Soil Organic Carbon Mapping cookbook

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Copyright and bla

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Foreword

Under the leadership of the International Technical Panel on Soils (ITPS), members of the Global Soil Partnership (GSP) conducted a soil carbon mapping programme, where existing data in national soil information systems were used to develop 1 km grids of soil carbon stocks, following a guideline with background and detailed specifications. These grids fulfill the criteria developed for the version 0 grids of Global Soil Information System (GLOSIS) under Pillar 4 of the GSP.

This cookbook provides step-by-step guidance for developing 1 km grids for soil carbon stocks. It includes the preparation of local soil data, the compilation and pre-processing of ancillary spatial data sets, upscaling methodologies, and uncertainty assessments. Guidance is mainly specific to soil carbon data, but also contains many generic sections on soil grid development, as it is relevant for other soil properties.

Therefore, this first edition is the beginning of a series of updates and extensions, necessary to cover a larger variety of upscaling approaches. Experiences gained throughout 2017 during the GSOC map programme, through applications at country scale and various trainings scheduled for 2017, shall be considered in the next editions. Also, the section on uncertainties will be adjusted to more practical implementation steps.

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Chapter 3

Presentation

The Global Soil Partnership (GSP) aims to promote sustainable soil management at all levels and in all land uses through normative tools that rely on evidencebased science. Understanding the status of a given soil, including its properties and functions, and relating this information to the ecosystem services that soil provides becomes a mandatory action before making decisions on how to manage a soil sustainably. To achieve this, the availability of and use of soil data and information is fundamental to underpin soil management decisions. For this reason, members of the GSP have decided to establish a Global Soil Information System (GLOSIS) that relies on national soil information systems.

In the process of establishing GLOSIS, a number of tools and networks are being created, including the International Network of Soil Information Institutions (INSII), a soil data policy and more. Taking advantage of this process and responding to a request for support in developing the Sustainable Development Goal Indicators, especially Indicator 15.3, the GSP Plenary Assembly instructed the Intergovernmental Technical Panel on Soils and the GSP Secretariat to develop a Global Soil Organic Carbon Map (GSOCMap) following the same bottom-up approach as GLOSIS. To this end, members under the INSII umbrella developed guidelines and technical specifications for the preparation of the GSOCMap and countries were invited to prepare their national soil organic carbon maps according to these specifications.

Given the scientific advances in tools for mapping soil organic carbon (SOC), many countries requested the GSP Secretariat to support them in the process of preparing these national maps. An intensive capacity development programme on SOC carbon mapping was the answer to support countries in this process. Various regional and national training sessions were organized using an on-the-job-training modality to ensure that national experts were trained using their own datasets. To support this capacity development process, a reference knowledge source was needed, hence the GSP Secretariat invited a group of top experts to prepare a Soil Organic Carbon Mapping Cookbook.

This cookbook provides generic methodologies and the technical steps to produce a SOC map. This includes step-by-step guidance for developing 1 km grids for SOC stocks, as well as for the preparation of local soil data, the compilation and preprocessing of ancillary spatial data sets, upscaling methodologies, and uncertainty assessments. Guidance is mainly specific to soil carbon data, but also contains many generic sections on soil grid development due to its relevance for other soil properties.

The main focus of the guidance is on the upscaling of SOC stocks in the GSOCMap and as such the cookbook supplements the "GSP Guidelines for sharing national data/information to compile a Global Soil Organic Carbon (GSOC) map". It provides technical guidelines to prepare and evaluate spatial soil data sets to: * Determine SOC stocks from local samples to a target depth of 30 cm; * Prepare spatial covariates for upscaling; and * Select and apply the best suitable upscaling methodology.

In terms of statistical upscaling methods, the use of conventional upscaling methods using soil maps and soil profiles is still very common, although this approach is mostly considered empirical by soil mappers. Even though evaluations are based on polygon soil maps, the resulting SOC maps can be rasterized to any target grid. However, a spatially-explicit assessment of uncertainties is impossible. The use of digital soil mapping to upscale local soil information is increasingly applied and recommended.

This cookbook presents two approaches in detail, namely spatial modelling using either regression or data mining analysis, combined with geostatistics as regression kriging.

