Soil spectroscopy: a method for proximal soil sensing

Raphael VISCARRA ROSSEL
Soil & landscape program CSIRO Land & Water

2nd Global Workshop on Proximal Soil Sensing
15–18 May 2011

CSIRO

Summary

1. Proximal soil sensing - spectroscopy
2. The information content of soil spectra
3. Spectral libraries – The Global Spectral Library
4. Field measurements – proximal soil sensing
5. Concluding remarks

Techniques used for proximal soil sensing

'…the use of sensors in the field to obtain signals from the soil when the sensor's detector is in contact with or close to it.'

EM Range			γ-rays		X-rays		UV – Visible – Infra red					Micro and Radio waves									
Frequency (Hz)			10^{21}		10^{18}		10^{16}	10^{15}	10^{14}	10^{13}		10^{10}	10^{9}		10^{7}		10^{6}	10^{5}			
Wavelength (m)			10^{-12}		10^{-10}		10^{-8}	10^{-6}	10^{-5}	10^{-4}		10^{-1}	10^{1}		10^{2}		10^{3}	10^{4}			
Technique	INS	TNM	Active γ	Passive γ	XRF	XRD	UV	vis	NIR	mid-IR	LIBS	Micro	WSN	TDR	FDR	Capac	GPR	EMI	ER	ECh	Mech
Bio-Chemical																					
Carbon	D			i	D			d	D	D	D										
Nitrate-nitrogen										i	I							i	i	D	
Phosphorus	D				D				i	I											
Potassium				D					i	I										D	
Major nutrients	D				D				i	i	D									D	
Micronutrients	D				D		D		i	i	D									D	
Total Iron	D			i	D			i	I	I	D										
Iron oxides				i			D	D	D	D											
Heavy metals	D				D			i	I	I	D										
CEC				I					I	I								i	i		
Soil pH				I					I	I			D							D	
Buffering capacity									I	I										I	
Salinity																		D	D	D	
Physical																					
Colour								D													
Water content	D	D	D	I				i	D	D		D	D	D	D	D	D	I	I		D/I
Matric potential									I	I									D		
Clay				I				i	D	D								I	I		
Silt				I					I	I								i	i		
Sand				I					i	D								I	I		
Clay minerals				I	I	D		i	D	D	I							i	i		
Soil strength																					D
Bulk density			I	I					I	I							D				I
Porosity																					D

Viscarra Rossel et al., 2011 Adv. Agron.

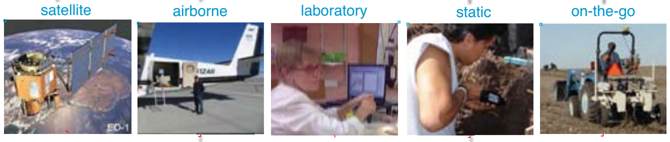
Spectrocopy for proximal soil sensing

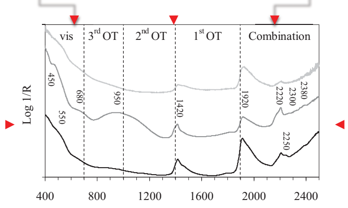
EM Range			γ-rays		X-rays		UV – Visible – Infra red					Micro and Radio waves									
Frequency (Hz)			10^{21}		10^{18}		10^{16}	10^{15}	10^{14}	10^{13}		10^{10}	10^{9}		10^{7}		10^{6}	10^{5}			
Wavelength (m)			10^{-12}		10^{-10}		10^{-8}	10^{-6}	10^{-5}	10^{-4}		10^{-1}	10^{1}		10^{2}		10^{3}	10^{4}			
Technique	INS	TNM	Active γ	Passive γ	XRF	XRD	UV	vis	NIR	mid-IR	LIBS	Micro	WSN	TDR	FDR	Capac	GPR	EMI	ER	ECh	Mech
Bio-Chemical																					
Carbon	D			i	D			d	D	D	D										
Nitrate-nitrogen										i	I							i	i	D	
Phosphorus	D				D				i	I											
Potassium				D					i	I										D	
Major nutrients	D				D				i	i	D									D	
Micronutrients	D				D		D		i	i	D									D	
Total Iron	D			i	D			i	I	I	D										
Iron oxides				i			D	D	D	D											
Heavy metals	D				D			i	I	I	D										
CEC				I					I	I								i	i		
Soil pH				I					I	I			D							D	
Buffering capacity									I	I										I	
Salinity																		D	D	D	
Physical																					
Colour								D													
Water content	D	D	D	I				i	D	D		D	D	D	D	D	D	I	I		D/I
Matric potential									I	I									D		
Clay				I				i	D	D								I	I		
Silt				I					I	I								i	i		
Sand				I					i	D								I	I		
Clay minerals				I	I	D		i	D	D	I							i	i		
Soil strength																					D
Bulk density			I	I					I	I							D				I
Porosity																					D

