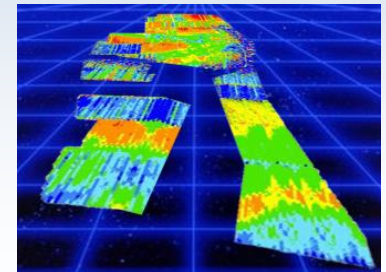


Soil moisture mapping using ground-penetrating radar as a pillar to sustainable and optimal environmental and agricultural management

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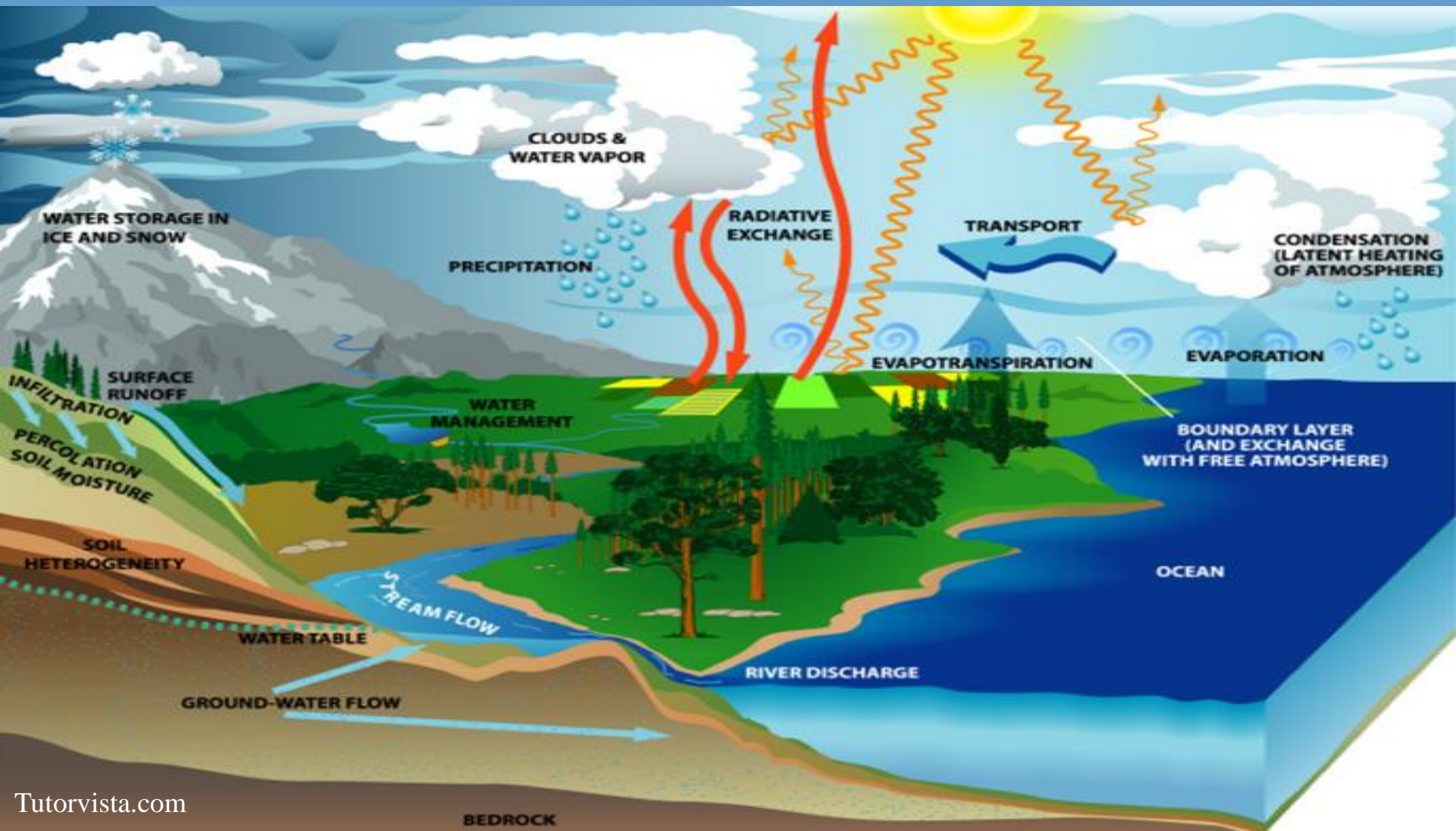


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Introduction

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

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.

SOURCES: Adapted from Major Land Resource Constraints map created April 2004 by P. Reich and H. Bowman of USDA/NRCS Soil Survey Division, World Soil Resources, Washington, D.C., from WRI, Soil Climate Map and S&D Soil Map of the World, 1995. CLASOD data by J. B. Coleman et al., 1991 (provided by K. Sebastian, IFPRI). Data on compaction in Europe from SCHEUERS&C 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 steered 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 Kuwaiti soil 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 fertilizers 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 stokes the country's famous dust storms.

