**	**75%-tile**	**Maximu m**	**Mea n**	**St. Dev.**
50 cm	2714	1.41	20.43	31.88	52.73	26.49	8.32
100 cm	2714	25.39	36.88	50.43	78.05	44.25	0.24

At the Washington County site, three cores extracted within areas of lower EC_a were identified as Oconee (1) and Cowden (2) soils. Two cores extracted in areas of higher EC_a were identified as Darmstadt (highest EC_a) and Coulterville soils. These field observations support the responsiveness of EC_a to observed differences soil pH and the implied spatial variations in sodium concentrations.

Figure 1 show plots of EC_a data collected with EM38-MK2-2 meter at the Washington County site. For display purposes, the same color scale and intervals have been used in each plot. The two plots show the spatial distribution of EC_a in both the shallower-sensing (0 to 75 cm) 50-cm (upper plot) and deeper-sensing (0 to 150 cm) 100-cm (lower plot) intercoil spacings. In each plot, the four-sided figure enclosed with a segmented line represents the location of a GPR grid, which will be discussed in a latter section of this report.

As evident in the plots shown in Figure 1, EC_a is not uniform across this site, but appears to form distinct interconnected *clusters* or *pock-mark* patterns. Similar to the "*clustered soil patterns*" discussed by Johnson (1990), the patterns evident in these plots (Figure 1) are comparatively broad and rounded. Areas of higher EC_a appear to form discontinuous, irregular, linear patterns across the site. These patterns, though interconnected and with some forming seemingly polygons, are rather broad, which is not a characteristic of ice-wedge pseudomorphs. Johnson (1990) reported a maximum ice-wedge cast width of 2 m, with most less than 1 m. Besides the ostensible linear and intersecting spatial patterns of higher EC_a, what is noticeable in these plots is the relative increase in EC_a with increasing depth. Assuming that the source of sodium and other soluble salts is influenced by the depth to the underlying Illinoian paleosols and/or proximity to the water table, the depth-EC_a relationships shown in these plots is reasonable. Spatial EC_a pattern may represent the upward migration and discharge of sodium and other salts caused by ground water flow through narrower ice-wedge pseudomorphs or involutions.