vis–NIR and mid-IR spectroscopy can measure (directly/indirectly) many soil properties

vis–NIR with remote and proximal soil sensing

Remote sensing — satellite, airborne; laboratory; **Proximal sensing** — static, on-the-go

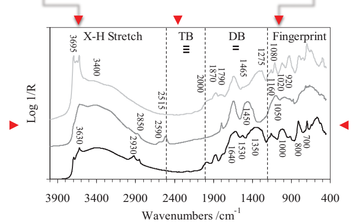




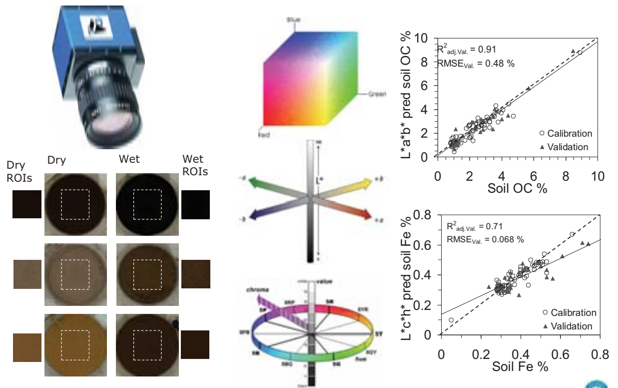
mid-IR with remote and proximal soil sensing

Remote sensing — satellite, airborne; laboratory; **Proximal sensing** — static, on-the-go

?

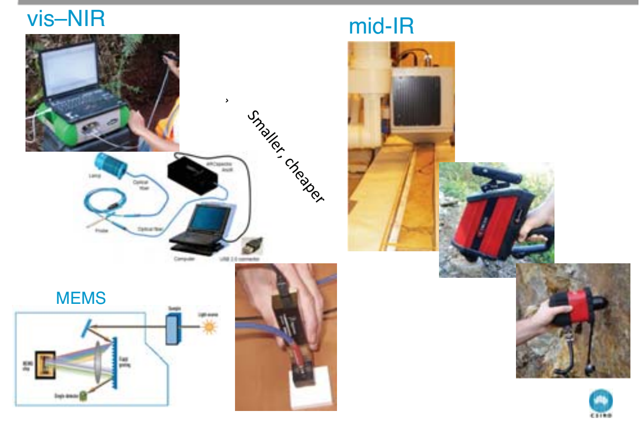


Visible range – soil colour



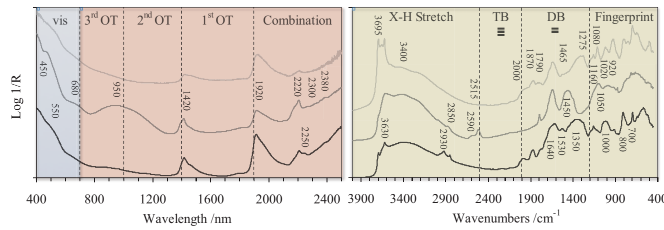
Viscarra Rossel et al., 2006 Geoderma; 2008 Biosys. Eng..