WESTERN EUROPE sealing



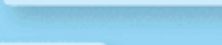
Covering of soils with buildings and roads has put beyond use large swaths of prime soil in European cities.



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 has 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, gypsum condition
- Low nutrient holding capacity
- Low moisture and nutrient status

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

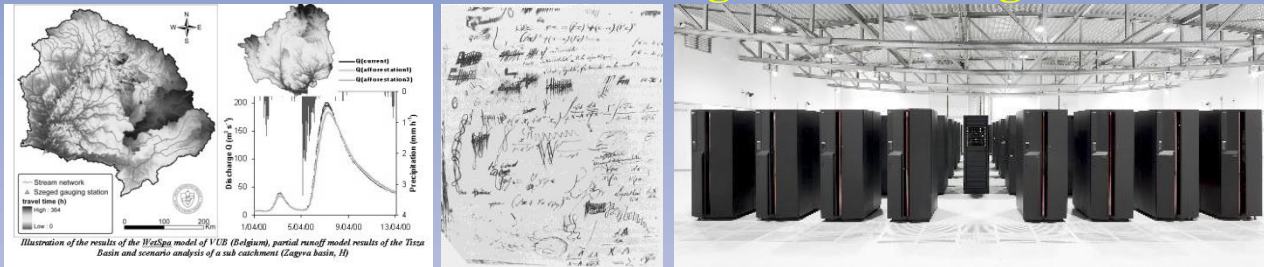
NOTE: Acid sulfate condition (0.09% of total map area) and steep lands (observed by erosion risk) are not shown.

