

A Modular Geoelectrical Monitoring System as Part of the Surveillance Concept in CO₂ Storage Projects

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Photo: Installation of VERA system



Statoil



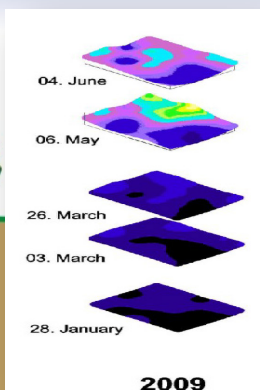
Technische Universität Berlin

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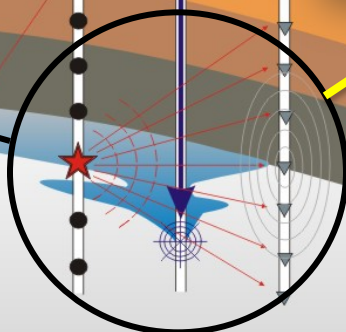
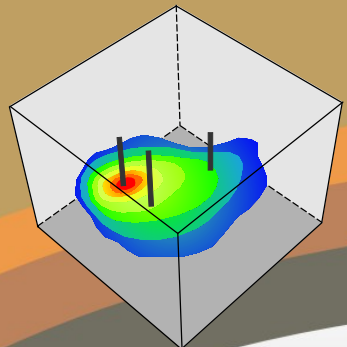
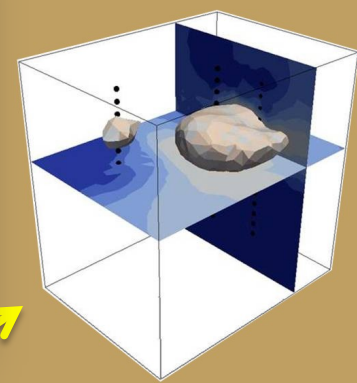
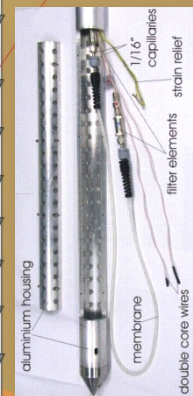
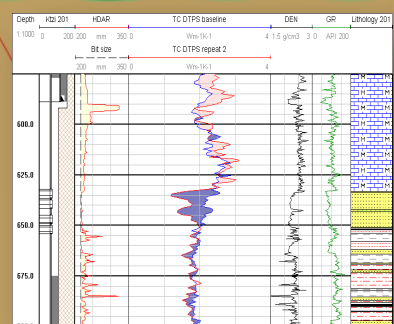
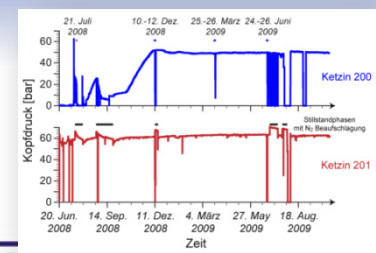
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TCCS-6 , June 14-16, 2011, Trondheim (Norway)

