

Developing a geophysical framework for Neolithic land-use studies: in situ monitoring and forward modelling of electrical properties at “Valther-Tweeling” (NL)

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Abstract

Boosting Neolithic land-use studies in the Low Countries requires optimal geophysical survey. Hereby, forward modeling such subtle soil features in a sandy soil could support survey design. The models are parametrized through soil sample analyses and in situ data collection over a feature. Supplemented by long term in situ monitoring, these results reveal variable detectability. This approach enables a quantitative approach for geophysical survey design.

Keywords

geophysical forward modelling; geophysical survey strategy; in situ monitoring; Neolithic land-use; soil physics

Introduction

Although many Neolithic settlements, consisting of artefact scatters, have been revealed on the sandy and loamy soils of Belgium and the Netherlands over the past decades, little is known about their structural layout and spatial organization. Redressing this current understanding of Neolithic land use requires the development of a framework to map related land-use traces with minimal intrusiveness. Hence, the “Working the land, searching the soil” project (Verhegge et al. 2021) was established to optimize the use of geophysical techniques to map and characterize Neolithic features along with existing prospection approaches.

Geophysical surveys of Neolithic feature sites, particularly those employing magnetometers on loess soils, have been satisfactory. However, more subtly contrasting features are not investigated geophysically in the sandy soils of the Low Countries, partially because a lacking quantitative basis for survey strategization. Furthermore, geophysical

studies into the geometry and composition of archaeological features and temporal variations in (di)electrical contrast could contribute to such a framework, but are still uncommon. We aim to develop a widely applicable framework embedded in archaeological practice and rooted in geophysical theory.

Materials and methods

Methodological approach

The potential (changing) contrasts between natural soil profiles and Neolithic archaeological soil features of the Low Countries are characterized by excavating vertical profiles on a range of natural (i.e. non-archaeological) and archaeological soil sequences. On these sections, in situ geophysical data are registered following De Smedt et al.

