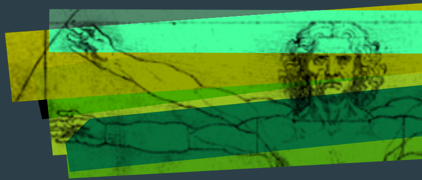
LE STUDIUM

CONFERENCES

ORLÉANS | 2023



International Union of Soil Sciences®

Digital Soil Mapping Working Group

GlobalSoilMap

7-9 February 2023

Soil Mapping for a Sustainable Future

2nd joint Workshop of the IUSS Working Groups Digital Soil Mapping and Global Soil Map

LOCATION

Auditorium du Musée des Beaux Arts
1 Rue Fernand Rabier
45000 Orléans - FR

UNDER THE AUSPICES OF

IUSS - International Union of Soil Sciences Digital Soil Mapping and Global Soil Map Working Groups

PROGRAMME - REGISTRATION

registration@lestudium-ias.fr

www.lestudium-ias.com

LE STUDIUM Loire Valley Institute for Advanced Studies

RÉGION CENTRE VAL DE LOIRE

Co-funded by the European Union

ORLÉANS MÉTROPOLE

ISRIC World Soil Information

INRAE

Association Française pour l'étude du sol

European Commission JOINT RESEARCH CENTRE

JUNON

LE STUDIUM
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ORLEANS | 2023

ABSTRACTS

Soil Mapping for a Sustainable Future

2nd joint Workshop of the IUSS Working Groups Digital Soil Mapping and Global Soil Map

ORGANIZING COMMITTEE

Sophie Gabillet, General Secretary

Dr Aurélien Montagu, Scientific Manager

Maurine Villiers, Communication and Events Manager

LE STUDIUM Loire Valley Institute for Advanced Studies • Région Centre-Val de Loire • FR

EDITO

Created in 1996 on the CNRS campus in Orleans La Source, LE STUDIUM has evolved to become a multidisciplinary Loire Valley Institute for Advanced Studies (IAS), operating in the region Centre-Val de Loire of France. LE STUDIUM has its headquarters in the city centre of Orleans in a newly renovated 17th century building. The amazing facilities are shared with the University of Orleans. In 2014 new developments and programmes linked to the smart specialisation of the Centre-Val de Loire region came to strengthen existing IAS cooperative relationships with the local and the international community of researchers, developers and innovators.

LE STUDIUM IAS offers to internationally competitive senior research scientists the opportunity to discover and work in one of the IAS's affiliate laboratories from the University of Tours, the University of Orleans, National Institute of Applied Sciences (INSA) Centre Val de Loire and ESAD Orléans, as well as of nationally accredited research institutions located in the region Centre-Val de Loire (BRGM, CEA, CNRS, INSERM, INRAE, IRSTEA). Our goal is to develop and nurture trans-disciplinary approaches as innovative tools for addressing some of the key scientific, socio-economic and cultural questions of the 21st century. We also encourage researchers' interactions with industry via the IAS's links with Poles of Competitiveness, Clusters, Technopoles, and Chambers of Commerce etc.

LE STUDIUM has attracted over two hundred LE STUDIUM RESEARCH FELLOWS and LE STUDIUM RESEARCH PROFESSORS for long term residencies. In addition to the contribution in their host laboratories, researchers are required to participate in the scientific life of the IAS through attendance at monthly interdisciplinary meetings called LE STUDIUM THURSDAYS and gathering members of the regional scientific community and industries.

For the period 2015-2021, LE STUDIUM operates with an additional award from the European Commission in the framework of the Marie Skłodowska-Curie Actions (MSCA) with the programme MSCA-COFUND for the mobility of experienced researchers. LE STUDIUM is also the official partner of the Ambition Research and Development 2020 (ARD 2020) initiated by the Region Centre-Val de Loire, that supports the specialisation strategy around 5 main axes: biopharmaceuticals, renewable energies, cosmetics, environmental metrology and natural and cultural heritage.

Researchers are also invited and supported by the IAS to organise, during their residency and in collaboration with their host laboratory, a two-day LE STUDIUM CONFERENCE. It provides them with the opportunity to invite internationally renowned researchers to a cross-disciplinary conference, on a topical issue, to examine progress, discuss future studies and strategies to stimulate advances and practical applications in the chosen field. The invited participants are expected to attend for the duration of the conference and contribute to the intellectual exchange. Past experience has shown that these conditions facilitate the development or extension of existing collaborations and enable the creation of productive new research networks.

The present LE STUDIUM CONFERENCE named "Soil Mapping for a Sustainable Future" is the 126^{th} in a series started at the end of 2010 listed at the end of this booklet.

We thank you for your participation and wish you an interesting and intellectually stimulating conference. Also, we hope that during these days in our region some of you will see an opportunity to start a productive professional relationship with LE STUDIUM Loire Valley Institute for Advanced Studies and research laboratories in the Centre-Val de Loire region.

Yves-Michel GINOT

Chairman
LE STUDIUM

INTRODUCTION

This conference will be hosted by le STUDIUM Institute for advanced studies (Orléans, France). It will bring together the International Union of Soil Sciences Working Groups 'Digital Soil Mapping' and 'Global Soil Map'.

Digital soil mapping (DSM) is the modern way of creating soil maps and spatial soil information systems using numerical models. DSM is now widely used to create accurate maps of soil properties from field to global scales. This conference will present advances in science, state-of-art of spatiotemporal assessment, addressing the challenges and the mechanics of its various implementations for a sustainable future and soil health management from the field to the globe. It will bring together scientists in the field of DSM and end-users of their products.

Presentations will include, among others:

- global, regional and national state-of-the art of DSM products,
- methodological advances in DSM, including testing new modelling approaches and incorporating/selecting new co-variates,
- sampling issues,
- validation/evaluation methods of the performance of prediction,
- evaluation of uncertainty and communication of the uncertainty to end-users,
- uses of DSM products for decision-making, soil management and conservation, land-use planning, and evaluation/preservation of ecosystem services.

TABLE OF CONTENTS

SESSION 2 : CASE STUDIES

SESSION 3 : COVARIATES & REMOTE SENSING

SESSION 4 : SAMPLING, VALIDATION & UNCERTAINTY

SESSION 5 : PEDOLOGICAL KNOWLEDGE AND DSM

SESSION 6 : DIGITAL ASSESSMENT OF SOIL FUNCTIONS AND SERVICES

WITH THE SUPPORT OF

French Agency for Ecological Transition (ADEME)

At ADEME – the French Agency for Ecological Transition – we are resolutely committed to the fight against global warming and the degradation of resources.

On all fronts, we mobilize citizens, economic stakeholders and territories, giving them the means to move towards a resource-efficient, low-carbon, fairer and more harmonious society.

In all areas – energy, air, circular economy, food waste, waste, soil, etc. – we advise, facilitate and help in financing numerous projects, from research to sharing solutions.

At all levels, we put our expertise and foresight capacities at the service of public policies.

ADEME is a public institution working under the supervision of the Ministry of Ecological Transition and Territorial Cohesion and the Ministry of Higher Education and Research.

Organisation

ADEME, whose head office is located in Angers, has more than 1,000 employees divided into

- 3 sites for the central services in Angers (Maine-et-Loire), Montrouge (Hauts-de-Seine) and Valbonne (Alpes-Maritimes);
- 17 regional offices, 13 in mainland France and 4 in overseas territories, which cover the whole of France through 26 locations;
- 3 representations in the overseas territories;

Accelerating the ecological transition towards a society that is resource and energy efficient, supportive, job-creating, more human and harmonious.

Three main priorities have been set for ADEME to mobilise and support citizens, territories and economic and public stakeholders: furthering the deployment of the ecological transition, contributing to collective expertise for the ecological transition and innovating as well as preparing the future of the ecological transition.

For each of these priorities, ADEME's CSR strategy, designed in 2019, sets a goal for how it should be implemented.

Address: 20 avenue du Grésillé, BP 90406 - 49004 Angers CEDEX 01 - France

Contact: https://www.ademe.fr/contact/

French Soil Science Society (AFES)

The French Soil Science Society (https://www.afes.fr/) brings together all those interested in the various aspects of soil studies. It works to facilitate the exchange of knowledge about soils in order to contribute to the preservation of this natural environment and this fundamental but threatened resource. Its actions are divided into three main areas:

- Promoting knowledge in soil sciences: through the journal Étude et Gestion des Sols and the provision of more than 1200 documentary and educational resources
- Recognizing the soil science skills of experienced experts, teachers and trainers in soil science as well as young researchers.
- Facilitating exchanges between civil society actors and experts by organizing events aimed at various audiences (World Soil Day, Soil Study Days, Network of Research and Participatory Science Project Leaders)

Faced with the profusion of information disseminated in the media, and in a context of strong increases in pressure on soils, Afes, as a learned society, plays an essential role as a direct and reliable channel between research and civil society.

The Association's main goals are:

- To promote the development of Soil Science, in all its fundamental and applied aspects, including in education at all levels;
- To create and strengthen links between the different persons and groups interested in the different branches of Soil Science and its applications;
- To create, develop, maintain and animate relations with similar organizations in Europe and at the international level, in particular with the International Union of Soil Science to which Afes belongs, and within which it represents French soil science specialists;
- To promote the communication of research results, the dissemination and sharing of information related to soil science;
- To promote and popularize soil knowledge among all publics. In particular, Afes strives to raise awareness of soil management and soil protection.

Adress : c/o Inrae, CS 40001 Ardon, F-45075 Orléans cedex 2

Contact : communication@afes.fr

French General Commissariat for Sustainable Development (CGDD)

MINISTÈRE
DE LA TRANSITION
ÉCOLOGIQUE
ET DE LA COHÉSION
DES TERRITOIRES
Liberté
Égalité
Fraternité

The French General Commissariat for Sustainable Development (CGDD) is the data, studies, R&D and strategy department of the Ministry of Ecological Transition and Territorial Cohesion and of the Ministry of Energy Transition. Thanks to its transversal positioning, the CGDD plays an integrating and coordinating role for the Ministries' policies, but also at the interministerial level. Its mission is to promote the integration of the ecological and energy transition within public policies and among socio-economic actors (local authorities and public actors, companies and associations, citizens).

The CGDD coordinates France's implementation of the Agenda 2030 and the 17 sustainable development goals. It leads the environmental dialogue through the National Council for Ecological Transition (CNTE).

The CGDD contributes to the greening of the economy and to the financing of the ecological and energy transition by coordinating the Ministries' economic thinking and by evaluating the consequences of public policies from a sustainable development perspective.

The CGDD promotes the mobilization of research, innovation and expertise for the benefit of ministerial policies, relying on the Ministries' scientific and technical network (INRAe, IGN...). In terms of studies and data, it hosts the ministerial statistical service, which produces and disseminates environmental information.

Having healthy soils so that they can continue to provide vital ecosystem services (carbon storage, natural hazard prevention, food production, etc.) is a crucial issue for the Ministry of Ecological Transition and Territorial Cohesion. Therefore, the CGDD contributed to the creation of the scientific interest group on soils (GIS Sol) in 2001. The GIS Sol carries out inventory and monitoring programs. The French soil quality measurement network (co-financed by CGDD and Ademe) has made it possible to establish indicators on metals and metalloids, organic carbon, persistent organic pollutants, biomass and, finally, microbial diversity.

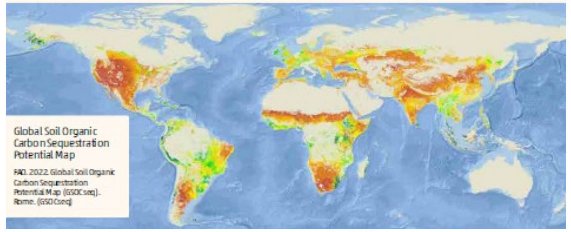
Address : Tour Sequoia, 92055 La Défense – France

Contact : https://www.statistiques.developpement-durable.gouv.fr/contact

Global Soil Parnership (GSP)

GLOBAL SOIL
PARTNERSHIP

The Global Soil Partnership (GSP) of the Food and Agriculture Organization (FAO) is a globally recognized mechanism established in 2012 whose mission is to position soils in the Global Agenda through collective action. Its key objectives are to promote Sustainable Soil Management (SSM) and improve soil governance to guarantee healthy and productive soils, and support the provision of essential ecosystem services towards food security and improved nutrition, climate change adaptation and mitigation, and sustainable development.



Within the framework of the Global Soil Information System – a spatial data infrastructure that connects soil information from national institutions and bolsters their knowledge systems – the GSP has produced a series of soil maps through unique country-led processes. Global maps on soil organic carbon (SOC), SOC sequestration potential, salt-affected soils and black soils have been launched and contribute to an informed decision-making process at country level. This has been made possible by the unique position of the GSP, which operates through regional soil partnerships and national focal points designated by FAO members, thus enabling direct liaison with national soil entities and experts.

The GSP is devoted to creating a robust, diverse, and ever-growing network to promote sustainable soil management and soil governance globally. Since 2012, the GSP's capacity development programme has reached more than 7 000 national experts from over 170 countries.

Address: Viale delle Terme di Caracalla, I-00153 Rome, Room B-708Bis - Italy

Contact: GSP-Secretariat@fao.org

French National Research Institute for Agriculture, Food and Environment

Created on January 1, 2020, the French National Research Institute for Agriculture, Food and Environment (INRAE) is a major player in research and innovation. INRAE carries out targeted research and resulted from the merger of INRA and IRSTEA. It is a community of 12,000 people with 273 research, experimental research, and support units located in 18 regional centres throughout France. INRAE has 14 scientific divisions, each structured around specific disciplines while encouraging interdisciplinarity. Internationally, INRAE is among the top research organisations in the agricultural and food sciences, plant and animal sciences, as well as in ecology and environmental science. It is the world's leading research organisation specialising in agriculture, food and the environment. INRAE's goal is to be a key player in the transitions necessary to address major global challenges. Faced with a growing world population, climate change, resource scarcity, and declining biodiversity, the Institute has a major role to play in building solutions and supporting the necessary acceleration of agricultural, food and environmental transitions.

AgroEcoSystem Division

Head of Division : Thomas Nesme

Presentation of our missions :

- Understand the functioning and evolution of agroecosystems, design and evaluate them at their different scales of organization
- Understand the functioning and evolution of agroecosystems, design and evaluate them at their different scales of organization
- Support the agroecological and digital transition of different forms of agriculture
- Address food and environmental issues in the context of global changes

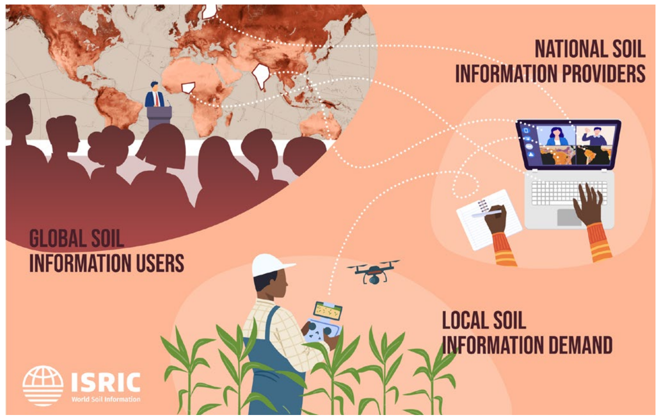
Address: 228 route de l'Aérodrome CS 40509 - 84914 Avignon cedex 9 - France

Contact: dpt-agroecosystem@inrae.fr

ISRIC – World Soil Information

ISRIC – World Soil Information increases the availability and use of soil data, information and knowledge to enable sustainable land management around the world by:

- offering harmonised and quality assessed soil data and information products targeted to the needs of various global users, such as the World Soil Information Service (WoSIS) and SoilGrids
- strengthening national soil information providers through training and a community of practice
- developing information services (e.g., models, apps, websites) in support of sustainable land management decision making, such as the World Overview of Conservation Approaches and Technology (WOCAT) and Land Soil Crop Hubs
- providing education and awareness programs for scientists, policy makers and general interest groups via our World Soil Museum



Website: www.isric.org

Contact: info@isric.org

International Union of Soil Sciences (IUSS)

The International Union of Soil Sciences (IUSS) is the global union of soil scientists since 1924 and a member of the International Science Council.

The objectives of the IUSS are to foster all branches of the soil sciences and their applications and to give support to soil scientists, and those who use or rely on soils, in the pursuit of their activities to enhance knowledge and understanding of soils and the promotion and adoption of best practices and policies based on the current scientific understanding of soils.

The IUSS promotes knowledge of the soil resource in its relationship with the ecosystems that sustain it.

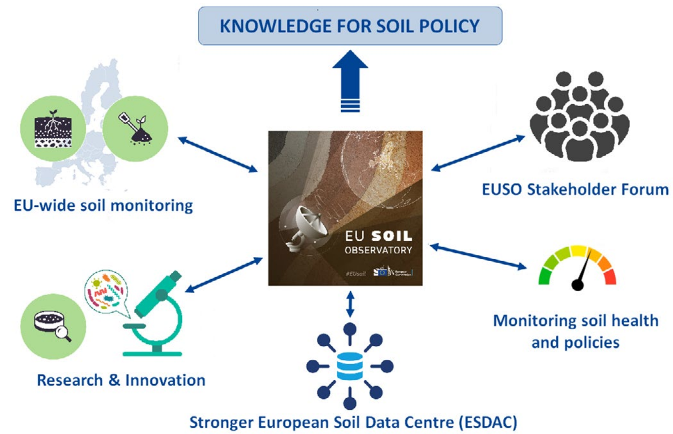
The scientific activities of IUSS are undertaken through four Divisions and each Division has 4 to 6 Commissions and several working groups such as the IUSS Working Groups Digital Soil Mapping & Global Soil Map.

Website: https://www.iuss.org/

Address: Spittelauer Laende 5, 1090 Vienna - Austria

European Commission's Joint Research Centre (JRC)

The European Commission's Joint Research Centre (JRC) brings support to this conference as part of the EU Soil Observatory that was launched in December 2020 in response to the increasing policy interest in soils under the umbrella of the European Green Deal objectives.



Since its creation, the EU Soil Observatory finds itself anchored into a strengthened policy context and a growing attention on the need to protect and enhance soil health. EUSO is expected to play in important role in this new context, to help support and inform the policy agenda on soil, interact with the research activities and raise the public's awareness of the need for soil protection.

Website: https://esdac.jrc.ec.europa.eu/euso

Ambition Research & Development CVL JUNON PROGRAMME

JUNON

CONTEXT & OBJECTIVE

JUNON is an ambitious research programme to develop a digital research cluster on the continental environment (agricultural, urban, forestry and river) in the Centre-Val de Loire region.

This cluster aims to design digital services to improve the monitoring and understanding of the environment, for better management of natural resources.

JUNON is led by BRGM, the French geological survey, (Bureau de Recherches Géologiques et Minières), and involves five research organisations and numerous laboratories (Centre INRAE Val de Loire, CNRS, University of Orléans, University of Tours). It also involves non-academic partners, such as the DREAM water and environment competitiveness cluster, the Agreen Tech Valley cluster, Orléans-Val de Loire Technopôle and LE STUDIUM IAS.

JUNON is a continuation of the ARD 2020 PIVOTS programme, which has promoted the emergence of seven experimental platforms dedicated to monitoring, environmental metrology and remediation of the various anthropised environments (subsoil/soil/water/air).

- JANUSS (Soil/Air)

Air quality and greenhouse gases in the Centre Val de Loire region - synergy of data players for the development of digital twins "agro/ecosystems-atmosphere" interface

- JUNEAU (Water)

Quantitative and qualitative behaviour of La Beauce plain aquifer - Contribution to the elaboration of two digital twins WATER-quantity and WATER-quality on the basis of a common observatory representative of the Beauce plain

- DATA

Collection, storage, exploration, representation and combination of the JUNON programme's data

- DIGITAL TWINS

Interoperability of data and software bricks, design of environmental digital twins as well as their implementation and evaluation.

- PREDICTION

New multi-source and explainable predictive AI models for environmental data analysis and monitoring

Géosciences pour une Terre durable brgm | INRAE | cnrs | Université d'ORLÉANS | université de TOURS | DREAM | FRANCE Water Team

RÉGION CENTRE VAL DE LOIRE | Co-funded by the European Union | ORLÉANS MÉTROPOLE | LE STUDIUM Loire Valley Institute for Advanced Studies | Agreen Tech Valley | Orléans Technopole

French Ministry of Agriculture and Food Sovereignty (MASA)

MINISTÈRE DE L'AGRICULTURE ET DE LA SOUVERAINETÉ ALIMENTAIRE
Liberté Égalité Fraternité

In France, the Ministry of Agriculture and Food Sovereignty (MASA) is the administration in charge of agricultural, fisheries, food and forestry policy. It also organizes education and research in these areas. The Minister of Agriculture participates in the development and implementation of the European Union's Common Agricultural Policy, together with its European counterparts. The Ministry of Agriculture is also strongly involved in France's national strategy for sustainable development.

Examples of MASA soil partnerships:

Gis Sol

- GIS Sol: Scientific Interest Group on Soils, whose mission is to set up and manage the French soil information system in order to meet the demands of public authorities and society. The GIS Soil conduces four major complementary programs: the Inventory, Management and Conservation of Soils (IGCS), the Soil Quality Measurement Network (RMQS), the Soil Analysis Database (BDAT) and the national collection of analyses of Trace Metal Elements (BDETM). (www.gissol.fr)

RNEST Réseau National d'Expertise Scientifique et Technique sur les sols

- RNEST: National Network of Scientific and Technical Expertise on Soils, createdin 2016, in response to the observation that scientific and technical expertise and initiatives on French soils were scattered, this network aims to federate French research, development, and innovation (RDI) stakeholders with soil-related activities (forest, agricultural, urban, industrial fallow land, contaminated sites, natural areas, etc.). The main objectives of this network of soil experts are : to promote interactions and coordination among French RDI actors dealing with soil-related activities, to support public policies and develop a shared understanding of recent public policies concerning soil, to promote knowledge and tool transfer to the users (farmers, political decision-makers, land-use planners, ...) and strengthen the visibility of French scientific and technical expertise related to soils at national and European levels, (iv) to foster the development of collaborative and transdisciplinary work that meets the needs of all stakeholders regarding soil management. (www.rnest.fr)

Website: www.alimagri.fr
Address: Hôtel de Villeroy, No. 78 rue de Varenne 75007 Paris

Orléans Metropole

The Orléans Metropole, seat of the capital of the Centre-Val de Loire Region (2.5 million inhabitants), is made up of 22 municipalities (290,000 inhabitants), and is the focal point for home/work relations within an urban area of over 400,000 inhabitants.

Orléans Métropole is a major player because of its contribution to the definition of :

- land use (role in planning land use via urban planning and the Territorial Coherence Scheme (SCoT), which are compatible with other planning documents: the Local Housing Programme (PLH), the Urban Mobility Plan (PDU), the Commercial Development Document (DAC), etc.);
- the management of the degree of soil sealing (role of development and management of public interest services via sanitation and water in a context of zero net artificialization - ZAN);
- soil quality and productivity (role in protecting and enhancing the environment and the living environment, promoting sustainable agricultural practices via urban agriculture and the emergence of a centre dedicated to agricultural technology companies in Orléans, etc.)
- soil modelling (financial support provided by Orléans Métropole to the digital twins project as part of the ARD JUNON research programme led by BRGM)
- skills linked to digital business (financial support for the IOT School, etc.).

In addition, Orléans is home to a number of key stakeholders working in relation with the water cycle (the Loire Bretagne Water Agency and the Dream Water and Environment competitiveness cluster), and internationally renowned scientific institutions such as BRGM, INRAE, CNRS and the University of Orléans, which offer top-level skills in geoscience, digital technology, mathematics and environmental metrology. Orléans and its surroundings has the particularity of being the French hub for soil (INFO&SOLS database) and subsoil (BRGM databases) data collection.

Furthermore, Orléans Métropole, in conjunction with the Orléans Technopole, supports deeptech companies and project leaders with a 360° service offer. It also supports R&D projects, in line with its innovation skills but also higher education and research.

For all these reasons, the "Soil mapping for a sustainable future" event, scientifically coordinated by the Info&Sols research unit of the INRAE Orléans site, is fully in line with the strategic actions of Orléans Métropole and its ecological transition roadmap. This international event contributes to the international influence of Orléans Métropole, and positions it as the French capital of Earth sciences.

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SCIENTIFIC COMMITTEE

CHAIR

Dominique Arrouays

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Chair of the GlobalSoilMap Working Group of the International Union of Soil Sciences - Past member of the IPCC (Nobel Peace Prize, 2007). Three best papers in Pedometrics (2008, 2010, 2019). Gold medal of the French Academy of Agriculture (2014). Past member of the ITPS of the UN-FAO Global Soil Partnership (2013-2015). Chair of the GLADSOILMAP Consortium. Cited by Food-Tank among the 13 most influential soil scientists from around the globe working to better understand soils and promote practices for maintaining healthy, fertile lands (2017). Top 2% of global researchers (Stanford list). Member of the Editorial boards of: Geoderma, Geoderma Regional, Remote Sensing, Frontiers in Soil Science, Soil Security. Editor-in-Chief of the French Journal of Soil Science. More than 200 referred journal articles. - INRAE, InfoSol, France.

CO-CHAIR

Laura Poggio

ISRIC - World Soil Information - NL

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Chair of the Digital Soil Mapping Working Group of the International Union of Soil Sciences since 2016 - Best paper in Pedometrics (2016) - Member of the editorial boards of: Geoderma, Geoderma Regional. Leader of the world program "SoilGrids" - Laura is working on the development of modelling approaches for new mapped soil products (properties and functions) to support sustainable land management in a changing climate. She is chair of the EGU SSS10: Metric, Informatics, Statistics and Models in Soils. Member of the GLADSOILMAP Consortium. ISRIC - World Soil Information, The Netherlands.

SCIENTIFIC COMMITTEE MEMBERS

Kabindra Adhikari

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Kabindra Adhikari is a soil scientist, and has published more than 50 journal articles related to digital soil mapping (DSM) with an h-index of 22, developed the national DSM products in Denmark for the GlobalSoilMap.net project, actively involved in developing DSM in Nepal. Geoderma best Review Paper awardee 2016, Co-editor of book "Remote Sensing of Soils: Mapping, Monitoring and Measurement" by Elsevier Publications. Associate Editor in Pedometrics, Section of Frontiers in Soil Science, PeerJ, and Agronomy journals, Guest Editor of Special Issue "Recent Advances in Soil Monitoring and Mapping in Agriculture Systems" of Agronomy, Guest Editor of Special Issue "Digital Soil Mapping for Agri-Environmental Management and Sustainability" of Land - USDA - Agricultural Research Service, USA.

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Best Paper in Pedometrics 2019. Dan Yaalon Medal of the best young scientist of the International Union of Soil Sciences 2022. He has published more than 70 journal articles with an h index of 35. Member of the Editorial boards of Geoderma, Associated Editor in Pedometrics Section of Frontiers in Soil Science, Guest Editor of Remote Sensing. - ZJU-Hangzhou Global Scientific and Technological Innovation Center, China.

