Coordinating and integRating state-of-the-art Earth Observation Activities in the regions of North Africa, Middle East and Balkans and Developing Links with GEO related intiatives toward GEOSS

GEO-CRADLE Project Meeting 2
16th November, 2016

(4.2) The role of soil spectroscopy for food security & tools to create a SSL

Eyal Ben Dor
The Remote Sensing Laboratory, Tel Aviv University

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Eratosthenes Research Centre
Limassol, Cyprus

The GEO-CRADLE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690133.

Why Soils Are Important

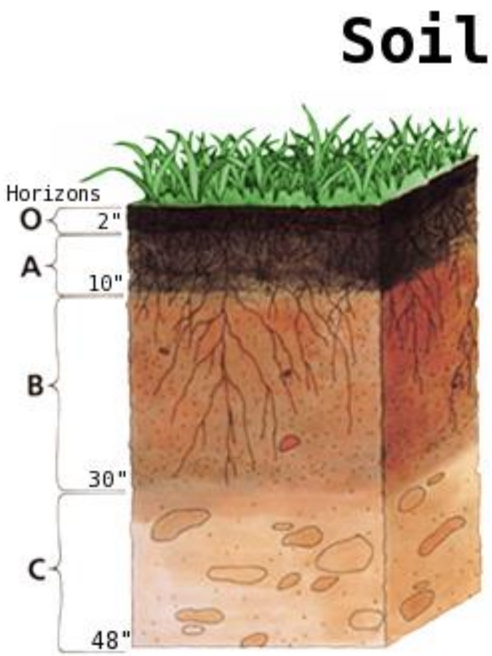
- Plants grow on soils .
- Plants support animal life.
- Plants and animals support human life.
- World population is rapidly increasing, with food demand.
- A large part of the world's population has inadequate nutrition.
- Soil affects all the above

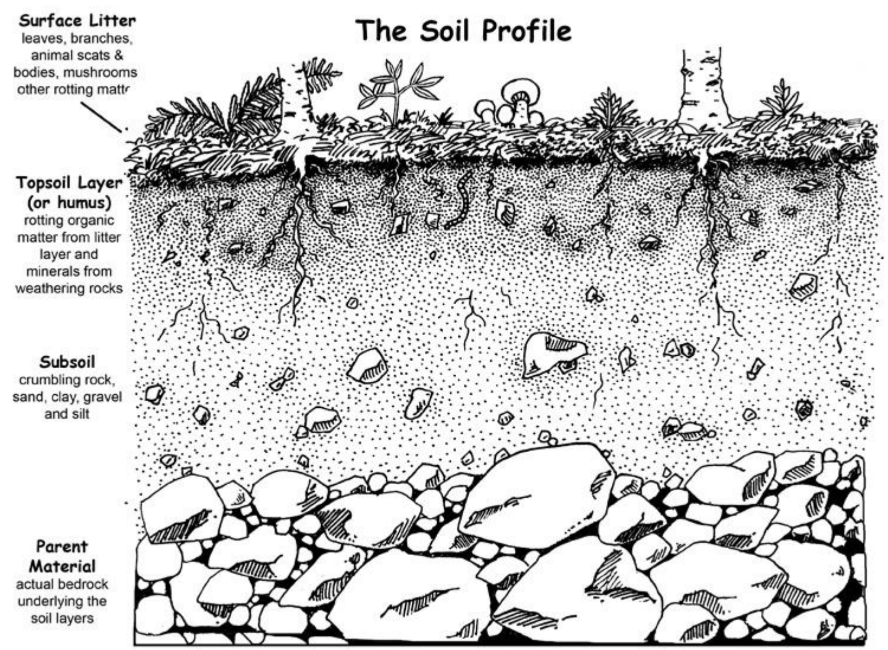
Definition 1

Soil

The upper layer ***al which is dug,***
plow ***957)***

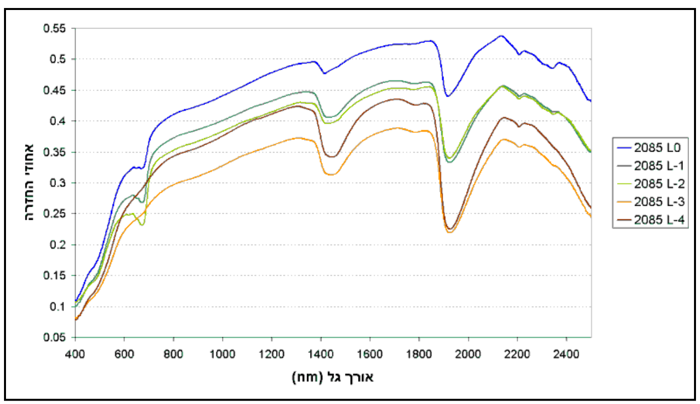
medium for plants to grow





Definition 2

- Soil Spectroscopy refers to the reflectance/emittance part of the electromagnetic radiation that interacts with the soil matter across the VIS-NIR-SWIR-TIR spectral region range (0.35-14μm).



Point – one pixel

Definition 4

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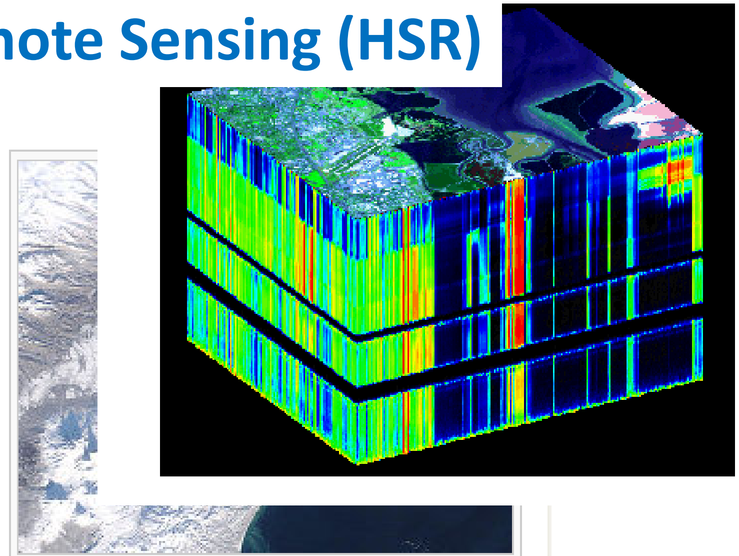
Imaging spectroscopy

Hyperspectral Remote Sensing (HSR)

From Wikipedia, the free encyclopedia

Imaging spectroscopy is the simultaneous acquisition of spatially coregistered images in many spectrally contiguous bands. To be scientifically useful, such measurement should be done using an internationally recognized system of units. The image produced by imaging spectroscopy is similar to an image produced by a digital camera, except each pixel has many bands of light intensity data instead of just three bands: red, green and blue.

Imaging spectrometer data acquisition allows the quantitative and qualitative characterization of both, the surface and the atmosphere, using geometrically coherent spectrodirectional radiometric measurements. These measurements can then be used for the unambiguous direct and indirect identification of surface materials and atmospheric trace gases, the measurement of their relative concentrations, subsequently the assignment of the proportional contribution of mixed pixel signals (e.g., the spectral unmixing problem), the derivation of their spatial distribution (mapping problem), and finally their study over time (multi-
te



Ash plumes on Kamchatka Peninsula, eastern Russia. A MODIS image.

adjusted From A. Goetz 1994

Simultaneous acquisition of images in many registered spectrally- high resolution continuous bands at selected (or all) spectral domains across the UV-VIS-NIR-SWIR–MWIR-LWIR spectral region (0.3-12μm)

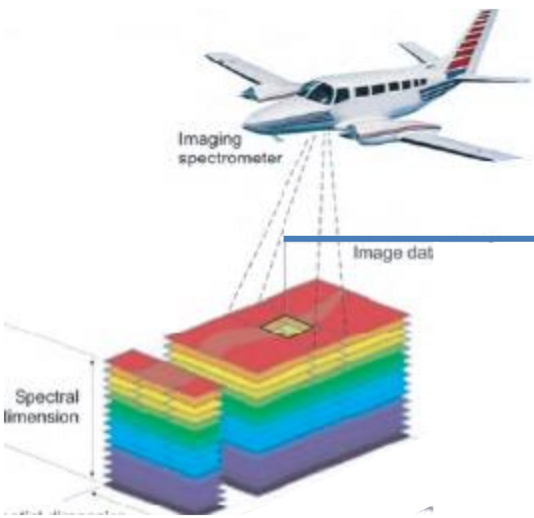
Strong Link between Point and Image Spectroscopy

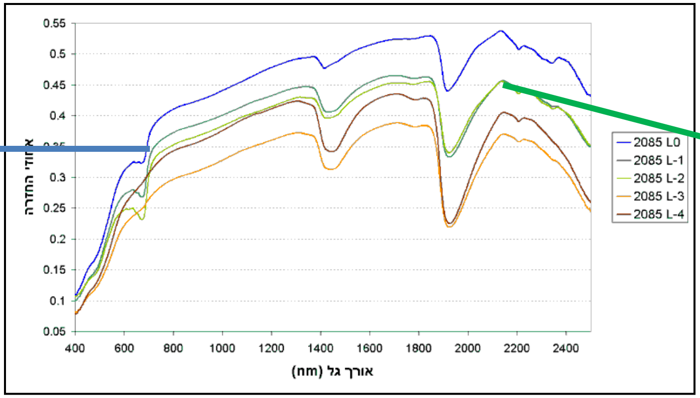
Image Spectroscopy

Geology
Vegetation
Water

Point Spectroscopy

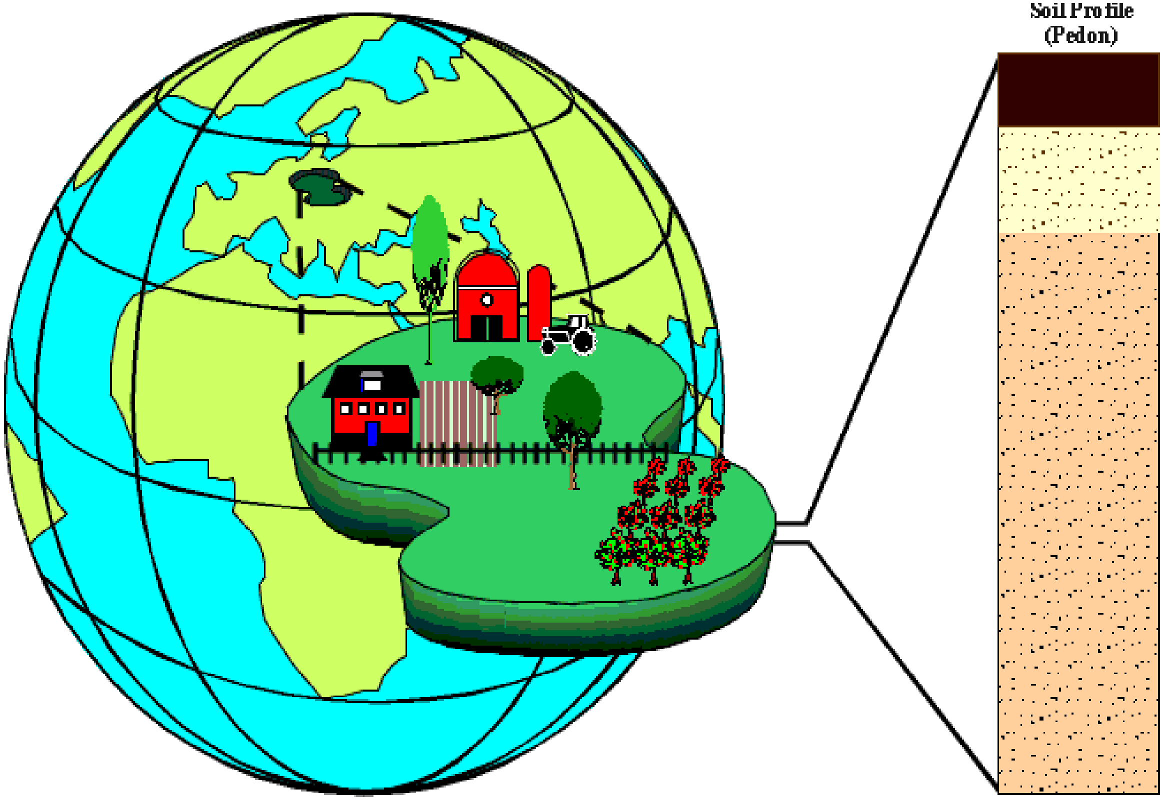
Soil





Soil as a Complex System

Soil is a complex system characterized by chemical and physical attributes that provides an overview on the agricultural functions of the soil as a food producer