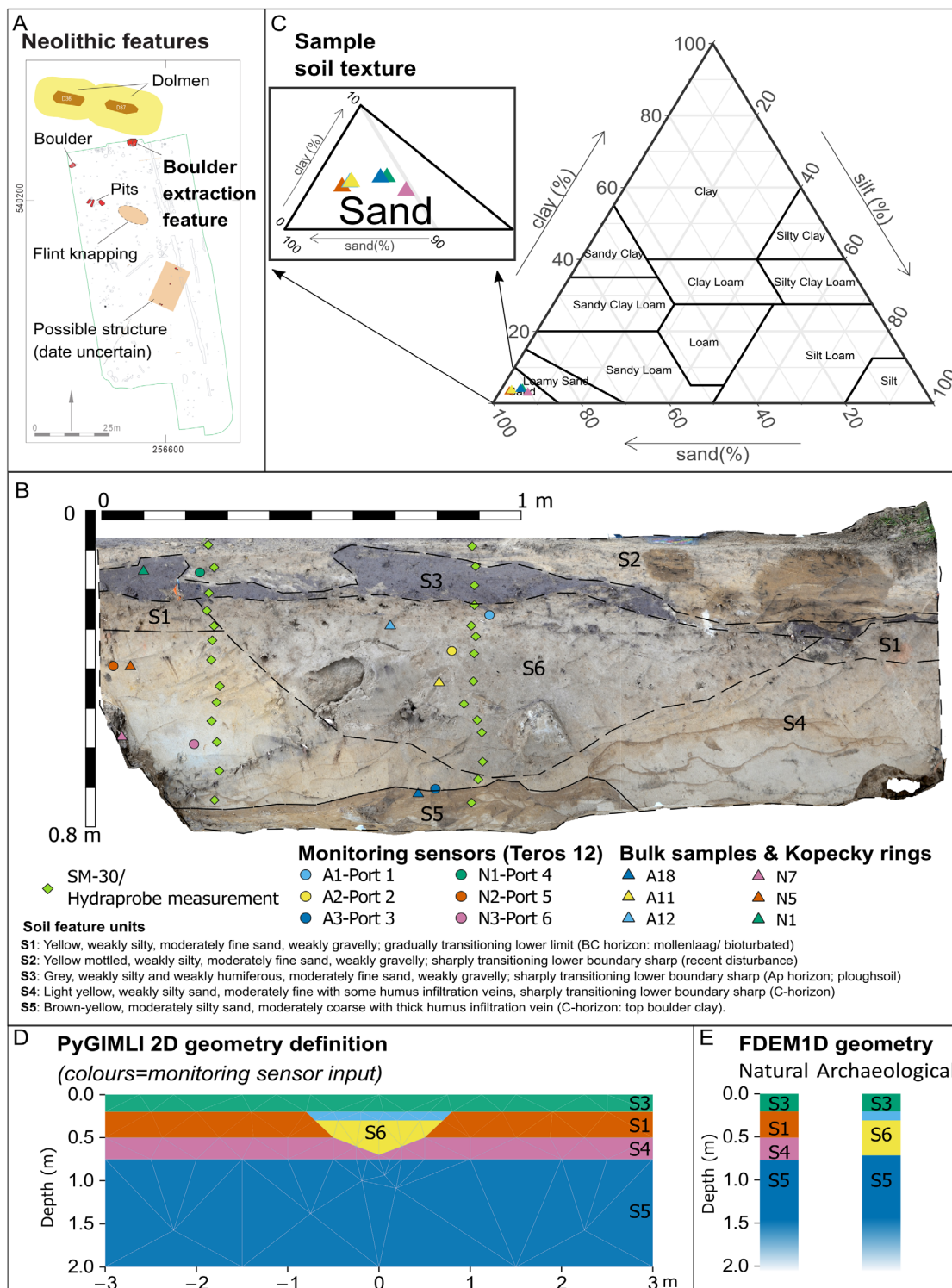


Fig. 1: a) Site map with the excavated soil features and dolmen (adapted from Fens et al. 2016). The feature under investigation is marked in bold, b) Orthophoto of the section wall of the excavated profile pit at Valther-Tweeling with the observed soil feature units, positions of profile measurements, samples and monitoring sensors. Macroscopic descriptions of the delineated natural and archaeological soil feature units at the bottom, c) results of the soil texture analysis on the USDA soil triangle. Colours according to sample locations (see Fig. 1b), d) simplified 2D profile geometry used in PyGIMLI. Colours represent monitoring sensors (see Fig. 1b) used as input, e) simplified 1D geometry used in FDEM1D. Colours represent monitoring sensors (see Fig. 1b) used as input.