This first edition of the cookbook will be followed by a series of updates and extensions that would be necessary to cover a larger variety of upscaling approaches. The experiences gained throughout 2017 during the implementation of the GSOCMap capacity development programme will be considered in the next editions. This will especially include updates in the section on uncertainties which will be adjusted to provide more practical implementation steps.

It is our hope that this cookbook will fulfil its mandate of easily enabling any user to produce a SOC or other soil property map using soil legacy data and modern methods of digital soil mapping in contribution to improved decision making on soil management.

Chapter 4

Soil property maps

R Baritz

4.1 Definitions, objectives

Soil property maps represent spatial information about soil properties to a certain depth or for soil horizons. Conventionally, soil property maps are generated as polygon maps, with properties from typical soil profiles representing soil mapping units. Digital Soil Mapping (DSM) allows more accurate spatial mapping of soil properties, including the spatial quantification of the prediction error. The quality of such predictions improves with increasing number of local observations (e.g. soil profiles) available to build prediction model. Whenever possible, DSM is recommended.

The development of soil property maps via digital soil mapping is spatially flexible. For different soil properties (e.g. concentration and stocks of nutrients in the soil, carbon, heavy metals, pH, cation exchange capacity, physical soil properties such as particle sizes and bulk density, etc.), various depth classes and spatial resolution can be modelled depending on project and mapping objectives and available input data. For GSOCmap, a 1 km grid is pursued. The same methodology and input data can also be used to produce higher resolution soil grids.

The mapping of global soil organic carbon stocks (GSOC) will be the first implementation of a series of other soil property grids to be developed for GLOSIS, based on the typical GSP country-driven system. GSOCmap will demonstrate the capacity of countries all around the globe to compile and manage national soil information system and to utilize and evaluate these data following agreed international specifications. The GSP Secretariat, FAO and its regional offices, as well as the Regional Soil Partnerships, are all challenged together with the GSP members, especially the members of the International Network of Soil Information Institutions INSII), to establish national capacity and soil data infrastructures to enable soil property mapping.

4.2 Generic mapping of soil grids: upscaling of plot-level measurements and estimates

The following table presents an overview of different geographic upscaling approaches, recommended to produce soil property maps, in particular GSOCmap.

Digital soil mapping is based on the development of functions for upscaling point data (with soil measurements) to a full spatial extent using correlated environmental covariates, for which spatial data are available.

DSM: concept of environmental correlation that explores the quantitative relationship among environmental variables and soil properties and could be used to predict the latter; multivariate prediction techniques

Chapter 5

Preparation of local soil property data

GF Olmedo & R Baritz

5.1 Soil profiles and soil augers

Soil profiles are complex real world entities. Soil profiles are composed of soil layers which form soil horizons; the soil layers have different properties and these properties are evaluated with different methods. As we know, soil and vertical soil properties are landscape elements and part of matter dynamics (water, nutrients, gases, habitat). Local soil samples or soil profiles add a third dimension into the spatial assessment of soil properties in the landscape.

Most commonly, soil are described as vertical profiles using soil pits (sometimes also augerings, but this is less accurate). Soil profiles are described using macro-morphological properties. These properties can be assessed in the field without analysis by making a field inventory or land evaluation. For additional quantitative analysis, soils are then sampled by genetic horizon or by depth class.

Sampling of soils is the basis to obtain quantitative information. Depending on the goal of a project, sampling can be quite diverse. Sampling can follow the description of the soil, or can be conducted without, for example using a spade or auger to generate a composite sample (for a certain depth independent of the morphological features such as soil horizons). Sampling locations can be representative for a certain location, project, field, or mapped object, such as a soil type.

5.2 Soil database

In order to process and evaluate soil information from field assessments, soil profile and analytical information needs to be stored in a database. This can be a set of simple Excel Spreadsheets, or a relational or object-oriented data base management system (Baritz et al. 2009). When working in R, SoilProfileCollections from the R 'aqp' package could be a useful tool. Tables 2.1 – 2.3 are examples of how soil information can be stored. The advantage of such organization is the possibility to develop relational databases which can be easily queried. Such a systematic approach will support the organization of national soil information and will reduce errors in future modelling exercises (Baritz et al. 2009).