→ from observations to sustainable and optimal soil and water management

Observation: characterizing and monitoring the environment

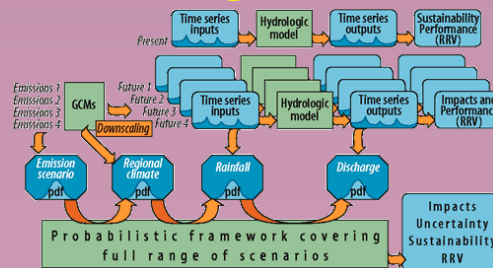


Process understanding and modeling



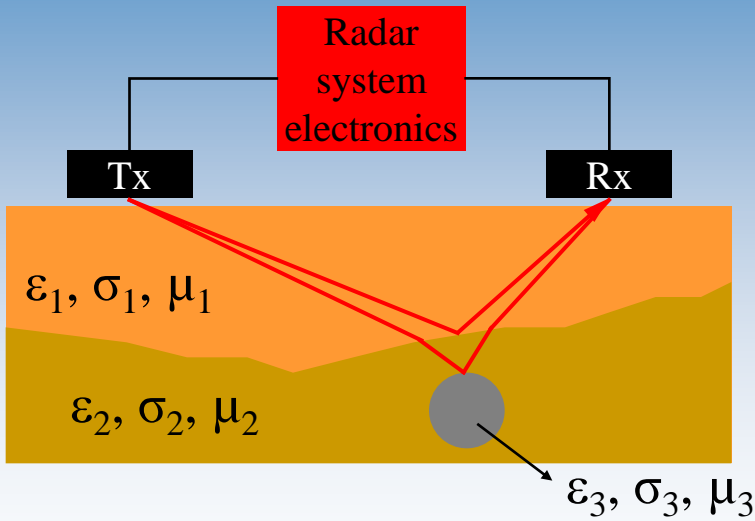
Inaccessibility
Variability

Management strategies and decision support



Bridging the scale gaps between observations, modeling, and management

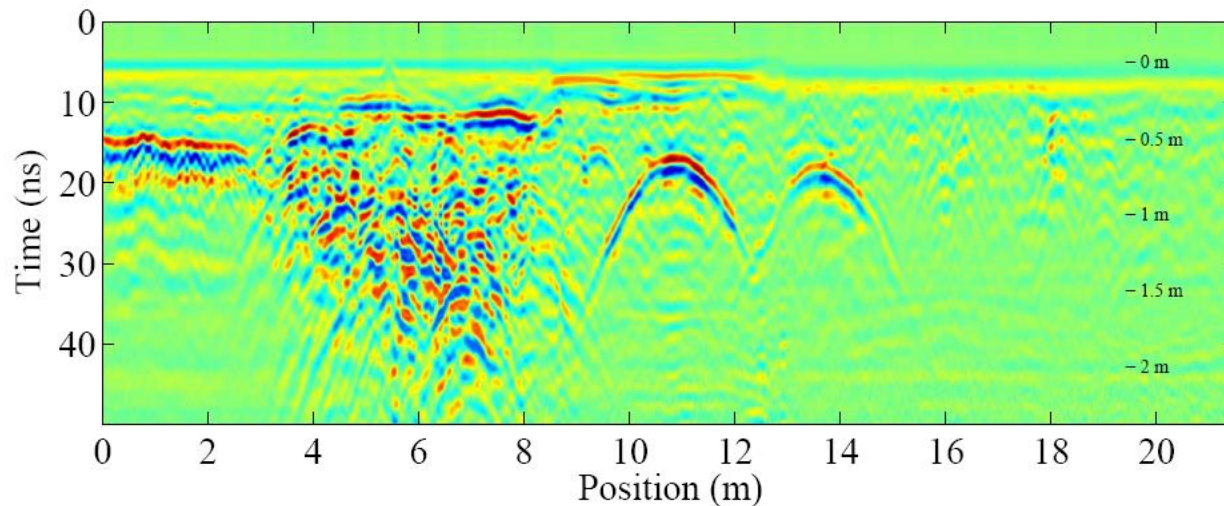
Ground-penetrating radar (GPR)



