Soil spectroscopy enables digital soil mapping and land resource assessments

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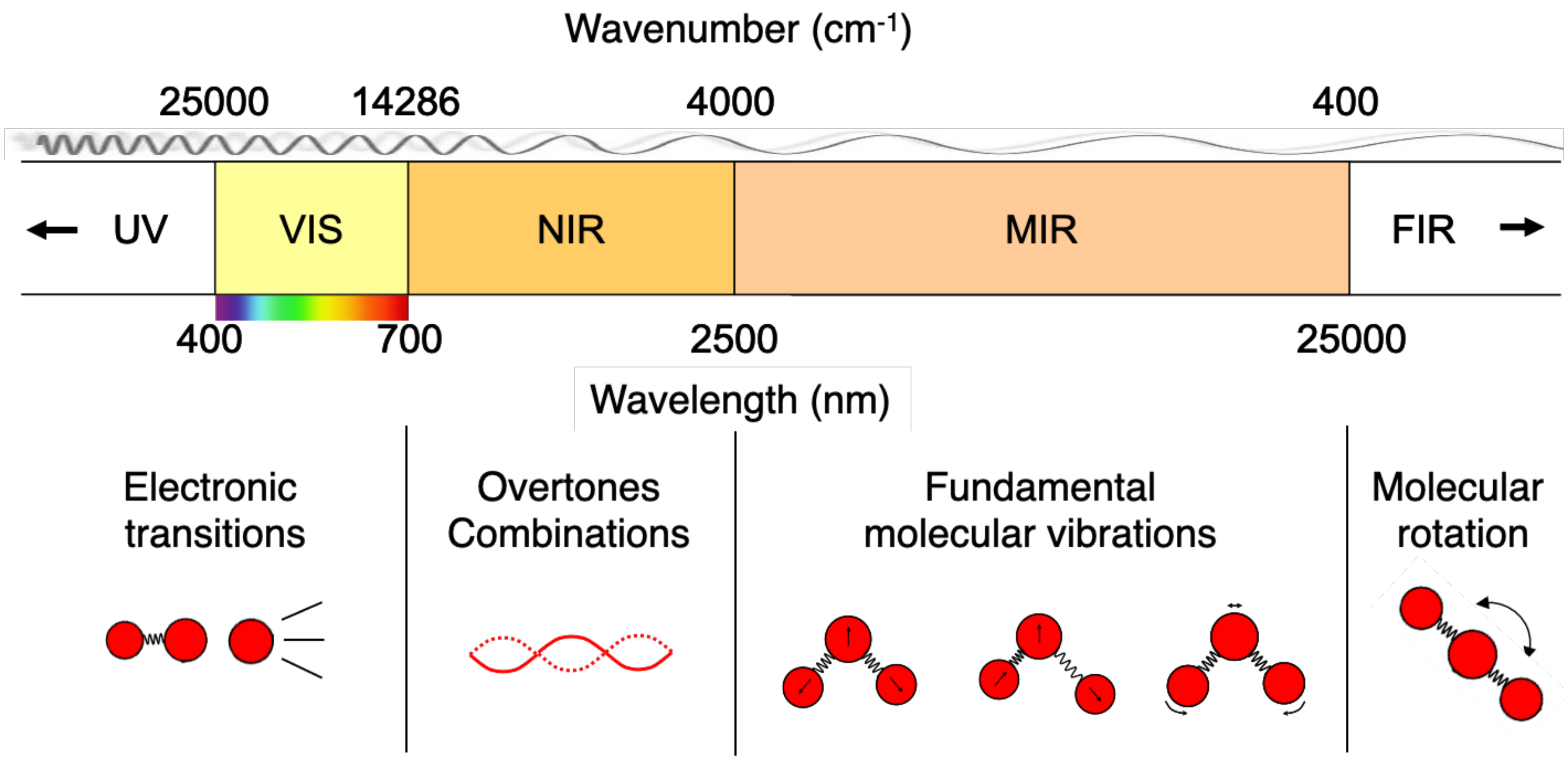
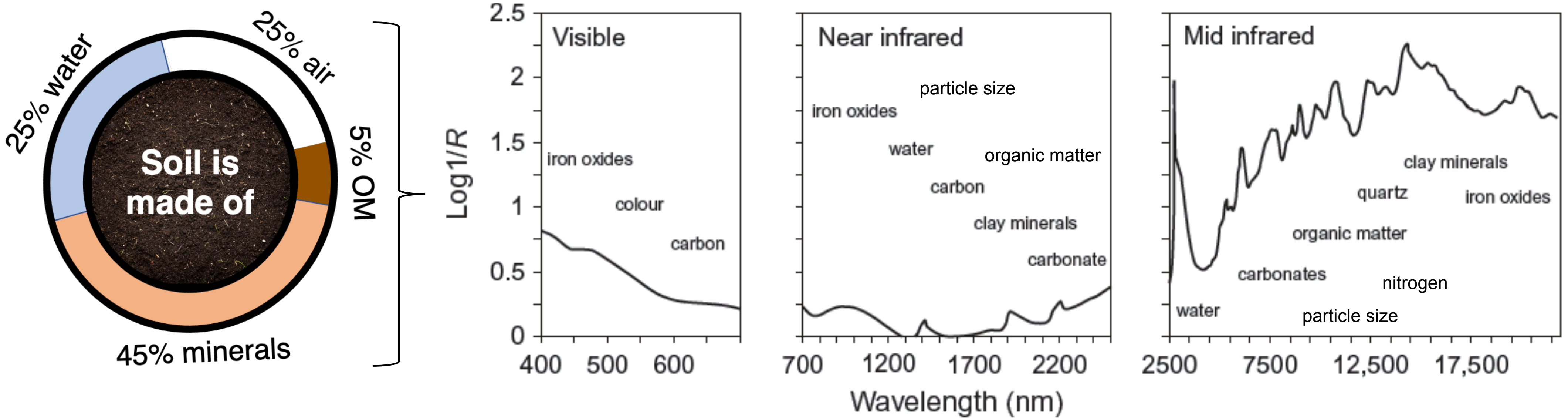
Curtin University

Soil spectroscopy



Spectra measure soil composition

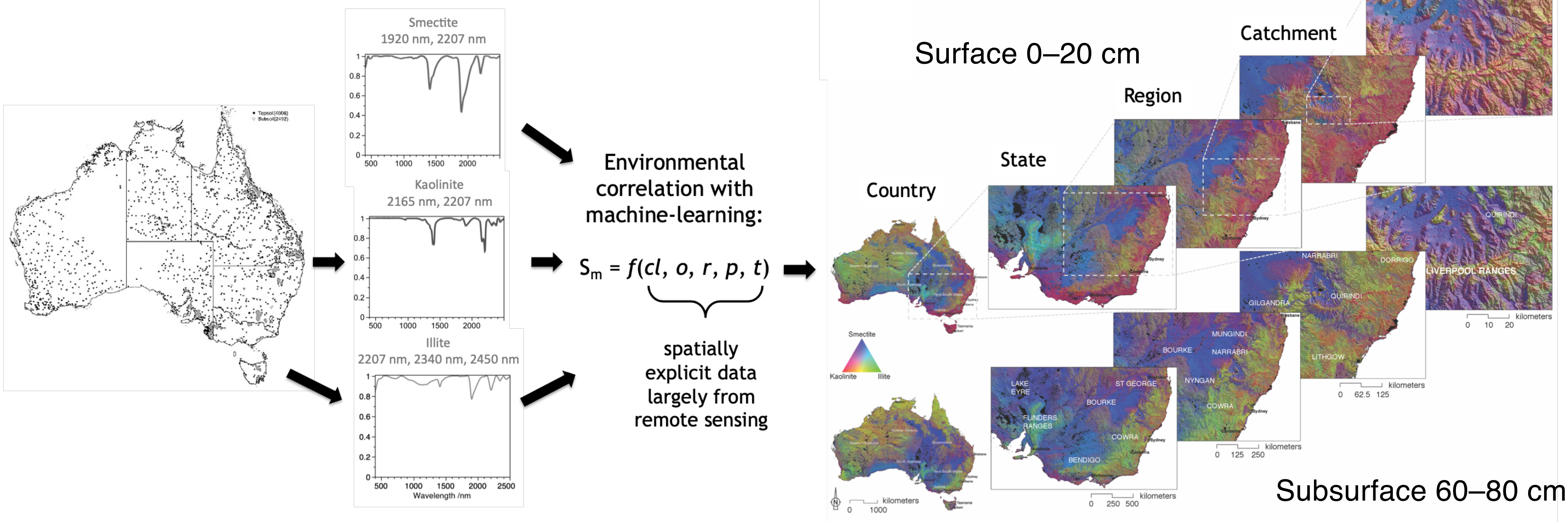


A single spectrum can effectively provide information on the soil and its properties

