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Natural Resources Conservation Service

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Subject: SOI – Electromagnetic Induction (EMI) Comparative Field Studies

Date: 13 November 2001

To: Dr Carolyn Olson
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Purpose:
The EM38DD meter has been found to produce non-stable and unreliable data. Though results from previous field studies with the Dualem-2 meter do not suggest that this instrument is plagued with these problems, no specific field tests of the instrument's measurement stability have been conducted. The purpose of this investigation was to conduct comparative field studies using different electromagnetic induction instruments in areas of low conductivity soils.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Roger Eigenberg, Research Scientist, USDA-ARS, USMARC, Clay City, NE
Robert Ransom, Soil Scientist, USDA-NRCS, Statesville, NC
Milton Martinez, Soil Specialist (Database), USDA-NRCS, Statesville, NC
Richard Taylor, President, Dualem Inc., Milton, Ontario, Canada

Activities:
Field activities were completed in Mecklenberg County, North Carolina, on 24 October 2001.

Conclusions:

1. This study reconfirms that the EM38DD meter produces non-reproducible and unreliable data. Inconsistent results over specific observation points are believed to be related to design flaws in the meter's coil orientations. The manufacturer of the EM38DD meter is aware of this flaw and has recommended that all users return the instruments for modifications designed to correct this instability.

2. The EM38 meter produces stable and replicable results. Compared with the EM38DD meter, the Dualem-2 meter provides stable measurements of apparent conductivity. The Dualem-2 meter is portable, menu driven and keypad operated, and therefore is easier to run than the EM38DD meter. Its ease of operation and robust design makes the Dualem-2 a preferred dual dipole meter for use by soil scientists. The Dualem-2 meter can simultaneously recorded measurements in both dipole orientation while being operated in the continuous mode and thus provide more data and comprehensive coverage of sites. Storing data to a hard drive eases and expedites fieldwork.

3. Hands on training were provided to all participants on the operation of the EM38 and EM38DD meters, and GEM300 sensor. Participants completed comparative field tests that evaluated the suitability and reliability of these devices.

I wish to commend the enthusiasm and assistance of Robert Ranson and Milton Martinez. Their selection of sites, field assistance, and knowledge of the soils, geology, and landscapes were of great valuable to this investigation.

With kind regards,

J. A. Doolittle

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Comparative Studies with the EM38, EM38DD and Dualem-2 Meters:
For years, Geonics Limited has been the leader in EMI. Meters developed by Geonics Limited are widely used and accepted as standards by the research and applied geophysics community. The EM38 meter has been used extensively in agronomic research, soil survey investigations, salinity appraisals, and more recently for high intensity surveys and precision farming initiatives. In many of these surveys or investigations, responses from both dipole orientations are desired. Each dipole orientation provides different depth-weighting functions and depths of penetration. The horizontal dipole orientation is more sensitive to changes in apparent conductivity that occur near the surface. The vertical dipole orientation is more sensitive to changes in apparent conductivity that occurs at greater soil depths. Having both measurements greatly improve interpretations.

A major drawback of the EM38 meter is the device's inability to simultaneously record measurements in both dipole orientations. With the EM38 meter, surveys can either be completed in a *station-to-station* mode (with measurements taken in one or both dipole orientations at each observation point), or in a *continuous* mode (with measurements obtained in only one dipole orientation). In the *station-to-station* mode, to obtain measurements in both dipole orientations, a measurement is made in one dipole orientation, then the meter is rotated and re-nulled prior to obtaining the measurement in the other dipole orientation. This tedious operation slows survey speeds and precludes the simultaneous collection of data in both dipole orientations. For surveys conducted with the EM38 meter operating in the *continuous* mode, the device cannot be rotated and measurements can only be taken in one dipole orientation. Consequently, two separate surveys are required to obtain measurements in both dipole orientations. The EM38DD and the Dualem-2 and -4 meters have been recently developed (Geonics, 2000; Taylor 2000) to operate in the *continuous* mode and to simultaneously measure both dipole orientations without having to rotate or re-calibrate the meter.

In a comparative study with the EM38 meter in Illinois, the capacity to simultaneous measure responses in both dipole orientations and the lack of the requirement to repeatedly re-nulling the EM38DD meter decrease survey time by 56 percent. However, in studies conducted in Illinois, Iowa, Ohio, and Colorado significant differences in measurements and resulting spatial patterns were obtained from data collected at the same observation points with the EM38 and EM38DD meters. This is of great concern, as it is imperative that closely matching results be obtained with these meters. Comparative tests have been conducted with the Dualem-2 and Dualem-4 meters in Iowa and Ohio. In these studies, data collected with the Dualem-2 and Dualem-4 meters were strongly and significantly correlated with data collected with the EM38 and EM31 meters, respectively.

Coil misalignment, calibration errors, and system noise are believed to be responsible for the inconsistent measurements obtained with the EM38DD meter. With the EM38DD meter, the vertical dipole transmitter coil (master unit) and horizontal dipole receiver coil (slave unit) are sensitive to slight changes in the placement and orientation of the meter on the ground surface. As a consequence, slight changes in placement or orientation can cause significant changes in the measured response. These changes are most evident over resistive ground suggesting that much of the variability arises from the instrument rather than from the conductivity of the soil. It is believed that the amount of orientation variability can be lessened if the EM38DD is transported in a mechanically stable way. However, noise that is internal to the instrument will still appear in data that is collected over resistive terrain.

Geonics Limited is aware of the EM38DD meter's instability and has responsively and repeatedly taken steps to correct this problems. We first brought the stability problem of the EM38DD meter to the attention of Geonics Limited in November 2000. In May 2001, we conducted field test in Niagara, New York, with Mike Catalano of Geonics, Limited. The EM38DD meter was returned to the manufacturer for modifications after each of these tests. In October, the company advised all users to return their EM38DD meters for additional modifications. The principal reasons for this study were to ascertain the stability of meters developed by Dualem, Inc., and to conduct signal response tests with GEM300 sensor operating at several frequencies and at different heights. Data collected with the GEM300 sensor operating at different frequencies and heights were provided to Rick Taylor of Dualem, Inc., but are not discussed in this report.

Equipment:
The instruments used in this study included the Dualem-2 meter; EM38, and EM38DD meters; and GEM300 sensor.

