Current Developments in Imaging Spectroscopy for Soil Property Mapping and Land Degradation

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ESA Worldsoils – Soil Surface Conditions at the EO scale

- Increasing availability of large Soil Spectral Libraries (SSL)

➢ Basis for accurate estimation of soil parameters

- Challenge: Surface conditions at the EO scale

(1) Young emerging crops

(2) After harvest residues

(3) Mixed tree/crops

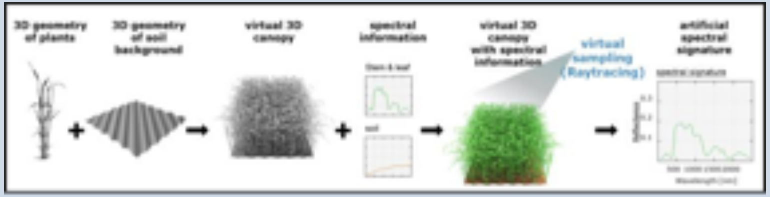
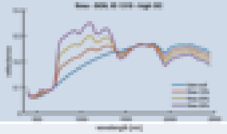
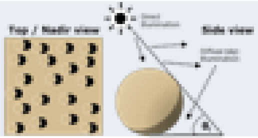
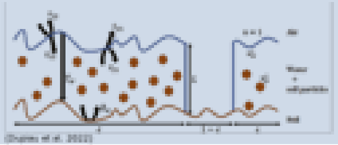
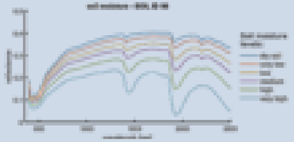
(4) Surface roughness

(5) Soil moisture

- Aim: Simulation of "landscape-like" reflectance spectra (Spatially Upscaled Soil Spectral Libraries: SUSSL) → Improve data basis for spectral soil modelling

Simulation of Spectral “Disturbance Effects”

- Simulated aggregated and mixed pixels: Step-wise green crop, surface residues, trees, soil moisture and roughness are added to 158 LUCAS bare soil spectra

Disturbance effect	Mixing steps	Modelling principle
(1) Early green crops	10, 20, 30	• Virtual 3D soil / plant landscape scenario • Monte Carlo-ray-tracing technique • HySimCaR, Kuester et al., 2014, 2021 
(2) Crop dry residues	10, 20, 30	
(3) Forest/Trees	10, 20, 30	• Linear mixing with tree spectrum • ECOSTRESS speclib (*pinus ponderosa*)  
(4) Soil Roughness (microtopography)	10, 20, 30	• Simulation of “shaded soil” • MODTRAN diffuse sky irradiance  
(5) Soil moisture	very low, low, medium	• Physically based simulation of soil moisture • MARMIT 2.0 model • Bablet et al., 2018; Dupiau et al., 2022  

Assessment of the impact on SOC prediction performance

❑ **CNN model applied to all LUCAS agricultural soils (n_val = 2,675, n_cal = 6,242)**

