

ABSTRACT

This study explores the use of LSTM (Land Surface Temperature and Emissivity) data to improve the retrieval of essential soil parameters: soil texture, Soil Organic Carbon (SOC), and calcium carbonate (CaCO₃) at the Jolanda di Savoia agricultural site in Northern Italy. Our research addresses the challenge of accurately separating Land Surface Temperature (LST) and Land Surface Emissivity (LSE) from thermal infrared (TIR) remote sensing data. We focus on refining Temperature Emissivity Separation (TES) and In-Scene Atmospheric Correction (ISAC) methods to obtain high-quality LSE spectra. Key improvements include optimizing atmospheric correction using normalized difference indices for water vapor and updating the empirical emissivity relationship within TES by incorporating LSTM's optical band data (e.g., NDVI). The integration of spectral libraries is also investigated as an alternative constraint in TES solutions. Results show that it is possible to estimate SOC, the best-case estimation of SOC using HyTES data yielded: RMSE = 0.81, R² = 0.64, and RPD = 1.68.

INTRODUCTION

Soil characterization is vital for sustainable agriculture and environmental monitoring. Traditionally, this involves time-consuming and resource-intensive sampling. However, remote sensing, particularly in the TIR domain, offers a non-invasive and efficient alternative.

Key Soil Parameters	Importance for Sustainable Management
Texture (Clay, Silt and Sand)	Water retention, nutrient availability
Soil Organic Carbon (SOC)	Soil health, carbon sequestration
CaCO ₃	pH buffering, nutrient cycling

The upcoming Copernicus Land Surface Temperature Monitoring (LSTM) mission by ESA, expected around 2028-2029, represents an unprecedented opportunity for Earth monitoring. Beyond primary agricultural applications, LSTM explicitly targets "mapping and monitoring soil composition," highlighting its potential for detailed soil property assessment. This study, part of the ESA-MOST Dragon 6 cooperation, aims to explore LSTM data's full potential for improving key soil biophysical parameter retrieval.

- Spatial resolution: 50 m
- Revisit time: 1-3 day

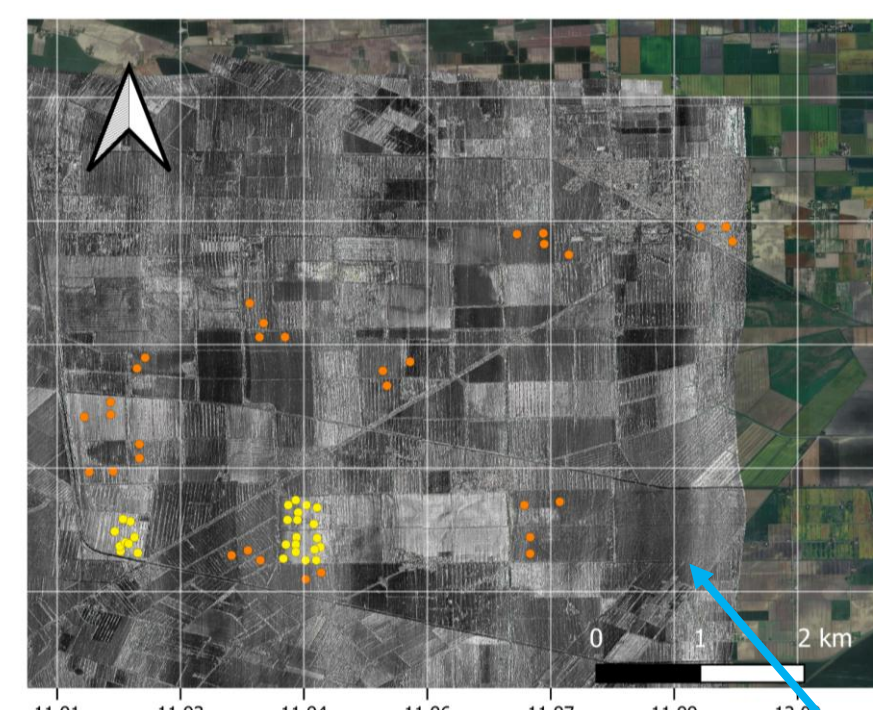


OBJECTIVES

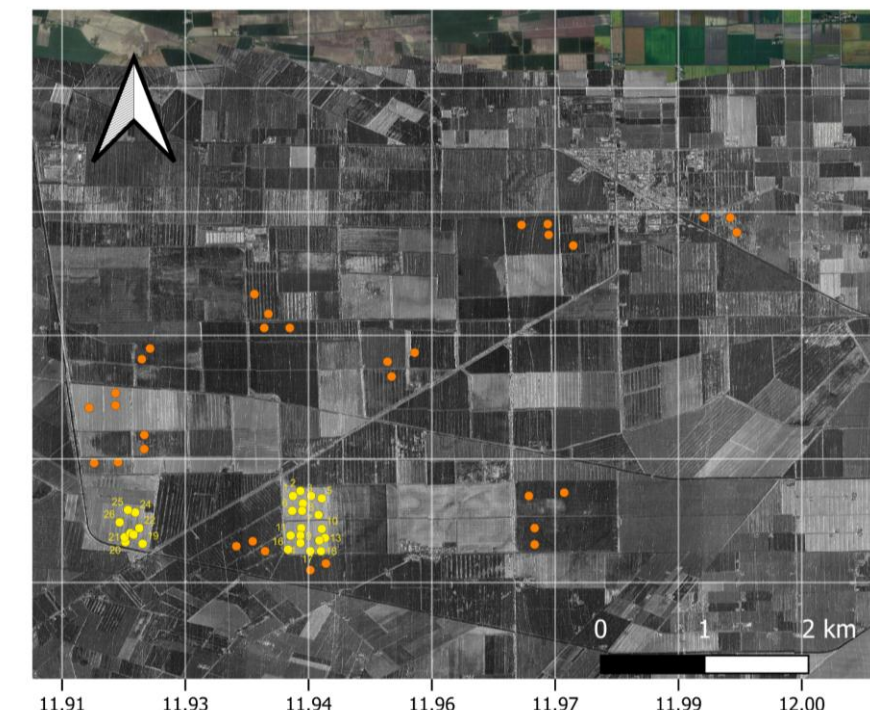
- Develop a method to estimate optimal water vapor relative to a reference atmospheric profile using normalized difference indices from MODTRAN simulations. Apply this index to enhance atmospheric correction algorithms such as In-Scene Atmospheric Correction (ISAC) and Inter-Channel Correlated Automatic Atmospheric Compensation (ICCAAC).
- Update empirical Temperature and Emissivity Separation (TES) relationships by investigating methods to refine the ϵ_{min} -MMD relationship by incorporating ancillary information from LSTM's co-registered optical bands (e.g., NDVI), developing vegetation-dependent parameters or stratifying the relationship based on NDVI values
- Integrate spectral libraries by exploring the integration of spectral libraries as an alternative or complementary approach to constrain the TES solution