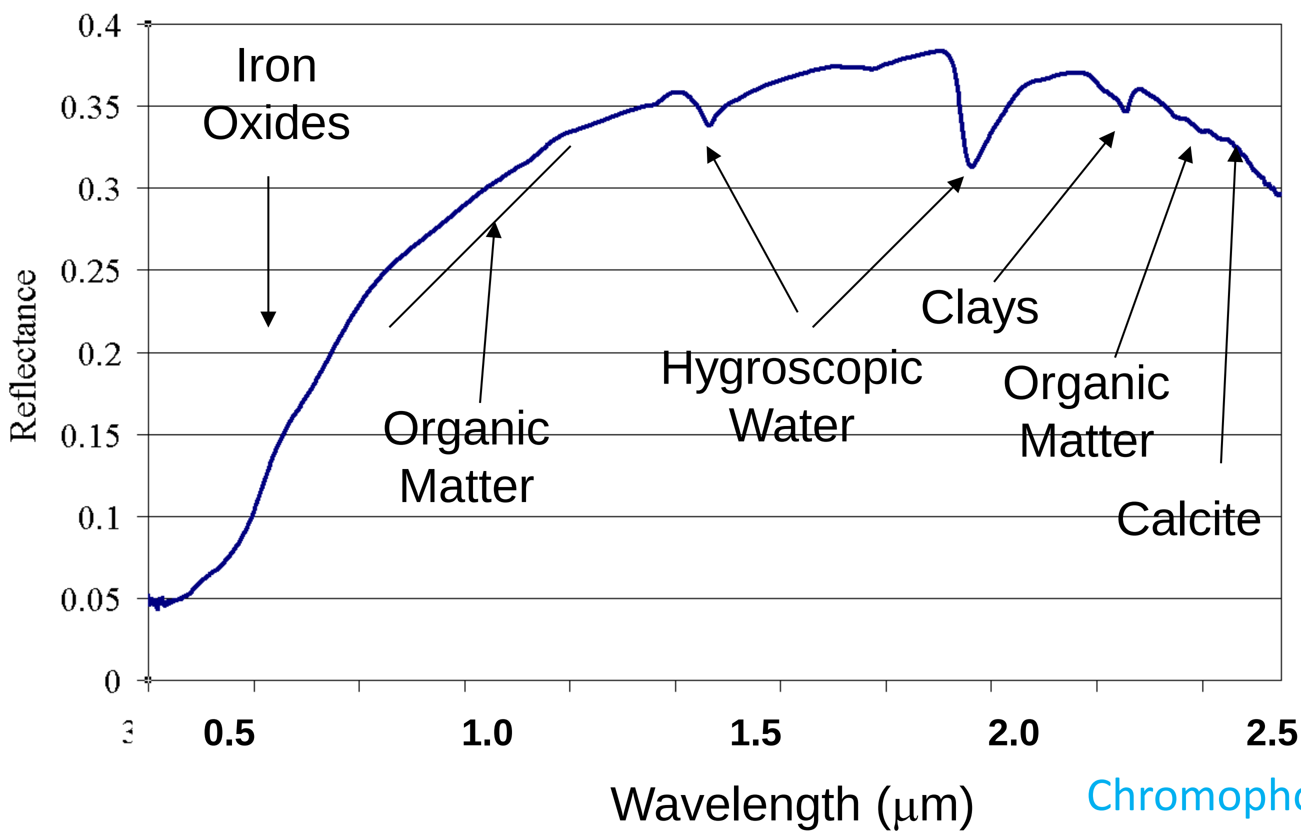
Soil is composed of

Clay
silt
sand
organic matter
carbonates
iron oxides
water
particle size
air
Cations
Anions
Flora
Founa

Return Impact

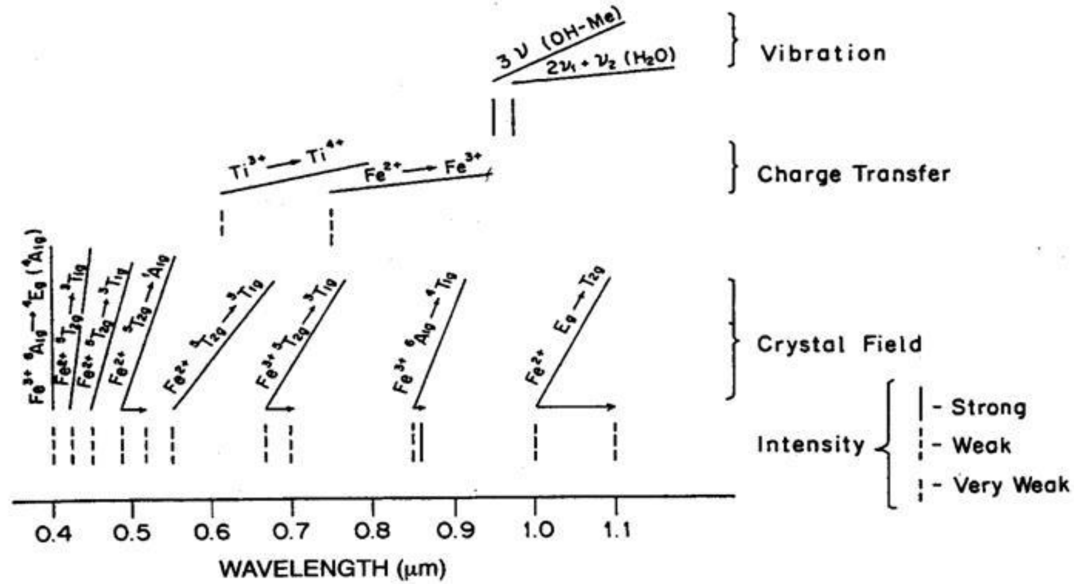
A typical Soil Spectrum

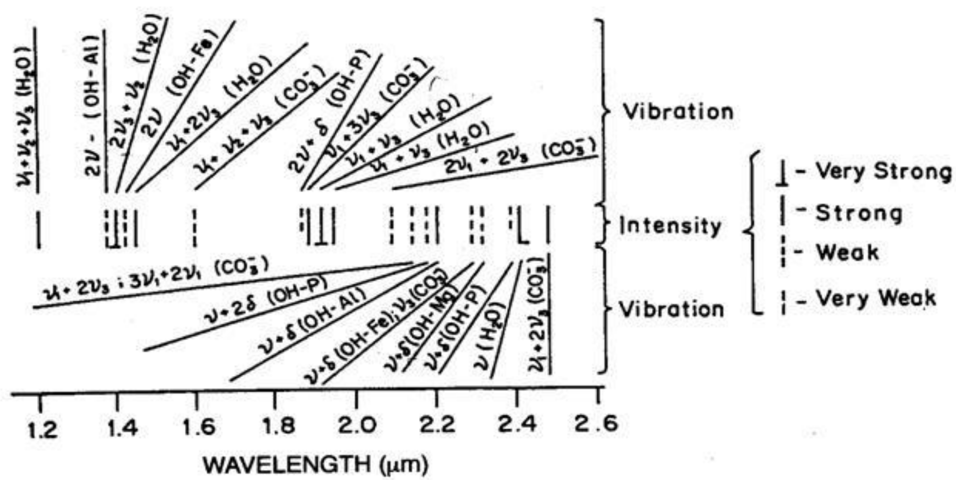
An effective way to simplest the complexity of the soil system



Chromophore = An attribute that interact with the electromagnetic radiation

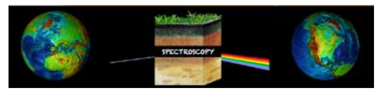
Absorption Mechanism

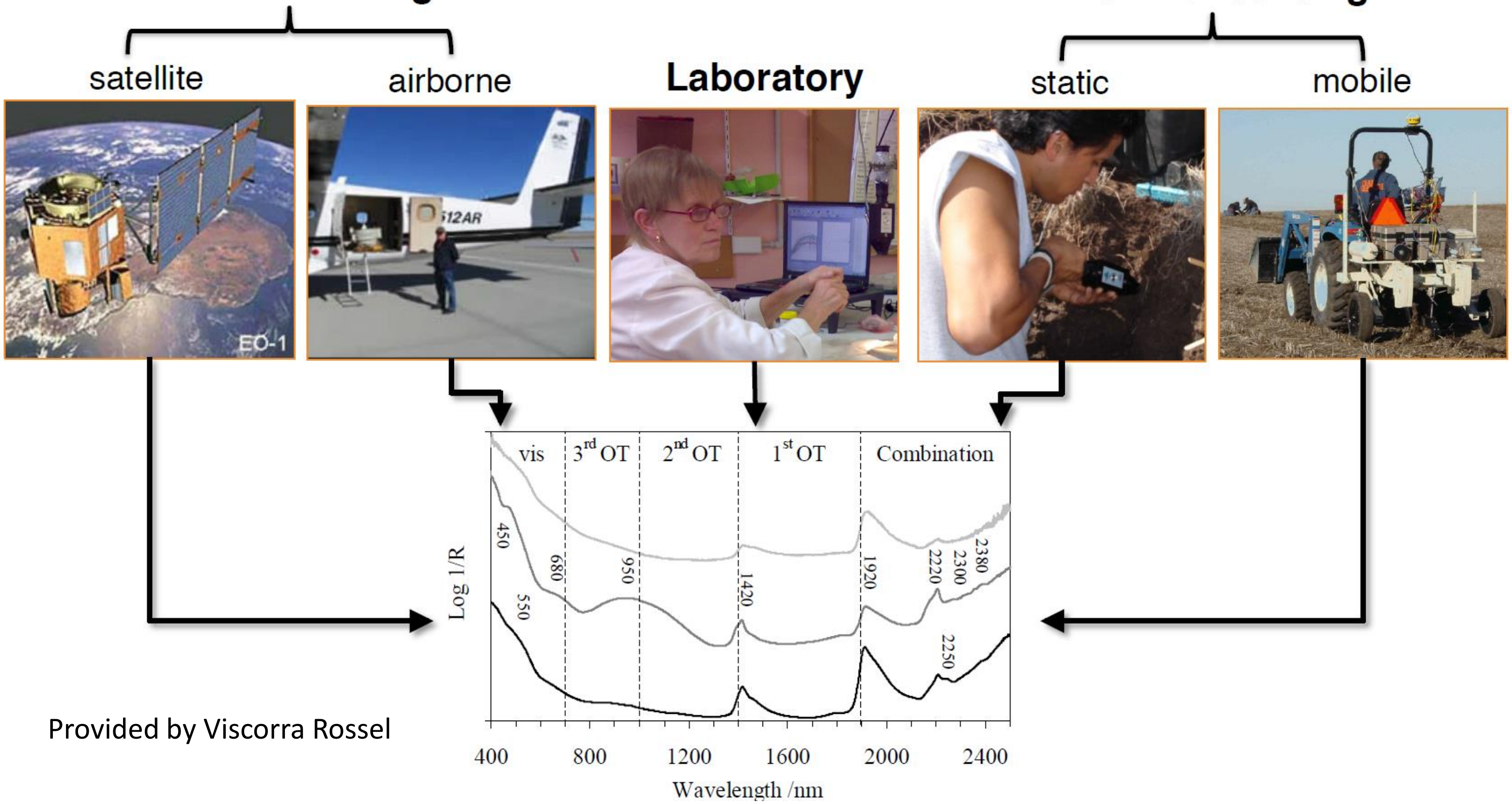




Soil Spectroscopy

Why so much interest in soil spectroscopy?





