Soil Sensing for Measuring and Mapping

ISRIC Springschool 2019

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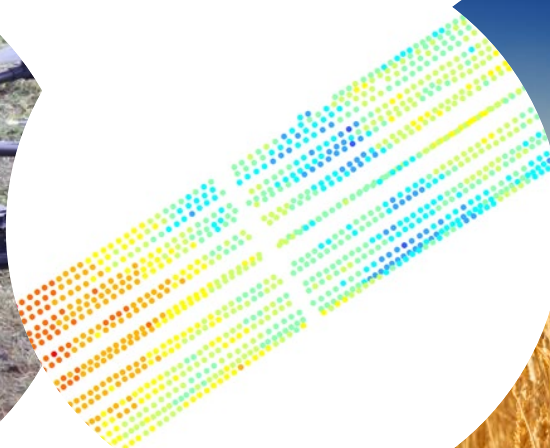

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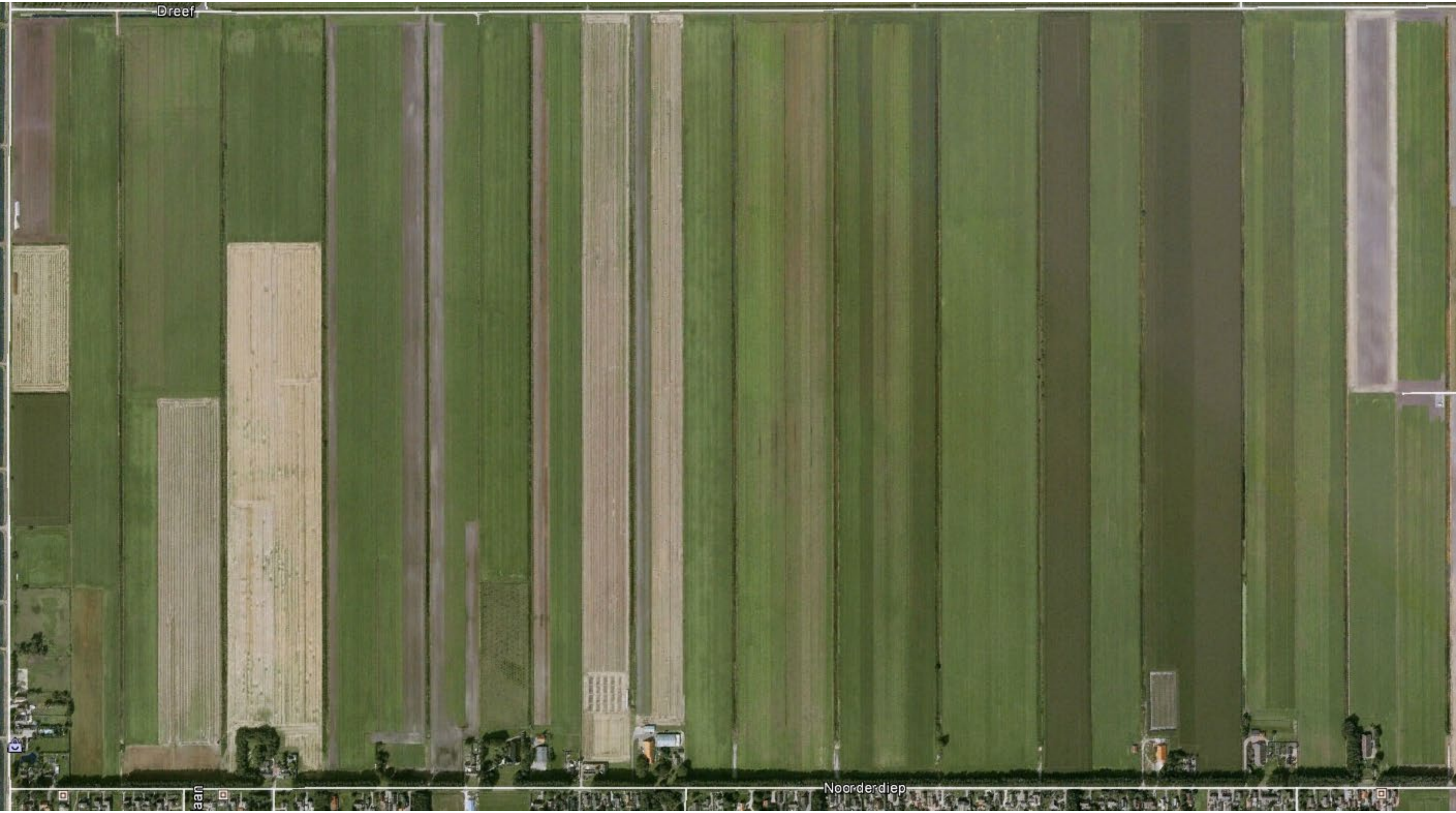
Summer 2005



Slide courtesy: MGI Remote Sensing course, Wageningen University

Spring 2005

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Why soil data?

Use cases for private and public sector on:

- Sustainable Land Management
- Food Security
- Land Degradation (Neutrality)
- Soil Organic Carbon (SOC)

THE GLOBAL GOALS
For Sustainable Development

International Initiatives:

- Global Soil Partnership
- Sustainable Development Goals
- Paris Agreement
- 4p1000
- Green Climate Fund

GLOBAL SOIL PARTNERSHIP

4 POUR 1000 LES SOLS POUR LA SÉCURITÉ ALIMENTAIRE ET LE CLIMAT

United Nations
Framework Convention on
Climate Change

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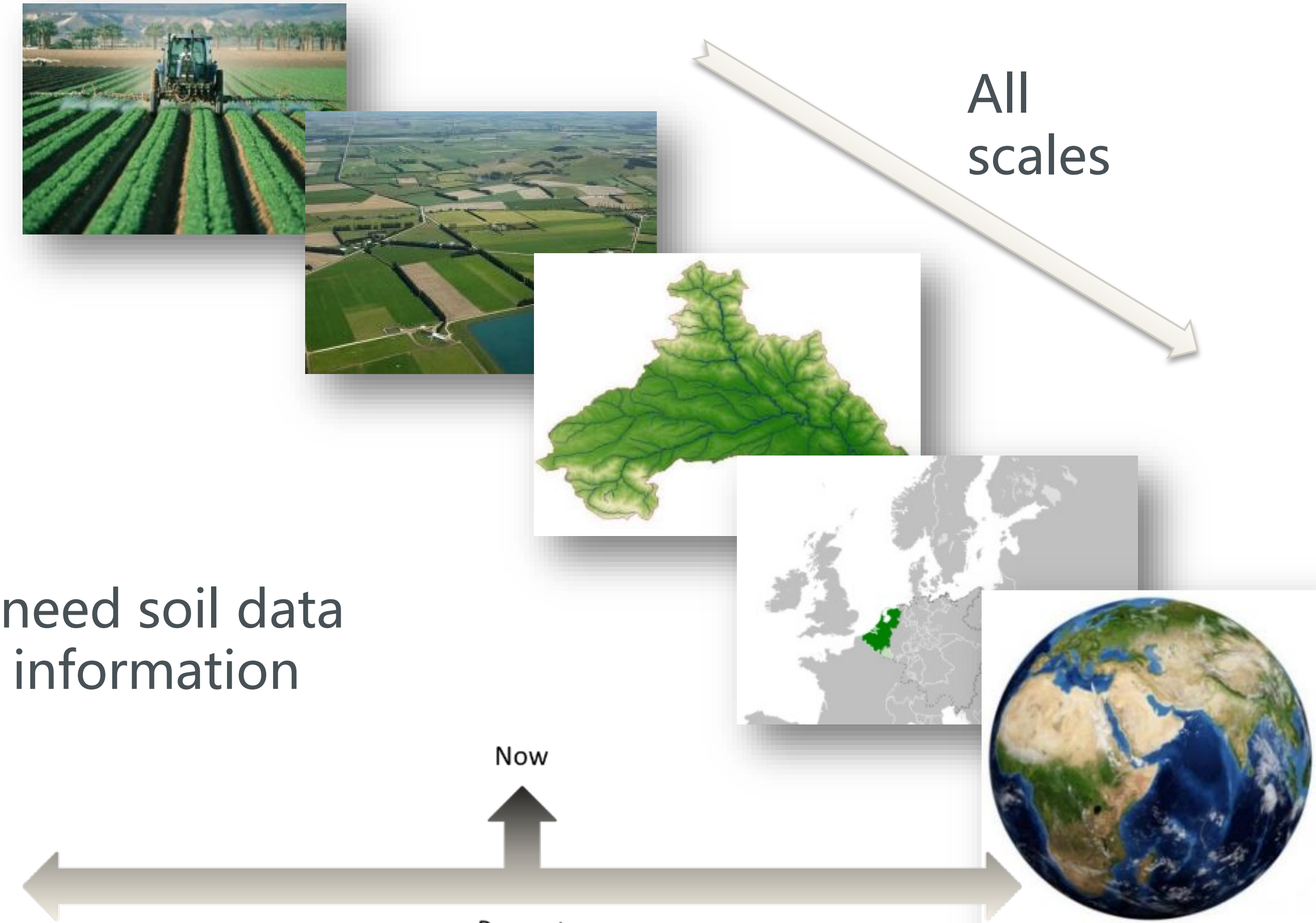
GODAN Global Open Data for Agriculture & Nutrition

Global Soil Services



All
scales

We need soil data
and information

Now

Past

Present

Future

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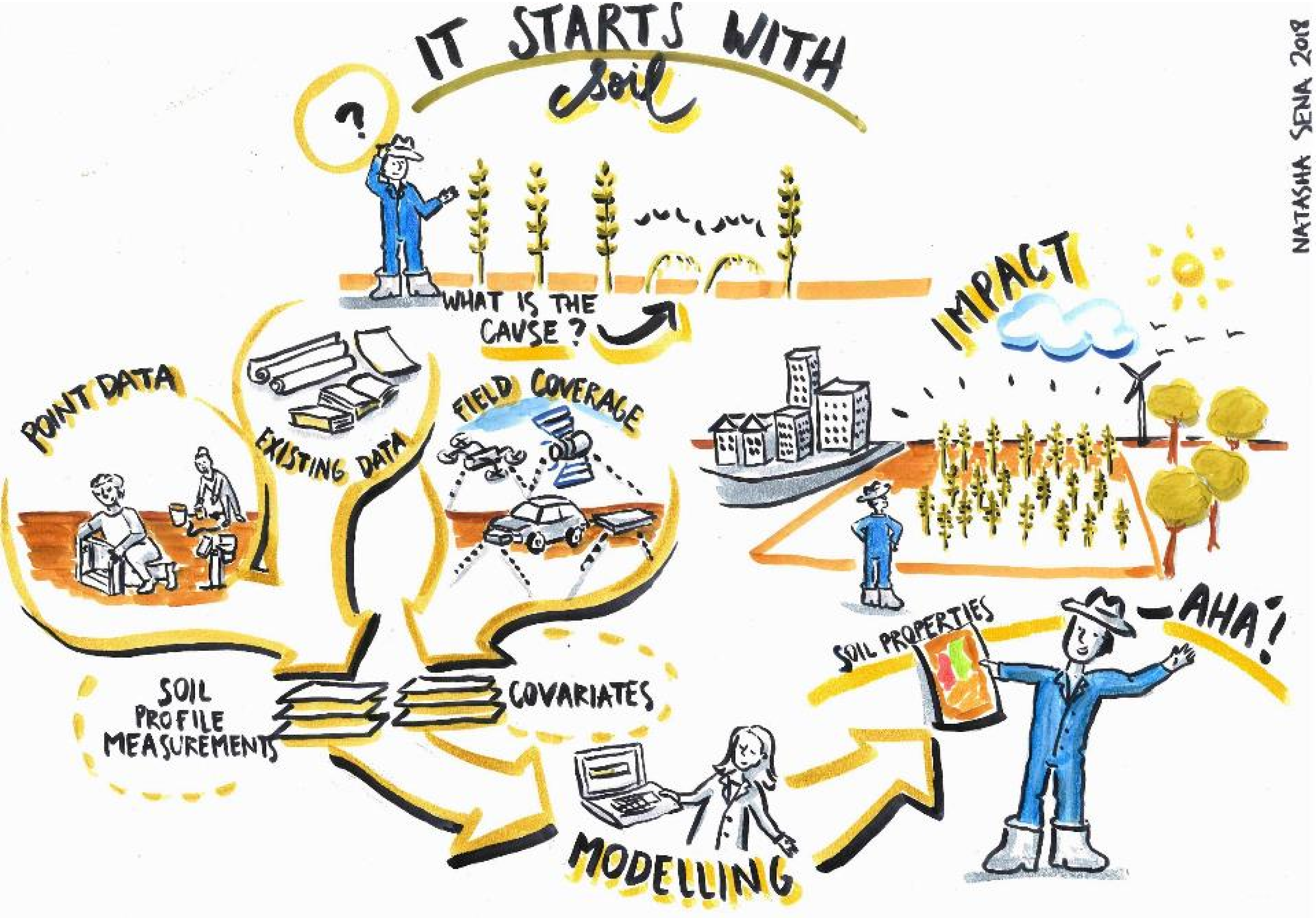

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More information: Fenny van Egmond - WENR

Outline

1. Fundamentals of spectroscopy
2. Available techniques
3. Spectral-based soil information
4. Digital Soil Mapping example
5. Points of consideration
6. Questions & Answers (Padlet invite)

Questions

1. Which different soil sensing techniques are available?
2. How can sensing techniques complement traditional soil inventories?
3. 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

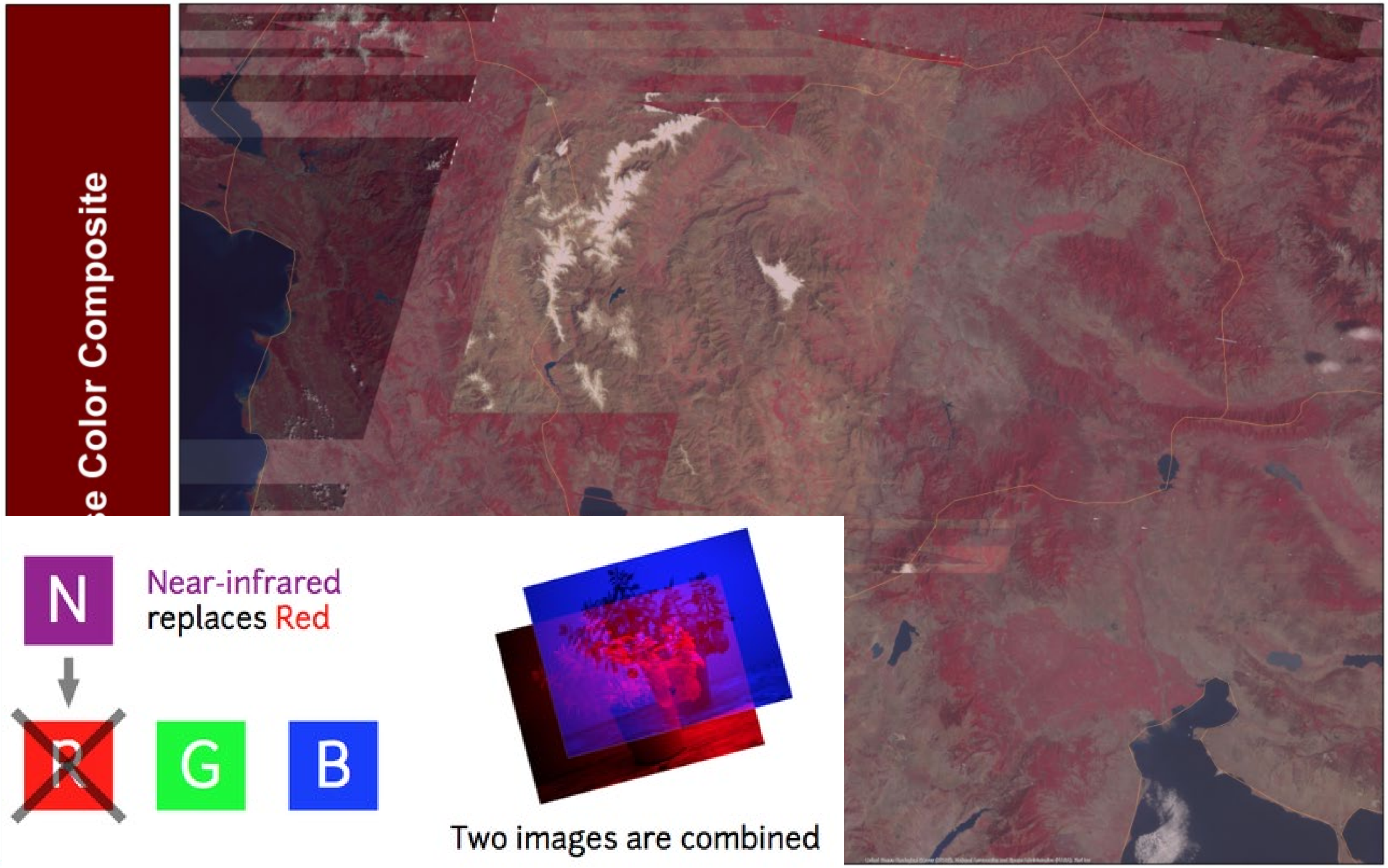
Measuring & Sensing technologies

- Measuring & monitoring
    - Cost effective
    - Non-destructive
    - Time efficient

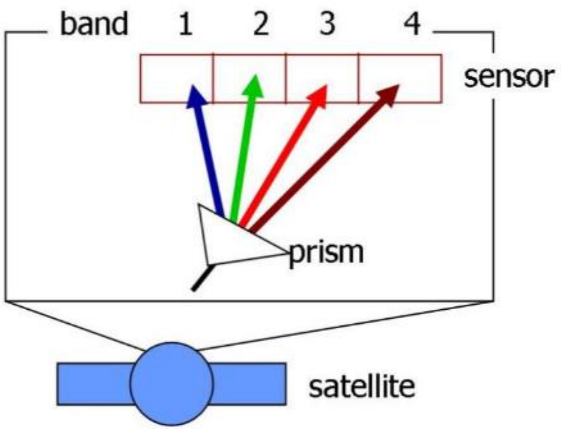
- Applications in agricultural, plant and environmental sciences

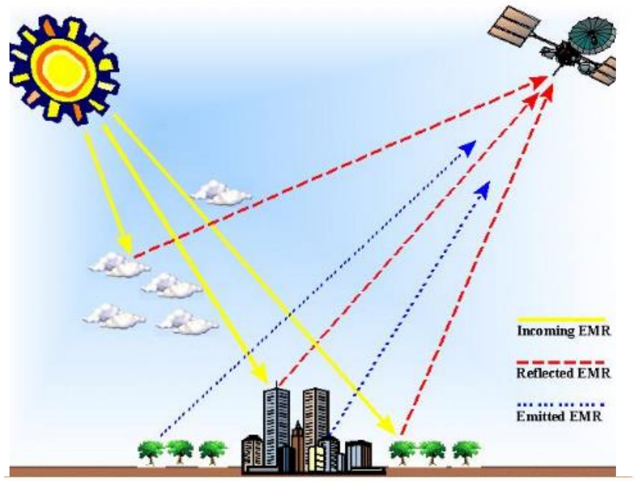

regular
RGB
photo
R
G
B
Image © 2017 DigitalGlobe
© 2017 Google
© 2009 GeoBasis-DE/BKG
Google Earth
2002
Imagery Date: 7/8/2013 51°58'58.18" N 5°39'21.79" E elev 0 ft eye alt 4213 ft