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

Electromagnetic contrasts

→ Reflection, transmission



Management of city infrastructures: project control, monitoring and maintenance

Roads, underground pipes and cables



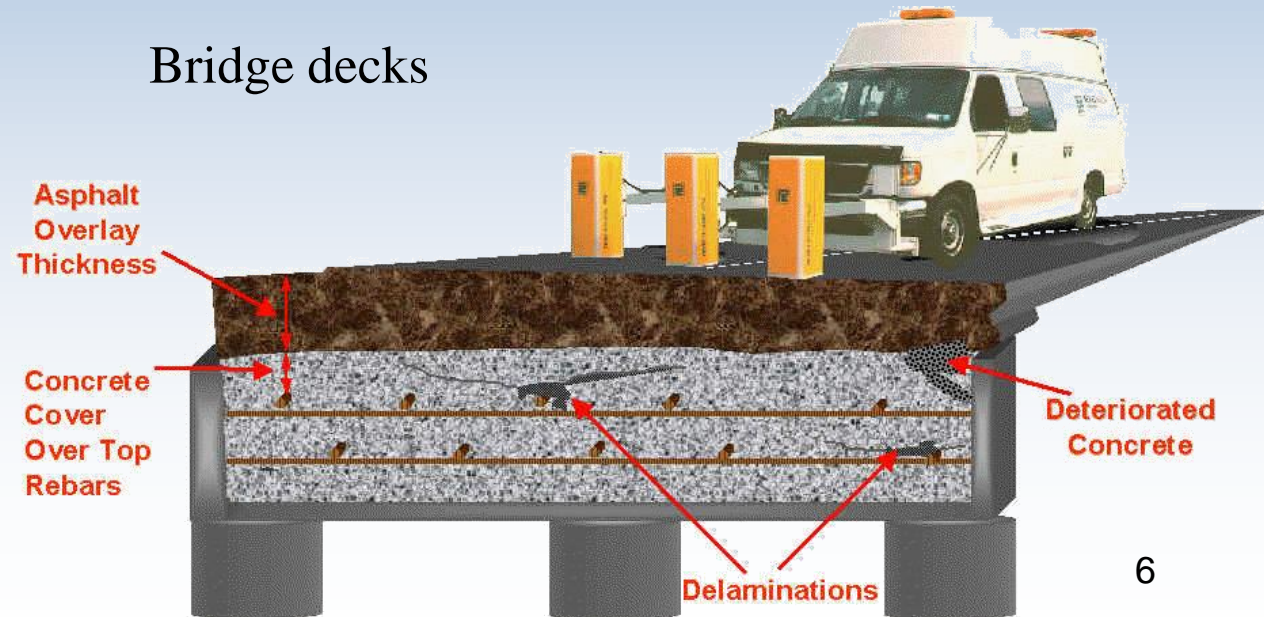
Buried tanks



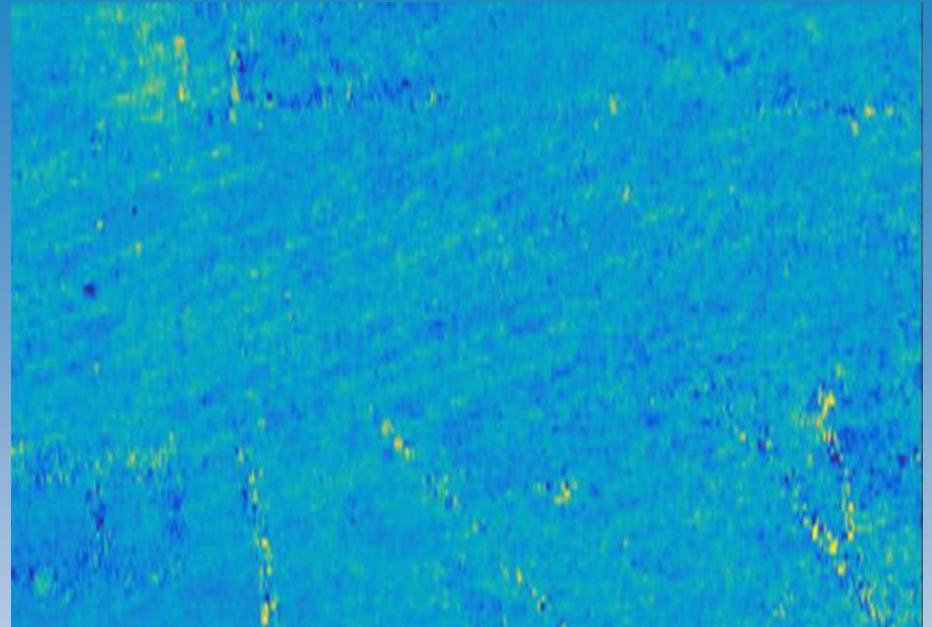
Tunnels



Bridge decks



Archeology



Geology





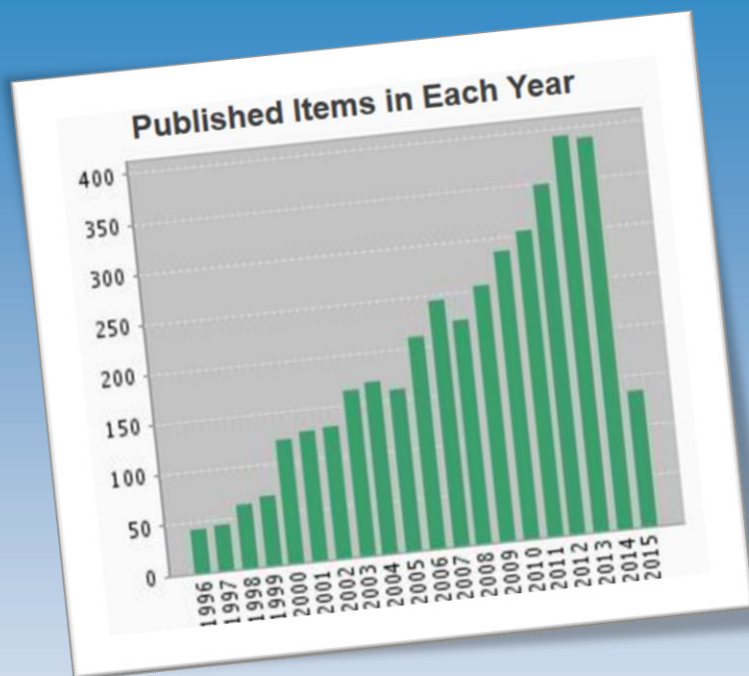
Security and natural disasters



Forensics

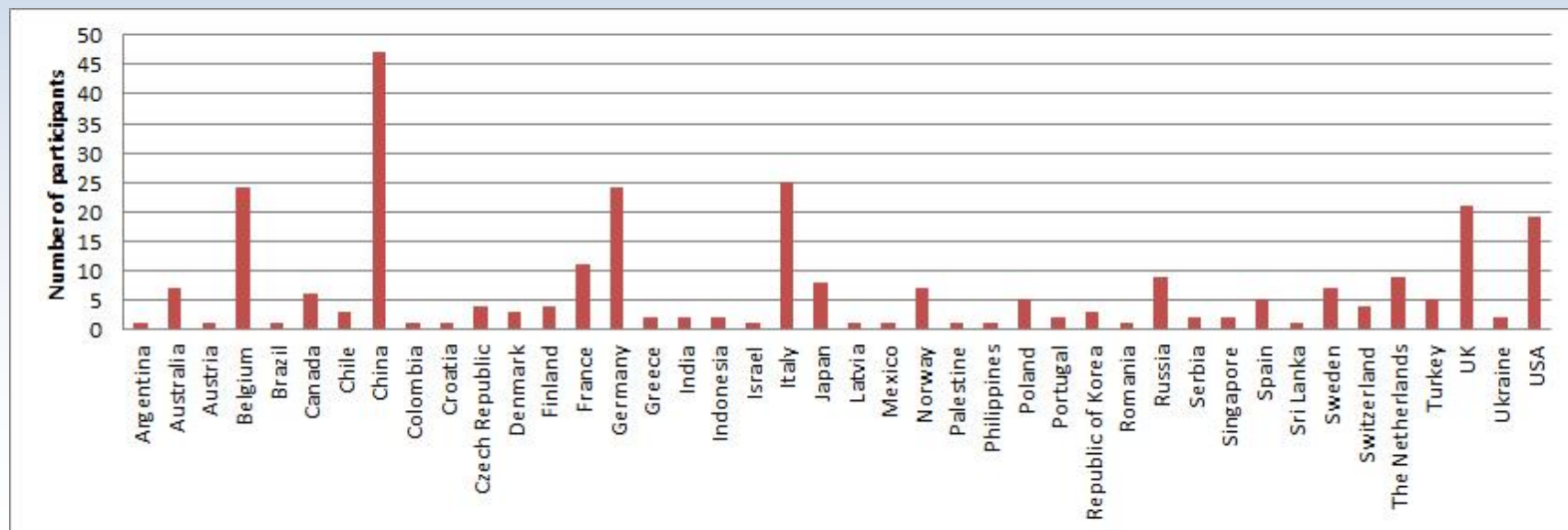


Evolution of GPR research in the world



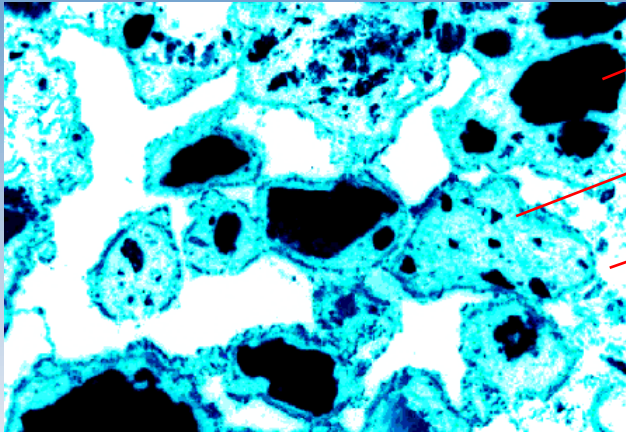