Dualem Inc. manufactures the Dualem-2 meter.[1] This meter is portable and requires only one person to operate. Taylor (2000) has described the principles of operation of this meter. The Dualem-2 meter consists of one transmitter and two receiver coils. One receiver coil and the transmitter coil provide a shallower-sensing perpendicular geometry (P). The other receiver coil provides a deeper-sensing horizontal co-planar geometry (HC) with the transmitter coil. This dual system permits two depths to be measured simultaneously without rotating the coils. The depth of penetration is "geometry limited" and is dependent upon the intercoil spacing, coil geometry, and frequency. The Dualem-2 has a 2-m intercoil spacing between the transmitter and the two receiver coils and operates at a frequency of about 9800 Hz. It provides penetration depths of 1.3 and 3.0 m in the P and HC geometries, respectively. No ground contact is required with this meter. The meter is keypad operated and measurements can either be automatically or manually triggered. The meter's processor has 1 megabyte of memory.

Geonics Limited manufacturers the EM38 and EM38DD meters.[1] These meters are portable and require only one person to operate. Geonics Limited (1998 and 2000) has described principles of operation for the EM38 and EM38-DD meters, respectively. No ground contact is required with these meters. The depth of penetration is geometry limited. Lateral resolution is approximately equal to the intercoil spacing. The EM38 and the EM38-DD meters have a 1 m intercoil spacing and operate at a frequency of 14,600 Hz. They have effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 1998). The EM38-DD meter consists of two EM38 meters bolted together and electronically coupled. One unit acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one unit acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on).

The GEM300 multifrequency sensor is manufactured by Geophysical Survey Systems, Inc.[1] This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20,000 Hz with a fixed coil separation (1.6 m). Won and others (1996) have described the use and operation of this sensor. With the GEM300 sensor, the penetration depth is considered "skin depth limited" rather than "geometry limited." The skin-depth represents the maximum depth of penetration and is frequency and soil dependent: low frequency signals travel farther through conductive mediums than high frequency signal. Theoretical penetration depths of the GEM300 sensor are dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequencies. Multifrequency sounding with the GEM300 allows multiple depths to be profiled with one pass of the sensor.

Study Sites:
Two study sites were selected in Mecklenberg County, North Carolina. The first site was located northeast of Huntersville in an area of Cecil sand clay loam, 2 to 8 percent slopes, eroded. The very deep (> 1.5 m), well drained Cecil soil is on ridges

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[1] Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

and side slopes of the Piedmont uplands. The subsoil averages 35 to 60 percent clay in the upper part but ranges to as much as 70 percent clay in some pedons. The soil is dominated by low activity clays. Cecil soil is deep to saprolite and very deep to bedrock. Cecil soil formed in residuum weathered from felsic, igneous and high-grade metamorphic rocks of the Piedmont uplands. Cecil is a member of the fine, kaolinitic, thermic Typic Kanhapludults family.

The second site was located northwest of Huntersville in an area of Enon sandy loam, 8 to 15 percent slopes. The very deep, well-drained Enon soil is on ridge tops and side slopes in the Piedmont. Enon soil is moderately deep (0.5 to 1 m) to saprolite and very deep to bedrock. This soil formed in clayey residuum weathered from mafic or intermediate igneous and high-grade metamorphic rocks such as diorite, gabbro, diabase, or hornblende gneiss or schist. Enon soil is a member of the fine, mixed, active, thermic Ultic Hapludalfs family. Included with Enon soil in mapping is areas of Helena soil in the ravine (Aquic Hapludults).

Results:

Instrument Stability Test:

A test was conducted to test the stability of measurements obtained with slight shifts in the orientation and position of the four instruments. The test was conducted in an area of Cecil soil. At one observation point, each meter was rotated in 45° increments through 180° over a known spot. The results of this study are shown Table 1. At a given point, by rotating the EM38DD meter on the ground surface, values of apparent conductivity varied by as much as 16.3 and 9.4 mS/m in the horizontal and vertical dipole orientations, respectively. At the same point, by rotating the EM38 meter, values of apparent conductivity varied by as much as 0.7 and 0.5 mS/m in the horizontal and vertical dipole orientations, respectively. The average standard deviation for measurements obtained by rotating the EM38 meter on the ground surface through eight rotations over one observation point was only 0.23 and 0.16 mS/m in the horizontal and vertical dipole orientations, respectively. In comparison, the average standard deviation for measurements obtained by rotating the EM38DD meter on the ground surface through eight rotations over one observation point was 5.57 and 2.96 mS/m in the horizontal and vertical dipole orientations, respectively. The maximum range in apparent conductivity that was observed by rotating the EM38DD meter at this observation point (see Table 1) almost equaled the range observed across the entire site (see Table 2).

Table 1
Stability of EMI Responses for Various EMI Instruments
Area of Cecil Soil
(All values are in mS/m)

	EM38 Meter		EM38DD Meter		Dualem-2 Meter		GEM300 Sensor					
Rotation	**VD**	**HD**	**VD**	**HD**	**HC**	**P**	**6030V**	**6030H**	**9810V**	**9810H**	**14790V**	**14790H**
0	1.4	2.6	-6.6	13.7	-3.3	2.5	-4.0	-3.8	-4.0	-4.7	-2.2	-4.3
45	1.3	2.4	-14.8	2.0	-1.6	0.9	-3.5	-4.5	-3.4	-5.4	-1.4	-5.3
90	1.4	3.0	-12.4	3.4	-2.7	1.1	-2.6	-5.4	-3.8	-6.4	-1.6	-3.0
135	1.2	2.7	-16.0	0.6	-2.8	2.4	-2.6	-7.1	-4.7	-5.5	-1.8	-3.1
180	1.7	2.3	-12.0	10.2	-1.9	1.0	-2.9	-6.9	-4.4	-5.4	-1.9	-3.4
225	1.3	2.5	-12.5	9.3	-3.8	0.9	-2.9	-6.6	-3.5	-5.8	-1.3	-3.0
270	1.4	2.8	-15.3	2.2	1.1	3.0	-2.6	-6.4	-3.4	-5.5	-1.1	-3.0
315	1.2	2.8	-11.4	-2.6	-1.7	1.7	---	---	---	---	---	---
Standard Deviation	0.16	0.23	2.96	5.57	1.51	0.84	0.54	1.27	0.51	0.51	0.38	0.89
Minimum	1.2	2.3	-16.0	-2.6	-3.8	0.9	-4.0	-7.1	-4.7	-6.4	-2.2	-5.3
Maximum	1.7	3.0	-6.6	13.7	1.1	3.0	-2.6	-3.8	-3.4	-4.7	-1.1	-3.0
Range	0.5	0.7	9.4	16.3	4.9	2.1	1.4	3.3	1.3	1.7	1.1	2.3

