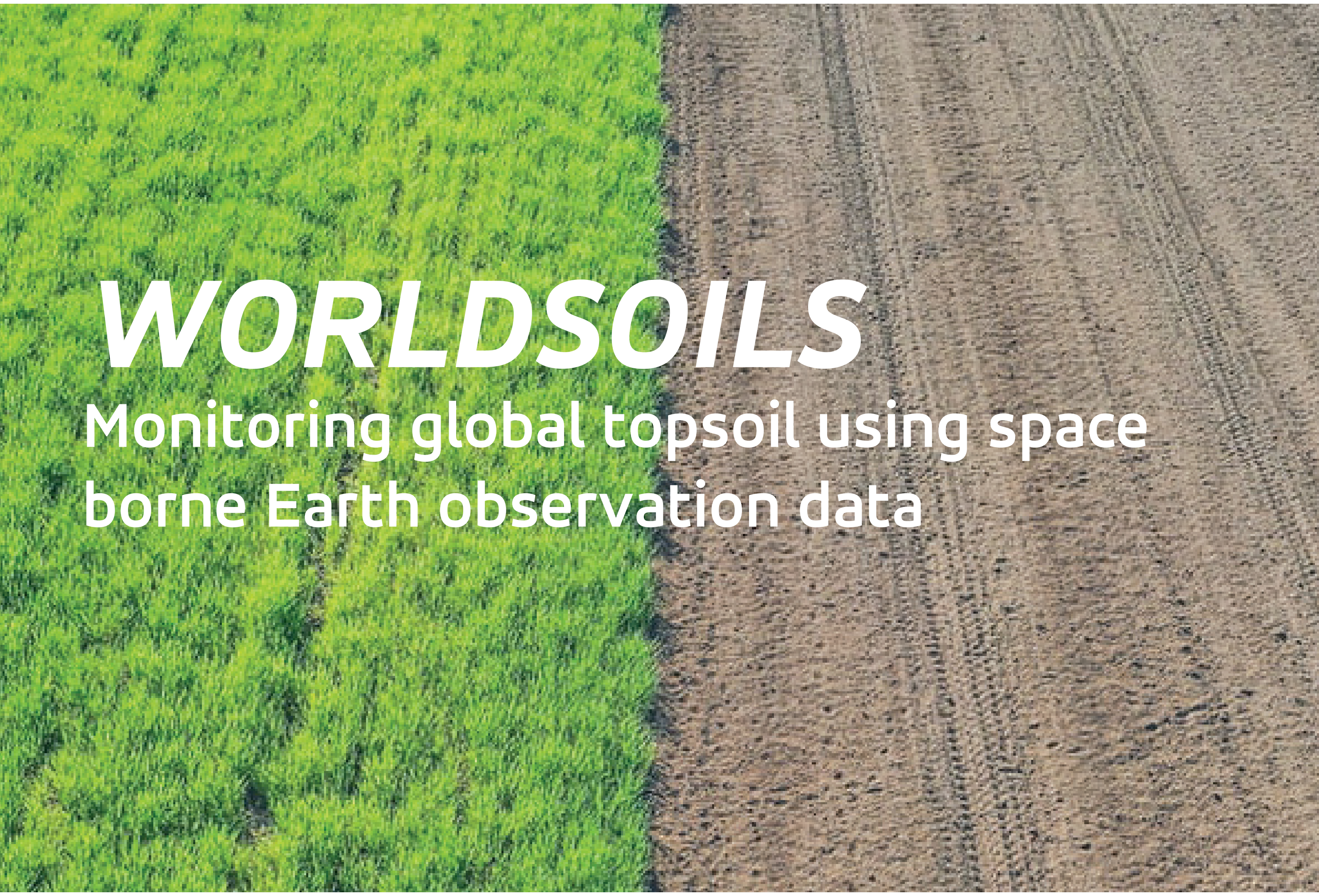

WORLDSOILS

Monitoring global topsoil using space borne Earth observation data

WORLDSOILS PORTFOLIO

Soil is one of the principal substrata of life on Earth, serving life functions such as plant growth, gas exchange with the atmosphere, retention of water and nutrients, habitat for microbiota and the ground for land ecosystems.