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CO₂



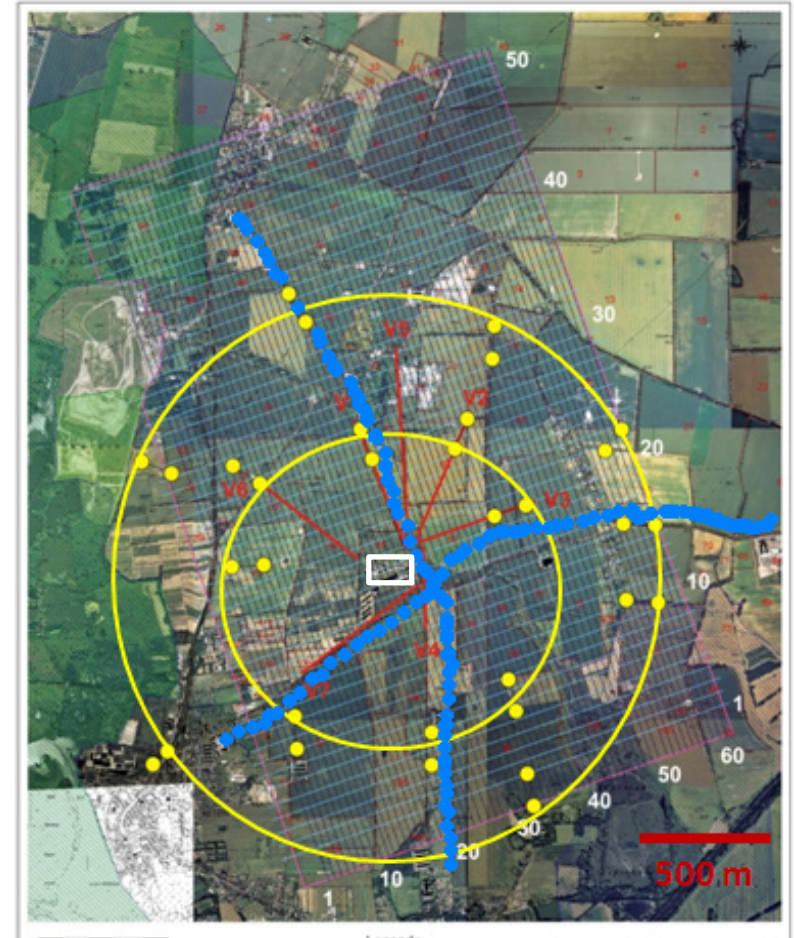
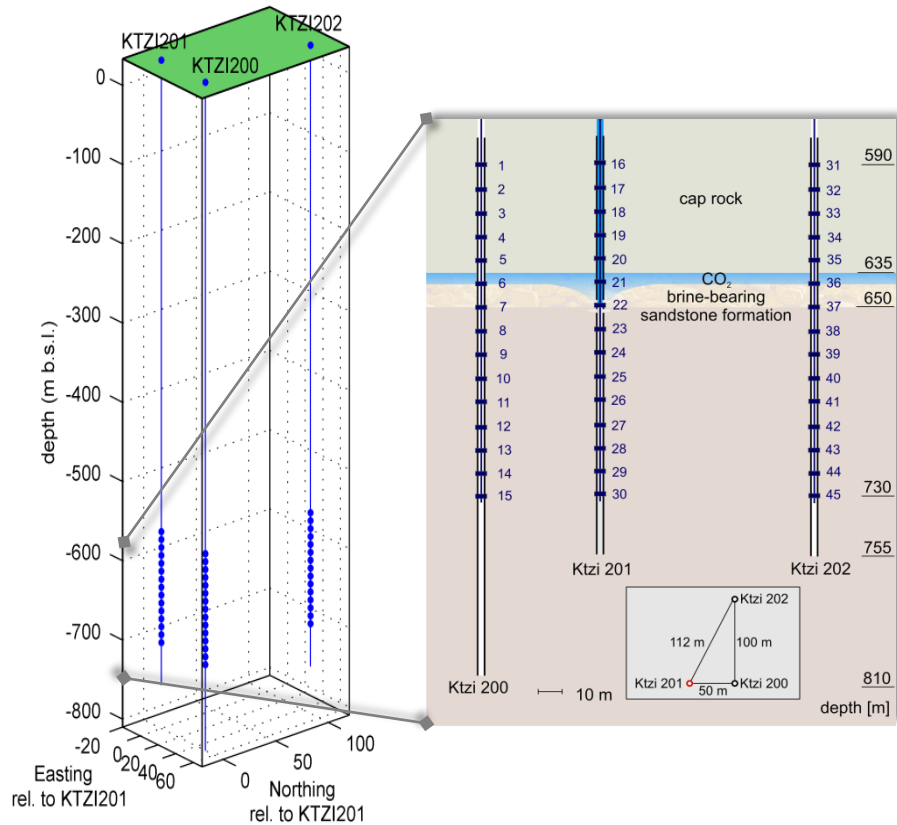
monitoring

cap rock

reservoir

- Saline aquifer developed with three wells
- Injection operation is safe and reliable
- Monitoring detects the CO₂ plume
- Now: phase of data integration