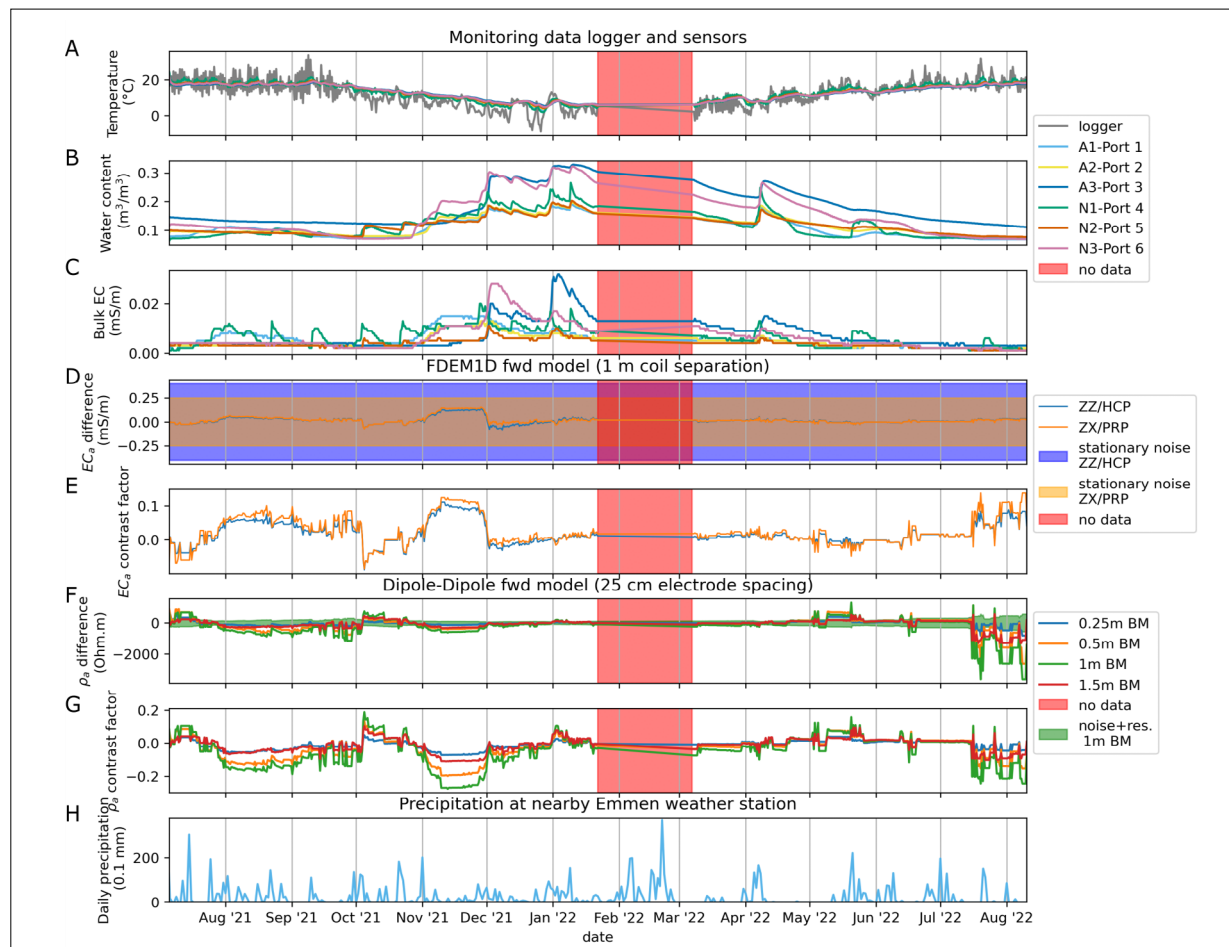


Fig. 2: a) Temperature monitoring data of the ZL6 data logger and Teros 12 soil sensors, b) Soil moisture content monitoring data of the Teros 12 soil sensors, c) Bulk electrical conductivity data of the Teros 12 soil sensors (corrected to 25°C), d) Difference of the FDEM1D models (1 m coil separation in horizontal coplanar (ZZ/HCP) and perpendicular (ZX/PRP) configuration) of the archaeological and natural sequence, expressed as LIN approximated ECa. Colour shading indicates stationary noise in comparable Dualem sensors (Delefortrie et al. 2014), b) Contrast factor (Schmidt et al. 2017) of the FDEM1D ECa, c) Difference of the PyGIMLI ρ_a model within and outside the feature. Colour shading indicates the instrument resolution and noise, approximated for a Geoscan RM85 (Geoscan Research 2019), d) Contrast factor of the PyGIMLI ρ_a , e) Daily precipitation data of the nearest weather station (333-Emmen, Royal Netherlands Meteorological Institute).

(2019) with a magnetic susceptibility meter (SM-30, ZH-Instruments) and a coaxial impedance dielectric reflectometer probe (Hydraprobe, Stevens Water), registering real dielectric permittivity (ϵ) and bulk electrical conductivity (EC). Furthermore, Kopecky ring and mixed bulk samples are gathered from every observed soil horizon or archaeological layer to determine bulk density, porosity, water and organic matter content, texture and cation exchange capacity. At selected sites, monitoring stations (Teros 12 with ZL6, Meter Group) are installed to examine temporal changes in temperature, bulk EC (corrected to 25 °C), ϵ and moisture content (derived). Once geophysical properties and soil feature geometry are established, and at

least year-long monitoring data is collected, geophysical forward modelling allows evaluating cross-temporal geophysical signals to strategize surveys. In tandem with this novel archaeological fieldwork and survey strategization approach, pedophysical models are developed to predict EC and ϵ (phases) requiring only basic soil properties of bulk samples by removing fitting parameters (Mendoza Veirana et al. 2021).

