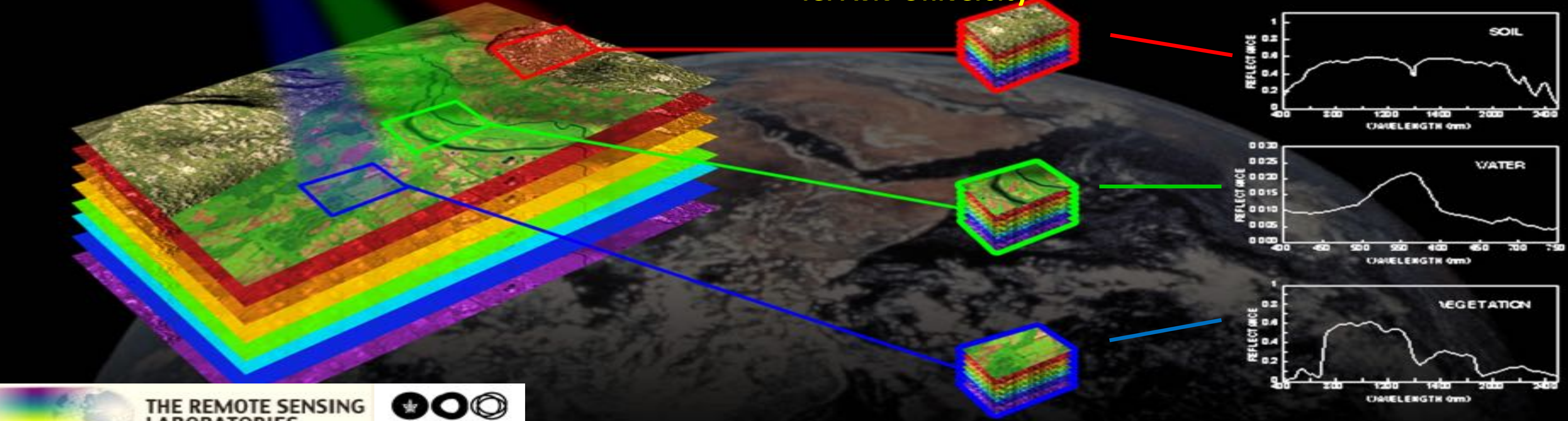
Estimation Of Water Infiltration Rate In Mediterranean Soils Using Airborne Hyperspectral Sensors

icolas Francos[1], Nikos Tziolas[2], Maximilian Brell[3], Sabine Chabrillat[3], Nunzio Romano[4], Paolo Nasta[4], Yijian Zeng[5], Brigitta Szabó[6], Salvatore Manfreda[7], Giuseppe Ciraolo[8], János Mészáros[6], Ruodan Zhuang[9], Bob Su[5], Eyal Ben-Dor[1]

Department of Geography
Porter School of Environment and Earth Science
Tel Aviv University



THE REMOTE SENSING LABORATORIES

TEL AVIV UNIVERSITY אוניברסיטת תל אביב

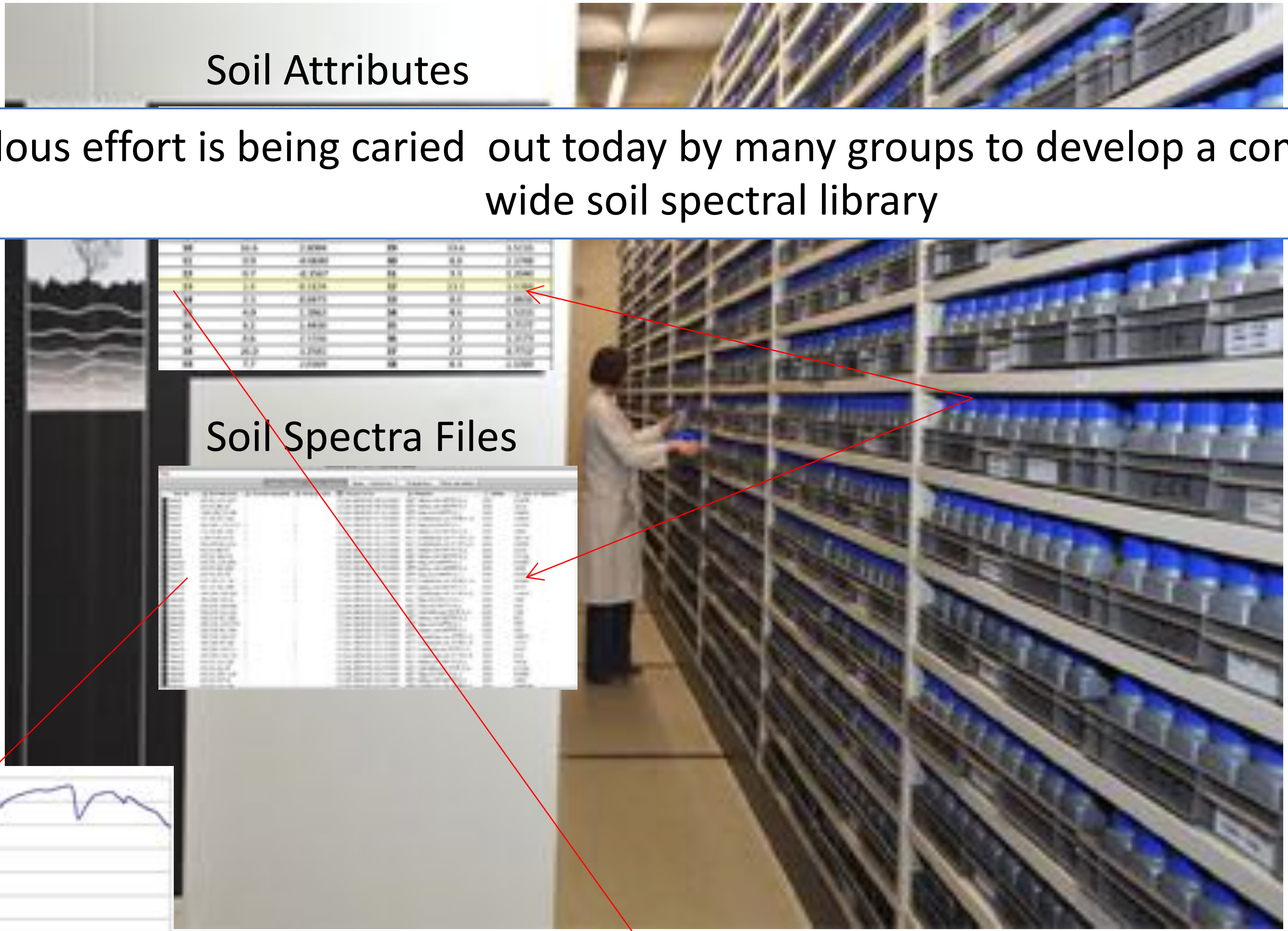
The Problem

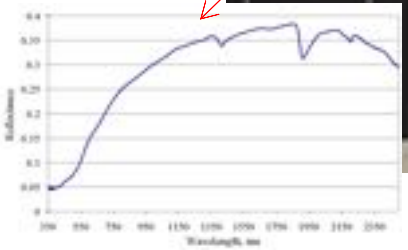
- Soil Spectral Libraries are an important set of data to develop quantitative models to map soil properties
- The SSL however not able to mimic the surface condition as they are seen by EO means (disturbed by sampling, sieving, and drying)
- Soil Sealing is emerged due to physical and biogenic processes on the upper micrometer of the soil surface
- Although the crust "horizon" is neglected within the soil profile – it has a significant impact on the soil stabilization and water regime

Soil Spectral Library : The Practical Structure

Soil samples at storage, with wet chemistry data plus reflectance spectra measured under a well accepted protocol process and ancillary data

A Tremendous effort is being caried out today by many groups to develop a comprehensive word wide soil spectral library

