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Digital soil resource inventories: Status and prospects in 2015

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Abstract—Eleven years ago the author published a paper (Soil Use and Management 20(3): 296–301) titled “Digital soil resource inventories: status and prospects”, which concluded that, at the time, the quantity and quality of digital soil survey information at global, national, regional, and local scales was increasing dramatically, however with several problems (1) lack of metadata, (2) limited interpretations for professionals who are not soil specialists, (3) geodesic incompatibility with other digital data, (4) frequent reorganization of websites, and most seriously (5) much digital data was proprietary and only available for sale or under license. The current paper updates the situation to mid-2015, with an inventory of publically available soil geographic databases, their coverage, the type of information and intended purposes. These are summarized in a portal maintained by the author[1]. With regard to the deficiencies identified eleven years ago: metadata provision is much improved; more products come with interpretations; geodetic incompatibility has largely been overcome by metadata and conversion programs; websites still change frequently and are often confusing; much data is still proprietary or not generally accessible. Over the next several years several disruptive technologies are predicted to radically change how on-line soil survey information is collected, compiled and disseminated. The question of open access to primary data is not resolved.

Keywords: soil geographic databases, spatial data infrastructure

1 Introduction

Eleven years ago this author published a paper (Rossiter 2004) titled “Digital soil resource inventories: status and prospects”, surveying the state of digitally-available primary soil information (point observations, polygons and grids) as well as secondary information, i.e., interpreted for end users. The present paper has the same objective. The intervening ten years have been a decade of dramatic progress in information technology, large disciplinary data initiatives such as OneGeology[2] and WorldClim[3], and interdisciplinary spatial data infrastructures such as Infrastructure for Spatial

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[1] http://www.css.cornell.edu/faculty/dgr2/research/sgdb/sgdb.html

[2] http://www.onegeology.org/

[3] http://www.worldclim.org/

Information in the European Community (INSPIRE)[4]. This paper reviews to what extent the soil mapping and soil data provision community has participated in this progress. The view is from an interested user, searching the internet for publically-available primary soil survey information. If I have missed something, it is likely too difficult for others to find.

2 Forms of on-line soils information

These can be categorized as (1) freely downloadable GIS-ready coverages, with adequate metadata to allow users to produce their own products such as customized maps, model inputs, and interpretations; (2) same but available only on off-line digital media, typically DVD-R; (3) commercially-available (under license or for purchase), in both formats; (4) viewable and printable on-line but not available as a digital product; (5) non-georeferenced scanned maps as images, sometimes with their original accompanying documentation (e.g., soil survey reports), in both formats. Of these the most useful is the first form. A variant of (1) is data provided dynamically as a Web Feature Service (WFS). A variant of (4) is data provided dynamically as a Web Map Service (WMS), where the GIS data remains with a map server but can be integrated into the user's GIS.

Another categorization is by the originating institution. Comprehensive general-purpose soil resource inventories (SRI), also called soil surveys, usually with interpretations, have traditionally been produced by national soil survey organizations. Other government institutions, for example forestry or irrigation departments, have sometimes made special-purpose surveys. Development projects and consultants have made surveys of limited areas, often as interpreted rather than primary products, e.g., suitability for irrigation projects. These sources have been combined into synoptic products by institutions with international mandate, notably the FAO[5], the European Soil Bureau[6], and ISRIC-World Soil Information[7].

Yet another categorization is by type of information: (1) soil types in some classification system; (2) "static", or at least slowly-changing, soil properties; (3) dynamic soil properties, notably soil moisture and temperature; (4) interpretations directly usable by modelers and land managers.

3 Users of on-line primary soils information

Potential users include (1) soil mappers within the producing organization; (2) land use specialists within the producing organization, using the primary information to make interpretations; (3) government departments responsible for land use planning, public lands management, and taxation; (4) soil mappers in other organizations, using these maps as a basis for more detailed or generalized products; (5) land use specialists in other organizations, e.g., development consultants; (6) land managers and their consultants; (7) environmental modelers of e.g., surface energy balance or watershed hydrology, (8) outdoor recreation enthusiasts such as hunters and hikers.

