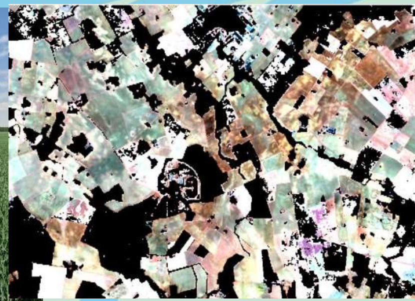
Workshop “O Solo : Indicadores da sua qualidade e boas práticas agrícolas no contexto de alterações climáticas”– Benavente, Portugal - 21 de Março 2024

Mapping of soil organic carbon from satellite remote sensing (STEROPES project)

Mapeamento do carbono orgânico do solo a partir de sensoriamento remoto por satélite (projeto STEROPES)





Emmanuelle VAUDOUR
Université Paris-Saclay, UMR EcoSys, INRAE Versailles-Saclay, France

Johanna Wetterlind, Luboš Borůvka, James Biney, Diego Urbina-Salazar, Asa Gholizadeh, Fabio Castaldi, Dominique Arrouays, Anne C. Richer-de-Forges, Mohammadmehdi Saberioon, Pasquale Nino, Silvia Vanino, Fenny van Egmond, Renaldas Žydelis, Didier Michot, Youssef Fouad, Artur Lopatka, Jose L. Gabriel, Nádia Castanheira, Ana Marta Paz, Muhammed Halil Koparan, Cantekin Kivrak, Frank Liebisch, Raimonds Kasparinkis, Lucas de Carvalho Gomes

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INRAE université PARIS-SACLAY

iniav Instituto Nacional de Investigação Agrária e Veterinária, I.P.

STEROPES
EJP SOIL
Στεροπῆς

Στερόπης

STEROPES project of EJP SOIL

Stimulating novel Technologies from Earth Remote Observation to Predict European Soil carbon

https://ejpsoil.eu/soil-research/steropes/

STEROPES
Stimulating novel Technologies from Earth Remote Observation to Predict European Soil carbon

https://ejpsoil.eu/soil-research/steropes/

Στερόπης

- Duration in months: 42. Budget 2.3 M€
- Started in February 2021
- *Topic*: MT1 “Good knowledge of the present status of agricultural soils: Innovative techniques for soil mapping and assessing spatial and temporal variation of soil properties”
- *Project leaders*: Emmanuelle VAUDOUR (INRAE, France)-Johanna WETTERLIND (SLU, Sweden)
- *Partners :* EV-ILVO (Belgium), CZU (Czech Republic), AU (Denmark), INRAE (France), CREA (Italy), UL (Latvia), LAMMC (Lithuania), WR (Netherlands), IUNG (Poland), INIAV (Portugal), INIA (Spain), SLU (Sweden), AGS (Switzerland), TAGEM (Türkiye)

Στεροπῆς

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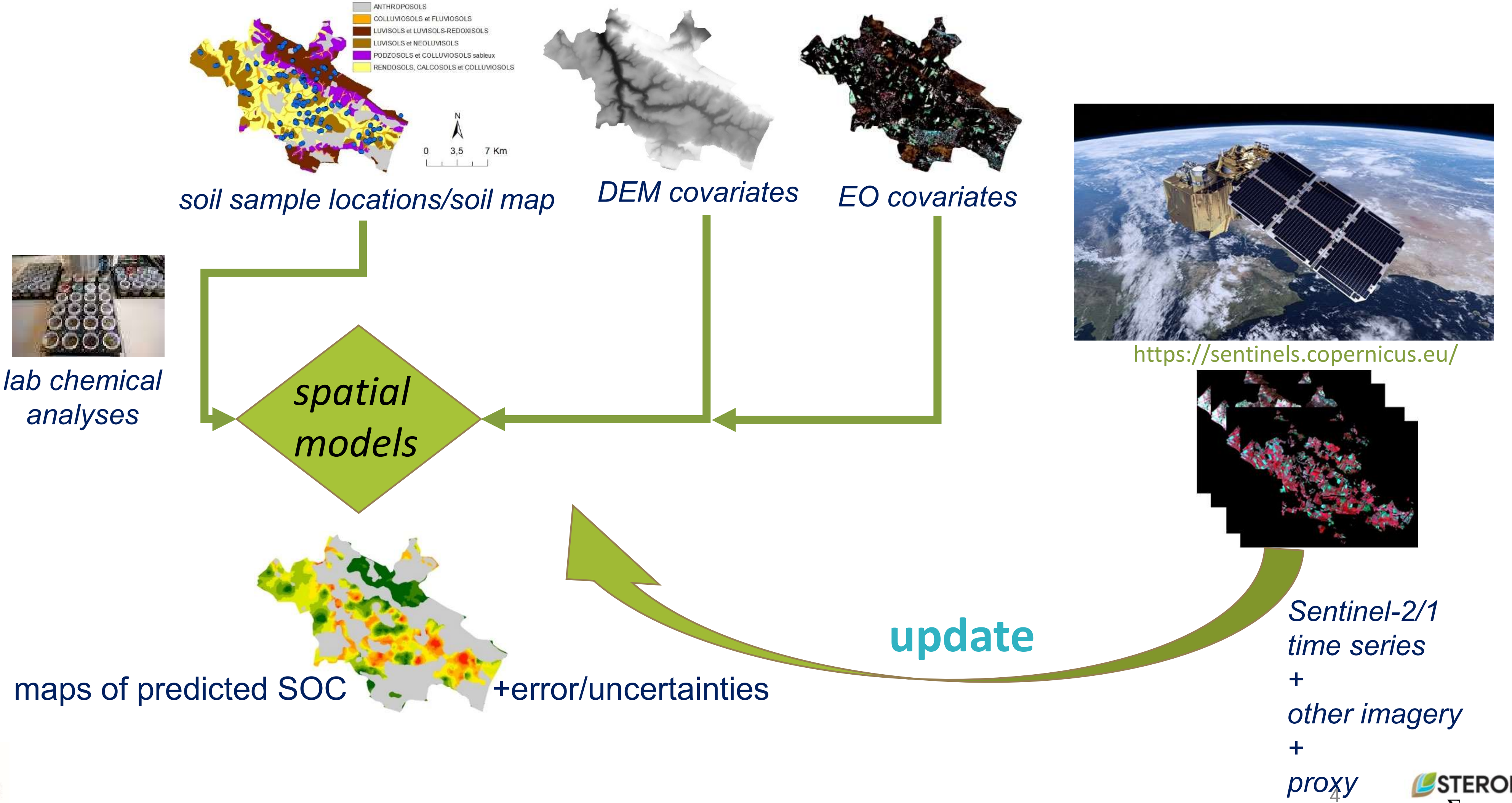
Context: need to spatially estimate and monitor many soil properties for decision support and land management from Digital Soil Mapping (DSM)



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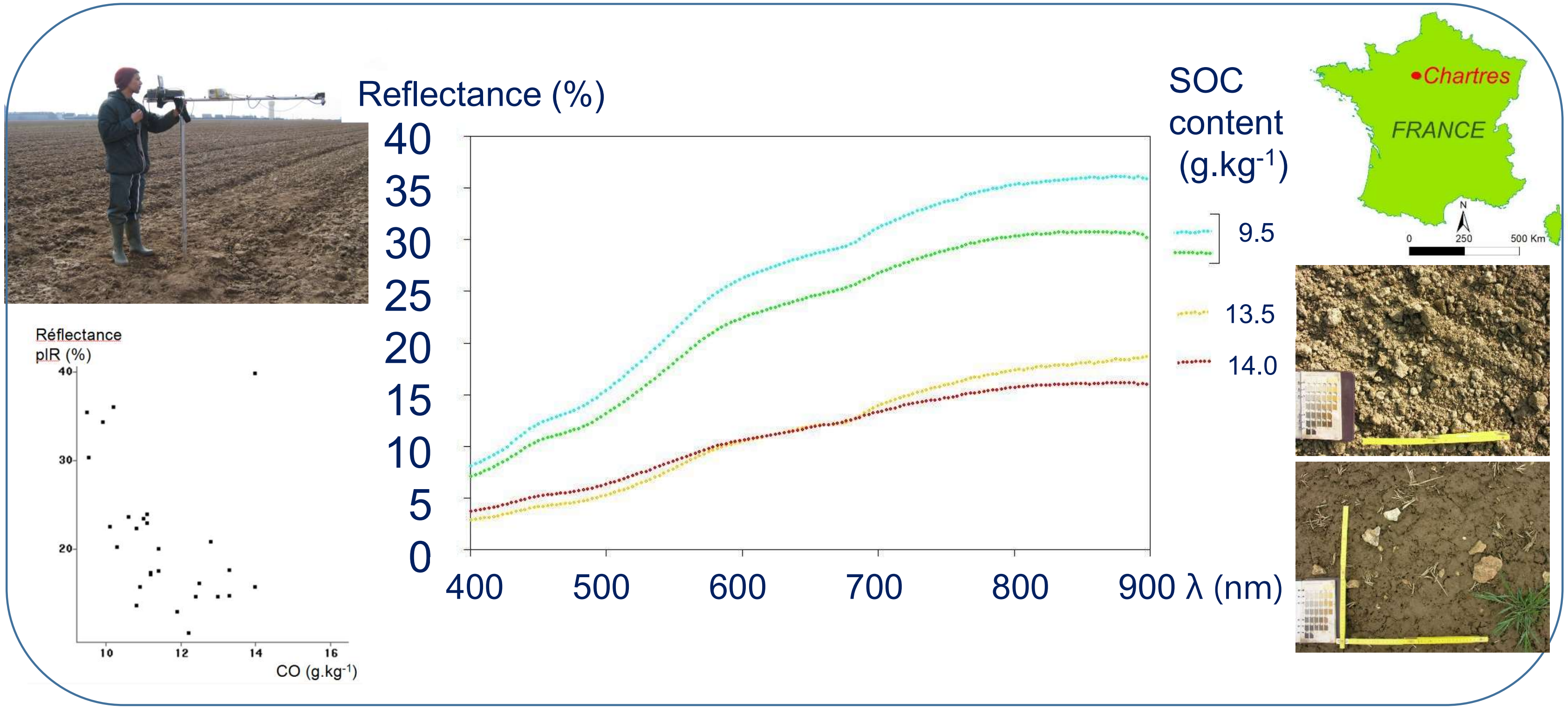
STEROPES Στεροπῆς

SOC content influences soil reflectance



BERTHIER et al., *Etude et Gestion des Sols* 2008

La Beauce

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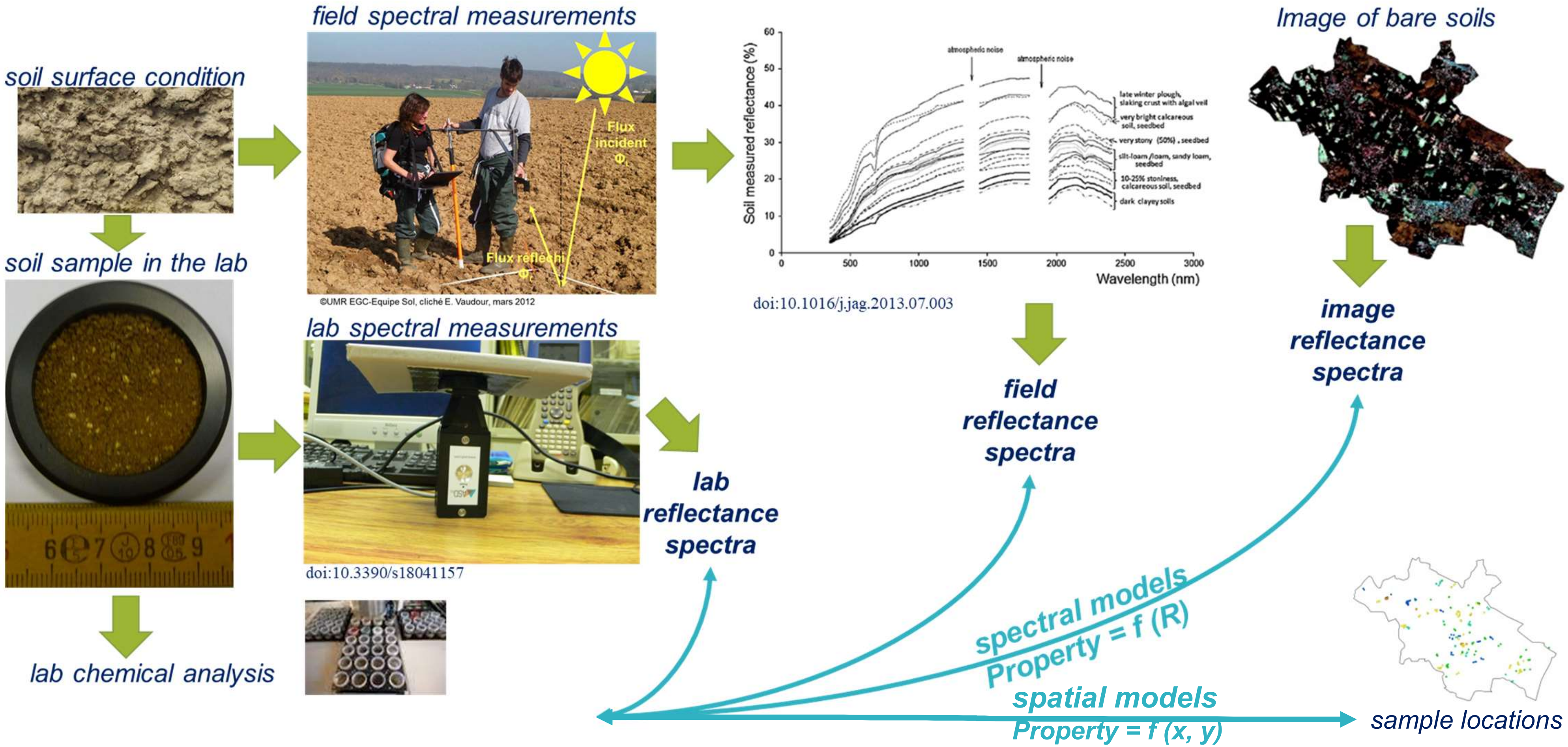
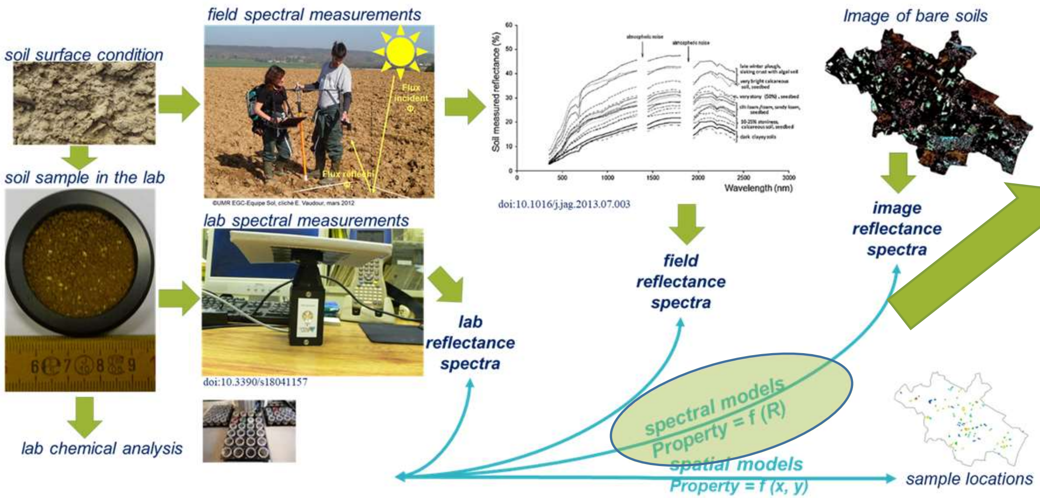
STEROPES Στεροπῆς

Overall background : soil properties have spectral (& spatial) features that enable to construct spectral models



Project objectives



1. **assess robustness of spectral models according to agroecosystems/soil types**
   - At regional scale 10 to 10000 km²
   - At farm/field local scale – 0.01 to 3 km²
2. **assess/account for disturbing/influencing soil surface factors**
   - soil moisture
   - soil texture
   - dry and green vegetation
   - salinity
3. **incorporate 1- and 2-results into spatial models**
   - best performing methods/data
   - uncertainty assessment

Project structuration

- WP0 – project coordination — Emmanuelle VAUDOUR (AgroPT), Johanna WETTERLIND (SLU)

AXIS 1

- WP1 – spectral models — **Lead Lubos BORUVKA (CZU)**, deputy lead Emmanuelle VAUDOUR (AgroPT)

AXIS 2

- WP2 – disturbing factor: soil moisture — **Lead Pasquale NINO (CREA-LP)**, deputy lead Artur LOPATKA (IUNG)
- WP3 – influencing factor: soil texture — **Lead Johanna WETTERLIND (SLU)**, deputy lead Frank LIEBISCH (Agroscope)
- WP4 – disturbing factor: crop residues — **Lead Mehdi SABERIOON (ILVO)**, deputy lead Johanna WETTERLIND (SLU)
- WP5 – disturbing factor: soil salinity — **Lead Emmanuelle VAUDOUR (Agro-PT)**, deputy lead Ana Marta PAZ (INIAV)

AXIS 3

- WP6 – Data fusion for improving accuracy — **Lead Fenny VAN EGMOND (WR)**, deputy lead Gabriele BUTTAFUOCO (CREA-LP)
- WP7 – additional activities regarding spectral models and soil sampling strategy — **Lead Lubos BORUVKA (CZU)**, deputy lead Emmanuelle VAUDOUR (AgroPT)

extension WP

Instituto Nacional de Investigação Agrária e Veterinária, I.P. (iniav)

Where are we now?