The Dualem-2 meter and the GEM300 sensor produced stable fairly measurements over this observation point. At this observation point, by rotating the Dualem-2 meter on the ground surface, values of apparent conductivity varied by as much as 2.1 and 4.9 mS/m in the perpendicular and horizontal coplanar geometries, respectively. The standard deviation for measurements obtained by rotating the Dualem-2 meter through eight rotations over one observation point was only 0.8 and 1.5 mS/m in the horizontal and vertical dipole orientations, respectively. At the same observation point, by rotating the GEM300 sensor at hip-height, values of apparent conductivity varied by as much as 3.3 and 1.8 mS/m in the horizontal and vertical dipole orientations, respectively. The average standard deviation for measurements obtained at three frequencies by rotating the GEM300 sensor at hip-height through eight rotations over one observation point was 0. 9 and 0.5 mS/m in the horizontal and vertical dipole orientations, respectively.

Figure 1 is a plot of the data collected by rotating the EM38, EM38DD, and Dualem-2 meters over the same observation point. The EM38 meter produced the most stable results. The EM38DD meter provides the least stable results. Though less stable than the EM38 meter, a majority of the measurement obtained with the Dualem-2 meter were within 2 mS/m of one another. The Dualem-2 has the widest intercoil spacing of the devices used in this study and will consequently scan a greater volume of earthen materials than the other instruments. Compared with the EM38 meter, the larger intercoil spacing of the Dualem-2 may partially account for its greater variability in measurements over the observation point. For the two dual dipole meters (EM38DD and Dualem-2), the Dualem-2 meter provided the most stable measurements.

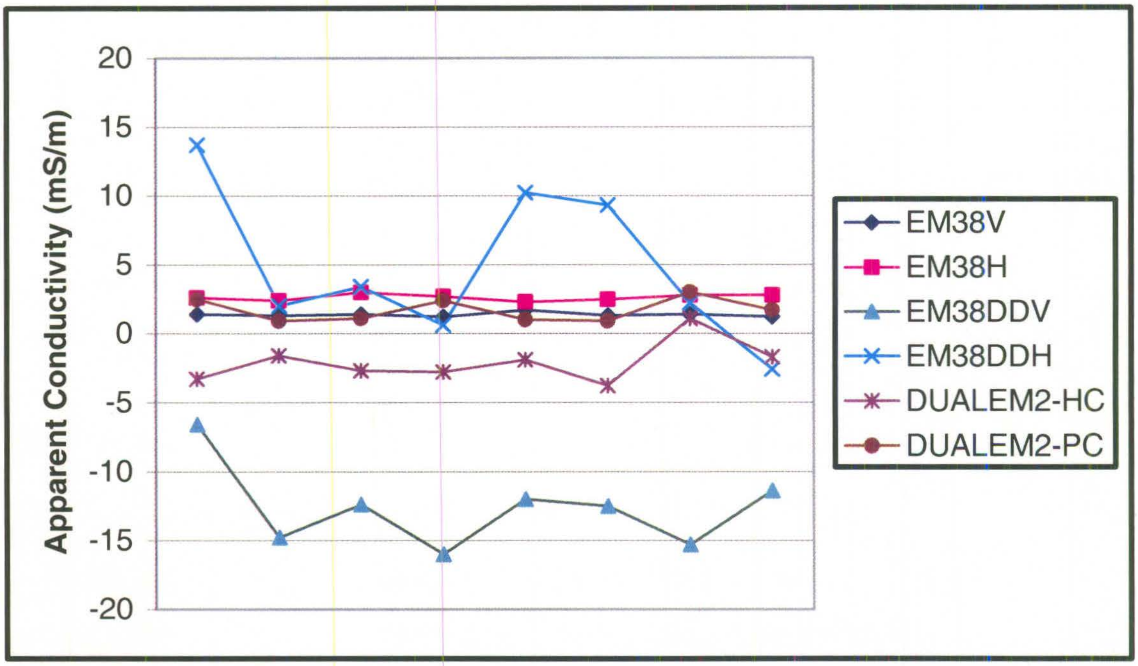

Figure 1 Comparative test of the EM38, EM38DD, and Dualem-2 meters. Each meter was rotated by 45° through eight positions about a point on the ground.

Figure 2 shows a plot of the data collected by rotating the GEM300 sensor over the same observation point. The same scale has been used in Figure 2 as was used in Figure 1. Results were fairly stable for each frequency and dipole orientation.

Site 1

A 100 by 150 ft grid was established across an area of Cecil sandy clay loam, 2 to 8 percent slopes. The grid interval was 25 ft. Survey flags were inserted in the ground at each grid intersection and served as observation points. This procedure provided 35 observation points. Each instrument was operated in the station-to-station mode. At each observation point, measurements were made in each dipole orientation or geometry with the EM38, EM38DD, and Dualem-2 meters placed on the ground surface and with the GEM300 sensor held at hip height. The GEM300 sensor is not designed to operate on the ground surface. If operated on the ground surface, anomalous measurements will be recorded because of direct coupling with the soil.

Basic statistics for data collected at Site 1 with the EM38DD, EM38, and Dualem-2 meters are listed in Table 1. The EM38DD meter characterized the site as having a low to moderate, and variable (both spatially and vertically) apparent conductivity. With the EM38DD meter, apparent conductivity averaged 12.4 and 8.5 mS/m in the horizontal and vertical dipole orientations, respectively. The higher apparent conductivity measured with the meter in the shallower-sensing horizontal dipole orientation is attributed to the presence of finer textured soil materials within the subsoil. The lower apparent conductivity measured with the meter in the deeper-sensing vertical dipole orientation is attributed to the presence of resistive saprolite and bedrock at greater soil depths.