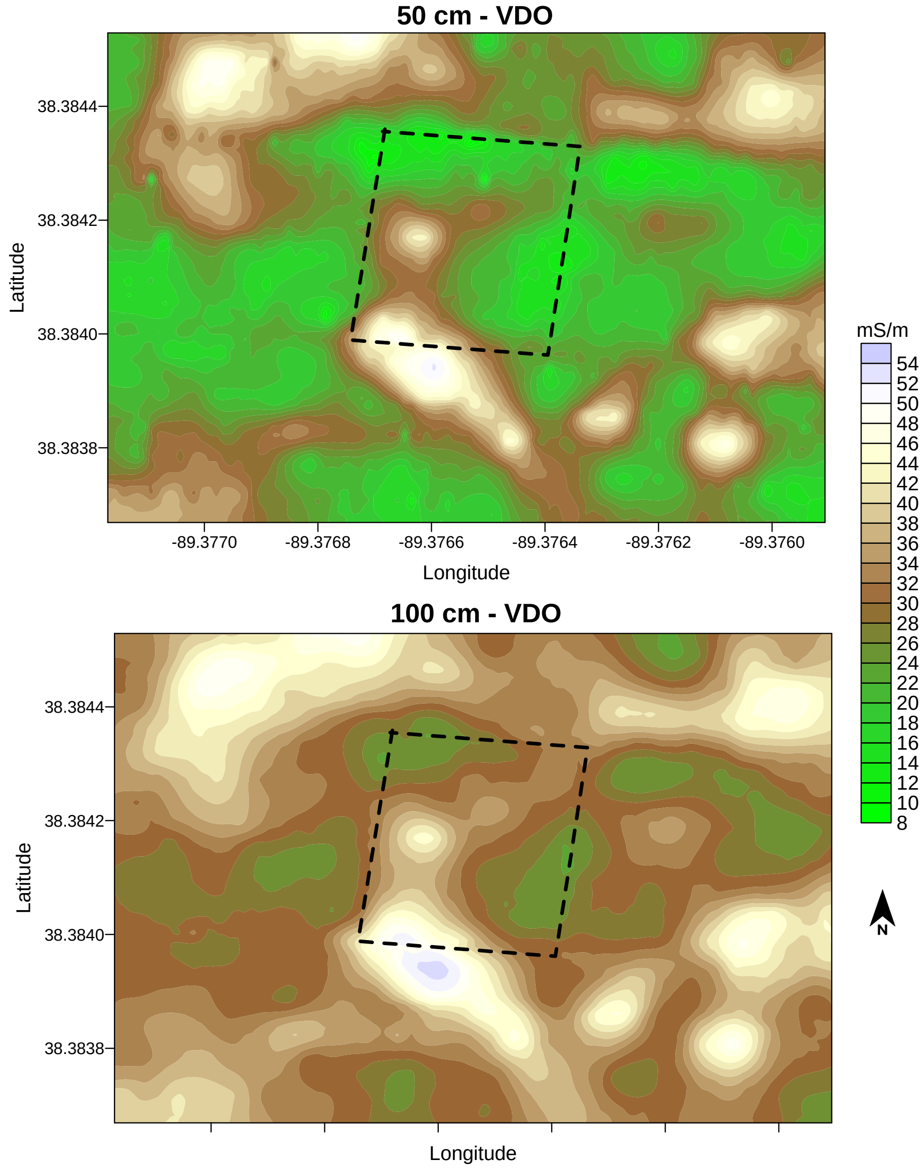


Figure 1. Spatial distribution of EC_a *collected with the EM38-MK2-2 meter operated in the vertical dipole orientation (VDO) at the Washington County site. Plots show data for the shallower-sensing 50-cm (top) and the deeper-sensing 100-cm (bottom) intercoil spacings.*

Montgomery County site:

Table 4 provides basic statistics for the EMI survey that was completed with the EM38MK2-2 meter at Site 1 in Montgomery County. Comparing Tables 3 and 4, results from the EMI survey at Site 1 in Montgomery County were similar to those from the Washington County site. At both sites, EC_a increases and becomes more variable with increasing measurement depth. However, at Site 1 in Montgomery County, the averaged EC_a was slightly higher and measurements were more variable with depth. Within Site 1 in Montgomery County, EC_a ranged from about 0.0 to 86.8 mS/m. With the shallower-sensing, 50-cm intercoil spacing, EC_a averaged 23.4 mS/m, and one-half of the measurements were between about 15.5 and 30.9 mS/m. With the deeper sensing, 100-cm intercoil spacing, EC_a averaged about 51.0 mS/m, and one-half of the EC_a measurements were between about 42.9 and 60.4 mS/m.

Table 4. Basic statistics for the EMI survey that was conducted at site 1 in Montgomery County with the EM38MK1-2 meter operated in the vertical dipole orientation

Intercoil Spacing	Numb er	Minimu m	25%-tile	75%-tile	Maximu m	Mea n	St. Dev.
50 cm	4215	0.02	15.49	30.88	60.96	23.36	10.58
100 cm	4215	24.49	42.89	60.35	86.83	50.96	12.78