Subramanian Dharumarajan

ICAR-NBSS&LUP - IN

Email: sdharmag@gmail.com

Senior Scientist is pioneer of digital soil mapping in India. Actively involved in developing digital soil mapping products for India at different levels using novel approaches. He has handled various projects financed by French Natural Research Agency, World Bank, MOEF&CC, Dept. of Space (Govt. of India) and State Planning Commission in various capacities. More than 80 research papers in peer reviewed journals and received various national and international awards such as Indian Council of Agricultural Research (New Delhi)-outstanding scientist award, Indian Association of Soil and Water Conservationists (Dehradun)-young scientist award, Indian Society of Soil Survey and Land Use Planning (Nagpur)-Young scientist award and Endeavour Fellow (Australia). Leader- IndianSoilGrids Working Group, Lead editor of book "Remote Sensing of Soils: Mapping, Monitoring and Measurement" by Elsevier Publications - National Bureau of Soil Survey and Land Use Planning, Bangalore, India.

Gerard Heuvelink

ISRIWageningen University & ISRIC - World Soil Information - NL

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Special professor in Pedometrics and Digital Soil Mapping at Wageningen University (NL), visiting professor of the Chinese Academy of Sciences (Beijing, China). Past chair of the Pedometrics Commission of the IUSS (2003-2006), former president of the Netherlands Soil Science Society (2004-2007). Winner of the best pedometrics paper award in 2006 and 2017. Recipient of the Richard Webster medal of the Pedometrics Commission in 2014 and of the Peter Burrough medal of the International Spatial Accuracy Research Association in 2020. Chair of the Organizing Committee of the 25-th anniversary Pedometrics Conference in Wageningen in 2017. Recognized by the Web of Science Group as a Highly Cited Researcher in 2019 and 2020. Deputy Editor of the European Journal of Soil Science, Editorial Board member of Geoderma, Spatial Statistics, Journal of Integrative Agriculture, and International Journal of Applied Earth Observation and Geoinformation.

Zamir Libohova

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Secretary of the Digital Soil Mapping Working Group of the International Union of Soil Sciences. Chair of the Digital Detection, Interpretation, and Mapping of Soil and Landscape Properties Working Group (S835) and Soil Geomorphology Committee (S835) of the Pedology Division of the ASA-CSSA-Soil Sci Soc. America. Member of the editorial boards of: Agronomy, Frontiers in Soil Science, Geoderma Regional, Remote Sensing. Member of the GLADSOILMAP Consortium - United States Department of Agriculture, ARS, USA.

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Past Chair of the Pedometrics Commission of the International Union of Soil Sciences. Two best papers in Pedometrics (2001 & 2014). Recipient of Richard Webster Medal 2022. Highly cited researcher from 2019 to 2021 (Clarivate Web of Science). Top 2% of global researchers (Stanford list). Australian field leader in Soil Sciences 2020 by The Australian newspaper. Published more than 240 refereed journal articles with an h index of 81. His work has a global impact on the causes and controls of soil carbon and the potential of soil carbon sequestration to mitigate climate change. Editor in Chief of Geoderma. Member of the editorial board of: Geoderma Regional. Member of the GLADSOILMAP Consortium - The University of Sydney, Australia.

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Soil Geography and Landscape group - NL

Email: titia.mulder@wur.nl

Past Chair of the Pedometrics Commission of the International Union of Soil Sciences. Current general board member of the Dutch Soil Science Society. Best paper in Pedometrics (2013). Geoderma best paper (2013). Pedometrics Margaret Oliver Medal (2019). Associate editor European Journal of Soil Science and Frontiers in Soil Science, Editorial board member of Geoderma Regional. Member of the GLADSOILMAP Consortium. Wageningen University, The Netherlands.

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SPEAKERS

SESSION 1: GLOBAL, CONTINENTAL AND COUNTRY REPORTS

SHORT KEYNOTE

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Dr. S. Dharumarajan, Senior Scientist working in National Bureau of Soil Survey and Land Use Planning, Bangalore, India. He is pioneer of digital soil mapping in India and has fourteen years of experience and expertise in the field of digital soil resource mapping and land degradation modelling. He is actively involved in developing digital soil mapping products for the country at different levels using novel approach. He has handled various projects financed by French Natural Research Agency, World Bank, MOEF&CC, Dept. of Space (Govt. of India) and State Planning Commission in various capacities. He has published more than 80 research papers in peer reviewed journals and received various national and international awards. Presently his research is focused on operationalisation of digital soil mapping products and integration of soil data for the wider environmental/earth modelling.

IndianSoilGrids – National level digital soil resource information for sustainable land use planning

IndianSoilGrids project is aimed to map the key GlobalSoilMap soil properties onto a three-dimensional grid at fine spatial resolution with local uncertainty estimates. Legacy soil datasets collected during national soil resource mapping project (1: 250K scale), reconnaissance survey (1: 50K scale), detailed soil survey (1: 10K scale) and SUJALA III project were used as soil input data for DSM models. Additional soil datasets were collected using cHLS method. Standard terrain covariates, satellite imageries and global climate model outputs were used for mapping of different soil properties as per GlobalSoilMap specifications. High resolution soil properties maps (30-250 m resolution) were developed for different parts of the country viz. Karnataka (19.1 M ha), Andhra Pradesh (16.02 M ha), Tamil Nadu (13.0 M.ha), Westernghats (5.0 M ha), Rajasthan (2.9 M ha) Bundelkhand region (7.0 M ha), Vidarbha Region of Maharastra (9.7 M ha) and Bihar (9.4 M ha). The key soil properties predicted are soil depth (R2=30-42%), soil organic carbon stock (R2=7-43%), soil hydraulic properties (R2=24-39%), soil pH (R2=15-42%), cation exchange capacity (R2=5-75%), particle size fractions (sand: R2=41-48%, silt: R2=29-52%, clay: R2=18-39%), coarse fragments (R2=21%) and bulk density (R2=1-36%). High soil variability was captured in Deccan plateau and Westernghats compared to Indogangetic plain. The predicted soil maps are used for preparation of crop suitability, soil and water conservation plan and development of agricultural land use plan. These soil databases could aid the policymakers to take timely decisions for soil resource management, revert the land degradation process and to preserve soil quality by executing suitable land use policies.

TALK

Taciara Zborowski Horst

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MapBiomas Soils: Revealing the spatio-temporal dynamics of soil carbon stocks and their relationships with changes in climate and land cover and use in Brazil

Brazil is one of the countries whose economy is largely dependent on land use, also their main source of greenhouse gas emissions. Still, the country does not have detailed information on how organic carbon stored in their soil varies in space and time. The Soils Working Group (WG), created under the MapBiomas Network in 2021, aims to reveal the spatio-temporal dynamics of soil organic carbon (SOC) stocks in Brazil, and their relationship with main vectors of change, climate and land use and land cover (LULC). Employing field and satellite data, cloud computing, and machine learning, the WG is producing a historical series of maps in the first 30 cm covering the period 1985-2021, with a temporal resolution of one year, and spatial resolution of 30 m. The series was made possible through intense collaboration with public and private organisations, which expanded the availability of open data via the Data Repository of the Brazilian Soil (FEBR). The WG goal is to produce annual updates of this series and its local and global uncertainty measures. To understand the spatio-temporal variation in SOC stocks across Brazil, the modelling framework is defined such as in a factorial experimental design. So far, the temporal dynamic of SOC has been modelled as a function of multiple representations of LULC maps, available for the above mentioned time extension. Once the effects of LULC changes are better understood, studies will begin on how to represent the space-time dynamics of soil management systems and, then, climate variables. In this oral presentation, we will give an overview of the theoretical and technological framework employed to produce those SOC stocks information considering i) a large-scale territory and ii) limited soil data that comes from multiple sources and are unbalanced distributed through space and time. Furthermore, we will show how this framework can be used to reveal the relationship between SOC stocks and LULC change and climate over decades.

TALK

Yusuf Yigini

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FAO-GSP's Capacity Development Programme for bridging the digital divide in digital soil mapping

Building upon the successful launch of four global soil property maps, including the Global Soil Organic Carbon Map, the Global Soil Organic Carbon Sequestration Potential Map, the Global Map of Salt-affected Soils and the Global Black Soil Distribution Map, FAO's Global Soil Partnership (GSP) has perfected its country-driven approach over the years.

This process focuses on leveraging, enhancing and promoting national expertise. Unlike previous top-down global assessments, countries are supported in generating meaningful soil information themselves, ensuring both the sovereignty of national data and the effective bridging of global data gaps.

One hundred twenty-two countries form part of the GSP's International Network of Soil Information Institutions (INSII) and are involved over the entire workflow, from concept development to final endorsement of the global maps. With its global outreach, its direct work with governments, and its consideration of local expertise and needs, the GSP has proven proficient at overcoming soil data gaps and fragmentation in a uniquely participatory way.

To date, the GSP has reached more than 1200 national experts from 120 countries with more than 60 training sessions and supported countries in the production of high quality data products focusing on key soil threats, the potential of soil resources to address the impacts of the climate crisis, and combating food insecurity.

TALK

Suzann Kienast-Brown

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Soil landscapes of the United States (SOLUS): A 21st century raster soil survey inventory

Soils are a critical component of natural systems. Soil knowledge is required to explore and address questions regarding ecological function, climate change, conservation, and land management at any scale. A variety of soil information products are needed to meet the demand and diversity of current environmental challenges. The US National Cooperative Soil Survey (NCSS) is striving to address that need by creating and publishing a range of relevant products. The NCSS Digital Soil Mapping Focus Team has developed a continental-scale 30-m covariate dataset offering users over 200 different terrain and spectral derivatives by watershed and continental mosaic for use in modeling and analysis. The next phase of continental-scale 10-m covariates is underway. The Team has also produced SOLUS100, a set of 100-m resolution key soil property maps for the continental US, and work has begun on a 30-m maps (SOLUS30). These NCSS sanctioned datasets will be publicly available via Google Earth Engine's Data Library. The vision is to incorporate dynamic soil properties with the current set of static soil properties and develop interpretations for use and management from these products. Fundamental pedology and communication of soil knowledge will be the primary focus of this effort, yielding a framework for delivery of seamless raster-based soils data for all areas of the US on annual cycles. This framework will foster an environment of continuous improvement and support a complete, consistent, correct, comprehensive, and current inventory of the soil resources of the US.

TALK

Daniele De Rosa

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Soil organic carbon stocks in European agricultural soils: how much have we lost in the last decade?

The new EU Soil Strategy aims to increase soil organic carbon (SOC) in agricultural land to enhance soil quality as well as to offset the CO2 emissions through soil carbon sequestration Therefore, the quantification of current SOC stocks and the spatial identification of the main drivers of SOC depletion in the EU is paramount in the preparation of agricultural policies aimed at enhancing the resilience of EU agricultural systems. In this context, changes of SOC stocks (Δ-SOC) at pan-EU level between 2009 and 2018 were estimated by fitting a quantile Generalised Additive Model (qGAM) on Δ-SOC data obtained from the revisited points of the Use/Land Cover Area Frame Survey (LUCAS) soil survey performed in the 2009, 2015 and 2018. Point specific edaphic, environmental and land use change information (2009-2018) were used as predictive variables. Following model validation, gridded predictive variables at 500 m resolution were used to estimate total Δ SOC at pan-EU level. The analysis shows that land use and land use change i.e. continued grassland (GGG) or cropland (CCC), from grassland to cropland (GGC or GCC) and vice versa (CGG or CCG) was one of the main drivers of SOC changes. The CCC was the factor that returned the lowest negative influence on Δ-SOC, while the GGG the highest. This confirms the positive C sequestration potential of converting cropland to grassland. In the EU+UK, the estimated current (2018) topsoil (0-20 cm) OC stock in agricultural land below 1000 m a.s.l was 9.3 Gt , with a Δ SOC of -0.75% in the period 2009-2018. The relatively highest estimated SOC losses were concentrated in the central-north EU while marginal losses were observed in the south-east. However, it should be noted that changes in SOC are quite small given the short time interval. Therefore, it is envision that longer term monitoring of SOC will be needed to better assess stock changes trends.

TALK

Antonio Bispo

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Comparison of LUCAS and national Soil Information Monitoring System (SIMS) datasets – Exploring the technical possibilities to support the development of an EU harmonized monitoring system

Soil is crucial for life as it provides us food and fibre, regulates water and climate, and hosts thousands of organisms. A recent assessment states that 60-70% of soils in Europe can be considered as unhealthy due to different soil degradation processes [1]. Soil monitoring is needed to determine the current soil properties, assess the soil status and detect soil changes over time.

Many EU member states implemented Soil Information Monitoring Systems (SIMS) that are quite heterogeneous (sampling scheme, resolution, measurement methods, …) [2]. In 2009, to develop a homogeneous dataset for EU, the European Commission extended the periodic Land Use/Land Cover Area Frame Survey (LUCAS) to sample and analyse the main properties of topsoil in EU. This survey was repeated several times since 2009 and offers a consistent spatial database [3].

Recently the EU Soil strategy for 2030 called for the implementation of an EU Soil Observatory (EUSO) that should become a dynamic and inclusive platform aiming to support policymaking by providing the Commission Services and the broader soil user community with the soil knowledge and data flows needed to safeguard soils [4]. An attractive solution would be to pool all available data at all scales (local, national, European), including monitoring (SIMS, LUCAS) and other data in EUSO to provide a clear and up to date picture of soil status in Europe. This induces the question how to assemble these data from different monitoring systems, developed with different purposes? The first step is a compatibility study to determine whether or not different SIMS could be used together to provide meaningful national statistics and maps.

Within EJP SOIL WP 6, we developed a comparison protocol between LUCAS and SIMS, where we propose a framework to localize the differences between the two datasets. A next step is to produce transfer functions to commonly used LUCAS and SIMS datasets regarding different sampling strategies and measurement methods.

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TALK

Bas Kempen

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Soils4Africa: a continent-wide sampling design for soil assessment and monitoring in Africa

The Soils4Africa project, funded under EU H2020, aims to develop a soil information system that serves information on the prevalence and spatial distribution of soil quality indicators and constraints relevant for sustainable intensification of agriculture in Africa, that can be used as baselines for monitoring changes in soil conditions in the future. This continental SIS for Africa is inspired by LUCAS Soil of the EU.

Soil samples will be collected at 20,000 locations across agricultural land using uniform procedures for fieldwork as well as lab analysis to ensure consistency. Here we present a sampling design for continental assessment of soil conditions of the agricultural land in Africa. The extent, and different types of agricultural land was classified from Copernicus imagery. The resulting 'map of agricultural land' at 100m resolution comprises the target population, which covers 8.8M km2.

From the target population we selected 20,000 sampling units by probability sampling. This allows model-free and unbiased estimation of the parameters of interest of the sample population – or relevant sub-areas thereof such as for land cover types – and their associated uncertainty. The sampling design took into account the following requirements: samples should be composite samples from a small block and sampling locations should be clustered to increase operational efficiency.

We designed a three-stage sampling scheme (Brus, 2022) with stratified (by farming system) random sampling in the first stage, and simple random sampling in the second and third stage. For the first stage, the 100m pixels are clustered into 2x2km blocks. These form the primary sampling units (PSUs), each containing between 1 and 400 agricultural land pixels. 5000 PSUs are selected with probability proportional to the area of agricultural land in the PSU. Within each, 4 100m pixels (secondary sampling units) are selected and within each of these 5x5m block (tertiary sampling unit) will be sampled.

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Laura Poggio

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Mapping of complex soil properties using global legacy data

Digital Soil Mapping (DSM) is an established methodology to create maps of soil properties at different resolutions and over different extents. Many DSM projects across the globe have provided information on primary soil properties, such as soil textural fractions, soil carbon content, cation exchange capacity and soil reaction. DSM can also be used to map complex soil properties, i.e., properties that are difficult to measure directly in the laboratory but that can be derived from primary soil properties by pedotransfer functions. Important examples are available water capacity, soil carbon density and stocks, and erodibility. There are two approaches to map such properties: 1) "model first, interpolate later", where the complex property is calculated at point locations and then mapped; and 2) "interpolate first, model later", where the complex property itself is calculated from interpolated maps of the primary properties. We present and discuss these two approaches for global applications, using legacy data with a non-uniform and biased spatial distribution for training and the SoilGrids workflow. We compare the results for available water capacity of the 0 to 100 cm depth interval and soil carbon densities for six depth layers. There are substantial differences in point-wise evaluation metrics and in landscape patterns, which are larger than the uncertainty quantified by Quantile Regression Forest.

László Pásztor

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Some approaches on linking (bridging gaps between) different (scale) DSM products

Recently, spatial soil information in the form of various DSM products are getting to be more and more widespread. Digital(ly compiled) soil maps are even sometimes used as ancillary information in the elaboration of finer scale ones, which are frequently expected by various stakeholders. However, different (scale) products, their (dis)similarities may cause headache in the application, interpretation by their users. In Hungary, we are also starting to face and try to cope with this type of "problems". In our paper, some approaches will be presented and discussed on linking or bridging gaps between different scale DSM products. The following topics will be shortly touched:

- Initiative on the elaboration of HUNSoilHydroGrids, the 3D Soil Hydraulic Database of Hungary at 100 m resolution as the national realization of EUSoilHydroGrids.
- Initiative on the elaboration of watershed scale, high(er) resolution 3D soil hydraulic databases supported by the implementation of vast, recently digitized legacy soil data.
- A pilot on the downscaling of a national level (GSM comfort, 100 m resolution) SOC map to field scale based on the hyperspectral imagery provided by PRISMA.
- LUCAS Topsoil based recompilation of certain national DSM products formerly elaborated using Hungarian Soil Information and Monitoring System (SIMS) as reference, partly initiated by EJP Soil project to test the joint application of the two types of observation datasets in the production of more harmonized DSM products in Europe.

TALK

Anatol Helfenstein

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Machine learning for mapping soil organic matter changes over 70 years in 3D at 25m resolution in the Netherlands

The Soil Deal for Europe aims to restore the capacity of soils to support ecosystem services. In order to achieve these goals, modelling soil health indicators in space and over time is necessary as a foundation for policies to ensure the sustainable use and protection of this vital resource. We developed and implemented an operational modelling platform in 3D space and over time (3D+T) at 25 m resolution for the Netherlands called "BIS-4D". We used BIS-4D to map soil organic matter (SOM) changes, one of the most important characteristics defining soil health, from 1953-2022. We used over 912'000 SOM field estimates and laboratory measurements from over 343'000 locations for model calibration and prediction, as well as a wide range of 2D, 2D+T and 3D+T environmental covariates. We expected SOM changes to be largely due to land use changes and peat degradation. Therefore, dynamic 2D+T and 3D+T covariates were derived from time series maps of land use and starting depth and thickness of peat horizons. Predictions and their uncertainty were quantified using the Quantile Regression Forest algorithm. 3D+T SOM maps were validated in three ways: a) for 1953-2011 using 10-fold cross-validation; b) specifically for 1993-2000 and 2018, where designed-based statistical inference was possible using a probability sample; and c) at locations that were sampled between 1953-1999 and resampled in 2022. We computed the mean error (ME), root mean squared error (RMSE) and model efficiency coefficient (MEC) as accuracy metrics and the prediction interval coverage probability (PICP) as an evaluation of the prediction uncertainty. Results showed that spatial patterns were realistic and properly reproduced, but that prediction of temporal dynamics was more challenging. Our research may provide insight into future scenarios of SOM changes not only in the Netherlands, but also global hotspots where conversion of peatlands, land reclamation and agricultural intensification is yet to occur.

TALK

Luboš Borůvka

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Transferability of soil spatial prediction models between different regions of the Czech Republic

There are many models used for spatial prediction of soil properties in digital soil mapping. However, they are usually calibrated for the target area and not transferred between regions. It is not convenient particularly for regions that are remote or less accessible. The aim of this study was to test: (i) If models developed in one region can be applied in another region without the need of recalibration; (ii) If the success of model transfer depends on the similarity of the regions; (iii) If it depends on the type of model; (iv) If it depends on the soil property.

Models for spatial prediction of soil organic carbon (SOC) and pH content in soils were developed separately for three different districts of the Czech Republic, namely (i) Rychnov nad Kněžnou on the east of the country, (ii) Liberec on the north, and (iii) Domažlice on the south-west. Available legacy soil data were used, supported by numerous relief parameters (altitude, slope, aspect, horizontal and vertical curvature, contributing area, topographic wetness index, etc.), land use type, and geology. Several model types were applied, including regression trees, random forests, multivariate adaptive regression splines, and artificial neural networks. The models developed for each of the districts were then applied to the other two districts. Model performance was evaluated in each district on a subset of data not used for calibration.

Some transferred models performed pretty well in another district, in some cases even better than other model types calibrated in the target area. The performance of the transferred models depends on their structure, robustness, and also on the similarity of conditions between the regions where they were developed and calibrated and where they were applied. Therefore, the transfer of models between Domažlice and Liberec districts provided better prediction success, as they have more similar conditions, than transfer between Rychnov nad Kněžnou and the other two districts.

TALK

Stirling Roberton

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Demonstrating the use of ANSIS - The Australian National Soil Information System

Soil is our most valuable natural capital asset. In Australia, there is currently a lack of nationally consistent, timely and accessible soil data to support development and management decisions at national, regional, and local levels. This presents a significant problem. In response, the CSIRO is leading an investment with the Australian Government to re-develop our national soil information infrastructure – ANSIS, The Australian National Soil Information System. ANSIS will federate and harmonise disparate soil data sets from private and public data custodians, and will develop the information standards and governance procedures to ensure enduring effectiveness of the infrastructure into the future.

A core component of the ANSIS investment is focused on demonstrating the use of the system – i.e. Demonstrating how different users may engage with the ANSIS infrastructure to develop soil information products which improve the management of the soil resource. Through this process, we will demonstrate the value of soil data collection and harmonisation, along with identifying the power of leveraging discrete datasets with a national system to achieve co-benefits for the individual data custodian and other user groups. Whilst multiple user groups exist, the DSM community is one key user group which will benefit substantially from consistent and harmonised data that has been federated from the private and public sectors.

In this presentation, we will demonstrate how the ANSIS infrastructure may be used to develop soil information products at national, regional and local levels. These will be focused on 1) Mapping soil organic carbon sequestration potential across Australia; 2) A framework which allows for soil state and trend to be identified soil natural capital assessments; and, 3) Approaches which demonstrate how national-level data may be leveraged with local farm-specific data to provide novel insights towards improving the spatial management of the land manager's soil resource.

SHORT TALK

Nicolas Saby

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Bayesian modeling of spatio-temporal trends in soil properties using INLA and SPDE

The assumption of spatial and temporal stationarity does not hold for many ecological and environmental processes. This is particularly the case for many soil processes, often driven by factors such as biological dynamics, climate change and anthropogenic influences. For better understanding and predicting such phenomena, we develop a Bayesian inference framework that combines the integrated nested Laplace approximation (INLA) with the stochastic partial differential equation approach (SPDE). We put focus on modeling complex temporal trends varying through space with an accurate assessment of uncertainties, and on spatio-temporal mapping of processes that are only partially observed through soil variables measurements.

We model observed data through a latent (i.e., unobserved) smooth process whose additive components are endowed with Gaussian process priors. We use the SPDE approach to implement flexible sparse-matrix approximations of the Matérn covariance for spatial fields. The separate specification of the spatially varying linear trend allows us to conduct component-specific statistical inferences (range and variance estimates, standard errors, confidence bounds). For observed data following a Gaussian distribution, we add independent measurement errors. We also include in our model covariate information on parent material, climate and seasonality.

In this work, we used this approach to study possible trends in space and time of several agronomic properties of agricultural soils in France. We used a large dataset, comprising more than 2 million values collected over the French mainland over a 30 years period (1990-2019). This database, called the 'French Soil tests database', gathers soil test results produced by soil test laboratories on the request of farmers. We compared also our results with a more classical spatio-temporal geostatistical model.

Overall, our results demonstrate the high potential for the use of historical data stored in such large databases combined with advanced statistical models.

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SHORT TALK

Alexis Durocher

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Mapping of trace elements contents in French soils using data from the soil quality measurement network

Trace elements (TE) are naturally present in soils and some are considered as essential nutrients for plant growth as well as human and animal health. However, at higher level of concentration, all trace elements become potentially toxic. This work aims to model and explains the spatial variation of the content of a set of TE using digitals soil mapping approaches. The content of the TE are measured using samples collected within the framework of the French soil monitoring network. The total and available content of 11 TEs (As, Hg, Tl, Cd, Co, Cu, Cr, Ni, Pb, Zn, Mo) for 2 depth intervals (0-30 and 30-50 cm) and 2 extractions methods are investigated leading to a total of 32 maps. We compared the quality of the maps produced by three mapping approaches: quantile random forest (QRF), ordinary kriging (OK) and a combination thereof by kriging with external drift (KED) by considering the prediction of the QRF as the drift. We used a set of 116 covariates and also tested the added value of using spatial covariates aiming to represent human activities. The maps are compared in term of model efficiency and the quality of the representation of the prediction uncertainty obtained by cross-validation of the data used to fit the models. We found that the quality of the maps is low whatever the algorithm used. Kriging approaches better predict the content than QRF for most of the cases, as shown by a mean MEC of 0,133 for KED and OK together compared to 0,107for QRF. 12 maps are better predicted by OK indicating a poor correlation with the covariates. Understanding of controlling factors of TE content variation is also discussed for the best KED or QRF maps using Shapley value, method from coalitional game theory (Wadoux et al, 2022).

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SHORT TALK

Giulio Genova

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A global map of solum thickness based on legacy data

The thickness of the soil is a fundamental property for many applications related to agricultural practices (e.g., rootable depth), water management and carbon stocks. The definition of "soil thickness" depends on context and applications. Soil thickness by any definition is not easily measured in situ because of the gradual transitions from pedologic soil to regolith, making it also a challenging variable to reliably map. Legacy data rarely record this valuable information because many surveys are limited to the topsoil only. This creates the problem of right-censored data where most observation do not record the full depth. When thickness is recorded, inconsistencies across datasets may happen due to surveyor's interpretations of horizons and layers designations. Many approaches to model and map soil depth have been used ed, from mechanistic models to empirical-statistical models. In this study we extracted relevant information from the WoSIS database and integrated it with expert-derived information to provide a global map of "solum thickness". We choose the definition of "solum thickness" (I.e. depth of A and B horizons) to try to overcome some of the definitions issues for soil thickness. The observations queried can be reasonably considered as having reached the bottom of the B horizon. Therefore, the problem of right-censored data was limited. The solum thickness was then mapped using Quantile Regression Forest using covariates describing the soil forming factors, following the scorpan approach. Results were assessed with k-fold cross-validation. Initial results are reasonably accurate in areas with high density of observations, while less accurate in regions with a lower density.

