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DEVELOPMENT OF 3D GEOELECTRICAL RESISTIVITY FOR MAPPING OF GAS MIGRATION IN LANDFILLS

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SUMMARY: Methane is a powerful greenhouse gas and growing concern regarding global climate changes and landfill gas is regarded as one of the major sources for methane migration to the atmosphere. In this study we present research work with the objective to evaluate the use of 3D geoelectrical resistivity to detect gas migration in landfills. Extensive field experiments were conducted at the Filborna landfill site in Helsingborg, Sweden, in August 2008. In general, the resistivity measurements showed results corresponding to results reported from previous investigations in waste. In this paper we present results showing the influence of rainfall events on the resistivity, and the correlation between gas flux and resistivity near the surface.

1. INTRODUCTION

The global contribution of greenhouse gas emissions from landfills is considerable. Methane is a particular powerful greenhouse gas and landfills are rated as the second largest anthropogenic source of methane emissions to the atmosphere (Spokas et al., 2009). The migration of methane and carbon dioxide from a specific landfill depends on several aspects, such as the nature of the soil cover system, the gas collection system, and daily management. There are two major advantages in collecting landfill gas; the environmental benefit of reducing the amounts of methane and carbon dioxide emissions to the atmosphere, and the advantage of providing the market with alternative of renewable energy, for example as vehicle fuel or electricity.

It has been pointed out that the electrical resistivity is suitable for monitoring of water fluxes in landfills since it links with moisture content and ionic content in the water (e.g., Guérin et al., 2004). In recent years resistivity has been used at landfills for various applications like mapping landfill cover (e.g. Leroux et al., 2007), and for studies of moisture migration processes during leachate recirculation at bioreactor landfills (e.g., Marcoux, et al., 2007, and Rosqvist et al, 2007). As a consequence of the expected sequential nature of the sub-surface landfill gas migration, it has been shown that zones with landfill gas migration can signal themselves by large variations in resistivity (Rosqvist et al., 2011). It is, however, also expected that the variations in resistivity will be related to other processes such as changes in soil temperature and soil moisture content.

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We present research work with the objective to further investigate the possibilities to develop the geoelectrical resistivity technique to better understand the process governing gas migration in landfills. The study presented here in gives emphasise to the temporal and spatial dependence of resistivity measurements for gas migration detection. In this paper we present results from a field campaign performed in August 2008.

2. MATERIALS AND METHODS

2.1 Field site

The field site measured 20 by 16 meter and was placed on top of an old MSW landfill, the Filborna landfill site, Helsingborg, Sweden. The Filborna landfill is one of the biggest and oldest, still active, landfills in Sweden covering an area of more than 35 hectare of land. The experimental measurements presented herein were performed on the Filborna landfill site in August 2008. Nine parallel resistivity lines were monitored under nearly two months with a remote controlled system. In addition to the resistivity monitoring the weather was recorded locally and gas flux measurements for spatial and temporal flux variability were performed. Figure 1 show a photo of the experimental site where the yellow stripes show the positions for the measurements of resistivity.

Figure 1. Photo showing the experimental site at the Filborna landfill, Helsingborg, Sweden

2.2 Resitivity measurements

Resistivity is a geoelectrical imaging method which is based on measurement of the potential distribution arising when electric current is transmitted to the underground via electrodes. The electrical resistivity of soil materials generally depends on the moisture content, temperature, porosity, and on the pore water salinity. In this study resistivity monitoring was carried out along nine parallel lines with the ABEM Lund Imaging System multi-electrode system (Dahlin and Zhou, 2004). The lines were separated by 2 meter and with an electrode spacing of 0,5 meter, resulting in a 16 by 20 meter experimental site. The system is computer controlled and consists of a resistivity instrument, a relay-switching unit, four electrode cables, connectors and steel electrodes. The resistivity measurements were monitored using a remote controlled system and designed for 3D-measurements and 3D-interpretation. All data for each complete set of measurements were inverted using Res3Dinv, and a true 3D-model was computed for each measurement.

2.3 Gas flux measurements

During the field campaign, the resistivity measurements were performed together with static chamber measurements at six fixed plots. Three of the six plots were placed over relatively high resistivity zones (plots K1, K2 and K3) and the other three over lower resistivity zones (plots K4, K5 and K6). The same plots were kept during all chamber measurements. In this paper we show results from two plots, K2 and K3 where the soil cover material was characterized as humus rich sandy soil. The location of the gas flux measurement plots was based on results from previous resistivity measurements where the resistivity map was used to get an overview picture of zones of high and low resistivities. A static chamber setup with a volume of 12 dm^3 was used for measurements, where septum sealed openings for air sampling was placed on the top. For every measurement, the chamber was placed on the ground and sealed for air leakage with wet clay. Once the chambers were placed on the ground and sealed with clay, a 20 ml gas sample was collected with a syringe and saved in a 10 ml glass vial. After 10 and 20 minutes respectively, the gas sampling was repeated to complete the measurement series of one single flux measurement.

