Resistivity mapping with GEOPHILUS ELECTRICUS – information about lateral and vertical soil heterogeneity

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Abstract

GEOPHILUS is a novel system for mapping complex electrical bulk resistivity of soil with rolling electrodes. Amplitude and phase data are measured simultaneously for four frequencies within a range between 1 mHz and 1 kHz. The sensor design and its technical specification allow measuring the electrical parameters at five depth levels up to 1.5 m depth. Using DGPS for positioning and a suitable cross-country vehicle, it is possible to map about 100 ha/day recording 1 data point per second and 18 m line spacing.

Keywords: electrical conductivity, maps, soil stratification.

Introduction

To describe soil heterogeneity not only lateral but also vertical, variation of soil properties has to be considered. Stratified soils with undulating layers of different soil texture affect the hydrology and consequently the soil fertility. Because soil sampling is time consuming, geophysical techniques are applied for imaging the spatial soil heterogeneity. Conductivity mapping using mobilized sensors in combination with GPS technique is a well established method. Most devices image lateral soil heterogeneity for one or two depth levels without information about stratification. The interpretation is based on the assumption that either topsoil is more or less homogeneous and lateral variation is only caused by differences in topsoil thickness or that the conductivity pattern are only determined by topsoil heterogeneity. More data are necessary to distinguish between these two models. Based on summarized practical experiences with existing equipment (Gebbers et al., 2009), the GEOPHILUS sensor was developed.

Materials and methods

<u>Technical parameters of the sensor</u>

GEOPHILUS represents a modular system, which is compatible with several arrays of electrodes. Currently, the system consists of six pairs of galvanic coupling electrodes (equatorial dipole-dipole configuration) and a special SIP instrument (spectral induced polarization) developed by Radic Research, Germany. The system is capable of recording complex resistivity (amplitude and phase) simultaneously for four frequencies within a frequency range between 1 mHz and 1 kHz. Excluding SIP-method, most devices work with fixed signal frequency, either low frequency (direct current - DC method) or in the range of kHz (electromagnetic induction method, EMI) or even higher (capacitive method). DC method measures resistivity and is more sensitive to high resistive soils, EMI measures conductivity with higher sensitivity for conductive soils. Both high resistive and high conductive soils are extremes and can provide small signal to noise ratio. Working with several frequencies gives additional possibilities to improve the signal quality and/or to use information from the spectra (Lueck & Ruehlmann, 2010).

The recent sensor design (Fig. 1a) and its technical specification allow measuring the electrical parameters at five depth levels up to 1.5 m. Increasing dipole spacing results in a remarkable smoothing of the sensitivity curve with its maximum at greater depths (Fig. 1b). Channel 1 is mostly influenced by the upper 0.5 m, 50 % of the signal of channel 5 reflect the depth range between 0.25 and 1.5 m.

