Food and Agriculture Organization of the United Nations

soil & landscape science lab

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Global soil spectroscopy for the common good

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GLOSOLAN
2nd Plenary meeting on spectroscopy

2 - 4 November 2021

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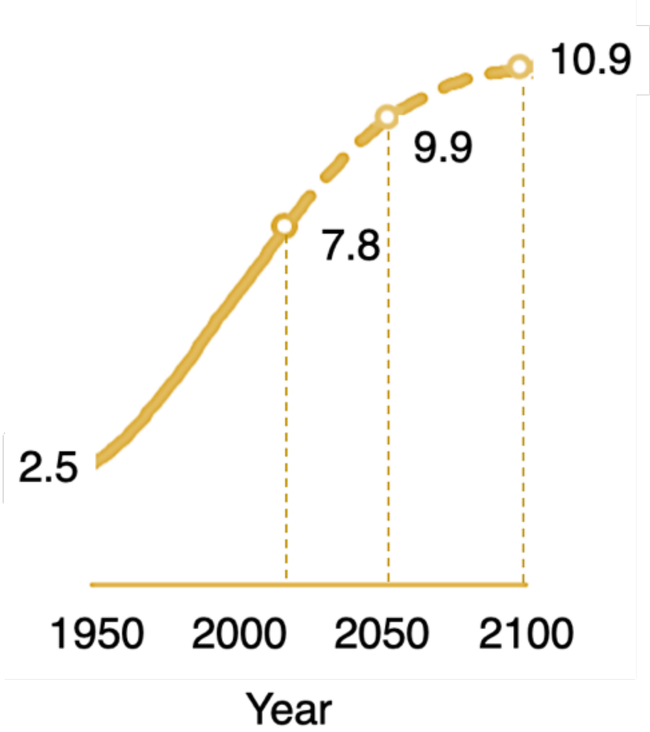
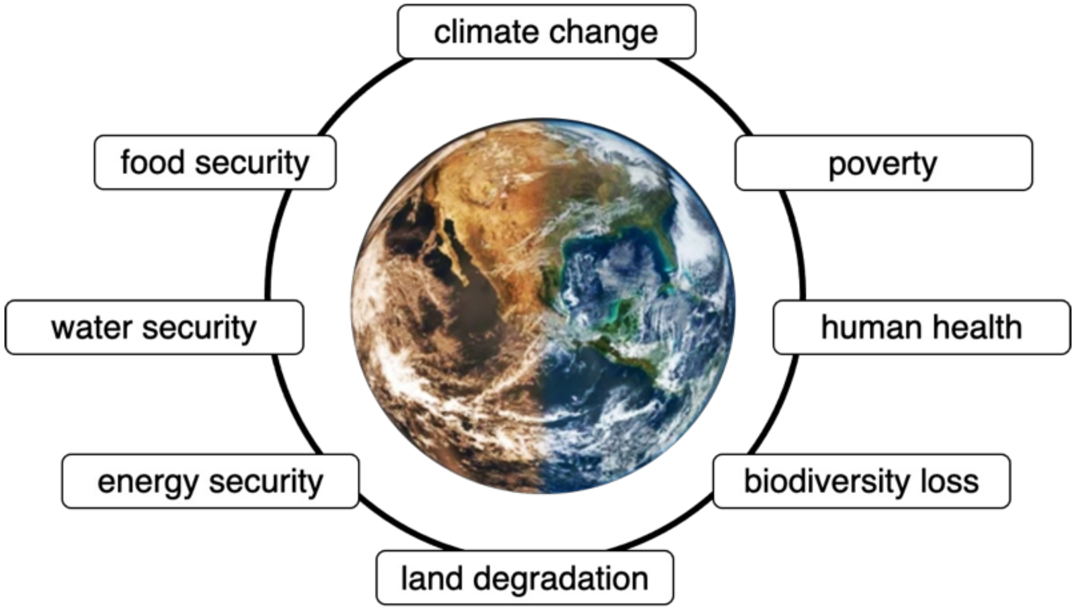
Global environmental challenges

World Population
(billions)

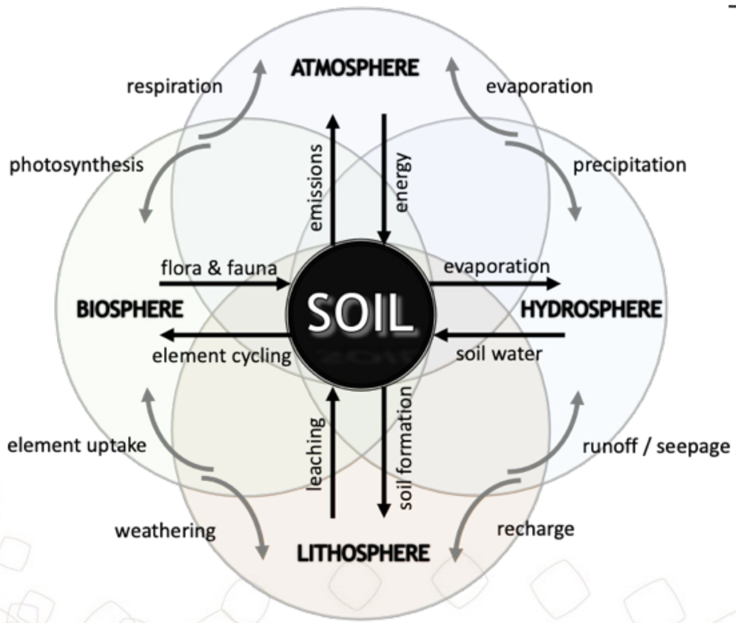


Impact on environment

- consumption of resources
- production of wastes



Soil is central to our response



Adapted from Lal *et al.* (1998)

1. Biomass production
2. Storage, filtering of water
3. Biodiversity
4. Physical and cultural environment
5. Source of raw materials
6. Carbon pool
7. Archive of geological and archeological heritage

