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Micro ERT measurements for seismic liquefaction

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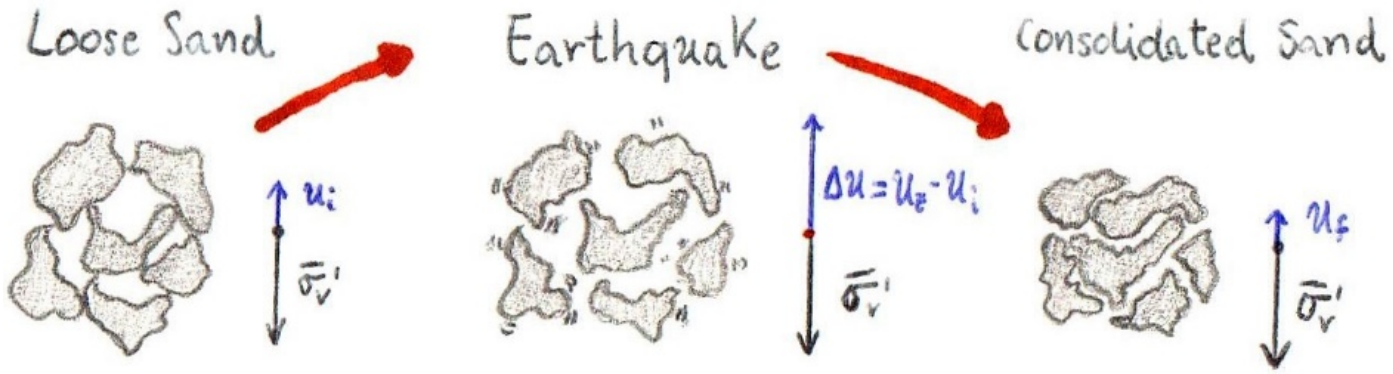
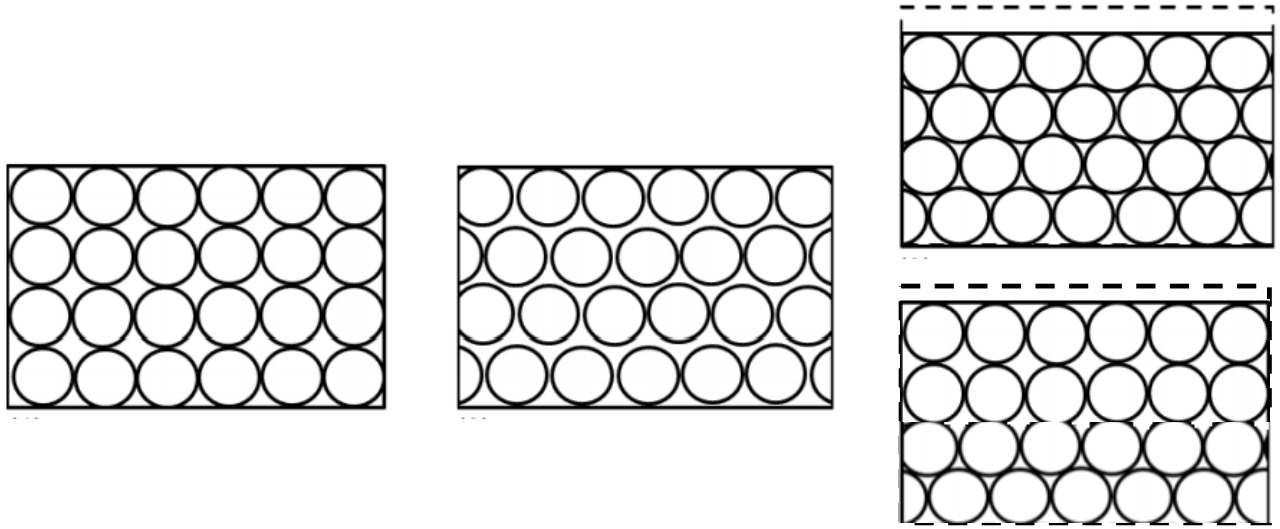
Liquefaction is…

…a drastic reduction of effective stresses in sandy saturated soils, caused by the set up of excess pore pressure Δu due to a natural or anthropic forcing





General Consolidation → 1 Interpretation

Local consolidation/ dilatation → 2 Interpretation

The basic idea

who › Sandy soils - Loose granular soils (liquefiable)

what › Changing in hydrogeophysical (**ρ**) and mechanical parameters ($\mathbf{v_{s,p}}$)

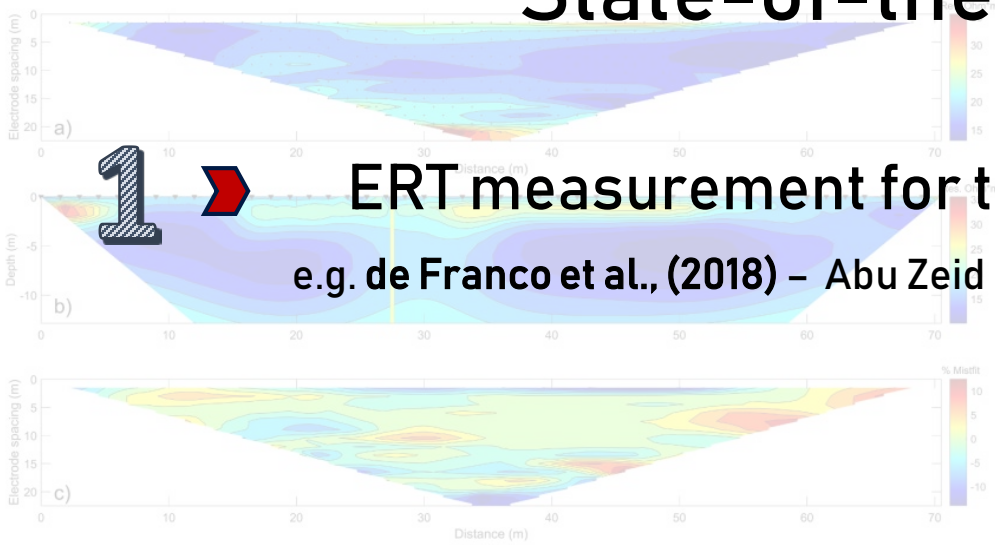
why › Seismic action

how › Monitoring rapid variations of the most sensitive physical parameter

*At field and **laboratory scales***

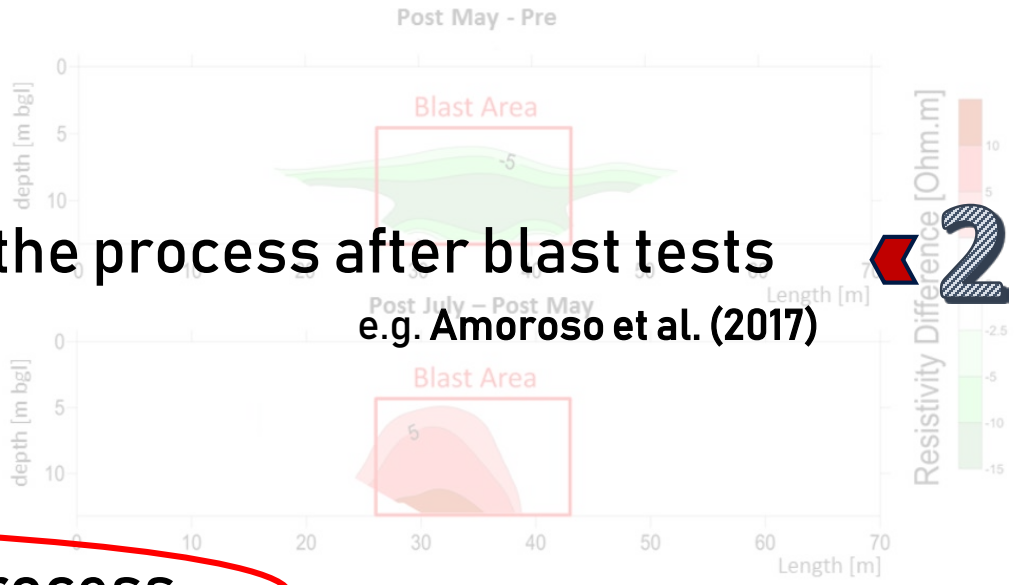
› Time lapse ERT to follow the process

State-of-the-art ERT/Liq. relationship



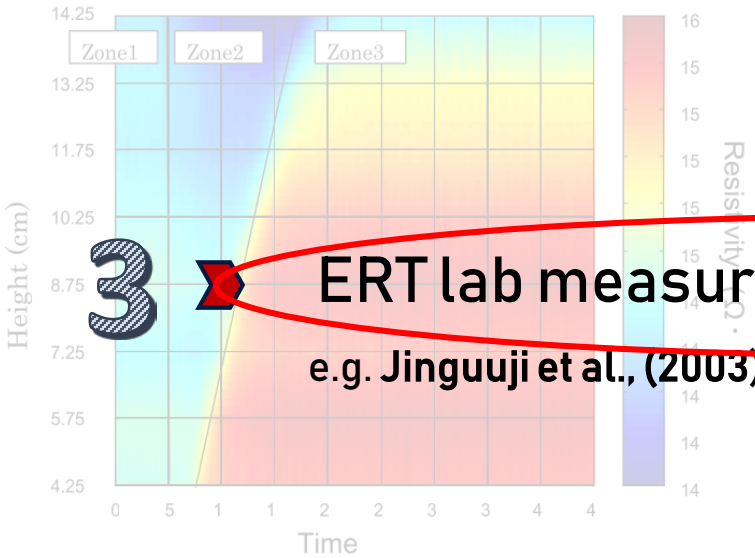
1 ERT measurement for the characterization post-event

e.g. **de Franco et al., (2018)** – Abu Zeid et al., (2012) – Apostolopoulos et al., (2013) – Giocoli et al. (2014)



