Soil Sensing for Measuring and Mapping Soils

ISRIC Springschool 2018

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Outline

- Fundamentals of spectroscopy
- Available techniques & Scales
- Spectral-based soil information
- Digital Soil Mapping example
- Points of consideration

Questions

1. Which different soil sensing techniques are available
2. What are the typical scales of the different soil sensing techniques and devices
3. How can sensing techniques complement traditional soil inventories
4. What are the main challenges of using soil sensing techniques

1. Fundamentals of spectroscopy for environmental analysis

Q1 Which different soil sensing techniques are available

Measuring & Sensing technologies

- Measuring & monitoring
  - Cost effective
  - Non-destructive
  - Time efficient
- Applications in agricultural, plant and environmental sciences

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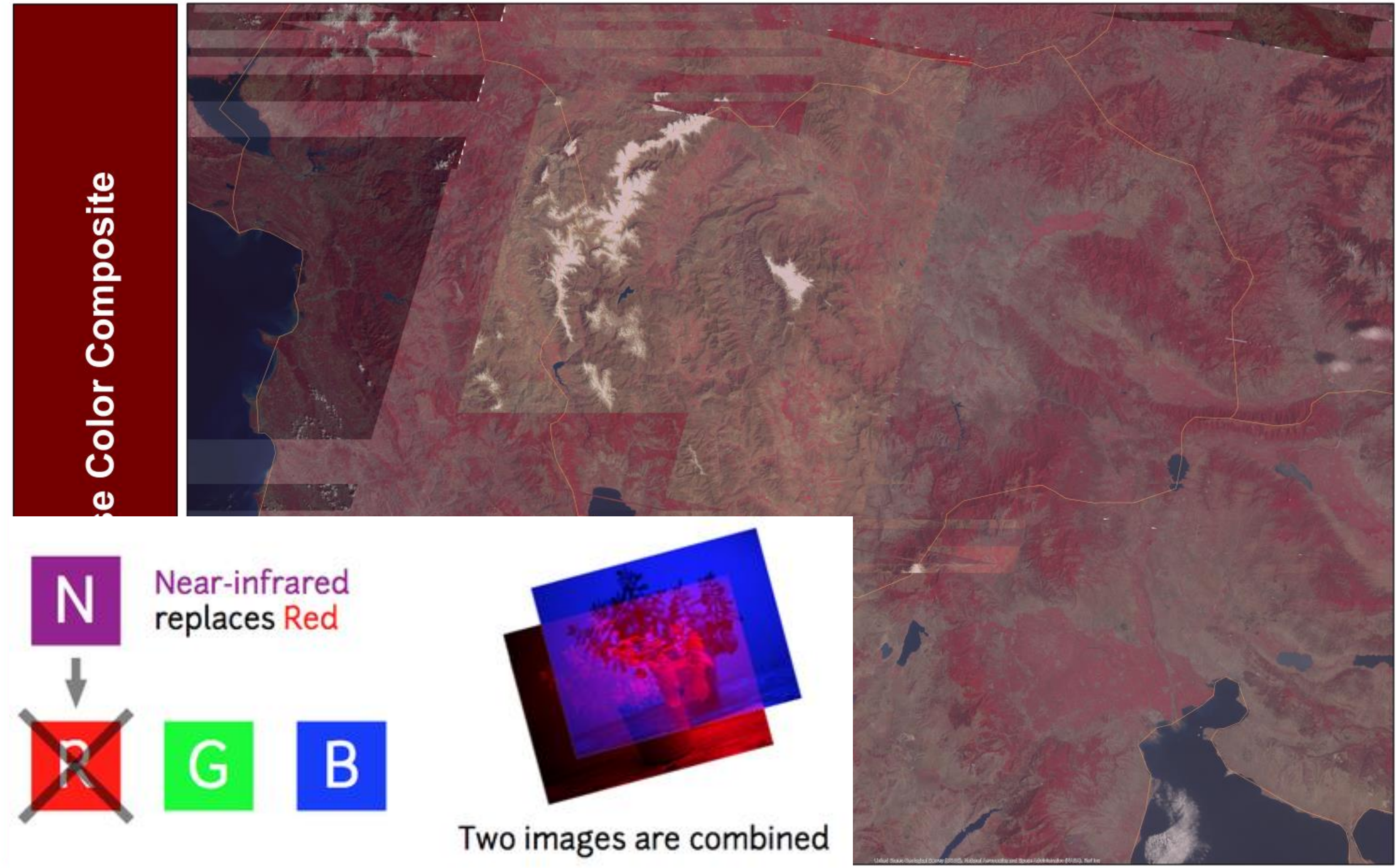
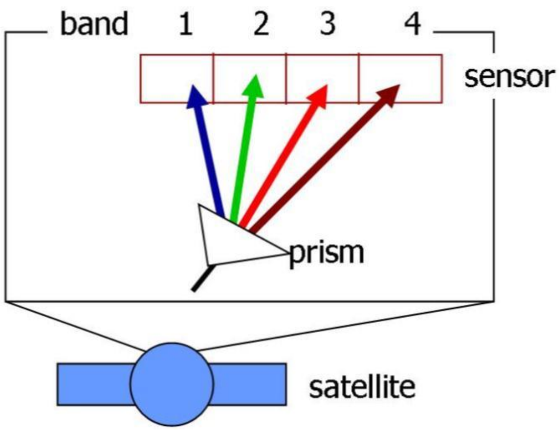
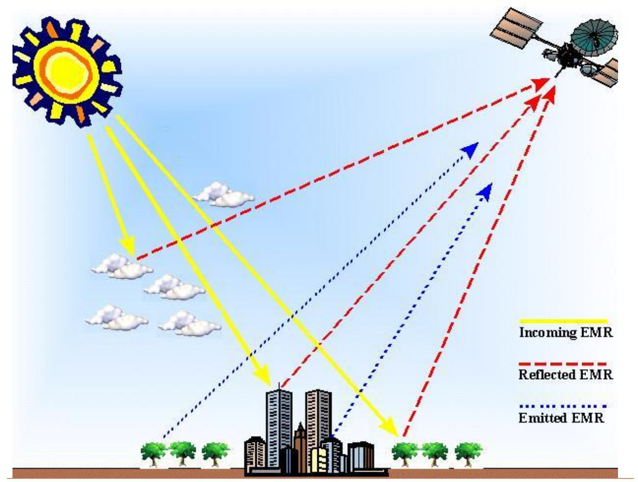
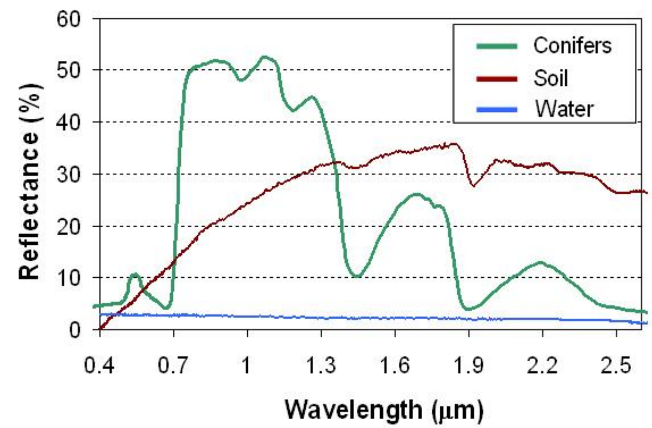


Introduction Remote Sensing (RS)