Case study: Valther-Tweeling

While investigations of several natural soil sequences assist in developing pedophysical models, the results of one archaeological site, next to dolmen D36 and D37 at

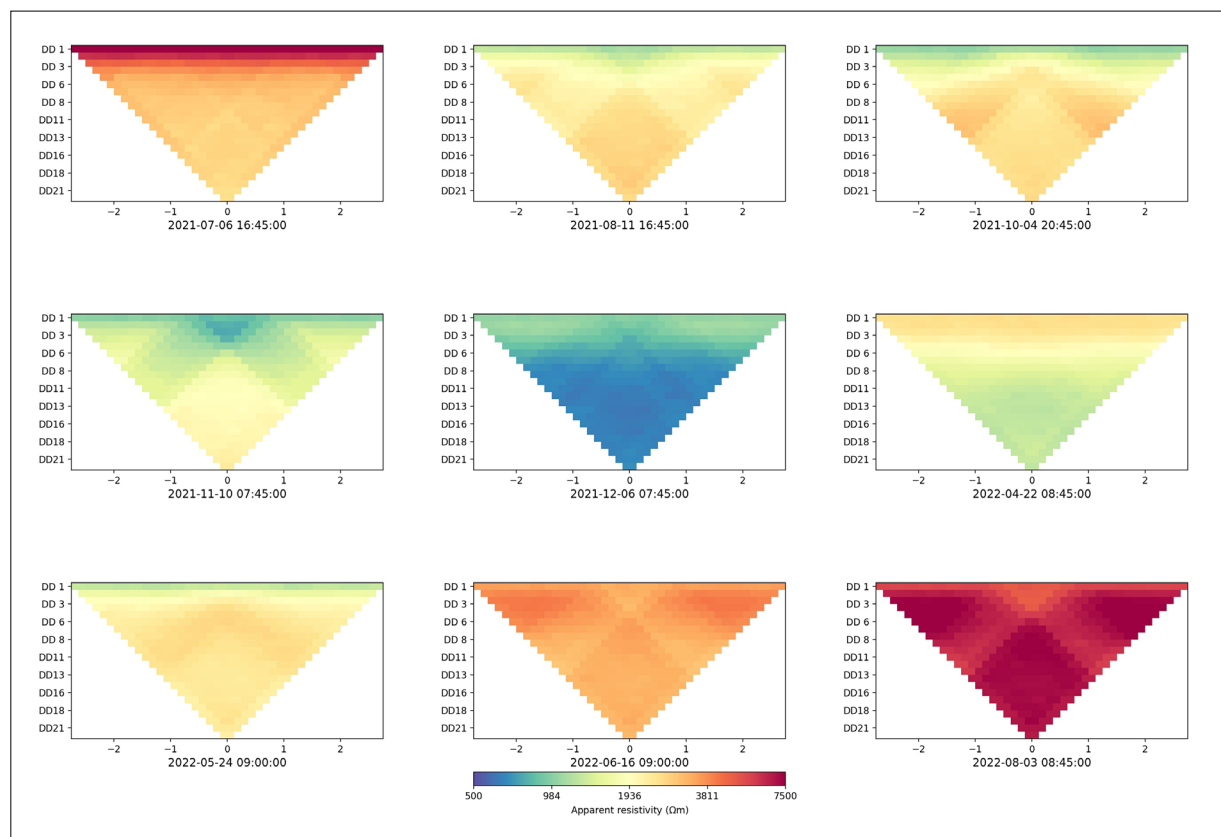


Fig. 3: Mosaic of divergent PyGIMLI ρ_a section models throughout the monitoring timespan.

