Earth Observation for Soil Health & Sustainable Land Use Management

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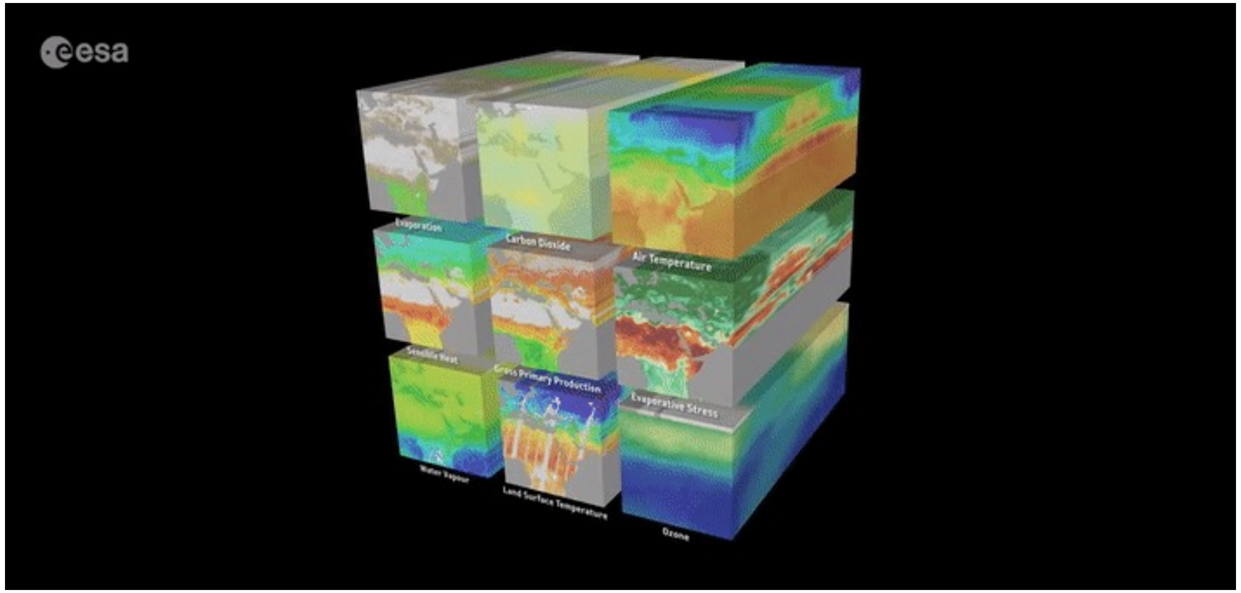
Contents

What does the term soil health denote?

"the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain or enhance the quality of air and water, and promote plant, animal and human health (Doran et al. 1996, Doran & Zeiss 2000)"

Earth observation Data

- instrumental in understanding, monitoring, and managing soil health.
- provide essential insights into various soil parameters and processes, enabling effective decision-making to ensure sustainable land use and preservation of this vital natural resource

