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Decay-Curve Analysis for the Quantification of Data Error in Time-Domain Induced Polarization Imaging

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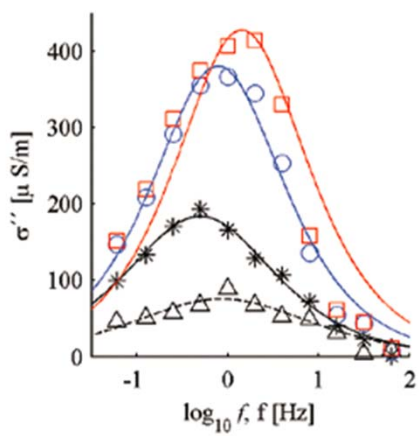
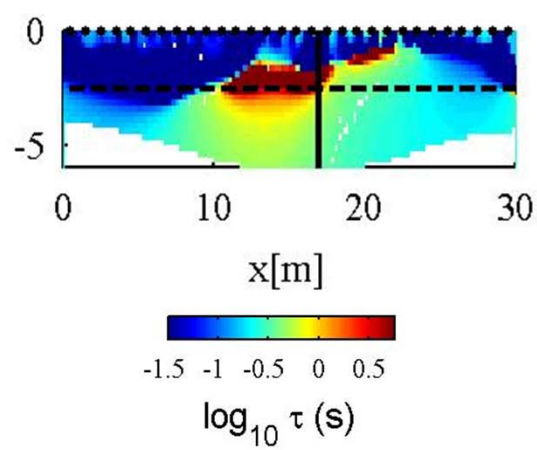
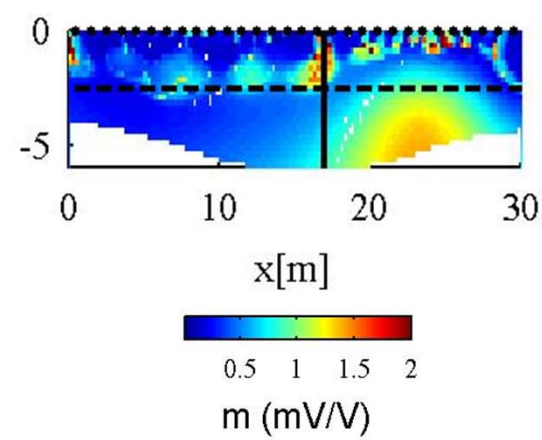
Delineation of Naturally Reduced Zones (NRZ)

- IP measurements can provide information about the accumulation of metallic minerals (e.g., FeS) accompanying the activity of iron-reducing microorganisms
  - Bio-stimulation
  - Microbiological “Hot-spots”



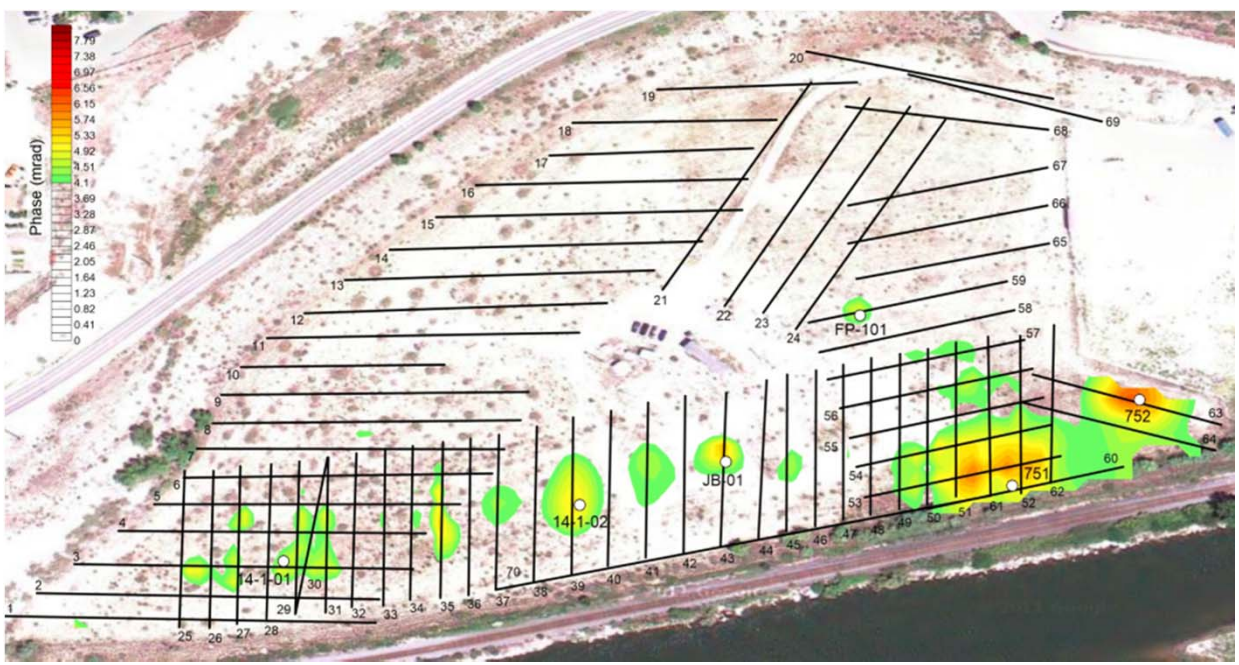


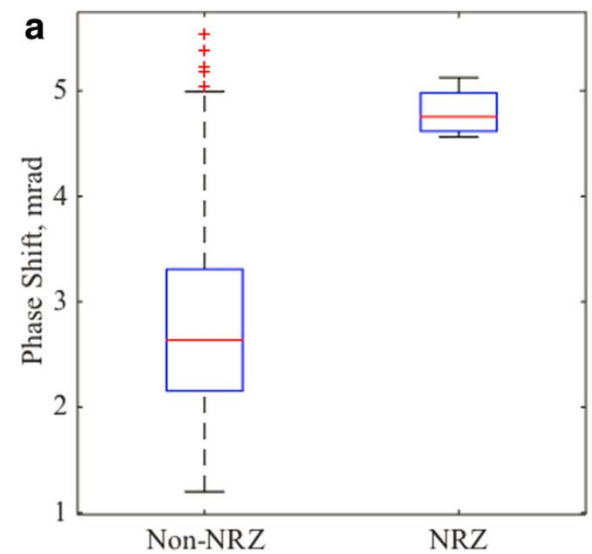


Flores Orozco et al., NSG 2013

Delineation of Naturally Reduced Zones (NRZ) at the Rifle site

- Estimation of lithological unit and NRZ based on IP imaging and wellbore data in a stochastic framework
- 65 IP profiles and 17 ERT profiles
- 171 wells