SHORT TALK

Lucas Gomes

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Towards the three generations of soil mapping in Denmark and beyond

Denmark has a long history in soil assessment to orient policymakers and farmers, and this knowledge has supported the development of intensive agricultural systems while maintaining the provision of ecosystem services (e.g., clean water). An overview of historic soil surveys and pedologic mapping approaches in Denmark can generate useful information for mapping soil functions, identifying gaps and proposing directions for future research. We identified three generations of soil mapping since 1688. The first Danish land and soil maps were created by farmers, agronomists, and governmental staff using conventional mapping approaches. This method was based on the soil surveyor's knowledge of the local environment. The map units were characterized by polygons, which were determined by manual measurements using special chains in the 17th century, and later topographical maps were used to delineate the different soil classes and properties. The second generation of maps marked a transition from conventional mapping approaches to the use of digital soil mapping (DSM) techniques. This process enabled mapping soil classes using multiple explanatory variables related to soil forming factors. The third generation is characterized by the use and development of DSM techniques to predict soil classes or values of soil properties. During this period, the DSM framework was emerging worldwide, and Denmark contributed to the development of methods and covariates. The soil maps produced in the last two decades helped to improve our knowledge about the spatial distribution of soil properties in Denmark, but also contributed to mapping soil functions such as water regulation, filtering of pollutants, and carbon sequestration. Despite comprehensive knowledge of the soil resources and functions, the Danish politicians still hesitate to take measures to protects the soil resources against loss of carbon, erosion, compaction, and sealing.

SHORT TALK

Budiman Minasny

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Mapping lithium in Australian soils

Lithium (Li) is one of the critical elements in Australia as it is the main element for renewable energy storage. This study aims to map Li content across Australia's soils to understand its spatial distribution to investigate potential areas for future exploration. We used soil samples collected by the National Geochemical Survey of Australia, 1315 sites, top (0–10 cm) and bottom (60–80 cm) catchment outlet sediments. The covariates include spatial layers on climate (rainfall and temperature), parent material (gamma radiometric and magnetic intensity), soil (clay and sand content, bare earth images from Landsat satellite), and topography information. We used the Cubist regression tree algorithm with 50 bootstrap sampling to model the Li distribution across Australia. The models validated on an independent Northern Australia Geochemical Survey dataset, show a good prediction with an RMSE of 3.82 mg/kg for the top depth. The variables of importance in the Cubist model indicated that the first three Landsat bands (of bare earth) and gamma radiometric dose strongly impact Li prediction. The digital soil Li maps shows area with high Li concentration in existing mines and potential new Li exploration areas. This study demonstrates that digital soil mapping framework is advantageous for mapping critical elements.

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From paper to pixels: the history and outlook of soils observations in the US

Soil observations are the foundation of soil mapping. Emphasis is usually placed on the left side of the CLORPT and SCORPAN equations, but experience shows that the quality and quantity of training data representing the right side of those equations is paramount. The United States (US) National Cooperative Soil Survey (NCSS) has an extensive collection of soil observations dating back to the ~1950s, and totalling more than 650K, which were originally collected to develop the US Soil Survey Geographic Database (SSURGO). In the future those same soil observations are expected to provide continuing value to soil survey activities, digital soil mapping, dynamic soil property models, ecological site development, and research. This presentation will give a broad overview of the NCSS soil observation data assets, their future applications, and technical challenges. Efforts are currently underway to collect new data, integrate additional cooperator data, enhance the existing data, and evaluate gaps. Curating such a large and diverse collection of data is a significant workload, which is often underestimated. However, it is a worthwhile investment for conservation planning, farm bill programs, environmental assessment, many other public programs, and ultimately to inform land management decisions.

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Predicting and Mapping Soil pH in Danish Wetlands Using a Random Forest Regression Model

Soil pH is a master variable that controls numerous soil processes, making it essential to understand its spatial variation for stakeholders across scientific disciplines (Ausseil, Chadderton, Gerbeaux, Stephens, & Leathwick, 2011; Roudier et al., 2020; Zhang, Schmidt, Heung, Bulmer, & Knudby, 2022). A mapping application of great interest is the classification of peatlands in which soil pH plays a pivotal role in identifying raised bogs and fens, the former being characterised by acidic soils. This study looks at predicting and mapping soil pH within Danish wetlands. About 9,850 samples were collected at four different depths (0-34, 34-68, 68-102, and 102-136 cm). Topsoil samples (0-34 cm depth) were all analysed in detail, whereas only a few samples from the remaining depths were tested. Therefore, we only used the topsoil samples as input data within the modelling. We also employed 42 environmental covariates covering the spectrum of the 'scorpan' factors at a spatial resolution of 30.4 m across the wetland areas of Denmark (~ 9000 km2). We first carried out variable selection (i.e., Recursive Feature Elimination) and then ran a random forest regression model, which yielded promising results (MSE = 0.43, R2 = 0.50, and RMSE = 0.65), in line with Adhikari et al. (2014)'s national mapping that yielded similar results (R2 = 0.46 and RMSE = 0.61). Hyperparameter tuning using Python's GridSearchCV did not improve the model any further. The most important variables in predicting soil pH include bioclimatic variables, precipitation, elevation and some of its derivatives. Finally, we assessed prediction uncertainty using the 90% prediction interval. Low soil pH areas were underestimated by our model as low soil pH values were under-represented in our soil dataset.

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SHORT TALK

Sylwia Pindral

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Mapping soil organic carbon stocks in mineral soils in Poland

The state of the world's soil resources is that about 33% of the world's soil is moderately or heavily degraded in the contour of erosion, salinity, compaction, acidification, and contamination. The presented losses influence not only production but also relate to soil carbon storage, the provision of macro- and micronutrients to plants, and water storage in soils. In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development. This study indicates that soil is the world's largest terrestrial carbon reservoir and a resource that supplies 95% of the world's food, therefore sustainable soil management is a key to adapting to climate change, protecting biodiversity, and providing a wide range of ecosystem services. One of the most important soil condition indicators is the soil organic carbon content (SOC).

SOC is a key indicator of soil quality and fertility, and reporting its loss is a requirement that must be met by the Member States of the European Union. In Poland, more than half of the soils are made of sands, with a low colloidal clay concentration, threatened by acidification, therefore the increase in the content of organic carbon in such soils may be a challenge for Polish agriculture.

The study aims to present the carbon stocks in agricultural mineral soils in Poland. We used the national dataset (n> 30,000) of soil organic carbon (SOC) in the top 20 cm layer. The content of SOC does not exceed 6%. The data from the monitoring of soil properties on carbon 2020 by IUNG-PIB with the cooperation of the Ministry of Agriculture and Rural Development and the National Chemical and Agricultural Station and the Regional Chemical and Agricultural Stations. The digital map was generated from the data collected by IUNG-PIB under various programs. We used the method of GWR - Geographically Weighted Regression commonly used in spatial analyses. This geostatistical method was used to create the national map of bulk density and soil organic carbon content. The organic carbon stock was calculated according to the method adopted by Zeng et al., 2021; Khan and Chiti 2022. The presentation of preliminary data shows that in the mineral layer 0-20 cm used for agricultural purposes there are almost 600 million tons of organic carbon, which accounts for approximately 1% of the resources of the European Union member states.

SHORT TALK

Nicolas Saby

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Pathways to improve national soil property maps by harmonizing national and European soil reference datasets

Digital Soil Mapping (DSM) employs statistical techniques to predict soil property continuously in space (and time) at unobserved locations, using measurement of this property (reference data) at a finite number of sampling locations. Since the 2000's, the European Commission and the Joint Research Center developed DSM maps over Europe, using datasets from the LUCAS Topsoil program as reference data. In parallel, most of European countries developed comprehensive national soil surveys and soil monitoring systems (SMS) in order to produce their own reference data for the production of national DSM maps.

The objective of this work is to develop a DSM framework that could take advantage of both reference data from LUCAS and national SMS to develop harmonized soil information at the European scale for improved decision making at the national scale. In this study, we tested several options:

- combine national and European reference data in one statistical model using common EU-wide covariates,
- produce two separate inference models for the national and European reference data and combine the predictions in a final step using simple mean or more complex approach taking into account the quality of the maps,
- Sampling optimizing of the reference data used for model inference by feature space coverage sampling of both reference datasets.

To compare the different products, we validate the predictions using a 10-fold cross validation iterated 20 times. We tested these approaches to map topsoil pHH2O in France, Italy and Hungary as pilot tests. Preliminary results indicate that the best outcome for each country requires a tailor-made approach, based on the quantity and quality of available national reference data and assessment scale.

This work supports the achievement of the objectives of the EJP Soil Project, the development of an EU-wide, but country-driven soil mapping to produce thematic soil maps for common variables available in the LUCAS Soil Inventory and SMSs.

SHORT TALK

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Comparison and harmonization of LUCAS topsoil database with the Hungarian National
Soil Information System from two different years

An interesting challenge has been addressed in the European Joint Programme Cofound on Agricultural Soil Management regarding the harmonization of national soil databases with the continental LUCAS topsoil database for the purpose of monitoring soil carbon, fertility and land degradation. Since soil survey at national scale is very cost- and labour intensive, the compilation of more accurate soil maps relies more and more on combining existing datasets to improve the poor spatial resolution of up-to-date soil surveys. While the LUCAS topsoil database is considered up-to-date, it leaves a lot to be desired at national-scale. Using the LUCAS topsoil database to complement the Hungarian Soil Information and Monitoring System (SIMS) is an option to create more detailed soil-property maps. The different sampling strategies and laboratory analysis methods required the data to be converted, so the two datasets can be directly compared to each other, and later used together for digital soil mapping. To achieve the best results and comparison, two sets of topsoil data were used from 2009 and 2015 from both LUCAS and SIMS respectively. This way, swiftly changing soil properties (pH, CaCO3, OC, P, K) were available for a more accurate side-by-side comparison of the two datasets. We created maps for the soil properties mentioned above of both the LUCAS and SIMS database with the ancillary data of 28 environmental covariates using random forest kriging with 10-fold cross-validation. The spatial resolution of the maps was 100 x 100 m. The rasters were then compared directly to each other using linear regression. The results let us to conclude that the LUCAS and national soil databases can and should be harmonized, merged and used together for creating more accurate soil maps at national and continental scale.

SESSION 2: CASE STUDIES

TALK

Philippe Lagacherie

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Exploring the contribution of farmers to local digital soil mapping

In spite of their fine resolution, the Digital Soil Mapping (DSM) products that are now available at global or national scale do not provide accurate representations of the local soil patterns as required by the end-users acting at local level (Lemercier et al, 2022). A local Digital Soil mapping approach that would model separately the local soil variations within smaller areas (watersheds, municipalities) should be preferable. However, this approach requires investments in quantitative spatial soil sampling that are most often inaccessible for a local user. As an alternative, we explored in this study the possibility of using the soil knowledge of the local farmers (Richelle et al, 2018) for applying local DSM approaches. The approach was applied in the Gopalapura village (Karnataka, India).

Elicitation of the soil knowledge of the farmers had two steps. First a local soil typology was co-built by a group of 27 farmers and the soil surveyors following the approach described in Lagacherie et al, (2021). Second the farmers were asked to locate each soil type within the area of interest. The output was a set of sites labelled with a soil type. This new farmer soil data was compared with a very detailed (1/12,500) soil map. This allowed to evaluate the ability of farmer soil data to discriminate and further map three qualitative soil properties (textural class, gravel class, and soil map). Finally, a DSM model was built to map the farmer soil types over the Gopalapura village territory

The results showed good to moderate agreements between soil survey and farmer soil information according to soil properties. Beyond the expected increase of performance of soil properties predictions, it is also expected that using the farmers' soil knowledge in DSM approaches will contribute to a better appropriation of the developed DSM products.

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TALK

Mark Philip Philipsen

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Peat Mapping with Heterogeneous Features and Graph Neural Networks

Depending on their state and use, peatlands may either release or sequester significant amounts of carbon. Current estimates of the condition and extent of peatlands are subject to a high degree of uncertainty [1]. To ensure an effective and targeted effort in preserving and restoring peatlands, detailed, accurate, and up-to-date models of peatlands are needed.

The best models are achieved through a mix of available data sources, whether in situ, proximal, or remote measurements [1]. The main challenge in building models, that incorporate data from different sources, is fusing data with varying availability and density such that it can be ingested by point-based models such as Random Forest or grid-based models such as Convolutional Neural Networks. We propose to bypass this problem by connecting each measurement in a graph, retaining the original resolution and density. By utilising Graph Neural Networks (GNNs), features are efficiently aggregated spatially through neighbouring nodes in the graph. The flexibility of Heterogeneous GNNs, in particular, makes the model robust to missing modalities or holes in the graph. We demonstrate our method for a 10-ha field located in Jutland, Denmark, modelling peat depth with data from multiple geophysical sensors, remote sensing modalities, and maps.

The benefits of the method include: (1) Faithful spatial aggregation of features, (2) arbitrary output resolution due to the graph existing in a continuous space, (3) no need for laborious, error prone, and inefficient interpolation of feature maps.

So far, GNNs have seen extremely limited use in soil mapping. One example is its use for modelling soil moisture by capturing the important spatio-temporal correlations that influence soil moisture levels [2]. We are excited about future improvements to our method and its application to more study areas and nation scale models.

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SHORT TALK

Giulio Genova

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Digital soil mapping with covariates at different resolution for Mongolia

Digital Soil Mapping (DSM) establishes a statistical relationship between the measured values at point observations and environmental covariates selected to describe the soil forming factors and to explain the spatial variability of the soil properties. These relationships are then used to map the target soil properties across the area of interest. In this study, we used 1423 measurements on soil organic carbon and pH for the 0-20 cm soil layer from a Mongolian soil survey organised within the framework of the "National Program to Combat Desertification" to determine the primary soil quality indicators for desertification assessment in Mongolia. It was conducted based on the state network of the Meteorological and Environmental Research Agency starting in 2012. The samples are collected from 1500 monitoring points every 5 years.

We used data from the monitoring round between 2012 and 2015, and two sets of covariates for modelling predictive relationships. The first is the set used in SoilGrids at 250 m resolution with over 400 layers available of which about 180 were used for the modelling, after de-correlation. The second is a reduced set of about 40 covariates at 100 m resolution derived mainly from Sentinel 1 and 2 images, ERA5 for climate data and ALOS for morphological information. In this study we compared the results of the two models, with both point-wise evaluation matrices based on k-fold cross-validation and assessment of spatial patterns. Performance of the two models was rather similar with a slightly more accurate predictions by the model using the 100 m covariates set. The spatial patterns were different at national level and the 100m covariates set also displayed more details in some regions.

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Comparative analysis of multiple linear regression and random forest models for the predictive mapping of peat thickness across management zones in the raised bog of Store Vildmose

Peatlands are important ecosystems for regulating carbon (C) fluxes between land and the atmosphere. However, their human-driven degradation, stemming from agriculture, weakens the C storage function on one hand and amplifies greenhouse gas (GHG) emissions on the other. Coupling peatland degradation with changing climate is expected to further enhance the GHG emissions in the future (Harenda, Lamentowicz, Samson, & Chojnicki, 2018). In Denmark, concerted efforts are underway to conserve and restore peatlands. This necessitates establishing accurate inventories of the physicochemical properties of peat such as the thickness, C content, and bulk density for C stock estimation. In view of this, we mapped the peat thickness of Store Vildmose - a 345-ha drained Danish peatland. The study area was stratified into three management zones (MZs) based on the variability in the digital elevation model (DEM). An unsupervised clustering algorithm (ISO Cluster) was used to differentiate shallow, intermediate, and thick peat areas (MZs). Relevant environmental predictors on topography and proximal geophysical sensing data were employed for the predictive peat thickness mapping. The two statistical modelling methods applied per MZs were multiple linear regression (MLR) and random forest (RF), to assess the linear and nonlinear relationships between covariates and the target variable (peat thickness), respectively. Our findings show that the MLR model performed poorly in the shallowest MZ where the peat had been intensively extracted. However, the RF models proved more efficient in estimating peat thickness across MZs than the MLR models based on the comparatively lower error metrics and higher R2 values obtained. In the future, we aim to improve predictions in shallow peat areas by investigating potentially relevant predictors that were not used.

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A case study in Brazil of how the digital soil mapping products can be efficiently applied in-situ

The civilisation lives in a world of maps and soil maps are vital at regional and farm levels to achieve best management agricultural practices (BMAP)(Hartemink et al., 2013). However, most of the available soil maps are scarce at those cartographic scale, which for BMAP have to be the most detailed as possible. Therefore, the objectives of this study were to (i) present the potentiality of using the digital soil mapping (DSM) products such as soil chemical and physical attributes, indices, mineralogy, and properties to extrapolate previous soil survey maps at 1:20000 scale; (ii) show the use of DSM products on yield environment for sugarcane; and (iii) prove qualitatively that the extrapolated soil maps using DSM products have a fair relationship with previous research in the region of interest (ROI). The ROI covers almost 2,598 km2, São Paulo state, Brazil. The soil survey at farm level conducted covered almost 86.52 km2, which is ~3.33% of the total area (96.67% of the unmapped area). Thus, we created a point grid (centroid) with 30 m spatial resolution, which was the same as the DSM products used. Such grid intended to retrieve the representative soil mapping unit of each geometric polygon. It was retrieved 117,413 points representing twenty-seven soil mapping units (SMU) of seven soil orders at a first categorical level according to the Brazilian Classification System (Santos et al., 2018) and seven yield environment for sugarcane production (Demattê and Demattê, 2009). The prediction of the SMU were performed using the random forest machine learning regression method (Breiman, 2001). The level of association between the SMU and yield environments was 0.34 ($p<0.01$) by the Cramer's V coefficient displaying a very strong relationship. The qualitatively evaluation of the extrapolated soil maps and relationship with previous research in the study area proved that DSM products can be efficiently used for field application based on this case study in Brazil.

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SHORT TALK

Ruhollah Taghizadeh-Mehrjardi

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Spatial extrapolation of soil information in different environmental conditions

Data-driven machine learning (ML) models became a promising alternative in soil mapping. However, the generalization ability of ML models between different environments has been debated. With only training data from a reference area, ML models tend to produce weak results in terms of generalizability. To overcome this drawback, we proposed the use of a semi-supervised learning approach for extrapolating soil information from the reference to target areas. We further evaluated the ability of the semi-supervised learning (SSL) approach compared to a supervised learning (SL) approach for extrapolating soil classes in different environmental conditions. Technically, SSL used soil observations from the reference area together with covariates from reference and target areas. Our results demonstrate the superiority of SSL over SL for generating soil information in the target areas. These findings allude that leveraging covariate information from the target area during training of the SSL models in the reference area could successfully improve the generalization capabilities of the models. Furthermore, we acknowledged lower accuracy and higher uncertainty of spatial extrapolation (SSL) compared to spatial interpolation (SL) in the target area. This indicated the impossibility of matching soil-forming factors between reference and target areas.

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SHORT TALK

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Self-supervised learning of Vision Transformers for digital soil mapping in arid lands

In arid environments, prospecting cultivable land is carried out under difficult climatic conditions over vast areas that are difficult to access. However, the soil is often bare, with little vegetation cover, making it easier to observe from the air. Remote sensing techniques offer to explore vast and difficult to access areas at lower cost. Deep learning in particular has expanded remote sensing analysis, first with convolutional networks and more recently with vision transformers (ViT, Dosovitskiy et al. 2020).

The main drawback of deep learning methods is their reliance on large labeled datasets, which are often lacking in drylands. However, recent studies demonstrate that ViTs can be trained in a self-supervised manner to take advantage of large amounts of unlabeled data to pre-train models, as shown with DINO (Caron et al. 2021) or MAE (He et al. 2021). These models can then be finetuned to learn a supervised classifier with few labeled data, or used directly as visual feature extractors for unsupervised tasks.

In our study, we trained ViTs in a self-supervised way with tilled satellite images of a dryland area of 9,500 km² at a resolution of 336m² in Saudi Arabia. The resulting models are used to extract features describing the bare soil to group patches into unsupervised clusters and predict variables describing the soil (cover, pH, XRF).

The generated clusters are currently compared to 662 soil samples along a kilometer grid to evaluate the quality of the obtained features with respect to chemical (pH) and mineralogical (XRF) soil properties. So far, our implementation correlates well with expert assessed land cover. Preliminary analysis shows promising results concerning pH prediction. XRF is still in computation.

Using our method, we plan to automatically generate a clustered map of an area. This first automated spatial analysis could be used by experts to design a sampling strategy and optimize field work in difficult to access areas.

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SHORT TALK

Yue Zhou

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High-resolution soil organic carbon mapping at the field scale in Southern Belgium (Wallonia)

Accurate soil organic carbon content estimation is critical as a proxy for carbon sequestration, and as one of the indicators for soil health (Lal, 2015; Wiesmeier et al., 2018; Smith et al., 2007). Meanwhile, soil property maps are increasingly becoming available because of digital soil mapping (DSM) initiatives throughout the world (Minasny and McBratney, 2016; Arrouays et al., 2017; Chen et al., 2022). Such maps with broad geographic extent highlight patterns of soil properties such as SOC and are useful for assisting decision making at national and regional scales. Nevertheless, they do not provide enough detail for farmers in order to allow them to restore their most degraded soils or to be used in the framework of carbon accounting (Malone et al., 2017, 2018).

Here, we collected 497 soil samples during 2015 and 2019, as well as five environmental covariates (organic carbon (OC) input from the crops, normalized difference vegetation index (NDVI), elevation, clay content and precipitation) at a resolution of 30 m. We then aggregated these to represent agricultural fields and compiled a soil organic carbon (SOC) content map for the agricultural soils of Wallonia using Gradient Boosting Machine (Friedman, 2001). We calculated OC input from both main crops and cover crops for each individual field. As the cover crops do not occur in the agricultural census, we identified cover crops based on long time-series of NDVI values obtained from the Google Earth Engine platform. The quality of the SOC predictions was assessed by validation data and we obtained an R2 of 0.77. The Empirical Mode Decomposition (Huang, 1998) indicated that OC input from crop residues and NDVI were the dominant factors at field scale, whereas the remaining covariates (Climate, topography and soil texture) determined the distribution of SOC at the scale of the entire Walloon region.

The SOC map showed an overall northwest to southeast trend i.e. an increase in SOC contents up to the Ourthe river followed by a decrease further to the South. The map shows both regional trends in SOC and effects of differences in land use and/or management (including crop rotation and frequency of cover crops) between individual fields. The field-scale map can be used as a benchmark and reference to farmers and agencies in maintaining SOC contents at an appropriate level and optimizing decisions for sustainable land use.

SESSION 3: COVARIATES & REMOTE SENSING

TALK

Emmanuelle Vaudour

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Satellite-based spectral approaches to map topsoil organic carbon content for croplands: overview of past approaches and hot topics

About 60 satellite-based spectral approaches for soil organic carbon (SOC) assessment have been achieved from several satellite sensors, study scales and geographical contexts in the past decade (Vaudour et al., 2022). Most of them relied on pure spectral models derived under bare soil conditions and have been carried out for temperate annual cropping systems in Europe, China and North America at the scale of small regions, of some hundreds of km2 since 2019. Dry combustion and wet oxidation were the analytical determination methods used for 50% and 35% of the satellite-derived SOC studies, for which measured topsoil SOC contents, with a SOC value of ~15 g.kg−1 and a range of 30 g.kg−1 in median, mainly referred to mineral soils, typically Cambisols and Luvisols and, to a lesser extent, Regosols, Leptosols, Stagnosols and Chernozems. Most satellite-derived SOC spectral prediction models used limited pre-processing and were based on bare soil pixel retrieval after NDVI thresholding. About 1/3 of these models used partial least squares regression, while another third used random forest, and the remaining included other machine learning methods. The accuracy that is yielded through multispectral satellites such as Sentinel-2 can be considered a valuable trade-off compared to hyperspectral airborne acquisitions.

The capability to detect SOC changes that are likely to occur due to agricultural management is key for implementing satellite-derived approaches. i.e., for defining the adequate bracket of prediction accuracy and uncertainties. The issues that need to be addressed refer to the adequacy of approaches according to agroecosystems and soil cultivation methods, in accordance with adequate analytical methods, sampling methods and sampling sizes. Hot topics include considering temporal mosaicking, testing/mitigating the influence of possible disturbing factors and achieving all-performance evaluations and uncertainty analysis of spatial model predictions.

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Modelling and interpreting variations in soil organic carbon content at regional extent using deep learning with a combination of remotely sensed and laboratory spectral data

While many studies have compared the use of proximal or remote sensing spectroscopy for soil mapping in distinctive models [e.g., 1, 2], very few have attempted to bridge the two sources of spectral data for instance to model soil organic carbon (SOC) content [e.g., 3-4]. The present study aimed at assessing the predictive power of a deep learning algorithm called Convolutional Neural Networks (CNNs) for SOC content mapping using fused proximal and remote sensing spectral data for the Skjern river catchment located in Denmark. Although relatively small (c. 2,500 km2), the selected catchment area has been densely surveyed over the years (approx. 2,550 existing topsoil observations). Laboratory visible-near infrared (Vis-NIR) spectra and Sentinel-2 (S2) images, topography and climate data were compiled to be employed as predictors. Environmental covariates being available at two different resolutions (i.e., 10 m and 30.4 m) enabled evaluating the influence of resolution on CNN predictive results, both in terms of accuracy and interpretation. The selected CNN models were analysed using a model-agnostic interpretation technique (i.e., SHAP), yielding crucial information for further use of the predictive maps. The most accurate CNN model based on 10-m resolution data performed better than the model based on coarser resolution (lower RMSE and higher R2). This finding confirmed the CNN model generalized better from finer resolution data (extracting more spatial contextual information). The three covariates displaying the largest SHAP contributions were the first principal component calculated from topsoil Vis-NIR spectra (for both CNN models), a layer originating from S2 data and a topography layer (band 4 and elevation for 30.4-m based model, NDVI and MRVBF for 10-m based model). These first interpretation results underlined the importance of combining spectral data from proximal and remote sensing sources.

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The application of multiple digital soil mapping techniques within the framework of geomorphology and soil data correlation

The United States National Cooperative Soil Survey program has been investigating and inventorying soils for over 100 years. Over this period, the development of conceptual soil-geomorphic-climate relationships through an extensive process of soil data correlation has been established as a foundational framework for soil survey. As cooperative soil survey efforts continue across the US, digital soil mapping techniques are now being integrated within this framework.

This research demonstrates the application of digital soil mapping techniques within the framework of data-supported conceptual soil-geomorphic-climate relationships and soil data correlation techniques for updating a soil map within the 5504 km2 Upper Rio Puerco watershed in northern New Mexico, USA. This was a multi-stage effort that involved several key topics in digital soil mapping including: 1) legacy pedon data capture and harmonization, 2) initial soil class modelling, 3) uncertainty-guided field sampling, 4) soil-geomorphic-climate correlation to produce a robust legend of soil classes, and 5) final remodelling of soil classes with all observations. We also introduce strategies for observational data augmentation to address class imbalance, and strategies for modelling multiple sub-areas and joining predictions into a seamless product.