Provided by Viscorra Rossel

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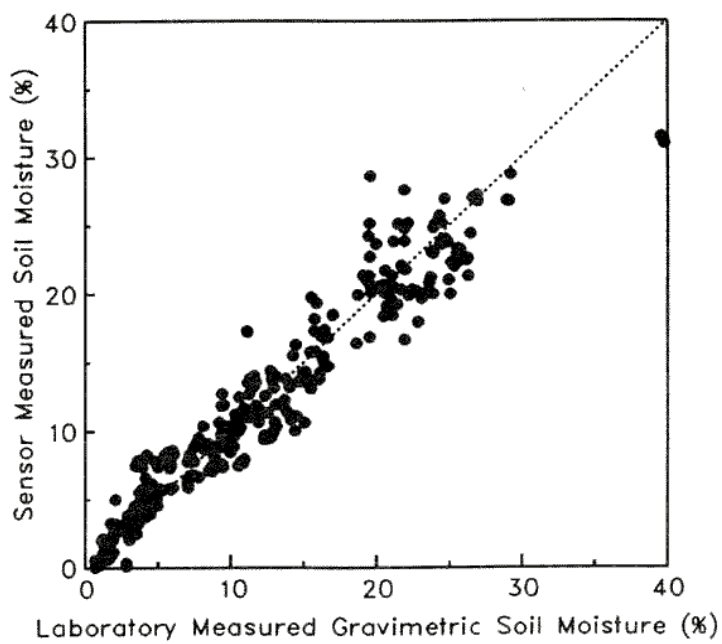
Soil Spectroscopy

Quantitative Information on soil attributes can be Extracted from soil spectral information

Dalal, R.C., and R.J. Henry. 1986. Simultaneous determination of moisture, organic carbon and total nitrogen by near infrared reflectance spectroscopy. Soil Science Society of America Journal 50:120-12



Simple, rapid, inexpensive and
can be applied from large domains (laboratory, field, air and space)

Soil Spectroscopy

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Examples of some of the soil attributes that can be extracted from spectral library (1)

Soil attribute	Spectral region	Spectral range (nm)	Multivariate method[a]	n_{calib} | n_{valid}[b]	RMSE	R^2	Authors
Mg; g/kg	VIS–NIR	400–2500	modified PLSR	315		0.90	Cozzolino and Moron (2003)
Mg (exch.); cmol(+)/kg	VIS–NIR	350–2500	MARS	493 | 246	11	0.81	Shepherd and Walsh (2002)
Mg (exch.); mg/kg	VIS–NIR	400–2498	PCR (9)	30 | 119	12.8	0.68	Chang et al. (2001)
Mg; mmol(+)/kg	UV–VIS–NIR	250–2500	PCR	121 | 40		0.63	Islam et al. (2003)
Mn (DTPA); mg/kg	MIR	2500–25,000	PLSR	183		0.57	Janik et al. (1998)
Mn (exch.); cmol/kg	MIR	2500–25,000	PLSR	183		0.66	Janik et al. (1998)
Mn (Mehlich III); mg/kg	VIS–NIR	400–2498	PCR (12)	30 | 119	56.4	0.70	Chang et al. (2001)
OC; %	MIR	2500–20,000	PLSR			0.92	Janik and Skjemstad (1995)
OC; %	MIR	2500–25,000	PLSR	188		0.93	Janik et al. (1998)
OC; g/kg	MIR	2500–25,000	PLSR (17)	177 | 60		0.94	McCarty et al. (2002)
OC; (acidified soil) g/kg	MIR	2500–25,000	PLSR (19)	177 | 60		0.97	McCarty et al. (2002)
OC; %	NIR	1100–2500	MLR (1744, 1870, 2052)	72 | 48		0.93	Dalal and Henry (1986)
OC; %	NIR	1100–2500	RBFN	140 | 60	0.32	0.96	Fidêncio et al. (2002)
OC; %	NIR	700–2500	PCR	121 | 40		0.68	Islam et al. (2003)
OC; g/kg	NIR	1100–2498	PLSR (18)	177 | 60		0.82	McCarty et al. (2002)
OC; mg/kg	NIR	1100–2300	PLSR (8)	180 x-val		0.94	Reeves and McCarty (2001)
OC (acidified soil); g/kg	NIR	1100–2498	PLSR (17)	177 | 60		0.80	McCarty et al. (2002)
OC; g/kg	VIS–NIR	400–2498	PLSR (6)	76 | 32	0.62	0.89	Chang and Laird (2002)
OC; g/kg	VIS–NIR	350–2500	MARS	449 | 225	0.31	0.80	Shepherd and Walsh (2002)
OC; dag/kg	VIS–NIR	350–1050	PLSR (5)	43 | 25	0.36		Viscarra Rossel et al. (2003)
OC; %	UV–VIS–NIR	250–2500	PCR	121 | 40		0.76	Islam et al. (2003)
OM; %	MIR	2500–25,000	PLSR (4)	31 x-val	0.72	0.98	Masserschmidt et al. (1999)
OM; %	NIR	1000–2500	MRA (30 bands)	39 | 52		0.55	Ben–Dor and Banin (1995)
OM; %	VIS–NIR	400–1100	NN	41		0.86	Daniel et al. (2003)
OM; %	VIS–NIR	400–2400	SMLR (606, 1311, 1238)	15 | 10		0.65	Shibusawa et al. (2001)
P (avail.); mg/kg	MIR	2500–25,000	PLSR	186		0.07	Janik et al. (1998)
P (avail.); mg/kg	VIS–NIR	400–1100	NN	41		0.81	Daniel et al. (2003)
pH	MIR	2500–20,000	PLSR			0.72	Janik and Skjemstad (1995)
pH	NIR	1100–2300	PLSR (8)	180 x-val		0.74	Reeves and McCarty (2001)
pH	NIR	1100–2498	PLSR (11)	120 | 59		0.73	Reeves et al. (1999)
pH	VIS–NIR	350–2500	MARS	505 | 253	0.43	0.70	Shepherd and Walsh (2002)
pH_{Ca}	MIR	2500–25,000	PLSR	183		0.67	Janik et al. (1998)

R.A. Viscarra Rossel et al. / Geoderma 131 (2006) 59–75

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Soil Spectroscopy

Examples of some of the soil attributes that can be extracted from spectral library (2)

Soil attribute	Spectral region	Spectral range (nm)	Multivariate method[a]	n_{calib} | n_{valid} [b]	RMSE	R^2	Authors
OC; %	MIR	2500–20,000	PLSR			0.92	Janik and Skjemstad (1995)
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OM; %	VIS–NIR	400–1100	NN	41		0.86	Daniel et al. (2003)
OM; %	VIS–NIR	400–2400	SMLR (606, 1311, 1238)	15|10		0.65	Shibusawa et al. (2001)
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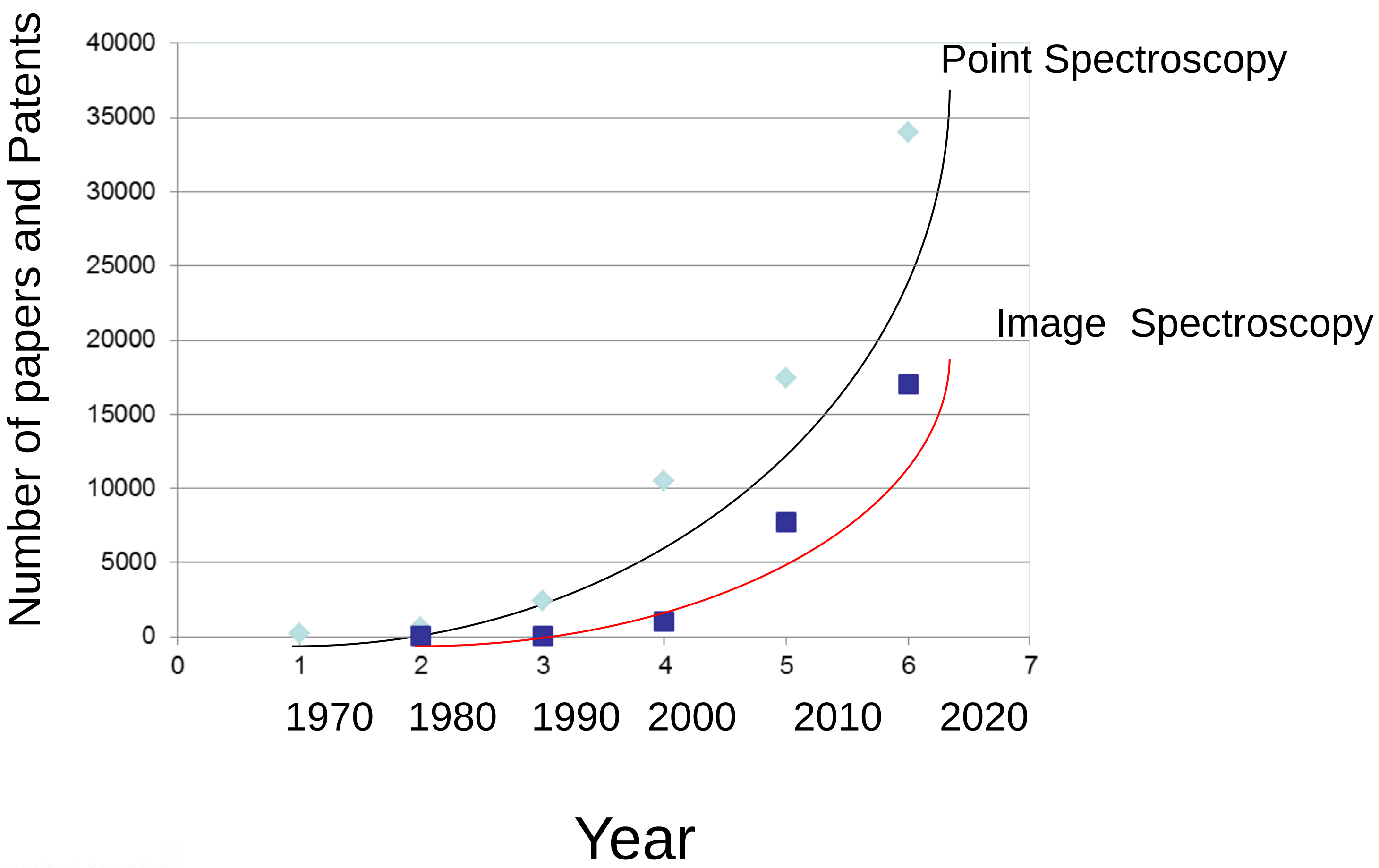
Soil Spectroscopy

Number of papers published in soil spectroscopy over the years : Point and Image domains