Cost-effective soil measurement and sensing are key

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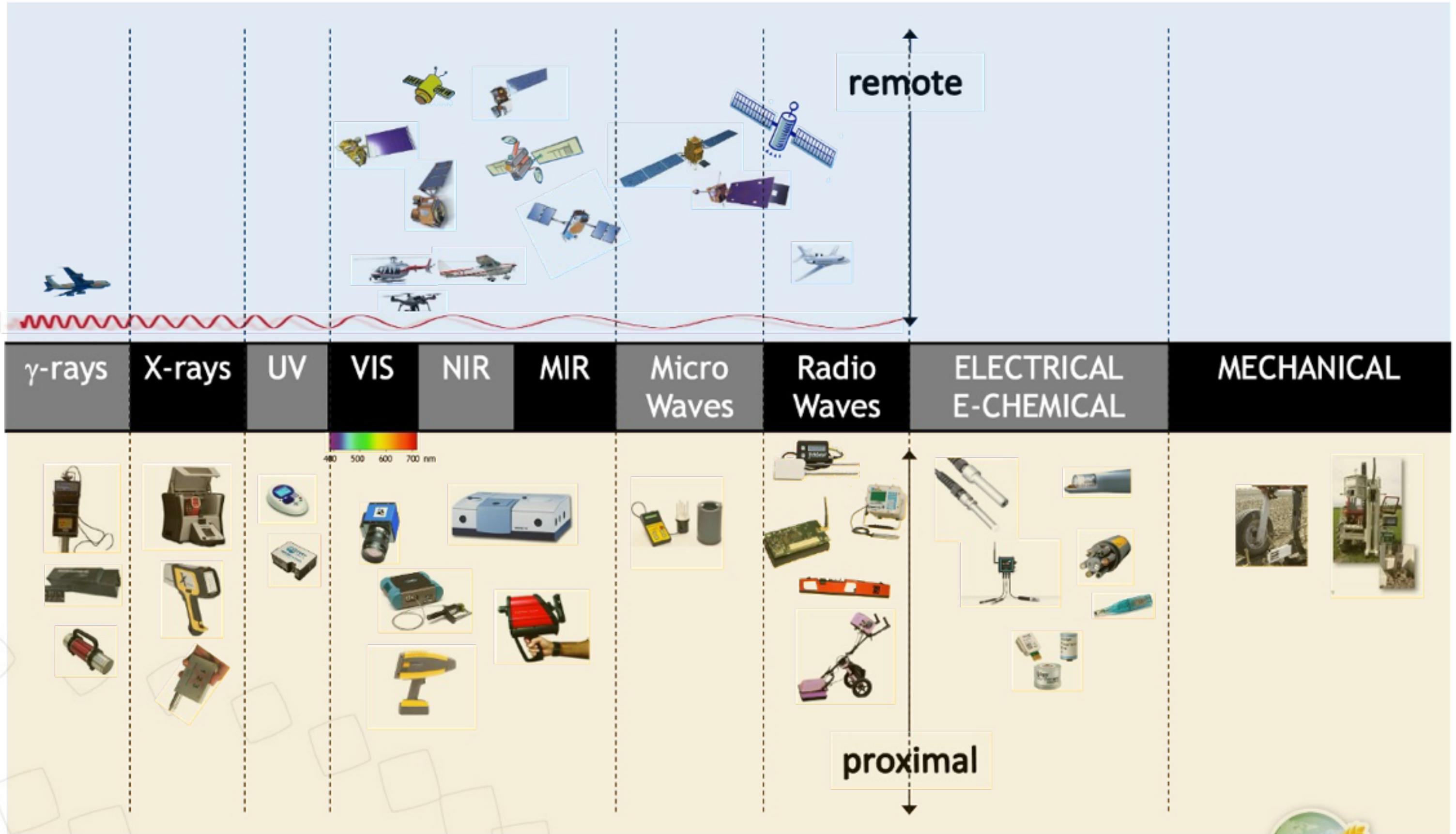
To measure
is to know.
If you can not
measure it,
you can not
Improve it.

- Lord Kelvin



Viscarra Rossel et al. (2011 Adv.Agron)

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Soil spectroscopy

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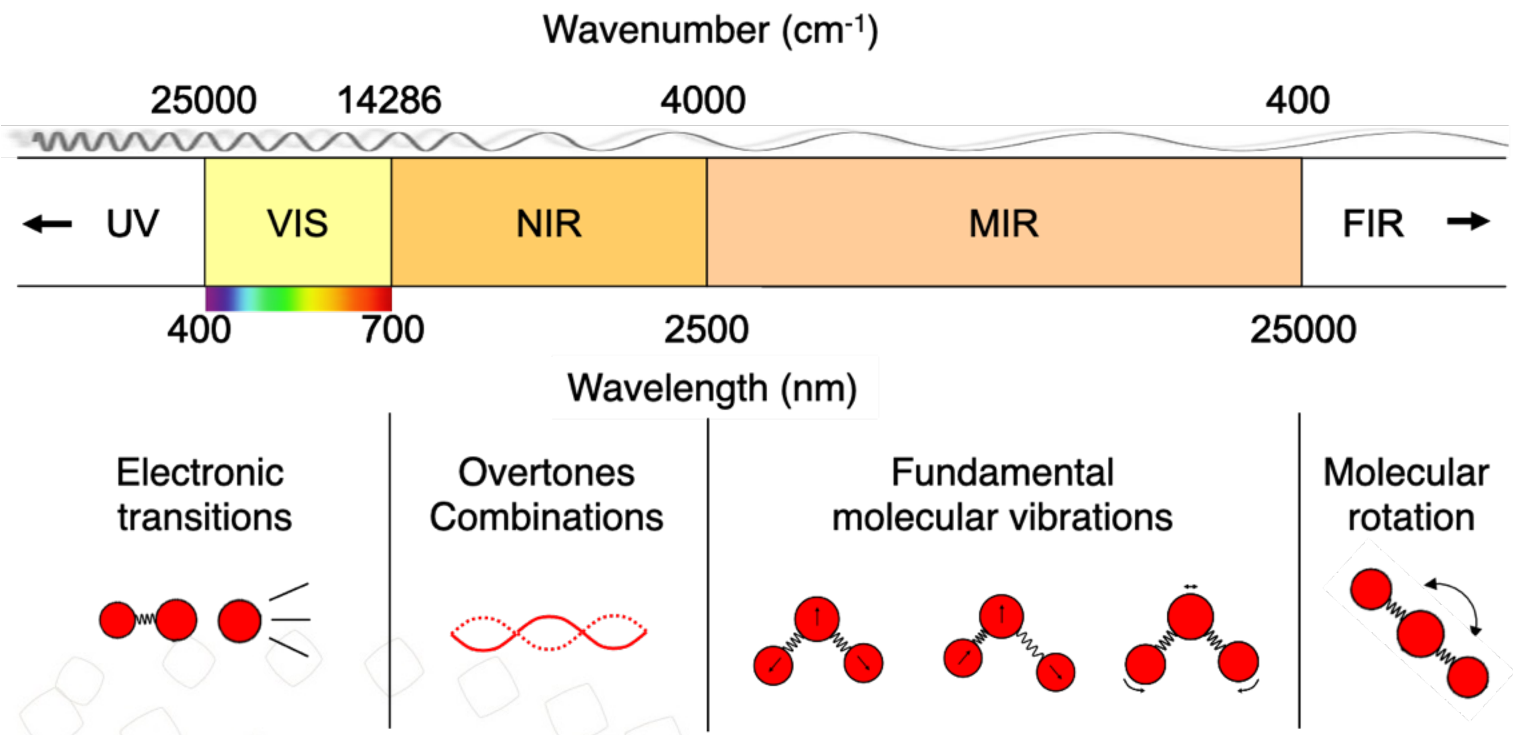
Spectroscopy



wavelength ⇔ wavenumbers
$cm^{-1} = 10^7 / x$ nm

Soil spectroscopy

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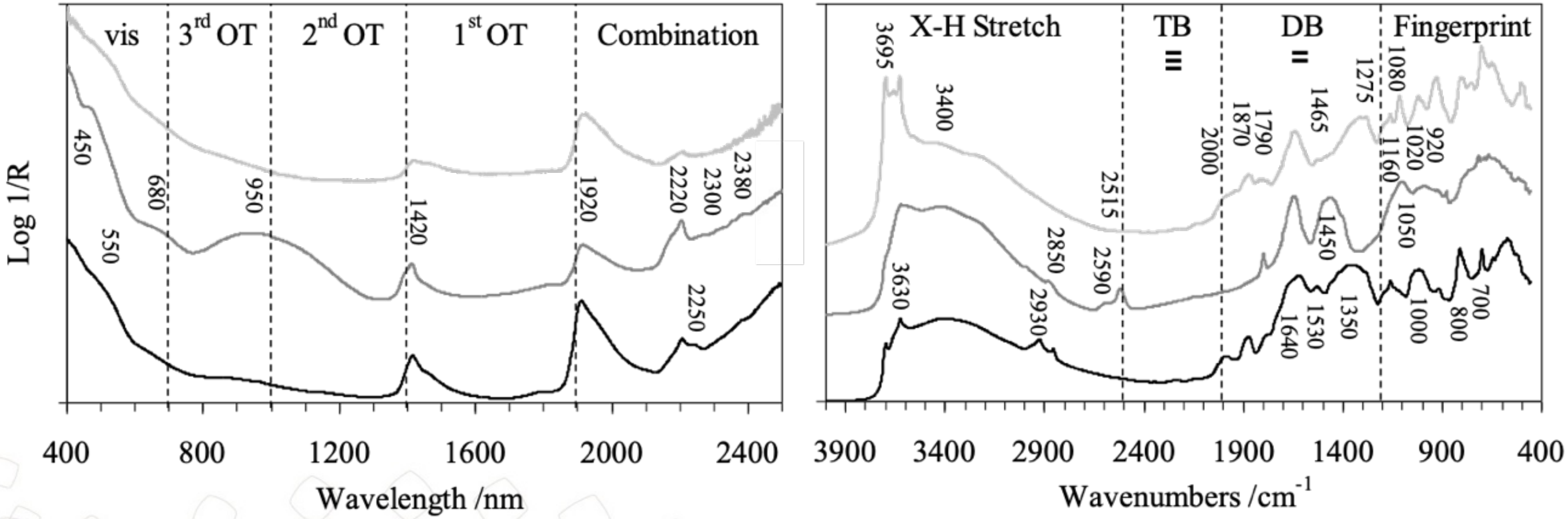
vis: electronic transitions
NIR: combinations and overtones