TALK

Virginia Estévez

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Improving prediction accuracy for acid sulfate soil mapping by means of variable selection

Acid sulfate soils can cause environmental damage and geotechnical problems, making them one of the most harmful soils existing in nature. In order to reduce possible damage derived from this type of soil, it is fundamental to create occurrence maps showing their localization. Nowadays, occurrence maps can be created using machine learning techniques. The accuracy of the maps depends on two factors: the dataset and the machine learning method. Previously, different machine learning methods have been evaluated for acid sulfate soil mapping [1]. In order to improve the precision of the acid sulfate soil probability maps, in this study, we have added more environmental covariates (17 in total) to the raster dataset and applied eleven variable selection methods to select the most relevant environmental covariates for the classification and prediction of acid sulfate soils. The predictive abilities of each group of selected variables have been analyzed using Random Forest and Gradient Boosting. From the best results obtained, an acid sulfate soils occurrence map has been created. Compared with previous studies in the same area, variable selection has improved the accuracy by 15-17% for the models based on Random Forest. The present study confirms the importance of variable selection for the prediction of acid sulfate soils.

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TALK

Anders Bjørn Møller

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The potential of satellite time series, bare soil composites and erosion models to map soils at high resolution

In the last few decades, satellite images have become increasingly detailed and available. Many studies have used the valuable data provided by the images for mapping soil properties, but two main issues have hindered the realization of their full potential. Firstly, when plants cover the soil, researchers must rely on the vegetation as a proxy for soil variation. Secondly, in areas with intensive agriculture, human land use decisions and management often overshadow the effect of the soil on the vegetation. To overcome these issues, a series of studies have combined satellite images of intermittently bare soils into composites to provide coherent images. Other studies have used time series of satellite images to gain information on plant responses to soil conditions over time. However, only few studies have integrated these two sources of information. This study therefore aimed to assess their respective and combined uses to map soil organic matter (SOM) and texture for Denmark at 10 m resolution, based on 45,000 topsoil observations. We also included layers of parent materials, topographic variables, spatial position and erosion model outputs.

We used a bare soil composite based on all available Sentinel 2 images for Denmark. We also obtained a time series of vegetated images for the drought year 2018, for which we expected a maximum impact from soil variation. The results showed that the bare soil composite was especially important for mapping SOM, clay and silt (2 – 20 µm). The vegetated images were mainly important for models to predict intermediate texture fractions (20 – 200 µm). However, they also contributed to the predictions for SOM and coarse sand. In all cases, the inclusion of the satellite products improved the overall accuracy compared to previous Danish soil maps. The relative improvements were even larger at field scale, as the satellite products provided a much better ability to account for intra-field soil variation.

SHORT TALK

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Extraction of the stable component of electrical surveys of soils and the consequence on the mapping of their thicknesses

The objective of this study was to present a geostatistical approach called automatic factorial cokriging (AFACK), which allows capturing the time-invariant part between the spatio-temporal measurements of a signal, called stable component in the sequel. The stable component achieved by AFACK was then used as a covariate in a multivariate estimation algorithm to map a static soil property pattern. The underlying idea was to highlight that the spatial estimates of a static soil property pattern is well achieved by integrating, in a multivariate estimation algorithm, the stable component over the time of a covariate instead of its single acquisitions. Through three surveys of soil resistivity measurements carried out on three dates on the soil of an agricultural plot, results revealed that the time-stable component of the electrical signal is better linked to the thickness of soil (ST). In addition, the mapping of ST by collocated cokriging (CC), using any stable component between two or more electrical resistivity surveys carried out by AFACK, leaded to an invariable map of ST, unlike the maps achieved by CC using, as covariate, soil electrical surveys considered individually. Statistical indicators resulting from leave-one-out cross-validation (LOOCV) showed that CC using any invariant part of the signal outperforms CC using the single acquisitions. Correlation coefficient (r), mean absolute error (MAE) and root mean square error (RMSE) values range between 0.93 and 0.94; 4.33 and 5.03; 0.75 and 0.88, respectively, for estimates using as a covariate an invariant part of the signal. While values of these statistical indicators range between 0.64 and 0.74; 7.20 and 8.69; 1.25 and 1.52, respectively, for estimates by CC using single acquisitions. Values of these indicators are almost invariant regardless of the invariant part used in CC, unlike the scenario using the surveys individually.

SHORT TALK

Emmanuelle Vaudour

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Assessing the capability of Sentinel-2 time-series to estimate soil organic carbon and clay content at local scale in croplands

The use of remote sensing data methods is not only promising but also, whenever relying on freely available time series such as Sentinel-2 (S2), affordable for the mapping of soil properties of the ploughed layer over croplands for the implementation of "carbon farming" approaches. Carried out in the framework of the ongoing STEROPES project of the European Joint H2020 Program SOIL, this work is focused on the feasibility of S2 based approaches for the detailed mapping of topsoil clay and organic carbon (OC) contents at the local scale, for cropland sites of contrasted climate and soil types. Four pixelwise temporal mosaicking methods, using a two years-S2 time series and several spectral indices (NDVI, NBR2, BSI, S2WI), were developed and compared for i) pure bare soil condition, ii) driest soil condition, iii) average bare soil condition (Median) and iv) dry soil conditions excluding extreme reflectance values (R90). Three spectral modeling approaches, using the S2 bands of the output temporal mosaics as covariates, were tested and compared: i) Quantile Regression Forest (QRF); ii) QRF adding longitude and latitude as covariates (QRFxy); iii) Linear Mixed Effect Model (LMEM), that includes spatial autocorrelation of the soil properties. We tested pairs of mosaic and spectral approaches on ten sites in Türkiye, Italy, Lithuania, and USA where soil samples were collected and OC and clay content were measured in the lab. The average RPIQ of the best performances among the test sites was 2.50 both for OC (RMSE=0.15%) and clay (RMSE=3.3%). Both accuracy level and uncertainty were mainly influenced by site characteristics of cloud frequency, soil and soil management. Generally, the models including a spatial component (QRFxy and LMEM) were the best performing, while the best spatial mosaicking approaches mostly were Median and R90. The most frequent optimal combination of mosaicking and model type was Median and QRFxy for OC, and R90and LMEM for clay estimation.

SHORT TALK

Baptiste Girault

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Construction of crop successions using Land Parcel Identification System (LPIS) data in France from 2007 to 2020

The use of machine learning considerably increased in recent years, mainly due to advances in computing power and an easier access to it. At the same time, open data policies at European level enabled an easier access to many data sources (Southworth 2021).

Notably, thanks to the Copernicus satellite imagery programme, a wide range of land use mapping applications have been developed. In this context, access to quality data is essential to properly train and evaluate machine learning algorithms (Gounari et al., 2022). This allows robust and generalizable predictors to be applied over large areas.

At the European level, the combination of spatial imagery data (Sentinel) with data from the Land Parcel Identification System (LPIS; within the framework of the Common Agricultural Policy, CAP) is increasingly being used to map agricultural land use (Dobrinić et al., 2021; Orynbaikizy et al., 2020; Blickensdörfer et al., 2022). The use of these data in the training and evaluation of algorithms is decisive for the efficiency and generalization of the predictors obtained (Blickensdörfer et al., 2022). The research unit INRAE-SADAPT (French National Institute for Agriculture, Food and Environment) provides annual data on crop filiation and sequence at islet and parcel level for 2007-2014 and 2015-2020, respectively. These data are constructed from the information in the LPIS within the framework of the CAP using the RPG Explorer software (Levavasseur et al., 2016). They provide access to rich information, both temporally and spatially, on the whole of France's agricultural rotation. Our work presents the datasets of crop sequences produced from 2007 to 2020 at an islet/parcel level, and aims to validate or identify new uses of these data with respect to digital soil mapping, and make a possible generalization at the European level.

SHORT TALK

Yin-Chung Huang

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Using pXRF and Vis-NIR as an interpretable model to predict soil properties in podzolic soils of subtropical forest

To build a reliable map with acceptable uncertainty, sample collection and soil property determination are often the first step in digital soil mapping (DSM). With the progress of proximal sensing and digital soil morphometrics, data acquisition can rely on sensors such as portable X-ray fluorescence spectrometry (pXRF) and visible and near infrared spectrometer (Vis-NIR). However, most models failed to address the links between pedogenesis and sensor signals, and an interpretable model can certainly be much more robust for the application of DSM. This study investigated the possibility of establishing a model with interpretability regarding pedogenesis and soil components. Ten podzolic soils with 54 horizons in total were sampled and performed for the model. All horizons were subjected to the analysis of pH, clay, organic carbon, Alo+0.5Feo, pXRF, and Vis-NIR. Principal component analysis (PCA) was used to extract variances and reduce dimensions. The first and second components of pXRF in the PCA are related to the distribution of sesquioxides and organic matter, respectively. In addition, these components can be used to separate soil horizons by k-means (overall accuracy = 56%, kappa coefficient = 0.39). Regarding Vis-NIR, the first and second components are related to organic matter and sesquioxides, while over 90% of the variation are explained by PC1. Moreover, k-means with Vis-NIR principal components achieve a better result with an overall accuracy of 65% and a kappa coefficient of 0.53. Combining the principal components of pXRF and Vis-NIR, a multivariate regression model with explainable variables is established.

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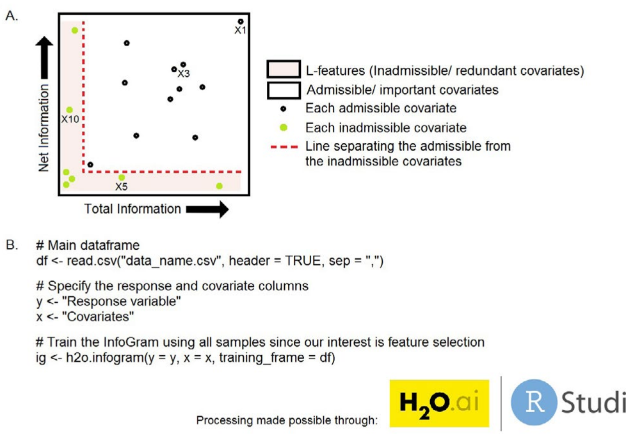
InfoGram: An interpretable covariate selection graphical tool for soil classification-related problems

Covariate or feature selection is one of the most important phases of most supervised machine learning pipelines. Recent studies demonstrate the benefits of leveraging covariate selection methods for optimal modeling and eventually promising digital soil mapping (DSM) products. Nonetheless, the results of many covariate selection methods are not easily interpretable and usually, most of these methods cannot handle covariate multi-dimensionality and inter-correlations. We, therefore, propose a novel InfoGram graphical tool as a type of covariate selection method based on information theory for soil classification-related problems. Applied to three soil datasets, the InfoGram appears promising based on its simple and easy-to-understand outputs. Hence, it warrants further investigation and application for soil-based supervised classification problems. Applying such a method is expected to enhance through visualization and interpretability the selection of relevant covariates for the development of superior models.



Schematic showing how covariates are selected based on the (A) InfoGram plot and the (B) code snippet used to execute the InfoGram function in the software R based on H2O.ai [Note: The admissible section of the plot is where all the useful covariates occur while all covariates in the red section are redundant (the so-called L-features)]

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Mapping Peat Thickness Using a Portable Gamma-Ray Sensor

Peatlands being excellent storage for terrestrial Carbon (C) play a crucial role in regulating climate and water and provide several important ecosystem services. Over the years, peatlands are heavily altered particularly by draining the water table for meeting energy and agricultural needs. This led to increased release of greenhouse gases (GHGs) into the atmosphere and dissolved C loss contaminating potable water. Climate change concerns have sparked interest in reducing the emission of GHGs from drained and degraded peatlands to counteract global warming. Comprehensive characterization of peat inventory providing details on the spatial extent, thickness, and water table depth is required to estimate the C stocks – for climate budgeting, improved land use planning and deciding appropriate management strategies. The conventional handheld probing for peat depth (PD) determination is labour-intensive and provides only localized and discrete measurements. Besides, these measurements can be inaccurate at times necessitating the evaluation of rapid alternative methods. Gamma-ray radiometric in general showed promise for delineating the spatial extent of peatlands. However, the use of this technique for estimating PD remains questionable as earlier studies made use of readily available airborne datasets of a coarser resolution. With technological advances, portable gamma-ray spectrometers that can provide on-the-go measurements of radionuclide concentrations are finding new applications in soil mapping. Given this, here, we explored the suitability of such a gamma-ray sensor for mapping PD at a highly variable (0 – 7.3 m) peatland area in Denmark. Further, we tested the suitability of different processing methods and evaluated the support extended by the readily available terrain attributes. Our results suggest that gamma-ray sensing can stand alone potentially predict the PD down to 4 m, beyond which other covariates can supplement in improving the prediction accuracy.

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Predicting top-soil chemical parameters on field scale based on various proximal sensing datasets

There is a demand for up-to-date detailed spatial information on soil physical and chemical parameters, especially on field scale. Proximal sensing methods provide wide range of non-destructive data with sub-meter spatial resolution which can be used as environmental co-variates in Digital Soil Mapping predictions of those soil parameters. In our study a nearly 25 ha, slightly sloping agricultural plot was surveyed with various geophysical tools, as well as a drone based hyperspectral sensor providing the spectral characters and the Digital Elevation Model (DEM) of the plot. Evenly distributed field samples were also collected in 86 locations across the plot. The resulting co-variates datasets: 126 spectral bands, DEM together with its 10 topographic derivatives and 18 rasterized, interpolated geophysical measurements were tested independently and in all possible combinations. During the evaluation process the Random Forest based Ranger model was used and optimized through Caret package on the 70% percent of the observation data while other part was used for testing. For model assessment correlation (R2), centred Root Mean Squared Error and comparison to observed standard deviation were used via Taylor-diagrams. Acceptable results (R2 > 0.5) were achieved on plasticity index and P2O5 content based on co-variate set containing all measured data and spectral data alone, respectively. Very good results (R2 > 0.85) were performed on pH using spectral and geophysical co-variates together and on Soil Organic Material content based on joint spectral and DEM layers.

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Bare soil imagery to support soil mapping on national scale

Soil maps are indispensable for an adequate evaluation of soil quality and soil related ecosystem services and thus to allow sustainable soil management. In Switzerland, existing soil maps are limited with respect to spatial coverage and scale, while attempts to update legacy soil data using recent Digital Soil Mapping (DSM) techniques are rare. There is a clear need for detailed and area covering soil maps on national scale. This study is framed by a DSM approach addressing topsoil organic carbon (soc) and clay. The data base consists of legacy soil data combined with multi-scale covariates for terrain, land use, and climate. The focus of the study lies on investigating spectral bare soil data as an additional data source. The use of bare soil images, derived from multi-temporal satellite imagery has been shown to be supportive for DSM. However, their large scale application is limited since bare soil cannot be detected on constantly vegetated surfaces such as grass- and woodland. Two objectives are addressed: First, genuine bare soil pixels are evaluated as additive DSM covariates. Second, synthetic bare soil images are predicted for the entire area and evaluated as additive covariates for DSM models referring to crop-, grass-, and woodland. Genuine bare soil composites were processed by aggregating non vegetated pixels from each Landsat image throughout a time span of 35 years. Synthetic bare soil images are based on a DSM like model setup using genuine bare soil pixels and DSM covariates. Predictive models for soil and synthetic bare soil were built using Random Forest and evaluated by independent and 10-fold cross validation. The use of genuine bare soil data for the DSM model results in an increase of R2 by 15% for soc and 10% for clay. DSM models using synthetic bare soil data show an increase in R2 by 8% (soc) and 3% (clay) for cropland. DSM performance for grass-, and woodland is not influenced by additional bare soil data

SESSION 4: SAMPLING, VALIDATION & UNCERTAINTY

KEYNOTE

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Gerard Heuvelink is a senior pedometrician with ISRIC – World Soil Information and a special professor in Pedometrics and Digital Soil Mapping of Wageningen University. He chaired the Pedometrics Commission of the IUSS from 2003 to 2006 and was president of the Netherlands Soil Science Society from 2004 to 2007. He received the Richard Webster medal for the best body of work that advanced pedometrics in 2014 and chaired the Organising Committee of the 25-th anniversary Pedometrics Conference in Wageningen in 2017. He has published over 175 articles in the international scientific literature and was recognized by the Web of Science Group as a Highly Cited Researcher in 2019, 2020 and 2022, with more than 9,700 citations. Gerard is also a Deputy Editor of the European Journal of Soil Science.

Accounting for measurement errors in calibration and validation of DSM models

It is good DSM practice to quantify the uncertainty of map predictions. While there are many causes of map uncertainty, such as the fact that covariates cannot explain all spatial variation of soil properties, that DSM models may not exploit all information provided by covariates, and that the sample size of the soil calibration data may be too small to accurately estimate model parameters and interpolate model residuals, an often ignored uncertainty source is that the calibration data themselves have measurement errors. Most digital soil mappers assume that these data are perfect. But we know that field and laboratory errors can be large, and that errors are amplified if proximal soil sensing is used instead of wet chemistry analysis. In this presentation I show how measurement errors in calibration data can be quantified and accounted for in DSM. Errors in the geographic position of soil data, such as prominent in soil legacy data, can be treated in a similar way. These positional errors are increasingly important because we use covariates at ever increasing spatial resolution. Measurement errors also affect statistical validation of soil maps. When we compute validation metrics by comparison of map predictions with independent observations we usually assume that the observations are perfect, but we know this is not true. Ascribing all differences between predictions and observations to prediction errors does injustice to the DSM model. We must and can correct for that.

TALK

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Informative probabilistic maps of soil nutrient levels

Geostatistical and machine learning methodologies are increasingly used to produce maps of the expected values of soil properties such as nutrient levels. These maps can inform farm and landscape management decisions but interviews with farmers and land managers reveal that the risk of soil properties being above, or below, critical thresholds is often of more interest than the expected value. The estimation of risk requires the uncertainty regarding spatial predictions of soil properties to be accurately quantified. Geostatistical models and machine learning techniques such as quantile random forests, quantify uncertainty in quite different ways. With geostatistical models the uncertainty is likely to be controlled by the local sampling density and the magnitude of the local expected value of the soil property. In contrast, for quantile random forests the uncertainty is a complex function of the covariates that are used within the algorithm. There is potential for quantile random forests to automatically identify regions where uncertainty is high based on landscape properties (i.e. covariate values) within that region. Such high uncertainty regions are unlikely to appear in geostatistical maps because they are inconsistent with the stationarity assumption of these models. We explore these issues with reference to broad-scale soils data from Malawi and the UK. We produce and validate risk maps for soil nutrient levels. The exact specifications of these maps are informed by interviews with Malawian land managers and standard UK fertiliser recommendations. We compare and contrast the usefulness of maps produced by geostatistical and machine learning methodology particularly focussing on the quantification of uncertainty and risk and consider the best ways in which to present the information contained in the maps.

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The effect of uncertain calibration and validation soil data on the prediction accuracy of pedotransfer functions

There is a growing demand for high-quality, inexpensive soil data to model soil processes and to map soil properties. Soil properties that are considered difficult to measure are frequently determined through pedotransfer functions (PTFs). Calibration and validation wet chemistry datasets are needed to build PTFs. However, these wet chemistry soil data are prone to measurement errors. In this contribution, we studied how measurement error in wet chemistry calibration and validation soil data affects PTF predictions and associated prediction uncertainty.

We developed PTFs to predict cation-exchange capacity (CEC), using data from the National Cooperative Soil Survey Soil Characterization (NCSS-SC) Database. CEC PTFs were fitted for the A and B horizons of Alfisols, Andisols, Mollisols and Vertisols in the United States of America. We developed PTFs through traditional multiple linear regression and modern random forest methods. Unfortunately, the NCSS-SC Database did not include repeated measurements of the same sample, which are needed to quantify measurement error1. Hence, proficiency testing scheme data from the Wageningen Evaluating Programmes for Analytical Laboratories (WEPAL) was used to obtain a best estimate of measurement error in CEC data.

The PTFs were fitted with and without accounting for measurement error in the calibration data to determine the effect on the PTF's prediction accuracy. Measurement error in the validation data was accounted for by incorporating the measurement error variance in the validation metrics2.

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Improving cross-validation of soil maps in case of clustered calibration data

The best way to assess soil map accuracy is through comparison of map predictions with independent observations obtained using probability sampling, so that design-based statistical inference can be used. However, in practice probability samples are often not available and digital soil mappers turn to cross-validation instead. Conventional cross-validation works well in case of non-clustered calibration data but it produces optimistically biased estimates of the map accuracy when the calibration data are spatially clustered. Spatial cross-validation aims to tackle this over-optimism but it starts from the wrong premise that spatial proximity of calibration points and validation points should be avoided at all times. It therefore leads to overpessimistic estimates of the soil map accuracy. In this presentation we describe and evaluate two alternative cross-validation methods for assessing soil map accuracy. The first uses inverse sampling-intensity weighting to correct for selection bias, where sampling-intensity is estimated by a two-dimensional kernel approach. The second methods takes a model-based approach. It develops a geostatistical model of the map errors, uses spatial stochastic simulation to generate error realisations across the entire study area and computes the map accuracy metrics from them. The methods were tested and compared against conventional k-fold cross-validation and spatial cross-validation to estimate

accuracy metrics of soil organic carbon stock maps covering western Europe. Results acquired for five sampling designs ranging from non-clustered to strongly clustered showed that the inverse sampling-intensity weighting and model-based method had smaller bias than conventional and spatial cross-validation for all but the most strongly clustered design. For the strongly clustered design, where large portions of the maps were predicted by extrapolation, spatial cross-validation was closest to the reference map accuracy metrics, but still biased.

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The effect of sampling density, grid resolution, modelling, and their interactions on accuracy predictions of soil properties

High resolution soil maps of soils and properties are needed for zone management applications like precision agriculture at field scales, and to support land evaluation and environmental assessments. The prediction accuracy of soil maps depends on multiple factors such as quality and quantity of soil data (i.e., availability of georeferenced points with measured properties, sampling design, availability of remotely sensed data, etc.), topography, and prediction models. Evaluating the influence of all factors and their interactions on the accuracy predictions requires a combination of georeferenced locations with measured soil property values collected from multiple topographic conditions based on different sampling designs. Such data sets are not always available due to constraints from limited budgets and access. Purdue University has multiple research centers throughout Indiana located in different topographic conditions and with available georeferenced points with measured soil properties and different sampling designs. The objective of this study is to assess the influence of sampling design and density, topography, digital elevation model resolution (DEM) and models and their interactions on prediction accuracies of soil organic matter (SOM) and cation exchange capacity (CEC), that are important for soil health and fertility. We present some preliminary results evaluating the performance of DSM using standard evaluation parameters like coefficient of determination (R2), root mean square error (RMSE), mean absolute error (MAE) and V-measure at Agronomy Center for Research and Education (ACRE). We discuss some of the findings and implications for sampling designs, topography, modelling, and their interactions.

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Impact of small scale variability on validation of spatial predictions of soil properties

Detailed soil maps are a prerequisite for soil management and the execution of soil related laws. In Switzerland, only for 16 % of its territory suitable soil maps are available. To fill this tremendous information gap digital soil mapping is currently implemented to increase mapping efficiency.

Needed level of map accuracy in terms of e.g. R2, RMSE or width of prediction intervals is, however, still an ongoing discussion. So far, map validation is carried out on point support although decisions are taken on areal entities of different extents. In addition, large small scale geological heterogeneity is typical for the Swiss soil forming conditions and contributes to base noise in point support validation.

One of our pilot study areas of 1000 hectares near Berne encompasses Quaternary glacial tills mixed with Molasse outcrops resulting in considerable small scale variation of soil formation. 1750 locations were sampled for model calibration. Additionally, 150 validation samples were determined by stratified random sampling to allow for unbiased estimation of accuracy statistics. Spatial predictions were computed for a 2 m pixel resolution which corresponds to the largest available resolution of covariates derived from the elevation model.

To evaluate the soil variability within one map pixel, i.e. under the same soil forming factors represented in the model, we sampled 5 additional sites within 1 m of 30 validation locations. This allowed to change from point to 2x2 m area support and to assess impact of small scale soil variability on accuracy measures based on point support. Quantification of local variances provided a first estimate of base noise introduced into point support validations. Map accuracy evaluation by end-users can be put into perspective with inaccuracies introduced by natural small scale variability. As a next step variability of soil surveyor descriptions and measurement errors will be considered as an additional source of base noise in accuracy measures.

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Composition of field-scale hydrological soil maps from sources of different data quality

Pluvial floods are a rising issue due to urban spreading and climate change. To enable soil-based consideration of pluvial flood risk and susceptibility in infrastructure planning and designing, high-resolution maps of hydrological soil properties are needed. The most relevant soil properties for pluvial flood risk predictions are the dominant runoff processes, water storage capacities and runoff coefficients, each for different scenarios of precipitation, land-use and initial soil moisture state. In a district of Austria, Upper Austria, such maps are developed from widely available environmental information by a combination of different data processing and regionalization methods.

In Austria, as in many other European countries, soil data are available in different resolution, quality and age for different land-use types. Four main land-use classes may be distinguished; agricultural land, forests, alpine and urban areas. While for agricultural soils multiple federal mapping and monitoring approaches are providing an adequate data base, information on forest soils is rare. Nevertheless, even in agricultural soils, hydrological soil properties are not mapped directly. In this project, pedotransfer functions (PTF) are developed for agricultural soils by machine learning approaches and evaluated together with established PTFs. For soils in forested and unforested alpine regions, a DSM regionalization approach is developed based on climatic, topography and geological predictor maps. In contrast, the hydrology of urban areas is mainly determined by the degree of imperviousness which may be derived from official land survey services and remote sensing.

The resulting pre-classifications for the different land-use classes are used as inputs for a final processing step which combines and harmonizes the mapped properties in high-resolution raster layers for the whole area of the district. Furthermore, maps are produced for different soil layers and the integrated soil profile.

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Impact of mapping methods on soil organic carbon estimations for varying surface areas, sampling densities, soils and environmental conditions: A global analysis

One of the most important challenges of digital mapping of soil properties lies in the accuracy of the mapping techniques. Numerous independent studies have been performed on the prediction accuracy of different mapping methods, yet little is known about their variations in accuracy due not only to the surface area considered and the density but also due to environmental factors and soil properties. The objective of this study was to evaluate the impact of mapping methods (G: Geostatistical, BI: Basic Interpolation, S&ML: Statistical and Machine learning, and RS: Remote sensing) on prediction errors (i.e. MAE: mean absolute error for accuracy and ME: mean error, bias) of soil carbon stocks (SOCs) for varying surface areas (A), sampling densities (SD), SOCs levels, soil depth (Zd), mean annual precipitation (MAP), mean annual temperature (MAT) and climate regions. Data from 37 studies worldwide with surface areas ranging from 0.03 to 85,000,000 km² and sampling densities ranging from 0.0003 to 1168 data points per km2 were considered. The findings showed that S&ML performed the best as its mean accuracy was 47 % and predictions were unbiased at 48.7 % followed by hybrid (70 %) with a bias of 52.2 %, BI (146 %) with a bias of 0.17 %, and G (134 %) methods with a bias of 72.8 %. The largest surface areas were the most accurate and unbiased predictions, and this was a surprising result. The highest prediction quality was obtained at the highest but also the lowest sampling densities. There is a general decrease in the mapping accuracy as SOCs and soil depth increase. Moreover, a decrease in accuracy from polar to tropical was correlated with a continuous accuracy decrease as MAP and MAT increased. Overall, MEp and MAEp showed a significant negative correlation with SOCs (r = -0.32; -0.18), while having a significant positive correlation with MAP (r = 0.30; 0.31). We found no significant association between the prediction errors and the other soil and environmental factors. These quantitative results may contribute to the improvement of soil organic C mapping for modelling methods in various soils and environmental conditions, and in turn improve pedology knowledge.