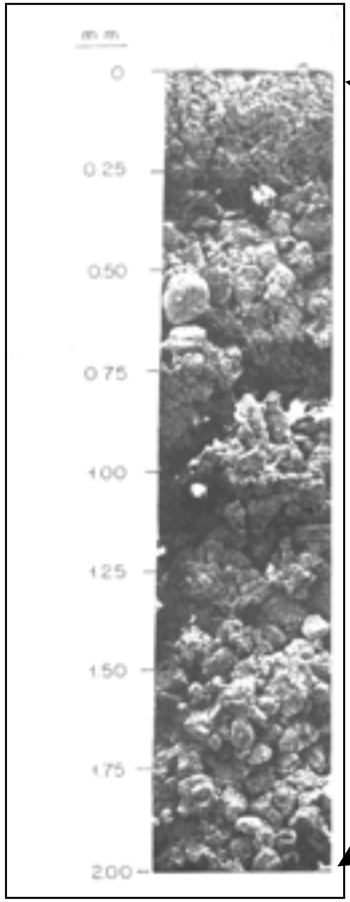


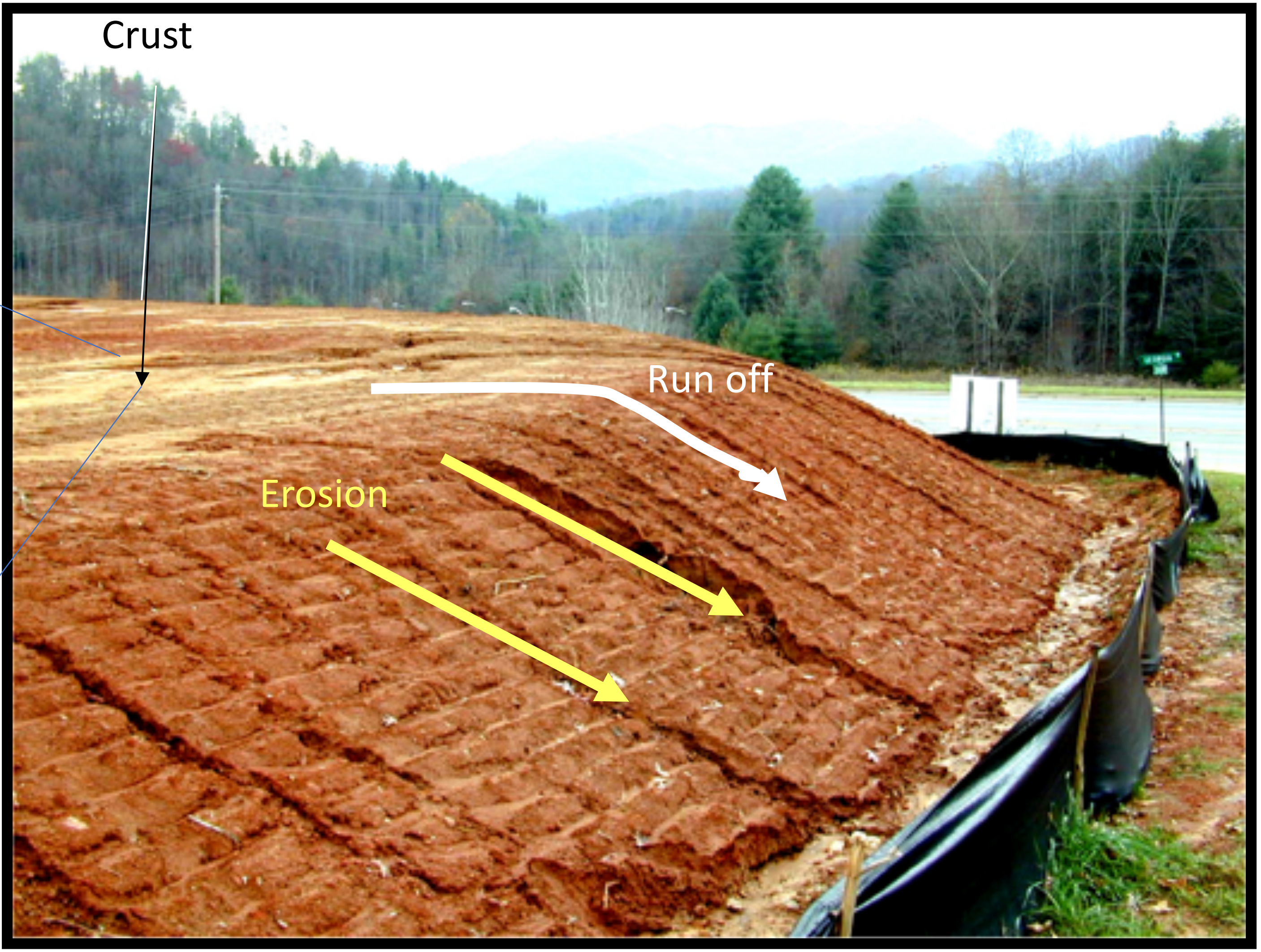


Sample	Location	OM	Clay	Lime….
A1	34,5467.67 36,654,32	2.4 %	34%	23.4%

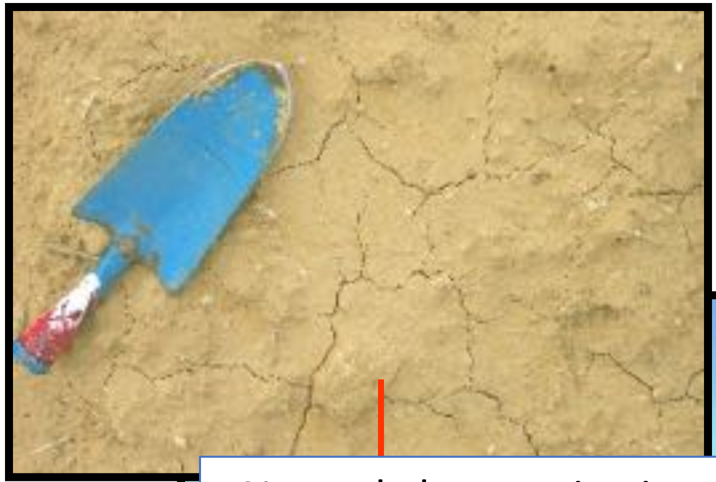
Soil Crust : Effect of Erosion and Water Runoff

Microscope Cross Section View of Physical Crust

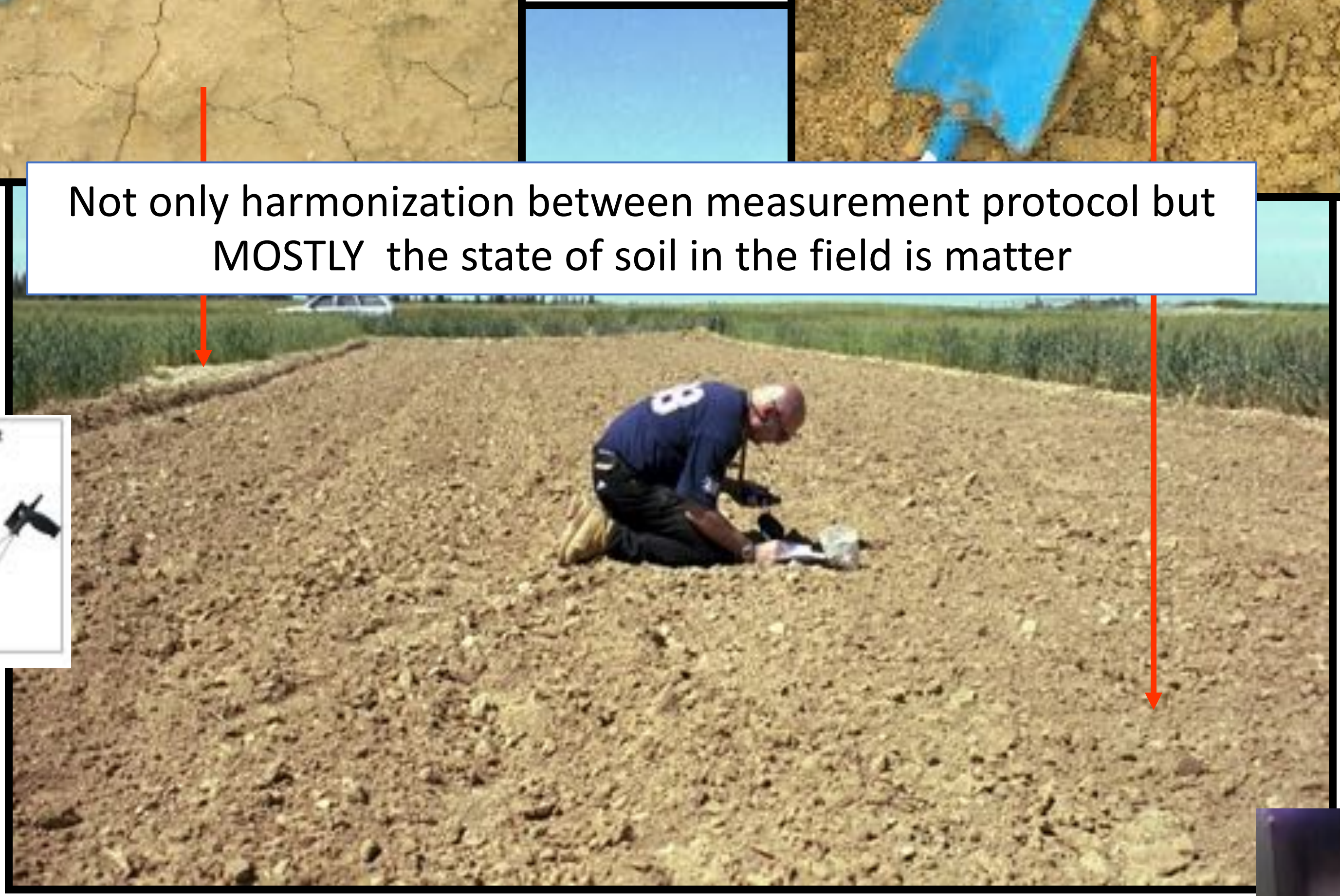




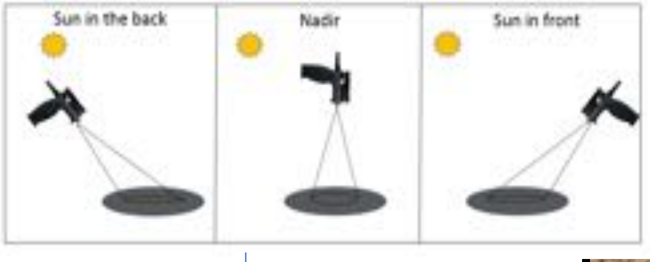
Crust



Braking Crust



Not only harmonization between measurement protocol but MOSTLY the state of soil in the field is matter



