
Food and Agriculture Organization of the United Nations
GLOSOLAN
Soil spectroscopy training workshops
WEBINAR 3
Online webinars
GLOBAL SOIL PARTNERSHIP

Acknowledgment of Country

We would like to acknowledge the Gadigal people of the Eora Nation, the traditional custodians of the land from which we are webcasting this presentation.

We recognise their continuing connection to land, waters and culture. We pay our respects to the Elders past, present and emerging.

A future for soil spectral inference

THE UNIVERSITY OF SYDNEY
Institute of Agriculture

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The University of Sydney

Webinar 3 0800-0930 CET Sep 23 2021
FAO Global Soil Partnership
GLOSOLAN Working Group on Soil Spectroscopy

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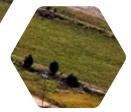
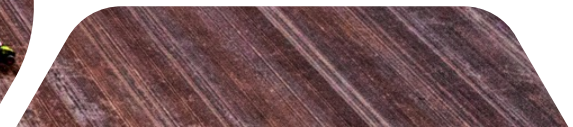
SOIL





GOALS

Partially DIDACTIC

Partially PROGNOSTIC

RECOLLECTION

Background

SOIL SPECTROSCOPY

1960s first work?

1980s digital, chemometrics

2000s NIR, MIR, spectral libraries

2020s field spectroscopy, inference

WHAT IS A SPECTRUM?

Spectrum *singular noun*

Spectra *plural noun*

Spectral *adjective*

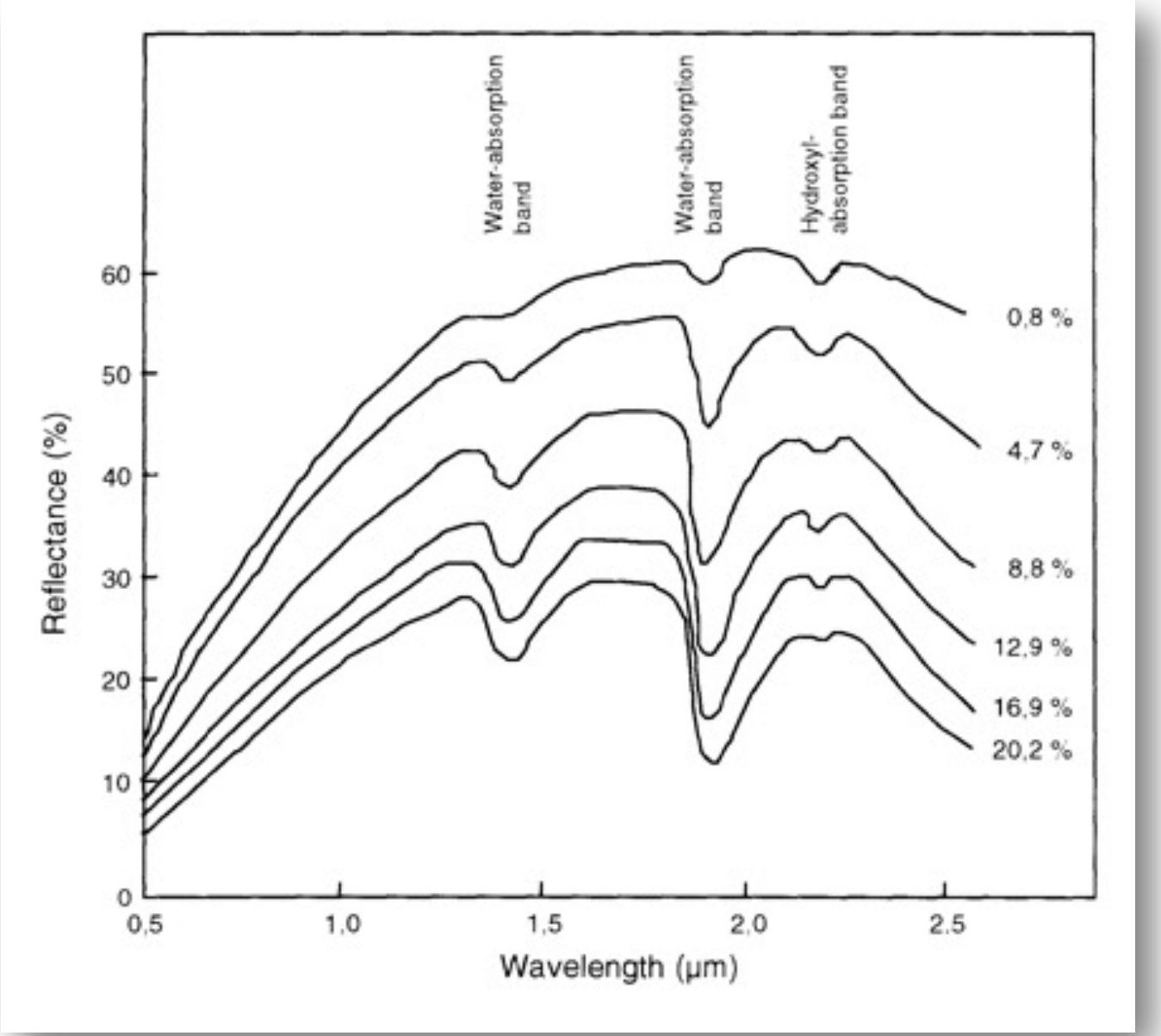
WHAT IS A SPECTRUM?

Response (reflectance, absorbance, conductivity etc.) as function of some systematic portion of a continuum (wavelength, frequency)

Digital spectrum – spectrum sampled at fixed wavelengths or frequencies.

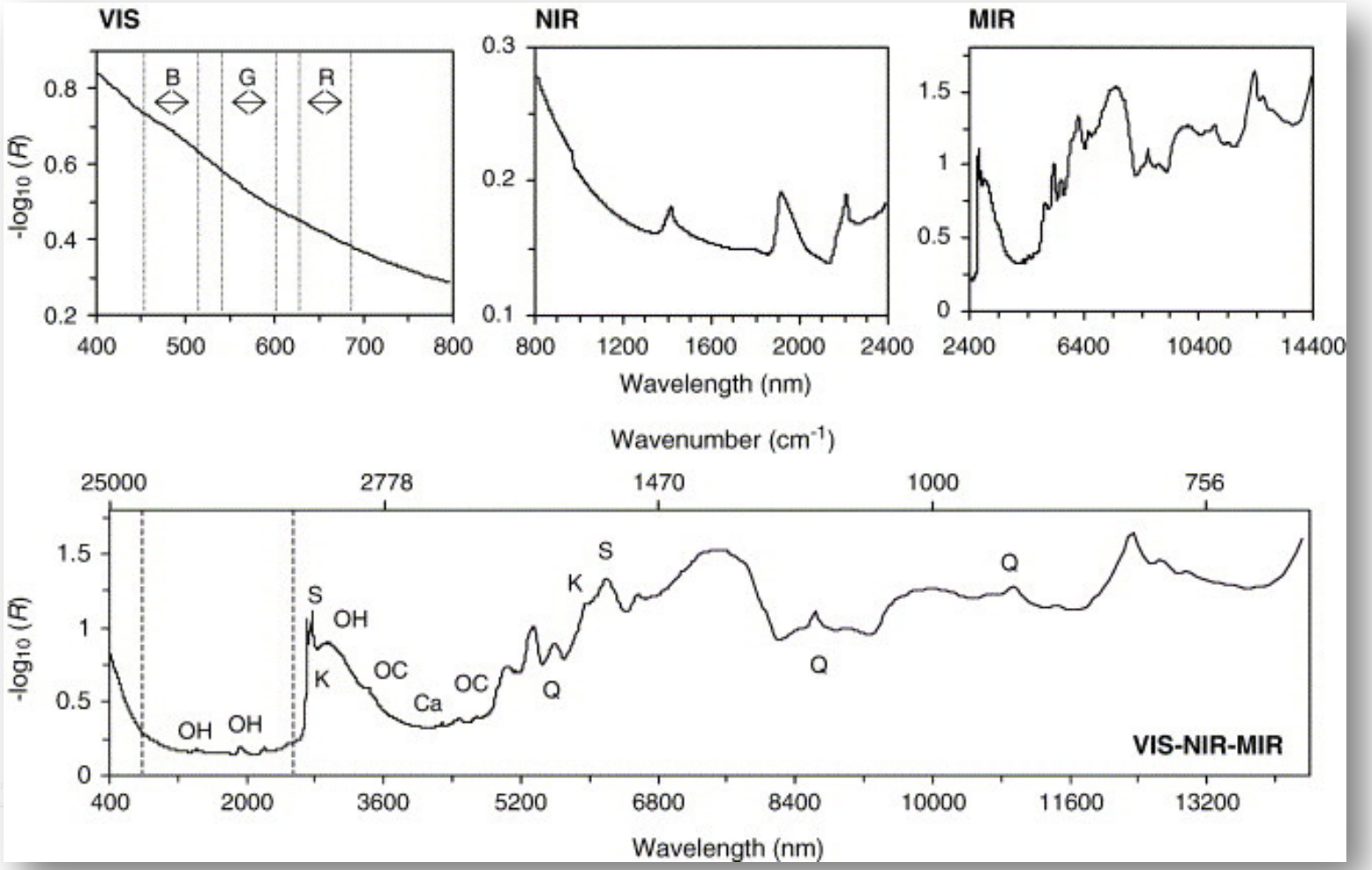
Vis-NIR reflectance spectrum – Newtonia silt loam

Bowers, S.A. & Hanks, R.J. 1965 Reflection of radiant energy from soils. Soil Science 100, 130-138.



Vis-NIR-MIR absorption spectrum

R.A. Viscarra Rossel, D.J.J. Walvoort, A.B. McBratney, L.J. Janik & J.O. Skjemstad 2006 Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. Geoderma 131, 59-75.



