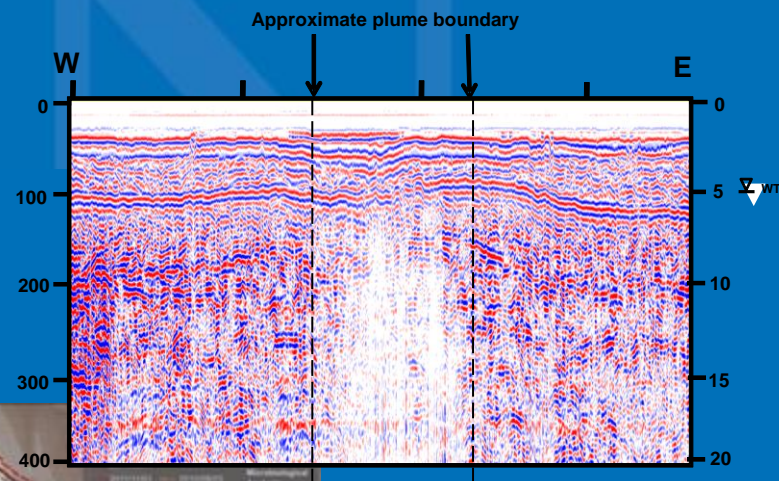
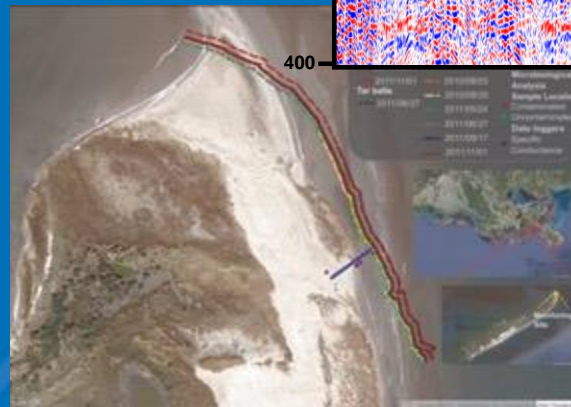
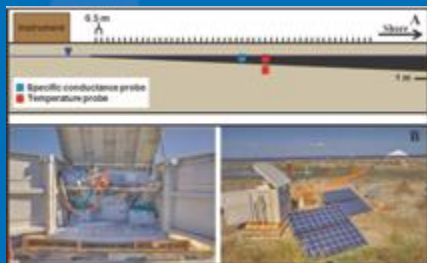


Geophysics for LUST sites

*Dale Werkema, Ph.D.
Research Geophysicist
US EPA, ORD
werkema.d@epa.gov*

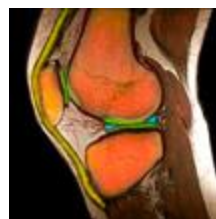


Why geophysics?

- Prior to expensive and invasive surgery we utilize medical imaging.
- Each medical imaging method is used for specific purposes.



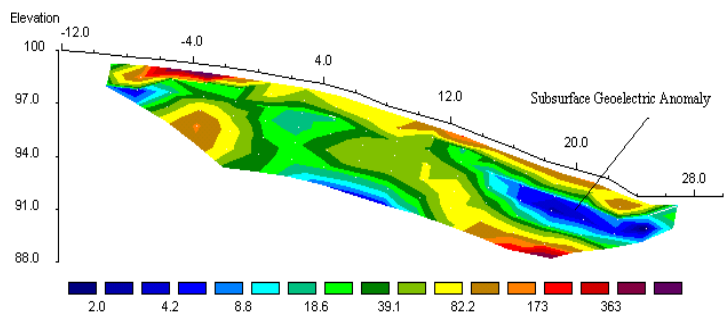
x-ray of knee



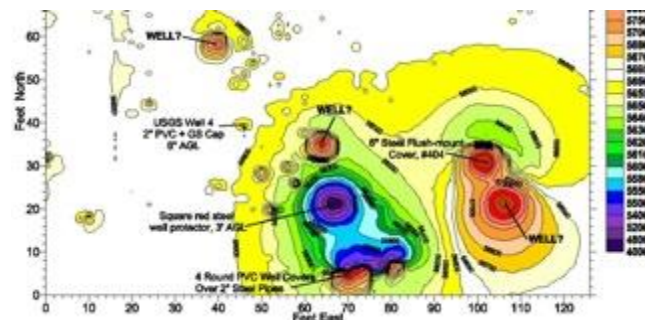
MRI of knee

images credit: Lee Slater

- Prior to expensive earth intrusive investigations (e.g., drilling, excavating, etc.) we can utilize geophysical imaging.
- Each geophysical method is used for specific purposes



Landfill plume mapping



Abandoned well mapping

Outline

1. Finding Underground Storage Tanks (USTs) and underground infrastructure
2. Mapping contaminant plumes
3. Monitoring active or passive remediation
4. High resolution characterization and Conceptual Site Model (CSM) development
5. Online resources – under development
 - Online Environmental Geophysics Textbook
 - Decision Support Tools

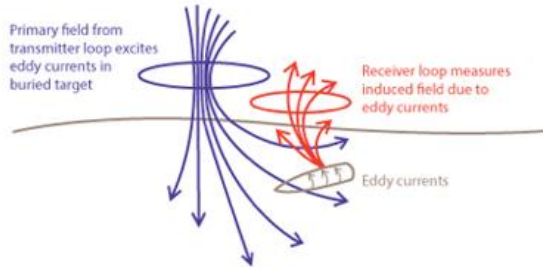
Geophysical methods include a set of tools in the site investigator's tool box.

1. Finding USTs & subsurface infrastructure

- What are the physical properties of the target, i.e. UST and associated infrastructure?
 - metal?, ferrous metal? fiberglass?
- Any potential interference?

Likely applicable geophysical methods:

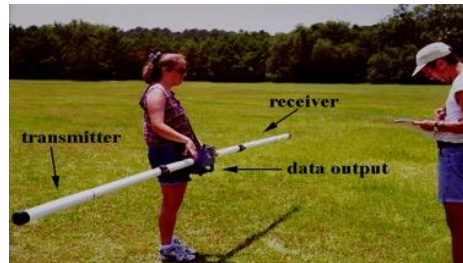
1. Magnetic
2. Electromagnetic
3. Ground Penetrating Radar (GPR)