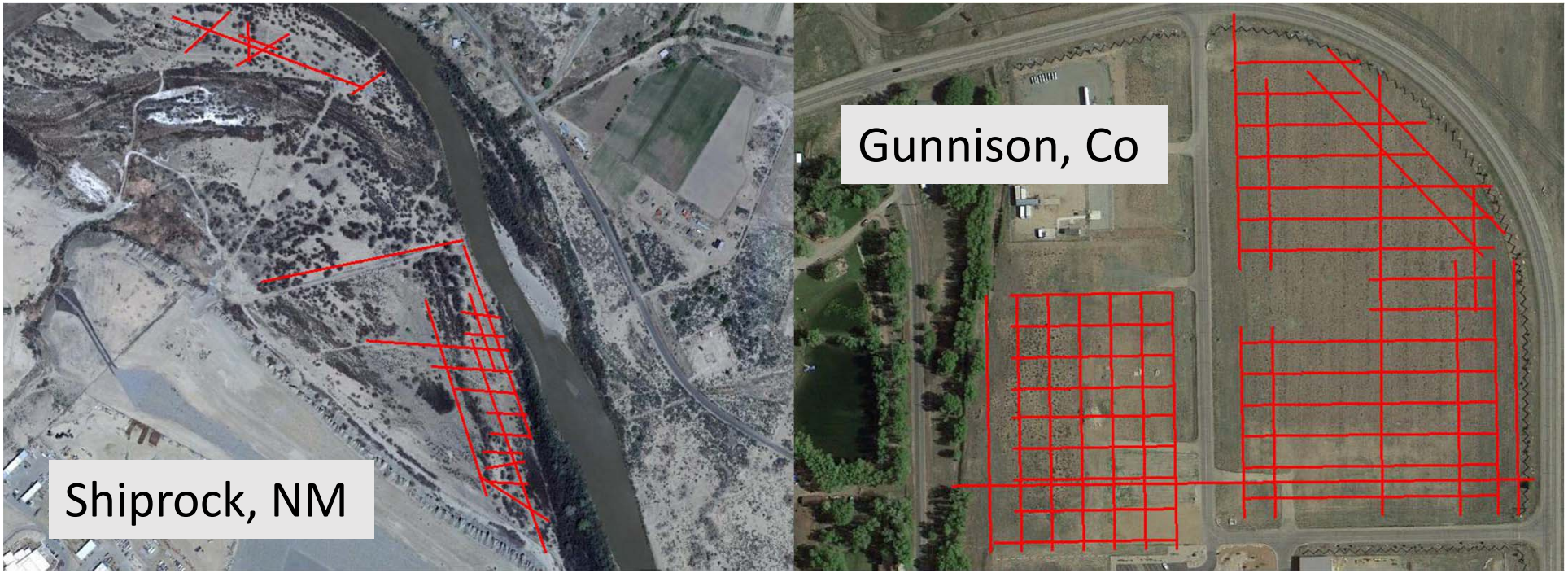




Wainwrigtht et al., WRR 2015

Delineation of Naturally Reduced Zones (NRZ) at other DOE sites

- Former uranium-processing facilities
- Large scale
- High spatial resolution required



Shiprock site (New Mexico, USA)

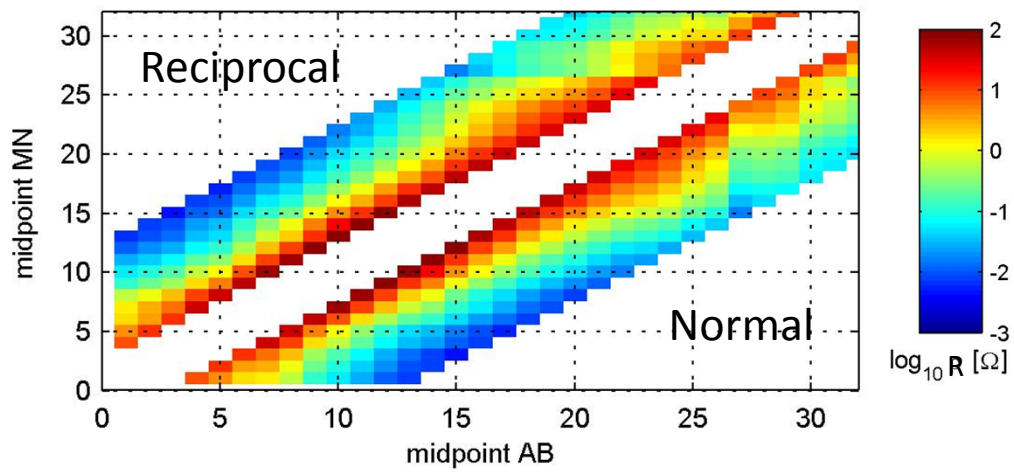
- Dry surface with gravels → contact resistances >30 kΩ
- Groundwater level at ~2 m depth
- Mancos formation underlying aquifer at ~6/7 m depth

Shiprock site (New Mexico, USA) TDIP Settings

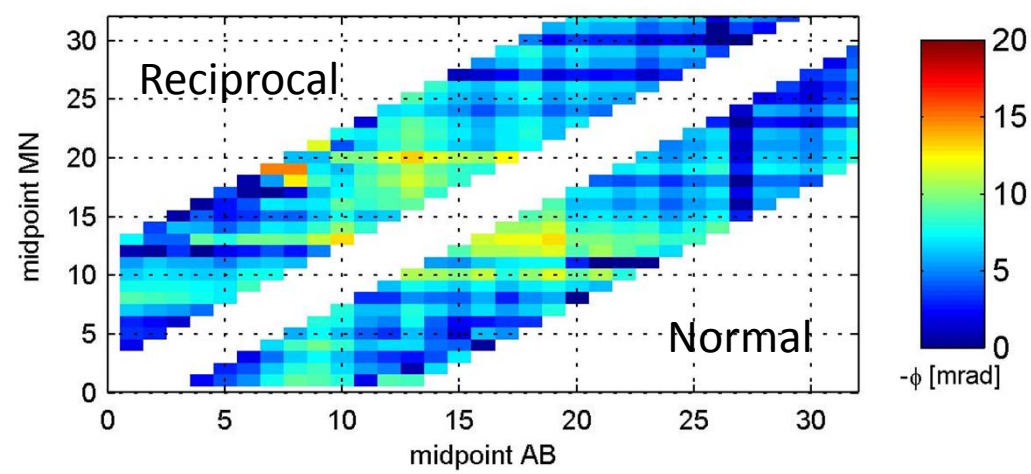
- Electrode separation of 2m
- Dipole-dipole skip-0
- 2s pulse length
- Syscal Switch Pro (IRIS) and ARES II (GF Instruments)
- Normal and reciprocal measurements
- 7m depth of investigation
- 21 lines
- 10 days

Shiprock: Raw data (dipole-dipole)

- Agreement between normal and reciprocal readings for a maximum of 5 electrodes separation between current and potential dipoles



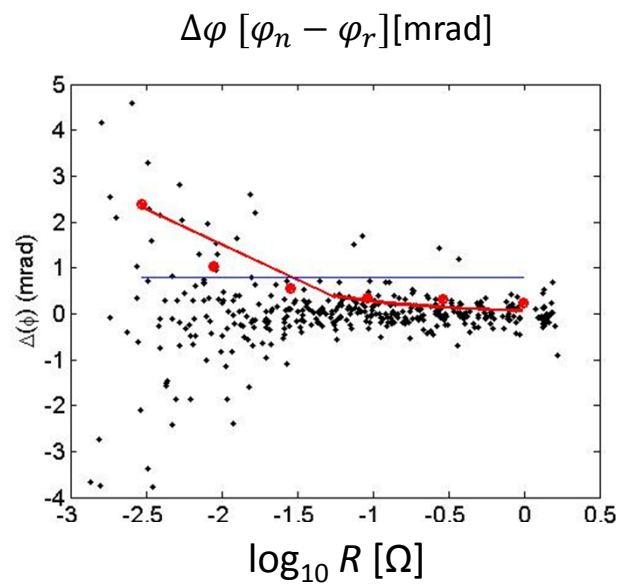
- Collection of multiple-gradient configurations to increase signal-to-noise ratio → Only normal readings



Shiprock: Data error quantification

- Statistical analysis of the normal-reciprocal misfit
  - Outliers removal
- Data error in phase measurements ($\varepsilon(\phi)$) as a function of associated resistances (R)

- Reciprocals only possible for Dipole-Dipole configurations!
- Artifacts in the inverted images → error underestimation for gradient measurements