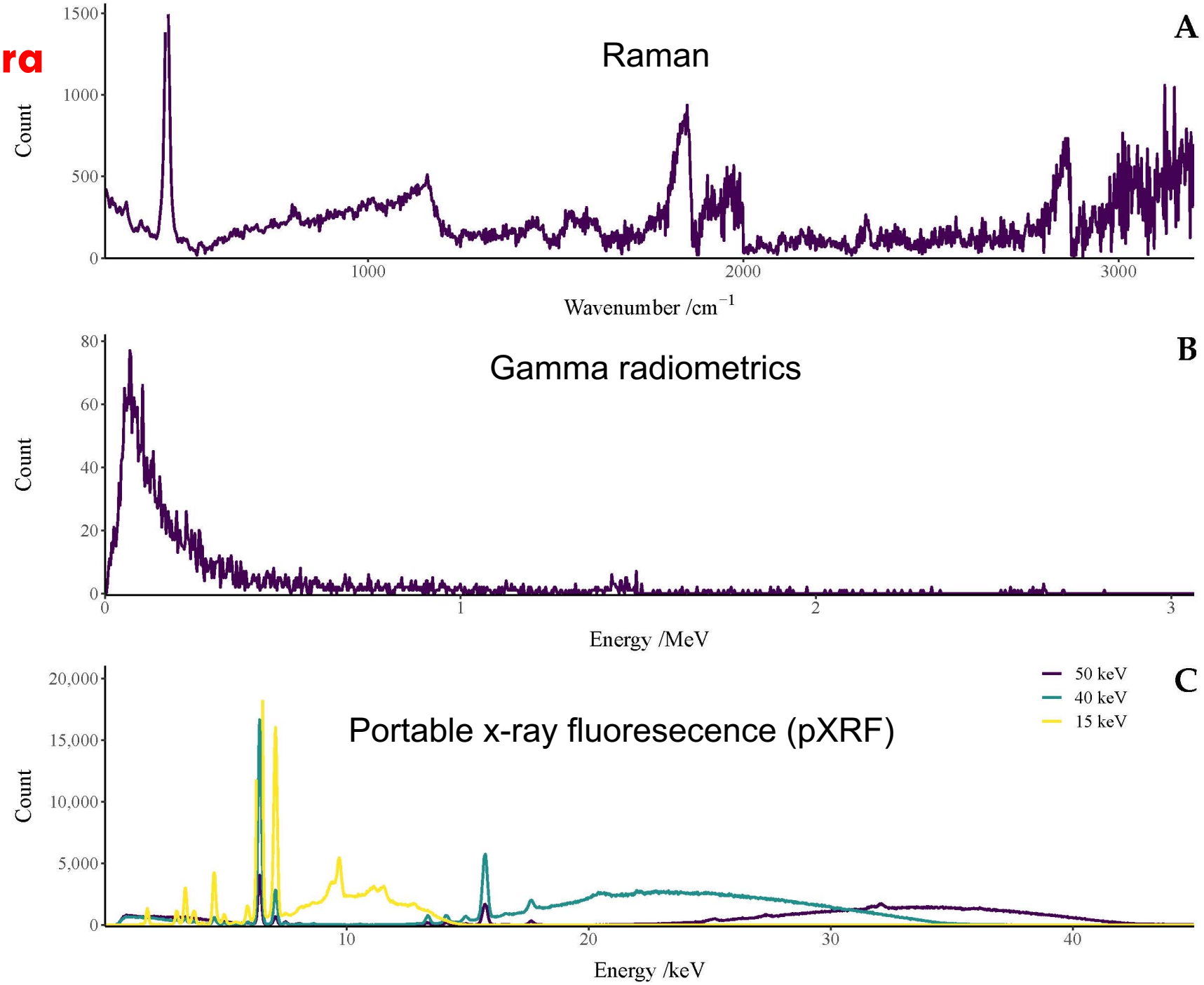
SOIL CONDITION & CAPACITY Indicators and MIR spectrometry

Biological	Chemical	Physical
Microbial Biomass	pH	Rooting Depth
Mycorrhiza populations	CEC	Stoniness
Particulate Organic Matter	Heavy Metals	Texture
Respiration	EC	Aggregate Stability
Potential N mineralization	Organic C & N	Slaking Index
Fatty Acid profiles	Extractable macronutrients	Water holding capacity
Soil enzymes	Total elements, Micronutrients	Bulk Density
	$CaCO_3$	Infiltration
	P retention	Penetration resistance

McBratney, A.B., Field, D., Morgan, C.L.S. & Huang, J. (2019). On soil capability,capacity and condition. Sustainability 11(12), 3350.

Poorly Estimated by MIR, Reasonably Estimated by MIR, Well Estimated by MIR

Other kinds of soil spectra



Wadoux, A.M.J-C., Malone, B., Minasny, B., Fajardo, M. & McBratney, A.B. (2021). *Soil Spectral Inference with R: Analysing Digital Soil Spectra Using the R Programming Environment*. Springer Nature.

Chapter 1 Fig 1

SOIL ELECTRIC SPECTRUM

Revil, A. (2013). Effective conductivity and permittivity of unsaturated porous materials in the frequency range 1 mHz-1 GHz. *Water Resour. Res.*, 49(W02517):306–327.

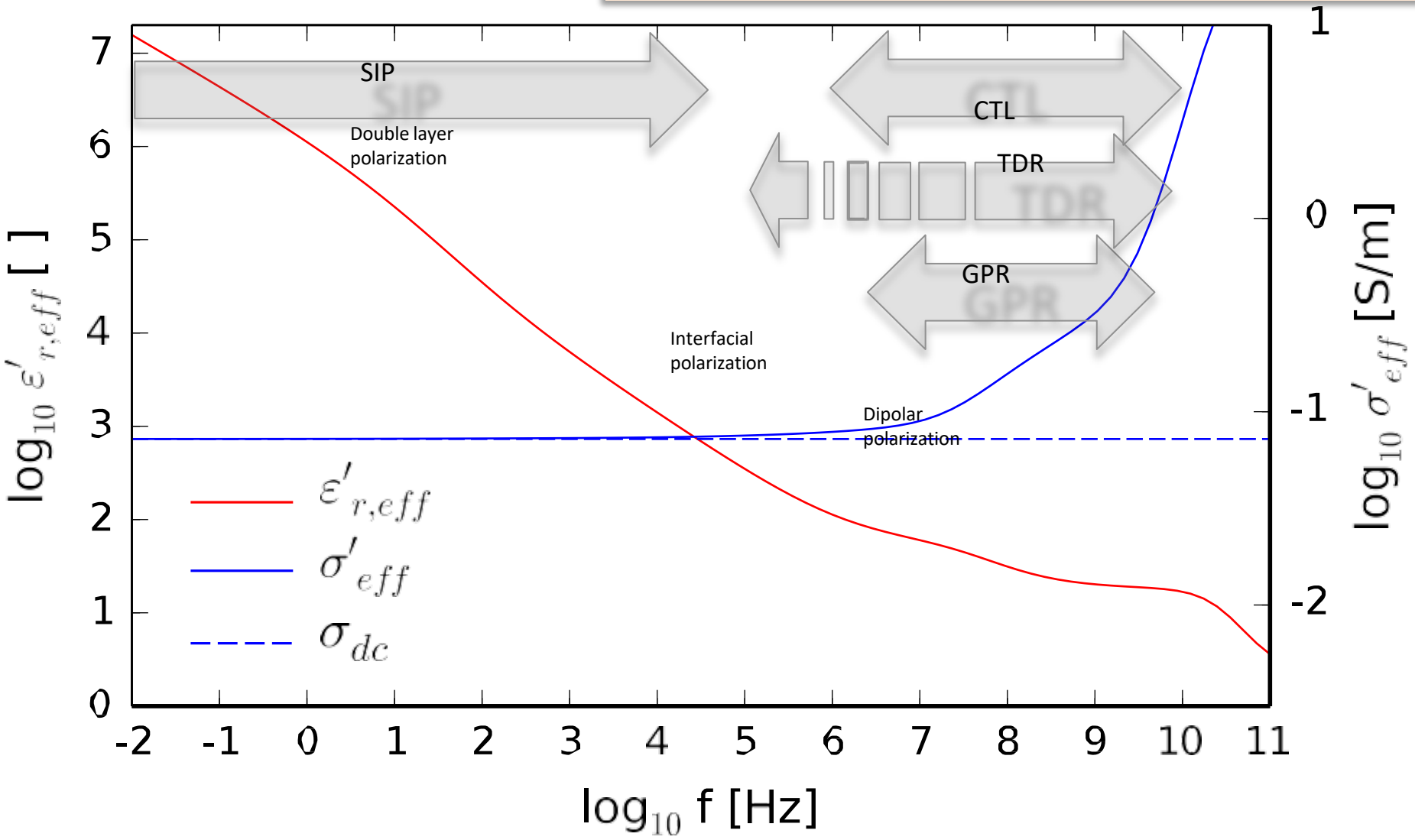


Fig. 3.1.: Real effective permittivity (red line) and conductivity (blue line) spectrum of soil indicating the frequency range of measuring methods (SIP, CTL, TDR and GPR) and polarization effects (after Revil,2013).

McBratney, Minasny, Mendonca Santos 2003 On digital soil mapping. Geoderma 117, 3-52.