Applications follow...

GPR 2014



Soil water content determination

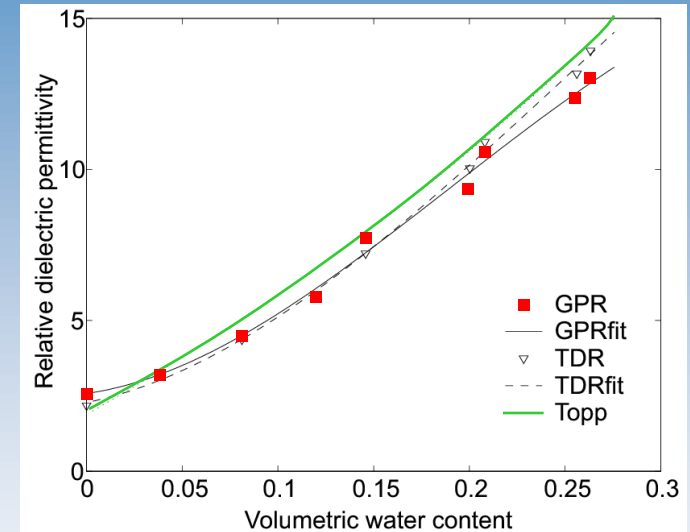
Relationship between soil water content and dielectric permittivity



soil grains $\epsilon_r \approx 5$

water $\epsilon_r \approx 81$

air $\epsilon_r = 1$



Empirical Topp's equation:

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

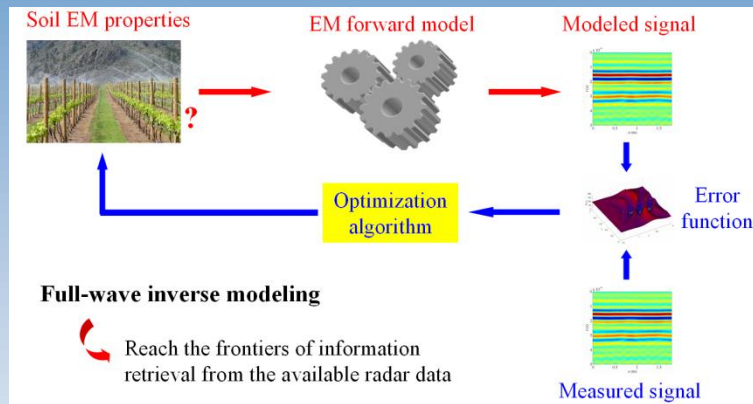
Dielectric mixing models (e.g., Complex Refractive Mixing Model CRIM):

$$\theta = \frac{\epsilon_b^\alpha - (1 - n)\epsilon_s^\alpha - n\epsilon_a^\alpha}{\epsilon_w^\alpha - \epsilon_a^\alpha}$$