Field Measurements

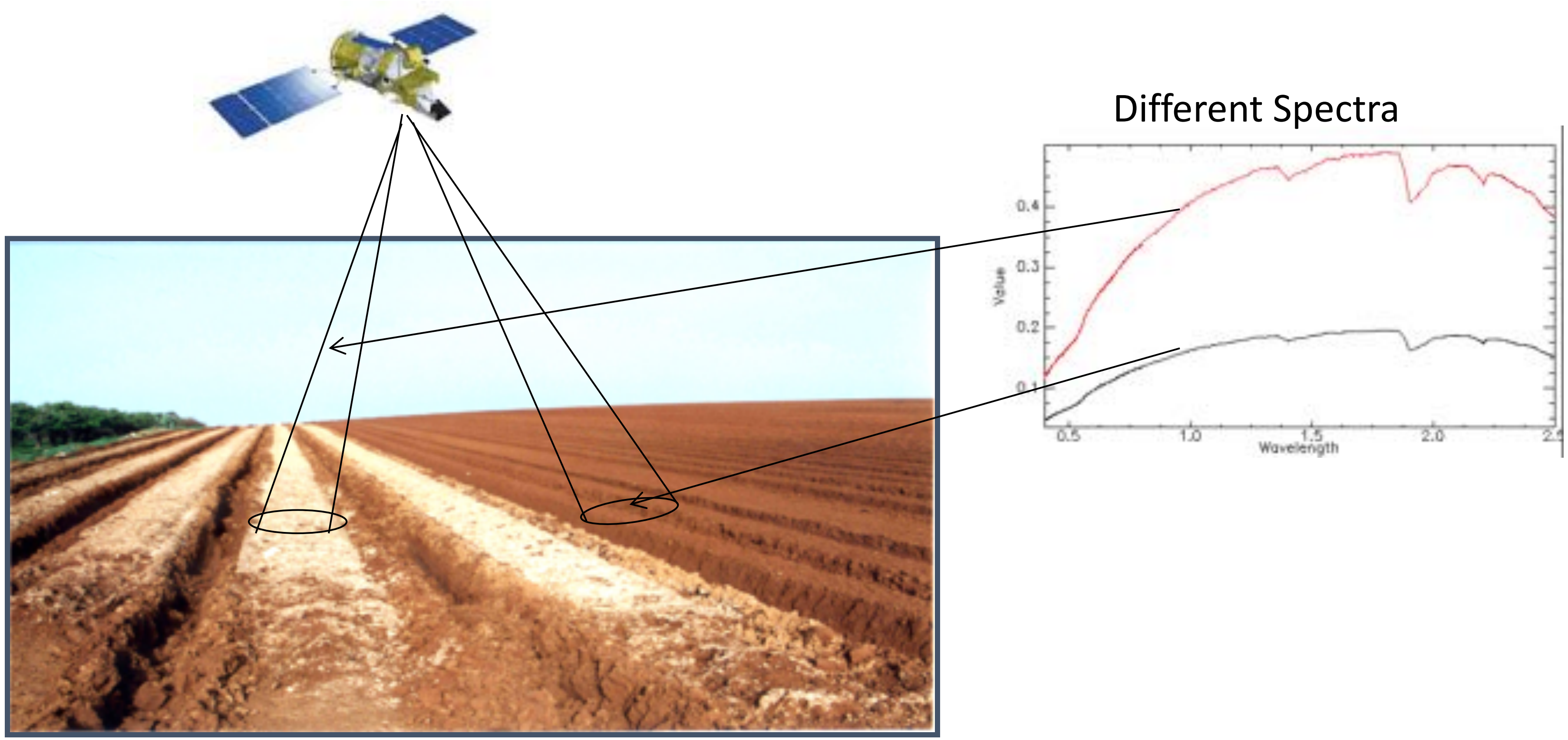
2mm grinding

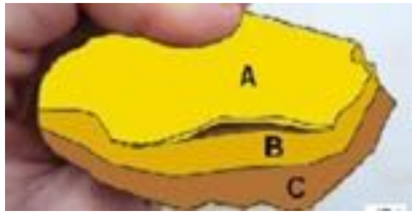
Lab Measurements

Soil physical crust in the field and way to measure soil reflectance

Same soil – Physical Crust

Different Spectra





Solution: Field SSL

De Jong S.M., E.A. Addink, D. Duijsing & L.P.H. van Beek, 2011, Physical Characterization and Spectral Response of Mediterranean Soil Surface Crusts. CATENA 86(1), 24-35

THE REMOTE SENSING LABORATORIES

The soil in the rain simulator is disturbed (just as the soil in the SSL

AND

does not mimic the field condition

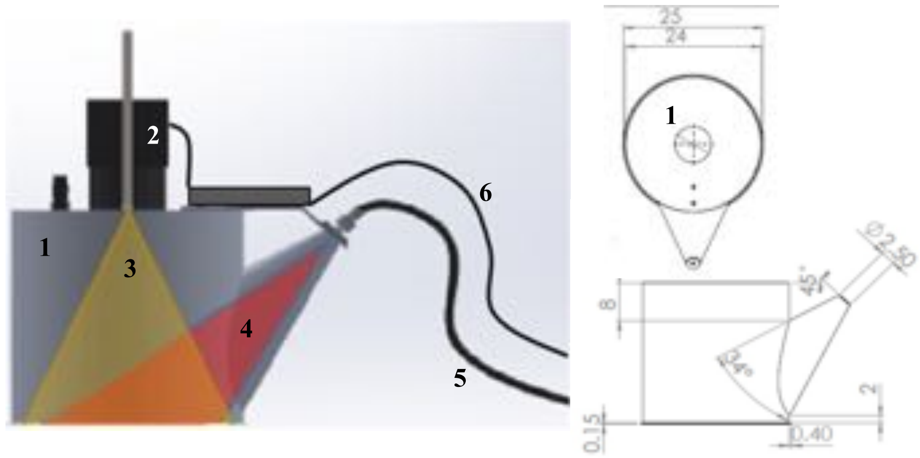
Undisturbed soil – Mimic the field condition: both spectral and infiltration rates are measured under the natural environment and at the viewpoint of the EO means

CHALLENGE: How to measure soil surface reflectance in the field and assess it directly to the surface-related properties

The SOIL field PROB assembly – SoilPro®

- The **SoilPro** is lightweight assembly and easy to operate, suitable to be connected to optic fiber of any field spectrometer.
- The **SoilPro** combines the advantages of the two common methods: acquiring a representative reflectance of large surface area, while keeping all factors
- constant.

The SoilPro - design and operation

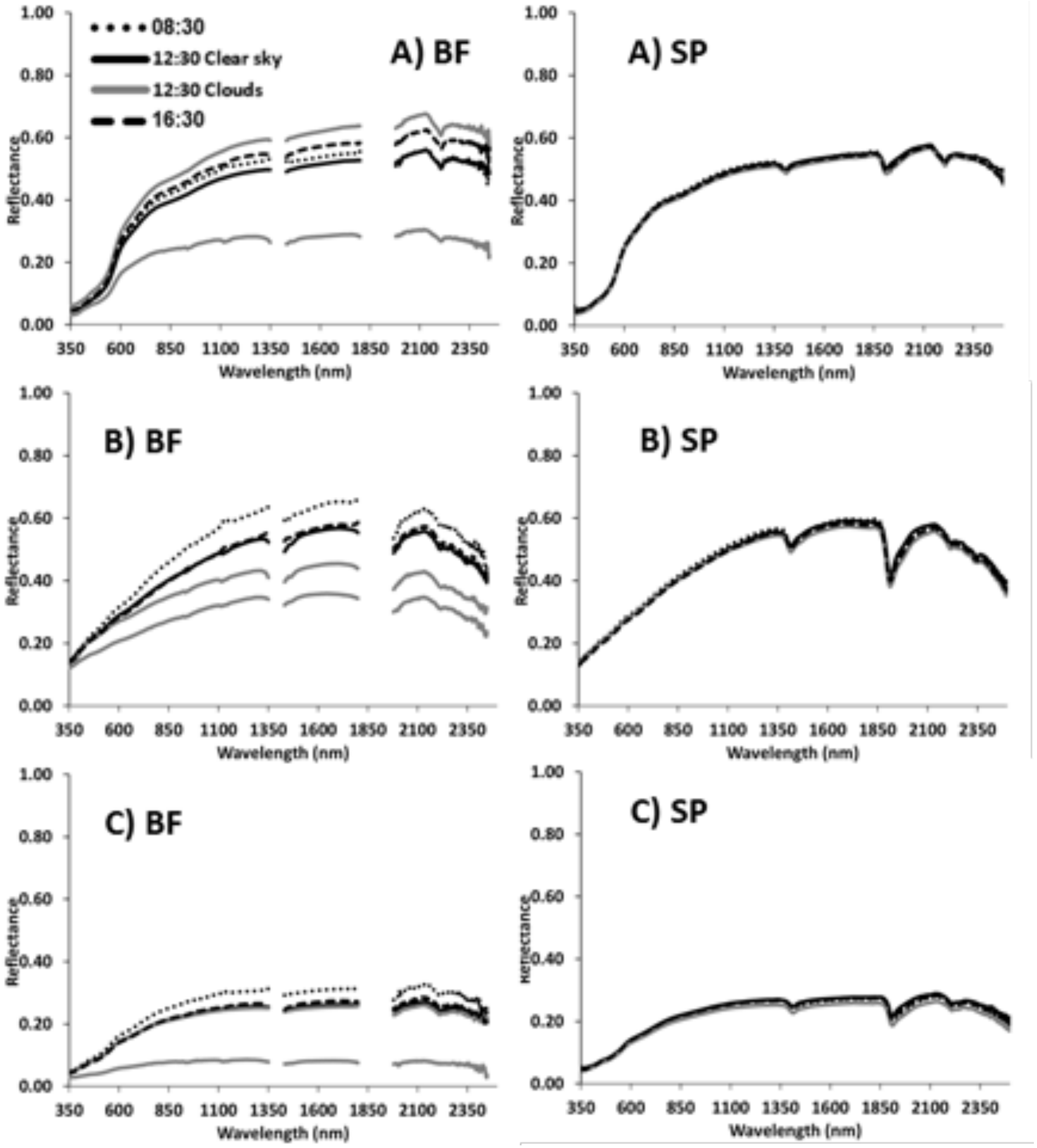


The SoilPro set up

1) SoilPro, 2) portable battery, 3) ASD® fieldSpec

The SoilPro in the field

Quality Performance SoilPro (SP) VS bare fiber (BF)



THE REMOTE SENSING LABORATORIES

WIR is defined as the length units per unit time of water entering into the soil. (Kirkham, 2014)

Using Water Infiltration Rate (WIR) by the SoilPRO®

- WIR is a very important hydrological parameter, which is strongly dependent on soil surface conditions.

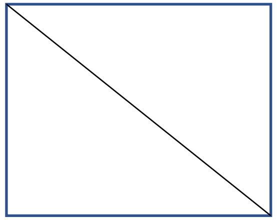
- WIR is an excellent soil property to investigate the gap between lab and field spectral observations

THE REMOTE SENSING LABORATORIES

***WIR* is defined as the length units per unit time of water entering into the soil.**(Kirkham, 2014)

Why WIR?

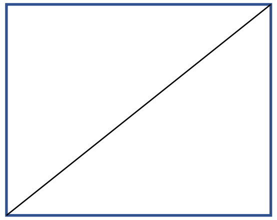
WIR



Energy Drops

Agassi et al., 1985 and 1994.

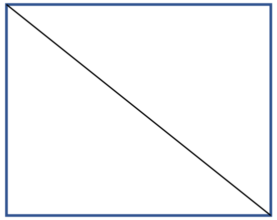
WIR



OM

Lado et al., 2004.

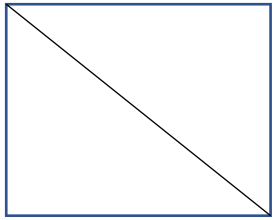
WIR



OM (Aliphatic Bonds)

Capriel et al., 1997.

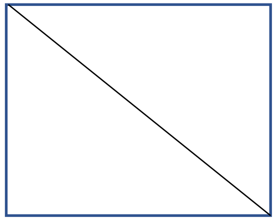
WIR



Clay

Ben Hur & Letey 1989.

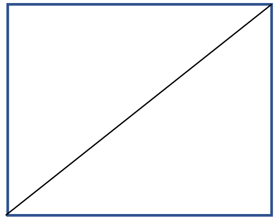
WIR (Seal & Erosion)



Smectite

Stern 1991.

WIR (Seal & Erosion)



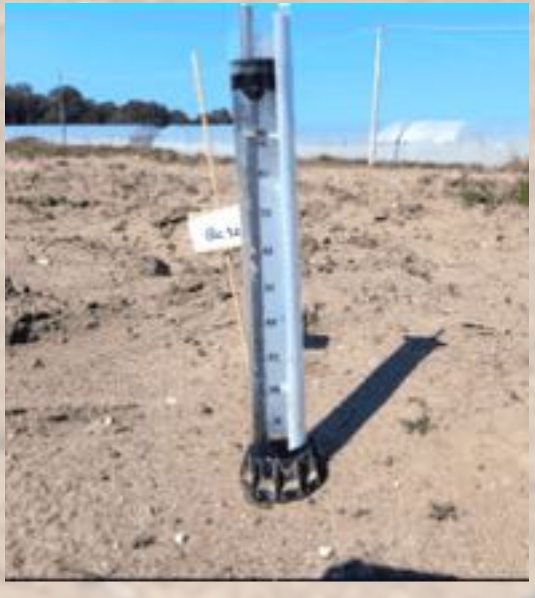
Illite & Kaolinite

Stern 1991.

