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

Subject: Soils – Geophysical Field Assistance **Date:** 31 January 2007

To: T. Niles Glasgow
State Conservationists
USDA-Natural Resources Conservation Service
2614 NW 43rd Street
P.O. Box 141510
Gainesville, FL 32614-1510

Rick Robbins
Acting State Soil Scientist
USDA-Natural Resources Conservation Service
2614 NW 43rd Street
P.O. Box 141510
Gainesville, FL 32614-1510

Purpose:
The purpose of this visit was to provide training to soil scientists located in the panhandle of Florida on the operation of the SIR System-2000 ground-penetrating radar (GPR), and the fundamentals of collecting and interpreting radar data.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Martin Figueroa, Soil Scientist, USDA-NRCS, Quincy, FL
Willie Nelson Jr., Soil Scientist, USDA-NRCS, Quincy, FL
Andrew Williams, Soil Scientist, USDA-NRCS, Milton, FL
Mikel Williams, Soil Scientist, USDA-NRCS, Quincy, FL

Activities:
All activities were completed during the period of 23 to 25 January 2007.

Recommendations:
In October 1999, I provided training to Eddie Cummings and Doug Lewis on the operation of the Subsurface Interface Radar (SIR) System-2000 ® radar units that had been recently purchased by the Florida Soil Staff. In February 2004, I returned to Florida and provided training to Eddie Cummings on the RADAN for Windows ® processing program. At that time, it was learned that the data transfer program was not compatible with the Windows XP operating system used by NRCS.

In the last five years, the SIR-2000 system radar unit, while highly functional, has been outpaced by technological advances and has been superseded by the TerraSIRch Subsurface Interface Radar (SIR) System-3000 ®. The availability of computers with larger storage capacities and faster operating speeds, and more sophisticated software programs have greatly improved GPR data processing, interpretation, and visualization. Radar records are now being stored, processed, and visualized through RADAN for Windows software. This rather expensive program was purchased for Eddie Cummings, but was not used because of the impasses over data transfer to modern computers. Operating systems and speeds on the SIR-2000 system radar unit are out-of-date and incompatible for transferring data to modern computers.   Grey scale printers, such as the T-104 printer presently used by the Florida staff to display radar records (as very poor quality strip chart records), are no longer supported by the vendor and are considered relics of the past.

Ground-penetrating radar was first used by USDA in Florida. This geophysical tool has had a rich and successful history of use by USDA soil scientists in Florida. If this program continues in Florida with the younger soil scientists that I worked with this week, I strongly recommend the purchase of a TerraSIRch Subsurface Interface Radar (SIR) System-3000. However, budget constraints may not make this possible at this time. As an interim measure, I would recommend the modification of the present SIR-2000 system to accept a flash card for data transfer. Radar data could then be transferred from the SIR-2000 system via a flash card reader into a field office computer for data processing, interpretation, and visualization through the RADAN for Windows software program that is presently available to these soil scientists. Although RADAN does not meet all CCE standards, a conditional waiver has been granted by the USDA-NRCS-ITC Software Test Laboratory (Fort Collins, Colorado) for the use of RADAN on CCE computers used by USDA-NRCS radar operators.

During my short visit to Florida, I purposely collected radar data on my SIR System-3000 radar unit and have included examples of radar data that were processed with the RADAN software in this report. I think that you will agree that these visualizations are not only vastly superior to the grey-scale strip chart records, but will improve interpretations and enhance reports supplied to our customers.

Responding to this perceived need, I was just quoted (Sales quote # 04079) by Ken Corcoran (Applications Specialist, Geophysical Survey Systems, Inc.) a cost of $700 for the upgrade (with removable CF card for data transfer) to one of Florida's SIR-2000 GPR units. In addition, the present SIR-2000 system lacks a needed DC power cable (part number FG2A/DC CBL; $430) and requires two new rechargeable 12 volt batteries (part number FGMODBP-12; $260). I also inquired about harness for the SIR-2000 system, which would allow pedestrian surveys, but this component is no longer available from the vender.