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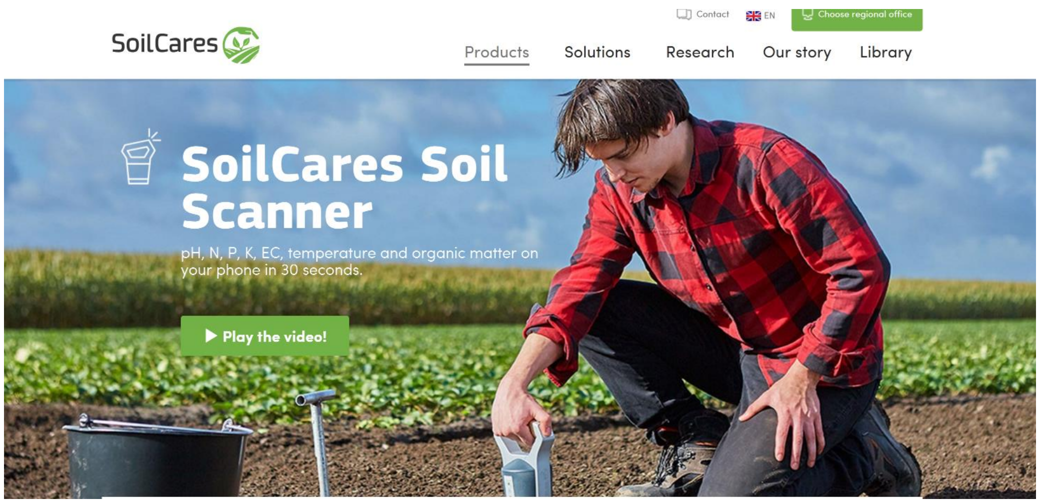
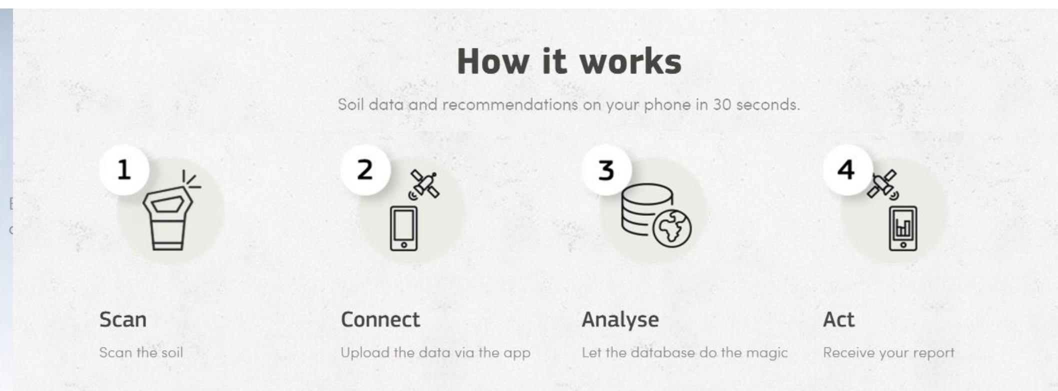
Soil Spectral Library : The Commercial Value (1)





http://www.soilcares.com/en/products/scanner/

Soil Spectral Library : The Commercial Value (1)

Rapid (and massive) analyses of soil samples with out the need for "wet" laboratories

2016

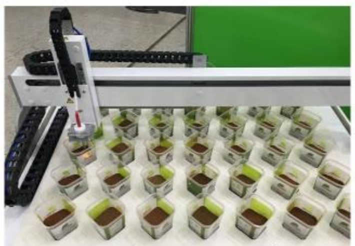
News

10.18.16 | Research, Development and Innovation

Innovative technology analyzes soil in just 30 seconds

Tweet | Compartilhar 87 | G+1

Photo: André Marcelo de Souza

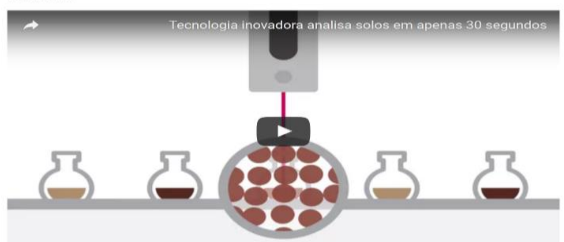


Embrapa Solos (RJ), in partnership with the private sector, has developed a technology package for the soil analysis that will revolutionize the market in Brazil. Called SpecSolo, it has the advantage of analyzing soil samples non-destructively, quickly and economically. Tens of fertility parameters (soil organic carbon, pH, calcium, magnesium, phosphorus, potassium, among others) and physical soil (clay, silt, sand) can be analyzed simultaneously in 30 seconds. Conventional analysis takes days to present the same parameters.

"The SpecSolo is based on the use of techniques of vibrational spectroscopy and artificial intelligence," explains André Marcelo de Souza, from Embrapa Solos researcher and responsible for technology. Souza explains that the technology makes use of accurate and efficient algorithms. "These algorithms", explains the scientist, "will use a robust database with over one million representative soil samples from Brazil." Souza says that the samples and related analytical data were obtained from one of the largest laboratories in the world soil analysis, the Brazilian Institute of Analysis (IBRA), development of project partner and co-responsible for technology.

"The SpecSolo analytical solution is one of the greatest innovations in the analysis of the last five decades soils in Brazil, resuming the mission of Embrapa to propose and implement new methodologies for soil analysis in the Brazilian agricultural scenario," reiterates the general head of Embrapa Solos Daniel Vidal Pérez. Both the instrument and technology have the seal of Embrapa. Therefore, the SpecSolo will be an official method recommended by the Company for soil analysis in Brazil.

How it works



For the duo of directors of IBRA Armando Saretta Parducci Parducci and Thiago Camargo, the partnership between Embrapa Soils and IBRA enabled the development of technology. "We are the pioneers in Brazil to build a robust database with such a significant number of samples of Brazilian soil, essential for the development and success of technology," says Armando Parducci.

In addition to the large database, the technology package SpecSolo has a unique hosted software in the cloud for processing information and innovative equipment dedicated to soil analysis, called SpecSolo-Scan.

The equipment has an automatic sampler that allows simultaneous analysis of 40 soil samples and autonomy to work alone for 20 minutes. After that time, the analytical results are generated automatically, remotely accessing the database. The results can be released according to the service purchased by the customer and may be in the form of analytical results of each soil parameter or interpretation of bands of soil fertility.

The project also includes an expert system to generate fertilizer recommendations and liming, according to the main manual available in the country. SpecSolo-Scan is the first commercial instrument near infrared spectroscopy and visible (VisNIR) the world to present an autosampler and an integrated system with database fully dedicated to soil analysis.

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soil analysis goes to the producer

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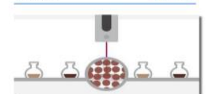

The need of Soil Spectral Library

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- For quantitative applications: many soil samples are needed (**Soil data mining of a “model” requires hundreds of spectra samples in order to provide reliable results**

- Users are gathering many soil samples mostly under local scale

- A need for regional and global scales’ library is essential

- Gathering local and regional spectral data (soil spectral library) needs agreed “standard and protocols”

Soil Spectral Library : The Practical Structure

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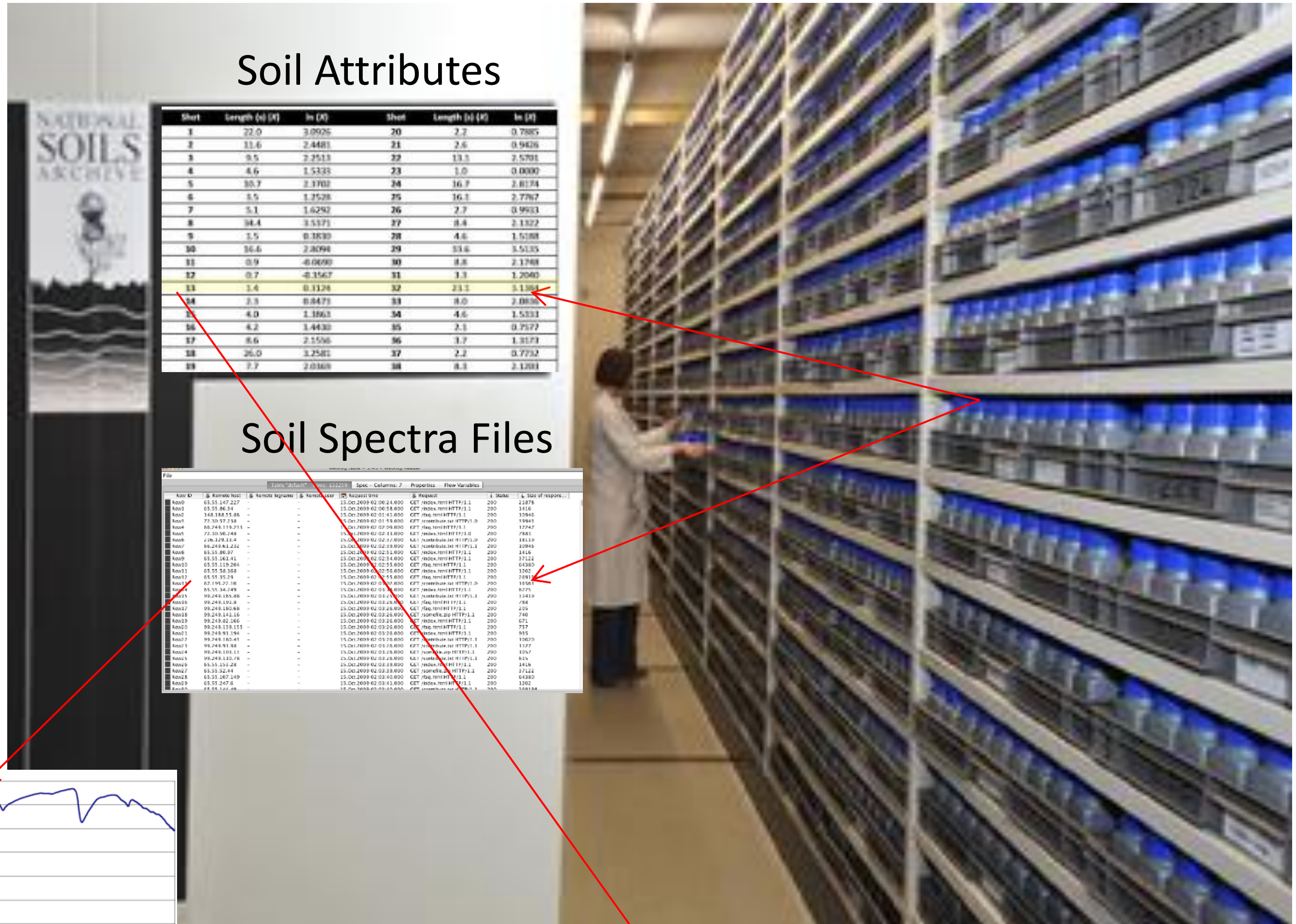
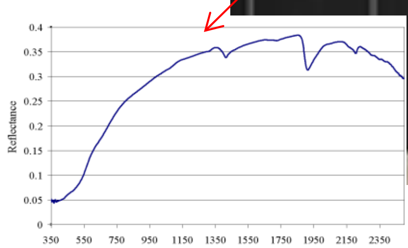
Soil samples at storage, with wet chemistry data plus reflectance spectra measured under a well accepted protocol process



Shot	Length (s) (X)	ln (X)	Shot	Length (s) (X)	ln (X)
1	22.0	3.0926	20	2.2	0.7885
2	11.6	2.4481	21	2.6	0.9426
3	9.5	2.2513	22	13.1	2.5701
4	4.6	1.5333	23	1.0	0.0000
5	10.7	2.3702	24	16.7	2.8174
6	3.5	1.2528	25	16.1	2.7767
7	5.1	1.6292	26	2.7	0.9933
8	34.4	3.5371	27	8.4	2.1322
9	1.5	0.3830	28	4.6	1.5188
10	16.6	2.8094	29	33.6	3.5135
11	0.9	-0.0690	30	8.8	2.1748
12	0.7	-0.3567	31	3.3	1.2040
13	1.4	0.3124	32	23.1	3.1384
14	2.3	0.8473	33	8.0	2.0806
15	4.0	1.3863	34	4.6	1.5333
16	4.2	1.4430	35	2.1	0.7577
17	8.6	2.1556	36	3.7	1.3173
18	26.0	3.2581	37	2.2	0.7732
19	7.7	2.0369	38	8.3	2.1203