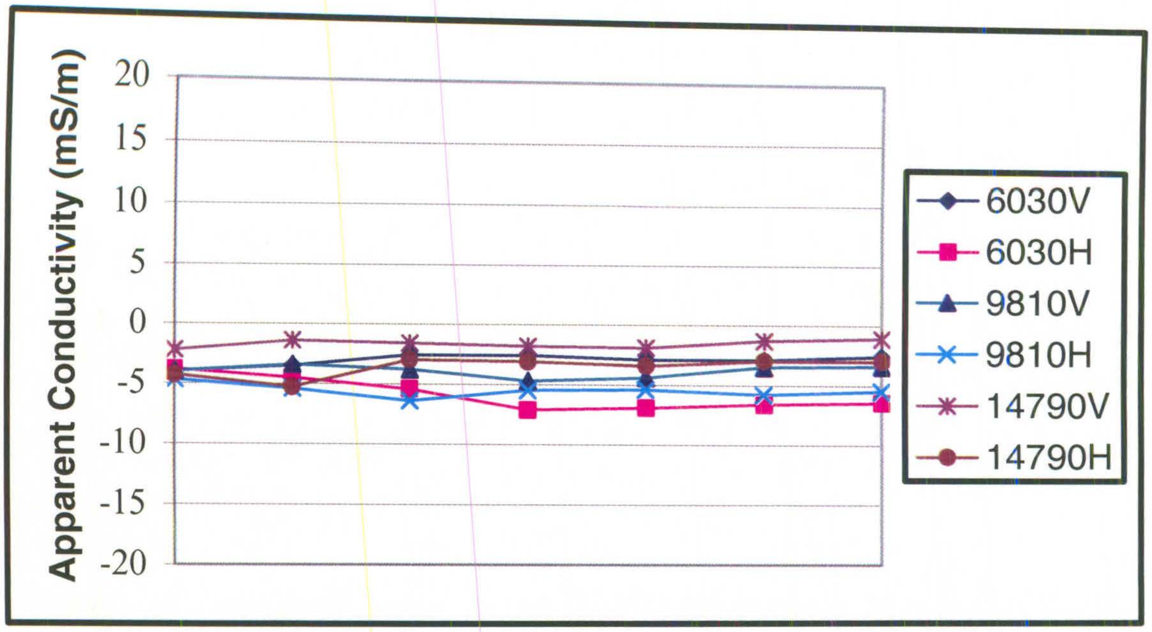

Figure 2. Comparative test of the GEM300 sensor. The sensor was rotated by 45° through seven positions about a point on the ground.

The EM38 and Dualem-2 meters characterized this site as having a low and exceedingly invariable (both spatially and vertically) apparent conductivity. With the EM38 meter, apparent conductivity averaged 4.0 and 2.3 mS/m in the horizontal and vertical dipole orientations, respectively. With the Dualem-2 meter, apparent conductivity averaged 2.5 and 1.1 mS/m in the perpendicular coplanar (P) and the horizontal coplanar (HC) geometries, respectively. Based on the data shown in Table 1, apparent conductivity recorded with the EM38 and Dualem-2 meters are similar. However, responses recorded with the EM38DD meter were noticeably higher and more variable than those recorded by the other two meters.

Table 2
Basic Statistics
EM38DD, EM38, and Dualem-2 Meters
Area of Cecil Soil, Mecklenberg County
(All values are in mS/m)

	EM38DD Meter		EM38 Meter		Dualem-2 Meter	
	Vertical	**Horizontal**	**Vertical**	**Horizontal**	**HC**	**P**
Average	8.5	12.4	2.3	4.0	1.1	2.5
Minimum	-1.9	-2.7	1.5	2.0	-0.5	1.2
Maximum	21.3	36.4	3.2	6.8	4.3	3.5
First	3.1	5.9	2.1	3.1	0.3	2.2
Third	14.2	18.9	2.5	4.6	1.7	2.9
SD	6.7	9.8	0.4	1.3	1.1	0.5

Figure 3 shows the spatial distribution of apparent conductivity collected with the EM38DD and EM38 meters. The upper and lower set of plots represent data collected with the EM38DD and the EM38 meters, respectively. The spatial distributions of apparent conductivity collected with both instruments in the horizontal and vertical dipole orientations are shown in the left- and right-hand plots, respectively. In each plot, the isoline interval is 2 mS/m. The locations of the 35 observation points are shown in the upper, left-hand plot. The plots shown in Figure 3 are not similar. The EM38DD meter characterized the site as having higher and more variable apparent conductivity. This was not unexpected. Measurements obtained with this meter are not stable and have been frequently observed to be higher and more variable than those collected with the EM38 meter. The manufacturer is aware of this problem and has directed users to return the meter for further modifications.

The EM38 and Dualem-2 meters characterized the site as having low and relatively invariable apparent conductivity (range of 1.5 to 6.8 and –0.5 to 4.3 mS/m, respectively). Figure 4 shows the spatial distribution of apparent conductivity collected with the EM38 and Dualem-2 meters. The spatial distributions of apparent conductivity collected with both instruments in the shallower-sensing perpendicular geometry or horizontal dipole orientations are shown in the upper and lower, left-hand plots, respectively. The spatial distributions of apparent conductivity collected with both instruments in the deeper-sensing horizontal coplanar geometry or vertical dipole orientations are shown in the upper and lower, right-hand plots, respectively. In each plot, the isoline interval is 2 mS/m. For both instruments, spatial patterns are broad and seemingly dissimilar. The dissimilar patterns are, in part, a reflection of the extremely low range in apparent conductivity values measured within the site and the narrow contour intervals used in these plots. In addition, measurement errors are assumed to be about 2 mS/m (McNeill, 1980) and contribute to dissimilar spatial patterns. At this site, where the potential measurement error is almost equal to the range of observed values, the contribution of measurement error to the spatial patterns is great. Differences in the depth and volume of soil materials measured with both instruments will also contribute to these seemingly dissimilar spatial patterns.

Table 3 lists some of the basic statistics for the GEM300 sensor operating at three frequencies and in the horizontal (H) and vertical (V) dipole orientations. At most observation points and for each frequency, negative values occurred in the data. Negative values reflect not only the resistive nature of the soil, but the calibration of the sensor by its manufacturer. As spatial patterns and relative rather than absolute values are more important to interpretations, negative values do not cause this interpreter heartburn. However, at four observation points, clearly anomalous values (several orders of magnitude higher) were recorded. These anomalous measurements were attributed to signal interference from "*cultural sources*." The wide band and low transmission power of the GEM300 sensor makes it more susceptible than the other meters to this noise. However, in most data sets collected to date, similarly anomalous values have not been observed. These anomalous data points were removed from the data set.

