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Spatio-temporal modeling of soil characteristics for soilscape reconstruction

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A B S T R A C T

Full-coverage maps for several specific soil characteristics were produced at particular time-intervals over a time span of 12,716 years for a 584 km^2 large study area located in Belgium. The pedogenetic process model SoilGen2 was used to reconstruct the evolution of several soil variables at specific depths in the soil profile at various point locations (96 in total). The time span covered by the simulations encompassed the final part of the Younger Dryas and the Holocene up till the present. Time series on climate, organisms and groundwater table were reconstructed and supplied to the model as boundary conditions. Model quality optimization was performed by calibrating the solubility constant of calcite by a comparison of the simulated time necessary for decarbonization with literature values and evaluating the calibrated value over a wide range of precipitation surpluses representative for the regarded time period. The simulated final state was evaluated against measurements collected in a database representing the historic state of the soil at 1950. The simulated specific soil characteristics at the point locations were then used to produce full-coverage maps at the particular time-intervals by regression kriging. Such maps are believed to provide useful information for geoarcheological studies and archeological land evaluations.

1. Introduction

Since prehistoric times, man has lived in close interaction with the land, which aspects are believed to have influenced decision making on occupation and utilization of a region. For example, analyses of the spatial distribution of archeological finds and their possible correlation with physical/environmental variables were the subject of investigations since the 1970s (e.g., De Reu et al., 2011; Niknami et al., 2009). Anthropogenic activity, on the other hand, influences the environment as well (Knight and Howard, 2004; Oetelaar and Oetelaar, 2007). Usage of the land in prehistoric times encompassed not only settlement, but also the provisioning in livelihood for example through hunting and/or fishing and gathering, which was the main way of subsistence until the Mesolithic inclusive. Agriculture was practiced from the Neolithic onwards, its starting point, degree of continuity and intensity varying spatially (Crombé and Vanmontfort, 2007). Various types of pre- and protohistoric land use serving as biophysical attractors for occupation were listed by Zwertvaegher et al. (2010), together with their associated land qualities and characteristics. For example, the land utilization type rain-fed agriculture that is among other things influenced by land qualities such as moisture, oxygen and nutrient availability in the soil.

The component soil is an important factor in establishing the suitability of the land for several types of land use. Natural soil fertility is determined by the physical and chemical soil properties that are the product of several soil forming processes and are therefore variable through time. Mostly, only the present-day state of the soil is known, together with the condition of the parent material. Unless soil chronosequences are at hand, no information on past soil conditions is available (Finke, 2012). Therefore, process models using the knowledge on physical and chemical processes, are interesting tools in the reconstruction of the paleo-characteristics of the land (Zwertvaegher et al., 2010) that enable land evaluation and population carrying capacity assessment for past (pre-)historic situations. Such land evaluation can then be used to explain spatial variation in the density of soil occupation as recorded in archeological prospection (Finke et al., 2008). Concerning the factor soil, the pedogenetic process model SoilGen (Finke, 2012; Finke and Hutson, 2008) was used to provide the necessary variables for a specific time and depth of the soil profile at several point locations (Zwertvaegher et al., 2010). Currently, SoilGen is one of the few mechanistic models able to reconstruct depth profiles of soil variables such as clay content, OC content, base saturation, CEC, and pH and which was confronted to field measurements (Opolot et al.,

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in review; Samouëlian et al., 2012; Sauer et al., 2012). In contrast to soil development models that do not include the water cycle (e.g., MILESD, Vanwalleghem et al., in press), effects of climate change can be accounted for with SoilGen (Finke and Hutson, 2008), which is of great relevance when paleolithic and mesolithic periods are studied. With such model as a temporal interpolator, past situations can be reconstructed, not only for geoarcheological purposes such as in this paper, but also for the estimation of carbon stock pool size evolution over multimillenniums. Additionally, such model can also be used to evaluate scenarios of soil formation at the pedon scale and the landscape scales (Finke et al., in review; Vanwalleghem et al., in press).

The main objective of this work was producing full-coverage maps of the study area of soil characteristics relevant for past human occupation at certain points in time. To attain this, the model boundary conditions and initial conditions were reconstructed for the time period at hand. Additionally, the model reliability was maximized by calibration of the model-processes and evaluation of the simulated final state by comparison with the measured final state. Finally, the model outputs at several point locations were used in the reconstruction of full-coverage maps of specific soil characteristics.

2. Study area

The study area encompasses a total of 584 km^2 and is situated in the region of Flanders, in the northern part of Belgium (Fig. 1). Archeological investigations in the Flanders region revealed areas with high-site densities, as well as areas with very little archeological evidence, despite repeated archeological surveys. The study area was chosen to encompass both of these areas, as well as a broad environmental diversity, such as dry and wet soils, and topographical gradients.