mid-IR: fundamental molecular vibrations of soil mineral and organic structures

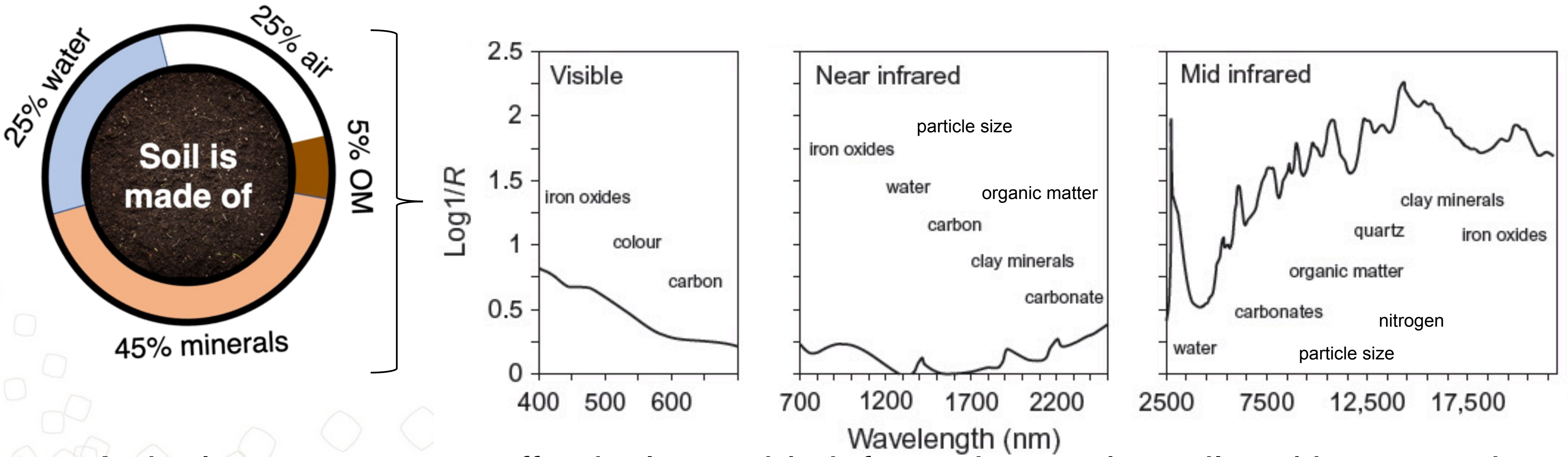


The spectral range to use depends on the application – each has advantages/disadvantage

Adapted from Viscarra Rossel *et al.* (2008)

Spectra encode fundamental soil information

Spectra measure the composition of soil which determines soil properties and functions



A single spectrum can effectively provide information on the soil and its properties

Soil spectroscopy research

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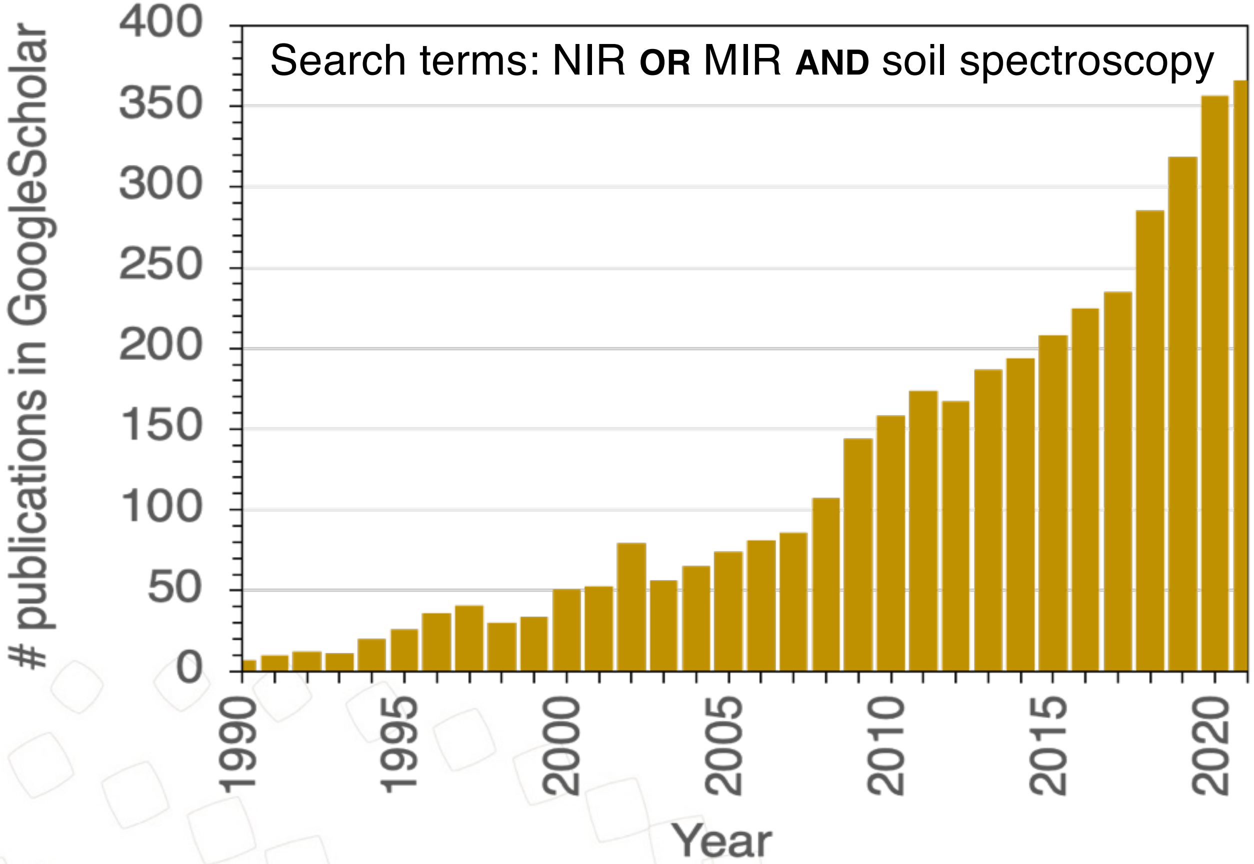

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Can measure spectra from different platforms