Table 3
Basic Statistics
Gem300 Sensor
Area of Cecil Soil, Mecklenberg County
(All values are in mS/m)

	6030V	6030H	9810V	9810H	14730V	14730H
Average	-3.8	-1.8	-4.6	-4.0	-4.0	-2.7
Minimum	-5.3	-3.5	-5.7	-9.4	-8.1	-4.8
Maximum	-2.4	-0.7	-3.2	-2.6	-1.0	9.1
First	-4.2	-2.1	-4.9	-4.2	-4.5	-3.8
Third	-3.4	-1.4	-4.1	-3.6	-3.2	-2.5
SD	0.7	0.6	0.6	1.1	1.4	2.5

Figure 5 shows the spatial distribution of apparent conductivity collected with the GEM300 sensor at three different frequencies: 14730, 9810, and 6030 Hz. For each frequency, spatial distributions of apparent conductivity collected in the horizontal and vertical dipole orientations are shown in the left- and right-hand plots, respectively. In each plot, the isoline interval is 2 mS/m. The locations of the observation points are shown in the upper, left-hand plot. In Figure 4, the data have been *zero adjusted* (for each frequency, the lowest recorded value becomes zero and all other values are increased by the same value used to raise the lowest value to zero). The sensor characterized the site as having a low and exceedingly invariable (both spatially and vertically) apparent conductivity. The four measurements believed to have been affected by cultural interference were removed from the data set. However, several point anomalies appearing in the plots of the horizontal dipole data recorded at frequencies of 14730 and 9810 Hz suggests that some minor level of cultural interference or equipment error remains.

Site 2

A 100 by 125 ft grid was established across the site. The grid interval was 25 ft. Survey flags were inserted in the ground at each grid intersection and served as observation points. This procedure provided 30 observation points. At each observation point, measurements were made in each dipole geometry or orientation with the Dualem-2 meter and the GEM300 sensor held at hip height. Each instrument was operated in the station-to-station mode.

Basic statistics for measurements obtained with the GEM300 sensor and the Dualem-2 meter are listed in Table 4. Both devices characterized the site as having low apparent conductivity. Compared with Site 1, data collected with the GEM300 sensor and the Dualem-2 meter at Site 2 were higher and more variable. These differences principally reflect differences in soil types.

Table 4
Basic Statistics
GEM300 Sensor and Dualem-2 Meter
Area of Enon Soil, Mecklenberg County
(All values are in mS/m)

	6030V	6030H	9810V	9810H	14730V	14730H	HC	P
Average	8.7	6.3	10.9	6.9	16.7	11.7	8.5	3.9
Minimum	3.8	2.9	6.2	4.0	11.6	8.2	4.7	1.7
Maximum	16.8	11.2	19.4	12.0	25.3	16.2	13.6	6.9
First	6.1	4.5	8.2	5.1	13.8	10.0	6.7	2.8
Third	10.6	7.4	13.2	7.9	18.7	13.0	10.0	5.1
SD	3.7	2.3	3.8	2.4	3.8	2.3	2.5	1.4

The spatial distributions of apparent conductivity collected with the GEM300 sensor and the Dualem-2 meter are shown in figures 6 and 7, respectively. In Figure 6, the spatial distributions of apparent conductivity collected with the GEM300 sensor in the horizontal and vertical dipole orientations are shown in the left- and right-hand plots, respectively. In Figure 7, the spatial distributions of apparent conductivity collected with the Dualem-2 meter in the perpendicular and horizontal coplanar geometries are shown in the left- and right-hand plots, respectively. In each plot, the isoline interval is 2 mS/m. In each figure, the locations of the 30 observation points are shown in the upper left-hand or left-hand plot. For each instrument, apparent conductivity increases with increasing penetration depth. Other than amplitude, the spatial patterns of apparent conductivity are remarkably similar in all plots shown in figures 6 and 7. This similarity suggests that each instrument is influenced by the same volume of earthen materials and has closely similar observation depths regardless of coil geometry, orientation, or frequency.

Table 5 shows the correlation coefficients for measurements obtained with the GEM300 sensor operating at different frequencies and in the vertical (V) and horizontal (H) dipole orientations, and the Dualem-2 meter in the horizontal coplanar (HC) and perpendicular (P) geometries. Pearson correlation coefficients (r) are extraordinarily high and all are significant at the .001 level. These relationships suggest that both instruments are measuring similar volumes of earthen materials. These relationships also suggest that the GEM300 sensor is measuring similar depths and volumes of soil materials at different frequencies. The GEM300 sensor appears to be most sensitive to soil properties that occur at shallow depths. The depth of observation is restricted. For this area of Enon soil, the use of one frequency with measurements in both dipole orientations will provide as much information as multi-frequency soundings with the GEM300 sensor.

Table 5

Correlation Between Apparent Conductivity Measurements obtained with the GEM300 Sensor Operating at Different Frequencies and in the Vertical Dipole Orientations.

	6030V	6030H	9810V	9810H	14730V	14730H	HC	P
6030V	1.000	0.914	0.955	0.959	0.995	0.958	0.951	0.913
6030H		1.000	0.912	0.945	0.920	0.925	0.829	0.820
9810V			1.000	0.955	0.997	0.950	0.956	0.914
9810H				1.000	0.954	0.970	0.895	0.871
14730V					1.000	0.952	0.951	0.913
14730H						1.000	0.897	0.914
HC							1.000	0.928
P								1.000

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COMPARATIVE EMI STUDY IN AN AREA OF CECIL SANDY CLAY LOAM, 2 TO 8 PERCENT SLOPES