- WP0 – project coordination — Emmanuelle VAUDOUR (AgroPT), Johanna WETTERLIND (SLU)

AXIS 1

- WP1 – spectral models — Lead Lubos BORUVKA (CZU), deputy lead Emmanuelle VAUDOUR (AgroPT)

AXIS 2

- WP2 – disturbing factor: soil moisture — Lead Pasquale NINO (CREA-LP), deputy lead Artur LOPATKA (IUNG)
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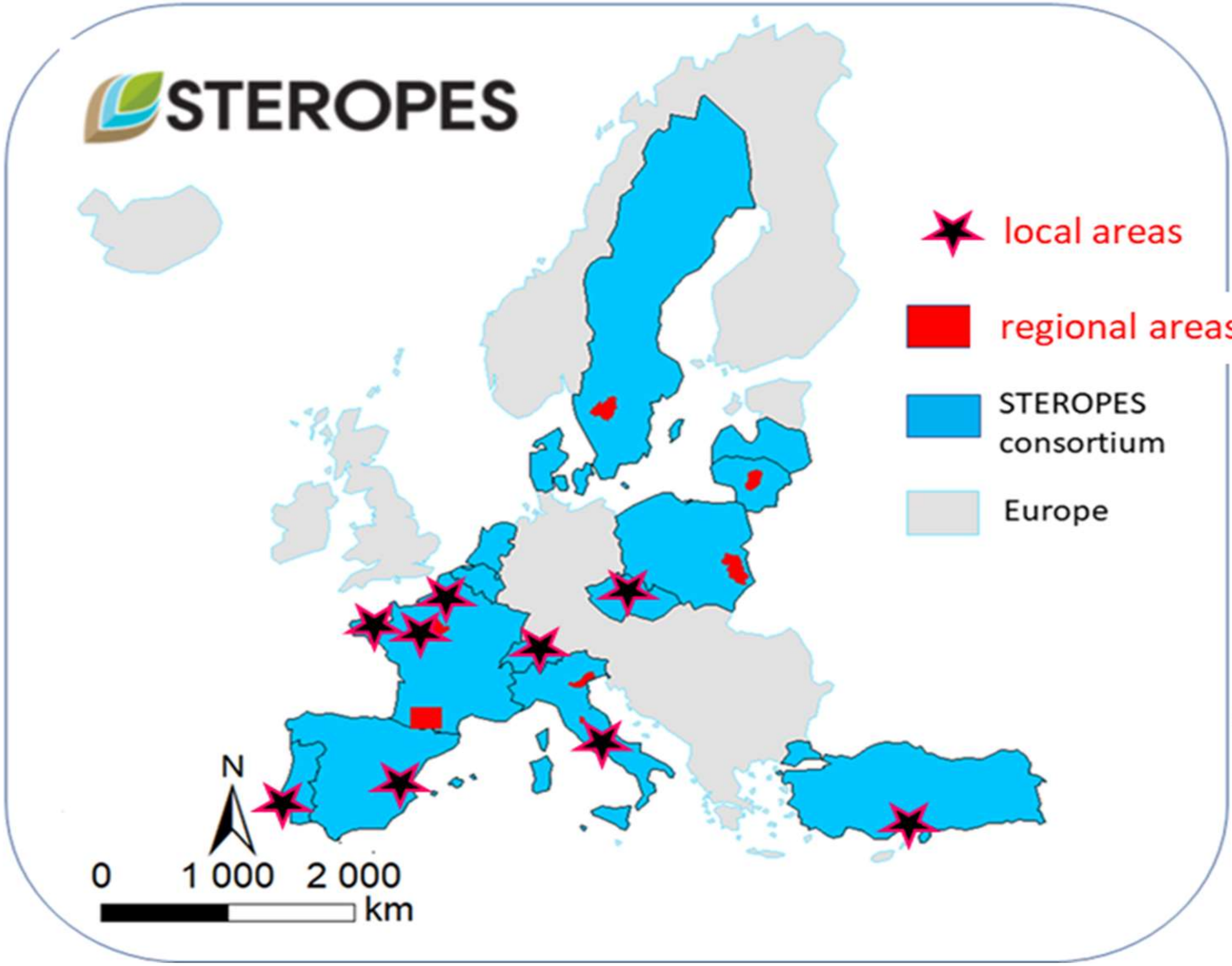
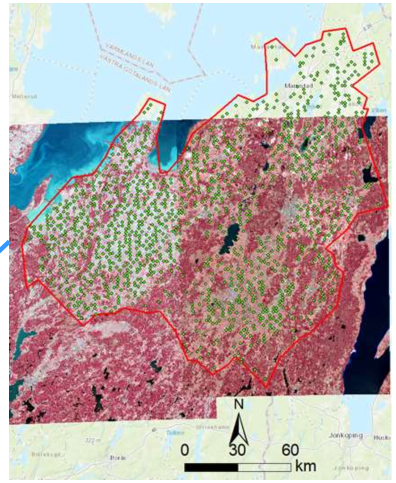
- WP7 – additional activities regarding spectral models and soil sampling strategy — Lead Lubos BORUVKA (CZU), deputy lead Emmanuelle VAUDOUR (AgroPT)

in progress

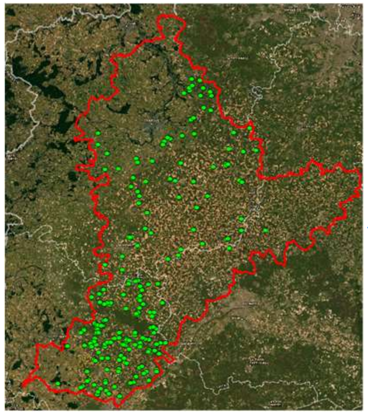
Collected datasets



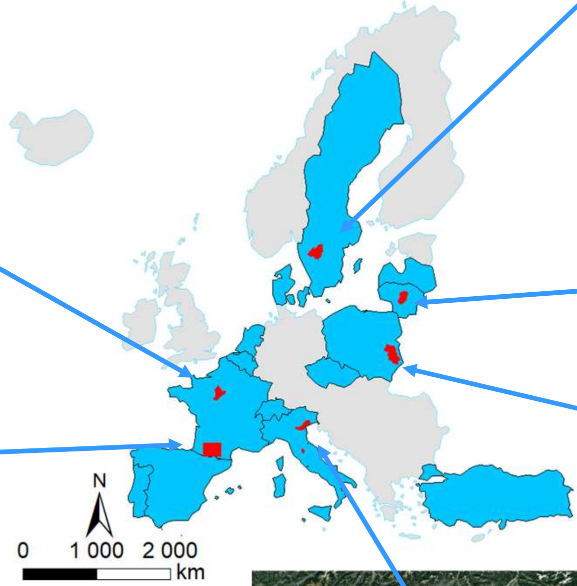
Collected datasets at regional scale

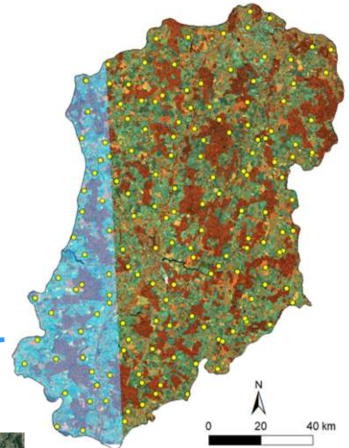


Västra Skaraborg

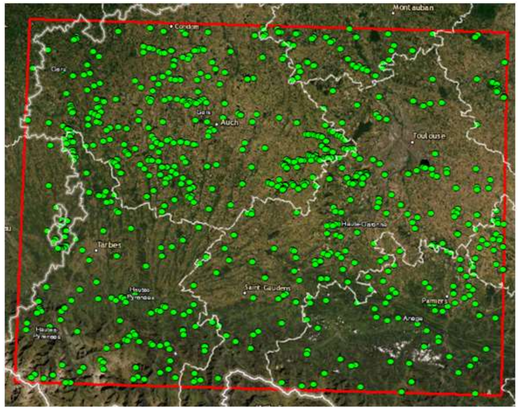


Beauce





Nevezis Plain

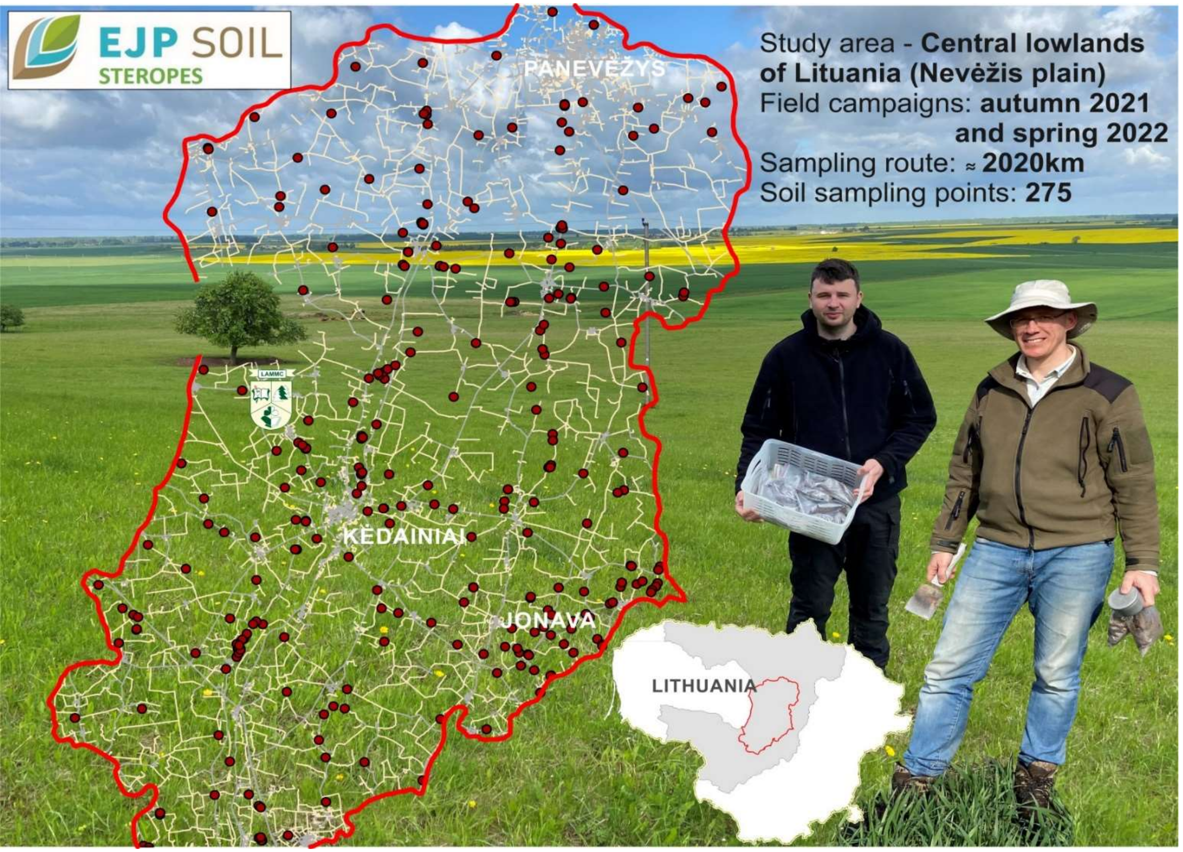


Pyrenean piedmont

Wieprz watershed

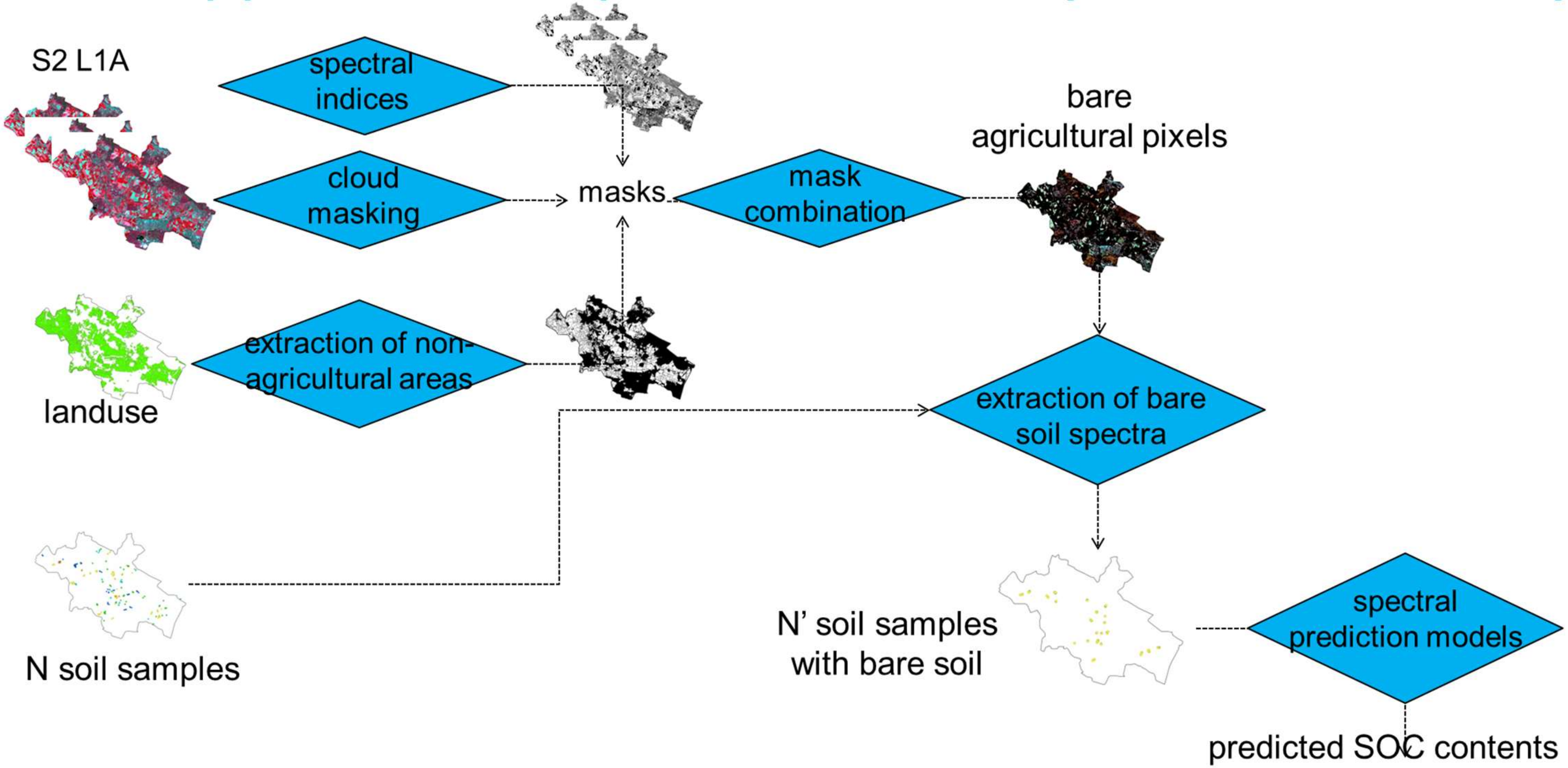
Tuscany-
Val di Chiana

Field campaigns



LAMMC, Lithuania

Overall approach for spectral models (STEROPES-WP1)



Achievements

achievement	description	detail
international conference	6 talks, 11 posters	Living Planet ESA 2022, Bonn, Germany Soil Mapping for a Sustainable Future. 2nd joint Workshop of the IUSS Working Groups Digital Soil Mapping and Global Soil Map, Feb 2023, Orléans, France SoilCET symposium 2024 ESA4SOIL symposium
Multi-partners papers	Vaudour et al., 2022 Castaldi et al., 2023 Bazzi et al., 2023	3 published; 3 in prep (Wetterlind et al; Zydelis et al.; Vaudour et al)
Single-partner paper/software mentioning STEROPES as funding source	Urbina-Salazar et al., 2021 Mzid et al., 2022 Urbina-Salazar et al., 2023 Richer-de-Forges et al., 2023 Dodin et al., 2023 Zayani et al., 2023 Saberioon, 2023 Lopatka, 2023 Castaldi, 2023	7 published; 1 submitted (Khosravi et al.) ; 1 in prep (Dodin et al)
special issue	Special issue proposed and edited in the framework of the STEROPES consortium	

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Review

Satellite Imagery to Map Topsoil Organic Carbon Content over Cultivated Areas: An Overview

Emmanuelle Vaudour [1,*], Asa Gholizadeh [2], Fabio Castaldi [3], Mohammadmehdi Saberioon [4], Luboš Borůvka [2], Diego Urbina-Salazar [1,5], Youssef Fouad [6], Dominique Arrouays [5], Anne C. Richer-de-Forges [5], James Biney [2,7], Johanna Wetterlind [8] and Bas Van Wesemael [9]

1 Université Paris-Saclay, INRAE, AgroParisTech, UMR EcoSys, 78850 Thiverval-Grignon, France; diego.urbina-salazar@inrae.fr
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5 INRAE, InfoSol, 45075 Orléans, France; dominique.arrouays@inrae.fr (D.A.); anne.richer-de-forges@inrae.fr (A.C.R.-d.-F.)
6 UMR SAS, Institut Agro, INRAE, F-35000 Rennes, France; youssef.fouad@agrocampus-ouest.fr
7 The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, Department of Landscape Ecology, Lidická 25/27, 60200 Brno, Czech Republic
8 Department of Soil and Environment, Swedish, University of Agricultural Sciences, 53223 Skara, Sweden; johanna.wetterlind@slu.se
9 Georges Lemaître Centre for Earth and Climate Research, Earth and Life Institute, Université Catholique de Louvain, 1348 Louvain-la-Neuve, Belgium; bas.vanwesemael@uclouvain.be
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check for updates

Citation: Vaudour, E.; Gholizadeh, A.; Castaldi, F.; Saberioon, M.;

https://doi.org/10.3390/rs14122917

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ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

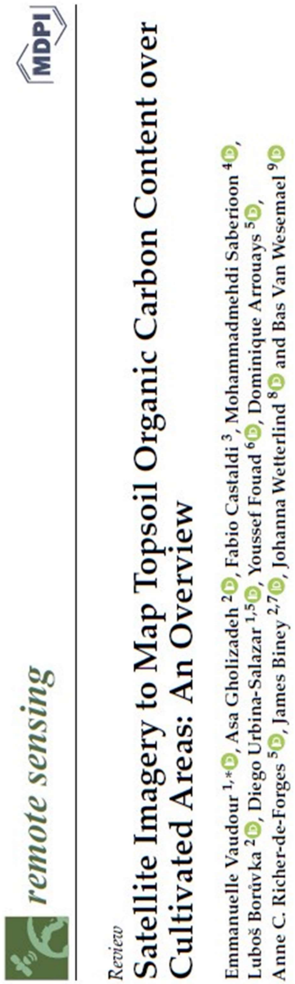
Assessing the capability of Sentinel-2 time-series to estimate soil organic carbon and clay content at local scale in croplands

Fabio Castaldi [a,*], Muhammed Halil Koparan [b], Johanna Wetterlind [c], Renaldas Žydelis [d], Ialina Vinci [e], Ayşe Özge Savaş [b], Cantekin Kıvrak [f], Tülay Tunçay [b], Jonas Volungevičius [d], Silvia Obber [e], Francesca Ragazzi [e], Douglas Malo [g], Emmanuelle Vaudour [h]

[a] Institute of BioEconomy, National Research Council of Italy (CNR), Via Giovanni Caproni 8, 50145 Firenze, Italy
[b] Soil, Fertilizer and Water Resources Central Research Institute Ankara, Turkey
[c] Swedish University of Agricultural Sciences, Department of Soil and Environment, Skara, Sweden
[d] Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Lithuania
[e] Environmental Protection Agency of the Veneto Region (ARPAV), Italy
[f] Atatürk Soil Water and Agricultural Meteorology Research Institute, Kırklareli, Turkey
[g] South Dakota State University, Department of Agronomy, Horticulture & Plant Science, Brookings, SD, USA
[h] Université Paris-Saclay, INRAE, AgroParisTech, UMR EcoSys, 91120 Palaiseau, France

https://doi.org/10.1016/j.isprsjprs.2023.03.016

Timeline of satellite derived-SOC studies


MDPI
remote sensing
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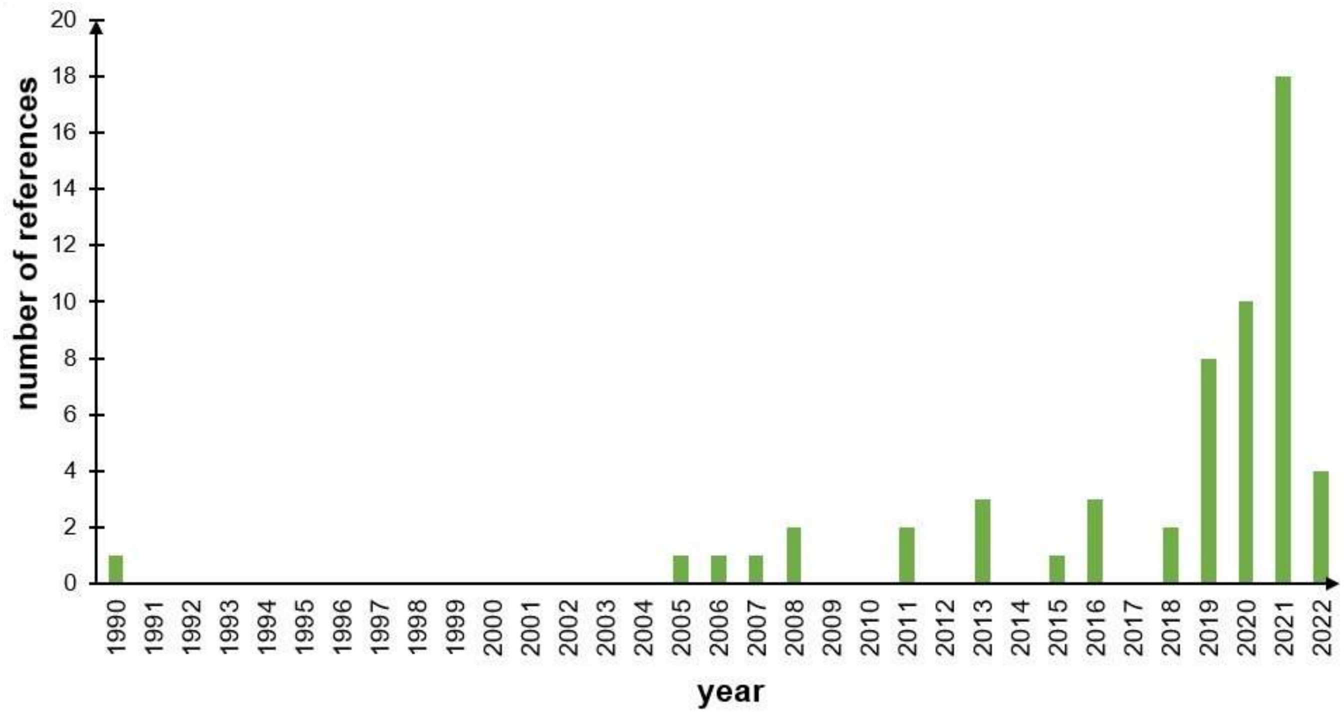
1990 to early 2022