The samples collected from the chambers with syringes were analysed in a laboratory through separation by gas chromatography (GC, Shimadzu 17A) and detection by flame ionization detection (FID).

3. RESULTS

In general, three main areas of difference in resistivity were observed from the data generated during the measurements. One area with low resistivity (below 10 Ωm), that agrees well with the position of a known subsurface compost wall in the field site. A second area showed resistivity values in a range up to approximately 50 Ωm, corresponding to values for MSW reported in previous publications (e.g., Rosqvist et al., 2011). The third area, characterized by high resistivity values, appears in a zone near the surface above the subsurface compost wall. In this area resistivity values over 500 Ωm were registered. In Figures 3 and 5, changes in resistivity data over time is visualised in 3D-volumes. The changes in data were calculated by the difference in resistivity between two subsequent measurements. In the 3D-volumes (Fig. 3 and 5), resistivity changes in the range -30% to + 30% are shown. Below, results of changes in resistivity are compared with rainfall events (section 3.1) and gas flux measurements at the surface (section 3.2).

3.1 Correlation with a rainfall event

On August 18 there was a rainfall event that started approximately at 12 PM and continued for 8 hours (Fig. 2). It was a low-intense rainfall at 0,2 mm per two hour during the first hours, and then with an increasing intensity.

The resistivity measurements during the first hours of rainfall (Fig. 3, above) showed a relatively even distributed increase in change resistivity near the surface.

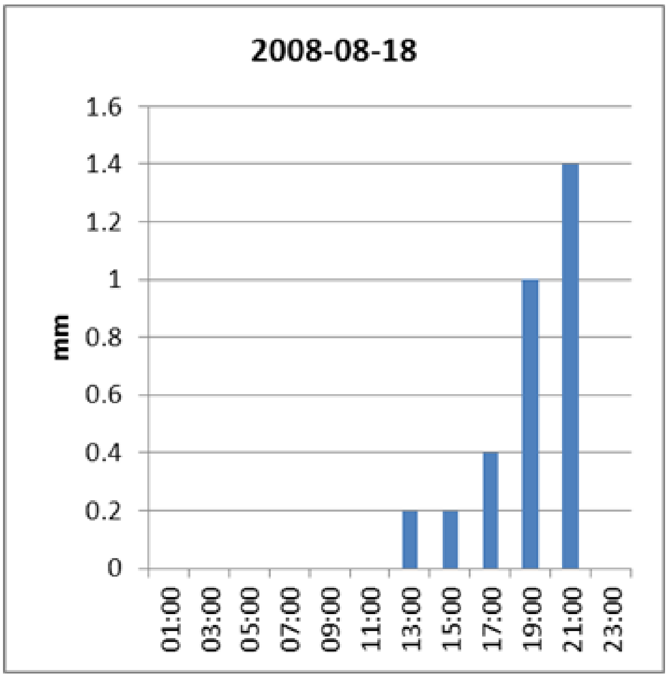


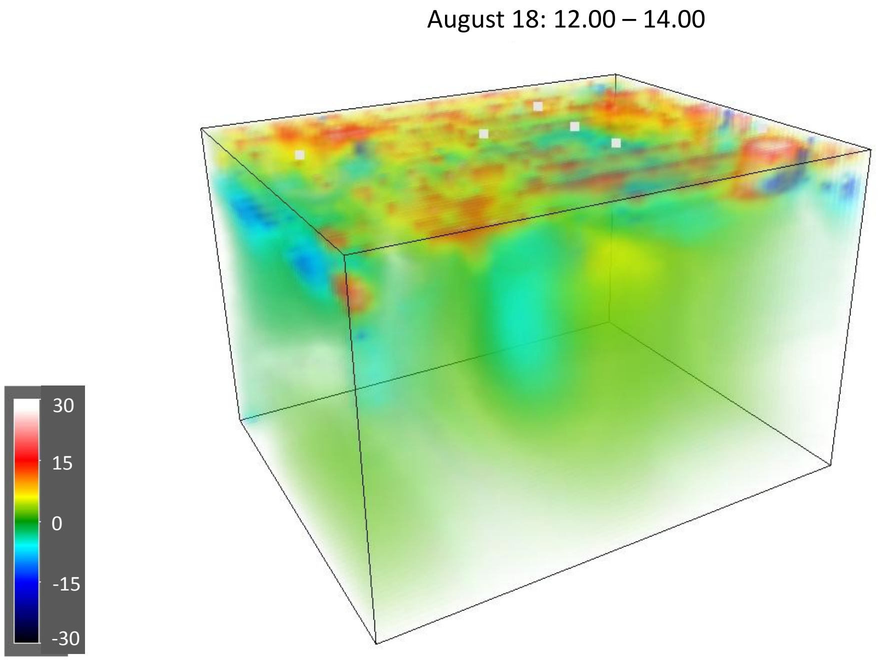
Figure 2. Rainfall data on August 18, 2008 at the Filborna landfill site (mm/2 hours)

