

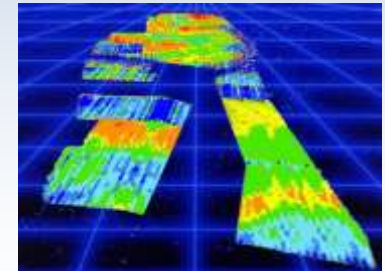
Real-time mapping of soil moisture at the field scale using ground-penetrating radar

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Université catholique de Louvain
Belgium*



Université catholique
de Louvain

UCL

Université catholique de Louvain (Belgium)

Education

- Funded in 1425
- 26000 students, 120 nationalities
- Staff: 5500 (professors, scientists, etc.)
- Budget 360 millions EUR
- 10 Faculties, 50 departments, 200 laboratories
- 37 bachelor and 172 master programmes, etc.
- 3 science parks, 2 university hospitals
- Nobel price in medicine: de Duve, 1974
- 126th university in the world (THES 09)



Research and Development

- Biotechnology
- Cancerology
- Environment and sustainable development
- Biomedical engineering

- Cryopreservation
- Materials
- Communication and IT
- Nanotechnologies



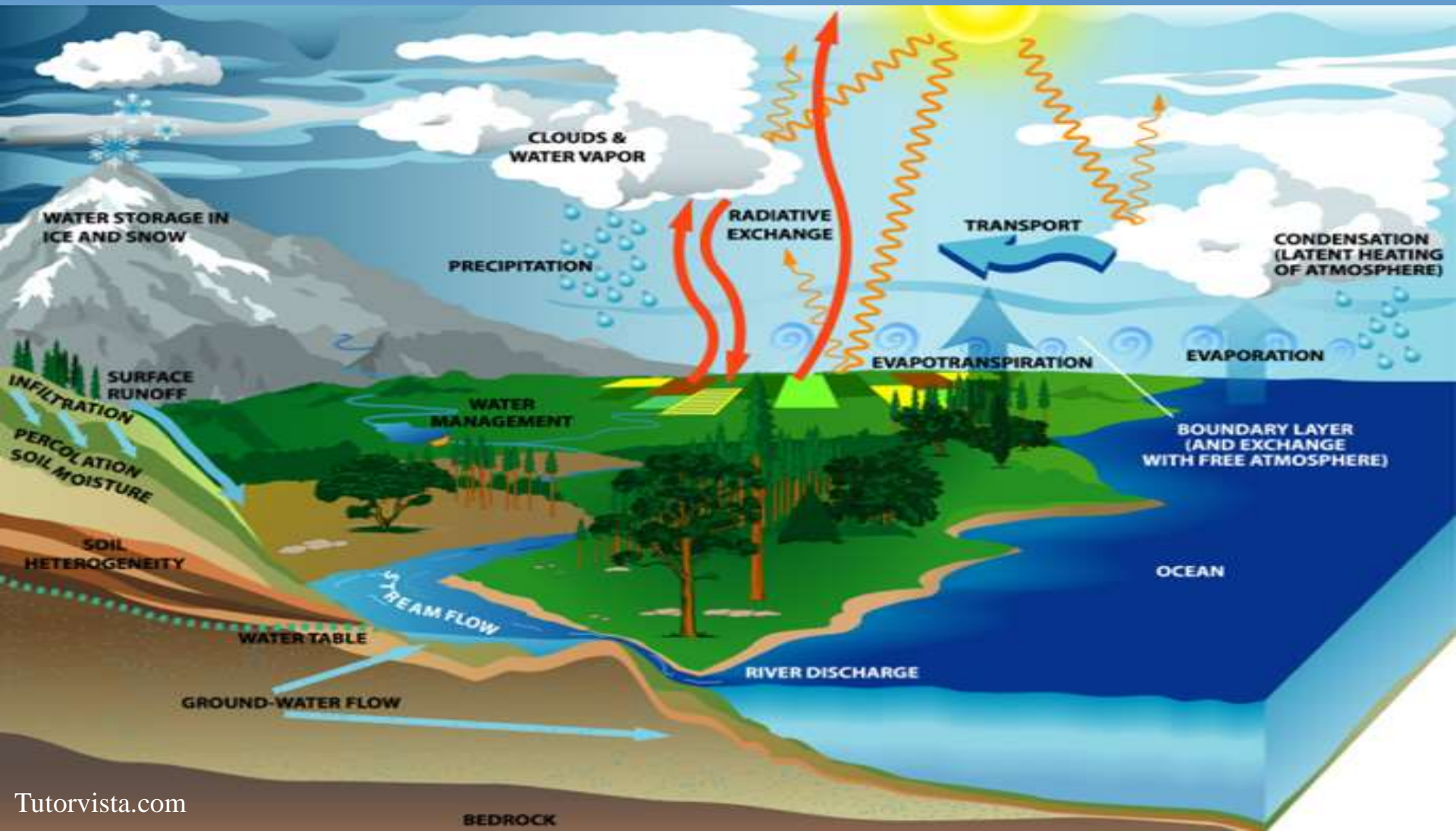
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Introduction

Soil moisture governs: infiltration and runoff, evaporation, energy exchanges with atmosphere, plant growth (food & energy production), contamination



Human activities, but also natural processes, lead to soil degradation worldwide: erosion, compaction, pollution, desertification, sealing, salinization, nutrient depletion

Science

Soil and Trouble

WHEN PEOPLE INTENSIVELY TILL FIELDS and clear-cut forests, they can damage or destroy topsoil that took centuries to accumulate. Just how vulnerable soils are depends on underlying conditions. Mismanaged soils in windswept lands can easily turn into desert, for example, and saline soils can become salt-encrusted wastelands.

This map shows the main barriers to productive farming, along with erosion risk, derived from climatic and soil conditions. Overlaid as cross-hatching are regions reported to be highly or very highly degraded according to a global survey of soil experts published in 1990. The hot spots illustrate examples of the worst soil degradation, from the most common physical type—water erosion—to chemical forms, such as that caused by pollution from industrial chemicals and war.

An interactive version of this map appears online at www.sciencemag.org/cgi/content/summary/304/5677/1614.

SOURCE: Adapted from Major Land Resource Constraints map created April 2004 by P. Kish and H. Boman of USDA/NRCS, Soil Survey Division, World Soil Resources, Washington, D.C., from 1976 Soil Criteria Map and 1982 Soil Map of the World, 1:800,000, CLC/DB data (J. R. Gibbert et al., 1991) provided by K. Smetacek, 1976. Data on compaction is from SCHUBERT (2000).



UNITED STATES
erosion
Decades of water erosion on tilled fields has degraded soil across the Midwest and Great Plains, although no-till agriculture has recently stemmed losses.



CENTRAL & EASTERN EUROPE
compaction
Soviet-era intensive tillage has left 11% of topsoil across Central and Eastern Europe too densely packed to allow sufficient water and nutrients to reach plant roots.



IRAQ
pollution
During the first Gulf War, 40 million tons of Kuwait's oil were drenched with oil. Experts fear that soils in Iraq are being damaged by fuel and other chemicals spilled during the current conflict.



KAZAKHSTAN & UZBEKISTAN
pollution, desertification
Shrinkage of the Aral Sea, due to diversion of water from its tributaries, has exposed a seabed laced with herbicides and pesticides. The tainted dust is picked up by the wind and poisons farmland.