SHORT TALK

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Modelling multiple soil properties with multivariate random forest

In digital soil mapping (DSM) soil maps are usually produced in a univariate manner, and therefore, when multiple soil properties are mapped the underlying correlation structure between these soil properties is ignored. This may lead to inconsistent predictions and simulations. For example, soil organic carbon and total nitrogen maps produced independently may show unrealistic carbon-nitrogen ratios (Heuvelink, et al., 2016). In the last decade the production of soil maps with machine learning models has become increasingly popular as these models are able to capture complex non-linear relationships between soil properties and environmental covariates. However, producing soil maps with multivariate machine learning models is still lacking and requires much investigation in DSM. In this paper we present the combined mapping of multiple soil properties with a multivariate random forest model (Segal & Xiao, 2011). We applied this model to mapping soil organic carbon and total nitrogen, and we compared it with results of two separate univariate random forest models. The comparison was done by means of stochastic simulations determined by sampling from the conditional distributions of the soil properties, given the covariates, as estimated by quantile regression forest (Meinshausen, 2006). The results show that the multivariate random forest model is superior in terms of maintaining the dependence structure between carbon and nitrogen, and consequently, is also able to produce more realistic carbon-nitrogen ratios. The models were also compared based on prediction accuracy. We found that the accuracy of the multivariate random forest model is comparable to that of the univariate random forest models. We also performed a similar comparison between a regression co-kriging model and two separate regression kriging models.

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SESSION 5: PEDOLOGICAL KNOWLEDGE AND DSM

KEYNOTE

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Laura main interests are in pedometrics and digital soil mapping, how to develop new covariates from remote sensing products and how to integrate soil data in the wider context of environmental modelling. Laura is working on the development of modelling approaches for new mapped soil products (properties and functions) to support sustainable land management in a changing climate. Reproducible research and the use of open source tools for spatial analysis are key components of the methodological development. She has a PhD in Soil Science and worked is spatial modelling since 2008. She was chair of the IUSS Working Group in DSM since 2016. She is chair of the EGU SSS10: Metric, Informatics, Statistics and Models in Soils. She is member of the editorial boards of Geoderma and Geoderma regional. One of her papers won the Best paper in Pedometrics award in 2016.

Including pedological knowledge in DSM: models, maps and evaluation. Is the missing element?

The commonly-used scorpan approach to Digital Soil Mapping is purely correlative, between observations at points and the values of covariates at those points. Four main components are normally included in a scorpan-based exercise: 1. point observations, 2. covariates, 3. model, and 4. evaluation.

An-often-used approach is of maximum complexity: different quality observations are thrown together with the largest possible number of covariates, along with the most complex model (e.g., ensembles of many models). The resulting products are almost always evaluated with point-wise metrics with sometimes not large differences or improvement between models. Spatial patterns are rarely compared with soil geography. Often global models are used for local interpretations. Most of the currently-applied models (statistical, machine learning, artificial intelligence) have similar performances when evaluated point-wise. Further work should be done to include more the local and spatial structure component, the 'n = neighbourhood' of scorpan. To do this it seems that what is often missing is the expertise of the soil scientist, both the pedologist (soil formation) and soil geographer (how soils are distributed on the landscape).

How can the knowledge of a soil scientist be systematically incorporated into the scorpan approach? Would this really improve DSM products, making them both more accurate at points and closer to soilscape patterns? This talk will address how pedological knowledge could be included in each of the four components and the potential advantages and disadvantages of doing so. Can soil scientists provide sufficiently accurate expert estimation of soil properties at un-measured locations? How can we integrate soil geographer's understanding of the landscape and its evolution, pedogenesis and soil geomorphology? How can we select and create covariates that represent the soil forming factors as such, not just correlations with these? Can soil experts help with uncertainty estimates and product evaluation? Can the expertise of soil geographers be included in comparison of products and recommendation for the most suitable, given defined user needs ?

Budiman Minasny

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Assessing soil organic carbon change using pedogenon sampling and digital soil mapping

Soil carbon is central to planetary health; however our continuous injudicious use of soil for cropping has depleted its stock, yet there is a lack of an approach that can map how much carbon in the soil has been lost and what is its sequestration potential. He we use the concept of pedogenons to identify soil groups that are formed from the same soil-forming factors. We surveyed the lower Namoi Valley area, NSW, Australia (1700 km2), representing 13 pedogenons. Within each pedogenon, we sampled regions that are still under native vegetation and areas under cropping. The observations of soil organic carbon were mapped at every 10 cm depth interval up to 1m to produce SOC under natural condition and under agricultural. By comparing the two SOC maps, we assessed soil carbon change and potential SOC sequestration.

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Beyond prediction: interpreting complex models of soil variation

The field of digital soil mapping has recently shifted attention towards the use of complex statistical and algorithmic tools from the field of machine learning. These models are particularly useful for their predictive capabilities and are often more accurate than classical statistical models, but they lack interpretability, and their functioning cannot be readily visualized. In this presentation I will examine the opportunity to obtaining scientific explanation from these flexible data-driven models and algorithmic strategies, in particular machine learning. Then I will discuss ways to evaluate complex models of soil variation and provide an overview of how model-independent methods can serve the purpose of interpreting and visualizing differentiable aspects of a soil model. The presentation will be illustrated with the interpretation of a complex soil model for large-scale organic carbon mapping.

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Exploring the relationship between soil organic carbon sequestration potential and clay activity in Australia

Clay is an important component of soils that interacts with and protects soil organic carbon (SOC) via the formation of organo-mineral compounds. The SOC/clay ratio has been proposed as a simple index to assess how carbon-saturated a soil is, with a lower value indicating a degraded soil that can potentially capture a large amount of carbon. However, not all clays are created equal, and their reactivity play an important role on their capacity to protect SOC. Using continental scale SOC, clay and cation exchange capacity (CEC) digital soil maps of Australia, we explore this relationship for different land uses and climates. As a result, we are able to estimate the maximum sequestration potential possible for croplands, comparing it with out estimates of maximum technical sequestration potential, generating maps at the continental scale.

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Integrating Machine Learning and Knowledge-Based Soil Inference Classification in the White Mountain National Forest, USA

Soil survey activities in the Northeast United States have been successfully employing digital soil mapping methods for many years. Continued innovation in soil inventory processes supports NRCS initiatives such as ecological site inventory and dynamic soil survey. The 12-STJ Soil Survey Office is using methodology that combines machine learning and knowledge-based classification for soil mapping. Previous projects have employed an almost entirely knowledge-based approach to soil mapping, but there are steps in the process that benefit from incorporating other proven digital soil mapping techniques in order to enhance soil inventory on all lands. The White Mountain National Forest soil survey project has been progressing since 2010, with pedon observation data collected to support NRCS and partner goals, in addition to piecemeal acquisition of LiDAR that necessitated an evolving mapping methodology. To complete the soil survey, existing pedon data is used to train random forest models, the results of which are used as a starting point for iterative knowledge-based soil inference. The variable importance metrics of the random forests algorithm serve to objectively narrow the number of environmental covariates utilized, improving the consistency of the modeling process. Data splitting is employed to allocate training and test data from existing pedon observations, and the refined covariate sets may be incorporated in a conditioned Latin hypercube sampling design to provide sample points for model refinements in unmapped areas. Local soil scientists' expert knowledge is used to set aside data that best represent target mapping classes, and these data are used for case-based soil inference using ArcSIE, the results of which are used to refine the final predictions. The combination of machine learning and knowledge-based approaches is expected to improve model performance and classification results, as well as provide a foundation for future projects in the area.

SHORT TALK

Jessica Philippe

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The Importance of Soil-Landscape Knowledge in Digital Soil Mapping to Drive Innovation of Soil Information Products

Digital soil mapping is the prediction of spatially explicit information about soil types or properties using the quantitative relationship between observations made in the field or laboratory and environmental raster data. This quantitative approach to soil mapping requires pedologic knowledge about soil-landscape relationships to be successful. The USDA-NRCS Soil and Plant Science Division has adopted digital soil mapping as a rigorous approach to soil mapping for both soil type and continuous soil properties at local, regional, and national scales. The success of digital soil mapping in the US Soil Survey Program has required development of a framework to support this work including training, standards, project support, and products. All soil and ecological scientists in the Soil and Plant Science Division are expected to have a minimum working knowledge of digital soil mapping to complement their authoritative soil-landscape knowledge and fully participate in the daily activities of soil survey. Digital soil mapping provides innovative methods to combine invaluable existing data and critical soil-landscape knowledge into the generation of relevant raster-based soil information products to meet a variety of existing and emerging needs for a diverse audience of users.

SESSION 6: DIGITAL ASSESSMENT OF SOIL FUNCTIONS AND SERVICES

LONG ORAL PRESENTATION

Alexandre Wadoux

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Mapping the function store of carbon for the five dimensions of soil security

The soil security concept has been recently put forward to maintain and improve soil resources inter alia to provide food, clean water, climate change mitigation and adaptation, and to protect ecosystems. We recently proposed a provisional quantitative framework which suggests indicators for each of the soil security dimensions –condition, capacity, connectivity, capital and codification– for a set of functions, services, and threats to soil. In this study, we report on the first continental quantitative assessment and mapping of the six dimensions of soil security for the function 'soil as a carbon store'. A total of four indicators representing the soil's current condition and capacity are estimated and mapped for the Australian continent: genosoil soil organic carbon (SOC) content, mineral associated organic carbon in the fine fraction, SOC content and SOC:clay ratio. These are complemented with maps of credit carbon market price (capital), stakeholder's perception of the importance of maintaining soil carbon storage using participatory surveys (connectivity) and local and international directives on carbon storage regulation (codification). These maps provide the first spatial evaluation of a single function across the five dimensions of soil security for continental Australia. They will serve as a basis to estimate a local index of Australia's soil resilience to the threat of decarbonisation.

Tiffany Allen

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Sampling Design for a Dynamic Soil Survey in the Coweeta Watershed Basin, USA

Dynamic Soil Survey is a new and evolving approach in the USDA-NRCS Soil and Plant Science Division that incorporates temporal soil properties into soil survey. Dynamic Soil Survey combines recent advances and long-standing knowledge in pedology, ecology, and hydrology with improvements in digital technology that allow the dissemination of real-time information to planners and land managers to help choose the best conservation or management practices. Successful implementation of Dynamic Soil Survey relies heavily on collaboration within the National Cooperative Soil Survey (NCSS). The NCSS Program is a partnership of Federal land management agencies, State agricultural experiment stations, universities, private-sector organizations, counties, conservation districts, and other special-purpose districts, and provides a mechanism to engage partners and stakeholders to ensure meets the needs of customers to address existing and emerging resource concerns. A Dynamic Soil Survey project has been established at the Coweeta Hydrologic Laboratory in partnership with the United States Forest Service to generate updated soil maps using digital soil mapping methods and collect temporal soil properties affected by soil biology and land use management. The updated soil survey explored different sampling design techniques including grid sampling, spatial coverage sampling, AHELS, and weighted stratification based on management zones to support digital soil mapping activities. The weighted stratification method was chosen based on comprehensive representation of covariate distribution and management zones. This field sampling scheme was used to support sampling for map development, dynamic soil sampling protocols, and implementing a long-range soil moisture monitoring study. The next steps in the Coweeta project will maximize the interaction of the ecosystem through ecological state and transition models and facilitate the linkage of local climate station data to advance Dynamic Soil Survey. In addition, it will serve as a model for how to leverage resources and expertise to accomplish the goal of providing more dynamic products to meet the needs of users.

Pierre Baert

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Assessing the 3D distribution of SOC by integrating advanced erosion models as co-variates in a DSM-approach – a case study of a Silt Loam cropland soil (Belgium)

Although agricultural intensification since the green revolution has increased crop yields, it also resulted in a range of environmental issues, including increased erosion rates and declined soil organic carbon (SOC) stocks. Recent studies in the context of climate change are fuelling the debate on whether the current high rate of erosion induces a source or sink of C. In order to improve our understand on how erosion impacts the overall SOC storage capacity of croplands, this study analyses the 3D distribution of SOC as a function of water and tillage erosion in a conventionally cultivated field in the Belgian silty loam region. This study highlights the importance of using a DEM at appropriate resolution in order to allow the integration of an advanced erosion model as a co-variate within a DSM approach with the objective to create detailed SOC maps. More precisely, we have been combining (i) the WaTEM/SEDEM model, predicting both soil loss and sedimentation due to water and tillage, with (ii) a soil sampling campaign, resulting in a SOC spatial distribution model as function of both types of erosion. The results show that tillage erosion has a significant influence on the SOC stocks in the top 70 cm, which is particularly strong in the top 40 cm, whereas the influence of water erosion is less strong but mostly significant along the entire profile. Moreover, the SOC stock is considerably lower on the eroded slopes than on the plateau, but increases considerably in areas characterized by the deposition of sediments. Our 3D SOC prediction shows that the erosion within the studied cropland resulted in a net C sink mainly due to the accumulation of C in these sediment depositional areas (i.e. a sink of 12%), whereas when taking only the samples into consideration the opposite would have been suggested (i.e. a source of 8%). The latter underlines the importance of considering a DSM-approach when quantifying the net-impact of soil erosion on terrestrial C dynamics.

TALK

Jérôme Cortet

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Toward a European Atlas of Soil Fauna linking soil fauna and landuses

The protection of soil biodiversity is essential for ensuring soil functioning and provisioning of related ecosystem services, but also the conservation of species per se. For this purpose, it is essential to know what soil organism is where and how it is influenced by environmental, climate and human activities. Several maps have been proposed at global scales, for instance bacteria at the country level (Karimi et al., 2018), or at world scales for some taxa like earthworms (Phillips et al., 2019) and nematodes Van der Hoogen et al., 2019). However some of these previous maps have been sometimes controversial (James et al., 2021), mainly because of data gaps. Furthermore, links with land uses have been poorly explored, these publications mainly focusing on biogeographical aspects. Numerous studies (there are over 1400 published articles) have been elaborated in Europe regarding soil fauna. A data platform to store data on soil fauna already exists and is currently under further development to become a pan- European data warehouse for soil biodiversity (https://www.eudaphobase.eu/). Though, the data stored in this database until now comprises only a small percent of the available data. Hence, it is evident that a compiled dataset providing an overall understanding of the distribution of several taxa across European biomes and under different land use still is missing. Attempting to fill this gap, we start a new initiative within the framework of the Cost Action EUdaphobase CA18237: the creation of the first European Atlas of Soil Fauna. We aim to map, summarize and upscale the current knowledge on soil fauna to help in providing support to the scientific community and directions to stakeholders and policymakers. We seek collaboration (data holders and experts) to identify, collect and analyze data of all groups of micro, meso and macrofauna in Europe.

We will present here the first maps produced using the data collected at the European scale.

TALK

Suzann Kienast-Brown

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Digital Soil Mapping and Dynamic Soil Survey: A Vision for Soil Survey in the USA

Information about the type, properties, condition, and resilience of soil is essential for conducting environmental assessments and making land management decisions. Dynamic Soil Survey is a new and evolving approach that incorporates temporal soil properties, or those affected by soil biology and land use management, into soil survey in the USA. Dynamic Soil Survey combines recent advances and long-standing knowledge in pedology, ecology, and hydrology with improvements in digital technology. The integration of soil and ecological site inventory, dynamic soil properties, and climate and hydrology information allows soil scientists to better understand the variability and diversity of soil with the goal to provide relevant real-time information to support assessment and decision making. Digital soil mapping will be used to support all components of Dynamic Soil Survey. Predictions of soil type and both static and dynamic soil properties will provide foundational information for enhanced or custom interpretation of soil for management and use, soil moisture modelling, and modelling of ecological sites and states. A digital soil mapping framework will be used along with predictive soil maps to support environmental assessments. Successful examples of this exist in the southwestern USA, such as modelling of dust and salinity sources, and are being used to inform land management decisions. Digital soil mapping will be essential for developing a Dynamic Soil Survey in the USA that enables precision conservation and agriculture, multi-scale environmental assessments, and well-informed land management decisions nationwide.

TALK

James Moloney

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Soil information systems reduce the barrier to entry for soil natural capital accounting

Soil assets are often ignored within natural capital accounting (NCA) systems because of the challenge in quantifying soil properties through remote sensing alone. Digital soil maps are useful tools in assessing variation in soil assets for NCA, but national scale maps struggle to represent fine-scale heterogeneity1. As such, many soil NCA projects are built from scratch, requiring significant investment for soil sampling and laboratory analysis to identify the within field variability of natural capital stocks. Whilst techniques such as soil spectral inference and stratified sampling designs can assist in cost-effectively representing soil stocks at fine scales, current NCA systems do not often utilise existing soil information.

Memory-based learning techniques can assist in leveraging the most useful, or the most spectrally similar samples from a large spectral library, like a national dataset, to produce site-specific chemometric models2,3. Similarly soil information systems, large collections of soil properties and covariates, may be datamined to identify homosoils, locations of similar soil forming factors. Combined, these may supplement local soil information in the production of field scale digital soil maps4. These methods can reduce the laboratory and sampling costs of soil NCA projects and lower the barrier to entry.

Within this work, we produce maps of the stocks of three soil properties associated with natural capital, at the CSIRO Boorowa Agricultural Research Station in Australia. We demonstrate the use of memory-based learning techniques to leverage samples from the Australian national Vis-NIR soil spectral library to reduce the number of laboratory-analysed samples required to construct a suitable calibration model for proximal sensing. We also explore the use of the Australian National Soil Information System to supplement local soil information or reduce the sampling requirement to produce maps which can characterise stocks at a fine scale.

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TALK

Andree Nenkam Mentho

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Effect of soil maps on simulated yield for spatial crop modelling

Soil data are key inputs to numerous mechanistic crop models (Jones et al., 2003; Keating et al., 2003) and to spatialize crop models, spatially resolved estimates of soil input are necessary (Lagacherie et al., 2022). Many areas in the world with limited soil data coverage resort on existing digital soil mapping (DSM) products made at national, continental, or global scale to provide soil inputs to crop models (Hengl et al., 2015, 2017; Nenkam et al., 2022). However, many of these DSM products are coarse (>= 250 m) and usually poorly depict the local soil variation. The effect that this local variation has on the crop model outputs has not received much attention. Therefore, in this study, we fill this gap by testing whether crop models soil inputs need to be at finer spatial resolution to obtain accurate estimate of the yield. We proceeded as follows (i) we generated a finer resolution DSM product (at 30 m resolution) for easy to measure soil properties from which model's soil input would be derived, and then (ii) we evaluated and compared the effect of this DSM products and the existing ones on the mechanistic crop model APSIM (Holzworth et al., 2014; Keating et al., 2003) to predict crop yield. This effect is quantified in terms of the accuracy and uncertainty of the crop model predictions from each of the DSM products. The methodology is tested in the maize farming system in Mali, a country located in Western Africa where two main DSM products are available, one created at global scale (SoilGrids - 250 m resolution, Hengl et al., 2017) and another at national scale (Homosoil - 1 km resolution, Nenkam et al., 2022). These two products are complemented by high resolution DSM products. Our results show that soil data input have a negligible effect on crop

modelled maize yield. Soil inputs from coarser soil maps perform equally to the high-resolution soil map. We suppose that this effect is due on one side, to the uncertainty of coarse resolution maps and on the other side, to the overly insensitive nature of crop models. This research emphasizes the importance of accurate soil data as inputs to crop models and thus may serve as the basis to improve the soil database in countries like Mali aiming to increase the efficiency and usability of the soil related research output at unsampled locations.

TALK

George van Zijl

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Digital soil mapping - a viable tool for soil related land management decisions in large conservation areas

Protected areas are often regarded as pristine land, but in reality, they require rehabilitation and effective management to prevent increased land degradation. Soil management requires soil maps to make informed decisions, which is difficult to create in protected areas due to the large size of land, limited accessibility, little available soil data and limited budgets of such projects.

In this paper a hybrid expert knowledge and machine learning digital soil mapping method is used to create such maps for Benfontein, a 9900 ha protected area in South Africa. Soil associations were first mapped, and then soil properties were assigned to each soil class at the 10th, 50th and 90th percentile level, to indicate the range of properties at a 80% certainty. Interpretation of the maps included calculating carbon sequestration potential, through calculating the difference between the maximum carbon level for each association and the different percentile values, determining the K-factor of the USLE, and to map the off-road driving suitability through application of rules found in literature.

The soil association map was acceptable as it achieved a kappa value of 0.69. Additionally it was determined that the site has a large potential for carbon sequestration, the soils are relatively stable against water erosion, and off-road driving should be prohibited on approximately half the area.

The results indicate that the hybrid DSM method is viable to create useful soil maps in the unique settings of protected areas, and it could be applied in areas where the limitations of protected areas apply to inform management decisions.

TALK

Christian Walter

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Using digital soil mapping data from scenario studies to model changes in soil threats and soil ecosystem services - a meta-analysis

Prospective studies based on scenario analysis have recently developed strongly in soil science to assess how soil threats or soil ecosystem services may evolve in response to potential changes in climate, production systems or land management. This generally involves describing the dynamics of soil changes over time as a function of driving forces (e.g., climate change, public policies), but also assessing variations in space considering soil characteristics. A group of researchers participating in the SERENA project of the EJP Soil program conducted a meta-analysis to analyse the methods used in these prospective studies. This meta-analysis used approximately 100 articles referenced in Scopus or the WOS that followed an explicit scenario approach and model the evolution of one or more (a bundle) soil threats or soil ecosystem services.

The objective of the presentation is to analyse the published spatial soil information used in these scenario analyses, with particular attention to the use of information obtained by digital soil mapping (DSM). This analysis will answer a number of questions: (i) what type of soil information is used in the studies; (ii) is this information derived from common soil maps or was it obtained by DSM? What spatial resolution is used to describe the soils, and is it compatible with other spatial information (environment, land use, management practices)? Are uncertainties associated with the spatial representation of soils considered and how are they integrated in the scenario analysis?

This analysis will allow a quantification of the use of DSM products in exploratory studies in support of policy or territorial planning. A basis for discussion is provided to evaluate the existing limitations and margins in the potential of these data.

TALK

Marcos Angelini

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GSNmap: mapping soil nutrients to tackle imbalances worldwide

Access to food is threatened by climate change and the COVID-19 pandemic. Armed conflicts further threaten global food supply chains and have pushed up fertiliser prices. Sustainable management of soil nutrients is key to addressing these issues. During the Global Symposium on Soils for Nutrition in July 2022, the Global Soil Partnership (GSP) of the UN-FAO launched a global, country-driven initiative to map soil nutrient status and budget, promoting the development of national capacities in mapping techniques through regional online training sessions. The International Network of Soil Information Institutions (INSII) is the organisation within the GSP that executes this initiative. The GSNmap will be carried out in two phases. The first phase aims to generate baseline maps of macro and micronutrients, organic carbon, cation exchange capacity, texture, pH and bulk density, while the second phase consists of developing Nitrogen, Phosphorus and Potassium budget maps. In this work, we present the methodology of the first phase which assumes two scenarios of soil data: (1) soil nutrient data with coordinates, (2) soil nutrient data without coordinates, but with large area-support as an spatial reference (e.g. administrative units or ecological map units). For the first scenario, a conventional digital soil mapping approach using quantile regression forest for the modelling step and repeated k-fold cross validation for uncertainty assessment will be employed by the participating countries. For the second scenario, instead, a methodology to repeatedly simulate locations of the soil samples within the land units, which are subsequently used to train a model and make predictions will be proposed.

TALK

Manuel Martin

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Uncertainty assessment of the soil carbon balance in the context of the 4 per 1000 aspirational target: A case study for France

Increasing soil organic carbon (SOC) stocks is a promising way to mitigate the increase in atmospheric CO2 concentration. Based on a simple ratio between anthropogenic CO2 emissions and SOC stocks worldwide, it has been suggested that a 0.4% (4 per 1000) yearly increase in SOC stocks could compensate for current anthropogenic CO2 emissions. Here, we used a reverse RothC modelling approach to estimate the amount of C inputs to soils required to sustain current SOC stocks and to increase them by 4‰ per year over a period of 30 years. We assessed the feasibility of this aspirational target first by comparing the required C input with net primary productivity (NPP) flowing into the soil (0–23 cm layer), and second by considering the SOC saturation concept. Calculations which were performed for mainland France, at a 1 km grid cell resolution showed that a 30%–40% increase in C inputs to soil would be needed to obtain a 4‰ increase per year over a 30-year period (Martin et al., 2021). We assessed the uncertainty associated with this estimate using a first-order Taylor analysis. This analysis suggested a major contribution (58%) of the uncertainty related to the NPP flowing into the soils, to the carbon balance, for the 4 per 1000 target. The impact of the uncertainty related to soil properties was also taken into account. Although for mainland France, maps of clay content usually exhibit higher local inaccuracy compared to SOC maps, variance attached to clay content had a negligible impact on the overall carbon balance uncertainty compared to the variance attached to the SOC maps (0.2% vs. 7.3%). Last but not least, the uncertainty embedded in two pedo-transfer functions used in the process of estimating the carbon balance, also had a major impact, which advocates for their improvement. Overall, the Taylor analysis, although more adapted to simple models such as RothC, proved to be very efficient for unceratinty analysis. The results emphasize the need for better estimating carbon inputs into the soils in order to better characterize the soil carbon sequestration potential of land surfaces.

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Spatial prediction of maize yields using QUEFTS from digital soil maps – a comparison of methods

The Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model is a decision support tool that predicts crop yields as an indicator of soil fertility and can be used to evaluate yield responses to fertilisers. It was designed for field level output and runs on field-specific soil information. To regionalize QUEFTS outputs, soil maps could be considered as soil input data instead of (field) measurements.

Here we compare two methods for developing maps of QUEFTS output, i.e. maize yield and the yield-limiting nutrient (considering N, P and K), with Rwanda as a case study. We used a database containing soil analysis results of 999 samples collected across Rwanda. Pedo-transfer functions were applied to predict the required P-Olsen and Exchangeable K input for QUEFTS based on the soil data. For the "Calculate-then-Interpolate" (CI) method, the pedo-transfer functions and QUEFTS model were applied to the point data, and the model outputs were interpolated using random forest modelling. For the "Interpolate-then-Calculate" (IC) method, maps of the soil parameters were developed first. Subsequently the pedo-transfer functions and QUEFTS were applied to the set of soil maps, resulting in maps of the QUEFTS outputs.