In Figure 3, the raise in resistivity is shown as red and yellow patterns near the surface, whereas decrease is shown as green and blue patterns. It is suggested that the increase in resistivity at 12.00 to 14.00 near the surface indicate a build-up of gas pressure in the top layer of the soil cover, as the surface became wet, and thus, less permeable for gas migration. In the next time step (14.00 – 16.00, Fig. 3, below) there is a relatively even distributed decrease near the surface, shown as green and blue patterns near the surface. The decrease in resistivity could be due to increase in soil moisture content in combination with temperature changes due to the rainfall. Also migration of gas through the top layer of the soil cover into the atmosphere may influence the resistivity.

3.2 Correlation between changes in resistivity at depth, and flux measurements at the surface

Figure 4 shows a decrease in gas flux between two measurements performed at plot K2 and K3 on August 20. The decrease in flux for K2 and K3 were 500 to 280 and 990 to 390 mg/m^2/h respectively, corresponding to decrease of approximately 50-60% over a time span of a few hours. Over a five day period of measurements, the mean and median values for K2 and K3 were 260 and 280 mg/m^2/h (K2) and 390 and 410 mg/m^2/h (K3) and thus, the flux rates at 14.30 were close to mean/median values, whereas the previous fluxes measured at 11.00 (K3) and 13.00 (K2) where considerably higher.

In Figure 5 changes in resistivity recorded at the same time as the flux measurements were performed, are shown. The changes in resistivity between 10.00 – 12.00 (Fig 5, above) and 14.00 – 16.00 (Fig. 5, below) show an increase in the resistivity data in several zones close to the soil surface during the first time step (10.00 – 12.00), followed by a decrease in resistivity values during the second time step (14.00 – 16.00). During the intermediate time step (12.00 – 14.00) there was still an increase in resistivity in some of the zones, but a clearly less pronounced than in the previous time step. Thus, a general decrease in resistivity change were recorded in three time steps in between 10.00 to 16.00, and a corresponding decrease in the gas flux measurements were recorded.



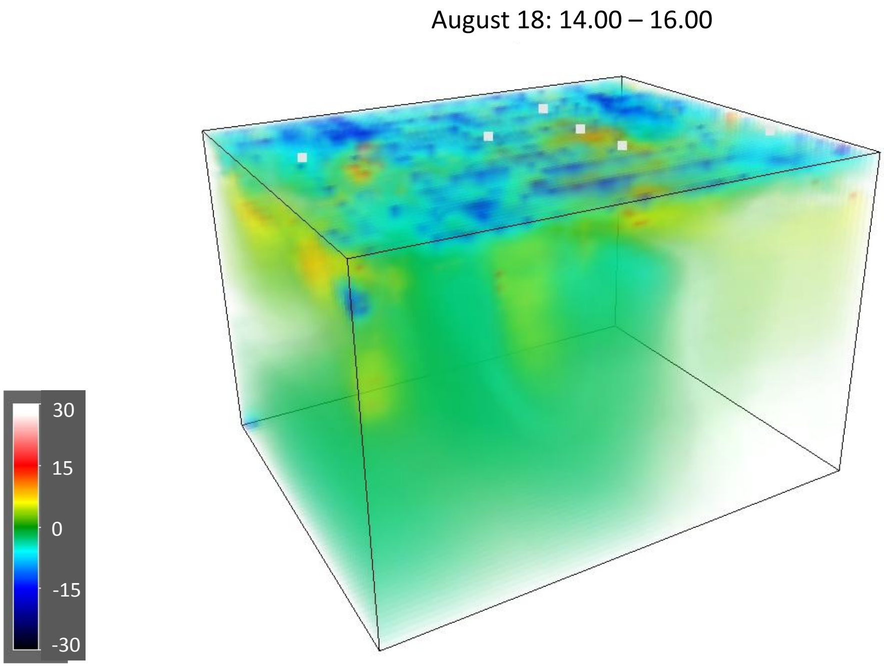


Figure 3. Changes in resistivity between 12.00 – 14.00 (above) and 14.00-16.00 (below) on August 18, 2008