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VAUDOUR et al., 2022 -https://doi.org/10.3390/rs14122917

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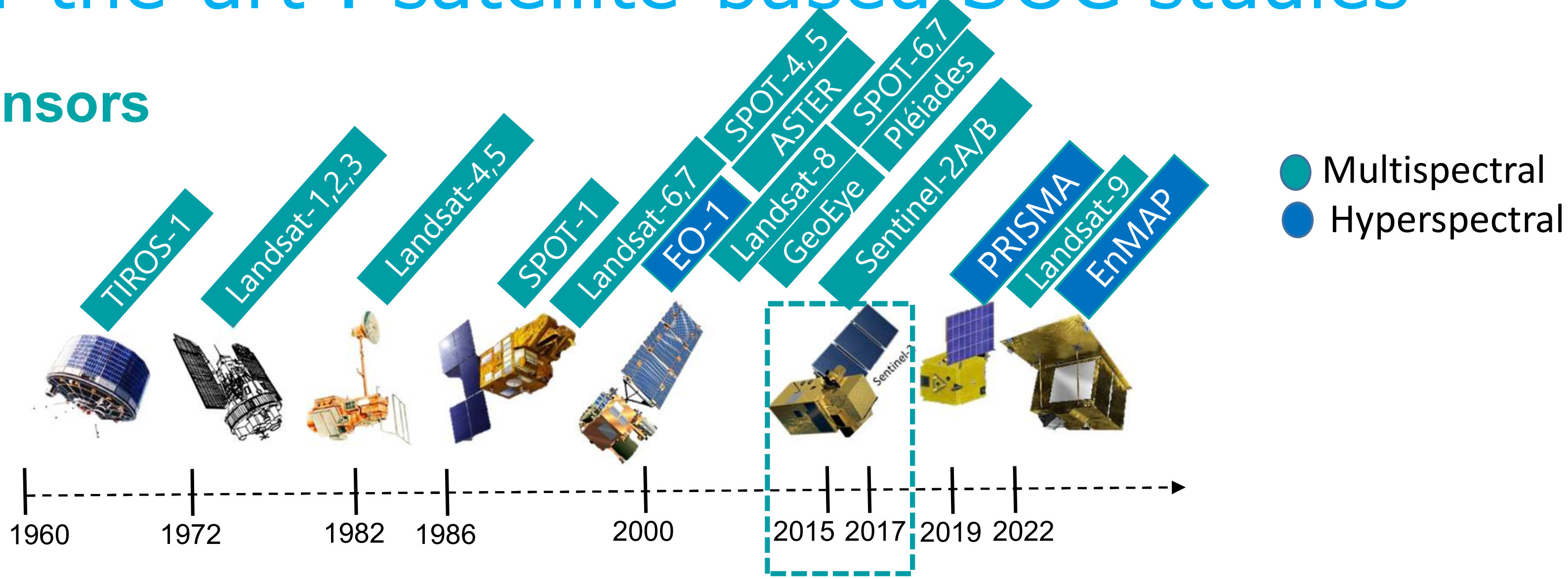
State-of-the-art : satellite-based SOC studies

Satellite sensors



Pioneering SOC studies from satellite imagery

East central Illinois

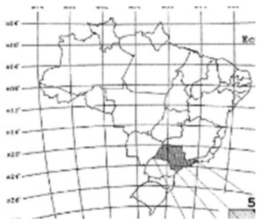
30 km^2

SPOT1

(Agbu et al., 1990)

Rafard, Brazil

2 km^2

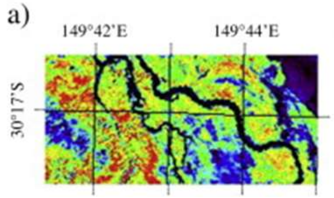


Landsat

(Nanni and Demattê 2006)

Narrabri, Australia

50 km^2

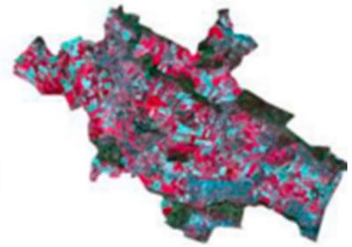


Hyperion

(Gomez et al., 2008)

Versailles plain, France

221 km^2



SPOT4

(Vaudour et al., 2013)

VAUDOUR et al., 2022 -https://doi.org/10.3390/rs14122917

SOC prediction methods via satellite imagery

1) Purely spectral

Satellite images
BSI

2) Spectral Bottom up

Castaldi et al., 2018

Satellite images

Soil spectral libraries

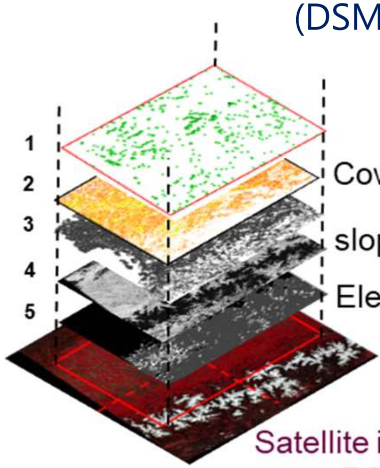
Orgiazzi et al., 2018

Demattê et al., 2019b

GEOCRADLE
Tziolas et al., 2019

3) Mixed

Digital Soil Mapping (DSM) McBratney et al., 2003



Satellite images
BSI

Advantages and disadvantages

1) Purely spectral

- Free access to satellite images
- assessment and interpretation of pure soil spectral data
- Soil sampling required

2) Spectral Bottom up

- Free access to satellite images
- no sampling required
- Spectral libraries available mainly at national and continental scales (difficult to use on smaller scales)

3) Mixed

- Free access to satellite images
- assessment and interpretability of influential covariates
- Specific covariates not available for all areas
- Soil sampling/legacy required

VAUDOUR et al., 2022 -https://doi.org/10.3390/rs14122917

World map of satellite-derived SOC studies

MDPI
remote sensing

Review

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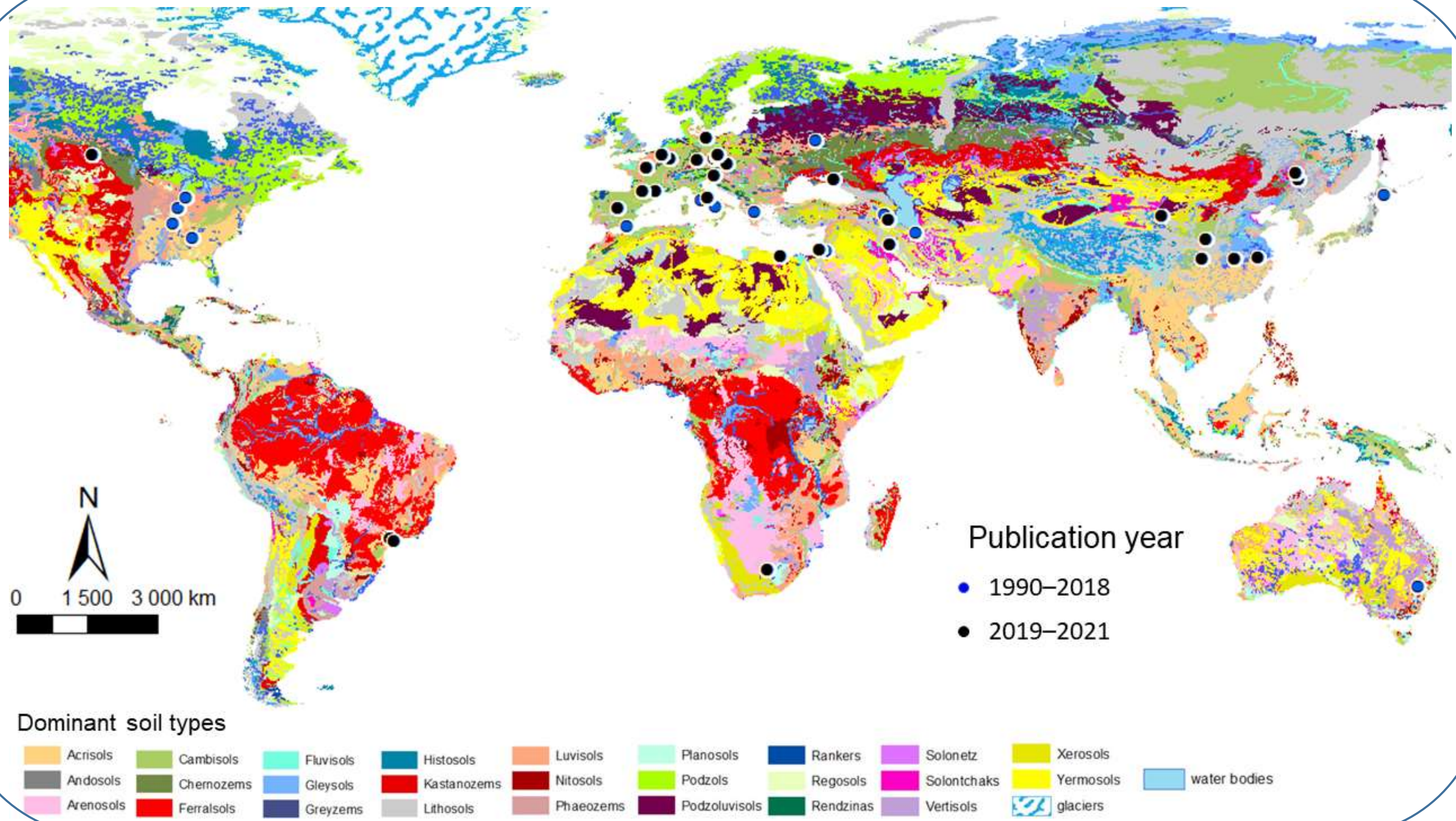

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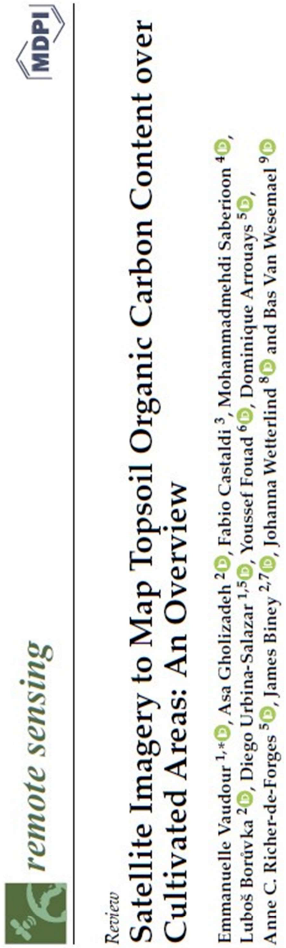
Main soil types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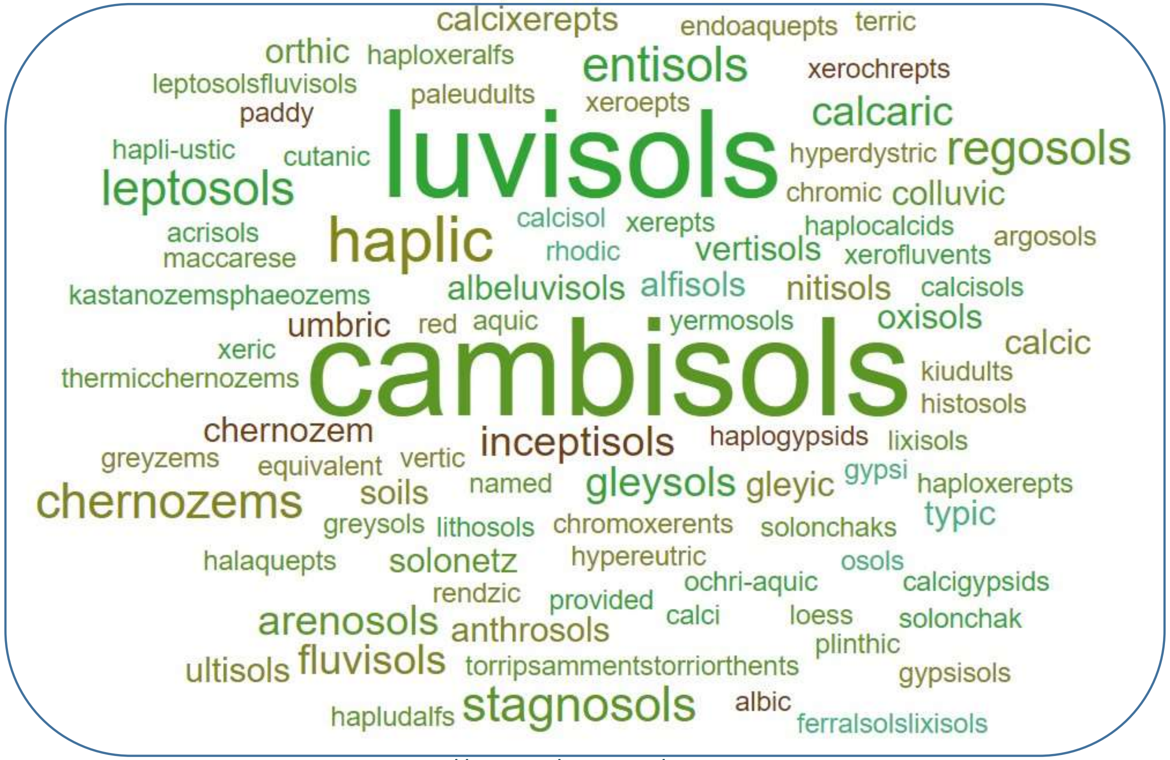

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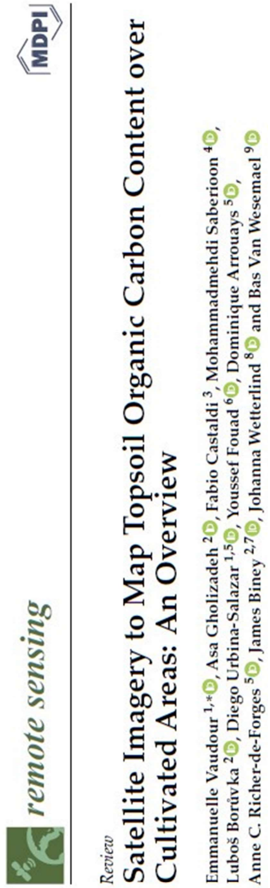
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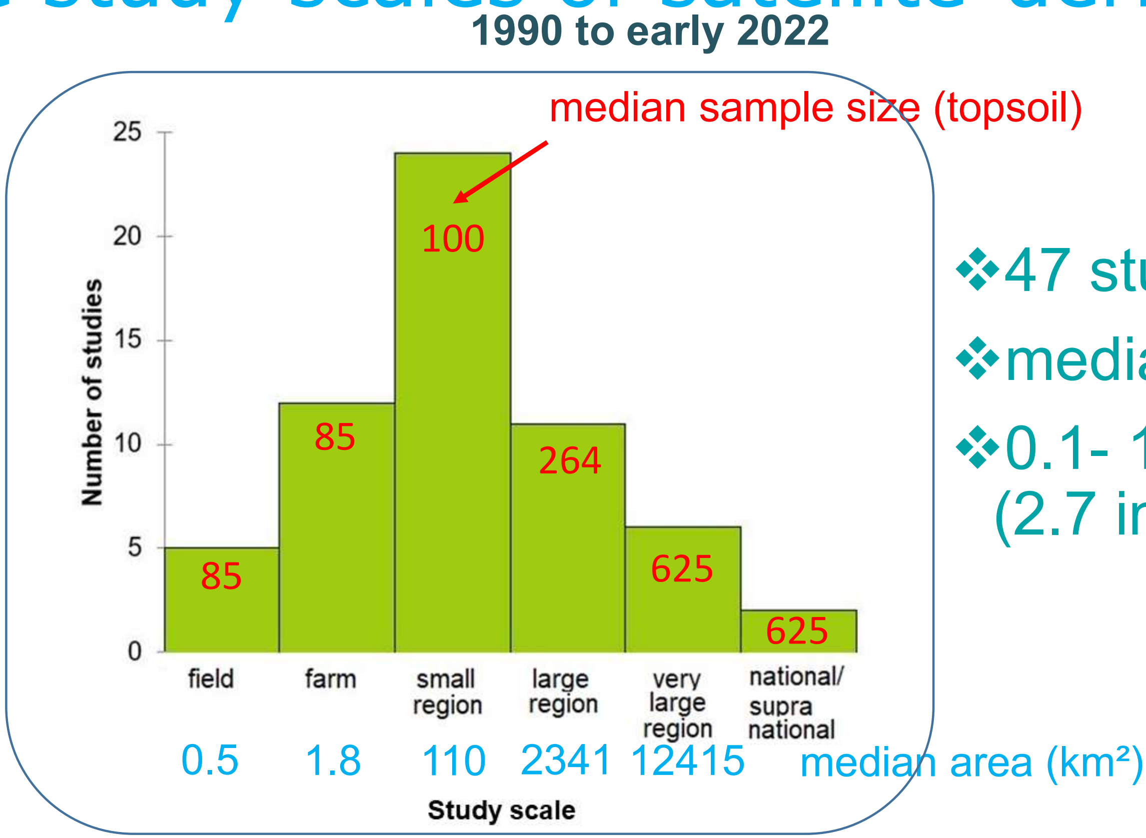
The study scales of satellite-derived SOC



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- 47 studies
- median area of 118 km²
- 0.1- 16.1 samples/km² (2.7 in average)