ESA is committed to use its Earth Observation (EO) monitoring capacities to support the EU soil regulatory framework and to concretise the ways EO can serve to monitor the requirements of the various soil health indicators stated in the proposed law.

WORLDSOILS has developed a pre-operational soil monitoring system to provide yearly estimations of Soil Organic Carbon (SOC) at regional and continental scale, exploiting multitemporal satellite observations, leveraging large soil data archives and modelling techniques.

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SOIL ORGANIC CARBON AND SATELLITE OBSERVATION

Soil is the largest terrestrial carbon pool; small losses or gains in soil organic carbon (SOC) represent significant sources or sinks of atmospheric CO_2. Spatial variability of SOC can be remarkable due to factors like local climate and soil characteristics, parent material, land cover changes, and agricultural management.

SOC is a measurable component of soil organic matter (SOM), and it has an important role in the physical, chemical and biological function of soils. SOM results from organic material such as plant and crop residues, fertilizers, like animal manure, and compost. SOC is one of the main indicators for soil quality and stimulates agricultural production. Moreover, it is crucial for climate change mitigation. Crops fix carbon in their biomass from the atmosphere through photosynthesis. Part of this biomass returns to the soil. Yet, without SOC crops are vulnerable to diseases and stress.

SOC is traditionally assessed by taking field samples analysed in the laboratory through wet digestion methods (carbon is oxidised by chromate in the preence of sulfuric acid) and dry combustion methods (thermal decomposition of organic and inorganic carbon to generate carbon dioxide). The inorganic carbon is then determined after reaction with hydrochloric acid. Laboratory, field and satellite spectroscopy have enlarged the methods for measuring soil parameters since the 1980's.

EO serves as a valuable data source for soil mapping, as satellite images allow monitoring over time and over large areas with a resolution that allows distinguishing within and between field patterns. Soil spectroscopy has become an established analytical technique for soil components such as C, N (nitrogen), clay and CEC (cation exchange capacity). Recently, similar spectroscopic techniques have been applied to optical remote sensing (RS) platforms offering the possibility of mapping large areas. Many studies have demonstrated the potential of remote sensing for SOC mapping either directly when soils are bare or indirectly by quantifying the dynamics of the vegetation.

WHAT DOES WORLDSOILS PROVIDE?

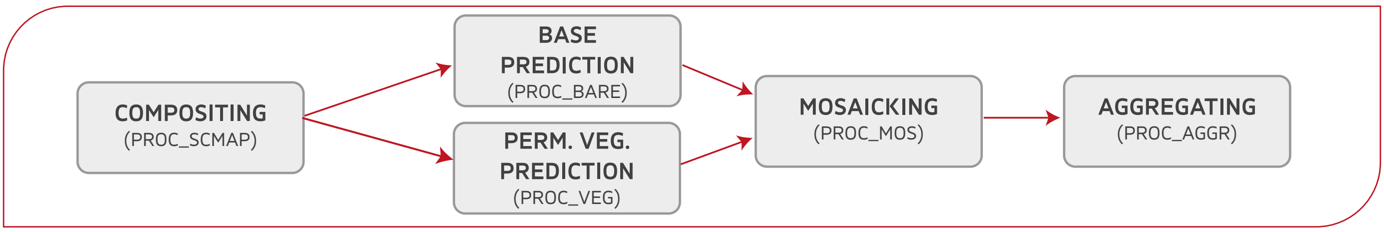
WORLDSOILS has developed a SOC prediction modular system based on regional soil models over various land covers (forest, cropland, grassland), capable of producing the following SOC maps, derived from EO and in situ measurements.

EO Product	Pixel Resolution (meters)	Minimum Mapping Unit (MMU, ha)	Periodicity and EO data
1. European topsoil SOC content	100 m	1 ha	Annual Integrating 3-years of Sentinel 2 imagery. 2018-2020, 2019-2021, 2020-2022
2. SOC pixel base uncertainty			
3. Regional topsoil SOC content	50 m	0.25 ha	
4. SOC pixel base uncertainty			

METHODOLOGY

EO plays an important role to provide spatially continuous and comprehensive input data for the SOC content prediction. In the last decade techniques have been developed to generate spectral reflectance composites of bare soils by integrating a large number of satellite acquisitions during a specific time period. In this way, the problem of temporal cover of the soils by vegetation can be reduced and the area for which soil spectra can be directly investigated is enlarged. Using this technique, several spectral and statistical composite products for soils are produced that serve as input for spectral as well as digital soil mapping approaches.