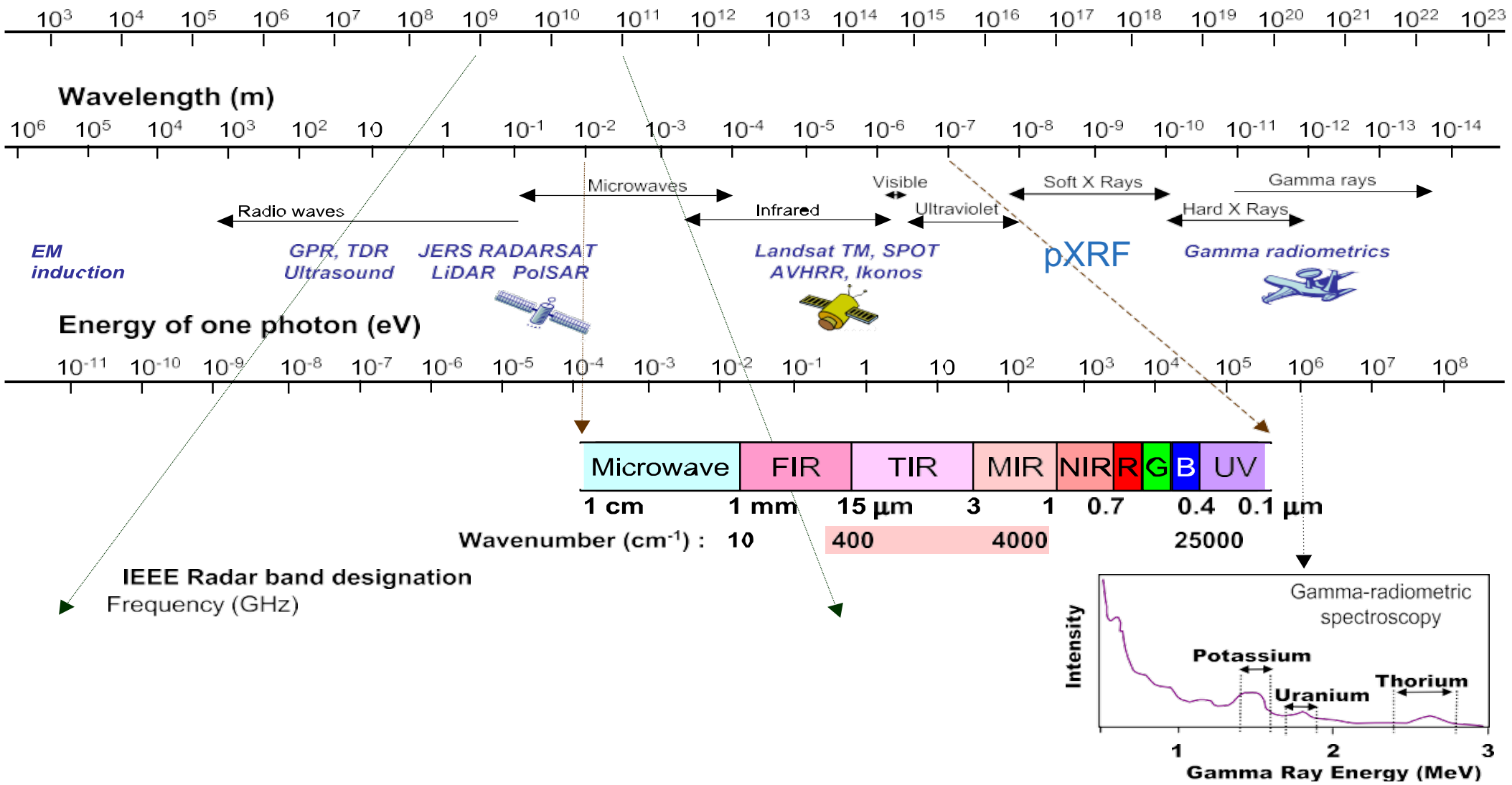
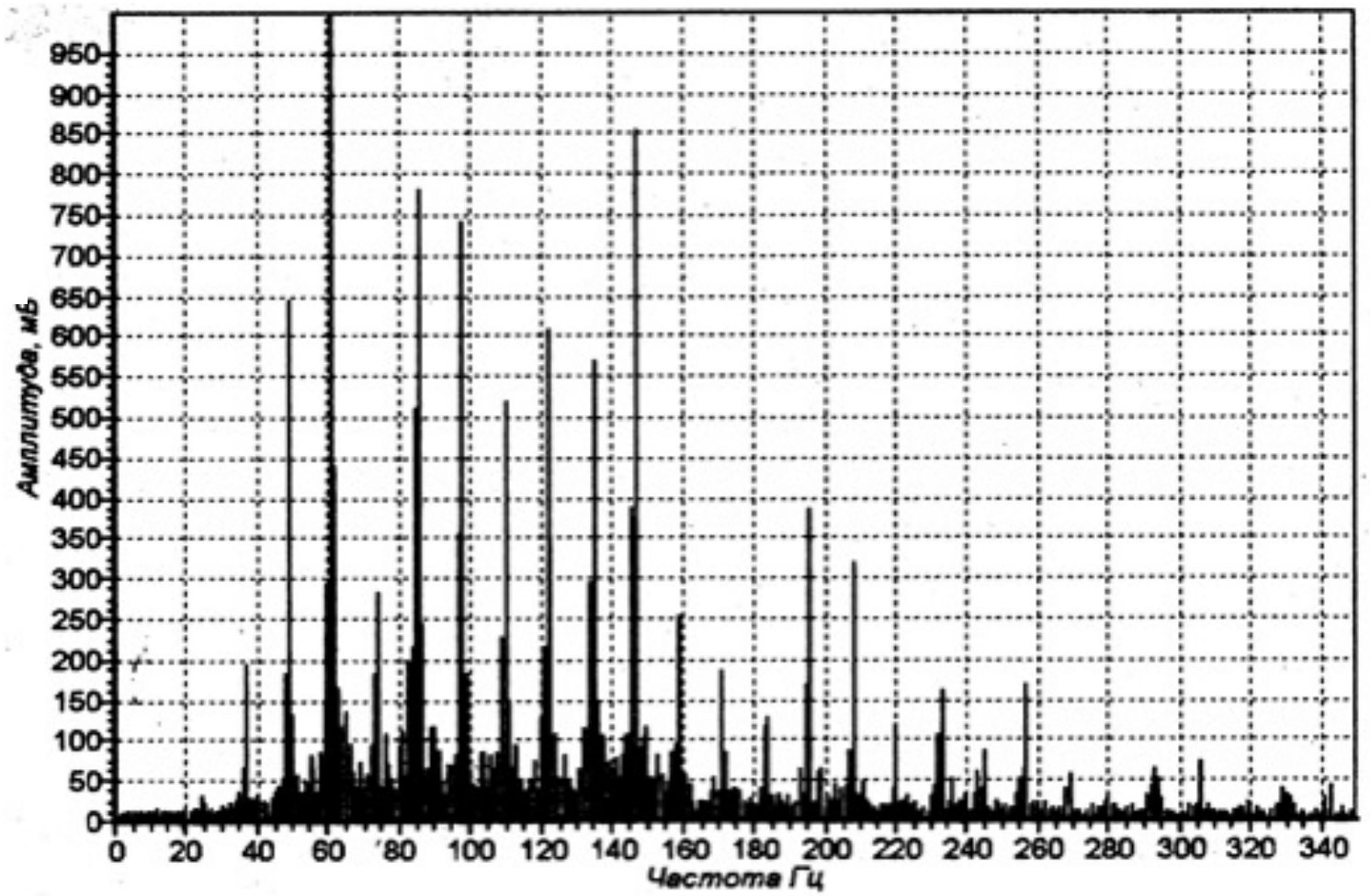


Fig. 1. The electromagnetic spectrum, highlighting the useful parts for obtaining information on soil and environmental variables through remote and proximal sensing. The boundaries for the infrared spectrum (NIR, MIR and FIR) are not consistent and vary between the chemical and remote-sensing literatures. The terms in this figure are based on remote-sensing literature, while the other literature defines the wavelength as: NIR: 0.7 to (2.5 – 5) Am, MIR: (2.5 – 5) to (25 – 40) Am and FIR: (25 – 40) to 1000 Am.

SOIL ACOUSTIC SPECTRUM

S I Evtushenko *et al* 2020 Identification of soils, grounds and lands strata using the acoustic spectral analysis. *IOP Conf. Ser.: Mater. Sci. Eng.* **913** 052043



Amplitude, VHF

Frequency, Hz

MANY NEW KINDS OF SOIL SPECTRA REMAIN TO BE EXPLORED

SOIL SPECTRAL INFERENCE

Soil inference

The prediction of a property or properties from other soil property or properties

SOIL SPECTRAL INFERENCE

Soil spectral inference

The prediction of a property or properties from a spectrum or spectra (direct) or from other soil property or properties predicted from the spectrum or spectra (indirect)

SOIL SPECTRAL INFERENCE

Soil inference system

A software engine for the systematic prediction of a property or properties from other soil properties

SOIL SPECTRAL INFERENCE

Soil spectral inference system

A software engine for the systematic prediction of a property or properties from a spectrum or spectra (direct) or from other soil property or properties predicted from the spectrum or spectra (indirect)

SOIL SPECTRAL INFERENCE

Soil spectral inference system

(Simpler definition)

A soil inference system driven (solely or mainly) from soil spectra

McBratney, A.B., Minasny, B. Viscarra Rossel R.A. 2006. Spectral soil analysis and inference systems: A powerful combination for solving the soil data crisis. Geoderma 136, 272-278.

EXPLANATION & DEMONSTRATION OF SOIL INFERENCE SYSTEM & SOIL SPECTRAL INFERENCE SYSTEM

Ed Jones

José Padarian

Revisiting Budiman's Webinar

Combination of Spectroscopy and Pedotransfer Functions in a Soil Spectral Inference System can improve predictability

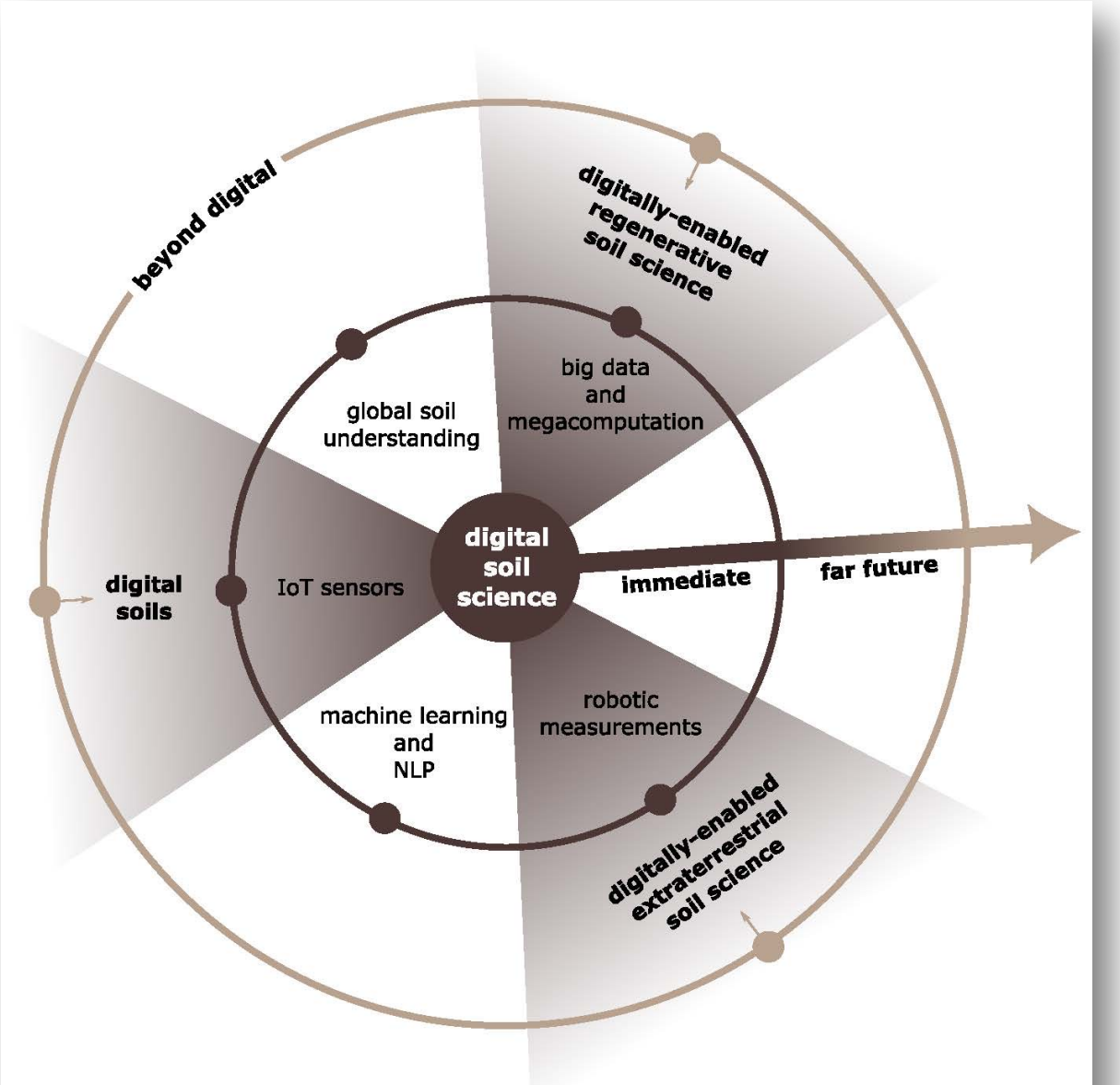
SOIL CONDITION & CAPACITY Indicators and MIR spectrometry

Biological	Chemical	Physical
Microbial Biomass	pH	Rooting Depth
Mycorrhiza populations	CEC	Stoniness
Particulate Organic Matter	Heavy Metals	Texture
Respiration	EC	Aggregate Stability
Potential N mineralization	Organic C & N	Slaking Index
Fatty Acid profiles	Extractable macronutrients	Water holding capacity
Soil enzymes	Total elements, Micronutrients	Bulk Density
	$CaCO_3$	Infiltration
	P retention	Penetration resistance

Poorly Estimated by MIR, **Reasonably Estimated by MIR**, **Well Estimated by MIR**


FUTURE

SOIL SPECTRA & DIGITAL SOIL SCIENCE



Wadoux, A.M.J-C., & McBratney, A.B. Digital soil science and beyond. (2021) *Soil Science Society of America Journal*. https://acsess.onlinelibrary.wiley.com/doi/full/10.1002/saj2.20296 Fig 3

Routine Lab Spectroscopy

Laboratory spectroscopy (on whole soil samples)

UV Vis NIR
MIR /(FTIR)
XRF
LIBS
LIFS
Raman

….