Table 2.1 stores site-level data, which describe the location of the soil description and/or sampling site: spatial coordinates, landscape attributes such as slope gradient and slope form, soil class, land cover type, rock type etc. In this table every row should hold a single soil profile. One column, usually the first one, should be the soil profile's unique identifier. Using the latter, soil information can be easily linked from one table to another.

Table 2.2 stores information from the soil description, such as horizon name, horizon thickness, organic matter content, carbonate content, soil color, etc. The first column contains the soil profile's unique identifier. It is important to include the upper and lower limits for each soil layer; in case the sampling strategy deviates from soil layers/soil horizons, the upper and lower depth of the sampling locations should be specified if possible. This information is needed for modelling soil properties over the soil profile.

Table 2.3 contains the results from the laboratory soil analysis and again lists the soil profile's unique identifier. Both tables 2.2 and 2.3 could also contain data for O horizons of forests, and H horizons for peat soils.

5.3 Completeness of measurements/estimates

The GSOC mapping guideline specifies which soil parameters are needed to produce a GSOCmap. Of course, other soil properties can be evaluated and modelled using this cookbook as well.

SOC stocks for soil horizons or targeted soil depths can be calculated using the equations in section 8.4.3 of the "GSP Guidelines for sharing national data/information to compile a Global Soil Organic Carbon map". Carbon concentration, bulk density and stone content for a certain depth or genetic horizon are needed to calculate the amount of carbon stored in that depth interval/soil horizon. In many countries, legacy data from former surveys and projects as well as from various owners and data sources are compiled. and very often, measured bulk densities are missing or are only available for few soil profiles, or are estimated. Stones in the soil profile are usually only estimated, and if augers are used for sampling, it is not assessed at all. Pedotransfer functions can be used to fill data gaps (bulk density), and interpolation approaches can be used to infer from measured depths to target depths.

a) Stones

The estimation of stoniness is difficult and time consuming, and therefore not carried out in many national soil inventories, or only estimated visually in the profile. Unfortunately, if soil inventories and sampling are done with simple pits or augers rather than standard soil pits, stones are very often not assessed.

As a proxy, it is recommended to derive national default values from well described soil profile pits by soil type.

b) Bulk density

The amount of fine earth is one of the basic estimation parameters to estimate SOC stocks in the mineral soil as well as in peat layers. It depends on the volume of soil considered (depth × reference area) and the bulk density (BD). BD expresses the soil weight per unit volume. When determining BD, it is important to subtract stones, if any, from the cylinder samples; if this is not done, BD is underestimated, and the resulting SOC stocks are overestimated. Stones in the cylinders are added to the total stone content in order to correct for the total amount of fine earth per volume of soil in a given area.

Most of the soil profiles in national databases come from agricultural land. Very often, BD estimates do not consider fine stones because top soils (e.g. plough layers) seem to be free of visible stones.

Example for Pedotransfer functions to estimate BD, based on the soil organic matter content in percentage:

Saini (1996) $BD = 1,62 - 0,06 * OM$ Drew (1973) $BD = 1/(0,6268 + 0,0361 * OM)$ Jeffrey (1979) $BD = 1.482 - 0,6786 * (logOM)$ Grigal et. al (1989) $BD = 0,669 + 0,941 * e^(- 0,06 * OM)$ Adams (1973) $BD = 100/(OM/0,244 + (100 - OM))/MBD$ Honeysett & Ratkowsky (1989) $BD = 1/(0,564 + 0,0556 * OM)$

Where MDB is the Mineral particle density, assumed to be the specific gravity of quartz, 2.65 Mg m-3. And OM is the Organic Matter Content, estimated as $SOC(\%)x1.724$

Each method is derived from a specific set of regional soils that is regionally adapted. Selection of the proper method for a given country shall be based on existing reviews and comparisons.

c) Soil carbon analysis

Rosell et al. (2001) have closely reviewed the different SOC and SOM estimation procedures, and have also drawn some conclusions about the sources of errors. Determination of SOC from dry combustion methods is least susceptible to errors.