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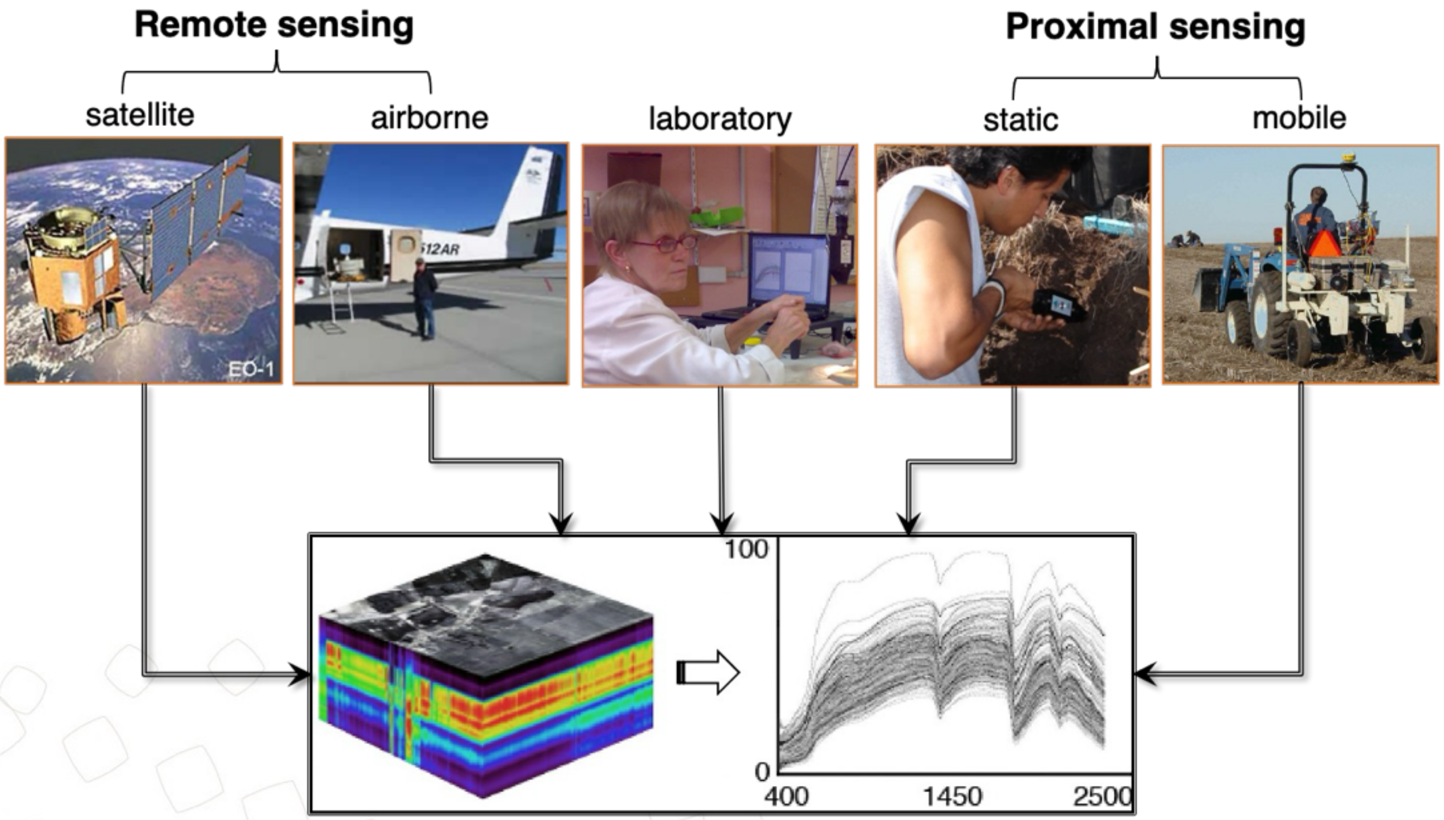

Adapted from Viscarra Rossel *et al.* (2016)

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Technologies are more accessible

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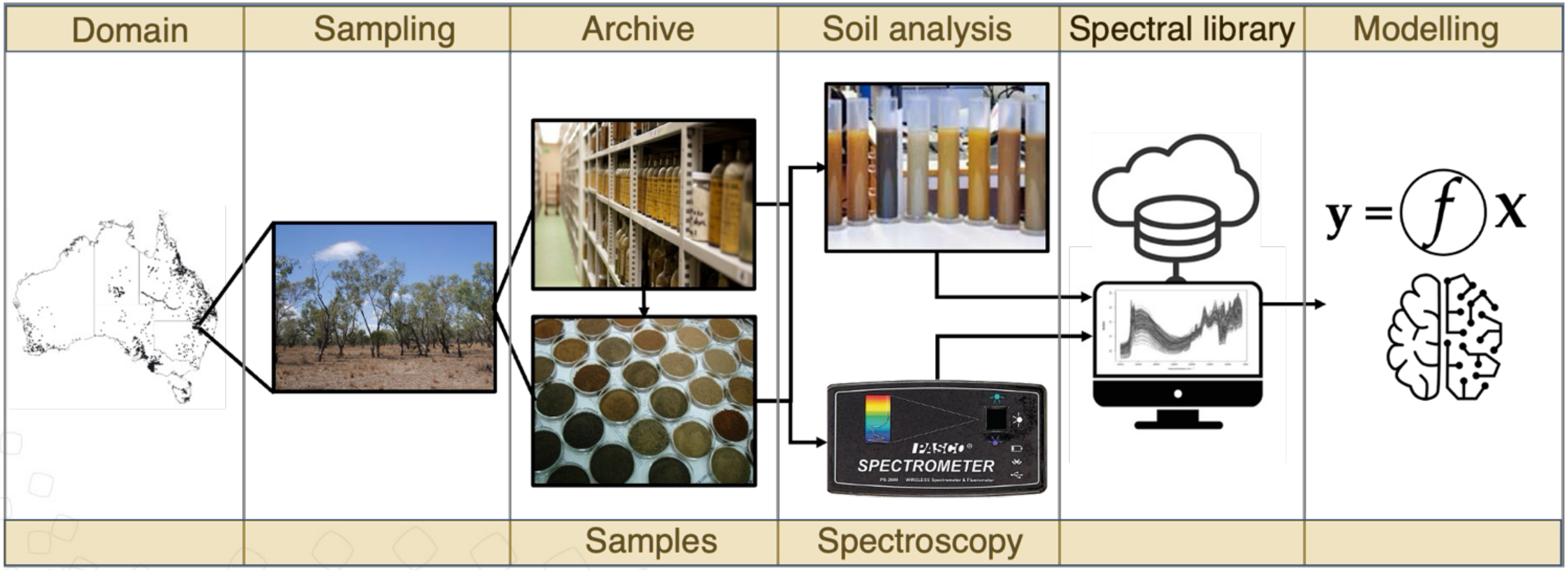
Spectrometers are becoming, smaller, cheaper, smarter, more energy efficient

Greater accessibility is not all positive: it has given some misinformed ‘entrepreneurs’ the idea that simply the technology and ‘machine learning’ can almost like magic get you results.

Viscarra Rossel et al. (2011 Adv.Agron)