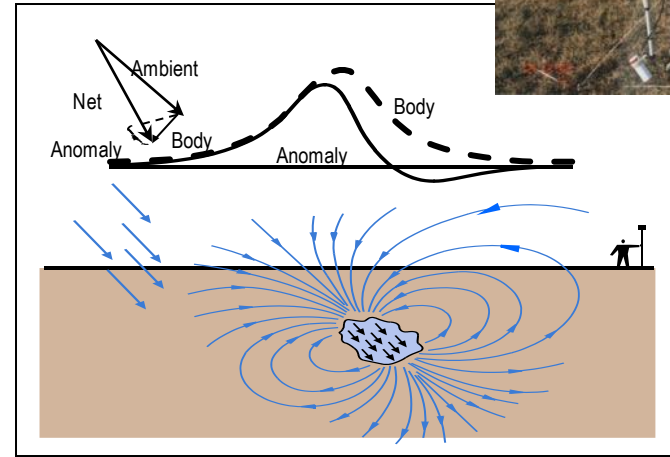
Geophex GEM2



Geonics EM-61



Geonics EM-31

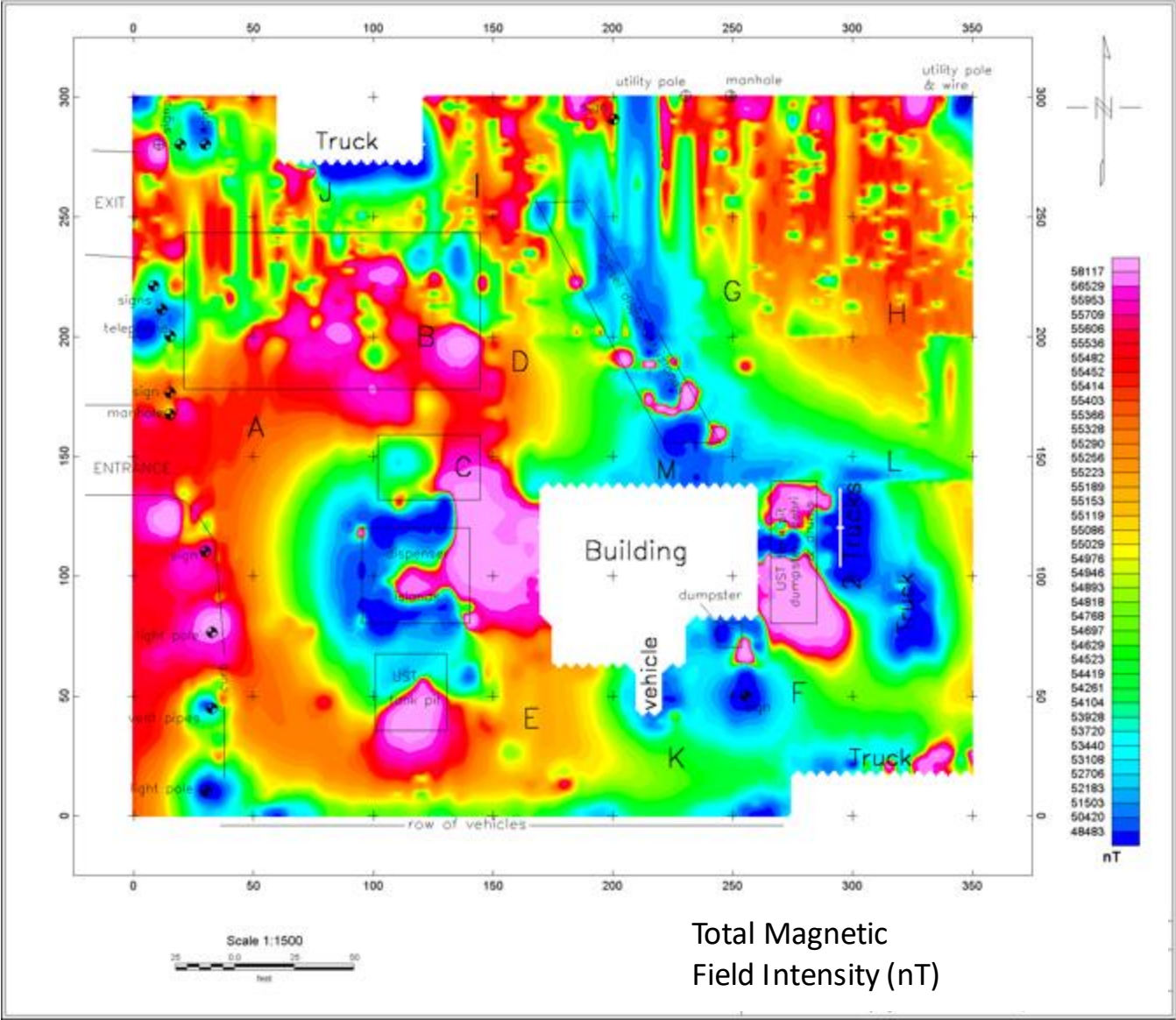


Geometrics G-858 Cesium vapor magnetometer

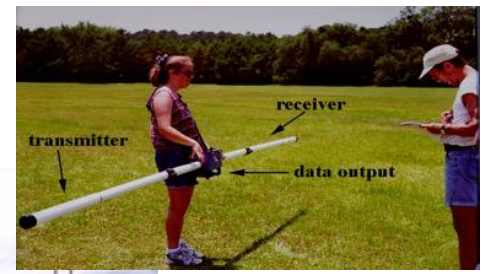
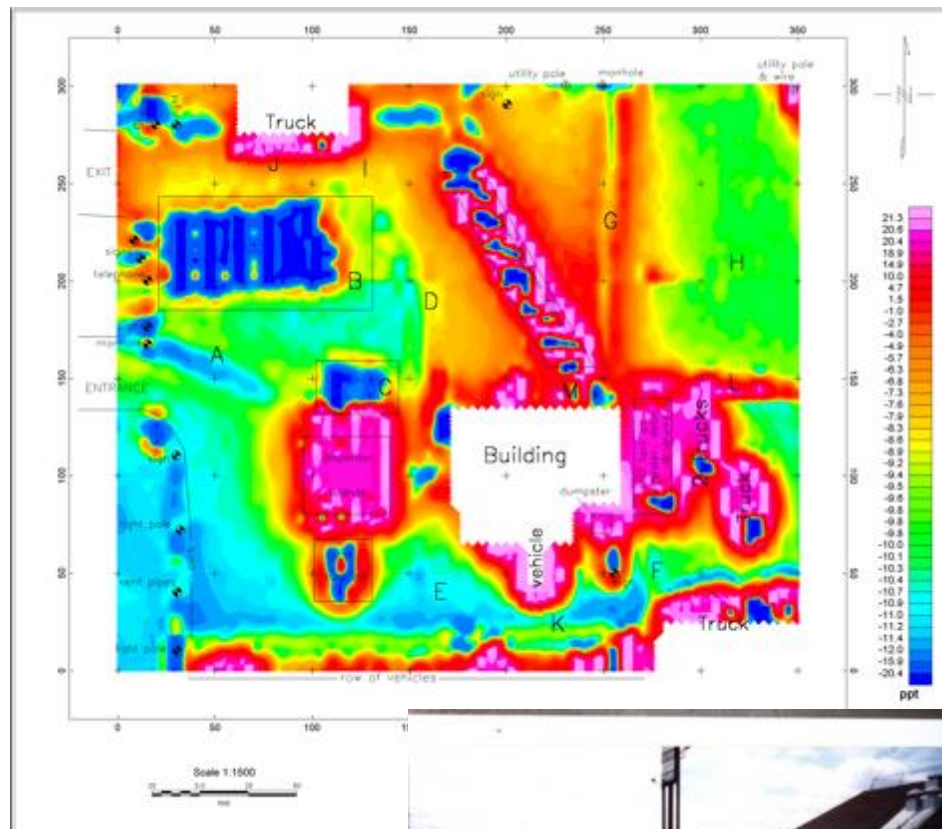


Mala GPR system

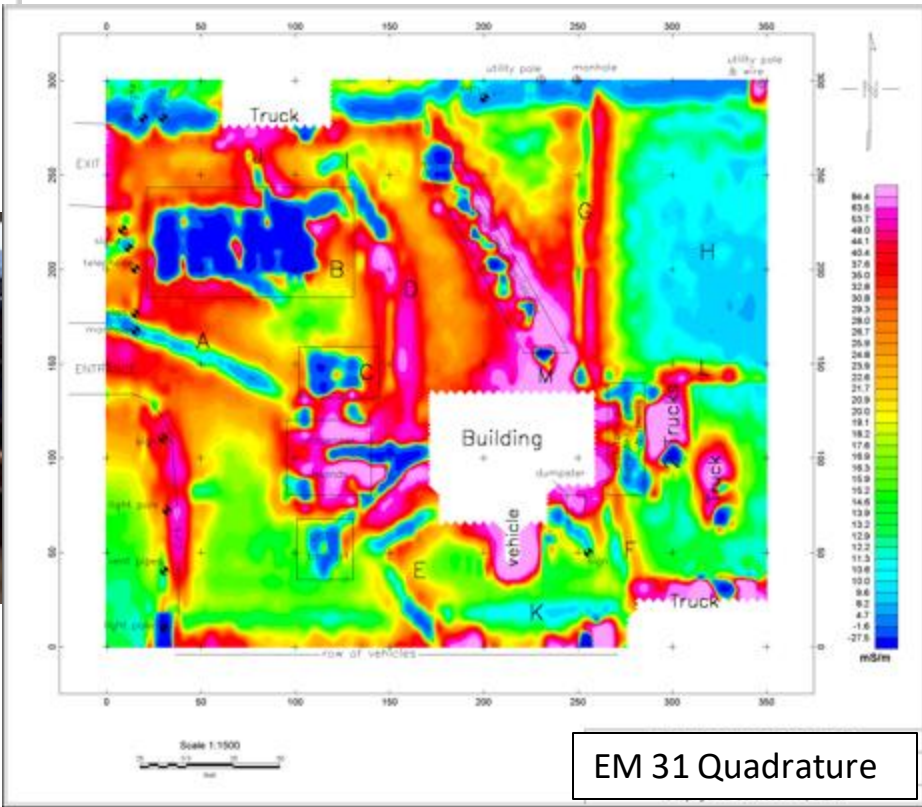
1. Finding USTs & subsurface infrastructure