- Best modelling approach

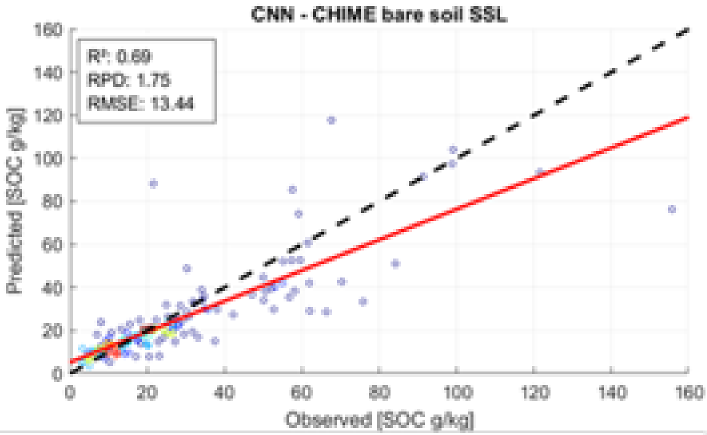
CHIME

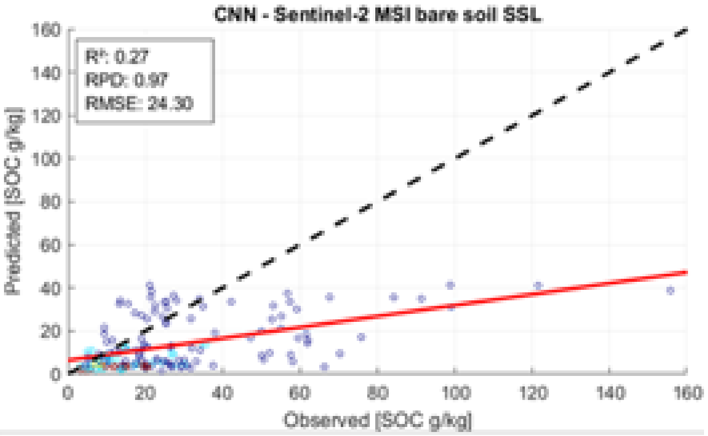
R^2 : 0.74
RPD : 1.97
RMSE: 6.67

Sentinel-2

R^2 : 0.40
RPD : 1.29
RMSE: 10.17

❑ **(1) CNN model applied 158 LUCAS agricultural soils (bare soil baseline for upscaling experiment)**



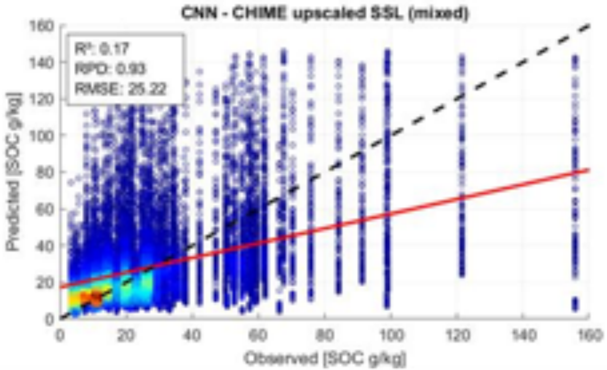


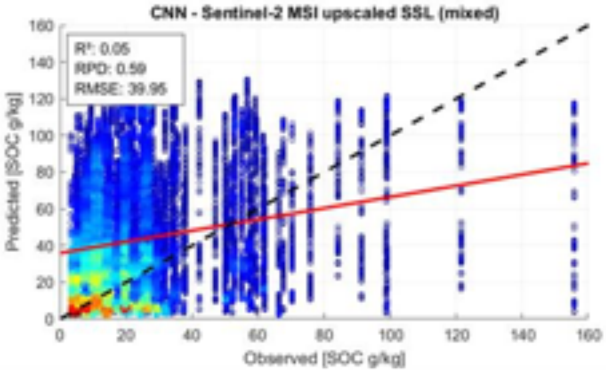
- Biased subsample consisting of highly variable soils

➢ Increase in RMSE

Assessment of the impact on SOC prediction performance

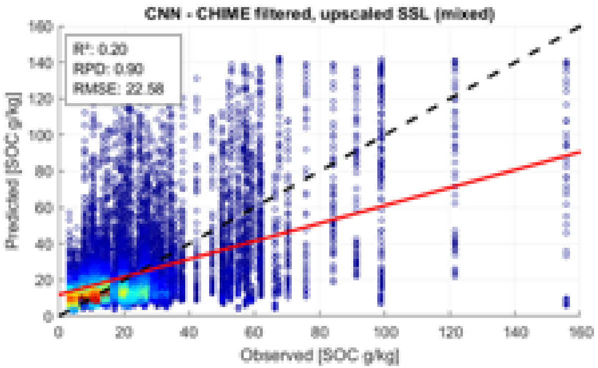
❑ (2) CNN model applied to the SUSSL (23,858 mixed spectra, 150 disturbance scenarios for each soil)