Developing a soil spectral library

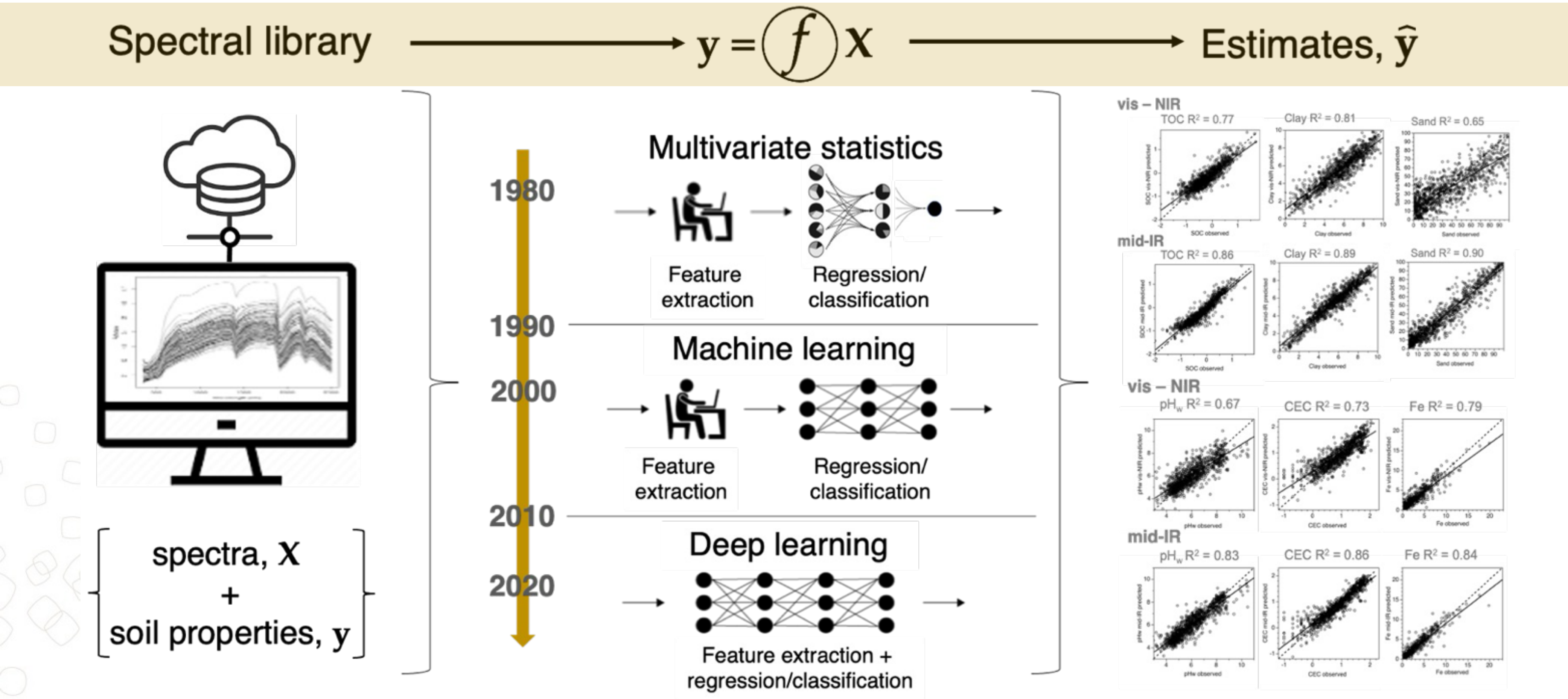


Shepherd & Walsh (2002; SSSAJ)
Brown *et al.* (2006; Geod)
Viscarra Rossel *et al.* (2008; AJSR)

Viscarra Rossel & Wester (2012; EJSS)
Stevens et al. (2013; PloSOne)
Shi et al. (2014; SciChinaEarthSci)

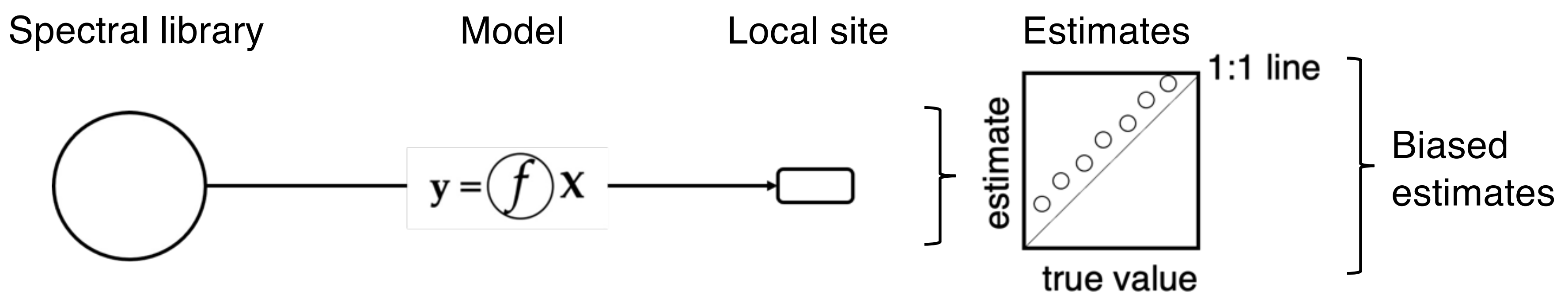
Viscarra Rossel et al. (2016; ESR)
Dematte et al. (2019; Geod)

Spectral modelling



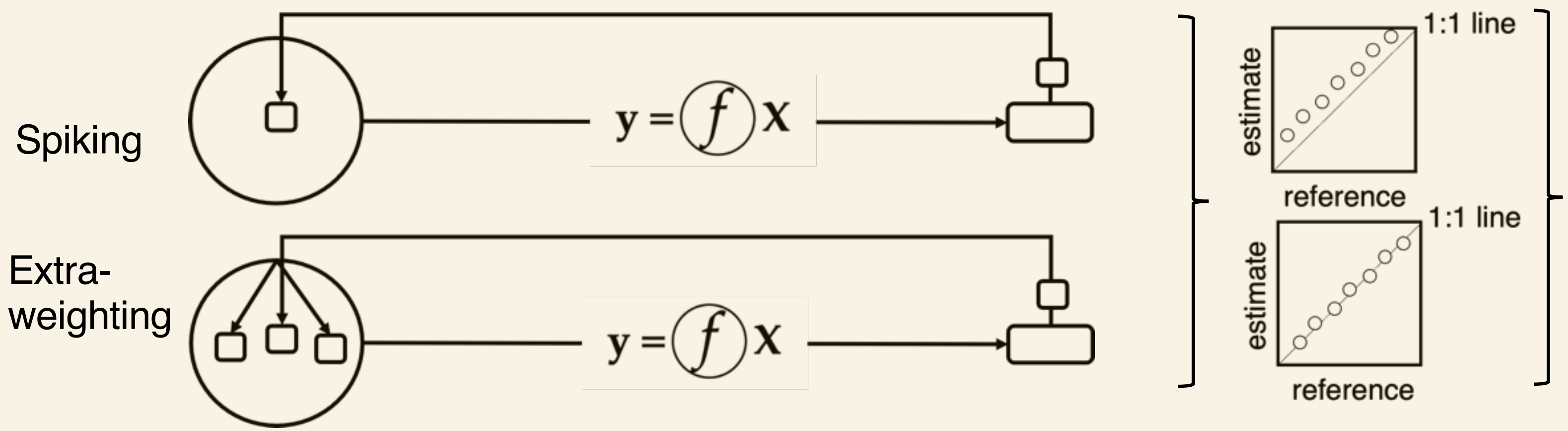
Viscarra Rossel (2008; CILS); Viscarra Rossel & Webster (2012; EJSS); Viscarra Rossel & Behrens (2010; Geod); Shen & Viscarra Rossel (2021; SciRep)

Challenge 1: How to use spectral libraries to fit locally



A possible solution: data augmentation

Spectral library | Model | Local site | Estimates



Simple to implement but limited success.

Can work with under some conditions

Data augmentation

Guerrero *et al.* (2010; 2014)

A possible solution: deterministic search

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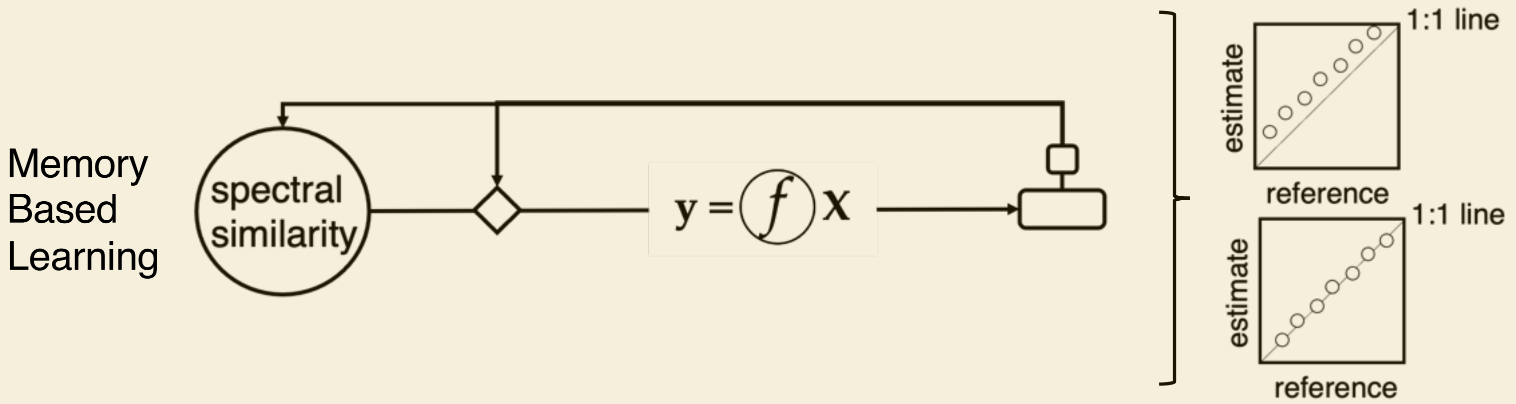
Spectral library	Model	Local site	Estimates



Variable success reported.