CHINA
desertification
The expansion of deserts due to farming and grazing slows the country's famous dust storms.



WESTERN EUROPE
sealing
Covering of soils with buildings and roads has put beyond use large swaths of prime soil in European cities.



CHINA
erosion
1.6 billion tons of soil per year wash into the Yellow River from China's Loess Plateau, which has the highest rates of water erosion in the world.



HIMALAYAS
erosion
Overgrazing and deforestation have spurred widespread soil erosion in the lower Himalaya Mountains, where natural rates are already high because of monsoonal rains.



AMAZON
erosion
Slash-and-burn agriculture in the Amazon exposes poor tropical soils that can sustain crops for only a few years before nutrients wash away.



SUB-SAHARAN AFRICA
nutrient depletion
Fields rarely left fallow and the scavenging of vegetation and dung have conspired to mine the soil of nutrients.



AUSTRALIA
salinization
Removal of vegetation has allowed the water table to lift underlying salts, leading to barren landscapes such as this one in Western Australia's wheat belt.

- PHYSICAL DEGRADATION
- ▲ CHEMICAL DEGRADATION

High and very high levels of soil degradation per Global Assessment of Soil Degradation (GLASOD)

- Highly erodible by wind or water
- Few constraints

Climate Constraints

- High temperatures
- Seasonal cold
- Seasonally excess water
- Seasonal dryness
- Continuous cold
- Continuous dryness

Physical Constraints

- High shrink/swell potential
- Minor root restricting layer
- Low structural stability
- Impeded drainage
- Low water holding capacity
- Shallow soils

Chemical Constraints

- Low organic matter
- High anion exchange capacity
- High aluminum
- Calcareous, gypsicous condition
- Low nutrient holding capacity
- Low moisture and nutrient status

- High phosphorus, nitrogen, and organic retention
- High organic matter
- Salinity/alkalinity

NOTE: Acid sulfate condition (0.09% of total map area) and steep lands (observed by erosion risk) are not shown.

➔ from observations to optimal and sustainable soil and water management

Observation: soil characterization and monitoring

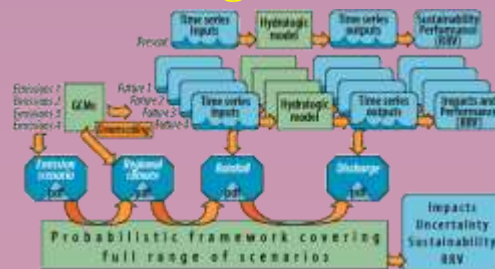


Process understanding and modeling



Soil:
- Inaccessibility
- High variability

Management strategies and decision support



Bridging the scale gaps between observations, modeling, and management

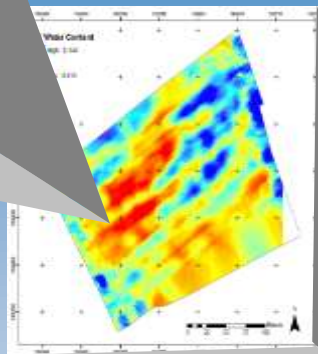
Soil moisture determination

Local scale

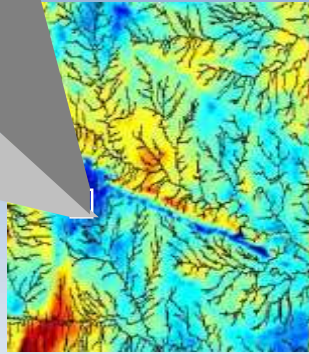


Soil sampling
Dielectric sensors

Field scale



Catchment scale



Geophysical methods
(ground-penetrating radar)

Remote sensing
(airborne, spaceborne)

Advantages:

- Easy to use

Disadvantages:

- Laborious (intrusive)
- Local characterization (100 -500 cm³)
- Shallow characterization (5-20 cm)

Advantages:

- Non-invasive
- Real-time mapping
- Root zone characterization

Disadvantages:

- Complex data processing
- Cost of equipment

Advantages:

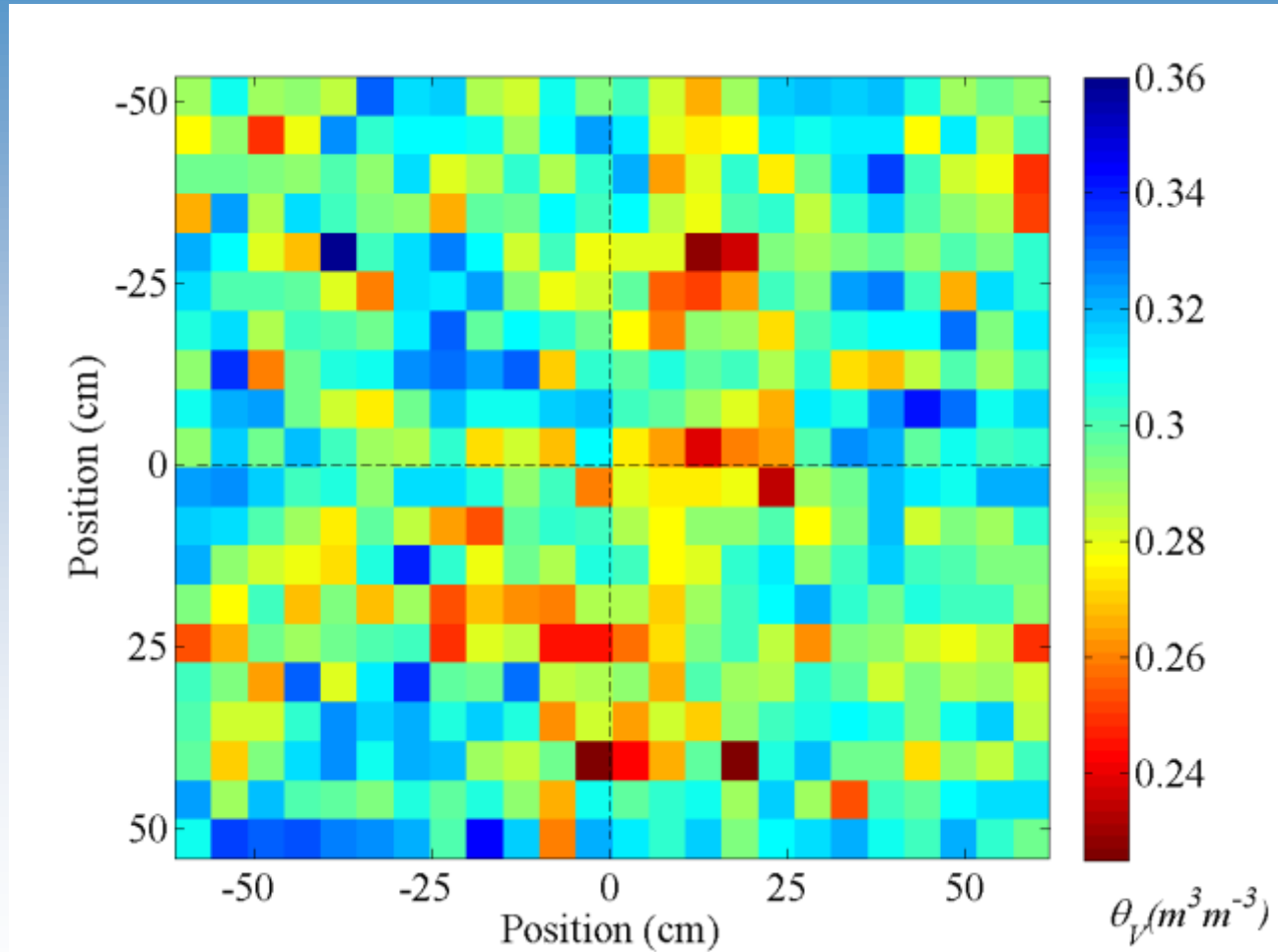
- Large scale characterization

Disadvantages:

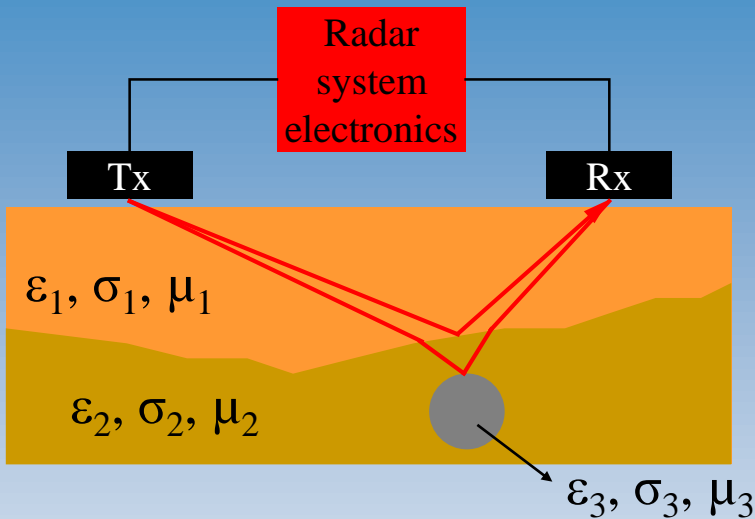
- Shallow characterization (0-5 cm)
- Availability of remote sensing data
- Accuracy limitations

Example of soil moisture variability at the 1 m² scale

➔ Local sensors are usually not representative of the larger scale moisture



Ground-penetrating radar (GPR) basic principles



- Dielectric permittivity ϵ → wave velocity
- Electric conductivity σ → wave attenuation
- Magnetic permeability μ

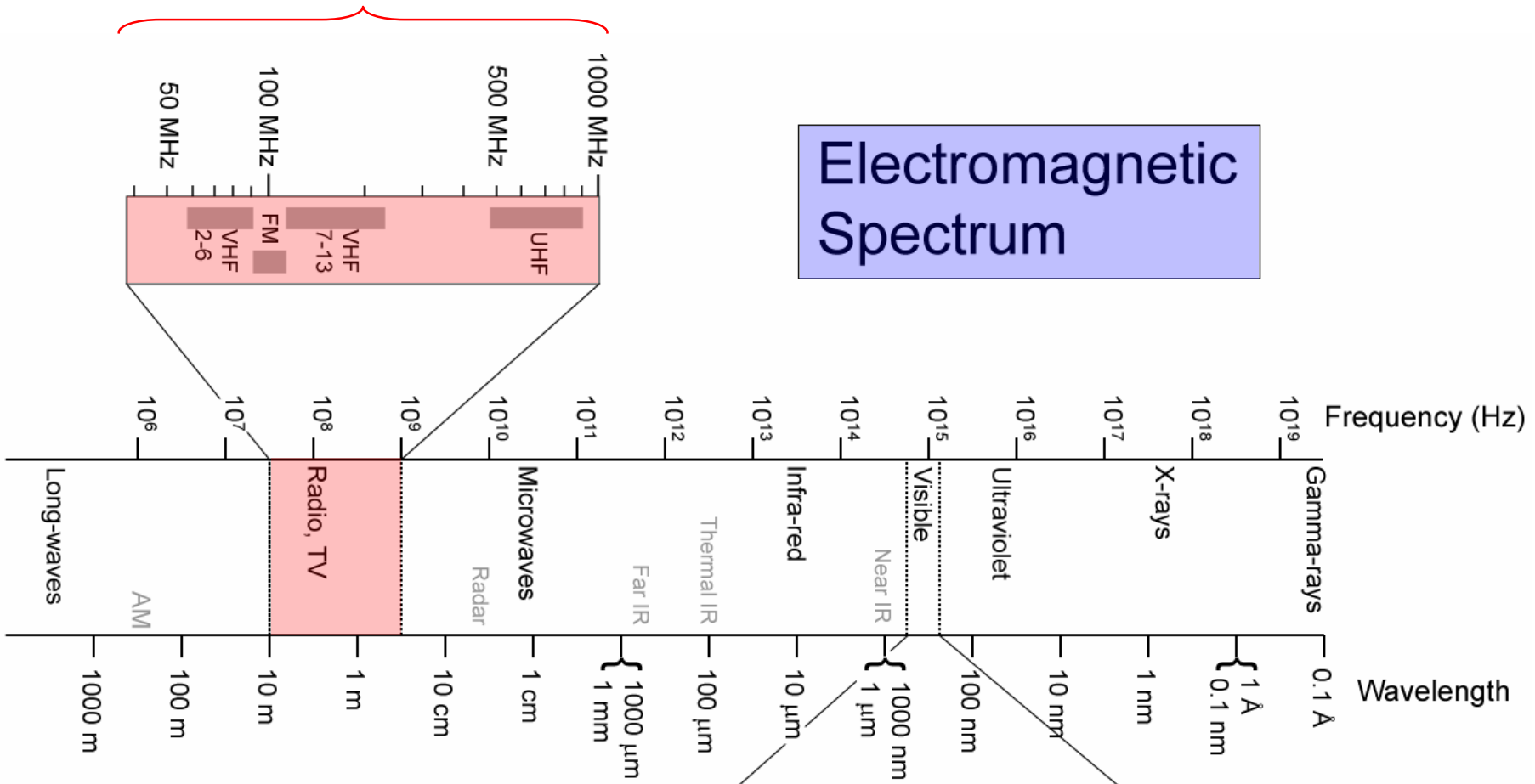
Electromagnetic contrasts

→ Reflection, transmission

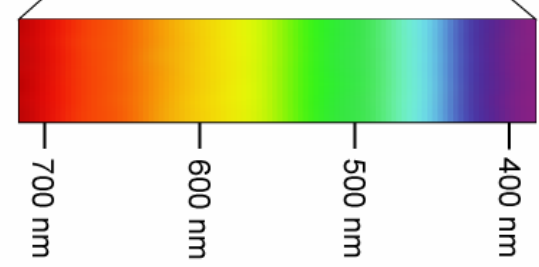
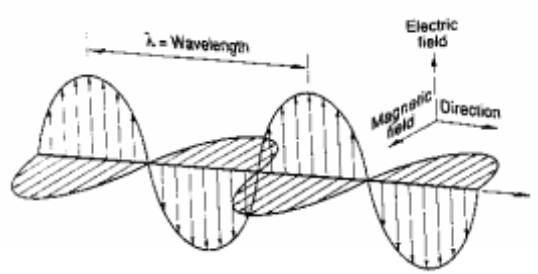
GPR operates by transmitting microwave electromagnetic energy down into the ground through an antenna. The transmitted energy is reflected from various electromagnetic interfaces. An antenna then receives the reflected signal.