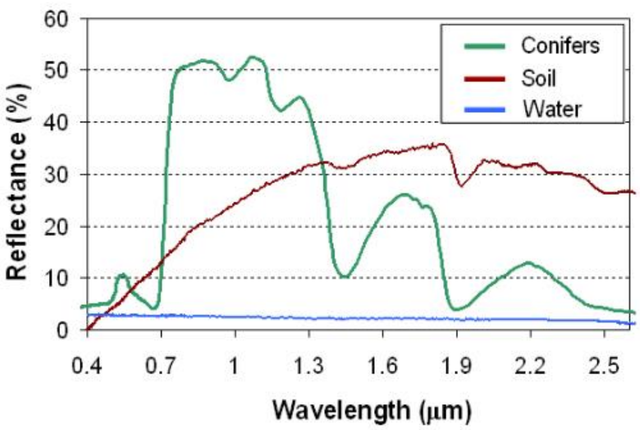
se Color Composite



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

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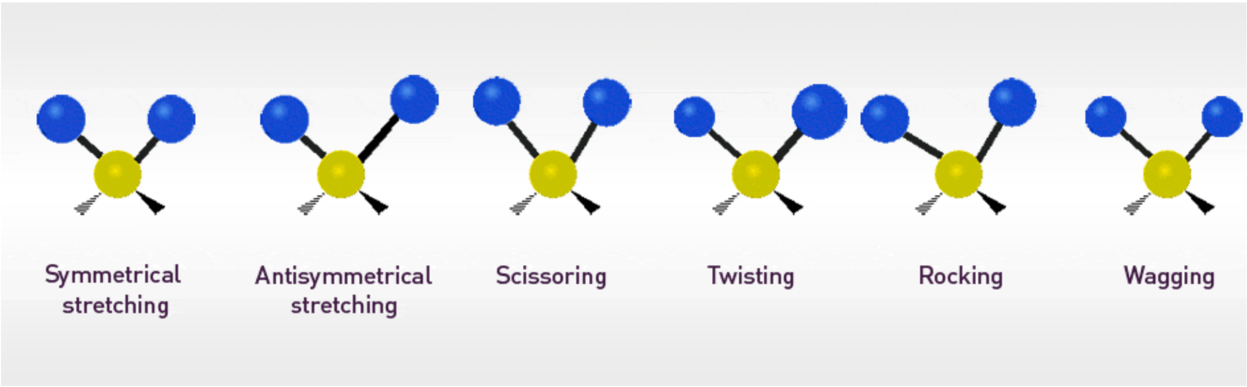
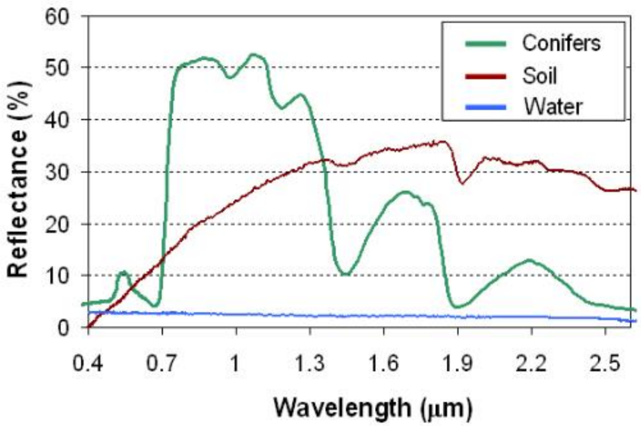




Molecular vibrations

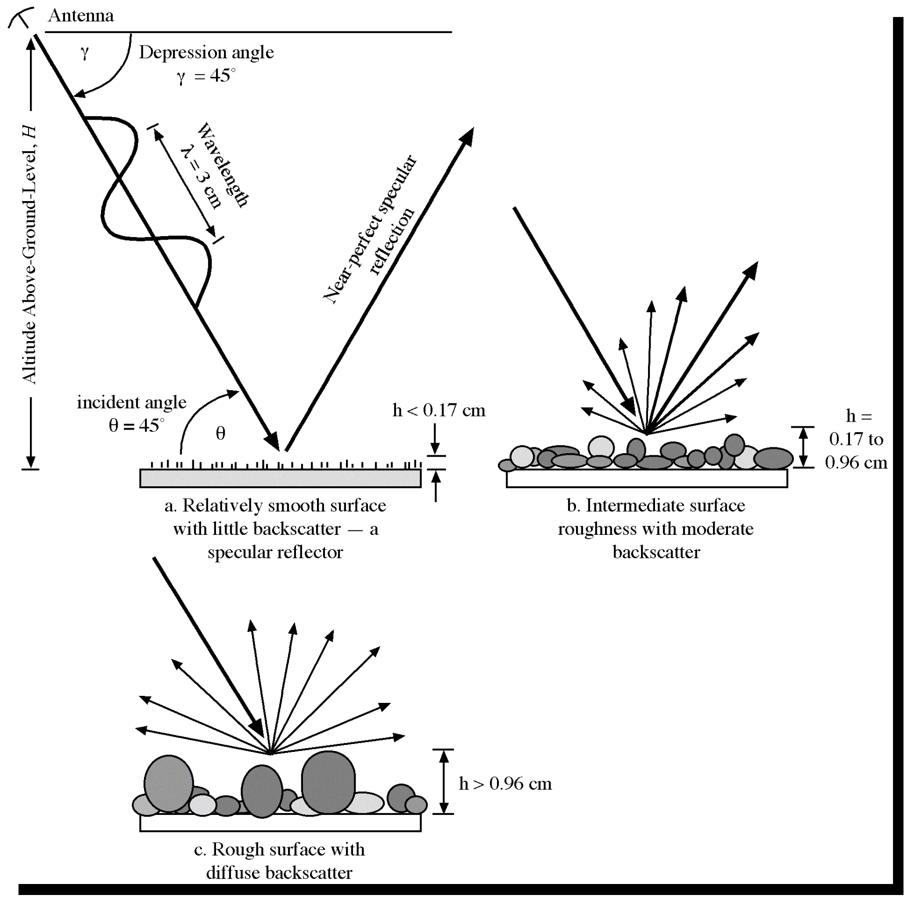
- When a molecule is irradiated, Energy is absorbed if the frequency of the radiation matches the frequency of the vibration

Main factors influencing soil reflectance

- For bare soils:
  - Roughness and texture
  - Organic matter content
  - Moisture condition (re-reflecting, OH^-)
  - Mineralogical composition (OH^-, CO_3^{2-}, Fe^{2+}, Fe^{3+}, …)
- Causes of specific absorption bands:
  - Electronic processes: short wavelength; absorption bands (energy jumps)
    - Fe: UV, 0.400 µm – 1.000 µm
  - Vibrational processes: long wavelength, (relatively) narrow bands.
    - OH: 1.450 µm, 1.950 µm
    - OH: >1.000 µm (minerals containing OH, H_2O)

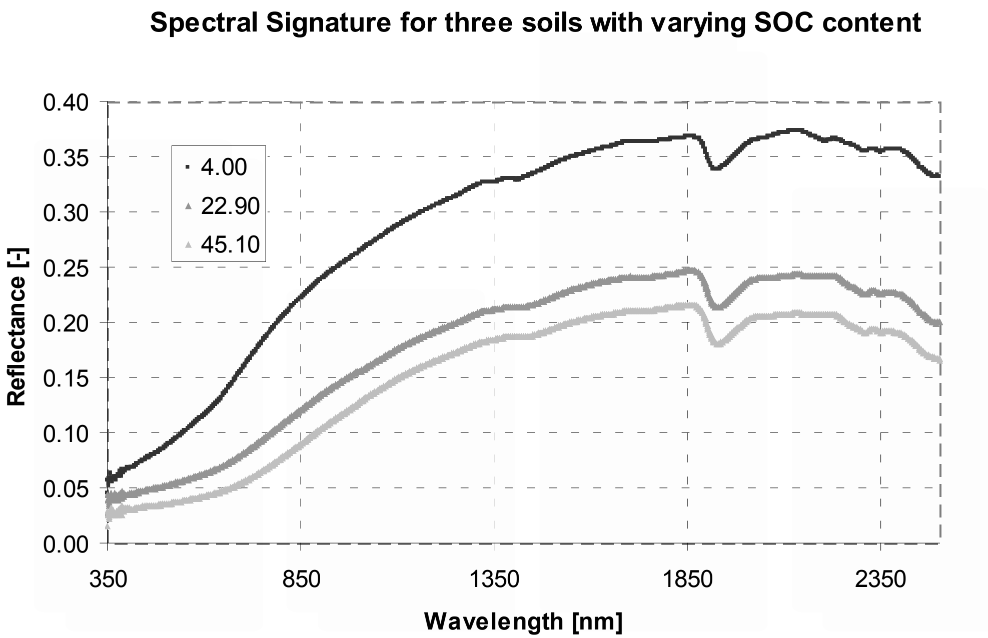
Surface Roughness

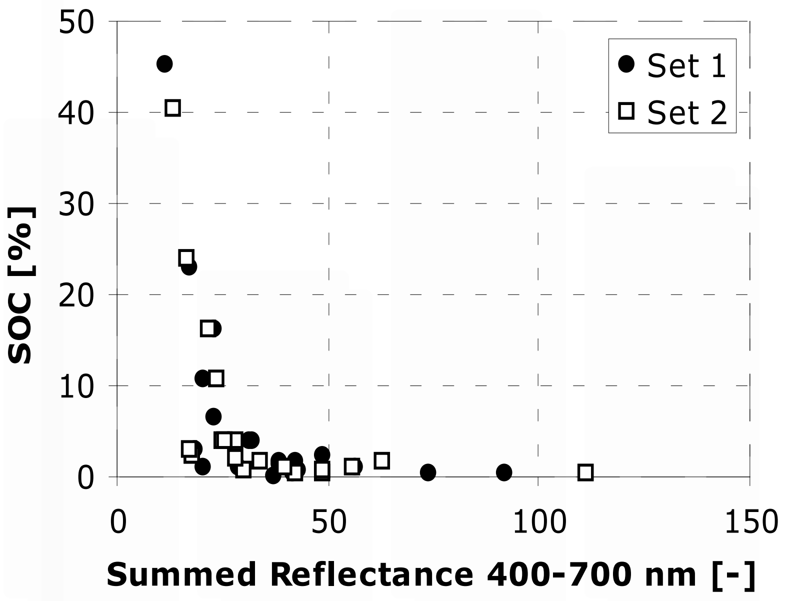
- Optical wavelength range
- A rough surface generally reflects less, due to self-shadowing effects and multiple scattering
- If a surface is smooth (particles smaller than wavelength), specular reflection is important.
- Conversely, a rough surface scatters EMR and thus appears bright.



Source: ERS 186 Environmental Remote Sensing; S. Ustin

Organic Matter





- increase in organic matter -> decrease in R
- Above 2% masking of other absorption features
- No distinct absorption features

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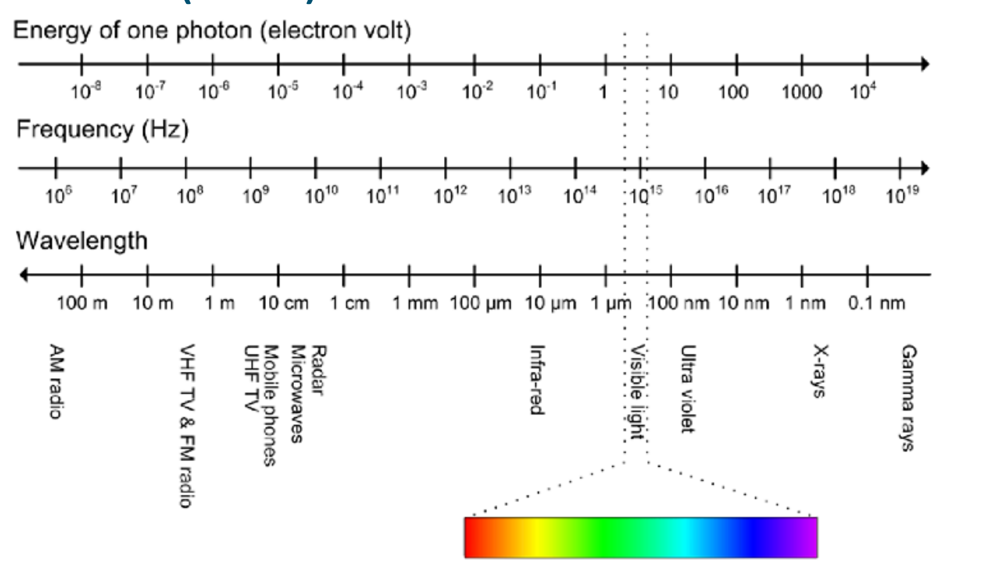
Slide courtesy: MGI Remote Sensing course, Wageningen University

2. Available techniques

Sensing technologies for soil inventory

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



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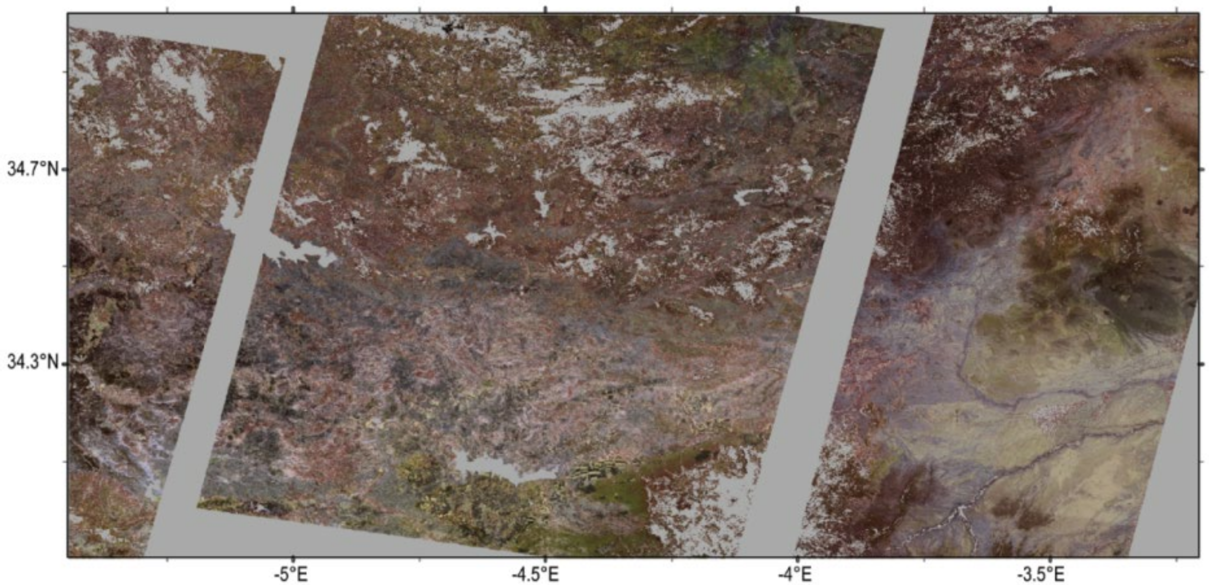
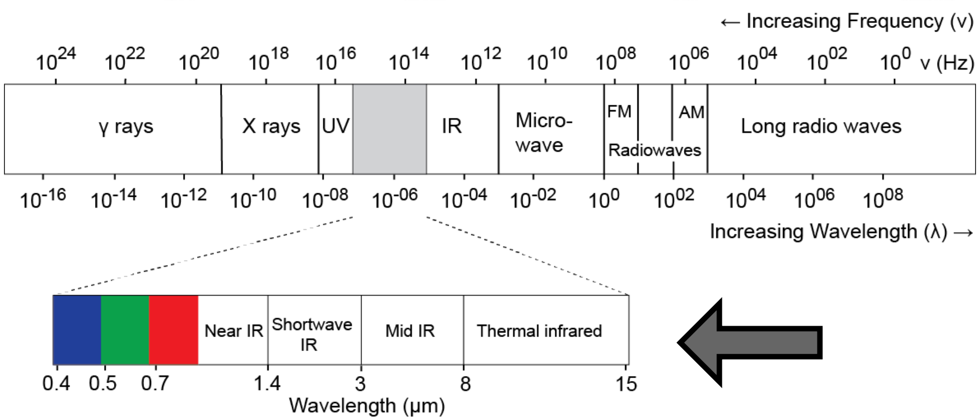
Slide courtesy: Ir. F.M. Egmond, ISRIC World Soil Information Wageningen

Optical Remote Sensing (RS)





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

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

Information about soils from remote sensing

(between 0.400 µm and 2.500 µm)

By observations of:

- Crop cover and vegetation
  - Relation between crop or vegetation and soil
  - Relation between crop development and soil
- Bare soil surface
  - Relation between soil surface and soil
- Topography (relief differences)
  - Relation between topography and soil