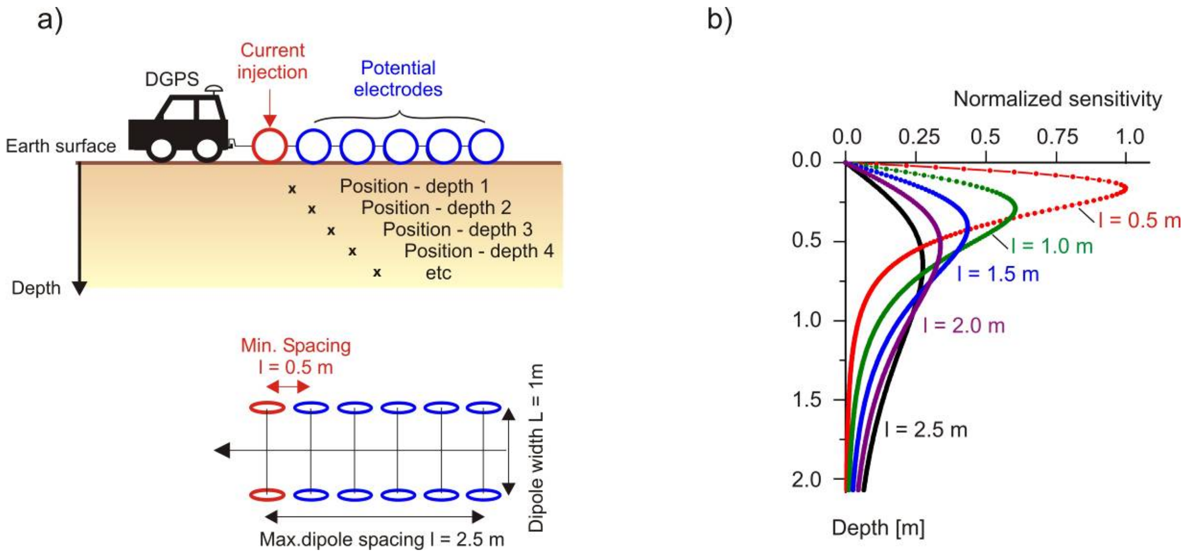

Figure 1. Scheme of the GEOPHILUS system (a) and sensitivity depth curves (b)

The applicability of the GEOPHILUS system has been demonstrated at several sites on soils with varying texture and consequently with different stratification and a wide range of electrical characteristics (resistivities from ~ 10 to 5000 Ohm m). A comparison with other conductivity mapping devices (VERIS3100, ARP03, EM38, CM138 and DUALEM) was performed on field scale.

Test sites

First of all, detailed investigations were done in Großbeeren (15 km south of Berlin) along a transect with known anomalies. The original soil consists of silty sand with low clay content (43 – 97 % sand, 2 – 50 % silt, 1 – 7 % clay). At a 200 m long test track, several structures (loam, peat, bricks and basalt powder) were installed in the soil. The installed loam body (clay content about 8 % and silt content about 40%) will be discussed in more detail.

The other site, the experimental farm Köllitsch (Saxony, Germany), is situated in the floodplain of the river Elbe. The site can be characterized by pronounced heterogeneity. Here, we can find a deposition of fluviatile loamy sediments on sandy, relatively unfertile subsoil. The thickness of the loam varies between a few centimeters up to more than one meter. The farm in Köllitsch started 10 years ago with conductivity mapping. Sensors like EM38 (430 ha), VERIS-3100 (250 ha) and GEOPHILUS (470 ha) were tested to evaluate the conductivity method as well as the different techniques.

Results and Discussion

Without data inversion, only lateral heterogeneity and tendency of stratification can be seen from all electrical field data. Inversion processes (post processing) allow imaging the exact geometry of soil structures and specific resistivity instead of apparent values.
In Großbeeren, GEOPHILUS data were compared with data from conventional electrical surveys with fixed electrodes. All considered configurations (Wenner, Schlumberger, Dipole-Dipole and Equatorial Dipole-Dipole) were able to image the conductivity contrast as well as the inclination of the sand-loam-contact. However, the sharpness of the images differs depending on the spacing and the geometry of the electrodes. The models in Figure 2 result from measurements with an Equatorial Dipole-Dipole-array. Working with fixed electrodes, the lateral resolution corresponds to the spacing between the electrodes. The lateral resolution of GEOPHILUS measurements depends on the driving velocity and the data transfer rate. For this study, an extreme high data resolution of 0.5 m was realized. Large fields are normally imaged with coarser point density (data rate of 1 point per second and velocity of 15 km/h result in point increments of about 4-5 m).

The loam body was not only visible in resistivity data (Figure 2) but in phase angle data too (not shown here).

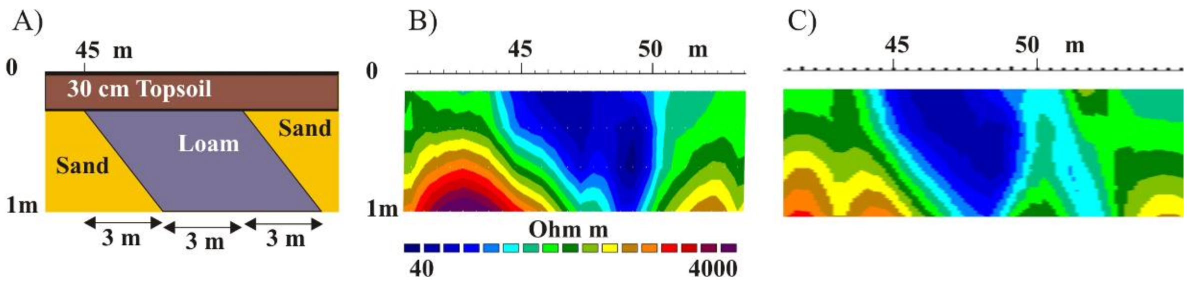

Figure 2. Sand-loam-contact in Großbeeren. A) Sketch of the situation, B) Resistivity model measured with fixed electrodes arranged as an equatorial dipole-dipole-array and C) Resistivity model from GEOPHILUS data

