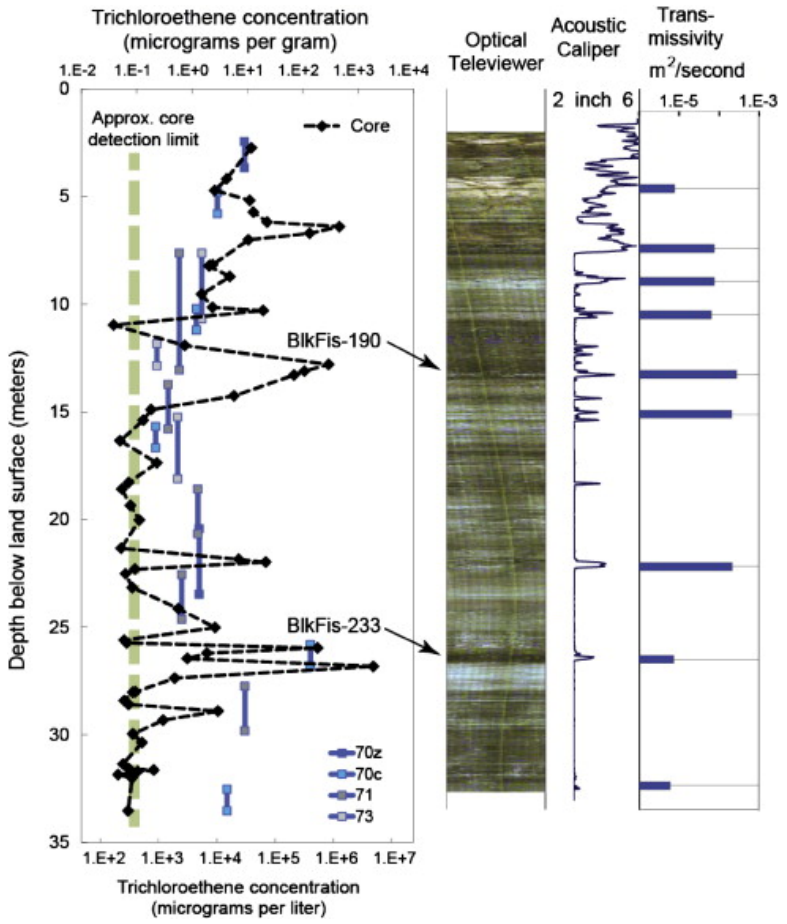
ERT monitoring : a tool to understand processes in bioremediation and to highlight solid waste hydrodynamics ?

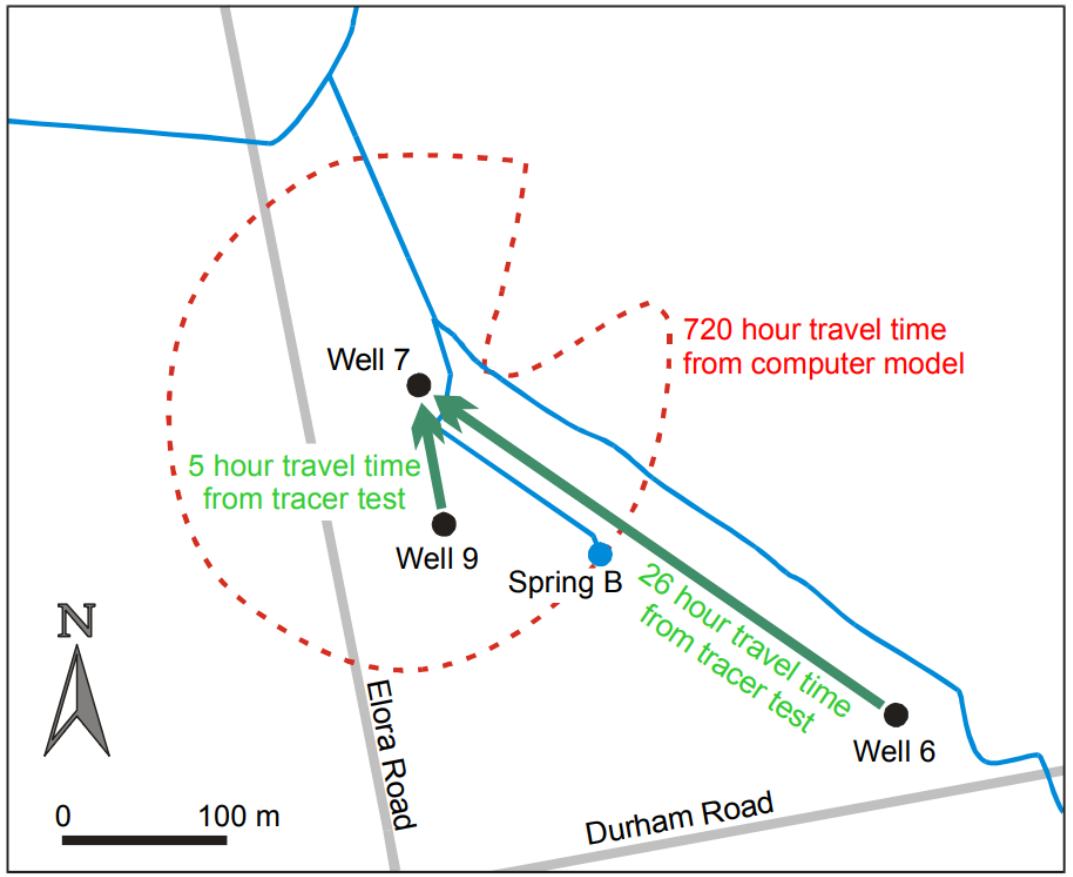
Frédéric NGUYEN, Gael DUMONT and David CATERINA

Need for a robust imaging and monitoring method

Need to image heterogeneity

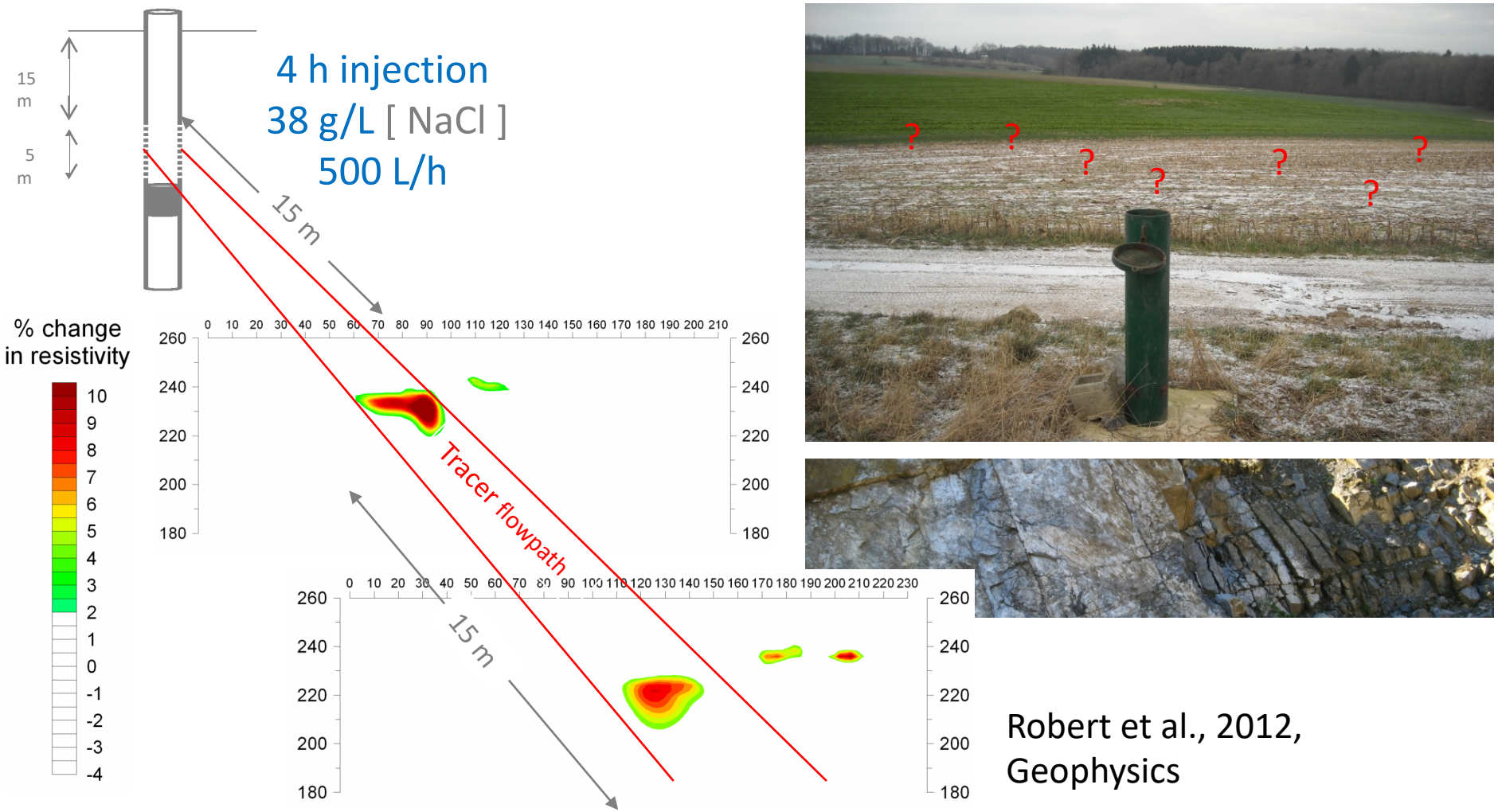


Goode et al., 2014, J. Contam. Hydrol.



