Spectral Imaging of Soils: past present and future

Eyal Ben-Dor

Department of Geography
Tel Aviv University
OUTLINE

- Definitions
  - Soil Spectroscopy and its information
  - Deep Learning to extract soil attributes
  - Soil Imaging and field spectroscopy, big data issues
  - Soil Spectral libraries and importance
  - Soil standardization
  - Image visualization
  - Interests
  - New Spectral dimensions
  - Sensors and Platforms (airborne): big to light maned aircraft to drones (VNIR only)
  - Satellites program
Soil

Definition 1

The upper layer of the earth (0-2 m) represents its loose surface material which is dug, plowed, and is a medium for plants to grow (Thompson 1957).

Soil profile:
- **Surface Litter**: leaves, branches, animal scales, and bodies, mushrooms, other rotted matter.
- **Topsoil Layer (or Humus)**: rotted organic matter from litter layer and minerals from weathering rocks.
- **Subsoil**: crumbling rock, sand, clay, gravel, and silt.
- **Parent Material**: actual bedrock underlying the soil layers.
Strong Link between Point and Image Spectroscopy

- Image Spectroscopy
- Geology
- Vegetation
- Water
- Soil

Point Spectroscopy
Soil Spectrum – An elegant way to simplest the complexity of the soil system

Iron Oxides
Hygroscopic Water
Clays
Organic Matter
Calcite

Reflectance

Wavelength (μm)

Soil Spectrum – An elegant way to simplest the complexity of the soil system

Reflectance

Wavelength (μm)
Quantitative spectroscopy – Chemometrics
First article on soil spectra quantification 1965 demonstrated the power of soil spectroscopy

**Clayey Soil and Soil Moisture**

**Reflection of Radiant Energy from Soils**

Bowers, S. A.; Hanks, R. J.

*Soil Science* 1965 Vol. 100, No. 2

When radiant energy is incident on any surface it is distributed through three different processes: reflection, absorption, and transmission. Thus, reflectance = absorbance + transmittance = 1, where unity is equivalent to the energy in the incident beam. Transmittance, however, with opaque materials, such as soils, is zero, and increasing the reflectance therefore decreases the absorbance an equivalent amount. The possibility of influencing the various thermally dependent soil processes, such as evaporation, by changing the reflectance is worthy of consideration. Such a consideration first requires a determination and evaluation of the factors that influence reflectance, and this was a primary objective of the experiment in stimulus coordinates and, in general, indicated an increase in the Y coordinate—the luminosity function—as particle size decreased. Leudert (14) stated that the grey tones in photographs of drying foreshores of sand beaches are indicative of superficial moisture content and the predominant grain size occurring on the beach. Zwerman and Andrews (18), working with enameled surfaces, stated that at a given wavelength a material of given refractive index reflects light with an intensity that varies inversely as the particle diameter. The increase in reflectance with fine milling is attributed to the increased interface between opacifier and frit.

Bowers and Hanks, 1965
1980 – First Soil Spectral Library

5 spectral types in USA  Around 4000 spectra

Common method 1990-2002

Multiple Linear Regression Analyses

**Calibration**

\[ C_{p} = b_{0} + b_{1}L_{1} + b_{2}L_{2} + b_{3}L_{3} + \ldots + b_{n}L_{n} \]

Sample Number

\[
\begin{align*}
1 & \quad C_{m1,1} \ C_{m1,2} \ C_{m1,i} \\
2 & \quad C_{m2,1} \ C_{m2,2} \ C_{m2,i} \\
\vdots & \quad \vdots \quad \vdots \\
j & \quad C_{mj,1} \ C_{mj,2} \ C_{mj,i}
\end{align*}
\]

**Validation**

\[ C_{p} = b_{0} + b_{1}L_{1} + b_{2}L_{2} + b_{3}L_{3} + \ldots + b_{n}L_{n} \]

Sample Number

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\begin{align*}
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\vdots & \quad \vdots \quad \vdots \\
j & \quad C_{pj,1} \ C_{pj,2} \ C_{pj,i}
\end{align*}
\]
Soil Spectroscopy: An Alternative to Wet Chemistry for Soil Monitoring

Today: Supervised Machine Learning for data mining

The Unscrambler©
SPSS©
Matlab©

Drawbacks

- Limited output
- Limited configuration
- Requires Programming knowledge
- No Automation for Pre-processing

PARACUDA©

Tomorrow: Automated Deep Learning Approach

- One click button
- No need to be expert in machine learning approach
- Extracting the best model
- Image application
Software for data mining and image illustration

Paracuda-II®
An automated data mining machine for soil chemometric analysis (point and imaging)
E. Ben Dor

FAST & AUTOMATICS
What is Code Ocean?