Mobile conductivity sensors are used on large fields. With GEOPHILUS, we have practical experience along a virtual transect of more than 1000 km length corresponding to the mapped field area of about 1300 ha. GEOPHILUS data image the lateral soil heterogeneity as well as other conductivity sensors. Figure 3 gives a first impression about some results in Köllitsch. All tested sensors imaged the similar pattern caused by former river channels. All datasets show sharper contrasts for the whole depth range than for the upper horizon. GEOPHILUS data indicate additionally an increase of resistivity with depth. Comparing different methods and equipment in more detail, the depth sensitivity curves and the actual soil moisture have to be considered. Here, individual color scales were used to emphasize the pattern of heterogeneity.

Whether phase data provide additional information depends on the precise situation. Phase data can give additional information e.g. about salinization, compaction or metal pipes. The variation of phase data with frequency is much higher than the variation of resistivity data and the spectra depend on absolute resistivity values. In high conductive areas, high frequencies may result in strong signal to noise ratio improving the data quality for resistivity measurements. However, small frequencies should be preferred for inversion because uncontrolled effects at the electrodes increase with frequency.

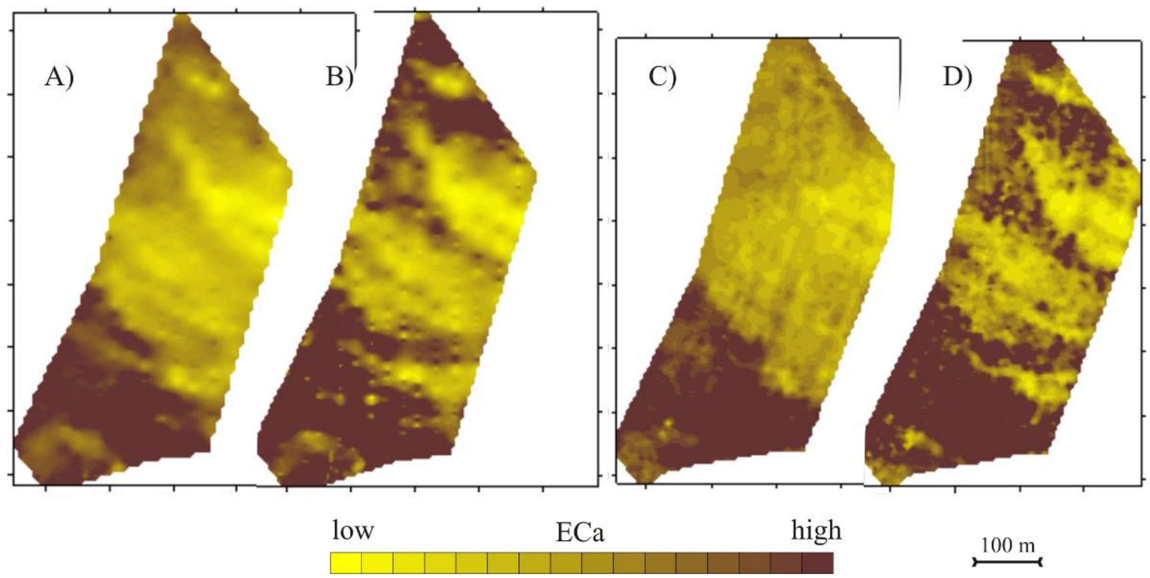

Figure 3. Conductivity maps with individual color scale. Resistivitiy data were transformed to conductivity values. GEOPHILUS data with different dipole-spacing A) l = 0.5 m and B) 1.5 m, VERIS3100 data – C) shallow reading and D) deep reading

Conclusions

The overall consistency of the individual maps as well the obvious stratification confirmed by independent data indicates good data quality.

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