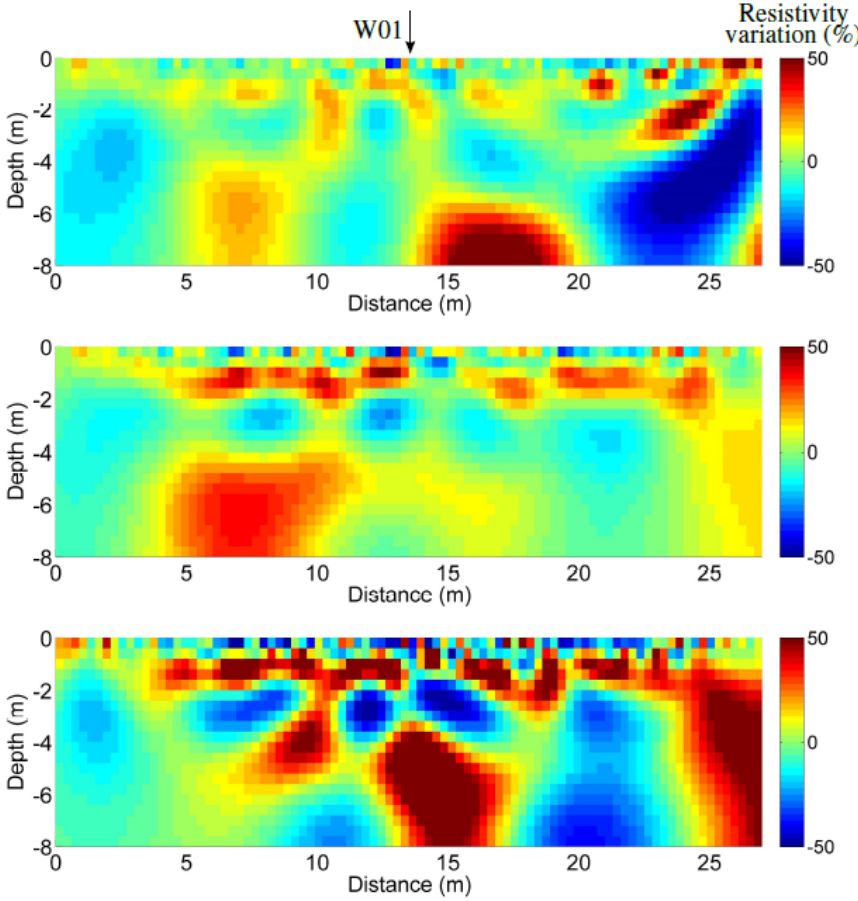
Worthington et al., 2002

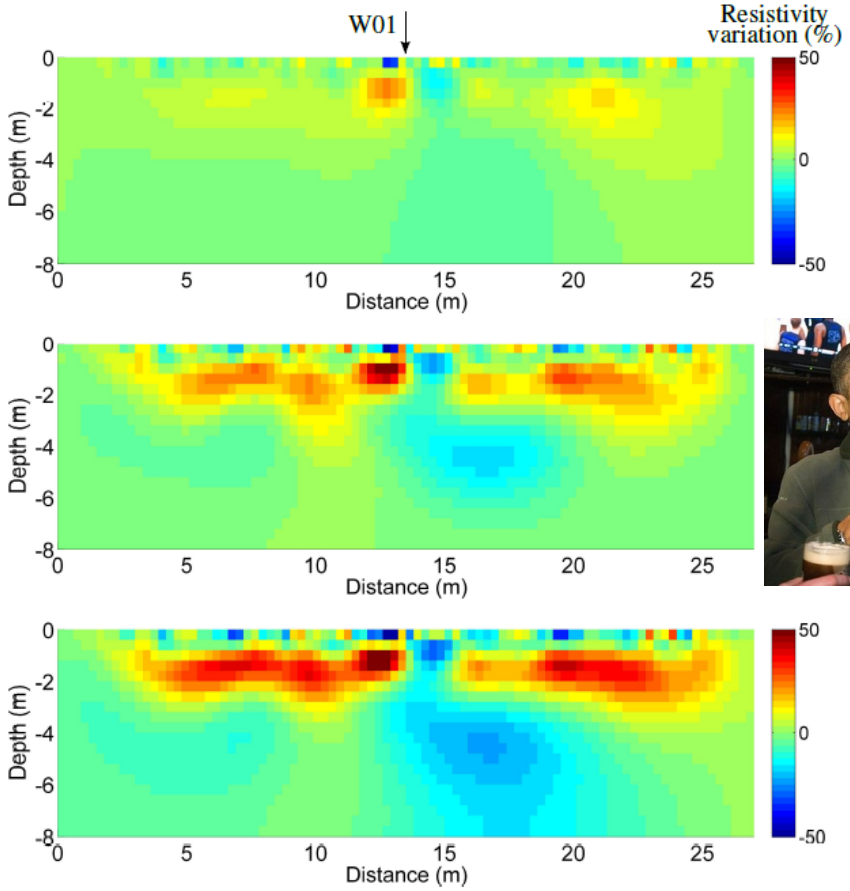
Monitoring allows controlling remediation and/or action and to understand processes



Robert et al., 2012, Geophysics

Finally robust means useful and feasible and is the key to market adoption/scientific success





Lesparre et al., 2017, Geophysics

Shedding light in municipal solid waste hydrodynamics

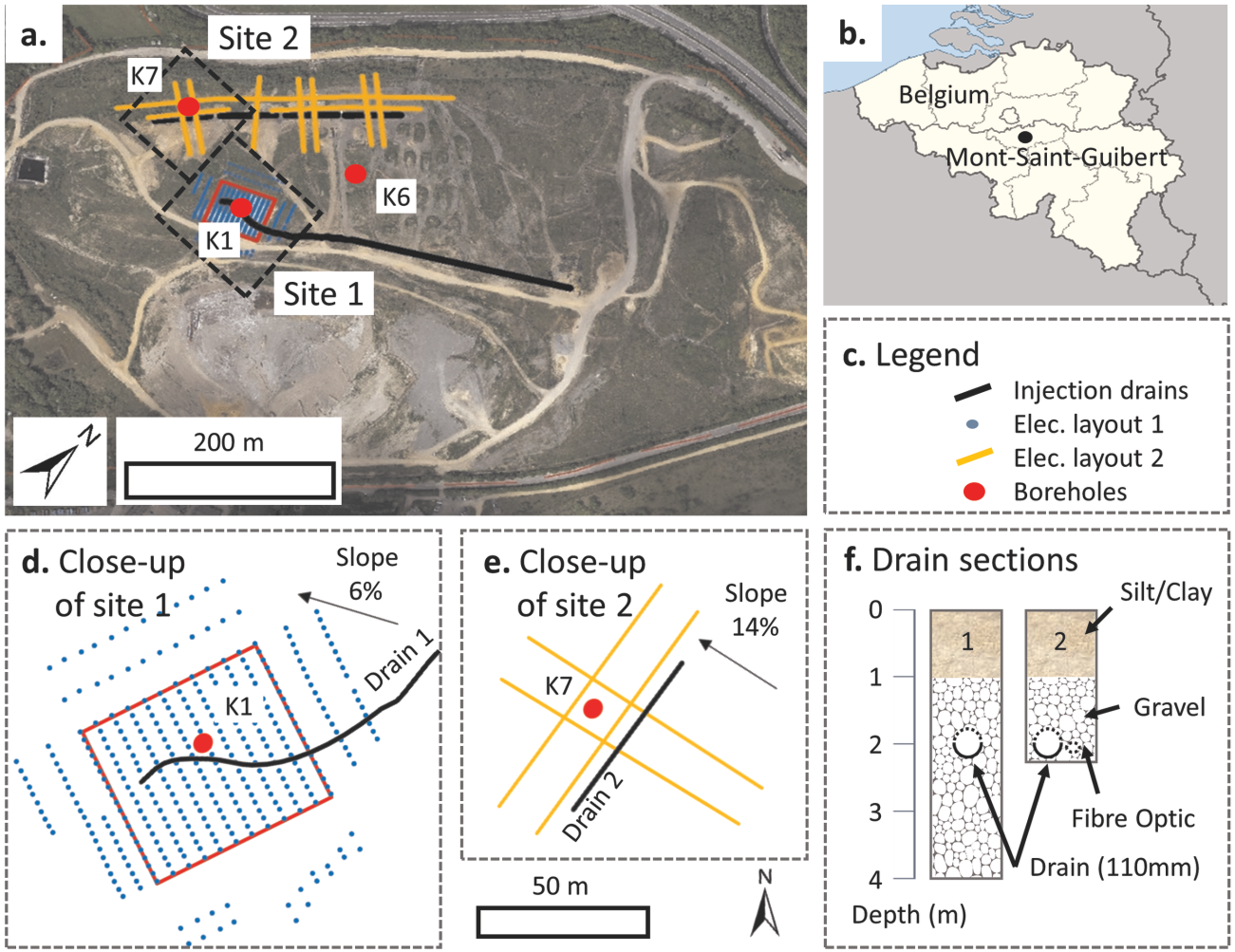
Europe has more than **500,000 landfill sites**, with an estimated 90% of them being classed as “non-sanitary” landfills.

Water content controls the completeness and the kinetics of biodegradation

Water/leachage re-circulation increases biogas production and shorten exploitation time