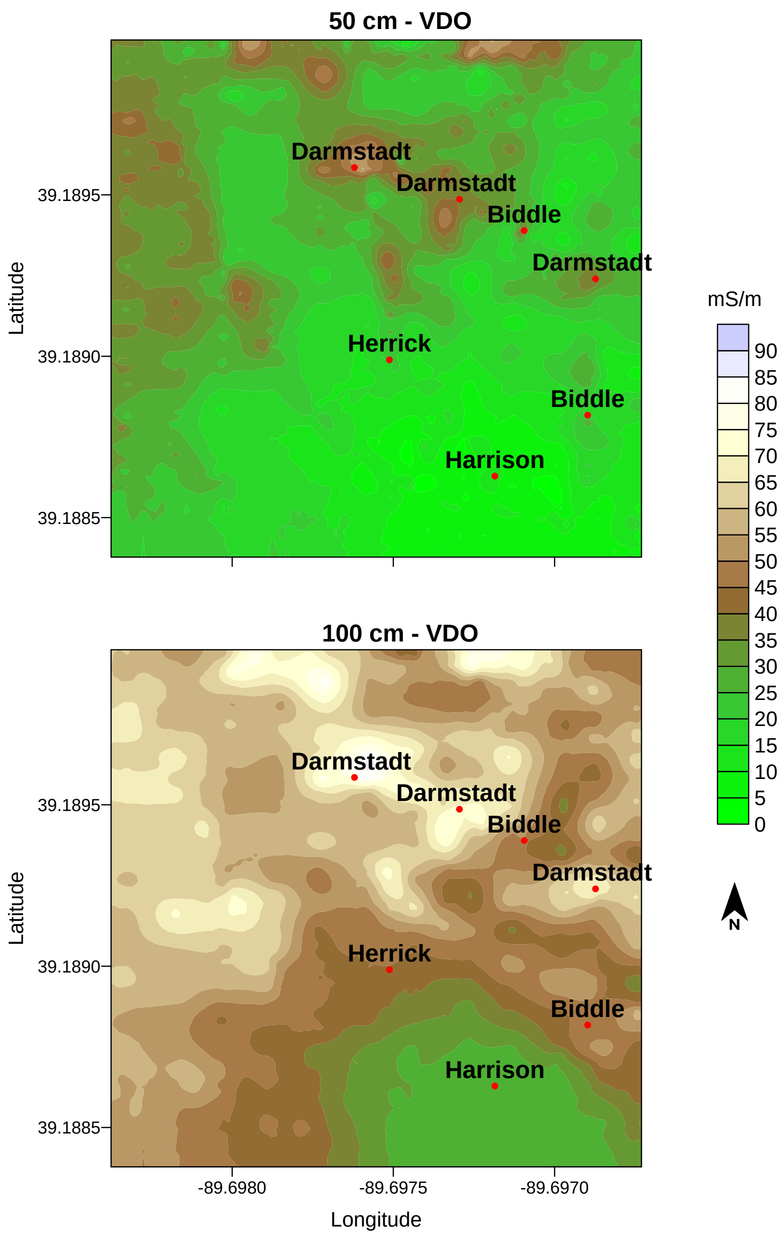


Figure 2. Spatial distribution of EC_a collected with the EM38-MK2-2 meter operated in the vertical dipole orientation (VDO) at site 1in Montgomery County. Plots show data for the shallower-sensing 50-cm (top) and the deeper-sensing 100-cm (bottom) intercoil spacings.

Figure 2 contains plots of EC_a data collected with EM38-MK2-2 meter at site 1 in Montgomery County. The names and locations of the soils identified at seven core sites are shown in Figure 2. Cores extracted in areas of higher EC_a (>65 mS/m in VDO) were identified as Darmstadt soils. A core extracted from a higher-lying swell in the southeast corner of the survey area was identified as Harrison soils. This soil displayed the lowest EC_a (< 30 mS/m in VDO), had a thicker silt loam mantle, and noticeably lowers pH.

Soil scientists were guided to the core sites by the EC_a data displayed on the screen of a field computer using the TrackmakerEM38MK2 program. With this program, the measured EC_a data were color-coded and displayed on the field computer. This display allows soil scientists to immediately observe the results of EMI surveys and to move directly to sites of different EC_a for sampling and verifications of factors influencing the EC_a. The soils identified at these core sites displayed increasing soil pH and EC_a with increasing depth. These results support the use of EMI to map variations in the concentrations of sodium in the SAS of central Illinois.

Table 5 provides basic statistics for surveys that was completed with the EM38MK2-2 meter at Site 2 in Montgomery County. Comparing Tables 4 and 5, results from the EMI survey at the two sites in Montgomery County are closely similar. This likeness reflects the similarity of soils at these sites. At both sites, EC_a increases and becomes more variable with increasing measurement depth. Within site 2 in Montgomery County, EC_a ranged from about 0.6 to 84.0 mS/m. With the shallower-sensing, 50-cm intercoil spacing, EC_a averaged 32.1 mS/m, and one-half of the measurements were between about 25.4 and 37.2 mS/m. With the deeper sensing, 100-cm intercoil spacing, EC_a averaged about 50.1 mS/m, and one-half of the EC_a measurements were between about 43.4 and 55.7 mS/m.

Table 5. Basic statistics for the EMI survey that was conducted at site 2 in Montgomery County with the EM38MK1-2 meter operated in the vertical dipole orientation

Intercoil Spacing	Number	Minimum	25%-tile	75%-tile	Maximum	Mean	St. Dev.
50 cm	6573	0.57	25.41	37.17	74.55	32.11	9.53
100 cm	6573	27.84	43.43	55.66	83.98	50.11	9.13