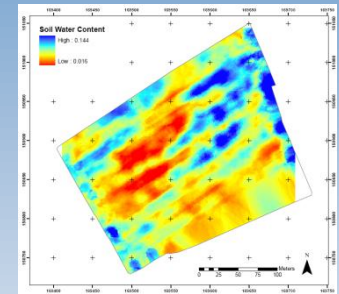
GPR for determining the electrical properties of materials

➔ Resorting to full-wave forward and inverse modeling of the GPR data is necessary to maximize information retrieval capabilities

System design



Product

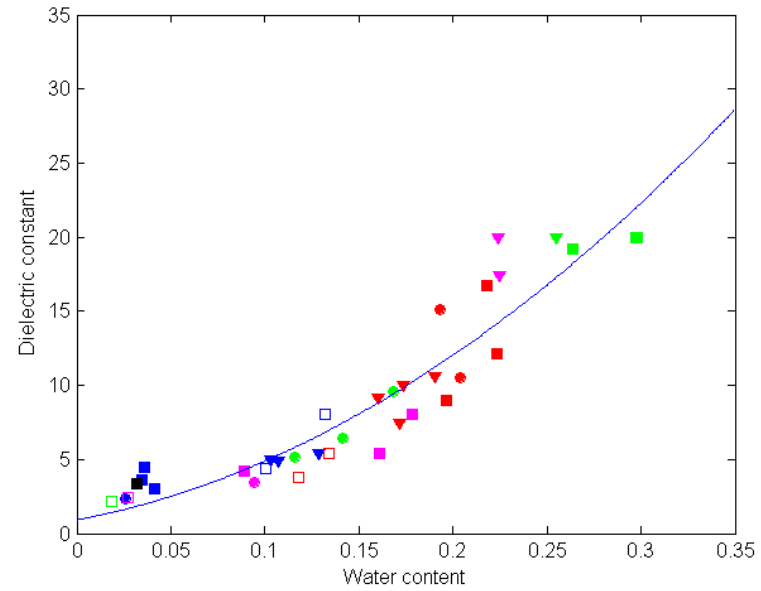


Signal inversion

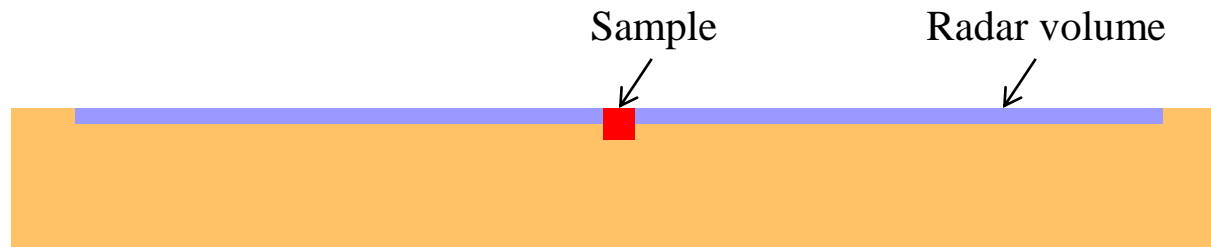


Examples of application (Lambot et al., NSG, 2008)