Some of these users prefer, or can only understand, interpreted information. Primary soil survey data is widely used in environmental modeling, e.g., pollution risk assessment (Sekhon et al. 2014), soil hydrology (Toth et al. 2012), gas flux (Yao et al. 2013) and watershed hydrology (Yu et al. 2014), just

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[4] http://inspire.ec.europa.eu/

[5] http://www.fao.org/soils-portal/en/

[6] http://eusoils.jrc.ec.europa.eu

[7] http://www.isric.org/

to mention a few recent examples. Modelers typically need primary, rather than interpreted, information, because they build their own interpretive models.

4 Status of primary soil survey information

Here I review the current status of on-line static or slowly-changing soil survey information over world, regional, national and local extents.

4.1 Area coverages (polygons and grids)

World:

The most detailed compiled and edited product is the Harmonized World Soil Database (HWSD)[8] (IIASA et al. 2012), supported by the FAO and compiled by IIASA. This is a gridded product (21 600 x 43 200) with a consistent 30 arc-second (approximately 1 km^2 at the equator) resolution. Although 1 km^2 corresponds to the mimimum legible delineation (MLD) of a 1:200k map, considering a 5x5 grid cell window as the MLD, the resulting map scale is 1:1M.

Data sources for the HWSD include SOTER, European Soil Database, Soil Map of China, the WISE profile database and the digitized 1:5M scale FAO-UNESCO soil map of the world. This latter was produced in stages from 1971-1981 and thus is seriously outdated. The resulting raster database consists of 21 600 rows and 43 200 columns, which are linked to harmonized soil property data. The use of a standardized structure allows for the linkage of the attribute data with the raster map to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry). Although the product is consistently formatted, there are extreme differences in the level of categorical and cartographic detail, depending on the source. Surprisingly, some well-studied areas (USA, Canada) are only represented by the 1:5M source and not by the much more detailed national soil survey databases. ISRIC is currently updating the HWSD with improved basis polygons, a single classification system (FAO Revised Legend 1988), estimates of uncertainty and seven soil depth slices (layers) of representative synthetic profiles, following the SOTER specifications. Soil parameter estimates are recomputed for each component soil unit using an elaborate taxotransfer scheme that evolved from earlier work with FAO, IIASA and ISRIC and contributions by ISRIC to HWSD via the SOTER programme and WISE project. The above procedure considers 20 soil properties, five textural classes (SOTER criteria), seven depth layers up to 2 m depth, and broad climate as an important covariate in the taxotransfer scheme.

A global product produced by digital soil mapping methods is SoilGrids1km from ISRIC-World Soil Information[9] (Hengl et al. 2014). This is a collection of consistent soil property and class maps of the

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[8] http://www.iiasa.ac.at/Research/LUC/luc07/External-World-soil-database/HTML/index.html

[9] http://www.isric.org/content/soilgrids

world at 1 km resolution, produced using documented statistical models, from primary data (points and polygons) provided by soil survey organizations and environmental covariates which cover the whole world, including long-term NDVI time series and WorldClim layers. The soil polygon covariate is the HWSD, so that areas with poor HWSD resolution (e.g., USA) have much less spatial precision than those with the best HWSD resolution (e.g., China). Newer editions of SoilGrids may replace the HWSD with either an updated HWSD or may omit it altogether; although it covers the whole world it is not a consistent coverage. The authors have chosen 3D regression with splines for continuous soil properties and multinomial logistic regression for soil classes. Both of these provide uncertainty: confidence limits from the kriging prediction variance for continuous properties, probability of membership for soil classes. An advantage of this product is that it is easily updatable: provide improved soil polygons, points, or environmental covariates and re-run the models. The data is available for download[10] and via an API[11] for incorporation into user-written applications. It can also be viewed via a SoilInfo tablet and smart phone application[12], "providing free access to soil data anytime anywhere...for everyone". The mapping method can be used at finer resolutions (see AfSoilsGrid250m, below), depending only on the availability of covariates at these resolutions and sufficient calibration points.

The GlobalSoilMap.net consortium[13] (Arrouays et al. 2014) has since late 2007 been working towards a gridded soil map of the world at a nominal 100 m resolution. Specifications (Science Committee 2013) include a consistent geometry and tiling method, depth increments, properties, and uncertainty description. Each regional node is free to use any method to populate the grid according to the specifications. The first publically-available product is from Australia (see below).