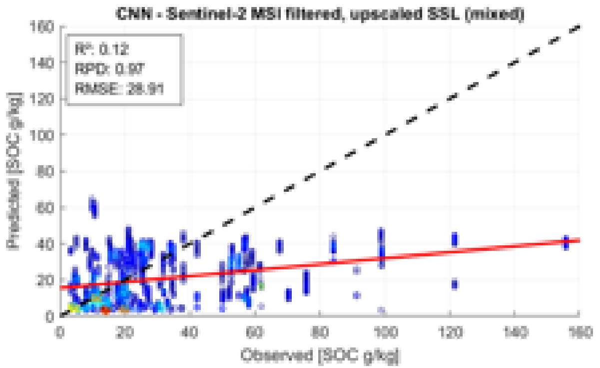




- Disturbances have strong influence on SOC prediction
- ➢ Strong Increase in RMSE

❑ (3) CNN model applied to SUSSL after revised thresholding





- Filtering removes most severe effects
- ➢ Decrease in RMSE
- ➢ But still almost 3% SOC error for S2, 2% for CHIME

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ESA Worldsoils – Soil Surface Conditions at the EO scale

- Challenging surface conditions at the EO scale are an essential factor for the decrease in SOC prediction accuracy
- Filtering approaches using spectral indices can only differentiate the most heavily disturbed cases -> residue error still too high
- Multispectral satellites are very limited to detect dry crop residue and moisture
- CHIME is more performant than Sentinel-2

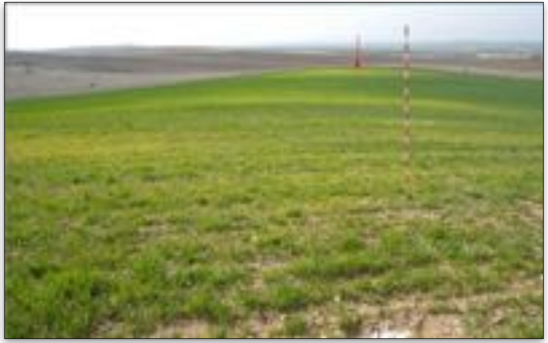
Outlook: Development of “landscape like” spectral library provides test ground for testing of correction methods

  - LUT-based inversion for soil parameter estimation (testing adaption of the Soil–Leaf–Canopy, SLC model)
  - ML / AI training of disturbed scenarios (hybrid methods)

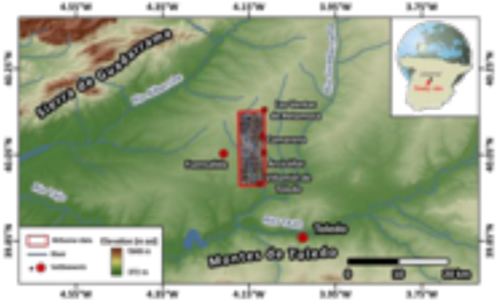
Impact of soil degradation on crop productivity

- Camarena long-term research site for soil remote sensing
- Soil surface characteristics, soil erosion stages, and vegetation conditions are strongly related at field plot scale

Degraded field site (SU) Left: under fallow, Right: with barley cultivation

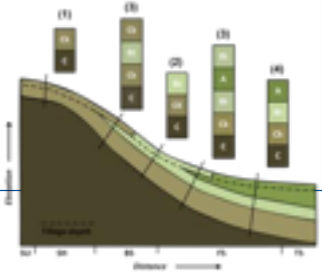


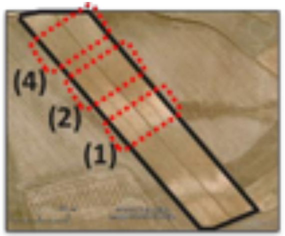
Camarena, central Spain



Soil profile modification by tillage & rainfall along slopes

- ➢ Exposure different soil horizons





Research objective

- ➢ Estimation of the impact of soil degradation on crop productivity (e.g., LAI and grain yield) (**Milewski et al., 2022**)

Impact of soil degradation on crop productivity

AHS VNIR-SWIR-TIR

Green vegetation canopy (growing season, May 2017)

- Field sampling
  - LAI measurements
  - Crop grain yield
- AHS (VNIR-SWIR-TIR) hyperspectral data
  - Image pre-processing
  - Crop canopy Reflectance & Temperature