Since based on similarity, affected by measurement disturbances.

Deterministic search

Ramirez-Lopez *et al.* (2013)

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A possible solution: stochastic/evolutionary search

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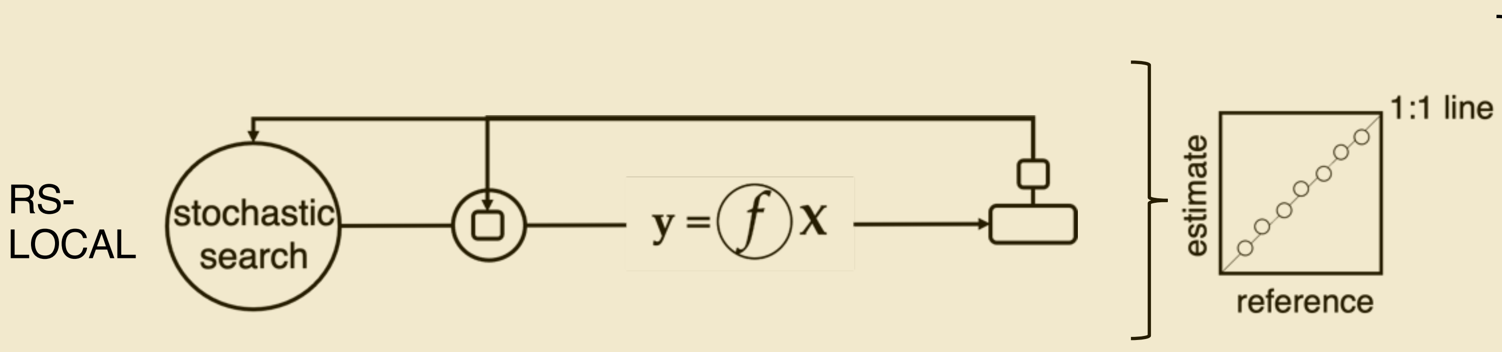
Spectral library | Model | Local site | Estimates



Promising results.

Selection of 'fittest' instances, thus, less affected by measurement disturbances.

Stochastic, evolutionary search / transfer learning (instances)

Lobsey, *et al.* (2017)

A possible solution: deep transfer learning

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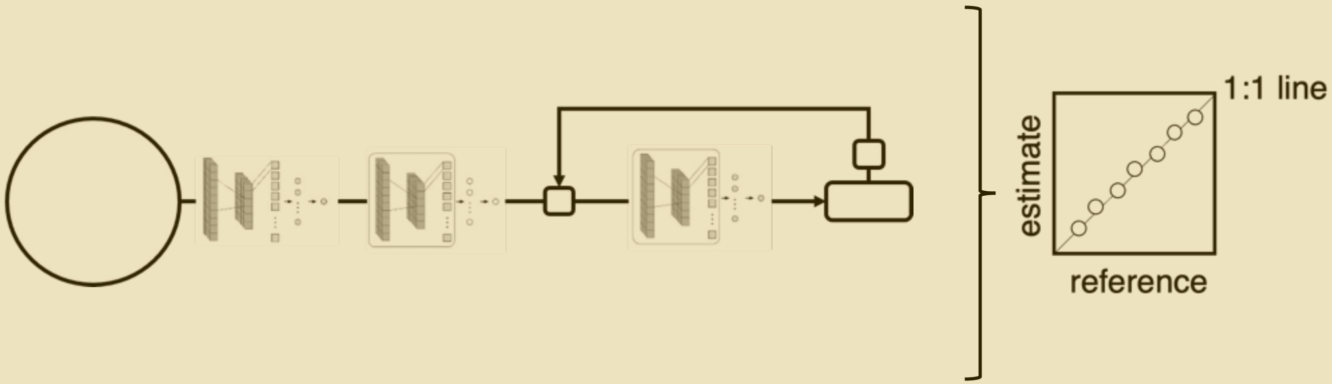
Spectral library | Model | Local site | Estimates

Deep TL



Transfer learned features. Need more exploration – seem promising.

Useful for calibration transfer

Deep transfer learning (representations)

e.g. Liu, *et al.* (2018); Padarian et al. (2019);
Shen & Viscarra Rossel (2021)
Tsakiridis et al. (2021)…etc.

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Challenge 2: The G.I.G.O. concept is very relevant

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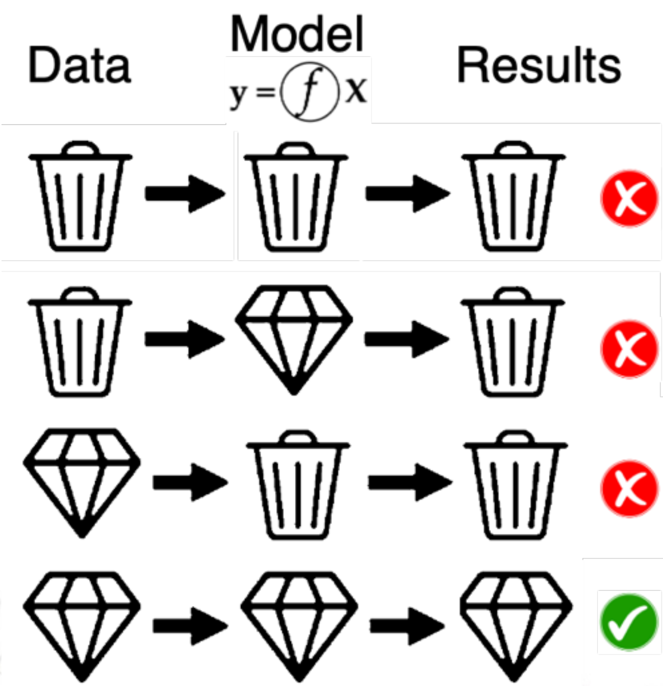

Quality of outputs determined by quality of inputs **AND** quality of modelling

Key considerations for building spectral libraries and to ensuring quality outputs (ordered list):

1. Reference soil analysis (phys, chem, bio)
2. Soil sample handling and preparation
3. Spectral modelling
4. Spectroscopic measurements
5. The soil sampling design