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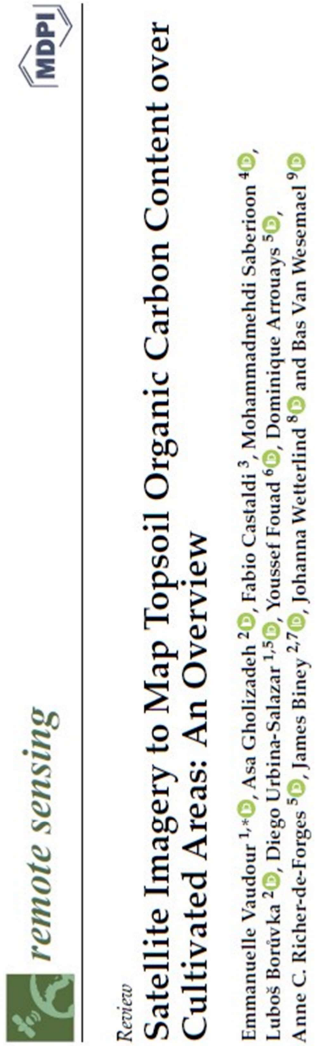
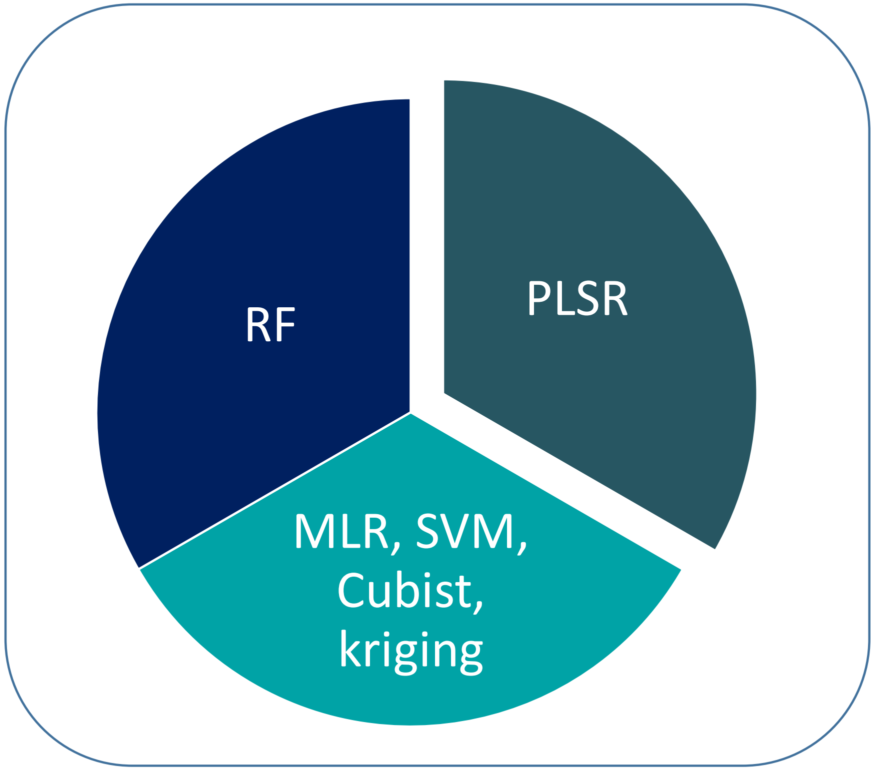


Satellite-derived SOC spectral models



VAUDOUR et al., 2022 -https://doi.org/10.3390/rs14122917

- ❖mainly built from bare soil reflectance
- ❖PLSR and RF dominant

➢ comparison of algorithms in progress through STEROPES

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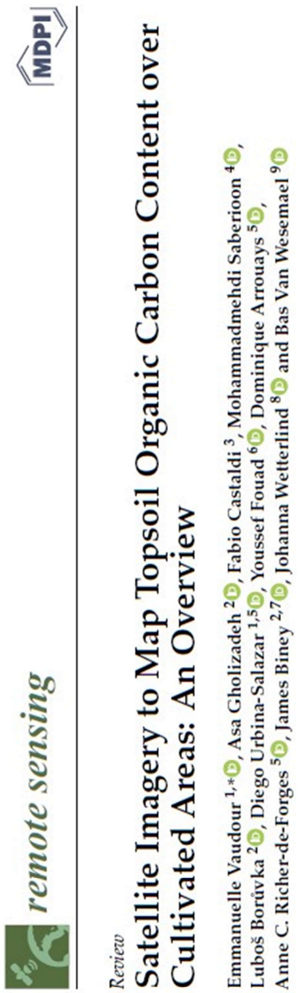
 STEROPES Στεροπῆς

Overall performance of spectral models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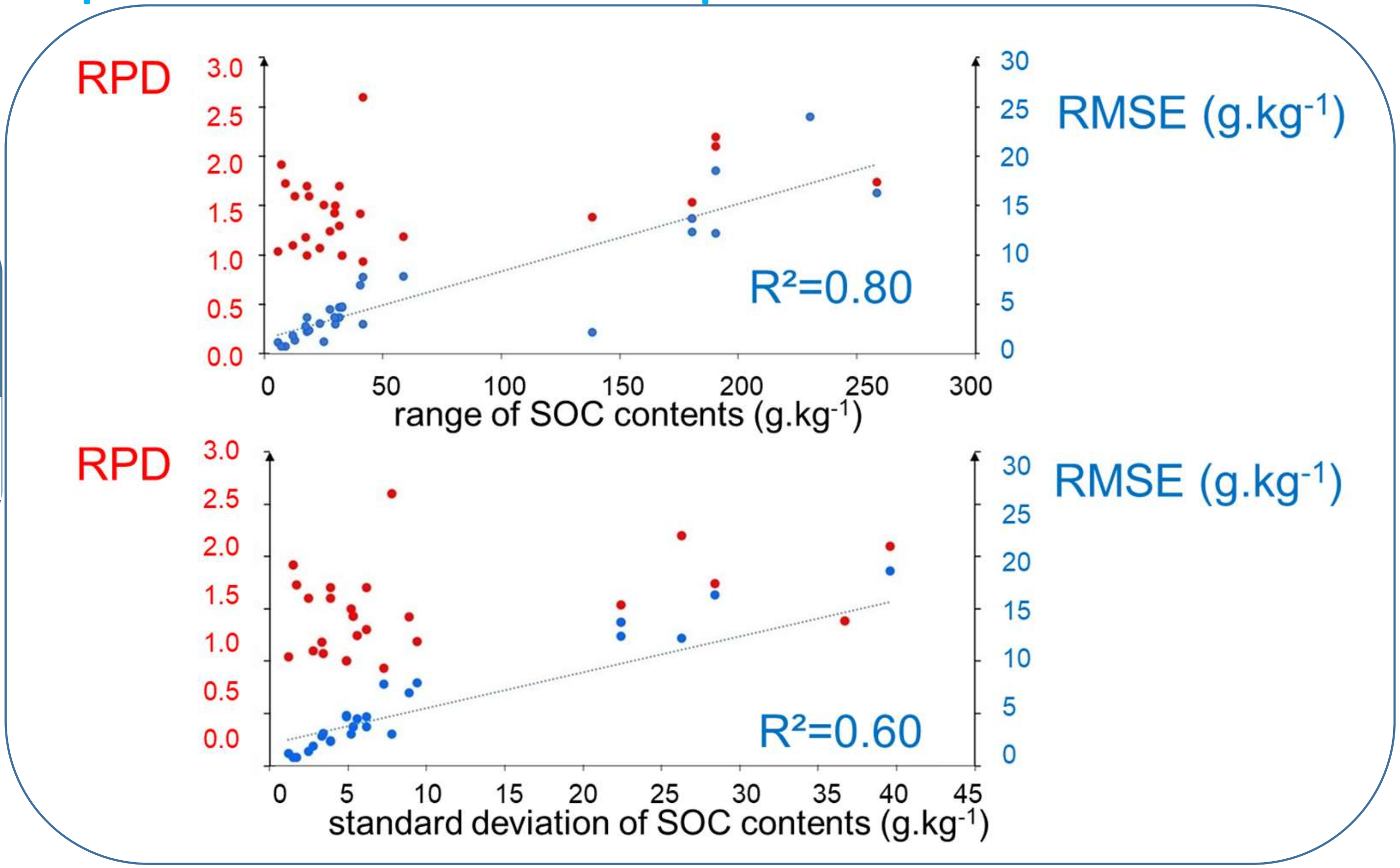
Residual prediction deviation

$$RPD = \frac{\sigma_y}{RMSE}$$



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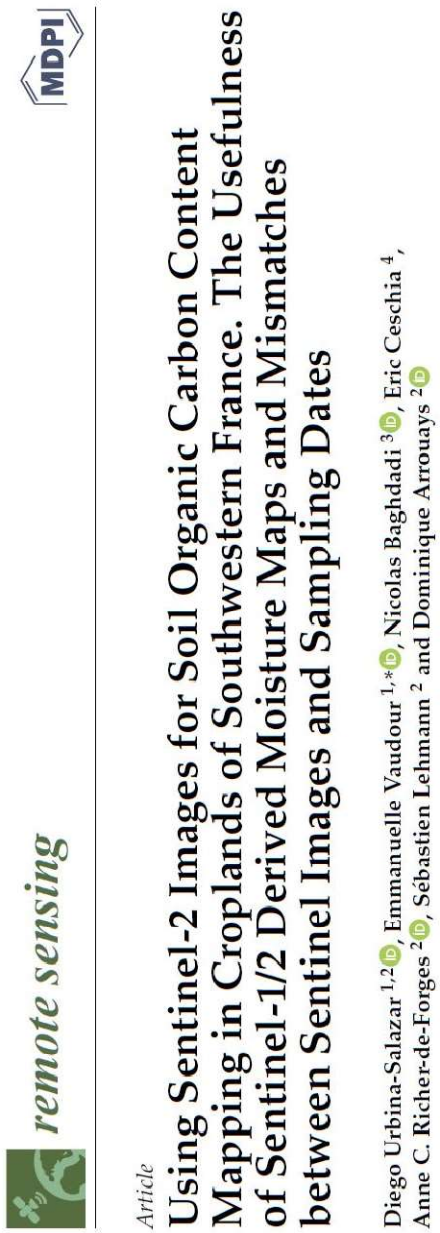

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remote sensing

Article

Using Sentinel-2 Images for Soil Organic Carbon Content Mapping in Croplands of Southwestern France. The Usefulness of Sentinel-1/2 Derived Moisture Maps and Mismatches between Sentinel Images and Sampling Dates

Diego Urbina-Salazar [1,2], Emmanuelle Vaudour [1,*], Nicolas Baghdadi [3], Eric Ceschia [4], Anne C. Richer-de-Forges [2], Sébastien Lehmann [2] and Dominique Arrouays [2]

Soilscapes well captured from Sentinel-2

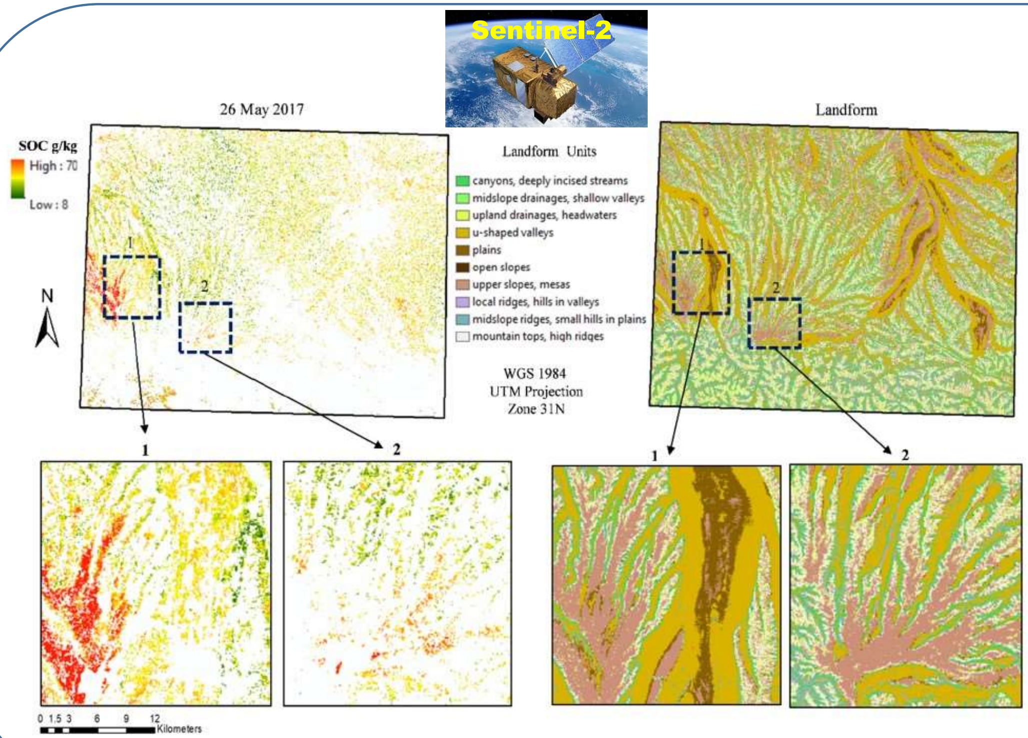

Figure 7. Zooming into the SOC map and the landforms of the study area.

URBINA-SALAZAR et al., 2021 - doi.org/10.1016/j.rse.2019.01.006

RMSE~6 $g.kg^{-1}$
RPD 1.6

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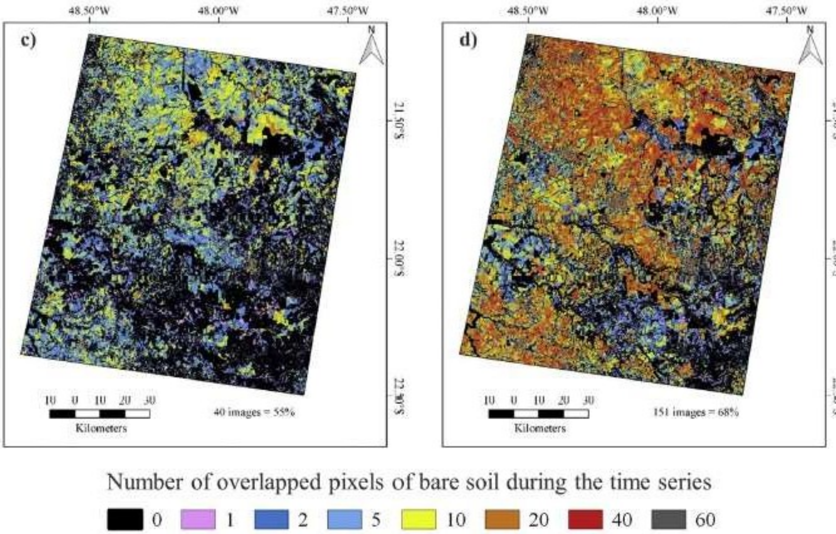
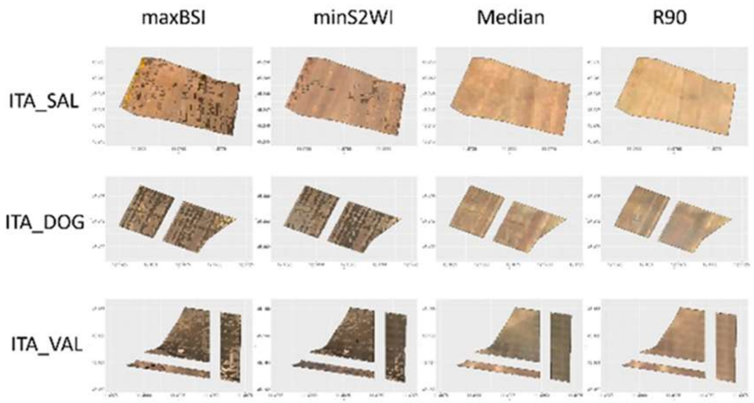
Temporal mosaics of bare soil reflectance

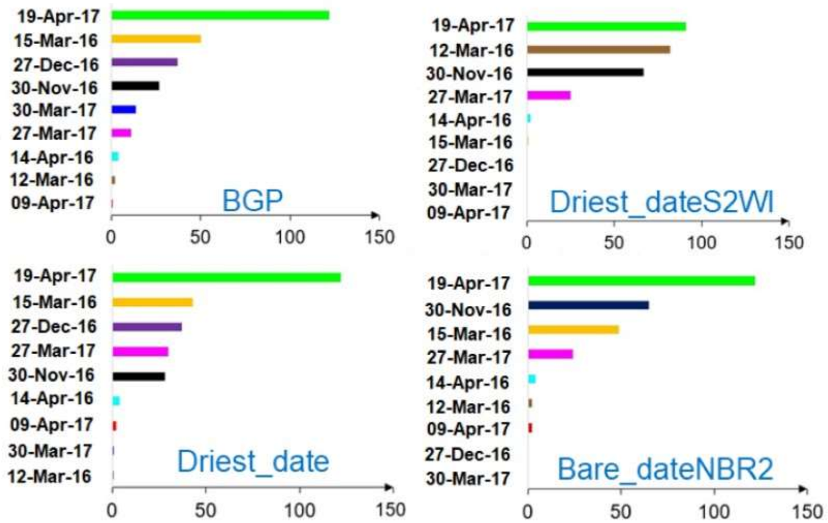


Demattê et al., 2018
https://doi.org/10.1016/j.rse.2018.04.047

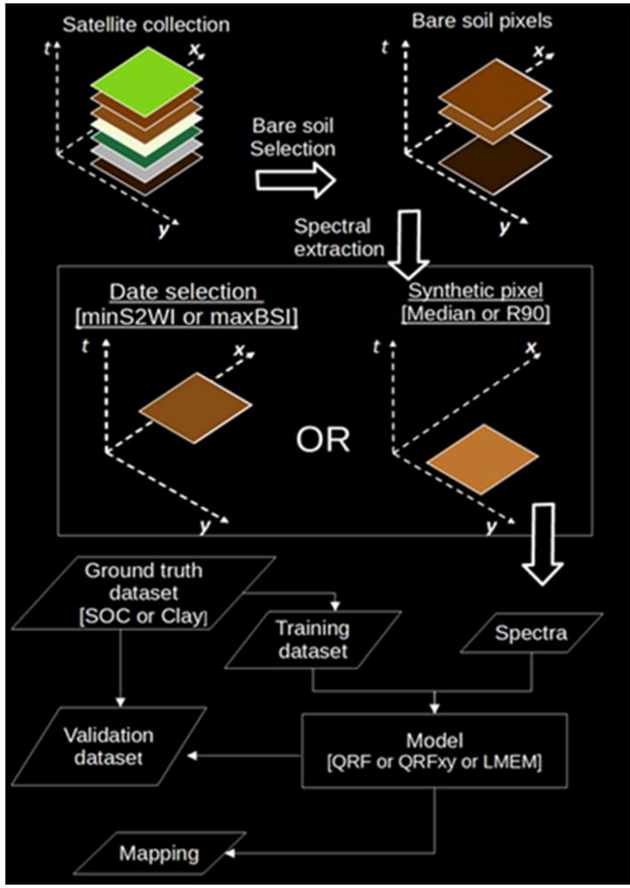


Castaldi et al., 2023
https://doi.org/10.1016/j.isprsjprs.2018.11.026

strategies:
-indices thresholding/masking
-per pixel or per date

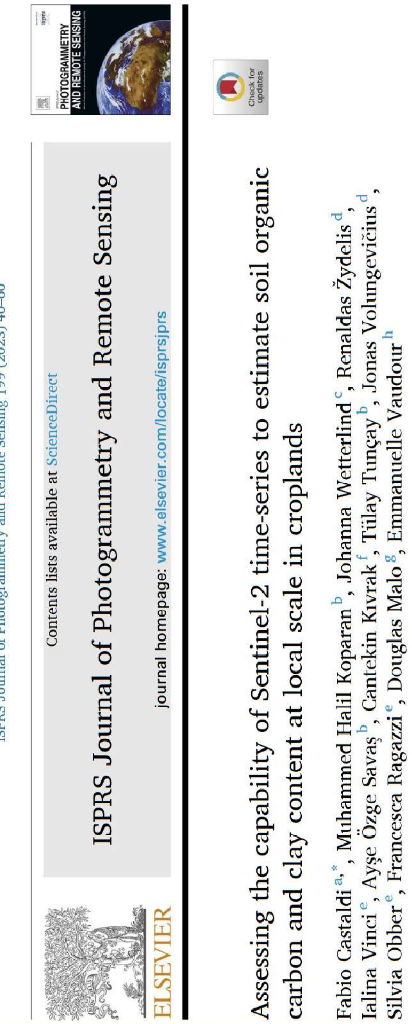


Vaudour et al., 2021
https://doi.org/10.1016/j.jag.2020.102277



Castaldi et al., 2023
https://doi.org/10.1016/j.isprsjprs.2018.11.026

Clay and SOC mapping from Sentinel-2 time series at within-field/farm scale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ISPRS Journal of Photogrammetry and Remote Sensing