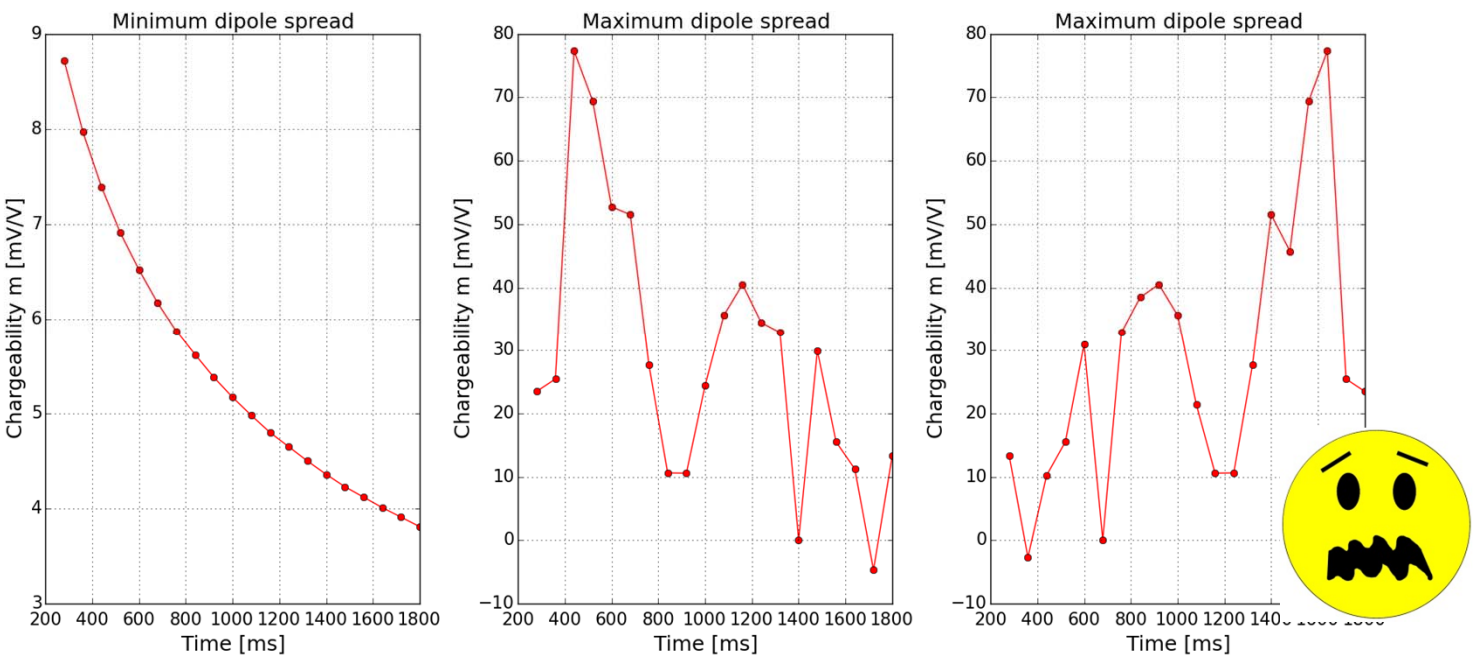


$$\varepsilon(\phi) = aR^{-b}$$

Flores Orozco et al., GEO 2012

Analysis on the quality of the voltage decay curve in TDIP measurements

- Integral chargeability measurements
- CRTomo (Kemna, 2000) → linear conversion from chargeability to phase-shift



Decay-Curve Analysis in time-domain IP (TDIP)

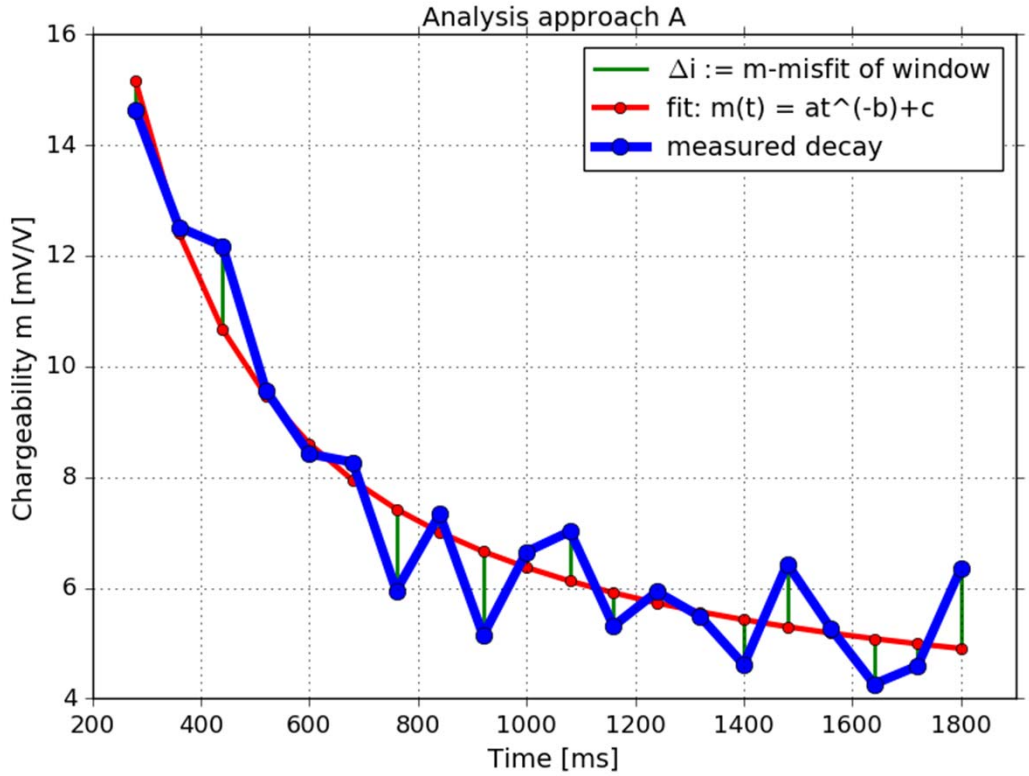
Objectives:

- Evaluation of the quality of the voltage decay curve in TDIP to assess erroneous measurements (outliers)
- Quantification of the quality of the decay curve as an alternative to normal-reciprocal analysis?
- Quick assessment of data quality (and inversion)

→ needed to be performed on site during data collection

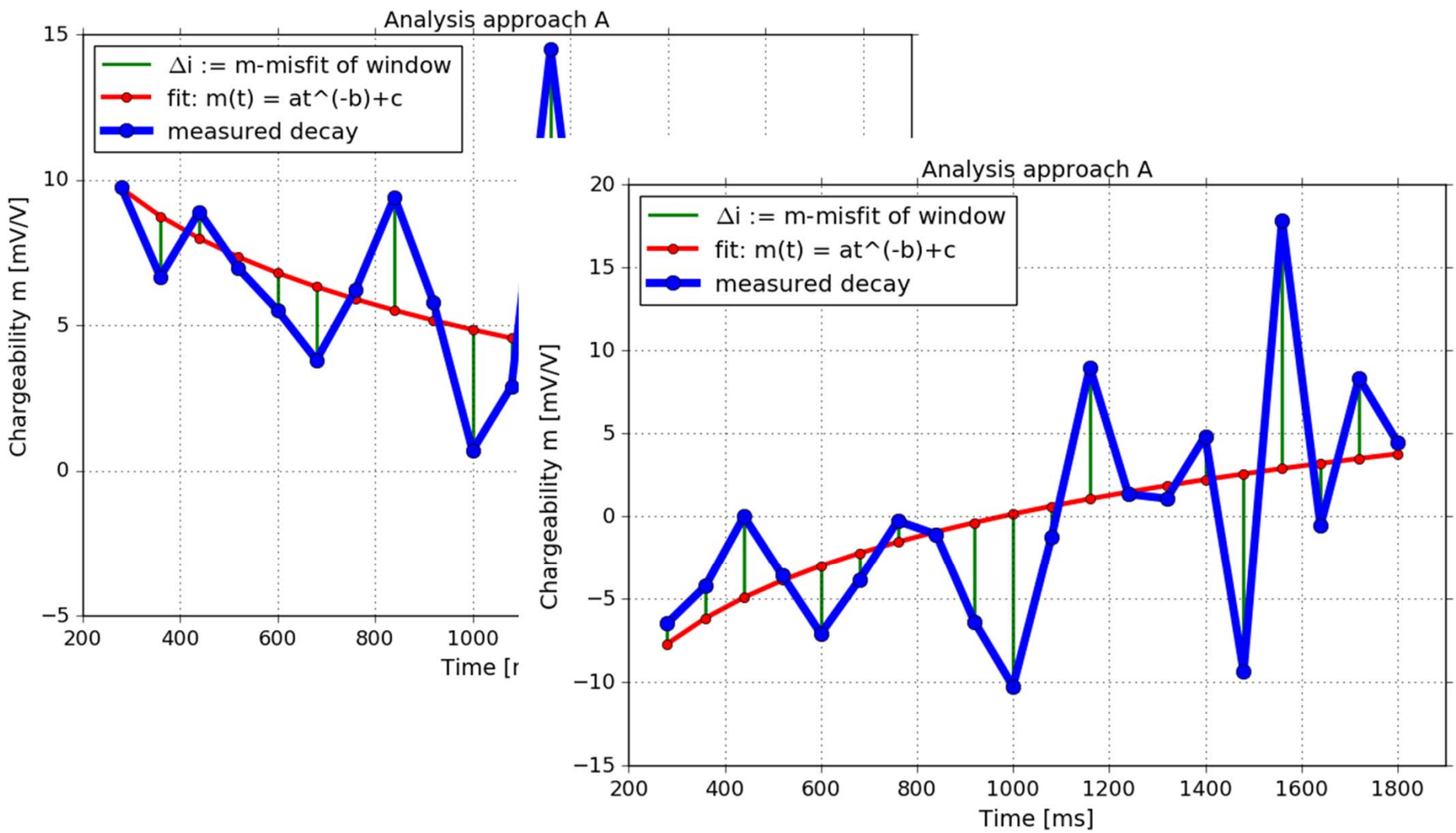
Fitting a power-law model to measured voltages in the decay curve