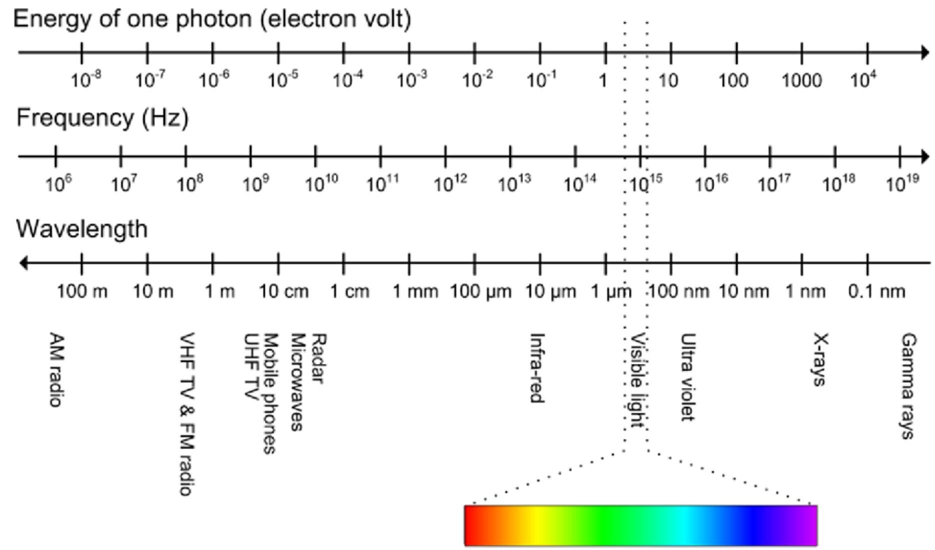




- RS is the science/ are the techniques of deriving information about the Earth's land and water areas from images at a distance
- It relies upon measurement of electro-magnetic (EM) energy reflected or emitted from the objects of interest at the surface of the Earth

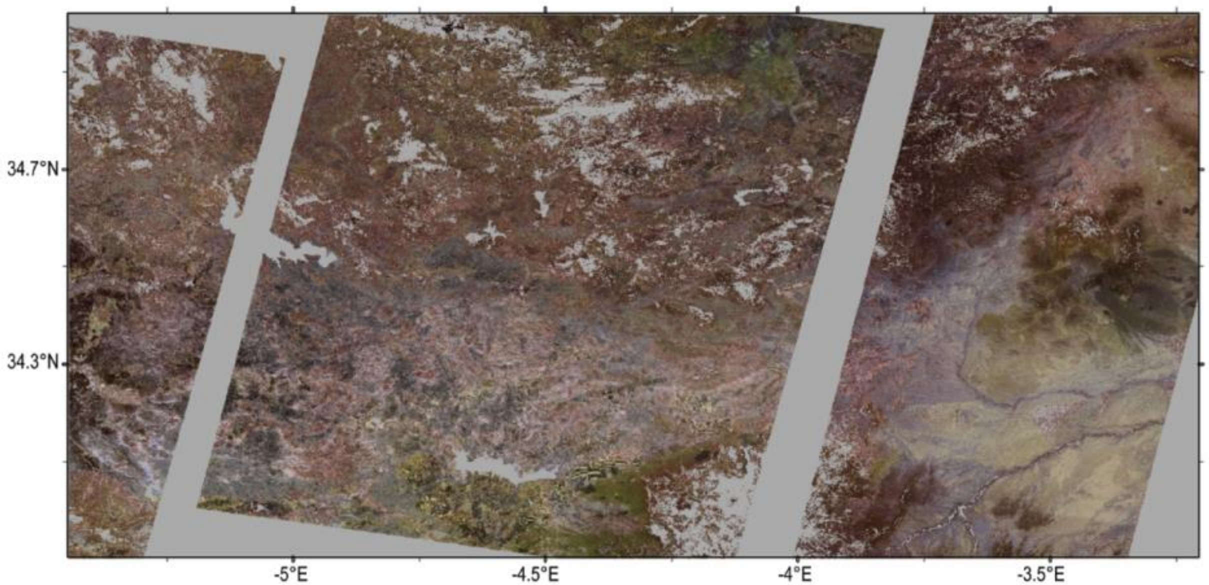
Sensing technologies: wavelengths, sensor, tools

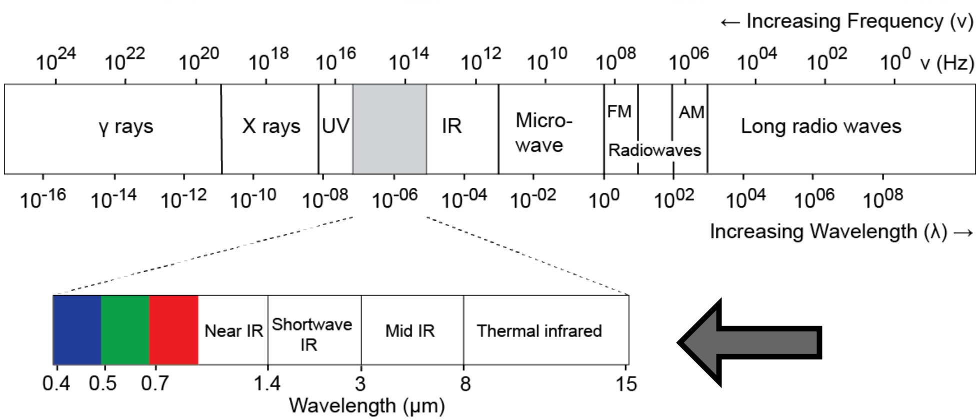
- Remote Sensing
- Soil spectroscopy (VIS/NIR/MIR)
- Gamma-ray spectroscopy
- Electro Magnetic/Electrical Conductivity (EM/EC)
- Radar/Ground Penetrating Radar (GPR)
- Rontgen Diffraction (XRF)



Slide courtesy: Ir. F.M. Egmond, ISRIC World Soil Information Wageningen

Remote Sensing (RS)





- Low spectral resolution (i.e. few bands)
- Space or airborne
- High spatial coverage
- Temporal coverage
- Usage: Mapping & Monitoring

Mulder, V. L. (2013), Spectroscopy-supported digital soil mapping, 188 pp, PhD thesis, Wageningen University, Wageningen.