Ground-penetrating radar

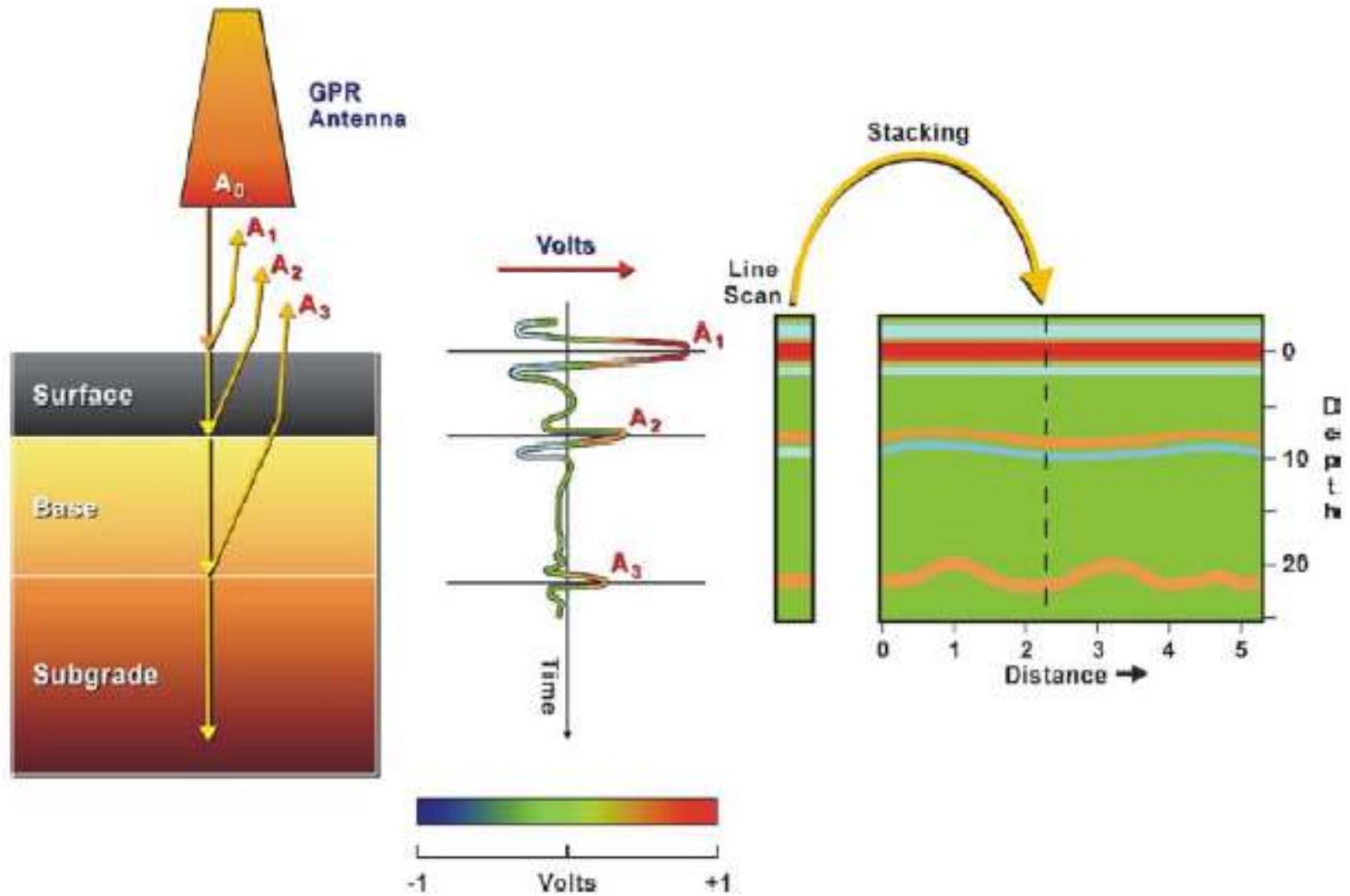
Electromagnetic Spectrum



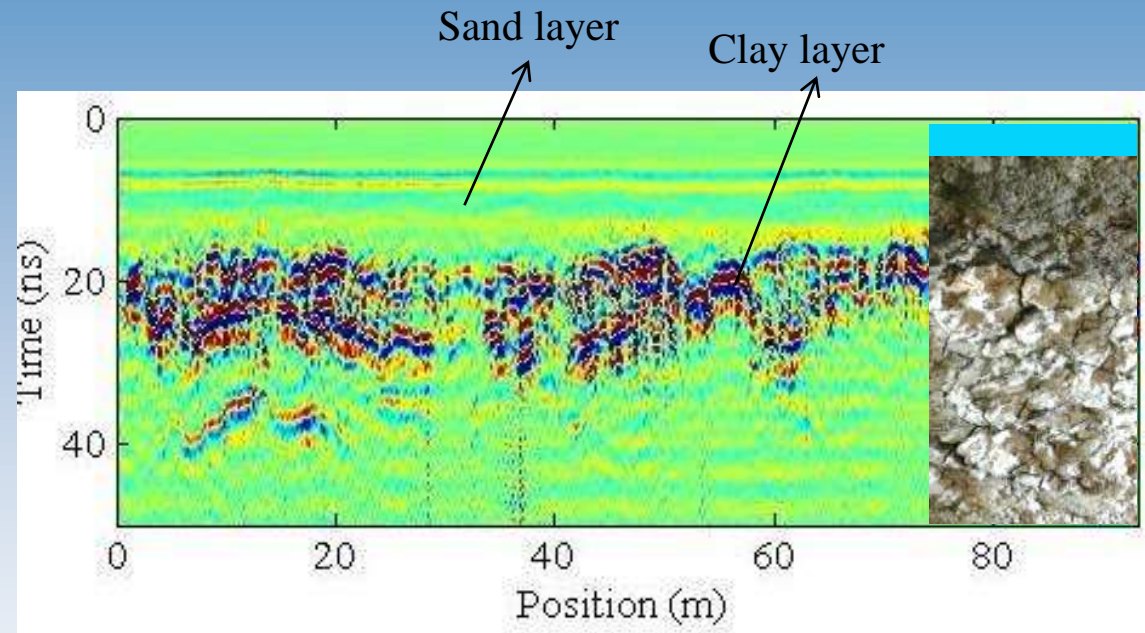
$$\lambda = \frac{c}{f}$$



Subsurface imaging principles



Example of GPR measurements in a vineyard (Saint-Emilion, France)