- Fitting parameters are computed for each decay curve
- Computed misfit between the measured and modeled decay curve for each IP window (*Δi*)

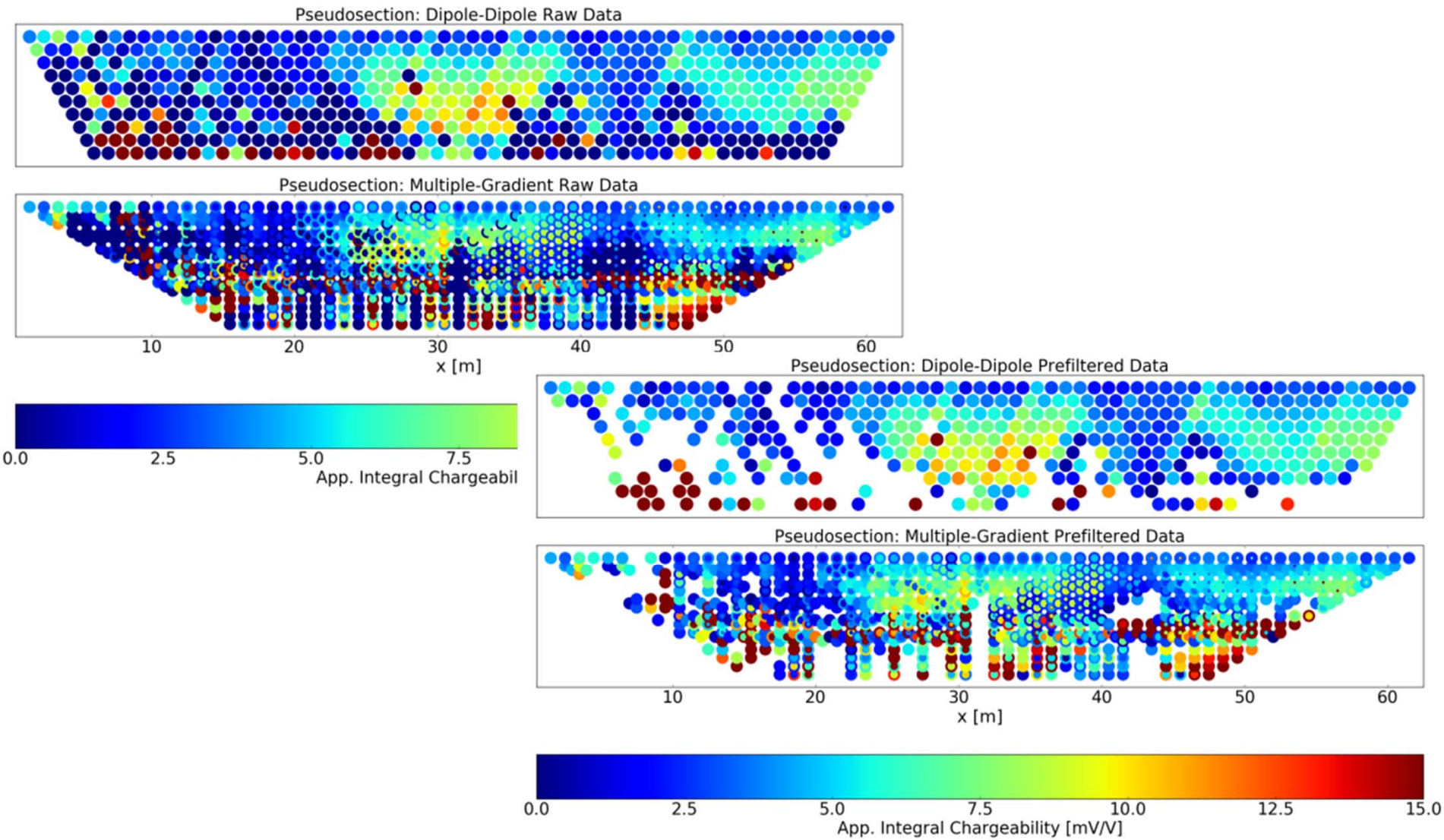


$$m_{mod} = at^{-b} + c$$

First outlier definition

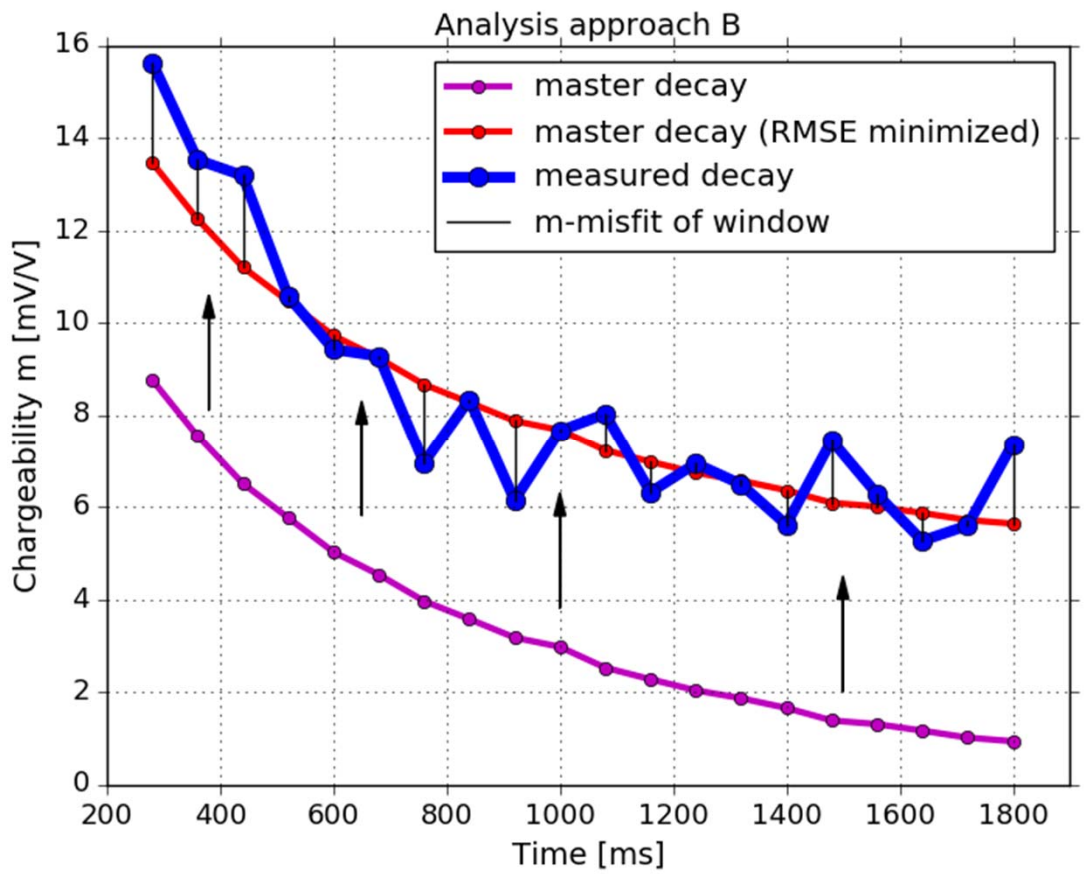


First outlier definition: no decay curves, but not enough….