It was my pleasure to work in Florida and to be of assistance to your staff. It was my pleasure to work with Andrew, Martin, Mikel, and Willie. I found these young soil scientists to be very enthused with GPR technology. The National Soil Survey Center pledges its continued assistance in providing whatever GPR training and guidance is needed by the Florida staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
B. Ahrens, Director, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
D. Hammer, National Leader, Soil Investigation Staff, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
C. Love, MLRA Office Leader, USDA-Natural Resources Conservation Service, 3381 Skyway Drive , P.O. Box 311, Auburn, AL 36830
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697
A. Williams, Soil Scientist, USDA-NRCS, Soil Survey Office, 5230 Willing Street, Milton, FL 32570

Equipment:
A Subsurface Interface Radar (SIR) System-2000 ® ground-penetrating radar unit has been reassigned to soil scientists stationed in the Quincy Soil Survey Office. This unit was formerly operated by Eddie Cummings. During the course of this visit, the unit and its essential components were examined. The digital control unit (DC-2000) is in very good working condition, as are the 200 and 400 MHz antenna. A power cable that supplies power to the control unit is missing (during this visit, in order to supply power to the control unit, an adapter with clips was jury-rigged to the battery. This is improper.). A power cable needs to be ordered. One of the two batteries will not hold a charge and the other is questionable. Two, 12-volt rechargeable batteries need to be ordered to provide ample power to support GPR field investigations. The digital control unit is backpack portable, but lacks a carrying harness. The lack of a carrying harness limits surveys to areas that are accessible to a vehicle. A carrying harness would allow areas that are accessible by foot, but not by vehicle (e.g., wooded and/or wet areas) to be surveyed. Unfortunately, the carrying harness is no longer available or supported by the vendor.

The RADAN for Windows (version 5.0) ® software program was purchased by the Florida State Office for Eddie Cummings. This program is very expensive. GPR systems maintained by NRCS soil scientists in California, Massachusetts, New York, New Hampshire, North Carolina, and Pennsylvania also have the RADAN processing software. These soil scientists find that this software greatly improves the clarity of subsurface information and interpretations. The software enables the processing of radar records, which can significantly improve interpretations. RADAN software enables the production of terrain corrected images which can greatly improve soil-landscape interpretations. Three-dimension time sliced images have been used effectively to locate cultural features such as buried drainage tiles, utility lines, and other artifacts. Color enhanced radar images not only improve interpretations, but provide impressive diagrams for inclusions in reports to customers.

Figure 1. A modification to the Massachusetts's SIR System-2000 unit permits GPR data to be stored and transferred via a flash card.

When NRCS converted from the Windows NT operating system to XP, the transfer of GPR data into PC and laptop computers became more problematic. The SIR System-2000 unit was designed for data transfer with operating systems and speeds used at the time of its development. Present operating systems and speeds have proven incompatible with the software installed in the SIR System-2000 unit. In the last year, unsuccessful attempts were made by NRCS IT staffs in Massachusetts and New York to accomplish data transfer from SIR System-2000 units. It was learned through discussions with technical specialists at Geophysical Survey Systems, Inc., that GPR data transfer from the SIR System-2000 into modern computers, though possible, is ill-advise and difficult. Two courses of action can be considered: Purchase a new SIR System-3000 unit to replace the current SIR System-2000 unit (about $14,000 with GSA discount), or modify the existing unit to accept a flash card (then transfer the data via a flash card reader into PC or laptop computers in which the RADAN for Windows software program is installed) ($700). The former course of action was taken by the New York staff; the last course of action was taken by the Massachusetts staff. Figure 1, shows the not too pretty, but workable modification to a SIR System-2000 unit. Unfortunately, the slot for the flash card is covered with duct tape and care must be exercised so that dirt and moisture does not get into the control unit.

The data shown in this report were collected with a TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (Salem, NH).[1] The SIR System-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 System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program. Processing included setting the initial pulse to time zero, header and marker editing, distance normalization, color transformation, and range gain adjustments. The Super 3D QuickDraw program developed by GSSI was used to construct a 3D pseudo-image of the radar records collected at the Goldsboro site.

Field Training Exercises:
Short transect lines were established at each site. Each soil scientist was given the opportunity to setup and operate the SIR System-2000 unit. At most sites, radar records were collected with both the 200 and 400 MHz antennas. The radar records were reviewed on the video screen, and display settings and interpretations were discussed. At each site ground-truth soil cores were taken to verify interpretations.