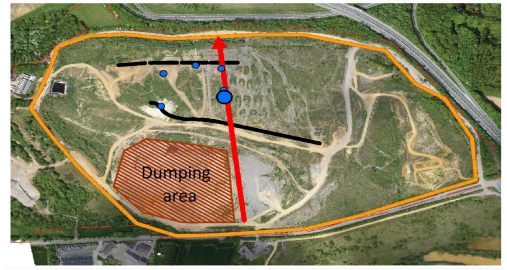
Dumont et al., 2017, Geophysics

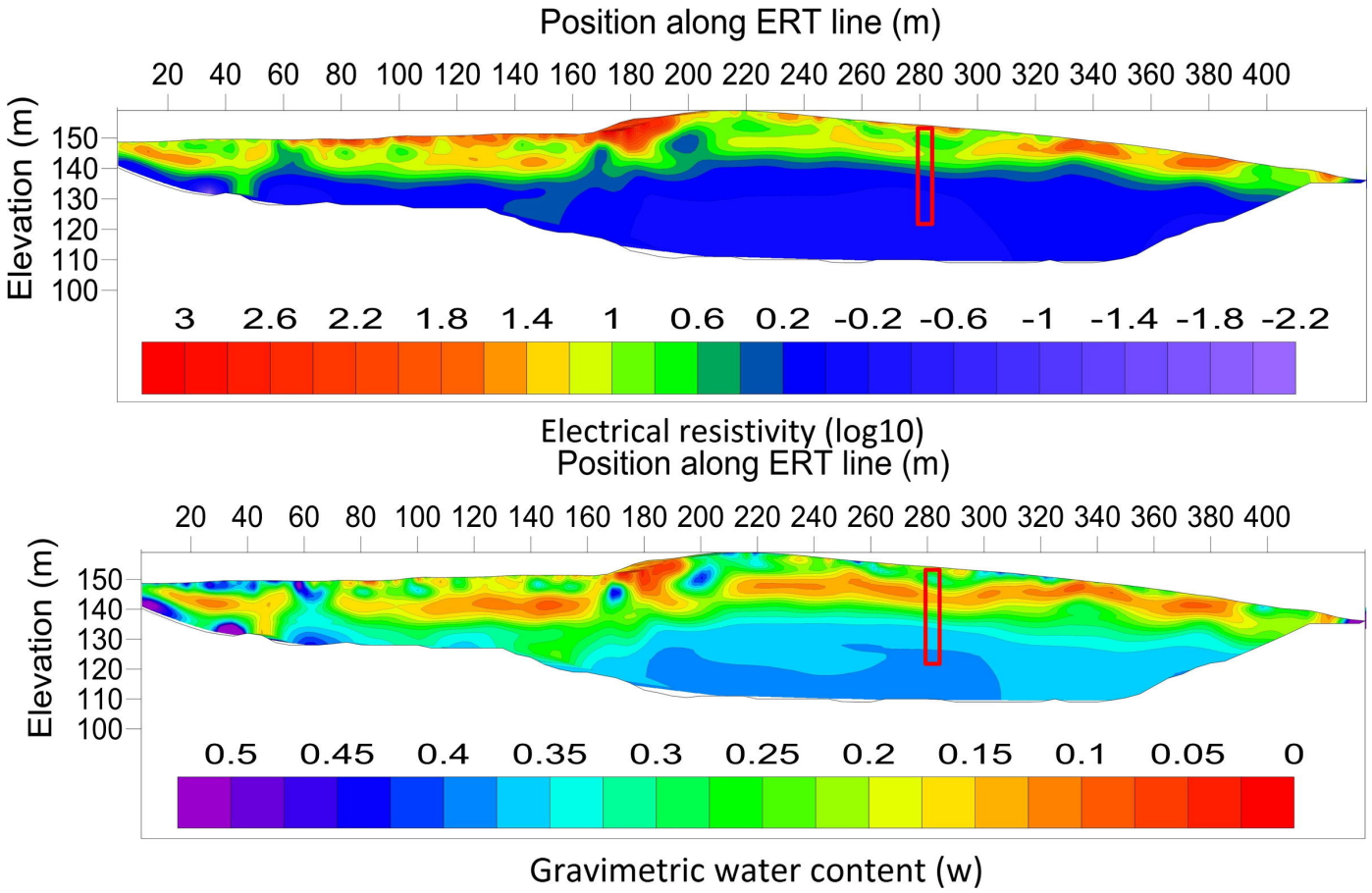
Site and set-up

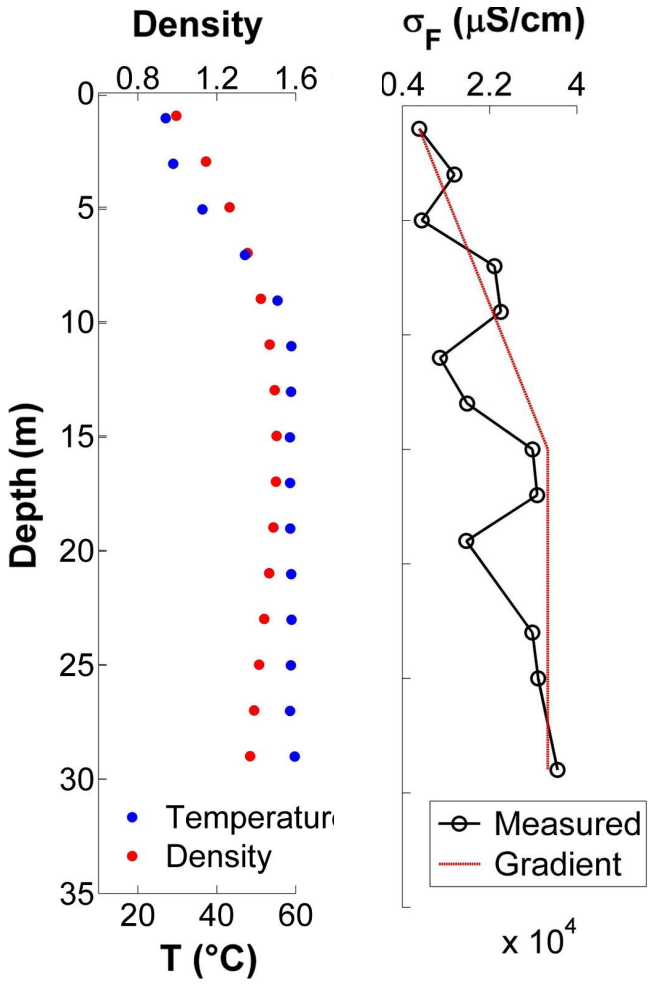


	SITE 2 (DRAIN SECTION 1)
DRAIN FEATURES	110 mm perforated tube, 4 m depth 50 m long 100-120 m³/h injection
INJECTION TIMING	Individual injection experiment: 60 m³(30/7/2014) and 275 m³ (11/8/2014)
T° DATA	Along injection drain
ERT MONITORING	4 lines of 32 electrodes (2.5 m spacing) 1152 data points Hourly (30/7/2014 – 19/8/2014)