Management of city infrastructures: project control, monitoring and maintenance

Roads, underground pipes and cables



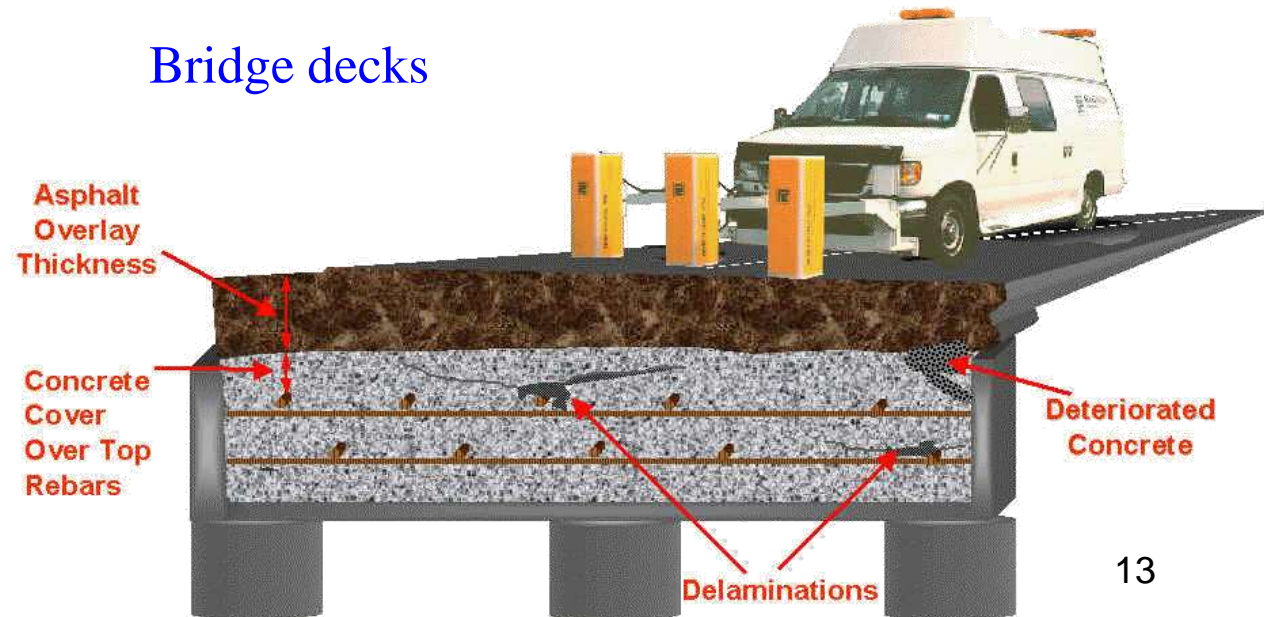
Buried tanks



Tunnels



Bridge decks





Archeology

Geology





Security

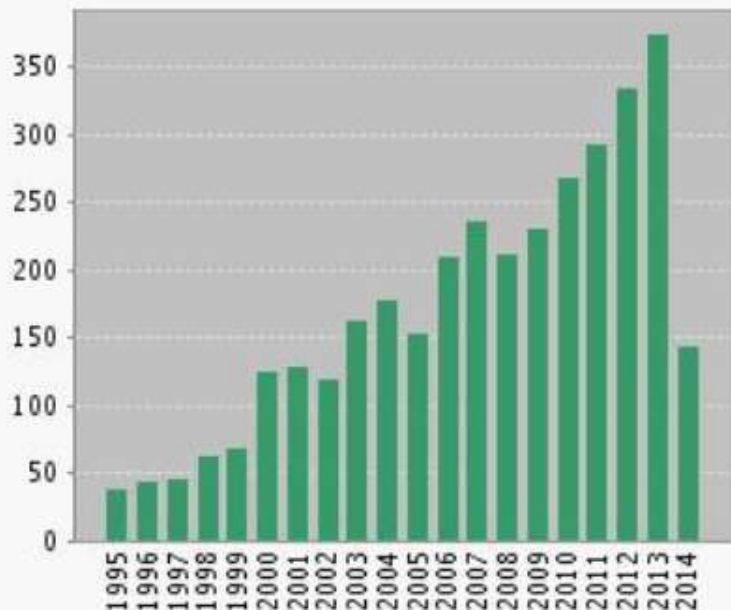


Forensics



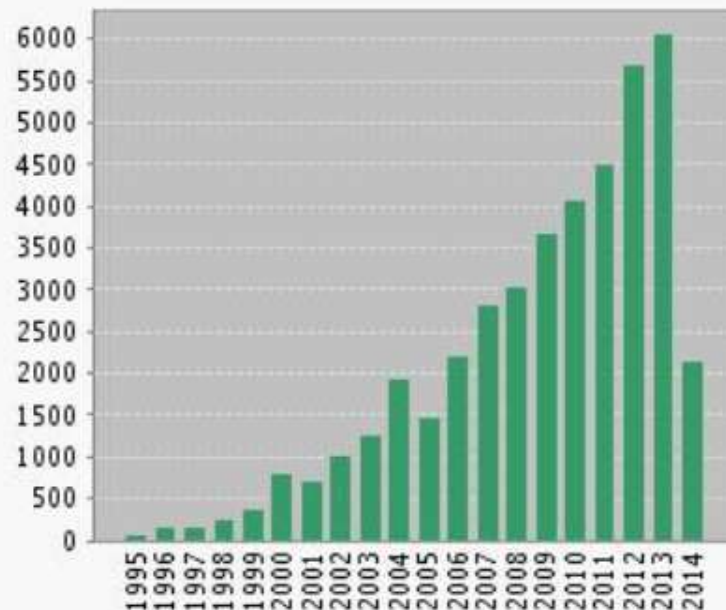
Evolution of GPR research in the world

Published Items in Each Year



The latest 20 years are displayed.
[View a graph with all years.](#)

Citations in Each Year



The latest 20 years are displayed.
[View a graph with all years.](#)

Results found: 3532

Sum of the Times Cited [?]: 42770

Sum of Times Cited without self-citations [?]: 24440

Citing Articles [?]: 18744

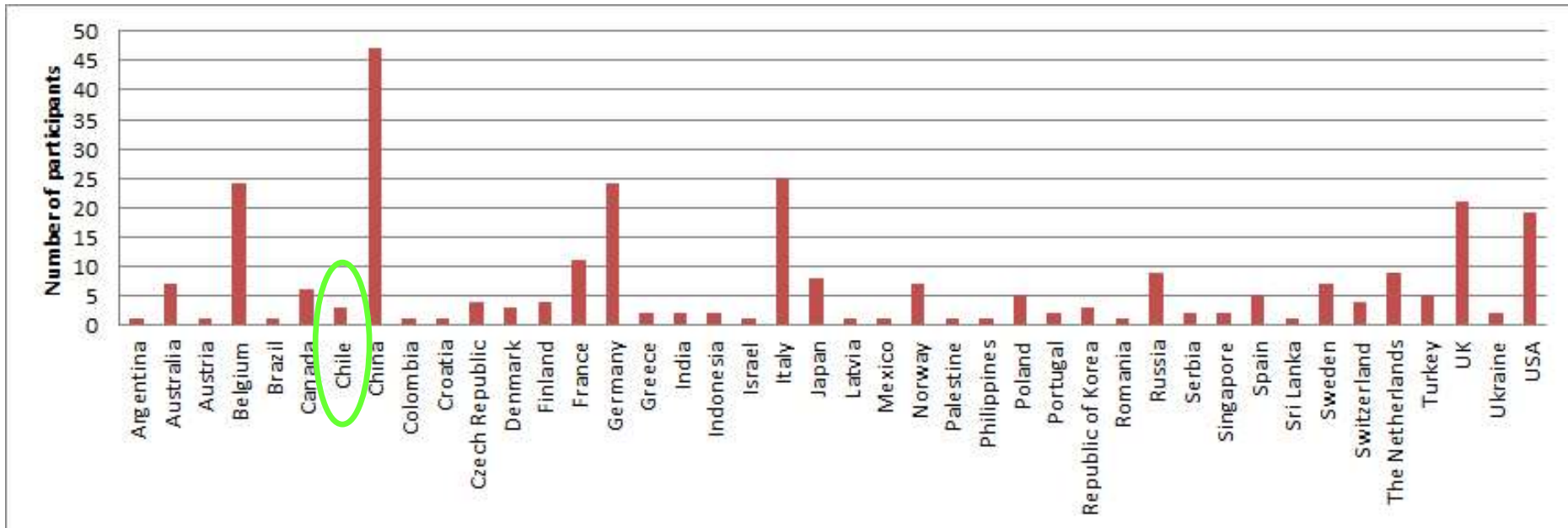
Citing Articles without self-citations [?]: 15827