To collect the data required for construction of a 3D GPR pseudo-image, a 10 by 10 m survey grid was established at Goldsboro site. Along two parallel axes, survey flags were inserted into the ground at a spacing of 100 cm, and a reference line was established between matching survey flags on opposing sides of the grid using a distance-graduated rope. GPR traverses were conducted along the reference line. The 200 MHz antenna was towed along the graduated rope and, as it passed the 100-cm graduations, a mark was impressed on the radar record. Following data collection, the reference line was sequentially displaced 100-cm to the next pair of survey flags to repeat the process. A total of 11 traverses were required for the grid at the Goldsboro site.

GPR Basics:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, bedrock, stratigraphic layer) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (v) are described in the following equation (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 the equation:

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

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.

Based on the measured depth and the two-way pulse travel time to a known, subsurface reflector, and equation [1], the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profiles were estimated. For the upper part of the soil profiles, the estimated E_r ranged from about 4 (Lakeland soil) to 18 (Plummer soil).

Study Sites:
Sites were located in pastures, cultivated fields, or cleared areas in Washington County. The Lakeland site is located along a dirt access road off of Green Hill Road (30.48837 ^{o} N Lat., 85.63599^o W Long.) This site is located in a polygon of Lakeland sand, 0 to 5 % slopes. The Centenary site is located in a wooded area off of Chain Lake Road (30.49704 ^{o} N Lat., 85.66434^o W Long.). This site is located in a polygon of Chipley-Albany-Hurricane complex, 0 to 5 % slopes. The Plummer site is located in a dried-up lake basin near Wages Pond Road (30.50074 ^{o} N Lat., 85.59728^o W Long.) in Sunny Hills. This site is located in a polygon of Plummer soils. The Bladen site (30.62241 ^{o} N Lat., 85.77972^o W Long.) is located off of Pioneer Road just west of Vernon. This site is located in a polygon of Bladen soils. The Goldsboro site (30.76285 ^{o} N Lat., 85.48164^o W Long.) is located near the intersection of Sewell Farm and Brickyard Roads just east of Chipley.

Table 1 lists the names and symbols of the soil map units traversed with GPR during field training exercises. The taxonomic classifications of the named soils are listed in Table 2. These very deep soils form in sandy, loamy, and/or clayey marine sediments.

.

Table 1. The names and symbols for the soil map units identified in the study areas.

Map Unit Symbol	Map Unit Name
7	Bladen soils
55	Chipley-Albany-Hurricane complex, 0 to 5 % slopes
63	Lakeland sand, 0 to 5 % slopes
87	Plummer soils
GdB	Goldsboro loamy coarse sand, 2 to 5 % slopes

Table 2. Taxonomic classifications of the soils identified in the study areas.

Soil Series	Taxonomic Classification
Albany	Loamy, siliceous, subactive, thermic Grossarenic Paleudults
Bladen	Fine, mixed, semiactive, thermic Typic Albaquults
Centenary	Sandy, siliceous, thermic Entic Grossarenic Alorthods
Chipley	Thermic, coated Aquic Quartzipsamments
Goldsboro	Fine-loamy, siliceous, subactive, thermic Aquic Paleudults
Hurricane	Sandy, siliceous, thermic Oxyaquic Alorthods
Lakeland	Thermic, coated Typic Quartzipsamments
Lynchburg	Fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults
Plummer	Loamy, siliceous, subactive, thermic Grossarenic Paleaquults
Surrency	Loamy, siliceous, semiactive, thermic Arenic Umbric Paleaquults

Results:
The Lakeland site provided an example of an excessively drained, sandy soil that has high potential for deep penetration with GPR. The low clay and moisture contents of Lakeland soil results in high propagation velocities and low rates of signal attenuation. While this soil is highly suited to GPR, soil profiles and radar records often lack contrasting features. In Figure 2, the low amplitude subsurface reflections (colored in shades of red) evident in the upper 2-m of the radar record represent reflections from lamellae and tree roots (see hyperbola in the upper 1-m, below the 10- and 11-m distance marks). Moderate amplitude reflections (shades of yellow and green) are evident

in the lower part of this radar record. These reflectors represent thin lamellae and thicker strata that have higher clay and moisture contents.