1. Finding USTs & subsurface infrastructure



Geonics EM-31

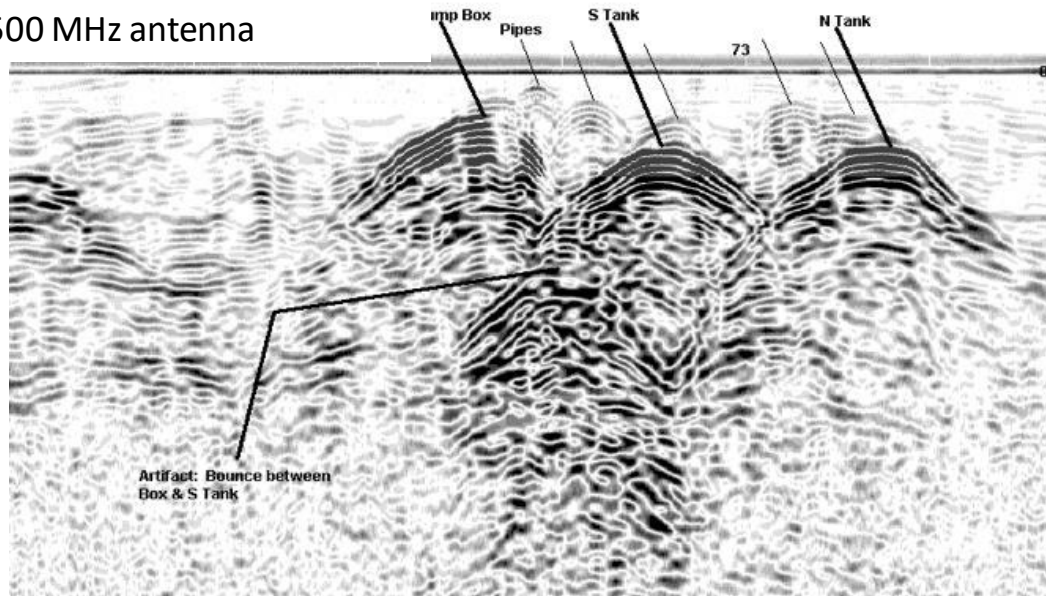


EM 31 Quadrature

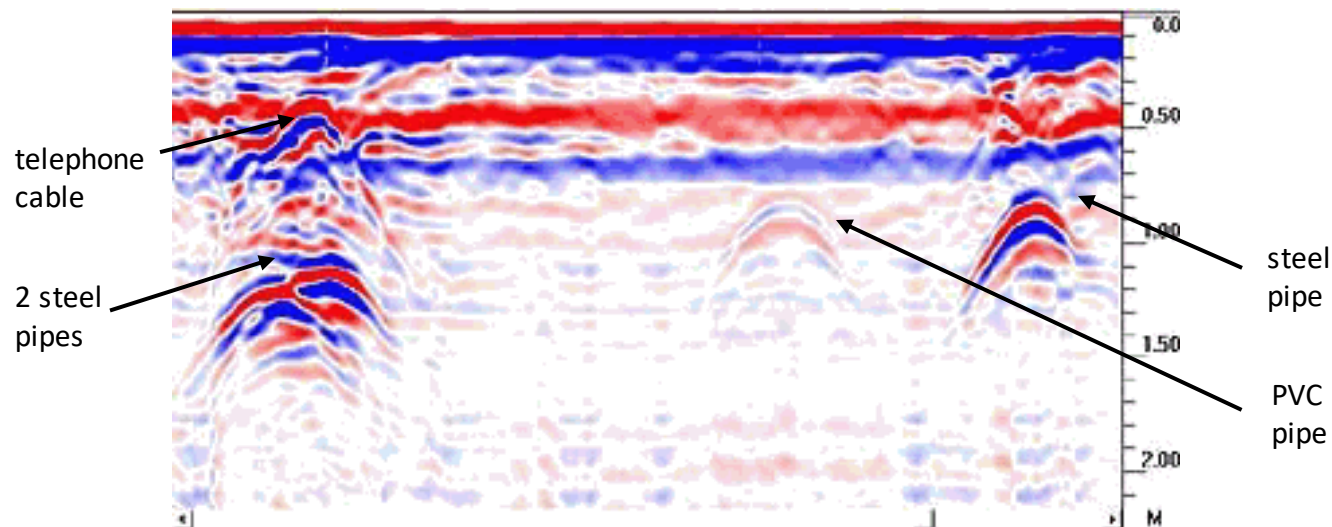
1. Finding USTs & subsurface infrastructure

Ground Penetration Radar (GPR) UST and utility examples

A) 500 MHz antenna



B) 400 MHz antenna



GSSI antenna

- pipes oriented perpendicular to the profile.
- Darker reflections show higher amplitude due to greater electrical property impedance.
- Faint reflections show muted or low amplitude reflections due to the attenuation of the GPR energy from electrically conductive material.

Note: Hyperbolic Reflections

2. Mapping contaminant plumes

Direct Current (DC) Resistivity

Archie's Law for Porous Media w/o clay

$$\rho_e = a \phi^{-m} S^n \rho_w$$

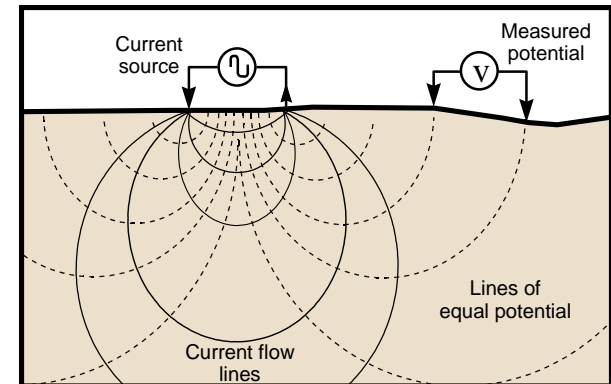
ρ_e = resistivity of the earth

ϕ = fractional pore volume (porosity)

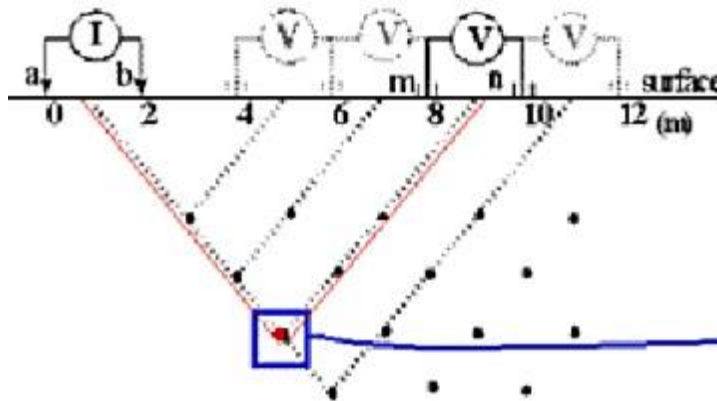
S = fraction of the pores containing fluid