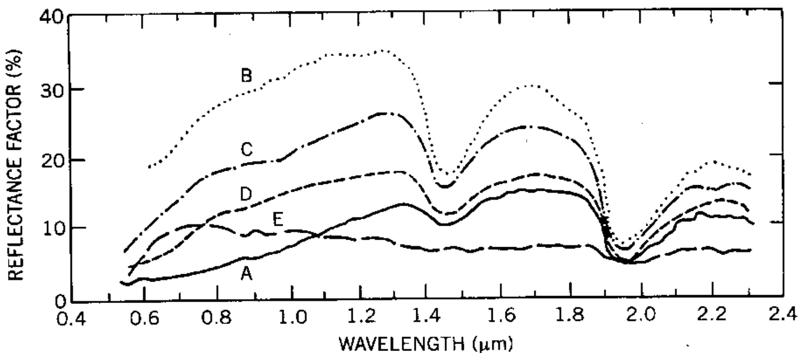


Sample	Location	OM	Clay	Lime….
A1	34,5467.67 36,654,32	2.4 %	34%	23.4%

First Soil Spectral Library

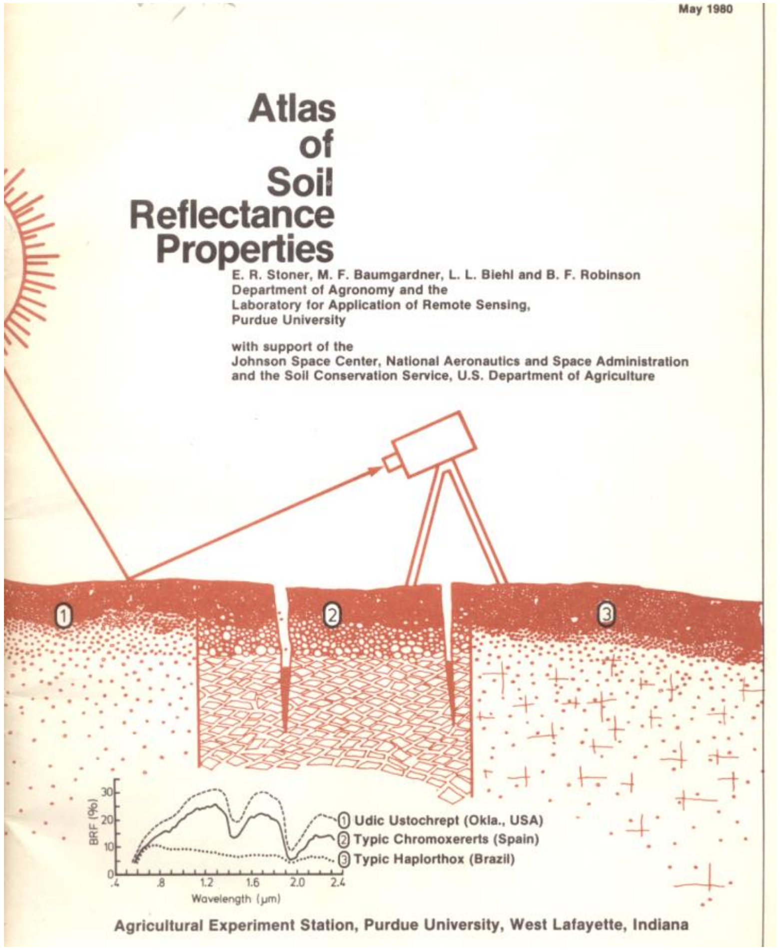
1980

5 spectral types
in USA



Stoner, E.R. and M.F., Baumgardner, 1981. Characteristic variations in reflectance of surface soils. Soil Science Society of American Journal 45: 1161-1165

Around 4000 spectra

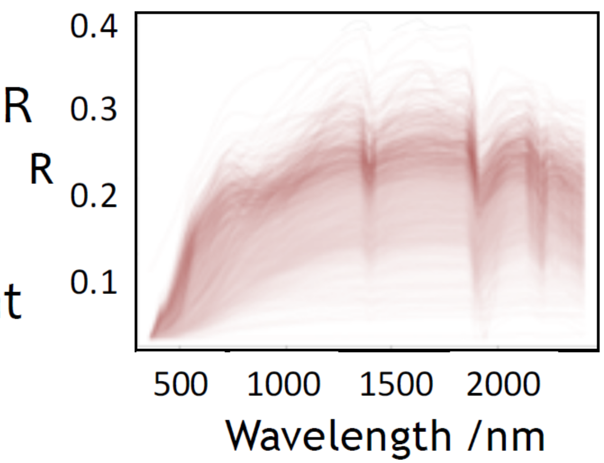


The Global Soil Spectral Library (GSSL)

In 2006 *Raphael Viscorra Rossel* understood the GSSL importance and initiated an activity toward establishing the first GSSL

Global spectral library project

- Started in 2008 as voluntary collaboration in response to growing interest in soil vis–NIR spectroscopy



- Scientists from each continent coordinated and developed guidelines and protocols

- Aim to bring together a community of scientists, encourage research, development of new applications and adoption of spectroscopy in the soil, earth and environmental sciences.

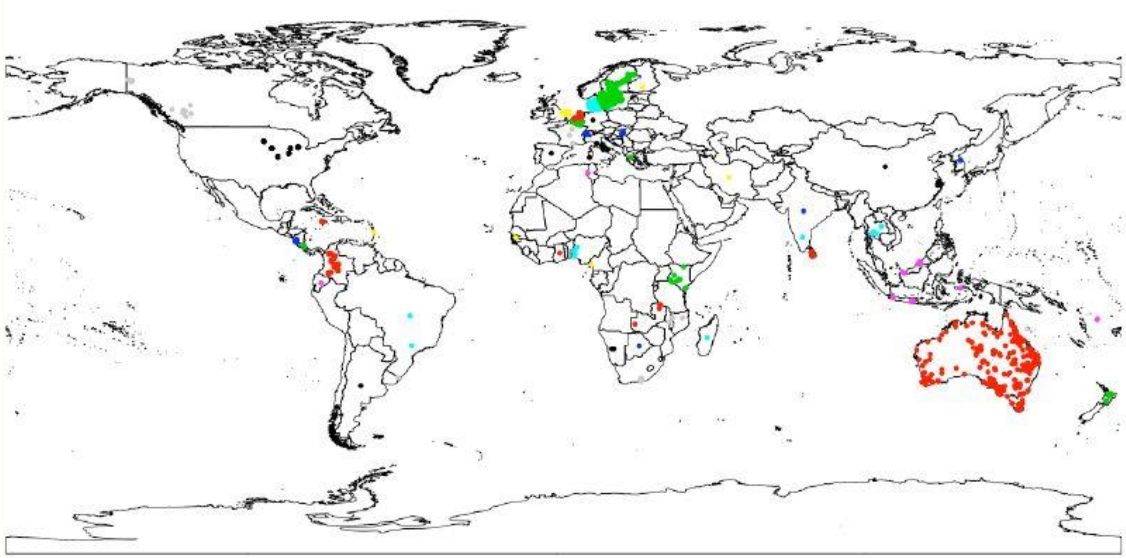
provided by Viscorra Rossel

First World Soil Spectral Library

Current global distribution of spectra

2008

Argentina	64
Australia	355
Belgium	262
Botswana	4
Brazil	528
Brunei	147
Cameroon	1
Canada	130
China	147
Colombia	172
Costa Rica	49
Cuba	15
Denmark	210
Ecuador	8
Finland	1
France	233
Germany	183
Ghana	1
Greece	1
Hungary	17
India	2
Indonesia	7
Iran	142
Israel	220
Italy	100
Jamaica	3
Kenya	100
Korea	92
Madagascar	18
Malaysia	2
Martinique	67
Mozambique	6
Namibia	4
Netherlands	95
New Zealand	210
Nicaragua	23
Nigeria	7
Samoa	3
Senegal	72
South Africa	113
Spain	493
Sri Lanka	6
Sweden	396
Switzerland	160
Thailand	6
Tunisia	89
UK	392
Uruguay	2
USA	1361
Zambia	6



Total of 6721 spectra

Not all representative – e.g. China only field-scale data

Coords for Brazil, Argentina and Ecuador coming

Coords for large part of USA still to be added

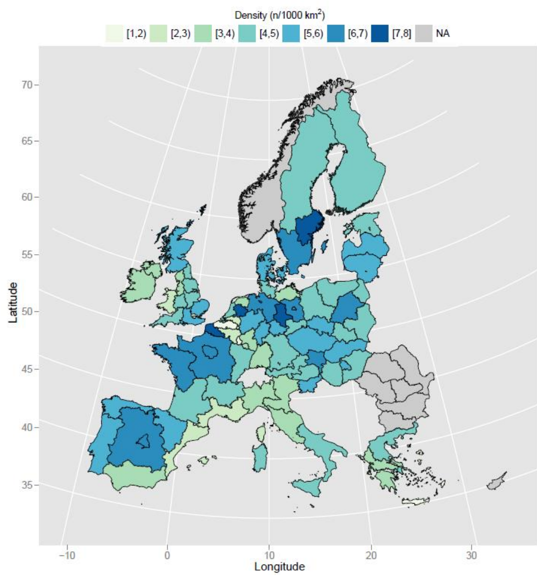
No samples in Russia and eastern Europe

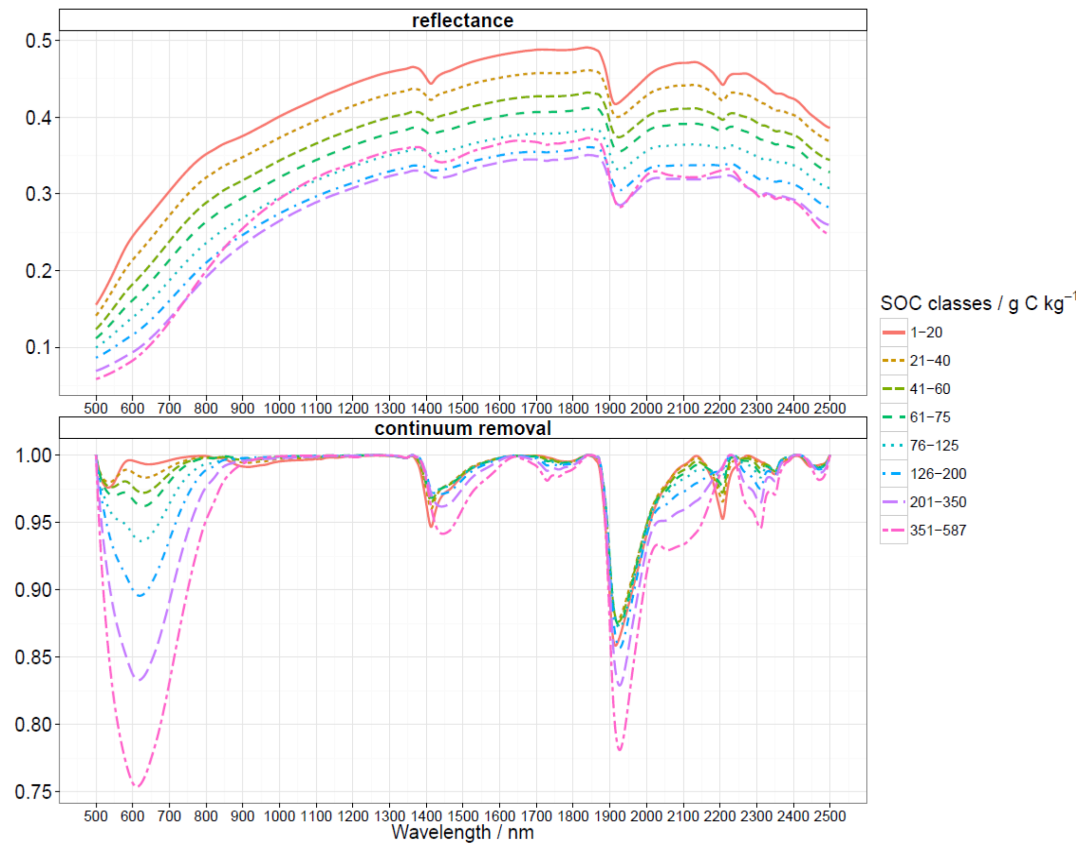
http://groups.google.com/group/soil-spectroscopy/files

The European Soil Spectral Library

The LUCAS spectral library

2011





- Current status:
- 23 European countries
- ~20,000 high quality spectral readings
- Metadata: Clay, silt, sand, OC, pH, CEC, $CaCO_3$, Geographical coordinates, land use, etc