Dry combustion by Loss on Ignition, LoI: SOC is re-calculated applying a conversion factor: It is commonly assumed, that organic matter contains an average of 58% organic carbon (so-called Van Bemmelen factor 1.724; for non-organic horizons: SOC = SOM / 1.724). For organic horizons, conversion factor ranges from 1.9 to 2.5 (Nelson and Sommers 1982). The inorganic carbon is not resolved, since typically, temperatures between 400 and 550°C are used.

Wet oxidation: Since wet oxidation is applied without additional (external) heating, low temperatures of around 120° (internal heat) are typical. Thus, the oxidation of carbon is incomplete, and a so-called oxidation factor needs to be applied. With external heating, the C-recovery of the method becomes improved, up to complete recovery. No correction against the mineral carbon is needed. Wet oxidation should typically only be applied to samples with $< 5\%$ organic matter.

Usually, an average of 76% organic carbon is recovered, leading to a standard oxidation factor or 1.33 (Lettens et al. 2005).

d) Carbonates

In case the total organic carbon is determined with temperatures $>$ 600-800°C, the proportion of mineral soil in CaCO3 has to be subtracted in order to derive the amount of organic carbon (inorganic carbon is also oxidized). The pH value gives the first indication whether the sample has to be analyzed for inorganic carbon or not.

It is crucial to report in the metadata whether national SOC values refer to total C or if the inorganic component has been considered.

e) Depth

The standard depth for GSOCmap is **0 to 30 cm**. Subdivisions are possible depending on the available data, by genetic horizon or depth classes. The following depths are additionally considered for GSOC map (optional): Forest floor: thickness [cm] subdivision in horizons depending on national soil inventory method (e.g. L, F, H) Peat: $>$ 30 , $<$ 100 depending on national data

5.4 Completeness of depth estimate

Soil properties are commonly collected from the field inventories (see Table 2.2) or from sampling and analysing horizons and/or fixed depths. Since a fixed target depth of 30 cm is required for GSOC (other depth classes will be recommended in the future, following the GlobalSoilMap specifications (reference)), data holders are confronted with the following options:

- **Option 1**: Soil sampling has already considered this depth: data can be directly used for upscaling see "Upscaling Methods" section)
- **Option 2**: Horizons or layers/depth classes are sampled; but aggregation is needed over the 0-30 cm.
- **Option 3**: The target depth (0-30 cm) was not completely covered by sampling e.g. only the A horizon or a topsoil layer (e.g. 0-20 cm) has been sampled. For both options 2 and 3, additional processing is needed (e.g. equal-area splines).

For both options 2 and 3, transformation is needed using e.g. equal-area splines. In the case of option 3, the use of equal-area splines was first proposed by PonceHernandez et al. (1986), and later tested against real data (Bishop et al. 1999). This technique is based on fitting continuous depth functions for modelling the variability of soil properties with depth. Thus, it is possible to convert soil profiles to standard depths, but also to fill gaps. The equal-area spline function consists of a series of local quadratic polynomials that join at 'knots' located at the horizon boundaries thereby the mean value of each horizon is maintained by the spline fit. They are called equal-area splines because the area to the left of the fitted spline curve is equal to the area to the right of the curve.

5.4.1 Technical Steps (Equal area splines using R)

In R environment, the easiest way to apply equal-area splines is using the function GSIF::mpspline from the R package GSIF (Hengl 2016, see section 4.3.2). For illustration, a sample dataset has been used (see Chapter 5.). This function requires data stored as SoilProfileCollection (SPC) using package aqp. Nevertheless, data in any local soil database or in tables like the ones proposed before (Tables 2.1, 2.2 and 2.3) can be transformed to a SPC.

The function GSIF::mpspline has several arguments. One of the arguments is the lambda value mentioned before. The proposed default value is 0.1. Another argument for this function is the target standard depths. The function produces spline-estimated values at these depths. However, this function also produces spline-estimated values at 1 cm increments.

The following technical steps require 'R' and certain packages.

```r
# Load aqp package
library(aqp)
# Load GSIF package
library(GSIF)
```

Chapter 6

Preparation of spatial covariates

R. Baritz & Y. Yigini

6.1 DEM-derived covariates

6.1.1 DEM source data sets

Currently, two global level 30 m DEMs are freely available: the Shuttle Radar Topographic Mission (SRTM) and the ASTER Global Digital Elevation Model (GDEM). They provide topographic data at the global scale, which are freely available for users. Both DEMs were compared by Wong et al. (2014). Comparison against high-resolution topographic data of Light Detection and Ranging (LiDAR) in a mountainous tropical montane landscape showed that the SRTM (90 m) produced better topographic data in comparison with ASTER GDEM.