vis–NIR & mid-IR…smaller, cheaper instruments



2. The information content of soil spectra

Visible, NIR and mid-IR spectra

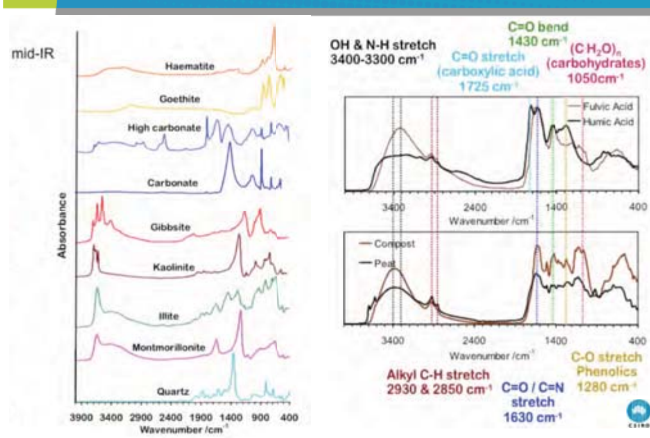


vis: electronic transitions

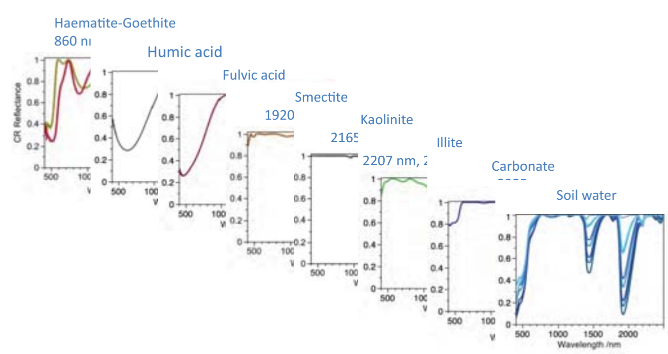
NIR: combinations and overtones

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

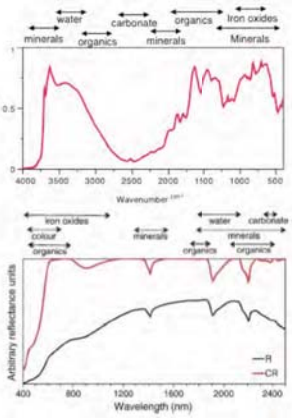
The information content of mid-IR soil spectra



The information content of vis–NIR soil spectra



Spectra - an integrative measure of soil



A soil spectrum measures soil composition:

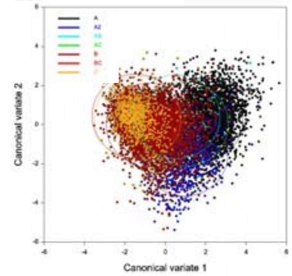
- Iron oxides
- Clay minerals
- Carbonates
- Colour
- Organic matter
- Water
- Particle size

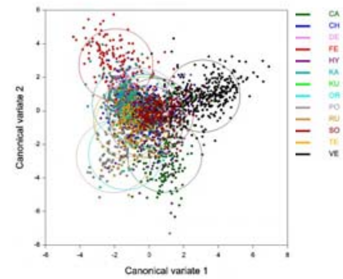
SOIL

Discriminating soil horizons and profile classes with vis–NIR spectra

Soil horizons

Australian Soil Classification (ASC) orders





60–90 % correct allocation

63–97 % correct allocation

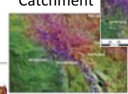
Viscarra Rossel & Webster, 2011 EJSS

High spatial resolution vis–NIR mapping

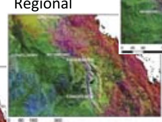
Digitally mapping the information content of Australian soil vis–NIR spectra