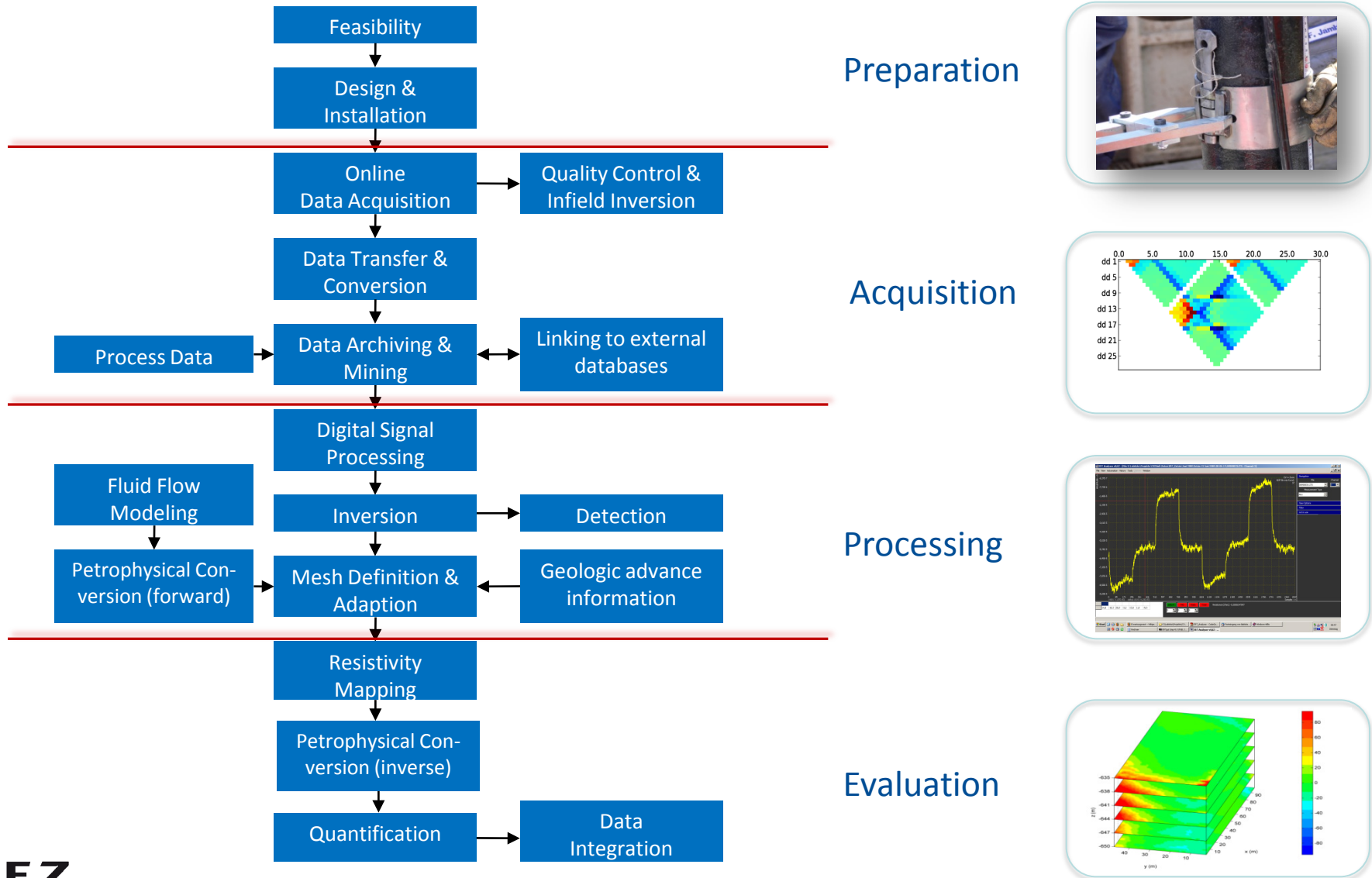
The Ketzin ERT Concept: Combination of Crosshole & Surface-Downhole Measurements



Permanent installation of **Vertical Electrical Resistivity Array (VERA)** in the three Ketzin wells (at insulated casing)

Concentric circles with 16 surface dipoles ● & crossed profiles — for enlargement of observation area, dipole length: 150 m, $r_1 = 800$ m, $r_2 = 1500$ m)

The Ketzin Geoelectrics as Modular Monitoring System (MMS)