ERT measurement to study the process after blast tests 2

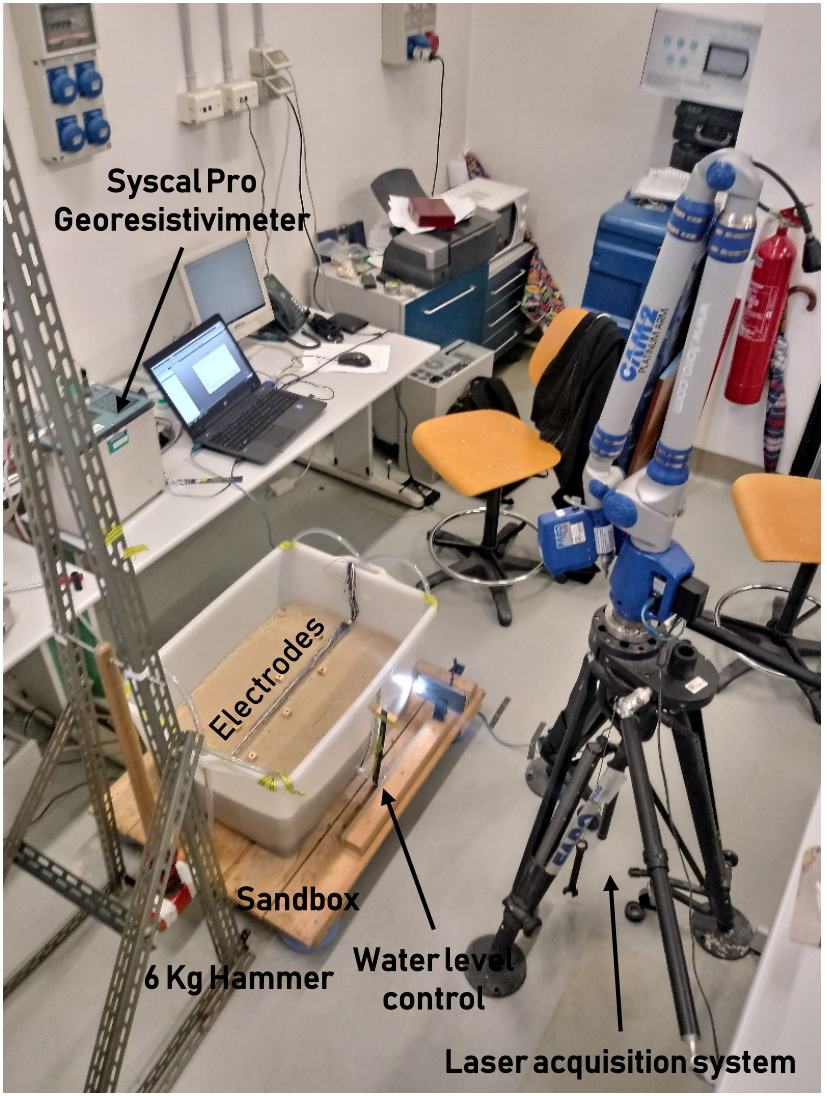
e.g. **Amoroso et al. (2017)**

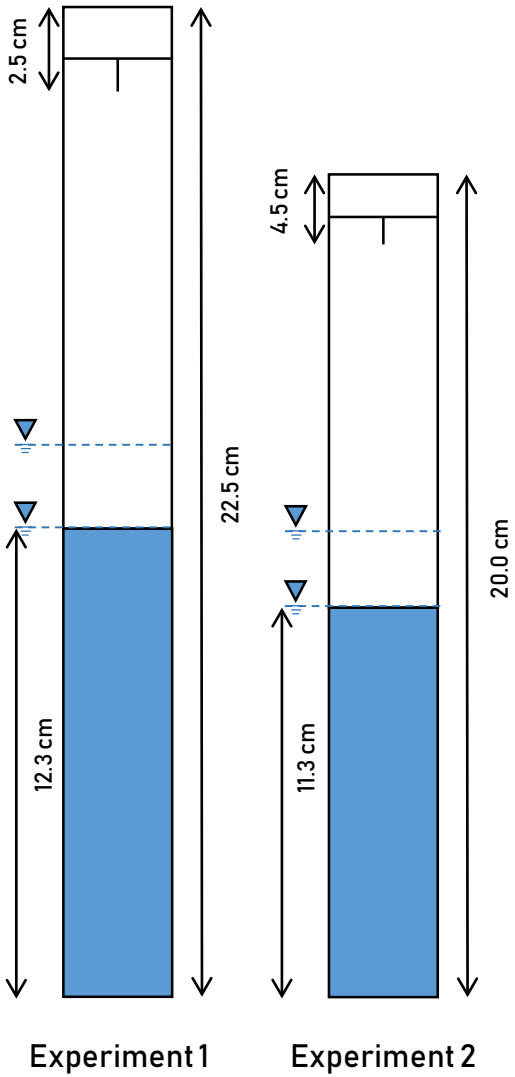


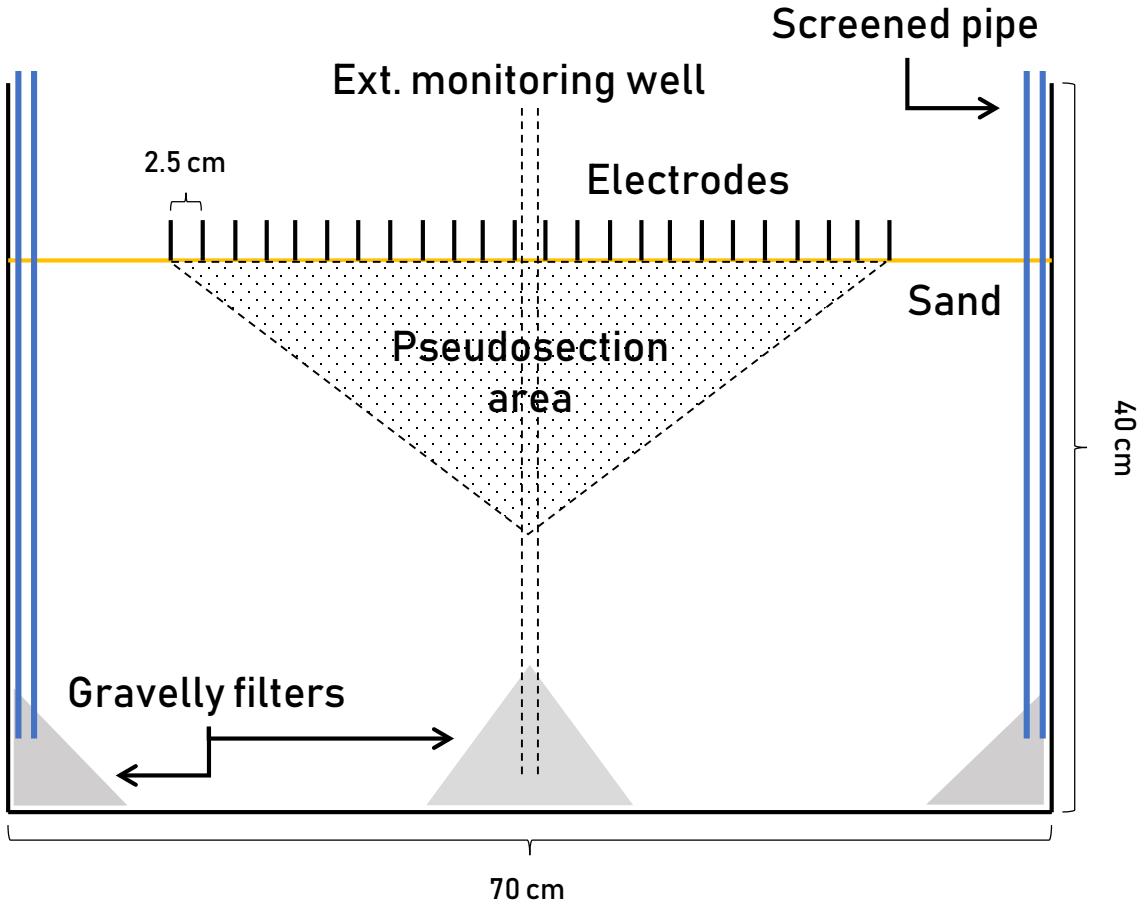
3 ERT lab measurement to follow the process

e.g. **Jinguuji et al., (2003)**

Set up of the experiments

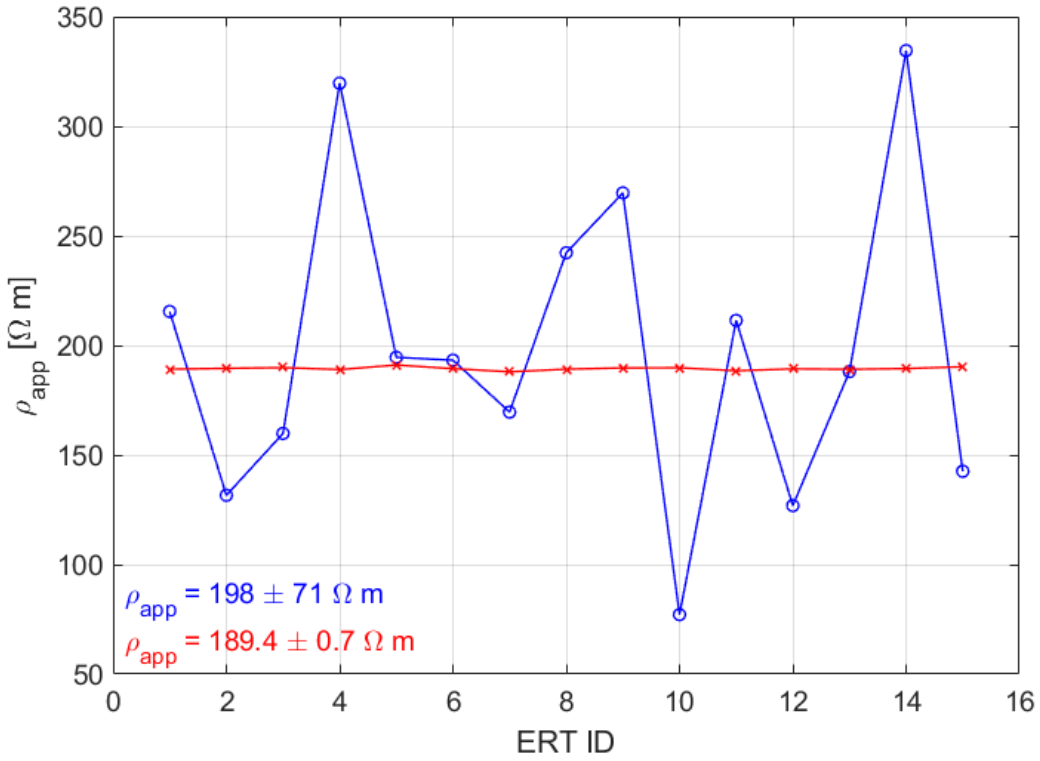




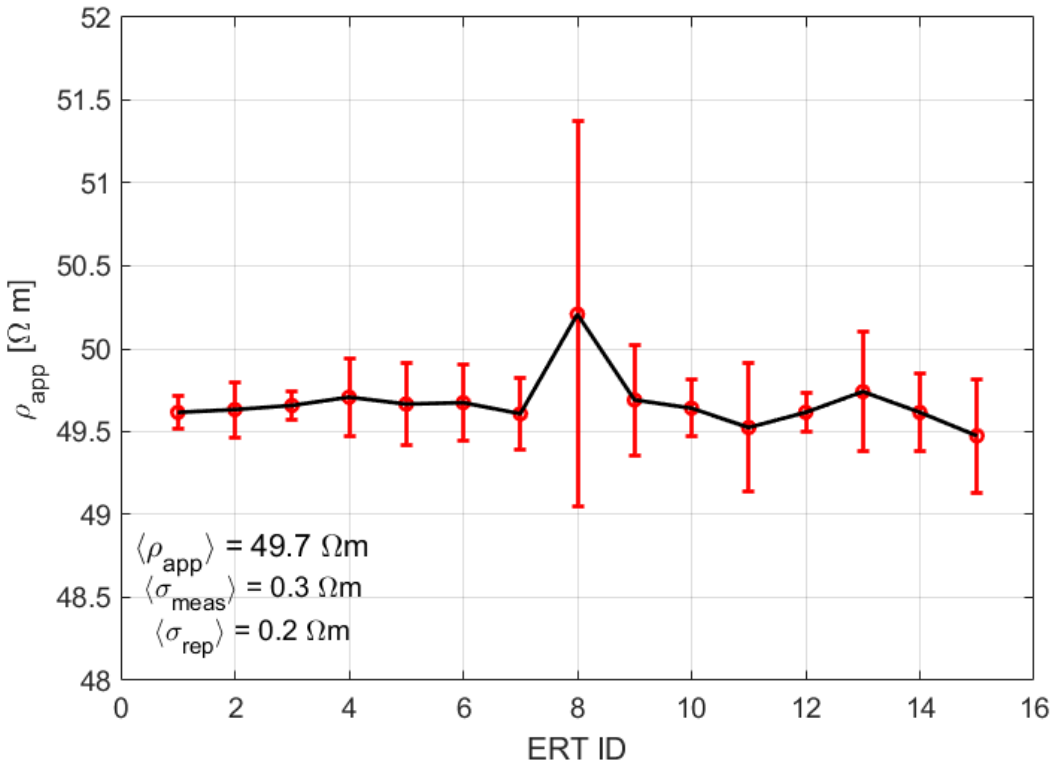


The resistivity measurements

Experiment 1



Experiment 2



No constraint on MN (blue) 50 V on MN (red)