Irrigation areas in Tunisia



Different characterization scales and inherent variability

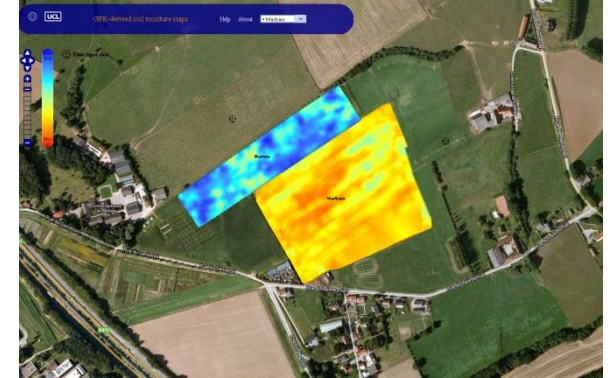


High-resolution, real-time mapping of soil moisture

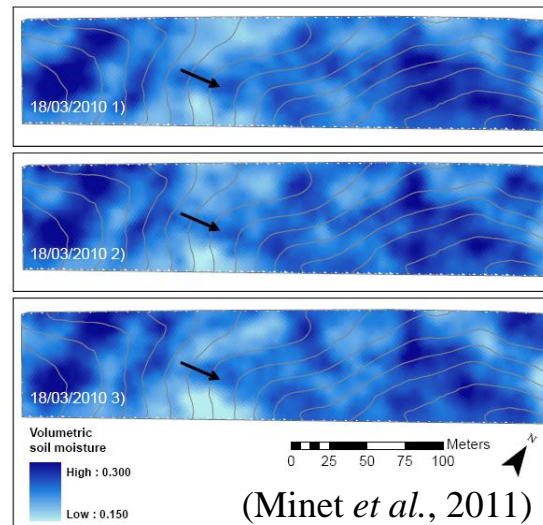
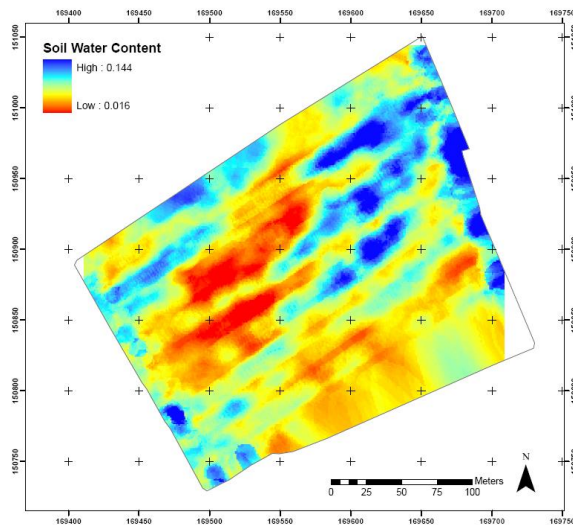
Handheld system



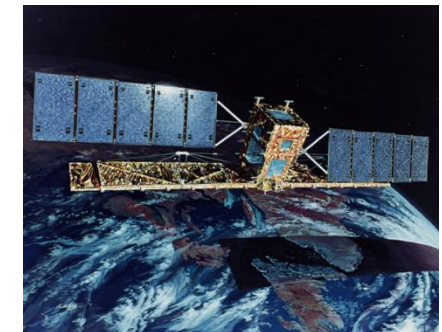
Automated platforms



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



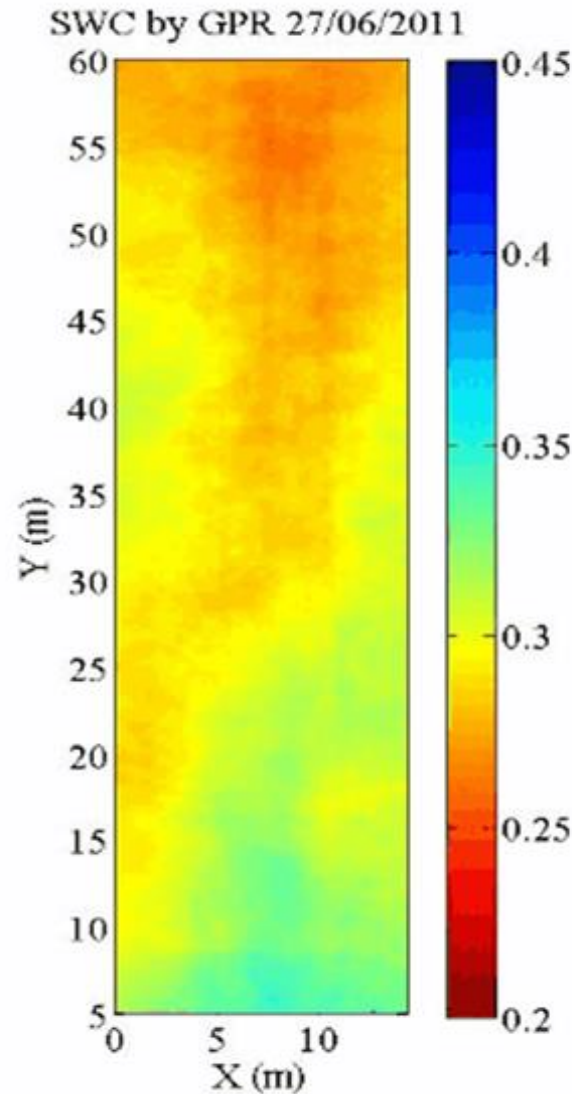
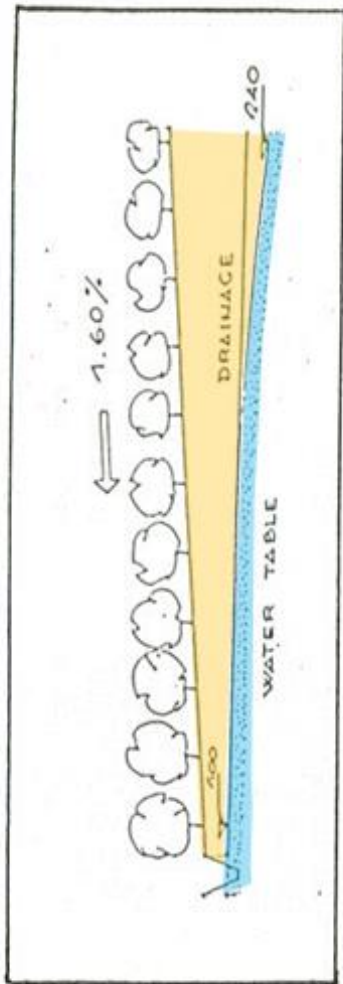
Radarsat