Digital mapping of the information content of soil spectra

Direct spectral measures of clay mineralogy

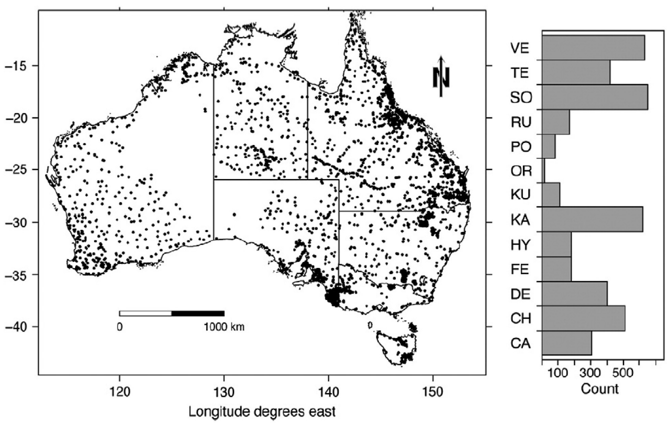
- vis–NIR spectroscopy + digital soil mapping



- Filling a gap in soil clay mineral information

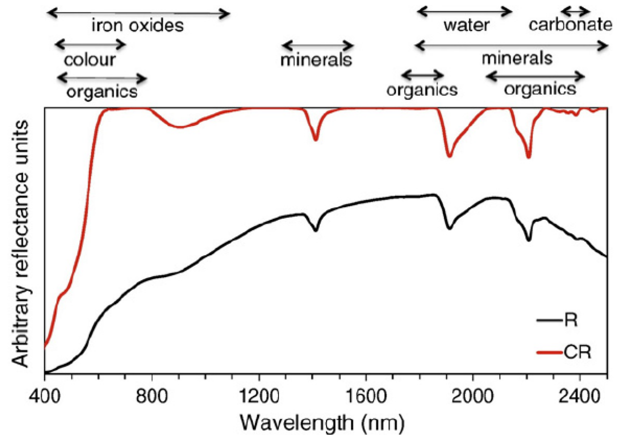
Digital soil maps of kaolinite illite, smectite
90 x 90 m

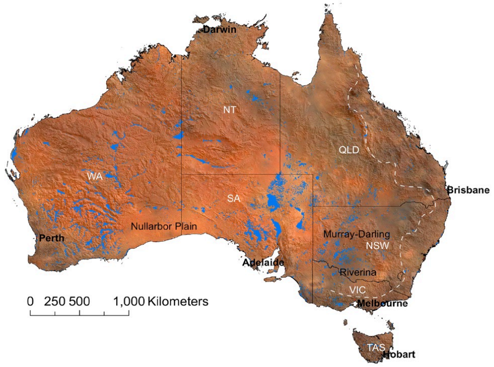
Quantifying soil colour, iron oxides, organo-mineral composition



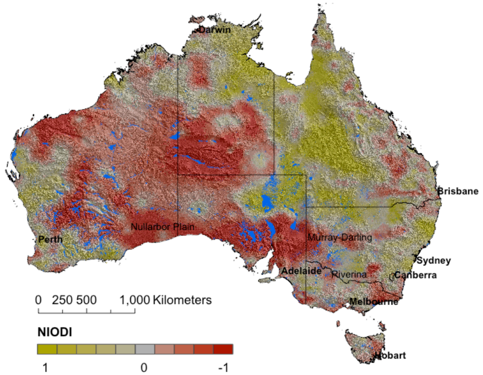
Measured vis–NIR spectra of 5,000+ archived representative soil samples from Australia

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

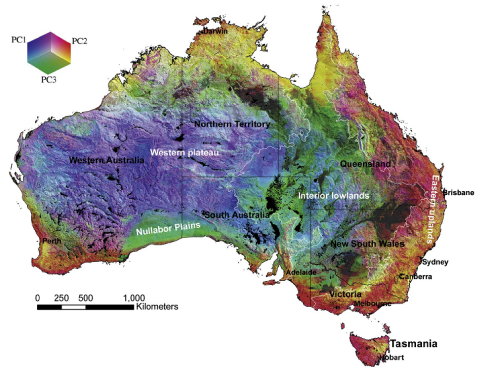




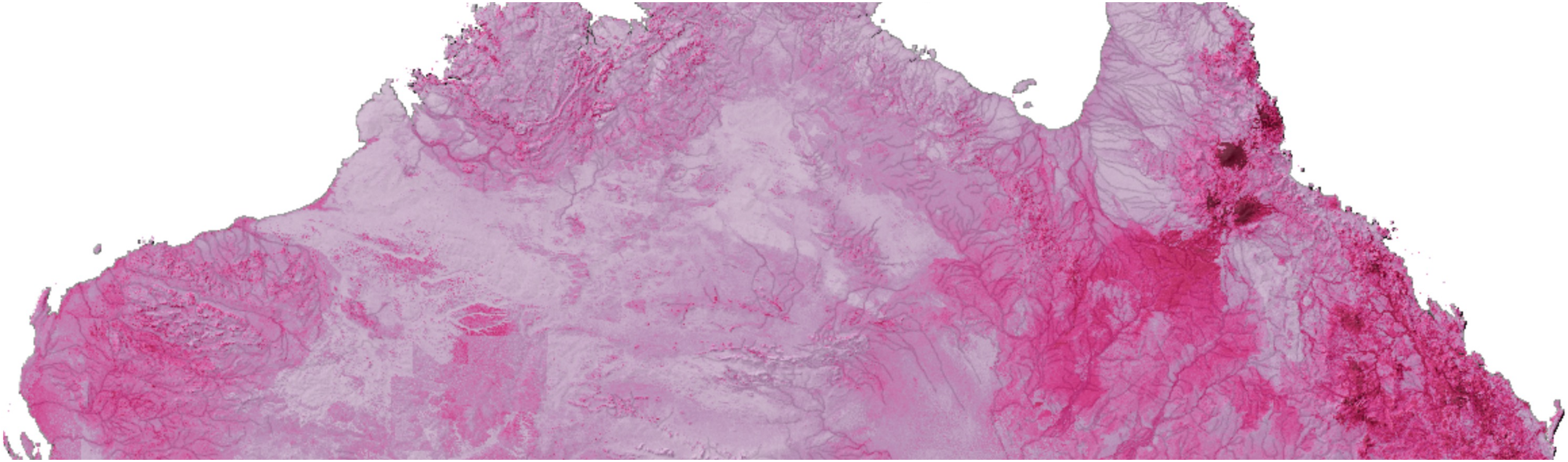
RGB composite but also maps of Munsell HVC