Water content characterization

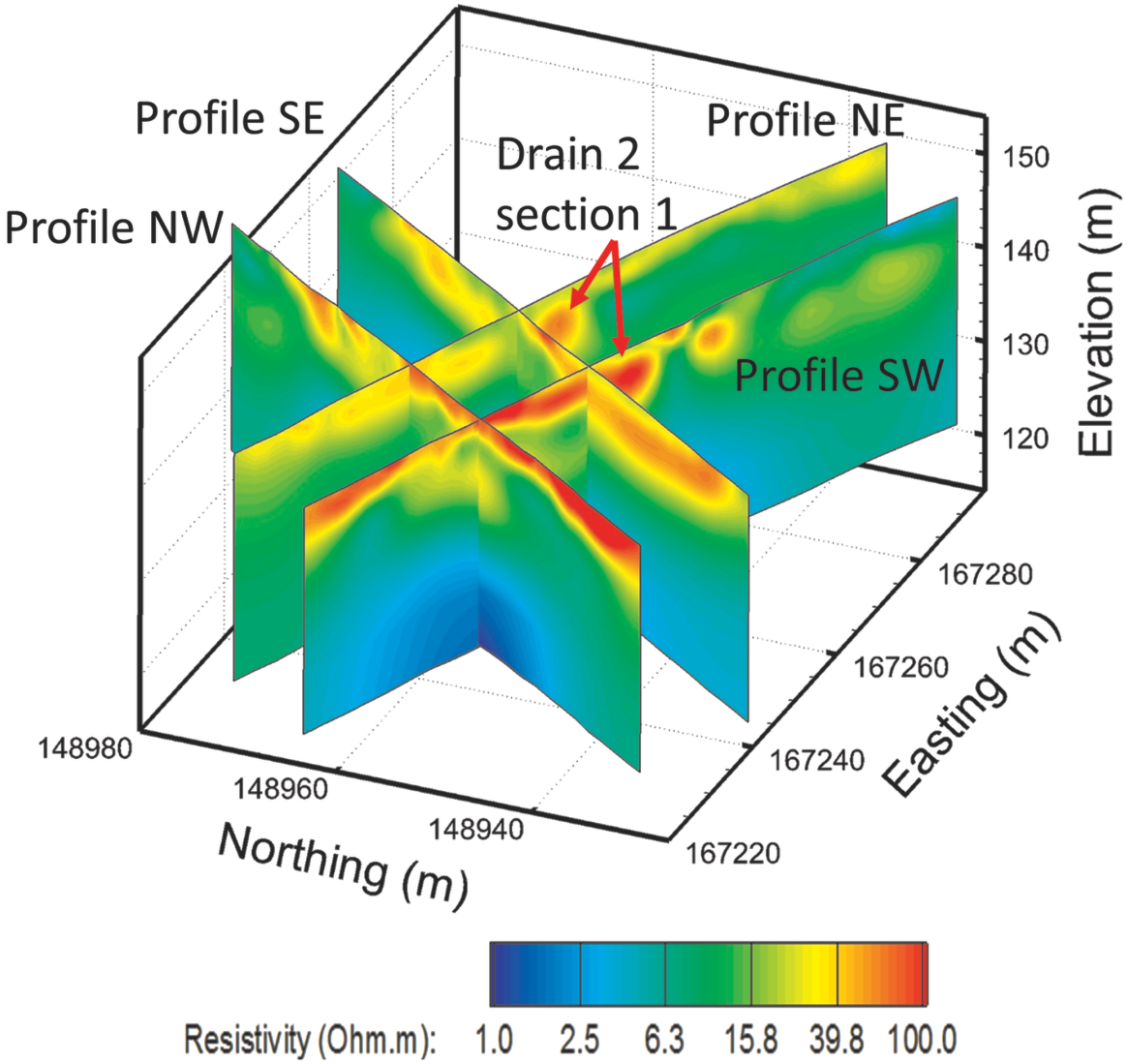




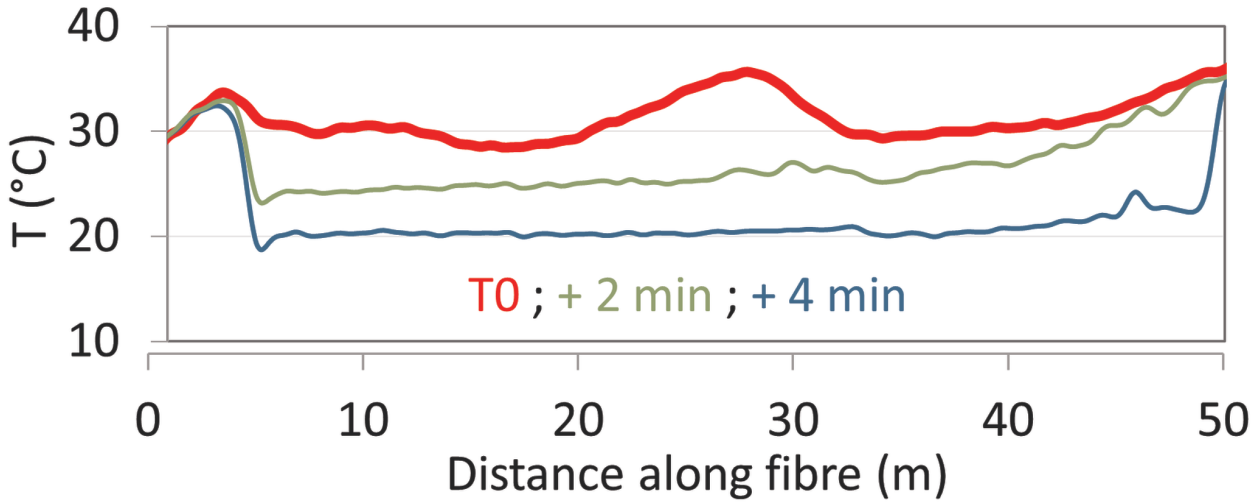


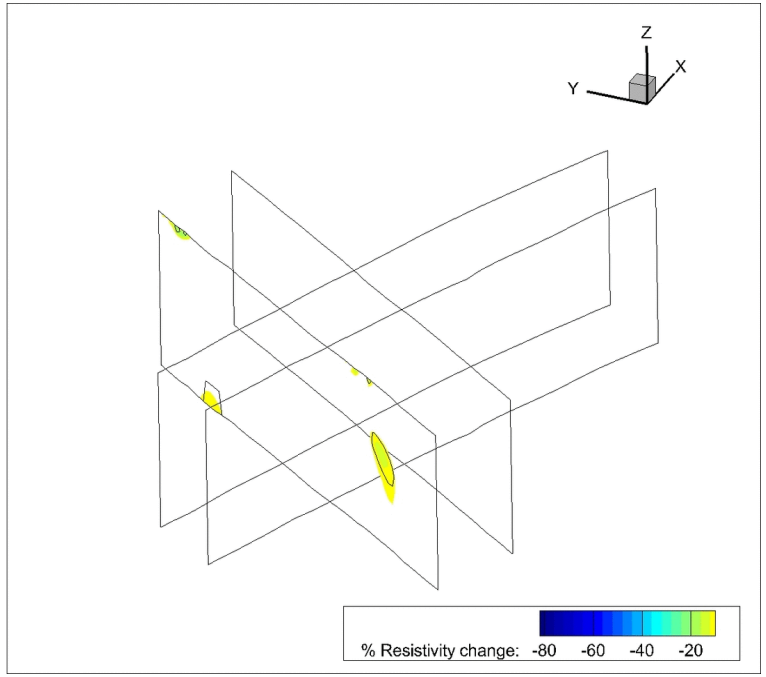
Dumont et al., 2016, Waste Management

Baseline

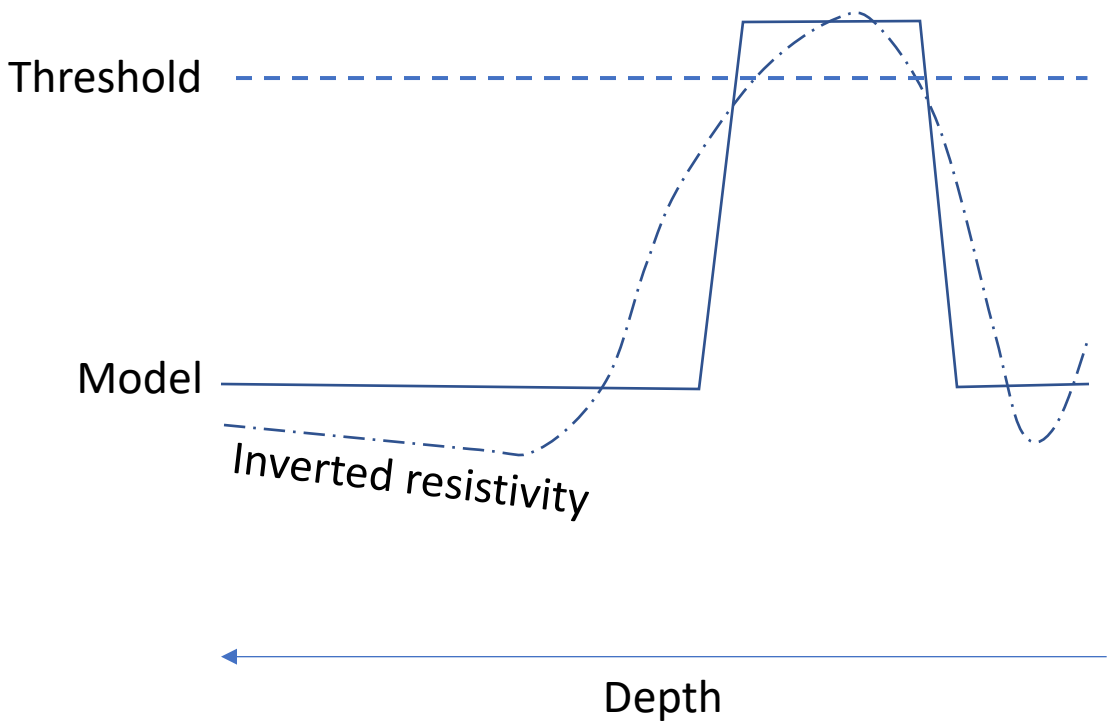

Profile SE
Profile NE
Drain 2
section 1
Profile NW
Profile SW
150
140
130
120
Elevation (m)
167280
167260
167240
167220
Easting (m)
148980
148960
148940
Northing (m)
Resistivity (Ohm.m):
1.0
2.5
6.3
15.8
39.8
100.0

Drain temperature monitoring (60 m³ @ 110 m³/h)





Threshold definition to delimitate the water plume extent (other approach, see Sylvain Moreau talk)



A forward/inversion numerical benchmark testing different:

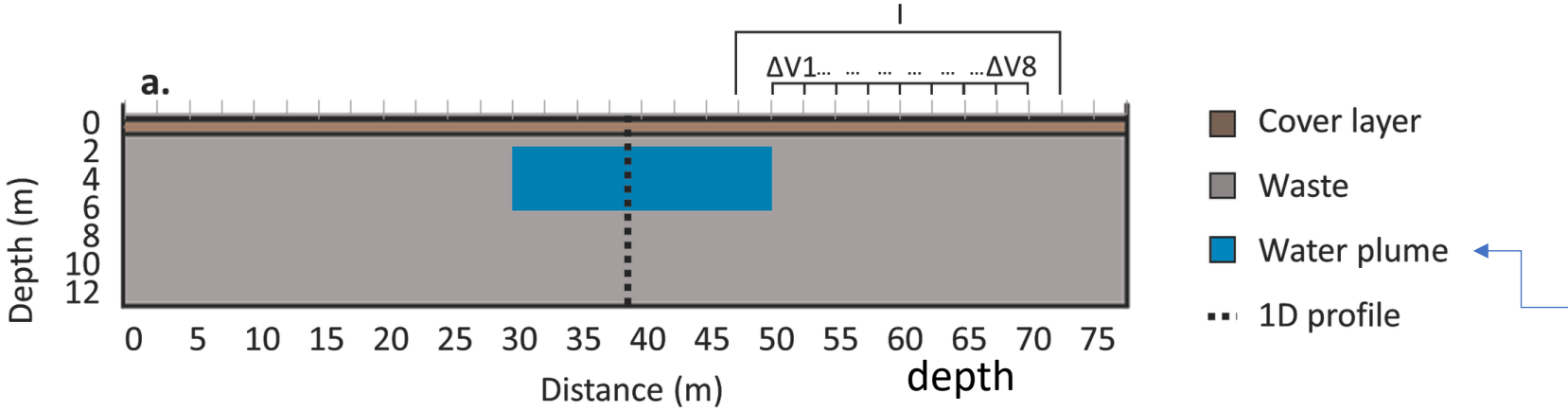
- Water content increase
- Depths of the plume
- Plume heterogeneity
- Initial water content

will find that for our set-up a 70% of the maximum change magnitude threshold was relatively robust

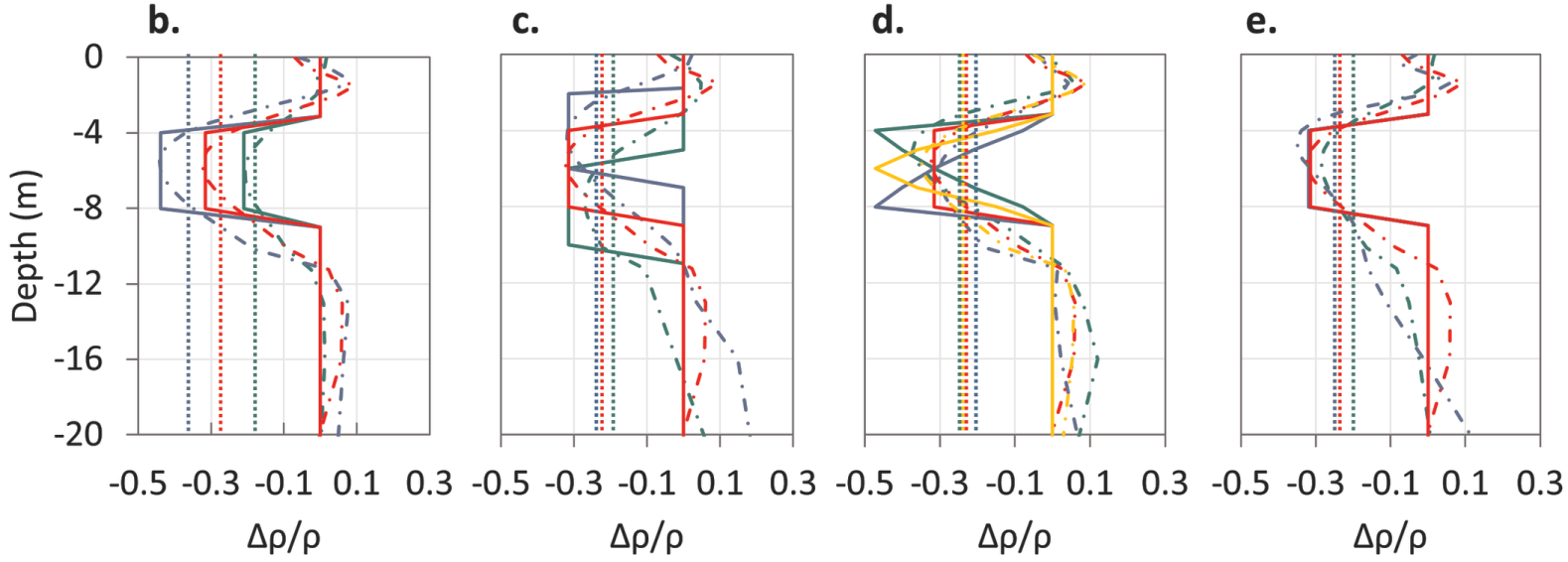
Other approaches may consider

- Image processing
- MGS inversion
- MICS approach

Threshold definition to delimitate the water plume extent



25% to 30% water content, corresponding to a 20% relative change of water content and a -31.5% relative change of resistivity



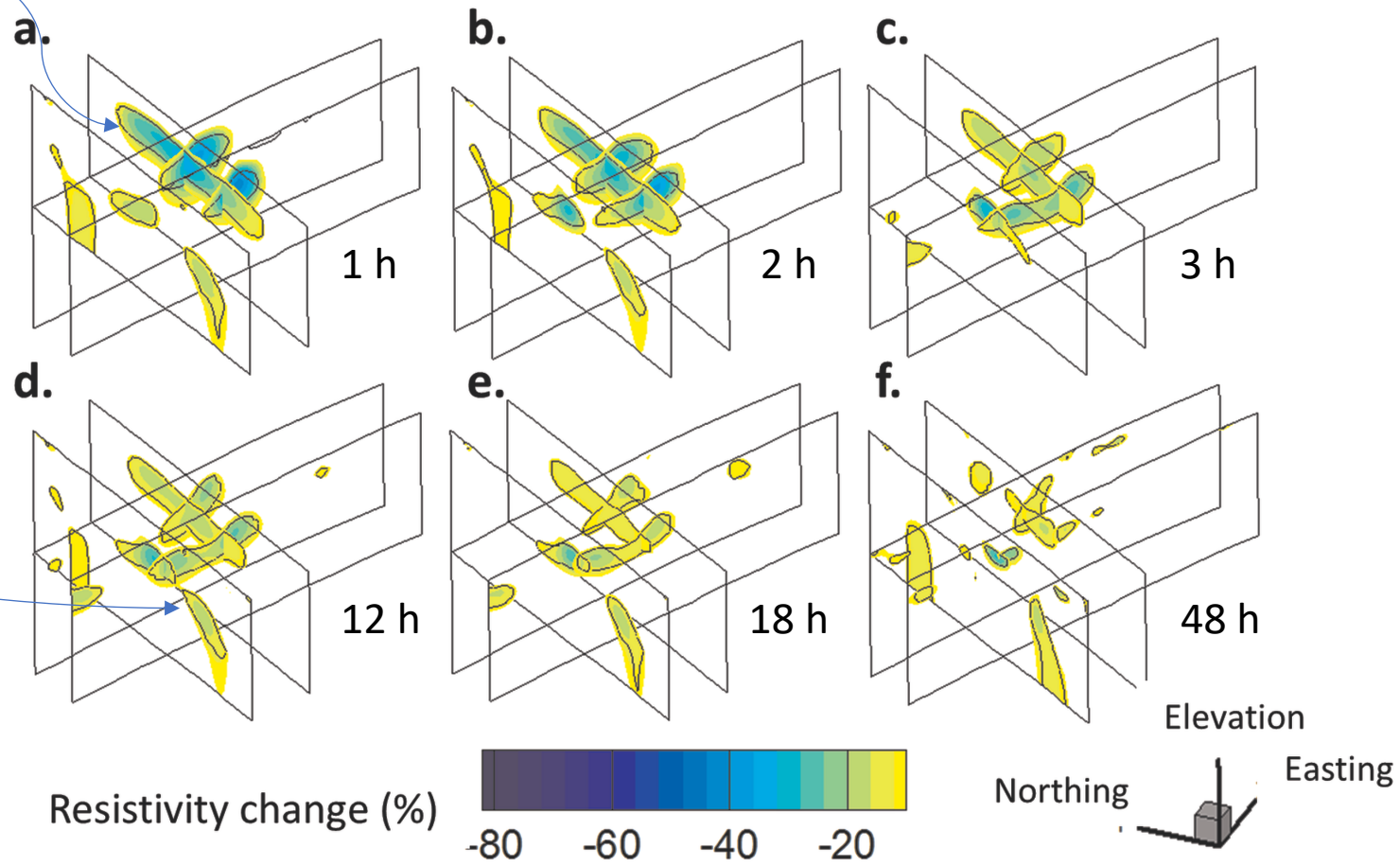
Effect of water content | Depth | Heterogeneity | Initial water content