Average Citations per Item [?]: 12.11

h-index [?]: 72



Participants per country (300)



GPR for determining soil permittivity and water content

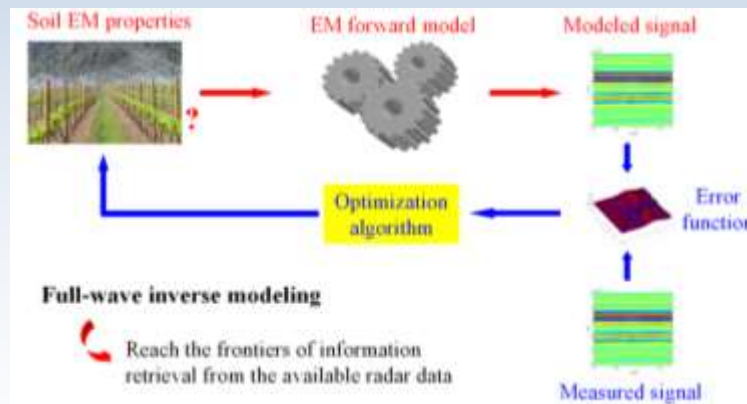
➔ Resorting to advanced GPR data processing is necessary to maximize information retrieval capabilities and accurate estimates

The UCL invention



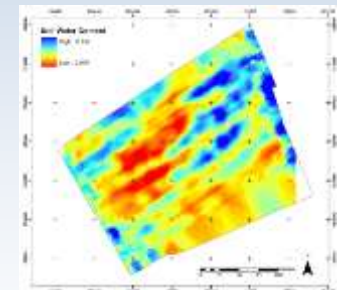
Patent PCT/EP2012/055416 (WO 2012/130847 A1)
« *Method and device for characterization of physical properties of a target volume by electromagnetic inspection* »
by Sébastien Lambot, Université catholique de Louvain, Belgium

System design



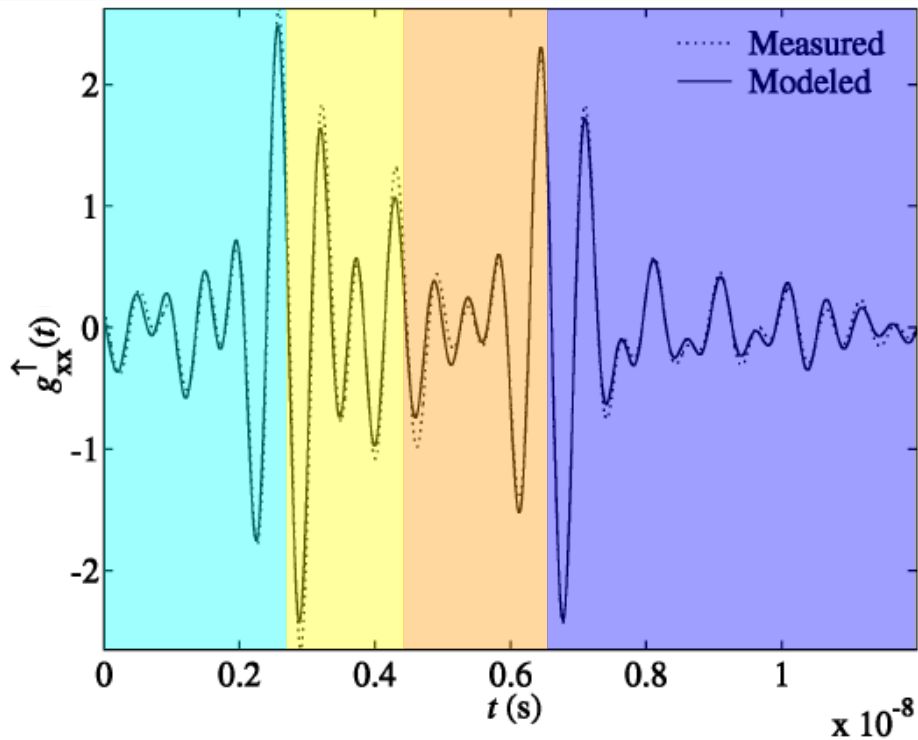
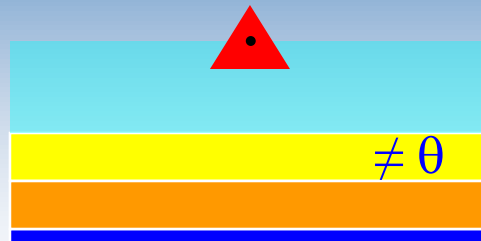
Signal inversion