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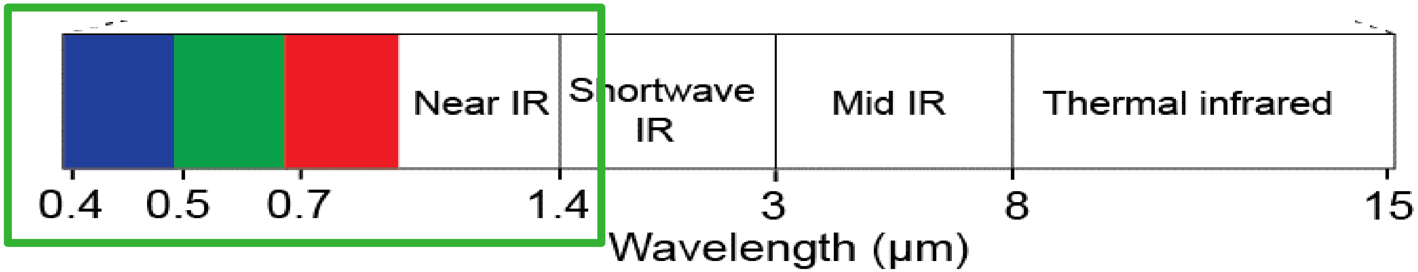
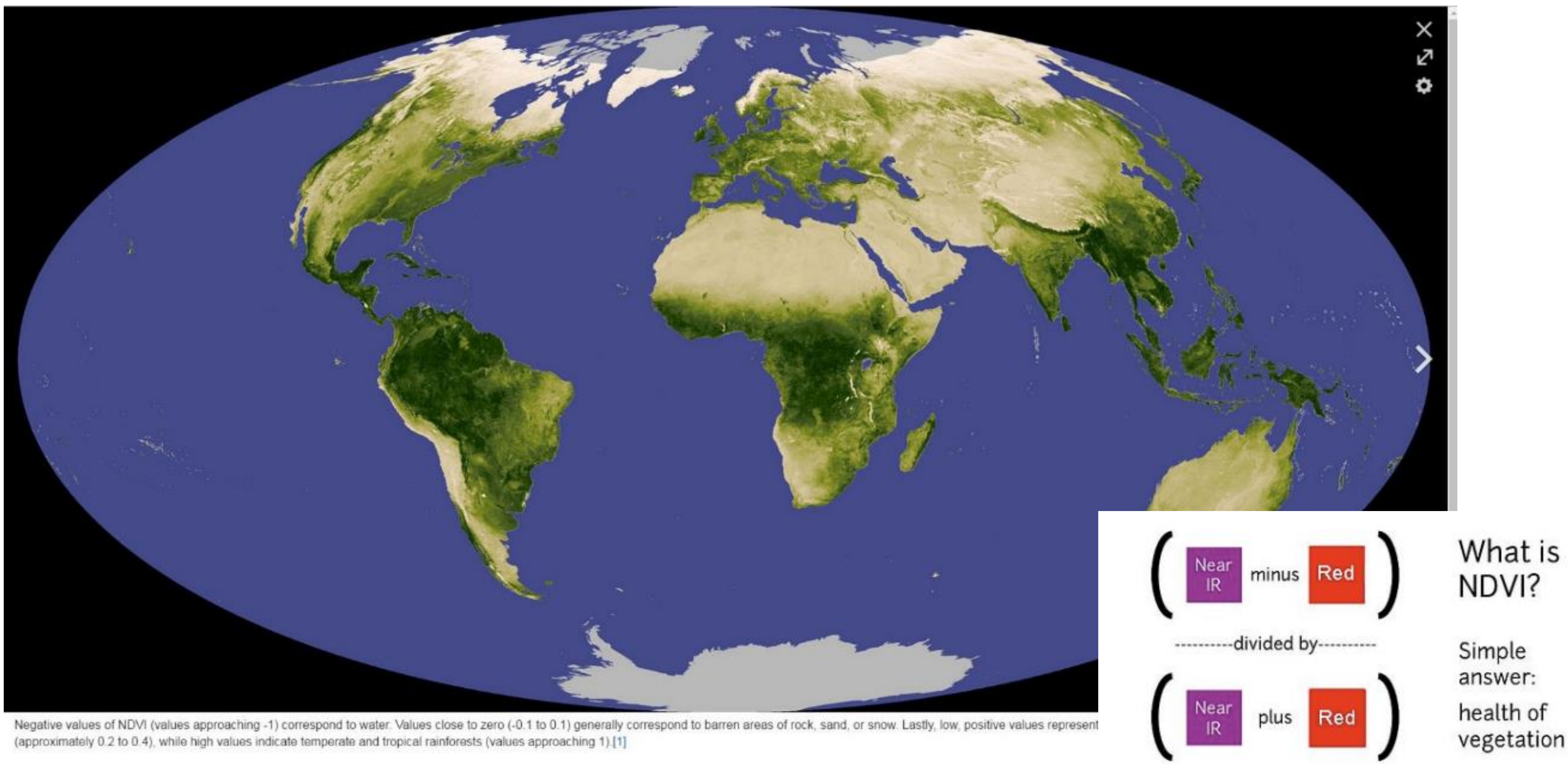
Slide courtesy: MGI Remote Sensing course, Wageningen University

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]

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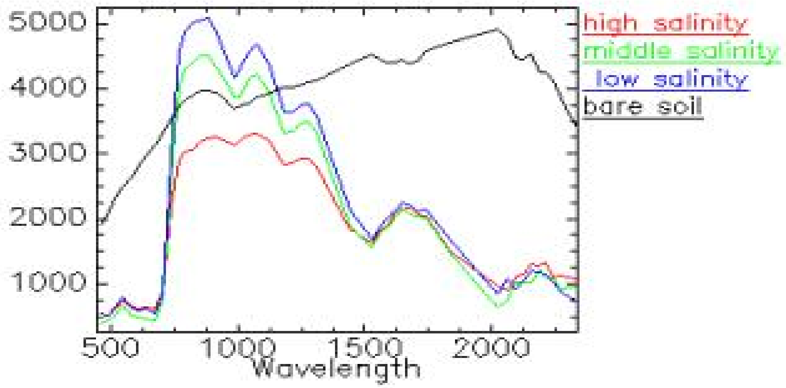
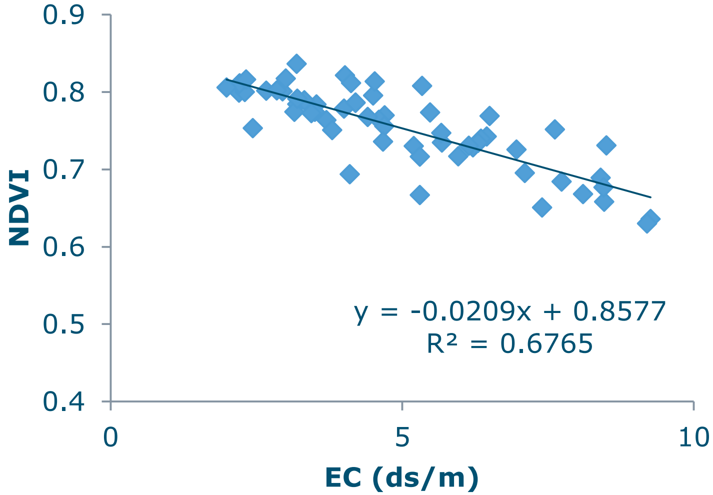
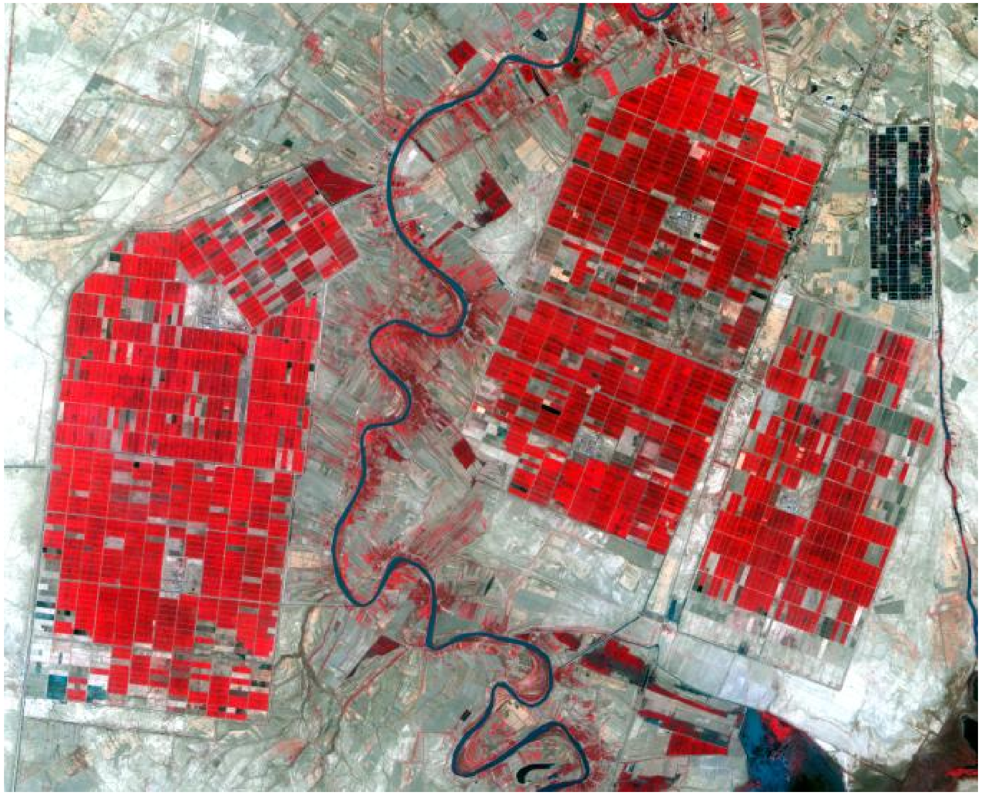
Info about soils from remote sensing – Vegetation development







Hyperion – 2 sept 2010 -- courtesy: Saeid Hamzeh & Harm Bartholemeus MGI course Advanced Remote Sensing

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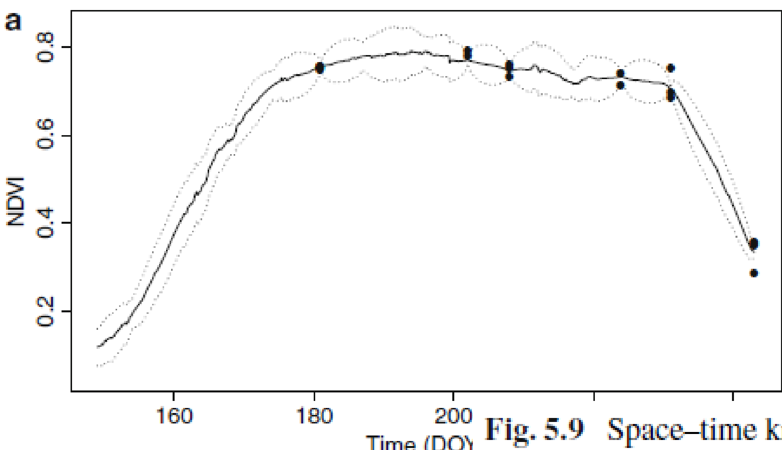
Space time crop modelling using NDVI

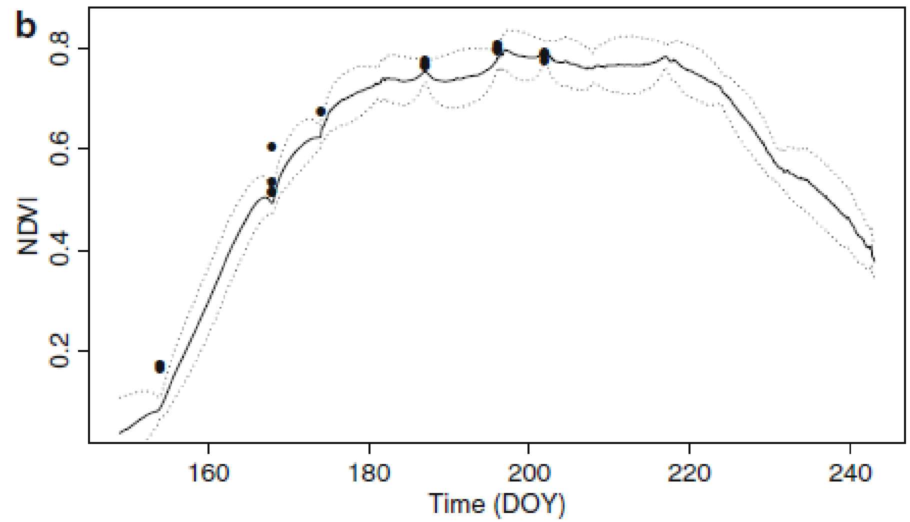
Chapter 5

Space–Time Geostatistics for Precision Agriculture: A Case Study of NDVI Mapping for a Dutch Potato Field

G.B.M. Heuvelink and F.M. van Egmond

Abstract Many environmental variables that are relevant to precision agriculture, such as crop and soil properties and climate, vary both in time and space. Farmers can often benefit greatly from accurate information about the status of these variables at any particular point in time and space to aid their management decisions on irrigation, fertilizer and pesticide applications, and so on. Practically, however, it is not feasible to measure a variable exhaustively in space and time. Space–time





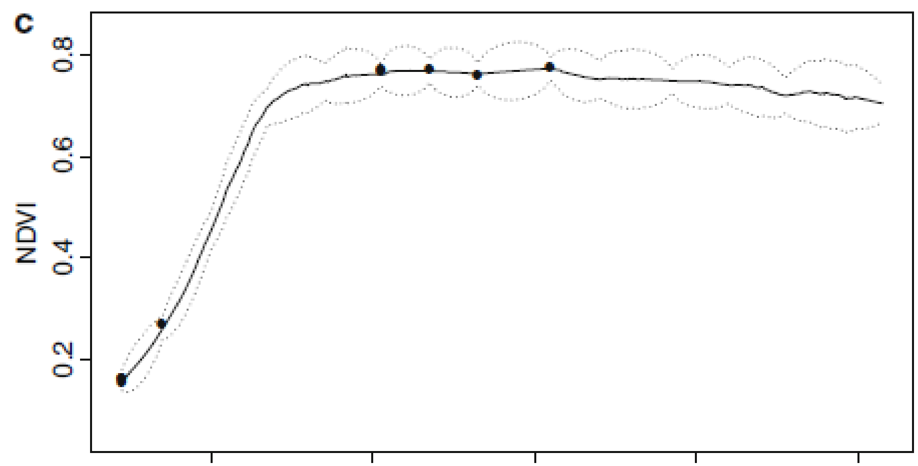


Fig. 5.9 Space–time kriging results for three arbitrary locations: (**a**) centre and (**b**) north-west corner of the Sofista parcel, and (**c**) centre of the Innovator parcel. The *solid line* is the regression kriging prediction, *dotted lines* represent the 95% prediction intervals derived from the kriging standard deviation. The dots are NDVI observations within a circular neighbourhood with radius 2 m

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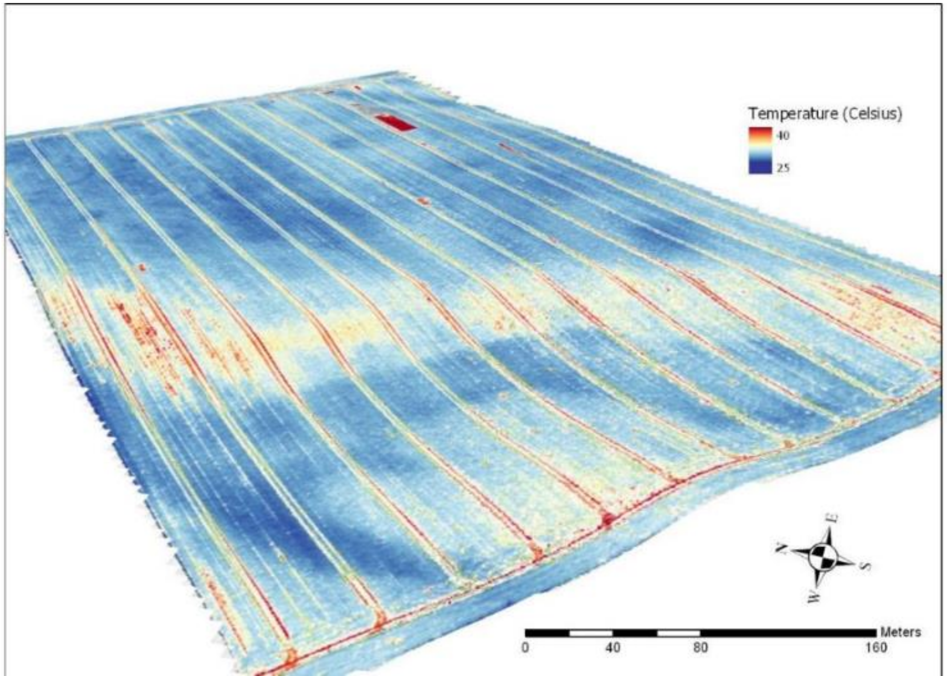
Relation between soil surface and soil

Slide courtesy: MGI Remote Sensing course, Wageningen University

Information on available moisture

- Combination of measurements yields more information:
  - Point measurements at representative or dry locations at the field
  - Continuous measurements at 1 or more depths (often based on EC)
  - Handheld measurement (often TDR)
  - Field covering measurements of the crop, soil, temperature, elevation
- 1+1=3
- Eg. Temperature -> plantstress
  by soil moisture + elevation



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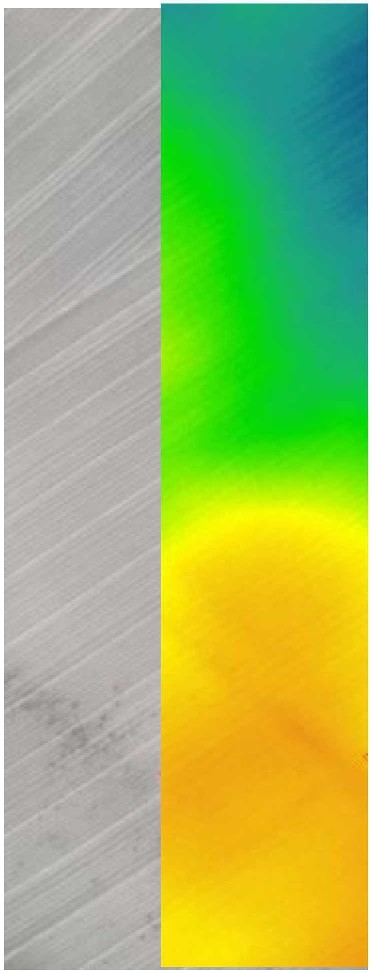
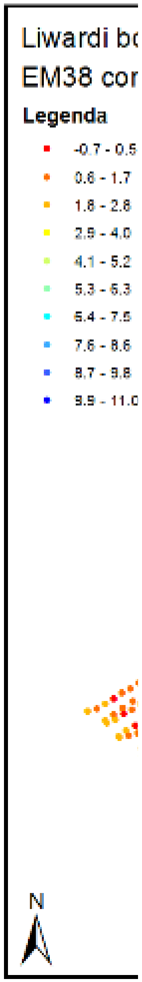
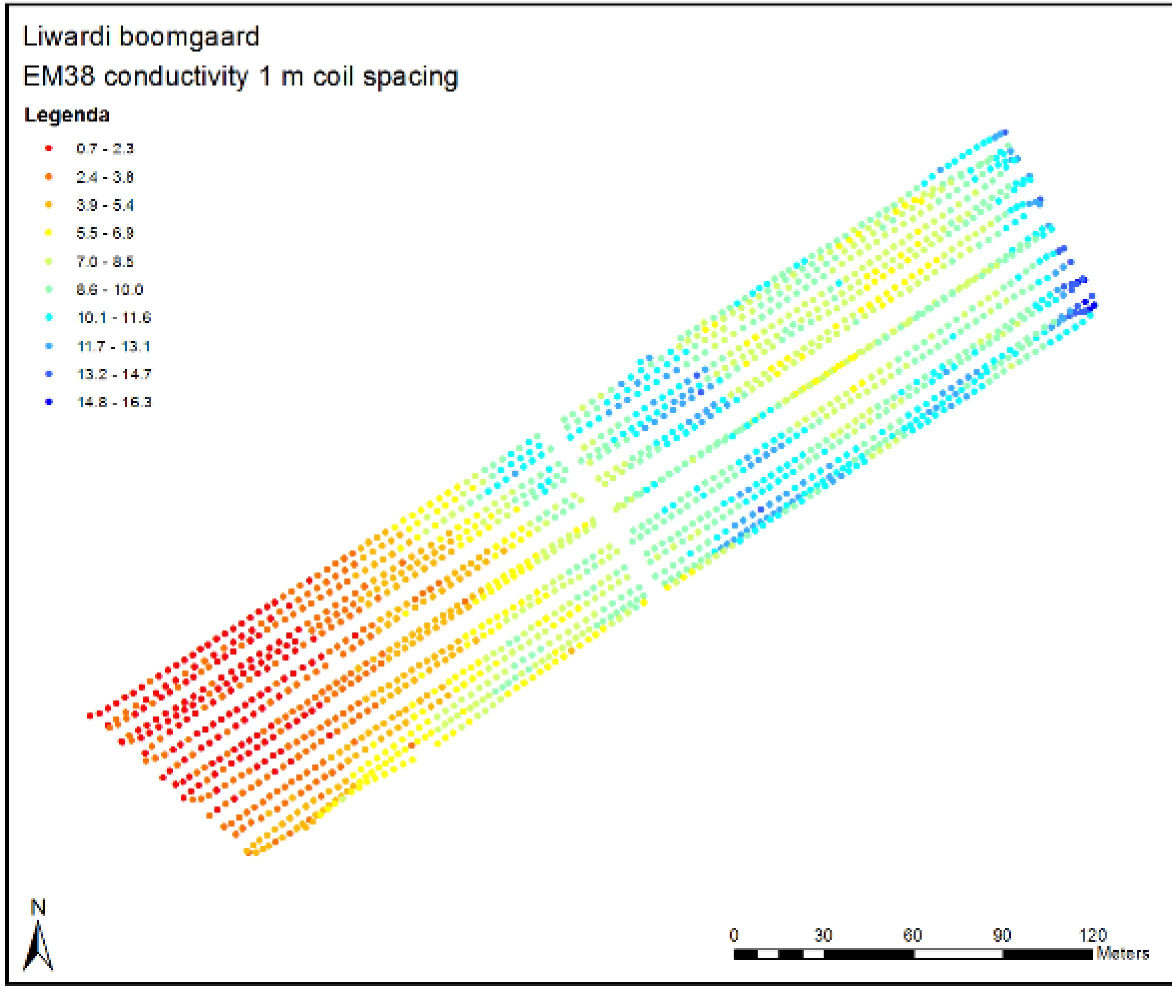
Correlation between crop and soil