Implications of the chosen method (i.e. CI or IC) on QUEFTS predictions on a national scale were evaluated using set-aside locations. Interestingly, the results show a strong effect of the chosen method on the QUEFTS output that could have serious implications on the use of the QUEFTS outputs for decision-making, for instance for developing regionalized fertilizer recommendations. Correlations between mapped yield predictions and predictions on set-aside evaluation locations were similar for the CI ($r = 0.444$) and IC ($r = 0.439$) methods. However, maize yields calculated from gridded soil maps with the IC method were strongly overpredicted, likely as a result of smoothing of the soil maps that is a consequence of statistical modelling and prediction.

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Assessment of the topsoil organic carbon saturation in Hungary using machine learning-based pedotransfer function with uncertainty propagation

Stakeholders and policymakers have been becoming more and more interested not just in the potential organic carbon (SOC) saturation level of soils but also in spatially explicit information on the degree of SOC deficit, which can support future policy and sustainable management strategies, and carbon sequestration-associated spatial planning. The objective of our study was to develop a cubist-based pedotransfer function (PTF) for predicting and mapping the saturated SOC content of the topsoils (0–30 cm) in Hungary, and then compare this map with the actual SOC map to assess the degree of SOC deficit. It was assumed that topsoils covered by permanent forests can be practically considered as saturated in SOC. Using the monitoring points of the Hungarian Soil Information and Monitoring System located in forests as reference soil profiles, we developed a cubist-based PTF using not just soil properties but also environmental covariates as predictors, and then mapped the saturated SOC content at a resolution of 100 m. We also quantified the prediction uncertainty of the saturated SOC content using first-order Taylor expansion, where not just the uncertainty of the predictors but also the uncertainty associated with the PTF were taken into account. The transparent model structure of cubist allowed to show that not just the physicochemical properties of soils (e.g., texture, pH) but also environmental conditions, such as topography (e.g., slope, altitude) and climate (e.g., temperature, evaporation), characterizing the landscape are important factors in predicting SOC saturation. Our results also pointed out that there is SOC deficit on large part of the country (approx. 80%) showing high spatial variability. It was also revealed that the most considerable potential for additional SOC sequestration can be found related to soils with medium to high actual SOC content.

SHORT TALK

Léa Courteille

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Towards an Interactive Uncertainty Visualization for Soil Quality Maps obtained by Digital Soil Mapping to Support End-user Decisions

Estimations of local uncertainties provided by geostatistical and machine learning models are rarely linked directly to the decision-making process for which soil information is required (Wadoux et al, 2021, challenge 9). End-users of Digital Soil Mapping products require intuitive visualizations of uncertainties that can support their decisions.

Taking the example of a soil potential multifunctionality index (SPMI) map developed for the coastal plain of the Occitanie Region (Angelini et al, submitted), we explored different uncertainty visualizations, each presenting a tradeoff between an? uncertainty level and the spatial resolution. Initial SPMI estimations available at 25m resolution were increasingly spatially aggregated by grouping the neighboring pixels having similar values of predicted SPMI. Mean values of SPMI were calculated for each resulting polygon and the errors on the mean SPMI values were estimated by propagating the predicted uncertainties at 25 m pixel using a spatial stochastic simulation technique (Vaysse et al, 2017). The within-polygon variance of the predicted SPMI was also calculated as an indicator of heterogeneity of the resulting polygons. All this information was presented through an interactive interface allowing the user to explore the different visualizations with their control parameters that decreased (uncertainty) or increased (heterogeneity) as spatial resolution decreased.

The resulting visualisations of the SPMI map are to be submitted to a panel of end-users in view of eliciting their preference in real-life situations of decision making.

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SHORT TALK

Sebastian Gutierrez

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Spatio-temporal changes in organic carbon for Danish croplands

Soil organic carbon (SOC) storage is a possible means of reducing atmospheric CO2 levels (Zhao et al., 2020). It is therefore necessary to predict OC carbon sequestration potentials based on C stabilization processes across ecosystems, land uses, soil depths, and timescales (Angst et al., 2021). Indices based on easily quantifiable soil parameters can help to verify the progress towards achievable OC sequestration goals (Prout et al., 2022). For example, Dexter et al. (2008) found that the clay/OC ratio could estimate OC sequestration in the soil.

We used the Danish 7-km soil monitoring grid to map temporal changes in the Dexter index as an indicator of the soil potential for C sequestration in the arable lands of Denmark.

We derived the index for points collected in 1986, 1997, 2009, and 2019 at the 0 – 25 cm depth interval. The covariates comprised static (DEM derivatives, geology, georegion) and dynamic layers (bioclimatic layers and Landsat-derived vegetation indices). We obtained a regression matrix with a space-time overlay. We then filtered the data to retain the most important covariates to fit a quantile regression forest model (Meinshausen, 2006), and we used 10-fold spatio-temporal cross-validation to evaluate the model performance (Meyer et al., 2018). We mapped the median predictions at a 30.4 m resolution for each year, as well as the 90% prediction interval based on the 5 and 95 percentiles. We validated the model with non-revisited points for 2009 and 2019.

After filtering, the bioclimatic layers had more predictive power than the static layers. There was a decreasing trend for Clay/OC in the eastern part of Denmark with different implications for zones with C-saturated and unsaturated soils. Non-revisited points in 2009 and 2019 showed an R2 of 35 and 36%, respectively. We found that a monitoring grid dataset and a machine learning model validated in space and time can be integrated to yield information about temporal OC changes in arable lands.

SHORT TALK

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Complementary approaches to capture spatial relationships among soil-based ecosystem services

Whereas ecosystem services (ESs) are seen as a tool to support decisions on land management, it has been argued that much of their potential to do so has been underexploited. For instance, most of the approaches rely on estimation of ESs through indicators of them derived from land cover and land use spatial products, neglecting soil so far. Here we show that soil-based ecosystem services (SESs) could also be useful spatially explicit tools to guide decision makers, through the usage of SES's bundles (relationships among SESs that are consistent in space and time). We used indicators of SESs derived from data (produced through soil digital mapping) on soil properties from the plain area of Emilia Romagna in Italy, and applied both spatially-explicit (bivariate local indicators of spatial association, bilisa) and non-spatially-explicit (k-means multivariate clustering) tools to capture SESs relationships. Comparisons between bilisa clusters for SESs actual carbon sequestration-productivity (CST-PRO) vs water infiltration capacity-PRO (WAR-PRO) showed a change of the direction of the synergy between CST and WAR, but such switch was limited to certain pedolandscapes. Thus, management practices that try to maximise CST and WAR at the same time are unlikely to succeed in some, but not all, soil types. Moreover, the combined use of spatial clusters for more than one couple of SESs, outperforms the use of a single pair at time, unveiling additional information about SES relationships. Furthermore, SESs distribution was not homogeneous among non-spatial clusters. In this way, tradeoffs between provisioning services (PRO) on one hand, and regulating services (habitat for biodiversity, water storage capacity and CST) on the other were evident among the different nonspatial clusters. Overall, our approach highlights how SESs can be useful in guiding land management decisions, and how inherent soil properties play a role in determining the relationships among SESs.

TALK

Johan Leenaars

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Scaling of fertilizer recommendations for major crops in West Africa using digital soil maps; a proof of concept

Site-specific fertilizer recommendations for major food crops in West Africa have been updated and mapped by ISRIC – World Soil Information in collaboration with IFDC and experts from the NARs of Benin, Burkina Faso and Ghana. The project served as a proof of concept and was carried out in the context of the USAID - West Africa Fertilizer Program which was implemented over five years in collaboration with the Economic Community of West African States (ECOWAS). A tiered approach was developed which makes use of the Africa SoilGrids as input including maps of soil nutrient contents produced by DSM using soil analytical data selected and standardized from near 70,000 sample locations and derived maps of the soil's Root Zone Plant-Available Water Holding Capacity (RZ-PAWHC). In the first tier, a simple model for the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) was parameterized with georeferenced fertilizer trial data compiled from a number of countries and used, together with available maps of attainable, water-limited, yield of millet, sorghum, maize, rice and cassava, to calculate and map soil nutrient supply, crop nutrient demand and the unfertilized and fertilized crop nutrient uptake and yield together with the corresponding nutrient efficiencies. Herein, crop nutrient demand at attainable target yield was downsized using the RZ-PAWHC map and compared with soil nutrient supply to map the nutrient gap (deficiency) and the corresponding NPK fertilizer recommendation. These recommendations proved poorly related with the reported ones which however proved largely due to the heterogeneity in the criteria that the reported recommendations had been derived by the various parties in the first place. Crop yield responses seemed very reasonably modelled when considering only those trials for which nutrient uptake, serving model parameterization, had been reported. We therefore considered the first tier maps of yield response to be consistent and reliable. The maps were added to regional covariates in a second tier to model and map the fertilizer recommendations, as reported from the fertilizer trial data, using machine learning (RF). This resulted in reasonable to good validation statistics, partly due to the limited number of trials, but also in an important loss of spatial variation and thus site-specificness. We therefore maintained the first tier recommendations. These were spatially aggregated by agroecological zones and the variance within each zone was expressed by probability distributions. The variance in NPK fertilizer recommendations proved more determined by crop nutrient demand (driven by soil water) than soil nutrient supply (driven by soil fertility) and basically reflects the variance in attainable yield as determined by climate and limited by the soil's RZ-PAWHC. The impact of soil water availability is insufficiently well modelled with QUEFTS which provides room for improving the approach. Ultimately, the proof of concept provides an operational framework for progressive and collaborative updating and upscaling of fertilizer recommendations across the region, adding value to additional and adequate soil-crop-response data and digital soil maps.

POSTERS

SESSIONS 1 & 2: COUNTRY REPORT AND CASE STUDIES

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An overview of the Consortium GLADSOILMAP supported by the LE STUDIUM Loire Valley Institute for advanced research studies (France). Joining efforts between sub-national, national, continental and global scale digital soil mapping of soils, soil properties and soil functions

The research Consortium GLADSOILMAP (https://www6.inrae.fr/gladsoilmap-consortium/) has been funded by the LE STUDIUM Loire Valley Institute for advanced research studies (France). Its main aims were to put together the research efforts in digital soil mapping (DSM) from sub-national to global scales. It involved specialists in DSM and lithological mapping from five countries (AU, FR, NL, NZ, USA) and 7 institutes. Other people from various institutes and countries joined these efforts.

We summarize the network of this consortium. We classify the numerous scientific publications published under his auspices. It achieved considerable work and noticeable advances. It helped to develop collaborations between many Institutes and countries, and to strengthen the link between the Digital Soil Mapping and GlobalSoilMap Working Groups of the Commission Pedometrics of the IUSS. LE STUDIUM helped these advances and decided to organize this international Conference "Soil mapping for a sustainable future" in Orléans (France).

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A new semi-automatic data processing pipeline: from text recognition of soil legacy data to feeding the French national soil database DONESOL

Several experiments recently confirmed that the performances of Digital Soil Mapping models were strongly influenced by the spatial density of the sites with measurements of soil properties that are used for calibrating the machine learning Models used in Digital Soil Mapping - DSM (Lagacherie et al, 2020).

A straightforward way for increasing this spatial density consists in amplifying the rescue of legacy soil data that have been accumulated by the soil surveyors across the globe since the last seven decades (Arrouays et al, 2017). However, in the French territory, and to our knowledge, there is not a study that considered to automatize and incorporate the retrieval of this type of data into DSM projects. Hence, we present in this paper a semi-automatic data processing pipeline that allows the digitization of soil profiles and their integration into the French national soil database (DONESOL).

Our pipeline performs several correction and verification steps to ensure that all extracted data is not erroneous and meet the DONESOL database requirements. The proposed pipeline consists of three main steps performed on soil legacy data: (1) document scanning, (2) text recognition and (3) data wrangling. The first step aims to dematerialize data from paper to digital documents. Next, the pipeline extracts and recognizes variables, soil properties and study locations from structured and semi-structed tables detected in the first step. Finally, the data is wrangled (e.g., soil depth harmonization) and spatialized in order to meet the DONESOL database requirements.

Our premilitary evaluation is that our proposed semi-automatic pipeline can be very time-efficient, since it allowed us to go from a data entry time of about 10 minutes/sheet without counting the verification time to 1.5 minutes/sheet. This evaluation is further confirmed by processing 8792 soil profile sheets provided by our partner BRL.

value to additional and adequate soil-crop-response data and digital soil maps.

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Comparing Global and European Soil Databases for Clay, Silt and Sand Contents

Soil texture and depth are critical inputs for determining hydrological parameters in flood risk modelling. Global and European scale databases are used to model runoff, but their accuracy is poorly known. The objective of this study was to compare clay, silt and sand contents for freely available soil databases to a reference dataset in Southeast France.

The databases compared in this research included Soilgrids1, EU2, EU-derived3, and GISSOL4. The reference database was obtained from the Société du Canal de Provence (SCP); it includes 1,412 soil texture analyses values for the Provence Alpes Cote D'Azur (PACA) region. Some of the samples are for different depths in the same profile, so the final reference database included 608 clay, silt and sand values for the 0-30 cm depth. Comparisons between databases were based mainly on Pearson correlation coefficients (r). The use of geomorphological features, such as ridges, valleys, peaks, recti-linear slopes... was tested using the r.geomorphon GRASS tool5 and multiple linear regression to see if these features could improve textural class predictions.

The GISSOL 90 m spatial resolution raster database is the most reliable among the databases tested with correlations of close to 0.70 with the reference database for all textural classes. Correlation coefficient values drop sharply for the next best performing database, Soilgrids, with r-values of 0.38, 0.45, and 0.58 for clay, silt and sand, respectively. The EU database had corresponding r-values of 0.15, 0.34, and 0.35, respectively. Finally, the EU-derived database had the lowest r-values due in part to a large number of 0-value cells in the raster dataset. Geomorphological features were not significant for any of the textural classes and only GISSOL and geology were retained in a backward stepwise regression model; r-values were only marginally improved. Work is starting on comparing soil depth values.

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Geostatistics contribution in forensic science for the origin identification of soil traces

Pedological traces (or soil traces) are relatively unknown microtraces in forensic science. However, floors are the source of many traces transferred to shoes, clothing, tires or many other surfaces. During their investigations, the investigators can use them to confirm or deny the passage of a person, an object or a vehicle in a place.

Currently, the analytical strategy implemented at the Institute for Criminal Research of the National Gendarmerie (IRCGN) is based on a comparative approach focusing on the similarities between different samples.

If no identification of the origin of a soil has been carried out to date in France, the interest of a geolocation of a soil sample is certain (search for bodies, cold case...). A Predictive Soil Provenancing method was applied to Australian soil1. Using kriging methods on soil parameters published by the Commonwealth Scientific and Industrial Research Organization (CSIRO), it is possible to reduce the search area by 77 to 40% of the initial area, when the 6 variables are considered individually, and up to 8% of the initial area, if they are nested.

The objective is to carry out a cartography making it possible to locate a sample of ground on the territory, starting from the Australian model: is it applicable to the French territory? How to implement it? How to improve it?

In order to apply this method to France, it is necessary:

– identify the different variables (texture, content, etc.) characterizing a soil

– determine the spatio-temporal evolution of these parameters

– search for existing databases containing the variables of interest

– apply the geolocation of samples of known origin, characterized in the laboratory by implementing statistical and geostatistical methods.

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Comparison of soil information from different sources. Coherence, complementarities, interest of their joint use for digital soil mapping of topsoil texture. A pilot study on forest soils in the department of Loiret (France)

Climate issues coupled with the under-representation of forest data in soil databases urge to a better harmonization of data between the different organisations for a more efficient management of forests. This study focuses on forests' soils from the Loiret's French department, and is based on a comparison of ad hoc soil data from the French National Forest Inventory and the Loiret's pedologic reference document. Comparison of soil types and topsoil textures showed several differences between the two data sources. These differences can either be explained by potential confusions in the field or by some mismatches between organisations' protocols.

After a statistical analysis of the Loiret's environmental covariables, the combined use of environmental variables and digital soil mapping through Randomforest algorithm enabled to predict topsoil textures on the whole Loiret's forests. The results of that process seem to detect systematic bias in some IFN's data, but these data can detect smaller spatial patterns.

Finally, several ways of protocols' improvement are suggested for a better data harmonization between the organisations, such as a collection of soil textures available for IFN workers' calibration of field texture allocation.

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Leveraging legacy soil data for national DSM in a data-rich country: opportunities and obstacles in Austria

Predictive or digital soil mapping (DSM) has made dynamic progress over the last two decades (Piiki et al. 2021, Chen et al. 2022). In Austria, DSM techniques have been used to create regional maps of parent material (Gruber et al. 2019), plant-available water storage capacity (Simon et al. 2020), or soil hydraulic parameters (Krammer et al. 2016). More recently, DSM has been applied to derive high-resolution hydrological maps on subnational scale (Gadermaier et al. 2021).National-scale soil maps are, however, still scarce. While this can partly be attributed to difficulties associated with sampling, mapping and modelling soils of an alpine landscape, decades of research in Austria have produced a rich legacy of soil point data. These include the Agricultural Soil Map of Austria (~11.7k profiles), the Austrian Soil Assessment for tax purposes (~460 reference profiles), the Austrian Forest Soil Survey, and the Soil Surveys carried out on subnational level by the nine Federal States. The last two datasets are contained in the national soil information system BORIS, which in total contains point data for additional ~10k sites. Back-of-the-envelope calculations thus suggest an average profile density of ~260 per 1000 km² to be potentially available for DSM, which would place Austria among the top nations globally. Together with an increasing set of spatial covariates, this point legacy data could serve as excellent input for DSM methods to produce soil property maps on a national scale.

Yet, efforts of data standardization and harmonization are lagging behind technical developments in the field of DSM. This contribution explores Austrian legacy soil data and develops a road map towards a standardized, harmonized soil point data set to support the development of national-scale DSM products.

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Predictive mapping of wetlands for mainland France using a machine learning procedure

Wetlands ecosystems represent key environmental compartments, as they regulate hydrological, biogeochemical and ecological processes, but they are under threats. In France, attention paid to wetlands has increased over the past decade in response to recent evolution of the legislation concerning water authorities' activities. Indeed, criteria for identification and delineation of wetlands based on soil and vegetation characteristics are considered in the French legislation since 2008. Consequently, there is a growing demand for knowledge of the spatial distribution of the wetlands, both at the territorial and national management levels.

This study aimed at providing a predictive map of wetlands at the scale of the metropolitan territory of France, in a raster format of 5 m resolution. The predictive and mapping approach was based on a machine learning method (Random Forest), using environmental variables available for the entire study area: change in elevation from the nearest stream, topographic wetness and position indices (TWI and TPI), distance to waterbodies and geology. Approximately 135,000 legacy punctual observations of soil hydromorphic features or typical vegetation were used for calibration. The probability of occurrence of wetland was predicted and then was then thresholded by hydro-eco-region to produce a binary map. To assess the quality of prediction, an independent dataset of more than 4,000 soil observations was collected in 2021.

The accuracy of the wetland prediction was satisfactory regarding the indexes of accuracy: PR-AUC for the quantitative map and F1 score and overall accuracy for the binary map. These maps should be a major tool to consider the area and nature of wetlands impacted by urban and rural planning, and to elaborate and evaluate public policies at national, but also regional and local scales. Feedbacks from local stakeholders and end-users were collected to promote and accompany the delivering of the data.

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Using homosoils for quantitative extrapolation of soil mapping models

Since the early 2000s, digital soil maps have been successfully used for various applications, including precision agriculture, environmental assessments and land use management. Globally, however, there are large disparities in the availability of soil data on which digital soil mapping (DSM) models can be fitted. Several studies attempted to transfer a DSM model fitted from an area with a well-developed soil database to map the soil in areas with low sampling density. This usually is a challenging task because two areas have hardly ever the same soil-forming factors in two different regions of the world. In this study, we aim to determine whether finding homosoils (i.e., locations sharing similar soil-forming factors) can help transferring soil information by means of a DSM model extrapolation. We hypothesize that within areas in the world considered as homosoils, one can leverage on areas with high sampling density and fit a DSM model, which can then be extrapolated geographically to an area

with little or no data. We collected publicly available soil data for clay, silt, sand, organic carbon (OC), pH and total nitrogen (N) within our study area in Mali, West Africa and its homosoils. We fitted a regression tree model between the soil properties and environmental covariates of the homosoils, and applied this model to our study area in Mali. Several calibration and validation strategies were explored. We also compared our approach with existing maps made at a global and a continental scale. We concluded that geographic model extrapolation within homosoils was possible, but that model accuracy dramatically improved when local data were included in the calibration dataset. The maps produced from models fitted with data from homosoils were more accurate than existing products for this study area, for three (silt, sand, pH) out of six soil properties. This study would be relevant to areas with very little or no soil data to carry critical soils and environmental risk assessments at a regional level.

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Regional scale mapping of topsoil carbon sequestration potential in Taiwan

Increasing soil organic carbon (SOC) sequestration is considered as one of the effective solutions for climate change mitigation and adaptation, thus developing accurate prediction and mapping methods is important for estimating the carbon stock in soils of regional scale. In addition, due to there is an upper limit of SOC storage, the capacity of SOC saturation must be evaluated before calculating the SOC sequestration potential (SOCSP). The objectives of this study are to model and map SOCSP at regional scale using digital soil mapping and to compare the differences in those among different land use (paddy, upland, orchard, forest and other). The study area is in Zhuoshui River basin (3156 km2), which located in central Taiwan. The SOC saturation of topsoil (0-30 cm) was estimated by Hassink equation (Hassink, 1997), and the SOCSP was calculated by the difference between the SOC saturation and fine fraction SOC stock (Chen et al., 2018). Regression Kriging approach was used for modeling and mapping the SOCSP with several environmental covariates. The performance of SOCSP prediction was assessed by validation data and we obtained an R2 of 59, and the spatial distribution of SOCSP was mainly controlled by climatic and topographic factors such as temperature and elevation. The average SOCSP of the paddy field (4.97 kg m-2) in this study area is higher than the other land use types (0.10-2.33 kg m-2), and the most of forest topsoil in the slope and mountain areas are over-saturated with a SOCSP less than 0. We also found that the SOCSP of plain areas (4.47 kg m-2) are significantly higher than those in slope (0.76 kg m-2) and mountain (0.05 kg m-2) areas. In total, the SOPSP for the topsoil of this study area was about 2.28 Mt, which accounts for 19.5 % of total SOC saturation capacity. Our results also provide suitable sites for carrying out sustainable soil management to increase SOC stocks.

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National scale mapping of surface soil thickness in mountainous, upland, and hilly areas of Japan

In Japan, about 75% of the national land area is covered by mountains, upland, and hills, with most of the land covered by forests. Recently, increased abnormal heavy rainfall caused an increase in the landslide disaster on the slope of those areas. Although soil thickness is one-factor controlling landslide risk, any detailed spatial estimation has not been reported. The studies about DSM in Japan have long been behind those in Europe, the U.S., China and so on, in part because of the difficulty of estimation due to the very complicated topography and tephra. Recently, Yamashita et al. 2022 have considered those factors based on 10 m DEM and successfully mapped soil carbon stocks at a national scale. In this presentation, our objective is to estimate the soil-thickness map based on the report and consider some issues specific to soil-thickness data such as censored data.

We estimated and mapped the soil thickness at a national scale by some machine learning model (random forest, random survival forest, neural network, and so on). Several sampling pre-processing procedures were compared (e.g., k-means, cLHS) to correspond to spatially biased data. The training dataset was mainly 1) intensive soil profile data of the National Forest Soil Carbon Inventory and 2) legacy soil profile data surveyed for the first national soil map 40-50 years ago (spatially skewed data).

As a result, the map of probability of soil thickness above 60 cm was estimated with an accuracy of kappa 0.4, by random forest model, and the under-sampling using k-means. The map well reproduced that soil thickness was deeper in the upper part of the slope at a local scale and the northeast part at a regional scale. In the pacific-rim region, the volcanic soil distribution might be crucial for regional-scale mapping of soil thickness in addition to the topographic effect.

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GloSIS: Global and National Soil Information Systems

The Global Soil Information System (GloSIS) is a spatial data infrastructure that brings together soil information collected by national institutions and other data holding entities. GloSIS provides the tools to store, process and share the spatial data. The infrastructure is aimed at the exchange and retrieval of soil information collected by (national) soil information institutes through a web-based platform. This will be achieved in a decentralised manner, with source institutions largely retaining their data and controlling outside access to their products. The broad vision is that of a federation of soil information systems (SIS), and interoperable data sets. Through GloSIS these systems will 'communicate' (exchange) data in a commonly recognisable way. This federated system of the GSP and its supporting capacity development programme will empower countries and other data providers facilitating a standardised soil data infrastructure and easy querying and exchange of soil data at national, institutional, regional and international scales. The FAO's Global Soil Partnership has been supporting participating countries and institutions by devising ad-hoc solutions that target different national soil information and data realities. Over the last decade, the FAO's GSP has supported the launch of 7 national SIS as well as a regional one. A comprehensive step-by-step technical manual and accompanying off the shelf software bundle addressing topics ranging from basic data management and harmonisation to the establishment of fully fledged national and/or regional soil information systems are currently being developed.

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Predictive mapping of the Guerrara region's soil landscapes (Northern Sahara, Algeria)

Difficulties in acquiring sufficient data for soil mapping have forced soil cartographers to rely on new techniques and methods based on digital soil mapping, which are used in development planning and strategic decision-making for agricultural development, sustainable land management, and climate change mitigation and adaptation. Soil heterogeneity offers complex systems that are difficult to characterize because they combine the variability of landscape processes with the variability caused by anthropogenic land management. The objective of this study was to advance data-based digital soil mapping techniques by developing an approach that can integrate digital surface topography, auxiliary data as well as optical and radar remote sensing products to characterize the soil landscapes of the Guerrara region, which is located in the northern Sahara desert (Algeria), under hyper-arid climate. This approach is suitable for multi-scale mapping, allowing the inclusion of a wide range of covariates (Slope, Aspect, Curvature, surface roughness, band ratios, MSAVI, NDSI, gypsic index , carbonate index, etc.) and the mapping of spatially homogeneous soil landscape units that are essential for hydrological models, land and ecosystem management decisions, and risk assessment.

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Digital Soil Map and Soil Information System in Nepal

Digital Soil Map of Nepal (DSM) of Nepal was prepared by National Soil Science Research Centre (NSSRC), NARC with support from Nepal Seed and Fertilizer Project, NSAF/CIMMYT and formally, it was launched on February 24, 2021 by the Prime Minister of Nepal, Mr. KP Sharma Oli which was prepared using 23, 273 soil samples data and now it has been updated with 30548 soil sample data covering all 77 districts and all seven provinces. It has been used for problem identification, planning and resource management; to design strategies for soil fertility and fertilizer management to improve crop productivity, estimate total fertilizer requirements and the gap in fertilizers supply in a specific area and also to correct soil acidity, alkalinity and micronutrient deficiency problems. For effective use, we developed "DSM Management Directives" and training on its use has been given in all provinces. We do update regularly at every two years. Based on soil properties derived from DSM, we also revised national fertilizer recommendation for major crops with specific to domain. Soil Health card has also been initiated in Nepal. Since the launch of the Digital Soil Map there are 297 registered users. Users (researchers and professionals) have downloaded data in raster format 2055 times. There have been about 1581 requests for accessing data via application programming interfaces (APIs). In the last 16 months, the web portal has been visited 5398 times with 27845 searches for the link on search engines. So far searches were made from 167 countries (Nepal, India, USA, Pakistan, UK, etc. being leading visitors). Based on the data input on DSM, soil statistics has been revised and now clear information on soil has been derived. DSM in Nepal has been a major achievement of the agricultural sector and its impact is yet to be analyzed.