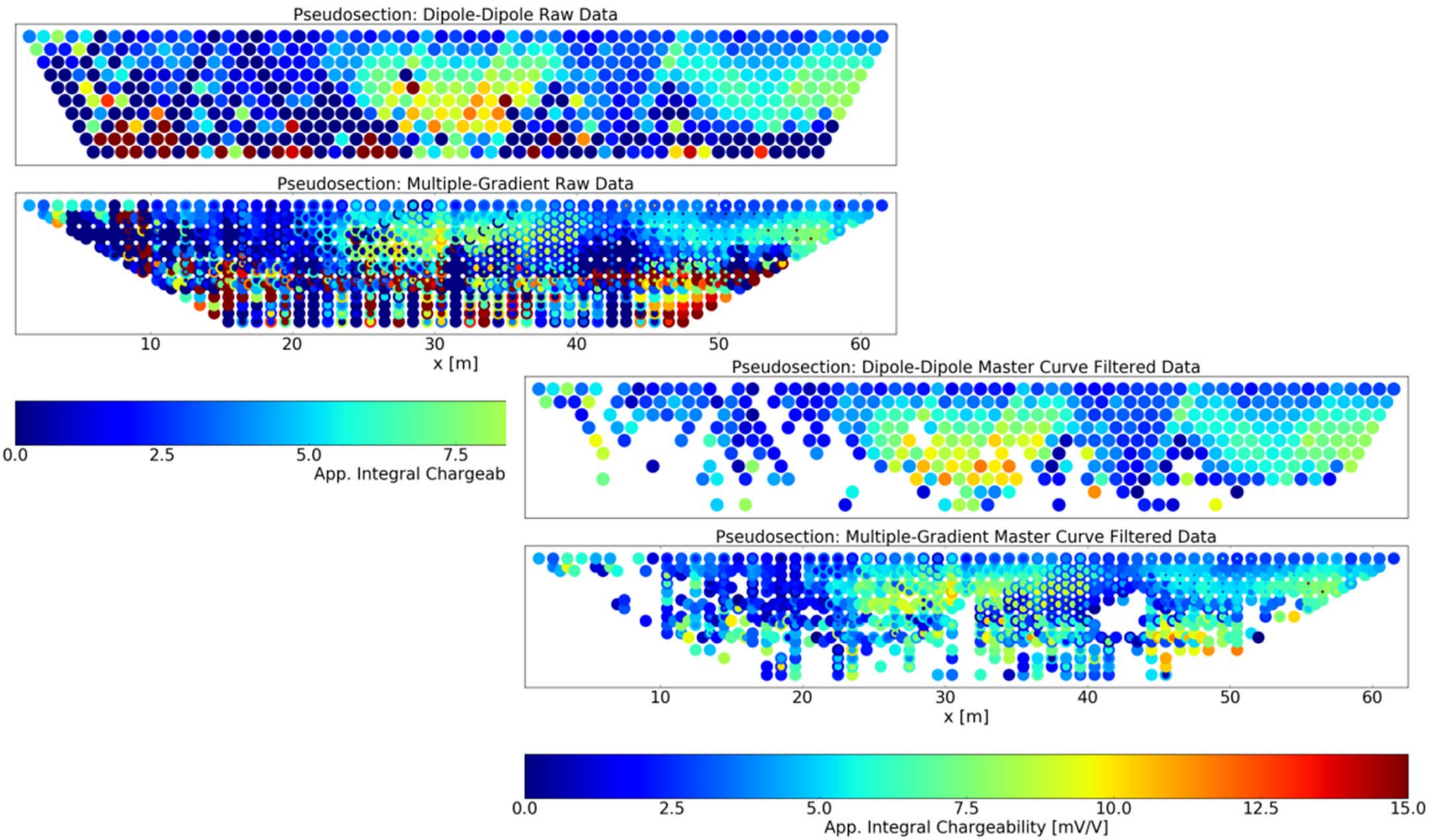


Spatial comparison of the measured decay curves: Master curves

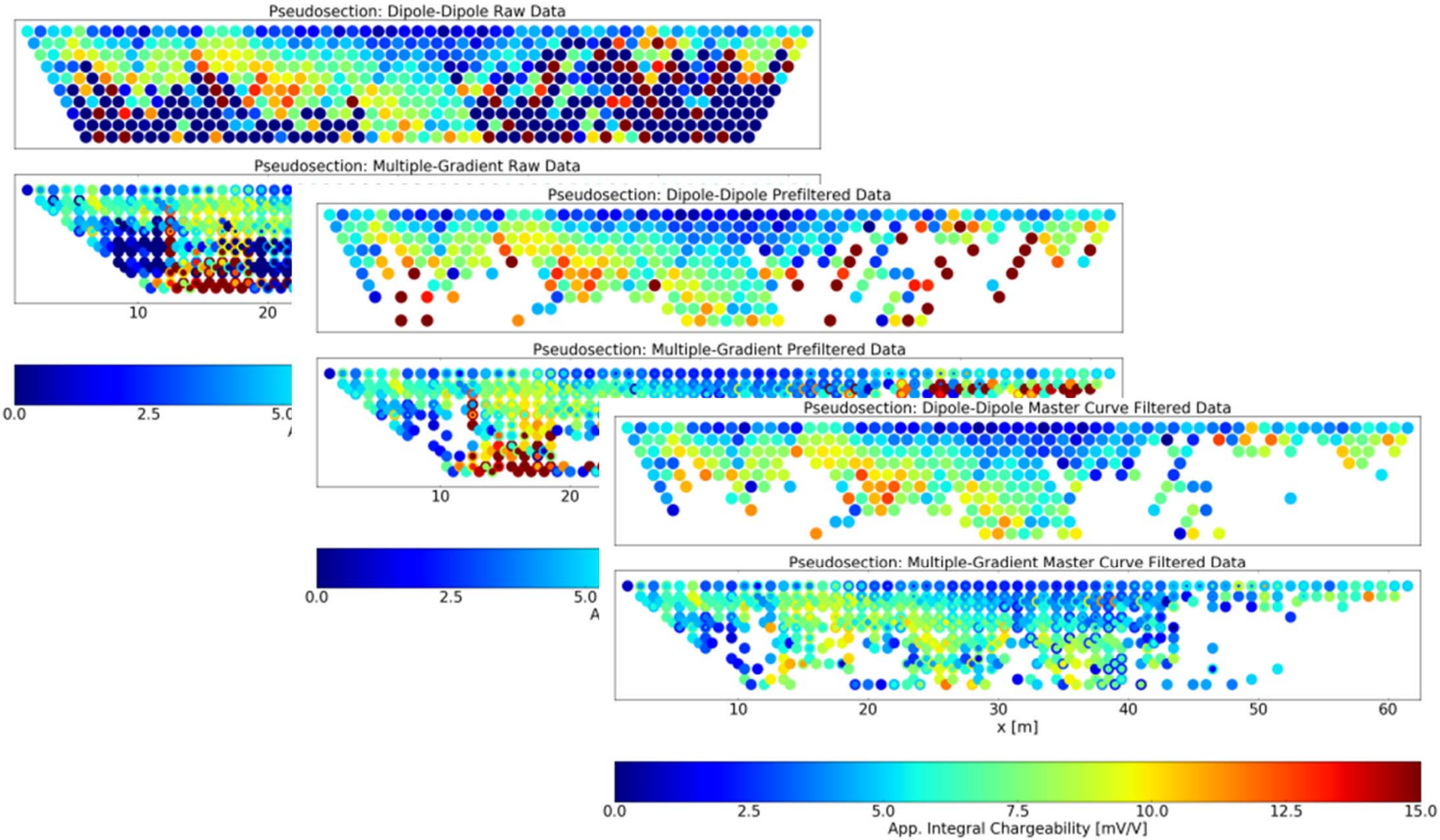
- A power-law model is fitted to all decay curves measured for each current injection
- The master curve is then shifted to fit the individual decay curves
- Removal of large misfits enhances spatial correlation in the data