Bare soils (under fallow, Aug 2011)

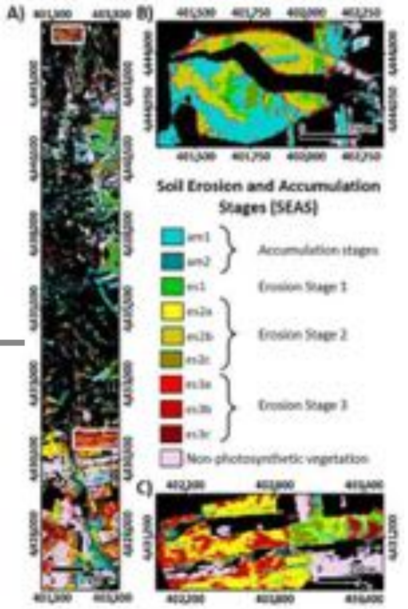
- AISA (VNIR-SWIR) hyperspectral data
  - Bare soil Reflectance
  - Classification of Soil Degradation Stages

PLSR modelling of plant physiological parameters: LAI, grain yield

Crop Water Stress Index (CWSI, T_{canopy} & T_{air})

Meteorological data (T_{air})

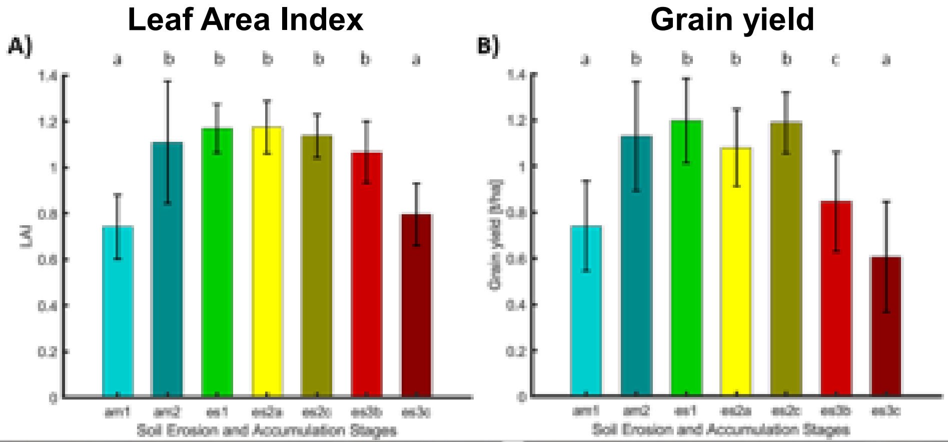
Impact of soil degradation on crop productivity

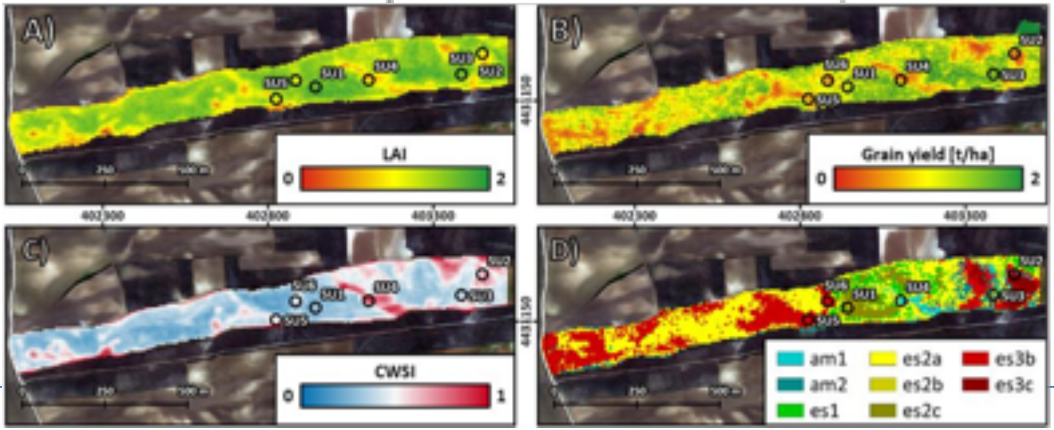


Schmid et al. (2016)