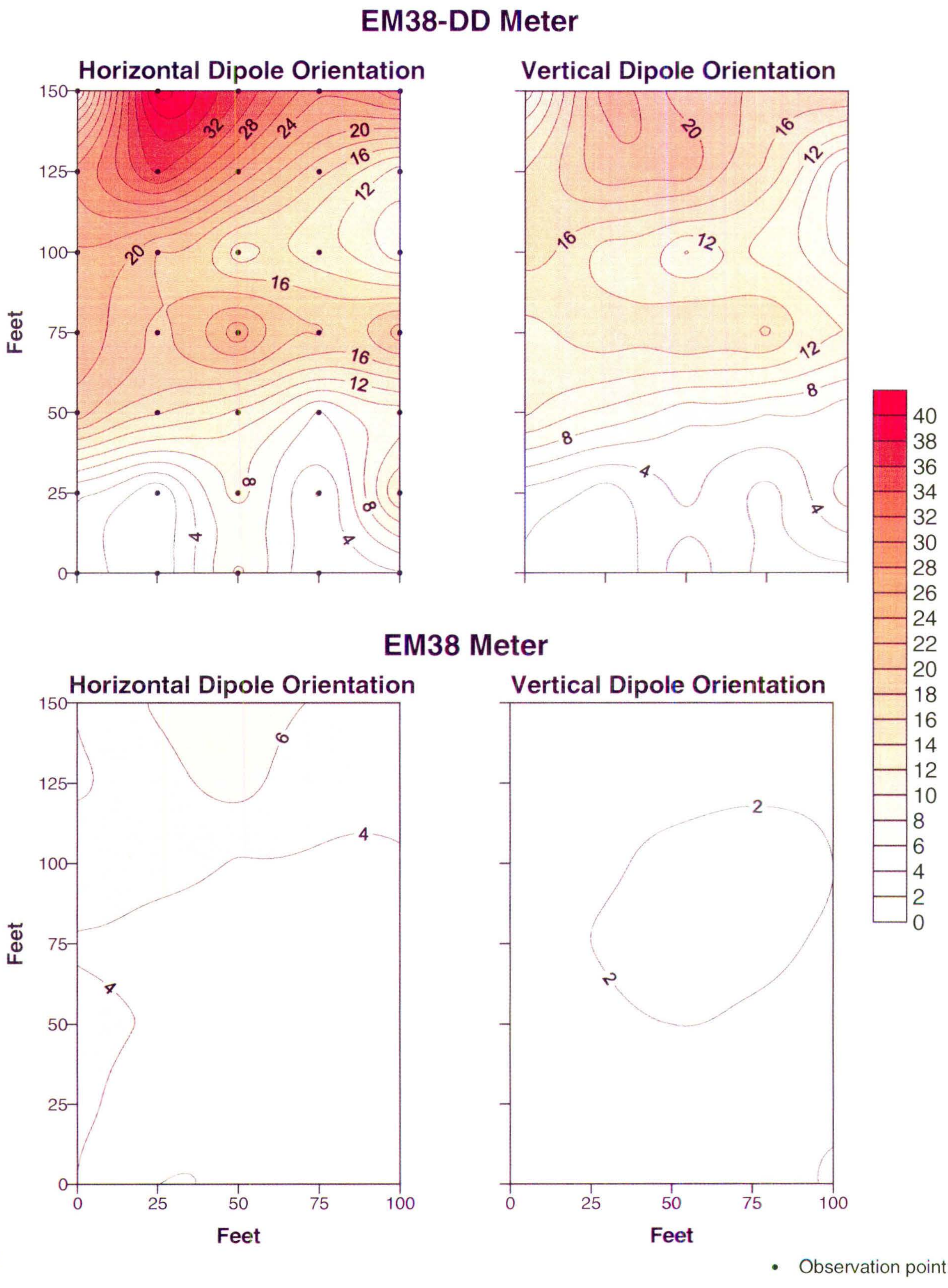

Figure 3

COMPARATIVE EMI STUDY IN AN AREA OF CECIL SANDY CLAY LOAM, 2 TO 8 PERCENT SLOPES

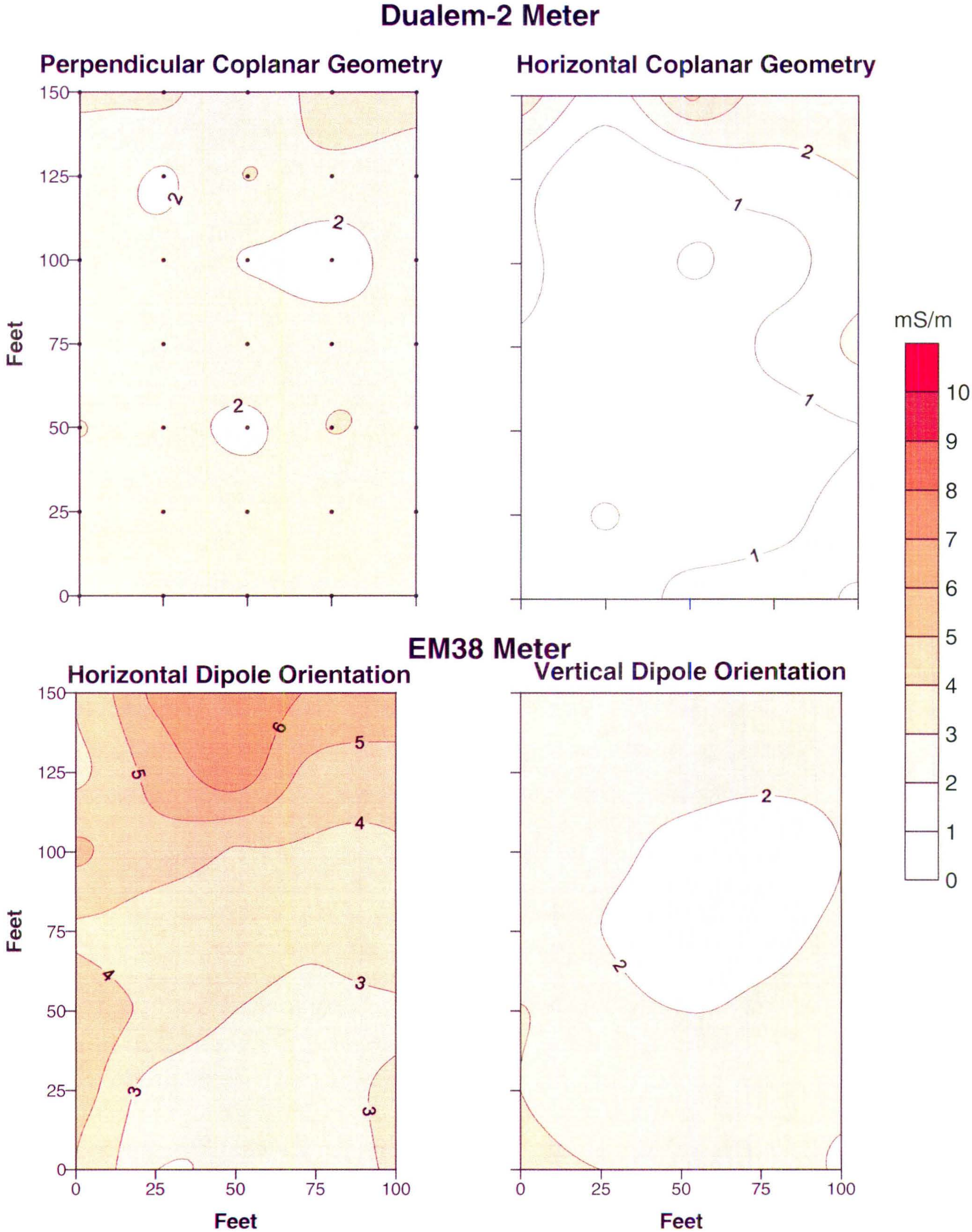

Figure 4

• Observation point