Product

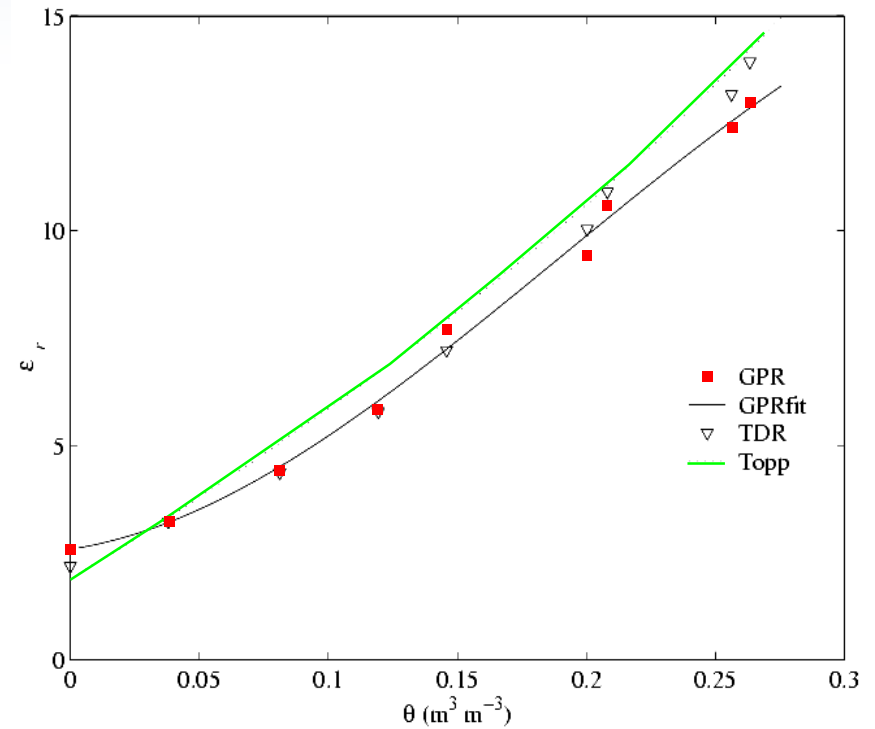


Electromagnetic model validation

Configuration



Frequency domain



Inversion results

High-resolution, real-time mapping of soil moisture



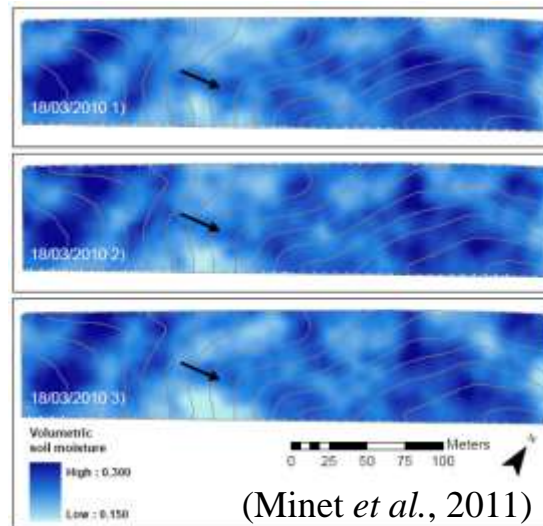
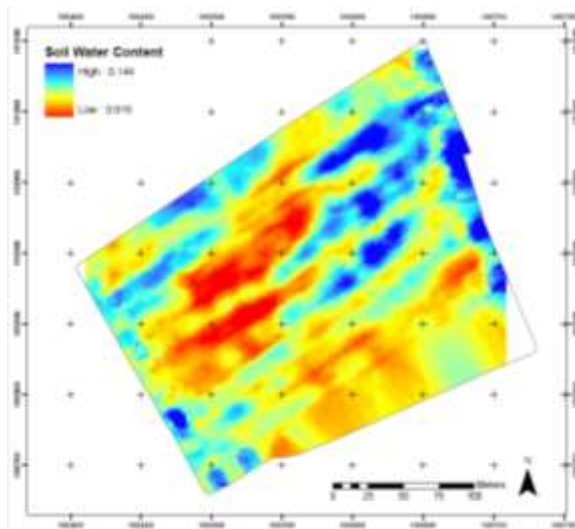
Handheld system



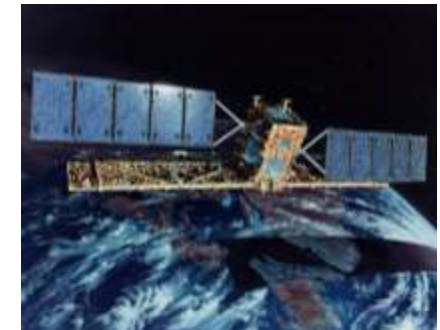
Automated platforms



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



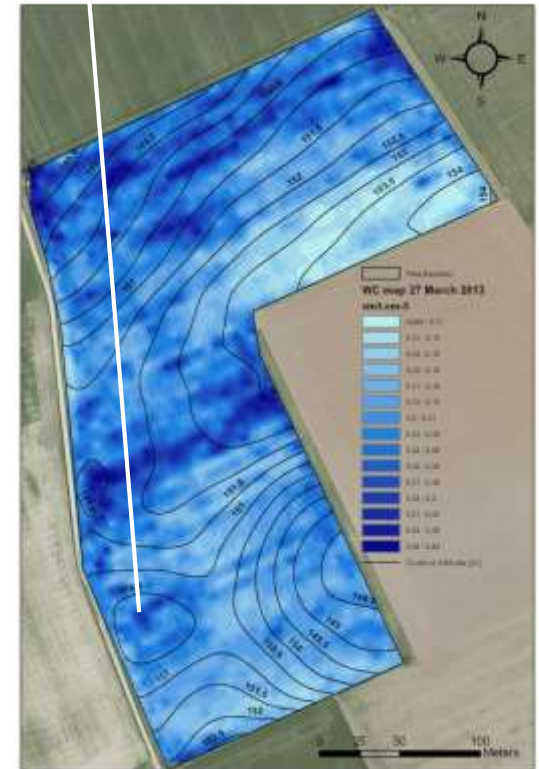
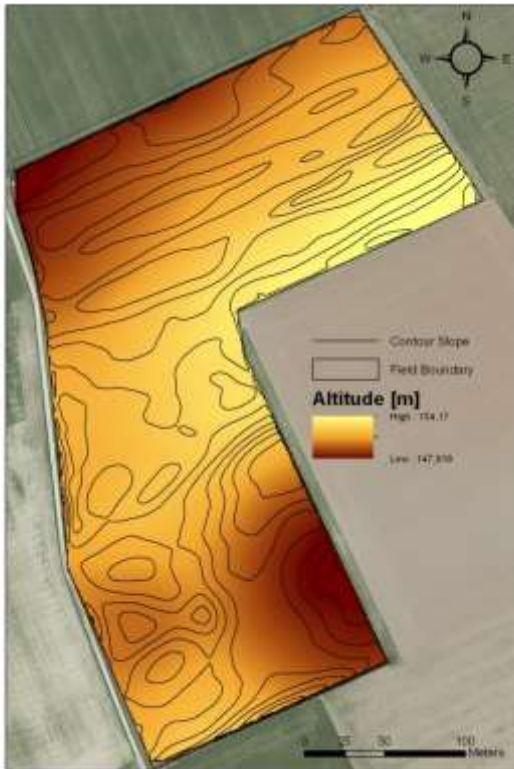
Radarsat



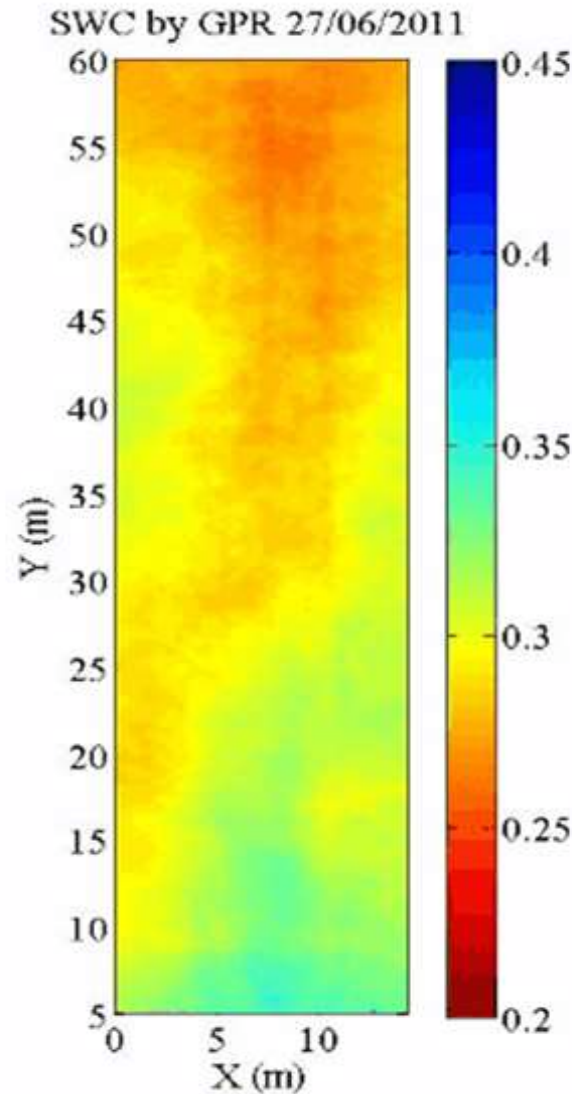
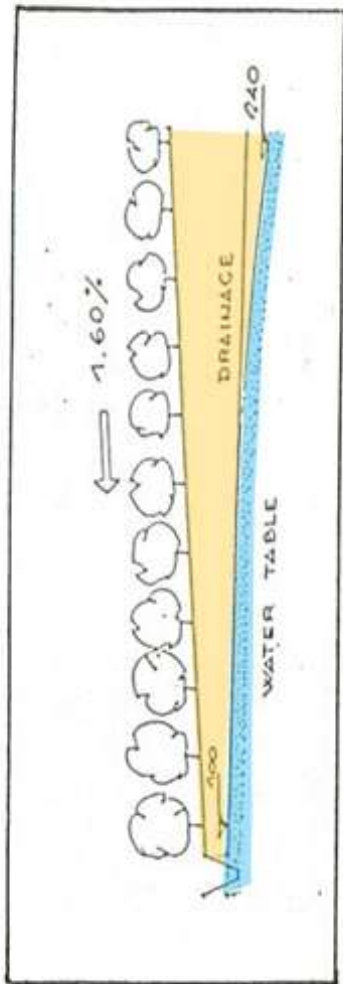
Catchment scale