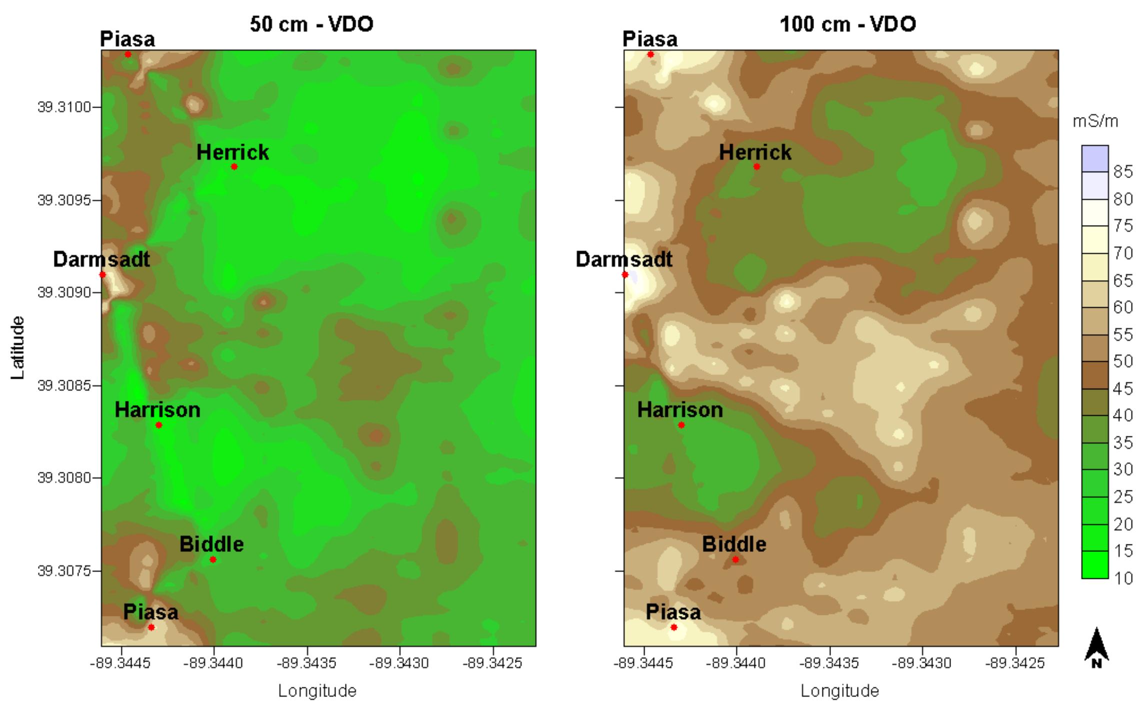


Figure 3. Spatial distribution of EC_a collected with the EM38-MK2-2 meter operated in the vertical dipole orientation (VDO) at site 2 in Montgomery County. Plots show data for the shallower-sensing 50-cm (left) and the deeper-sensing 100-cm (right) intercoil spacings.

Using same procedures that were used at site 1, five soil cores were extracted and examined at site 2 in Montgomery County. Once more, soil scientists were guided to these core sites by the EC_a data displayed on the screen of a field computer using the TrackmakerEM38MK2 program. The soils identified at the core sites displayed increasing clay contents, soil pH, and EC_a with increasing soil depths. These results provide additional encouragement for the use of EMI to map variations in the concentration of sodium and the distribution of SAS in central Illinois.

Figure 3 show plots of EC_a data collected with EM38-MK2-2 meter at site 2 in Montgomery County. The locations and identities of the soils observed at the cores sites are also shown. The three cores extracted in areas of higher EC_a (> 60 mS/m in VDO) were identified as Darmstadt and Piasa soils. The Darmstadt soils observed in cores extracted from this site belonged to the fine rather than the fine-silty family. A core extracted from a higher-lying swell in the southwest portion of the survey area was identified as Harrison soils. This soil has a relative low EC_a (< 35 mS/m in VDO), thicker silt loam mantle, and noticeably lowers pH. At both sites, areas of Herrick and Biddle soils have intermediate EC_a (Herrick 40 to 45 mS/m and Biddle 45 to 55 mS/m in the VDO). Because of distinct combinations of physical and chemical properties, soils will display unique ranges in EC_a. Values of EC_a can be used to help identify and determine the composition and distribution of these soils within soil delineations.

<u>Champaign County:</u>
Table 6 provides basic statistics for the high-intensity surveys that were completed with the EM38DD and EM31 meters on two research fields near the town of Savoy. Soil EC_a was relatively invariable across these fields. However, the presence of buried utility lines, which crossed these field in a north-south direction, produced anomalous (both positive and negative) EMI responses. The presence of these utility lines is responsible for the large range in recorded EC_a values in these fields. In Table 6, the meters and dipole orientations are listed from top to bottom according to increasing penetration depth (0 to 75 cm, 0 to 150 cm, and 0 to 600 cm). Hence, the averaged EC_a is seen to increase then decrease slightly with increasing soil depth. This trend suggests an intermediate layer of higher clay, moisture and/or soluble salt contents that is underlain by a more electrically resistive layer.

Table 6. Basic statistics for the EMI surveys conducted at the University of Illinois Farm with the EM38DD and EM31 meters

Intercoil Spacing	Number	Minimum	25%-tile	75%-tile	Maximum	Mean	St. Dev.
EM38 HDO	6173	22.38	30.88	35.13	47.38	33.12	3.26
EM38 VDO	6173	30.63	40.50	44.88	64.13	42.81	4.06
EM31 VDO	8183	-40.33	30.99	35.10	94.20	33.30	6.73

Figure 4 contains plots of EC_a data collected with EM38DD meter over an area that spans the two research fields. The upper plot shows data collected in the shallower-sensing, horizontal dipole orientation (HDO); the lower plot shows data collected in the deeper-sensing, VDO. Spatial EC_a patterns collected in the HDO are relatively nondescript as EC_a values appear uniform at these shallow soil depths. Spatial EC_a patterns collected in the VDO are more descriptive. Not only does EC_a appear to be more variable at deeper soil depths, but the influence of utility lines produces anomalous responses across the east-central portions of the survey area. In the lower plot (Figure 4), spatial EC_a patterns appear reasonably similar to available soil and yield maps of these two fields.