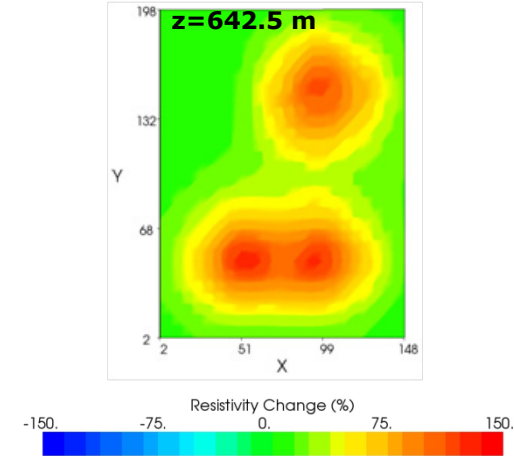
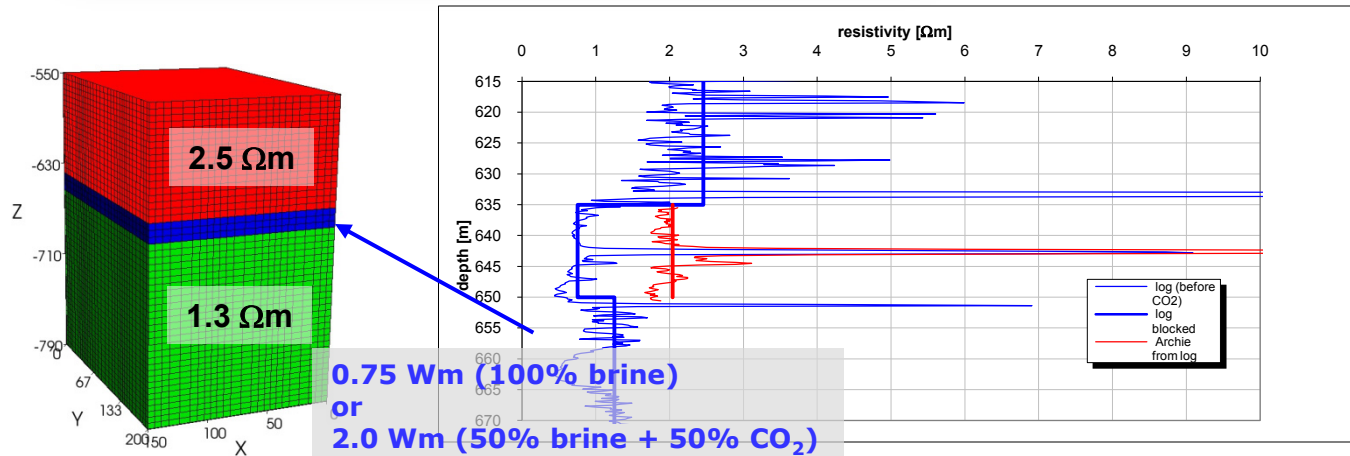
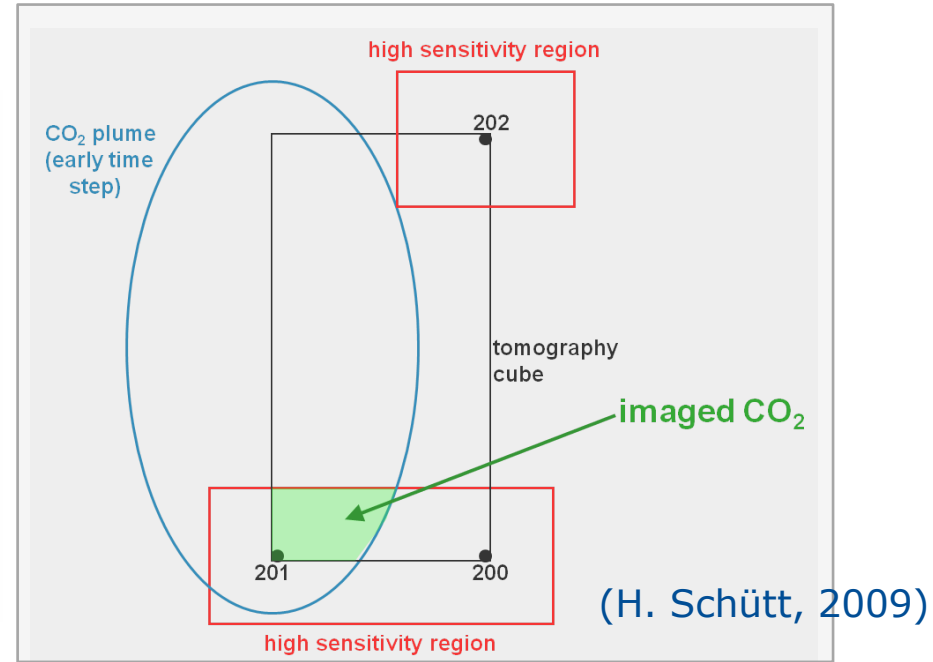
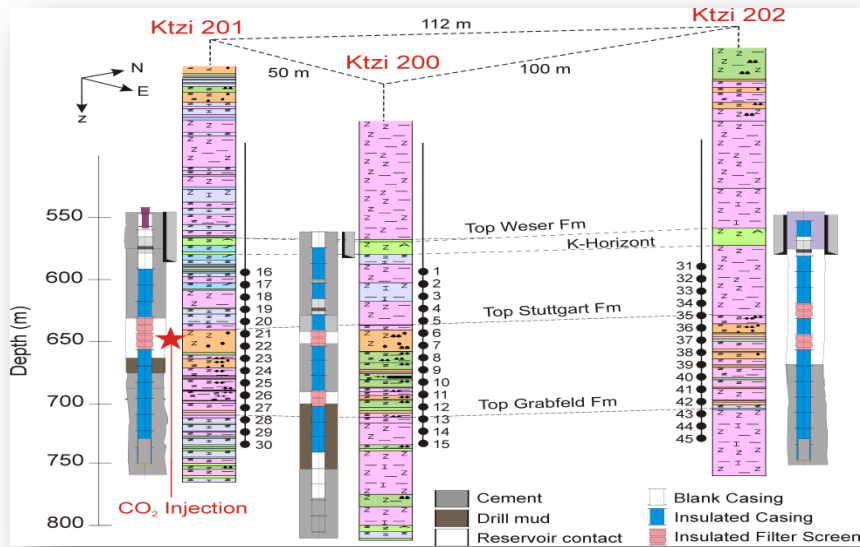