Impact of soil degradation on crop productivity

Soil Erosion and Accumulation Stages (SEAS)		Classification Symbol
Accumulation stage (am) : deposits at downslope positions		am1
		am2
Erosion stages (es)	Stage 1 (es1) : slightly eroded soil. Presence of A horizon	es1
	Stage 2 (es2) : moderately eroded soil. Loss of A horizon, presence of subsurface weathered horizon	es2a
		es2b
		es2c
	Stage 3 (es3) : strongly eroded soil. Loss of A and B horizon. Outcropping of C horizon / parent material	es3a
		es3b
		es3c



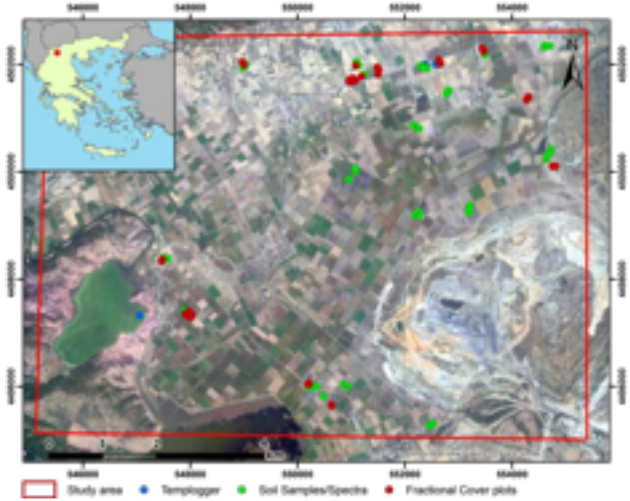


Impact of soil degradation on crop productivity

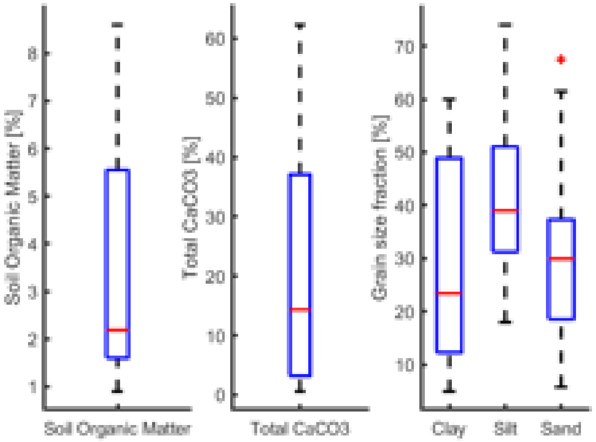
- Soil surface characteristics, soil erosion stages, land management and vegetation conditions are strongly related
- Estimations of LAI, grain yield & crop water stress (CWSI) are significantly related to the soil degradation status
  - Lowest LAI, yield and water stress at highly eroded soils and sandy accumulation zones
- **Outlook:** Combined remote sensing based monitoring of soil and vegetation resources exploiting upcoming hyperspectral EO datasets (PRISMA, EMIT, EnMAP, CHIME, SBG,…)
- 2021-2022:
  - 28 PRISMA scenes (19 cloud free)
  - 2 EnMAP scenes (commissioning phase)

Synergies of VNIR-SWIR and LWIR Hyperspectral Remote Sensing Data for Soil Property Mapping