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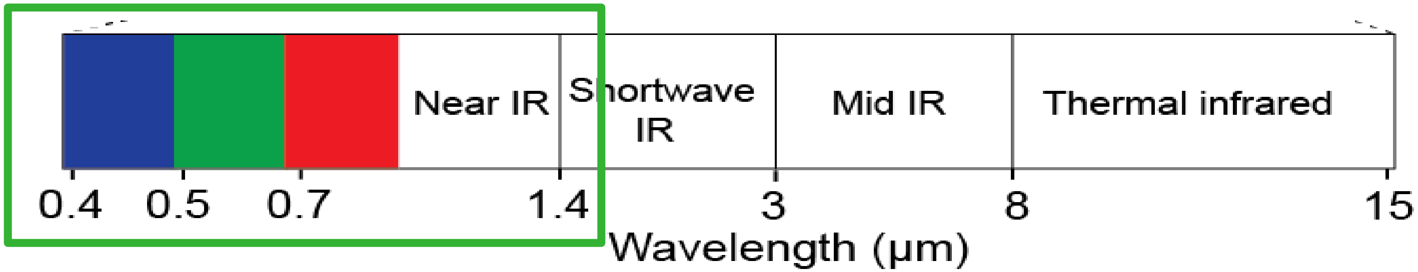
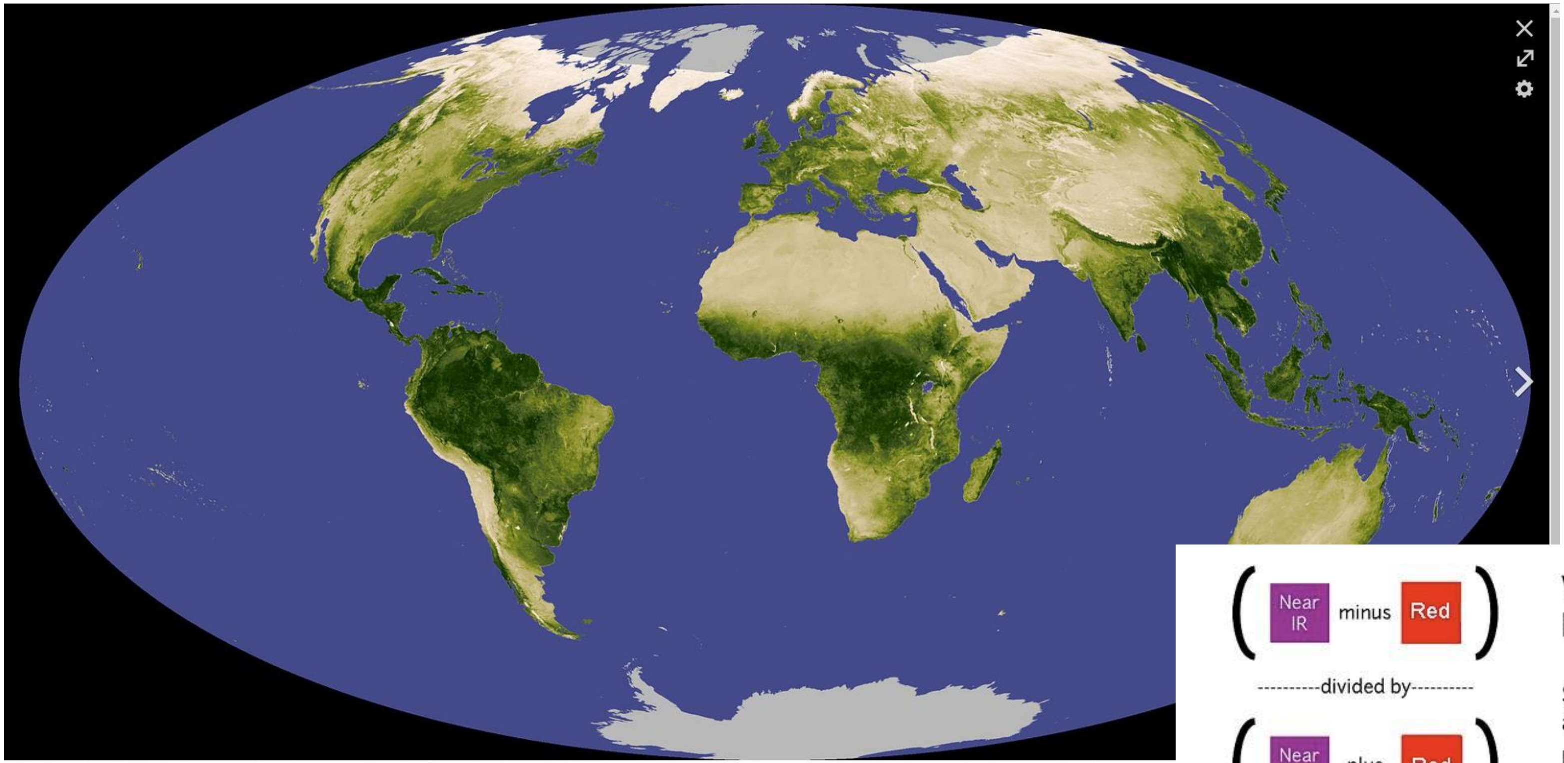
Remote Sensing (RS): Indices – MODIS NDVI





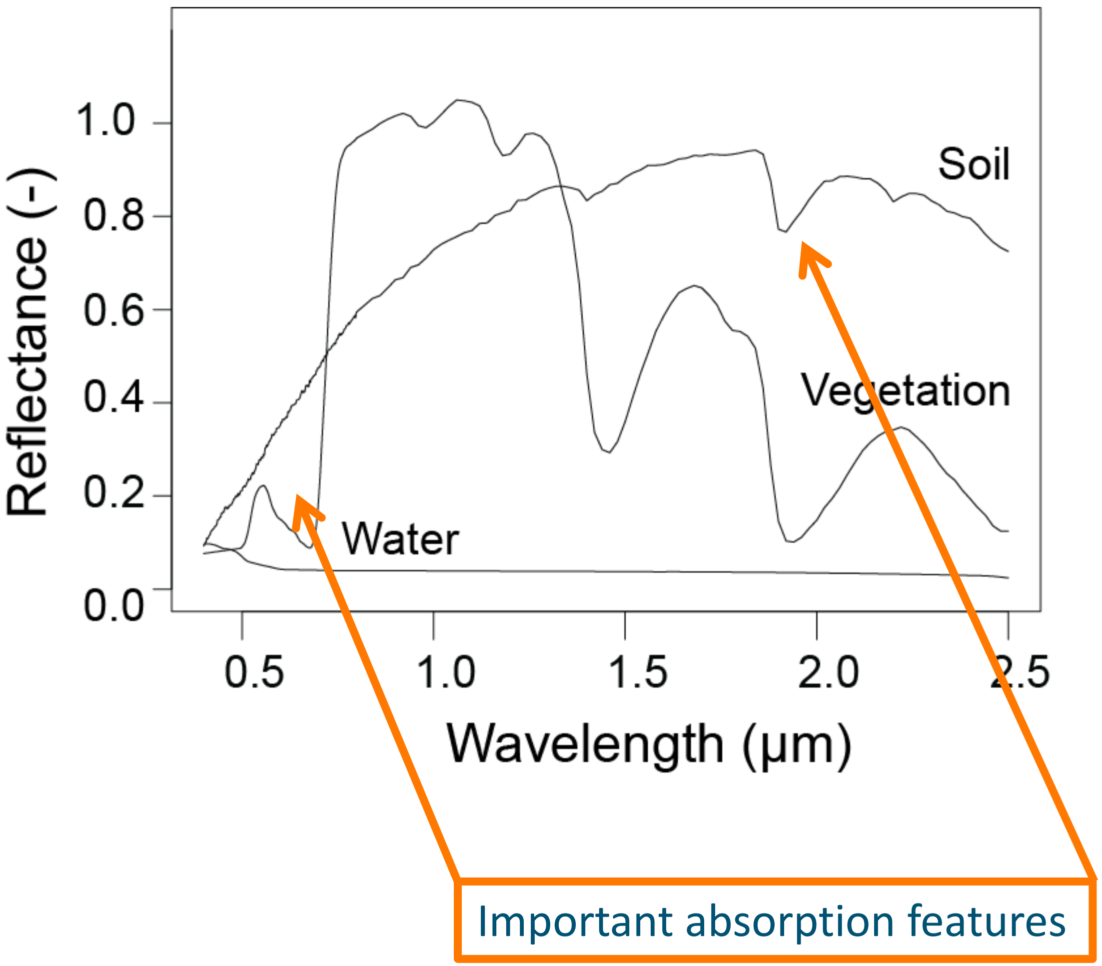
Negative values of NDVI (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Lastly, low, positive values represent
(approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1).[1]

What is NDVI?