Preparation

Feasibility Study

Well completion



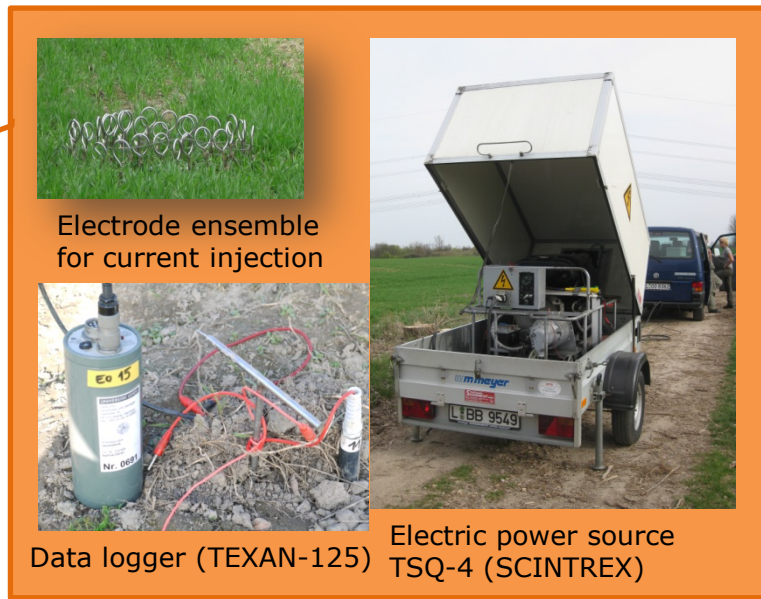
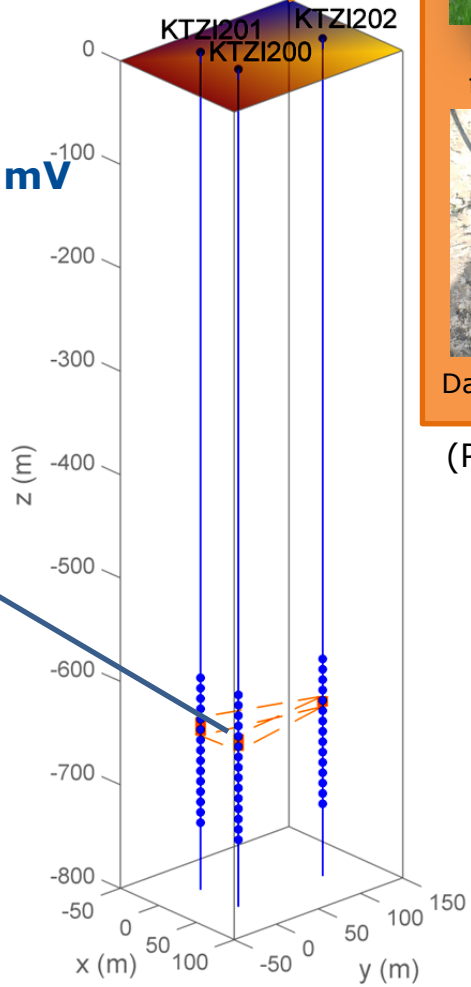
Design & Installation

Site-specific Customization of Surface and Downhole Equipment.

- current: **2.5 A** max.
- channels: **15**
(for potential registration)
- measured voltage: **50 μ V** to **100 mV**
- signal period: **8 s**



(Photos: Courtesy of GFZ)

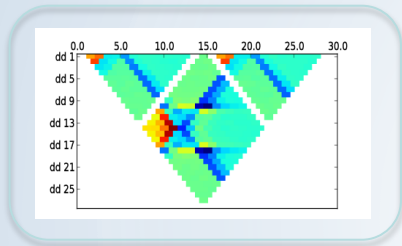


(Photos: Courtesy of University Leipzig)

current: **4 – 10 A**
 voltage: **500 – 1300 V**
 signal period: **16 s**
 Length of time series ~ **1 h**