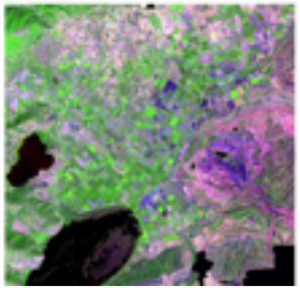
Study area: Amyntaio, Northern Greece



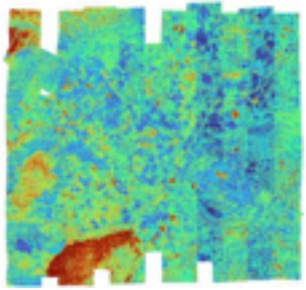
Highly variable soil types



VNIR-SWIR



LWIR



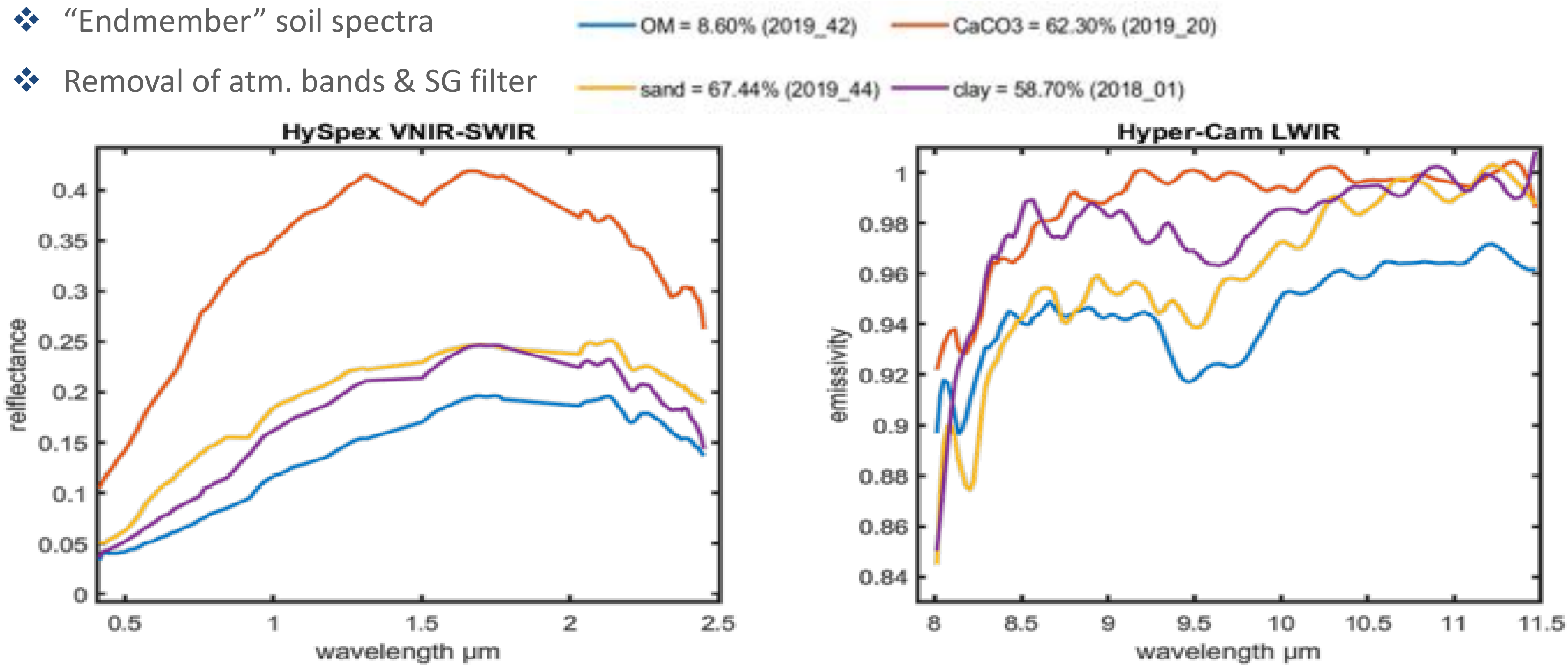
- VNIR-SWIR reflectance, LWIR emittance
- 532 spectral bands

Research objective

- Improvement of soil property (SOC, carbonates) estimation by including LWIR information

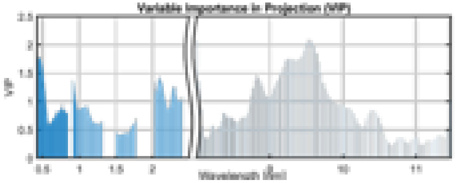
Synergies of VNIR-SWIR and LWIR Hyperspectral Remote Sensing Data for Soil Property Mapping