Second outlier definition: comparison to the master curve

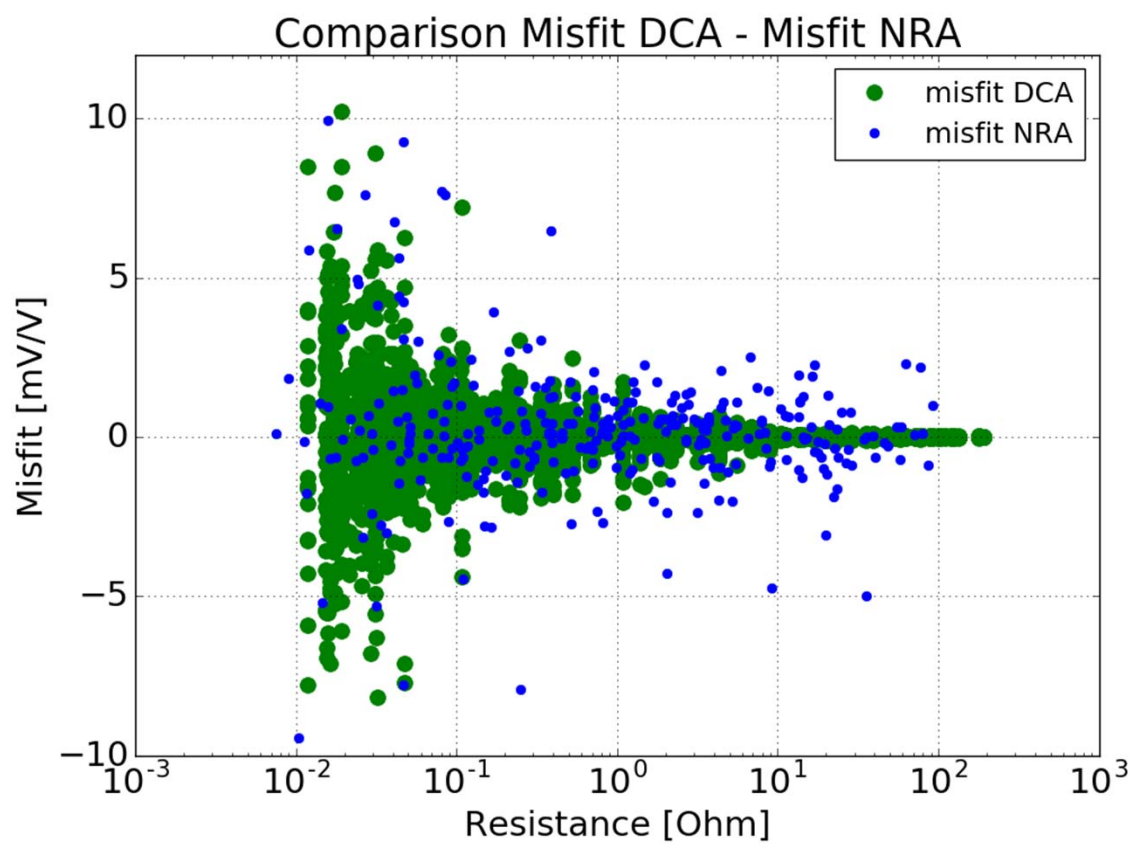


DCA with filtering after comparison with master decay curves seems to be particularly useful for noisy data

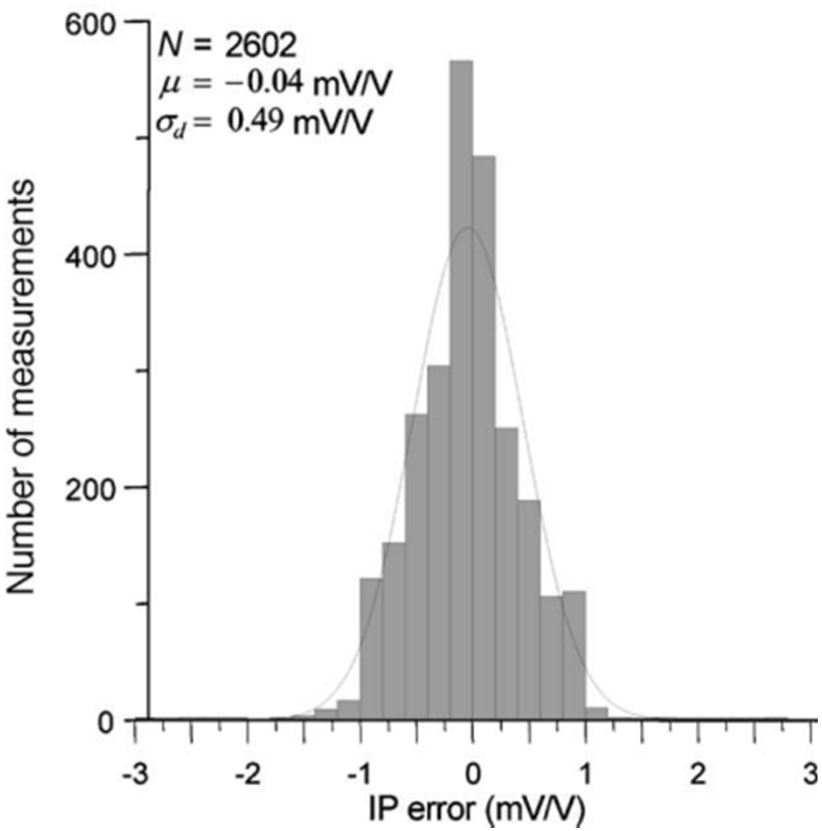


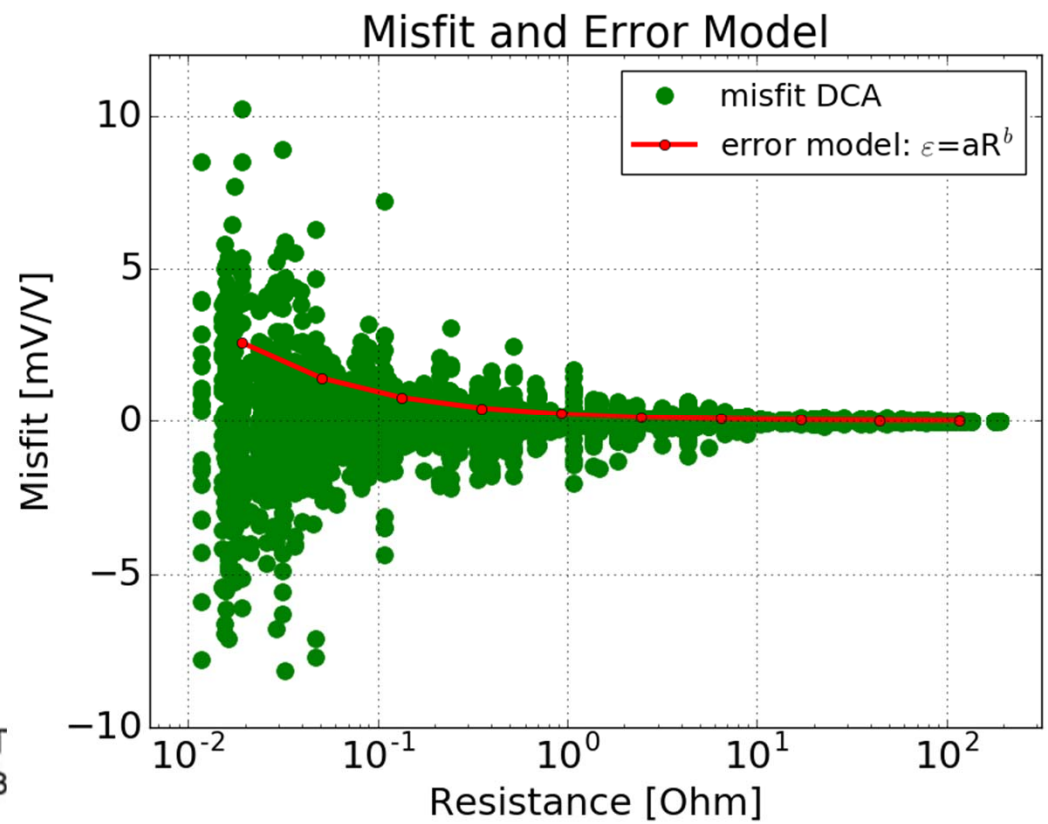
Comparison between the decay-curve analysis (DCA) and the normal-reciprocal analysis (NRA)