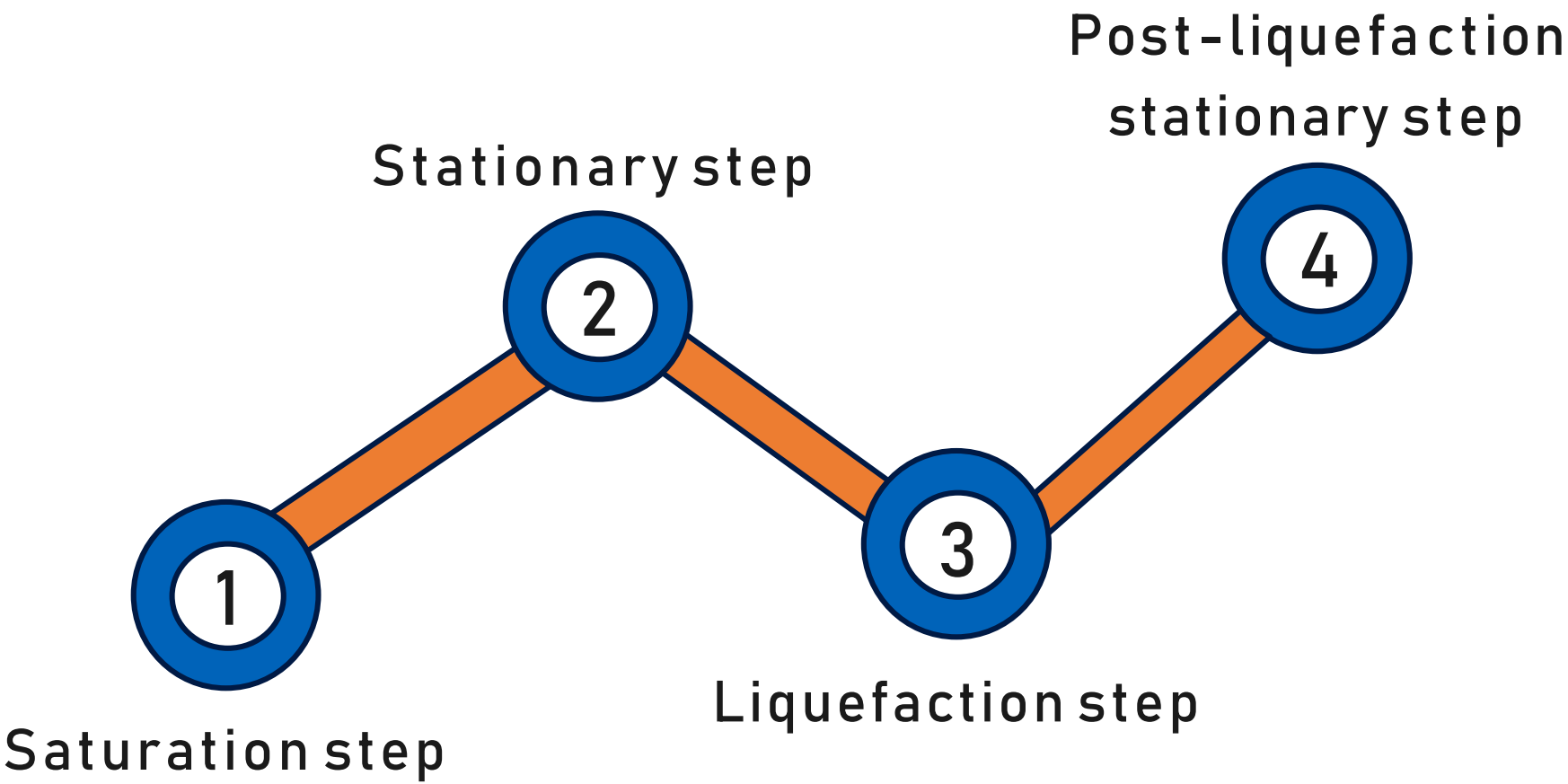
Repeatability Error on the stationary state

$$\sigma_{rep} \in [0.4\,;\ 13.2]\ \Omega m$$

Repeatability Error almost equal to the error on the single measure

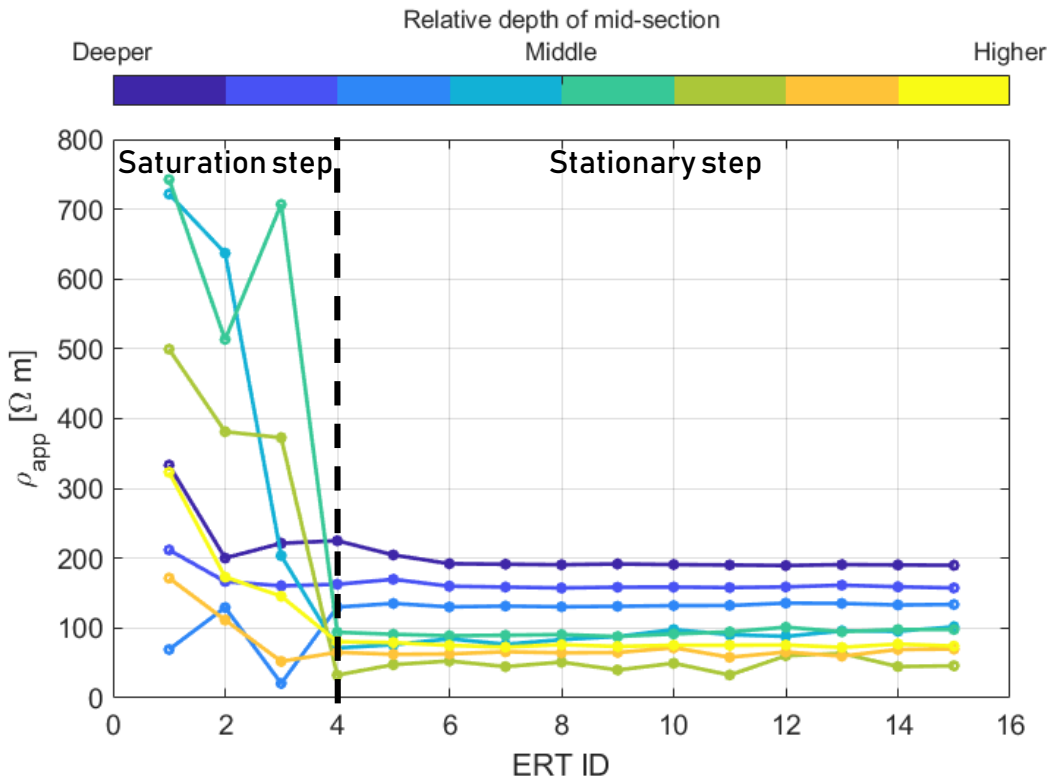
$$\sigma_{rep} \in [0.06\,; 4.23]\ \Omega m$$