Simple answer:

health of vegetation

Proximal Sensing (PS)



- High spectral resolution (i.e. many bands)
- Airborne, field or laboratory
- Detailed information
- Usage: spectral library

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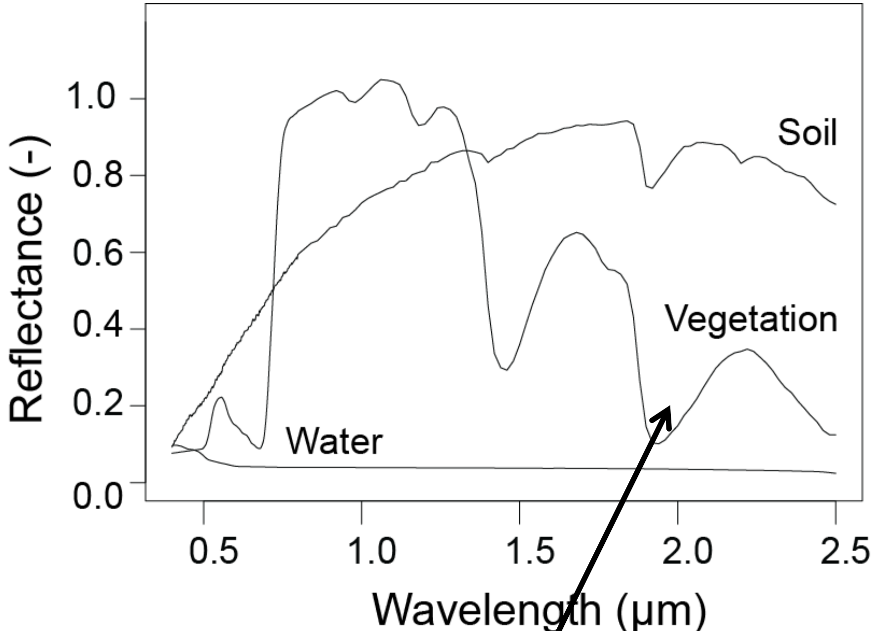
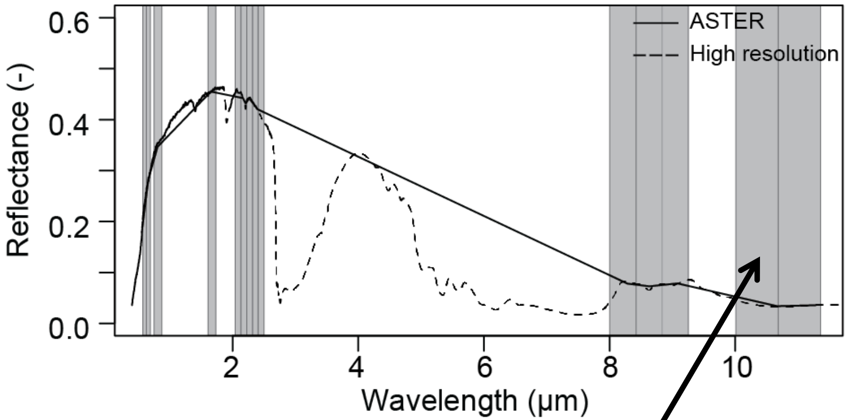
Mulder, V. L. (2013), Spectroscopy-supported digital soil mapping, 188 pp, PhD thesis, Wageningen University, Wageningen.

Proximal vs Remote Sensing





Broad bands

Absorption feature

Mulder, V. L. (2013), Spectroscopy-supported digital soil mapping, 188 pp, PhD thesis, Wageningen University, Wageningen.

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Geophysical Sensing (GS) techniques

- Techniques:
  - Gamma-ray spectroscopy
  - ElectroMagnetic induction (EM)
  - Magnetics
  - Ground Penetrating Radar
- Field, drone, airborne

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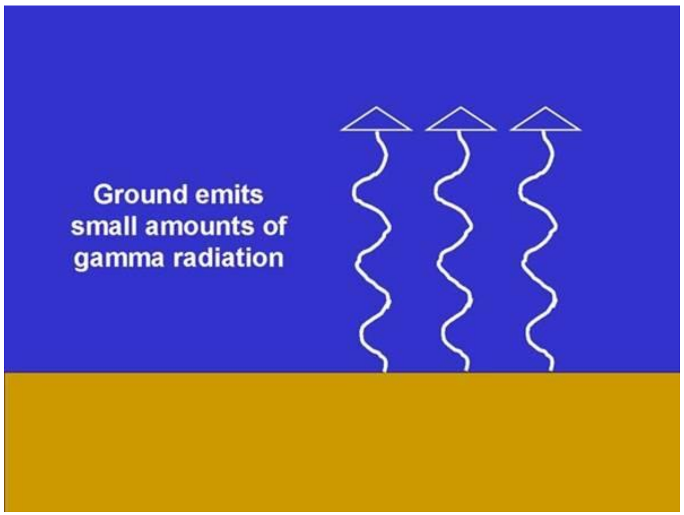
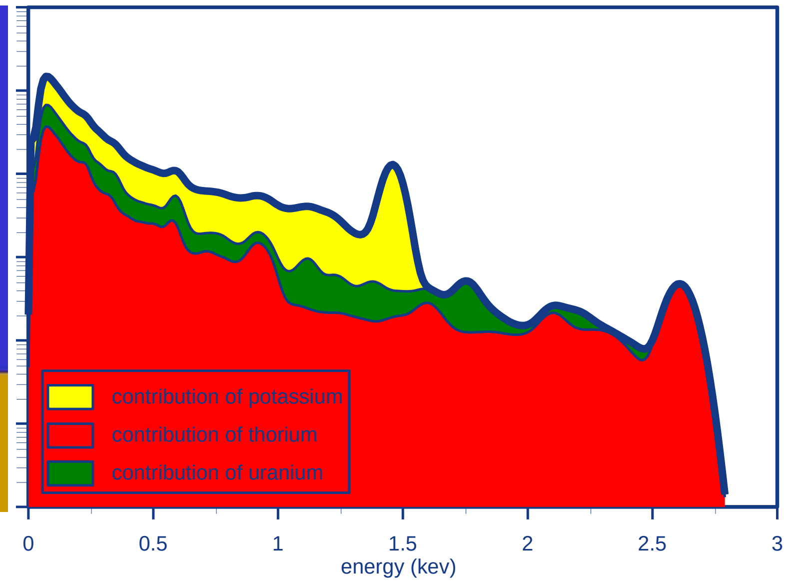
Gamma-ray spectroscopy





-Soil texture (clay, loam, sand, soil organic matter)
-Top 30 cm of the soil
-Little sensitivity to soil water content

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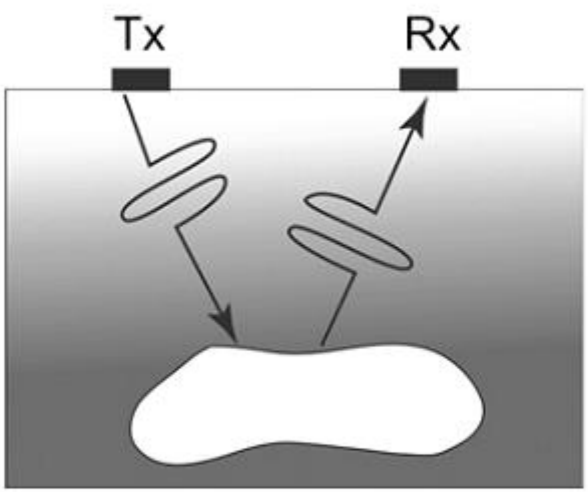
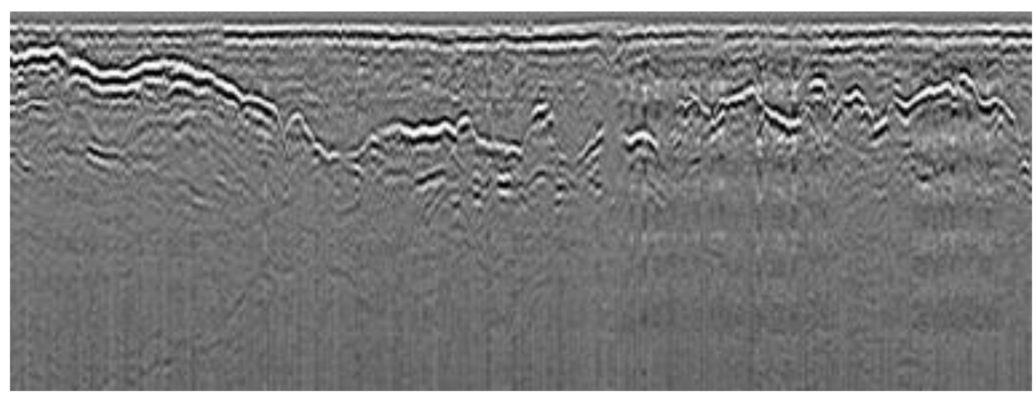
The Soil Company