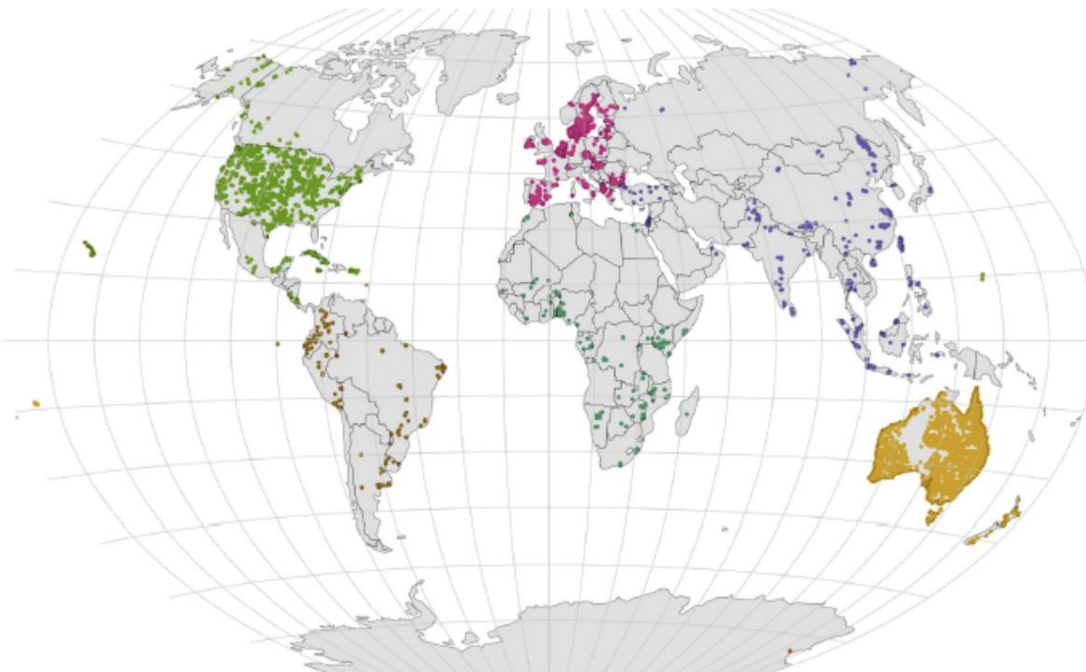
Creation of four subsets: Cropland, Grassland, Woodland, and Organic soils

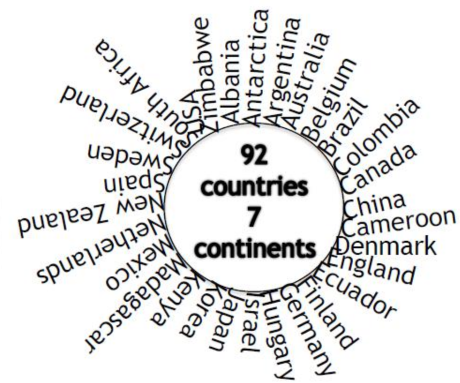
In 2015 Raphael effort yield the first GSSL

Global soil Soil VNIR-SWIR Spectra

Some 20,000 VNIR-SWIR (350-2500 nm) spectra from 12,509 sites

45 collaborators from 35 institutions





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GSSL

Global soil vis–NIR spectra in numbers

Continent

- 8646 **Oceania**
- 5198 **North, Central America**
- 3518 **Europe**
- 3097 **Asia**
- 1621 **Africa**
- 1407 **South America**
- 144 **Antarctica**

Position

- 84% with **coordinates**
- 60% from the **0–30 cm**
- 30% from the **30–100 cm**
- 10% from **> 1m**

Attributes

- **pH** 20,515 (20,515)
- **Organic C** 17,931 (9757)
- **Clay** 17,463 (10,064)
- **Sand** 12,058 (3395)
- **CEC** 9588 (5014)
- **Silt** 9542 (1280)
- **Fe** 4151 (3311)
- **$CaCO_3$** 2960 (1388)

Description

- 15% have **soil horizon**
- 95% with **FAO WRB**
- 80% with **land cover**

provided by Viscorra Rossel

GSSL

There is a publication on the global library

Authors: Those who contribute to GSSL established by Viscorra Rossel

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

ELSEVIER

A global spectral library to characterize the world's soil

CrossMark

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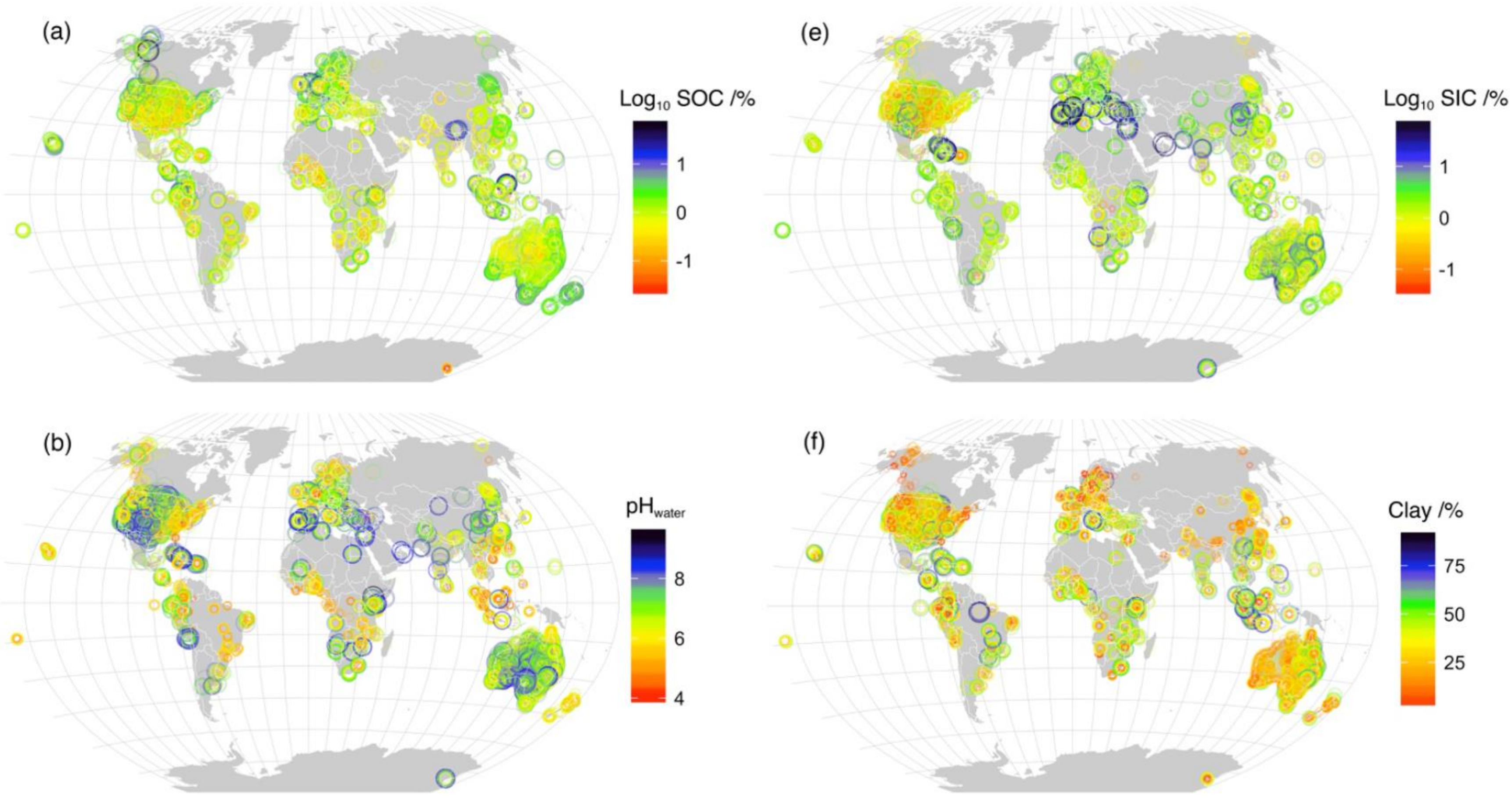
GSSL – Example

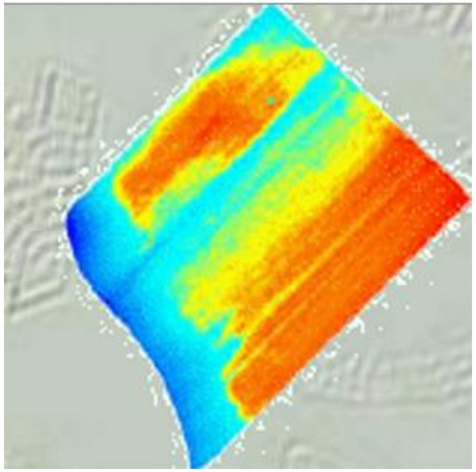
Chemomtric (non linear spectral data mining) from the GSSL