The experiment

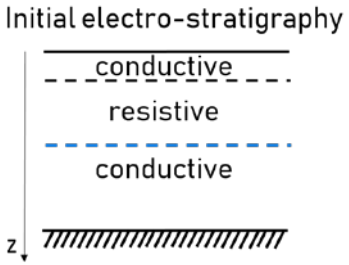


The Saturation and the stationary steps

Experiment 1

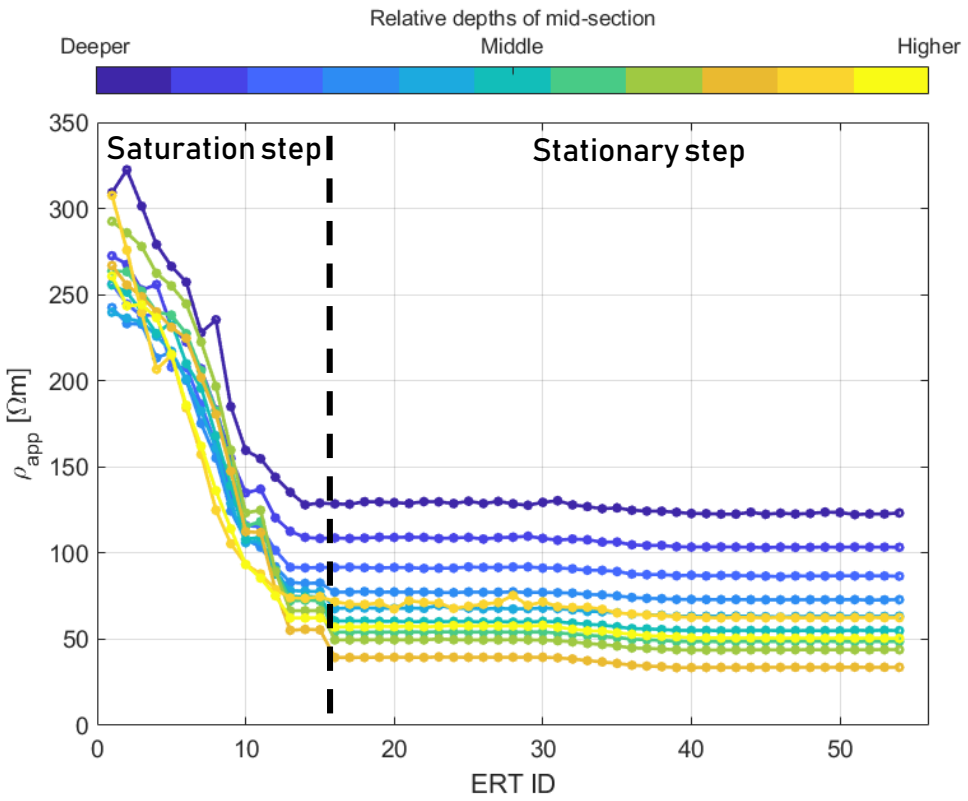


Initial hypothesis



Due to the water injection from the surface

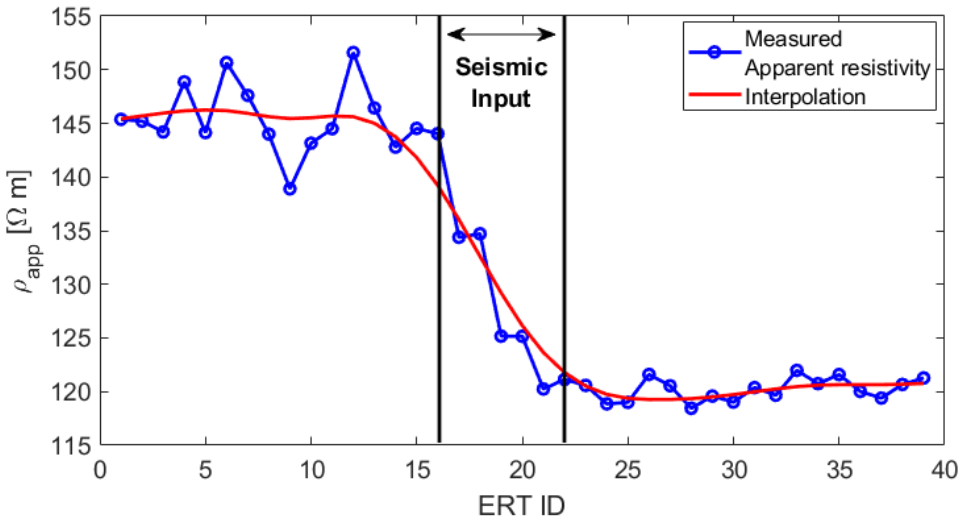
Experiment 2

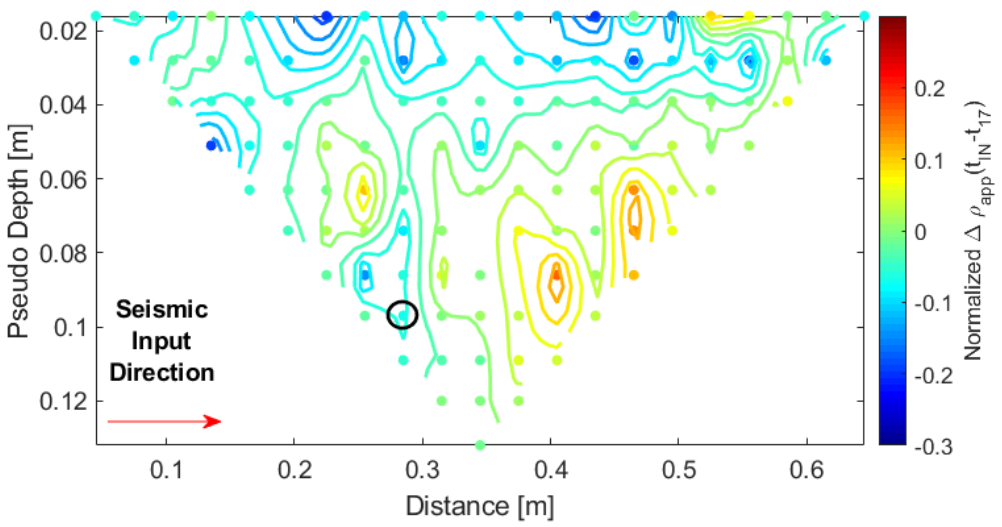


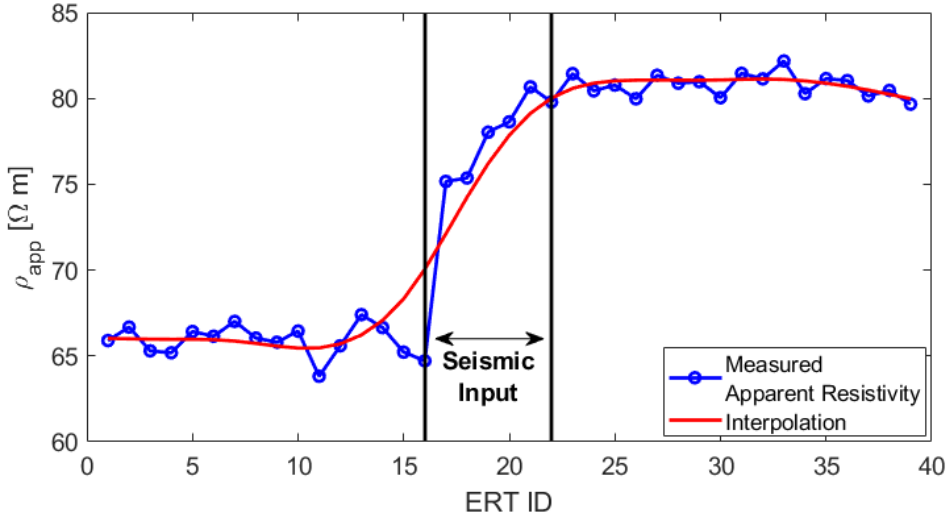
Preparation of sand with an initial S_w degree [0.46]

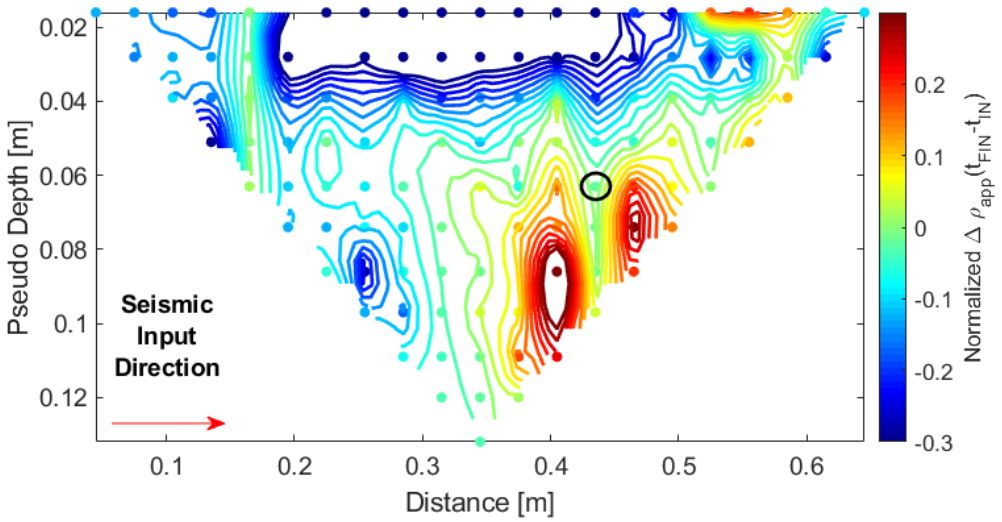
No change in this behavior… probably the "box effect"?

The Liquefaction step [Exp 1]

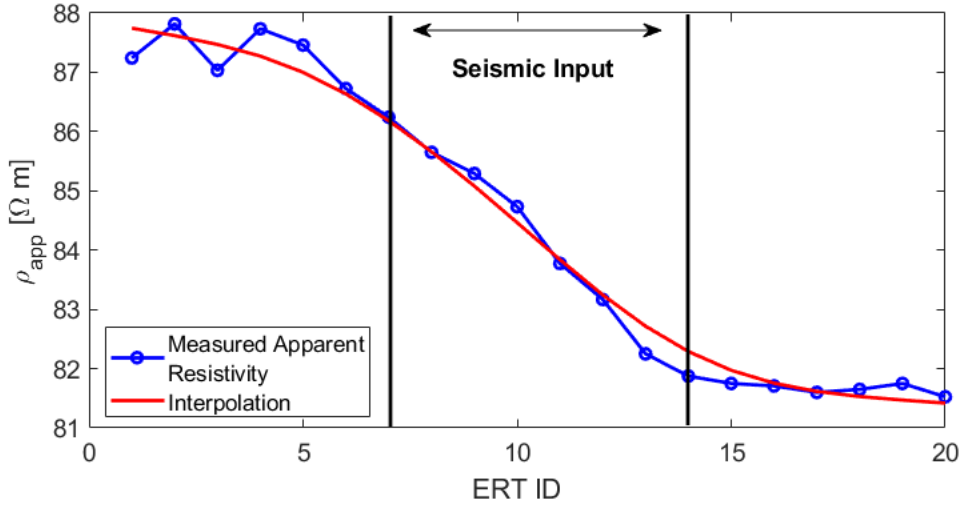


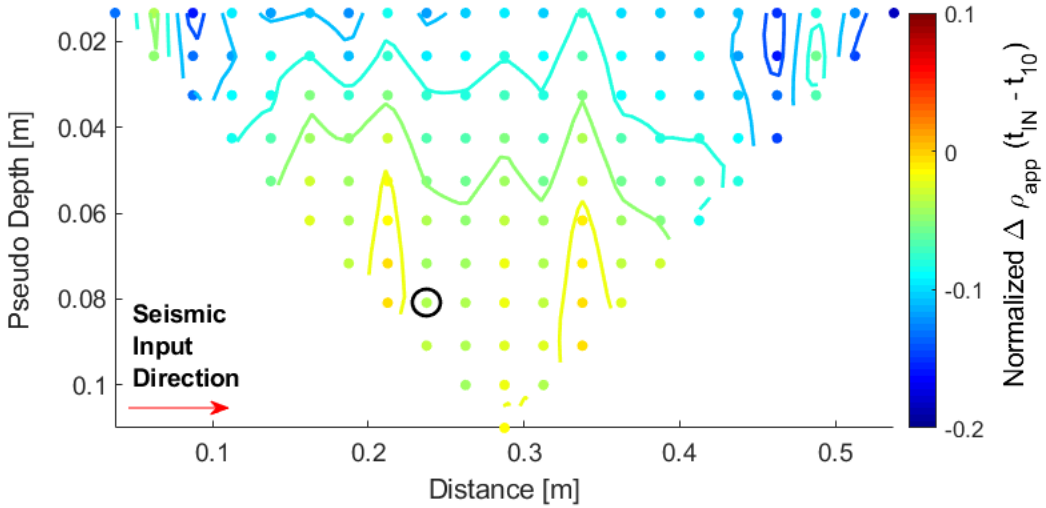


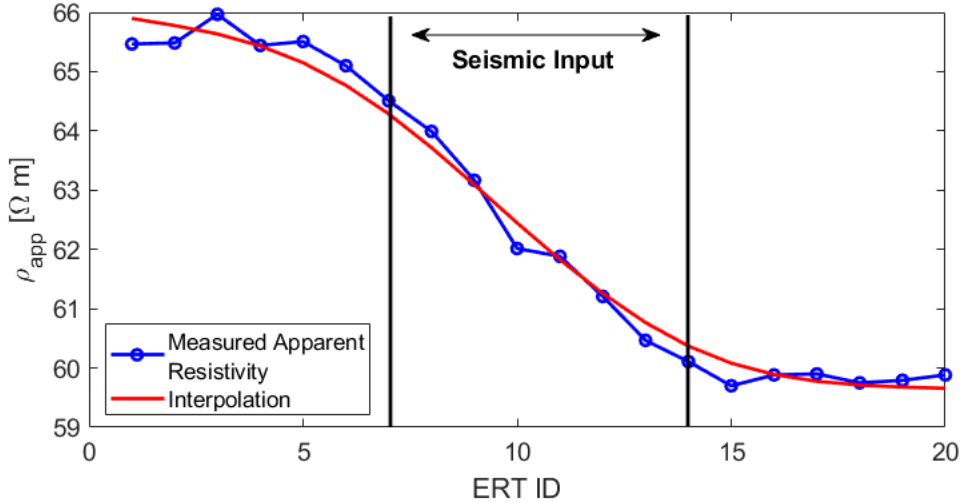


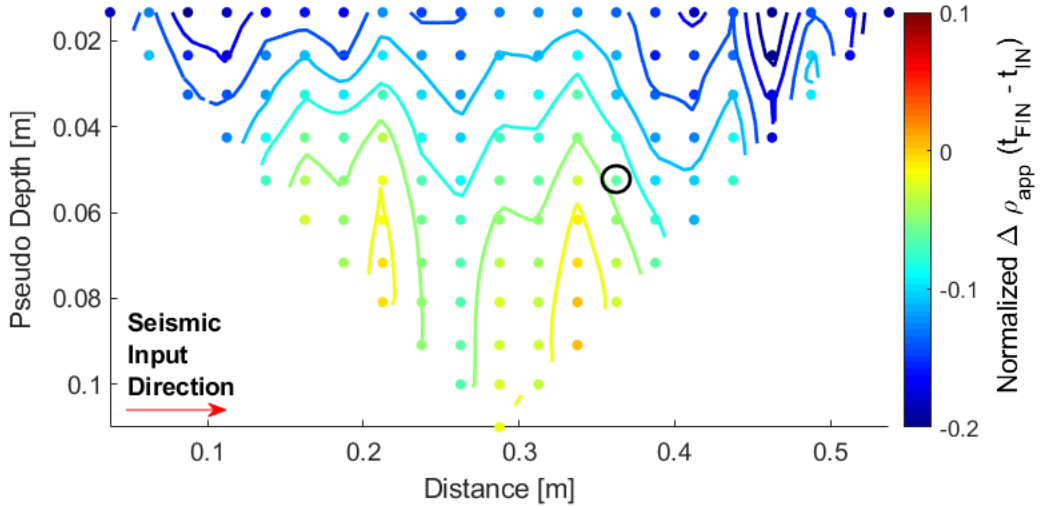


The Liquefaction step [Exp 2]