THE REMOTE SENSING LABORATORIES

Field Spectral Measurements using ASD connected to SoilPRO.

THE REMOTE SENSING LABORATORIES



The Mini-disk Infiltrometer

The experiments

Data Acquisition

▶ This dataset contain samples of 6 different fields along the Mediterranean Basin:

i) Kibbutz Sde Yoav, Israel (30 Samples)

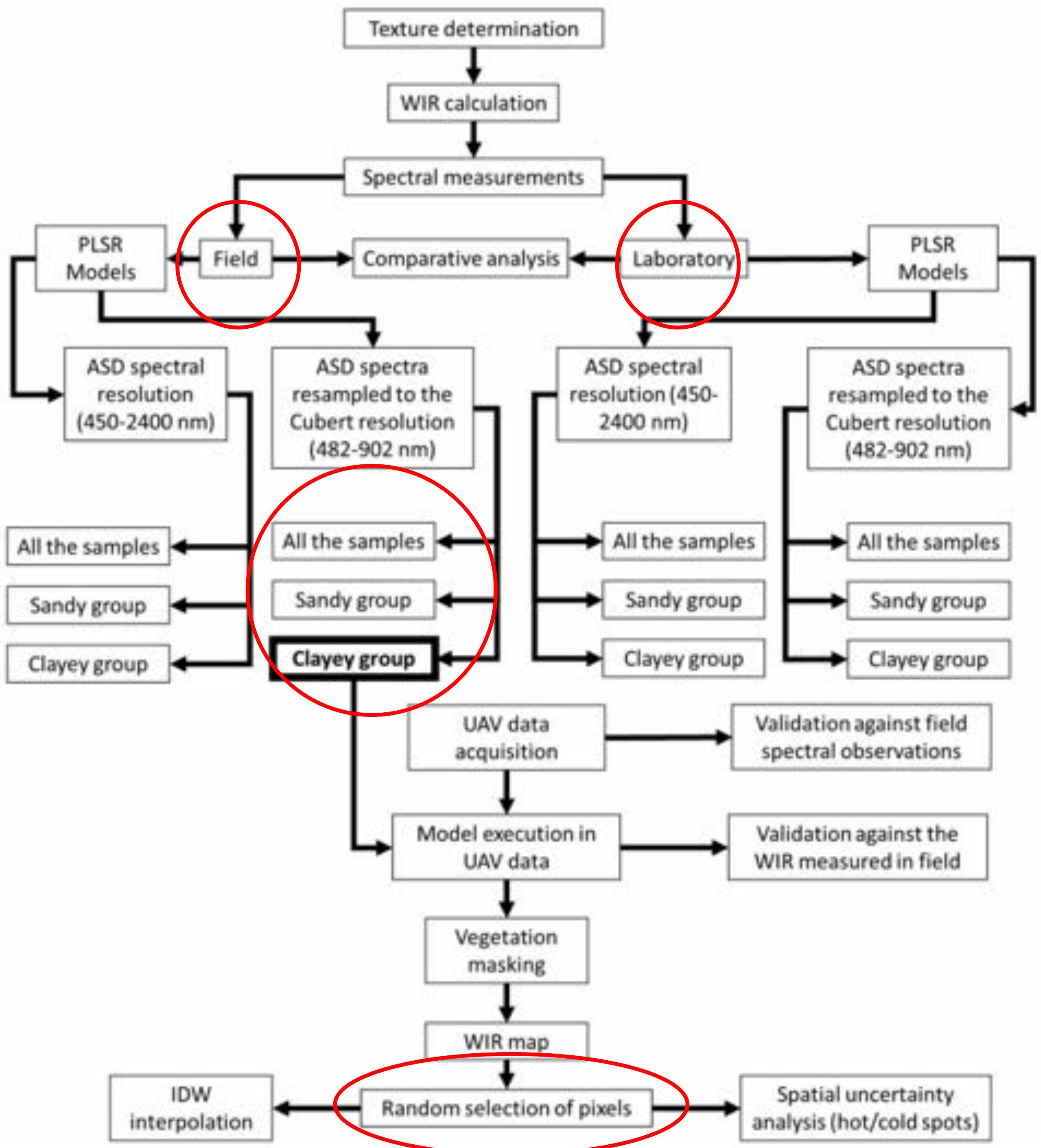
ii) Afeka, Tel Aviv, Israel (18 Samples)

iii) Alento, Italy (21 Samples)

iv) Aminteo, Greece (45 Samples of 3 different fields)

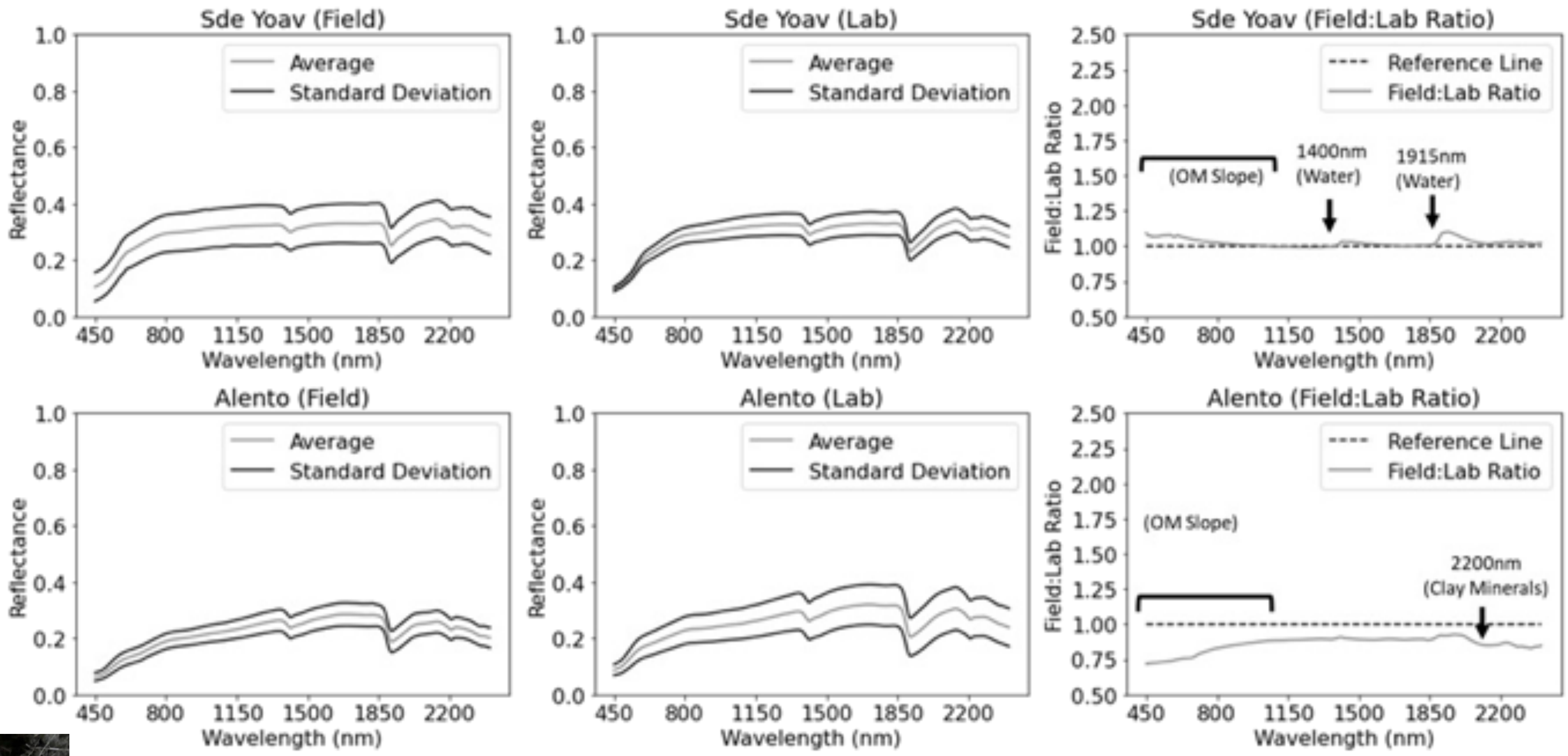
v) Southern Israel (110 samples)