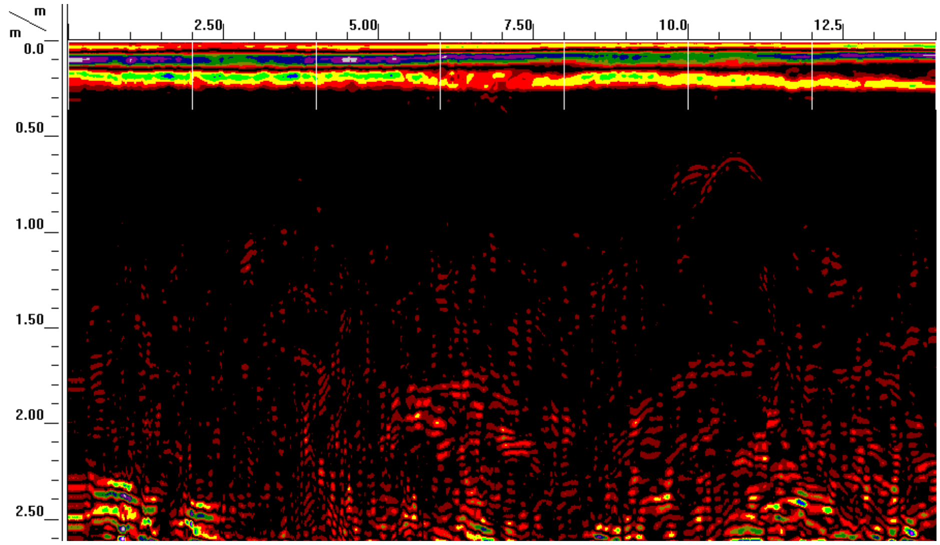

Figure 2. A radar record collected with the 400 MHz in an area of Lakeland sand.

The Centenary site provided an example of a soil that formed in sandy overlying loamy marine sediments with conspicuous and identifiable interfaces. In a radar record from the Centenary site (see Figure 3), abrupt and strongly contrasting changes in clay content produce moderate to high amplitude (colored white, grey, and blue) reflections. The upper-most set of high amplitude reflections represents the upper boundary of the argillic horizon. However, the irregular micro-topography of this surface and the low to moderate amplitude reflections from overlying lamella made the identification of this interface ambiguous in some portions of the radar record. The use of different color tables and color transformations assisted the identification and delineation of this interface. At this site, soil scientists practiced determining the depth to this interface and adjusting the E_r based on the depth to a known subsurface reflector.

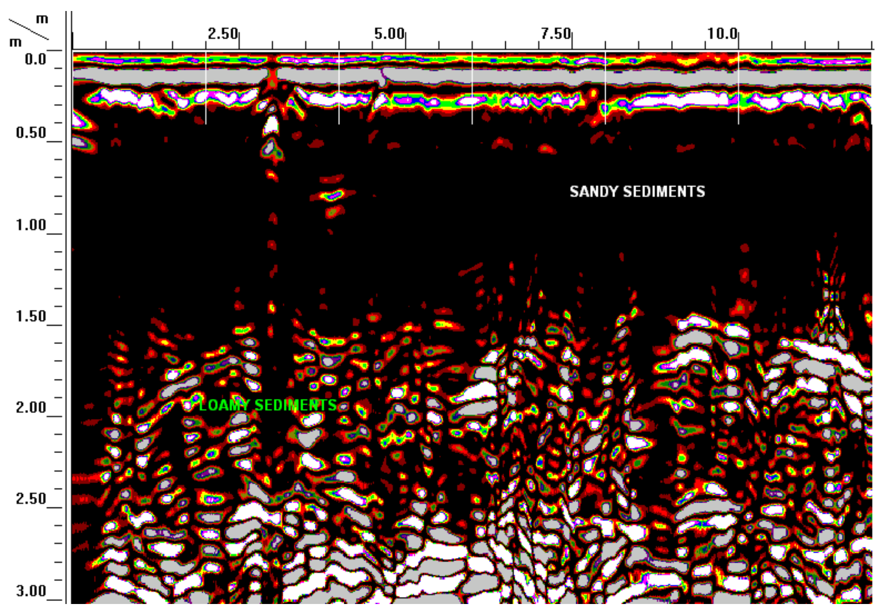

Figure 3. A radar record collected with the 400 MHz antenna in an area of Centenary soil.