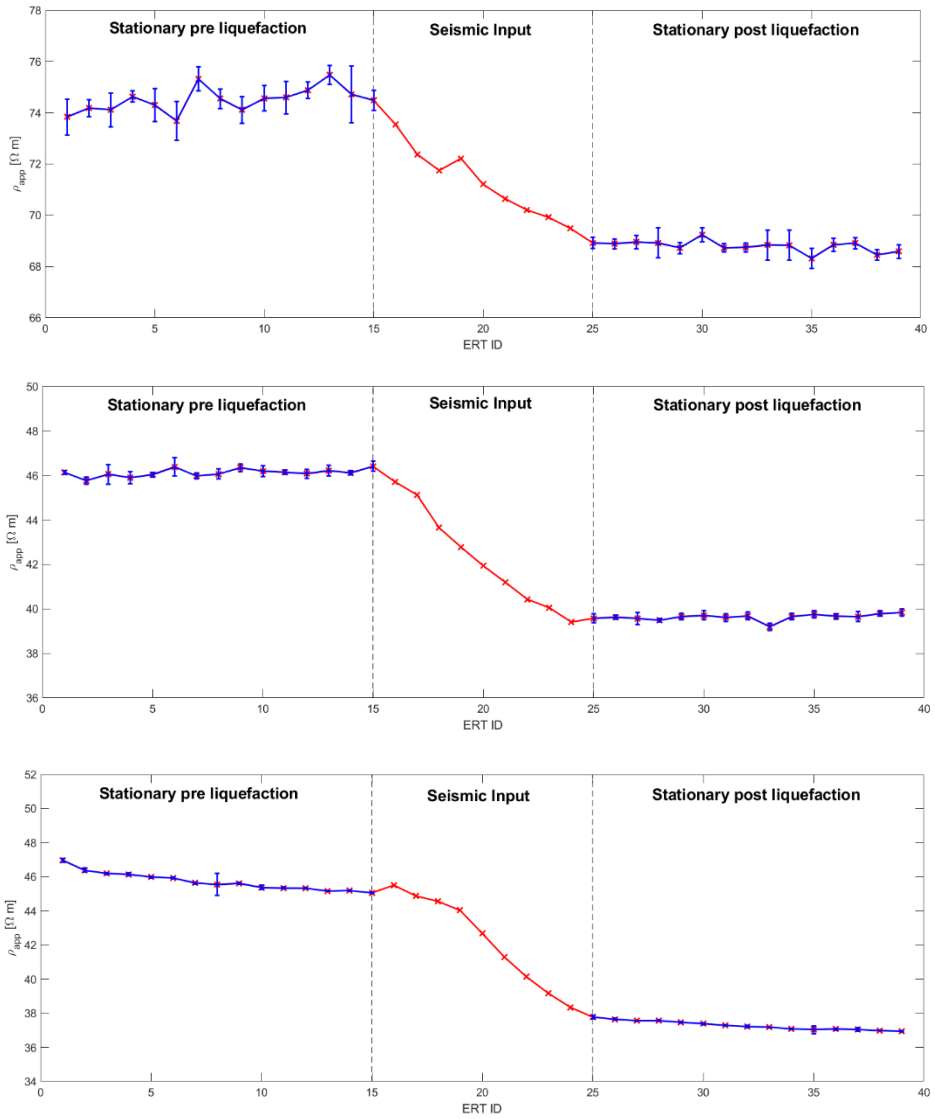


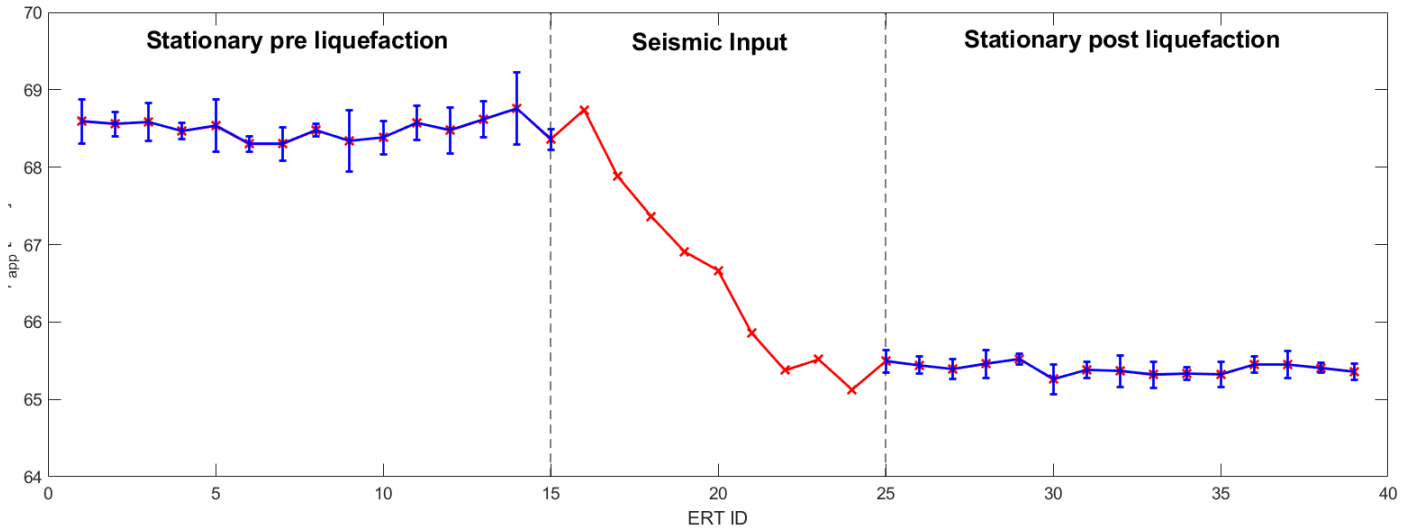






The Liquefaction step [Exp 2]





Examples of apparent resistivity variations after/during/post seismic input

The Time-Lapse ERT data inversion

Two inversion approaches for time-lapse processing

The difference approach

INPUT ρ_{i_a} $\langle\rho_0\rangle_a$

Inversion

OUTPUT ρ_i $\langle\rho_0\rangle$

Representation

$$\Delta\rho_d(t_i) = \frac{\rho_i - \langle\rho_0\rangle}{\langle\rho_0\rangle} \; [\%]$$

The ratio approach

INPUT $\frac{\rho_{i_a}}{\langle\rho_0\rangle_a} \rho_a^{hom}$

Inversion

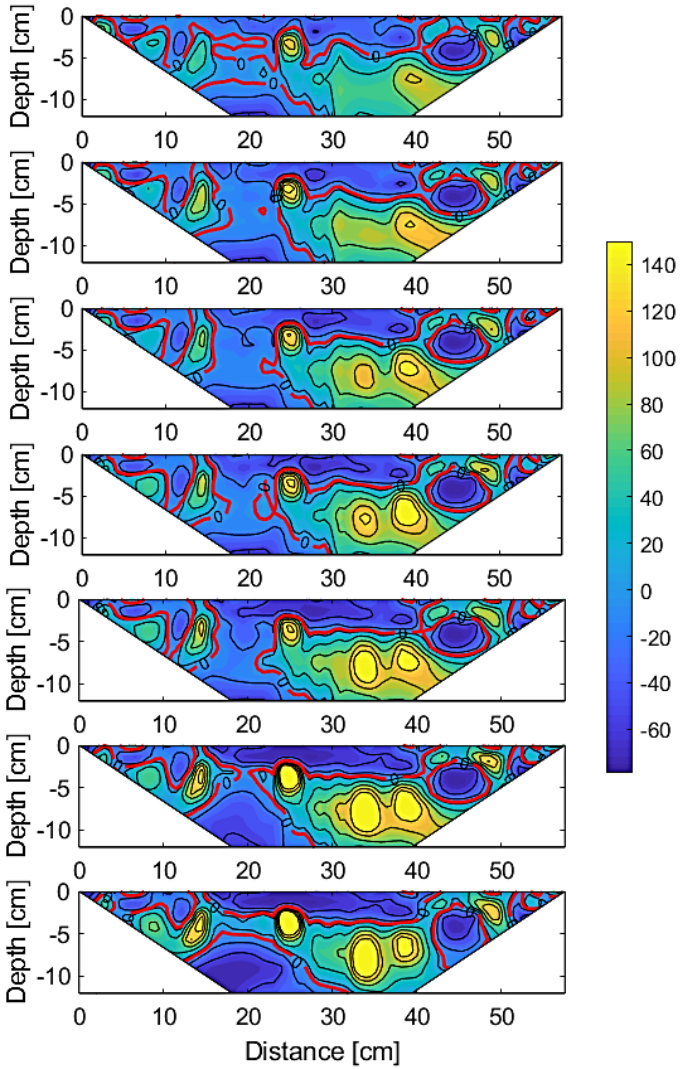
OUTPUT ρ_i^r

Representation

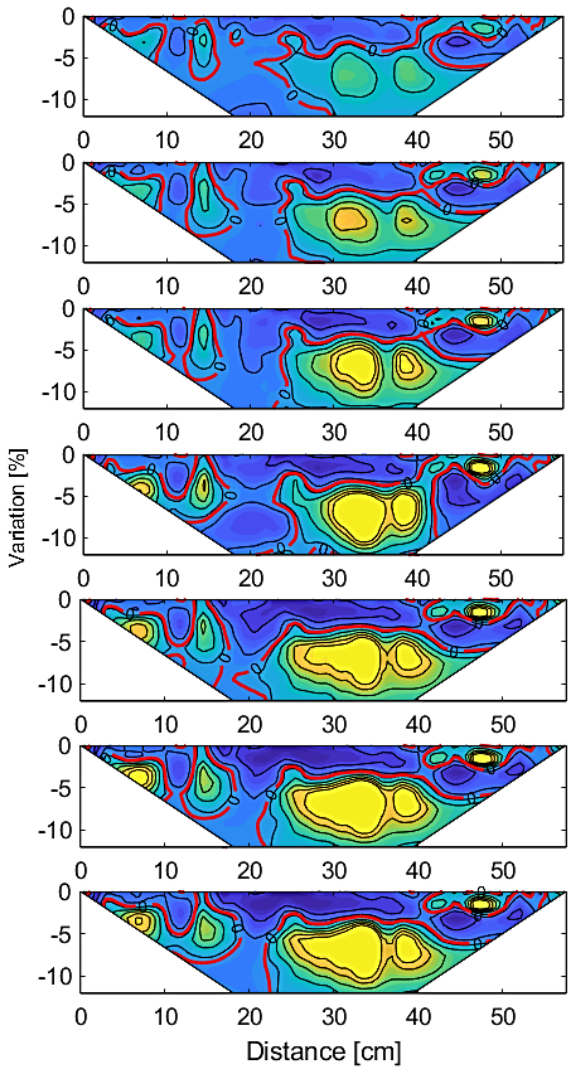
$$\Delta\rho_r(t_i) = \frac{\rho_i^r}{\rho^{hom}} - 1 \; [\%]$$