ρ_w = the resistivity of the fluid

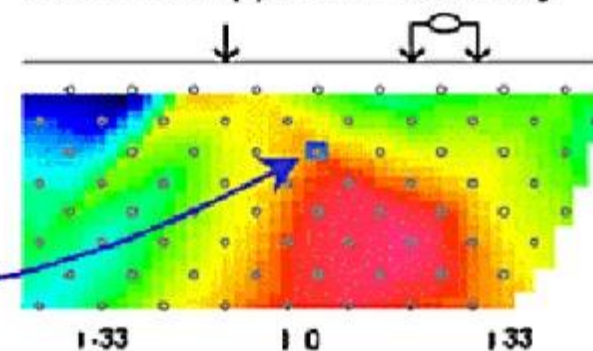
n , a and m are empirical constants



Resistivity Surveying



Observed Apparent Resistivity



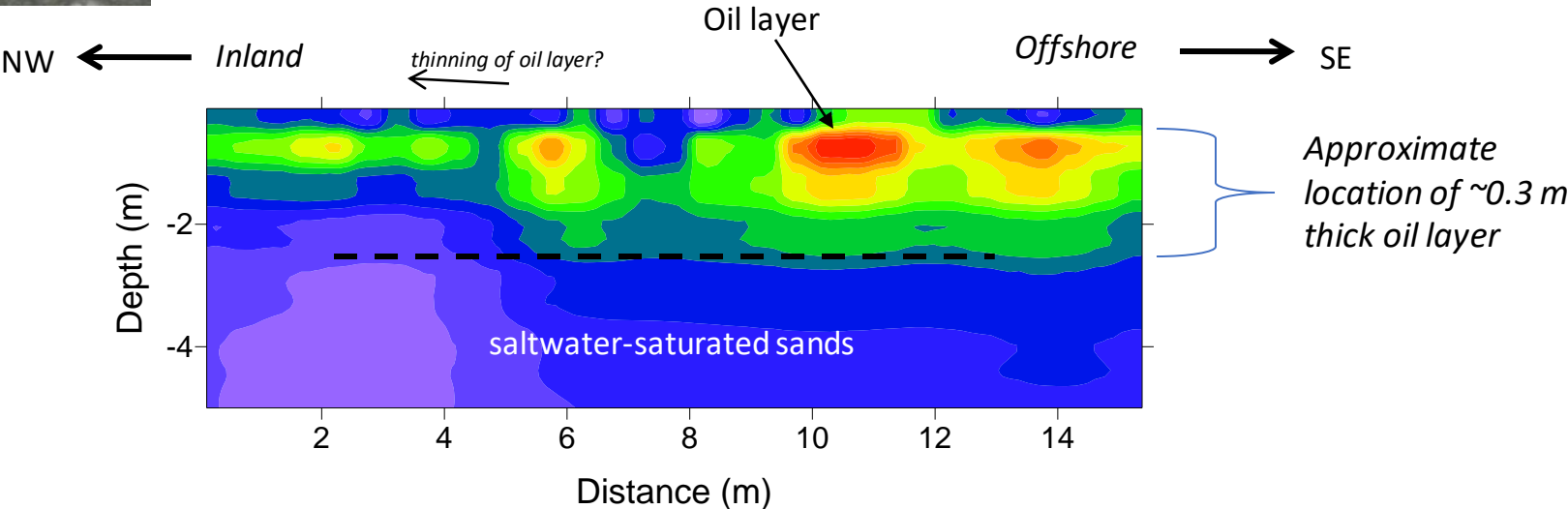
2. Mapping contaminant plumes

Deep Water Horizon Oil Spill Barrier Island Impact

DC Resistivity Results



Zone of immature oil contamination
imaged as resistive layer



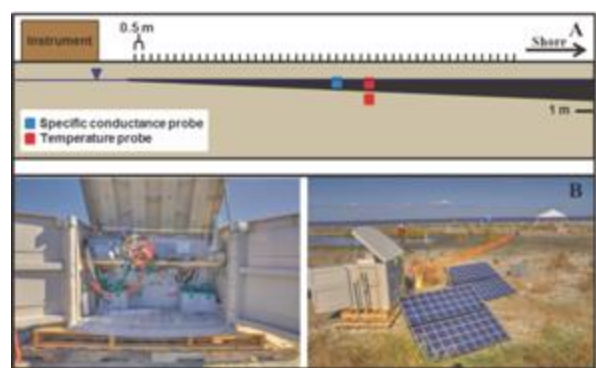
Oil layer

Oil impact thins away from the shoreline

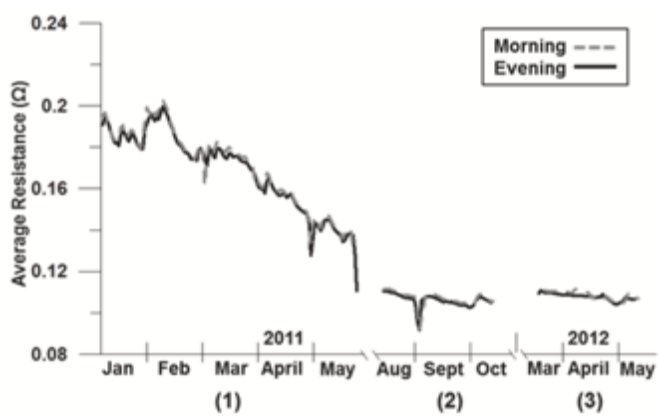


2. Mapping contaminant plumes

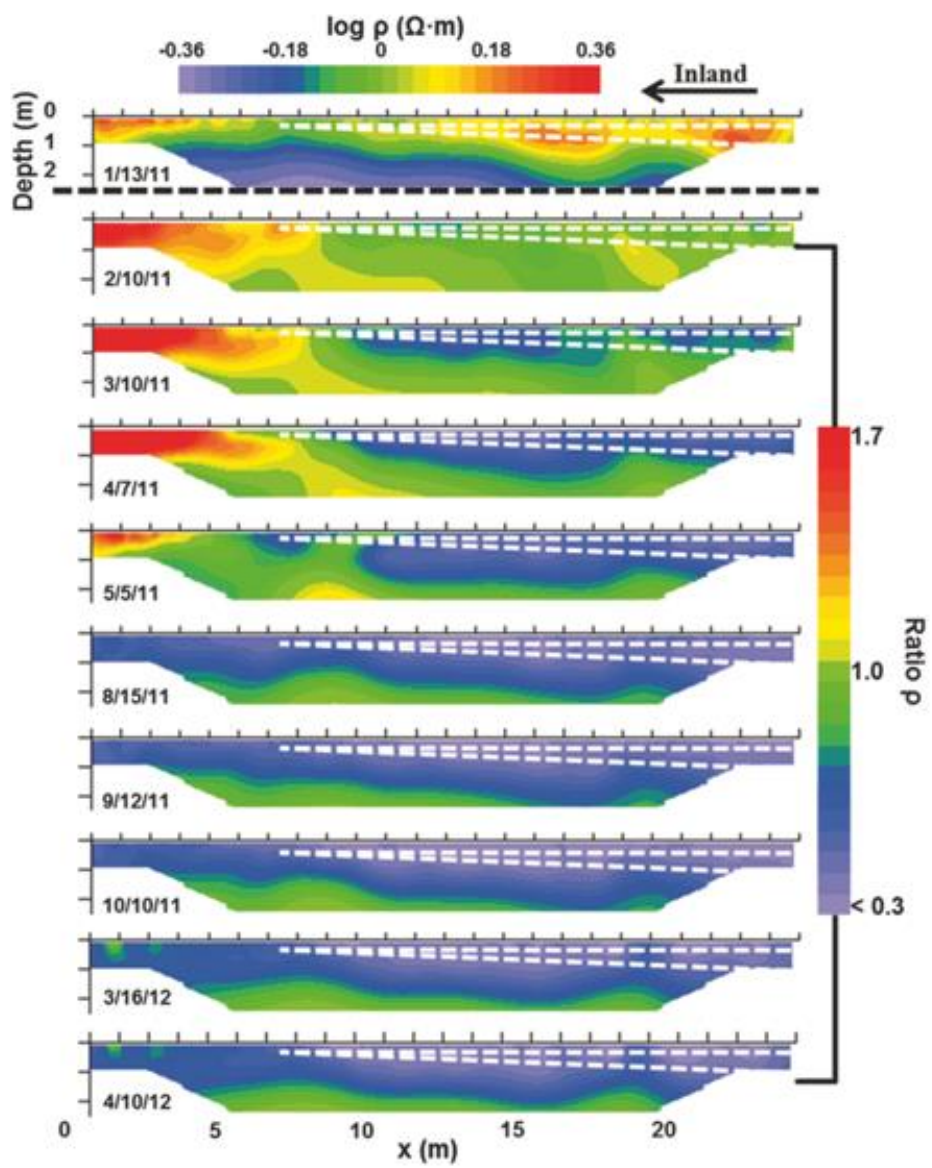
DWH Barrier Island Time-Lapse



Adaptation of field resistivity system to remote solar power acquisition



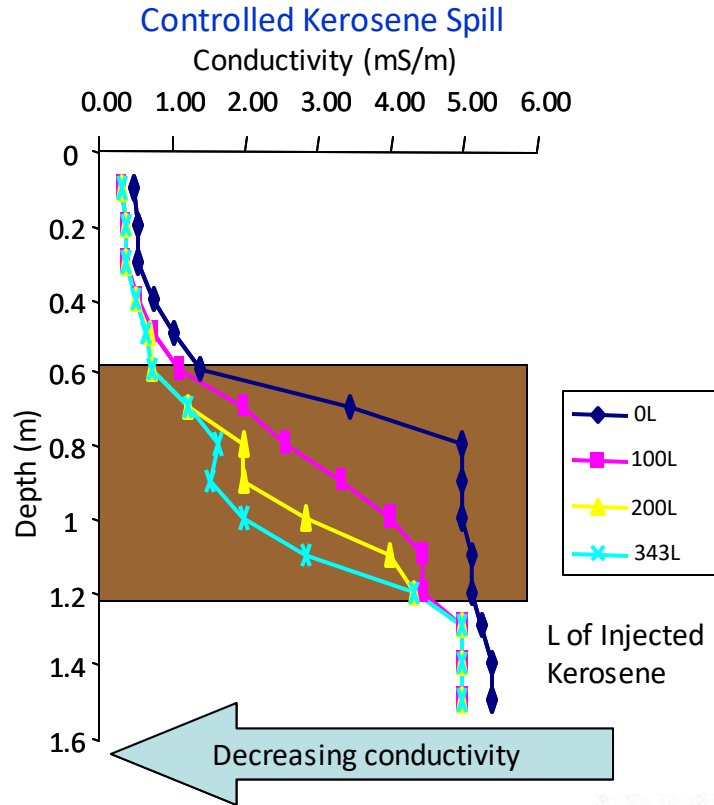
ave. resistance of anomaly vs. time