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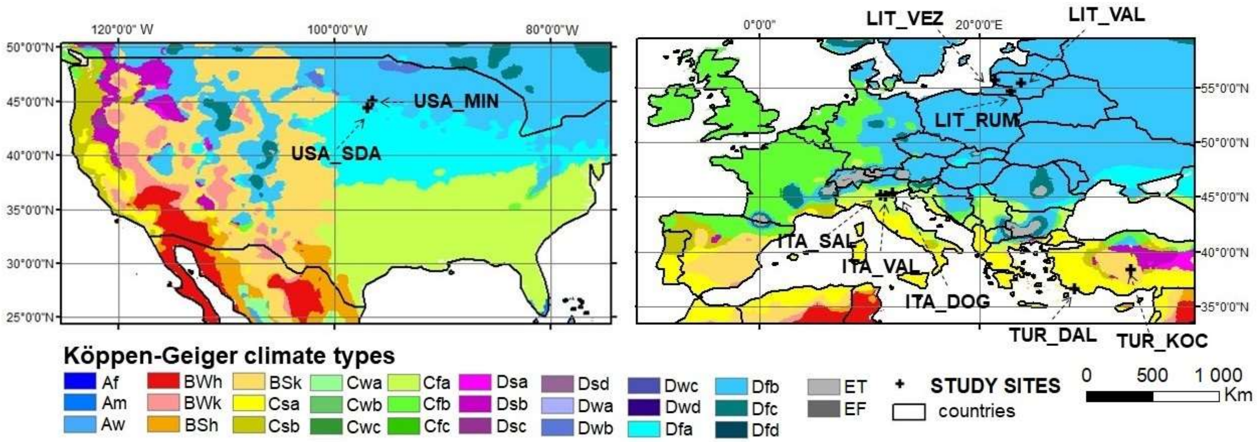
Assessing the capability of Sentinel-2 time-series to estimate soil organic carbon and clay content at local scale in croplands

Fabio Castaldi[a,*], Muhammed Halil Koparan[b], Johanna Wetterlind[c], Renaldas Žydelis[d], Ialina Vinci[e], Ayşe Özge Savaş[b], Cantekin Kıvrak[f], Tülay Tunçay[b], Jonas Volungevičius[d], Silvia Obber[e], Francesca Ragazzi[e], Douglas Malo[g], Emmanuelle Vaudour[h]



Site	Koppen climate class	Main soil types
TUR_KOC	Bsk	Calcaric Fluvisols; Eutric Vertisols
TUR_DAL	Csa	Calcaric Fluvisols
USA_SDA	Dwa	Haplic Chernozem; Calcic Chernozem; Chernic Gleysol
USA_MIN	Dfb	Haplic Chernozem; Calcic Chernozem; Chernic Gleysol
ITA_SAL	Cfa	Haplic Luvisols ; Hypereutric Cambisol
ITA_DOG	Cfa	Cambic Calcisols; Calcaric Calcic Gleysols
ITA_VAL	Cfa	Calcaric Gleysols; Haplic Calcisols
LIT_VEZ	Dfb	Glossic Albic Eutric Retisol; Epigleyic Albic Haplic Luvisol
LIT_VAL	Dfb	Endogleyic Endostagnic Endocalcaric Luvisol
LIT_RUM	Dfb	Endocalcaric Gleysol; Epigleyic Endocalcaric Cambisol

Castaldi et al., 2023 - doi.org/10.1016/j.isprsjprs.2023.03.016

- 10 cropland local sites with contrasted climate+soil types
- temporal mosaicking from 2 y-time-series?
- accuracy?

uncertainty?

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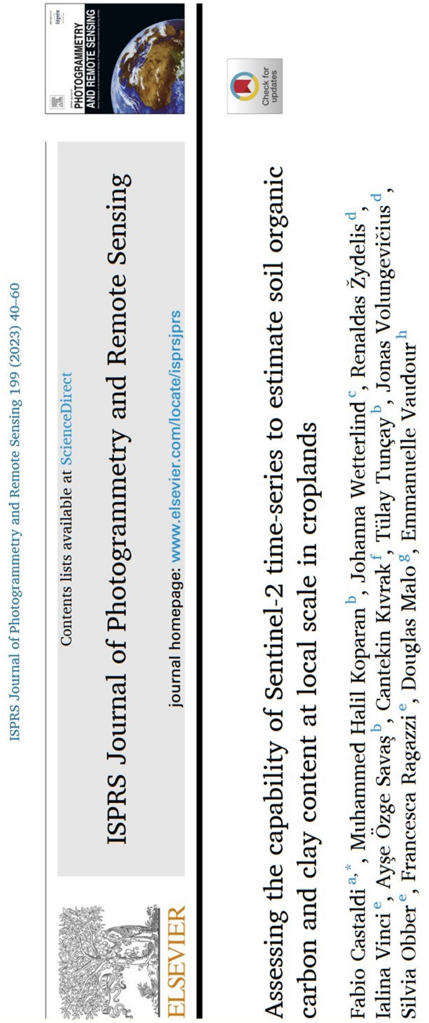
Overall approach


ISPRS Journal of Photogrammetry and Remote Sensing 199 (2023) 40–60
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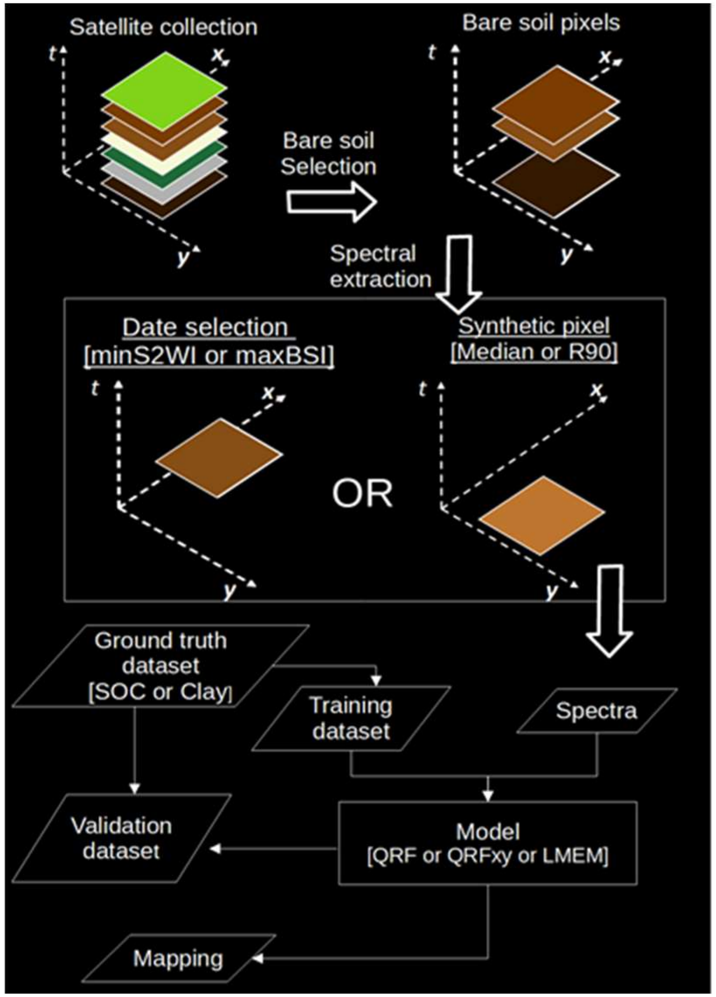

Castaldi et al., 2023 - doi.org/10.1016/j.isprsjprs.2023.03.016

- pixelwise thresholding → bare soil

NDVI<0.35, NBR2<0.125, BSI>0.021

- search for best conditions (4 strategies)

- prediction algorithms

Quantile Random Forest (QRF), spectral bands only

Quantile Random Forest (QRFxy), spectral bands + geographical coordinates

Linear Mixed effect Model (LMEM)

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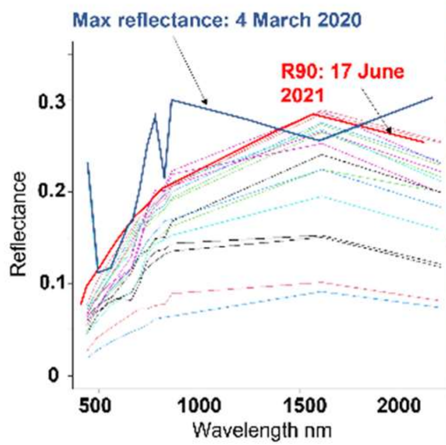
Search for best conditions

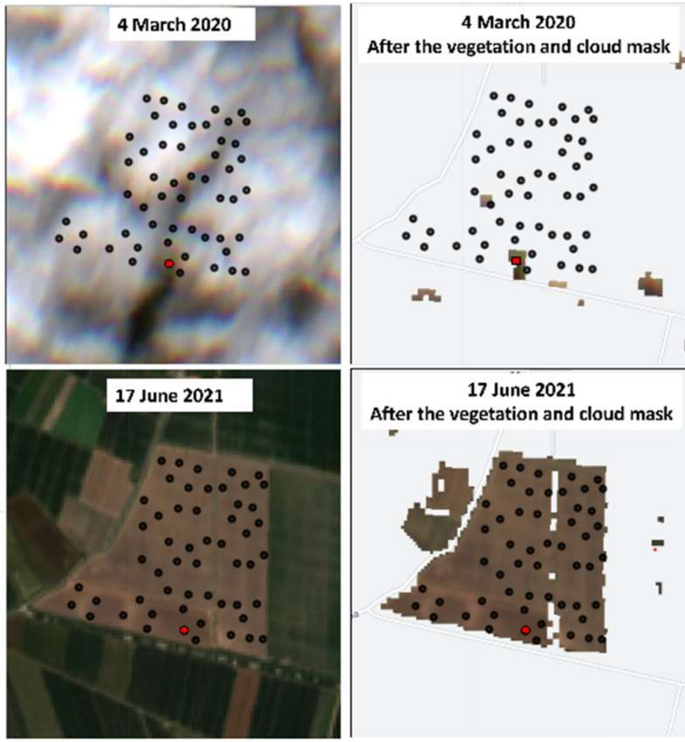
$$BSI = \frac{(B12 + B4) - (B8 + B2)}{(B12 + B4) + (B8 + B2)}$$

$$S2WI = \frac{B8A - B11 - B12}{B8A + B11 + B12}$$

strategy	description	acronym	Reference
①	maximizing bare soil index BSI	maxBSI	DIEK et al., 2017
②	minimizing soil moisture index S2WI	minS2WI	VAUDOUR et al., 2021
③	median reflectance	Median	CASTALDI, 2021
④	selecting the 90th percentile	R90	CASTALDI et al., in revision

Castaldi et al., 2023 - doi.org/10.1016/j.isprsjprs.2023.03.016





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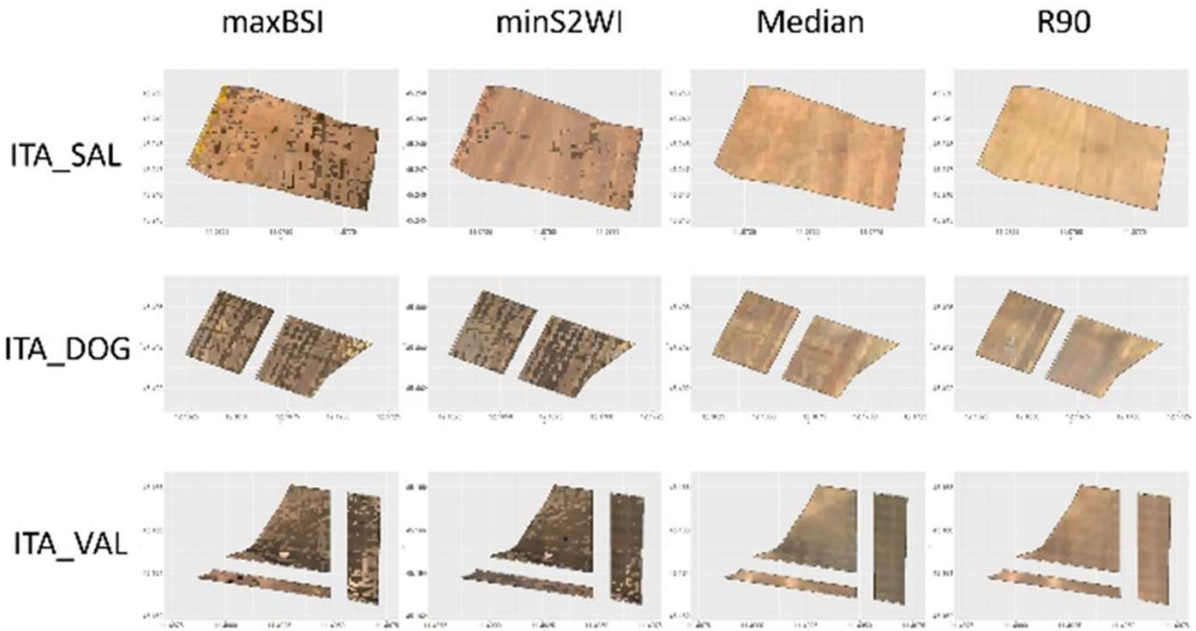
Comparison of temporal mosaics



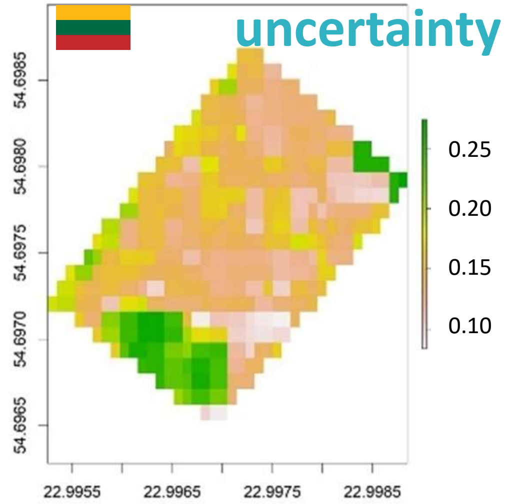
Castaldi et al., 2023 - doi.org/10.1016/j.isprsjprs.2023.03.016

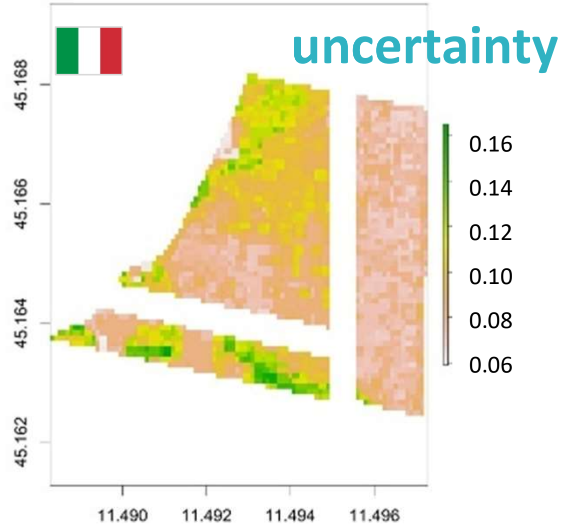
Uncertainty vs algorithm / temporal mosaic

Average uncertainty within 10 test sites

		minS2WI		Median		R90	
	Site	QRFxy	LMEM	QRFxy	LMEM	QRFxy	LMEM
SOC	**TUR_KOC**	0.11	0.23	0.11	0.46	0.11	0.22
	TUR_DAL	0.20	0.16	0.22	0.15	0.14	0.15
	USA_SDA	0.13	0.09	0.07	0.14	0.10	0.08
	USA_MIN	0.12	0.19	0.17	0.17	0.12	0.08
	ITA_VAL	0.13	0.11	0.09	0.80	0.09	0.12
	LIT_RUM	0.13	0.77	0.14	0.11	0.13	0.12
	Mean	**0.14**	**0.26**	**0.13**	**0.31**	**0.12**	**0.13**
Clay	**TUR_KOC**	0.11	0.40	0.18	0.80	0.11	0.75
	TUR_DAL	0.20	1.55	0.22	0.35	0.14	0.002
	USA_SDA	0.23	0.22	0.07	1.15	0.21	0.23
	USA_MIN	0.11	1.60	0.13	1.55	0.13	1.45
	ITA_VAL	0.08	0.71	0.08	0.05	0.08	0.45
	LIT_RUM	0.14	0.45	0.18	0.11	0.13	0.15
	Mean	**0.145**	**0.82**	**0.14**	**0.67**	**0.13**	**0.51**

CASTALDI et al., 2023





Castaldi et al., 2023 - doi.org/10.1016/j.isprsjprs.2023.03.016

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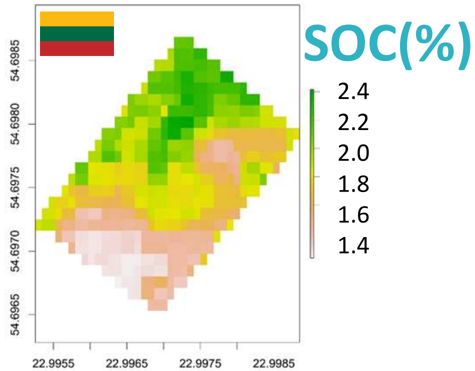
Accuracy vs algorithm / temporal mosaic

SOC

Frequency of Accuracy values >90% among the 10 test sites

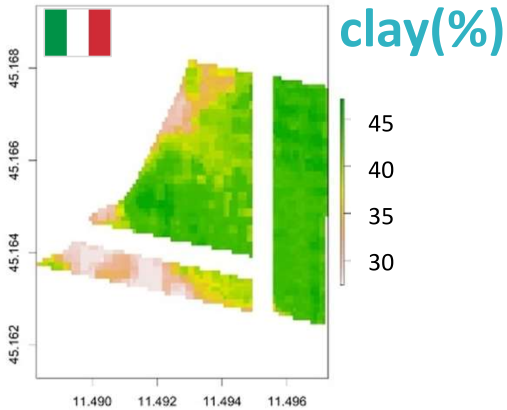
	maxBSI	minS2WI	Median	R90	Mean frequency
QRF	10%	50%	40%	50%	37.5%
QRFxy	40%	50%	60%	60%	**52.5%**
LMEM	30%	40%	30%	50%	37.5%
Mean frequency	26.7%	46.7%	43.3%	**53.3%**	