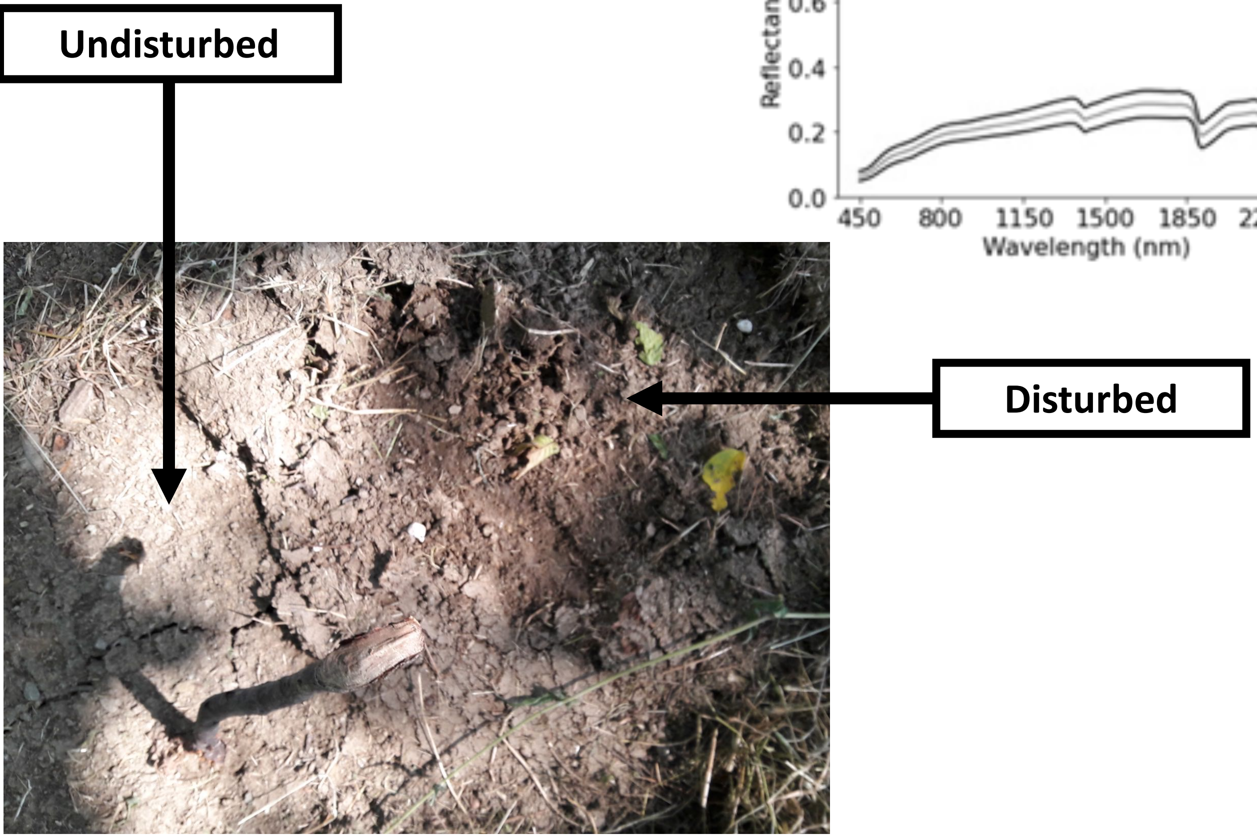
Flowchart


Texture determination
WIR calculation
Spectral measurements
PLSR Models
Field
Comparative analysis
Laboratory
PLSR Models
ASD spectral resolution (450-2400 nm)
ASD spectra resampled to the Cubert resolution (482-902 nm)
ASD spectral resolution (450-2400 nm)
ASD spectra resampled to the Cubert resolution (482-902 nm)
All the samples
Sandy group
Clayey group
All the samples
Sandy group
Clayey group
All the samples
Sandy group
Clayey group
All the samples
Sandy group
Clayey group
UAV data acquisition
Validation against field spectral observations
Model execution in UAV data
Validation against the WIR measured in field
Vegetation masking
WIR map
IDW interpolation
Random selection of pixels
Spatial uncertainty analysis (hot/cold spots)