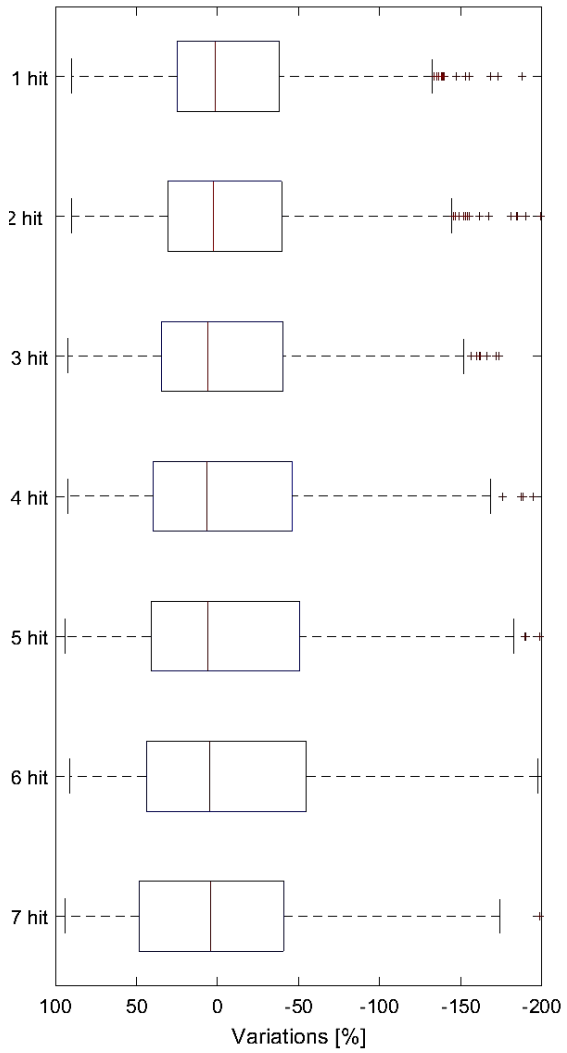
Time-Lapse results [Exp 1]

$\Delta\rho_d(t_i)$ [%]



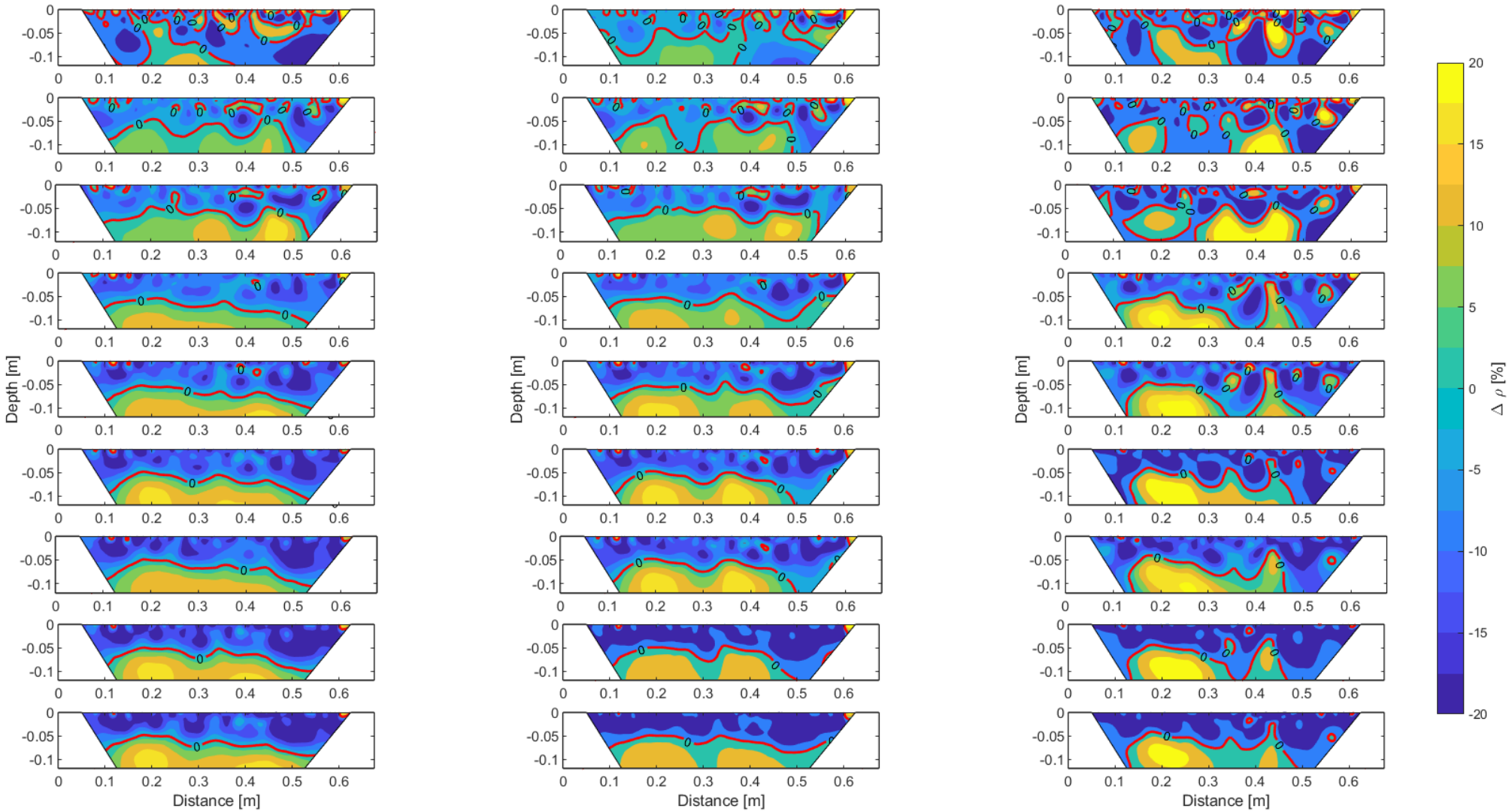
$\Delta\rho_r(t_i)$ [%]





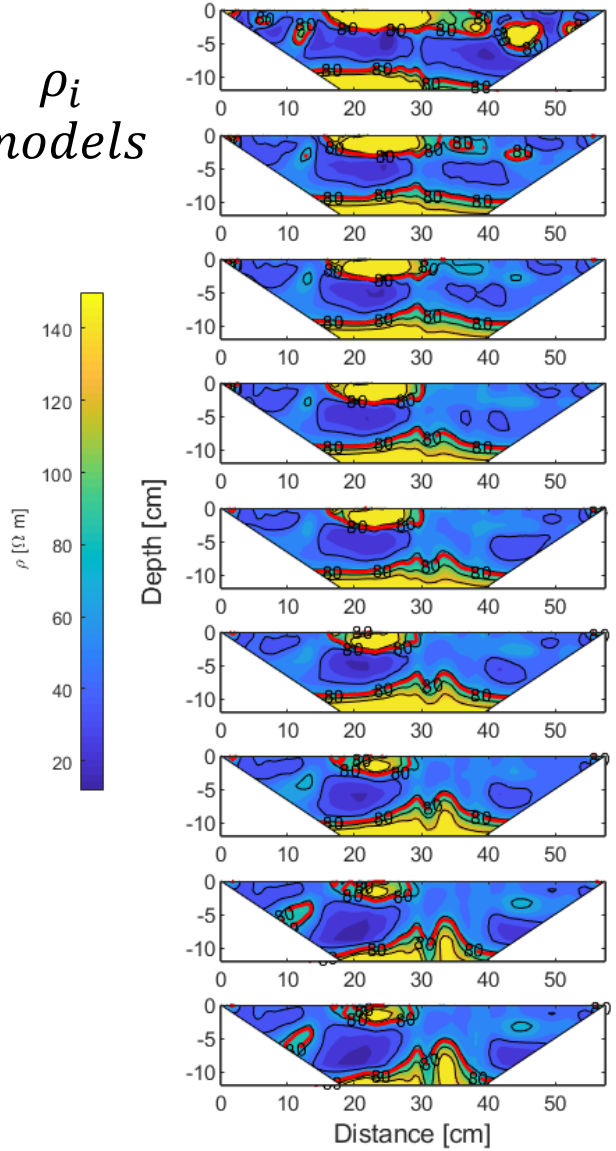
Time-Lapse results [Exp 2]

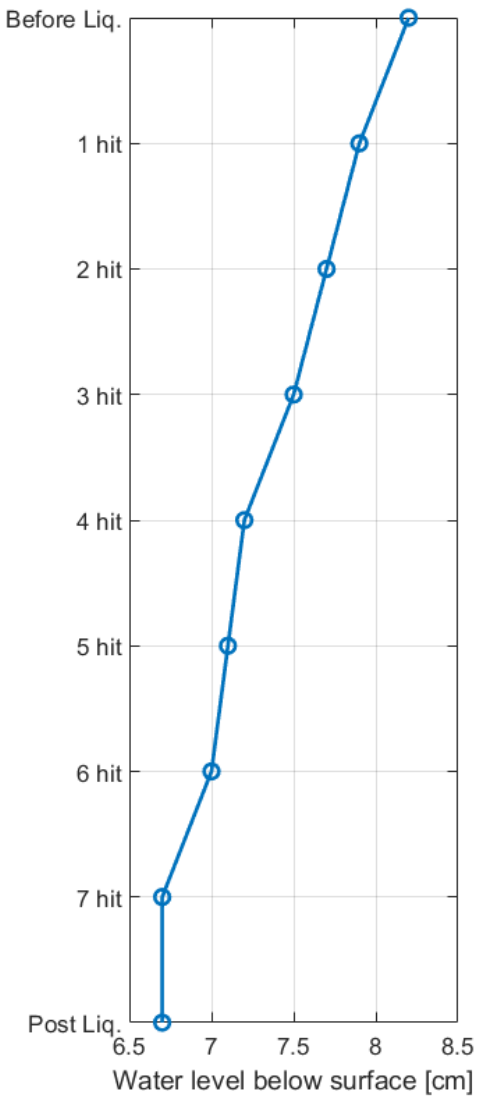
$\Delta\rho_d(t_i)$ [%] $\Delta\rho_r(t_i)_t$ [%] $\Delta\rho_r(t_i)_{100}$ [%]



Interpretations [Exp 1]

