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Review

The use of remote sensing in soil and terrain mapping — A review

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ABSTRACT

This article reviews the use of optical and microwave remote sensing data for soil and terrain mapping with emphasis on applications at regional and coarser scales. Remote sensing is expected to offer possibilities for improving incomplete spatial and thematic coverage of current regional and global soil databases. Traditionally, remotely sensed imagery have been used to support segmentation of the landscape into rather homogeneous soil–landscape units for which soil composition can be established by sampling. Soil properties have also been inferred from optical and microwave data using physically-based and empirical methods. Used as a secondary data source, remotely sensed imagery may support spatial interpolation of sparsely sampled soil property data. Soil properties that have been measured using remote or proximal sensing approaches include mineralogy, texture, soil iron, soil moisture, soil organic carbon, soil salinity and carbonate content. In sparsely vegetated areas, successful use of space borne, airborne, and in situ measurements using optical, passive and active microwave instruments has been reported. On the other hand, in densely vegetated areas, soil data acquisition typically relied on indirect retrievals using soil indicators, such as plant functional groups, productivity changes, and Ellenberg indicator values. Several forms of kriging, classification and regression tree analyses have been used jointly with remotely sensed data to predict soil properties at unvisited locations aiming at obtaining continuous area coverage. We expect that remotely sensed data from existing platforms and planned missions can provide an important data source supporting digital soil mapping. Yet, most studies so far have been performed on a local scale and only few on regional or smaller map scale. Although progress has been made, current methods and techniques still bear potential to further explore the full range of spectral, spatial and temporal properties of existing data sources. For example, space borne spectroscopy has been of limited use in retrieving soil data when compared to laboratory or field spectroscopy. To date, there is no coherent methodology established, where approaches of spatial segmentation, measurements of soil properties and interpolation using remotely sensed data are integrated in a holistic fashion to achieve complete area coverage. Such approaches will enhance the perspectives of using remotely sensed data for digital soil mapping.

Contents

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1. Introduction

Soil and terrain information is needed for policy-making, land resource management, and for monitoring the environmental impact of development. Lack of comprehensive information about global, national or local land resources increases the risk of releasing uninformed policy decisions, avoidable continued degradation of land and water resources, and excessive carbon emission to the atmosphere and renders it finally less likely that the Millennium Development Goals will be achieved. The viability and cost of vital infrastructure is affected by this information shortage just as much as the food and water security and response to environmental change (van Engelen, 2008). Global and regional models that address climate change, land degradation and hydrological processes need soil input parameters with complete area coverage, but currently there are only few spatially exhaustive datasets available (Anderson, 2008; Bastiaanssen et al., 2005).

In recent decades the soil science community has made great efforts to develop regional and global soil and terrain databases. Currently, there are several georeferenced soil databases available at map scales smaller than 1:250,000; namely the Harmonized World Soil Database at a map scale of 1:5 M (million) developed by the FAO-UNESCO (FAO et al., 2008); The European Soil Database at a map scale of 1:1 M, which is part of the European Soil Information System — EUSIS (Le Bas et al., 1998). The latter is the product of a collaborative project involving all the European Union and neighboring countries, that has been active for the past 20 years (King et al., 1994). Further, the latest version of the European Soil Database (v2.0) includes an extended geometric component 'The Soil Geographical Database of Eurasia' (Lambert et al., 2002), which also covers the Russian Federation, Belarus, Moldova and Ukraine (Morvan et al., 2008); The Soil and Terrain Digital Database (SOTER), which incorporates quantitative information on soils and terrain at map scales 1:1 M and 1:5 M (Oldeman and van Engelen, 1993); Although partly implemented, the Geo-referenced Soil Database for Europe at a map scale of 1:250,000, is an extendable database to which users can submit their local soil and terrain databases. For the latter, there is a manual aiming for consistence among soil surveyors (Finke et al., 2001). Other examples of soil databases with a continental scale are the SOTER database for different parts of Africa at a scale of 1:2 M (Dijkshoorn, 2003; van Engelen et al., 2006) and the SOTER database for Latin America and the Caribbean at a scale of 1:5 M (Dijkshoorn et al., 2005). There are many national soil databases such as the American Web Soil Survey (WSS) (Soil Survey Staff, 2010a) and the Soil Survey Geographic Data Base (SSURGO) from the Natural Resources Conservation Service (NRCS) (Soil Survey Staff, 2010b); the Australian Soil Resource Information System (ASRIS) from CSIRO Australia (CSIRO, 2010); Available from the Agriculture and Agri-Food Canada: the Canadian Soil Information System (CANSIS) and the National Soil Database (NSDB) of Canada (AAFC, 2010); and the Russian Soil map at a scale of 1:2.5 M (Stolbovoi and McCallum, 2002). For an extended inventory of available soil databases we refer to Rossiter (2004) and Nachtergaele (1999).

The above suggests there is already much soil information available. Nevertheless, a major problem is inconsistency in data acquisition because the data have been collected nationally at various scales, using different standards and methods. Apart from that, developing and transitional countries typically lack digital and accessible soil information. Available data sets for these countries are mostly at small-to-medium scales and have been produced through international projects. Larger scale digital soil data are limited in availability to the USA, Canada, Australia and Europe. However, available soil databases mapped at large scale often have inconsistencies, e.g. the present geographical coverage for the European continent is uneven between and even within countries. National and regional European networks are much denser in northern and eastern regions than in southern Europe (Morvan et al., 2008).

Remote sensing may offer possibilities for extending existing soil survey data sets. The data it provides can be used in various ways. Firstly, it may help in segmenting the landscape into internally more or less homogeneous soil–landscape units for which soil composition can be assessed by sampling using classical or more advanced methods. Secondly, remotely sensed data can be analysed using physically-based or empirical methods to derive soil properties. Moreover, remotely sensed imagery can be used as a data source supporting digital soil mapping (Ben-Dor et al., 2008; Slaymaker, 2001). Finally, remote sensing methods facilitate mapping inaccessible areas by reducing the need for extensive time-consuming and costly field surveys.

Although remote sensing and soil spectroscopy have been recognized as a potentially effective and cost-efficient technology, they are not yet routinely used in soil surveys. Our knowledge of how to apply advances in remote sensing to soil and terrain mapping is still incomplete (Ben-Dor et al., 2008). The ability to apply remote sensing methods and improve coherence in soil and terrain mapping on a global scale, could contribute to the Global Soil Observing System, which is planned by the Global Earth Observation System of Systems (GEOSS) to meet the need for land resources information (Battrick, 2005). Using more coherent data sets with exhaustive coverage would also improve the identification of threats to soil quality as identified by e.g. UNCCD (United, 1994), the EU Soil Thematic Strategy (Commission of the European Communities, 2006), the Canadian Soil Quality Program (Spiess, 2003), the United States Natural Resources Conservation Service (United States Department of Agriculture, 2006) and the Australian natural resource management (NRM) programs (Australian Government, 2010). Remote sensing has been used to identify these threats and to support soil functional mapping such as water and nitrogen stress (Liaghat and Balasundram, 2010; Yi, et al., 2008) and soil erosion (Ben-Dor et al., 2009; Metternicht and Fermont, 1998).

This paper aims to review publications from a wide range of sources and outlines a methodological framework that facilitates soil and terrain mapping from a soil survey-oriented view in combination with remote and proximal sensing methodologies. The review focuses