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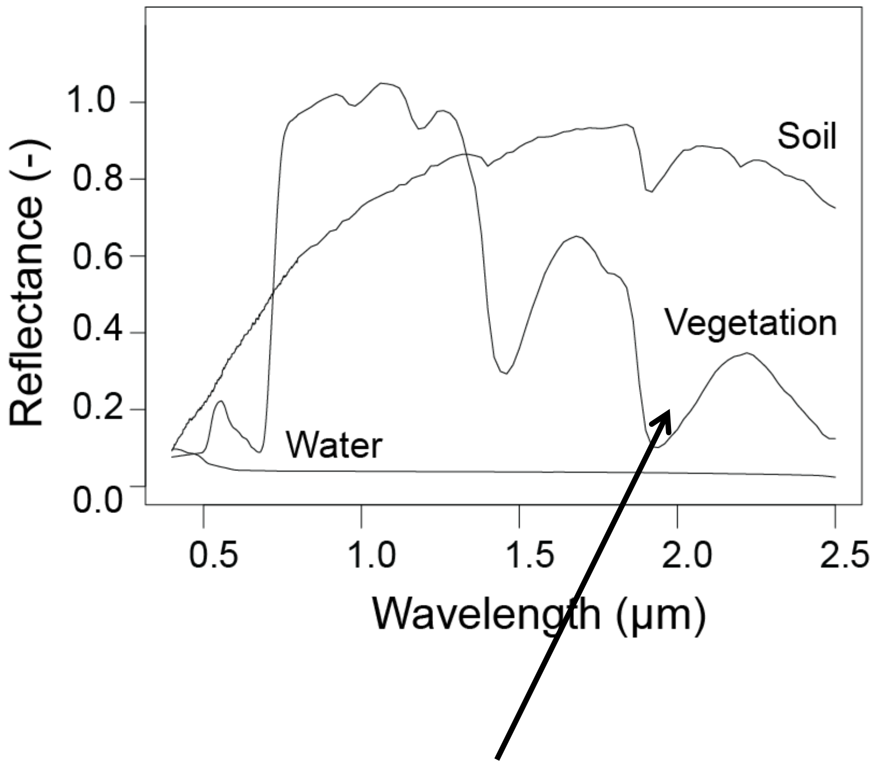
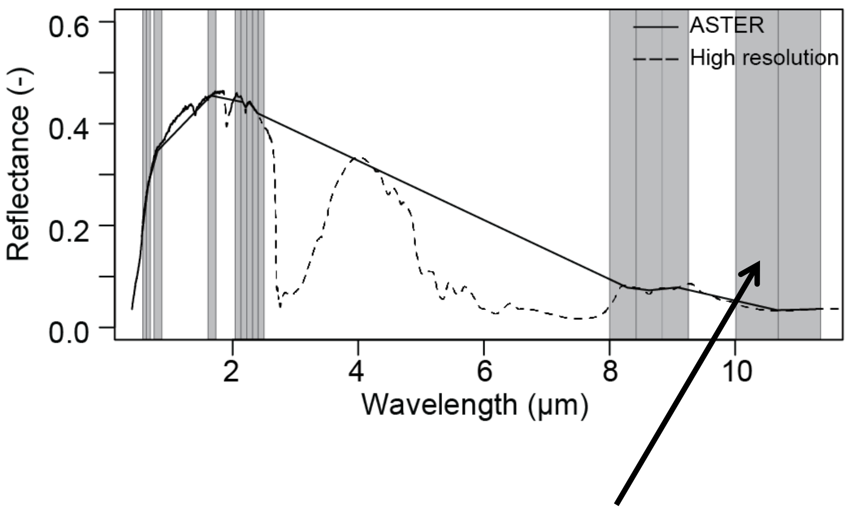
Proximal vs Remote Sensing

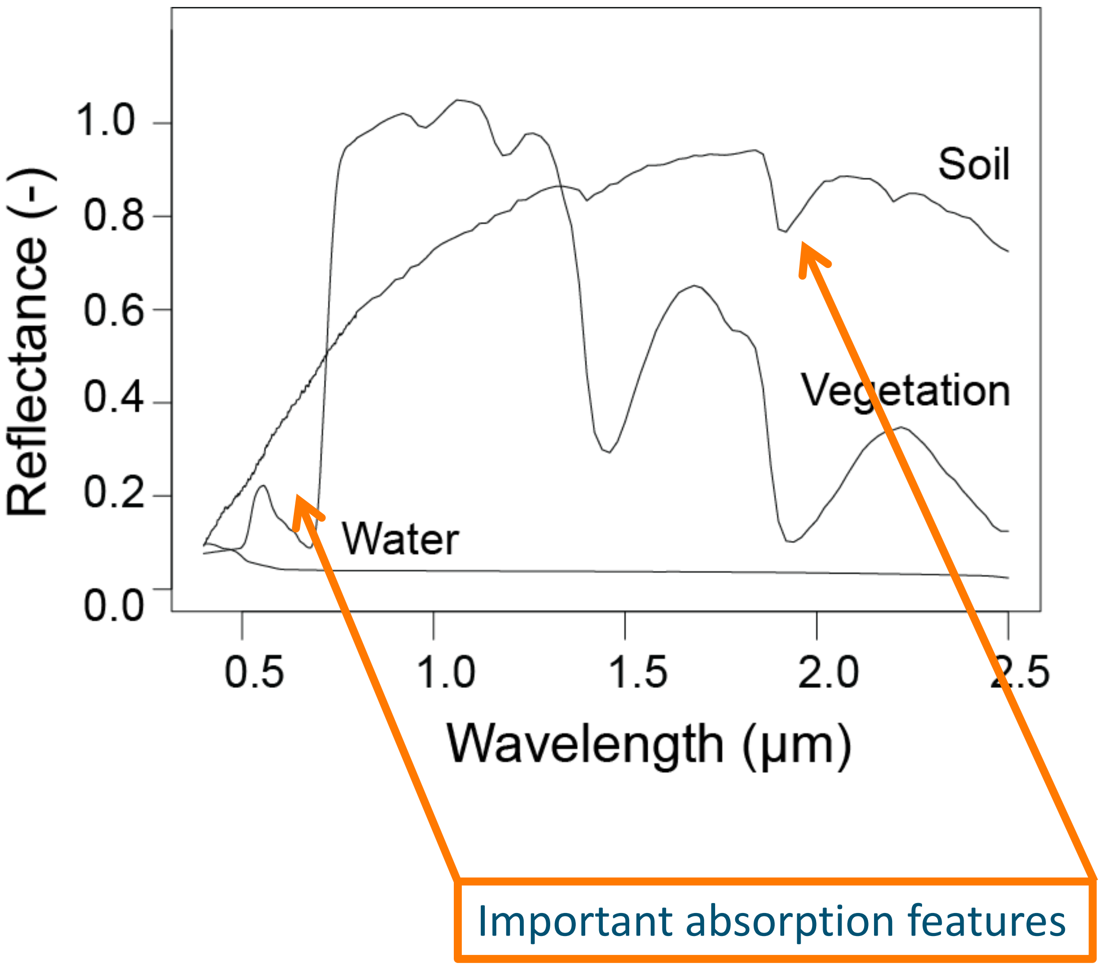




Broad bands

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

Proximal Sensing (PS)



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

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

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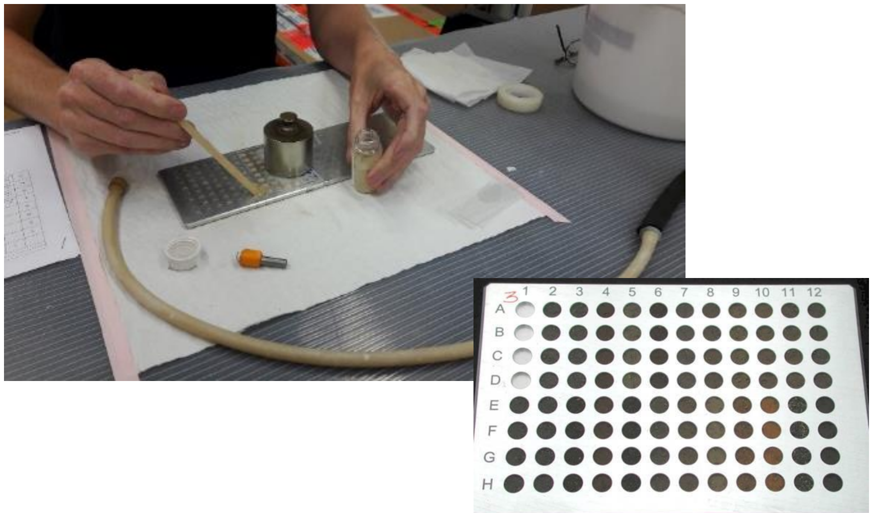
Mid infrared measurements



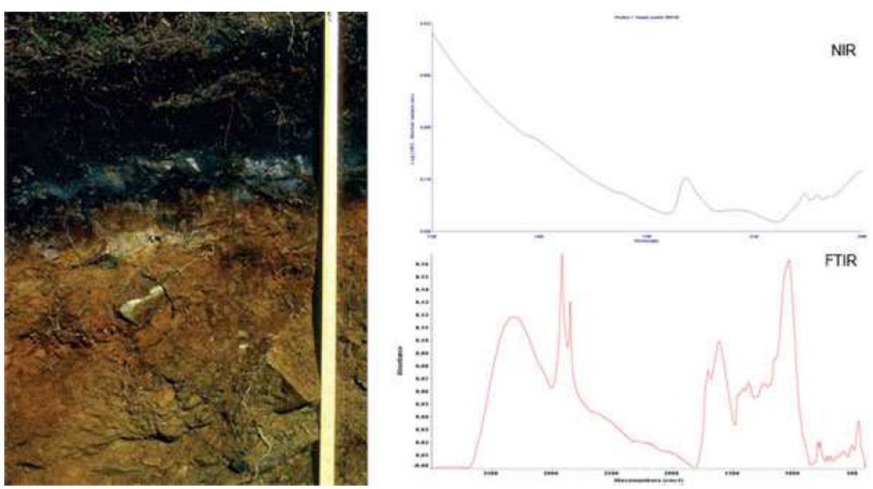
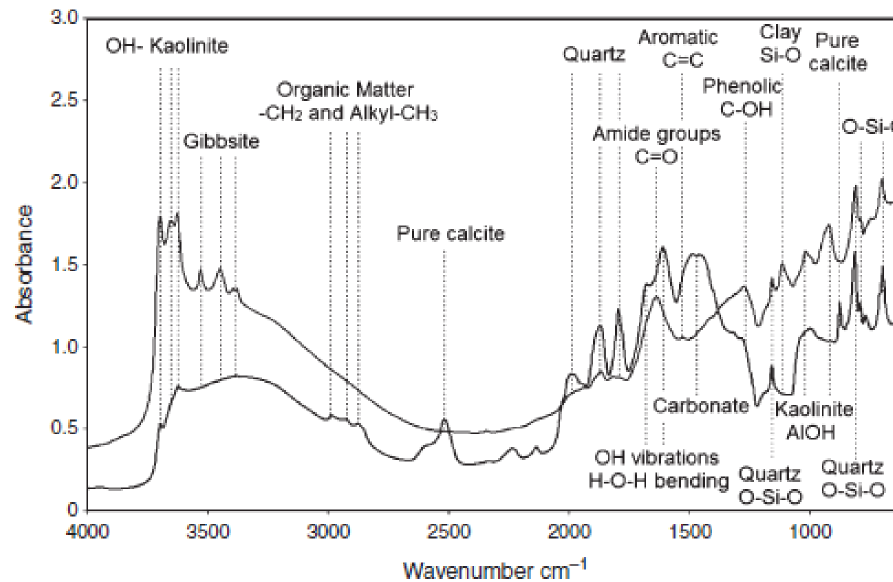


Figure 1. FT-IR and NIR spectra of the same highly organic soil sample with the soil profile.



Geophysical Sensing (GS) techniques

- Techniques:
  - Gamma-ray spectroscopy
  - Electro-Magnetic induction (EMI)
  - Ground Penetrating Radar
  - Penetrologger
  - Handheld XRF
  - Seismics, magnetics
- Point, field, drone, airborne

Gamma-ray spectrometer for soil mapping

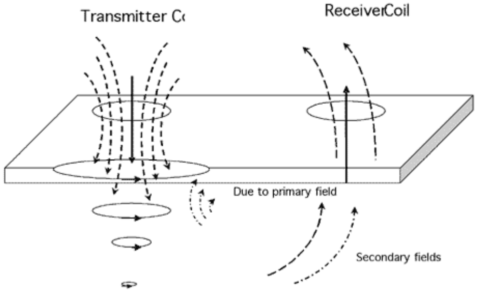
- Soil minerals differ in concentrations of (radioactive) chemical elements (provenance, texture)
- A gammaspectrometer records a spectrum of nuclide-specific energies: ^{40}K, ^{238}U, ^{232}Th, ^{137} Cs
- Passive signal: 0-30 cm depth
- Can be measured in the field <u>and</u> in the laboratory
- The relation can be used to translate field measurements to sediment information
- Little sensitivity to soil water content

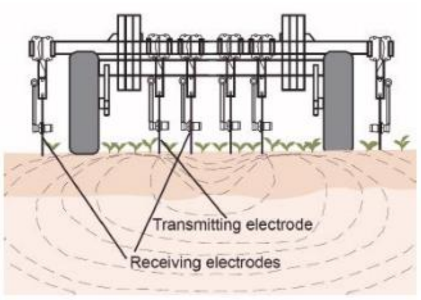
medusa

EC/EM-Electromagnetic induction

- Apparent soil electrical conductivity

- Measures a combination of:
  - Moisture
  - Clay/CEC
  - Salts
  - Porosity
  - 0.5 or 1.5 m depth





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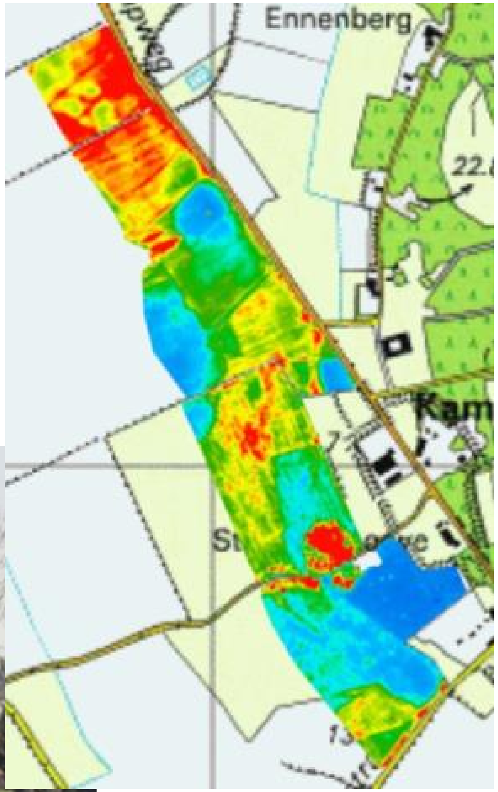
EC/EM-Electromagnetic Induction

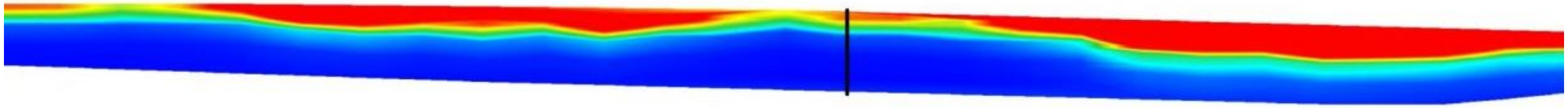
Dualem 21H (or EM38DD, EM31, CMD (mini-)explorer, TMsoilmapper)

- Electromagnetic induction
- Apparent soil electrical conductivity
- 4 coils: 0-0.5 ; 0-1 ; 0-1.6 ; 0-3.2 m

Mount:

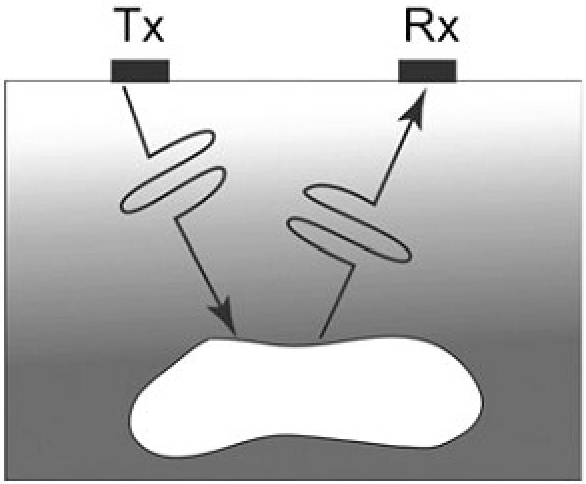
- RTK-GPS
- behind quadbike
- lines

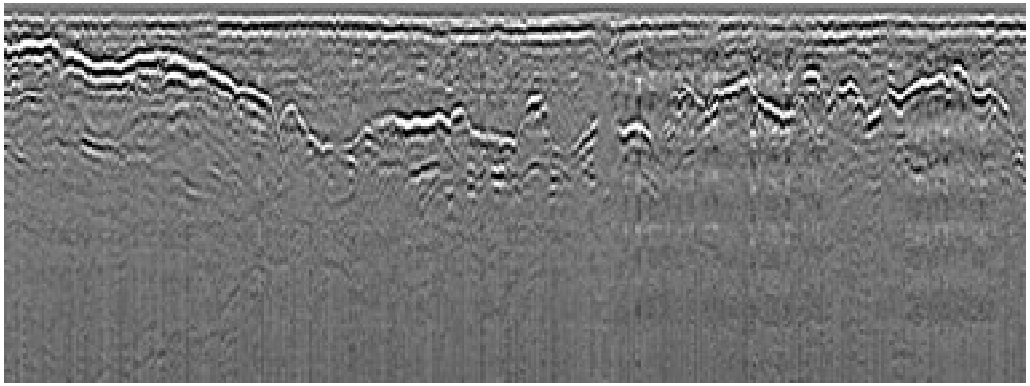




Ground Penetrating Radar

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





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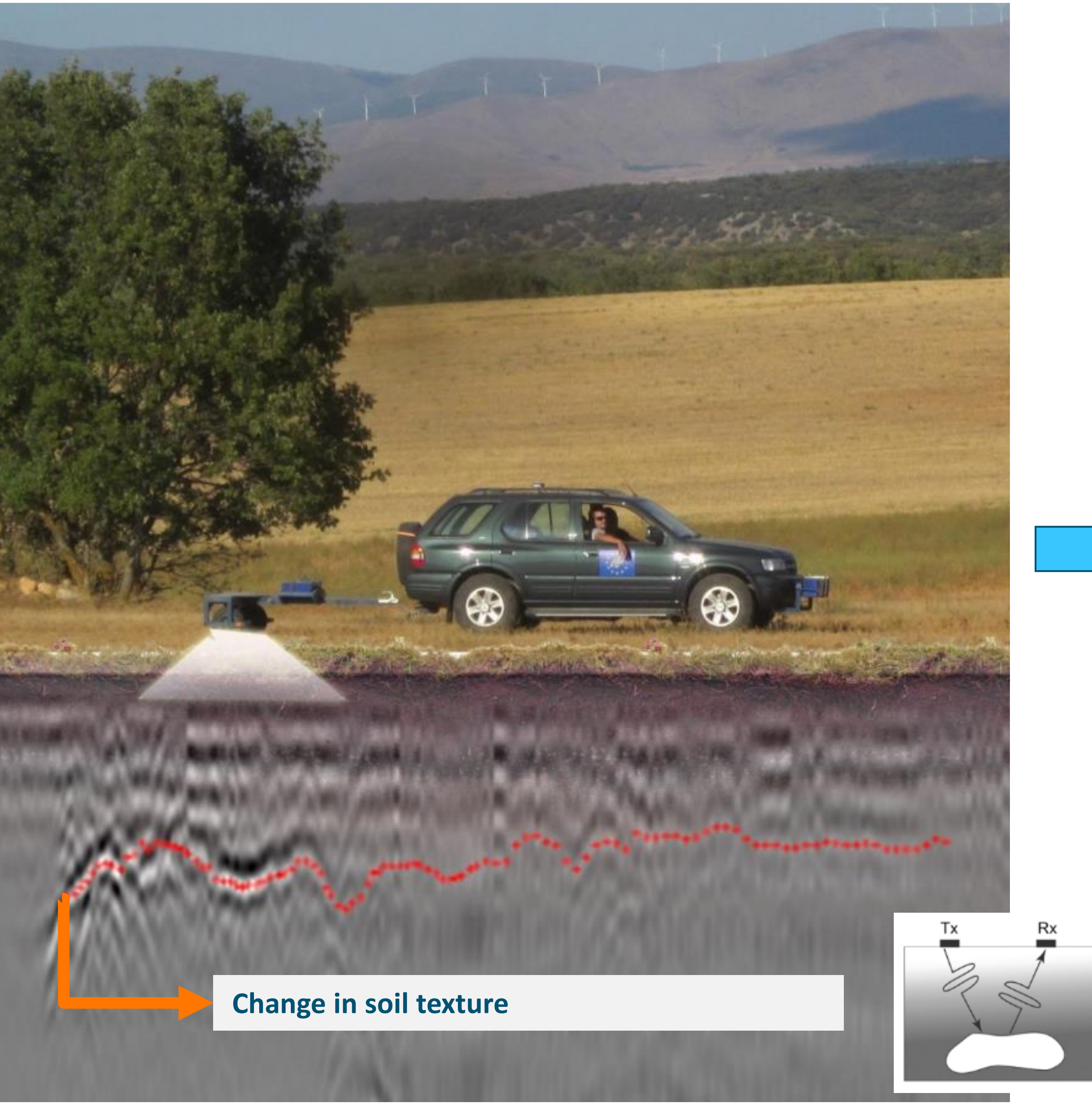
Ground Penetrating Radar (GPR)

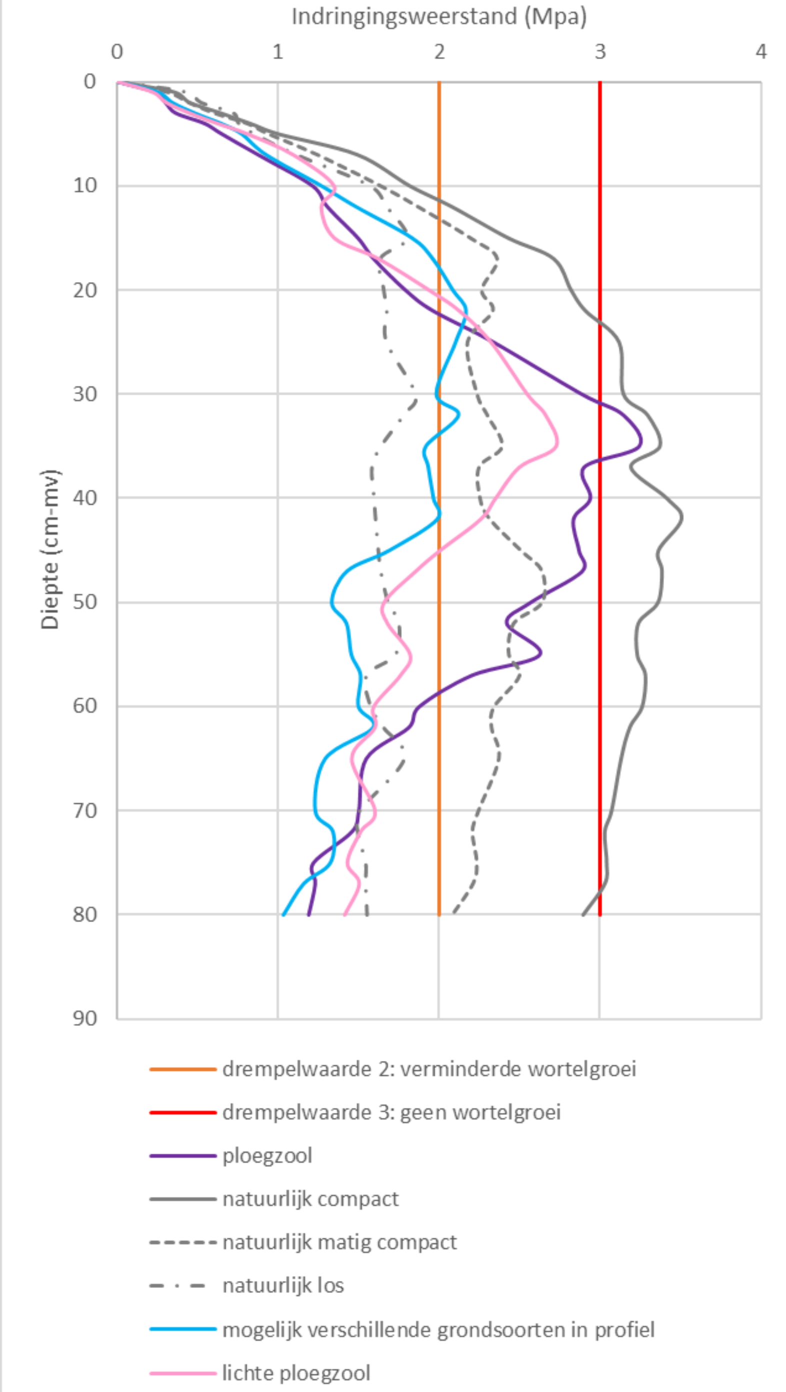


Maps of compacted layers/ soil depth

Manual or semi-automated analysis: time slices

Penetration resistance

- Indication for rootability/compaction
- Depends on:
  - Moisture content
  - Soil profile
  - Person
- Relation with bulk density
- Relevant for rootability and therefore crop growth, C sequestration, risk of crop damage by drought



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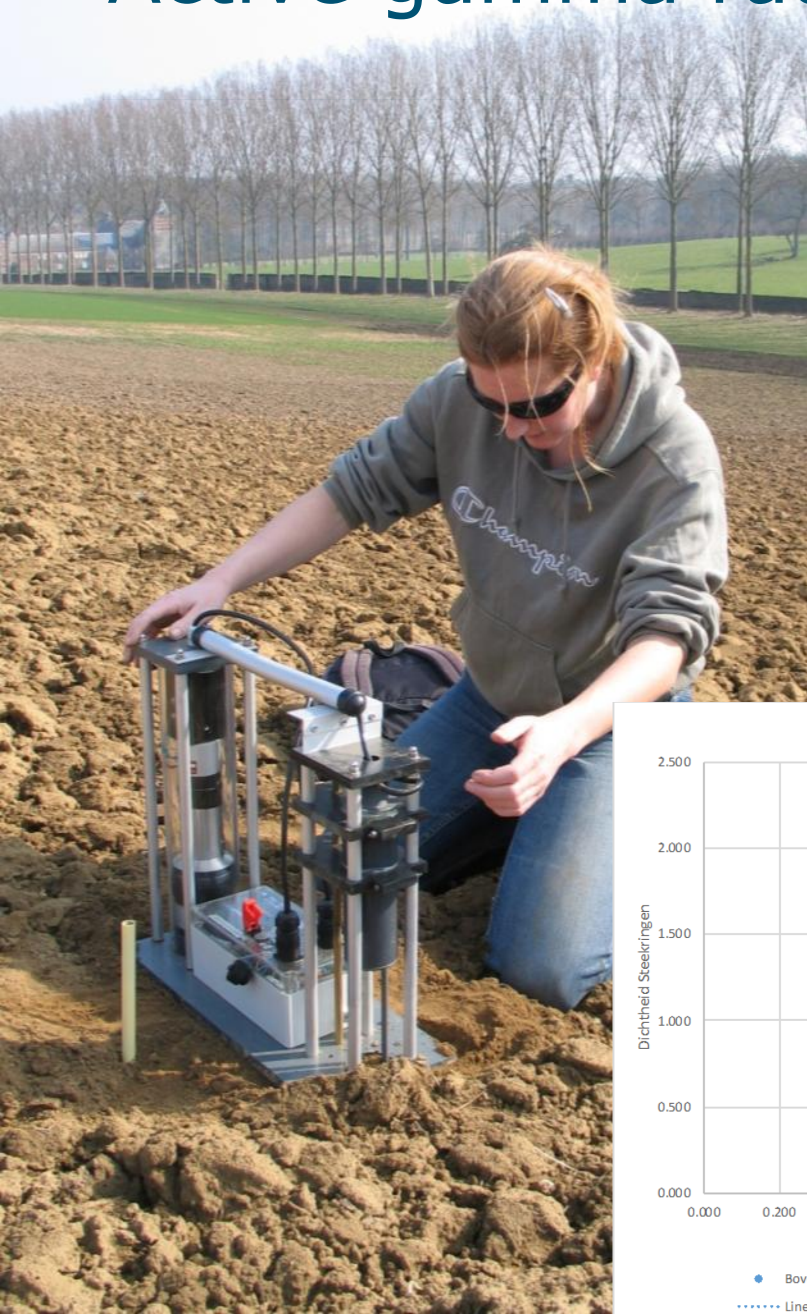
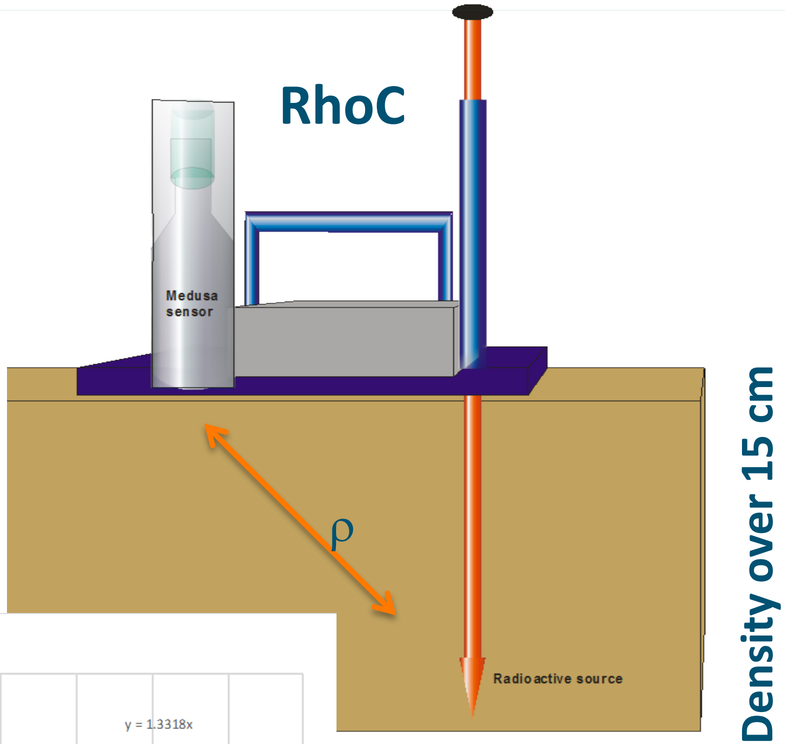
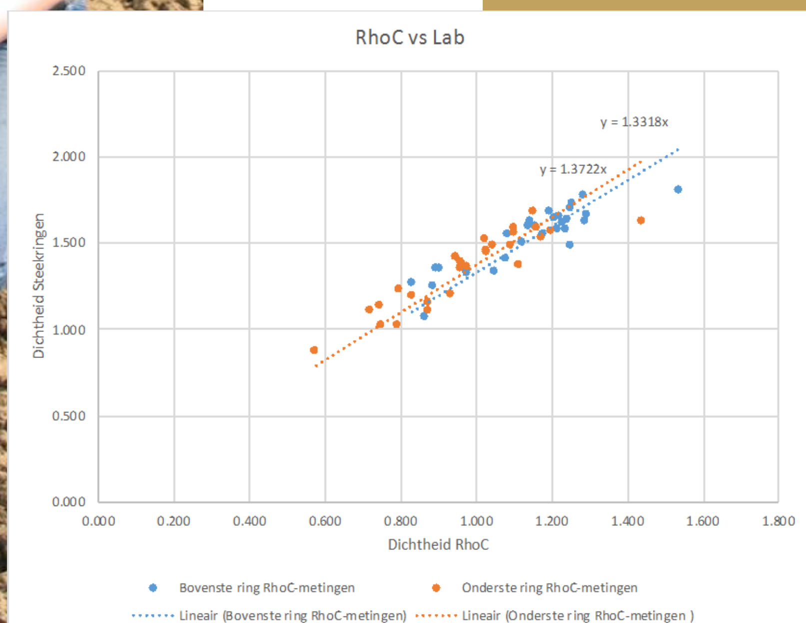
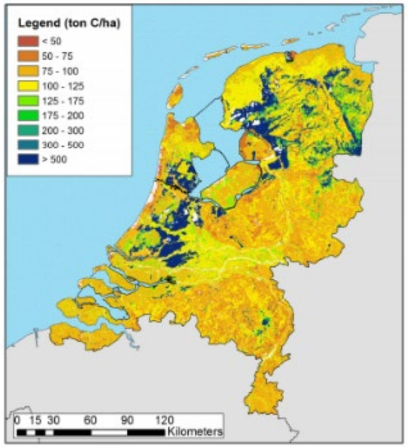
Active gamma radiation – total bulkdensity







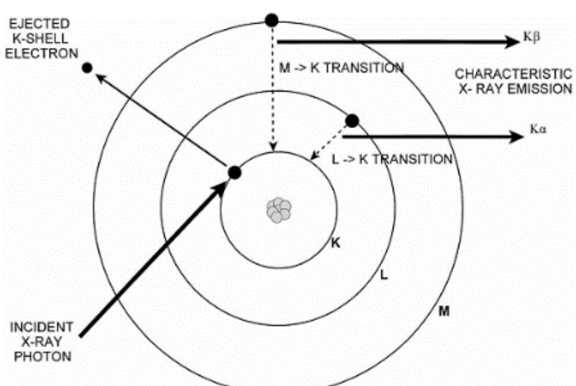


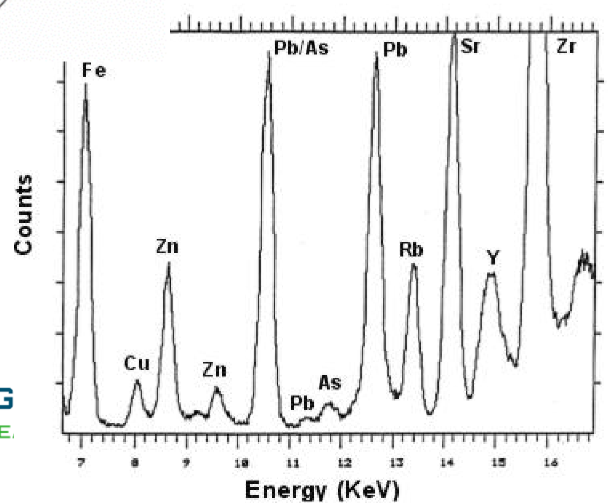
Chemical quality: XRF: X-ray Fluorescence

- XRF measures total element concentrations using Röntgen radiation
  - Fast, precise, non-destructive
  - Point measurements (0.1 cm sphere)
  - Should correct for moisture
- Concentrations in (mg/kg of ppm)