Issues

Sample preparation
Calibration

Sample preparation

UV Vis NIR
MIR /(FTIR)
XRF
LIBS
LIFS
Raman
….

Drying

Grinding (size?)

Calibration

UV Vis NIR
MIR /(FTIR)
XRF
LIBS
LIFS
Raman
….

James Hutton Institute, Scotland

How local?
How global?
How many?

Routine Field Spectroscopy

“Soil Sensing” Principle

Given real and significant natural soil variation in the field, a plethora of low cost, low precision soil data can produce high-value spatialised soil information

Spectroscopy is one way of generating such data

Mobile field spectroscopy (many possibilities)

Gamma radiometrics
Ground-penetrating radar
Portable NIR
Portable XRF
MIR
EMI?/ mag sus
UV Vis NIR
MIR /(FTIR)
XRF
LIBS
LIFS
Raman
....

Issues

Soil moisture effect
Sample presentation
Calibration
Mobilisation

Soil moisture effect

Gamma radiometrics
Ground-penetrating radar
Portable NIR
Portable XRF
MIR
EMI?/ mag sus
UV Vis NIR
MIR /(FTIR)
XRF
LIBS
LIFS
Raman
….

Likely to offer most interference

Affects some more than others

Remove effect by various algorithmic means

Sample presentation

Gamma radiometrics
Ground-penetrating radar
Portable NIR
Portable XRF
MIR
EMI?/ mag sus
UV Vis NIR
MIR /(FTIR)
XRF
LIBS
LIFS
Raman

....

In situ or Ex situ

Homogenisation

Lateral or Vertical travel

Calibration

Gamma radiometrics
Ground-penetrating radar
Portable NIR
Portable XRF
MIR
EMI?/ mag sus
UV Vis NIR
MIR /(FTIR)
XRF
LIBS
LIFS
Raman
….

More challenging than lab

Is global calibration feasible?

Mobilisation

Gamma radiometrics
Ground-penetrating radar
Portable NIR
Portable XRF
MIR
EMI?/ mag sus
UV Vis NIR
MIR /(FTIR)
XRF
LIBS
LIFS
Raman
….