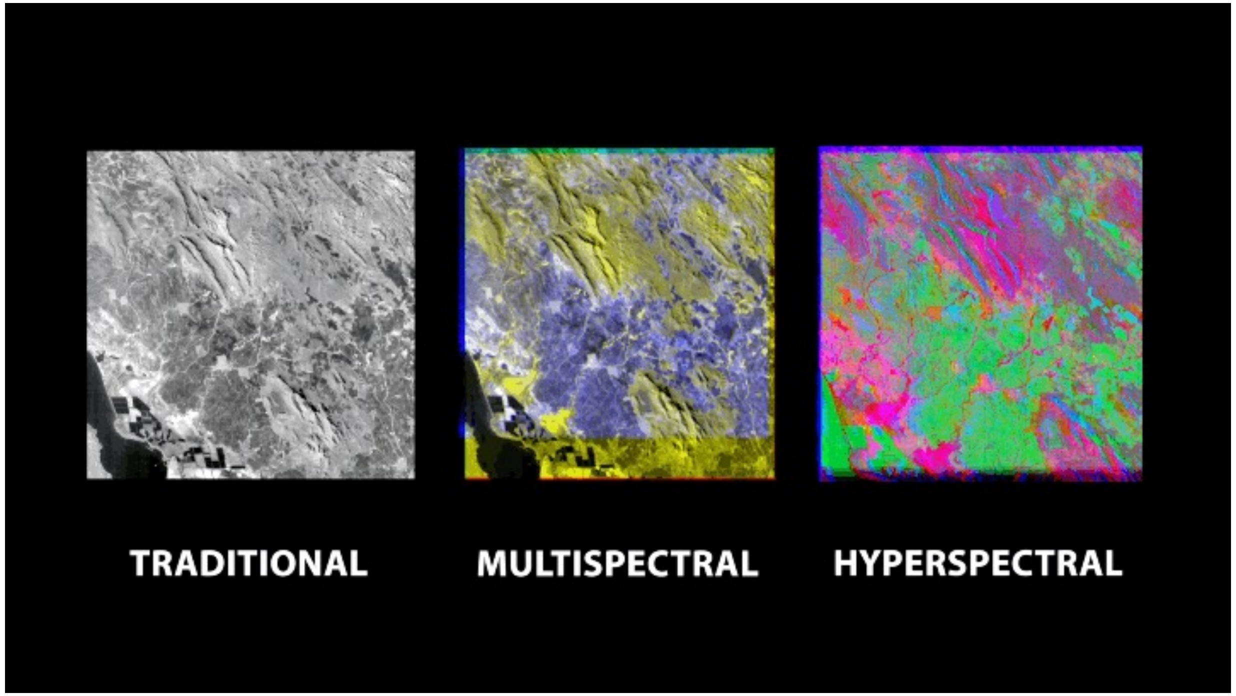


Earth observation Data

1. **Optical Data**:
   - Captured in the visible, near-infrared, and thermal infrared regions
   - Used for vegetation analysis, land use classification, and environmental monitoring.
2. **Radar Data (SAR - Synthetic Aperture Radar)**:
   - Utilizes radar signals to detect surface features regardless of weather or daylight conditions
   - Valuable for terrain mapping and detecting changes in land surface
3. **Infrared and Thermal Data**:
   - Measures thermal radiation emitted by the Earth's surface
   - Essential for monitoring temperature variations and volcanic activity

Earth observation Data

1. **Hyperspectral Data**:
   - Captures a wide range of narrow and contiguous spectral bands.
   - Enables detailed analysis for wate bodies mapping, crop health condition, and pollution monitoring.
2. **LIDAR Data**:
   - Utilizes laser pulses to measure distances and generate high-resolution 3D topographic maps.
   - Used in forestry, urban planning, and disaster risk assessment.
3. **Multispectral Data**:
   - Captures data across several discrete spectral bands.
   - Important for vegetation health assessment, land cover classification, and water quality monitoring.



Insights of EO data in soil health

- **Soil Composition and Properties**: can provide detailed **information about soil composition, including the presence of essential nutrients, organic matter, MC, and soil structure.** This data helps in understanding the soil's capacity to support plant growth and its overall fertility.
- **Land Use and Land Cover Changes**: allows **monitoring of land use changes**, including deforestation and agricultural expansion. These changes can significantly impact soil health by altering soil properties, erosion rates, and nutrient cycles.
- **Erosion and Degradation**: helps in assessing soil erosion and degradation **by monitoring changes in topography and vegetation cover**. Soil erosion **reduces soil fertility and affects its structure**, making it crucial to track and mitigate these processes.
- **Monitoring Soil Moisture**: can measure soil moisture content, an essential factor in understanding soil health. Soil moisture **affects plant growth, nutrient availability, and overall soil stability**. Accurate monitoring helps **optimize irrigation and water management practices**.

Insights of EO data in soil health

- **Identification of Contamination and Pollution:** can identify areas where soil contamination or pollution is prevalent. This information is crucial for identifying sources, assessing the extent of contamination, and implementing appropriate remediation strategies to restore soil health.
- **Crop Health and Productivity:** assists in monitoring crop health, growth, and productivity by analyzing VIs. This information is essential for managing agricultural practices, optimizing fertilizer application, and ensuring sustainable farming that maintains soil health.
- **Predicting Soil Health Trends:** when combined with ML and modeling techniques, can predict soil health trends over time based on historical and current observations. This predictive capability aids in making informed decisions for sustainable land management and agricultural practices.
- **Sustainable Land Management:** though their integration into land management practices, policymakers and stakeholders can make informed decisions to preserve and improve soil health. This includes implementing conservation measures, appropriate land use planning, and sustainable agricultural practices.