Clay

Frequency of Accuracy values >90% among the 10 test sites

	maxBSI	minS2WI	Median	R90	Mean frequency
QRF	10%	20%	20%	10%	15.0%
QRFxy	10%	20%	30%	30%	**22.5%**
LMEM	20%	0%	20%	40%	20.0%
Mean frequency	13.3%	13.3%	23.3%	**26.7%**	



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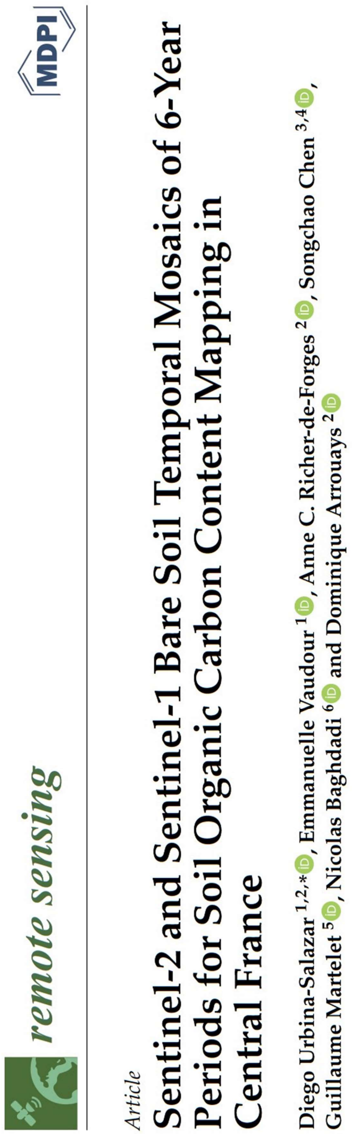
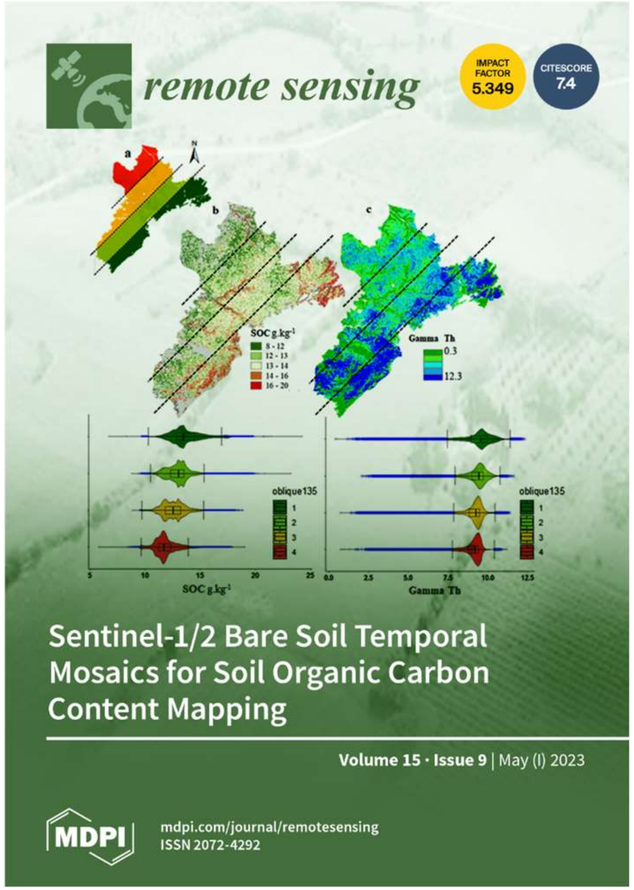


Sentinel-2 and Sentinel-1 Bare Soil Temporal Mosaics of 6-Year Periods for Soil Organic Carbon Content Mapping in Central France



- incorporation of soil moisture maps
- Importance of gamma-ray layers
- being applied for other datasets (Sweden)

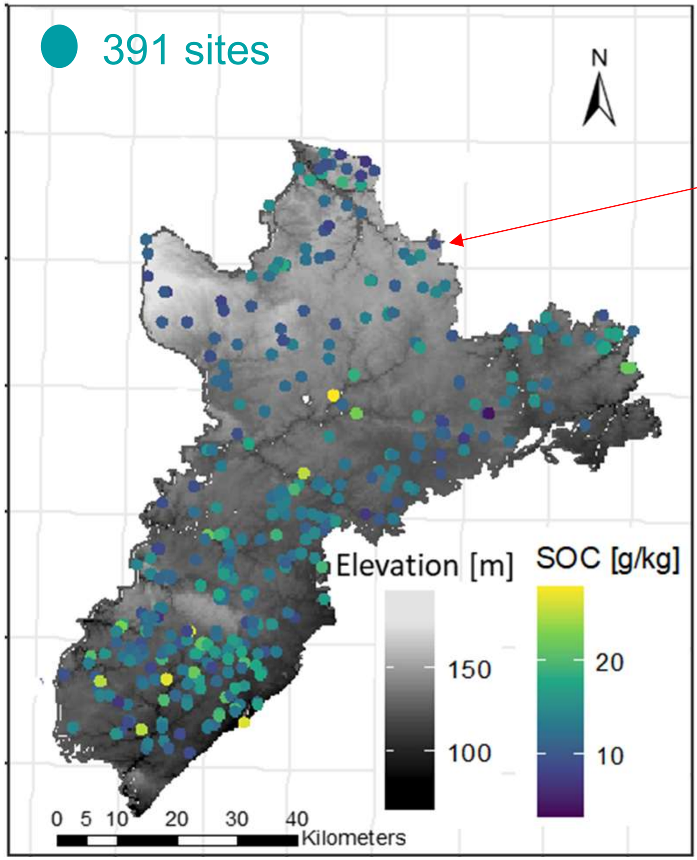
URBINA-SALAZAR et al., 2023 - DOI: 10.3390/rs15092410

Objectives

- evaluate the use of **S2 temporal mosaics of bare soil** (S2Bsoil) over a **6-year** period: best season?
- assess the effect of **Soil Moisture** (SM) as a covariate in the prediction models and **as criteria** to build S2Bsoil
- identify the most important **environmental covariates** derived from DEM, remote sensing data, lithology (soil parent material) map and airborne gamma-ray data.

Material & methods – Study area

La Beauce – 4838 km²



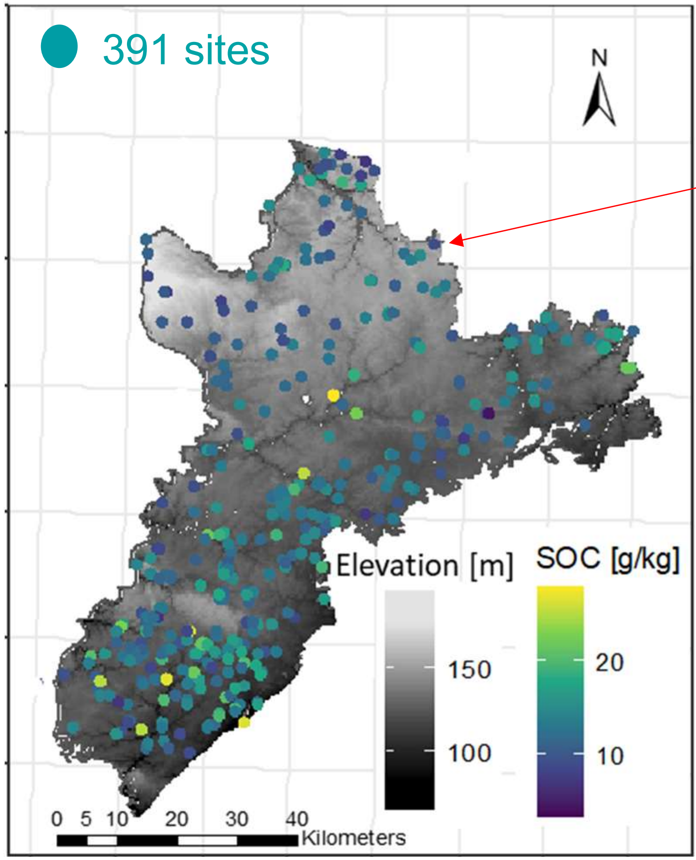
- Continental-oceanic climate
- > 80% croplands (LPIS)
- Annual crop rotation (wheat, rapeseed, sugar beet, maize)
- Beauce aquifer
- Loess deposits (deeper ->north)

Cambisols and Luvisols

Podzols, Gleysols, Fluvisols, Arenosols and Vertisols (southern border)

Material & methods – Study area

La Beauce – 4838 km²



- Continental-oceanic climate
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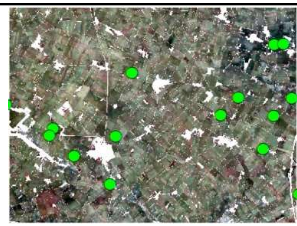
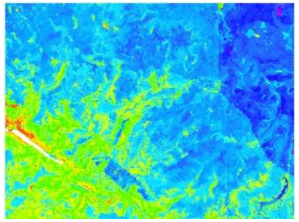
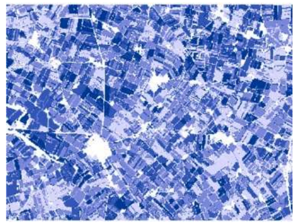
Cambisols and Luvisols

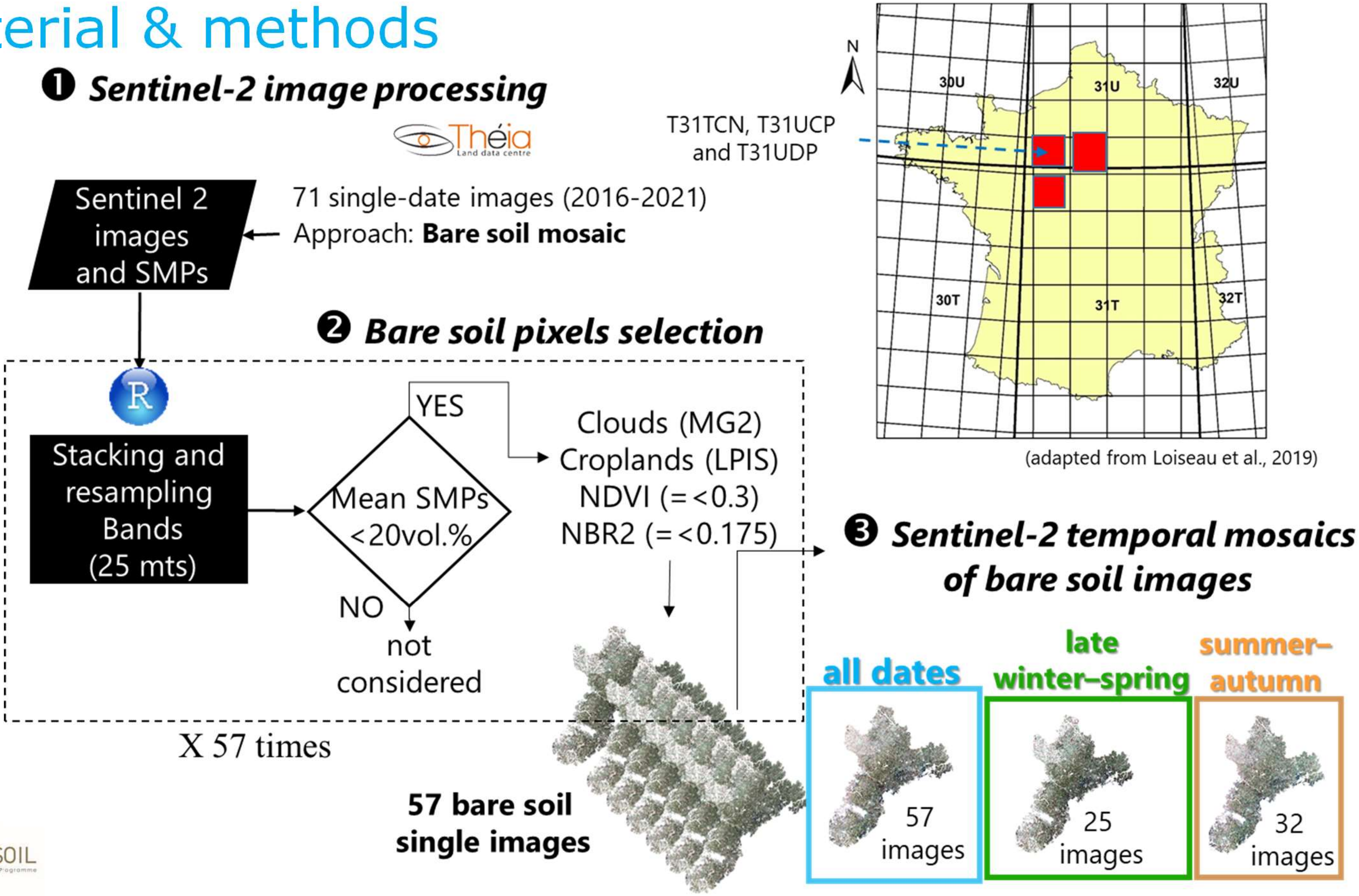
Podzols, Gleysols, Fluvisols, Arenosols and Vertisols (southern border)

Bibliothèque Nationale de France

Material & methods – data

Data type	Datasets	
soils	***DoneSol***: French soil profile database (341) ***RMQS***: French soil Quality Measurement Network (12) ***LUCAS 2015***: European Land Use and Land Cover Survey (50)	
parent material	**Map (1:1M)** **AGRI**: airborne gamma ray images	
satellite remote sensing	**Sentinel-2** ***SMPs***: soil moisture products derived from S1/2 **S2, MODIS (indices)**	
terrain	**DEM-derived variables**	

Material & methods



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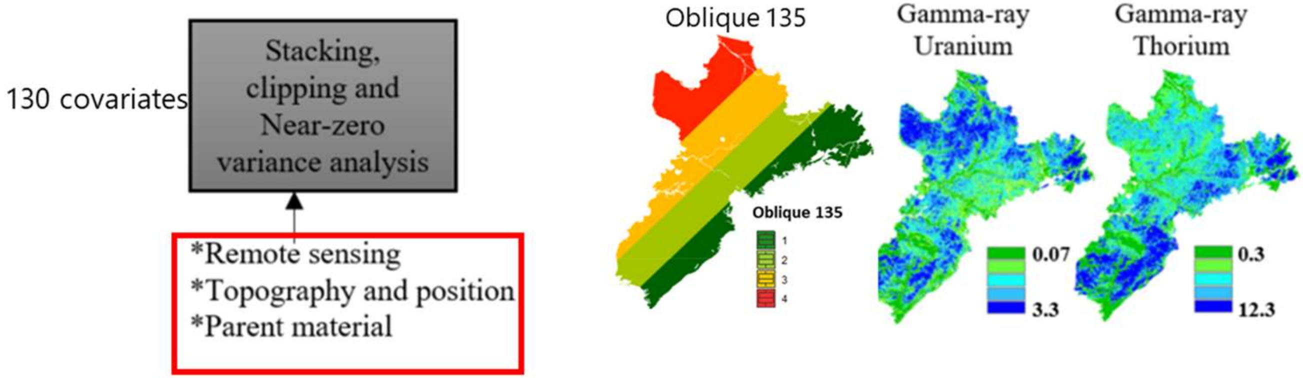
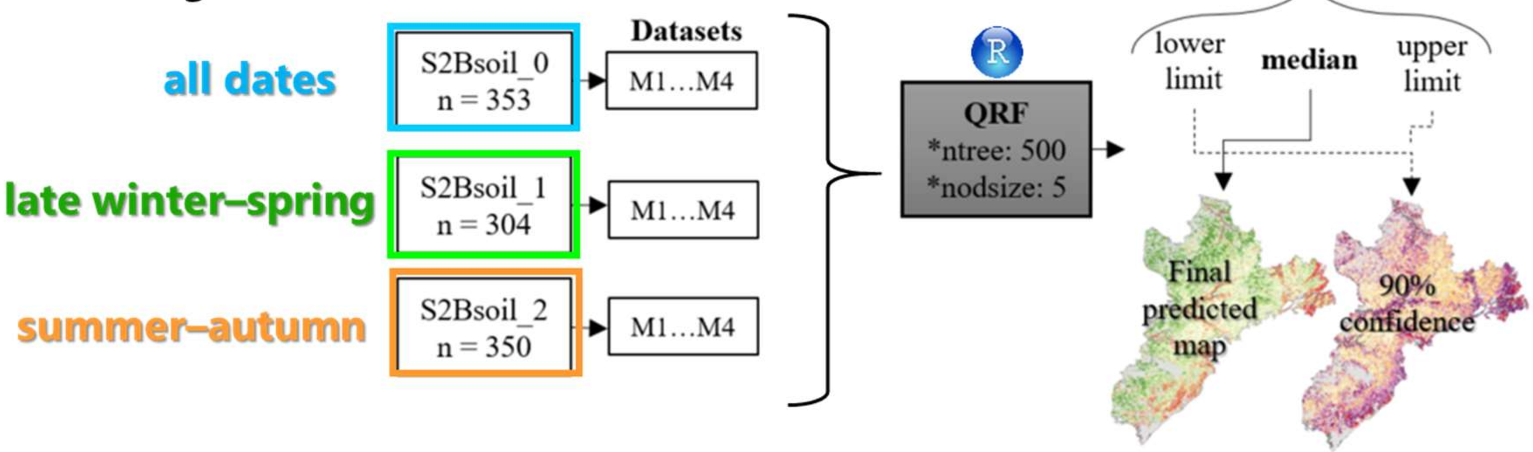
Material & methods

❹ Covariates preparation



❺ Soil organic carbon estimation models



model	Relying on (nb covariates)
M1	the bare soil reflectance of the **S2Bsoil bands** (10)
M2	M1+ **spectral indices** (24)
M3	M2 + **soil moisture** (25)
M4	M3+**topography**, **position** and **parent material** (85)