Figure 5 contains the plot of EC_a data collected with the EM31 meter operated in the VDO. Across these two research field, the range of EC_a recorded with the EM31 meter was about -44.3 to 94.2 mS/m. This range largely reflects the presence of the buried utility lines. With the EM31 meter, EC_a averaged 33.3 mS/m, and one-half of the measurements were between about 31.0 and 35.1 mS/m. These values suggest that over a depth of about 600 cm, the soils are comparatively uniform (spatially) in physical and chemical properties.

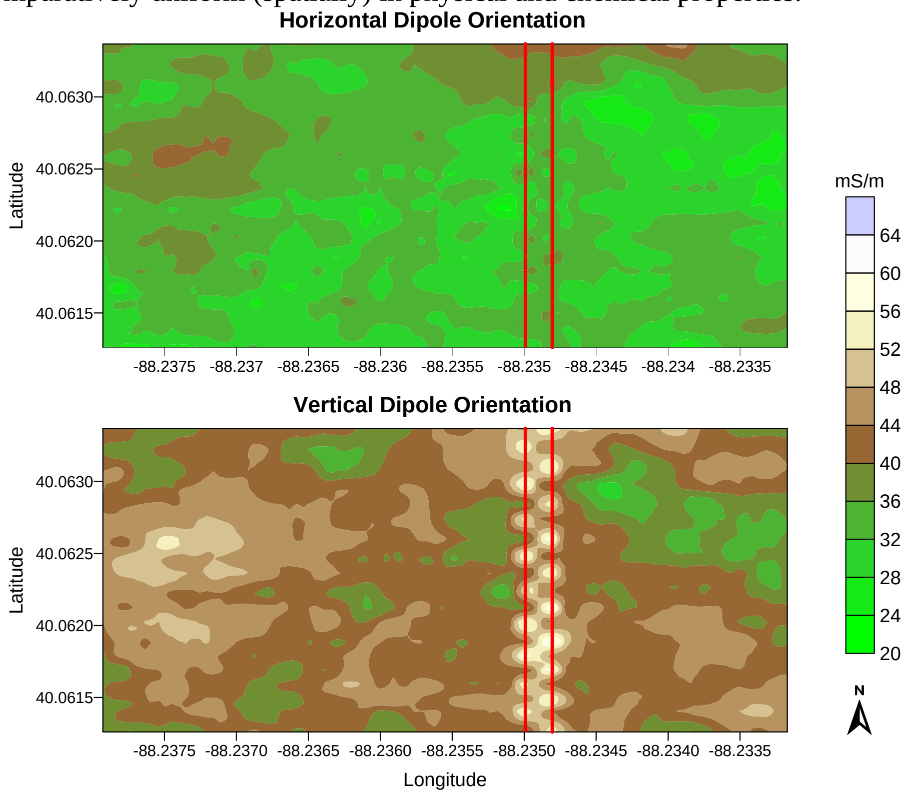


Figure 4. Spatial distribution of EC_a collected with the EM38DD meter on two University of Illinois research fields in Champaign County. Plots show data for the shallower-sensing horizontal (top) and the deeper-sensing vertical (bottom) dipole orientations. The red lines identify the approximate location of the buried utility lines.

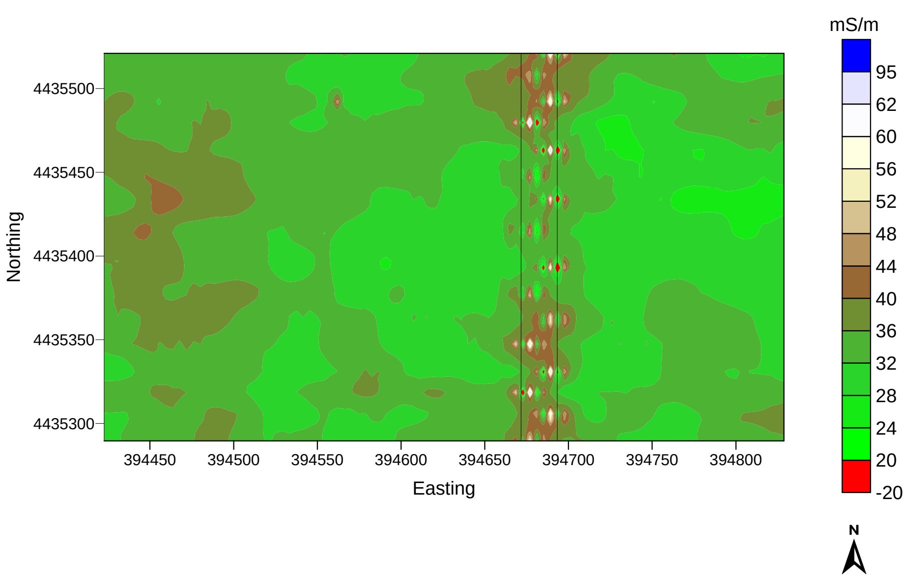


Figure 5. Spatial distribution of EC_a collected with the EM31 meter operated in the vertical dipole orientation on two University of Illinois research fields in Champaign County. The black lines identify the approximate location of the buried utility lines.