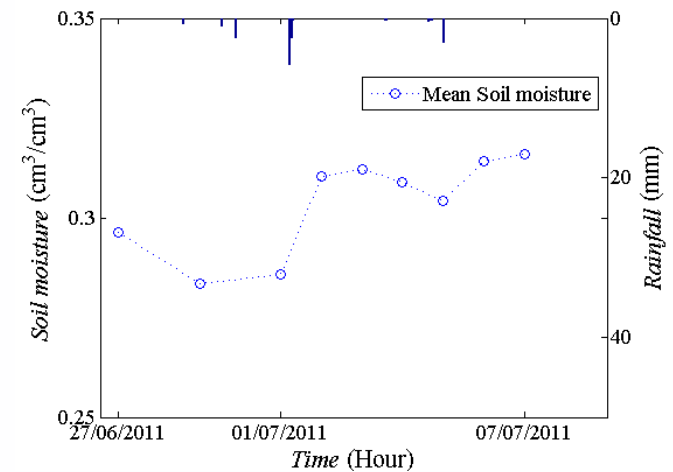
Catchment scale

➔ Towards digital soil mapping – improving remote sensing data products

Test site in Bologna (Italy)

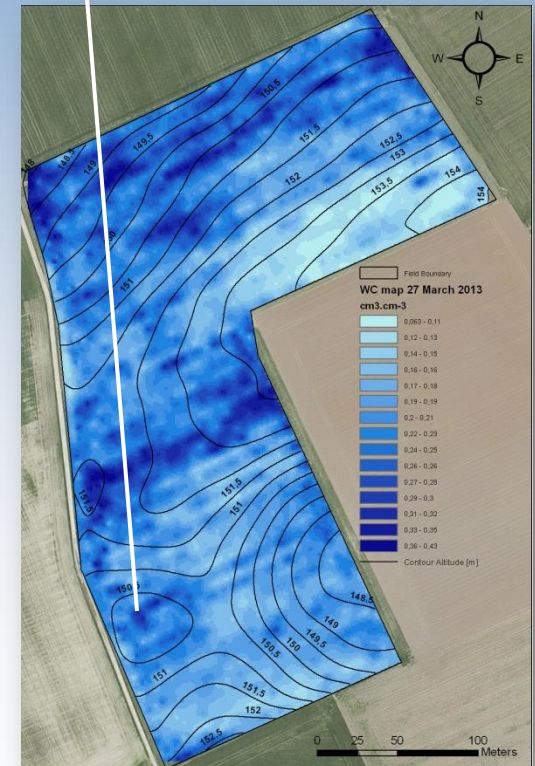
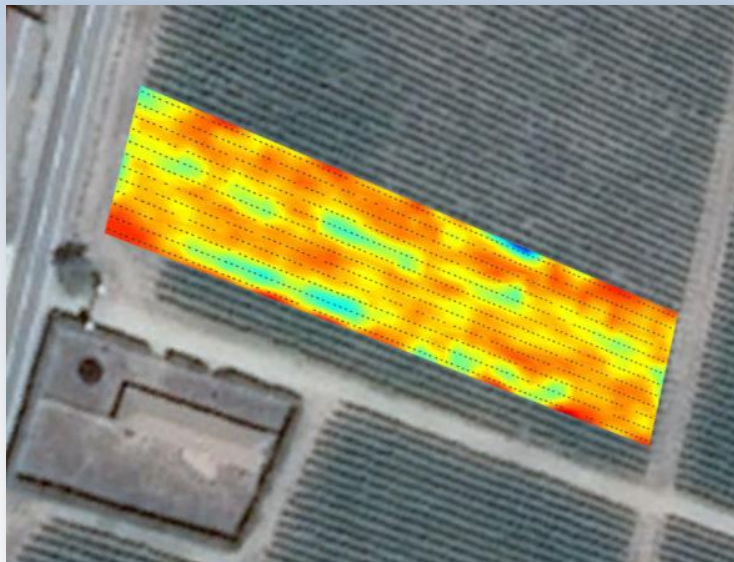


400 MHz GSSI antenna



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)