Slide courtesy: Ir. F.M. Egmond, ISRIC World Soil Information Wageningen

Ground Penetrating Lidar

- Reflection of radar signal in soil
- Soil structure/ abrupt texture changes
- Objects
- Fast
- 2 to 5 m depth





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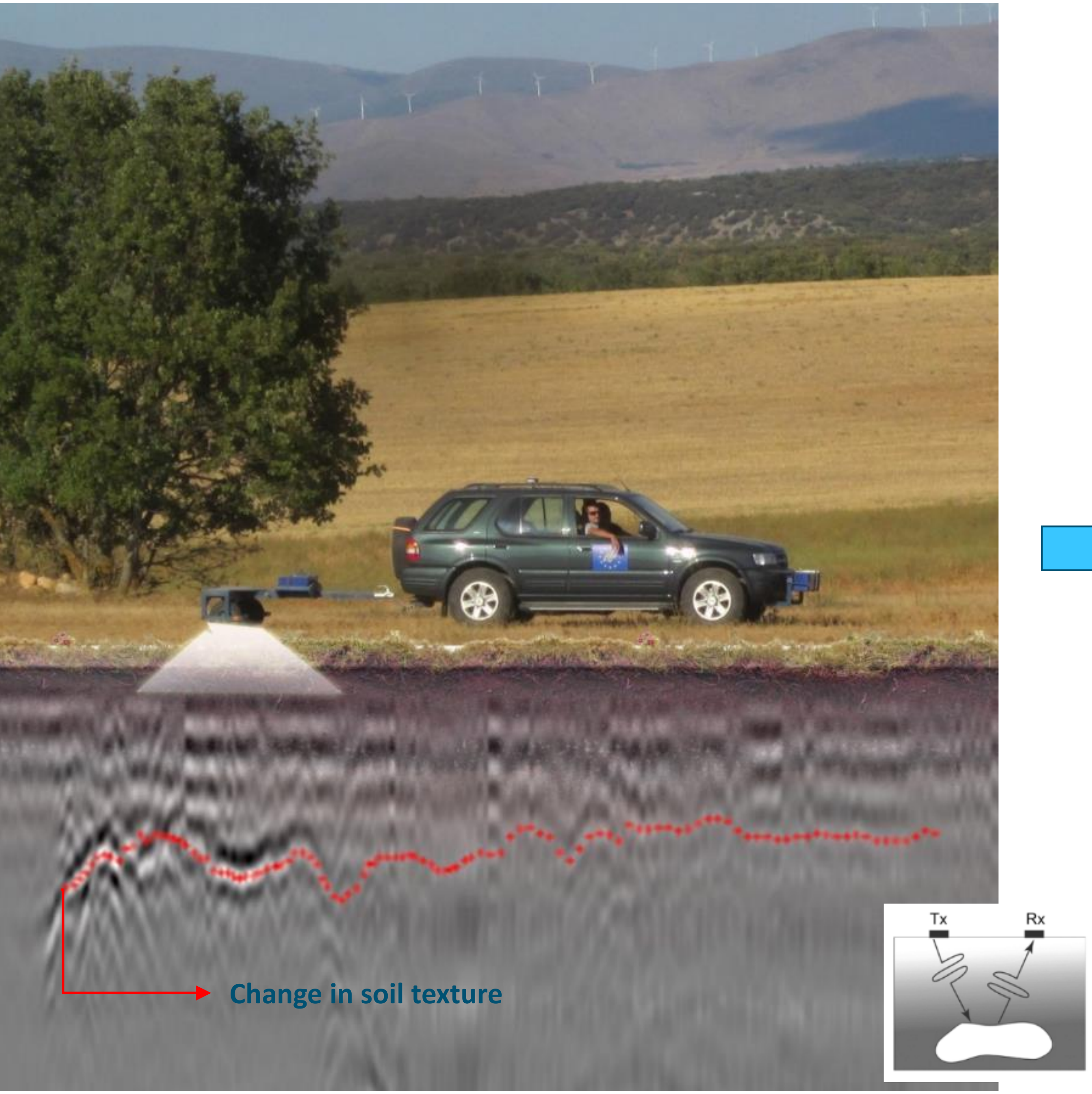
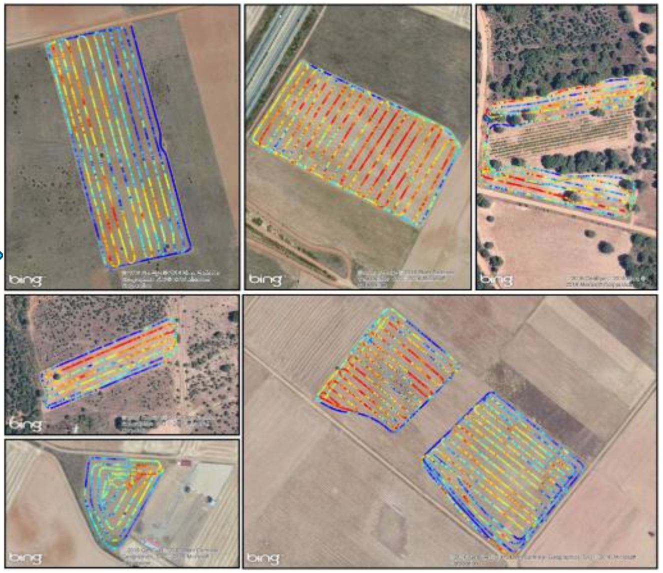
Ground Penetrating Radar (GPR)