Application

- Soil and sediment pollution
- Field monitoring
- Combination with MIR





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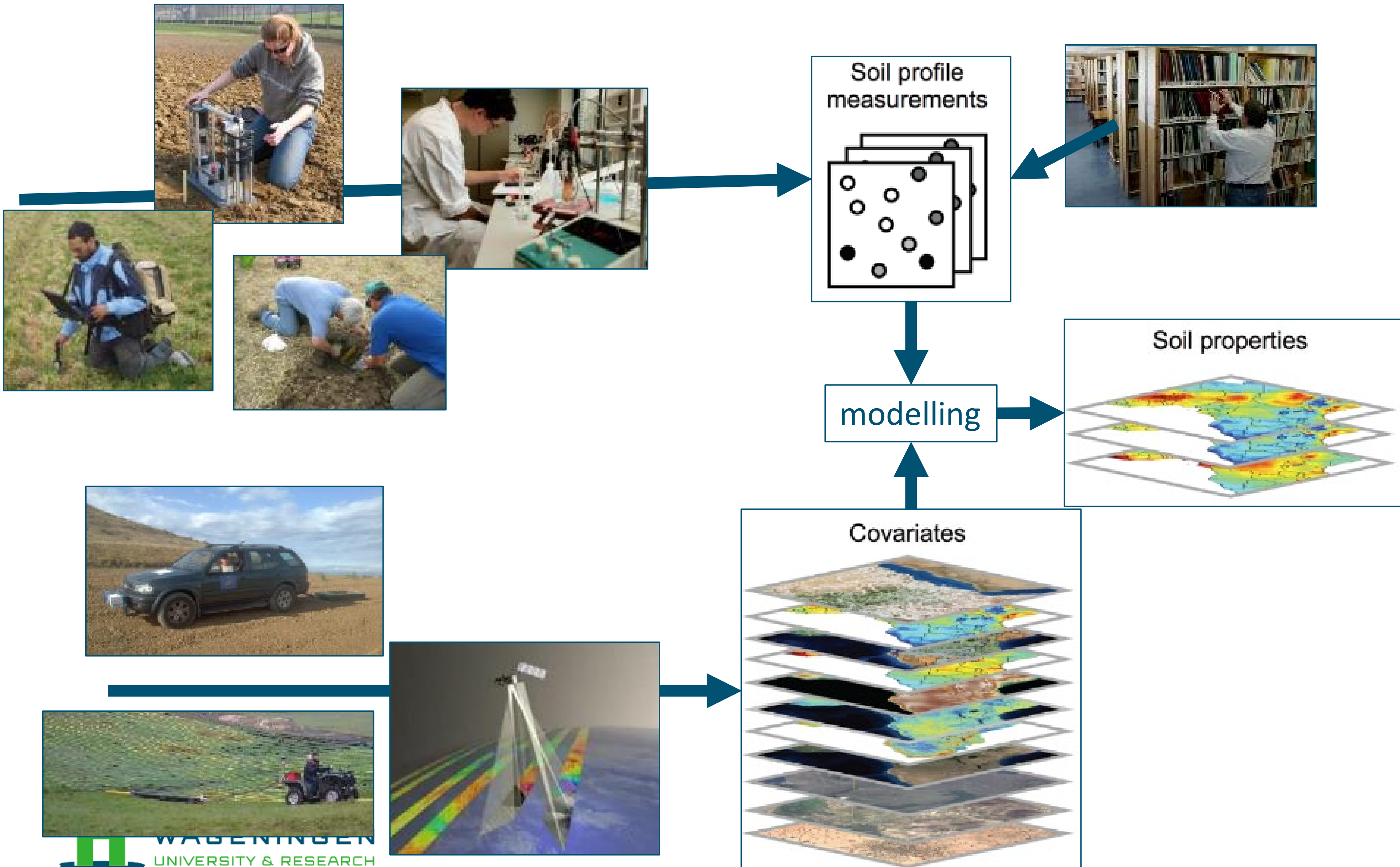
Total element composition: hXRF

- Application
  - Use protocol and reference samples for calibration
  - Take and properly mix sample
  - Measure in duplo
- Pay attention:
  - Radiation is carcinogenic: safe and careful use
  - Concentrations are incl. moisture
  - Use protocol for calibration and quality check
  - Take expected soil heterogeneity into account: small support

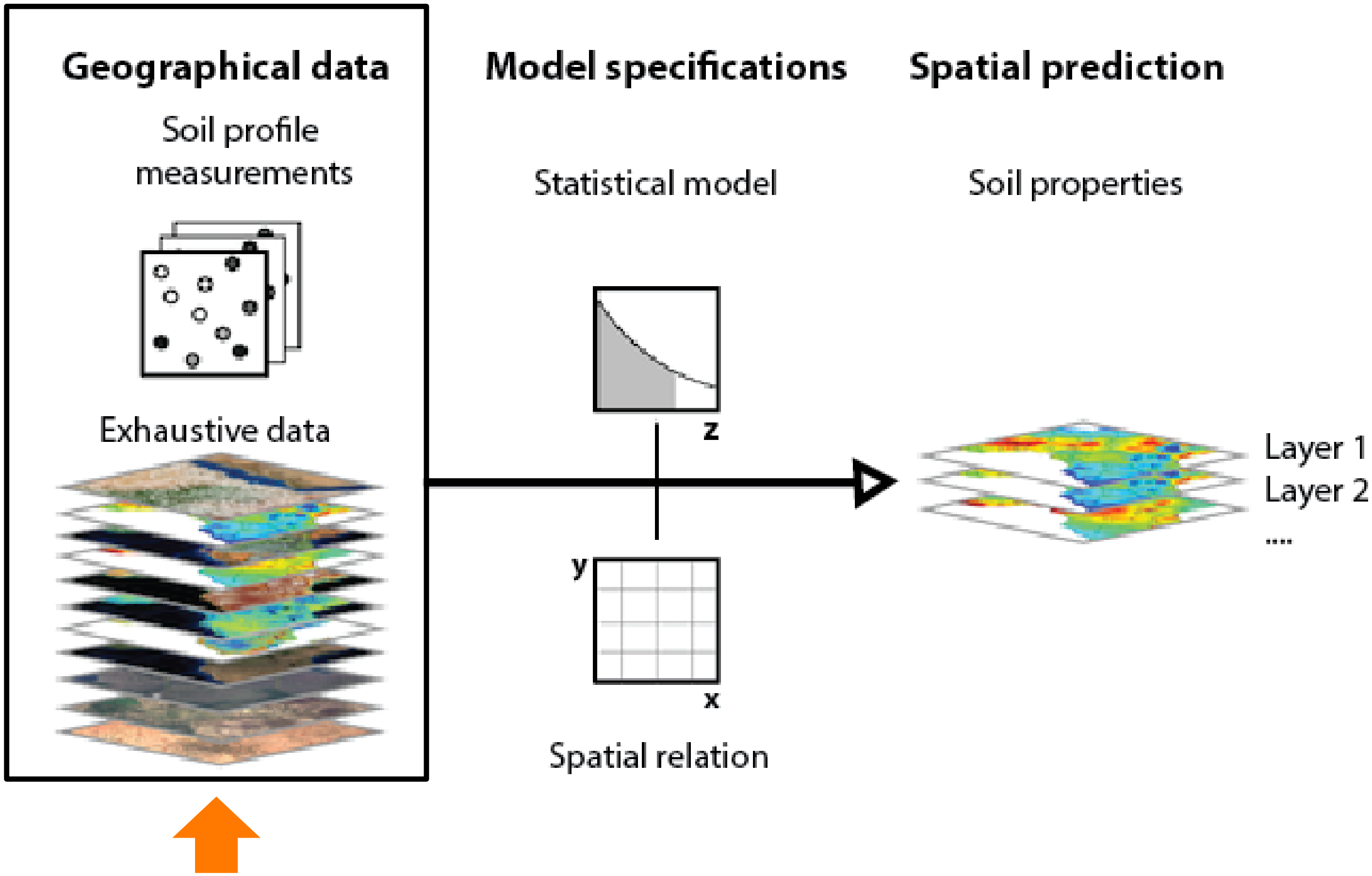
3. Spectral-based soil information

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

From data to information



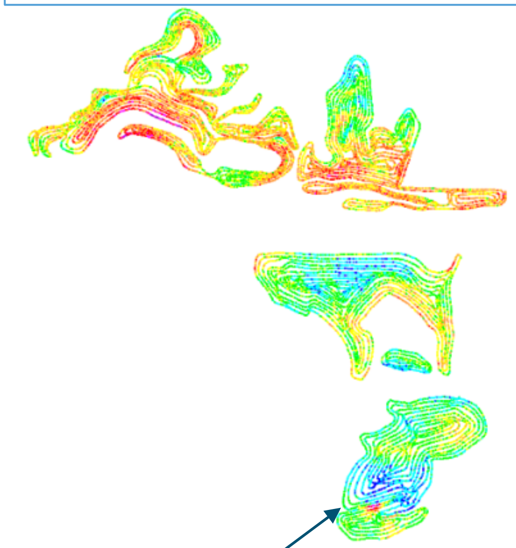
Soil Sensing for Digital Soil Mapping



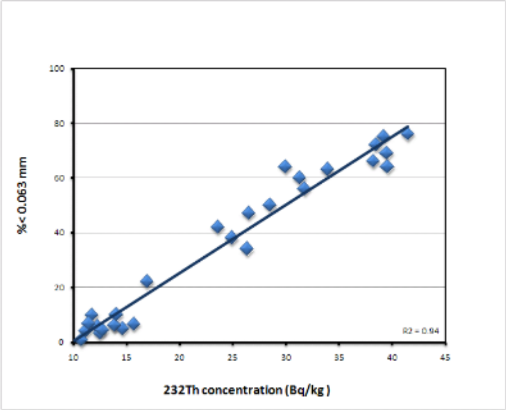
Source: Africa Soil Information Service, http://www.africasoils.net/data/digital-soil-mapping

Translating sensor data to maps

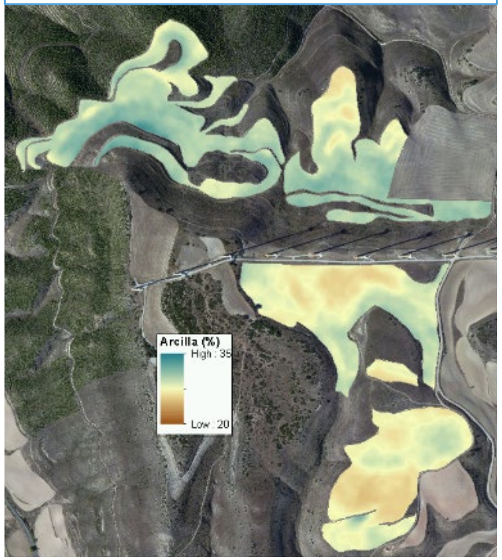
Gamma spectrometer (field)



Sample analyses (lab)



Clay content



Absolute concentrations are key!

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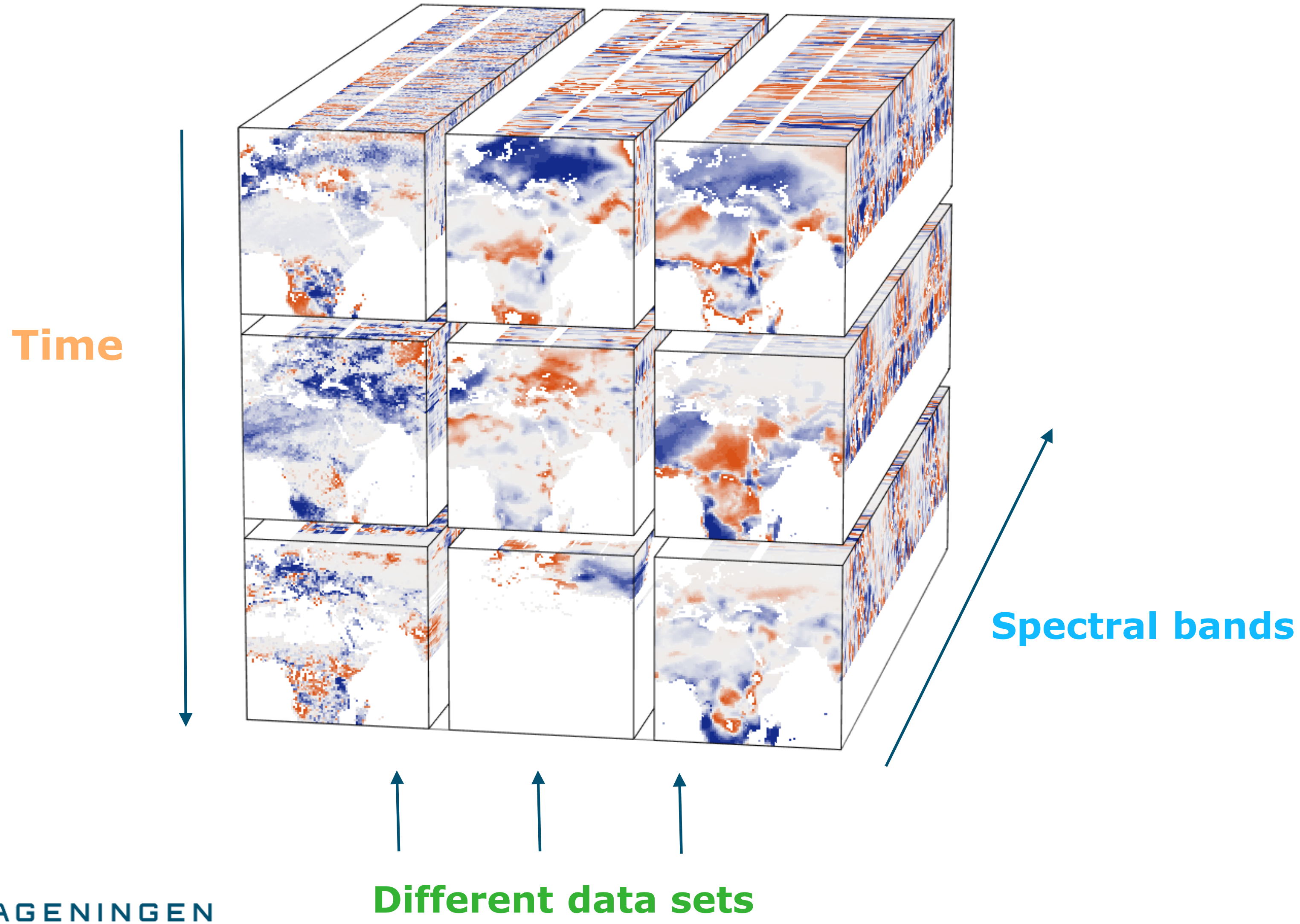
DSM & Data Cubes & Data Science



Source: earthsystemdatacube.net

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 after model calibration
- 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

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Frequently used Remote Sensing methods

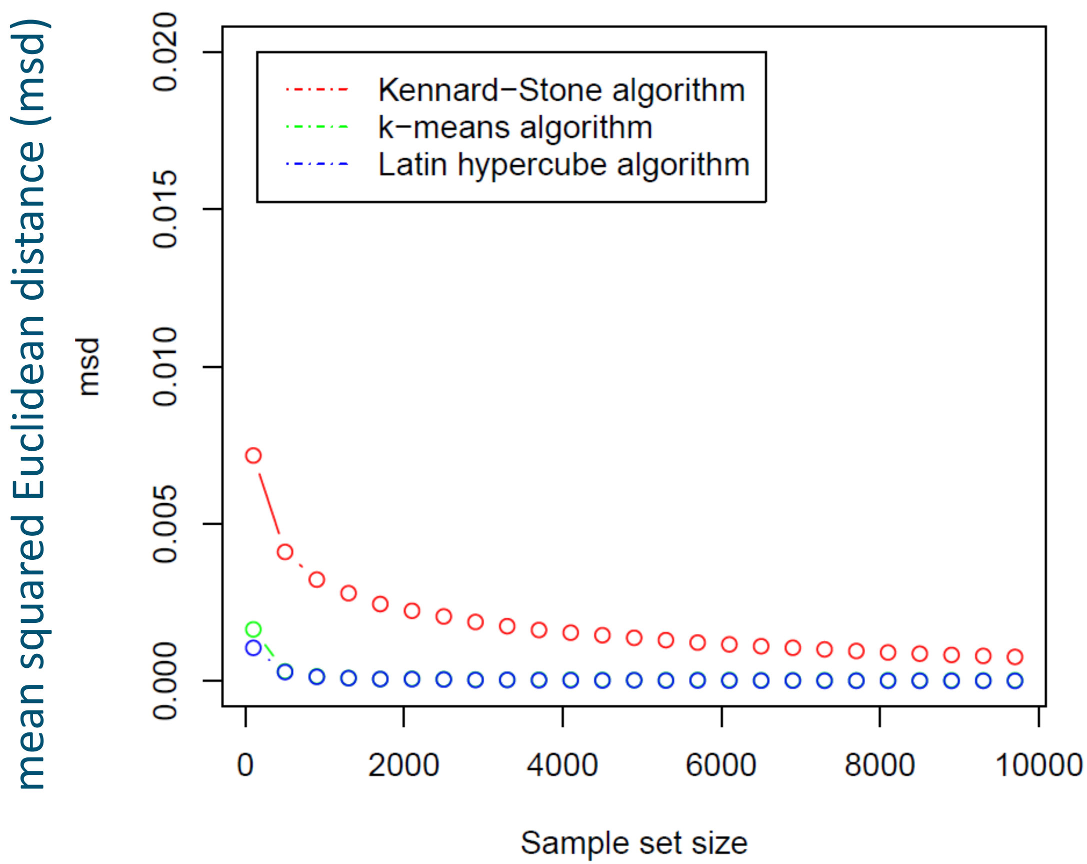
- Classification e.g. land use, delineation soil types
- Calculation of indices e.g. NDVI, SWI, ASTER GEOSCIENCE products (Tutorial)
- Spectral feature comparison e.g mineral mapping

Frequently used Proximal Sensing methods

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

Choosing calibration sample size and sampling algorithm (Wadoux)

- It was shown that prediction made from a large and diverse spectral library benefit from a local calibration
- This advocates the use of local models and efficient sampling strategies for building a spectroscopic model from a large spectral library.