15 months resistivity

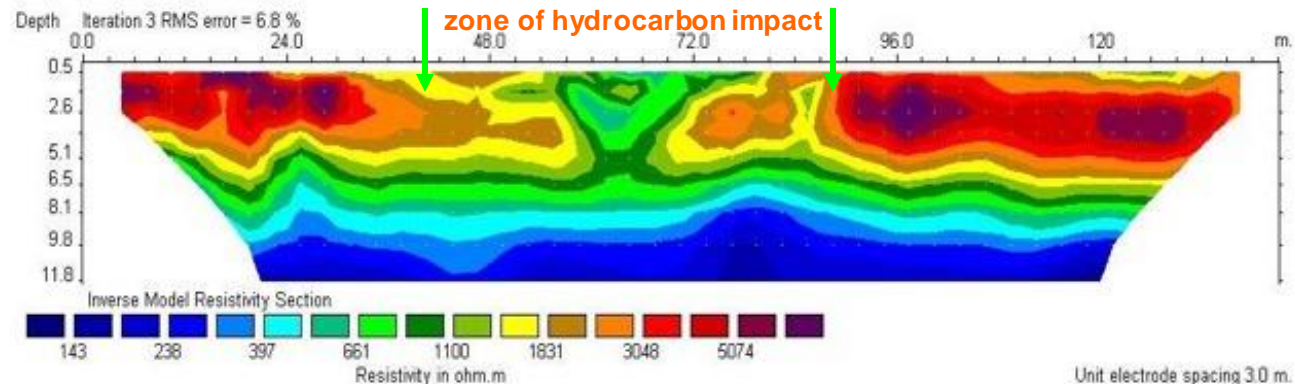
3. Remediation monitoring

Monitoring or measuring passive or active remediation using geophysics



De Ryck et al., 1993

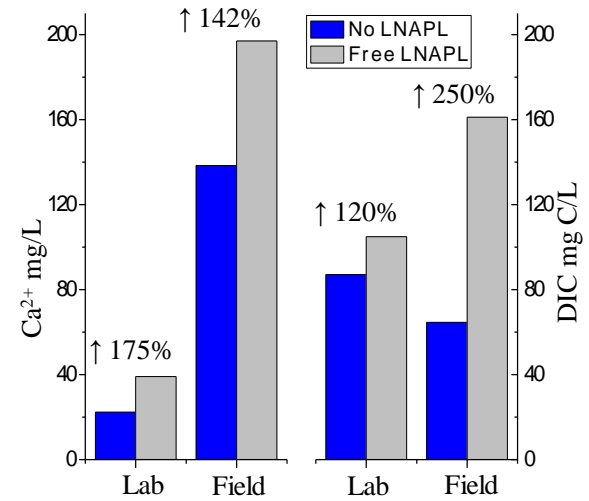
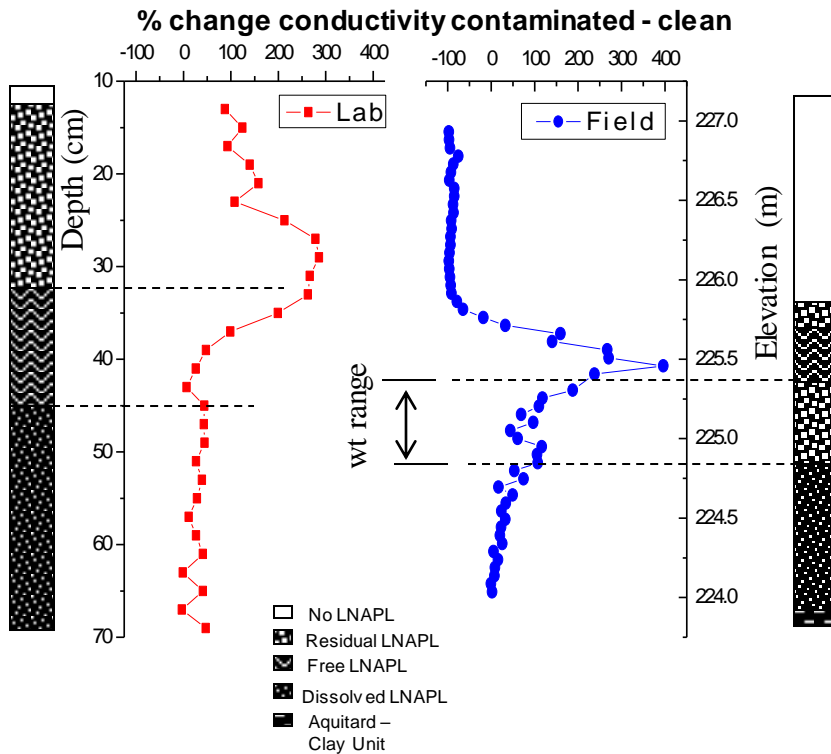
However...



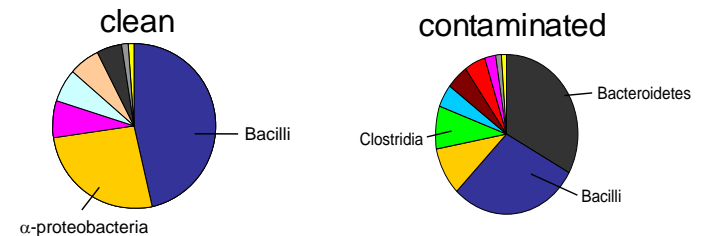
Maturity of plume should be considered

3. Remediation monitoring

Direct Current Resistivity of mature LNAPL plume



% change of Ca^{2+} and DIC

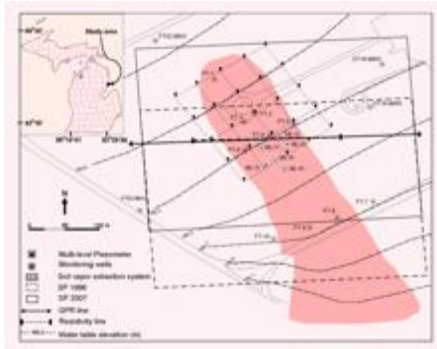


16S rRNA gene community composition

Geophysical response is coincident with microbiology and geochemical changes

3. Remediation monitoring

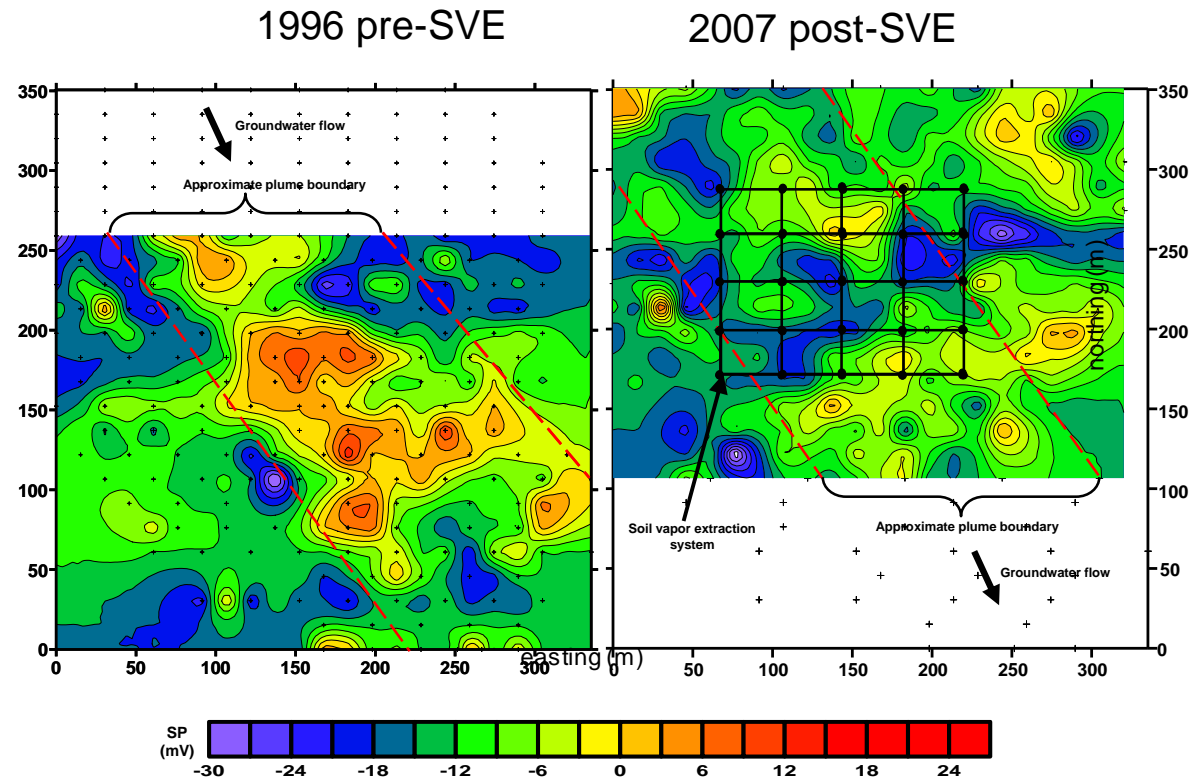
Soil Vapor Extraction (SVE) monitoring using Self-Potential (SP)