Vertical probe

Autonomous vehicle

Autonomous very low flying aircraft

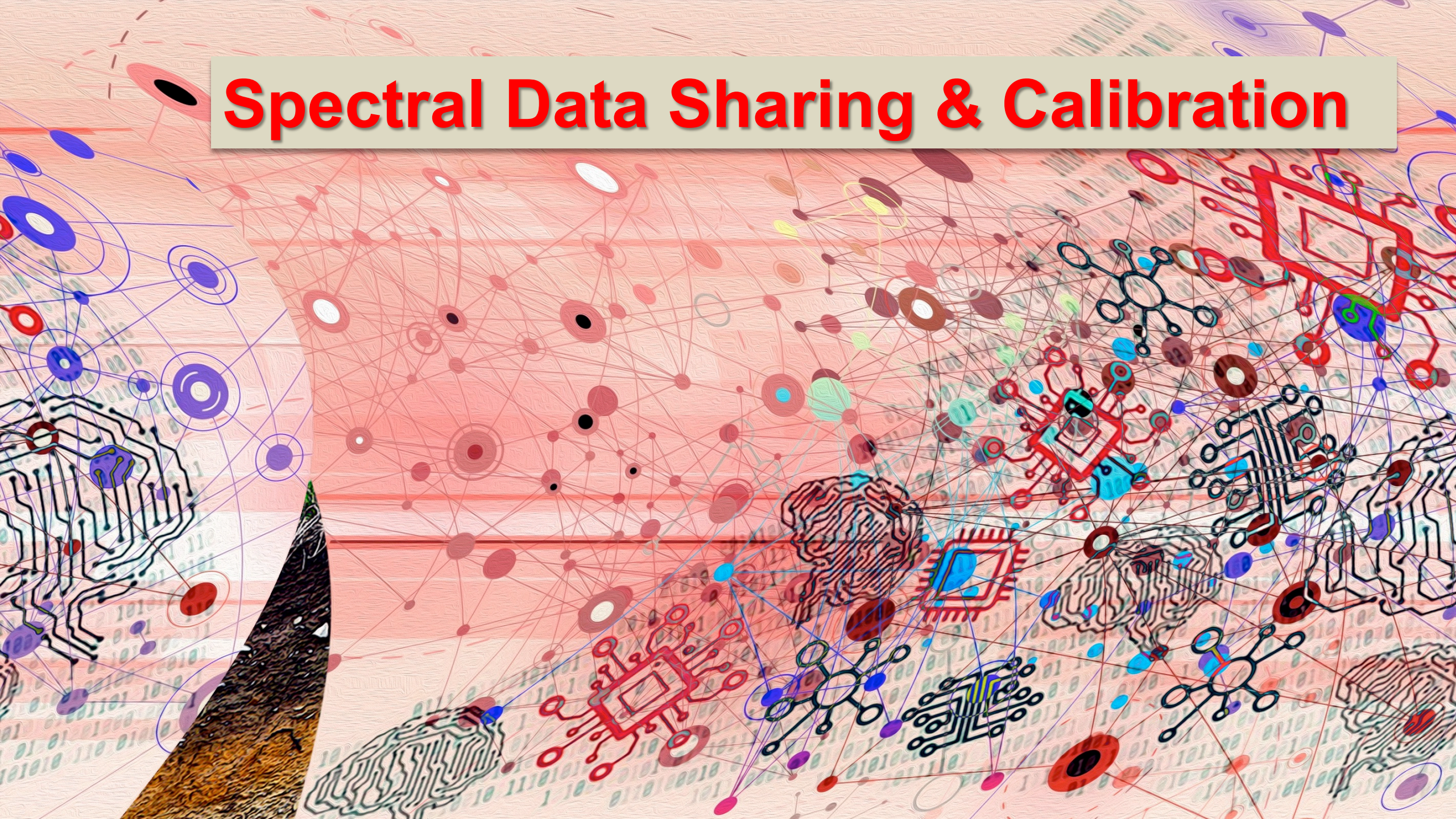
Endochoric soil probe


2019
siemirpa
THE UNIVERSITY OF SYDNEY

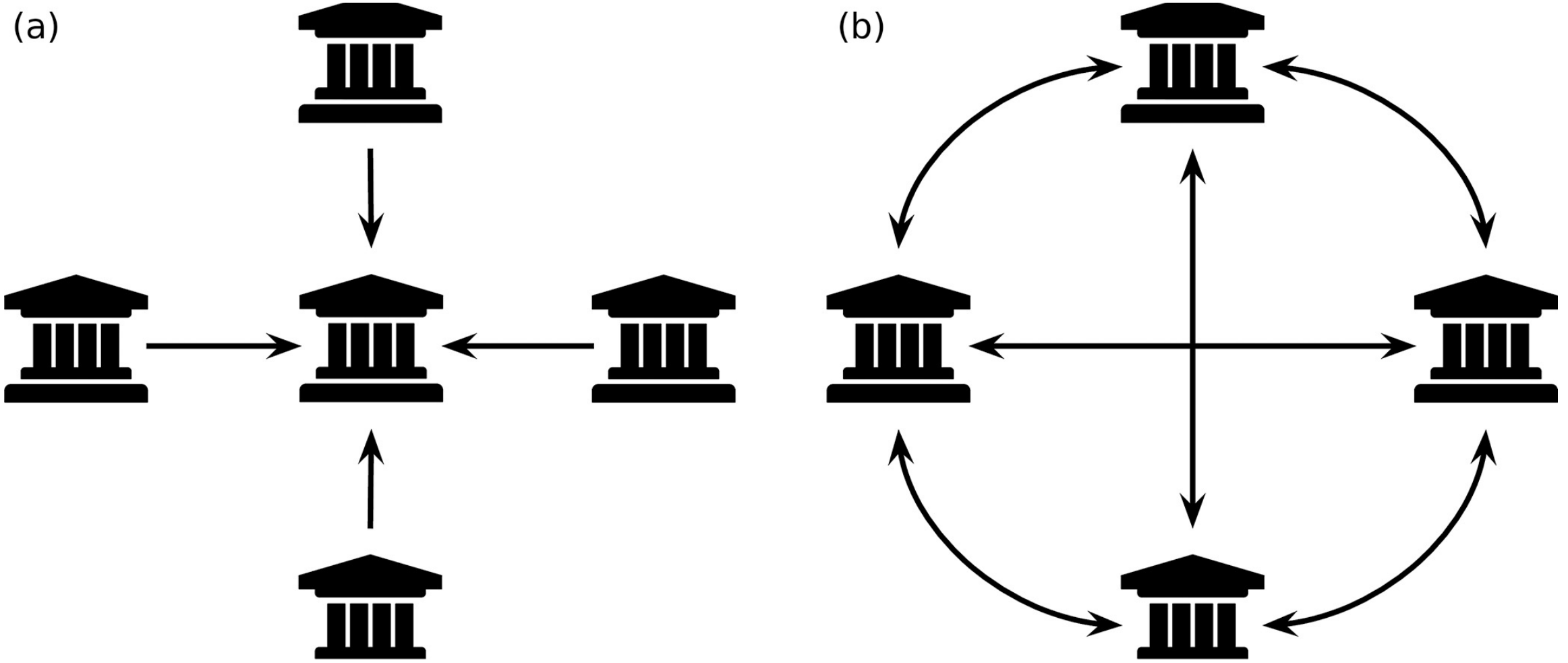

organo-digital

Chemometrics/Pedometrics Interface

Spectral Data Sharing & Calibration



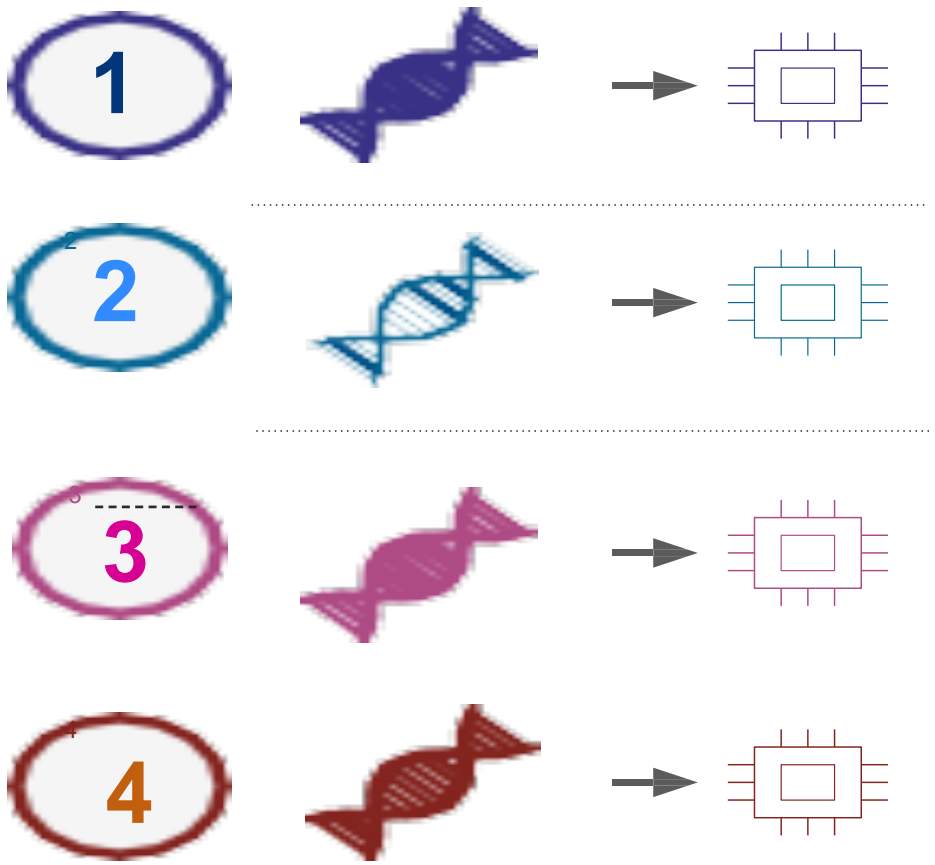
José Padarian and Alex B. McBratney
2020. A new model for intra- and inter- institutional soil data sharing. Soil 6, 89–94.



Data flows in two different soil information system infrastructures: **(a)** centralised; **(b)** decentralised.

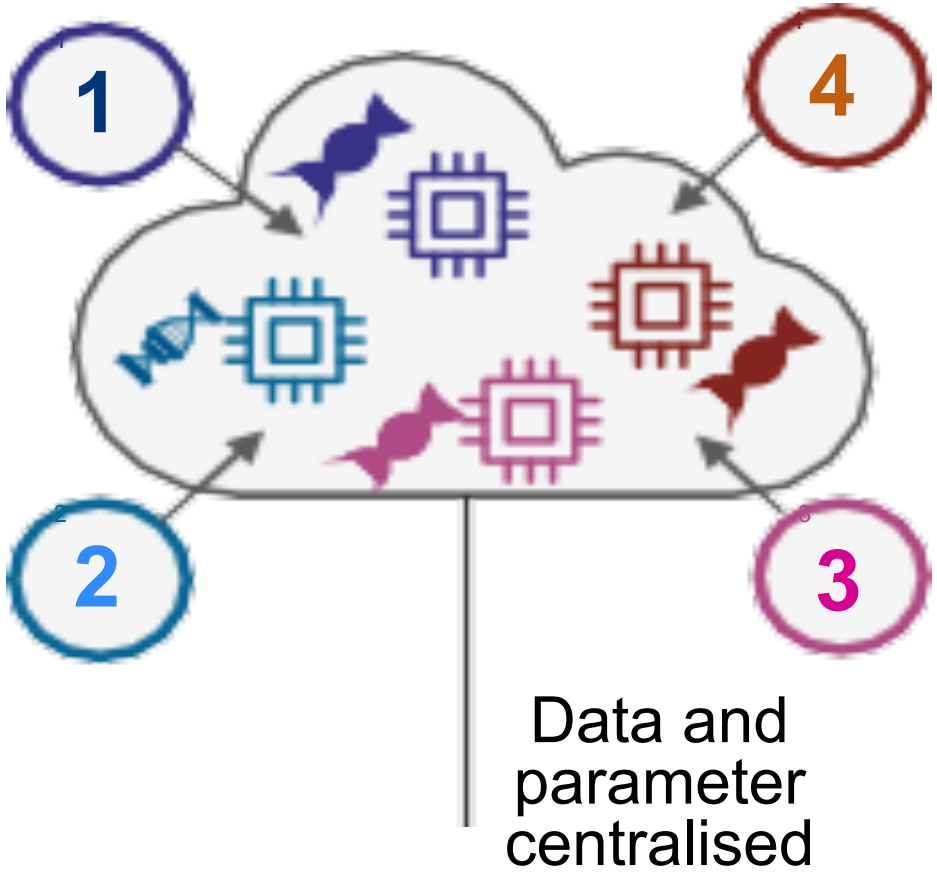
Potential use case discussed: global soil spectral library

Local learning



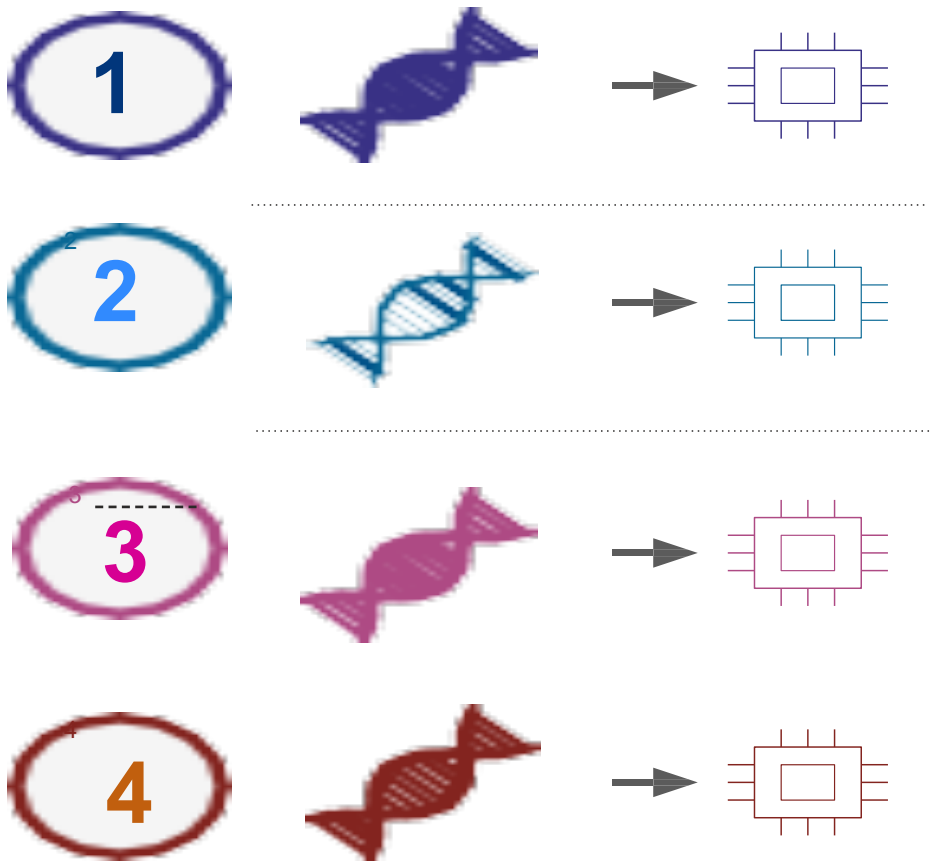
Disconnected

Central learning



Warnat-Herresthal, S. et al. 2021 Swarm Learning for decentralized and confidential clinical machine learning. Nature 594, 265-270.