The goal is to derive accurate LSE spectra (8-12.5 μ m) that can be applied to characterize agricultural topsoil properties, specifically its texture, SOC, and CaCO₃.

DATA ACQUISITION



HyTES L2 v. B109 @ 9.81 μ m

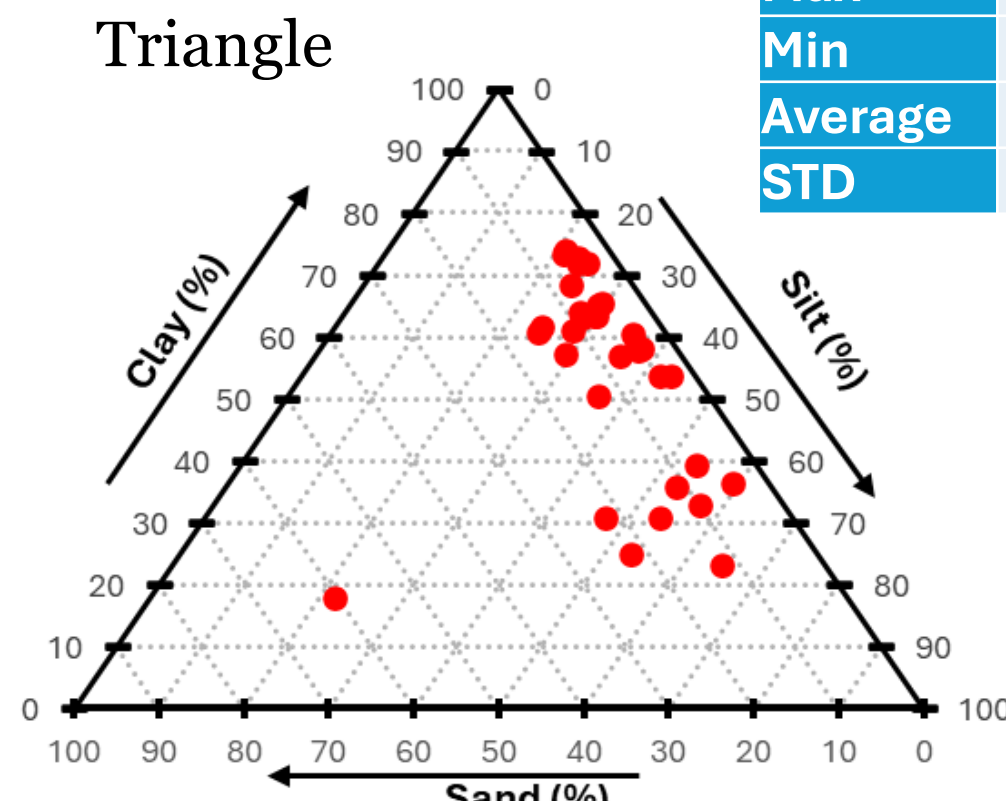


HyTES L1_CORR_IMAA-ICCAAC TES @ 9.81 μ m

Spatial and spectral anomalies

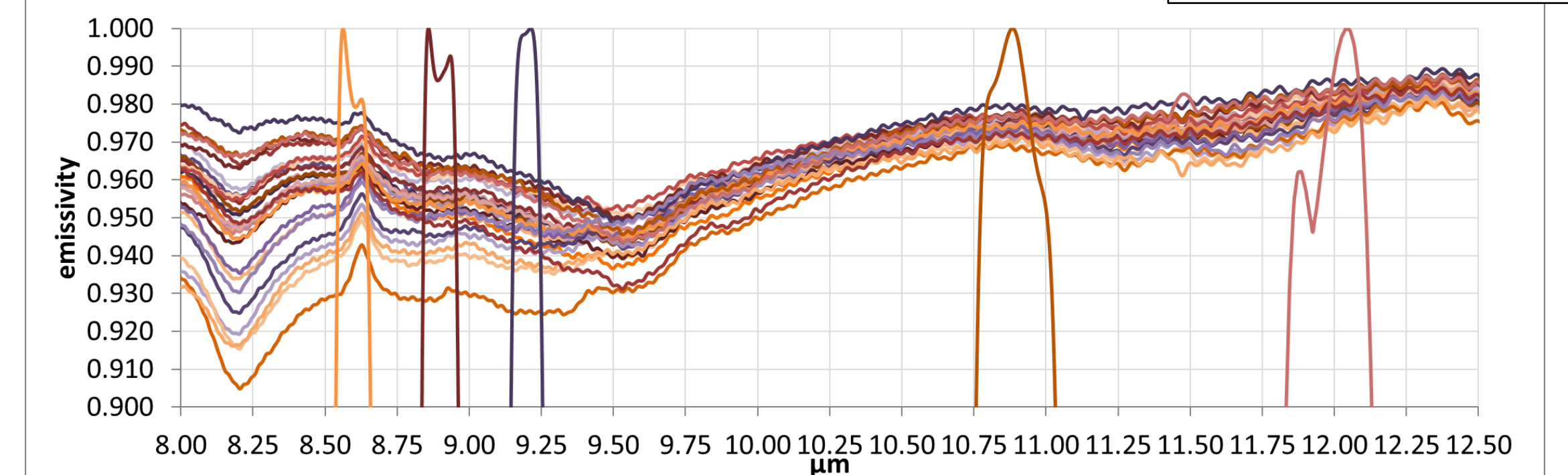
- Orange dots: 32 sample collected during 2021/2022 field campaigns @ 30m ESU for PRISMA/EnMAP
- Yellow dots: 27 samples collected in 2023 @ 3m ESU for HyTES survey.
- 27 JPL lab Nicolet FTIR analysis