Resistivity monitoring 1: 60 m^3 injection

injection drain : 45m large plume, while the drain is 50 m long (~2000 m^3)

Threshold to study plume hydrodynamics: 10 m/hour

The water retention time is small after two days



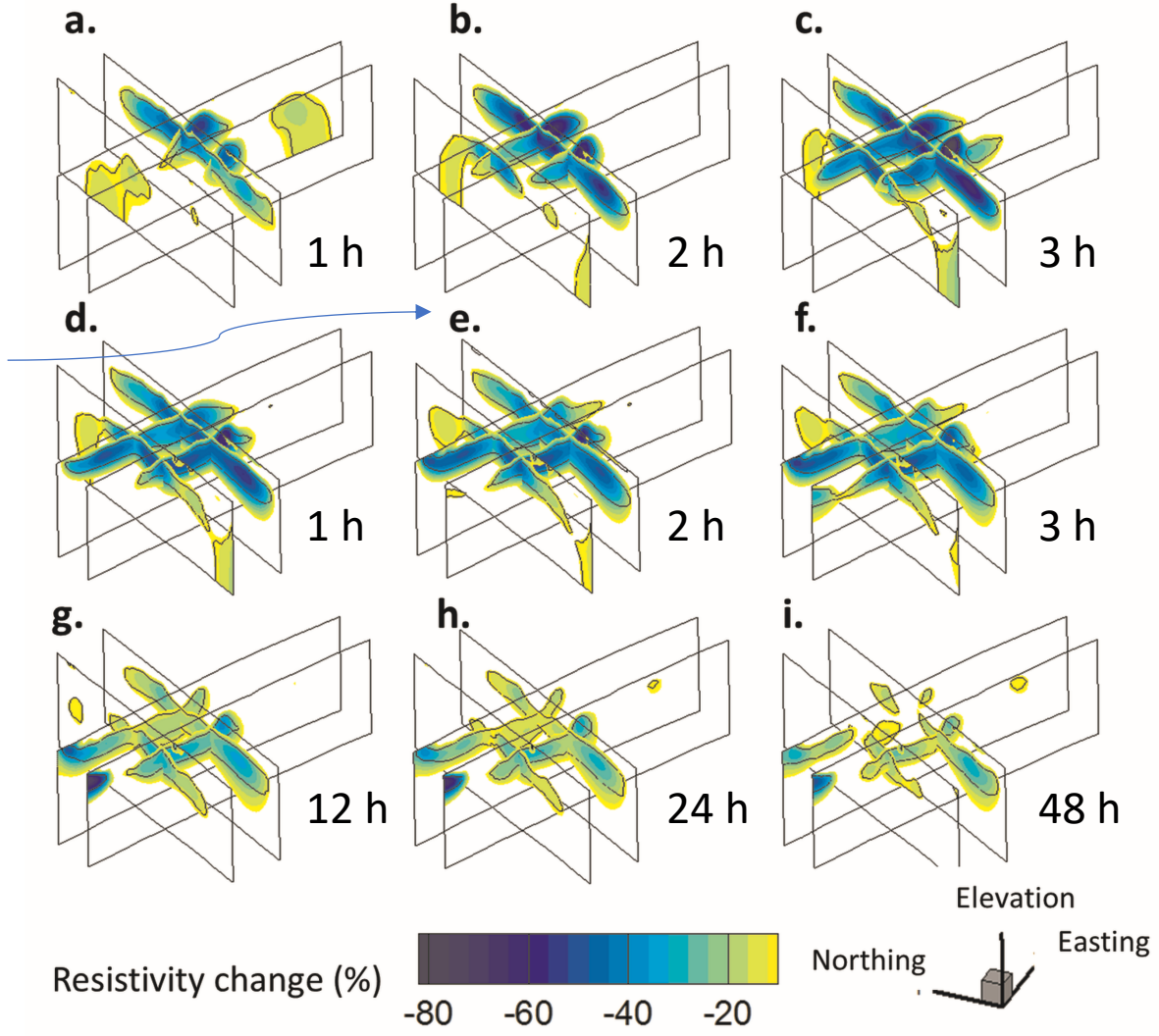
Resistivity monitoring 2: 275 m³/2.5h 12 days after the first injection test

During the injection : possible time smearing

Plume is about 8000 m³ (3.5% volumetric water content increase)

After the injection ended: 8 m/h

The vertical infiltration is very slow
Flow heterogeneity depicted



Conclusions and perspectives

We used ERT and DTS to :

- Assess large horizontal recirculation drain efficiency
- Monitor superficial waste humidification in a large retrofit engineered landfill

We were able to:

- Characterize the water plume extension and evolution through time with hourly resolution with valuable information on water flow anisotropy and heterogeneity
- Evaluate the variability of the water plume persistence over time

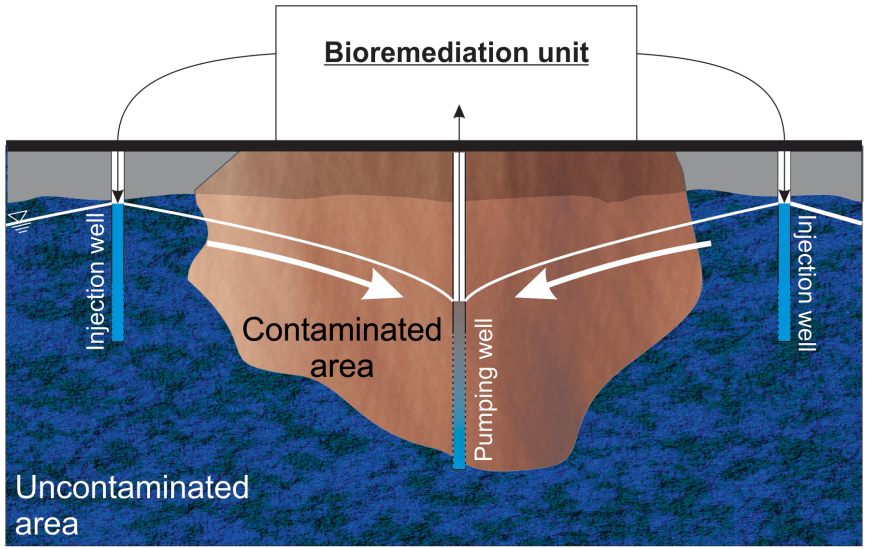
Progress needed (short term monitoring):

- ➢ Temporal resolution
- ➢ Robustness of quantification/uncertainty

Trying to understand biogeochemical changes of aged hydrocarbons (11+ years old)

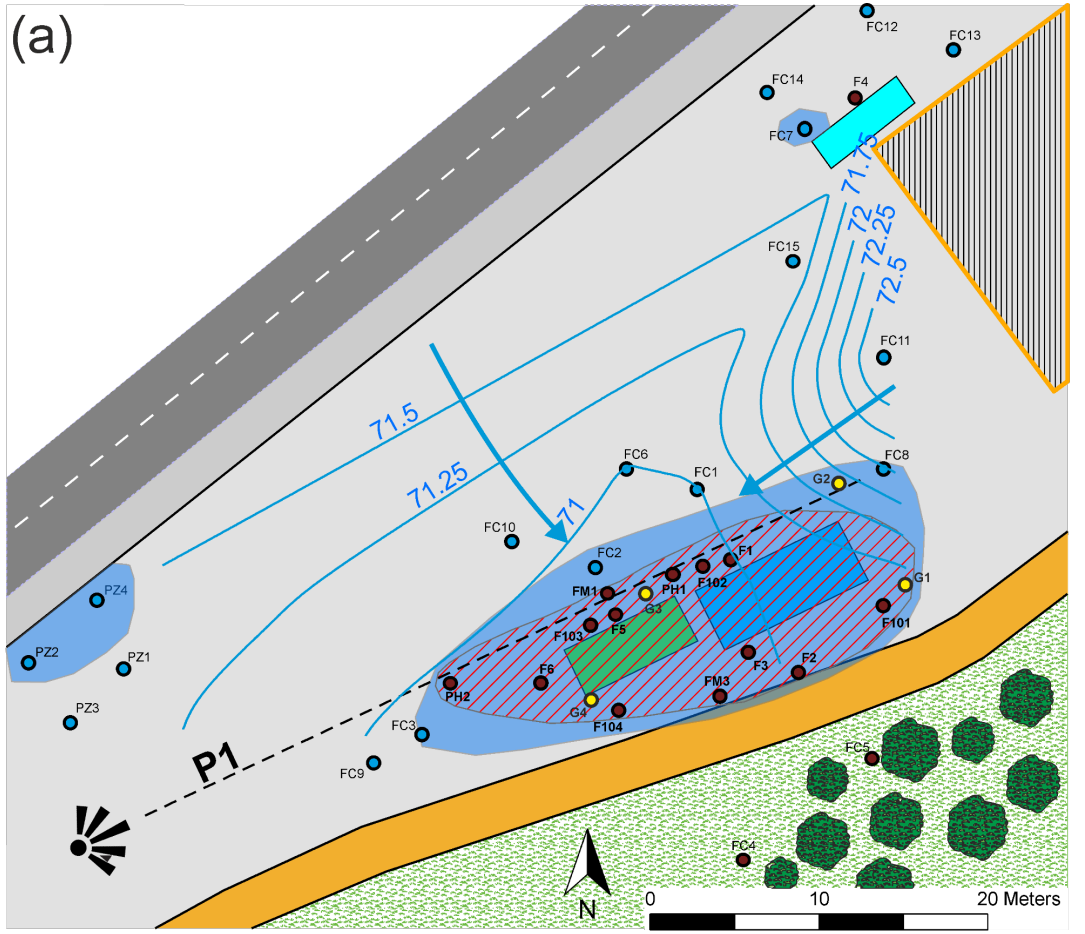
Caterina et al., 2017, J. Cont. Hyd.

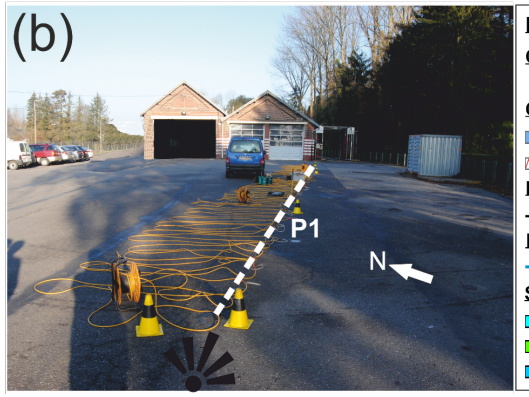
"Sounds like a power struggle between the spaghetti and the pickled onions."