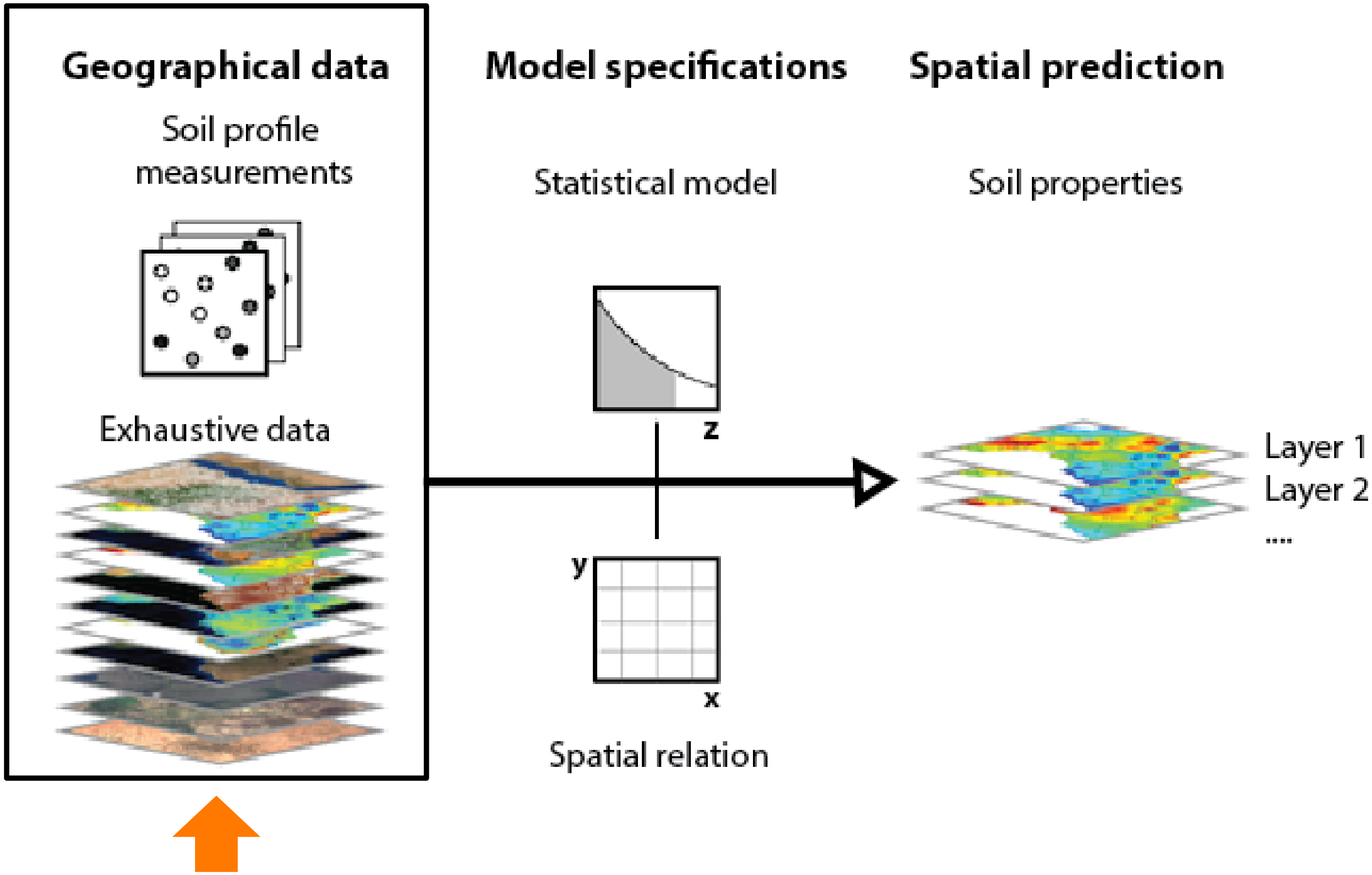
Maps of compacted layers/ soil depth



2. Spectral-based soil information

- Inventory & auxiliary data
- Examples Remote and Proximal sensing for soils
- Obtaining data

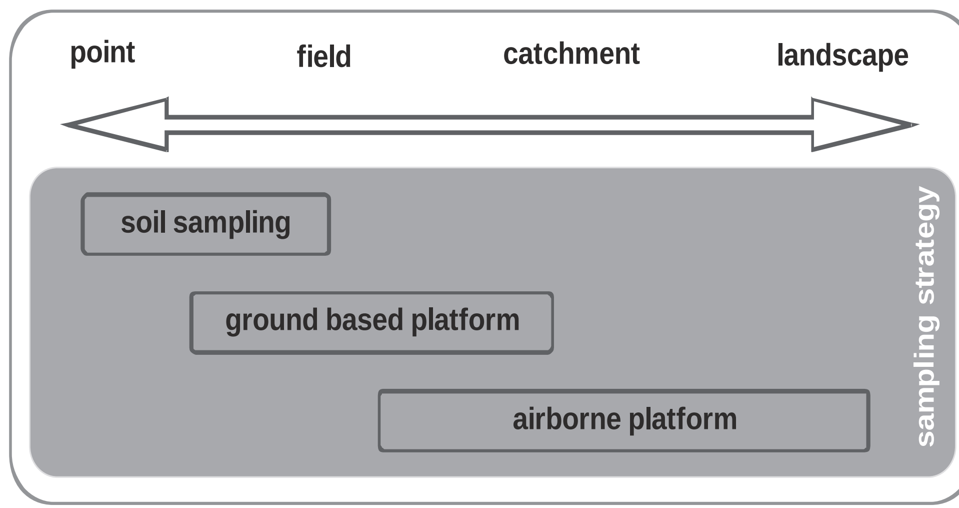
Soil Sensing for Digital Soil Mapping



Source: Africa Soil Information Service, http://www.africasoils.net/data/digital-soil-mapping

Soil sensing

- Extra tool in mapping: covariates.
- Choose technique based on question and scale.
- Remain proxies and are bound to physical laws.
- Ground truthing will always remain necessary.
- Provide highly detailed data in short time span at low cost.
- Fundamental knowledge of soil systems, geostatistics and measurement techniques is <u>crucial</u>.



Slide courtesy: Ir. F.M. Egmond, ISRIC World Soil Information Wageningen

Frequently used Remote Sensing methods

- Classification e.g. land use, delineation soil types
- Calculation of indices e.g. NDVI, SWI, ASTER GEOSCIENCE products (Tutorial)
- Spectral feature comparison e.g mineral mapping

Frequently used Proximal Sensing methods

- Spectral libraries & prediction models (Tutorial)
- Spectral deconvolution/Spectral Feature Analysis
- Memory-based learning

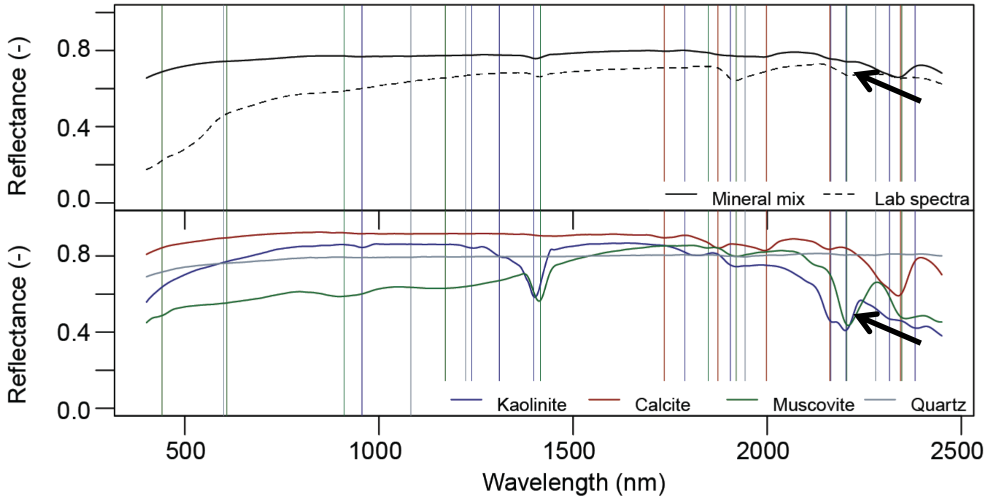
PS Spectral library

- Spectral library: large collection of soil sample and spectral data
- Calibration soil property prediction models
- Prediction of soil properties using only spectral data
- (Ideally) no need for expensive and time consuming chemical and physical lab analysis
- Methods: partial least squares regression (PLSR), random forest, cubist...etc.
- Usage: measuring & monitoring

PS Spectral library

- A global spectral library to characterize the world's soil
    - https://doi.org/10.1016/j.earscirev.2016.01.012
- Soil profile imaging
- SOC monitoring

PS Choice of Method

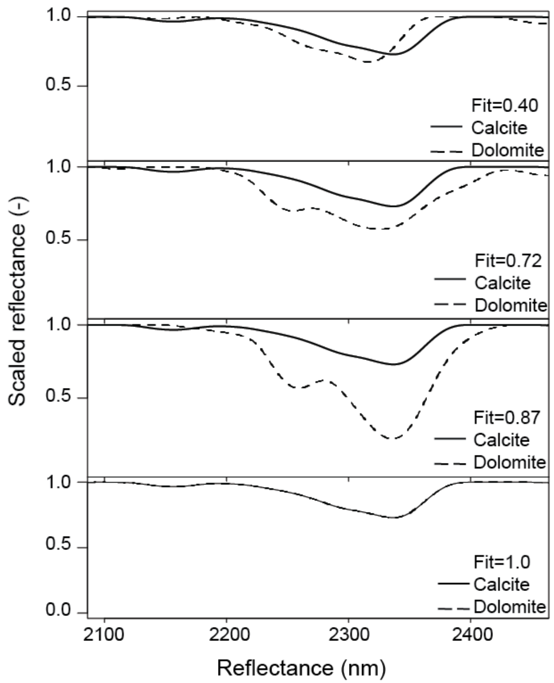


- Problem: Spectral mixing
- In this example: inference of mineralogy
  1. Many minerals in a single sample
  2. Absorption features not distinct

V.L. Mulder, S de Bruin, M.E. Schaepman, (2012). Retrieval of composite mineralogy by VNIR spectroscopy, 5th Global Workshop on Digital Soil Mapping 2012, Sydney, Australia.