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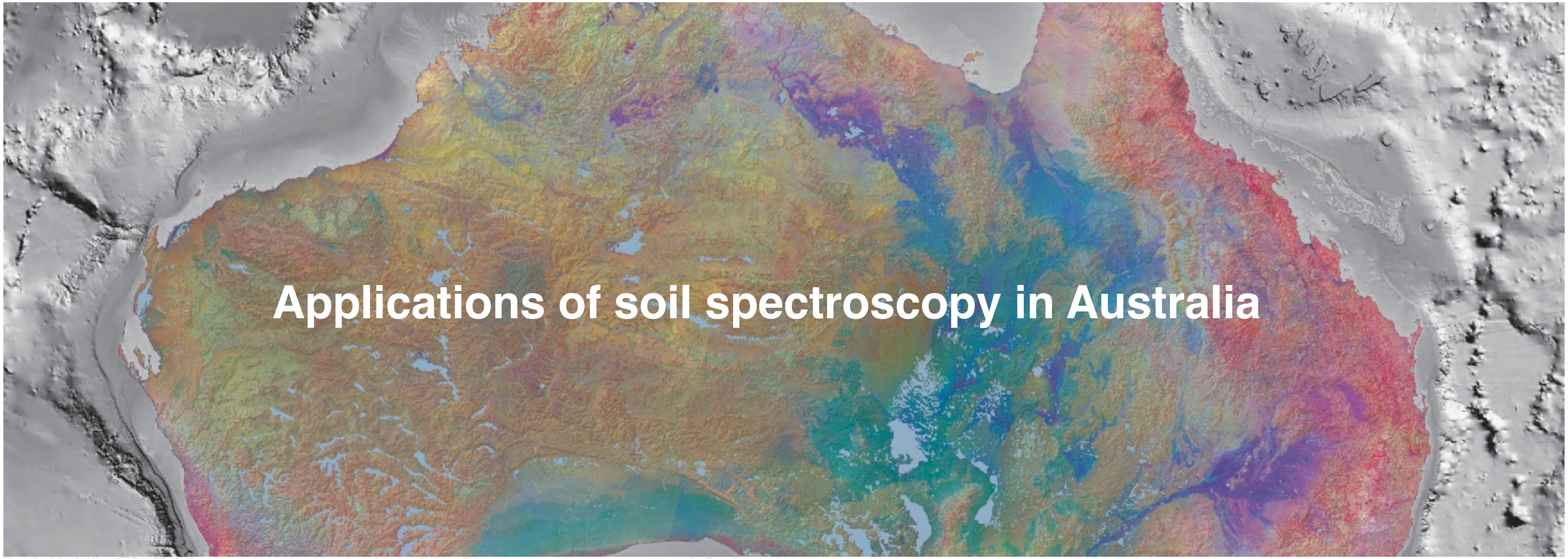
Applications of soil spectroscopy in Australia



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Example 1: Direct quantification colour and mineralogy

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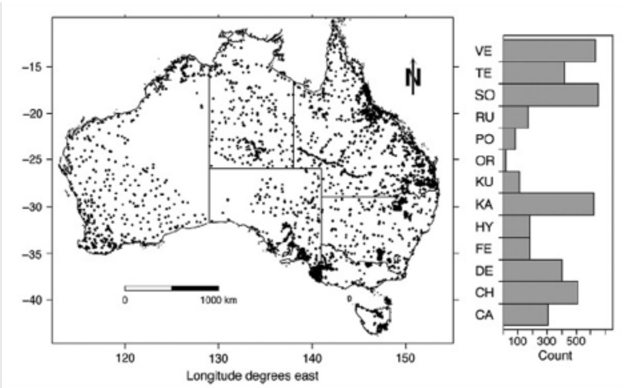
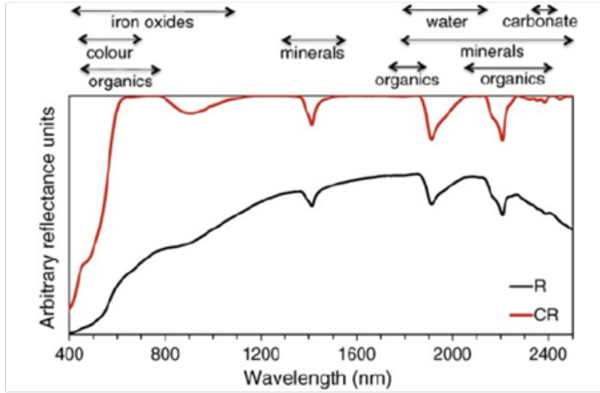
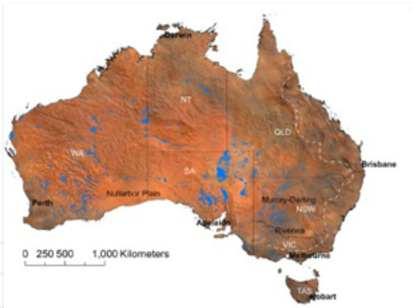


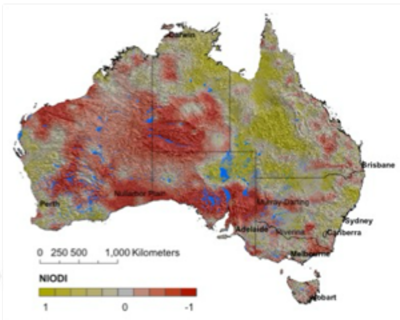
Measured vis–NIR spectra of 5,000+ archived representative soil samples from Australia

The vis–NIR spectra itself are informative, so digitally mapped their information content



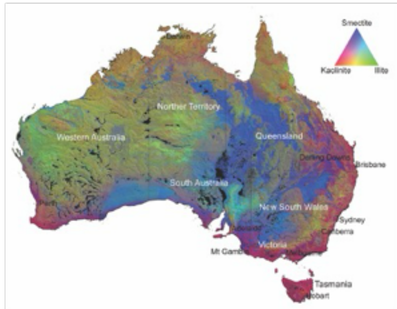


RGB composite but also maps of Munsell HVC



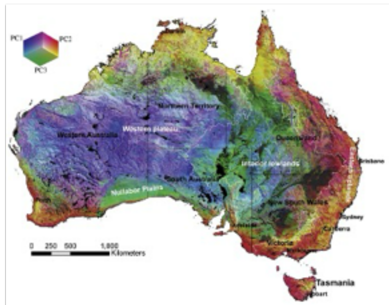
Probability of hematite or goethite

Viscarra Rossel et al. (2010; JGR-ES)



Maps of kaolinite illite, smectite 90 x 90 m

Viscarra Rossel (2011 ; JGR-ES)



Proxy for soil type 90 x 90 m

Viscarra Rossel & Chen (2011; RSE)

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Example 2: Continental-scale application

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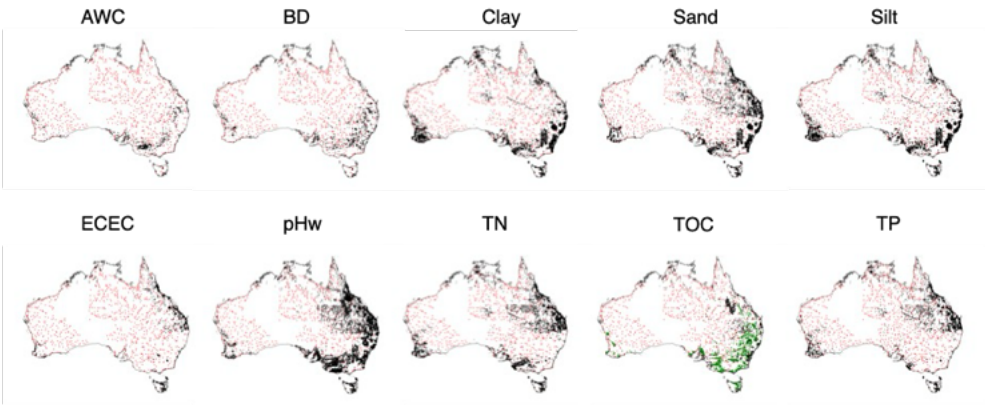