The Plummer site afforded an opportunity to further demonstrate the use of adjusting display gain functions to aid interpretations. The radar record shown in the upper plot in Figure 4 is displayed with a gain function of 1. Two subsurface interfaces are clearly evident in this plot. The upper subsurface interface (see "B") occurs at depths of about 1.5 to 1.6 m across most of the radar record. However, along the right-hand margins of this radar record, this interface occurs at a depth of only 88 cm. This interface appears segmented and has a noticeably wavy topography. In the upper plot of Figure 4, a lower interface (see C) plunges from a depth of about 1.9 m along the left-hand margin of the plot to a depth of about 3.0 m near the right-hand margin, where, because of attenuation losses suffered in the overlying materials, it becomes imperceptible. This interface appears continuous and has a smooth topography. The same radar record is showed in the lower plot of Figure 4, but with a display gain function of 4. The two interface identified in the upper plot are similarly recognized in the lower plot (see "B" and "C"). The use of a higher gain setting has added detail and clarity to this radar record. An additional interface (see "A") is now evident in the upper part of this radar record. This interface marks the upper boundary of a sandy loam argillic horizon. A green-color line has been used to identify this interface, which extends from a depth of about 110 cm near the 0-m distance mark to a depth of about 78 cm near the 24-m distance mark, where it becomes obscured by near surface reflections. High moisture contents weaken the electromagnetic gradient between the sandy surface layers and the medium textured subsoil, and make this interface indistinct on the radar record. The texture of the intermediate layer (see "B") in these plots was verified to be clay loam. With available processing and visualization techniques, interpretations are improved.

The Bladen site provided an example of a poorly drained, clayey soil that has very low potential for deep penetration with GPR. The high clay and moisture contents of Bladen soil results in high rates of signal attenuation and restricted depths of penetration. This site provided an example of a soil in which the use of GPR is inappropriate for most soil investigations.

Subsurface drainage tiles had been installed several years ago beneath the Goldsboro site. At several locations, shallow hyperbolic reflectors were identified on radar records. When cored, these reflectors were identified as either buried roots or disturbed soil materials. In an area with noticeable signs of subsurface soil disturbance, it was considered possible, that the auger hole had entered a trench in which a drainage tile had been buried, but had missed the tile. Even after multiple point probes, it was uncertain whether the area contained buried drainage tiles.

Figure 5 is a representative radar record form the Goldsboro site. An area of seemingly disturbed soil materials with an underlying, high-amplitude, hyperbolic reflector, believed to represent a buried drainage tile, is evident on this radar record beneath the 3-m distance mark. The shallow, planar reflection from an argillic horizon has also been identified (see "A") in this plot, as well as a weakly expressed subsurface interface (see "B"), which ranges in depth from about 1.6 to 1.75 m.