USDA Soil Texture Triangle



30m ESU	Clay (%)	Silt (%)	Sand (%)	SOC (%)	CaCO ₃ (%)
Max	17,46	19,65	1,84	0,55	0,00
Min	74,67	78,66	38,85	5,59	11,74
Average	51,44	38,89	9,67	2,54	3,24
STD	14,89	13,59	8,35	1,36	3,07

JPL Laboratory Emissivity Spectra VS LSTM SRF

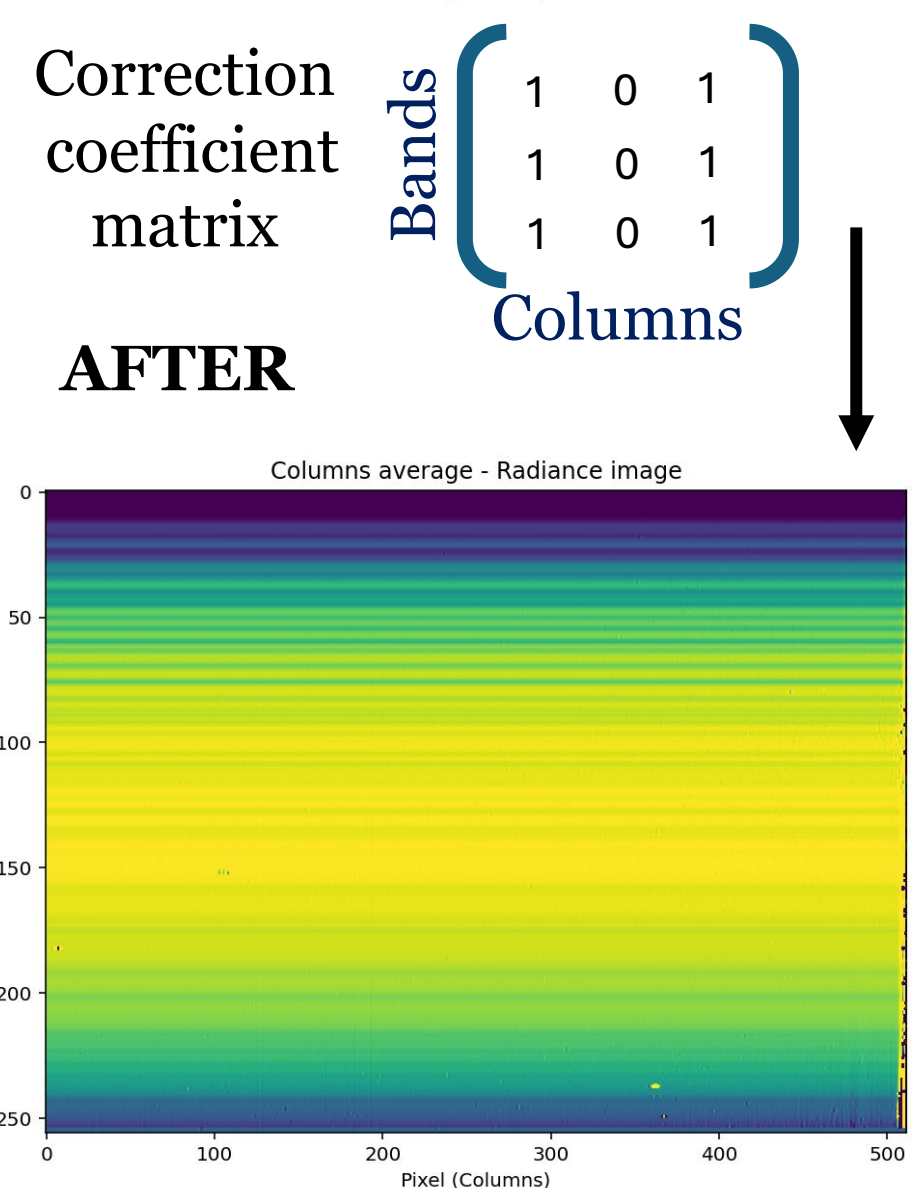
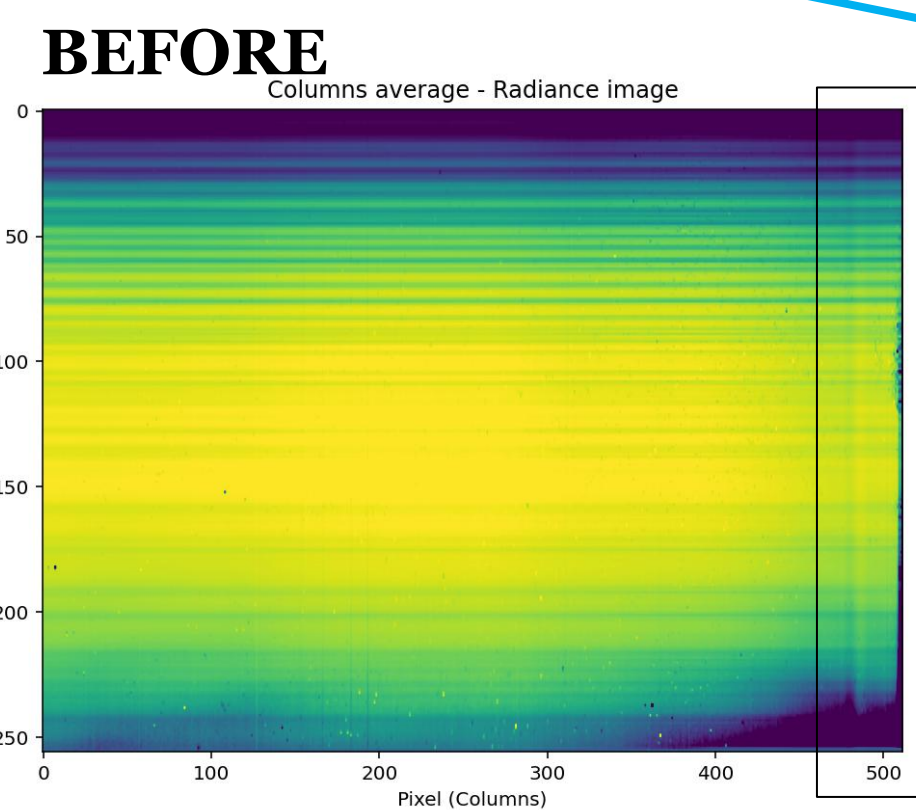
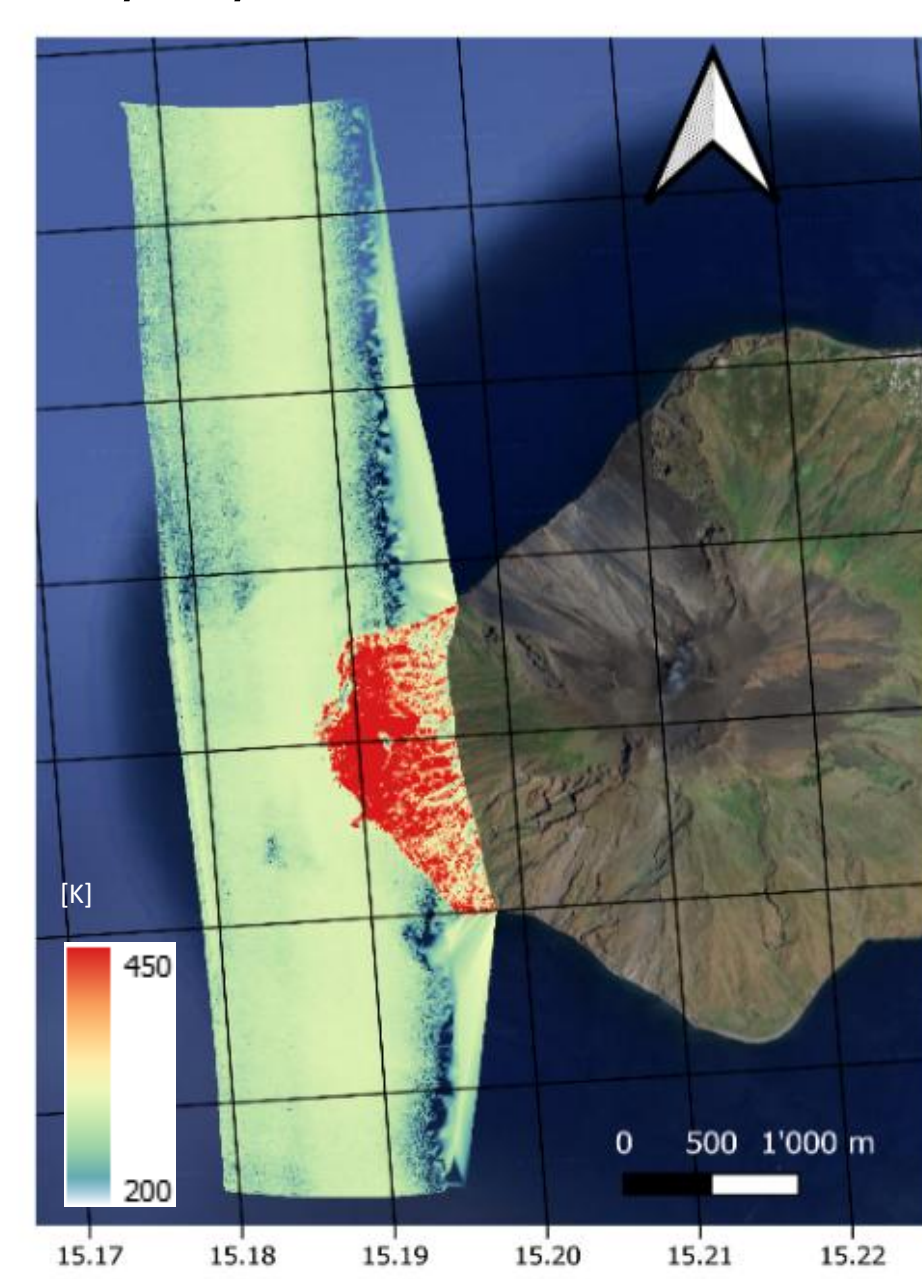