ρ_i *models*





$\Delta\rho$ could be a proxy of the changing of pore water pressure state

$$\Delta\rho = \langle\rho\rangle_{PL} - \langle\rho\rangle_{BL}$$

1

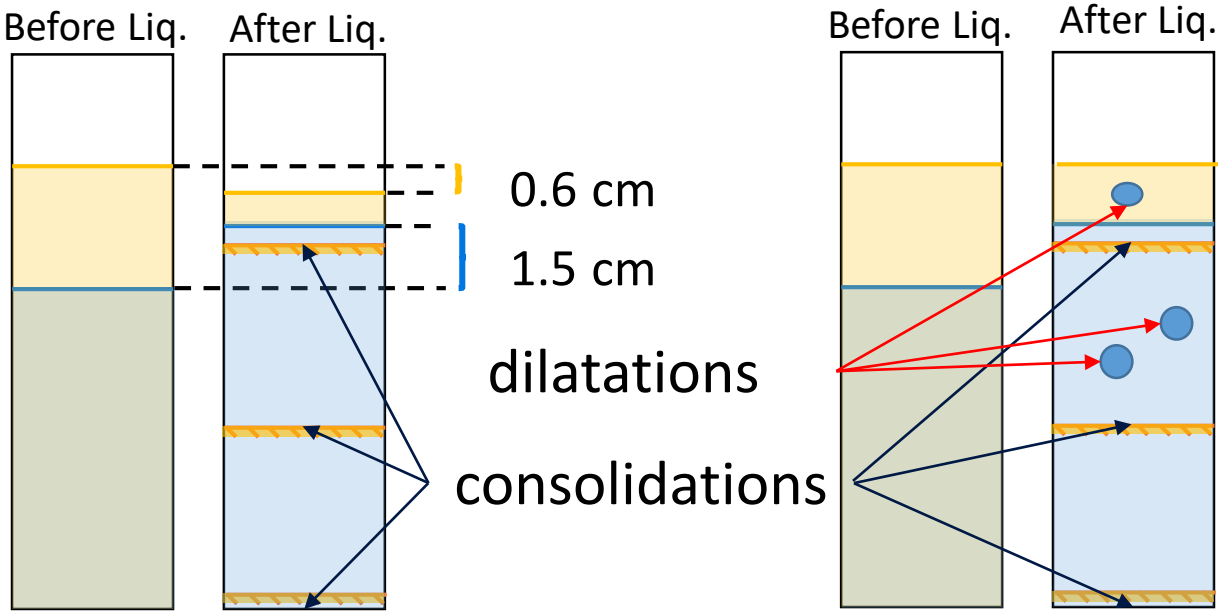
$\Delta S_w \simeq +6\%$

$\langle\Delta\phi\rangle \simeq -2\%$

2

$\Delta S_w \simeq +3\%$

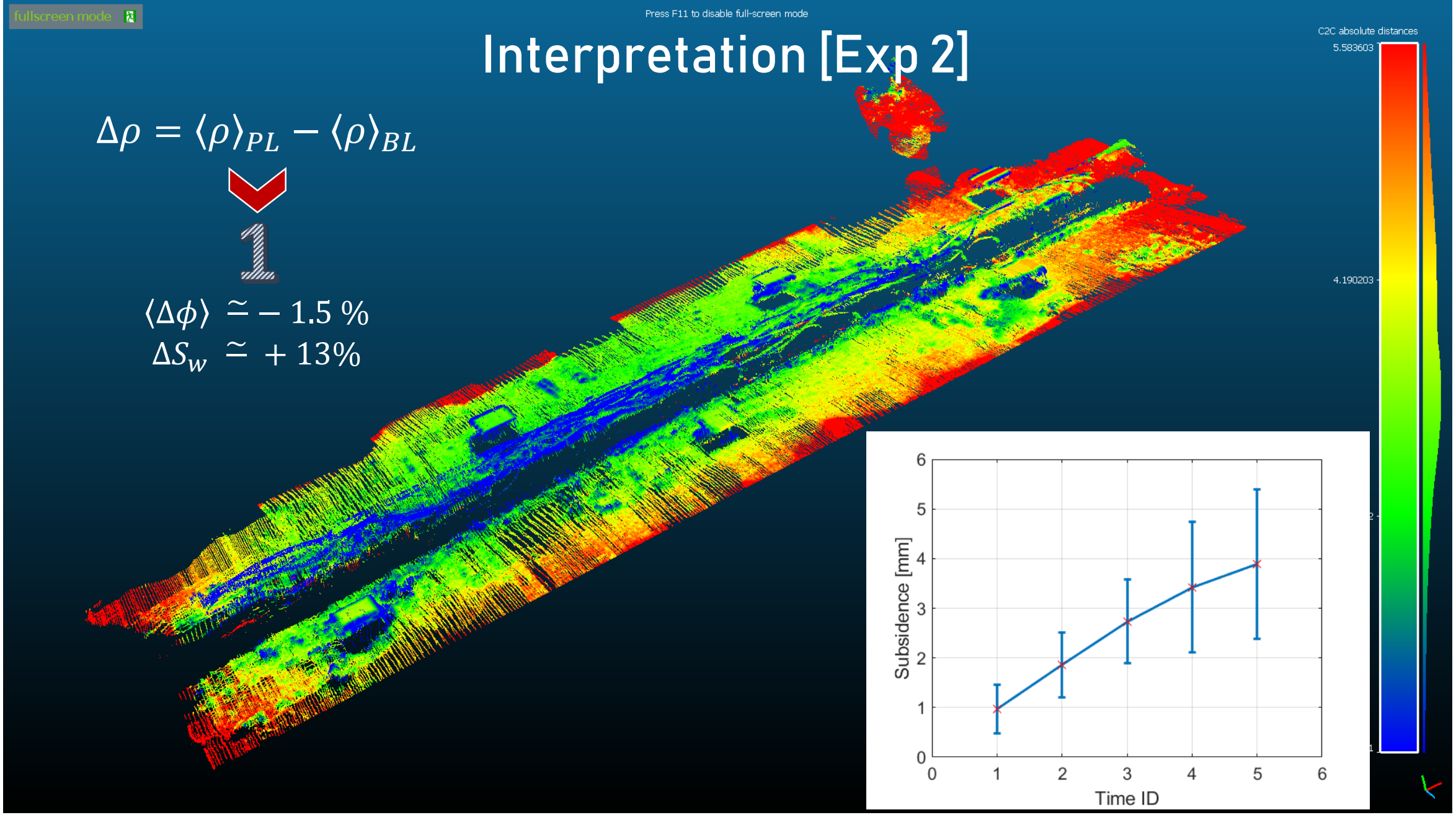
$\langle\Delta\phi\rangle \simeq +2\,\%$



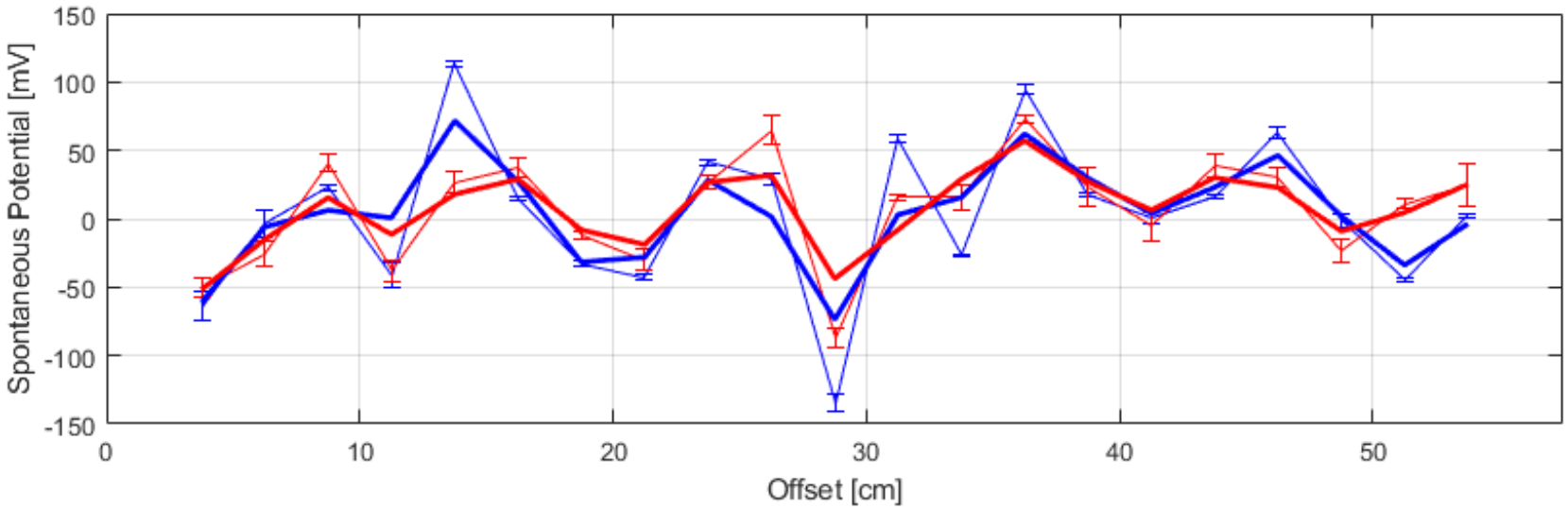
Interpretation [Exp 2]

$$\Delta\rho = \langle\rho\rangle_{PL} - \langle\rho\rangle_{BL}$$

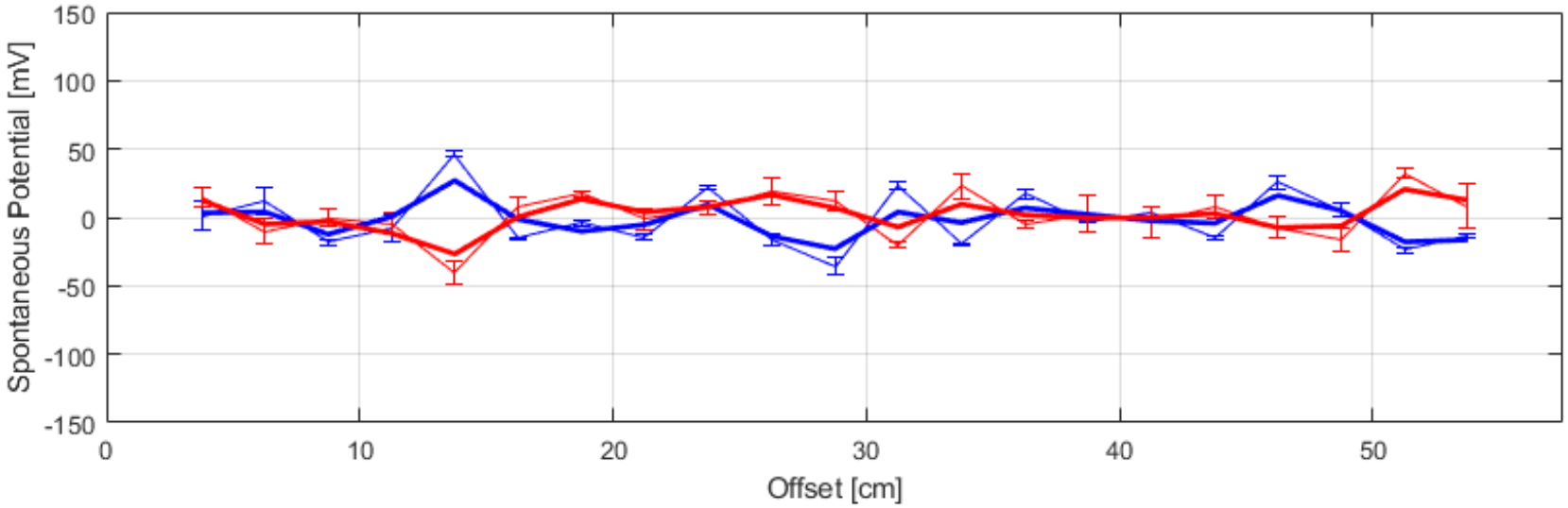
$$\langle\Delta\phi\rangle \simeq -1.5\ \%$$
$$\Delta S_w \simeq +13\%$$



What about the Self-potential measurements? [Exp 1]



