Are global soil information systems adequate in forecasting impacts of global change?

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Abstract
For large areas in the world, Africa, Latin America and Asia, global soil information systems like the Harmonized World Soil Database do not present adequate information to forecast impacts of global change. Analytical methods used in determining soil attributes are not standardized. Also, soil characteristics that are subject to vary under global change, like organic carbon, are based on observations over a range of time while current figures are missing. New data collection campaigns combined with digital soil mapping techniques might improve the information systems. A capacity building effort is needed to ascertain the use of these techniques.

Key Words
Global Soil Information Systems, global change, Harmonized World Soil Database, e-SOTER, GlobalSoilMap.net.

Global soil information systems

Soil Map of the World and SOTER

During the past decades the only available global soil geography database was the FAO-Unesco Soil Map of the World - SMW (1971-1981) at scale 1:5 million which is based on survey data collected in the nineteen sixties. FAO recognized that a rapid update of the Soil Map of the World would be a feasible option if the original map scale of 1:5 M was retained, and started, together with the United Nations Environment Programme (UNEP) and ISRIC, to fund national updates at 1:5 M scale of soil maps in Latin America following the standardized SOTER approach (FAO *et al.* 1998b). During the following years central, north eastern and southern Africa, Eastern Europe and Northern and Central Eurasia were covered, partly at scales 1:1 million (FAO and IIASA 1999; FAO and ISRIC 2000, 2003; FAO *et al.* 1998a; FAO *et al.* 2007).

Basic to the SOTER approach is the mapping of tracts of land (SOTER units) with a distinctive, often repetitive, pattern of landform, soil parent material, surface form, slope and soil (van Engelen and Wen 1995). Each SOTER unit represents a unique combination of terrain and soil characteristics; Figure 1 shows how the terrain and soils are represented by a SOTER unit in the database.

Soil analytical data held in comprehensive SOTER database have been analysed according to a range of methods and in various laboratories, and these are documented in the various data sets. Generally, however, there are many gaps in the measured soil analytical data stored in primary SOTER databases — typically, not all the attributes that can be handled in SOTER have been collected during the ground surveys that provided the legacy profile data. Such gaps in the attribute data will often preclude the direct use of primary SOTER databases for modelling; gaps are typically filled using consistent taxo-transfer procedures (Batjes *et al.* 2007)

An update of the SOTER methodology started in 2008 within e-SOTER, an EU Seventh Framework Program financed research project with 14 partners from Europe, Morocco and China (e-SOTER 2008). The project addresses four major barriers to a comprehensive soil observing system:

- Morphometric descriptions - enabling quantitative mapping of landforms (Dobos *et al.* 2005) as opposed to crude slope categories as well as newly developed DEM analysis using natural breaks;
- Soil parent material characterization and pattern recognition by remote sensing and using legacy data will enable a separation of soil processes within the landscape and will generate a parent material classification relevant for soil development;
- Soil pattern recognition by remote sensing will generate additional predictors of soil properties;
- Standardization of methods and measures of soil attributes to convert legacy data already held in the European Geographical Soil Database and various national databases to a common standard - so that they may be applied, e.g. in predictive and descriptive models of soil behaviour.

Harmonized World Soil Database
Recognizing the urgent need for improved soil information worldwide and its immediate requirement for the Global Agro-ecological Assessment study, the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) took the initiative of combining the recently collected regional and national updates of soil information with the information already contained within the Digital Soil Map of the World (FAO-Unesco 1995, 2003), into a new comprehensive Harmonized World Soil Database (HWSD, see FAO *et al.* 2009).

HWSD incorporates:

- The European Soil Database extended with information of the Northern Circumpolar soil map at 1:1 million scale
- The new Soil Map of China at scale 1:1 million produced by the Chinese Academy of Sciences.
- SOTER-derived databases for Eastern, Central and Southern Africa, South America and the Caribbean and parts of Asia
- For the areas not covered by the above mainly West Africa, North America, South Asia, and Australia, the “old” Soil Map of the World is still used.

GlobalSoilMap.net
A global consortium of scientific institutes and universities initiated in 2006 a program to use the latest satellite technology and global information layers, such as the Shuttle Radar Topography Mission 3 arc seconds (about 90 m) digital elevation model, to compile a new digital soil map of the world using state-of-the-art and emerging technologies for soil mapping and predicting soil properties at fine resolution (GlobalSoilMap.net 2009). Field sampling in the test areas stratified and is used to determine the spatial distribution of soil properties in order to develop reflectance spectral libraries for characterization of soil properties (Shepherd and Walsh 2002). The acquired soil properties are then used to predict soil properties in areas not sampled, making use of information reflecting state factors of soil formation; see for example (Hartemink *et al.* 2008; Lagacherie *et al.* 2006; McBratney *et al.* 2003) The GlobalSoilMap.net approach consists of several steps of which the first three concern the compilation of a digital soil map.

Data input is the first step and consists of the production of base maps of co-variates reflecting state factors of soil formation like topography, climatic information, land cover and geological variables relating to soil parent materials. Existing geo-referenced soil data, also known as soil legacy data, are also used (Carré *et al.* 2007). The second step involves the estimation of soil properties that are estimated using soil probability functions that express the probabilities of occurrence of a certain predictor value. Finally, during the third step, spatially inferred soil properties are used to predict more difficult to measure soil functions such as available soil water storage, carbon density and phosphorus fixation. This is achieved using pedo-transfer functions. An innovative element of the approach is that the overall uncertainty of the prediction will be determined by combining uncertainties of the input data, spatial inference model, and soil functions used.