EO data acquisition

Satellite-Based EO (S1,S2, Landsat 8) :

- Satellites equipped with various sensors capture data from space
- Provide global coverage and frequent revisits for monitoring changes over time

Aerial Photography:

- Captured from airplanes or UAVs equipped with imaging sensors
- Offers higher resolution than satellite imagery and is suitable for localized studies

Ground-Based and Remote Sensing Stations:

- Use fixed or mobile sensors on the ground to collect specific data
- Offer detailed, localized information for various applications

Latest trends in EO

- **Integration of Multi-Sensor Data**

EO data from various sensors (e.g., optical, radar, hyperspectral) are being integrated to provide a more comprehensive view of soil properties and health. This integration allows for **better characterization and monitoring of soil conditions**

- **Machine Learning (ML) and AI Applications**

Applied to analyze and interpret complex soil-related patterns and processes. Partial least-squares (PLS) multivariate regression, random forest (RF) are currently applied for soil properties estimation and mapping (Padarian et al., 2020). NNs and gradient boosting are efficient regression approaches (Meng et al., 2020). These techniques enhance soil health assessment, soil property prediction, and land management decisions.

- **High-Resolution Remote Sensing**

Advances in high-resolution EO technologies provide **finer spatial and spectral resolution, enabling detailed mapping of soil properties at a local scale**.

Latest trends in EO

- **Incorporation of UAVs (Drones) and Space**

the increase in low altitude systems (e.g., unmanned aerial systems (UAS), along with space-based missions covering different spectral domains and **obtaining data with higher spatial and temporal resolution resulted in a massive increase in EO big data analysis**. This fine-grained information is crucial for precision agriculture and localized soil management

- **Cloud storage and computing**

enhances the processing and analysis of data obtained from remote sensing technologies, such as satellite imagery or UAV ,drone-based sensors for monitoring soil health. The **high volume of imagery and spectral data can be efficiently processed, analyzed, and integrated with other data sources on cloud platforms to derive meaningful insights about soil conditions and trends**.

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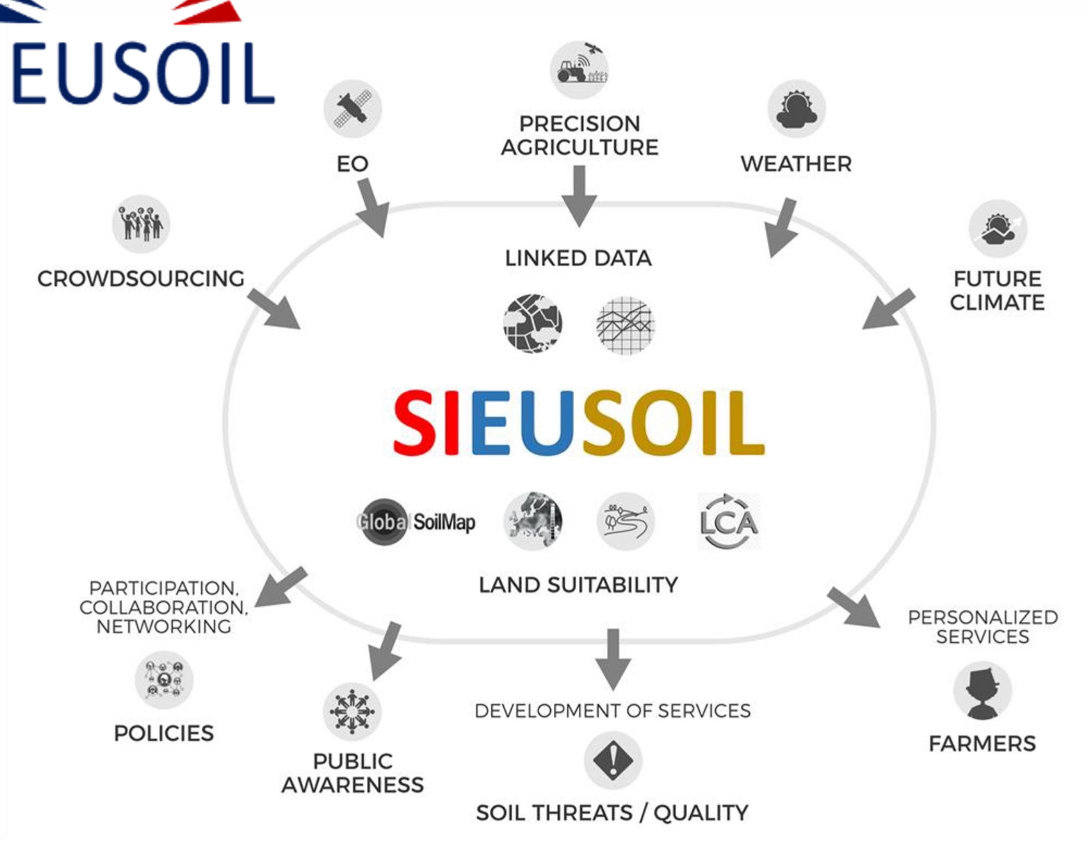