Spatial distribution of predictions



Viscorra Rossel 2015

Soil Mapping in the Field using Local SSL



Regional Soil Spectral Library

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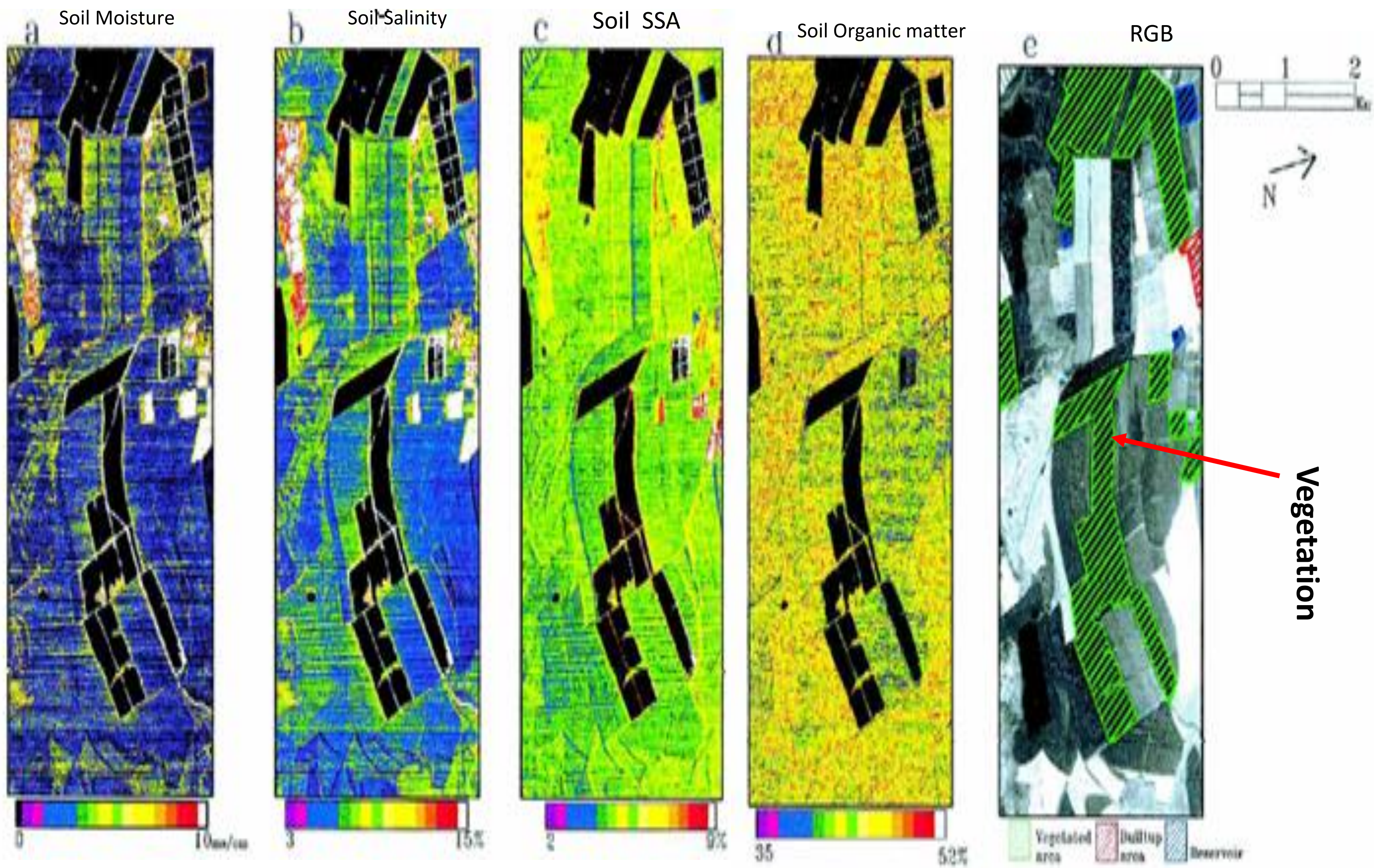
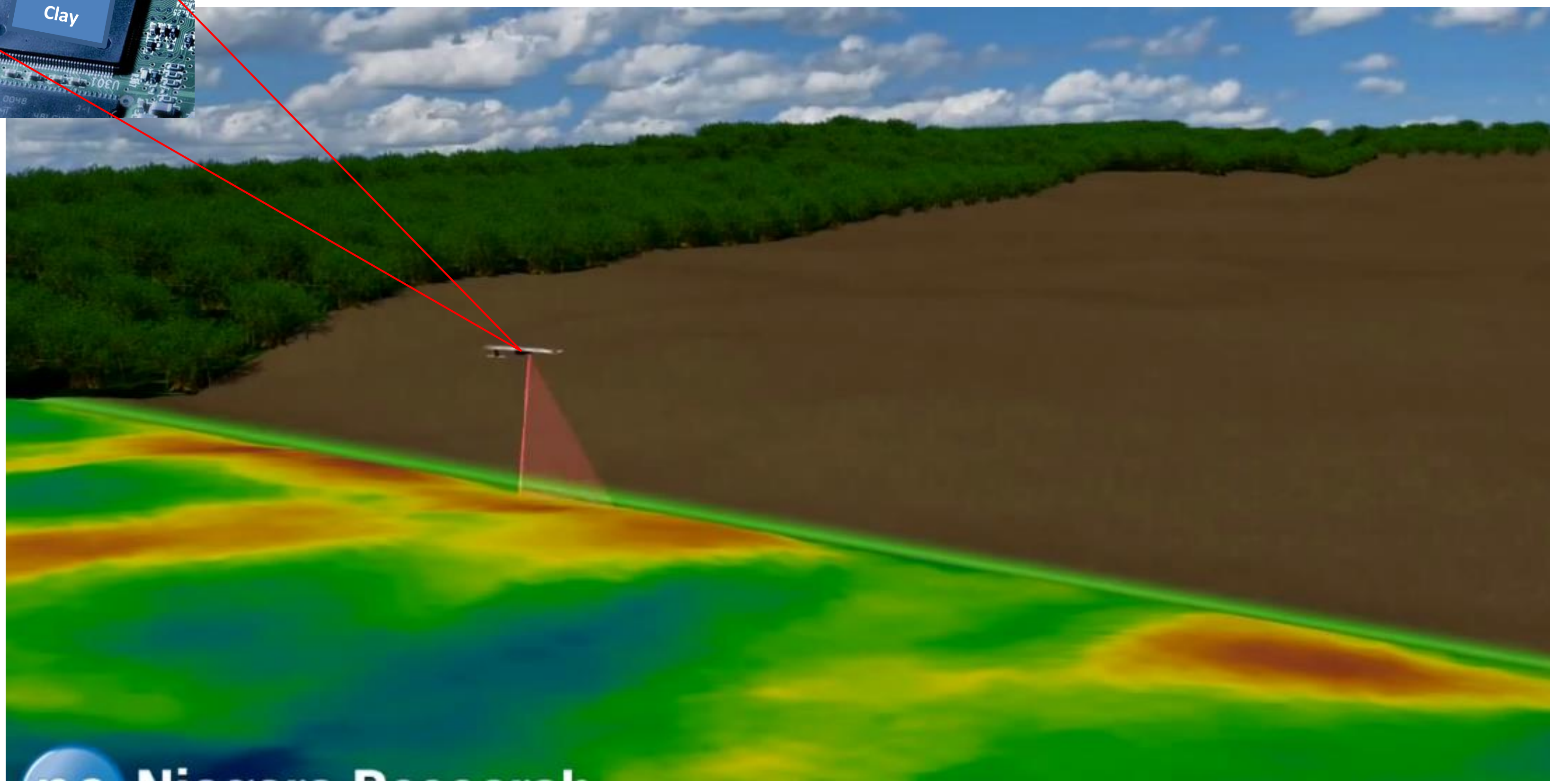
Agricultural Soil Mapping based on Local SSL and HSR technology



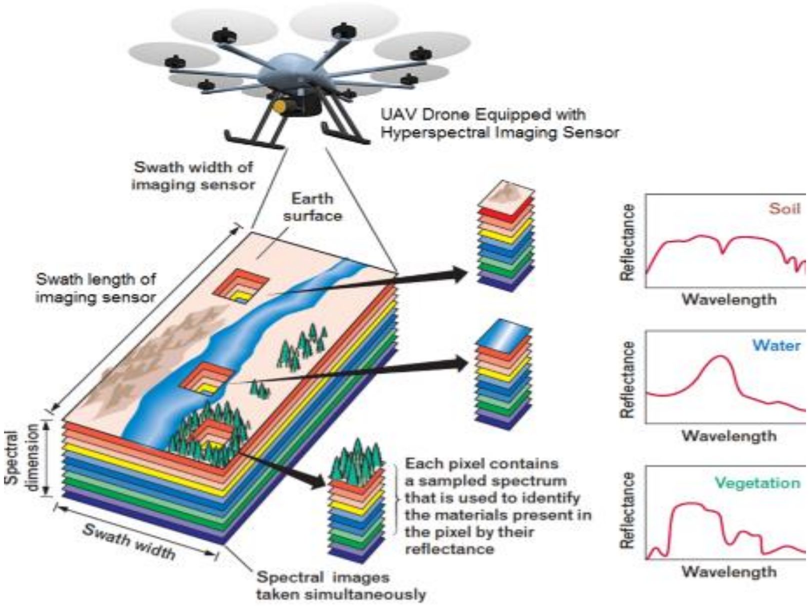
Ben-Dor et al., 2004

The concept of using GSSL using Airborne Sensors

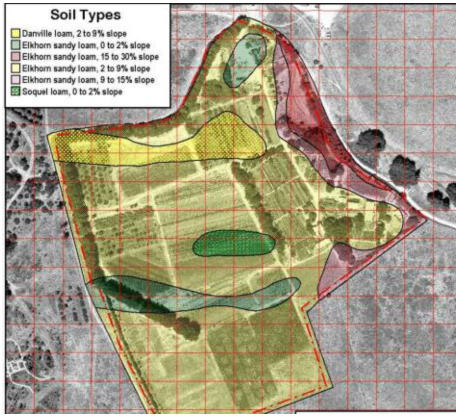
Drones



The Concept of Soil Mapping using LSSL and Drones in real time mode

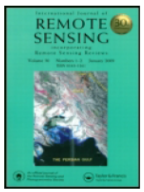


Model
from SSL



Standard

Lucky Bay | Wiely Bay



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Normalizing reflectance from different spectrometers and protocols with an internal soil standard

Veronika Kopačková & Eyal Ben-Dor

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Soil Mineralogy

Performance of Three Identical Spectrometers in Retrieving Soil Reflectance under Laboratory Conditions

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A wide range of electronic and mechanical noise factors can affect soil spectra when using different instruments or even when repeating a specific sample's measurements with the same spectrometer. In soil samples where very weak spectral features are monitored for chemometric purposes, alterations in wavelength location, peak absorption shape, or albedo intensity can limit the use of previously developed spectral models. To quantify this alteration and propose a standardization method, 12 soil samples and three different materials for internal standards (sand, glass and polyethylene) were analyzed. This population was concurrently measured with three identical spectrometers using a strict measurement protocol, and then by different operators with different protocols. Significant changes in the soil spectra were found when different operators performed the measurements, being reduced >50% when the strict protocol was applied. Sand was found to be the ideal internal standard for correcting the spectra to a reference spectrometer, even when different measuring protocols were used. This standardization also showed an improvement in the prediction of soil properties when applying chemometric spectral models even with different instruments, concluding that the use of an internal standard and a strict protocol must be applied for soil spectral measurements. As the measuring factors described in this research also affect any infrared diffuse reflectance spectroscopy measurements, the proposed method should be applicable to any instrumentation and configuration being used. This is crucial to enabling spectral comparisons between different spectrometers or, more importantly, to establishing robust chemometric models and to exchange soil spectral information.

Abbreviations: ASD, Analytical Spectral Devices, Inc.; CR, continuum removal; NIRS, near infrared analysis; PLS, partial least squares; RGB, red-green-blue color model; RMSEP, root mean square error of prediction; SAM, spectral angle mapper; TAU, Tel Aviv University.

Many reflectance spectroscopy applications have been developed for soils in the last 20 yr (Malley et al., 2004). Today, reflectance in the VIS-NIR-SWIR region is considered to be a solid and mature technique for qualitative and quantitative analyses of soil material (Ben-Dor et al., 2008b). Soil spectroscopy has advanced the discipline of soil science by providing a rapid and accurate methodology for quantitative analyses that bypasses the traditional "wet" laboratory analyses. Whereas most of the work in evaluating soil information from reflectance spectroscopy has been performed under controlled laboratory conditions, field applications are now rapidly gaining an important place in soil spectroscopy (Ben-Dor et al., 2009; Cecillon et al., 2009). Accordingly, portable spectrometers are being developed and utilized worldwide for many natural resource applications, such as soil, rock, vegetation, and water studies. In addition, a wide range of soil spectral measurements are being gathered around the globe with the intention of building a universal soil spectral library (Viscarra Rossel, 2009). However, this kind of initiative, or even the routine analyses of spectral data collected in one specific laboratory, are limited by the differences that are usually obtained when different spectrometers and protocols are used (Milton et al., 2009; Price, 1994). Spectral performance may vary among different types of spectrometers, or even among models from the same manufacturer, being therefore important to characterize

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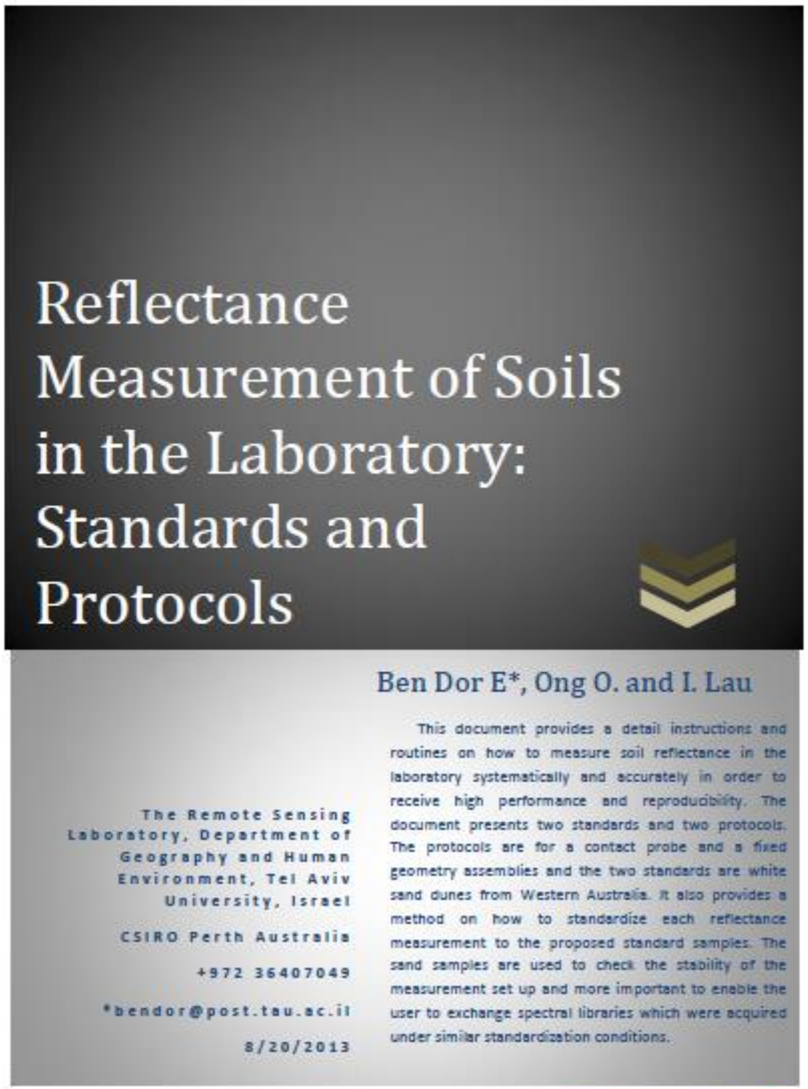
*Corresponding author (pimstein@uc.cl).