The Global Soil Partnership (GSP)[14] is a FAO-coordinated consortium "to improve governance of the limited soil resources of the planet… in accordance with the sovereign right of each State over its natural resources." One of its five "Pillars of action" is the fourth: to "enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines". As part of this, Omuto et al. (2012) produced a report on the status of global and regional soil information, and a working group wrote an action plan (late 2014), which has been transformed (mid-2015) to an implementation plan, and it is hoped (subject to financing) to a global soil information system.

Regional:

A product with a long history is SOTER[15], a collaborative activity of ISRIC, FAO, and UNEP, endorsed by the International Union of Soil Sciences (Oldeman and van Engelen, 1993) and used for a wide variety of regional assessments (e.g., Batjes et al. 2007). This is a well-structured soil geographic

10 http://soilgrids.org/

11 http://rest.soilgrids.org/

12 http://soilinfo.isric.org/

13 http://globalsoilmap.net

14 http://www.fao.org/globalsoilpartnership/en/

15 http://www.isric.org/projects/soil-and-terrain-database-soter-programme

database: polygons at scales 1:5M to 1:250k, depending on quality of source data with a linked relational database. This is hierarchical from terrain, through terrain component, to soil components, to profiles and representative horizons. Each product is internally harmonized across country boundaries, using a consistent mapping concept based on terrain units, and a consistent soil classification. Regions available are Central & Eastern Europe, southern Africa, central Africa, Latin America & the Caribbean. The concept of soil units within terrain units is not always in accordance with the soilscape (e.g., in volcanic areas), leading to some difficulties in delimiting and characterizing units. Soil components are not necessarily mappable at the target scale, in which case their proportions are estimated.

Dewitte et al. (2013) report on the Soil Atlas of Africa[16], which was produced as an update to the HWSD. Nominal scale is 1:3M, corresponding to a minimum legible area (MLA) of 225 km^2. It is available as PDF, as e-book, and for download as GIS coverage[17] on request.

ISRIC has used a similar methodology to the global SoilGrids1km to produce AfSoilsGrid250m[18], a finer-resolution product for the non-desert areas of Africa.

Europe is served by the European Soil Bureau (ESB), which has set up a European Soil Data Centre (ESDAC) to fulfill its responsibility for responding to the European Commission for policy support (Panagos et al. 2012). ESDAC includes the European Soil Portal[19] with access to the European Soil Database (ESDB), a 1:1M harmonized coverage. Single-property 1x1 km and 10x10 km grids have been extracted from this. Several "soil threats" gridded maps are available, including heavy metals in topsoils, soil salinization, susceptibility to compaction, organic C, and erosion estimates. The ESB operates under a complicated legal framework (EU-wide and national), and strives to make the primary data as open as legally possible; for restricted products at least the metadata is supplied, so that a potential user can judge the fitness for use.

National:

A few soil survey organizations provide free download of their polygons (map units) with associated attribute tables, e.g., Canada (CanSIS[20]), the USA, Australia (ASRIS[21]) and New Zealand (S-Map[22]). Some provide gridded data, e.g., Australia. Point observations (profiles) are only available for the USA; this very detailed database (with the extensive lab. tests required by USDA Soil Taxonomy) also includes some non-USA observations.

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16 http://eusoils.jrc.ec.europa.eu/library/Maps/Africa_Atlas/

17 http://eusoils.jrc.ec.europa.eu/library/maps/africa_atlas/data.html

18 http://www.isric.org/data/AfSoilGrids250m

19 http://eusoils.jrc.ec.europa.eu/

20 http://sis.agr.gc.ca/cansis/

21 http://www.asris.csiro.au/

22 http://smap.landcareresearch.co.nz/home

SOTER is available at scales of 1:1M (Argentina, Burundi, Cuba, Kenya, RSA, Rwanda, Senegal and the Gambia, Tunisia) and 1:2M (DRC).

The USA has two almost-complete polygon coverages: SSURGO 2.2 (semi-detailed, source scale 1:12 000 to 1:25 000) and STATSGO2 (1:250 000, generalized from SSSURGO). These are provided to the public by the Web Soil Survey interface[23], which allows the user to specify an area of interest. Two other interfaces to the same data source are provided by the California Soil Resource Lab[24]: SoilWeb, which uses Google maps, and SoilWebEarth, which uses Google Earth to allow a 3D view of the soilscape. The USA has gridded the SSURGO product at 30 m resolution (gSSURGO) and is experimenting with a disaggregation (dSSURGO) to this resolution using environmental covariates as a training set (Chaney et al. 2015); however this last-named is not yet publically-available.