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4. Digital Soil Mapping Examples

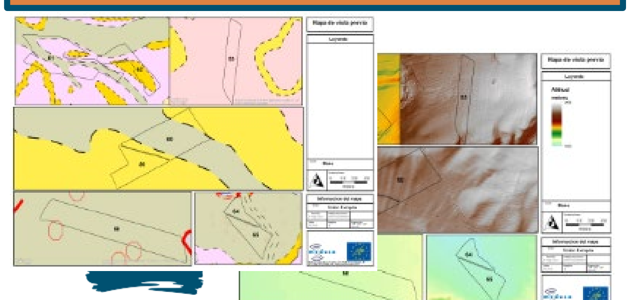
- Stacking data for understanding
- Map aggregation
- UAV gamma radiation

Understanding soil

Measurements

Mapping

Open data



Interpretation of the soil based on pits

Lab analysis

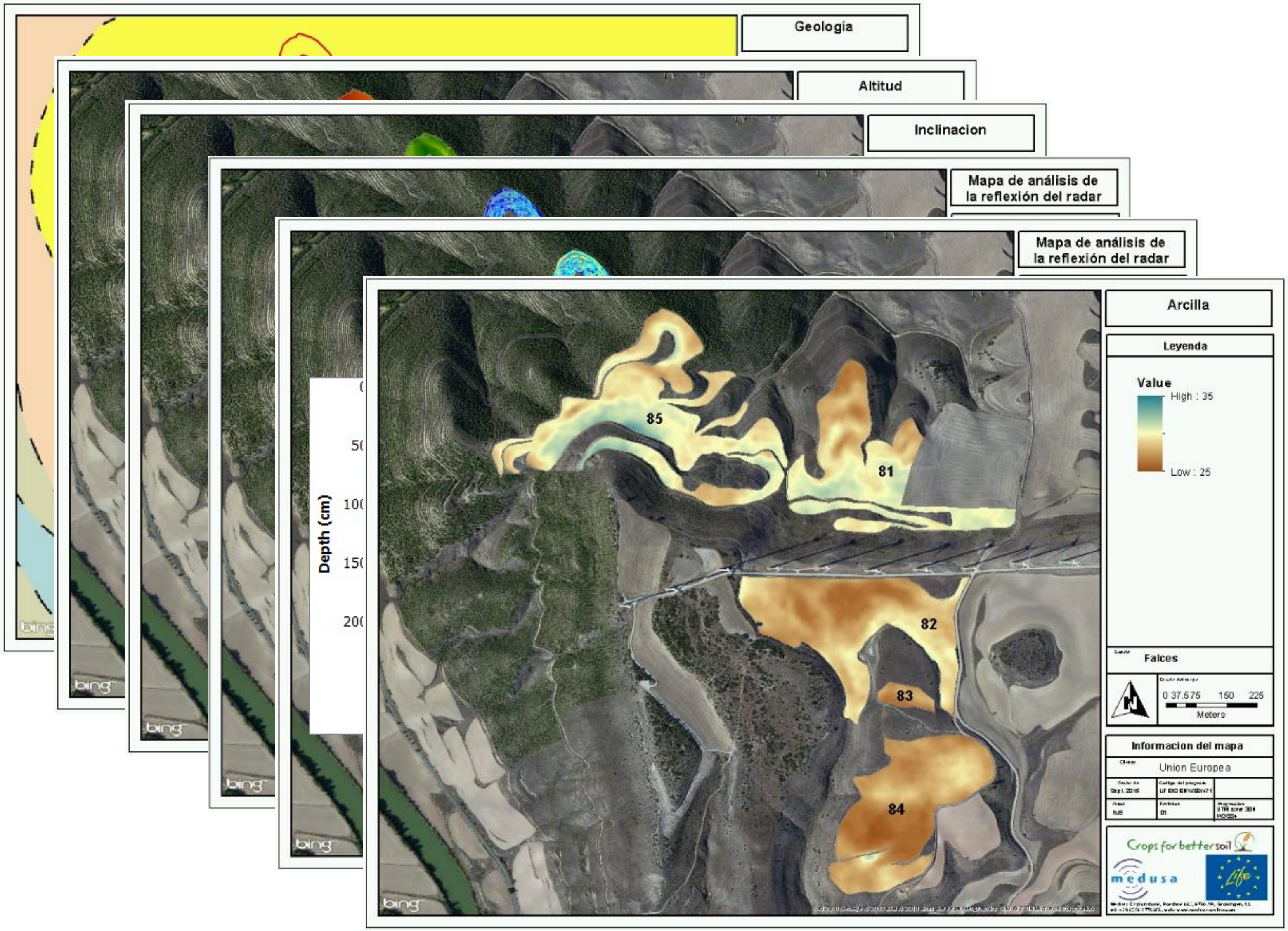
Finca	arcilla	Mat. Org.	Etc.
1	Promedio	promedio	...
2	promedio	Promedio	...

Comprehensive maps of the soil

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

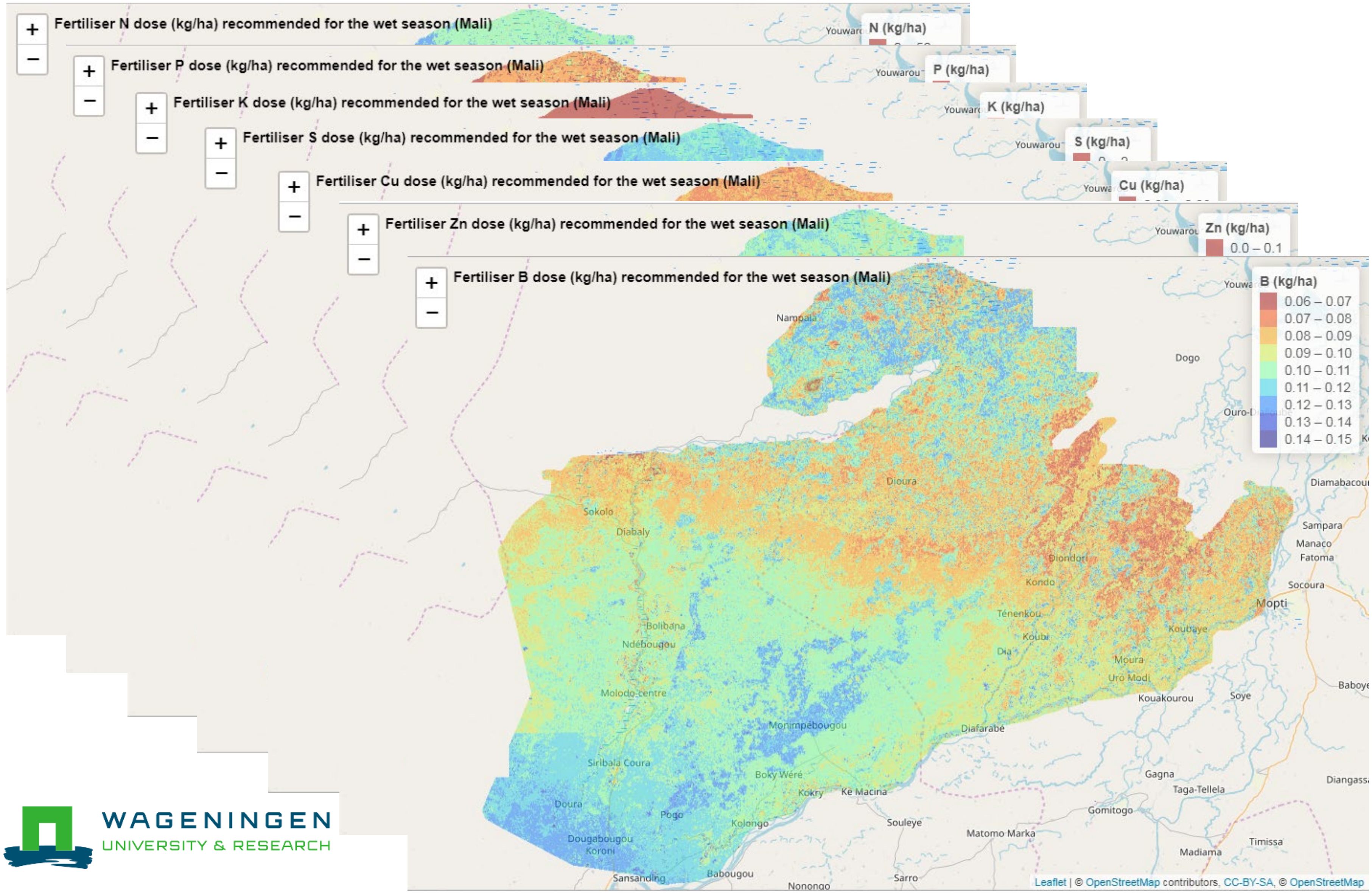
Crops for better soil

Example Falces - Navarra



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

Model results per country per season per nutrient



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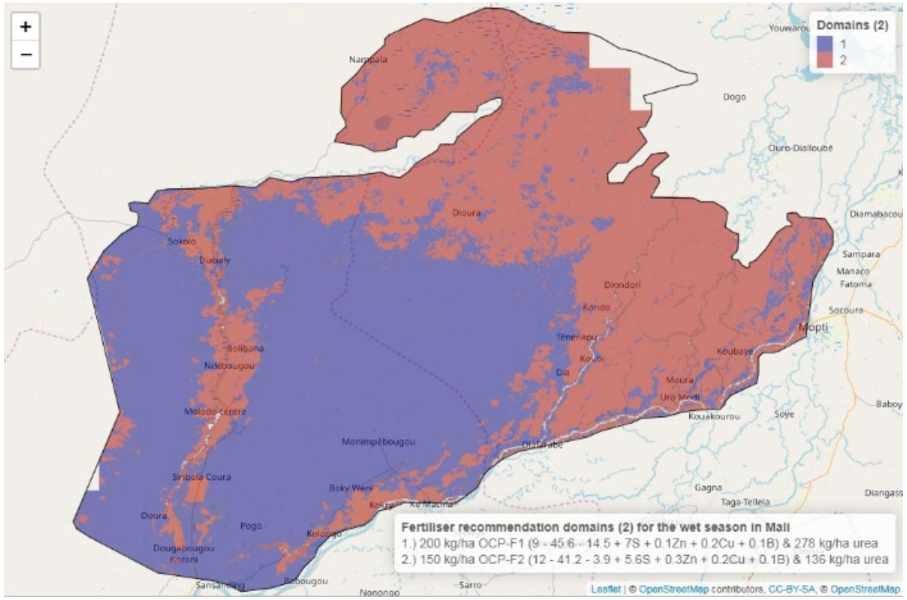
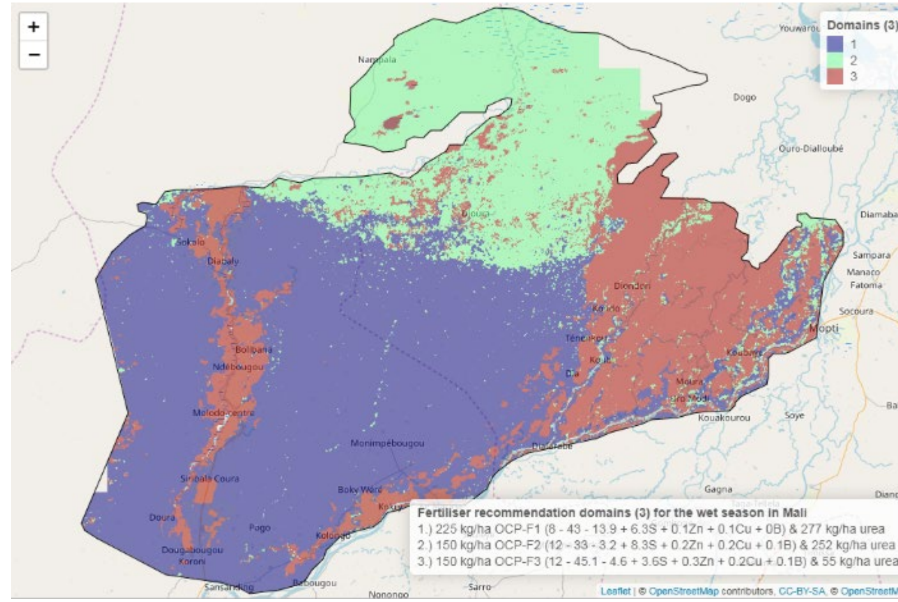
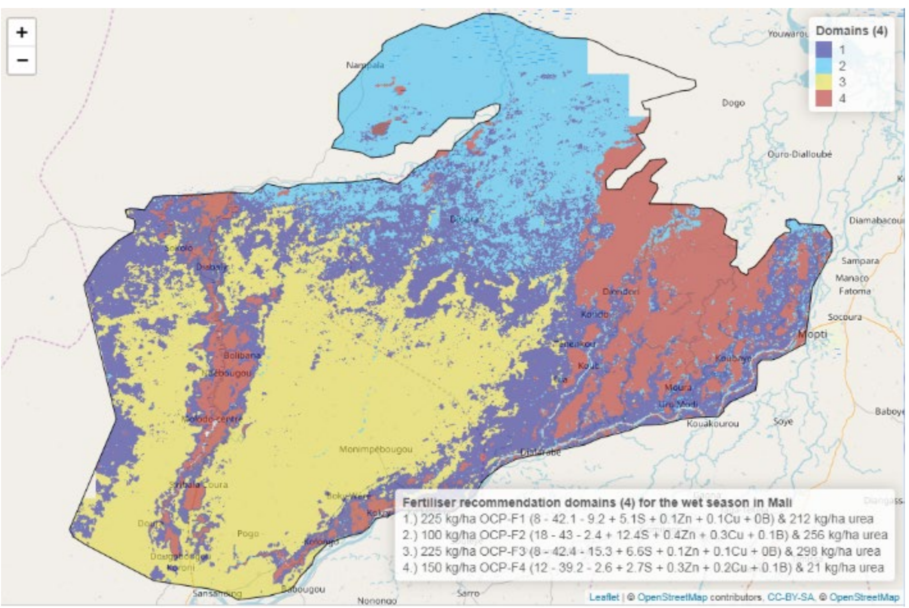
Aggregation/optimisation – Dennis Walvoort

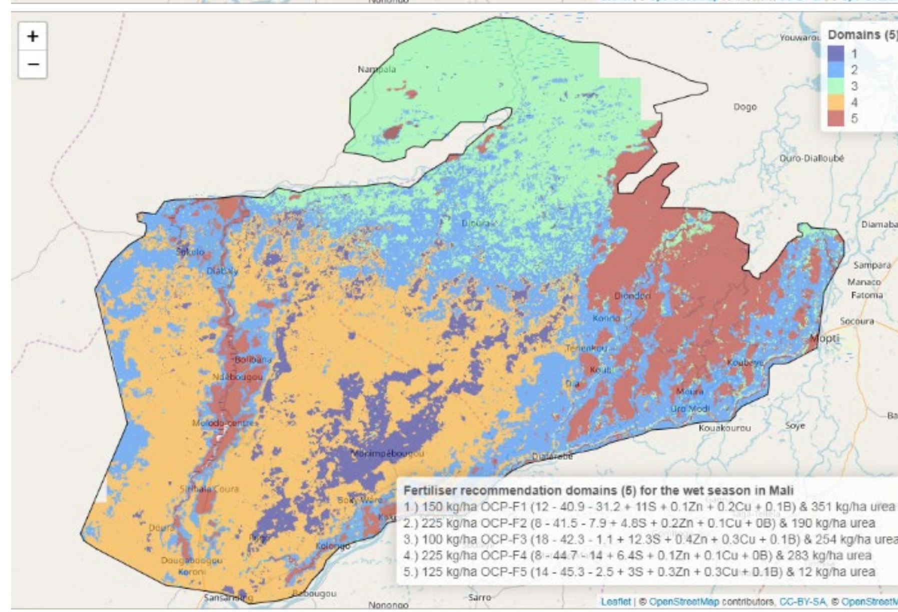
- Multi feature space (7 nutrients)
- Standardise (to give equal value to all layers; weights can be given if needed)
- Define number of classes (2, 3, 4, 5)
- Optimise multi feature space class boundaries
- Assign pixels to classes
- Cluster classes
- Iterate process
- Calculate outcomes