Former fire training facility, Oscoda, Michigan

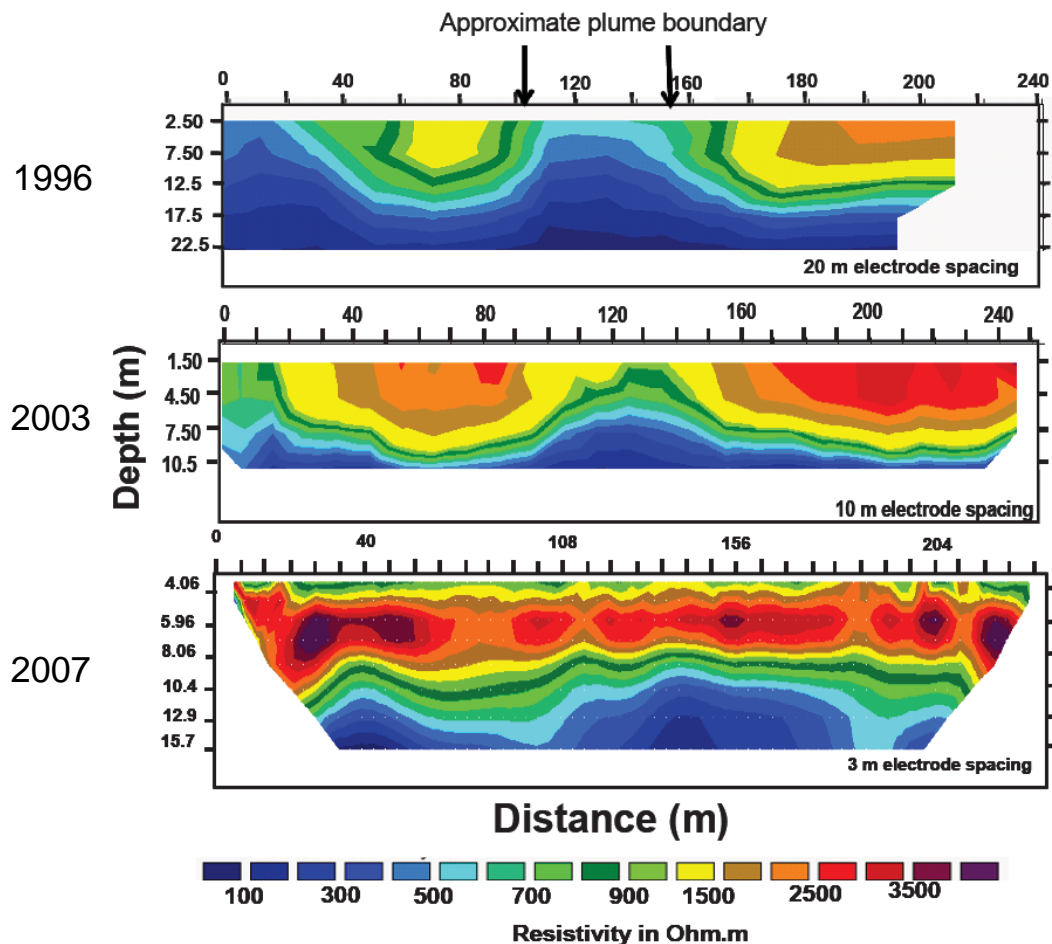
Large quantities of fuel were burned.

1990s, the free product 0.3 m thick and > 200 m down gradient

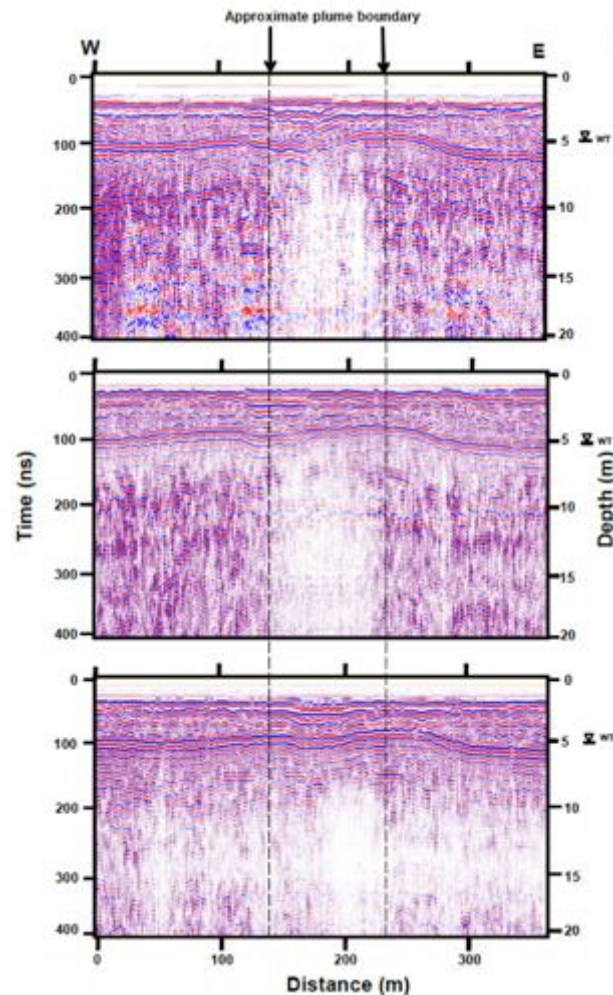


3. Remediation monitoring

DC Resistivity response to SVE system



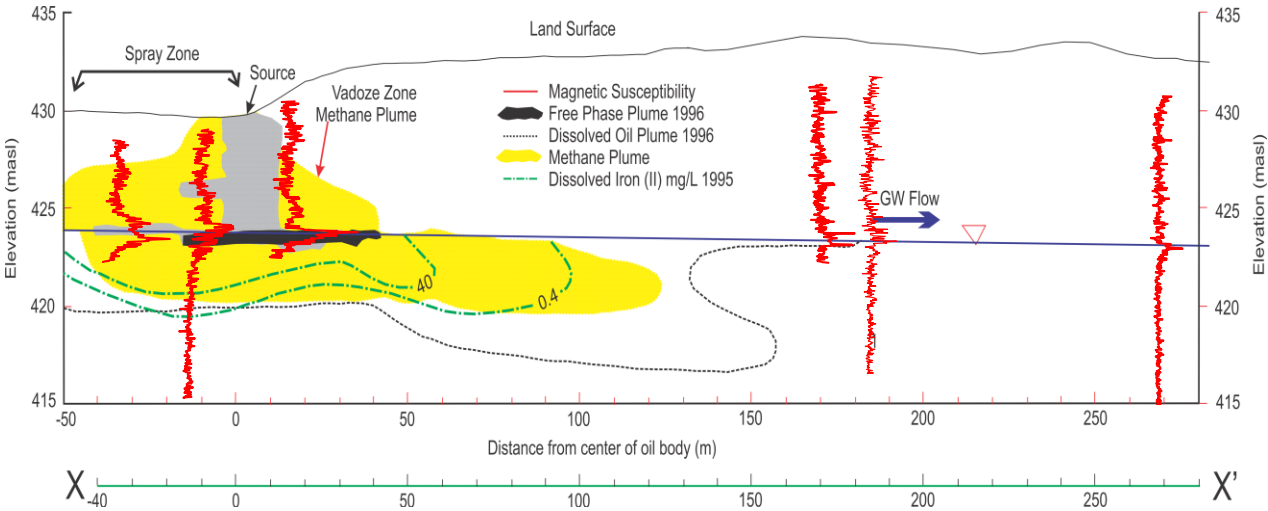
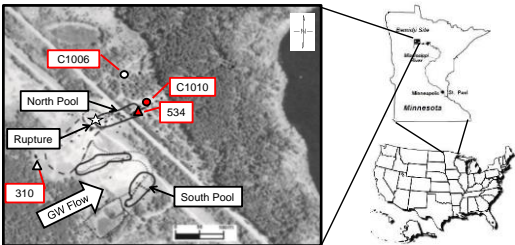
GPR Response to SVE System



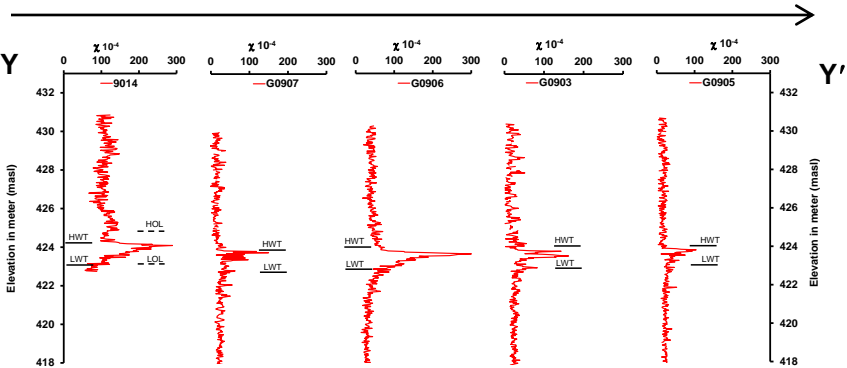
3. Remediation monitoring

Magnetic Susceptibility (MS)

MS measurements of the accumulation of magnetite can be adopted as a non-invasive technology for monitoring long-term natural attenuation of crude oil in the subsurface



free phase
plume
(FPP)