COMPARATIVE EMI STUDY IN AN AREA OF CECIL SANDY CLAY LOAM, 2 TO 8 PERCENT SLOPES GEM300 SENSOR

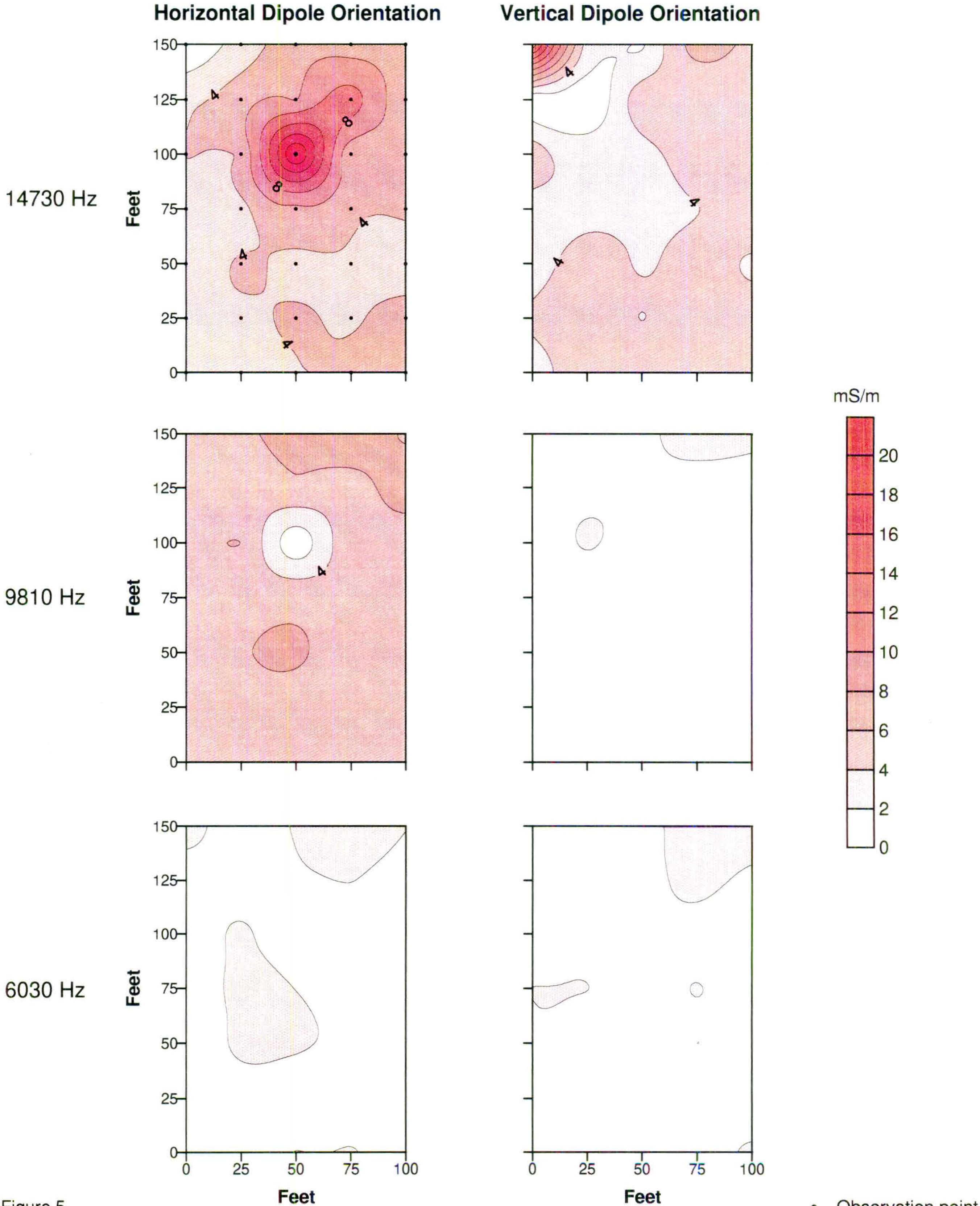

Figure 5

COMPARATIVE EMI STUDY IN AN AREA OF ENON SANDY LOAM, 2 TO 15 PERCENT SLOPES GEM300 SENSOR