Code Ocean is a cloud-based executable research platform that allows authors to share their algorithms in an effort to make the world’s scientific code more open and reproducible. Uploading your algorithms and associated data files to the Code Ocean site is easy. Anyone can run an algorithm posted to Code Ocean, modify it, and test the modifications. The published algorithm that an author posts will remain unchanged.

1. Find the code
2. Acquire the right hardware
3. Set up the environment
4. Import the right files
5. Installing all dependencies...packages, versions, OS etc...
6. Errors.. Debugging.. Errors.. Debugging
7. Run
8. Results
Spectral Archive
Soil Spectral Library: chemistry and spectroscopy

### Soil Spectra Files

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**Sample Attributes**

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**Soil Spectra**

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Past: 1980 – First Soil Spectral Library

Around 4000 spectra
Today: World Soil Spectral Libraries (no measurement protocols) – many users

Estimation of total number of soil spectra: 400,000
(1980 – 4,000)
There is a publication on the global library

A global spectral library to characterize the world's soil

R.A. Viscarra Rossel a, T. Behrens b, E. Ben-Dor c, D.J. Brown d, J.A.M. Demattê e, K.D. Shepherd f, Z. Shi g, B. Stenberg h, A. Stevens i, V. Adamchuk j, H. Aïchi k, B.G. Barthès l, H.M. Bartholomeus m, A.D. Bayer n, M. Bernoux l, K. Böttcher o, p, L. Brodsky q, C.W. Du r, A. Chappell a, Y. Fouad s, V. Genot t, C. Gomez u, S. Grunwald v, A. Gubler w, C. Guerrero x, C.B. Hedley y, M. Knadel z, H.J.M. Morrás aa, M. Nocita ab, L. Ramirez-Lopez ac, P. Roudier y, E.M. Rufasto Campos ad, P. Sanborn ae, V.M. Sellitto af, K.A. Sudduth ag, B.G. Rawlins ah, C. Walter s, L.A. Winowiecki f, S.Y. Hong ai, W. Ji aj
Past – no protocol for spectral measurements
Present and future: a new standard and protocol for global soil spectral library

Eyal Ben Dor a,*, Cindy Ong b, Ian C. Lau b

a Tel Aviv University (TAU), Israel
b CSIRO, Perth, Western Australia, Australia

Reflectance measurements of soils in the laboratory: Standards and protocols

Standardization – Reducing Non Systematic
Soil Internal Standard – Reducing Systematic Effects
Tomorrow: New **Standard** world wide Soil Spectral Library
Adaptation to Climate Change (ACC)

Improved Food Security – Water Extremes Management (IFS)

Access to Raw Materials (ARM)

Access to Energy (SENSE)

Protocol, SSL
WP 4 – TAU-i-BEC mission

• To establish a soil spectral library SSL for the North Africa, Middle East and Balkans

• To establish a basic foundation to use the SSL for EO means (from field, air and domains)

• To built a data base with a GEOSS sharing regulation
Spectral Sensors – laboratory and field
Field Spectrometer and Accessories

Past

PERS
1974

ASD
1994
Today and tomorrow: Many instruments
Today: Field soil measurement is leaning on the sun radiation
Today: Close moving chamber for 27/7 option
Tomorrow: Close chamber compatible with all spectrometers and easy to use

Soil field Probe (SoilPRO®)

Laboratory quality in field measurements
Past: Soil spectral Profiling
Tomorrow: Merging profiling spectroscopy with surface data
Imaging Systems
from heavy (past) to light sensors (present and future)

Petri SPECIM  March 23, 2015

“we have sold now way over 4000 spectrographs, of which ~110 have gone into airborne AISA systems!”
From point and scanning (past) to snapshot systems (present and future)
Imaging Platforms  (air borne)
Past: Heavy aircrafts and complicated constructions (airborne)
Present: light aircraft and UAVs (airborne)
**Tomorrow**: Combination between airborne and satellite

**High Altitude Pseudo-Satellites (HAPS)**

- Unmanned flying platform
- Running exclusively on solar power
  - batteries charged during daytime for operation at night
  - airborne for weeks ➔ months ➔ years
- Operating in the stratosphere (altitude ~20 km) to be
  - above weather (clouds, jet streams)
  - above regular air traffic
  - Covering local ➔ regional footprints

HAPS fill the gap between satellites and fuel-powered aircraft providing:
- affordable, persistent, local satellite-like services

HAPS are:
- enduring like a satellite
- focused like an aircraft
- cheaper than both of them

**20 Km**

**4 Weeks**
Interest
### Interest

How point spectroscopy driven the image spectroscopy of soils

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<td>Future</td>
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[Image: Graph showing the increase in interest and number of papers and patents for point spectroscopy and image spectroscopy over years.]
Past: Special Issues on Soil (Field) Spectroscopy

Quantitative Soil Spectroscopy

Jérome Chabrillat,1 Eyal Ben-Dor,2 Raphael A. Viscarra Rossel,3 and José A. M. matte4

Application Soil Science
Volume 2013 (2013), Article ID 616578, 3 pages
http://dx.doi.org/10.1155/2013/616578

Special Issue of JNIRS—Journal of Near Infrared Spectroscopy on NIR Spectroscopy of Soil

Special Issue on NIR Spectroscopy of Soil is 15 May 2015.