The Clayey Group

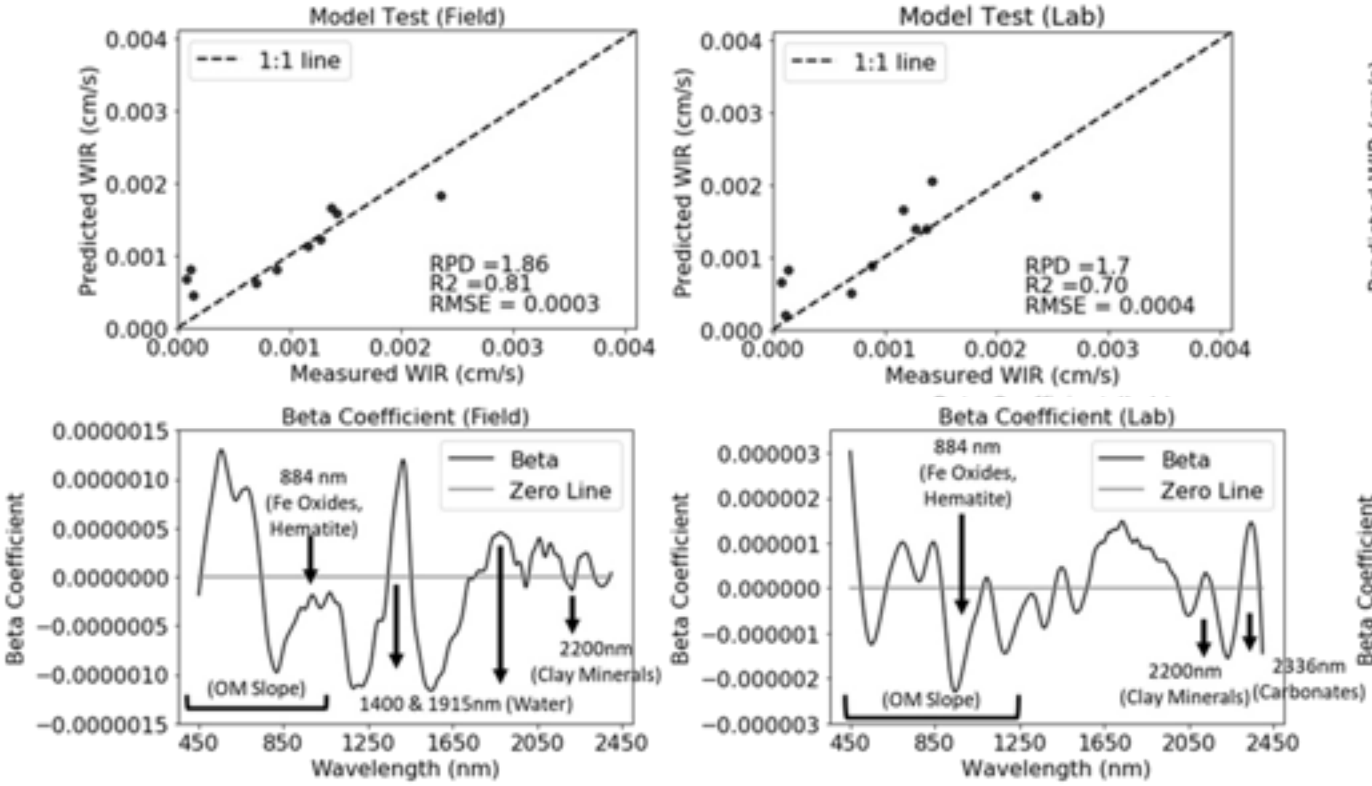
Same applies to the Sandy Group



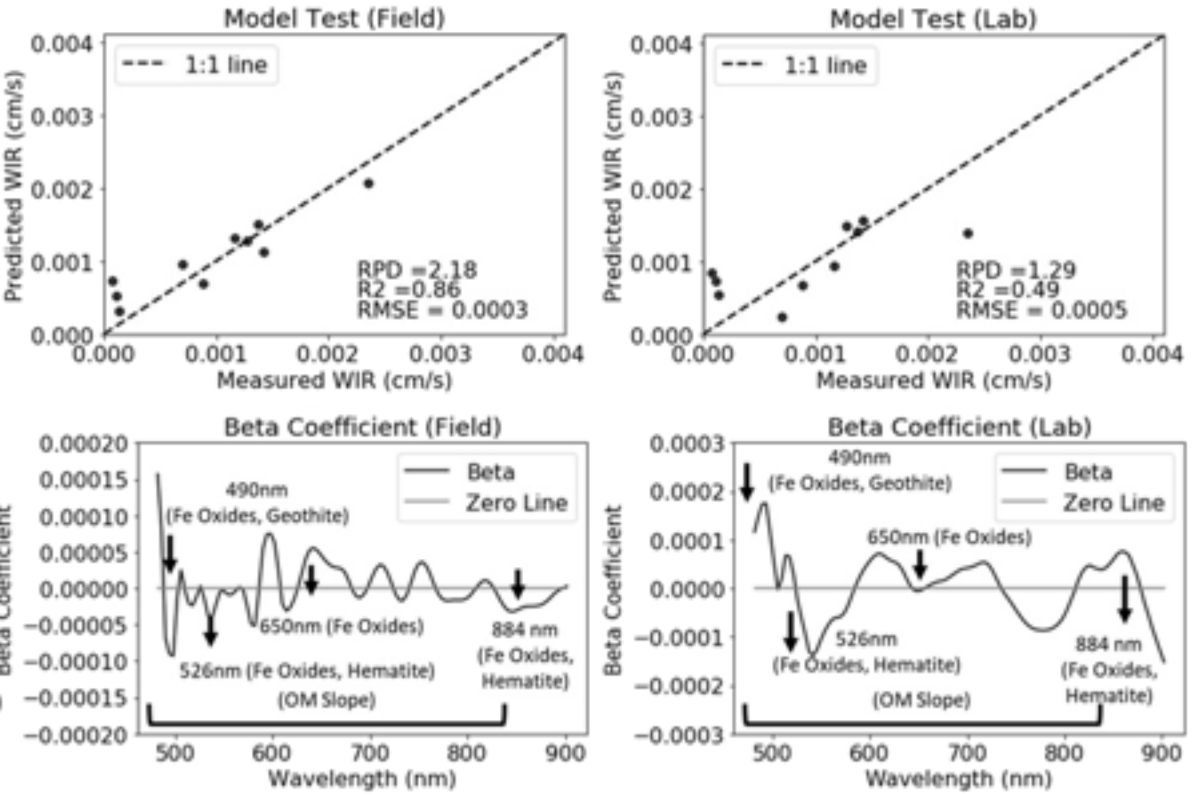


The Clayey Soils

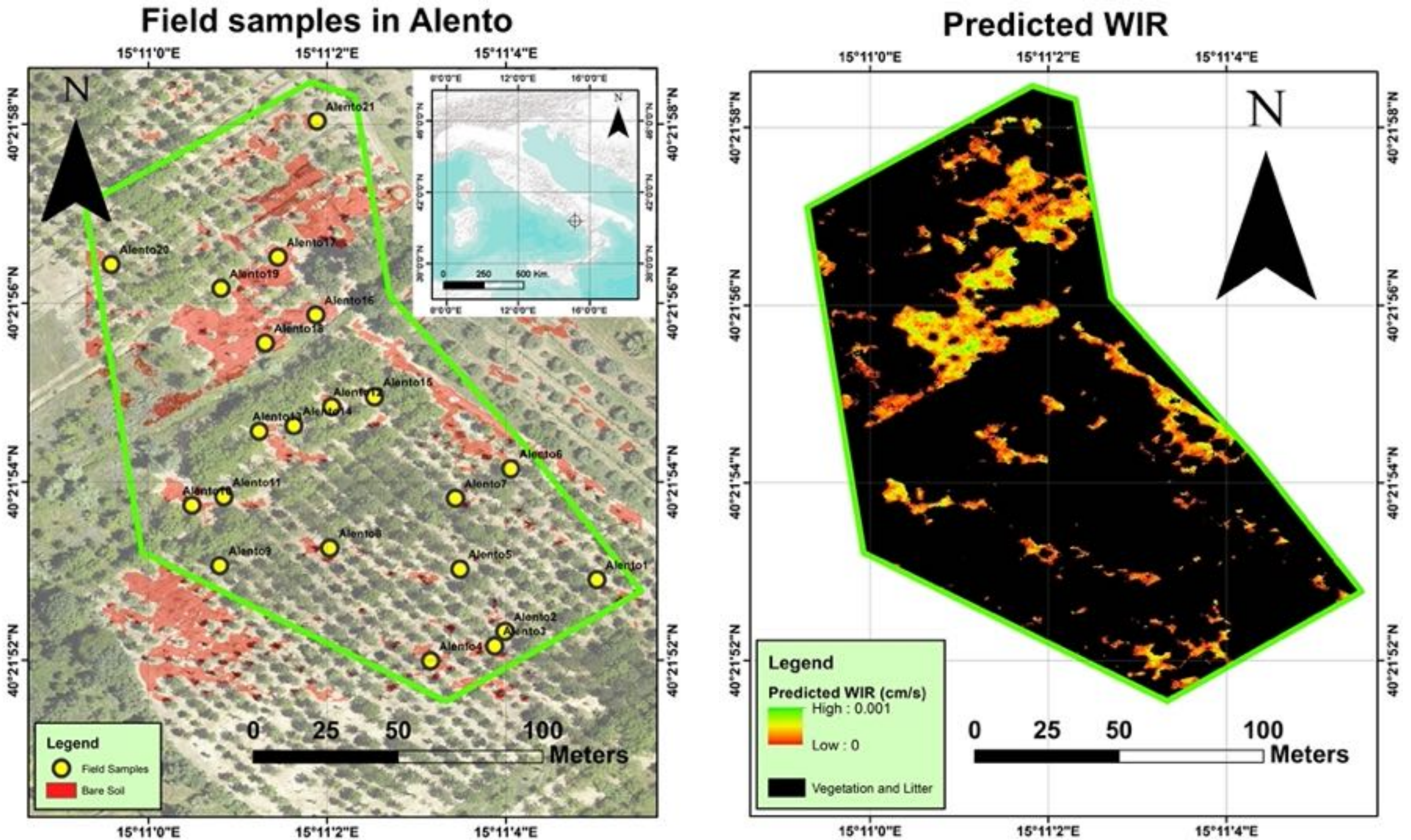
ASD SPECTRAL RESOLUTION (VIS-NIR-SWIR)



CUBERT UHD-185 SPECTRAL RESOLUTION (VIS-NIR)



THE REMOTE SENSING LABORATORIES

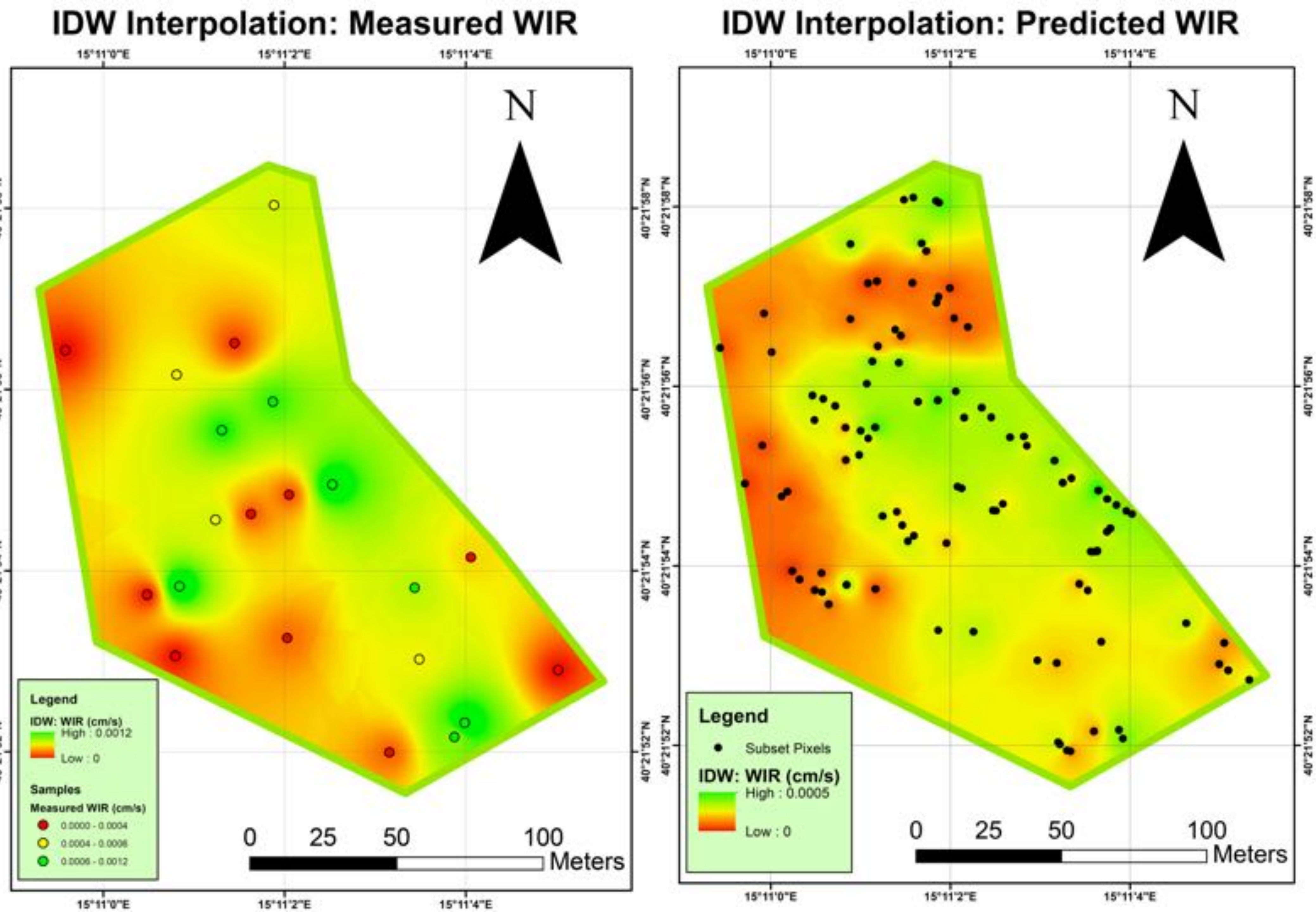

Field samples in Alento
15°11'0"E
15°11'2"E
15°11'4"E
40°21'58"N
40°21'56"N
40°21'54"N
40°21'52"N
N
Alento21
Alento20
Alento17
Alento19
Alento16
Alento18
Alento15
Alento12
Alento14
Alento13
Alento6
Alento7
Alento10
Alento11
Alento8
Alento9
Alento5
Alento1
Alento2
Alento3
Alento4
0 250 500 Km.
Legend
Field Samples
Bare Soil
0 25 50 100
Meters
Predicted WIR
Legend
Predicted WIR (cm/s)
High : 0.001
Low : 0
Vegetation and Litter

cubert

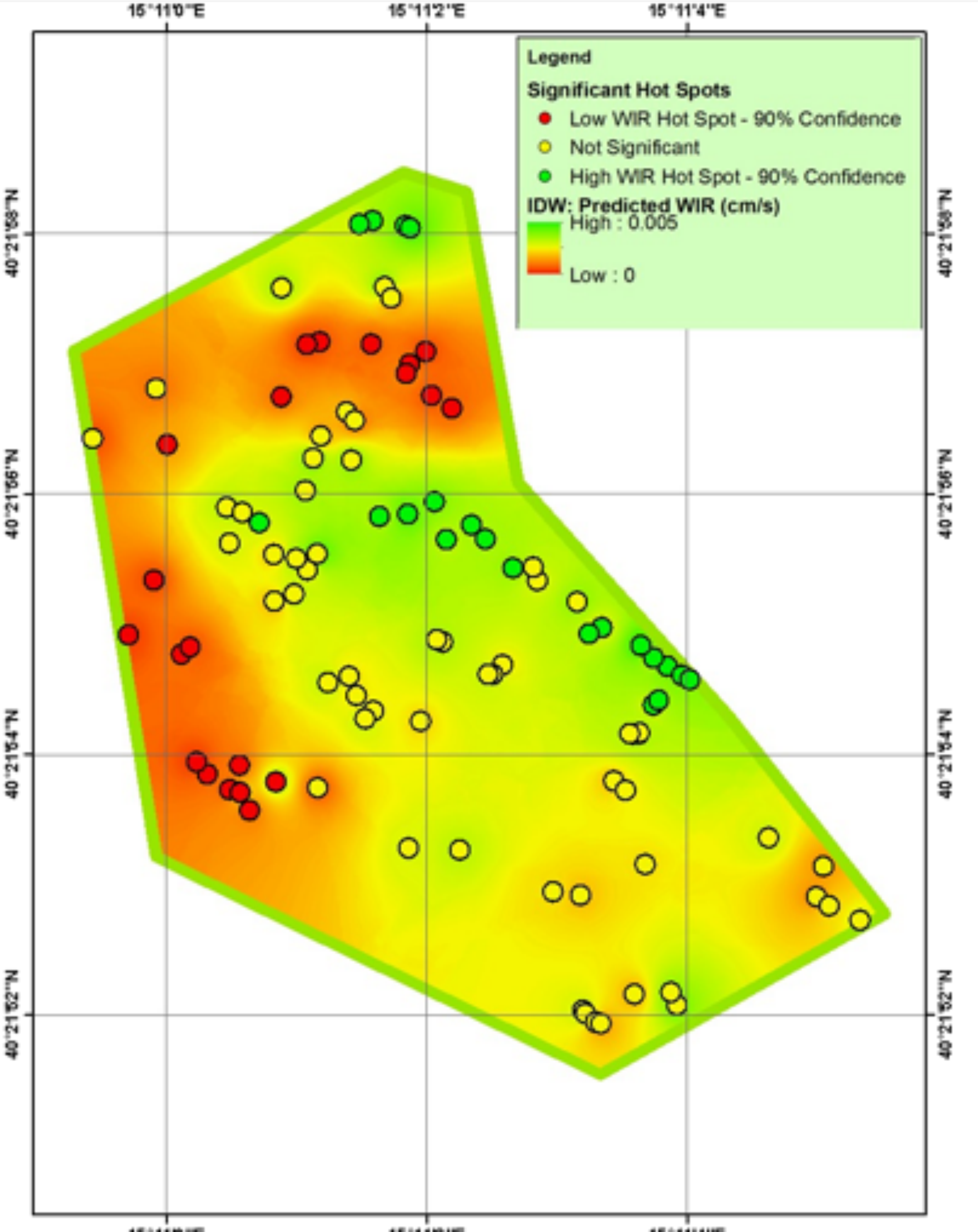
SPECIFICATIONS

Wavelength Range: 350 - 1000 nm	Technology: Light Field	Data Depths: 12 Bit
Number of Bands: 164	Sensor(s): 20 MP	Readout: Global shutter
FWHM: Constant 10 nm	Spectral Sampling: 4 nm	Max Frame Rate: 8 Hz
Max Resolution: 410 x 410 pixel	Wavelength Error: < 4 nm	Integration Time: 0.1 - 1000 ms
Weight: 350 g	Total Spectra / Image: 168 000	Field of View (FOV): 35°
Dimensions: 60 x 60 x 57 mm	Total Data Points (Data Points / Cube): 27 million	Power Consumption: 8 W