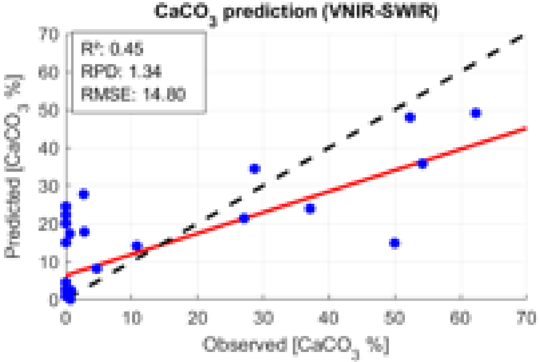
- “Endmember” soil spectra
- Removal of atm. bands & SG filter

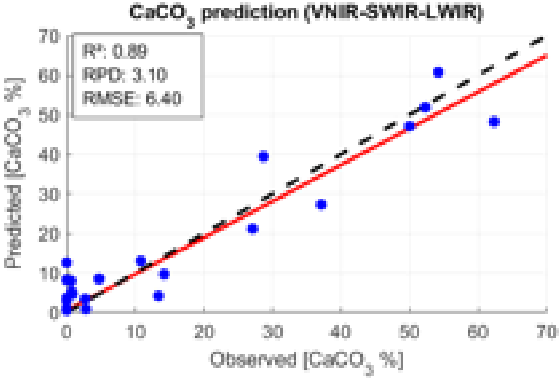


Synergies of VNIR-SWIR and LWIR Hyperspectral Remote Sensing Data for Soil Property Mapping

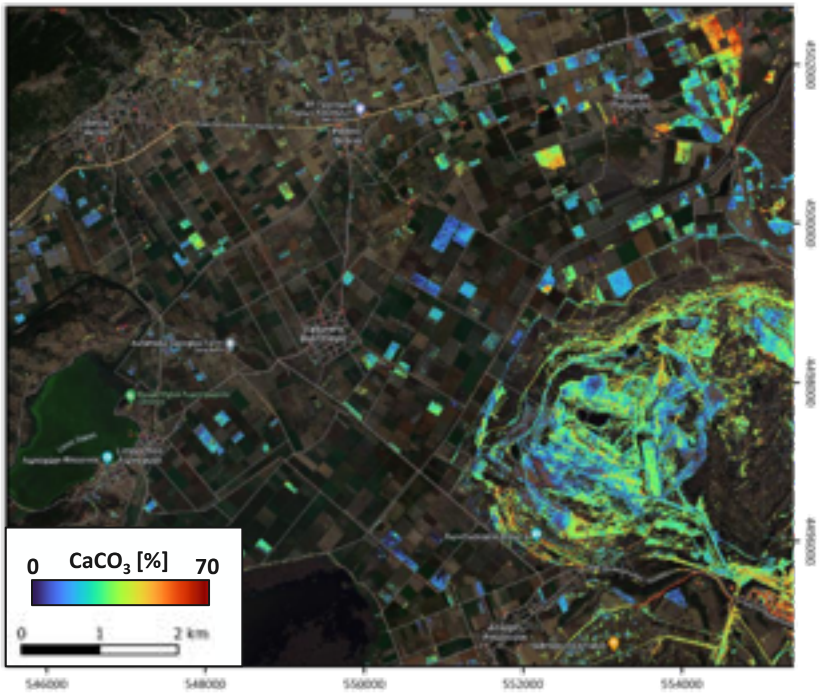
- Combined dataset improves $CaCO_3$ prediction
- Most important spectral regions VIS + NIR + LWIR (9-10 µm)