METHODS

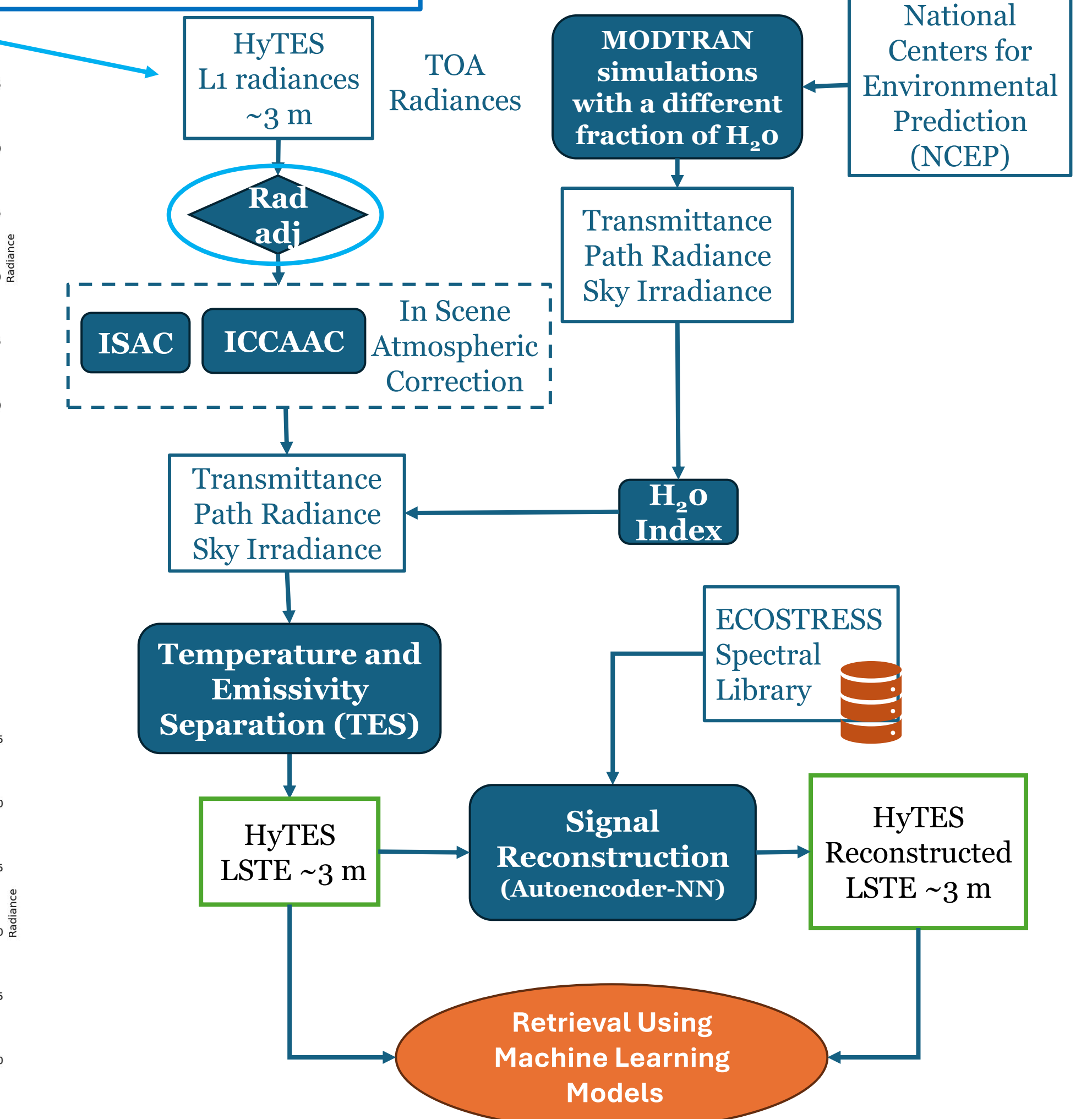
Spatial pattern correction

Deep-sea water has been used as a reference homogeneous target