GPR Results:
Based on field observations and data contained in the STATGO and SURRGO data bases, maps have been prepared at different scales and levels of resolution (http://soils.usda.gov/survey/geography/maps/GPR/index.html) by the USDA-NRCS showing the suitability of soils to GPR. Because of high levels of exchangeable sodium, sodium-affected soils have been considered unsuited to GPR. In SAS, sodium occupies more than 15 % of the soil's cation exchange capacity (CEC). In addition, SAS can have high levels of other cations (calcium, magnesium, potassium).

Figure 6 contains two, 2D radar records obtained with the 200 and 400 MHz antennas. These records were obtained in an area of Hoyleton soil. On these radar records, depths are expressed in cm; distances are expressed in meters. On each radar record a metal plate, which is 25 cm in diameter, is evident at a depth of 50 cm beneath the 2.0 m distance mark. This reflector produces a hyperbolic reflection (^ shaped). This reflector produced a higher-amplitude reflection on the radar record obtained with the 400 MHz antenna, but a very low-amplitude and hardly detectable reflection with the 200 MHz antenna. Other than this highly contrasting artifact, no subsurface features are clearly shown or are interpretable on these radar records.

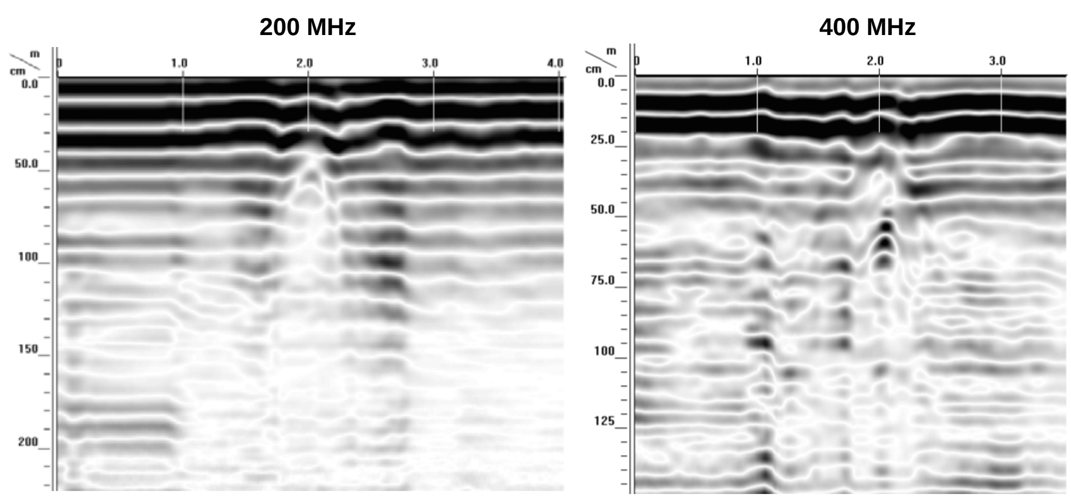


Figure 6. These two 2D radar records were recorded with the 200 (left) and 400 (right) MHz antennas. On each radar record, a 25 cm diameter, metal plate, which was buried at a depth of 50 cm, is evident beneath the 2.0 m distance mark.

The buried plate experiment was used to depth scale the radar records. Though no subsurface soil interface was clearly expressed on these radar records (Figure 6), in other areas of the Washington and Montgomery sites, the subsoil was evident. In general, with either antenna, penetration depths were restricted to the upper part of the argillic (Bt1) or natric (Btn1) horizon. Coarser textured (silt loam) surface layers (Ap and E horizons) form an abrupt and contrasting interface with the underlying, finer-textured (silty clay loam) argillic or natric horizons. This interface reflected a sufficient amount of energy to be visible on radar records. However, advanced signal processing was required to improve the clarity of this interface on 2D radar records and 3D pseudo images so that it could be identified and properly interpreted. Processing included: range gain adjustments, signal stacking, migration, and horizontal high pass filtration.