$CaCO_3$



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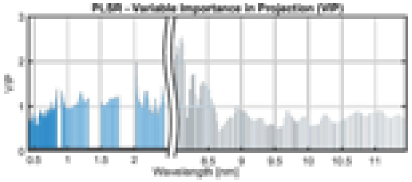
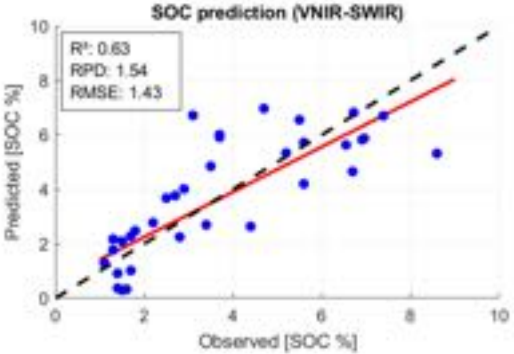
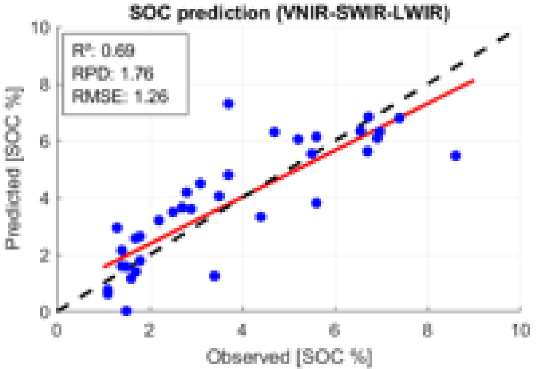
Synergies of VNIR-SWIR and LWIR Hyperspectral Remote Sensing Data for Soil Property Mapping

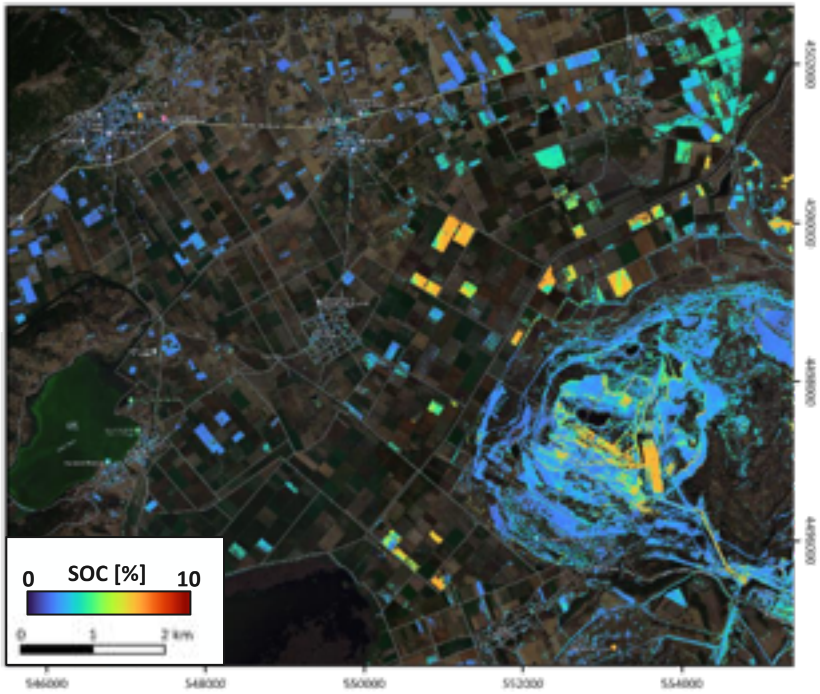
- Only small improvement by including LWIR information
- High SOC content in the alluvial plain and Lignite mine
- Most important spectral regions NIR + SWIR II + LWIR (< 8.5 µm)







SOC



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Synergies of VNIR-SWIR and LWIR Hyperspectral Remote Sensing Data for Soil Property Mapping

- Addition of LWIR information significantly improved spectral models and estimation of soil properties (SOC and $CaCO_3$)

Next steps

- Analysis of soil texture
- Combination and testing of hyperspectral optical and multispectral thermal EO sensors (e.g. EnMAP, CHIME, SBG, LSTM)
- Demonstration of potential for combining optical and thermal spectral information for global soil mapping and monitoring

2nd Workshop on International Cooperation in Spaceborne Imaging Spectroscopy
19-21 October 2022 | La Collinetta Eventi, Frascati IT

esa

EnMAP

WORLDSOILS

Thanks for your attention!

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