2015 is the International Year of Soils and JNIRS—Journal of Near Infrared Spectroscopy will publish a Special Issue on NIR Spectroscopy of Soil to celebrate the contribution of NIR spectroscopy understanding of this fundamentally important part of our environment.
Special Issues on Soil (Field) Spectroscopy

A special issue of Remote Sensing (ISSN 2072-4292).

Deadline for manuscript submissions: 31 July 2015

Impact Factor = 2.72

As for March 27, 2015
In Total (11)
Under Review (2)
Pending Major Revisions (2)
Revised Version Review (2)
Pending Editor Decision (1)
Published (3)
Rejected & Archived (3)
Remote Sensing of Soil in the Optical Domains

Eyal Ben-Dor
Tel Aviv University

Jose A.M. Dematte
University of Sao Paulo
About 150 members
“visNIR” community

Professional Groups

Dear Eyal BEN DOR,

This is an overview of the last update of your "Hyperspectral Applications for Soil" mailing list:

* 320 continuing members;

* 1 new member: LAGOUARDE Jean-pierre (lagouarde@bordeaux.inra.fr);

* 0 removed member;

* 0 refused member;

* 0 applicant;

You can manage all your EUFAR mailing lists in the back office mailing list page
Remote Sensing Applied to Soil Science

Eyal Ben Dar, Tel Aviv University, Department of Geography and Human Environment, School of Earth Science, Faculty of Exact Sciences, Tel. 03-6407049
Email: bendar@post.tau.ac.il

José Alexandre M. Dematté, University of São Paulo, College of Agriculture “Luiz de Queiroz”, Tel. +55 019-3417-2109, Email: jadematt@usp.br

5. Rationale
Remote sensing is a very important topic and a growing scientific field. With many satellites, airborne (manned and un-manned) platforms and new advance sensors, this research area attracts many scientists, stakeholders, governmental entities, environmental policies and decision makers. Accordingly, this field holds a significant interest at many countries worldwide while the scientific papers on this topic grows exponentially. For soils, this theme has a great potential to attract many researchers from all over the world that could not find yet nor appreciate them in the past WCSS Symposiums. Establishing of the soil remote sensing theme in the current WCSS Symposium will, beside of exchanging information and experiences between current and future users, to foster future activity in this promising technology with other soil themes within the WCSS. Indeed, we can say that this technology works in two fields, where one is the use of available data sources (ie. free images, google earth and others) and the other is the use of specific data acquisition processes. Researchers from other soil themes may have an access to the remote sensing technology and, accordingly, open new horizons for better science. In the proposed theme, a worldwide reputation of scientists will take part and contribute a fresh attitude to this old new technology that will no doubt contribute much to the soil science arena.

6. Objectives
The objectives of the symposium are to report on the development of:
   a. Updating of research on applications of remote sensing in Soil Science
   b. Soil remote sensing data analyses by chemometric methods
   c. Integration of the multi and hyperspectral sensors data for soil science
   d. Use of the remote sensing data in digital soil mapping, precision agriculture, soil attributes prediction, land use, soil monitoring and environment soil impact.
   e. Available platforms and data bases for soil remote sensing study
   f. Research integration
   g. Remote sensing and others soil science integration
Spectral Region
Mid IR for soil P (soluble and solid)

Space Programs
Space Programs
Hyperspectral Missions

Launch and Lifetime

2021/24

2018/19

HSR Orbital Mission

Past

Present

NASA, USA

Hyperion / EO-1

ESA, UK

CHRIS / PROBA

CAST, China

HJ-1A

ISRO, India

HySi

NASA/ONR, USA

HICO

ROSCOSMOS, Russia

RESURS-P

ISRO, India

GISAT

ASI, Italy

PRISMA

METI, Japan

HISUI

DLR/GFZ, Germany

EnMAP

ESA

FLORIS/FLEX

CNES, France

HYPXIM-P

NASA, USA

HysplR

ISA/ASI, Israel/Italy

SHALOM

SENTINEL 10
Soil monitoring from space are playing a major role in SHALOM and SENTINEL 10 missions.
Model from SSL

Tomorrow’s vision
Conclusions

• Soil Hyperspectral Remote Sensing is a growing field with a growing recognition.

• Soil Hyperspectral Remote Sensing has a great potential in many directions.

• The future is bright in soil spectral imaging base on the knowhow already accumulated and on the forthcoming advance technology (sensors, accessories, platforms).
Thank You for Your Attention

Makhtesh Ramon Israel