1. Pumping of contaminated water
2. Biological treatment in the bioremediation unit
3. Reinjection of the treated water amended with nutrients (nitrogen source) and electron acceptors (O_2) in the periphery

➢ Started in mid-2008, ended in mid 2011





Legend

Characterization points

Soil · Groundwater (piezometer) · Pumping wells

Contaminated areas

Groundwater contamination (C_{10}-C_{40}>0.3 mg/l)

Soil contamination (C_{10}-C_{40}>160 mg/kg)

Resistivity profiles

P1: Dipole-Dipole array (48 elecrodes - spacing 1 m)

Piezometry

Piezometric levels in metres above sea level

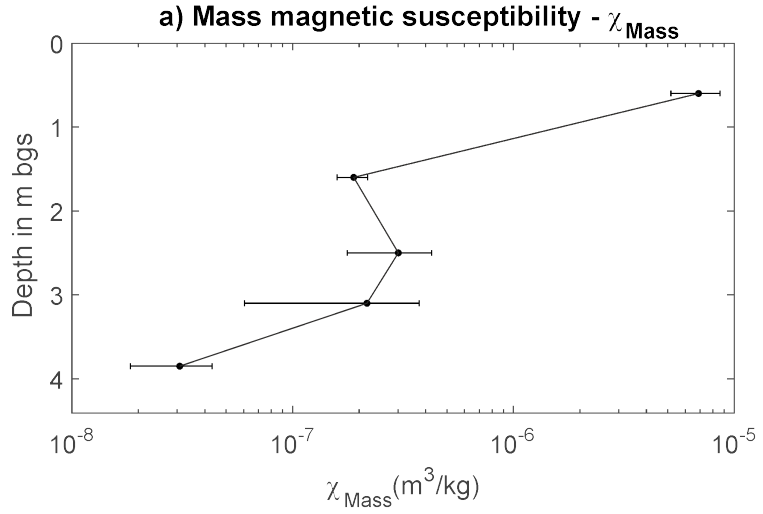
Situation

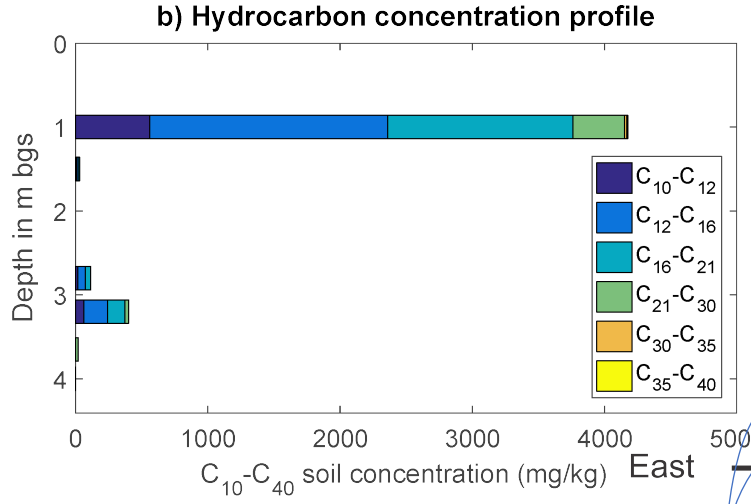
Fuel Tank 12000 L · Fuel Tank 20000 L · Fuel Tank 42000 L

Road · Sidewalk · Parking

Hangar · Dirt road · Parcel

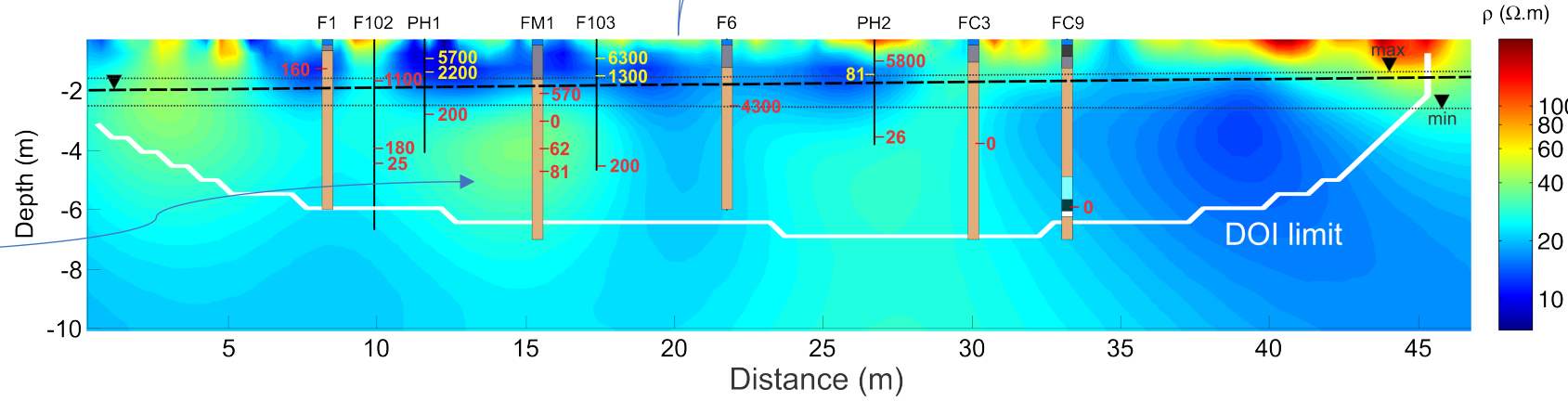
Baseline/characterization : December 2010





Low resistivity : release of carbonic acids, biomass accumulation and possible bioprecipitation of conductive minerals

Resistive anomalies in clayey sediments associated to trapped hydrocarbons



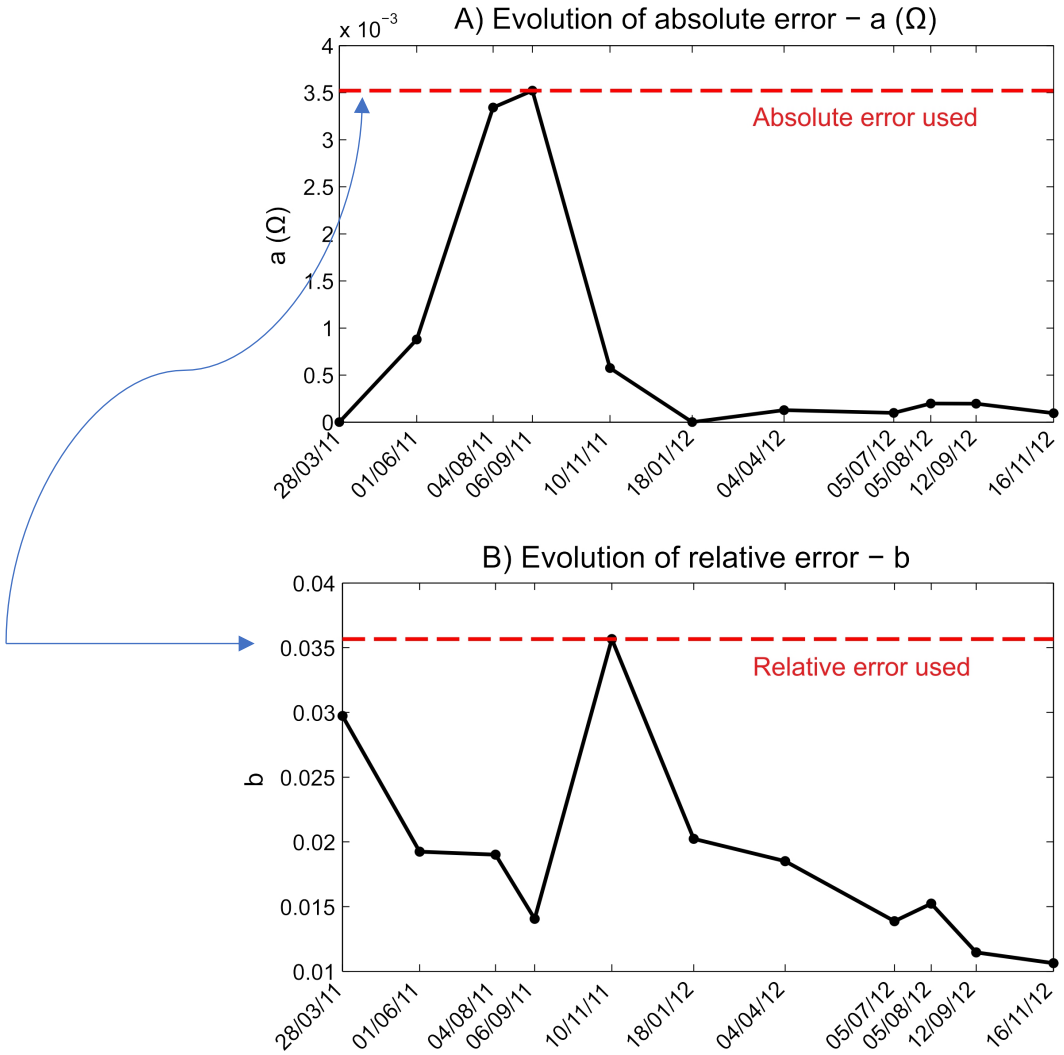
Inversion code: Kemna (2000)

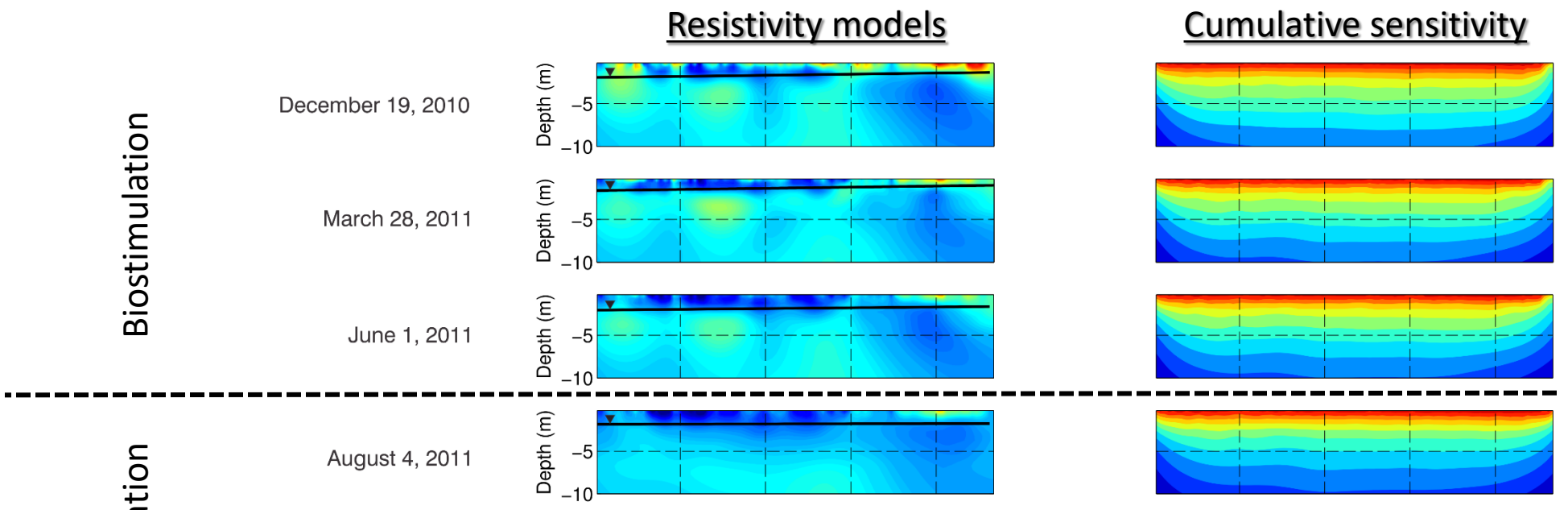
Lithology index

- Asphalt
- Ballast
- Backfill deposits
- Brown clayey loam
- Chalky-clay sediments
- Peat
- Altered chalks
- 1300 C10-C40 concentration in soil (mg/kg of dry matter)
- Groundwater level