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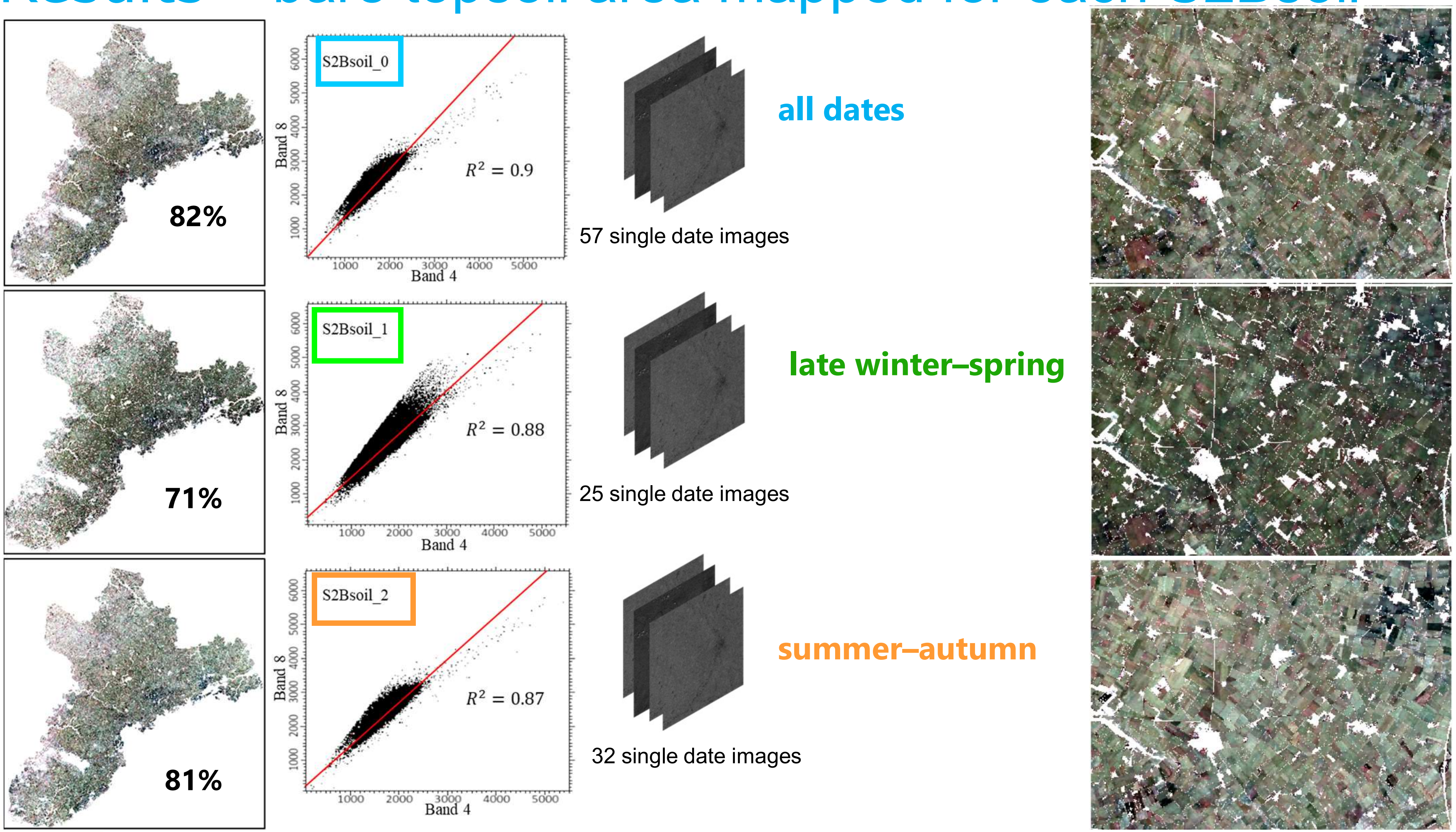
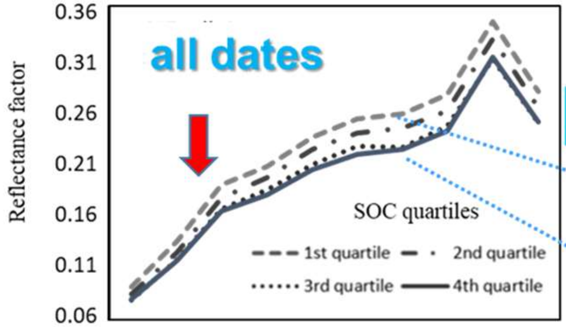
Results - bare topsoil area mapped for each S2Bsoil



Results –spectra of bare soil mosaics vs season

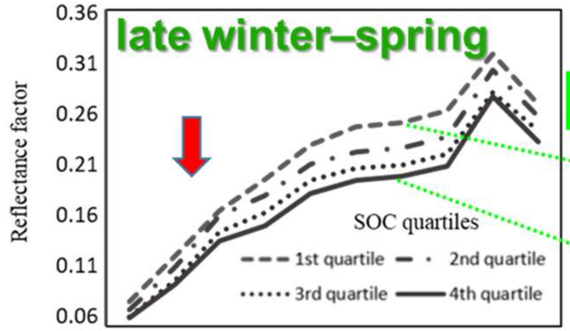


S2Bsoil	sites	SOC g.kg^{-1} Minimum	Q1	Median	Mean	Q3	Maximum	SD	Skewness	Kurtosis
S2Bsoil_0	353	3.46	11.40	13	13.4	15	27.8	3.34	0.86	4.83

3.46 – 11.4 g/kg

15 – 27.8 g/kg

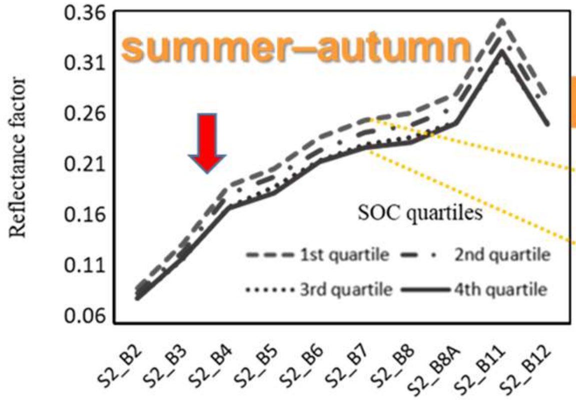
Decreasing trend of reflectance



S2Bsoil	sites	SOC g.kg^{-1} Minimum	Q1	Median	Mean	Q3	Maximum	SD	Skewness	Kurtosis
S2Bsoil_1	304	3.46	11.41	13	13.4	15	27.8	3.32	0.93	5.18

3.46 – 11.4 g/kg

15 – 27.8 g/kg



S2Bsoil	sites	SOC g.kg^{-1} Minimum	Q1	Median	Mean	Q3	Maximum	SD	Skewness	Kurtosis
S2Bsoil_2	350	3.46	11.39	13	13.4	15	27.8	3.35	0.85	4.82

3.46 – 11.4 g/kg

15 – 27.8 g/kg

Results

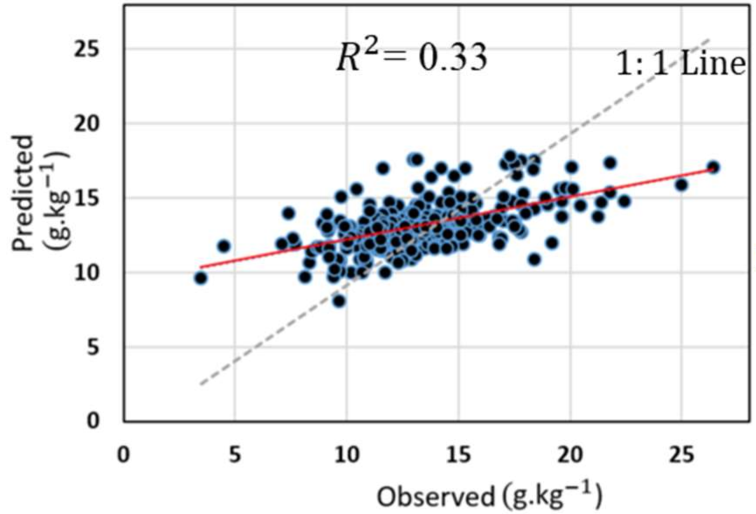
SOC model performance

S2Bsoil	Modeling Dataset	R^2	RMSE ($g.kg^{-1}$)
S2Bsoil_0	M1	0.18	3.00
	M2	0.19	2.98
	M3	0.15	2.98
	M4	0.26	2.75
S2Bsoil_1	M1	0.19	2.97
	M2	0.22	2.90
	M3	0.22	2.79
	M4	0.33	2.59
S2Bsoil_2	M1	0.11	3.17
	M2	0.11	3.14
	M3	0.12	3.00
	M4	0.27	2.71

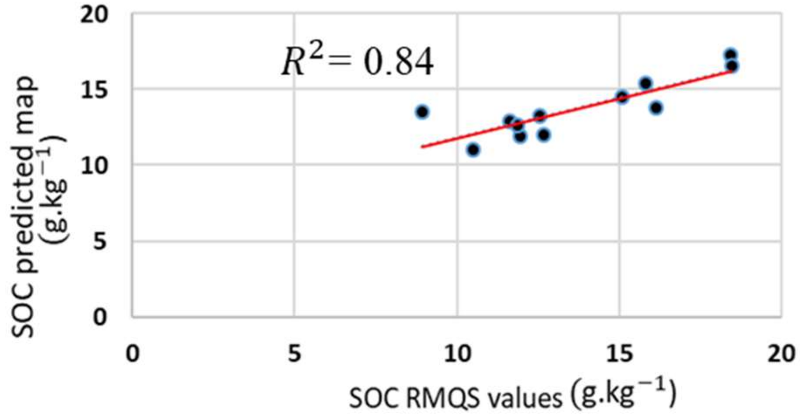
R^2, coefficient of determination; RMSE, root mean square error.

S2Bsoil	Modeling Dataset	Bias	Concordance
S2Bsoil_0	M1	−0.33	0.32
	M2	−0.31	0.33
	M3	−0.30	0.29
	M4	−0.20	0.40
S2Bsoil_1	M1	−0.32	0.35
	M2	−0.30	0.35
	M3	−0.28	0.34
	M4	−0.22	0.42
S2Bsoil_2	M1	−0.35	0.25
	M2	−0.30	0.24
	M3	−0.29	0.25
	M4	−0.21	0.39

- Decreasing performances when only the S2 bands were considered
- Best performance **late winter–spring** (M4 dataset)
- Poor performance **summer–autumn** (M1 dataset)



Amplitude not very large



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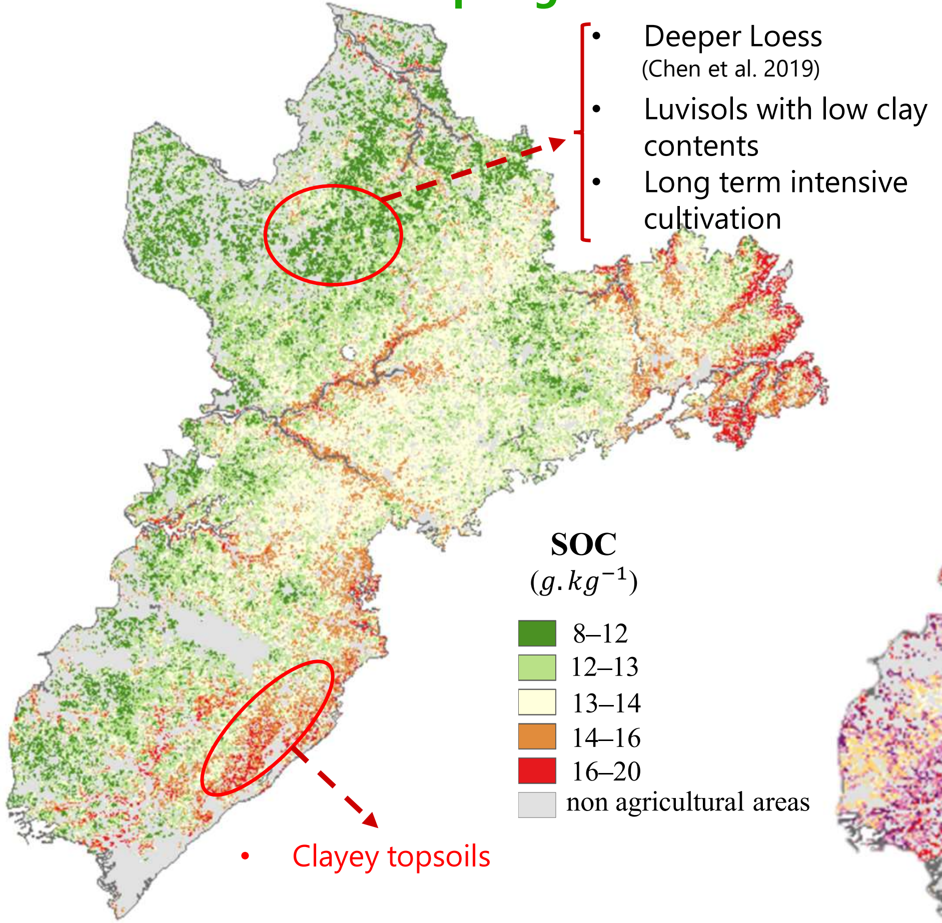
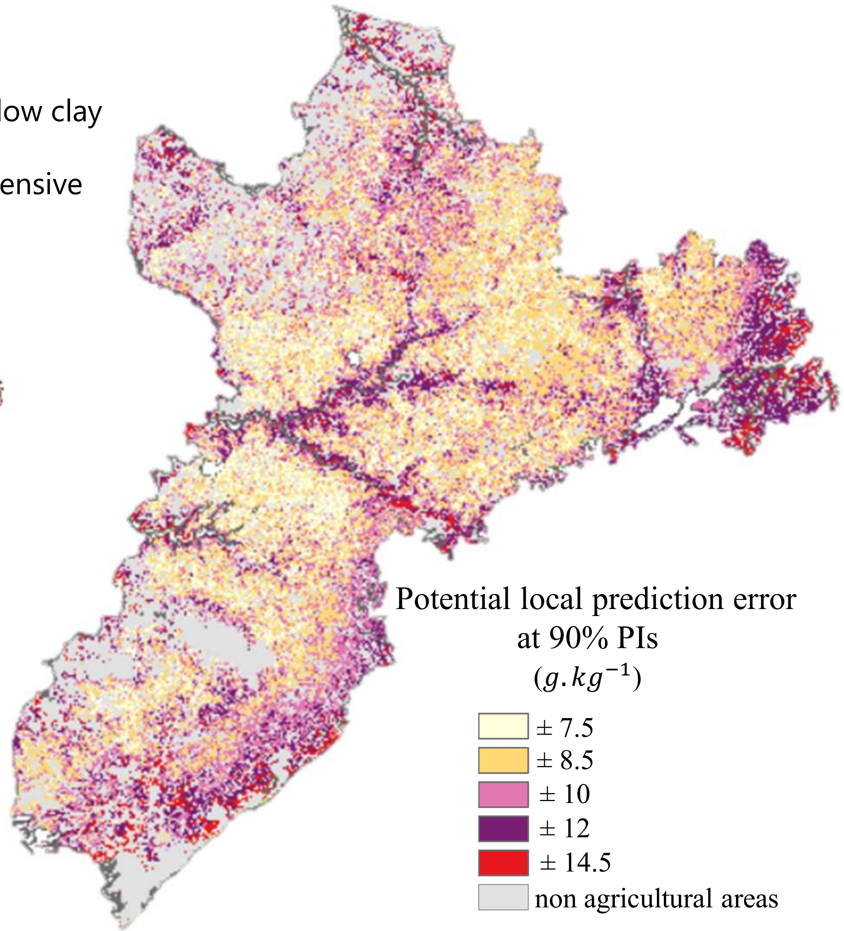
Results

SOC predicted map
late winter–spring



Uncertainty map



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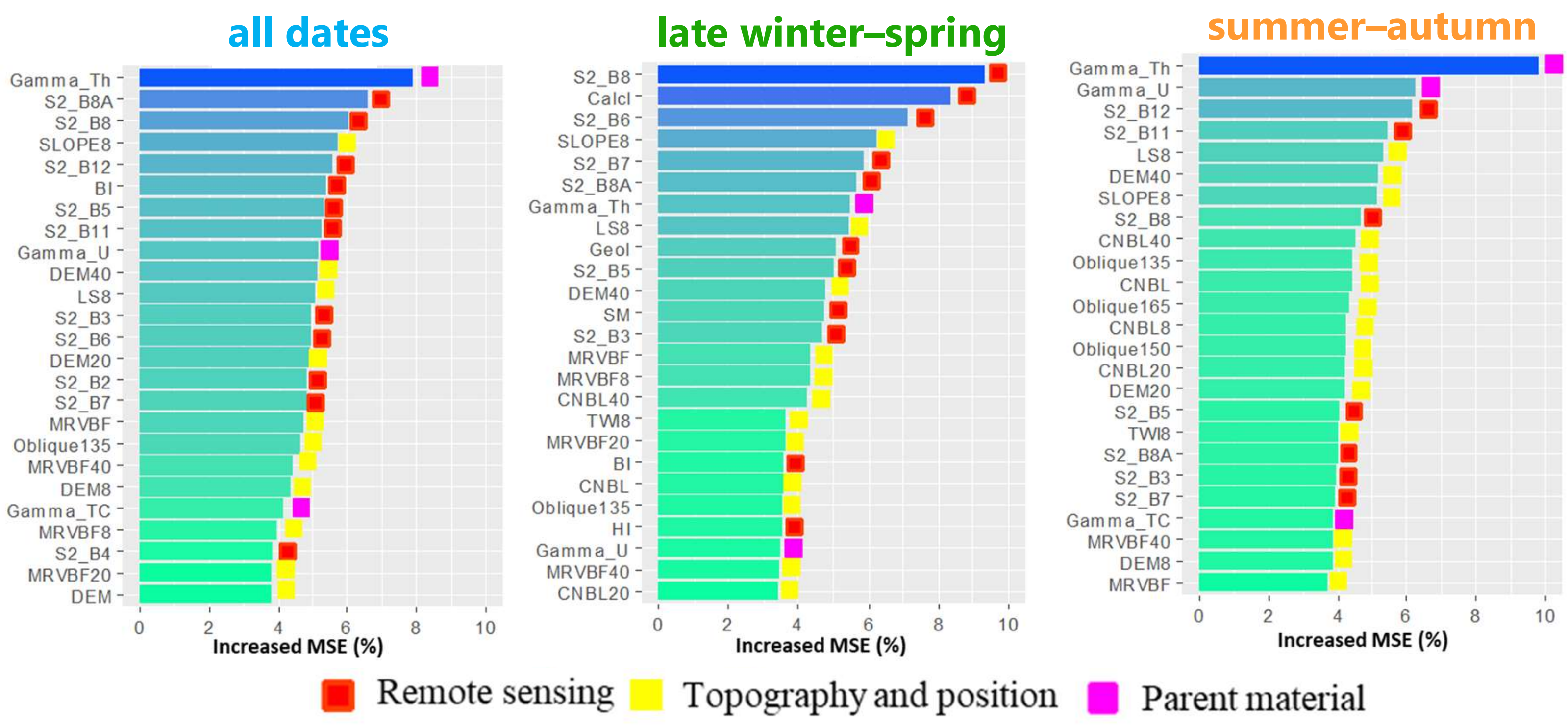
Results

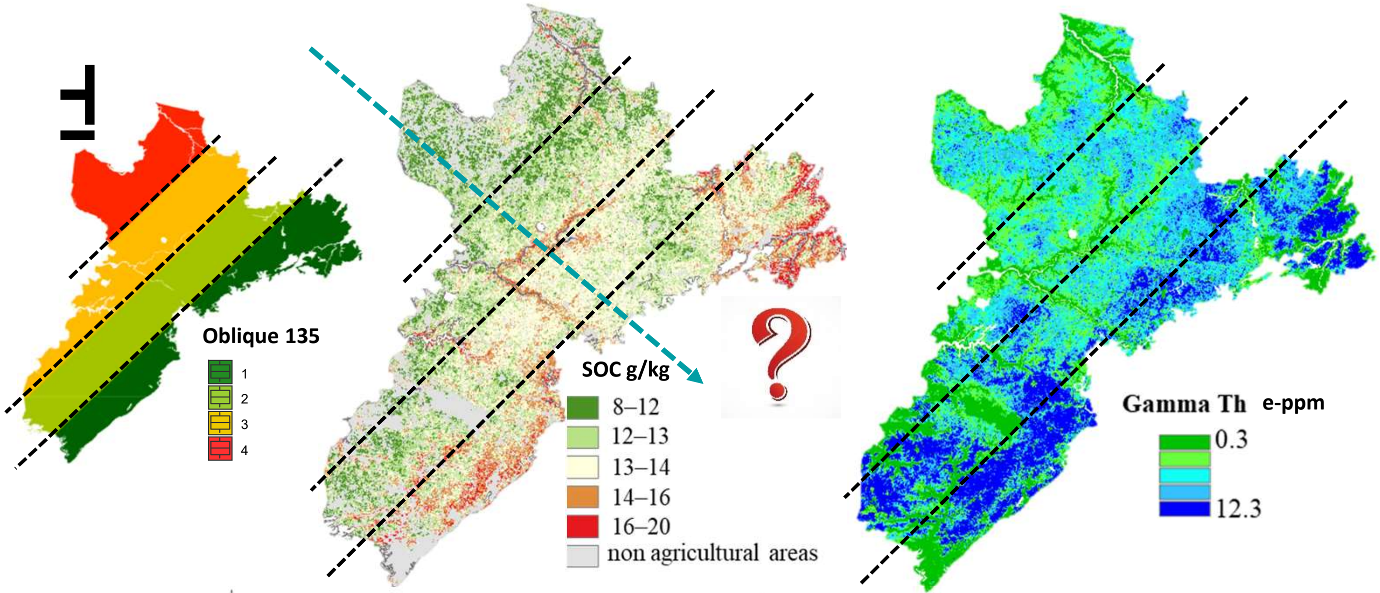
Relative importance of the environmental covariates for SOC prediction