- design, implementation and test of a shared China-EU Web Observatory platform that provided Linked (Open) Data to monitor status and threats of soil and land resources
- support sustainable management of soil, increase of land productivity sustainably, reduction of crop yield variability across time and space, and support the policy formulation process.
- Test of innovative practices and tools and their impact was assessed towards improved soil fertility, soil health and sustainable land use management

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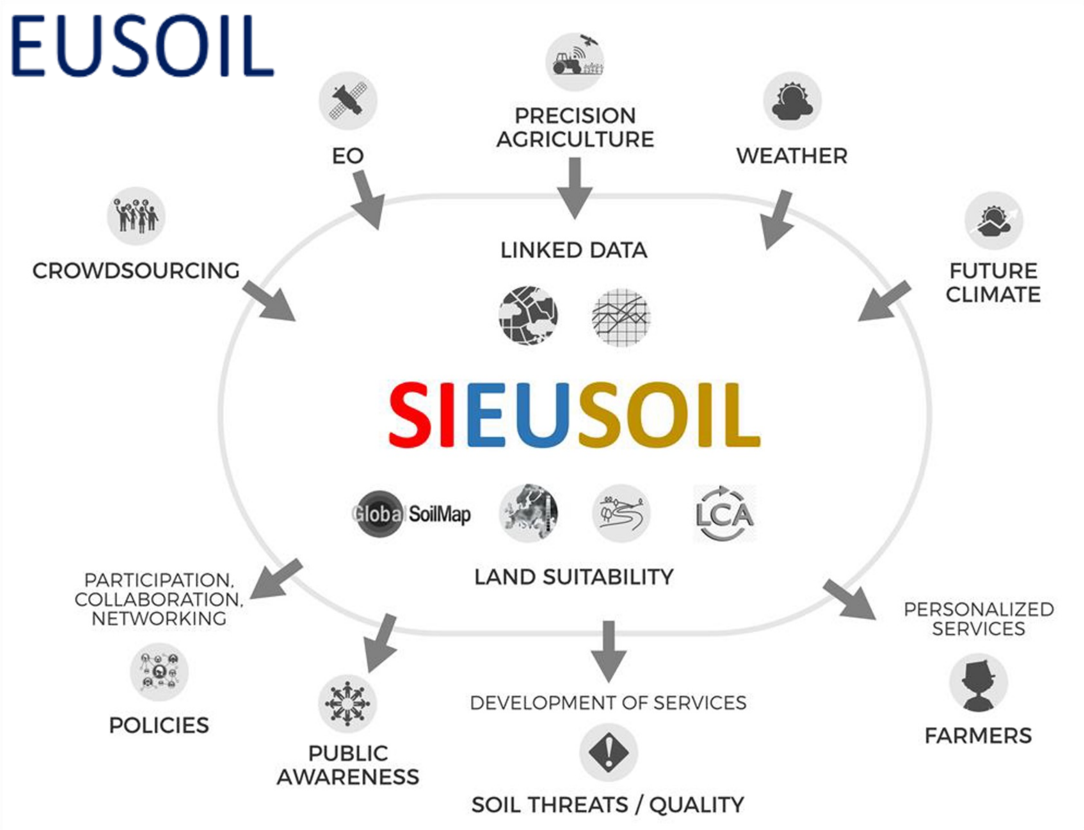