Protocol

A simple protocol has established for new users Since 2014



Reflectance Measurement of Soils in the Laboratory: Standards and Protocols

Ben Dor E*, Ong O. and I. Lau

This document provides a detail instructions and routines on how to measure soil reflectance in the laboratory systematically and accurately in order to receive high performance and reproducibility. The document presents two standards and two protocols. The protocols are for a contact probe and a fixed geometry assemblies and the two standards are white sand dunes from Western Australia. It also provides a method on how to standardize each reflectance measurement to the proposed standard samples. The sand samples are used to check the stability of the measurement set up and more important to enable the user to exchange spectral libraries which were acquired under similar standardization conditions.

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Reflectance measurements of soils in the laboratory: Standards and protocols

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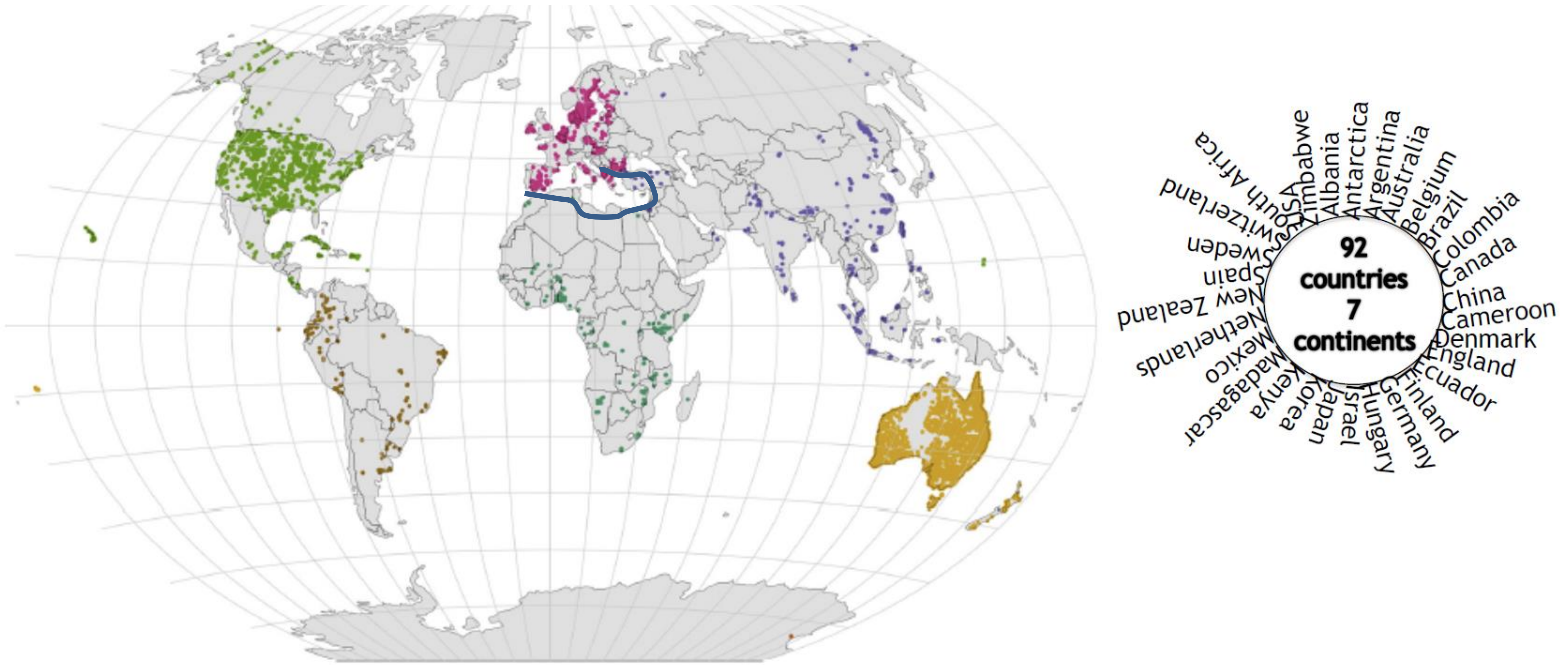
ABSTRACT

For the past 20 years, soil reflectance measurement in the laboratory has been a common and extensively used procedure. Based on soil spectroscopy, a proxy strategy using a chemometrics approach has been developed for soils, along with massive construction of soil spectral libraries worldwide. Surprisingly however, there are no agreed-upon standards or protocols for reliable reflectance measurements in the laboratory and field. Consequently, almost every user reconstructs his or her own protocol based on the literature, experience, convenience and infrastructure. This yields significant problems for comparing and sharing soil spectral data between users, as spectral variations can be encountered from one protocol to the next. This further prevents the generation of a

GEO-CRADEL PILOT

Enlarged the GSSL by Establishing the Foundation (knowhow, standard and protocol) to Build a Regional SSL

A Regional North Africa, Mediterranean, Balkan Soil Spectral Library



provided by Viscorra Rossel

The Concept of Soil Mapping using SSL and HSR from orbit

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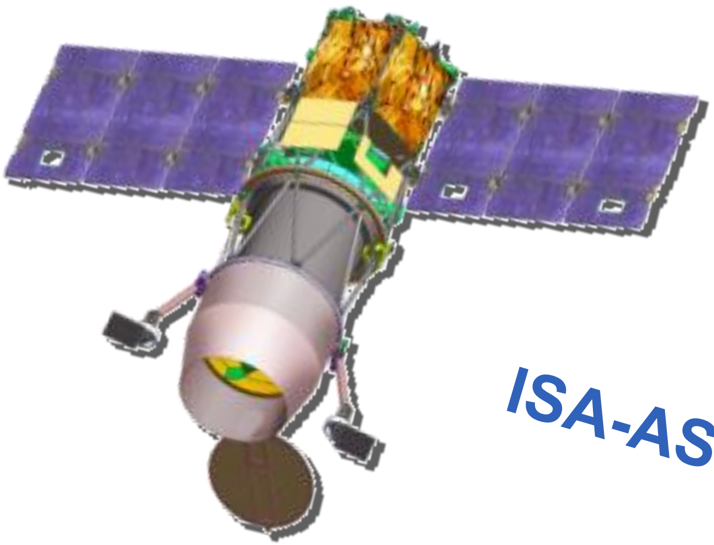
Product Name
Crop, Rangeland and Invasive Species Map
Burnt Area Map
Vegetation Status Indicators
Vegetation Damage and Stress Indicators
Fire Fuel Map
Mineral Map
Coastal Bathymetry Map
Urban And industrial Functional Area Map
Lithological Map
Lava Flow Parameters
Soil Surface Pollutants Map
Volcanic Gas And Aerosol Emission Map
Forest Species Map
Forest Biomass Map
Ice Cover Map
Soil Characterization Map
Land Cover Map
Land Cover Change Detection Map
Snow Cover Map
Forest Nitrogen and Chlorophyll Map
Wetlands Classification Map
Marine And Aquatic Quality And Productivity Indicators
Lava and ash distribution map
Snow And Ice Cover Characterization

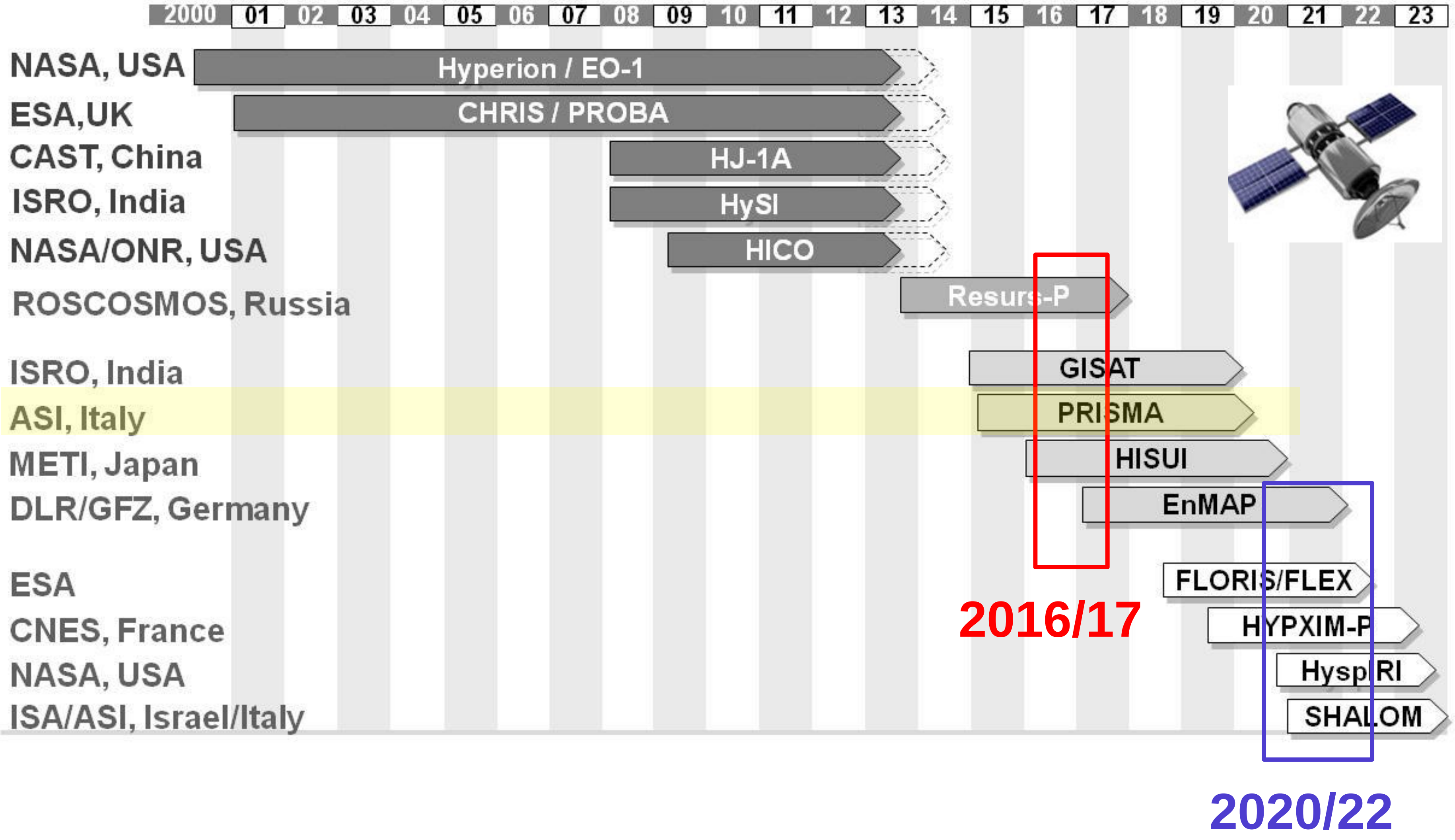
SHALOM (9m GDS)

SHALOM products that are based on GSSL



ISA-ASI

HSR Satellites



The Soil Spectroscopy Library
Summary

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- Reflectance spectroscopy (RS) of soils is an important property for Food Security issues world wide.
- Spectral libraries are generated under regional, national, continental and global scales.
- The GSSL initiative paves the road to accumulate libraries from all scales and resources global wide
- SSLs from North Africa, Mediterranean and Balkan countries should be extend in order to be a data base for modern precision agriculture activities
- Standard and protocols are existing and should used for the GEO-CRADLE's Reginal SSL PILOT

Thank You !!

CRADLE

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