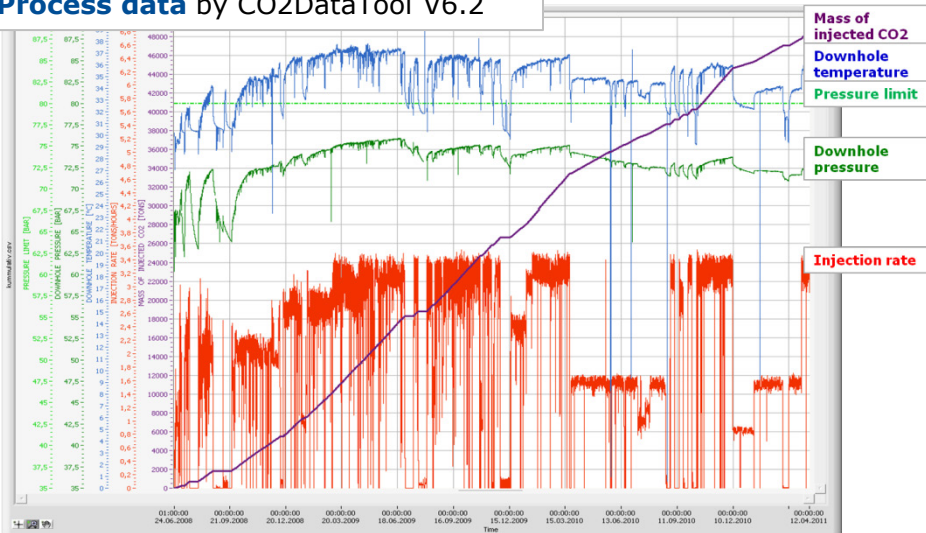


Acquisition



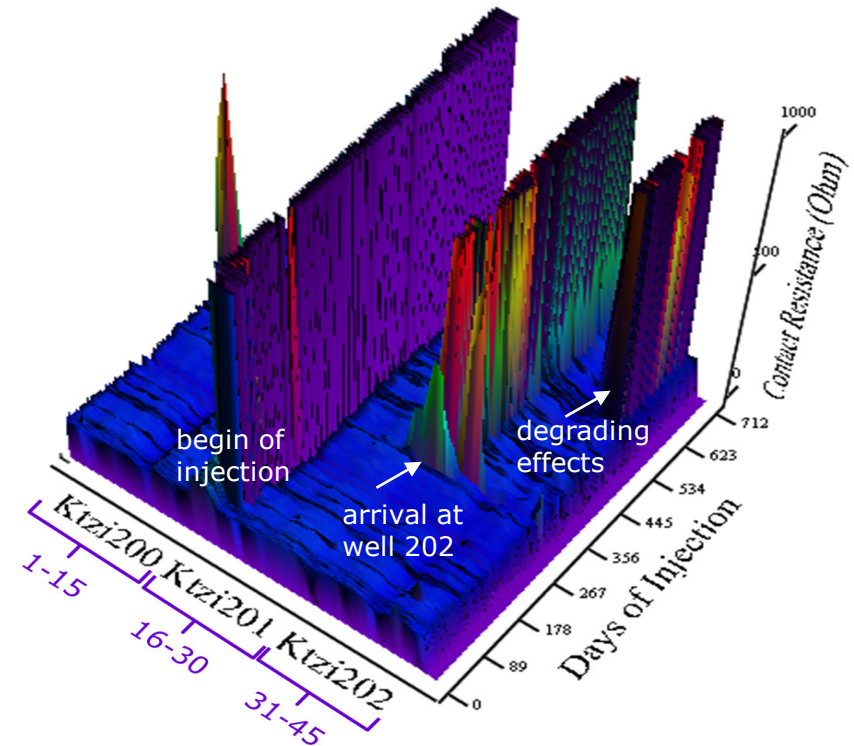
Analysis of Temporal Behavior and Quality of Field Data

Process data by CO2DataTool V6.2



→ ERT system was among the first instruments which detected the CO2 plume signature.

■ Matching with **process data** and **well completion data** can help to understand effects in the time-history of ERT data.