Sub catchment

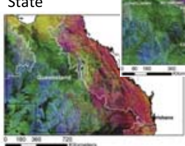
Catchment



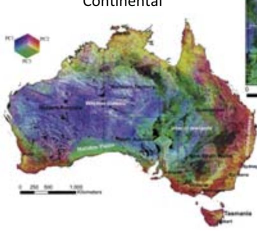
Regional



State



Continental



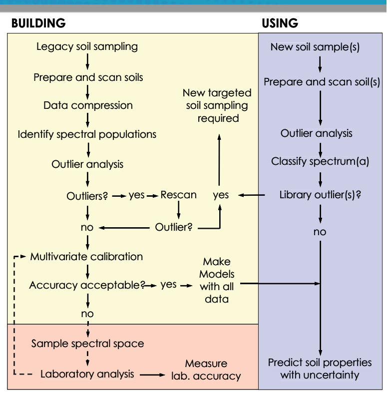
DSM performed on a 3 arcsecond (~ 90m pixels) grid using *s,c,o,r,p,a,n*

Viscarra Rossel & Chen, 2011 RSE

3. Spectral libraries

Soil spectral libraries

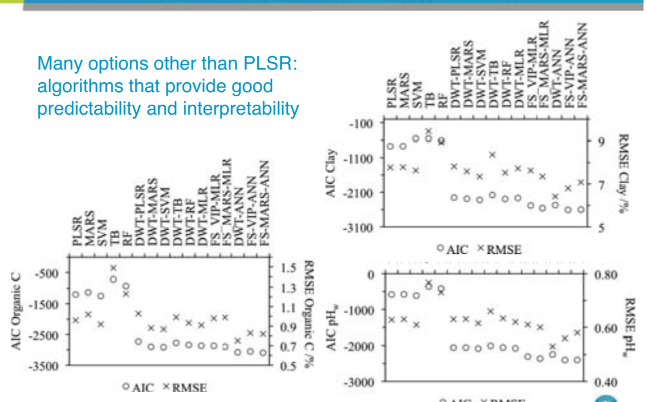
- Mineral identification
- Spectroscopic modelling
  - multivariate calibrations/ chemometrics



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

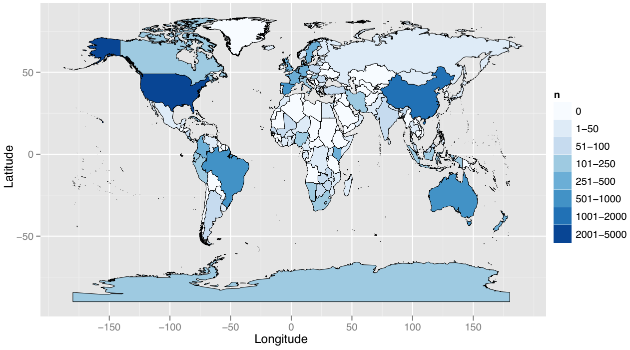
Spectroscopic modelling: **y** = *f*(**X**)

Many options other than PLSR: algorithms that provide good predictability and interpretability



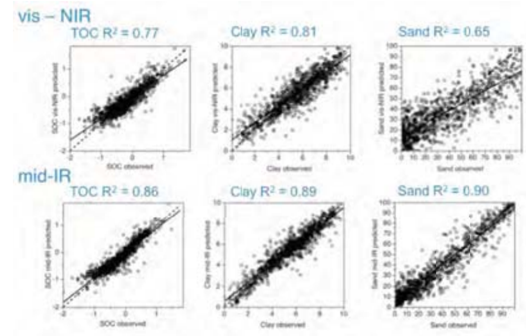
Viscarra Rossel & Behrens 2010 Geoderma

The global soil spectral library - GSSL



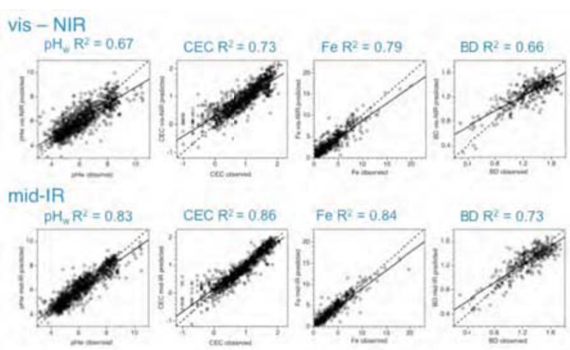
16,000+ spectra from 90 countries
All measured with vis–NIR and some with mid-IR