Probability of hematite or goethite



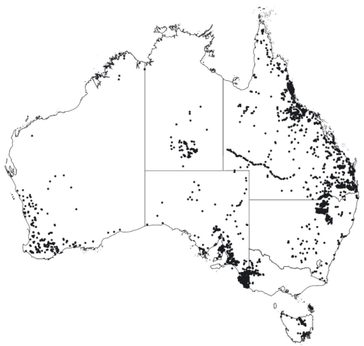
Proxy for soil type 90 x 90 m



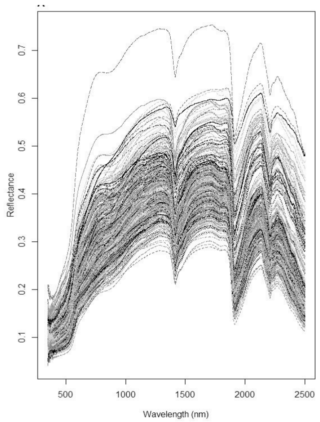
Soil spectral libraries and digital soil property mapping

Modelling soil properties requires soil spectral libraries

For example, the Australian spectral library



$y = (f) x$



Soil attribute	Mean	RMSE	SDE	ME	RPD
θ_{FC} /m^3 m^{-3}	0.32	0.06	0.06	−0.004	1.68
θ_{PWP} /m^3 m^{-3}	0.16	0.04	0.04	−0.001	1.95
$\text{Log}_{10}(W)$	0.56	0.21	0.21	0.005	1.54
Bulk density /g cm^{-3}	1.32	0.15	0.15	−0.003	1.87
Clay /%	32.0	8.49	8.48	0.51	2.35
Silt /%	12.5	5.50	5.47	0.58	1.63
Coarse sand /%	30.4	13.56	13.50	1.29	1.61
Fine sand /%	26.1	9.77	9.74	0.74	1.60
Total sand /%	55.1	12.00	12.00	−0.13	2.06
Log_{10}(Organic C)	-0.26	0.25	0.25	−0.01	2.17
Log_{10}(Total K)	-0.50	0.33	0.33	−0.04	1.87
Log_{10}(Total N)	-1.30	0.25	0.25	0.001	2.11
Log_{10}(C:N)	1.18	0.19	0.19	−0.001	1.40
Log_{10}(Total P)	-1.66	0.27	0.27	0.00	1.75
Log_{10}(Available P)	0.91	0.42	0.42	0.007	1.39
pH_{Ca}	5.31	0.57	0.57	0.05	2.16
pH_{Water}	6.95	0.63	0.63	0.002	2.28
CEC /cmol(+)kg^{-1}	15.6	7.08	7.06	0.51	2.13
Log_{10}(Exch. acidity)	0.42	0.28	0.28	0.009	1.49
Exch. Ca^{2+} /cmol(+)kg^{-1}	7.91	3.77	3.77	0.17	2.34
Log_{10}(Exch. K^{+})	-0.49	0.34	0.34	−0.02	1.65
Exch. Mg^{2+} /cmol(+)kg^{-1}	5.49	2.58	2.58	0.16	2.30
Log_{10}(Exch. Na^{+})	-0.41	0.37	0.37	0.0005	2.10
Extractable Fe /%	4.65	2.61	2.61	0.05	1.81

- CSIRO's soil archive holds 50,000+ soil specimens from with an incomplete set of analytical data
- Measured 20,000+ soils with vis–NIR (& mid-IR)
- Spectroscopic modelling predicted soil attributes

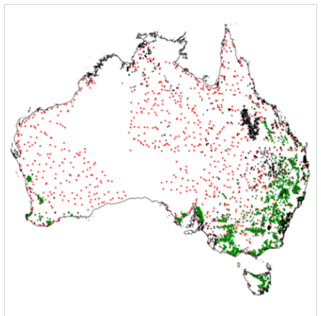
The Australian soil organic C baseline – facilitated by spectroscopy

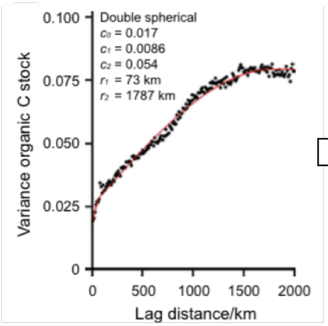
Years 2000 to 2013 only

SCaRP data | vis–NIR estimates | Legacy data

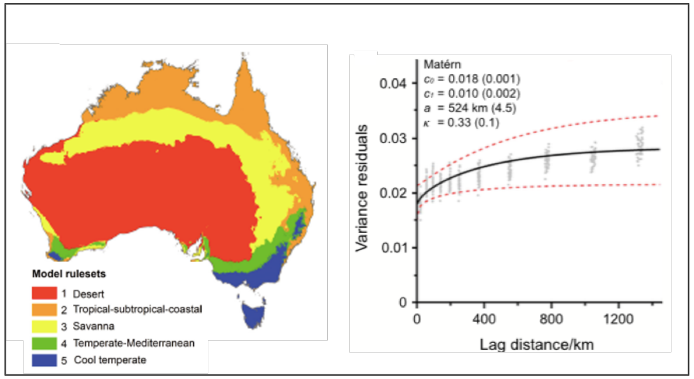
Harmonised to 0–30 cm

$$C_S = (C \times \rho) \times (1\text{-}g)$$

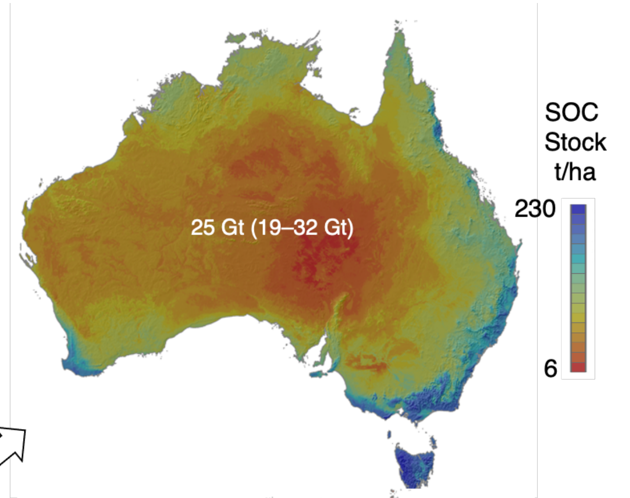


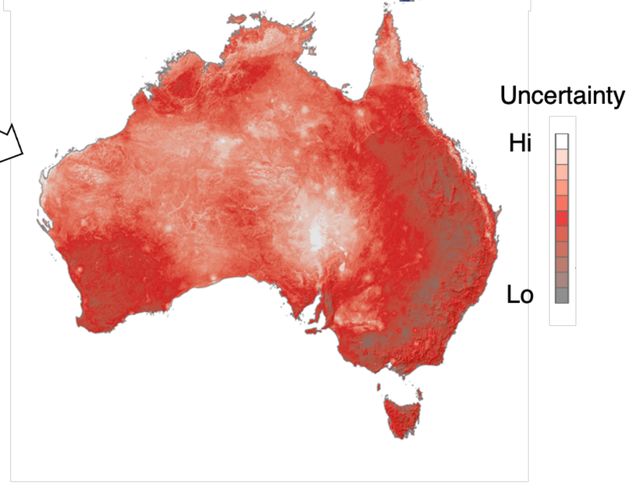


$$\hat{C}_S^b(\mathbf{u}_0) = \hat{\mu}_S^b(\mathbf{u}_0) + \hat{\varepsilon}_S^b(\mathbf{u}_0)$$



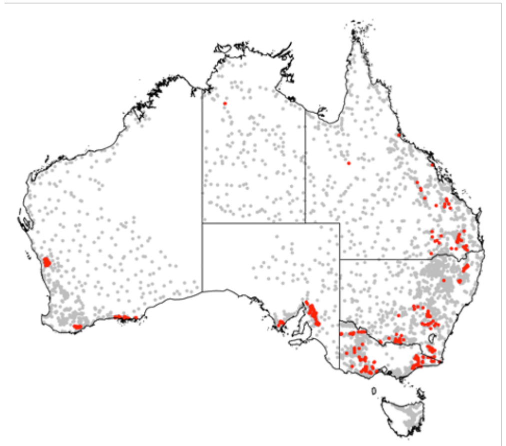
Continentally, climate is the biggest driver in the modelling. Regionally, soil, mineralogy, terrain and vegetation are important.