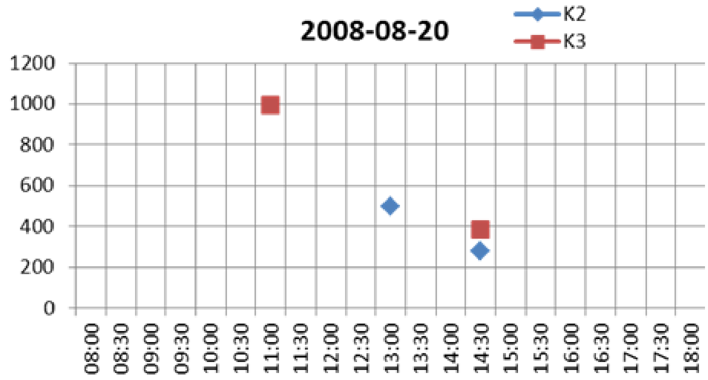
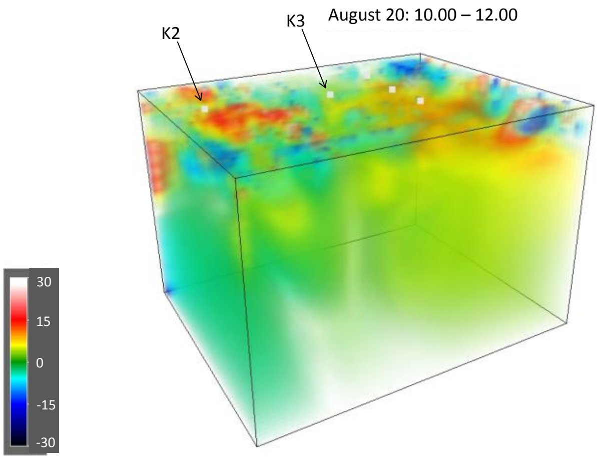


Figure 4. Results of gas flux measurements at K2 and K3 on August 20.



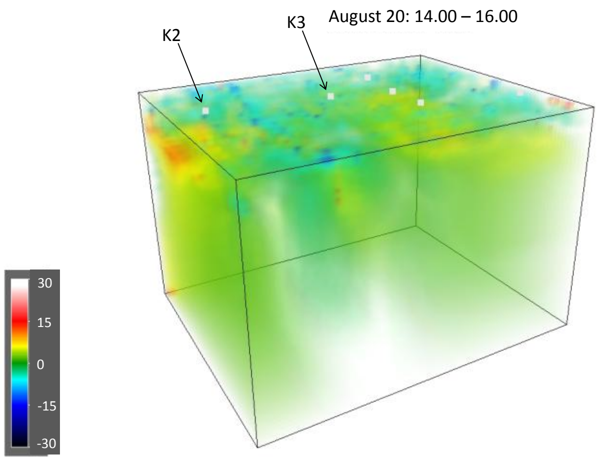


Figure 5. Changes in resistivity between 10.00 – 12.00 (above) and 14.00 and 16.00 (below) on August 20, 2008

4. DISCUSSION

In this study we present research work with the objective of evaluating the use of geoelectrical resistivity technique to detect landfill gas migration, based on extensive field experiments conducted at the Filborna landfill site in Helsingborg, Sweden, in August 2008. In general, the resistivity measurements showed results corresponding to results reported from previous investigations in waste. Also large variations in resistivity values were indicated and relatively high variability and high mean resistivity in the surface-near layers clearly indicate influence on the resistivity in the upper zone of the landfill. The variability and high resistivity may partly be explained by the presence and migration of landfill gas. However, also changes in soil moisture content and temperature may have a considerable influence on the resistivity data showed in this study.

Influence of rainfall events on the resistivity was shown on August 18 as a relatively even distribution of changes in resistivity near the surface. It was, however, not demonstrated that it is the changes in moisture content alone that is the source of changes in resistivity, most probably also other processes are involved, such as changes in temperature and gas pressure. In particular temperature changes may be of interest as the measurements were performed in the summer when rainfall events may cause relatively large variation in the soil temperature near the surface. Trends in resistivity changes and the gas flux data on August 20 indicate a relationship between resistivity close to the soil surface and gas emissions from the soil surface. However, the number of gas flux measurements was limited and therefore it is suggested that future investigations should aim at a better understanding of the correlation between surface gas flux and resistivity changes.

The correlations between rainfall and resistivity as well as gas flux and resistivity are interesting and promising visualisations of processes in the soil, even if it is complicated to interpret the variations of resistivity in detail. Several additional factors influencing the variations in resistivity besides the ones presented here should be considered. The ambient soil moisture, for example, probably affects the response of the resistivity to precipitation. It is therefore concluded that the resistivity technique has a potential for mapping of landfill gas migration. The relationship is however complex and site-dependent, but given a good combination of information from different field data, it appears to be possible to image the migration of gas inside a landfill.

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