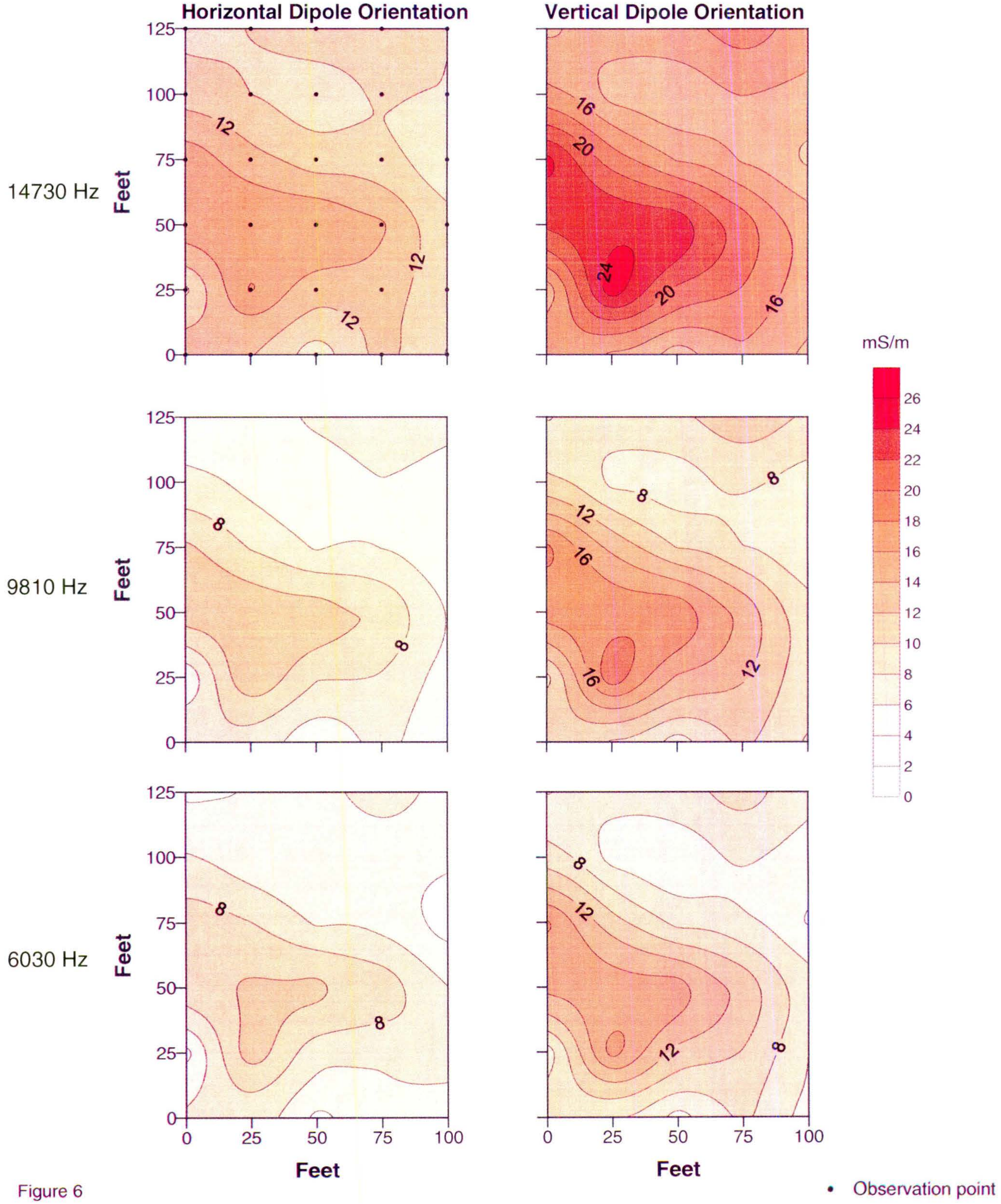

Figure 6

COMPARATIVE EMI STUDY IN AN AREA OF ENON SANDY LOAM, 2 TO 15 PERCENT SLOPES DUALEM-2 METER

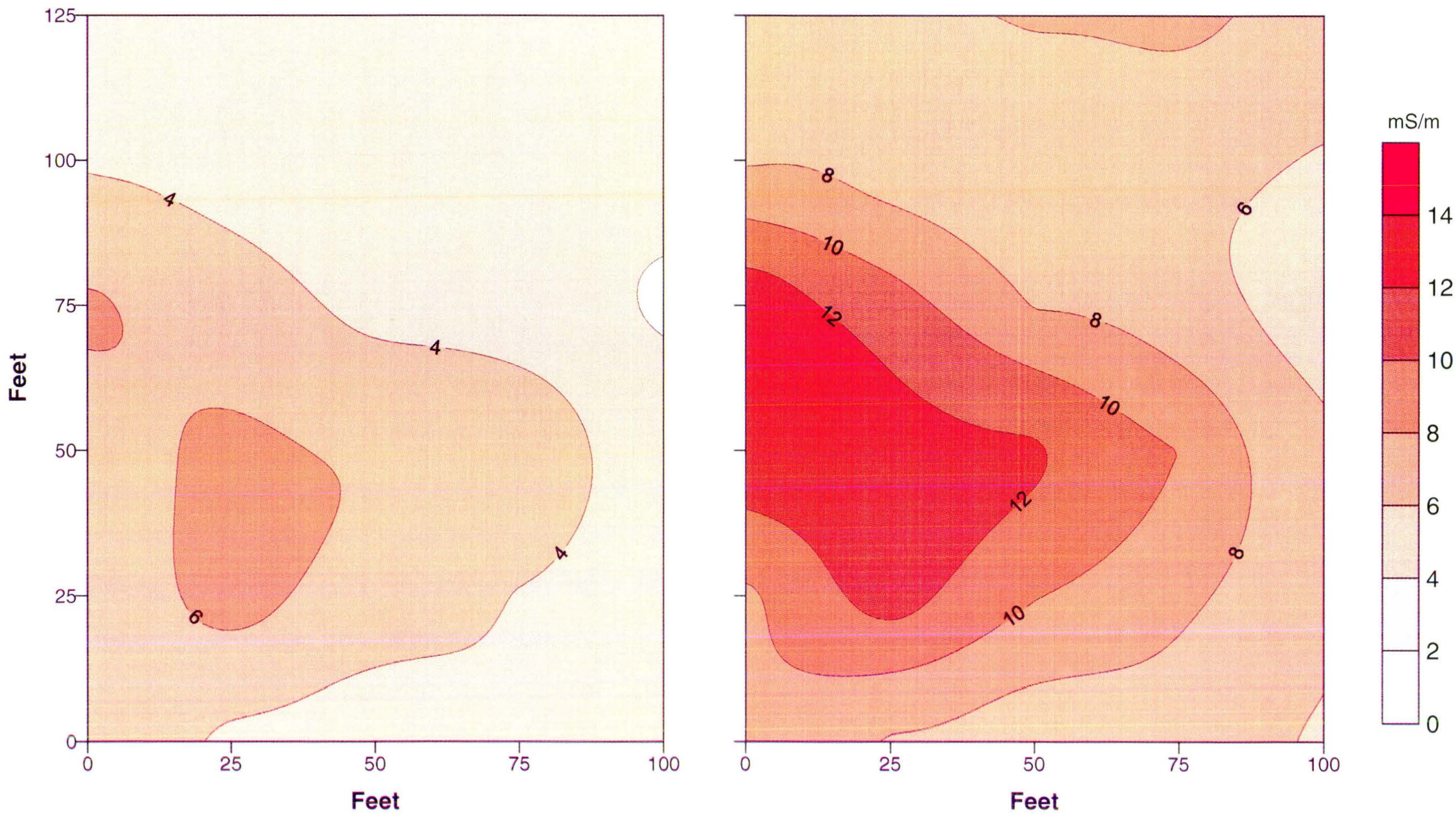

Figure 7

• Observation point