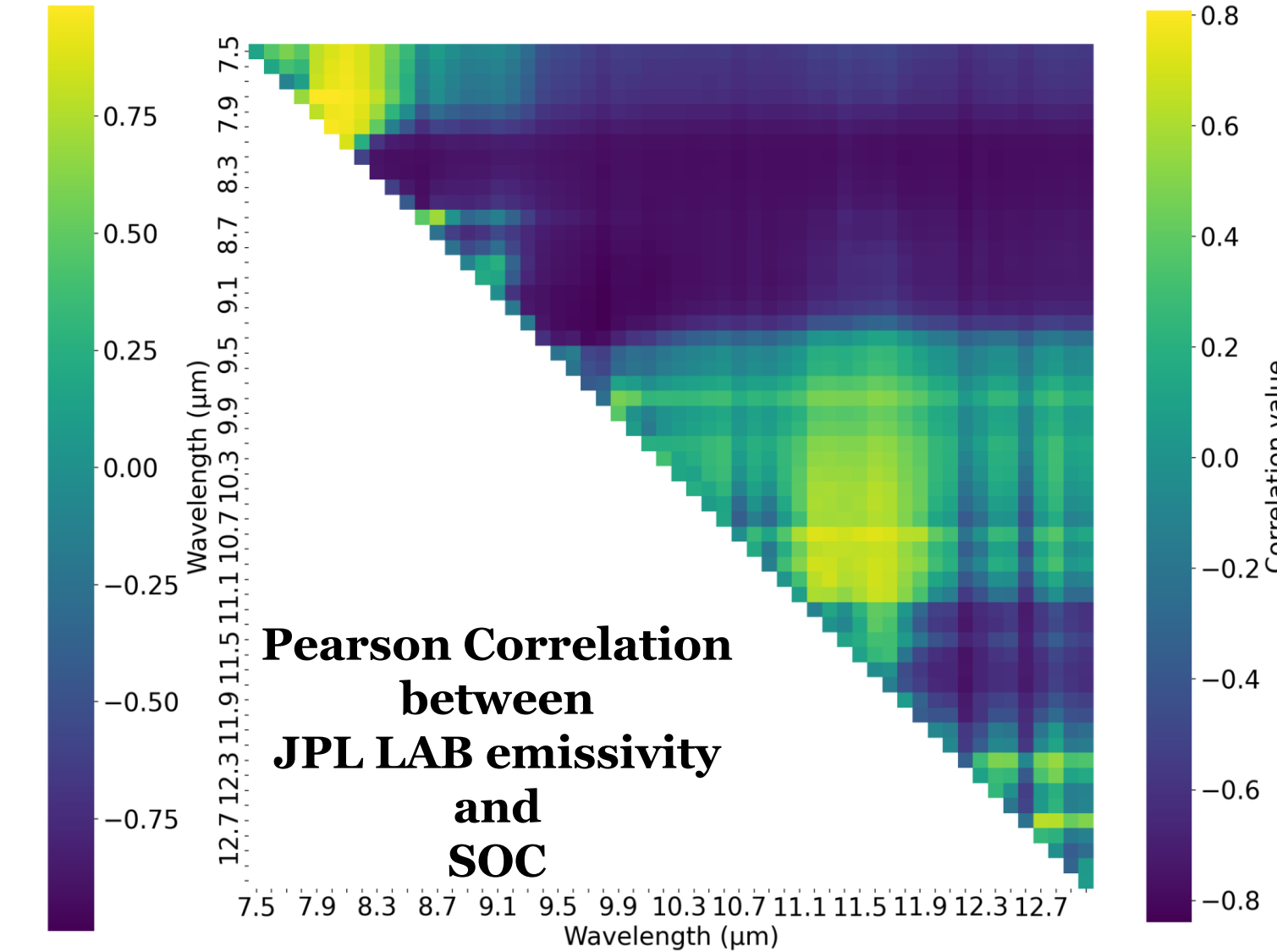
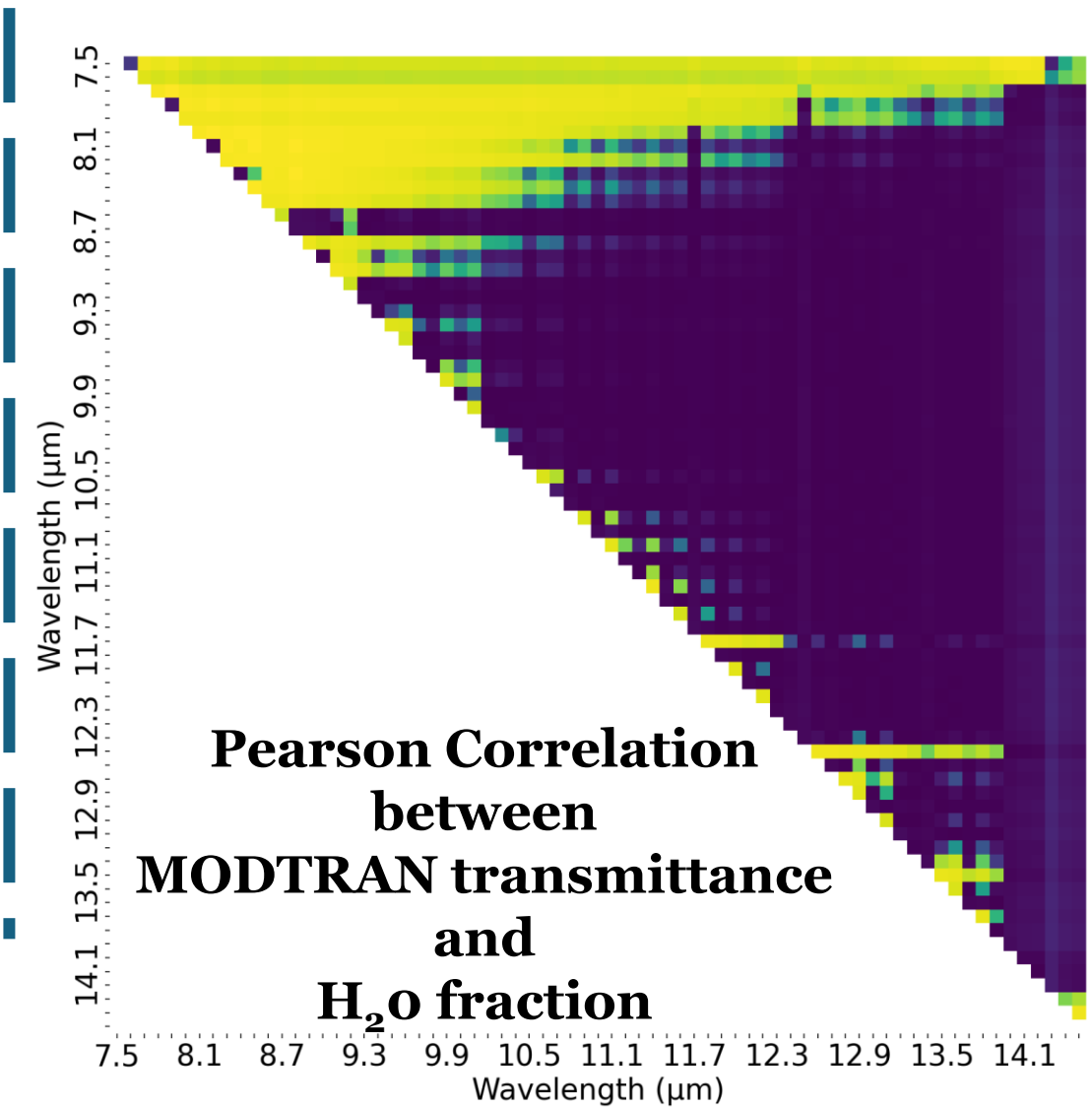
HyTES survey Stromboli L2 product of Stromboli 04/07/2023.