The digital soil mapping theories that underlie GlobalSoilMap.net are now being tested in various pilots in Africa and Australia of which the latter is probably the most advanced. The test results will progressively lead towards consensus. Nevertheless, as with any new methodology, a number of scientific and operational challenges still need to be resolved; these have been discussed in detail by various authors (see Hartemink *et al.* 2008; Lagacherie *et al.* 2006).

The role of Global Soil Information Systems in the forecasting of impacts of global change
Ideally GSIS should be able to forecast the effects of soils in a changing climate and the vice versa. Forecasts on the changes in soil properties and behaviour related to climate change are mainly focussed on the soil carbon cycle: how will the temperature rise affect the soil carbon content and how can the rising atmospheric CO_2 be mitigated by increased storage in the soil? Growing emissions of greenhouse gasses (CO_2 and methane) from melting permafrost soils are other impacts. Change in rainfall intensities in combination with desertification processes will have an impact on soil erosion. Changes in land use and management due to climate change will also have an impact on the underlying soils.

It is clear that information on the soil, in particular the current status, is needed if the soil science community wants to address these global issues. However, GSIS in their current form do not comprise this information on soil attributes that will vary under changing conditions. GSIS data were collected over a range of years and reflect passed situations. It is therefore imperative that new GSIS contain up-to-date values of attributes that have a direct relation with changing climatic conditions. New hyper-spectral sensors will allow to map some of the essential soil attributes in real-time. Regionally, such efforts are underway and it is expected that projects as GlobalSoilMap.net will make use of it in the near future.

What are the hindrances to development of improved soil geographic databases globally?
Large tracts of land in Africa, Latin America and Asia lack sufficient soil data critical in forecasting agricultural impacts, particularly food shortages. Various constraints limit easy solutions. Data collection campaigns and laboratories are costly although new analytical methods (diffuse reflectance spectroscopy) will lower the costs of analysis. Survey staff in many countries has been reduced to the minimum or is non-existent. New digital soil mapping techniques can compensate for some of the lack of survey data but not completely, but without capacity building these technologies will only flourish in countries with high-tech environments.

Conclusions

Current GSIS have a low predictive value many parts of the world, in particular Africa, South America and Asia. Available information is based on data collected in the past and doesn't necessarily reflect the status of some of the soil attributes that might be affected by climate change, like organic carbon and nitrogen. New data collection campaigns, in combination with new analytical techniques could contribute to fill the gaps in soil geographic databases.

References

Batjes NH, Al-Adamat R, Bhattacharyya T, Bernoux M, Cerri CEP, Gicheru P, Kamoni P, Milne E, Pal DK, Rawajfih Z (2007) Preparation of consistent soil data sets for SOC modelling purposes: secondary SOTER data sets for four case study areas. *Agriculture, Ecosystems and Environment* **122,** 26-34

Carré F, McBratney AB, Minasny B (2007) Estimation and potential improvement of the quality of legacy soil samples for digital soil mapping. *Geoderma*, 1-14

Dobos E, Daroussin J, Montanarella L (2005) *An SRTM-based procedure to delineate SOTER Terrain Units on 1:1 and 1:5 million scales*. EUR 21571 EN, Institute for Environment and Sustainability, Joint Research Centre, Ispra

e-SOTER (2008) *Project introduction*. available at http://www.esoter.net (last accessed 1-10-2009)

FAO-Unesco 1971-1981. Soil map of the world (1:5,000,000), Volumes 1-10. Unesco, Paris

FAO-Unesco 1995, 2003. The Digitized Soil Map of the World and Derived Soil Properties (version 3.5), *FAO Land and Water Digital Media Series 1*. FAO, Rome

FAO and IIASA (1999) *Soil and Physiographic Database for North and Central Eurasia at 1:5 Million scale*. Land and Water Digital Media Series 7, FAO, Rome

FAO and ISRIC (2000) *Soil and Terrain Database, Land Degradation Status and Soil Vulnerability Assessment for Central and Eastern Europe, Version 1.0, 1:2.5 million scale*. Land and Water Digital Media Series 10, FAO, FAO

FAO and ISRIC (2003) *Soil and Terrain Database for Southern Africa (1:2 million scale)*. Land and Water Digital Media Series 25, FAO, Rome

FAO, Cooperazione-Italiana, IGAD (1998a) *The Soil and Terrain Database for northeastern Africa. Crop Production System Zones of the IGAD subregion*. Land and Water Digital Media Series 2, FAO, Rome

FAO, ISRIC, Ghent University (2007) *Soil and terrain database for central Africa*. Land and Water Digital Media Series 33, FAO, Rome

FAO, ISRIC, UNEP, CIP (1998b) *Soil and Terrain Database for Latin America and the Caribbean - SOTERLAC (version1.0).* Land and Water Digital Media Series 5, FAO, Rome

FAO, IIASA, ISRIC, ISSCAS and JRC (2009) *Harmonized World Soil Database (version 1.1)*, FAO and IIASA, Rome and Laxenburg

GlobalSoilMap.net (2009) *Project overview* available at http://www.globalsoilmap.net/ (last accessed 27-10-2009)

Hartemink AE, McBratney A and Mendonca-Santos M (2008) *Digital Soil Mapping with limted data*. Springer Verlag, 445 p

Lagacherie P, McBratney A, Voltz Me (2006) *Digital soil mapping: An introductory perspective*. Elsevier, Amsterdam, 350 p

McBratney AB, Mendonça Santos ML, Minasny B (2003) On digital soil mapping. *Geoderma* **117,** 3-52.

Shepherd K and Walsh M (2002) Development of reflectance spectral libraries for characterization of soil properties. *Soil Science Society of America Journal*, 988-998.

van Engelen VWP, Wen TT (1995) *Global and National Soils and Terrain Digital Databases (SOTER), Procedures Manual (revised edition)*, FAO, ISSS, ISRIC, Wageningen