A2.3 Parameterise & implement model train

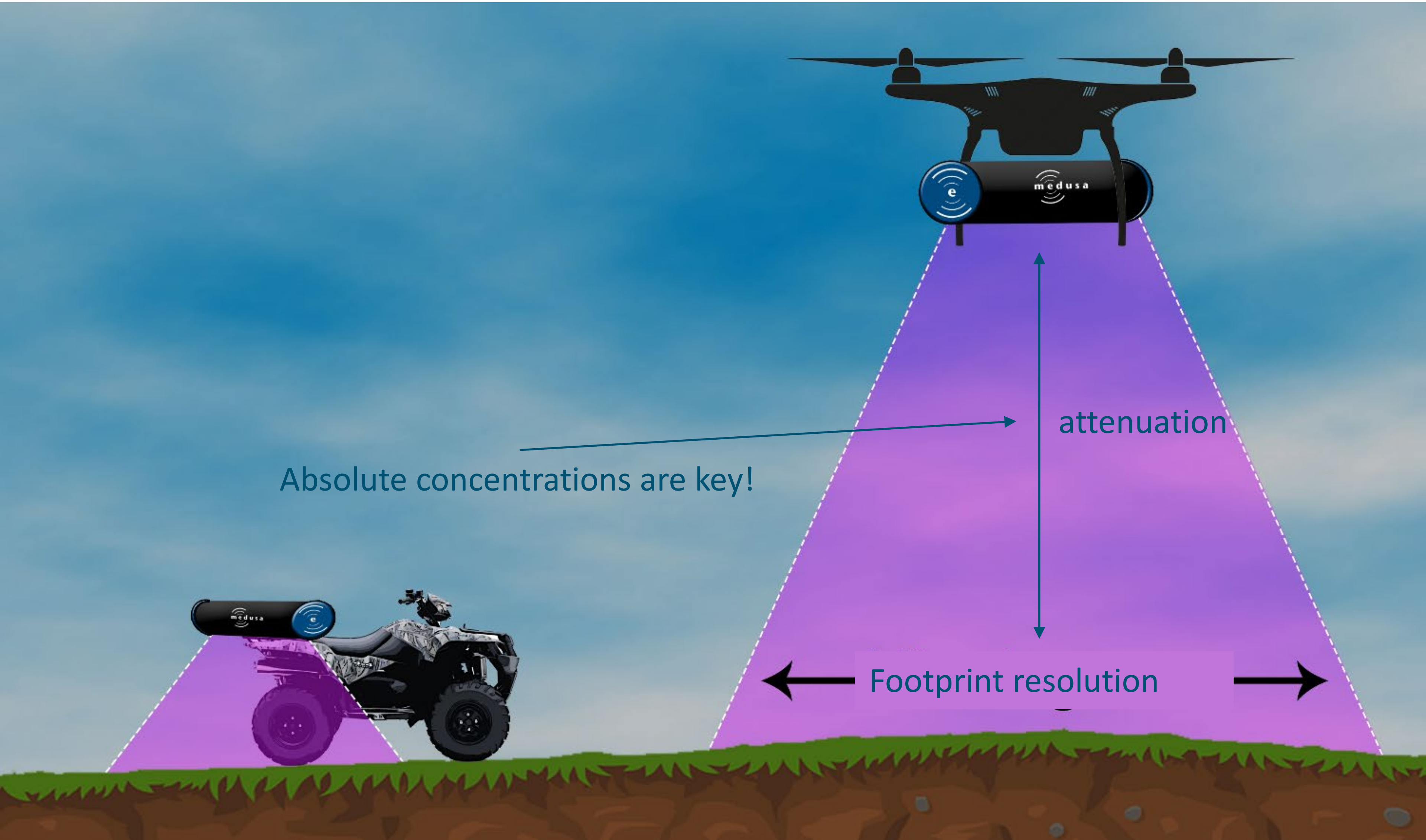




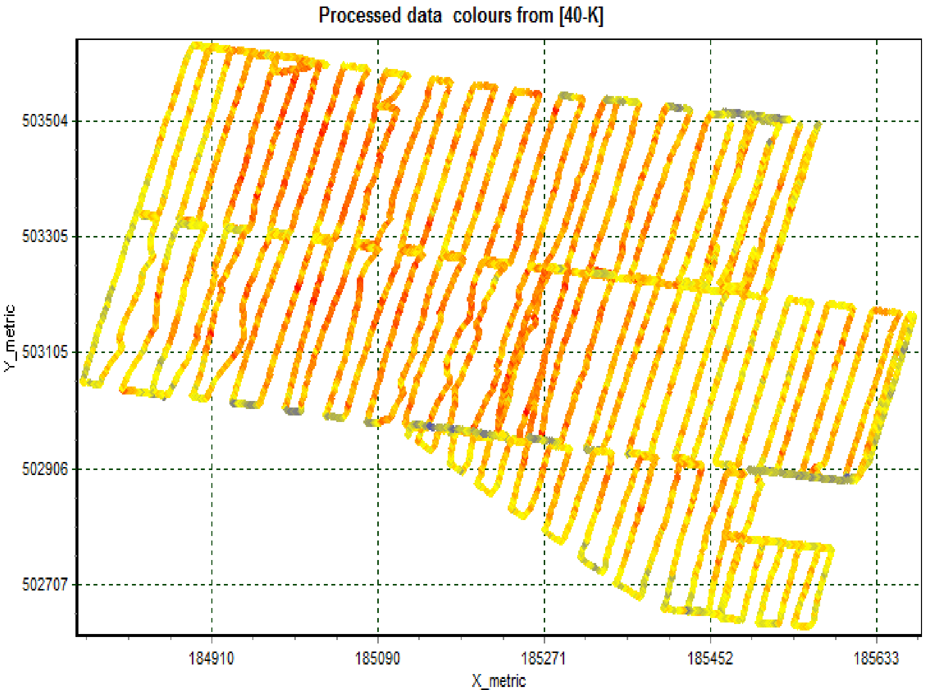


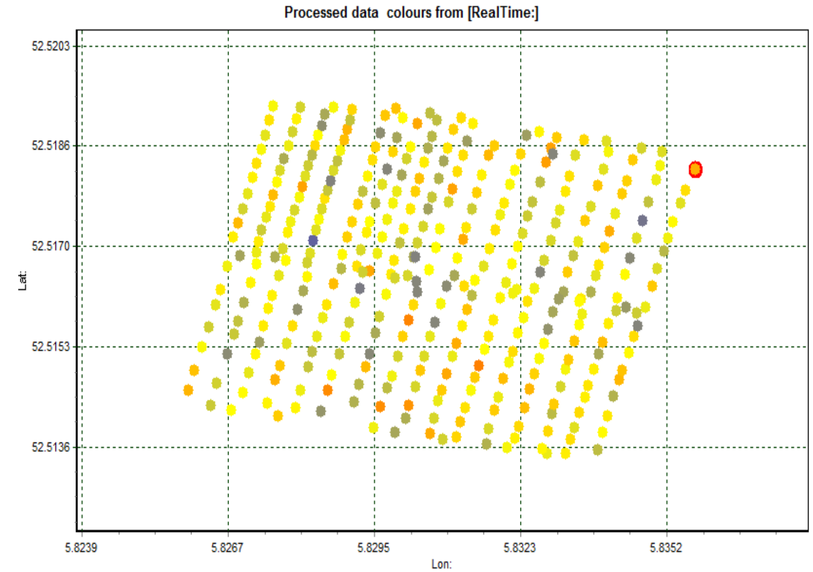


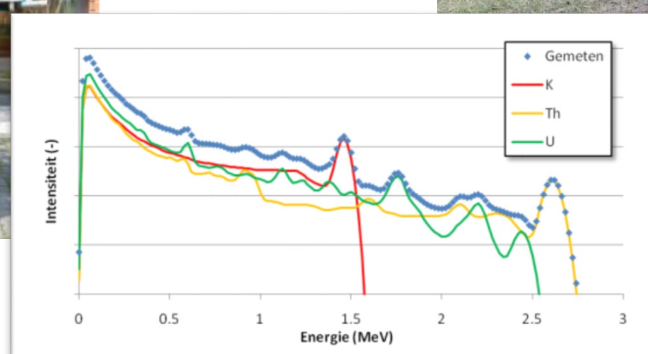
Ground to Drone borne: modelling



Field trials







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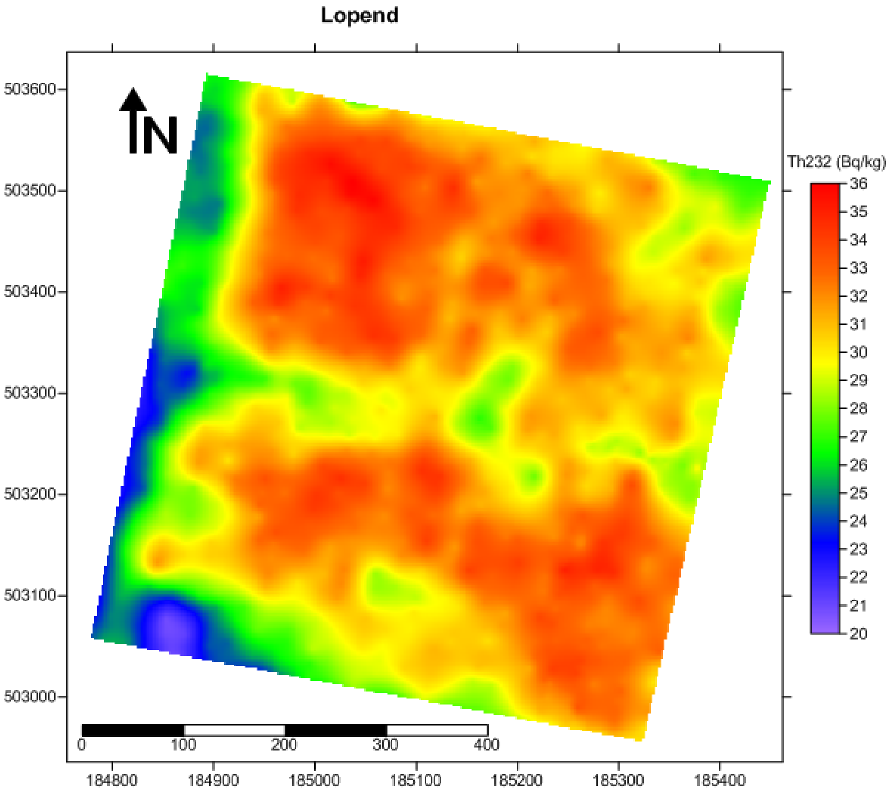
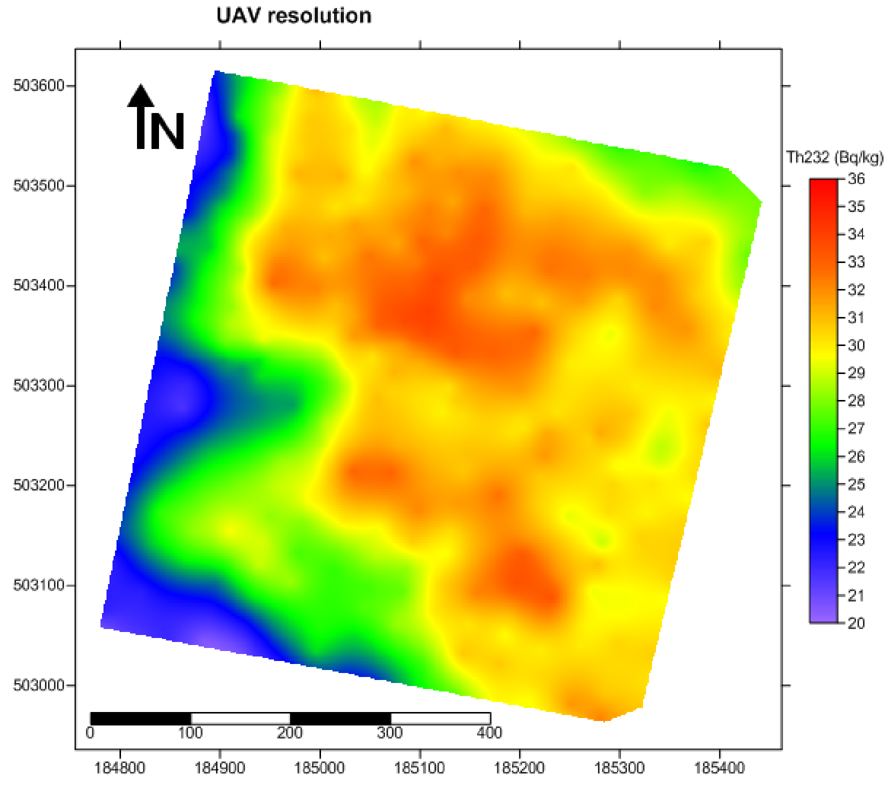
Thorium grids



Ground

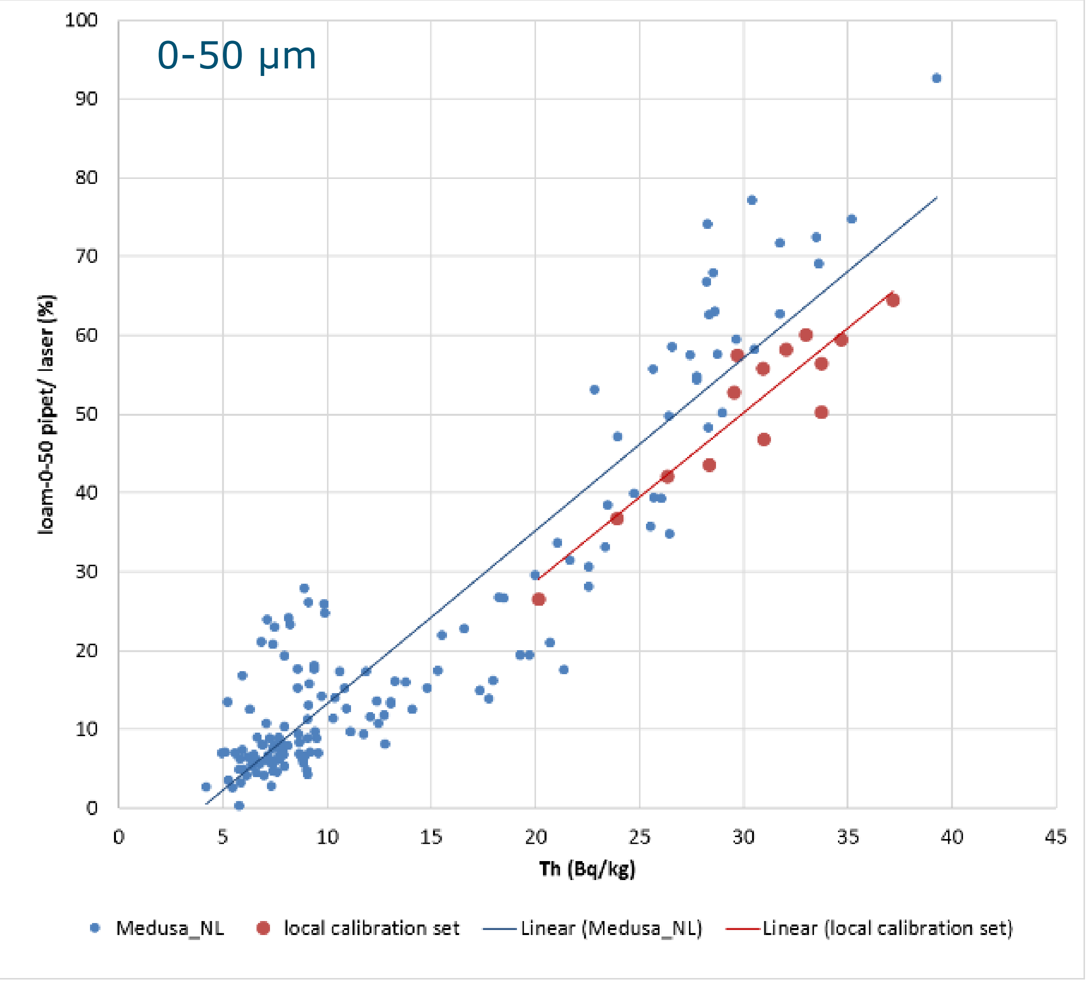


UAV

Calibrations

- Calibration set (red)
- National set (blue)
- Literature (van der Klooster et al., 2011)
- 0-2 µm clay
- 0-50 µm loam

- SVM approach by Heggemann et al. 2017



Conclusions application

- UAV measurements are more expensive but UAVs can access terrain with crops, low trafficability, fences, less accessible by roads
- Ground based measurements are cheaper in accessible areas and in areas that are less accessible to drones (e.g. trees, near airfields, roads)
- Temporal applicability may differ
- Cost difference is mainly dependent on calibration scale
- Accuracy depends more on calibration scale than on platform

- Start with the question, then assess required accuracy, then choose platform and the calibration
- Start a gamma radiation (nuclide compressed) 'library'

5. Points for consideration

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

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

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

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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

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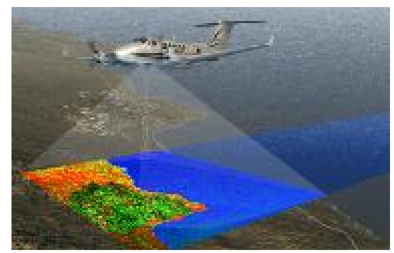
Other points

- 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

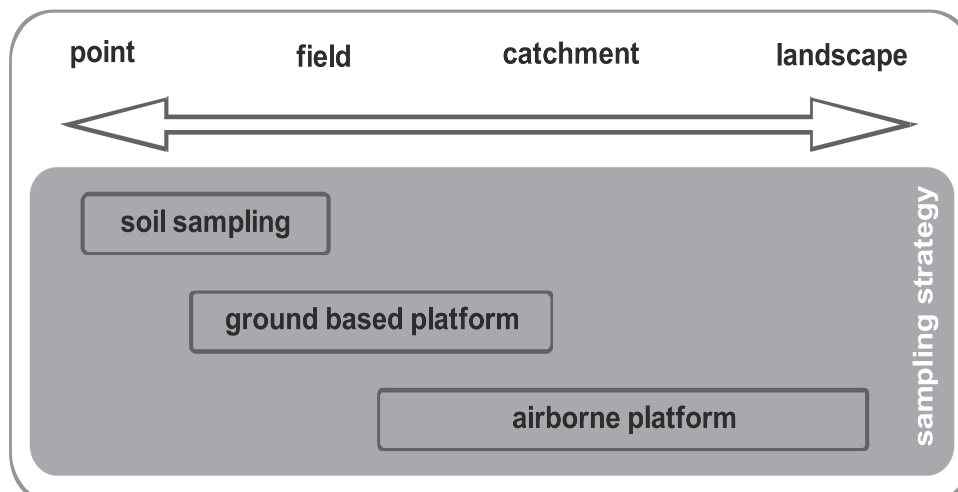
- Many RS and PS sensing technologies and data sets available
- Valuable information
    - Spectral
    - Spatial
    - Temporal
- Many datasets in DSM rely on Remote Sensing
- Evaluate the use of data against your scientific goals

Scales

Point	Field	Region	Country	Continent
Proximal + lab	Proximal + drones + airborne + satelites	Airborne + drones + satelites	Satelites + airborne	Satellites + airborne
				
Soil profiles Samples Fieldwork VISNIR XRF Temp. Moisture	VISNIR GPR Gamma-ray EM/EC Magnetics	VISNIR Gamma-ray EM Radar Magnetics	VISNIR Gamma-ray EM Radar Magnetics	VISNIR Gamma-ray EM Radar Magnetics

Soil sensing

- **Choose technique and platform based on question and scale.**
- Remain proxies and are bound to physical laws.
- Extra tool in mapping: covariates.
- 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


atellite
vehicle
10 Eddy covariance system
11 Groundwater observation well
12 Stream gauge
13 Automatic sample collector
14 Optical sensors
15 Position sensor
16 TDR probes
17 Tensiometer
18 LAI sensor
19 Gas exchange measuring device

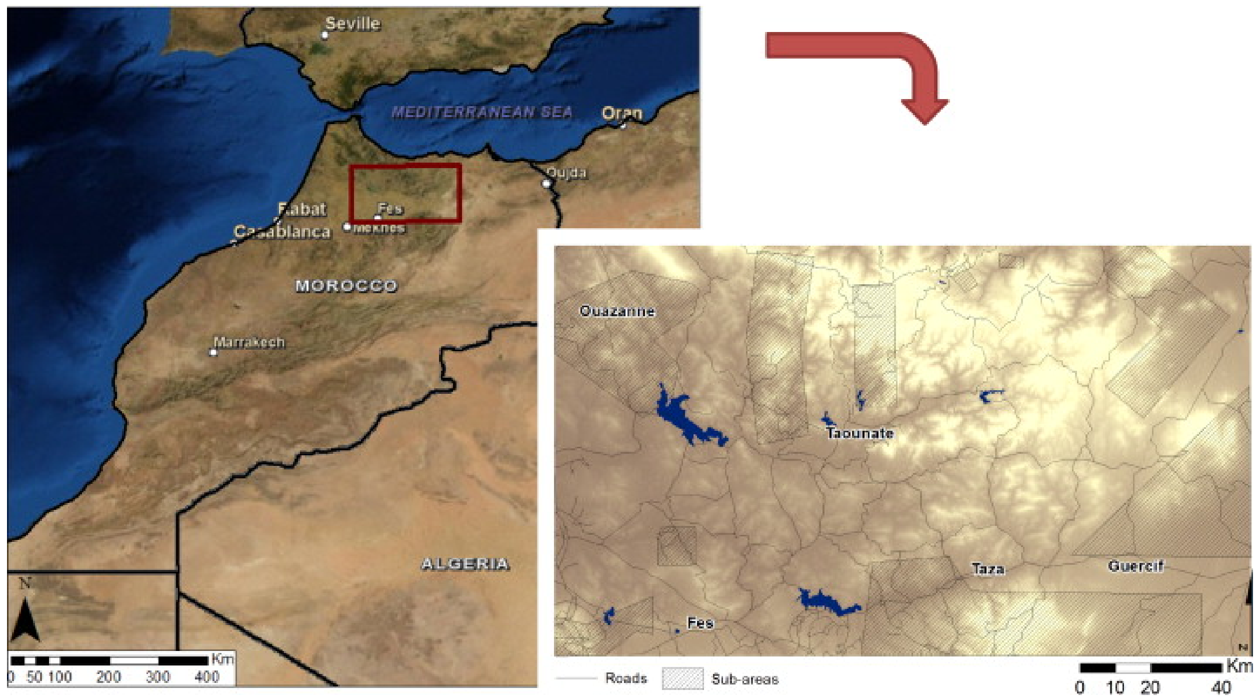
Do we understand what we see?

6. Questions & Answers

- https://padlet.com/vlmulder0/wniz5mv4a47t

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)