- Recommended for national level applications: 30 m GDEM / SRTM
- Recommended for global level applications: SRTM 90 m, resampled 1 kilometre.

In both cases noise and artefacts need to be filtered out. ASTER seems to contain more large artefacts (e.g. peaks), particularly in flat terrain, which are very difficult to remove through filtering.

> GRASS GIS or GDAL: use "mdenoise" module/utility to remove noise while preserving sharp features like ridges, lines and valleys.

SRTM contains many gaps (pixels with no-data). These gaps could be filled using splines. SAGA GIS has a module called 'Close Gaps with Splines' and other similar tools for doing this.

6.2 Parent material

Parent material has a crucial impact on soil formation, soil geochemistry and soil physics. Parent material, if not specifically mapped by soil mappers and included in soil maps, is usually available from Geology maps. These maps focus on rock formation, mineral components and age, and often lack younger surface sediments (even in quaternary maps). Parent material/rock types classified by soil mappers considers more strongly geochemistry and rock structure. The most commonly available approximation to parent material is certainly a geology map. Its geochemistry has essential impact on the soil chemistry, e.g. cation exchange capacity, base saturation, and nutrient stock. The rock structure determines the ability to disintegrate, which has impact on soil physical properties, like texture, skeleton content, permeability, and soil thickness.

National parent material and geology maps may be used. Other available datasets and data portals are given on the ISRIC WorldGrids website (worldgrids.org).

- OneGeology: The world geological maps are now being integrated via the OneGeology project which aims at producing a consistent Geological map of the world in approximate scale 1:1M (Jackson, 2007) http://www.onegeology.org/.
- USGS has several data portals, e.g. that allow browsing of the International Surface Geology (split into South Asia, South America, Iran, Gulf of Mexico, Former Soviet Union, Europe, Caribbean, Bangladesh, Asia Pacific, Arctic, Arabian Peninsula, Africa and Afghanistan) https://mrdata.usgs.gov/geology/world/.
- Hartmann and Moosdorf (2012) have assembled a global, purely lithological database called GLiM (Global Lithological Map). GLiM consists of over 1.25 million digital polygons that are classified in three levels (a total of 42 rock-type classes). https://www.geo.uni-hamburg.de/en/geologie/forschung/geochemie/glim.html).
- USGS jointly with ESRI has released in 2014 a Global Ecological Land Units map at 250 m resolution. This also includes world layer of rock types. This data can be downloaded from the USGS site (http://rmgsc.cr.usgs.gov/outgoing/ecosystems/Global/).

6.3 Soil Maps

Soil maps play a crucial role for upscaling soil property data from point locations. They can be the spatial layer for conventional upscaling, they can also serve as a covariate in digital soil mapping. Predicted soil property maps have lower quality in areas where the covariates such as relief, geology and climate so not correlate well with the dependent variable, here soil carbon stocks. This is especially true for soils under groundwater or stagnic water influence. This information is well-represented in soil maps.

FAO, IIASA, ISRIC, ISS CAS and JRC produced a gridded 1 km soil class map (HWSD). Global HWSD-derived soil property maps can be downloaded as geotiffs at http://worldgrids.org/doku.php/wiki:layers#harmonized_world_soil_database_images_5_km (see also section 3.6).

> Digitized small-scale national soil maps are the most important spatial layer for soil property mapping. The higher its resolution, the better soil maps contribute to high quality soil property maps - considering that the map should cover the target area/full country coverage.

6.4 Land cover/Land use

Besides soil, geology and climate, land use and/or land cover data are unarguably vital data for any statistical effort to map soil properties. There are many of various sources of data on land cover including global and continental products, such as GlobCover, GeoCover, Globeland30, CORINE Land Cover.