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Lithological map of metropolitan France

The data available on the geological maps at a scale of 1 :50,000 have been reworked to overcome stratigraphic ages. In the 2010's, these original geological maps were harmonized to cover each department area from metropolitan France. Each map was associated to a database that contains, among others, data related to lithology. The lithological data contained in the harmonized maps preserved all the descriptions but are not hierarchal and there is no classification, the text is free and the search for keywords or standardized terms is more difficult. These maps mainly display bedrock deposits and also superficial deposits, only when represented on the original maps. To build the lithological map of metropolitan France, we use a new lexicon that describe lithological information, an elementary building block of an Information System reference plateform. The initial information is broken down into three stages or « levels » which constitute the classification or hierarchy. Three levels are identified, from the main rocks families to sub-classes, and a fourth additional level is labelled as a « component » in order to preserve the entire lithological description. On the same method, a new legend was built. The colour and the symbols are indexed by the three lithological levels. Indeed, the graphic representation offers a quick look and a practical mapping too. The project was initiated in 2019, continued in 2020 with the integration of three new harmonized departments (New Aquitaine region) and a V1 version is expected by the end of 2022, designed to evolved. Indeed, one of the main difficulties is both to preserve the original description while associating lithological registers and lexicons of deposit environments. The main objective is to offer geoscientists more accessible, structured and harmonized data for their needs (soil mapping, soil geochemical mapping, risk management, subsurface characterization…).

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Soil organic carbon prediction and mapping using Sentinel-2 multi-temporal imagery data over Greek croplands

Numerous studies have been carried out in the monitoring of soil organic carbon (SOC) in exposed croplands at global and regional scales, demonstrating the potential of remote sensing to estimate SOC. This study aims to evaluate the efficiency of multitemporal analysis to estimate and map SOC content at national scale. Spectral data were extracted using Sentinel-2 multitemporal imagery (February to December 2020). LUCAS dataset was used, with a total of 643 samples. Bare soil masking was performed, using as a limiting factor the values between 0 and 0.25 to NDVI and NBR2 < 0.08, resulting in 180 samples. Datasets were randomly separated in calibration (75%) and validation samples (25%). SOC prediction was performed using Sentinel-2 multitemporal bands and 34 spectral indices. Quantile random forests (QRF) was applied to calibrate the predictive models in two separate modelling modes: Sentinel-2 bands averages (S2mean) and multitemporal Sentinel-2 bands (S2M). The accuracy of the predictions was evaluated through R2, RMSE and RPIQ. The prediction interval coverage probability (PICP) was calculated to verify if the uncertainty of the predictions were correctly evaluated. S2M achieved the best accuracy, reaching an R2 of 0.44, RMSE of 10.04, while the S2mean had a R2 of 0.07, RMSE of 12.08. S2M proved to be more powerful than the S2mean, due to the large amount of spectral information for each sample. For the PICP, S2mean obtained a value of 0.87, showing that the uncertainty was correctly evaluated, S2M had a value of 0.81, suggesting that the uncertainty would not be a realistic representation of the prediction uncertainty and potentially underestimated. Therefore, this study indicates that multitemporal Sentinel-2 imagery can improve the accuracy of SOC prediction. Further investigation is currently focused in test different combinations of thresholds in bare soil masking for better performance in SOC prediction and the prediction uncertainty in mapping.

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Spectral monitoring of cattle slurry and digestate spreading on wheat crop at the field scale (Nouzilly, France)

A better knowledge of soil management, especially organic amendment practices, appears to be key, not only for modelling their soil C dynamics but also to characterize soil surface condition for the purpose of satellite-based mapping of topsoil soil organic carbon content (Vaudour et al., 2022). A previous study dealt with cattle manure and green waste compost spread on bare soil, and found several spectral indices (named EOMI1 to 4) enabling to characterize such spreading events (Dodin et al., 2021). However, little is known about the spectral characteristics of exogeneous organic matter (EOM) in liquid form, such as pig slurry and digestates, and this especially when EOM is spread over emerging crop (Dodin et al., 2022). This study aimed to spectrally monitor spreading events through a field experiment carried out on emerging wheat in March-April 2022 in the INRAE farm of Nouzilly (Touraine, France). Field reflectance spectra over the range 400—2500 nm were simulated into Sentinel-2 (S-2) spectra. Five S-2 satellite images were acquired close to spreading events. Vegetation coverage was assessed using photographs taken in the field and the CanEye® software of INRAE. Then, in order to discriminate between treatments, the time series of spectral indices (EOMI, NBR2, EVI, NDVI) either derived from field or from satellite were analysed through several multivariate approaches of Ascending Hierarchical Clustering (AHC).

The AHC results obtained from the five EOM indices (EOMI1, 2, 3, 4 and NBR2) divided by EVI for all spectral samples in the field experiment lead to four classes, successfully discriminating between levels of EOM application. Our results suggest the capability of S-2 imagery to monitor spreading events over emerging vegetation.

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Gamma-ray spectrometry to determine soil properties for soil mapping in precision agriculture

Soil maps are critical for various land use applications and form the basis for the successful implementation of precision agriculture in crop production. High-resolution soil data is now required in the management of sustainable land-use practices and traditional soil maps often fail to provide these data. There is currently a stronger demand to understand soil variation at a finer scale. The use of gamma-radiometric data in conjunction with other information such as digital elevation models (DEM) or aerial photos has become an important source of data for digital soil mapping. The objective of this study was to determine the extent to which aerial gamma-ray spectroscopy, can successfully and practically be used to accurately determine soil management zones and topsoil properties for precision agriculture in the South African context. Airborne gamma-ray data was correlated with topsoil properties and soil types from a grid soil survey. The SCORPAN approach in the digital soil mapping was used for the predictive modelling and mapping of the soil properties and soil types. The covariate data consist of spectral, terrain and gamma data. The different soil properties were modelled using the Cubist and Random Forests regression decision trees. To predict the spatial distribution of soil types, the Multinomial Logistic Regression (MNLR) classification model were used. In this study the gamma-ray data was successful in predicting the soil particle fractions of sand, silt, and clay, as well as the soil carbon (C), calcium (Ca) and magnesium (Mg), and with the mapping of soil types. Gamma-ray data can be used to map soil properties and soil types accurately, with 50% of the conventional soil samples and observations. This is a saving in both time and money. More research needs to be done in bigger areas in South Africa to test the concept in the majority of crop production areas.

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A decision-level fusion-based scenario for production of more accurate land crop maps

Preparation of accurate land crop map is crucial for planning for food security. The main purpose of this study was to provide a decision-level fusion-based model for achieving higher accuracy in preparing land crop map. First, the features sets were extracted based on Sentinel-2 satellite images' spectral bands for an area in Ontario, Canada. Then, optimal features were selected based on training data and random forest (RF) varImp algorithm. Then, various classifiers including support vector machine (SVM), RF, and artificial neural network (ANN) were implemented to prepare land crop maps based on optimal features and training data. After that, land crop maps derived from different classifiers were combined using a fusion-based voting scenario at the decision level to improve the results accuracy, and new land crop map was prepared. Subsequently, performance of different scenarios was evaluated and compared based on ground observations. Mean percent uncertainty for Soybeans, Pasture/Forages, Winter Wheat, Corn, Spring Wheat and Follow classes were 13.5, 16.5, 15.7, 12.2, 27.5 and 14.9 %, respectively. The overall accuracy of RF, SVM and ANN classifiers in preparing the land crop map was 82, 78 and 75%, respectively, and this value is 88% for a voting scenario. The results of this study showed that combining the capabilities of different classifiers improved the accuracy of land crop classification.

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Combining time-series of Sentinel-1 and Sentinel-2 for soil organic carbon estimation and mapping. Application to agricultural soils of a catchment area in Brittany, France

The degradation of agricultural soils, in the context of climate change and a growing world population, requires the urgent implementation of sustainable management of soils to improve their health. Therefore, it is important to produce maps that provide accurate information on the current state of soils and allow monitoring of soil properties changes over space and time. This is particularly true in the context of the 4 per 1000 initiative (Arrouays et al., 2019), which requires quantifying soil organic carbon storage in order to assess the relevance of changes in agricultural practices.

This study is carried out in the framework of the STEROPES project of the European Joint H2020 Program SOIL1 (Vaudour et al., 2022) and POLYPHEME project through the TOSCA program of the CNES (French Space Agency). Both projects aim to update SOC maps based on the use of Sentinel satellite time-series. Our main purpose is to evaluate the accuracy of SOC content estimates predicted using Deep Neural Network (DNN) algorithm and combined time-series of Sentinel-2 (S-2) images and soil moisture derived from Sentinel-1 (S-1) radar images.

Our approach was implemented to map SOC content of 12 agricultural fields over the Naizin catchment area (12 km²) in Brittany, western France. In October 2020, 55 composite soil samples were collected from the top 5 cm within these fields and Sentinel time-series were constituted using images acquired between September 2020 and August 2021. Setting the cloud cover threshold to 5% resulted in 24 usable S-2 images. After testing different combinations for the DNN input data, the best results in estimating SOC contents were achieved with time-series combining S-2 images with several spectral indices derived from S-2 bands and soil moisture derived from S-1 images. Finally, our results showed that the implemented approach resulted in a relatively accurate SOC content map.

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Prediction of Soil Organic Carbon based on Sentinel-2 NDVI data in Sardinia, Italy

Major drivers of gains or losses in soil organic carbon (SOC) include land management, land use change, and climate change (Beillouin at al., 2022). Environmental variables are widely used in SOC prediction. However, it is still difficult to determine which methods and variables are effective for SOC mapping (Chen at al., 2022). While knowledge of the spatial distribution of soil SOC content and its mapping is closely linked to its conservation (Zeraatpisheh at al., 2021), a spatially explicit map of it on the Sardinian Island is non-existent. The peculiarity of the latter is a great variety of landscapes owing to the different parent material, climatic conditions, topography, vegetation, and geomorphology. The interaction of these features has produced many soil types, such as Leptosols, Regosols, Luvisols, Cambisols and Umbrisols, with large differences in SOC content. Therefore, the aim of this study was to quantify the spatial distribution of SOC stocks and associated uncertainties to a target depth of 0–30 cm based on a multiple linear regressions (MLR) approach for Pedological Units to fill this knowledge gap. Data for 4032 georeferenced topsoils, extracted from Sardinian Soils Database (DBSS), were divided into calibration (n=3000) and validation (n=1032) dataset. Environmental variables including temperature, precipitation, elevation, slope, distance from the coast and Normalized Difference Vegetation Index (NDVI) data have been explored and included as independent variables to establish the model and estimate the SOC stock. We selected all S-2 cloud-free images covering the Sardinian Island (by averaging the monthly values of the most recent images) obtaining an average annual NDVI value. This study presente an effective method to overcome the selection of auxiliary variables for digital soil mapping in Sardinian Island and indicate that NDVI was conducive for predicting SOC. The results and the method will show exhaustively in the Poster.

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Integration of remote sensing soil organic carbon mapping using vegetation composites

Soil organic matter is essential for preserving and maintaining a range of soil and ecosystem functions as well as supply and store carbon for climate change mitigation. This work focuses on SOC mapping of permanently vegetated areas by Digital Soil Mapping. The approach suggested was implemented in a test case area in central Europe. The remote sensing (Sentinel 2) covariates were derived from the Soil Composite Mapping Processor –SCMaP. The pre-processing contains the preparation of the EO database that is used for the SOC retrievals. It is based on per-pixel composites from time series of EO satellite imagery (mainly from Sentinel 2 archive). Soil SOC observations at various locations were related to the previously described environmental covariates. The soil observations were split in 10 equally sized fold. Model tuning was performed with a 10-fold cross-validation procedure applied to multiple combinations of hyper-parameters. Quantile Random Forests (QRF) was used to model and obtain the uncertainty by pixel. With this option the prediction is not a single value, e.g., the average of predictions from the group of decision trees in the random forest, but rather a cumulative probability distribution of the soil property at each location. Predictions were then assessed with classical performance measures, i.e., root mean squared error (RMSE) and model efficiency coefficient (MEC). The resulting models and maps indicated that the covariates generated by SCMaP improved the model performances compared to the covariates set used for SoilGrids.

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The Theia "Digital Soil Mapping" Scientific Expertise Centre of France

The THEIA Data and Services Centre (www.theia-land.fr) is a consortium of 11 French public institutions (CEA, CEREMA, CIRAD, CNES, IGN, INRAE, Institut Agro Rennes-Angers, CNRS, IRD, Météo France, and ONERA) involved in Earth observation and environmental sciences. THEIA was created in 2012 with the objective of increasing the use of spatial Earth Observation data by the scientific community and the public actors.

Theia's Scientific Expertise Centres (SECs) bring together researchers from French laboratories who conduct research and develop innovative methods to analyse satellite, airborne and in situ data acquired on continental surfaces.

Founded in 2015, the Theia SEC called "Cartographie Numérique des Sols" (in English called DSM which stands for Digital Soil Mapping) federates the efforts of French research laboratories developing digital mapping approaches for soil properties. Its end-products are maps of soil properties for scientists, policy makers, stakeholders and general public. The main data used are multispectral optical images (SPOT6, Pléiades), optical (Sentinel-2, Landsat8) and radar (Sentinel-1) time series, airborne hyperspectral images (Hymap), soil data, digital elevation models, airborne gamma-spectrometric data and near-surface geological data.

The SEC "Digital Soil Mapping" aims to support the transition from research to operational digital soil mapping in France as described above. These objectives are:

- To federate and capitalize on the efforts made by the French teams involved in methodological developments and algorithms applied to digital soil mapping and remote sensing of soils;
- To produce spatialized estimates of soil properties at the national scale according to GlobalSoilMap specifications;
- To transfer and disseminate skills in the field of digital mapping and remote sensing of soils to actors operating at regional or local scales in France and in other partner countries particularly in the tropics.

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Data Repository of the Brazilian Soil: curating multi source data for spatio-temporal mapping of soil properties

Most digital soil mapping exercises ignore the temporal variation of soil properties. Changes in land use, climate, and other dynamic environmental factors cause such variation. One of the reasons to ignore the temporal variation is the small amount of field data available for training predictive models. In Brazil, the scenario of low data availability began to change with the data sharing movement promoted by the Data Repository of the Brazilian Soil (FEBR). The FEBR retrieves historical data and receives soil data from public and private organizations. These data come in different amounts and levels of completeness, organization, and documentation. Among the data quality issues, the lack of sampling and laboratory analysis documentation is the biggest obstacle to data curation. The rescue or inference of spatial and temporal coordinates, omitted even in recent data, is the most affected curation step. Curation of the coordinates requires iterative inquiry of those responsible for the data. The inquiry helps to correct logical, spelling, and numerical inconsistencies in the data. The lack of documentation also hinders the standardization of data. Data standardization requires correctly identifying variables, measurement units, and analytical methods. The inquiry of data producers often results in little extra information about analytical methods. Experts, laboratory handbooks, and related publications serve as alternative sources of information. Overall, the curation process takes 30-45 days, and its success is not guaranteed. Despite these issues, we have curated data from 10k soil profiles. The MapBiomas Network used these data to create the first time series (1985-2021) of maps of carbon stocks in Brazil. The goal for the next year is to double the quantity of curated data. Because the bottleneck is the quality of the deposited data, the FEBR will provide data producers with a new data deposit platform and data management and curation workshops.

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Potential of using Sentinel-2 temporal mosaics over a 5-year period to map soil organic carbon (SOC) in Beauce, Northern France

Soil organic carbon (SOC) is key in the growth and development of crops on arable land, as the study of this attribute has reported a positive correlation with plant vigor and crop production at small, medium and large scales. Therefore, the stocking of SOC in croplands has become a strategy of the world's food security and the use of new tools such as earth observation data (EOD) for mapping and monitoring organic carbon in agricultural plots has shown to be a potential resource. However, pedological, climatic conditions and/or management practices are different in each study area around the world and may influence SOC predictions of the topsoil layer [1-2-3]; there is still a gap about the capability of satellite imagery to predict topsoil SOC variability over large regional extents. Further studies to determine the potential of satellite imagery and which other covariates have a stronger influence in supporting organic carbon mapping are still needed. This study was carried out in the framework of the STEROPES project aiming to answer such issue.

In order to predict topsoil SOC content over croplands in the Beauce region, France (4838 km2), this study addresses: the use of Sentinel-2 temporal mosaics of bare soil images (S2Bsoil) over a 5 y-period, the use of soil moisture maps derived from Sentinel 1 and 2 data over the same period, and the inclusion of Gamma-ray images and terrain-derived covariates in machine learning models.

Two S2Bsoil images were produced in two periods of the year February-May (semester1) and July-November (semester2) from images acquired between 2017 and 2021; clouds and shadows were masked. Values of the 10 bands (2,3,4,5,6,7,8,8A,11 and 12) were extracted from the two S2Bsoil images and acquired covariates taking 391 sites as reference. Then, quantile regression forest (QRF) models were run.

The bare soil coverage of S2Bsoil for semester 1 in the study area was 84 % while that of that for semester 2 was 90 %. The prediction performance of the model created in semester 1 was slightly more accurate than that of semester 2 (RMSE = 2.58 g/kg and RMSE = 2.71 g/kg, respectively). Band 8, thorium values of gamma radiometric data and slope were among the top ten most important covariates of both models.

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Soil diversity as a co-variate in digital soil mapping (DSM)

A myriad of co-variates such as terrain attributes, climatic data, aerial and satellite images, legacy maps, etc., as well as many indices derived from them, have been tested so far, and more and more are being added rapidly within the digital soil mapping (DSM) framework. And all this for the sole purpose of increasing the accuracy of predicted soil maps. However, one of the possible predictors, i.e. soil diversity, remains neglected. The cause may be the traditional concept of pedodiversity that defines it as a certain diversity of the soil mantel over a certain land area, and thus not providing any value at each raster cell. A solution may be adopting the potential pedodiversity (PPD) concept (Vacek et al., 2020) – pedodiversity at each raster cell computed from its circular surroundings using a moving window method — that can provide a comprehensive raster layer for DSM.

To test the PPD as a co-variate, a large dataset of 3721 forest soil samples spread all over Czechia was used to predict soil organic carbon content at two soil layers (organic and 0–30 cm). In addition to the PPD layer, 23 other co-variates consisting of climate data (average temperature and annual precipitation), 16 terrain attributes and forest characteristics such as forest type, forest composition, forest vegetation stages and edaphic categories, were collected.

Despite the very low (organic layer) and low (0–30 cm) predictive accuracy of the random forest models, the benefit of using the new co-variate was still observed, namely in increasing the variability explained from 18,6 to 19.4% and from 39.2 to 40.5% for organic and 0–30 cm layer, respectively, and in decreasing the mean square error from 48.7 to 48.2 and from 3.3 to 3.2 for organic and 0–30 cm layer, respectively. Although the contribution of the PPD layer may seem negligible, the fact that it ranked first (0–30 cm) and second (organic layer) in the importance rank may indicate that it is worth of further research.

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Relevance of Sentinel-2 satellite images for monitoring manure and digestate spreadings on annual crops and grasslands over a farm (Nouzilly, France)

In order to mitigate the nitrate pollution, application of exogeneous organic matter (EOM) shall be monitored in compliance with the "fertilizer closed periods" of the European Union. Spectral indices in the visible, near-infrared and shortwave infrared domain such as EOMI2 proposed by Dodin et al. (2021) enabled the detection of spreading events through field measurements and bidate comparisons, and their use shall be temporally extrapolated and tested for winter periods. The difficulty in identifying EOM application lies in their ephemerous spreading over the soil surface, in conjunction with the underlying soil characteristics, and possible interference with soil management practices such as manure burying. A proof of concept is proposed here, based on both Sentinel-2 and some well characterized fields of the experimental INRAE farm of Nouzilly (France) for which the EOM types, quantities and precise dates of their spreading were known over the 2018-2022 period. Over the experimental fields in this farm, spectral measurements were carried out on emerging wheat in March-April 2022 (Dodin et al., 2022).

This study relies on the Sentinel-2 time series of spectral indices (EOMI2, NDVI, S2WI, NBR2) and the temporal sequence of farmer's works for seven large fields. The focus is set on the differences in values of image pairs, between and after spreading, and an ascending hierarchical classification of indices values, consolidated by a thorough description of the agricultural practices of EOM spreading, crop rotations and tillage operations following spreading events.

A large part of the spreading events was marked by spectral changes for which the spectral index EOMI2 did enable to detect a change, despite low rates of application. About the three quarters of spreading events were detected from the considered Sentinel-2 time series. A systematic search of small variations remains to be further carried out in order to detect spreading events amidst a time series.

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Using CNN-LSTM deep learning model for enhancing predictive mapping of soil carbon with long time phenological information

The spatial distribution of soil organic carbon (SOC) serves as critical geographic information for assessing ecosystem services, climate change mitigation, and optimal agriculture management. Digital mapping of SOC is challenging due to the complex relationships between the soil and its environment. Except for the well-known terrain and climate environmental covariates, vegetation that interacts with soils influences SOC significantly over long periods. Although several remote-sensing-based vegetation indices have been widely adopted in digital soil mapping, variables indicating long term vegetation growth have been less used. Vegetation phenology, an indicator of vegetation growth characteristics, can be used as a potential time series environmental covariate for SOC prediction. A CNN-LSTM model was developed for SOC prediction with inputs of static and dynamic environmental variables in Xuancheng City, China. The spatially contextual features in static variables (e.g., topographic variables) were extracted by the convolutional neural network (CNN), while the temporal features in dynamic variables (e.g., vegetation phenology over a long period of time) were extracted by a long short-term memory (LSTM) network. The ten-year phenological variables derived from moderate-resolution imaging spectroradiometer (MODIS) observations were adopted as predictors with historical temporal changes in vegetation in addition to the commonly used static variables. The random forest (RF) model was used as a reference model for comparison. Our results indicate that adding phenological variables can produce a more accurate map, as tested by the five-fold cross-validation, and demonstrate that CNN-LSTM is a potentially effective model for predicting SOC at a regional spatial scale with long-term historical vegetation phenology information as an extra input. We highlight the great potential of hybrid deep learning models, which can simultaneously extract spatial and temporal features from different types of environmental variables, for future applications in digital soil mapping.

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Regional Mapping of Peatland Boundaries using Airborne Radiometric Data and Supervised Machine Learning

Peatlands are recognized as important carbon sequestration centres. Through restoration projects of peatlands in which the water table is raised, they may become carbon neutral or possibly carbon negative. National restoration plans require a knowledge of peatland extent and spatial distribution across large geographic areas.

Recently the availability of large geo-spatial datasets has increased. These range from soil, quaternary, and geology maps to airborne geophysical and satellite remote sensing data. Such datasets may provide a means to spatially map peatland extents and boundaries traditionally mapped via in-situ measurements. However, these datasets, and their relationship to the subsurface, are often complex. Modern Machine Learning methods can play a role in analysing such multi-variate data within the discipline of Digital Soil Mapping.

Current peatland maps are created using combination of optical satellite remote sensing and legacy soil/quaternary maps. Optical remote sensing cannot detect peatlands under landcover such as forest or grassland. Legacy maps are often created from sparse in-situ augur, borehole, or trial pit data. These types of measurements do not allow for accurate measurement of boundaries or intra-peat variation.

Modern airborne geophysical datasets offer a potential means to update national and local scale peatlands maps. Radiometrics, a geophysical method that measures radiation emitted from geological materials, is particularly suited to peatland studies. Peat is a mostly organic material and so is, generally, not a source of radiation. Peat is also saturated and water acts to scatter the emitted gamma rays. These effects combined means that peatlands act as a blanket to any source of radiation from below and show as "low" radiometric signal in the landscape.

This study aims to use Airborne Radiometric data combined with modern supervised machine learning classification techniques to examine and update the current spatial distribution of a peatland database in Ireland. The methodology shows that a direct measurement, such as Radiometrics, analysed in a supervised machine learning framework, provides more accurate and justifiable estimates of peatland extent in this region.

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Can we evaluate the accuracy of digital soil maps for local prediction of particle size distribution with hand-feel soil textures observations?

Digital maps of soil properties are now widely available at various scales. End users can now access multiple Digital Soil Mapping (DSM) products of soil properties, produced using different models, calibration/training data, covariates and at various spatial scales from global to local.

Therefore, there is an urgent need to provide easy-to-understand tools to communicate map uncertainty in order to help end-users assess the reliability of DSM products for use locally.

In this study, we used a large number of hand-held soil texture (HFST) data to evaluate the performance of various published DSM products on the prediction of grain size distribution in central France. We tested four texture prediction DSM products developed at different scales (global, continental, national and sub-national) by comparing their predictions with approximately 3,200 HFST observations made on a 1:50,000 soil survey conducted after the publication of these DSM products. Both visual comparisons and quantitative indicators of match between DSM predictions and HFST were used.

The comparison between HFST and DSM forecasts observed at low cost clearly showed the applicability of various DSM products, with prediction accuracy increasing from global to sub-national forecasts. This simple assessment can decide which products can be used locally and if more accurate DSM products are needed for end-users.

Compared to usual indicators based on equations and statistics, this visual assessment is easier to communicate in a simple way the performances of map predictions to the end-users. In this poster, we explain briefly the method and illustrate it by some striking figures. For more details, we refer to a recent publication in the journal Pedosphere.

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Does increasing number of field observations necessarily improve the mapping of parent material?

We have been testing the applicability of remotely sensed data and machine learning techniques in the digital mapping of parent material in a pilot area, an old mining region in the Dorog Basin, Hungary. A geological map correlated with the FAO code system of soil parent material was used for training and for testing the classification concerning the lithological composition.

To predict the parent material we applied various machine learning methods (DL, RF, GB, GLM, NB and Keras). Satellite imagery data was used both in form of native spectral bands and derived spectral indices. Various derivatives of SRTM provided morphological auxiliary data and digital soil property maps were also introduced into the modelling process as predictors. 200 visual field observation were collected to test the effect of increasing number of ground truth. The model has been run according to two scenarios:

- the randomly generated points from the geological map were replaced by the nearest field observation points with the increasing number of it by 50
- the increasing number of field observation points were added to the randomly generated points

To evaluate the usage of increasing number of field observations in the prediction, the resulting classified maps were validated several ways:

- we run some analysis on the predicted map to examine its overall accuracy.
- we checked the difference between the predicted and the original map;
- we also examined the number of predicted unique value of each pixel and the percentage of the most frequently predicted value.