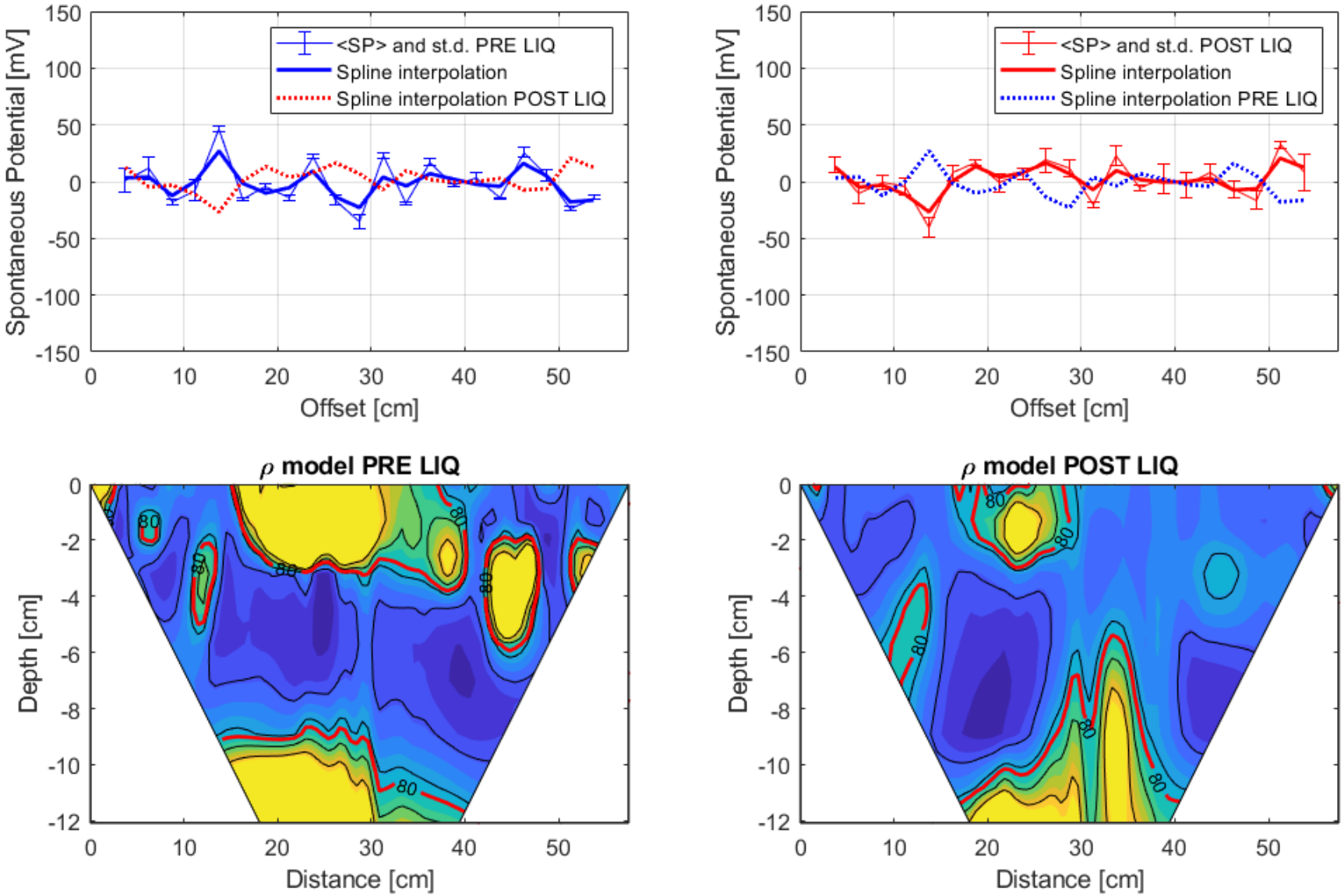
Real measures



Detrended measures

Flux variations?

What about the Self-potential measurements? [Exp 1]



Conclusion and Future works

- ✓ Time-Lapse ERT could be a useful method for monitoring the apparent resistivity variations due to the overpressures induced by the seismic input in liquefiable sands
- ✓ Through Archie's law it is possible to justify these variations as saturation and/or porosity variations
- ✓ Different behaviour of apparent resistivity in function of saturation degree

- ❑ To Link the $\Delta\rho$ and overpressures Δu, monitoring the system with Pore Pressure Transducers and performing triaxial dynamic tests on the HOSTUN sand
- ❑ To carry out the same inversions with a 3D model to eliminate the eventual "box effect" on the absolute resistivity model
- ❑ To correlate the observed variations with other possible observations of seismic parameters ($V_{P,S}$)

Thank you for your attention!

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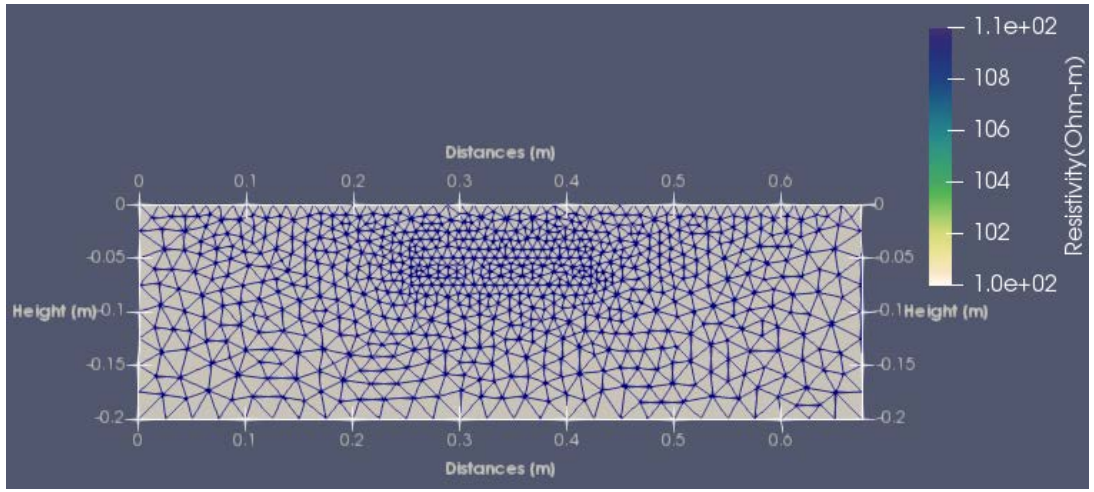
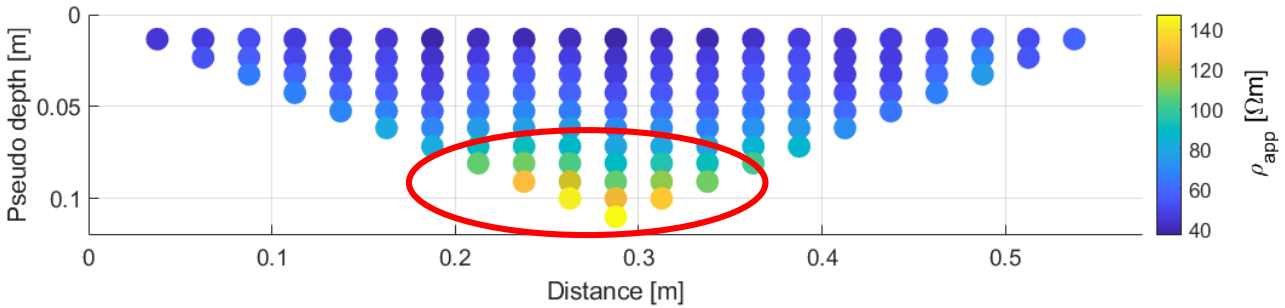
…probably the high resistivity effects of the box?





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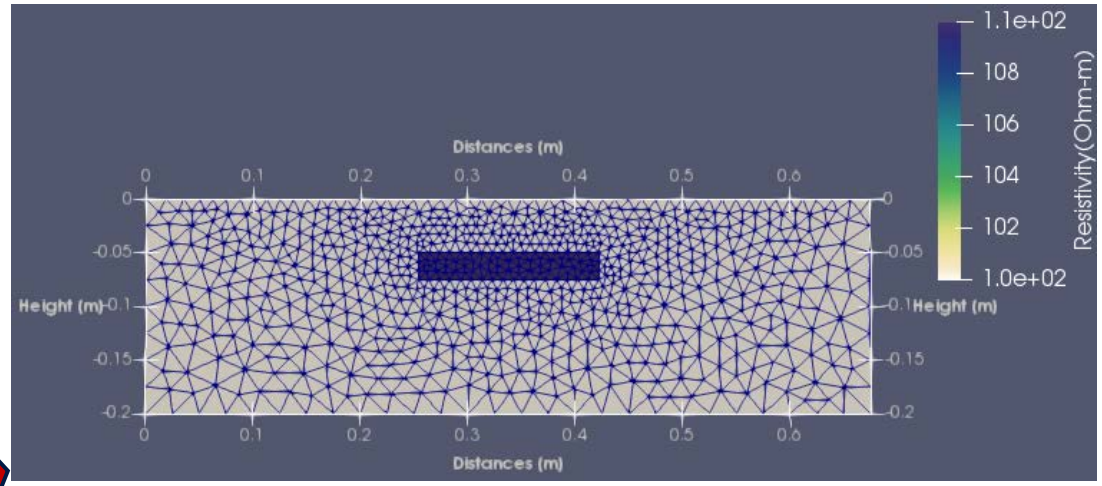


Forward of a 100 Ωm model and an evolving 110 Ωm anomaly for infinite boundary and box boundary

ρ_{app} absolutes are different for the more distant AB electrodes → influence

ρ_{app} varying in time → not influenced

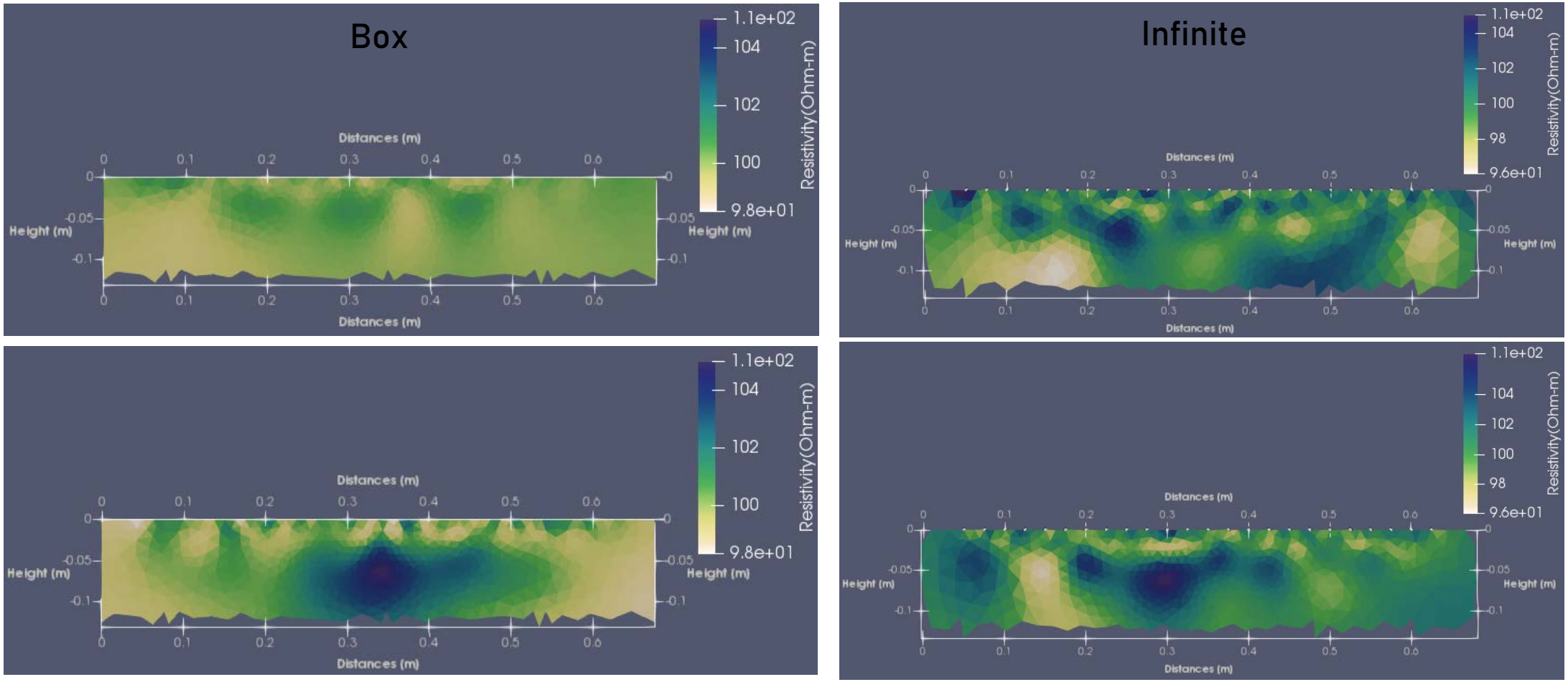
$\langle \Delta\rho_{app} \rangle < 1\%$

With infinite or finite boundary

…probably the high resistivity effects of the box?

t_0

t_1



Inversions for the presented model for infinite boundary and box boundary

ρ varying in time → not influenced

$\langle \Delta\rho \rangle = 1\%$

With infinite or finite boundary