Global vis–NIR vs. mid-IR – using model trees



Comparison using 3415 soils from 55 countries

Global vis–NIR vs. mid-IR – using model trees

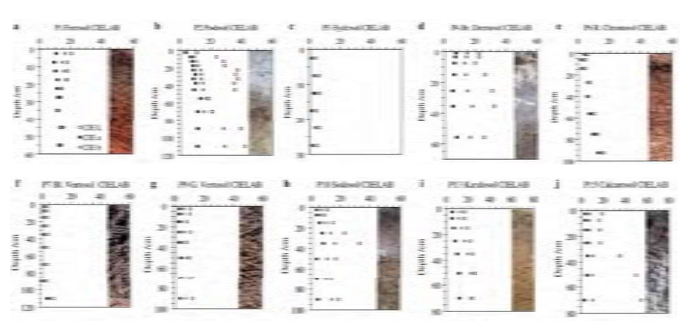


4. Field measurements – proximal soil sensing

1. Updating the pedologist's toolkit

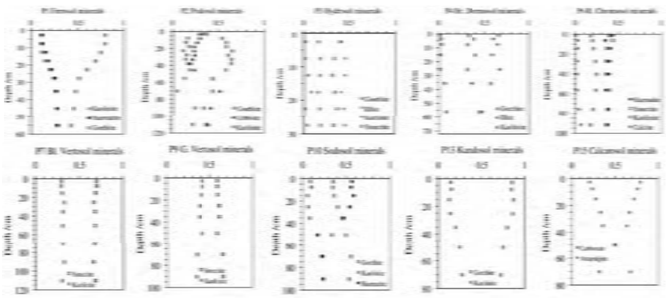
Lost of subjectivity – only qualitative at best

Spectroscopic measurements of soil colour



Colour in CIE Lab model but can also derive Munsell HVC

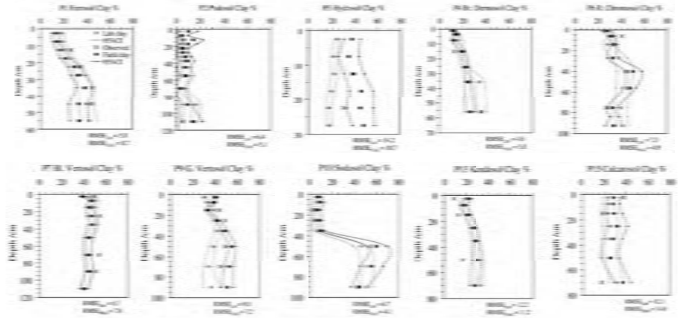
Measurements of soil mineralogy



Minerals measured directly from their characteristic absorptions

Viscarra Rossel et al. 2009 Geoderma

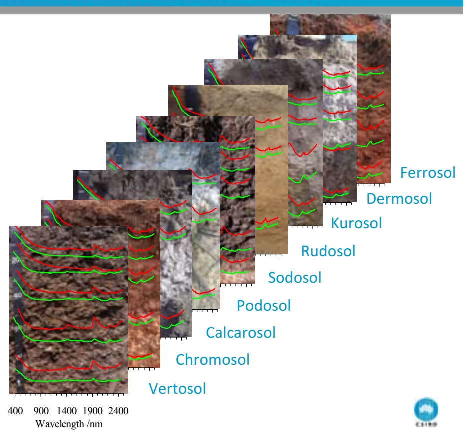
Measuring clay contents



Predictions using library 'spiked' with field spectra and bagging-PLSR

Viscarra Rossel et al. 2009 Geoderma

Assigning a soil classification



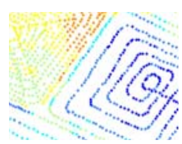
Discriminant analysis to assign ASC classifications