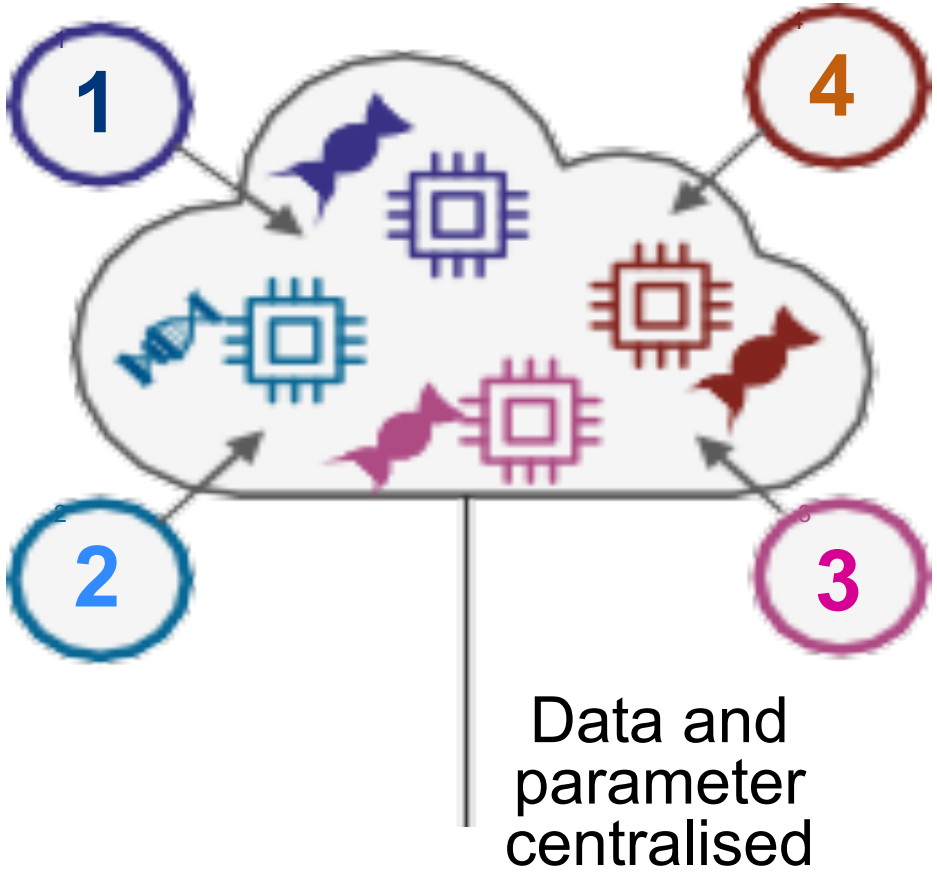
Local learning



Disconnected

Central learning

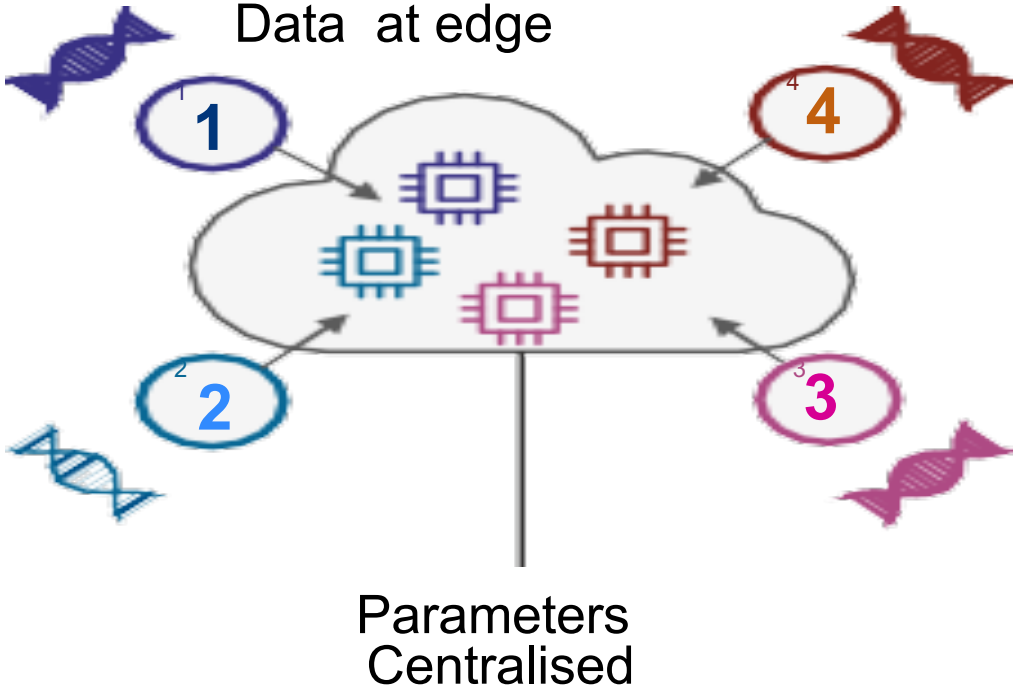
Current way of making soil spectral libraries – nationally regionally and globally



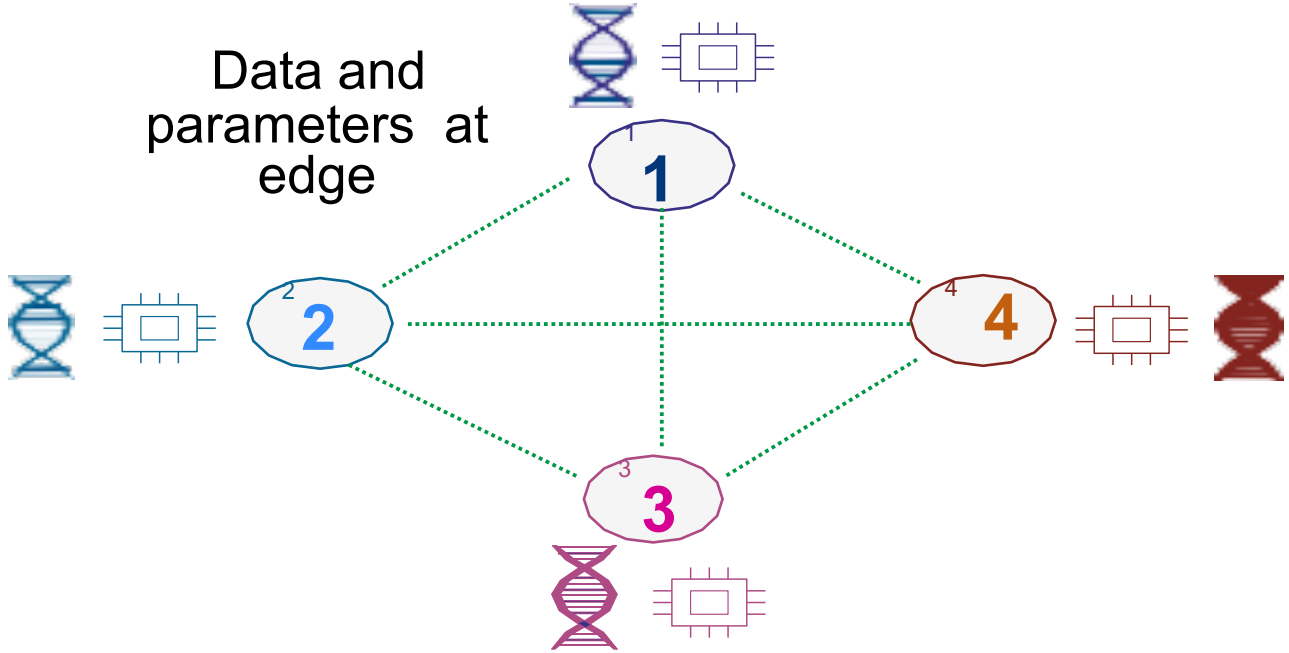
Data and parameter centralised

Warnat-Herresthal, S. et al. 2021 Swarm Learning for decentralized and confidential clinical machine learning. Nature 594, 265-270.

Federated learning

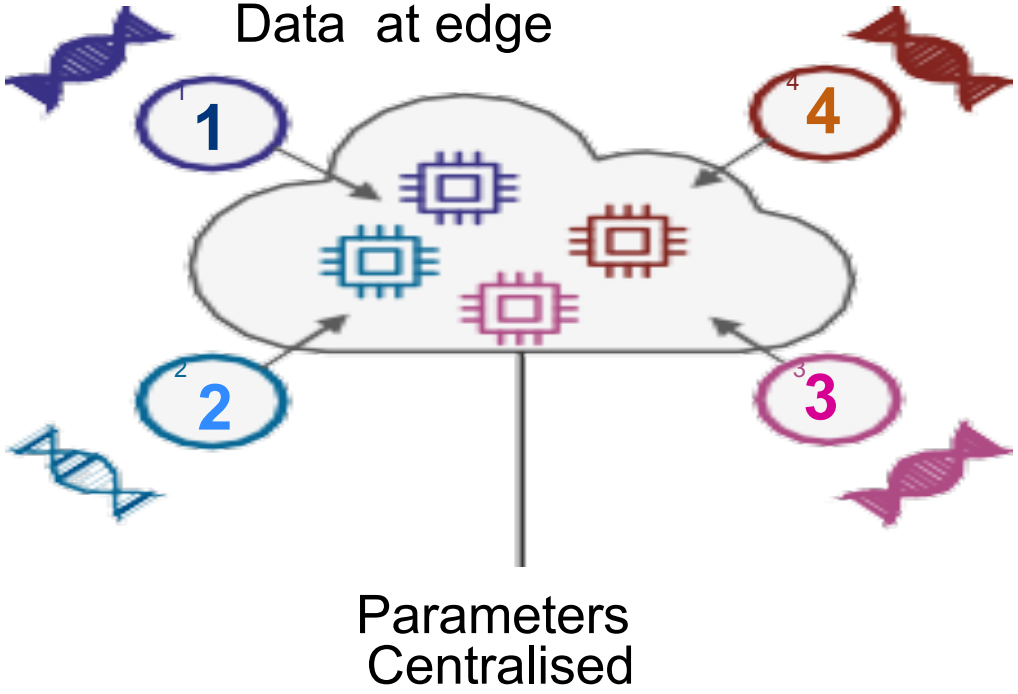


Swarm learning

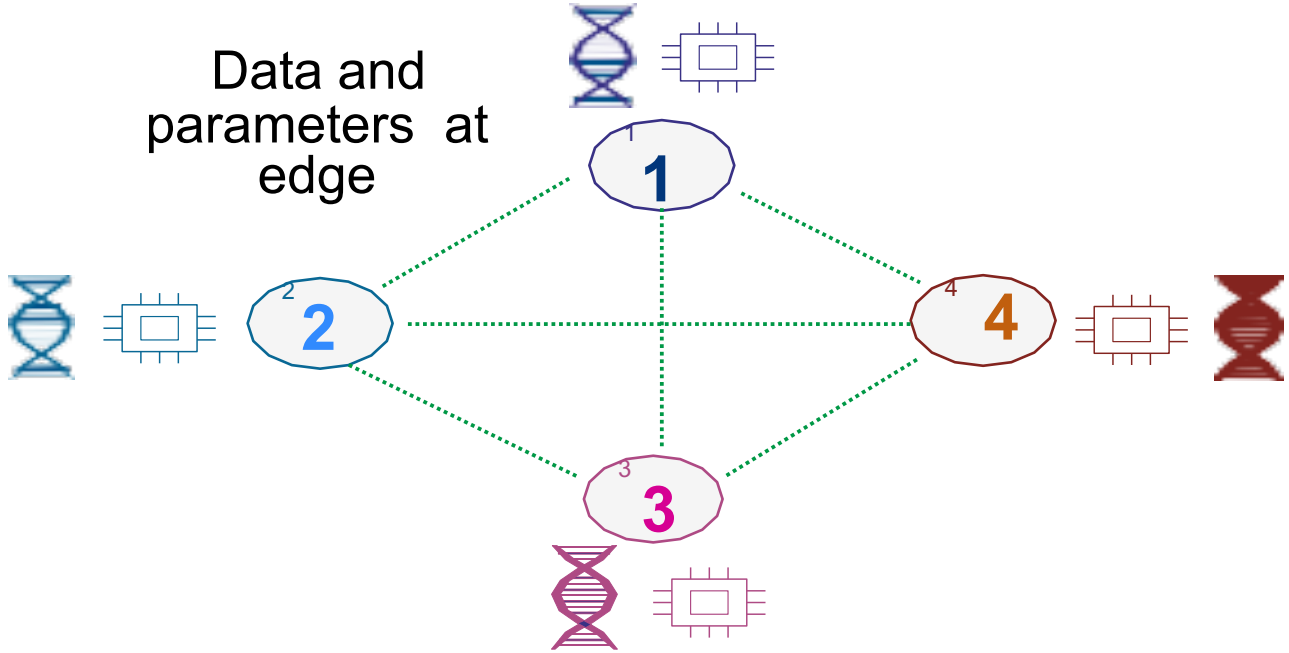


Warnat-Herresthal, S. et al. 2021 Swarm Learning for decentralized and confidential clinical machine learning. Nature 594, 265-270.