Many European countries have digital databases of polygons and/or points, but these are not immediately available on-line. Some have provided data viewers or static maps on-line, for example the Dutch[25]. Depending on national data policies, they may be provided by commercial contract, use agreement, cooperative project, or publically available. Some products are generalizations of more detailed products that are kept for internal use. For example, the Base de Données Géographique des Sols de France[26], available as ArcInfo coverages on CD-ROM for the cost of reproduction and postage, is a 1:1M generalization of several detailed products (Connaissance Pédologique de la France, Secteurs de Référence) at 1:50 000 or 1:100 000. These are only available under agreement to regional partners and cooperation projects.

Australia has produced the first national map to GlobalSoilMap specifications: the Soil and Landscape Grid of Australia[27]. This is managed as part of ASRIS. In addition to the soil properties it also provides many landscape attributes, e.g., the Prescott Index measure of water balance and solar radiation.

Local:

The national products listed in the previous section can be queried for any locality. There are a few purely local digital products. For example, SOTER is available at scale 1:250k for the upper Tana River basin, Kenya.

Standards:

Each product has its own standards, which are in general well documented. The three international standards are for the HWSD, GlobalSoilMap.net, and SOTER (Pourabdollah et al. 2012).

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[23] http://websoilsurvey.nrcs.usda.gov/

[24] http://casoilresource.lawr.ucdavis.edu/soilweb-apps/

[25] http://maps.bodemdata.nl

[26] http://gissol.fr/programme/bdgsf/bdgsf.php

[27] http://www.clw.csiro.au/aclep/soilandlandscapegrid/

4.2 Points

Georeferenced point observations (typically of soil profiles), generally with accompanying laboratory data, are especially valuable as uninterpreted primary information on soils at known locations. The largest freely-available sets are:

1. US National Soil Survey Center Soil Characterization Data[28]: (1) analytical data for more than 20,000 USA and 1,100 other pedons; (2) standard morphological pedon descriptions for about 15,000 of these.
2. SPADE: Soil Profile Databases for Europe[29]; actual or inferred profiles for each Soil Typological Unit in the 1:1M SGDBE;
3. LUCAS: Land Use/Cover Area frame Statistical Survey[30]; selected properties of approximately 20 000 topsoil samples from 25 European countries (coarse fragments, particle size distribution, pH, organic carbon, carbonates, P, total N, extractable K, CEC, multispectral properties).
4. WISE[31]: The result of various ISRIC projects, this contains about 11 000 non-harmonized profiles with attributes, of which 1 125 have been harmonized.
5. Africa Soil Profiles database[32] from the Africa Soil Information Service (AfSIS) and ISRIC; about 15 000 profiles.
6. World Soil Profiles[33] from ISRIC; about 32 000; allows users to submit their own profiles and create their own data entry templates.

4.3 Scans

Maps from the ISRIC collection have been scanned as non-georeferenced images by the European Soil Bureau, and published on-line and as DVD as the European Digital Archive on Soil Maps of the World (EuDASM)[34] (Panagos et al. 2011). The accompanying reports have not been included; many of these can be found in the Wageningen University library via a search interface[35] and are currently being scanned by ISRIC. A similar project but with focus on British soil survey activities (in the UK and former colonies) is the World Soil Survey Archive and Catalogue (WOSSAC) hosted by Cranfield University (England)[36].

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28 http://ncsslabdatamart.sc.egov.usda.gov/

29 http://eusoils.jrc.ec.europa.eu/projects/spade/

30 http://eusoils.jrc.ec.europa.eu/projects/Lucas/

31 http://www.isric.org/data/isric-wise-international-soil-profile-dataset

32 http://www.isric.org/content/africa-soil-profiles-database

33 http://worldsoilprofiles.org

34 http://eusoils.jrc.ec.europa.eu/esdb_archive/EuDASM/EUDASM.htm

35 http://www.isric.org/content/search-library-and-map-collection

36 https://www.wossac.com/

5 Status of dynamic soil information

The International Soil Moisture Network[37] collects volunteered datasets; one of the largest is from the former Soviet Union, digitized by the Global Soil Moisture Databank of the Rutgers University. The Soil Climate Analysis Network (SCAN) from the (USA) National Water & Climate Center[38] does give downloadable time-series of soil moisture, temperature, and snowpack for scattered stations across the USA and some for Puerto Rico and the US Virgin Islands. Texas A&M University has produced a harmonized and quality-controlled historical soil moisture database for the USA and some Canadian provinces[39].