Figure 7 is as a highly processed, 2D radar record, which was recorded with a 400 MHz antenna at the Washington County site. On this radar record, depths are expressed in cm; distances are expressed in meters. The interpreted depth to the subsoil has been highlighted with a green-colored, segmented line. Although the surface layer / subsoil interface varies in expression and clarity, it can be traced laterally, with reasonable confidence, across the radar record. In the upper part of this radar record, the intermittent and weakly-expressed, subsurface layer at "A" is suspected to represent the base of the plow layer. Triangles have been used to identify several point anomalies (generally overlying well-expressed and vertically arranged, reverberated signals). While the features that produce these reflections were not confirmed and are therefore unknown, clusters of nodules and/or concretions, or other contrasting soil materials are possible causal factors. With further ground-truth examinations, these narrow, vertical reverberations may be found to possibly represent dissimilar infilled materials in partially collapsed ice-wedges pseudomorphs. As noted by Johnson (1990), in Illinois, wedges are typically disrupted and show evidence of slumping, mass flow and collapse. As a consequence, ice-wedge pseudomorphs will be discontinuous and contain inclusions of similar materials, which will result in their poor and sporadic expressions on radar records.

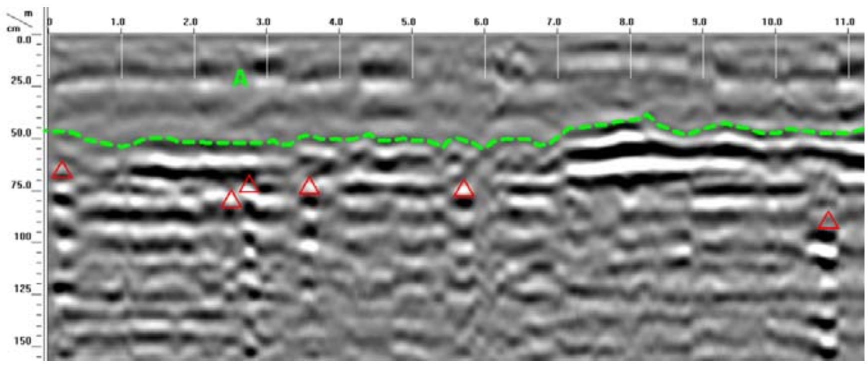


Figure 7. On this 2D radar record, which was recorded with a 400 MHz antenna, the interpreted depth to the subsoil has been highlighted with a green-colored, segmented line. Triangles identify point anomalies believed to be produced by clusters of nodules and/or concretions, other contrasting materials, or even ice-wedge pseudomorphs.

Figure 8 is a 3D pseudo-image of a grid site located in a delineation of Hoyleton-Darmstadt silt loams, 0 to 2 % slopes (912A), in Washington County. The radar records used to prepare this 3D pseudo-image were collected with a 400 MHz antenna. In this image, a 30 by 25 m wide, 45 cm deep inset has been removed from the solid 3D cube for display purposes. The base of the cutout cube closely approximates the depth to the Bt1 or Btn1 horizons. High amplitude reflections (white-colored) along the base of the cutout cube helps to identify the contact between the surface layers and the subsoil. This interface is deeper and has not been sliced by the base of the cutout cube in areas that are colored gray. A segmented, black-colored line defines the boundary of a relatively large area (A) composed of low amplitude signals. These low amplitude signals suggest deeper depths to the surface layers / subsoil contact. The shape of this area evokes a potential buried feature.