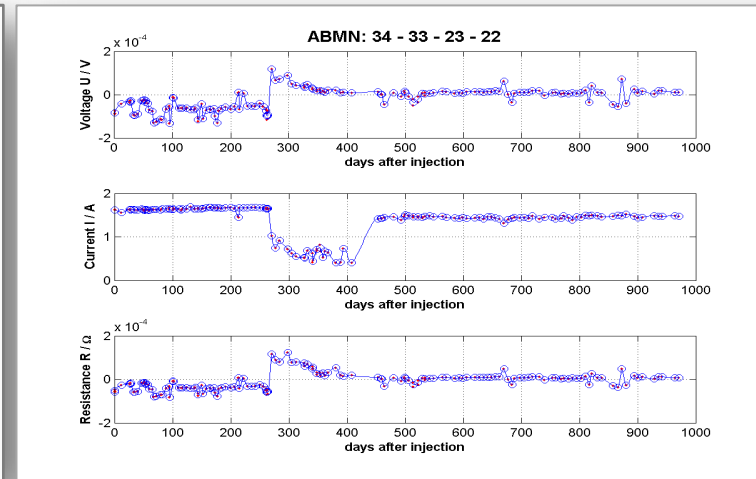
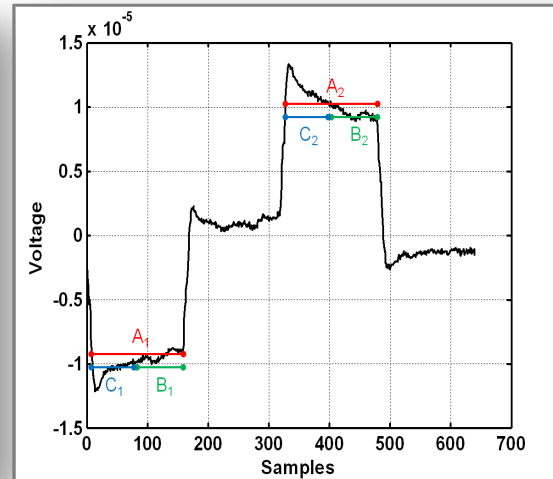
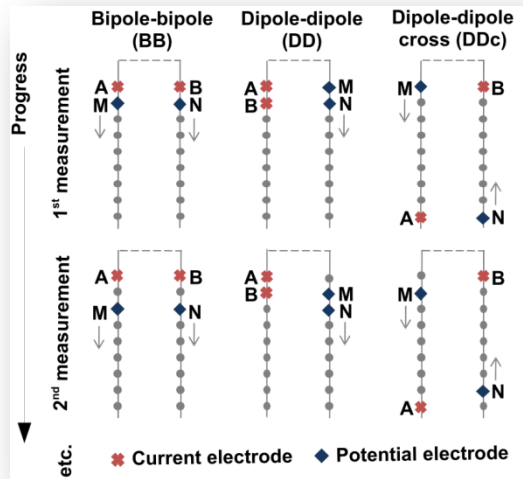


Valuable information from pre-inversion data available.

Example: Analysis of contact resistances of the VERA system (check before each survey).

Conditioning of Field Data by Pre-Processing Routines

- **Surface-Downhole data:** averaging and stacking of the multiple time-series.
- **Crosshole data:** the large variety of electrode acquisition schemes sets time constraints → only two-cycles of time series for all ABMN combinations have been measured.



Deployed electrode configurations for data acquisition.

Error evaluation for field data quality assessment.

Averaging and Spline interpolation of the complete ABMN-data set → provide stabilisation of time history.



Processing

Inversion Strategy

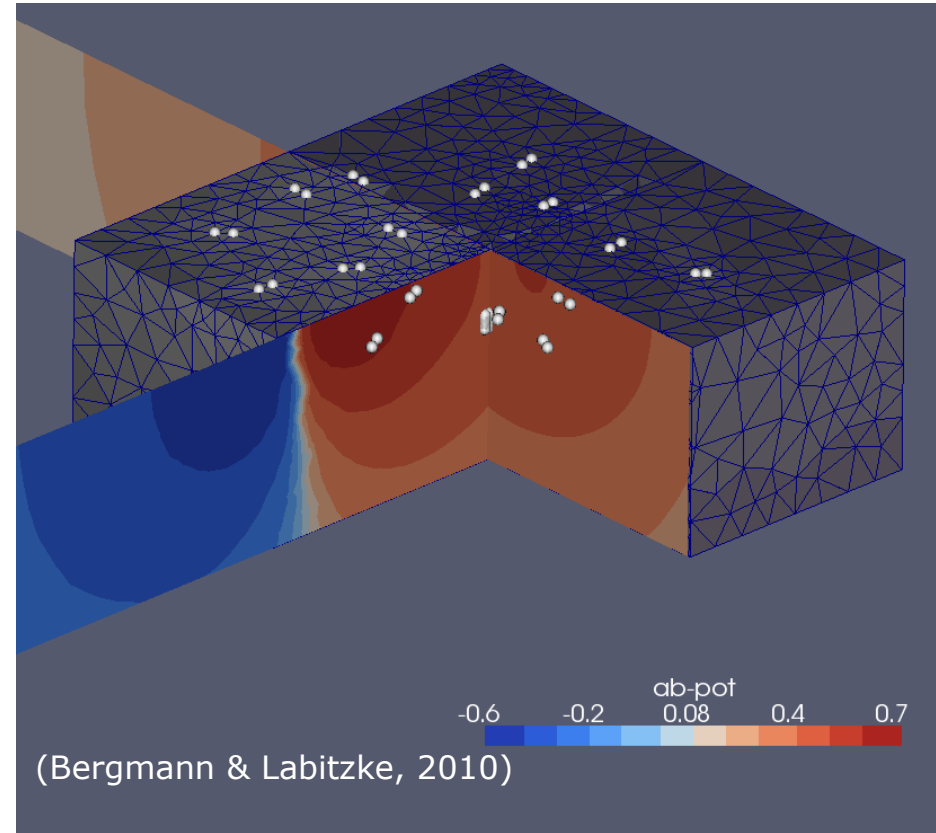
- Test of various program codes :
EarthImager, ERTLab, **BERT**
- Deployment of constraints,
e.g. resistivity logs and
laboratory results →