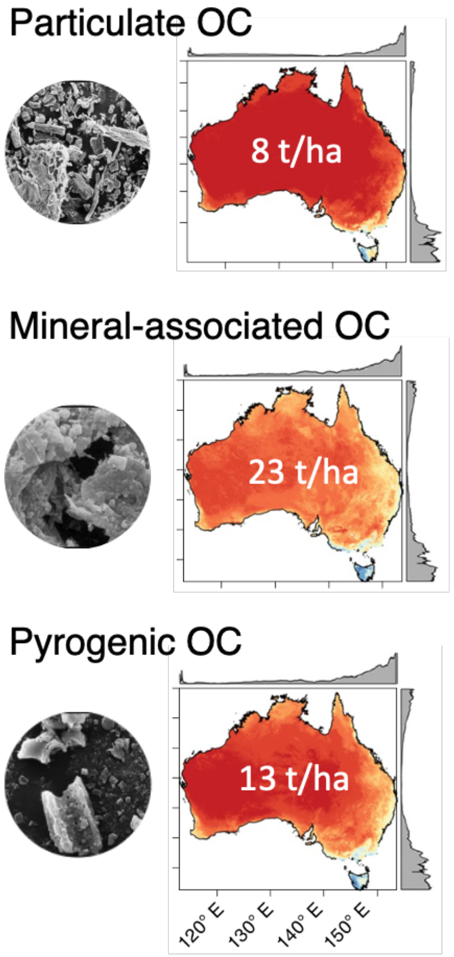


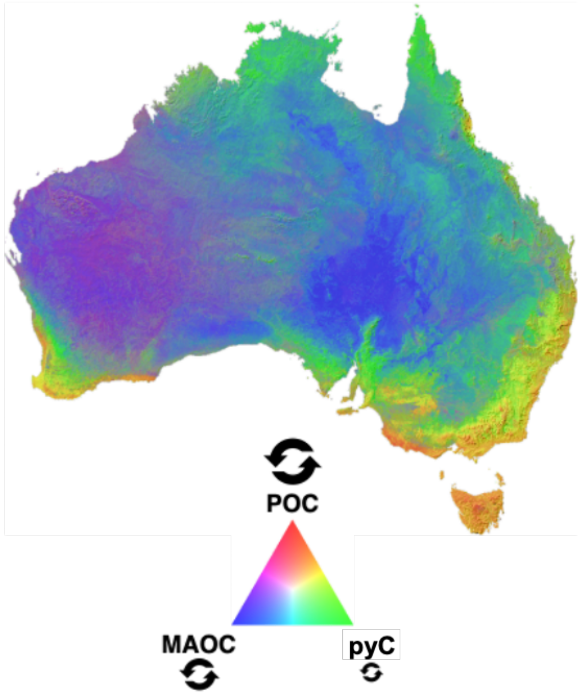
Spatial modelling of soil C composition – facilitated by spectroscopy

- Physical fractionation & NMR
- Spectral estimates of the POC, MAOC, PyC



- Digital soil mapping of the C fractions using environmental correlation with machine learning

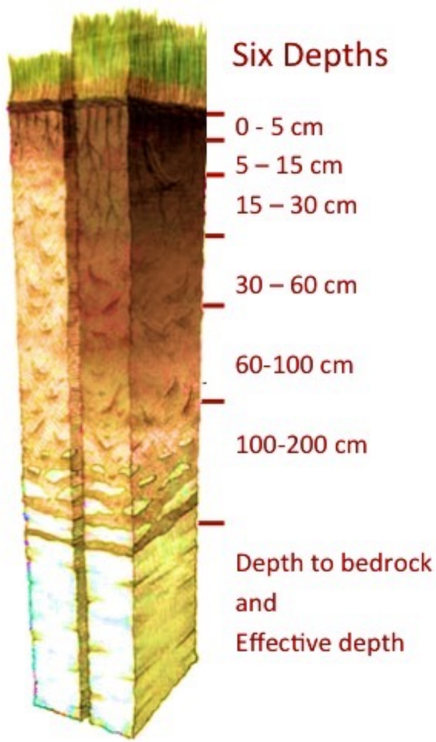


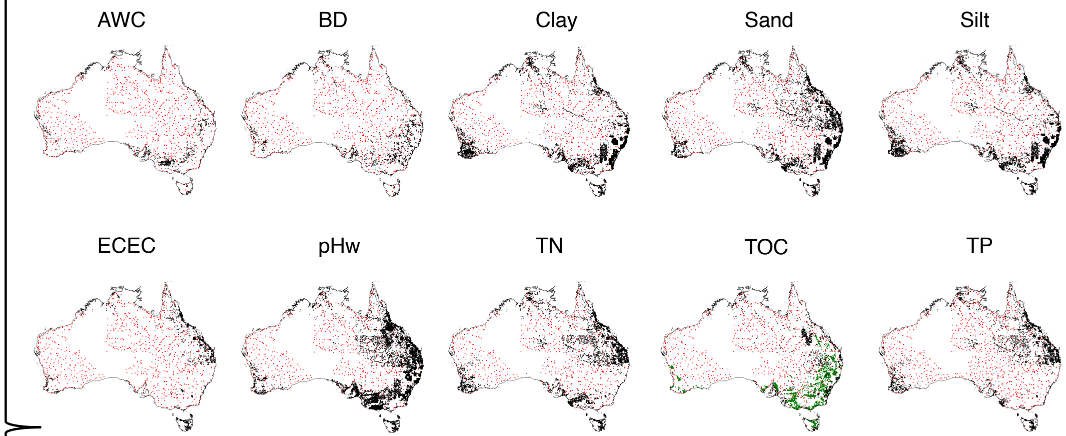


Baldock et al. (2013); Viscarra Rossel & Hicks (2015); Viscarra Rossel et al. (2019)

Australian digital soil property mapping enabled by spectroscopy

SLGA project to derive spatially explicit soil information to better understand interactions with other ecosystem components.