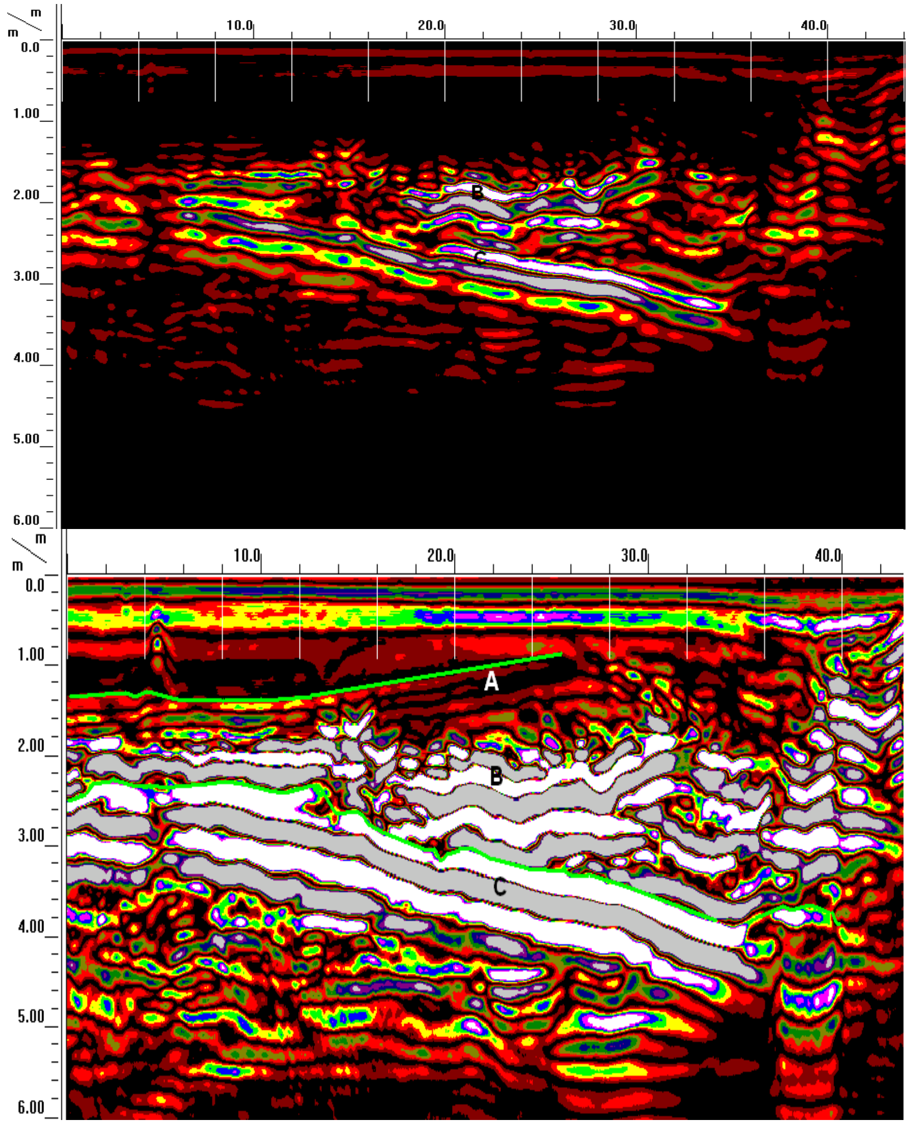

Figure 4. Two plots of the same radar record recorded in an area of Plummer soil. The upper plot is with a gain amplification of 1, the lower plot with a gain amplification of 4. The higher gain amplification was needed to bring out a weakly expressed sandy loam Bt horizon (see A in lower plot).

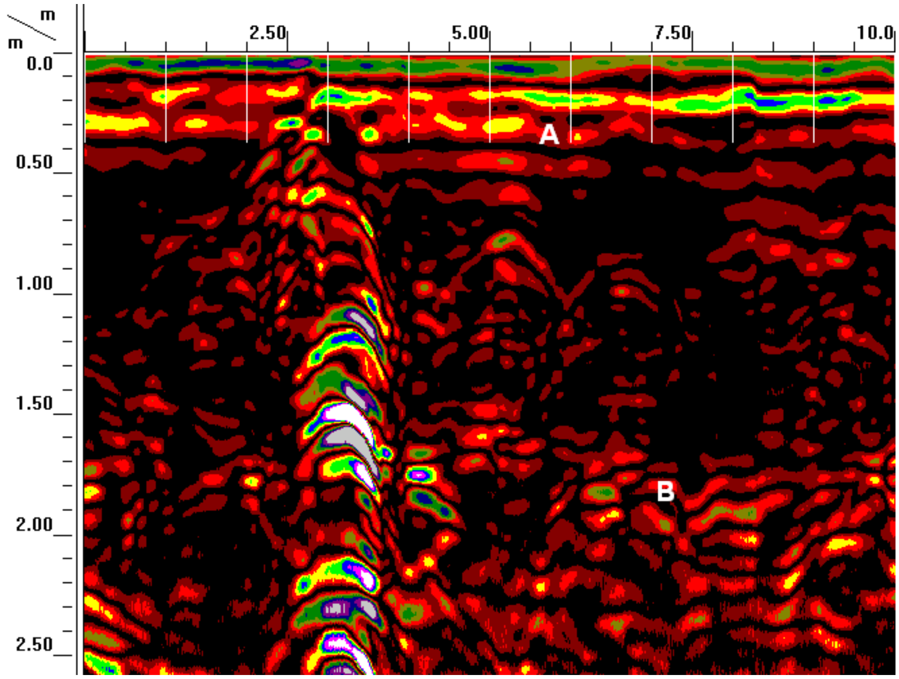

Figure 5. In this radar record from an area of Goldsboro soil, a suspected buried tile is located beneath the 3-m distance mark.