Federated learning



Swarm learning



Future way of making soil spectral libraries – nationally regionally and globally

Warnat-Herresthal, S. et al. 2021 Swarm Learning for decentralized and confidential clinical machine learning. Nature 594, 265-270.

Spectra for Soil Classification & Identification

The biggest challenge for the future in which soil spectroscopy can play a crucial role

A formal global digital quantitative system of soil classification

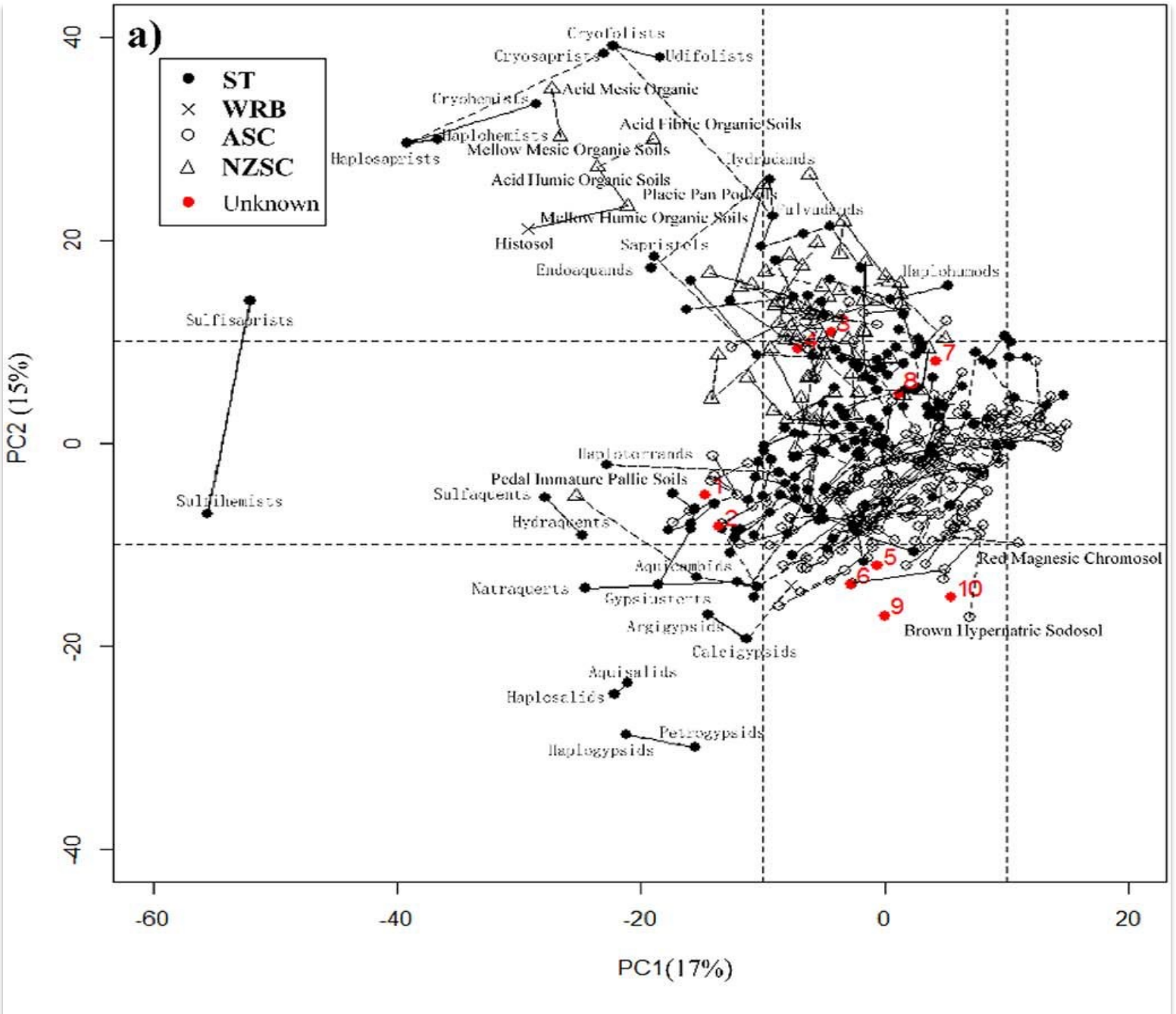
We don’t have it

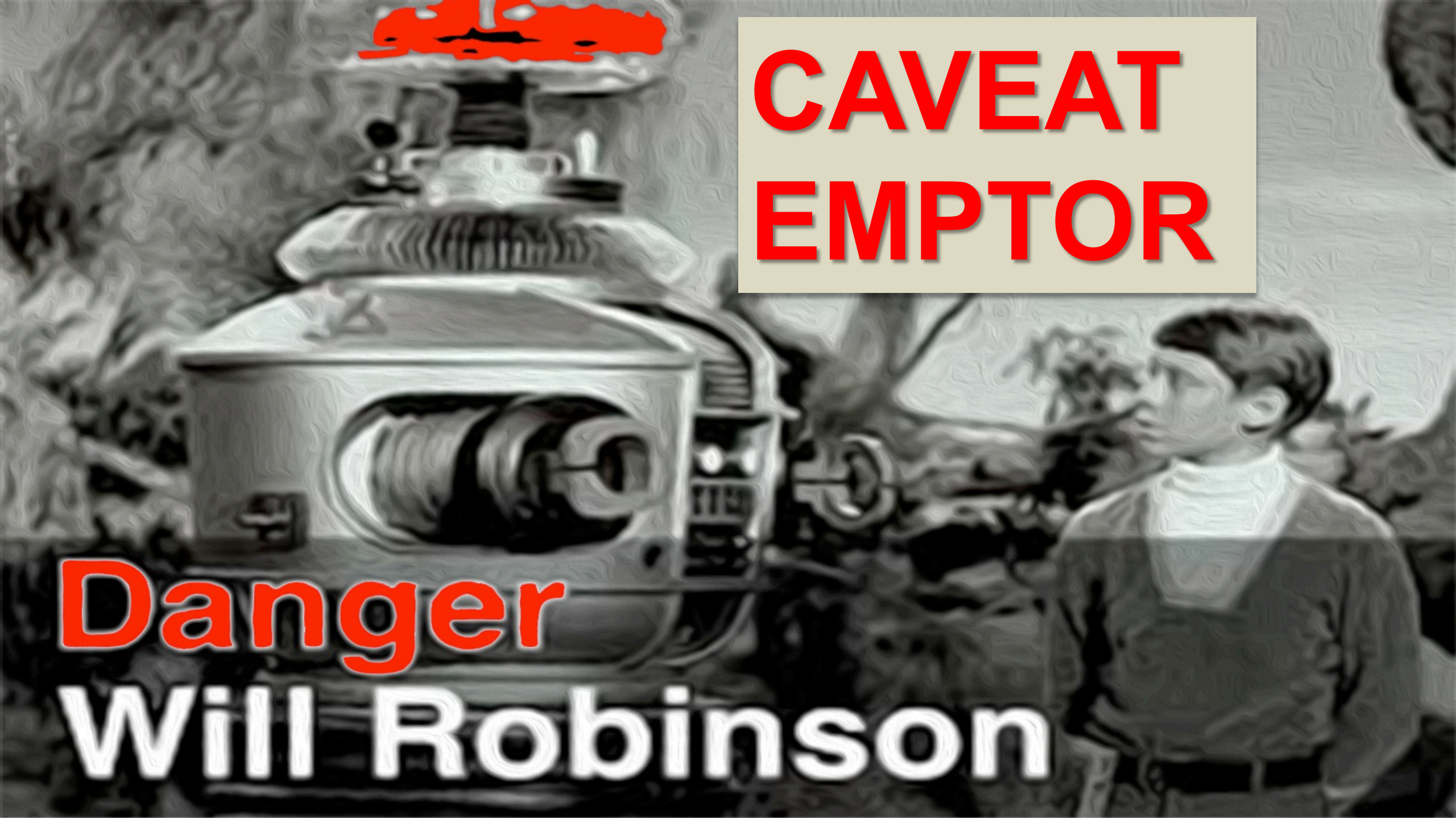
23 soil variables

Category	Variable
Physical (7)	coarse fractions, clay, silt and sand contents, water content, ice content, bulk density
Chemical (13)	organic carbon content, carbonate content, pH, cation exchange capacity, exchangeable cations (Ca, Na, Mg, K), acid saturation, base saturation, exchangeable sodium percentage, electrical conductivity, and gypsum content
Morphological (3)	soil colour expressed in L, a, b or red, green and blue

All derivable (in the field* or lab) from MIR/NIR soil spectra

Hughes, P. et al 2017. Creating a novel comprehensive soil classification system by sequentially adding taxa from existing systems. Geoderma Regional 11, 123-140.




CAVEAT
EMPTOR
Danger
Will Robinson

ARTIFICIAL INTELLIGENCE

A field of science that is primarily concerned with getting computers to do tasks that would normally require human intelligence.

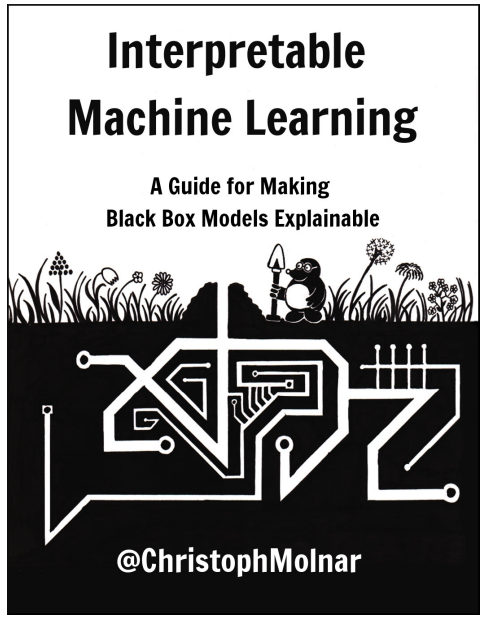
MACHINE LEARNING

A set of algorithms that allow computers to learn from data without being explicitly programmed