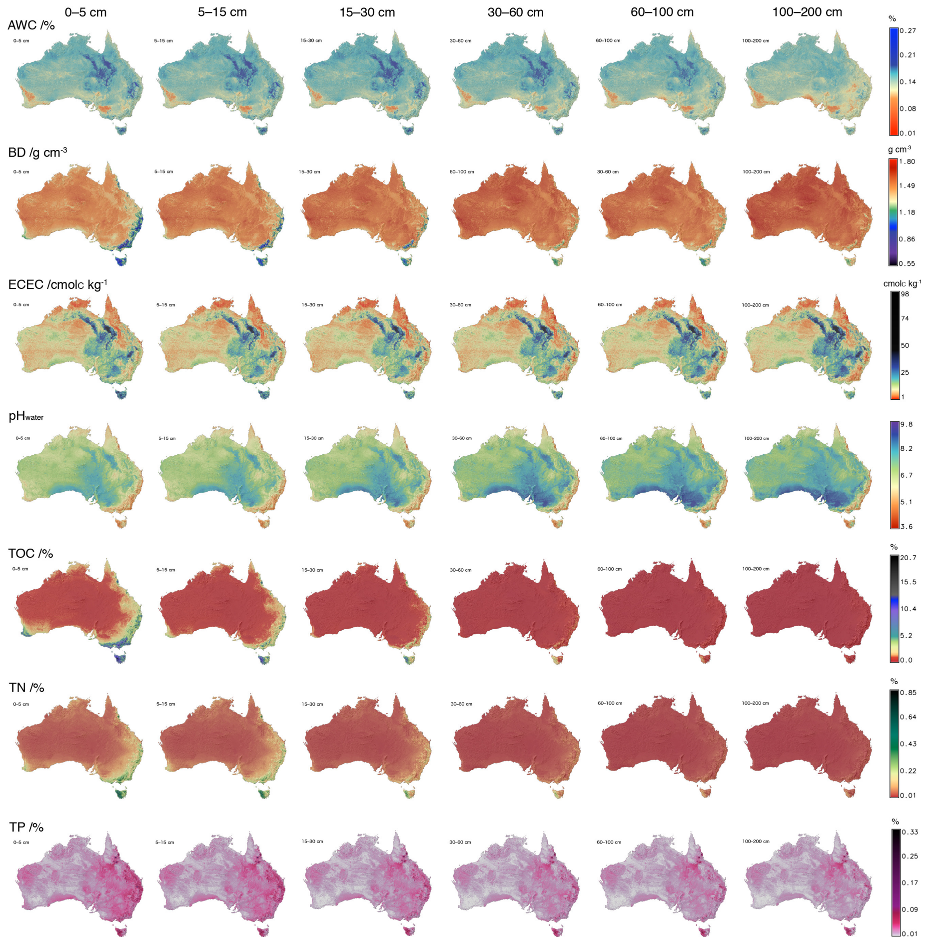


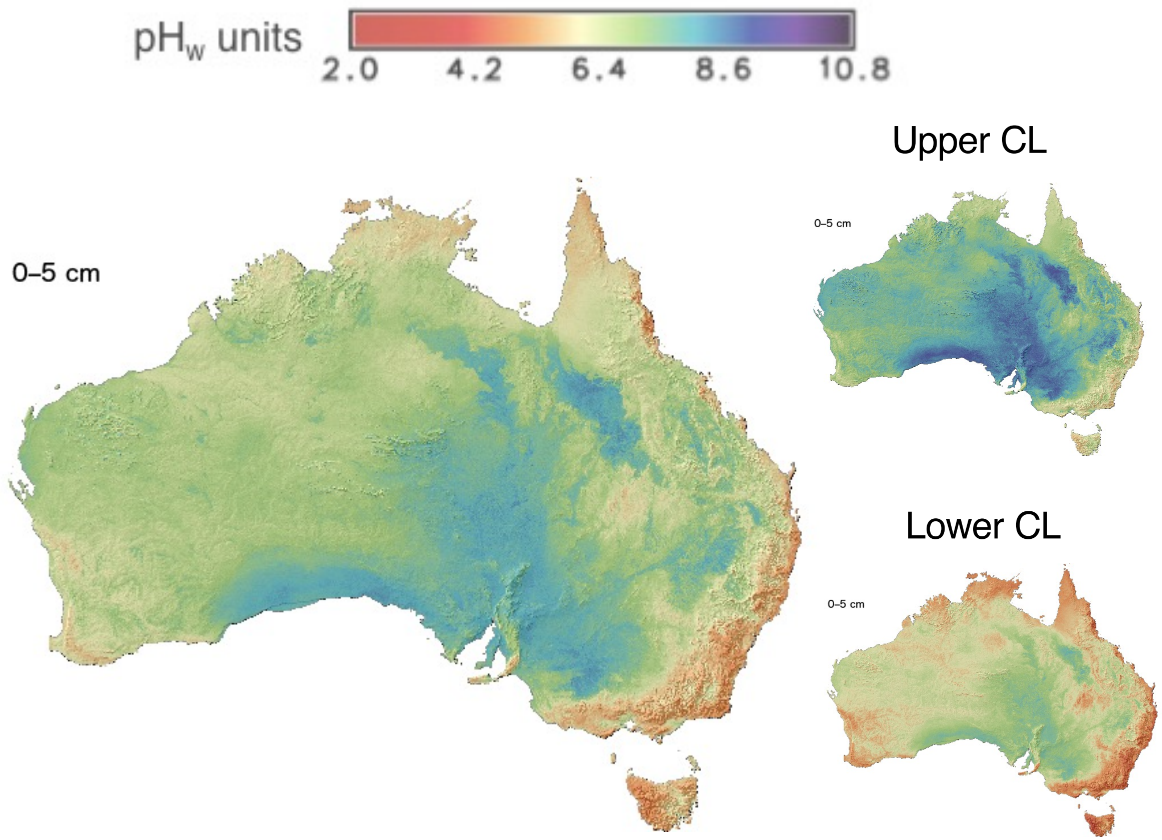


Combined soil property data + **spectroscopic predictions** of soil attributes **enabled continental scale digital soil mapping:** $S_a = f(cl, o, r, p, t)$

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

3D maps of soil properties





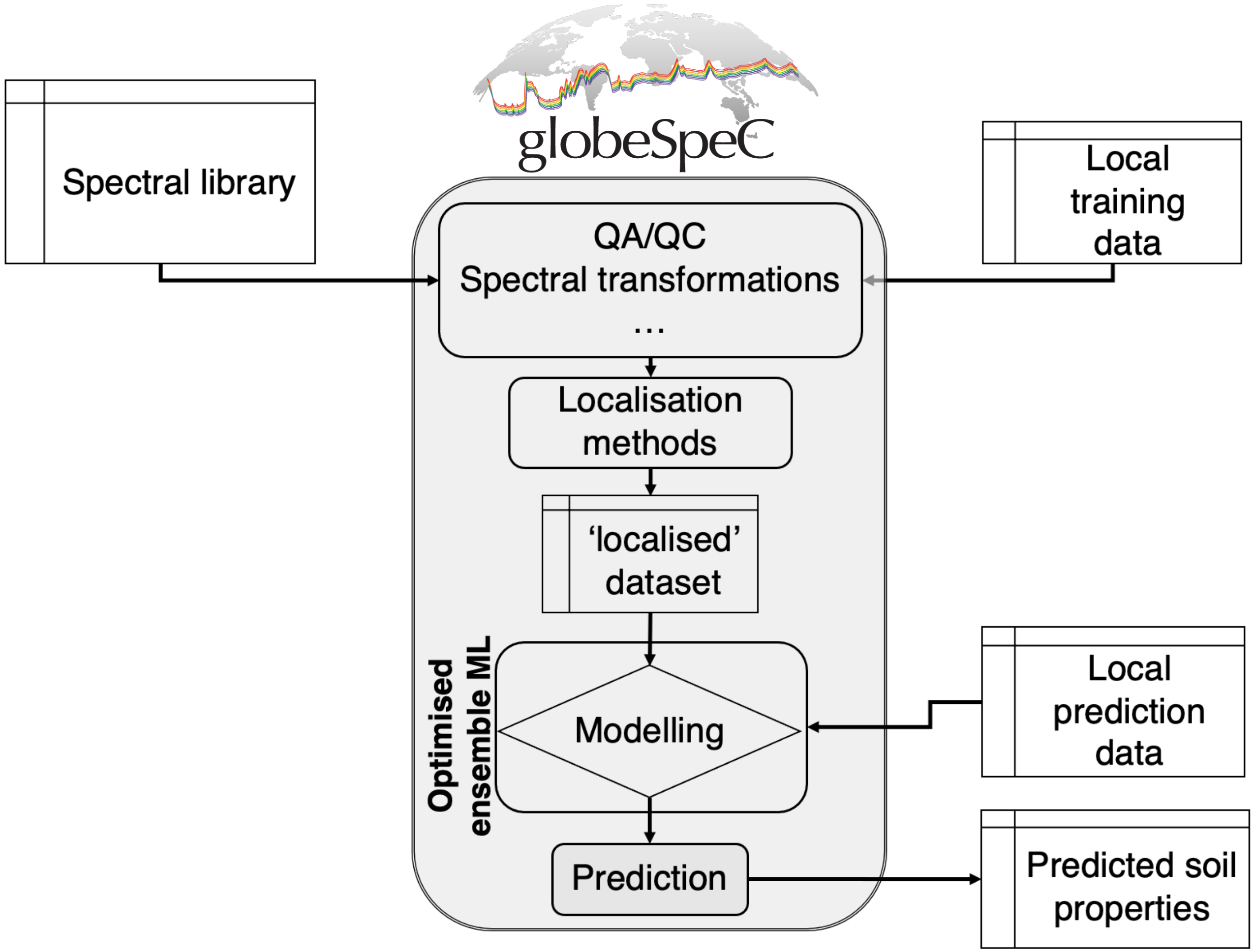
Coverage probabilities > 95%

- An online software platform to enables development and use of large (country, global) spectral libraries and localized spectral predictions