- Misfit between modeled and measured voltage in the decay curves plotted as a function of associated transfer resistances
- Comparison with the misfit between normal-reciprocal misfit, as a function of the associated resistance



Data-error quantification





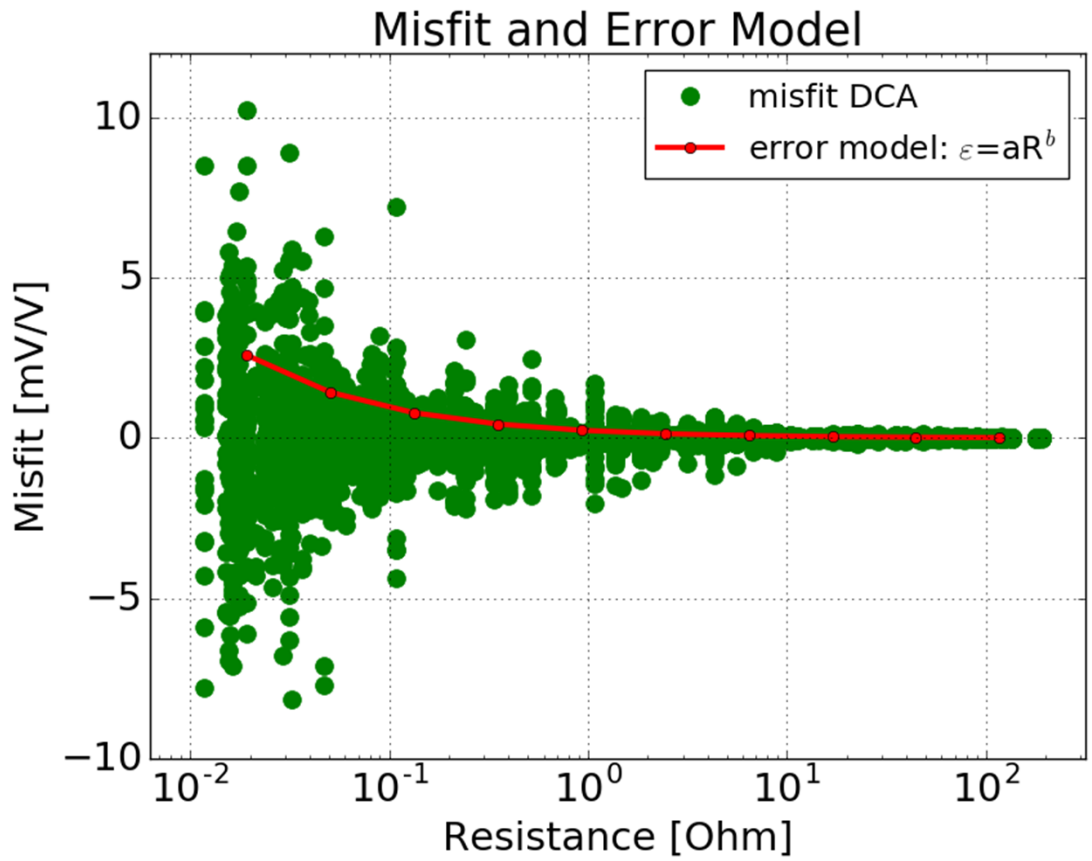
Slater & Binley, Geophysics 2006

Flores Orozco et al., Geophysics 2012

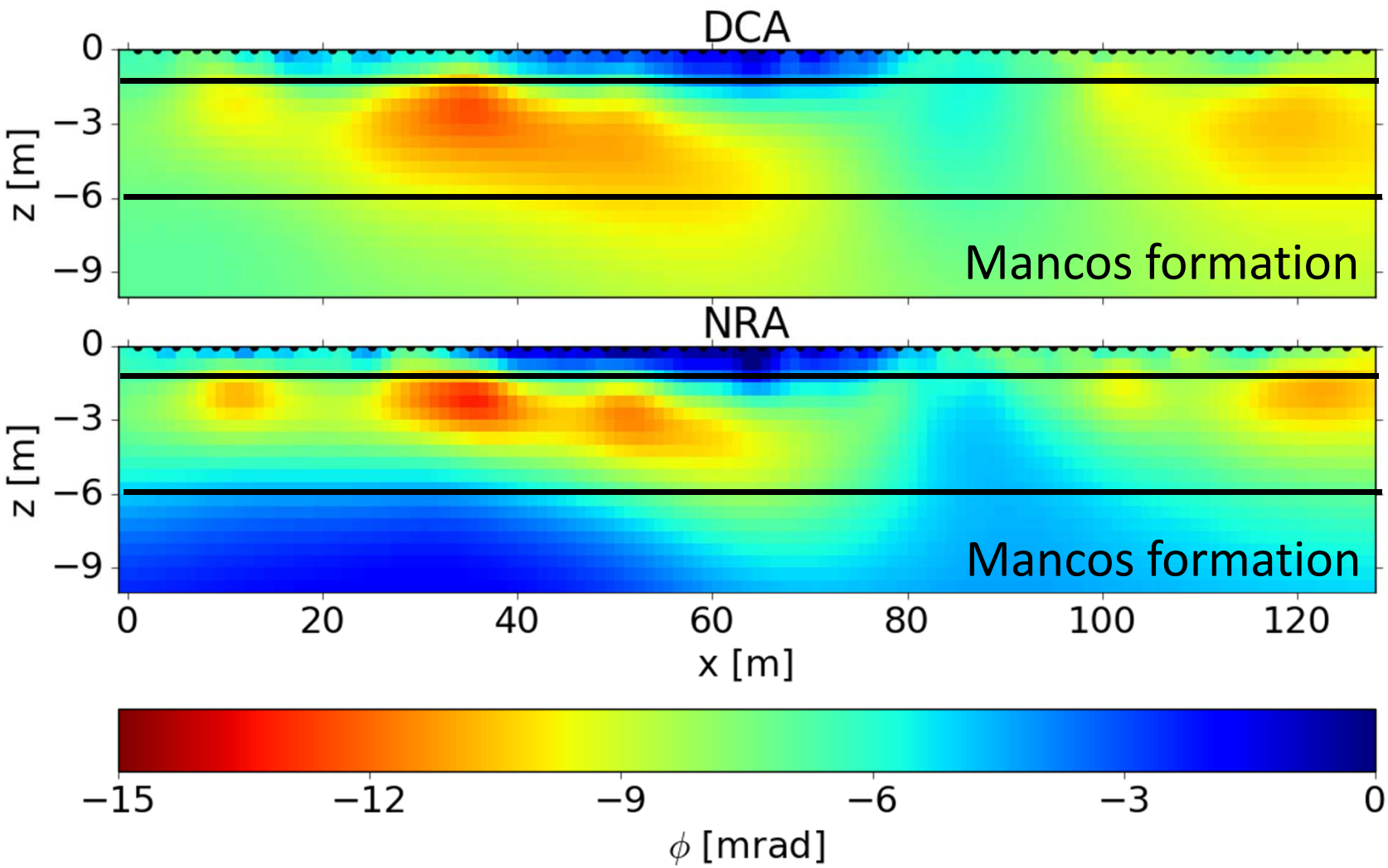
Quantification of data error based on the proposed DCA