Temporal variation in bulk resistivity as observed through ERT may be affected by inversion parameters

- Data weighting in relation to data noise quantification based on reciprocals: $|e| = a + b \times R$
- Convergence criteria of the GN approach in minimizing an objective function
  - all monitoring datasets were fitted to the same error–level
- Their consistency through time



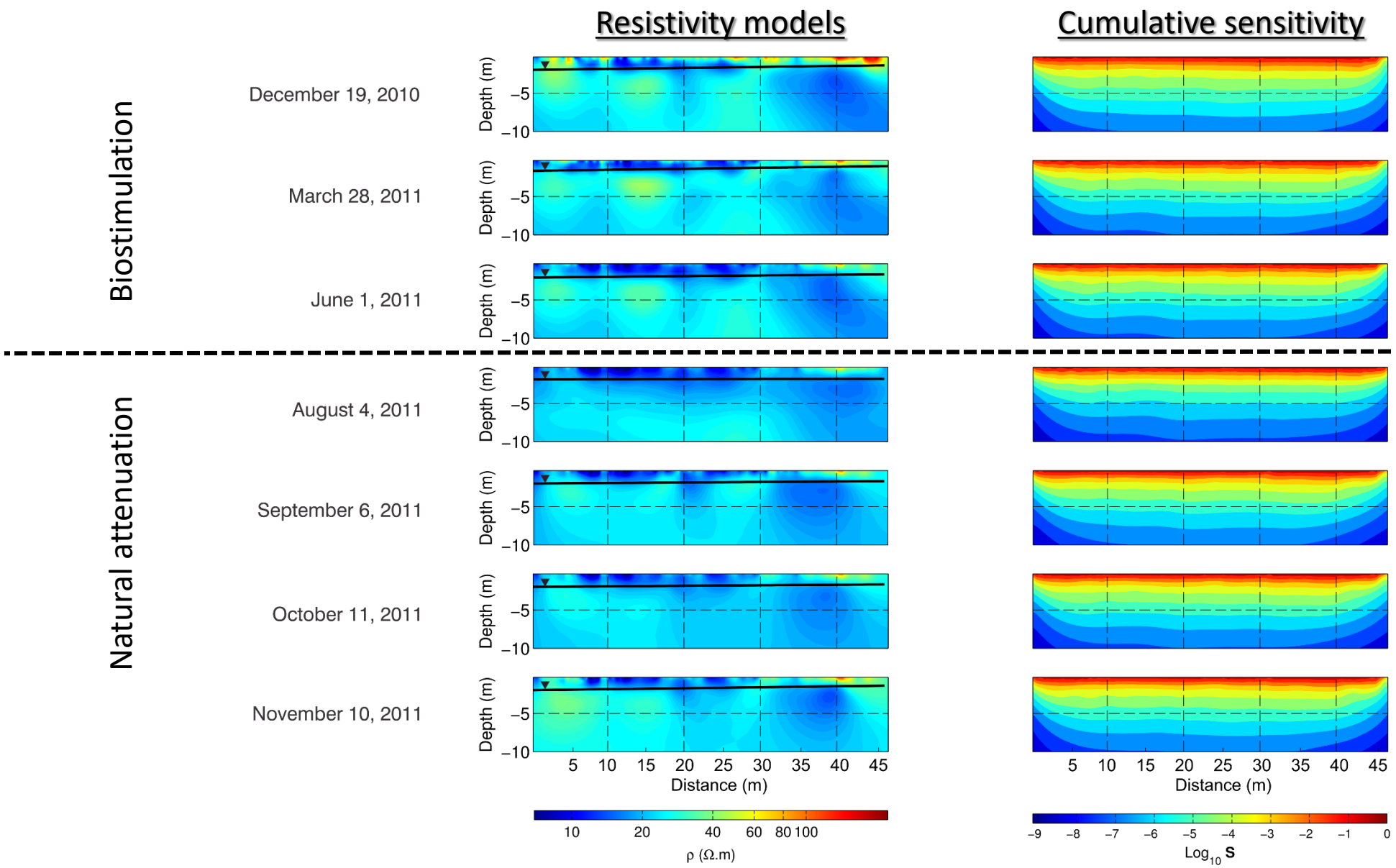


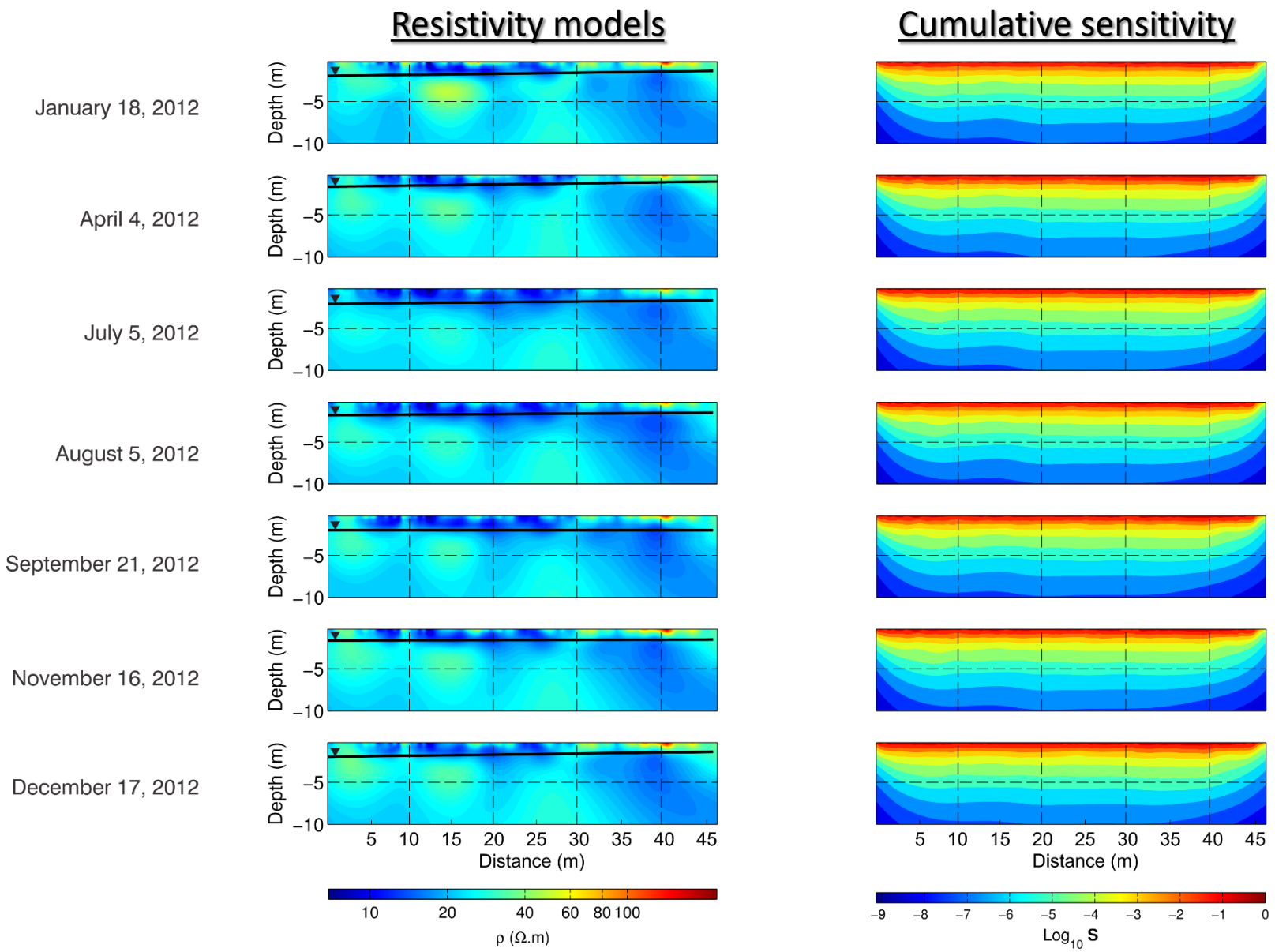
With measurements collected with

- a rather long time-gap,
- different hydrogeological conditions,
- different instruments,

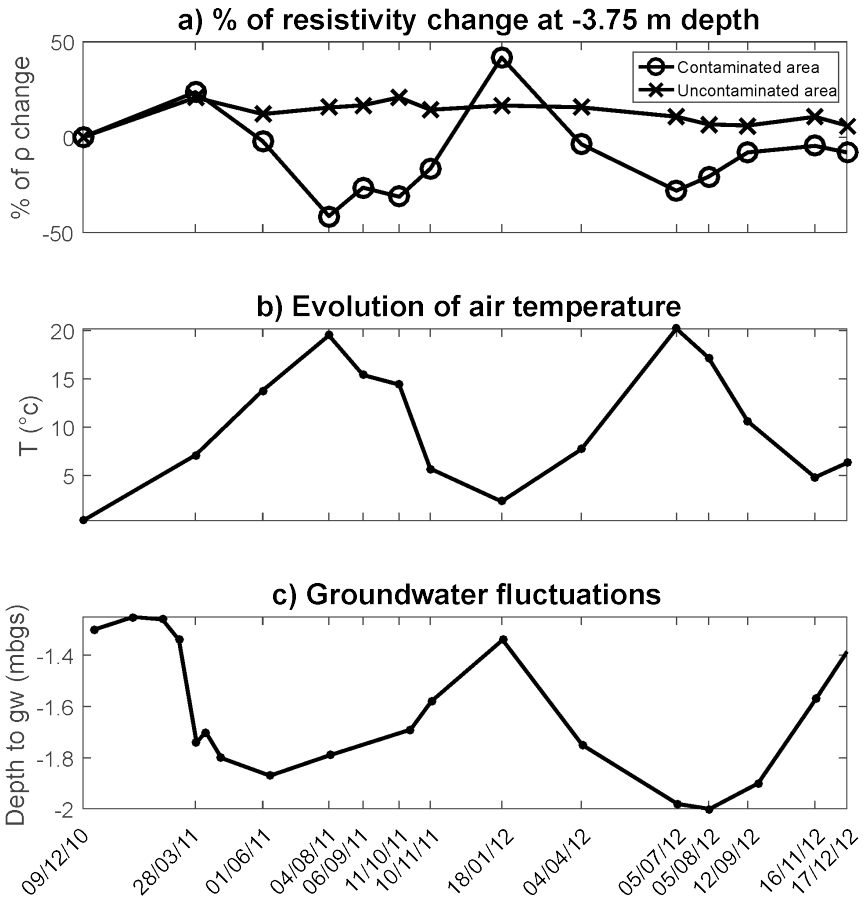
We considered an individual inversion approach (reconstructing m using d instead of Δm using Δd) with:

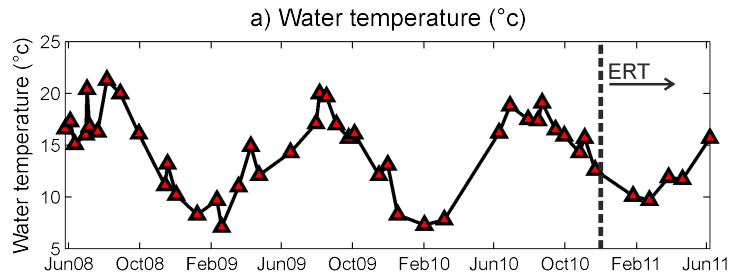
- the same starting model for all monitoring images (baseline) but NO reference model
- the same data weighting
- the same data set

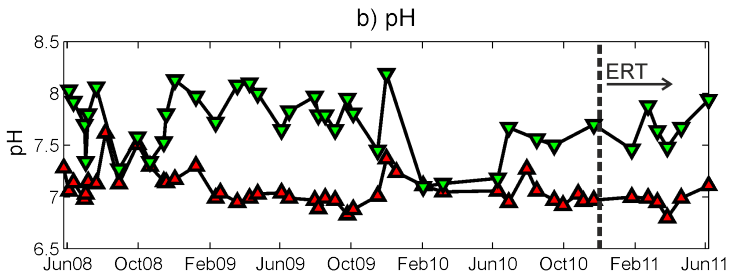

Resistivity models
Cumulative sensitivity
Biostimulation
Natural attenuation
December 19, 2010
March 28, 2011
June 1, 2011
August 4, 2011
September 6, 2011
October 11, 2011
November 10, 2011
Depth (m)
−5
−10
5 10 15 20 25 30 35 40 45
Distance (m)
10 20 40 60 80 100
ρ (Ω.m)
−9 −8 −7 −6 −5 −4 −3 −2 −1 0
Log10 S

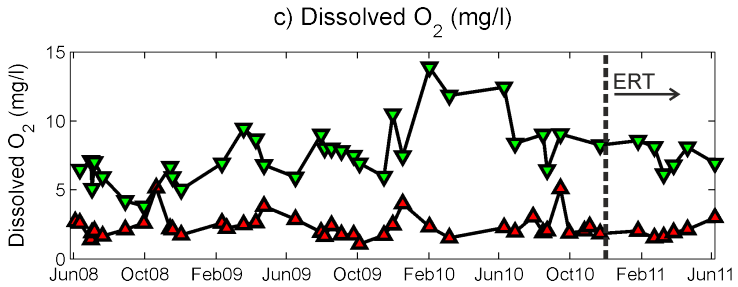

Resistivity models
Cumulative sensitivity
January 18, 2012
April 4, 2012
July 5, 2012
August 5, 2012
September 21, 2012
November 16, 2012
December 17, 2012
Depth (m)
−5
−10
5 10 15 20 25 30 35 40 45
Distance (m)
10 20 40 60 80 100
ρ (Ω.m)
−9 −8 −7 −6 −5 −4 −3 −2 −1 0
Log10 S

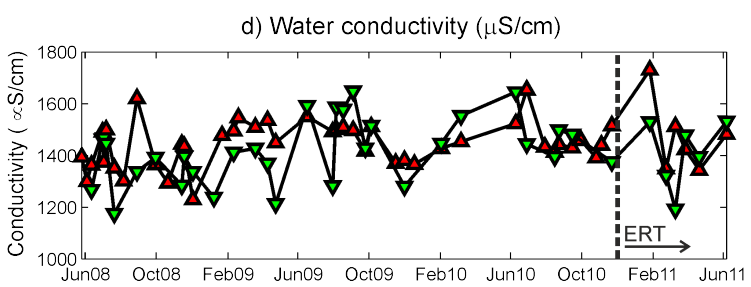
Zoom in the changes in resistivity

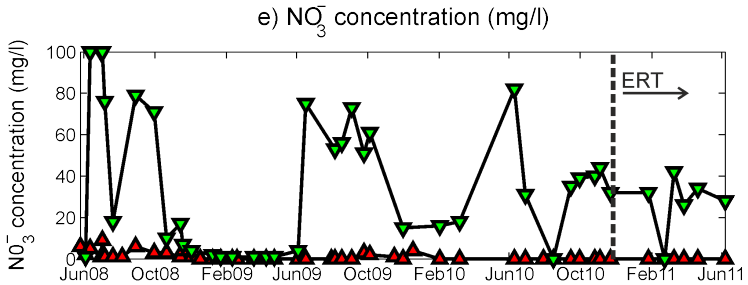




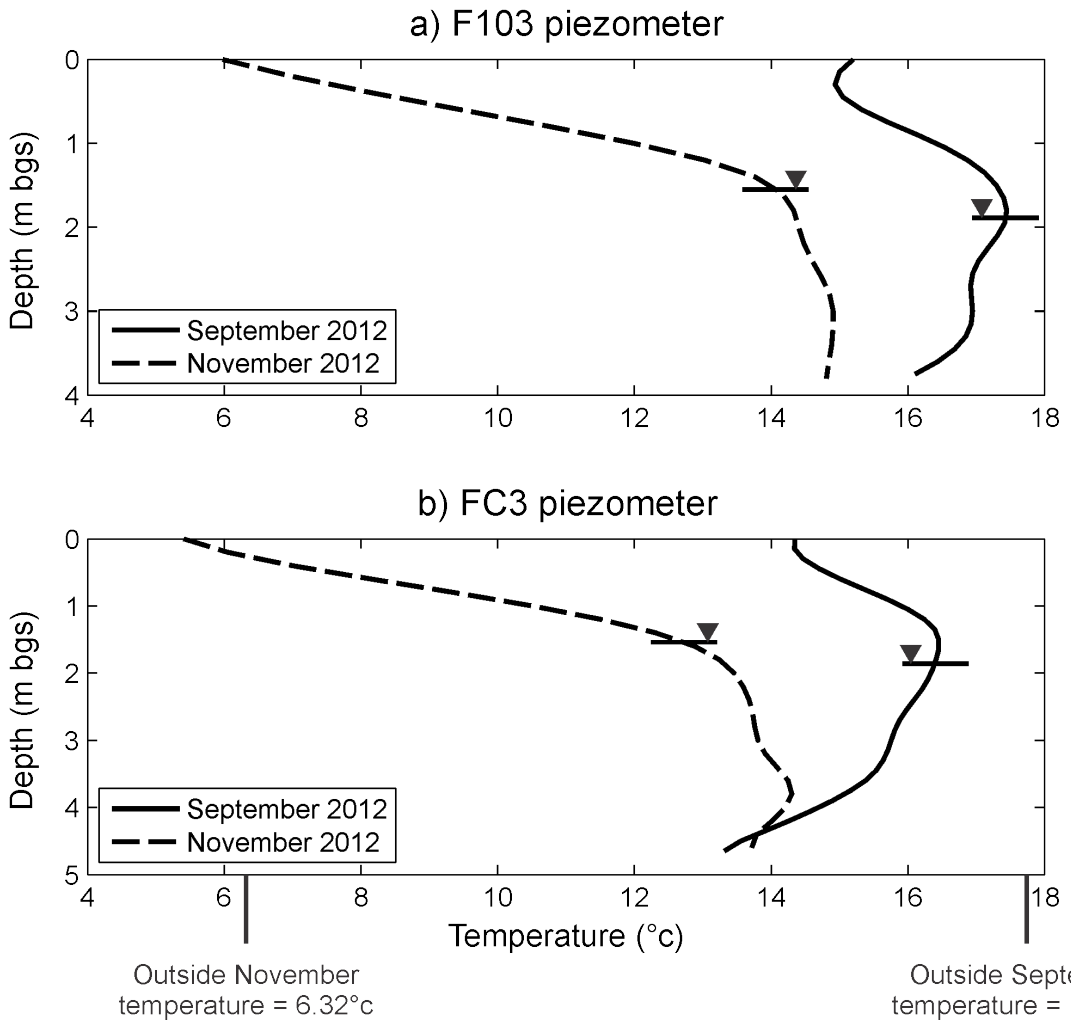


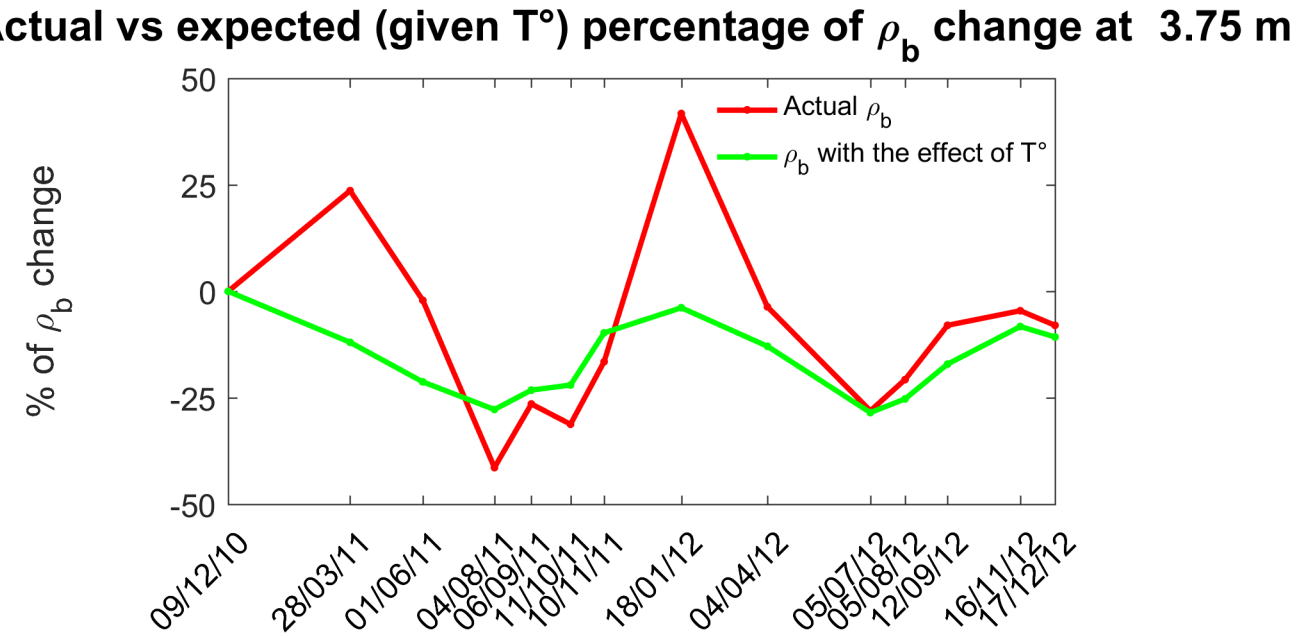






Temperature alone not able to explain the observed ERT changes quantitatively





Discussions

- Resistivity signature in the most contaminated areas:
  - above the GW level to low resistivity (< 10 Ω·m), as it has been observed in numerous studies.
  - below the GW level, resistive anomalies in clayey sediments associated to trapped hydrocarbons that do not undergo active biodegradation.
- Seasonal variations of the bulk electrical resistivity correlated to seasonal fluctuations in the GW level and temperature.
  - Controlled by microbial activity (release of metabolic products such as carbonic acids and biomass accumulation among other processes), which in turn is strongly influenced by seasonal variations.

Perspectives

- Laboratory to understand the impact of the different processes
- Complementary data to comfort interpretation
  - Geophysics (SIP, SP, MAG)
  - Bio and chemical data and need for direct evidences
- High temporal resolution to better catch the processes
- More field observations needed
  - Go beyond N=1, 2 or 3
- Robust inversion schemes over long period of time

Many thanks for the invitation

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