We experienced some interesting finding, which we tried to discuss, but assistance on their interpretation by the audience is heartily welcome.

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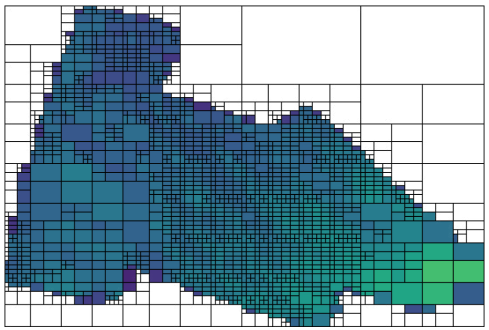
Variable resolution pixels or how to get rid of uncertainty maps

Since its inception, uncertainty assessment has been an integral component of digital soil mapping. However, most users find uncertainty maps difficult to perceive alongside the map of the target variable which leads to the underutilisation of such crucial information. Uncertainty maps are important since the quality of the map of the target variable varies in space. It would be useful if we could incorporate both sources of information into a single digital soil map. Some have experimented by fading or obscuring the target variable using the collocated value of the uncertainty. An alternative is to produce a map that has a constant uncertainty across it.

If we consider a 2 x 2 block of pixels (with predictions and associated uncertainties), a) the mean prediction represents an area 4 times larger than the base pixel size and b) the mean uncertainty is lower than the individual uncertainties. We take advantage of this property to create a new map representation using a quadtree by iteratively grouping map pixels until reaching a required target uncertainty. As a result, we obtain a variable resolution map (Fig. 1) where the final uncertainty is homogeneous. In the varying resolution constant uncertainty digital soil map -- users can immediately see where the soil is more variable or the uncertainty is large.



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Evaluating the quality of soil legacy data used as input of Digital Soil Mapping models

Most of the Digital Soil Mapping products now available across the globe have been developed from the deposits of punctual soil observations inherited from several decades of soil survey activity (Arrouays et al, 2017). By using these legacy data as input for calibrating our DSM models, we implicitly make the assumption that these legacy soil data are error-free. This assumption is obviously not true since several error sources may affect the values of soil properties that are registered in the soil databases (geo-referencing, laboratory methods, time, ...). To our knowledge, no reference on the importance of these soil legacy data errors have been established yet. The objective of this study was then to evaluate the quality of quantitative soil legacy data with reference to actual and certified soil laboratory measurements and to depict the different causes of differences between legacy and actual soil data.

The study was focused on a control sampling within the coastal plain of Languedoc (Southern France) at 137 locations where legacy measured soil profiles collected between 1955 and 1963 were available. At each location, four topsoil (0-20 cm) samples were collected at increasing distances (0, 5, 25 and 100 m) to characterize local variabilities of soil properties. Six primary soil properties were determined for each sample using modern certified soil laboratory methods.

The results revealed great differences between legacy and actual soil property values. A large part of these differences was caused by analytical biases that could be corrected by linear functions calibrated onto the control sampling data. We found also that one third of the non-corrigible differences was caused by the combination of an important non-GPS geo-positionning errors (31 m) and large local soil variabilities. Finally, for some properties, large parts of the differences remained unexplained (analytical errors, time, recording errors,...).

This study highlights the need to better control the quality of legacy soil data used in Digital Soil Mapping and to better account for this source of uncertainty to evaluate the quality of soil predictions and to understand their limitations.

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Accounting for operational constraints when sampling for Digital Soil Mapping. A Middle-East dryland case study

The conditioned Latin Hypercube sampling (cLHS) (Minasny and McBratney, 2006) is a widely used method in the Digital Soil Mapping community. This approach assumes that ancillary data can be used to generate a sampling scheme that is optimally representative of field variability by reproducing the distribution and correlation of available ancillary data. It has been proven to be efficient in many use cases, however, it does not allow to account for operational field constraints, which is mandatory when sampling in remote and inaccessible areas. In the past years, several authors have developed methods aiming to solve this issue (Roudier et al., 2012; Kidd et al., 2015). Despite this, none of those methods incorporate a generic cost constraint adaptable to contrasting situations. Therefore, this communication showcases a method derived from cLHS incorporating a cost constraint adapted to the dryland context including sampling cost (route distance, access to the zone, site sampling time), equipment cost, and analysis cost. The proposed method has been tested for sampling within a 662 points kilometric grid in a dryland context where soil analyses were conducted and several environmental co-variables are available as ancillary data. Discussions with field experts and the use of remote sensing images helped co-constructing a relevant access cost map and choose realistic cost values. The new method is compared to the classic cLHS and the adapted cLHS with cost basic constraint (Roudier et al., 2012) in terms of cost constraint and sample representation of ancillary data. Results show that the proposed method outperforms the two other methods in terms of cost constraint while providing a representation of ancillary data similar to the two other methods. Hence, this work provides a relevant solution for reducing sampling costs in remote and poorly accessible zones such as large dryland areas. Moreover, the relevance of using cLHS-derived algorithms for digital soil mapping as a sampling design will be discussed.

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Shapley values reveal the drivers of soil organic carbon stocks variation

Insights into the controlling factors of soil organic carbon (SOC) stocks variation is necessary both for our scientific understanding of the terrestrial carbon balance and to support policies that intend to promote carbon storage in soils to mitigate climate change. In recent years, complex statistical and algorithmic tools from the field of machine learning became popular for modelling and mapping SOC stocks over large areas. In this paper, we report on the development of a statistical method for interpreting complex models, which we implemented for the study of SOC stocks variation. We fitted a random forest machine learning model with 2145 measurements of SOC stocks for the 0-50 cm depth interval from mainland France and using a set of environmental covariates as explanatory variables. We introduce Shapley values, a method from coalitional game theory, and use them to understand how environmental factors influence SOC stocks prediction: what is the functional form of the association in the model between SOC stocks and environmental covariates, and how the covariate importance varies locally from one location to another and between carbon-landscape zones. Results were validated both in light of the existing and well-described soil processes mediating soil carbon storage and with regards to previous studies in the same area. We found that vegetation and topography were overall the most important drivers of SOC stock variation in mainland France but that the set of most important covariates varied greatly among locations and carbon-landscape zones. In two spatial locations with equivalent SOC stocks, there was nearly an opposite pattern in the individual covariates contribution that yielded the prediction: in one case climate variables contributed positively whereas in the second case climate variables contributed negatively, and that this effect was mitigated by landuse. This shows that SOC stock variation is complex and should be interpreted at multiple levels. We demonstrate that Shapley values are a methodological development that yielded useful insights into the importance of factors controlling SOC stocks variation in space. This may provide valuable information to understand whether complex empirical models are predicting a property of interest for the right reasons and to formulate hypotheses on the mechanisms driving the carbon sequestration potential of a soil.

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Mapping soil organic carbon stock and soil pH in an alpine pasture (Andossi Plateau, Northern Italy)

We mapped the soil organic carbon stock and soil pH of alpine pasture using different approaches to digital soil mapping. The main aim of the research is the prediction of the spatial distribution of SOC stock and soil pH. We applied different machine learning and deep learning models: ANNs, RF, MLR, KNN and SVR. The study area is the Andossi plateau, situated in the northern part of the Valchiavenna, a valley in the central Alps. According to the grazing plan, the Andossi plateau has an area of 350 ha with an average livestock rate of 0.71 bovines per hectare. The investigation area has an elevation between 1700 and 2050 m, with a south orientation. The Andossi plateau is characterized by lithological heterogenity. The dominant substrate in the south is carbonatic, while the predominant substrate in the north is acid, with glacial acid deposits present throughout the region in various thicknesses due to erosion. The vegetation types of the Andossi plateau are: Nardus stricta pasture, Sesleria grassland, earth hummocks, bentgrass and rich pasture. This diversity in the landscape has produced different soil types: Leptosols, Regosols, Cambisols, Umbrisols, Podzols, and Histosols.we used data from 280 soil sampling points. the sampling was done by horizons till the substrates or 50 cm.The SOC stock of all sampling points was calculated using the bulk density (BD) and the content of soil rock fragments. We used a pedotransfer function to estimate the BD in points where the presence of rock fragments was high and volumetric sampling was not possible. For the DSM approach, we used the following covariates: geomorphometric parameters, vegetation maps, and climatic information. to extract the geomorphometric parameters, a digital terrain model (DTM) with a pixel resolution of 4 meters was used. We obtained soil maps of SOC stock and soil pH for two soil layers (0–10 cm), (0–30 cm). Despite the correlation coefficient does not exceed 0.66, the best results were obtained by using ANNs models.

SESSIONS 6: DIGITAL SOIL ASSESMENT OF SOIL FUNCTIONS AND SERVICES

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Agricultural soil ecosystem services bundles definition through spatial analysis. A regional approach in Navarre (Spain)

Soils play a crucial role in the sustainable delivery of a large range of ecosystem services (ES) and ultimately on human well-being (Greiner et al., 2017). When such linkages are increasingly recognized, in a medium to long-term trajectories in the delivery of soil-based ecosystem services (SES) in relation to climate and land use or soil management are poorly known (Zank et al., 2016), particularly when it is not question of individual services but of bundles of services and of their relationships (Obiang Ndong et al., 2020). The service providing area (SPA) is the area involved in providing ES.

The region of Navarre (10,391 km2) is characterized by a high climatic variability, with a N-S precipitation gradient ranging from 2500 to 350 mm. This translates into a variability in terms of agricultural use, which represents 39% of the total area with 90.7% cropland and 9.3% grassland, and where more than 30% is irrigated. This agricultural use was characterized within the LIFE NADAPTA project, through a network of more than 150 agricultural plots in which a set of soil indicators were measured, including topsoil organic C, available water holding capacity and bulk density.

This work proposes the spatial analysis of the SES provided by the agricultural soils according to different stratification options of the territory, with the aim of identifying patterns in the support of SES within these stratifications. The hypothesis of the work is that a correct stratification of the territory can allow the clustering of the territory in SPAs and, therefore, the definition of bundles.

To this end, it is proposed first to select a set of SES (biomass production, erosion control, climate regulation, green water provision, and soil and water quality regulation) and to identify a series of indicators for their evaluation. Secondly, to evaluate them at the regional scale according to different stratification options within the region: no stratification, edaphoclimatic zones, land use and soil management.

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Mapping soil pH under future land use and climate changes in southeastern China

Mapping soil pH distributions is essential for evaluating soil quality and its ecological function. With the wide application of digital soil mapping, some soil properties represented by soil organic carbon have been mapped in different periods over a large time span, while the spatio-temporal distribution of soil pH, especially under climate changes, have been less quantified.

This study aims to estimate current topsoil pH in southeastern China, and predict its changes under a future intermediate emission scenario (SSP2-4.5). The study area belongs to the subtropical monsoon climate zone with a feature of abundant rainfall throughout the year, undergoing the problem of soil acidification. A space-for-time substitution approach was applied to predict soil pH using multiple linear regression (MLR) and extreme gradient boosting (XGBoost) methods. Precipitation, temperature, and land use were considered as dynamic covariates in modelling, extracted from previous datasets and general circulation models from the Couples Model Inter-comparison Project Phase 6 (CMIP6). The prediction could be used to identify potential areas under changes and thus help decision-making in soil management.

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Improving the annual crops mapping accuracy using feature level-based fusion of Surface biophysical properties

Preparing up-to-date land crop maps is one of the most important study directions in achieving food security and sustainable development in agriculture. Therefore, the aim of this study was to evaluate the impact of surface biophysical properties including surface greenness, wetness, imperviousness and reflectivity and feature level-based fusion of these properties on the accuracy of annual crops mapping. For this purpose, multi-temporal images of Sentinel 2 and an actual land crop maps prepared by Agriculture and Agri-Food Canada (AAFC) in 2019 were used for 3 site tests in Ontario, Canada. First, surface biophysical properties maps were prepared based on spectral indices including Normalized Difference Vegetation Index (NDVI), Index-based Built-up Index (IBI), Wetness, Albedo, and Brightness for different dates. Then, different datasets including single surface properties and a combination of several surface properties were generated. In the second step, land crop maps were prepared for each dataset based on the Maximum Likelihood Classification (MLC). Finally, accuracy of the land crop maps obtained from each of the datasets was evaluated based on omission and commission errors and overall accuracy metrics. The results showed that the mean temporal variation of NDVI, Wetness and IBI land crop classes was higher than Albedo and Brightness. Among agricultural products, the highest and lowest classification errors were related to wheat and soybeans, respectively. The average overall accuracy of land crop maps obtained from datasets including NDVI, IBI, Wetness, Albedo and Brightness were 66, 68, 63, 60 and 57 %, respectively, which by combining the surface biophysical properties, the overall accuracy of land crop maps increased to 80%. The results of this study indicate that the feature level-based fusion of surface biophysical properties the increases the accuracy of annual crops mapping.

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An approach to map nitrous oxide emission risk by soils at regional scale based on soil properties

Anthropogenic emissions of nitrous oxide (N2O), a potent greenhouse gas, are mainly due to agricultural practices. N2O is often emitted by soils after nitrogen fertilization when the reduction of nitrate into N2 is incomplete and the soil is in hydromorphic condition. To take action to reduce N2O emissions, we need to identify and locate areas that may be emitting N2O. An approach to map N2O emission risk by soils was therefore defined based on soil properties. The risk of N2O emission was assessed through three components; the Vulnerability: the ability of the soil to reduce N2O, the Hazard: the probability of soil water-logging and the Exposure: the addition of nitrogen to the soil. Vulnerability and hazard were considered to be specific of emission risk linked to the soils, while exposure depends on agricultural practices. Vulnerability and Hazard were thus used to estimate a risk of N2O emission by soils. They were estimated using soil databases of 1/250000 scale French soil map (Richer-de-Forges et al., 2019). The latter contain the drainage class information which allow inferring the hazard. They also have measurements of pH, CEC and clay content which allow estimating vulnerability through a pedotransfer function (Hénault et al., 2019). The approach was applied in the Haut-Loir watershed (3600 km²), a highly cropped area in the French Center Region. Using RRP at at 1:250000 scale enabled to assess N2O emission risk for the 20 soil types of the studied region. Contrasting risks were highlighted between different soil types and agricultural regions. High risk soils (~2% of the studied area) are generally found in valleys and are not under crop because of their hydromorphy and acidity, however attention should be given to medium risk soils (~32% of the area) which are mainly found in the western region. Different actions of mitigation depending on the degree of risk were suggested.

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Modelling the impact of agricultural management on soil carbon stocks and their mapping at the regional scale under tropical climate

Agricultural management has received increased attention over the last decades due to its mitigation potential in climate change by sequestering soil carbon (C) and reducing of greenhouse gas. Relying appropriate strategy of agricultural management at slopelands, soil C loss through lateral fluxes derived from erosion is significantly alleviated. In this study, we aimed to evaluate budget of the soil C at orchards with different agricultural managements (conventional farming (CF) and ecological friendly farming, (EFF)) on slopelands in Liouguei district (192 km2), southern Taiwan, and to predict variation of soil C stock in near future (2100 A.C.) under RCP 8.5 scenario provided by IPCC using machine learning model (random forest model). The results indicated that additional soil C input (+2.45 kg m-2 yr-1) in topsoils (0-30 cm) in the orchard with EFF treatment through soil survey data in 1986, 2015 and 2020 in our studied area. Additionally, the EFF effectively reduce lateral soil C flux (soil C losses) at least 2.27 times compared with the CF. In this study, regression Kriging approach was further used for modelling and mapping the soil C with several environmental parameters in present and near future. The performance of soil C prediction was assessed by validation data and we obtained an R2 of 0.94, and the spatial distribution of soil C was mainly controlled by "organic C inputs" and "soil properties, such as pH, bulk density and clay", and "elevation". We considered that the soil properties and elevation might be the constant parameters around the neighbour ochards in this study, and therefore soil C input in terms of agricultural management practice must be a crucial factor to determine soil C stock. The results of temporal evolution of soil C (from 2020 to 2100) under RCP 8.5 scenario further presented that soil C stock will increase by a rate of 150 kg ha-1 yr-1 as management practice of 1/3 orchard area (~250 ha) was turned into EFF from CF in this study, which the soil C stock of the orchards might explain about 15% variance in this regional area.

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Assessment of digital soil mapping using causal machine learning

Machine learning methods have been remarkably successful in extracting essential information from data in a wide range of application areas, including digital soil mapping (DSM). Despite the fact that these models are trained for high accuracy, there is a recent and ongoing high demand for understanding how a specific model operates and the underlying reasons for the model's decisions. The interpretation of the model is a critical step that could lead to the generation of new knowledge to improve our understanding of soils. Recent advances in causal machine learning enable the estimation of intervention impacts on the desired outcome for samples described by a set of observed characteristics. We present an extensible data-driven framework for DSM that leverages the observations and frames it as a geospatial impact assessment problem, where the estimated effects of the most important features on the final map can be discovered and used to guide decision-making. This is a causal machine learning task, and we discuss how this technique can make models simpler to explain. In particular, we investigate topographic features and employ double machine learning to estimate the heterogeneous effects of these topographic features on desired outcomes such as calcium carbonate (TNV), clay, and soil depth values in Iran's Kurdistan region. We find that in high areas, the effects of elevation and slope were insignificant, whereas the multiresolution index of valley bottom flatness (MRVBF) had a considerable effect on the outcomes.

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Tillage erosion as a covariate for the organic carbon mapping in cropland over Denmark

The compilation of environmental layers representing soil forming factors in the scorpan model is crucial in digital soil mapping (Lagacherie and McBratney, 2007). Data availability for producing these environmental layers has been a major barrier in soil mapping processes around the turn of the century (McBratney et al., 2003).

Recent technological developments in remote sensing tools have facilitated the cost-effective acquisition of environmental layers to support models in response to the current needs for environmental resource modeling (Lagacherie and McBratney, 2007). Therefore, deriving relevant environmental layers for characterizing soil-landscape relationships is an important field of study (Fan et al., 2022).

We aimed to explore the relevance of annual soil redistribution due to tillage operations as a covariate for mapping topsoil organic carbon contents on all arable land in Denmark. The patterns of tillage-induced soil redistribution were generated with WaTEM (Water and Tillage Erosion Model, Van Oost and Govers, 2006) calculating average soil translocation distances and soil fluxes in the direction of the steepest slope (Van Oost and Govers, 2006).

We used a 10-m resolution LiDAR DEM as WaTEM input. Since the change in terrain curvature drives tillage-induced soil redistribution patterns, we ran the model with differently smoothed versions of the DEM to characterize the model's sensitivity to DEM pretreatment. and the effect of the smoothing on the organic carbon prediction in croplands. We compared the WaTEM outputs with a Sentinel-2 multitemporal bare soil composite to assess their pertinence to characterize soil-landscape relationships.

The less smoothed outputs of WaTEM showed higher correlations with the bare soil composite bands in erosional zones. Further analyses are required to select the most suitable output of WaTEM to characterize the soil organic carbon dynamics, considering erosional and depositional processes in arable lands over Denmark.

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Using the 1:1 000 000 French Soil Geographical Database to assess relationships between soil ecosystem services on arable areas in France

The ecosystem services linked to soil functioning in agricultural ecosystems strongly depend on the soil properties, cropping systems (i.e. crops sequences and managements), and climate. To support land managers decisions about soil use and management practices, the assessment and mapping of trade-offs and synergies between ecosystem services (ES), as well as their underlying drivers, would be of major interest. We developed an innovative analytical approach based on i) the modeling of soil functioning using the STICS crop model and ii) the analyses of ES indicators using a multivariate regression tree combined with a spatially-explicit approach. We applied our approach to the main non-irrigated Paris basin of production – i.e. a most important agricultural production region of France – to evaluate relationships between agricultural production, two services to farmers (nitrogen provision to crops and water provision to crops), and three services to society (blue water provision, water quality regulation, and climate regulation). The input dataset used for ES modelling was based on the French National Ecosystem Assessment on agricultural systems, and included informations about the cropping systems, climate data from the SAFRAN grid, and soil information from the 1:1 000 000 French Soil Geographical Database. We demonstrated that water quality regulation, nitrogen provision to crops, and climate regulation have synergistic relationships in production situations in the Northeastern region of the study area, due to the types of crop rotation, frequency of cover crops in the crop rotation, the soil pH, and the soil available water capacity. We also demonstrated that cover crops can drive a trade-off between two key water-related services: water provision to crops and blue water provision. The results expressed by maps associated to ES trees are quite intuitive to interpret, even for non-scientists, and provide key information for managers and policy makers.

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Global soil functions modelling

The thickness of the soil is a fundamental property for many applications related to agricultural practices (e.g., rootable depth), water management and carbon stocks. The definition of "soil thickness" depends on context and applications. Soil thickness by any definition is not easily measured in situ because of the gradual transitions from pedologic soil to regolith, making it also a challenging variable to reliably map. Legacy data rarely record this valuable information because many surveys are limited to the topsoil only. This creates the problem of right-censored data where most observation do not record the full depth. When thickness is recorded, inconsistencies across datasets may happen due to surveyor's interpretations of horizons and layers designations. Many approaches to model and map soil depth have been used ed, from mechanistic models to empirical-statistical models. In this study we extracted relevant information from the WoSIS database and integrated it with expert-derived information to provide a global map of "solum thickness". We choose the definition of "solum thickness" (I.e. depth of A and B horizons) to try to overcome some of the definitions issues for soil thickness. The observations queried can be reasonably considered as having reached the bottom of the B horizon. Therefore, the problem of right-censored data was limited. The solum thickness was then mapped using Quantile Regression Forest using covariates describing the soil forming factors, following the scorpan approach. Results were assessed with k-fold cross-validation. Initial results are reasonably accurate in areas with high density of observations, while less accurate in regions with a lower density.

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Regolith Mapping of a catchment area to recommend the agricultural drains removal to combat the droughts of the SEICHE river : Analyse of the critical zone in hardrock aquifer

The SEICHE river is a river which, as its name suggests, is subject to severe and regular droughts. Added to this, is the installation of agricultural drains during the 1960s, 1970s and 1980s to optimize farming. With the advent of climate change which is reflected in the SEICHE catchment area by more regular droughts, we have imagine a method that can be recommended for the removal of certain agricultural drains and thus provide a gain of underground water for supports it from its low water level. After reflection, the cartography of the regolith, often underestimated on geological maps at 1/50,000 of the BRGM, but also the creation of a groundwater model, both combined with the geomorphology of the site, show that the drains installed under certain plots, are inefficient and useless for the improvement of agriculture. On the other hand, their deletions would allow an additional supply of groundwater to the SEICHE but beyond to the rivers located above the hardrock aquifers. Thus flat, non-clay soils where the unsaturated zone is deep enough do not need to be drained. This study makes it possible to better adapt the agricultural development according to this critical zone which is the regolithe and the preservation of both water resource and biodiversity.

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Application of machine learning techniques for soil erosion mapping on vineyards

The northern part of the Gerecse Hills, Hungary belongs to the Neszmély Wine Region, and is affected by intense soil erosion, which is a serious threat to sustainable agriculture. Three vineyards of the region were selected to quantify the amount of eroded soils.

In the first approach we used the Universal Soil Loss Equation (USLE) model which is based on empirical observations. We have modelled the seasonal and annual soil loss in high-resolution by monitoring the study sites with unmanned aerial vehicle (UAV). One year of monitoring showed the impact of seasonal variation in vegetation cover and rainfall on soil erosion rates. The results have been used to identify the high risky areas of erosion at each study site.

After the empirically based, spatially detailed quantification of erosion, we have been tested the applicability of machine learning techniques to predict soil erosion for the selected parcels in the same time period. The main idea was to use the empirically inferred erosion values as observation data to build parcel specific prediction models which are then tested on the other two parcels. In the model we have used (i) Sentinel 2 satellite data in the form of both native spectral bands and its derived spectral indices; (ii) terrain features derived from digital surface model created and aggregated from the UAV flights and (iii) formerly elaborated digital soil property maps as auxiliary data. Various machine learning methods (RF, GB, SVM) have been tested to find best performing predictions. Observation data were generated in the form of random points, in 100 representations. Model performances have been tested by proper measures by which the applicability of machine learning techniques for soil erosion mapping has been evaluated.

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Mapping of soil-based ecosystem services, soil threats and their evolution in European arable lands – A systematic review

The soil-based ecosystem services (SESs) are the ecosystem services provided by soils and their chemical, physical and biological properties, processes and functions i.e., carbon sequestration, biomass production, soil fertility and soil erosion control. On the other hand, soil and SESs are threatened by rapid environmental changes and anthropic activities identified as soil threats (STs). Soil erosion, soil organic carbon (SOC) loss, nutrient imbalance, soil acidification, soil contamination, compaction, soil sealing, soil salinization, loss of diversity are among the most important STs in agricultural landscape. This study analyses the existing maps of SESs and STs at the European-scale for arable land and their evolution under different scenarios based on a systematic review of the scientific literature. Only 9 documents on SESs mapping and 26 on STs mapping were found in the literature. The most commonly mapped SESs and STs were: erosion control (32%), climate regulation including carbon sequestration (27%), soil erosion (19%) and SOC loss (10%). Only three articles regarding the evolution of SESs and STs under different scenarios of climate and/or land use change were encountered. They consider soil loss by water erosion and loss of SOC as STs, and SOC stock as SES. Overall, conceptual, deterministic and statistical models were the most frequently used for SESs assessment. While for STs, deterministic models, statistical models and expert knowledge were the most frequently used. The limited number of publications, particularly in recent years, indicates that the complexity of SES and ST assessment at the European-scale, as well as their evolution under land use and climate change scenarios, requires further investigation. More studies should be developed to monitor the evolution of SESs and STs, evaluating methods to mitigate the reduction of SESs and the increase of STs thus contributing to the European agricultural and environmental policies and research.

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Soil mapping data for assessing soil security based on soil quality, erosion and production potential

Soil degradation in Korea is serious and is closely related to water erosion due to topography, rainfall pattern and intensive cultivation. Soil management was carried out in various ways to reduce soil loss and improve soil fertility. Recently, the importance of soil conservation, soil security, and sustainable soil management has grown and application methods are being developed, but there is still a lack of methods for evaluating and managing soil security in Korea. Therefore, we tried to evaluate soil security and develop soil management methods and systems accordingly. Three-dimensional matrix, which is consisted of soil erosion, soil quality and land productivity potential, was employed to assess the status of soil security. The quantity of soil erosion was determined by the Korean Soil Loss Equation (KORSLE). KORSLE is a Korean soil loss equation that reflects the characteristics of Korea based on RUSLE. The soil quality was based on the chemical properties of the soil. In this study, pH, SOM, available phosphorus, and exchangeable potassium were used. The data of soil series in south Korea was scored with the developed evaluation model, and each result was combined, and then classified into 5 grades. The productivity potential was based on the suitability classes of the 64 crops evaluated by Rural Development Administration of South Korea (RDA). Based on the level of soil security at each field, a pertinent BMP is recommended. This process was developed as the WEB-GIS-based system, and it can indicate soil security grades based on soil productivity, quality, and threat factors (soil erosion), and provide best management practice required for each soil security grades.

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