Error quantification for IP measurements (ϕ) as a function of the associated resistance (R)

$$\varepsilon(\phi) = aR^{-b}$$



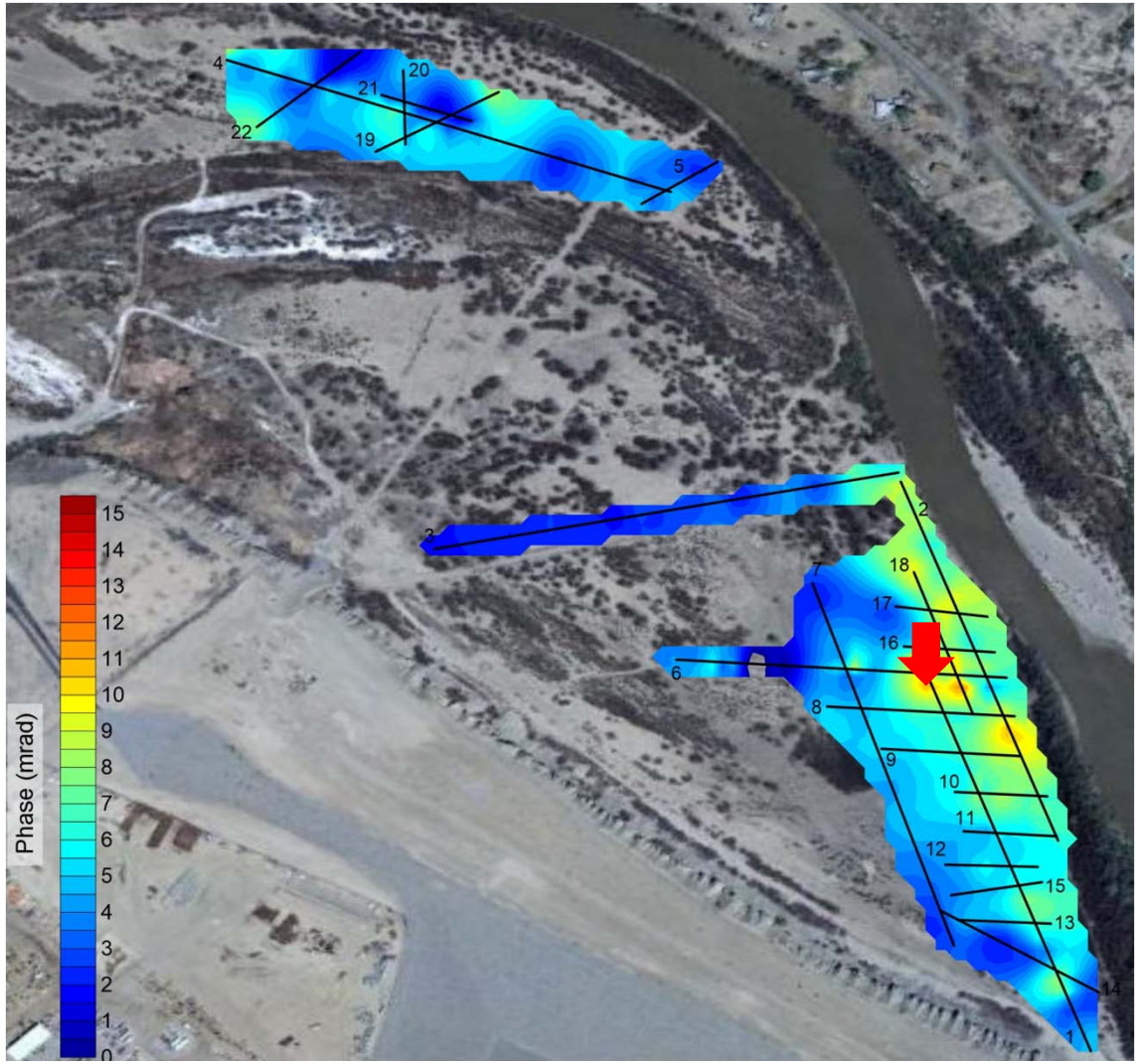
Inversion of the data following the DCA and the NRA



IP maps – 4 m depth

Clean anomalies with high IP response

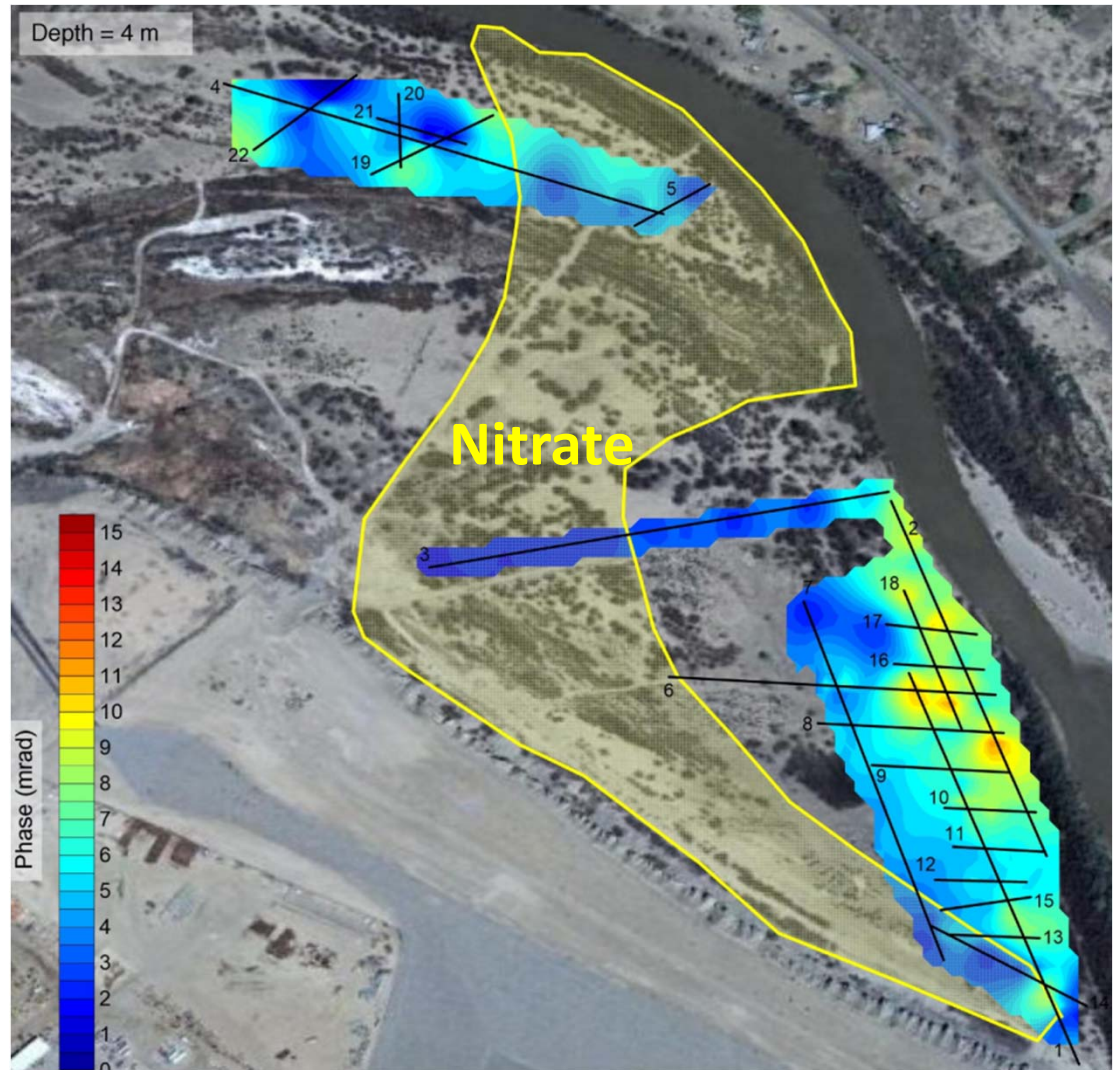
Recovered sediments after drilling revealed no NRZ



IP maps – 4 m depth

Nitrate plume → modification of the biogeochemical conditions to the site?

→ Mechanisms underlying the IP response?



Conclusions

- The proposed analysis of the decay curve (DCA) permits the assessment of data quality in time-domain IP measurements
- Automatic detection and removal of outliers
- Quantification of data error comparable to normal-reciprocal analysis
- Permits to quantify data error without the collection of normal and reciprocal measurements

- Further studies are required to understand the interpretation of IP imaging results in complex environments