In ***WORLDSOILS*** a hybrid approach has been developed that predicts SOC for permanently covered soils and bare soils separately. For permanently vegetated areas such as grasslands and forests, a so-called digital soil mapping approach can be used i.e. establishing a multi-variate or machine learning prediction model for geo-referenced SOC contents using a variety of spatially continuous environmental covariantes, spectral composites of bare soil and vegetation. For bare soils, the SOC content is modelled based on their spectral information using the soil reflectance composites. In both cases, soil characteristics provided by the LUCAS soil campaign 2018 survey are used to calibrate the models.



VALIDATION

The performance of the two SOC prediction models i.e. for vegetated areas and for bare soils is assessed by ten fold cross validation. The validation for the bare soil model has an R^2 of 0.41 and an RMSE of 18.07 g kg^{-1}. For the vegetated areas the R^2 is 0.28 and the RMSE is 67.35 g kg^{-1}. For three European regions i.e. Wallonia (Be), Czech Republic (Cz) and Macedonia (Gr) the SOC values predicted by the Worldsoils system have been validated against independent data i.e. geo-referenced datasets for agricultural soils provided by the National Reporting Centers for soils. The details on the validation are specified in the description sheets.

BENEFITS

Soil organic matter and its main component SOC are essential for preserving a healthy soil and maintaining soil fertility. It is proposed that soil health is dependent on the maintenance of four major functions: carbon transformations; nutrient cycles; soil structure maintenance and the regulation of pests and diseases. SOC improves the biological, chemical, and physical properties of soil, which in turn, increase water-holding capacity and structural stability. It is also integral in the formation of soil's amino acids. In addition, as one of the earth's most highly valued biopolymers, organic carbon is natural and renewable energy storage. Moreover, SOC content can be related to yield potential of cereals. It has been shown that SOC contents up to region-specific targets can reduce reliance on nitrogen fertilizer.

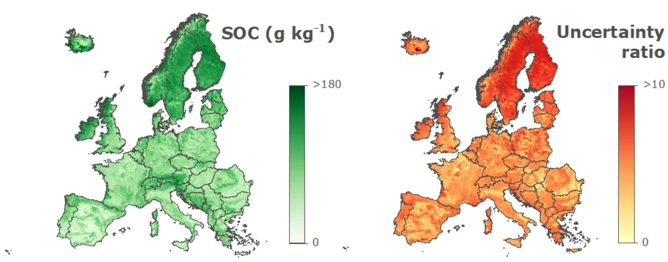
The CO_2 assimilated by plants through photosynthesis eventually ends up in the soil and contributes to the CO_2 that is removed from the atmosphere.

Satellite based information of soil parameters offers transparent, frequent, and cost-effective solutions covering the whole territory in a seamless manner.

Finally, SOC acts as a "buffer" for soil against extreme pH fluctuations. Steady pH is critical for soil and ecosystem functions. Depletion of SOC degrades soil quality, reduces biomass productivity, and adversely impacts water quality.

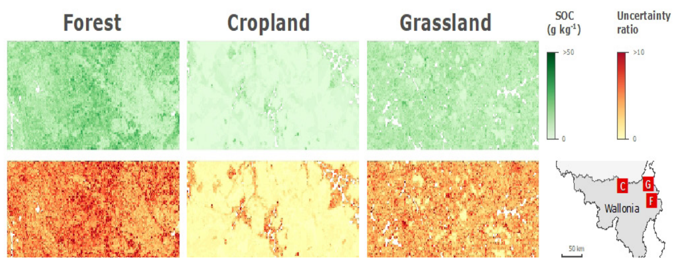
EUROPEAN TOPSOIL SOC CONTENT AND UNCERTAINTY, 100m.