Valther-Tweeling (NL), are addressed here. Here, the soil consists of coversand with a Gley-Podzol, of which the top was later disturbed by ploughing. A nearby, partially excavated, soil feature, interpreted as a boulder extraction pit (Fens et al. 2016) (Fig. 1a), was re-excavated and investigated following before mentioned methodology.

To plan upcoming surveys in the surrounding landscape, possibly holding Neolithic features, monitoring data are used to forward model the response of common electromagnetic induction instruments of both sequences using FDEM1D (Hanssens et al. 2019) (Fig. 1e). A 2D apparent resistivity (ρ_a) section with a dipole dipole array and 25 cm electrode separation was forward modelled using PyGIMLI (Rücker et al. 2017) (Fig. 1d).

Results

The profile description and photo (Fig. 1b) reveal the feature with greyish fill color. Despite the topsoil (S3) and backfill (S2) disturbance, sufficient feature fill (S6) was preserved for measuring and sampling. EC, ϵ , magnetic

susceptibility measurements of the natural and archaeological sequence during the excavation were very low and nearly indistinguishable (Verhegge et al. 2021 – Fig. 3). The analyzed soil samples consisted of sand with low clay and silt content (< 10%), barely exhibiting texture contrast (Fig. 1c) as do the volumetric water content and porosity (Verhegge et al. 2021 – Fig. 3).

Last year’s monitoring data expose significant bulk EC variability (Fig. 2c) and soil moisture (Fig. 2b) between the natural soil and archaeological feature fill. Temperature (Fig. 2a) change across the year is significantly larger than between the natural soil and archaeological feature fill but this is not reflected in the bulk EC due to the temperature correction. The difference of the modelled FDEM1D quadrature phase between archaeological and natural sequence, expressed as LIN approximated apparent conductivity (EC_a), increases mostly in November 2021, maximizing to 0.15 mS/m and a 0.12 contrast factor in ZX/PRP (Fig. 2a, 2b). The largest negative differences, down to -0.08 mS/m (contrast factor: -0.03), were modelled in early December 2021. However, these differences are below observed stationary sensor noise levels.

In the ρ_a models, the feature appears differently throughout the year. When recognizable on Figure 3, it appears mostly as a lower ρ_a anomaly, but e.g. on October 4th, 2021, a more resistive anomaly is detectable (Fig. 3 – top right). Comparison of various distances between the B and M electrodes (Fig. 2c, 2d) illustrate that a 1m separation generates the highest ρ_a difference and contrast factor throughout the year. In November 2021, the ERT model indicates a negative contrast factor (-0.27) and anomaly (590 Ohmm), which is beyond estimated RM85 noise. However, compared to the EMI EC_a model, larger differences and contrast factors are present more frequently throughout the year, markedly in resistive summer conditions.

Discussion and conclusion

Despite diachronic variation under the influence of soil moisture and temperature, the modelled EC_a signals of the monitored feature at “Valther-Tweeling” are too subtle to be measurable with current EMI sensors, while the ERT models do indicate a measurable signal. However, noise due to instrument use, external interference or natural soil variability was not included in the models yet. Nevertheless, electrical resistance survey also seems applicable across a larger timespan than EMI. Therefore, an electrical resistance survey is planned in late 2022-early 2023 to corroborate these findings. Correlation with precipitation data ratios (Fig. 2e) is still required to pinpoint suitable precipitation conditions preceding a survey.

Indeed, compared to initiating an electrical resistance survey at the site uninformed, executing it in established, optimally contrasting conditions at feature s6 and its surrounding soil should benefit survey results of the surrounding site and landscape as well. Importantly, the results illustrate the starting development of a quantitative framework for developing geophysical survey strategies for subtle (Neolithic) soil features, and complex archaeological features more broadly, without requiring repeated surveys. The presented approach is applicable to other sites and features by using pedophysical models to convert traditional soil properties into geophysical properties, such as EC or ϵ , to parametrize forward models if in situ geophysical data are unavailable. However, soil monitoring is still required to include soil moisture and temperature variations across time but this becomes more practical as affordability and user-friendliness of monitoring sensors is increasing. ■

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