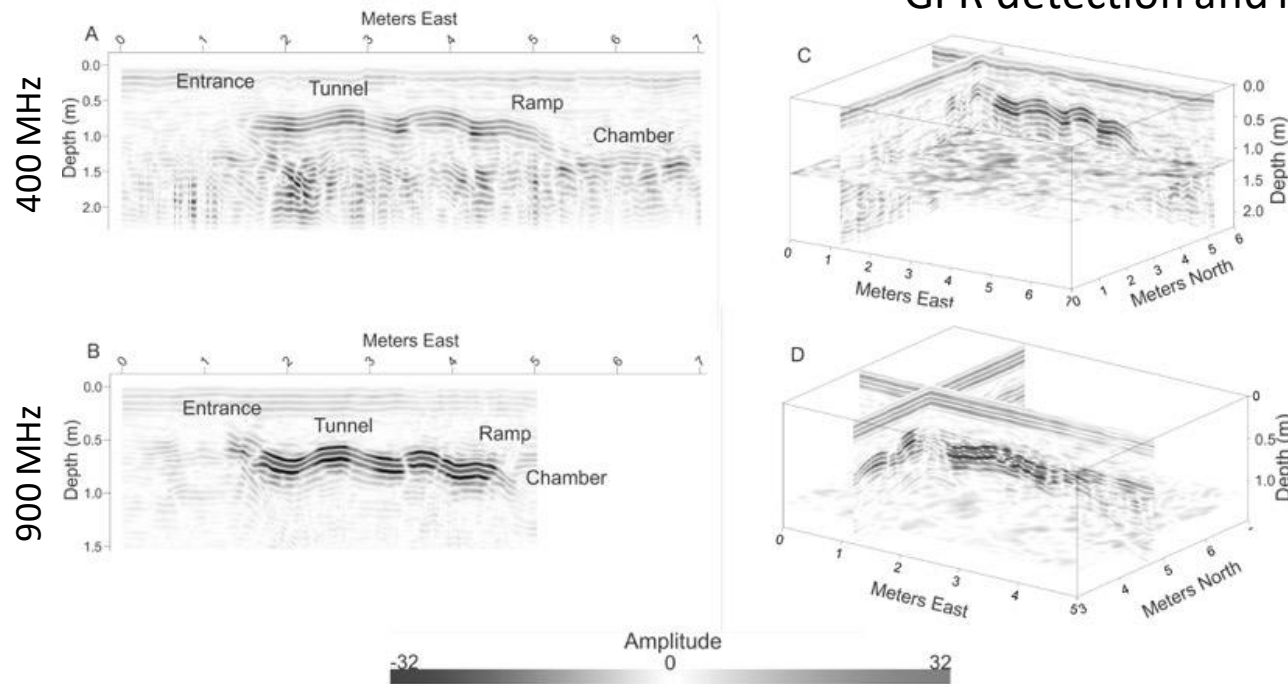


dissolved
phase plume
(DPP)

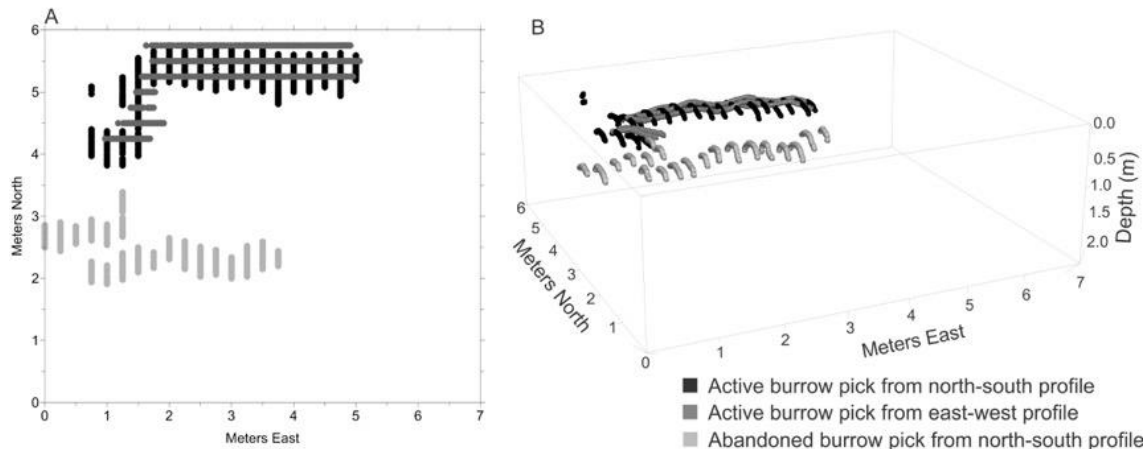


4. High Resolution CSM development

GPR detection and mapping of animal burrows



Groundhog burrow GPR image depicting the entrance shaft, tunnel, ramp, and chamber imaged with the 400 MHz antenna and the 900 MHz antenna.





Manual picks chosen for the identification of the groundhog burrow system through hyperbolic reflections in the 400 MHz data.

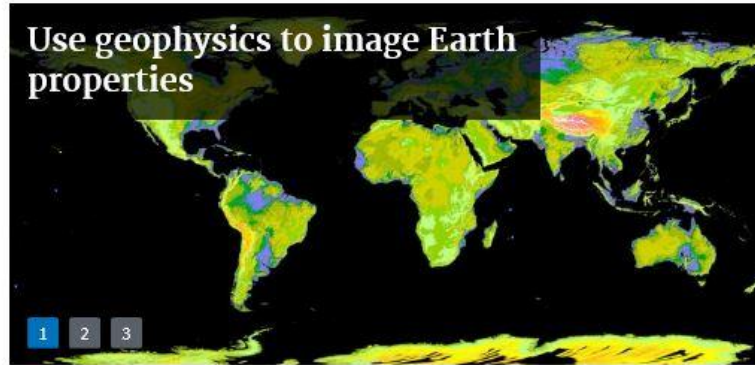
5. Models & Decision Support

Environmental Geophysics web presence: tech transfer, assistance, guidance, and decision support tools

Environmental Geophysics

CONTACT US SHARE    

Use geophysics to image Earth properties



FAQs

- What is Environmental Geophysics?
- Why should I care?
- Will it really help?

Environmental Geophysics explores the physics of the earth related to environmental problems. This site includes technical scientific content, decision support tools, predictive models, and data interpretation models to facilitate the proper use, application, and interpretation of geophysics to environmental problems.

About



- Overview
- [Geophysical Methods](#)
- Applications

Tools



- Decision support
- [Forward models](#)
- [Inverse models](#)

Related Links

- [Professional societies](#)
- [Journals](#)
- [Equipment](#)
- [Other Feds](#)
- [Universities](#)

Publications and Research



- EPA publications
- Ongoing research

Resources



- [Surface Methods](#)
- [Borehole Methods](#)
- [Marine Methods](#)
- [Geophysical Properties](#)
- [Inversion](#)
- [Terms](#)
- [References](#)

Once finalized this will be found at:

www.epa.gov/environmental-geophysics

Environmental Geophysics

[CONTACT US](#)[SHARE](#)[Home](#)[Geophysical Methods](#)[Borehole Geophysical Methods](#)[Marine Geophysical Methods](#)[Surface Geophysical Methods](#)[Electrical Methods](#)[Electromagnetic Methods](#)[Nuclear Methods](#)[Potential Field Methods](#)[Seismic Methods](#)[Inversion](#)[Geophysical Properties](#)[Density](#)[Electrical Conductivity and Resistivity](#)[Geomechanical \(Engineering\) Properties](#)[Magnetic Susceptibility](#)[Porosity](#)[Reflectivity](#)[Seismic Velocities \(VS,VP\)](#)

Surface Geophysical Methods

This section covers most of the commonly used surface geophysical methods.

- [Electrical Methods](#)
 - [Equipotential and Mise-a-la-Messe Methods](#)
 - [Induced Polarization](#)
 - [Resistivity Methods](#)
 - [Self-Potential \(SP\) Method](#)
- [Electromagnetic Methods](#)
- [Nuclear Methods](#)
- [Potential Field Methods](#)
- [Seismic Methods](#)

[Contact Us](#) to ask a question, provide feedback, or report a problem.

5. Models & Decision Support

ONLINE RESOURCES

Geophysical Decision Support System (GDSS – Beta Version)

INSTRUCTIONS DATA INPUT RESULTS

What is the objective of your geophysical project?

☐ Map and Locate Anthropogenic Objects
☐ Subsurface Contaminant Plume Detection
☐ Monitor Remediation Efforts
☐ Landfill Investigation
☐ CSM (Conceptual Site Model) Development

INSTRUCTIONS DATA INPUT RESULTS

What are the anticipated near surface geologic conditions?

☐ Unknown
☐ Competent Bedrock
☐ Fractured/ Weathered Bedrock
☐ Alluvial / Unconsolidated Sediment
☐ High Clay Content Unconsolidated Sediment
☐ Peat / Organic Sediment

INSTRUCTIONS DATA INPUT RESULTS

What is the type of land surface at the site?

☐ Rural: general rural land surface
☐ Suburban: 3 or more houses per acre
☐ Urban: high density city
☐ Industrial: warehouse, manufacturing, retail, etc.
☐ Active Military Base
☐ Service station: automobile service station
☐ Surface water body
☐ Inside a building

INSTRUCTIONS DATA INPUT RESULTS

Metadata
Notes
Methods
Citations

Abdel Aal,Gamal Z., Workema,Jr.,D.Dale, Sauck,William A., and Atekwana,Estelle A., "Geophysical Investigation of Vadose Zone Conductivity Anomalies at a Former Refinery Site, Kalamazoo, MI.", Symposium on the Application of Geophysics to Engineering and Environmental Problems, 2001.
Keywords: clay, conductivity, contamination, electromagnetic, GPR, ground penetrating radar, hydrocarbon, hydrocarbons, LNAPL, magnetic, monitoring, permeability, phase, resistivity, resolution, sand, vadose zone

Abdel Aal,Gamal Z., Slater,Lee D., and Atekwana,Estelle A., "Induced-polarization measurements on unconsolidated sediments from a site of active hydrocarbon biodegradation", Geophysics, Vol. 71, No. 2, pp. H13-H24, 2006/3.
Keywords: conductivity, contamination, experiments, field, geochemistry, hydrocarbons, induced polarization, IP, microorganisms, organic compounds, phase, scanning electron microscopy, soil pollution, water content

Waxman,M.H., and Smits,L.J.M., "Electrical conductivities in oil-bearing shaly sands", Soc.Pet.Eng. Vol. Trans. AIME 243, pp. 187-122, 1968.
Keywords: conductivity, electrical, electrical conductivity, ELECTROCAL-CONDUCTIVITY, sand, shaly sands

Abdu,M., Robinson,D.A., Seyfried,M., and Jones,S.B., "Geophysical imaging of watershed subsurface patterns and prediction of soil texture and water holding capacity", Water Resources Research, Vol. 44, pp. W00D18, 2008.
Keywords: clay, electromagnetic, electromagnetic induction, mapping, moisture, soil moisture, storage

Acworth,R.I., "Physical and chemical properties of a DNAPL contaminant Geology and Hydrogeology, Vol. 24, pp. 85-98, 2001.
Keywords: chemical analysis, chlorinated hydrocarbons, complex resistivity, co hydrochemistry, resistivity, sand, soil

Acworth,R.I., and Dasey,G.R., "Mapping of the hyporheic zone around electrical tomography and cross-creek electrical imaging, New South W 368-377, 2003.