6 Progress over the past decade

Comparing the current situation to that in 2004:

(1) There is much more digital geoinformation, and more is publically available. This is despite the low level of new soil survey activity.

(2) Online access and user interfaces to find and obtain geoinformation are much improved.

(3) Metadata provision is much improved. Although most of the above-listed databases do not use formal metadata standards, almost all have sufficient information for proper use. Some products include uncertainty estimates in metadata, and some as interpolated layers.

(4) Interpretations for professionals who are not soil specialists are excellent in some databases, notably the USA and Australia. Some organizations, such as the European Soil Bureau, use their databases to make separate interpretive products that are directly useable.

(5) Geodesic incompatibility with other digital data is far less of a problem. Many data providers have standardized on WGS84 geographic coordinates. The Europe-wide databases have standardized on ERTS89 coordinate system. But with easy conversions provided by the GDAL program[40] bundled with R[41] and most GIS, and the collection of coordinate reference systems in the EPSG database[42], combined with much better metadata, this problem becomes minor.

(6) Frequent reorganization of websites is still a big problem. The new organization may be better but data that could be found previously is now relocated. A related problem is the increasing number of datasets per site (in itself a good thing); this often makes finding a particular dataset more difficult.

(7) Much digital data is still proprietary and only available for sale or under license. Some is considered public but not made available to the general public in digital form, only as a view in a web mapping application or as a Web Mapping Service (WMS) layer for use in GIS.

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37 http://ismn.geo.tuwien.ac.at/

38 http://www.wcc.nrcs.usda.gov/scan/

39 http://soilmoisture.tamu.edu/

40 http://www.gdal.org/

41 http://www.r-project.org/

42 http://www.epsg-registry.org/

(8) There is a new generation of "geoportals" which provide an entry point to find digital geodata from multiple themes, including soils, for example INSPIRE from the European Commission[43]. These give exposure to soils data to users who might not find them otherwise, and to users who are looking for different coverages of the same area for integrated modeling.

7 Prospects

What will the next ten years bring us? Clear trends in the GIS world are (1) massive increase in data storage and processing power, allowing models to be run on large grids with many layers; (2) many new high-resolution sensors from satellite systems, providing almost unmanageable data streams, many of these useful as soil mapping covariates; (3) new ultra-resolution airborne and field sensors, including low-cost drone-borne LIDAR and spectrometers; (4) large, cheap networks of point sensors with automatic recording, e.g., soil moisture; (5) increasingly-powerful web services over a faster internet backbone, reaching most clients via very high-capacity links. Sensors will increase not only in number and coverage, but also in temporal resolution. The data volume will be too large for manual processing; this will require automated methods of quality control and summary, as is being developed for streaming sensors in environmental monitoring networks (Campbell et al. 2013).

In the digital soil mapping world the massive increase in spatiotemporal covariates will require new models. The temporal aspect is particularly interesting: there is no reason for a soil map to be static. For example, why use generalized soil moisture and temperature regimes, when we are able to give a detailed model of the soil moisture and temperature status, over depths as well as across the landscape, at temporal resolutions matching the sensors?

In the soil survey world, increasing emphasis will be on soil functions rather than properties. For example: (1) soil health and resilience, including soil biodiversity; (2) soil-related human health risks and benefits; (3) soil functioning within the hydrosphere and at the earth-atmosphere interface. These may require new concepts and models, but surely will require spatially-detailed properties that drive such models. Some may be directly mapable.

There will be a strong push for harmonized global coverages, especially useful for global modeling, at increasingly finer spatial resolutions. Examples are GlobalSoilMap, Pillar 4 of the Global Soil Partnership[44], and the Harmonized World Soil Database. It is unclear that the current observation density can support reliable products at the desired resolutions.

It is unclear how the near future will develop in terms of data access and data sharing. Many countries still have restrictive laws and do not recognize that primary data can have a large multiplier effect on the economy and general welfare of the citizenry, through unanticipated uses. Some institutions struggling with funding still see primary data as a revenue source, rather than as an advertisement for their specialist knowledge in aiding interpretations and modeling.

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[43] http://inspire-geoportal.ec.europa.eu/

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