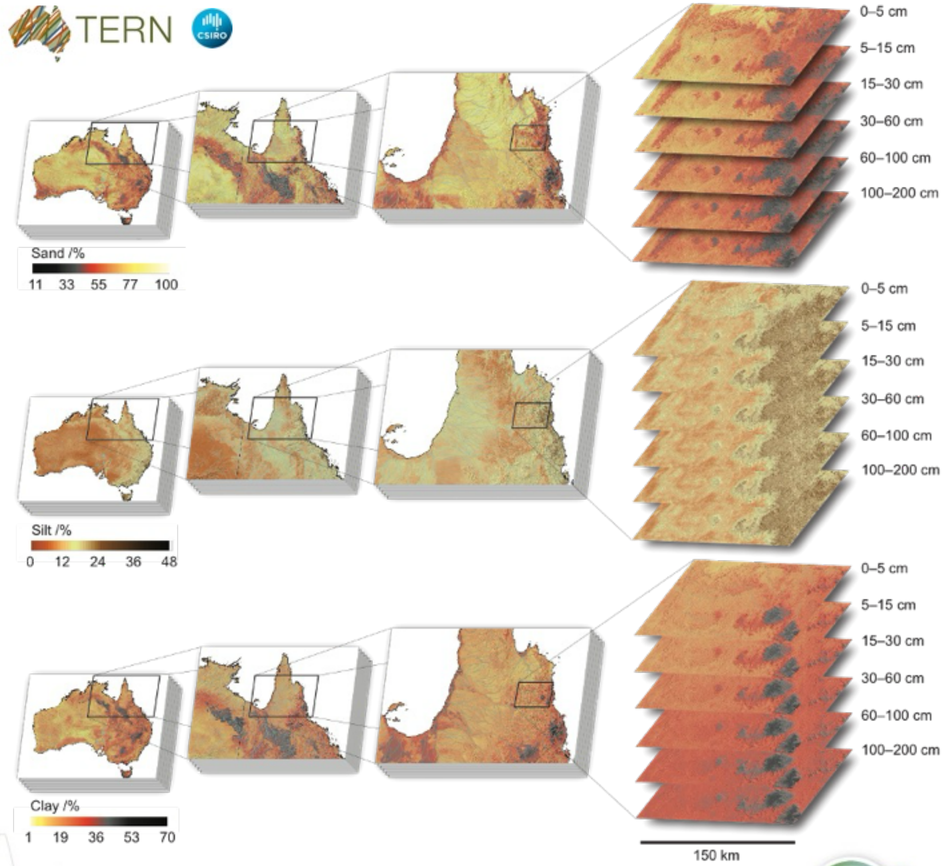

Combined soil property data + **spectroscopic predictions** of soil attributes **enabled continental scale digital soil mapping:** $S_a = f(cl, o, r, p, t)$

$$\widehat{S}^b_{\mathrm{A}}(\mathbf{u}_0, d) = \widehat{\mu}^b_{\mathrm{A}}(\mathbf{u}_0, d) + \widehat{\varepsilon}^b(\mathbf{u}_0, d)$$

Viscarra Rossel et al. (2015; AJSR); Grundy et al., (2015; AJSR)

Example 3: Farm-scale application

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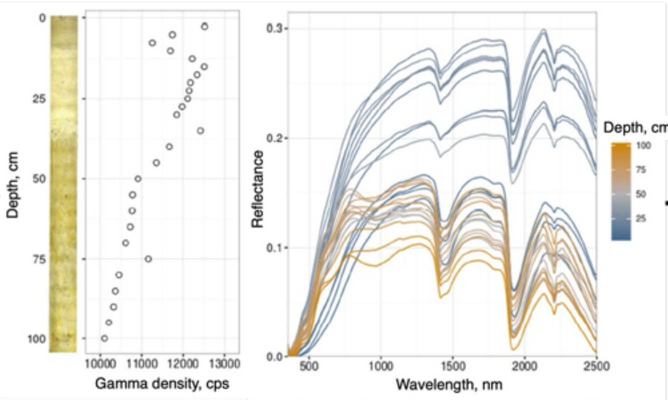
Automated soil core sensing

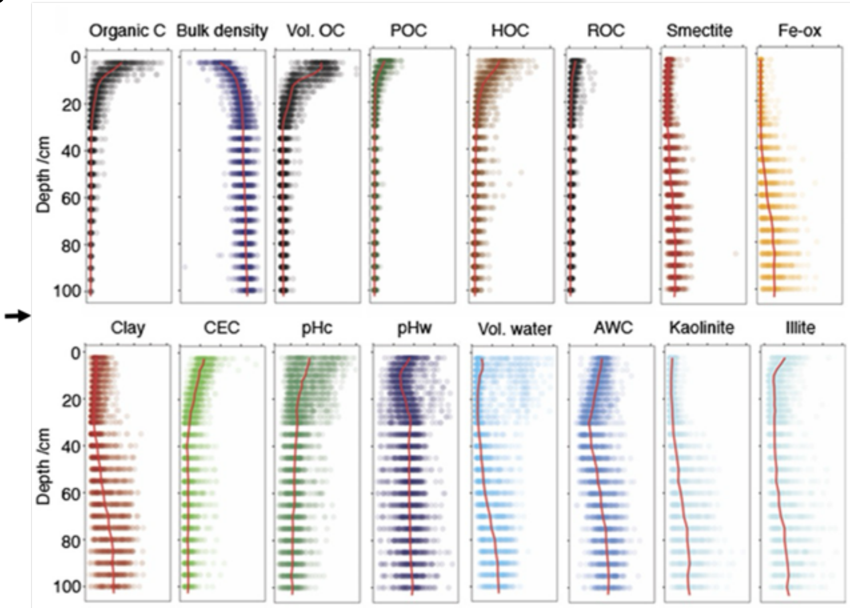
Sensors:
digital camera
densitometer
vis–NIR spectrometer

Local spectral modelling

Measurements of 150 soil cores for farm-scale assessment of soil condition



$y = f(x)$



Viscarra Rossel et al. (2017 EnvSciTech)

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globeSpeC

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Enabling global soil spectroscopy

- Develop a software platform that enables the use of large (country, global) spectral libraries
- The platform should be versatile and minimise complexity
- Should be dynamic and enable continual growth of the library
- Accessible by land managers, farmers, researchers …anywhere in the world and for the common good

Final remarks

- Soil spectroscopy in the current context refers mainly to the visible, near infrared and mid infrared regions of the EM spectrum
  - each has advantages/disadvantages
  - the spectral range to use can depend on the: application, availability of instrumentation, labour, costs,…etc.

- Soil spectra encode unique information on soil organic-mineral composition that can be used as soil ‘fingerprints’ to more objectively define soil type and composition and to monitor condition – more research on the direct use of spectra is needed

Final remarks

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- Standardisation of soil spectroscopy methods for development of spectral libraries is important, and robust protocols are essential, BUT lets not over-complicate what is one of the most precise and easy-to-use analytical techniques
  - personally, I think that more effort should be placed on the reference soil analysis, the sample preparation (drying, grinding, sample presentation…)

- Development of soil spectral libraries to represent the immense soil diversity is needed and this might be best done by countries with support and coordination by GLOSOLAN-Spec – hopefully globeSpeC can help enable this.

Final remarks

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- Spectroscopic modelling is ‘tricky’…one needs to understand the spectra, at least some experience and familiarity with robust modelling practice - more than simply applying a ‘machine learning’ algorithm in R

- In soil spectroscopy, don’t get fooled by the machine learning ‘hype’ – when appropriately used, ML is absolutely useful, sure, but it is not the only solution and alone will not solve the ‘localization’ challenge.
  For local modelling, with small-medium sized data with linear response, statistical methods like PLSR are most robust.

Final remarks

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- Soil spectroscopy is not magic, don't expect miracles. There will be situations where it might not work, for different reasons, e.g. because there is no fundamental basis for the modelling, because of the G.I.G.O principle, because of deficiencies in the sampling design, because the spectral library does not represent the local variability, etc…
- Lets not lose sight that there are other sensing methods that can also help to cost-efficiently acquire soil information. Their research and development is important because not any one single technique can do it all…not even soil spectroscopy.

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Thank you

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