PS Choice of Method: spectral feature analysis

- **Mineral Identification & Classification Algorithm (MICA) USGS Processing Routines in IDL for Spectroscopic Measurements (PRISM)**



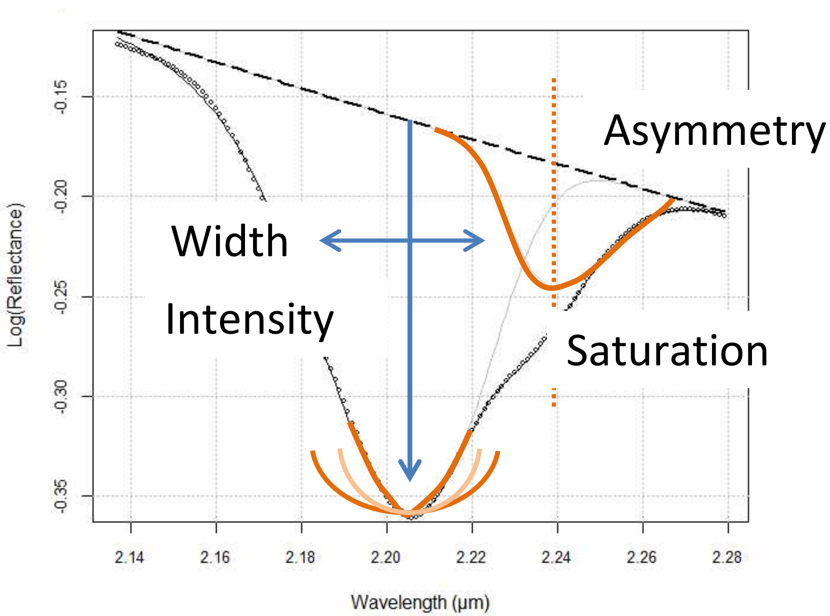
Results
- **Mineral categories**
- **Overall accuracy 52%**

Mineral	Calcite-rich	Calcite-poor
Kaolinite	38	17
Smectite	6	27
Dioctahedral Mica	40	34

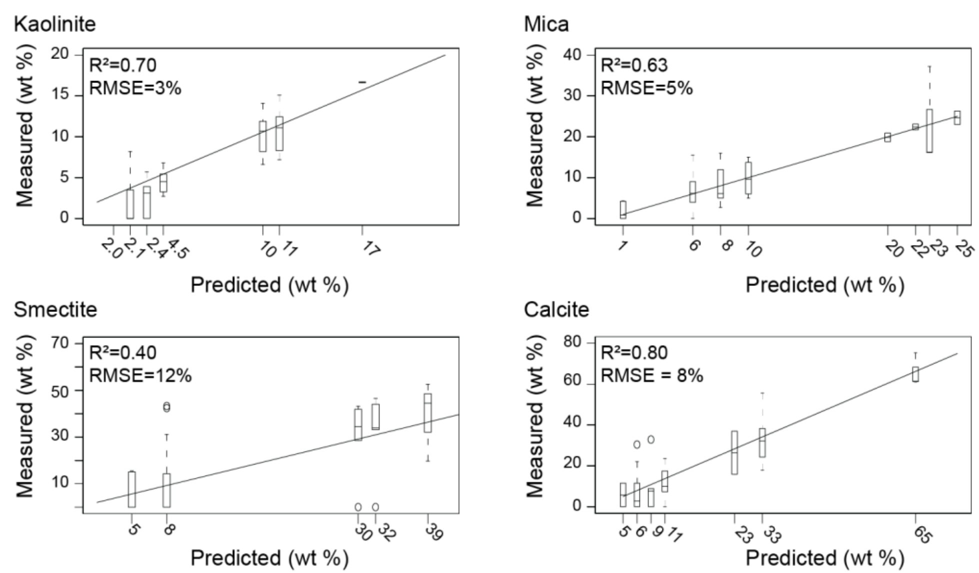
V.L. Mulder, S de Bruin, M.E. Schaepman, (2012). Retrieval of composite mineralogy by VNIR spectroscopy, 5th Global Workshop on Digital Soil Mapping 2012, Sydney, Australia.

PS Choice of Method: Spectral deconvolution

- **Method** (Pompillio et al., 2009)



- **Results (natural samples)**



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V.L. Mulder, M. Plotze, S. de Bruin, S., M.E. Schaepman, C. Mavris, R. Kokaly, M. Egli, M., (2013). Quantifying mineral abundances of complex mixtures by coupling spectral deconvolution of SWIR spectra (2.1-2.4 µm) and regression tree analysis. Geoderma, (207) 279-290. DOI: 10.1016/j.geoderma.2013.05.011

3. Digital Soil Mapping Example

Crops for better soil

Courtesy: Ir. F.M. Egmond, ISRIC World Soil Information Wageningen

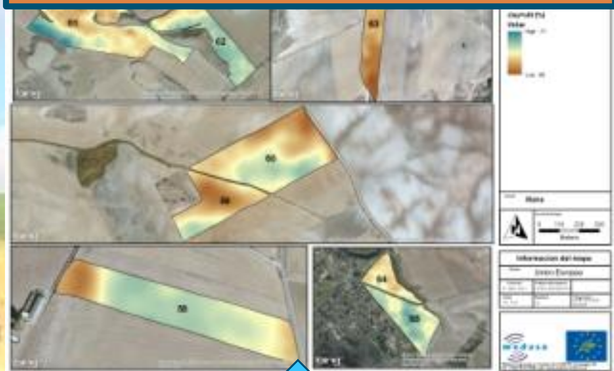
Understanding soil

Measurements

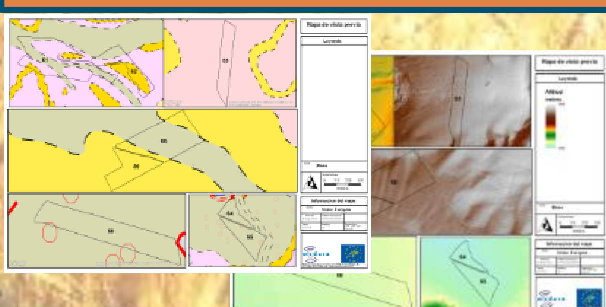
Interpretation of the soil based on pits

Comprehensive maps of the soil

Mapping



Open data



Lab analysis

Finca	arcilla	Mat. Org.	Etc.
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2	promedio	Promedio	...