THE REMOTE SENSING LABORATORIES

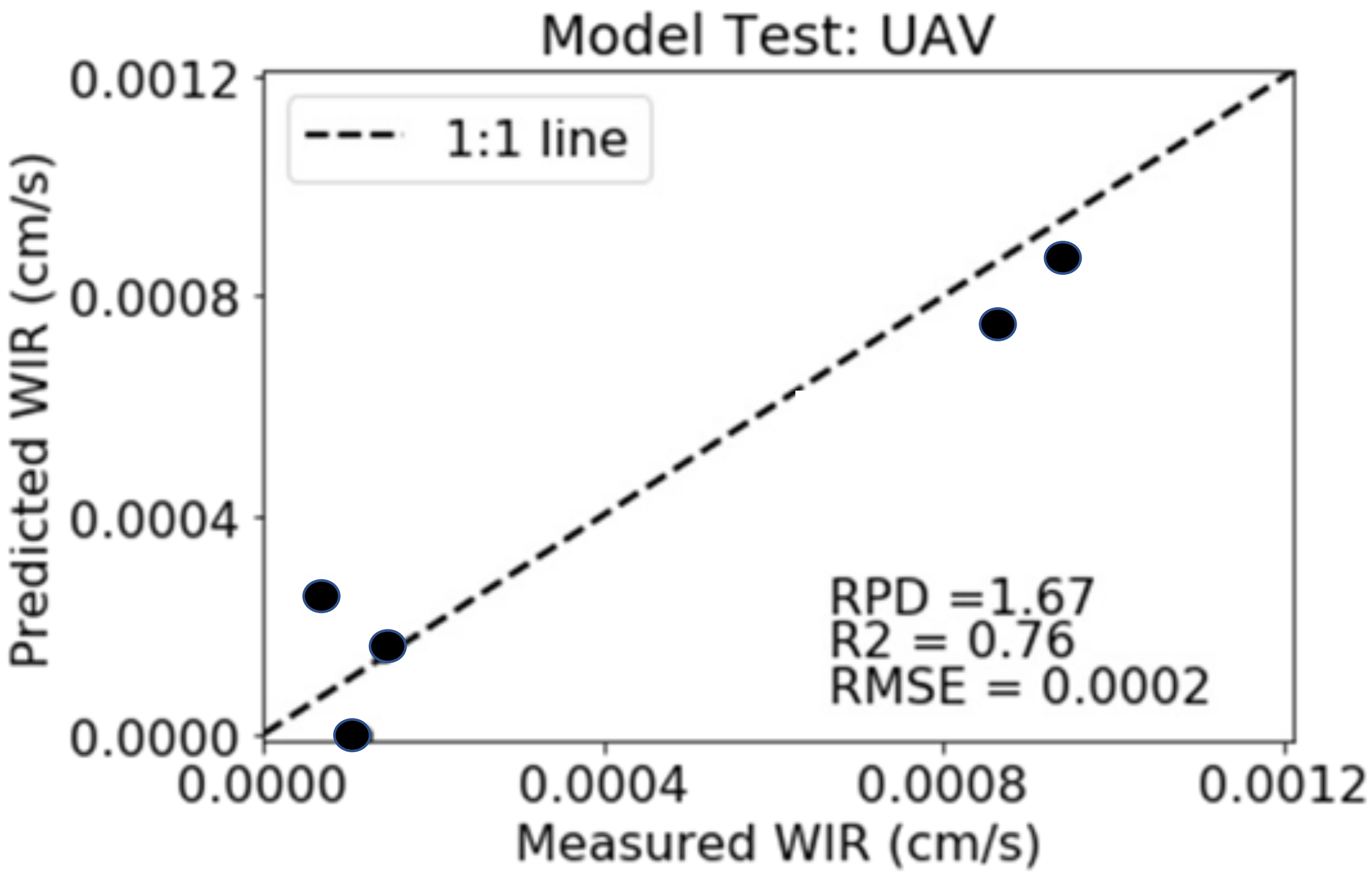

IDW Interpolation: Measured WIR
IDW Interpolation: Predicted WIR
15°11'0"E
15°11'2"E
15°11'4"E
40°21'58"N
40°21'56"N
40°21'54"N
40°21'52"N
N
Legend
IDW: WIR (cm/s)
High : 0.0012
Low : 0
Samples
Measured WIR (cm/s)
0.0000 - 0.0004
0.0004 - 0.0006
0.0006 - 0.0012
0
25
50
100
Meters
Legend
Subset Pixels
IDW: WIR (cm/s)
High : 0.0005
Low : 0
0
25
50
100
Meters

Spatial Uncertainty: Predicted WIR



THE REMOTE SENSING LABORATORIES

Validation


Model Test: UAV
1:1 line
RPD =1.67
R2 = 0.76
RMSE = 0.0002
Predicted WIR (cm/s)
Measured WIR (cm/s)
0.0000
0.0004
0.0008
0.0012

remote sensing

MDPI

Article

Mapping Water Infiltration Rate Using Ground and UAV Hyperspectral Data: A Case Study of Alento, Italy

Nicolas Francos [1,*], Nunzio Romano [2], Paolo Nasta [2], Yijian Zeng [3], Brigitta Szabó [4], Salvatore Manfreda [5], Giuseppe Ciraolo [6], János Mészáros [4], Ruodan Zhuang [7], Bob Su [3] and Eyal Ben-Dor [1]

1. The Remote Sensing Laboratory, Tel Aviv University, Zelig 10, Tel Aviv 69978, Israel; bendor@tauex.tau.ac.il
2. Department of Agricultural Sciences, AFBE Division, University of Napoli Federico II, via Università 100, 80055 Portici, NA, Italy; nunzio.romano@unina.it (N.R.); paolo.nasta@unina.it (P.N.)
3. Faculty of Geo-Information Science and Earth Observation, University of Twente, Hengelosestraat 99, 7514 AE Enschede, The Netherlands; y.zeng@utwente.nl (Y.Z.); z.su@utwente.nl (B.S.)
4. Centre for Agricultural Research, Institute for Soil Sciences, 1022 Budapest, Hungary; toth.brigitta@atk.hu (B.S.); meszaros.janos@rissac.hu (J.M.)
5. Department of Civil, Architectural and Environmental Engineering, University of Naples Federico II, via Claudio 21, 80125 Napoli, NA, Italy; salvatore.manfreda@unina.it
6. Department of Engineering, University of Palermo, Viale delle Scienze, Ed.8, 90128 Palermo, PA, Italy; giuseppe.ciraolo@unipa.it
7. Department of European and Mediterranean Cultures, Architecture, Environment and Cultural Heritage, University of Basilicata, 75100 Matera, MT, Italy; ruodan.zhuang@unibas.it

* Correspondence: nicolasf@mail.tau.ac.il

check for updates

Citation: Francos, N.; Romano, N.; Nasta, P.; Zeng, Y.; Szabó, B.; Manfreda, S.; Ciraolo, G.; Mészáros, J.; Zhuang, R.; Su, B.; et al. Mapping Water Infiltration Rate Using Ground and UAV Hyperspectral Data: A Case Study of Alento, Italy. *Remote Sens.* **2021**, 13, 2606. https://doi.org/10.3390/rs13132606

Academic Editor: Dominique Arrouays

Received: 25 April 2021
Accepted: 28 June 2021
Published: 2 July 2021

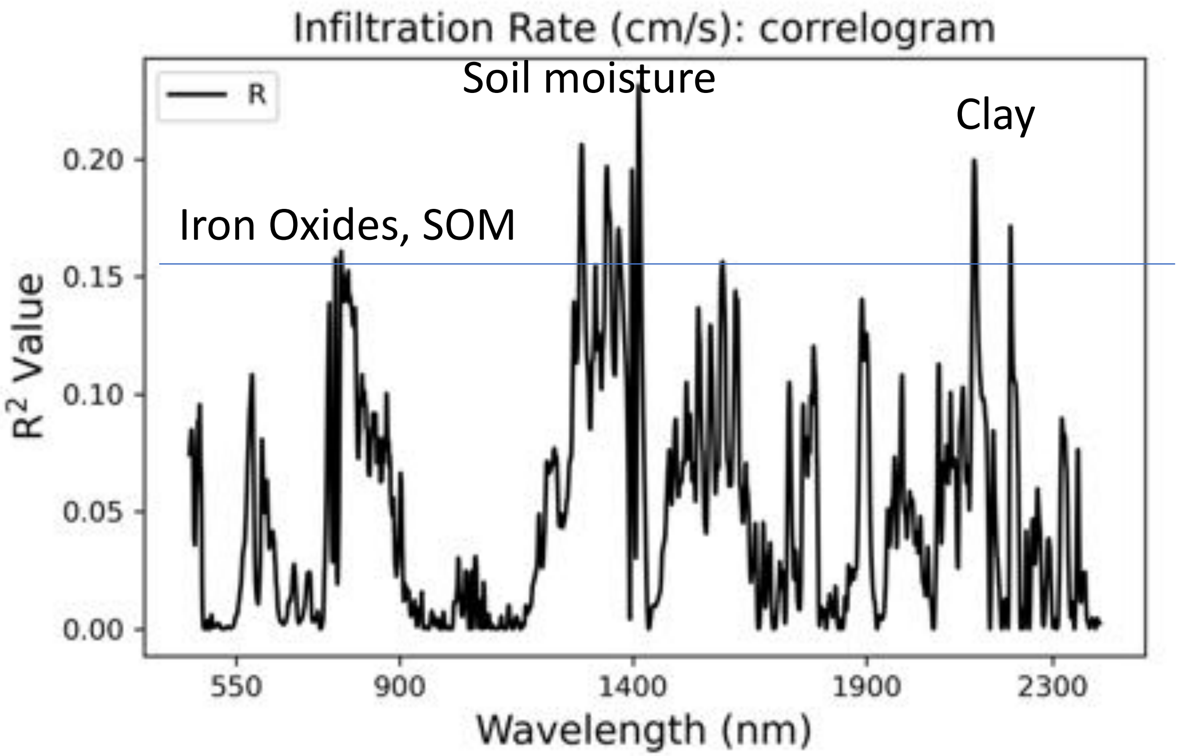
Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

