Soil moisture mapping using ground-penetrating radar as a pillar to sustainable and optimal environmental and agricultural management

Sébastien Lambot

sebastien.lambot@uclouvain.be

Earth and Life Institute,
Université catholique de Louvain
Belgium
Introduction

Soil moisture governs: infiltration and runoff, evaporation, energy exchanges with atmosphere, plant growth (food & energy), contamination
Human activities, but also natural processes, lead to soil degradation worldwide: erosion, compaction, pollution, desertification, sealing, salinization, nutrient depletion.
Observation: characterizing and monitoring the environment

Process understanding and modeling

Management strategies and decision support

Innaccessibility
Variability

Bridging the scale gaps between observations, modeling, and management

from observations to sustainable and optimal soil and water management
Ground-penetrating radar (GPR)

- Dielectric permittivity $\varepsilon$  → wave velocity
- Electric conductivity $\sigma$  → wave attenuation
- Magnetic permeability $\mu$

Electromagnetic contrasts

→ Reflection, transmission
Management of city infrastructures: project control, monitoring and maintenance

Roads, underground pipes and cables

Buried tanks

Tunnels

Bridge decks
Archeology

Geology
Security and natural disasters

Forensics
Evolution of GPR research in the world

Published Items in Each Year

Applications follow…

GPR 2014
Soil water content determination

Relationship between soil water content and dielectric permittivity

- soil grains $\varepsilon_r \approx 5$
- water $\varepsilon_r \approx 81$
- air $\varepsilon_r = 1$

Empirical Topp’s equation:

$$\theta = -5.3 \times 10^{-2} + 2.92 \times 10^{-2} \varepsilon_r - 5.5 \times 10^{-4} \varepsilon_r^2 + 4.3 \times 10^{-6} \varepsilon_r^3$$

Dielectric mixing models (e.g., Complex Refractive Mixing Model CRIM):

$$\theta = \frac{\varepsilon_{\theta}^\alpha - (1 - n)\varepsilon_{s}^\alpha - n\varepsilon_{a}^\alpha}{\varepsilon_{w}^\alpha - \varepsilon_{a}^\alpha}$$
Resorting to full-wave forward and inverse modeling of the GPR data is necessary to maximize information retrieval capabilities.

**GPR for determining the electrical properties of materials**

System design: Resolving electromagnetic properties through forward modeling.

Product: Map illustrating the electrical properties of the materials.

Signal inversion: Process for extracting information from measured radar data.
Examples of application  (Lambot et al., NSG, 2008)

Irrigation areas in Tunisia

Different characterization scales and inherent variability
High-resolution, real-time mapping of soil moisture

Handheld system

Automated platforms

(e.g., EU-FP7 DIGISOIL, BELSPO SENSAR projects)

Towards digital soil mapping – improving remote sensing data products
Field-scale applications

Test site in Bologna (Italy)

400 MHz GSSI antenna

Time-lapse monitoring
Root-zone soil moisture characterization
Conclusions

- New GPR full-wave inverse modeling techniques have been developed for non-invasive soil characterization
- High-resolution soil moisture maps can be obtained at the field scale
  - Shallow characterization for improving remote sensing
  - Root-zone characterization for precision agriculture

Precision agriculture perspectives

*Integrating the technology in a digital soil mapping applied context*

*(e.g., improve irrigation efficiency)*