➔ Towards digital soil mapping – improving remote sensing data products

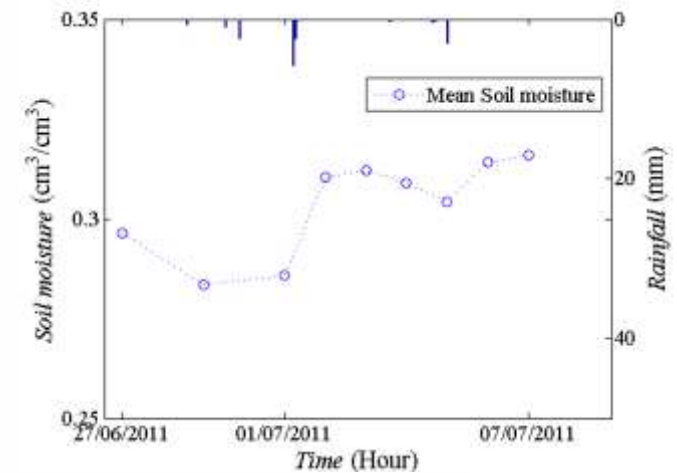
High-resolution, real-time mapping of soil moisture



Test site in Bologna (Italy)



400 MHz GSSI antenna

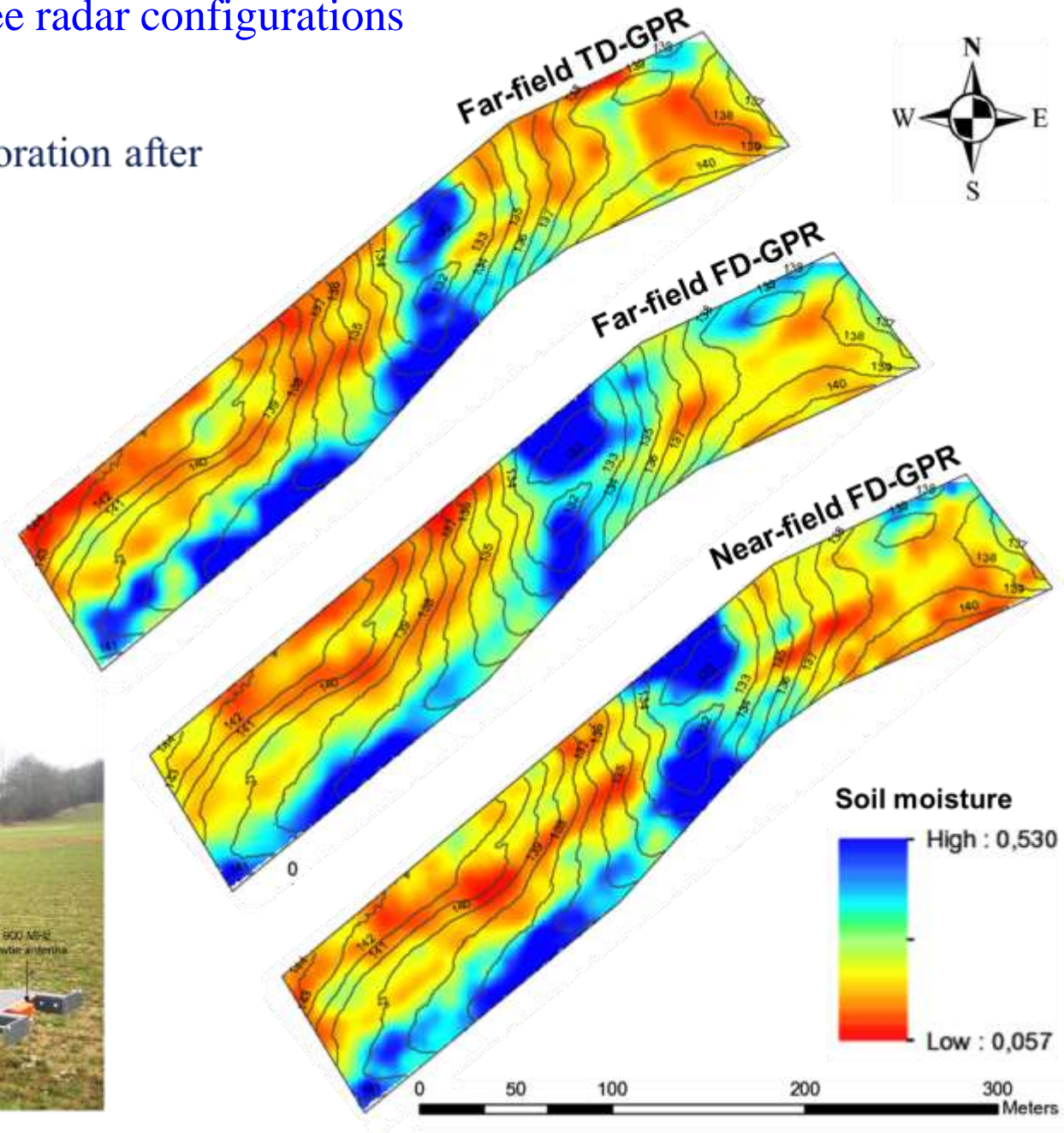


Time-lapse monitoring

Comparison between three radar configurations

Field condition: 4 days evaporation after a precipitation event.

All GPR approaches show relatively similar soil moisture patterns within the field. The differences could be explained by different characterization scales.



Conclusions

- *Ground penetrating radar is useful in many fields*
- *Intrinsic GPR electromagnetic models have been developed*
- *Full-wave inverse modeling permits non-invasive soil characterization and real-time mapping of soil moisture*

Perspectives

- *Adaptation to specific application contexts*
- *Integration with soil-plant-atmosphere models and management tools*

→ Precision agriculture



Gracias por su atención!