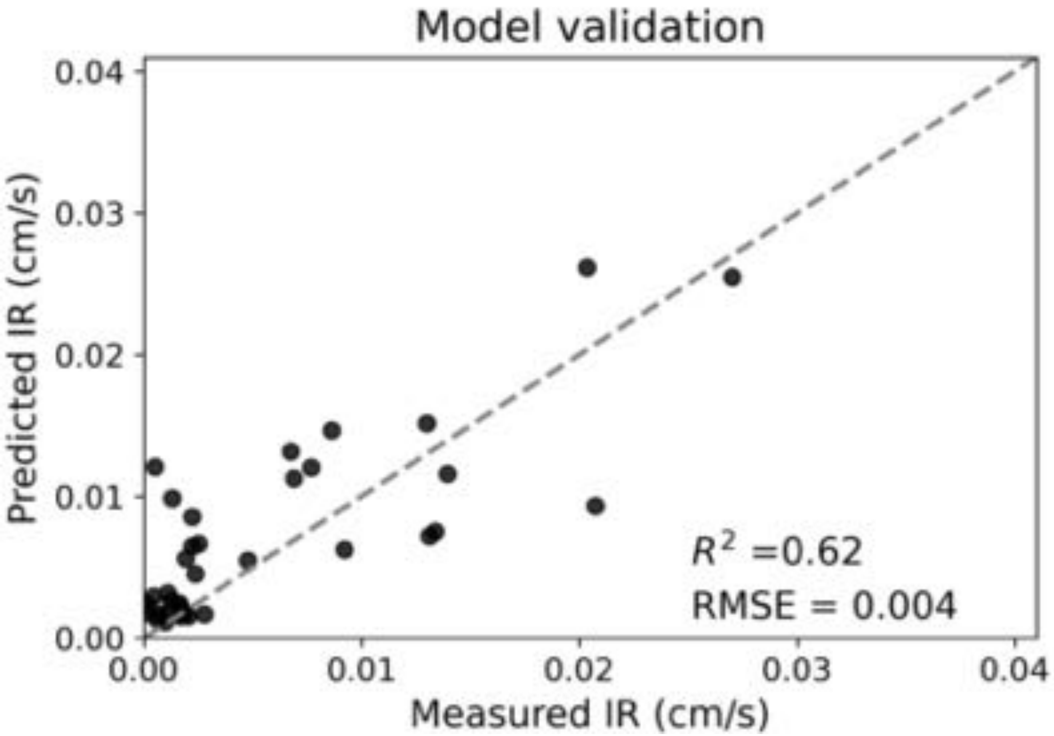
Abstract: Water infiltration rate (WIR) into the soil profile was investigated through a comprehensive study harnessing spectral information of the soil surface. As soil spectroscopy provides invaluable information on soil attributes, and as WIR is a soil surface-dependent property, field spectroscopy may model WIR better than traditional laboratory spectral measurements. This is because sampling for the latter disrupts the soil-surface status. A field soil spectral library (FSSL), consisting of 114 samples with different textures from six different sites over the Mediterranean basin, combined with traditional laboratory spectral measurements, was created. Next, partial least squares regression analysis was conducted on the spectral and WIR data in different soil texture groups, showing better performance of the field spectral observations compared to traditional laboratory spectroscopy. Moreover, several quantitative spectral properties were lost due to the sampling procedure, and separating the samples according to texture gave higher accuracies. Although the visible near-infrared–shortwave infrared (VNIR-SWIR) spectral region provided better accuracy, we resampled the spectral data to the resolution of a Cubert hyperspectral sensor (VNIR). This hyperspectral sensor was then assembled on an unmanned aerial vehicle (UAV) to apply one selected spectral-based model to the UAV data and map the WIR in a semi-vegetated area within the Alento catchment, Italy. Comprehensive spectral and WIR ground-truth measurements were carried out simultaneously with the UAV-Cubert sensor flight. The results were satisfactorily validated on the ground using field samples, followed by a spatial uncertainty analysis, concluding that the UAV with hyperspectral remote sensing can be used to map soil surface-related soil properties.

Keywords: water infiltration rate; hyperspectral remote sensing; soil spectroscopy; soil surface; unmanned aerial vehicle

PRISMA model using Field SSL
(Clayey Soils)

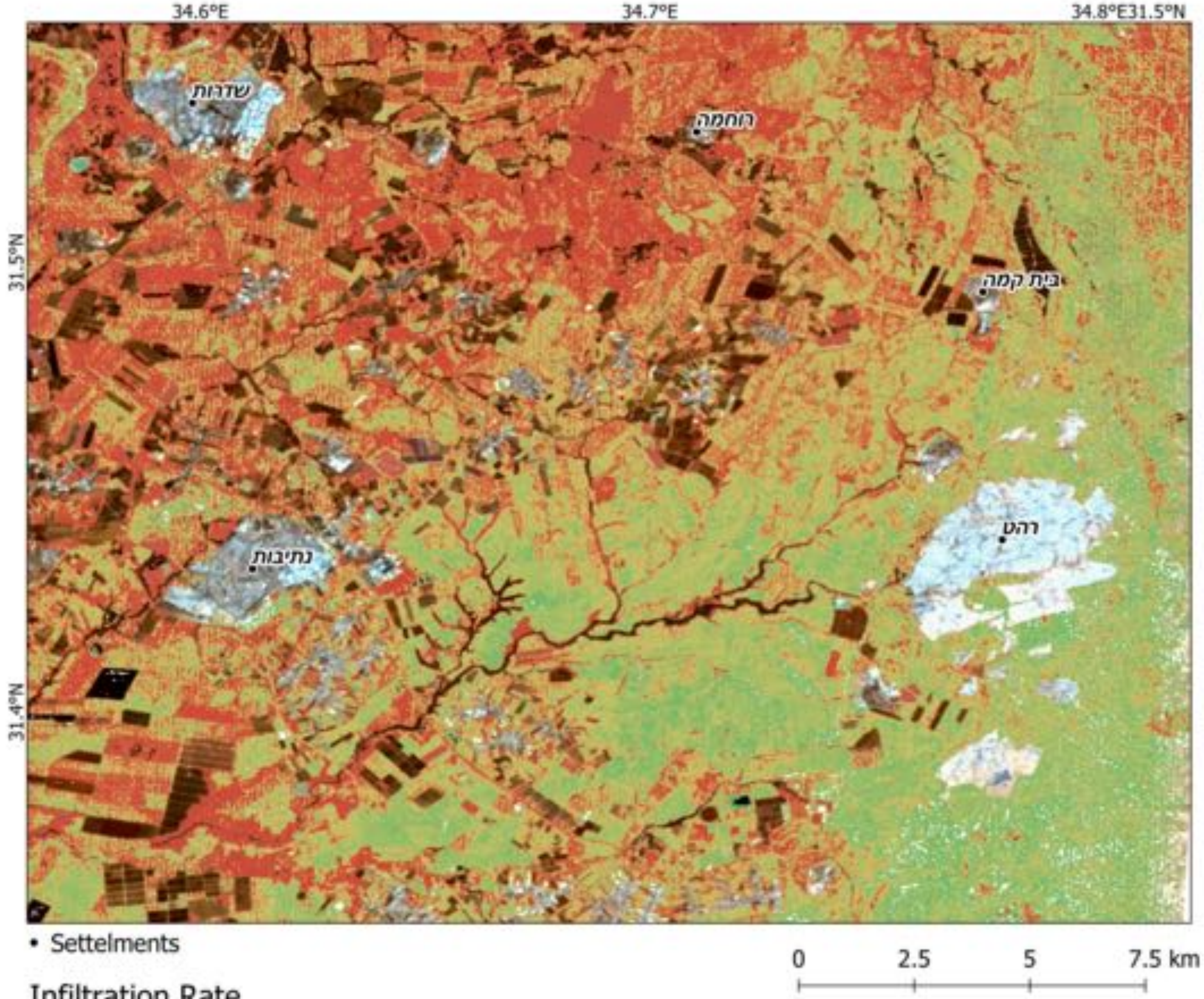
Important Features





THE REMOTE SENSING LABORATORIES

Infiltration Rate Map, South Israel, July 2020



• Settelments

Infiltration Rate

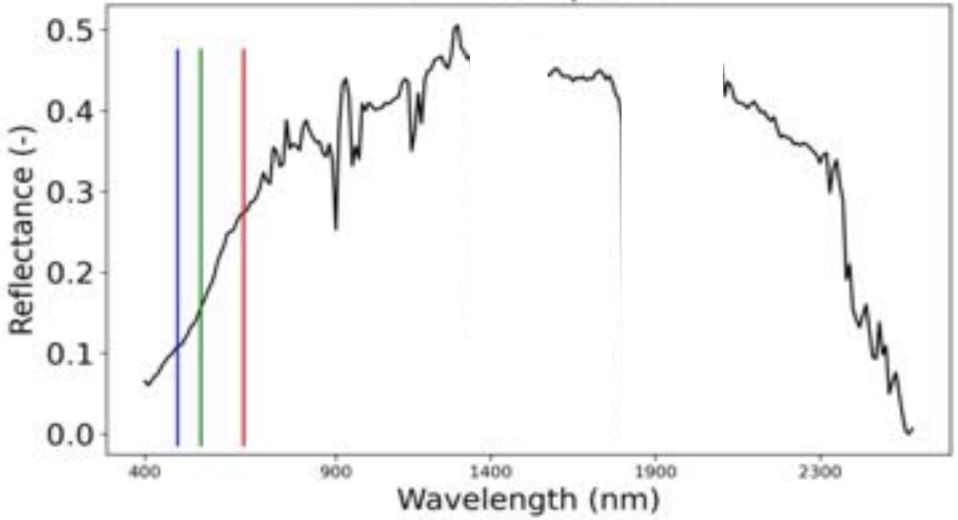
Low Infiltration — High erosion risk

Medium Infiltration

High Infiltration — Low erosion risk

Negev Southern Israel PRISMA image

PRIZMA Soil Spectrum



THE REMOTE SENSING LABORATORIES

Conclusions

- The soil surface reflectance is an important parameter to retrieve soil “seals” property (e.g. WIR).
- A method to measure soil “seal” reflectance properties in the field has been proposed using the SoilPRO®.
- The field-based models showed better results than the lab-based models
- The WIR is heavily dependent on the soil texture
- The soil attributes that control the WIR are: organic matter, texture, and iron oxides.
- Adopting the field-based model to map WIR using both UAV - HSR and Orbital-HSR is possible.

THE REMOTE SENSING LABORATORIES
TEL AVIV UNIVERSITY

Thank you!

TAU-RSL

bendor@post.tau.ac.il