Slide courtesy: Ir. F.M. Egmond,
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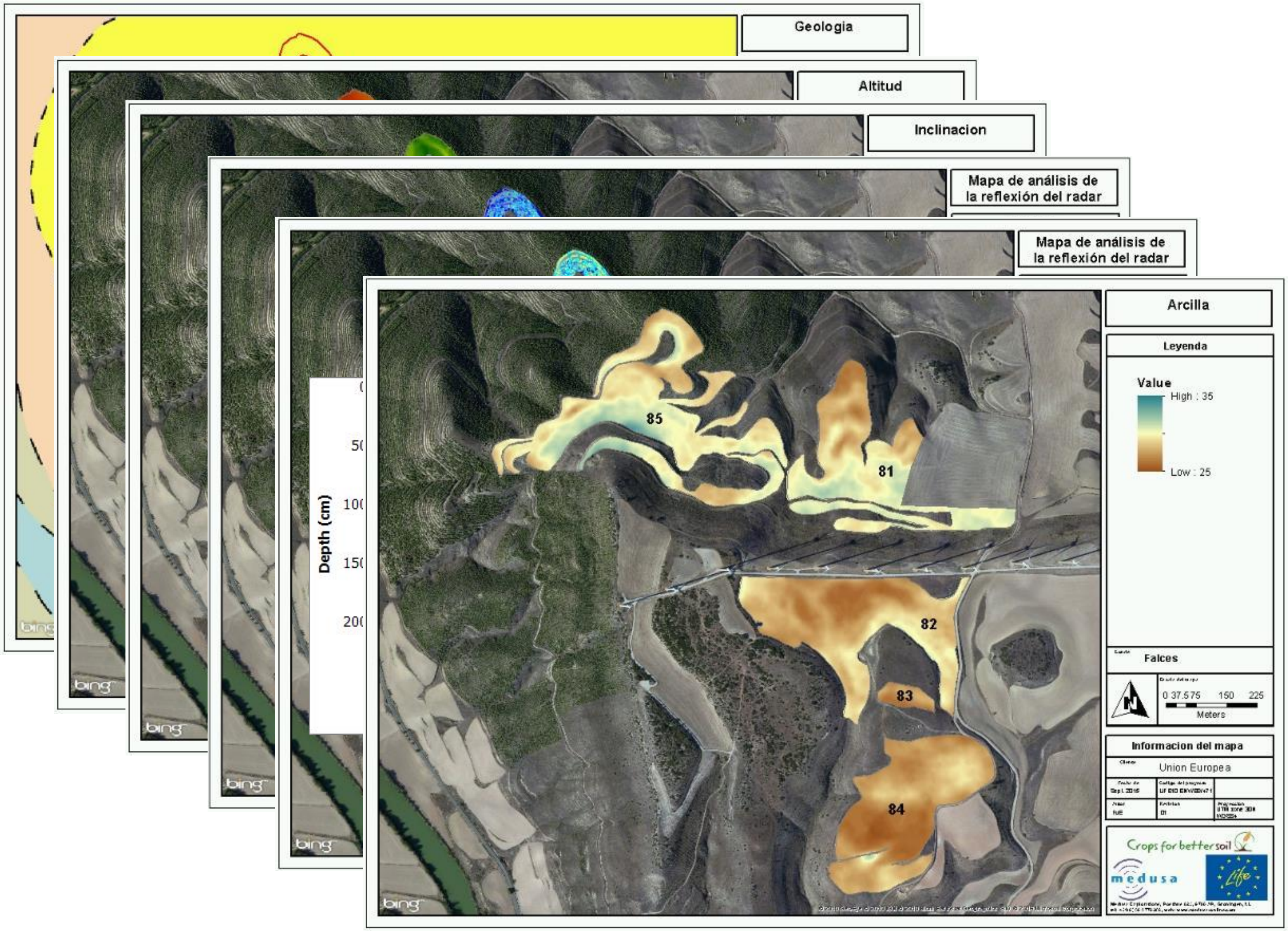
Crops for better soil

Example Falces - Navarra



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Crops for better soil

4. Points for consideration

Q4 What are the main difficulties of using soil sensing techniques?

Before drawing conclusion think about the meaning of the data in relation to the target property

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Key questions: Bare soil?

- Spectral signature bare soil
  - Commonly method: NDVI < 0.1-0.2
- Bare soil: some variability
  - Season, year, climate
  - Land use, cropping system
- No bare soil? Vegetation proxies – when and which vegetation properties
  - Top of the growing season
  - Leave-on/leave off
  - Outside of growing season

Spectral resolution

- What are the spectral characteristics of my target property
- Are there satellites that can directly retrieve this information or do I need a higher spectral resolution and would airborne or proximal sensing be more appropriate

- Use of data as reflectance or actually only suitable for calculating indices?
- Do not forget the physical meaning of the data you work with and using it solely as statistical numerical dataset to optimize a prediction model

Other points

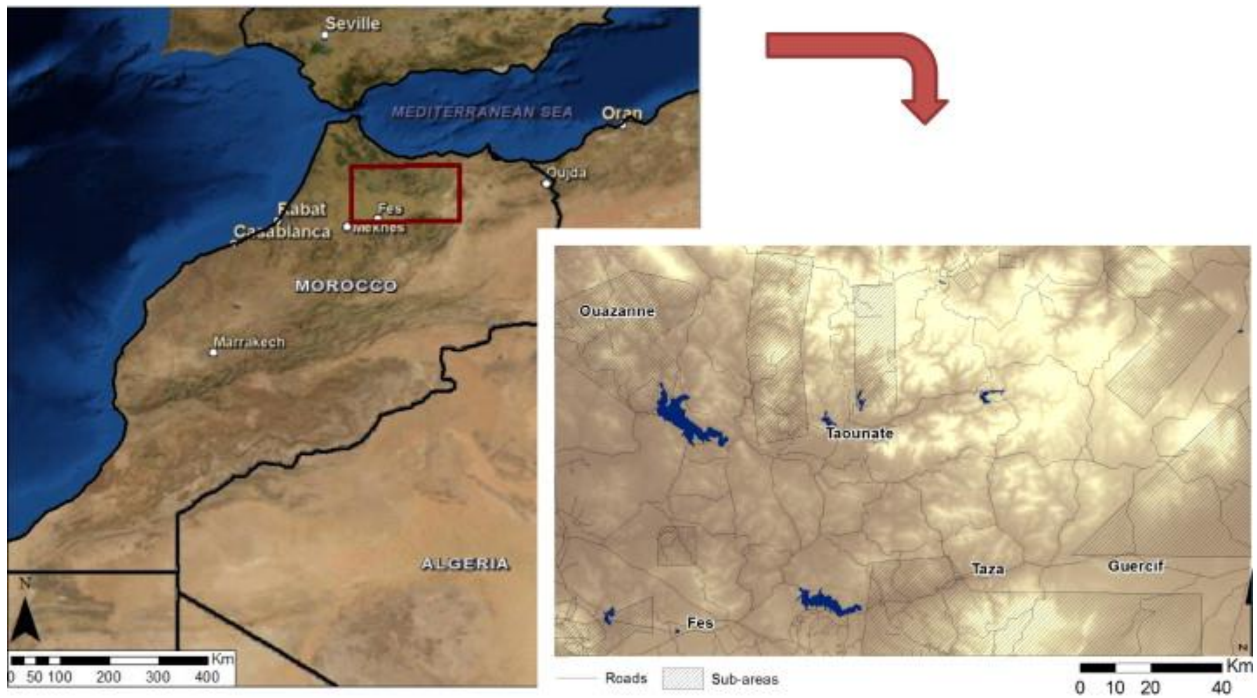
- Topography of the study area
- In mountainous areas many inaccuracies occur due to image distortions caused by differences in altitude and sloping areas
- What **pre-processing** has been performed on my data?
  - Think about the level of pre-processing and the possible limitations towards the prediction of the target variable
  - Atmospheric, topographic corrections, cloud removal etc.

Summary

- Many RS and PS sensing technologies and data sets available
- Valuable information
    - Spectral
    - Spatial
    - Temporal
- Many datasets in DSM rely on Remote Sensing
- Evaluate the use of data against your scientific goals

Tutorial: Soil Sensing - Measuring & Mapping soil properties

A case study in Morocco



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Content

Part 1: Estimating soil properties using a spectral library

- Point data: VNIR-SWIR spectroscopy
- How to fit a Partial Least Squares Regression model (PLSR)
- How to use the PLSR for predicting soil properties using the spectral library

Part 2: Using satellite data for mapping soil properties

- Exhaustive spatial data: ASTER satellite data
- Spectral data and derived indices
- Stepwise Multiple Linear Regression (MLR)