6.4.1 GlobCover (Global)

GlobCover is a European Space Agency (ESA) initiative which began in 2005 in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. The aim of the project was to develop a service capable of delivering global composites and land cover maps using as input observations from the 300 m MERIS sensor onboard the ENVISAT satellite mission. ESA makes available the land cover maps, which cover 2 periods: December 2004 - June 2006 and January - December 2009. The classification module of the GlobCover processing chain consists in transforming the MERIS-FR multispectral mosaics produced by the pre-processing modules into a meaningful global land cover map. The global land cover map has been produced in an automatic and global way and is associated with a legend defined and documented using the UN LCCS. The GlobCover 2009 land cover map is delivered as one global land cover map covering the entire Earth. Its legend, which counts 22 land cover classes, has been designed to be consistent at the global scale and therefore, it is determined by the level of information that is available and that makes sense at this scale (Bontemps et al., 2011). The GlobCover data can be downloaded at: http://due.esrin.esa.int/page_globcover.php

6.4.2 Landsat GeoCover (Global)

The Landsat GeoCover collection of global imagery was merged into mosaics by the Earth Satellite Company (now MDA Federal). The result was a series of tiled imagery that is easier to wield than individual scenes, especially since they cover larger areas than the originals. The great detail in these mosaic scenes, however, makes them large in storage size, so the Mr.Sid file format, which includes compression operations, was chosen for output. While GeoCover itself is available in three epochs of 1975, 1990 and 2000, only the latter two epochs were made into mosaics. Coverage: The GeoCover Landsat mosaics are delivered in a Universal Transverse Mercator (UTM) / World Geodetic System 1984 (WGS84) projection. The mosaics extend north-south over 5 degrees of latitude, and span east-west for the full width of the UTM zone. For mosaics below 60 degrees north latitude, the width of the mosaic is the standard UTM zone width of 6 degrees of longitude. For mosaics above 60 degrees of latitude, the UTM zone is widened to 12 degrees, centred on the standard even-numbered UTM meridians. To insure overlap between adjacent UTM zones, each mosaic extends for at least 50 kilometres to the east and west, and 1 kilometre to the north and south. Pixel size: 14.25 meters (V 2000) The data is available at: ftp://ftp.glcf.umd.edu/glcf/Mosaic_Landsat/ (FTP Access)

6.4.3 Globeland30 (Global)

GlobeLand30, the world's first global land cover dataset at 30 m resolution for the years 2000 and 2010, was recently released and made publicly available by China. The National Geomatics Center of China under the "Global Land Cover Mapping at Finer Resolution" project has recently generated a global land cover map named GlobeLand30. The dataset covers two timestamps of 2000 and 2010, primarily acquired from Landsat TM and ETM+ sensors, which were then coupled/checked with some local products. The data is publicly available for non-commercial purposes at: http://www.globallandcover.com/GLC30Download/index.aspx Further reading and other global data sources: http://worldgrids.org/doku.php/wiki:land_cover_and_land_use

6.4.4 CORINE Land Cover (Europe Only)

The pan-European component is coordinated by the European Environment Agency (EEA) and produces satellite image mosaics, land cover / land use (LC/LU) information in the CORINE Land Cover data, and the High Resolution Layers. The CORINE Land Cover is provided for 1990, 2000, 2006 and 2012. This vector-based dataset includes 44 land cover and land use classes. The time-series also includes a land-change layer, highlighting changes in land cover and land-use. The high-resolution layers (HRL) are raster-based datasets (100 m, 250 m) which provide information about different land cover characteristics and is complementary to land-cover mapping (e.g. CORINE) datasets. The CORINE Land Cover Data are available at: http://www.eea.europa.eu/data-and-maps/data

6.5 Climate

6.5.1 WorldClim V1.4 and V2 (Global)

WorldClim is a set of global climate layers (gridded climate data) with a spatial resolution of about 1 km2 (10 minutes, 5 minutes, 2.5 minutes are also available). These data can be used for mapping and spatial modelling.

The current version is Version 1.4. and a preview of Version 2 is available for testing at worldclim.org. The data can be downloaded as generic grids or in ESRI Grid format.