Keywords
Input Summary

Save as HTML ... View HTML Popup < Back

INSTRUCTIONS DATA INPUT RESULTS

Keywords

conductivity
electrical conductivity
electrical resistivity
electromagnetic
seismic
seismic methods
surface nuclear magnetic resonance

INSTRUCTIONS DATA INPUT RESULTS

Methods

(3) Surface Geophysical Methods > Electromagnetic Methods > Time-Domain Electromagnetic Methods

(3) Surface Geophysical Methods > Electromagnetic Methods > Frequency Domain Electromagnetic Methods >> Terrain Conductivity Method

(3) Surface Geophysical Methods > Electrical Methods > Resistivity Methods

(3) Surface Geophysical Methods > Electrical Methods > Equipotential and Mise-a-la-Messe Methods

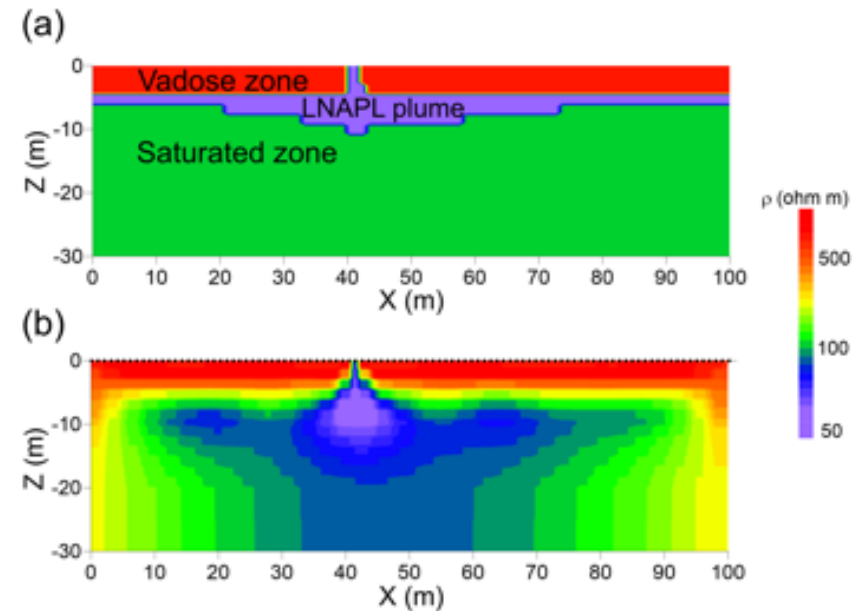
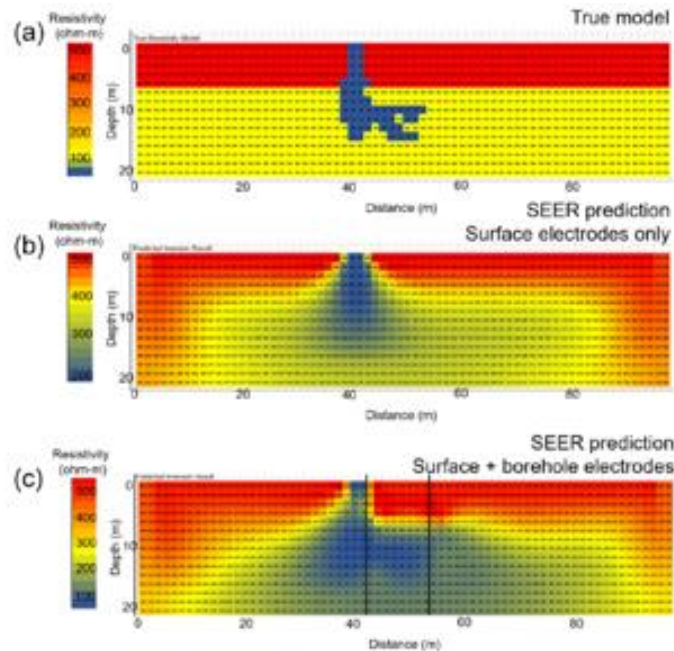
(2) Surface Geophysical Methods > Electromagnetic Methods > Ground-Penetrating Radar

<https://clu-in.org/characterization/technologies/geophysics/>

Werkema Jr., D.D., Jackson, M., and Glaser, D., EPA/600/C-10/004, 2010

5. Models & Decision Support

SEER – Scenario Evaluator for Electrical Resistivity



- (a) hypothetical target consisting of a mature LNAPL plume on the water table, and electrodes with 1-m spacing at land surface
- (b) the resultant electrical resistivity tomogram, assuming normally distributed random standard errors of 3%.

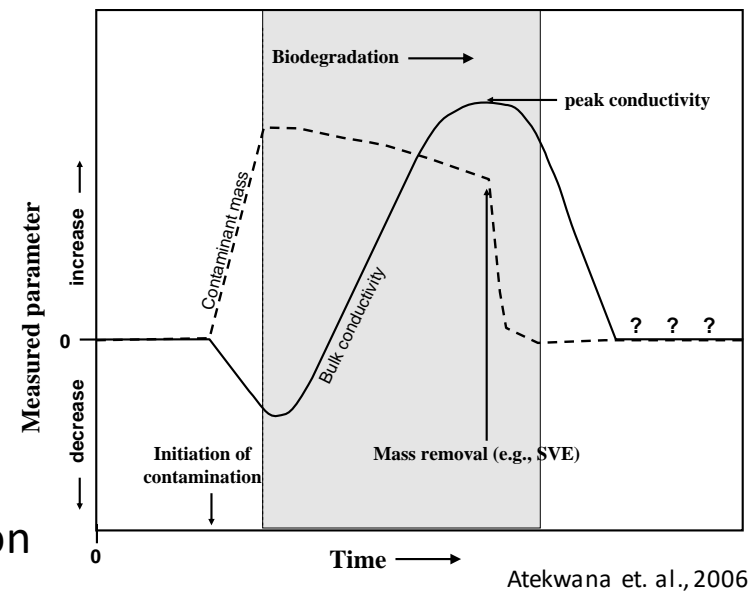
Concluding Thoughts

We can use, and are learning to use, geophysics to:

1. Find Underground Storage Tanks
2. Direct detection of some contaminants
3. Biological breakdown of contaminants and remediation
4. CSM development
5. Forward models and decision support systems help reduce uncertainty of results and inform stakeholders

The geophysical response is a function of the geology, hydrogeology, biology, and chemistry of the subsurface.

- Look for physical property contrasts, understand the mechanism of that contrast and if geophysical methods have the requisite resolution to detect the contrast.



What are the physical property contrasts?

Are these contrasts geophysically detectable?

Acknowledgement & Collaborators

- John Lane, Fred Day-Lewis, Marty Briggs, Carole Johnson, Eric White, Terry Neal: *USGS and University of Connecticut*
- Lee Slater, Dimitris Ntgarlantis, Judy Robinson, *Rutgers University*
- Estella Atekwana & Eliot Atekwana: *University of Delaware formerly OSU*
- Gamal Abdel Aal: *Assiut University, Egypt*
- Andre Revil: *Colorado School of Mines*
- Barbara Luke: *University Nevada-Las Vegas*
- Bill Sauck & Silvia Rossbach: *Western Michigan University*
- Yuri Gorby: *J. Craig Venter Institute*
- Students:
 - *UConn*: Emily Voyteck, John Ong, Rory Henderson
 - *UNLV*: Meghan Magill, Nihad Rajabdeen, Lisa Hancock
 - *Rutgers*: Jeff Heenan, Yves Robert-Personna, Sina Saneiyan, Sundeep Sharma, Angelo Lamousis,
 - *Oklahoma State U*: Farag Mawafy, Ryan Joyce, Dalton Hawkins, Brooke Braind, Cameron Ross, Carrie Davis, Che-Alota Vukenkeng,
 - *Colorado School of Mines*: Marios Karaoulis