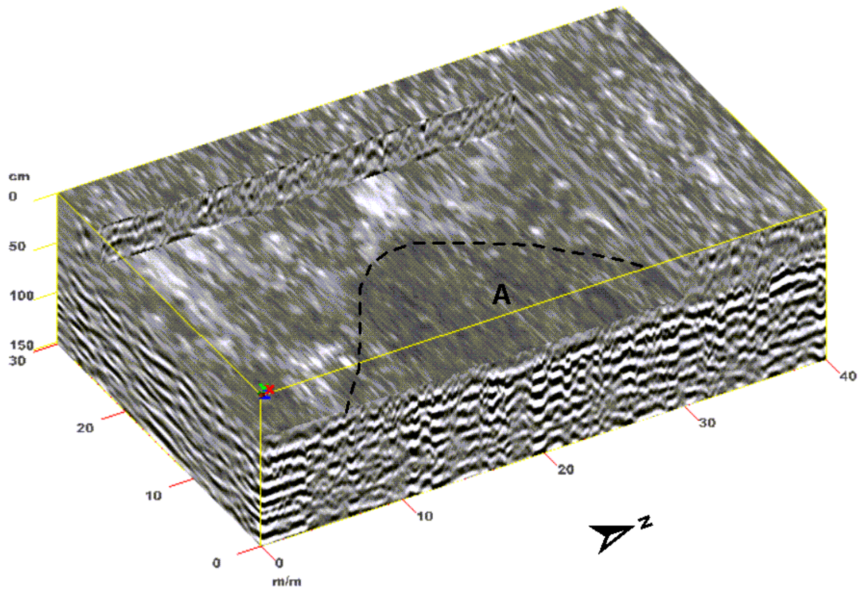
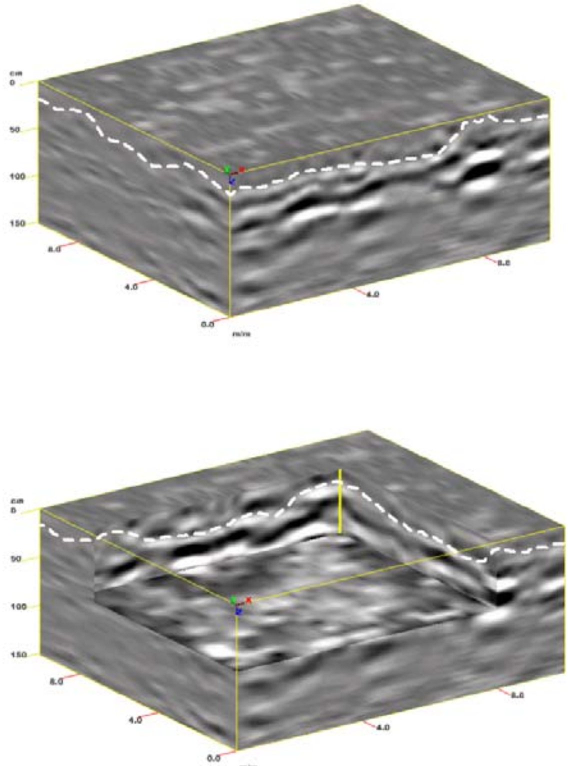


Figure 8. Radar records for this 3D pseudo image were collected with a 400 MHz antenna in an area of Hoyleton-Darmstadt silt loam, 0 to 2%. A 30 x 25 m, 45 cm deep inset cube has been graphically removed from this image.

Figure 9 contains two 3D pseudo-images from a small grid site located in a delineation of Herrick-Biddle-Piasa silt loams, 0 to 2 % slopes (894A), at site 1 in Montgomery County. The radar records used to prepare this 3D pseudo-image were collected with a 200 MHz antenna. The upper 3D pseudo-image is an intact solid cube. Along the exposed sides of this cube, a segmented, white-colored line has been used to identify the upper boundary of the subsoil. In the lower 3D pseudo-image, an 8 by 8 m wide, 70 cm deep cube has been removed from the solid 3D cube for display purposes. Along the exposed sides of this cube, a segmented, white-colored line has once again been used to identify the upper boundary of the subsoil. The base of the cutout cube exposes high amplitude (white-colored) reverberated signals from this interface. No meaningful subsurface information can be gleaned below the upper boundary of the subsoil. Subsurface interfaces are generally blurred and ill-defined on 2D and 3D radar images from this site.



These 3D pseudo images were collected with a 200 MHz antenna in an area of Darmstadt soils at a site in Montgomery County Site. The dashed white line indicates the interpreted depths to the Btn1horizon. In the bottom image, an 800 by 800 by 70 cm cube has been graphically removed.

The affects of SAS on GPR was explored at sites in Washington and Montgomery Counties. While the performance of GPR was poor, depths of penetration were more favorable than anticipated. It was anticipated that penetration depths would be restricted to the surface layer and the Btn horizon would not be detected with GPR. In areas of Darmstadt soil, penetration depths of 50 to 60 cm were obtained and the contact of the surface layers with the subsoil was detected. In SAS of Illinois, the responses of the 200 and 400 MHz antennas, while undeniably depth restricted, are comparable to similarly textured, non-sodium affected soils. Based on the results of this survey and others conducted in North Dakota, the affects of sodium on GPR needs to be examined more fully.

References:

Daniels, D. J. 2004. Ground Penetrating Radar; 2^{nd} Edition. The Institute of Electrical Engineers, London, United Kingdom.

Geonics Limited, 2008. EM38-MK2 ground conductivity meter operating manual. Geonics Limited, Mississauga, Ontario.

Geonics Limited, 2000. EM38DD ground conductivity meter: Dual dipole version operating manual. Geonics Limited, Mississauga, Ontario.

Johnson, W. H., 1990. Ice-wedge casts and relict pattern ground in central Illinois and their environmental significance. Quaternary Research 33: 51-72.

Nettleton, W. D., L. Bushue, J. A. Doolittle, T. J. Endres, and S. J. Indorante, 1994. Sodium-affected soil identification in south-central Illinois by electromagnetic induction. Soil Sci. Soc. Am. J. 58:1190-1193.