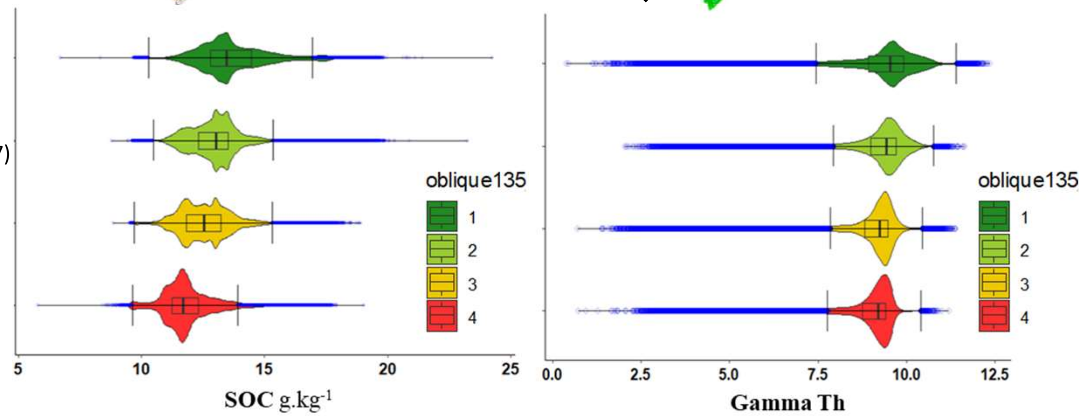
- NIR and SWIR
- **SM** -> “**late winter-spring**”
- Oblique coordinates at an angle of **135**°
- **Thorium** and **uranium** from airborne gamma-ray surveys

Results

Spatial trend



- The **wind direction** of the loess deposits (Northwest)(Borderie et al., 2017)
- **Loess** were mainly **deposited** in the **northern** part (Chen et al., 2021)



Discussion

+	• confirms **usefulness of S2 bare soil temporal mosaics** (Žížala et al., 2022; Dvorakova et al. 2023) • original in adding **SMPs=valuable** for selecting best dates (Vaudour et al., 2021; Urbina-Salazar et al. 2021)
−	• substantial soil sample dataset needed, **spatially representative / recent** • SMPs not exactly matching S2 images date, not available everywhere, not **easily upscalable** • **Thorium** is very interesting but not commonly available

Influence of percentile reflectance thresholding in Sentinel-2 temporal mosaicking on regional SOC and clay prediction performances: case of the Västra Skaraborg region (Sweden)

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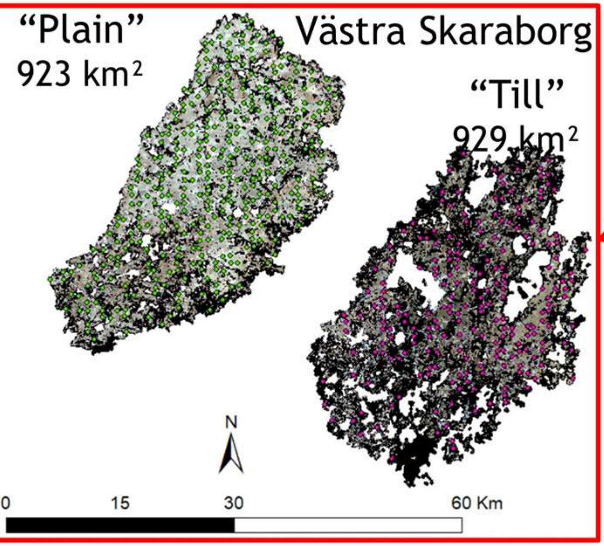
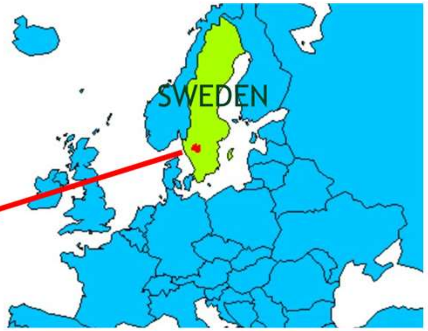
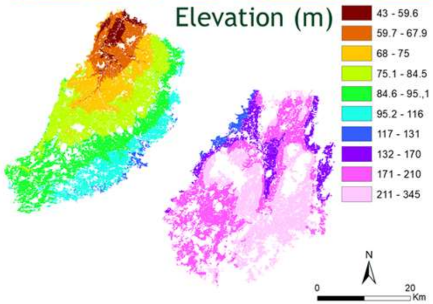
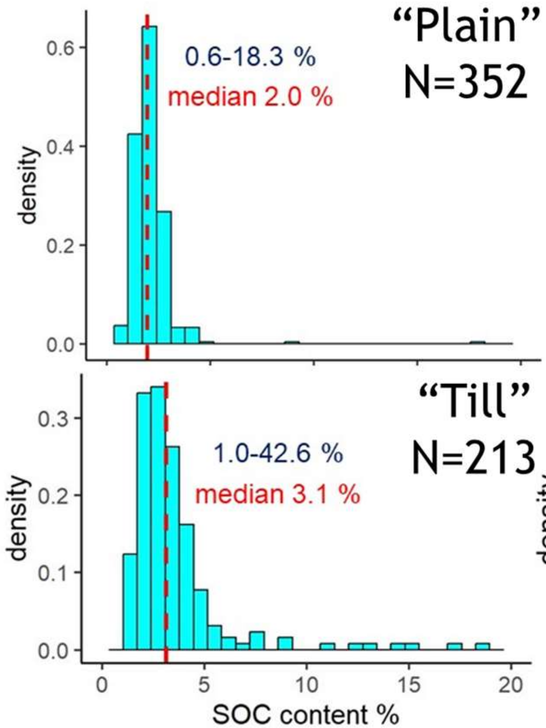
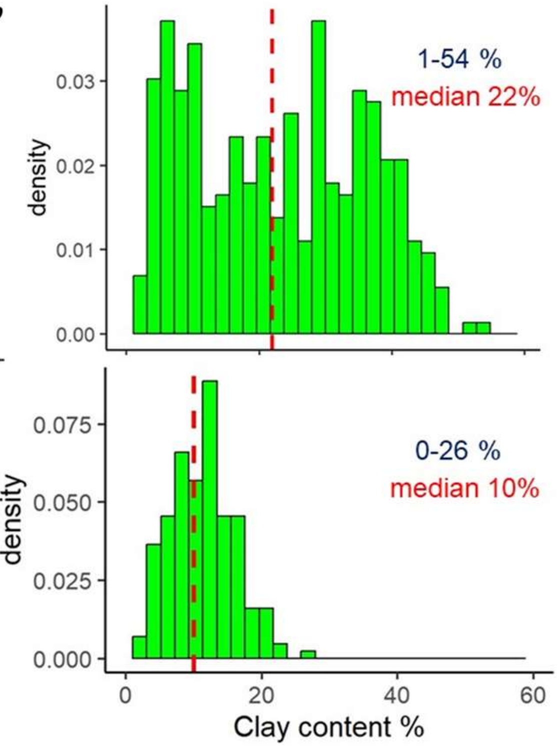
Μελικερτης





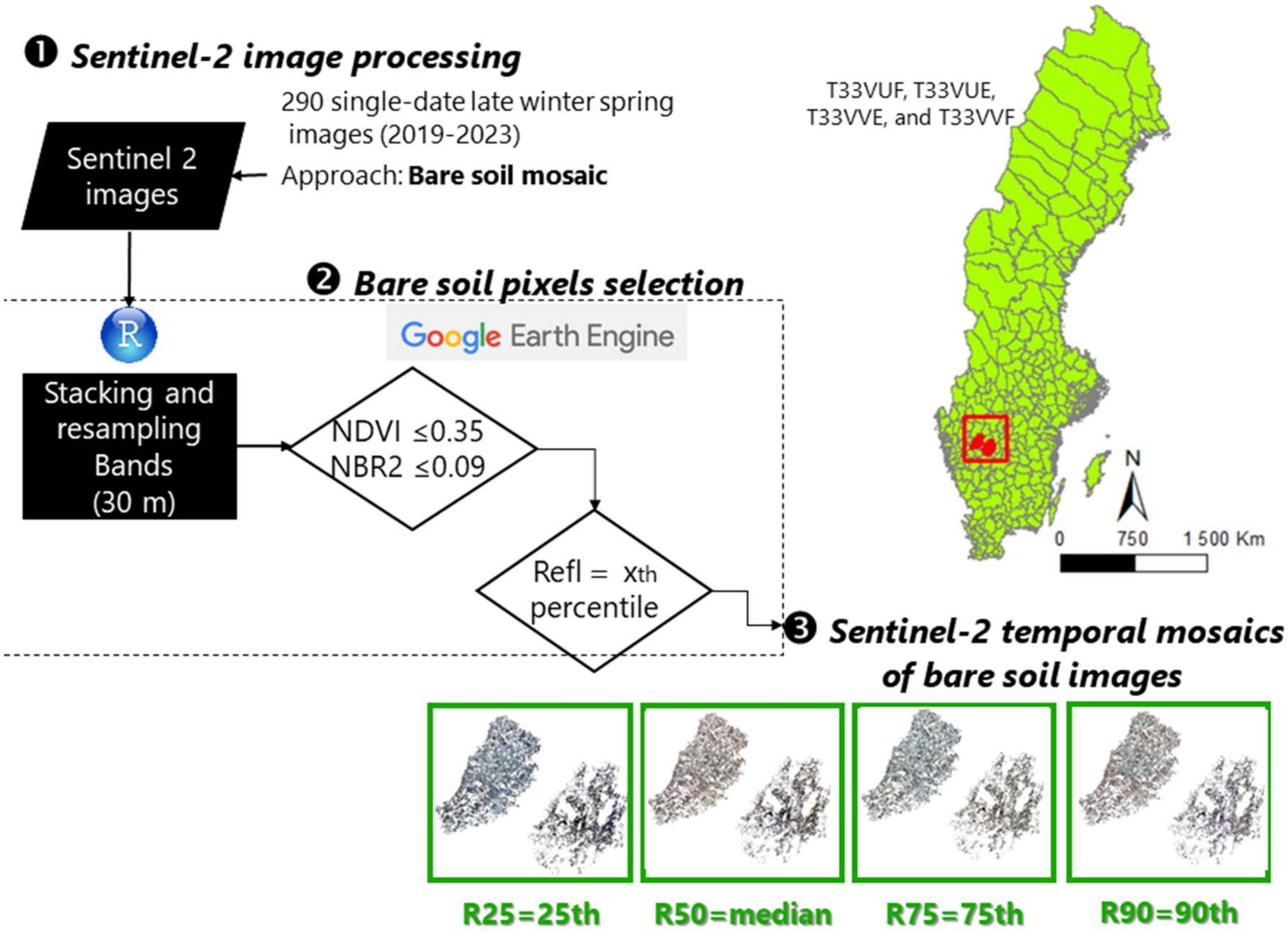






Στεροπῆς

STUDY AIM: for a boreal region, investigate the impact of percentile thresholding for temporal mosaicking of bare soils on the performance of both clay and soil organic carbon (SOC) content predictions



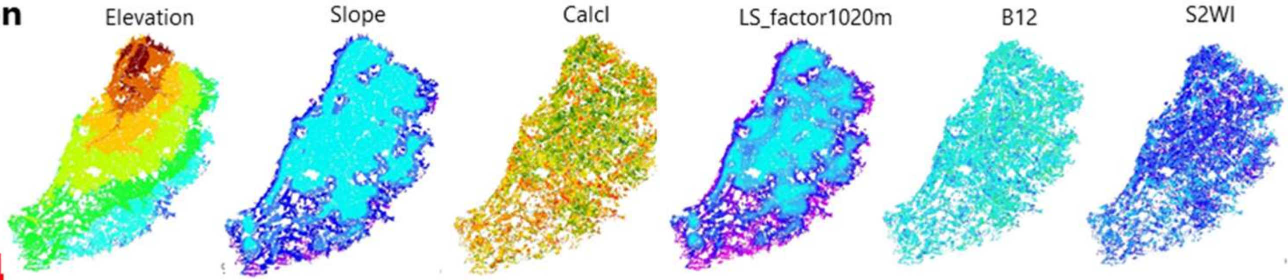
Materials & Methods

❹ Covariates preparation

92 covariates

Stacking, clipping and Near-zero variance analysis

*Remote sensing
*Topography and position
*Parent material



❺ Soil property estimation models

Model relying on

- S2bands
- terrain
- all (+indices+S1)

×

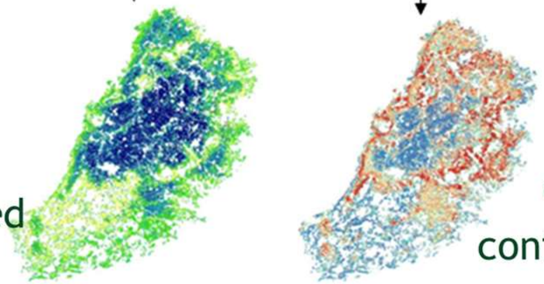
Bare soil temporal mosaic

R25, R50, R75, R90

QRF
*ntree: 500
*nodsize: 5

prediction

lower limit | median | upper limit



Results for SOC

"Plain" – SOC content

Temporal mosaic	Covariates	n	R^2	concordance	RMSE	bias	RPD	RPIQ
R90	S2 bands	274	0,14	0,27	0,62	-0,04	1,1	1,20
R75	S2 bands	273	0,10	0,21	0,62	-0,04	1,0	1,20
Median	S2 bands	273	0,13	0,22	0,62	-0,03	1,0	1,20
R25	S2 bands	274	0,15	0,29	0,62	-0,03	1,1	1,19
R90	Terrain	274	0,06	0,15	0,64	-0,05	1,0	1,10
R75	Terrain	273	0,10	0,17	0,61	-0,05	1,0	1,27
Median	Terrain	273	0,08	0,17	0,62	-0,06	1,0	1,25
R25	Terrain	274	0,06	0,15	0,64	-0,05	1,0	1,15
R90	All	274	0,18	0,25	0,60	-0,05	1,1	1,20
R75	All	273	0,18	0,22	0,60	-0,05	1,0	1,30
Median	All	273	0,15	0,21	0,60	-0,05	1,0	1,27
R25	All	274	0,18	0,27	0,60	-0,05	1,1	1,22

No clear performance decrease from R90 to R50 for SOC (≠ clay)

"Till" – SOC content

Temporal mosaic	Covariates	n	R^2	concordance	RMSE	bias	RPD	RPIQ
R90	S2 bands	126	0,13	0,26	1,1	-0,15	1,0	1,25
R75	S2 bands	127	0,10	0,23	1,1	-0,18	1,0	1,20
Median	S2 bands	127	0,20	0,32	1,0	-0,17	1,1	1,30
R25	S2 bands	127	0,25	0,38	1,0	-0,10	1,2	1,42
R90	Terrain	126	0,11	0,22	1,1	-0,18	1,0	1,26
R75	Terrain	127	0,13	0,21	1,1	-0,16	1,0	1,20
Median	Terrain	127	0,13	0,21	1,1	-0,16	1,0	1,20
R25	Terrain	127	0,13	0,21	1,1	-0,16	1,0	1,20
R90	All	126	0,25	0,30	1,0	-0,16	1,1	1,30
R75	All	127	0,22	0,27	1,0	-0,17	1,1	1,30
Median	All	127	0,21	0,28	1,1	-0,16	1,1	1,30
R25	All	127	0,27	0,33	1,0	-0,15	1,2	1,33

…even a slight increase from R90 to R25 for SOC (≠ clay) over Till

Results for Clay

"Plain" - Clay content

Temporal mosaic	Covariates	n	R²	concordance	RMSE	bias	RPD	RPIQ
R90	S2 bands	274	0,40	0,57	9,9	-0,180	1,30	2,2
R75	S2 bands	273	0,35	0,56	10,0	-0,400	1,27	2,2
Median	S2 bands	273	0,37	0,57	9,9	0,040	1,31	2,2
R25	S2 bands	274	0,27	0,46	11,2	-0,140	1,15	2,0
R90	Terrain	274	0,42	0,60	9,7	0,100	1,32	2,2
R75	Terrain	273	0,43	0,60	9,6	-0,008	1,33	2,3
Median	Terrain	273	0,46	0,61	9,6	-0,050	1,35	2,3
R25	Terrain	274	0,42	0,60	9,7	0,100	1,32	2,2
R90	All	274	0,56	0,70	8,3	-0,090	1,60	2,7
R75	All	273	0,54	0,67	8,4	-0,200	1,50	2,6
Median	All	273	0,54	0,66	8,7	-0,070	1,50	2,5
R25	All	274	0,50	0,64	9,0	-0,020	1,40	2,4

No performance decrease from R90 to R25 for SOC (≠ clay)

"Till" - Clay content

Temporal mosaic	Covariates	n	R²	concordance	RMSE	bias	RPD	RPIQ
R90	S2 bands	126	0,16	0,34	3,9	-0,40	1,10	1,30
R75	S2 bands	127	0,25	0,39	3,7	-0,20	1,18	1,36
Median	S2 bands	127	0,24	0,37	3,9	0,00	1,10	1,30
R25	S2 bands	127	0,14	0,26	4,0	-0,30	1,00	1,24
R90	Terrain	126	0,14	0,22	3,9	-0,16	1,10	1,33
R75	Terrain	127	0,24	0,3	3,8	-0,13	1,16	1,32
Median	Terrain	127	0,24	0,3	3,8	-0,13	1,20	1,30
R25	Terrain	127	0,24	0,3	3,8	-0,13	1,16	1,30
R90	All	126	0,22	0,33	3,7	-0,22	1,20	1,40
R75	All	127	0,31	0,37	3,6	-0,15	1,20	1,40
Median	All	127	0,27	0,34	3,7	-0,25	1,20	1,36
R25	All	127	0,26	0,32	3,7	-0,16	1,20	1,30

…even a slight increase from R90 to R25 for SOC (≠ clay) over Till

Conclusion (1)

- With a **smaller number** of images : still **possible** to achieve high bare soil **coverage** + better **performances**

- **“late winter-spring”** bare soil mosaic slightly more accurate

- S2 indices&bands, topography neighbor distances, OGC and gamma thorium = **key covariates** for La Beauce

- S2 indices&bands, topography = **key covariates** for Vestra Skaraborg

Conclusion (2)

- A number of achievements so far → state of the art, approaches for temporal mosaicking, several sampling campaigns, spectral & mixed approaches, uncertainty assessment, comparison of algorithms

- results for spectral approaches without/with soil moisture + mixed approaches

- collaborative work in progress for soil moisture, texture; extension WP begun, salinity to develop

Obrigado pela vossa atenção!