The soils of the study area are dominantly characterized by sand textures according to the Belgian classification, ranging from moderately wet to moderately dry, and loamy sand textures, with drainage classes from moderately wet to wet (Tavernier et al., 1960). This sandy substrate was largely deposited during the fluvial infilling of a valley system, called the Flemish Valley, formed during Pleistocene glacial and interglacial cycles (De Moor and van de Velde, 1995). These sediments were afterwards reworked by strong aeolian activity towards the end of the Pleniglacial and also during the Late Glacial. This resulted in the formation of parallel east-western oriented dunes and dune complexes with heights up to 10 m.a.s.l. (De Moor and Heyse, 1974; Heyse, 1979). Tertiary marine sandy and clayey layers are found in outcrops, such as the cuesta of Waas and the hills of Central West Flanders (De Moor and Heyse, 1974; Fig. 1). Calcareous gyttja infillings (marl) are present in several depressions along the southern border of the coversand dune area. The Moervaart depression is the largest of these depressions with an approximate length of 25 km (Crombé et al., 2012). In the alluvial plains of the major river valleys and in these semi-alluvial depressions, sand loam, clay and peat are also found. These are associated with wet to very wet, and even extremely wet locations (Tavernier et al., 1960). A distinct soil profile development is generally absent in these soils (Tavernier et al., 1960; Van Ranst and Sys, 2000).

Regosols and Arenosols found in sandy textures with excessive drainage are often due to recent sediment movement and redeposition in dune contexts (Van Ranst and Sys, 2000). In these cases, a buried Podzol is often found at a certain depth (Ameryckx, 1960). Several other stages of soil profile development in the more sandy textures are found in the study region, corresponding with WRB classified Cambisols, Albeluvisols and Podzols(IUSS Working Group WRB, 2006). Plaggic Anthrosols also occur in the study area, as

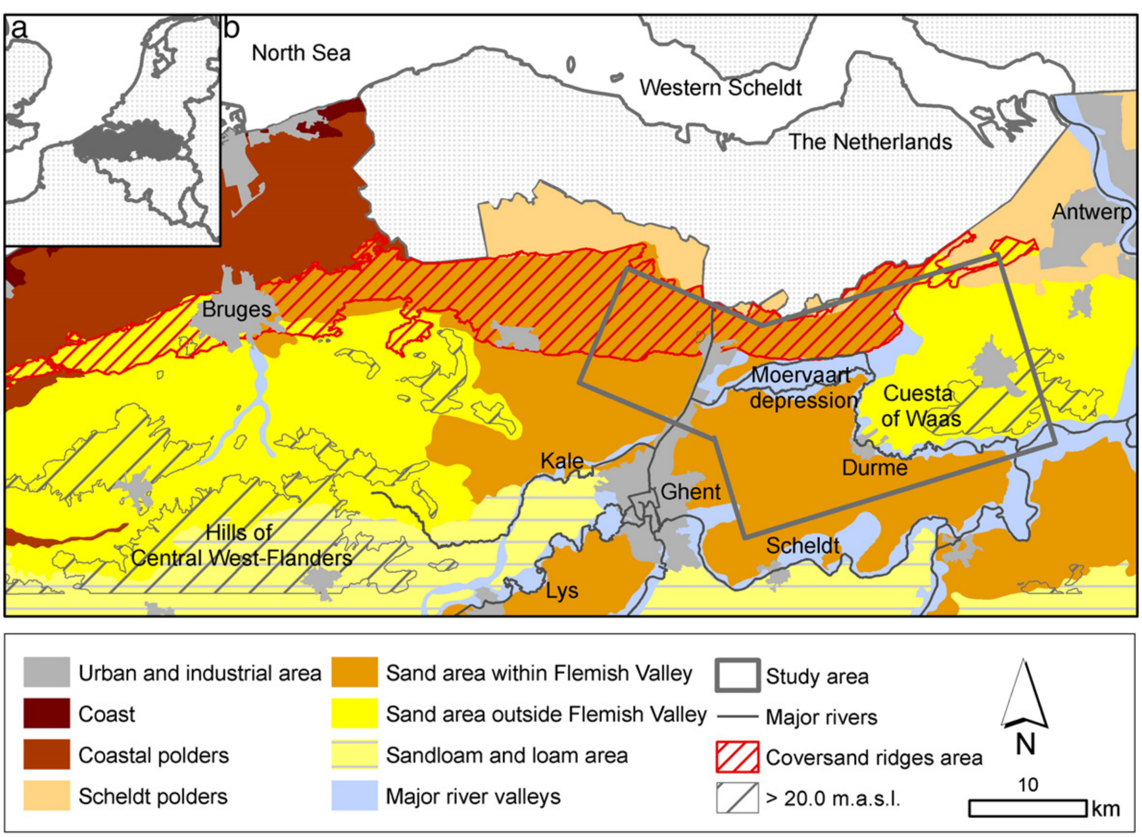

Fig. 1. a: Localization of Flanders (indicated in gray) within Belgium; b: localization of the study area within the northern part of Flanders, showing the main landscapes and geomorphological features. The delineated (hatched) entities "Hills of Central West-Flanders" and "Cuesta of Waas" consist of sediments of Tertiary age, other entities are of Quaternary age.