Product description	SOC content in the 0-20 cm top soil expressed in g kg^{-1} for 100 m resolution pixels
Methodology	Hybrid approach with separate models for permanently vegetated areas and croplands. Empirical models linking the SOC content in LUCAS sample points to spectra acquired by Sentinel 2 in corresponding pixel
Main applications	- First globally consistent and contiguous complete gridded soil property map of Europe - Indicator of soil health, as per Mission Area Soil Health and Food - By 2030, at least 75% of soils in each EU Member State should be in healthy condition or show a significant improvement towards meeting accepted thresholds of indicators, to support ecosystem services
Update frequency	Annual
Uncertainty	Prediction interval of the SOC content in the 0-20 cm topsoil per pixel, expressed as (P95-P5)/median
Map reliability	More than 83 % of the cross-validation points fall within the 70% prediction interval for the bare soil model. For the vegetated area model 94 % of the points fall within the 90 % prediction interval
Format of product	Classification image in raster format (.tif) and metadata (.txt) Optional delivery online
EO data	High Resolution: Sentinel-2 imagery
Covariates	Copernicus DEM, climate data: ERA5
In situ data	Field soil data is required for the calibration and the validation process. Optimal data sets include: georeferenced soil samples with a standardized sampling and analysis protocol such as the LUCAS soil campaigns
Archive length	2016 – Present
Spatial resolution	100 m
Min. mapping unit	1 ha
Composites length	An interannual composite of images is required to ensure the selection of adequate pixels. Three years, e.g: 2018-2020, 2019-2021, 2020-2022
Spatial coverage	Use of global coverage input data. Customizable at local/regional set up
Validation	A cross validation
Delivery	Download via web browser https://gui.world-soils.com/
Metadata	OGC - EU INSPIRE Standard
Property rights	ESA



REGIONAL TOPSOIL SOC CONTENT AND UNCERTAINTY, 50m.

Product description	SOC content in the 0-20 cm top soil expressed in g kg^{-1} for 50 m resolution pixels
Methodology	Hybrid approach with separate models for permanently vegetated areas and croplands. Empirical models linking the SOC content in LUCAS sample points to spectra acquired by Sentinel 2 in corresponding pixel
Main applications	- Screening of impacts of land management on SOC contents and in the future their evolution - Regular reporting on the state of the soils. However, a threshold for each region with similar soils and land use would have to be defined
Update frequency	Annual
Uncertainty	Prediction interval of the SOC content in the 0-20 cm topsoil per pixel, expressed as (P95-P5)/median
Map reliability	The reliability is expressed as the percentage of the sample points for which the reference SOC contents fall within the uncertainty range of the SOC prediction (based on the 2018-2020 map): 43 % for Wallonia (Belgium), 33% for the Czech Republic and 54 % for Macedonia (Greece)
Format of product	Classified image in raster format (.tif) and metadata (.txt)
EO data	High Resolution: Sentinel-2 imagery
Covariates	Copernicus DEM, climate data
In situ data	Field soil data is required for the calibration and the validation process. Optimal data sets include: geo-referenced soil samples with a standardized sampling and analysis protocol such as the LUCAS soil campaigns. Higher density data sets are available from the National Reporting Centers, currently used for the validation
Min. mapping unit	1 ha
Composites length	An interannual composite of images is required to ensure the selection of adequate pixels. The length of the composites is: 2018-2020; 2019-2021 and 2020-2022
Spatial coverage	Use of global coverage input data. Customizable to local/regional set up
Validation	Performed against an independent reference SOC dataset in agricultural soils provided by the National Reporting Centers on soils, distributed across agricultural land: - Wallonia: RMSE= 7.95g kg^{-1}; RPIQ= 0.88; bias= -0.25g kg^{-1} - Czech Republic: RMSE= 6.66g kg^{-1}; RPIQ= 0.95; bias= -0.31g kg^{-1} - Macedonia: RMSE= 8.2g kg^{-1}; RPIQ= 0.71; bias= 2.92g kg^{-1}
Delivery	Download via web browser https://gui.world-soils.com/
Metadata	OGC - EU INSPIRE Standard
Property rights	ESA



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