- Developed to be
  - versatile,
  - minimise complexity,
  - dynamic and
  - enable continual growth of library

- Accessible by land managers, farmers, researchers …anywhere in the world and for the common good

Development



R.A. Viscarra Rossel
- concept
- algorithms
- design
- testing

Z. Shen
- development
- algorithms
- testing

L. Ramirez-Lopez
- algorithms
- testing

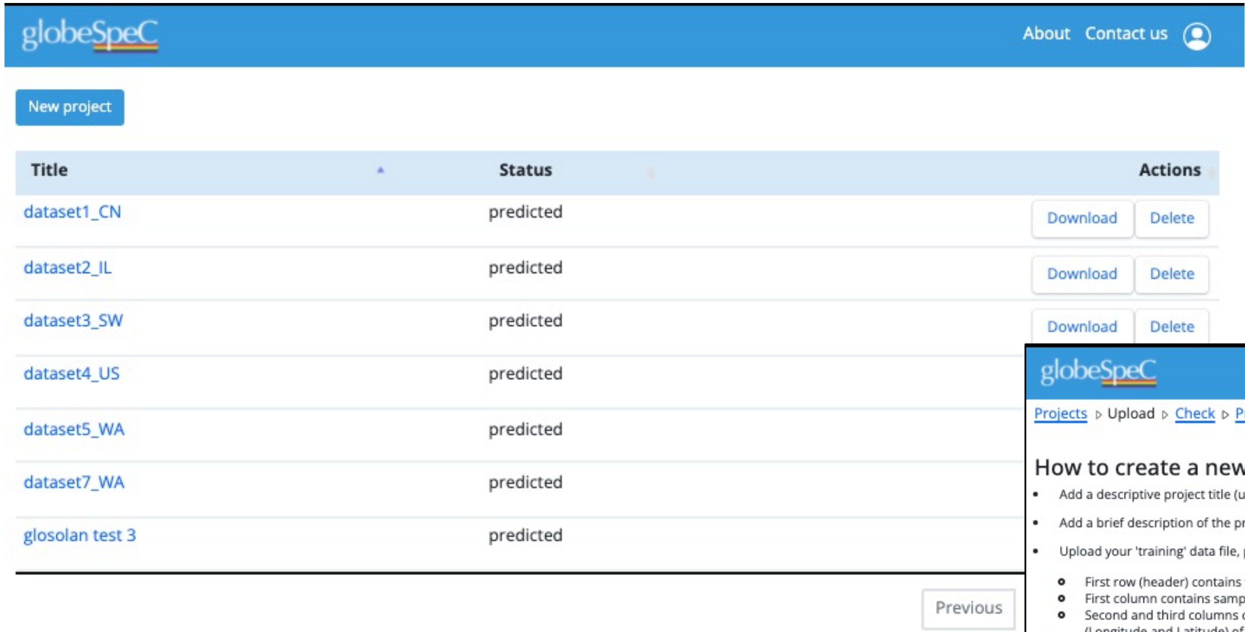
globeSpeC v0.1

- improvements to functionality
- broader testing
- proposed hosting at FAO under the GLOSOLAN-spec initiative

(spectroscopy can make more of a difference in less wealthy countries where the cost of soil information might be limiting)

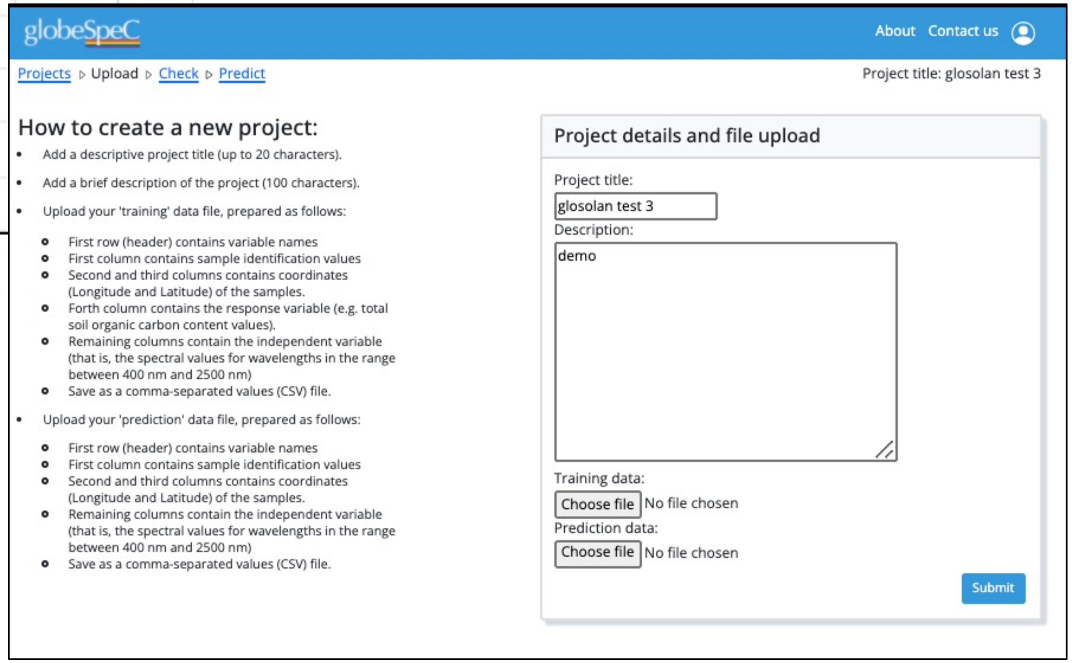
Project page

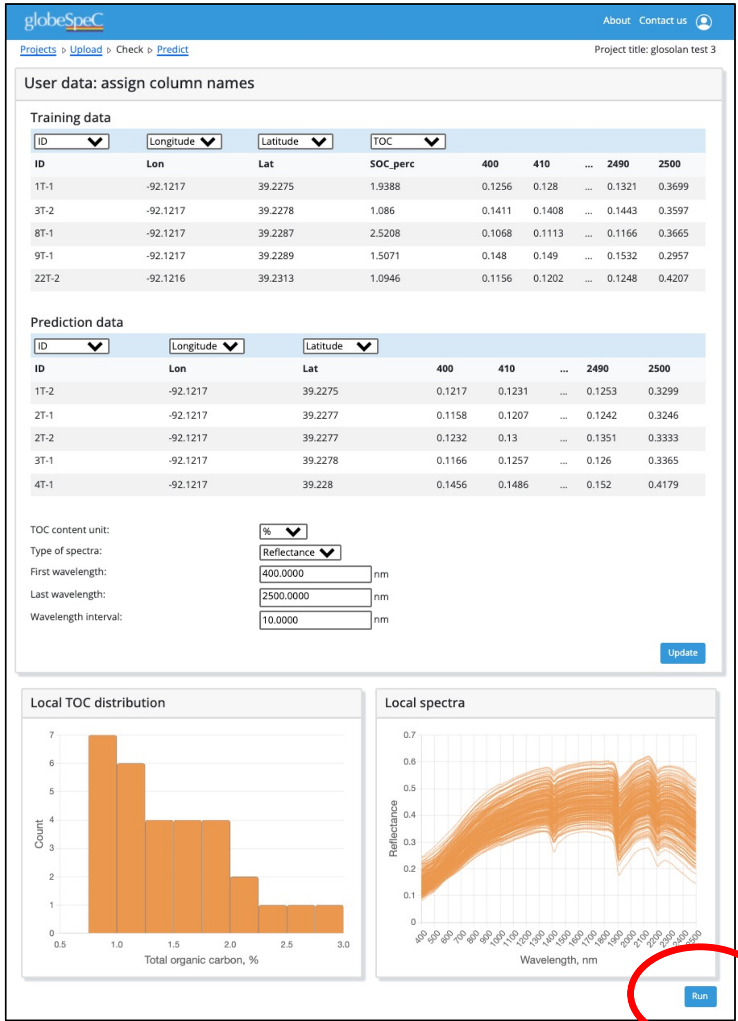
List of projects
Download report and predictions
Delete projects