The recent advent of digital GPR output and the availability of more powerful computers and advanced data-processing software allow the geometry and structure of subsurface features recorded on radar traverses to be analyzed from a three-dimensional (3D) perspective. Compared with 2D GPR records, 3D images often provide greater resolution and detail (Grasmueck and Green, 1996) and improved ability to identify weakly expressed subsurface features and patterns. To construct 3D images, relatively small areas (5 to 50 m on a side) are surveyed intensively using closely spaced (typically 10 to 100 cm) parallel GPR traverses. Data from the traverses are assembled to create 3D pseudo-images of the subsurface, allowing arbitrary cross-sections and time slices to be extracted from the complete data set.

In recent years, a sophisticated type of 3D GPR data manipulation known as “amplitude slice-map analysis” has been used in several investigations (e.g. Conyers and Goodman, 1997). In this procedure, amplitude differences within the 3D image are analyzed in "time-slices" to isolate differences within specific time (i.e. depth) intervals (Conyers and Goodman, 1997). Time-slice data are created by averaging the reflected radar energy horizontally between each set of parallel radar traverses within a specified time window to create a time-slice. The resulting time-slice displays the spatial distribution of reflected wave amplitudes, which can be interpreted as representing lateral changes in soil properties or the presence of subsurface features.

Figure 6 is a 3D GPR pseudo-image of the grid area within the Goldsboro site. This grid was created to help locate and confirm the identity of a suspected buried drainage tile system. In this image an 8.5 by 5 by 1.3 m volume has been removed. In this pseudo image of the grid area, no evidence of a continuous drainage tile is apparent. Four high-amplitude, hyperbolic point reflectors (see “A” in Figure 6) are evident along the base and side walls of this cut-out cube. These reflectors were evident on 2D radar records and some were suspected to represent a buried drainage-tile system. As evident in this pseudo-image, these four reflectors are not interconnected, but represent insular point anomalies (i.e., buried tree roots). Three-dimensional GPR imaging offers considerable potential for displaying and interpreting near-surface soil features. In this example, 3D GPR datasets provided information in excess of that which was extracted from the individual radar records (see Figure 5) alone and helped to resolve the issue of drainage tiles existing under the grid area.

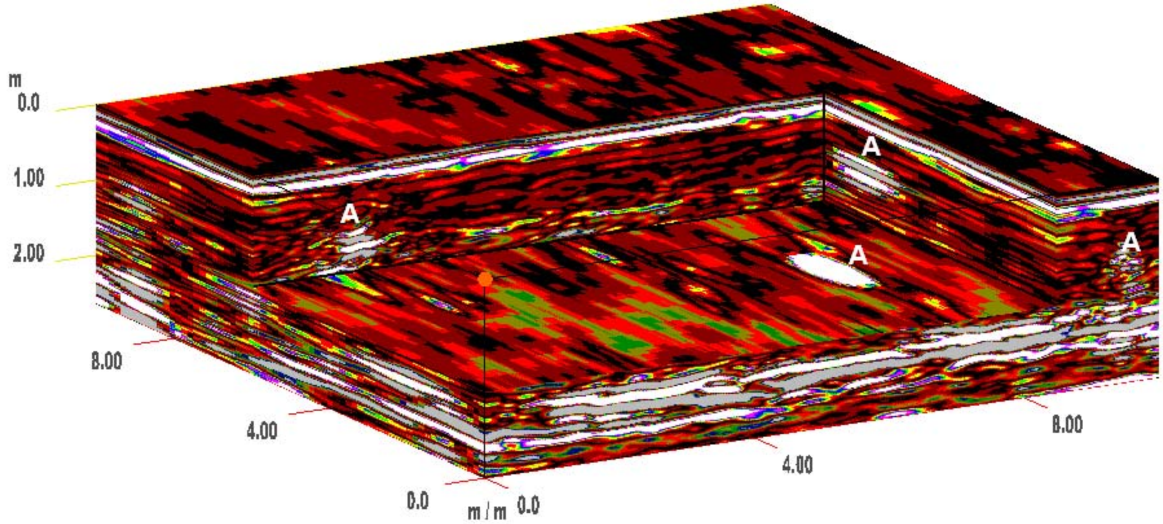

Figure 6. 3D GPR pseudo-image of the Goldsboro site with an 8.5 by 5 by 1.3 m volume removed

References:
Conyers L. B. and D. Goodman, 1997. Ground-penetrating radar: An introduction for archaeologists. Altamir Press: Walnut Creek, California.

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

Grasmueck, M. and A. G. Green, 1996. 3-D georadar mapping: Looking into the subsurface. Environmental and Engineering Geoscience 2(2): 195-220.