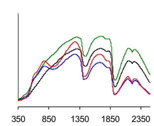
2. Mapping soil properties at Ginninderra farm

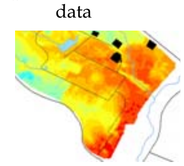
1
Acquisition of high resolution multi-sensor data

2
Use of reflectance spectra to measure soil properties of soil cores at various depths

3
Develop relationship between measured soil properties and sensor data



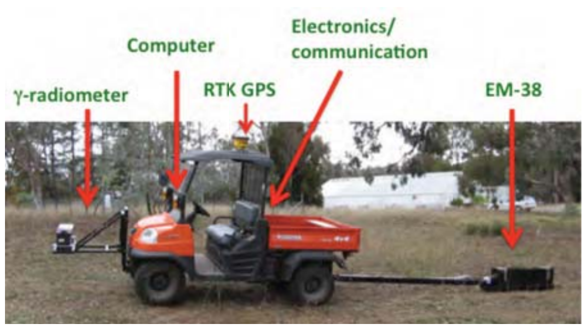




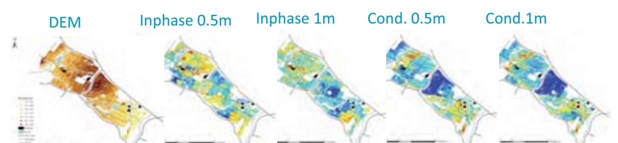
...a preliminary example

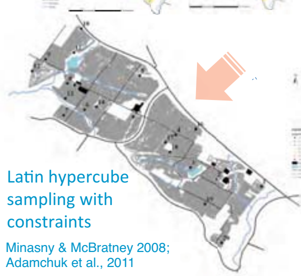
Acquisition of high resolution multi-sensor data

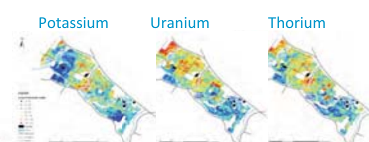
The 'eRover'



Multisensor data and soil sampling



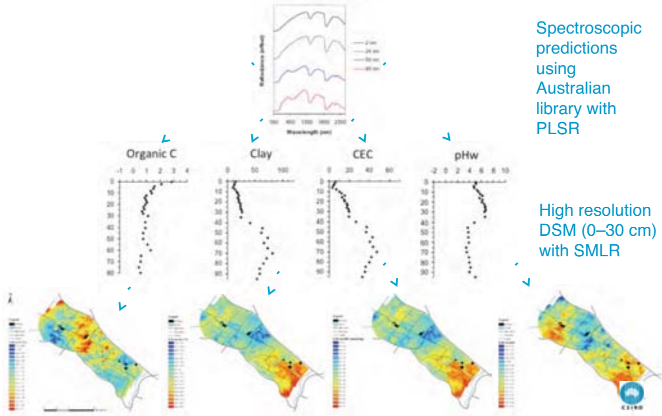




Latin hypercube sampling with constraints

Minasny & McBratney 2008; Adamchuk et al., 2011

Spectroscopic predictions and mapping



Spectroscopic predictions using Australian library with PLSR

High resolution DSM (0–30 cm) with SMLR

Concluding remarks

Development of spectral libraries is not PSS but is needed to support spectroscopic PSS

Soil spectra are integrative and measure the fundamental composition of soils: their organic matter, mineral and water contents – can be used for the assessment of soil condition!

The global soil spectral library combined will be made available for all to use

Proximal soil vis–NIR sensing – a useful tool for pedologists, for soil mapping…and monitoring!

Acknowledgements
Ms Fanny Collard
Mr Mark Glover
Ms Seija Tuomi

Thank you.

My contact details:
Raphael **VISCARRA ROSSEL**
Soil & Landscape Science
t. +61 2 6246 5945
m. +61 413 326 457
e. raphael.viscarra-rossel@csiro.au