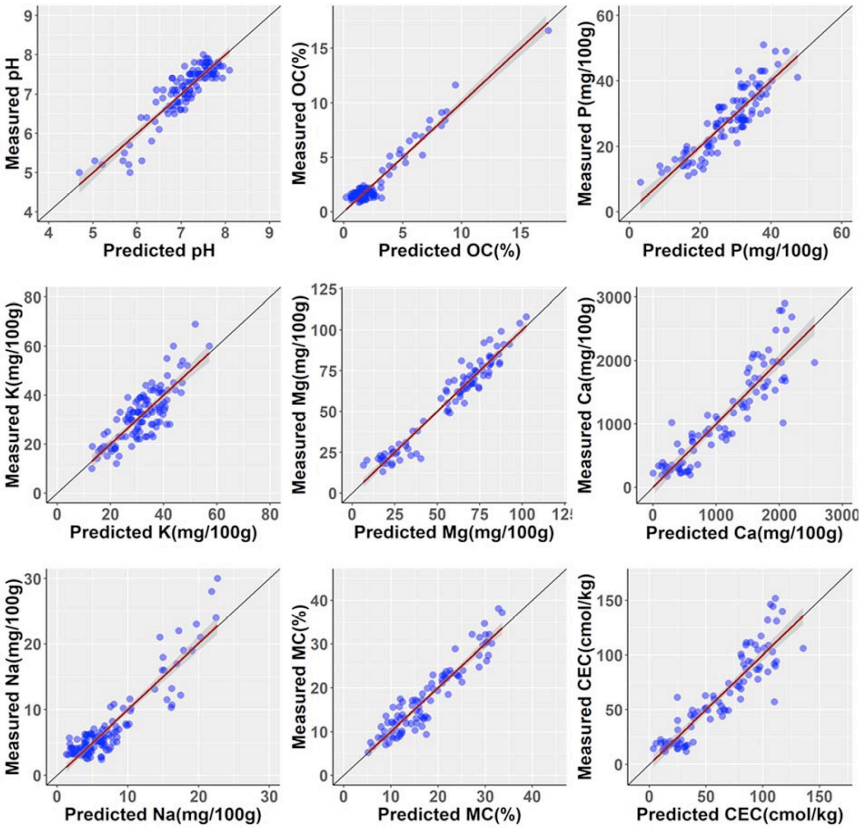
Geostatistical analyses & mapping

- **estimation of key soil quality, physical and fertility indicators**
- FRK non-stationary geostatistical interpolation method for

-processing massive line-scanning soil datasets

- creating smooth, interpolated maps of soil properties

- the popular kriging variant of Ordinary Kriging (OK) generated uniform patterns of spatial variation and delineated site-specific MZ
- The adopted data fusion approach took advantage of the complementary features provided by Sentinel-2 biophysical crop parameters.



Scatter Plots of measured versus on-line predicted soil attributes obtained with PLSR models in cross validation

Estimation of key soil quality, physical and fertility indicators

- on-line **Vis-NIR spectra based predictive models** (PLSR) for the **estimation of key soil quality, physical and fertility indicators** including pH, OC, SOM, P, K, Mg, Ca, Na, MC, CEC, SOM, K:Mg, and Ca:Mg at high sampling resolutions were obtained and independently validated
- **MZ maps and methodologies for variable rate fertilization (N,P,K) application** were created

Current Limitations-Challenges

- define policy priorities or parameters for soil protection
- define soil nutrient data sets both as individual indicators (N,P,K) and as a composite indicator of soil fertility
- assist the assessment of CAP performance though assessing soil individual indicators
- propose and design management practices towards the status improvement of agricultural soils and stop land degradation (e.g through VR fertilization, VR fertigation)
- pay more attention on the models' interpretability. Interpretability is important for debugging AI models and making informed decisions.
- Big Data Sustainability and Traceability through the construction of

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