New project

Upload data
for training
and prediction





Assign data and upload

Localisation and optimized modelling in near real-time: between 2–6 minutes depending on dataset

Run globeSpeC

Results displayed on a single page

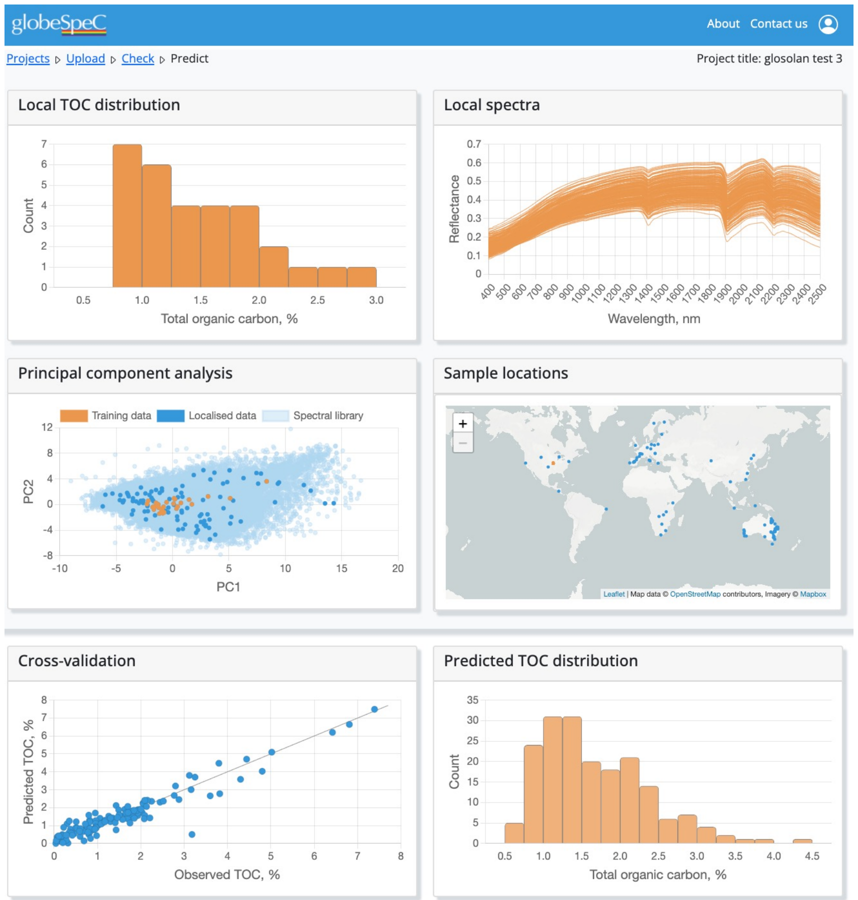
Example using USA data

Local data: soil property and spectra

Localised data selection and geolocation

Validations and predictions

Evaluation statistics



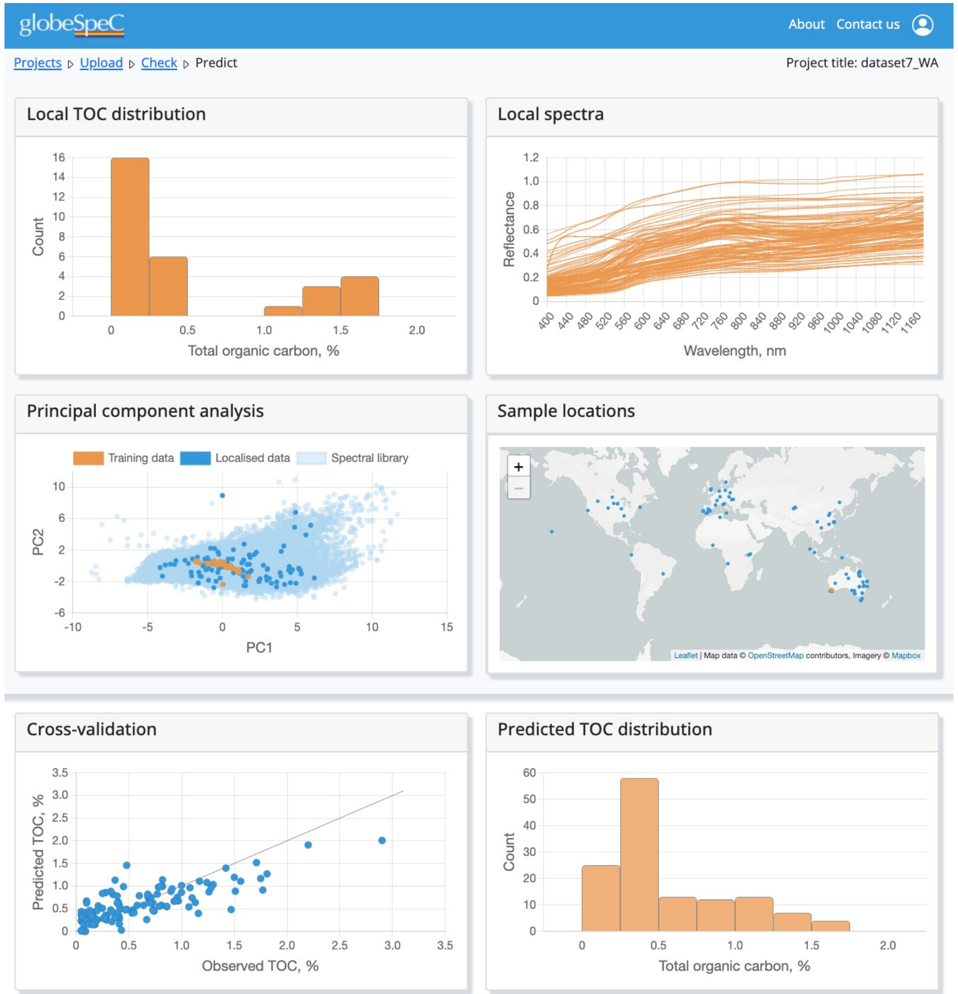
Cross-validation statistics

R^2	CCC	RMSE	ME	SDE	RPD	RPIQ
0.831	0.894	0.406	-0.025	0.415	3.642	-0.469

Example using Australian data

Can use spectra from different spectrometers as long as they are within the 350–2500 nm range (visible–near infrared).