The WorldClim data layers were generated by interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid. In V1.4, variables included are monthly total precipitation, and monthly mean, minimum and maximum temperatures, and 19 derived bioclimatic variables. The WorldClim precipitation data were obtained from a network of 1,473 stations, mean temperature from 24,542 stations, and minimum and maximum temperatures from 14,835 stations (Hijmans et al. 2005).

The Bioclimatic parameters are: annual mean temperature, mean diurnal range, iso-thermality, temperature seasonality, max temperature of warmest month, minimum temperature of coldest month, temperature annual range , mean temperature of wettest quarter, mean temperature of driest quarter, mean temperature of warmest quarter, mean temperature of coldest quarter, annual precipitation, precipitation of wettest month, precipitation of driest month, precipitation seasonality (coefficient of variation), precipitation of wettest quarter, precipitation of driest quarter, precipitation of warmest quarter, precipitation of coldest quarter.

WorldClim Climate Data are available at: www.worldclim.org (WorldClim 1.4 (current conditions) by www.worldclim.org; Hijmans et al., 2005. Int. J. of Clim. 25: 1965-1978. Is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License).

6.5.2 Gridded Agro-Meteorological Data in Europe (Europe)

CGMS database contains meteorological parameters from weather stations interpolated on a 25×25 km grid. Meteorological data are available on a daily basis from 1975 to the last calendar year completed, covering the EU Member States, neighbouring European countries.

The following parameters are available at 1 day time resolution; * maximum air temperature (°C), * minimum air temperature (°C), * mean air temperature (°C), * mean daily wind speed at 10m (m/s), * mean daily vapour pressure (hPa), * sum of precipitation (mm/day), * potential evaporation from a free water surface (mm/day), * potential evapotranspiration from a crop canopy (mm/day), * potential evaporation from a moist bare soil surface (mm/day), * total global radiation (KJ/m2/day), * Snow Depth Data Access: http://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx

6.6 GSOCMap - Data Repository (ISRIC, 2017)

ISRIC World Soil Information has established a data repository which contains raster layers of various biophysical earth surface properties for each territory in the world. These layers can be used as covariates in a digital soil mapping exercise.

6.6.1 Covariates and Empty Mask

The territories and their boundaries are obtained from the Global Administrative Unit Layers (GAUL)dataset: each folder contains three subfolders; covs: GIS layers of various biophysical earth surface properties mask: an 'empty' grid file of the territory with territory boundary according to GAUL. This grid to be used for the final delivery. . soilgrids: all SoilGrids250m soil class and property layers as available through www.soilgrids.org. Layers are aggregated to 1 km.

6.6.2 Data Specifications

File format: GeoTiff Coordinate system: WGS84, latitude-longitude in decimal degrees Spatial resolution: 1km

6.6.3 Data Access

ftp://gsp.isric2.org/ (username: gsp, password: gspisric) or ftp://85.214.253.67/ (username: gsp, password: gspisric)

LICENCE and ACKNOWLEDGEMENT *The GIS layers can be freely used under the condition that proper credit should be given to the original data source in each publication or product derived from these layers. Licences, data sources, data citations are indicated the data description table.*

6.7 Extending the soil property table for spatial statistics

The upscaling procedures (Chapter 6) depend on the rationale that the accumulation of local soil carbon stocks (and also other properties) depend on parameters for which spatial data are available, such as climate, soil type, parent material, slope, management. This information (Covariates) must be collected first. Details are provided above. The properties contained in the covariates can be extracted to each georeferenced sample site and added to the soil property table (Table 3.1). This table is used for training and validation of the statistical model for predicting the SOC stocks which subsequently can be applied to the full spatial extent.

6.8 Preparation of a soil property table for spatial statistics

The upscaling procedures (section 4) depend on the rationale, that the accumulation of local soil carbon concentrations and stocks (and also other properties) depends on influential parameters for which spatial data are available, such as climate, soil type, parent material, slope, management. Any parameter in the table of local soil properties, for which a spatial layer is available, may be included in the final table. Other covariates will be added in section 3. An example is the clay content, which may be derived from a soil type or parent rock map.

> In case this table is prepared for different depths, 0-10 cm, 10-30 cm, and if the host institution intends to develop different spatial models for different depths (e.g. separate spatial prediction model for litter and mineral soil 0-30), then the separate grids have to be added.