Temperature and emissivity separation workflow



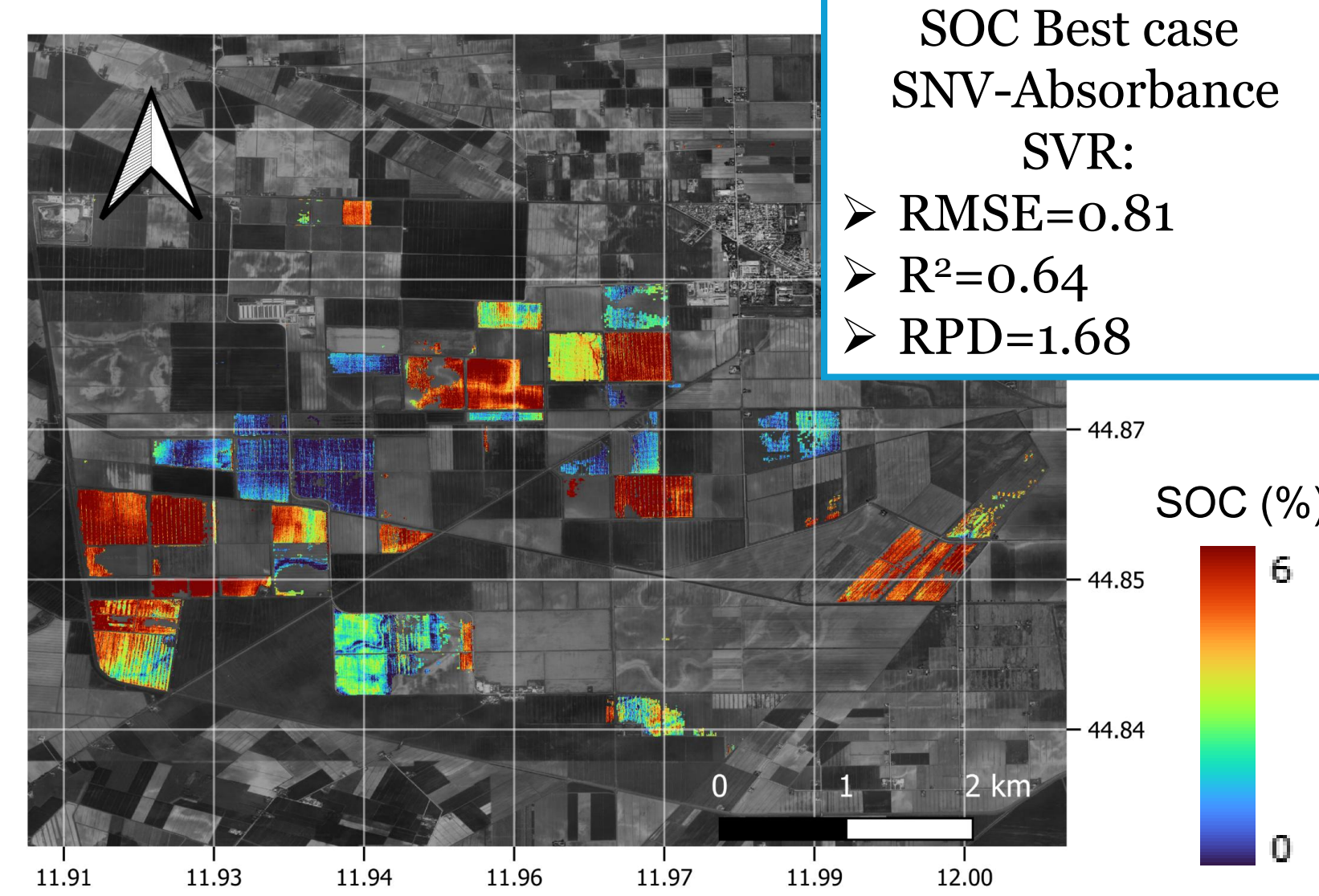
RESULTS



DISCUSSION

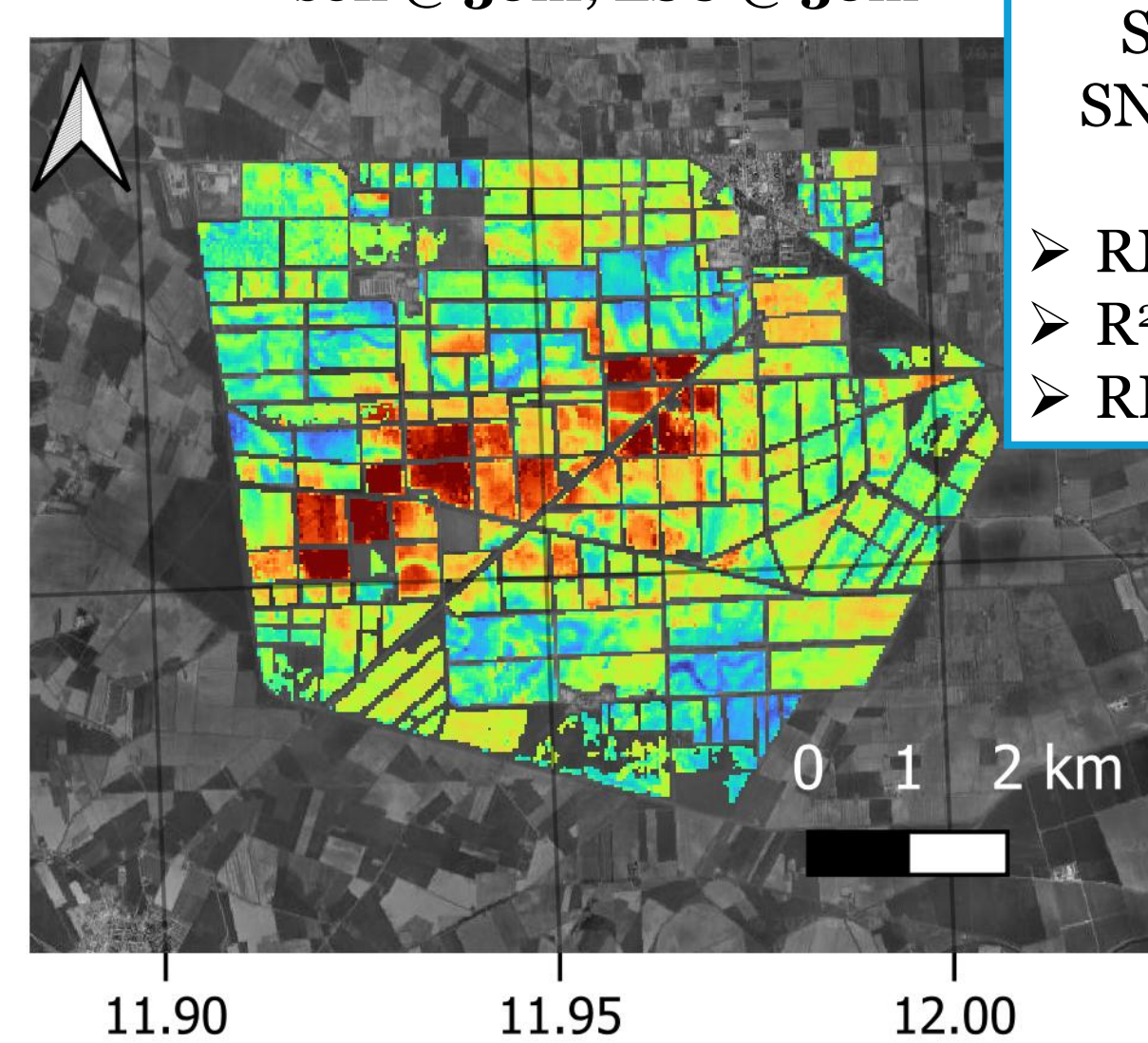
- Same problems as the VIS-SWIR sensor: the quality of the ML model depends on the spatial resolution and the presence of photosynthetic and non-photosynthetic vegetation
- ICCAAC, which exploits the correlations of atmospheric components across adjacent channels, is meant for thermal infrared hyperspectral data
- The quality of ISAC also depends on the MODTRAN output used to scale ISAC output

L1_CORR_IMAA-ICCAAC-TES_8-11.59 (203 Bands) @ 3m; ESU @ 3m



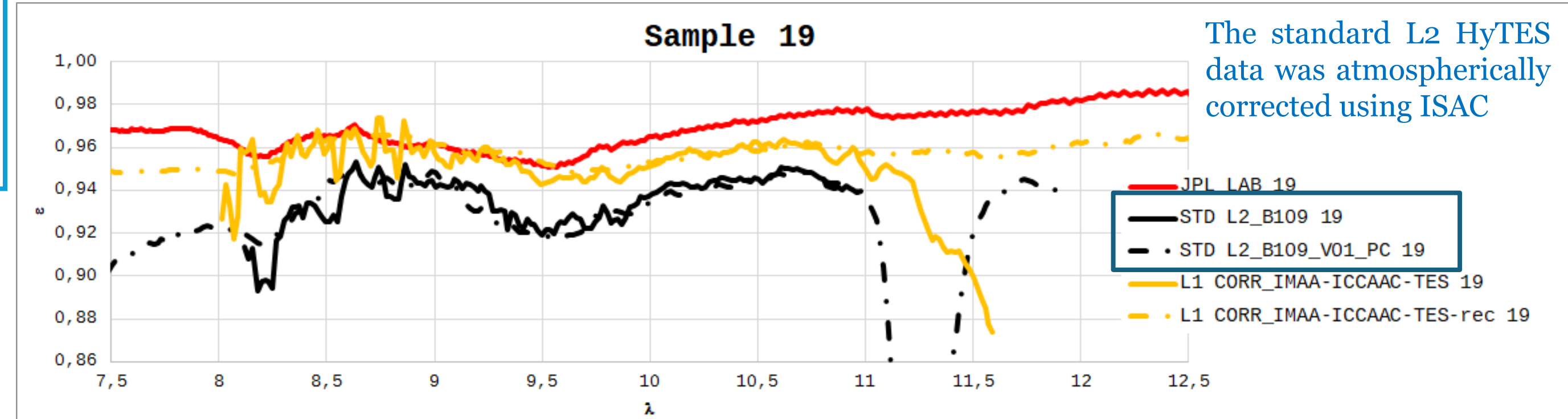
SOC Best case SNV-Absorbance SVR:
➤ RMSE=0.81
➤ R²=0.64
➤ RPD=1.68

EnMAP-Time series composite of bare soil @ 30m; ESU @ 30m



SOC Best case SNV-Absorbance GPR:
➤ RMSE = 1.06
➤ R² = 0.75
➤ RPD = 2.01

Sample 19



The standard L2 HyTES data was atmospherically corrected using ISAC

CONCLUSION

- The water vapor content in the atmosphere is the most critical factor for the atmospheric correction of thermal imagery. While the water vapor fraction is correlated with normalized transmittance indices, methods for accurately estimating its content still require further investigation.
- It is possible to estimate SOC from emissivity LSTM data. Using HyTES imagery and an SNV-Absorbance method with Support Vector Regression (SVR), we achieved the following metrics for the best-case scenario(SVR applied to SNV-Absorbance): RMSE = 0.81, R² = 0.64, and RPD = 1.68. However, the estimation of other soil properties, such as texture and CaCO₃ content, was hindered by a limited dataset and sensor noise, indicating a need for further research.