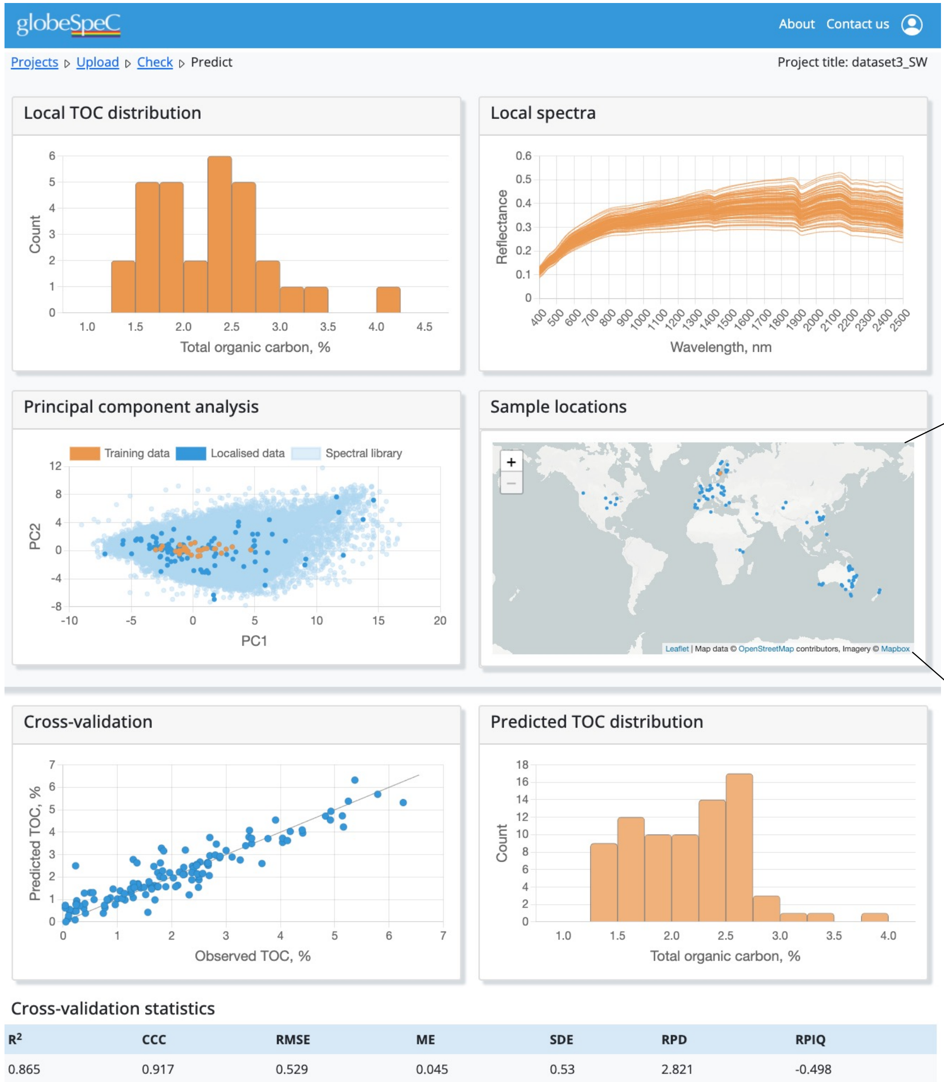
Next version will extend to also mid infrared (MIR).



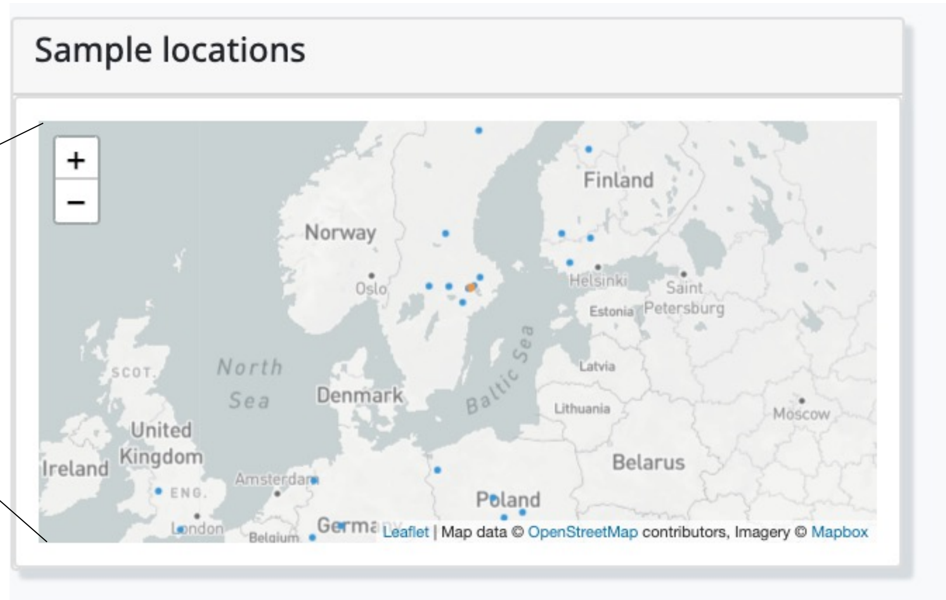
Cross-validation statistics

R^2	CCC	RMSE	ME	SDE	RPD	RPIQ
0.607	0.715	0.315	-0.017	0.319	1.69	-0.197

This example uses spectra from 400–1160 nm



Example using Swedish data

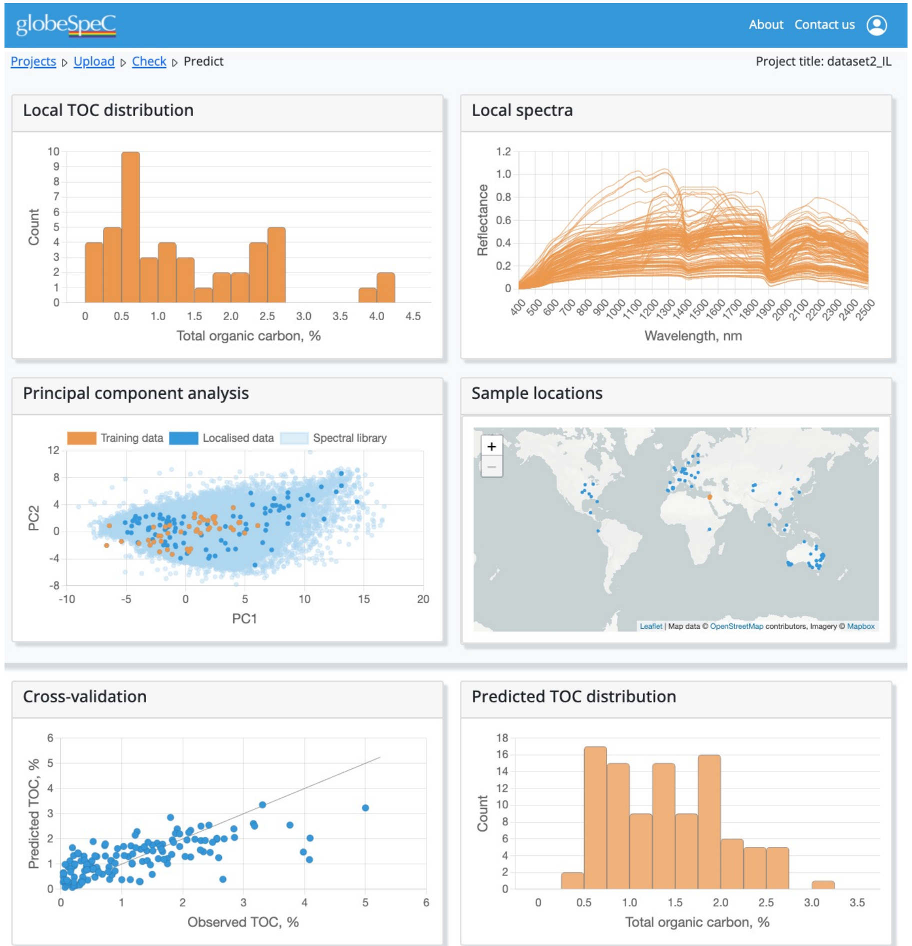


Interactive graphics

Example using data from Israel

Showing that the spectral library used here is lacking some similar samples to the ones from Israel

The larger and more diverse the spectral library, the better that globeSpeC will predict.



Cross-validation statistics

R^2	CCC	RMSE	ME	SDE	RPD	RPIQ
0.518	0.649	0.683	0.032	0.694	1.536	0.324

Thank you.

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