DEEP LEARNING

A more recently developed set of learning techniques

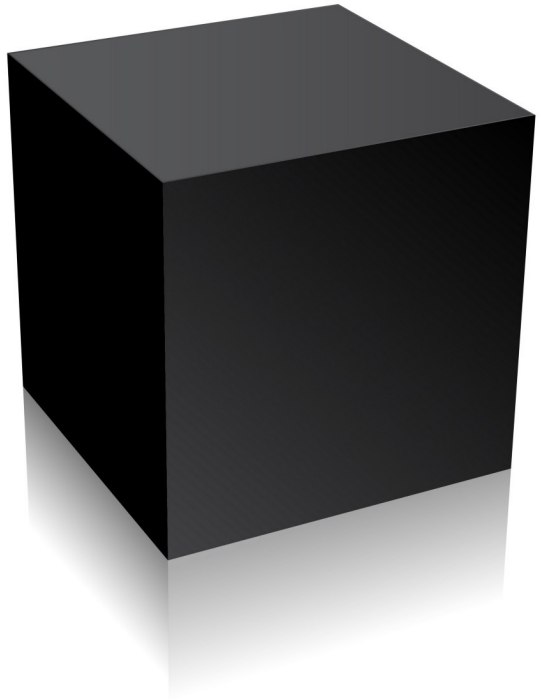
Photo Credit: From Noun Project by ImageCatalog, Becris and Dragthrust



Interpretation of the machine-learned spectral soil prediction models

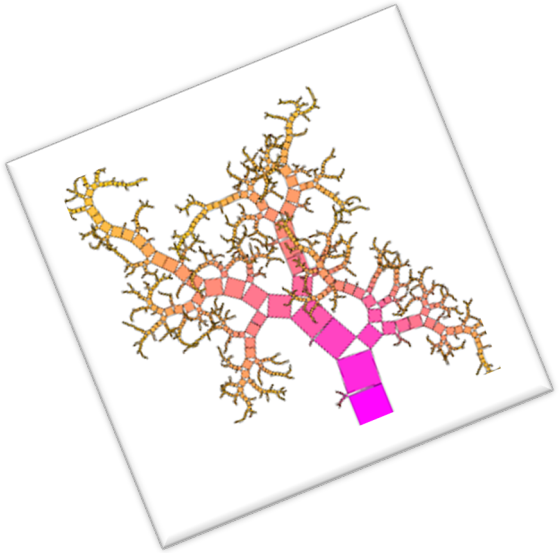
Can we interpret the models?
If we can't then …?

Proprietary soil prediction



AgTech SoilTech ENVTECH

Proprietary soil prediction



Do we need to know what is inside the black box?

Does it make sense?

AgTech SoilTech ENVTECH

Doing too much with too little?

Please don’t overfit or overstretch the data

Spectral predictions calibrated with too few observations are not predictive

Spectral predictions using calibrations models with too many parameters with respect to the data are not predictive


KEEP
CALM
ITS
THE
CONCLUSION

Conclusions…

1. There are many kinds of spectroscopy that are potentially useful for the rapid generation of soil information on whole soil – many are largely un-investigated.

Conclusions…

2. MIR, NIR pXRF and Gamma radiometry are the most deployable at present for whole soil

Conclusions…

3. Soil spectral inference systems will be the principal mode of operation – applicable to lab- and field-based systems

Conclusions…

4. In the lab, calibrations will be developed for many hundreds of soil properties using federated and swarm learning

Conclusions…

5. In the field, spectrometers of various kinds will be deployed on autonomous platforms to update a wide array of dynamic soil properties important for monitoring soil condition (‘health’)

Conclusions…

6. Principal applications will be for real-time agronomic and environmental decision-making including soil classification and diagnosis, soil monitoring

Would you like to say something new?
We would like to hear it

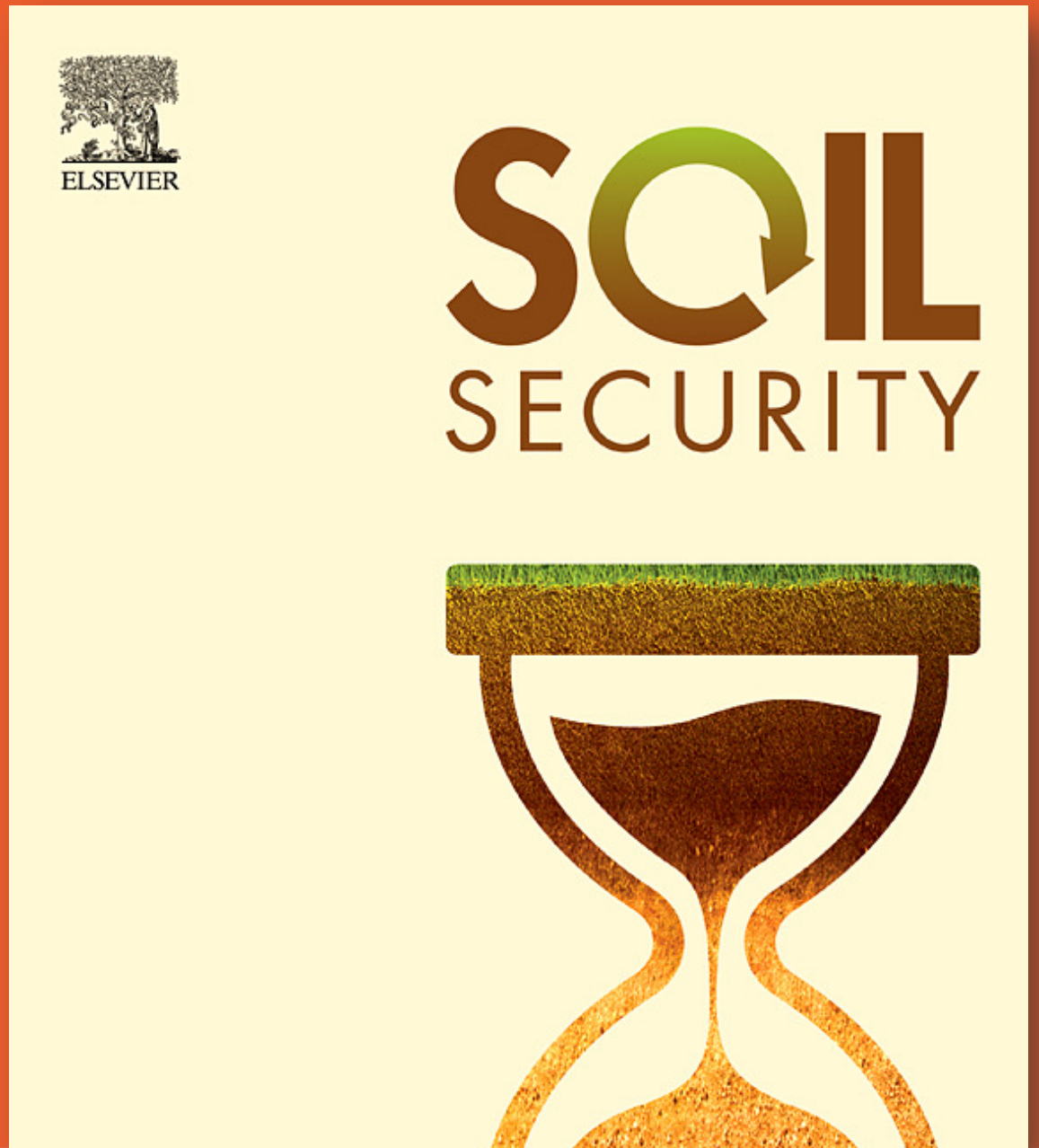
Publish in the new soil security journal

https://www.sciencedirect.com/journal/Soil-Security

We are currently developing a Special Issue on Soil Spectroscopy for Soil Condition and Capability

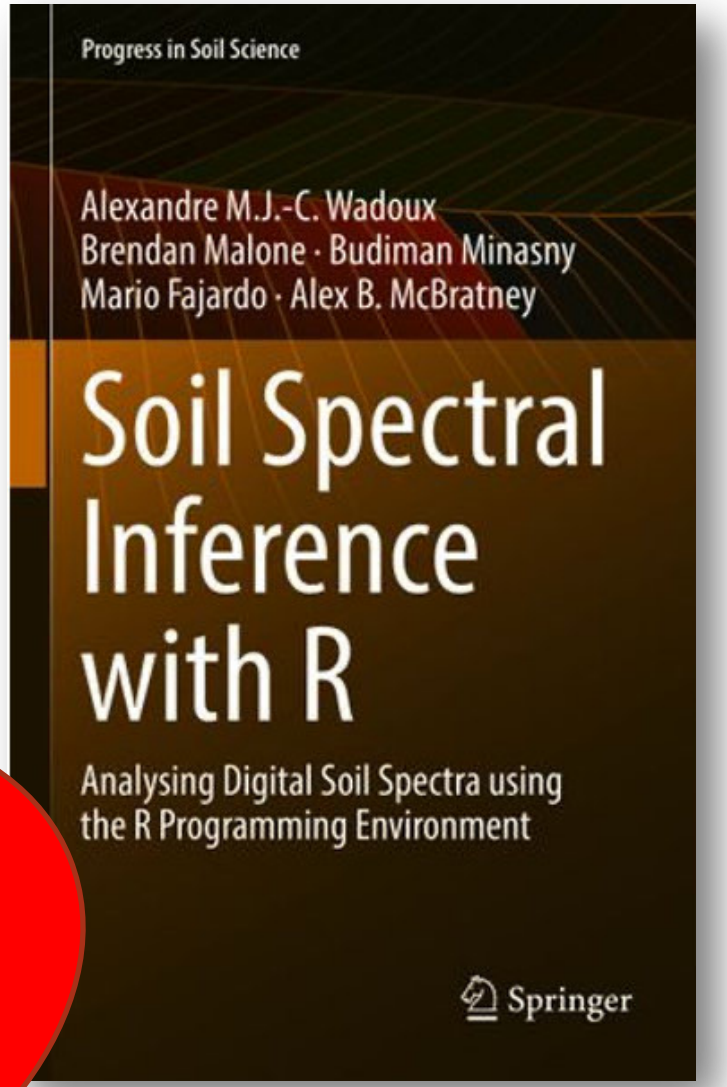
Contact
alexandre.wadoux@sydney.edu.au

THE UNIVERSITY OF SYDNEY



Training Course coming soon…

An overview of techniques for inferring information from soil spectroscopic data supported by a suite of software coded in R for performing these analyses.



THE UNIVERSITY OF SYDNEY

Training course based on book from University of Sydney and hosted by FAO GSP GLOSOLAN coming soon!

https://github.com/AlexandreWadoux/soilspec

SUPPORT *iuss.org*

International Union of Soil Sciences

THE PEAK BODY FOR THE WORLD'S SOIL SCIENTISTS

International Union of Soil Sciences

THE PEAK BODY FOR THE WORLD'S SOIL SCIENTISTS

SOIL SCIENCE

CROSSING BOUNDARIES, CHANGING SOCIETY

31 JULY - 5 AUGUST 2022

GLASGOW

22wcss.org

See you there!


Food and Agriculture Organization of the United Nations
GLOSOLAN
Soil spectroscopy training workshops
finis
THANK YOU ☺
Online webinars
GLOBAL SOIL PARTNERSHIP


Questions?