- 0.5 - 5 Ωm → low-res. environment
- small resistivity contrasts
- moderate resistivity changes
- thin target reservoir zone

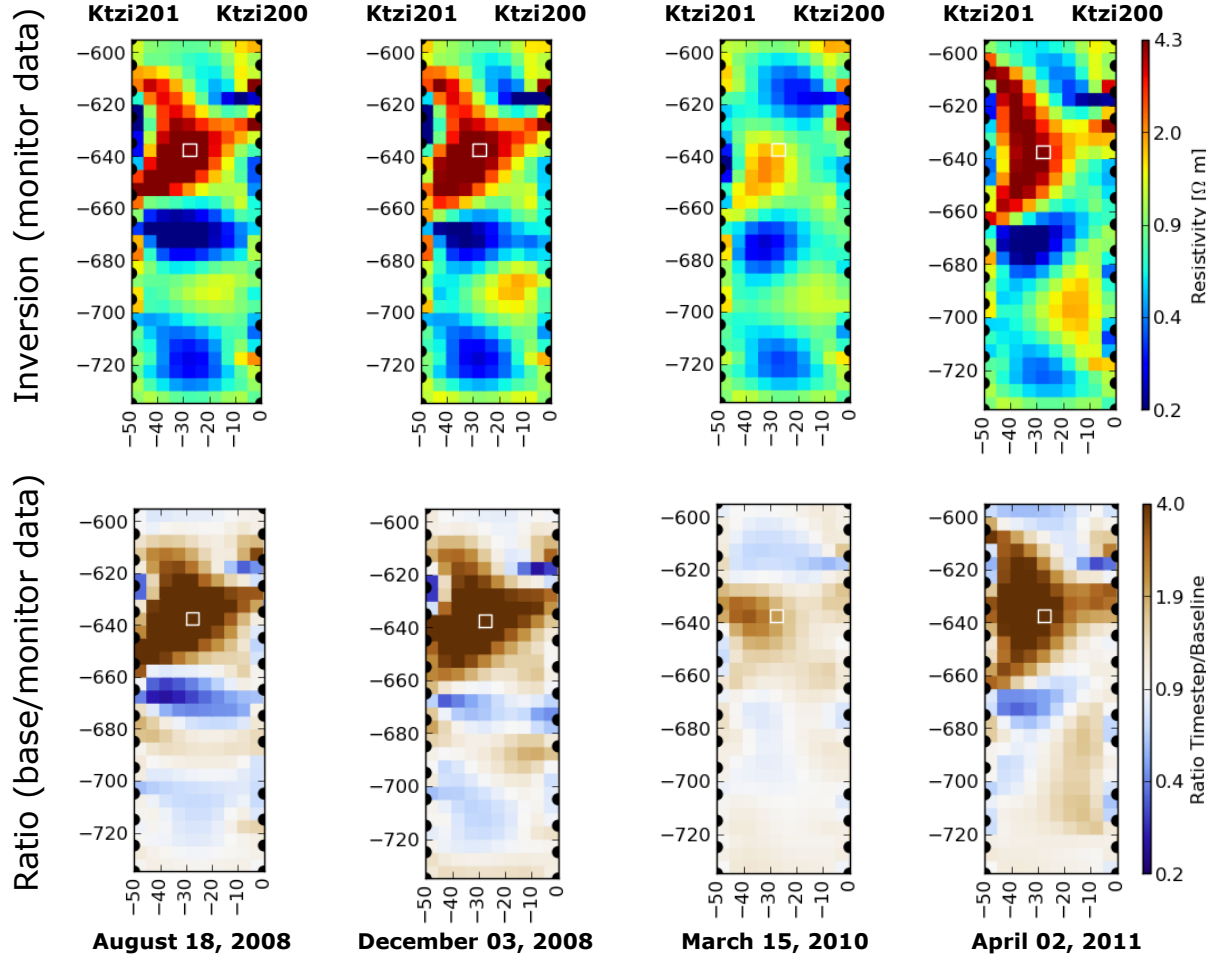
- Predefinition of most essential
parameters:

λ -regularization ,
 z - geometrical weight,
E- error weight

- Separate investigation of 2D inversion results for two observation planes.



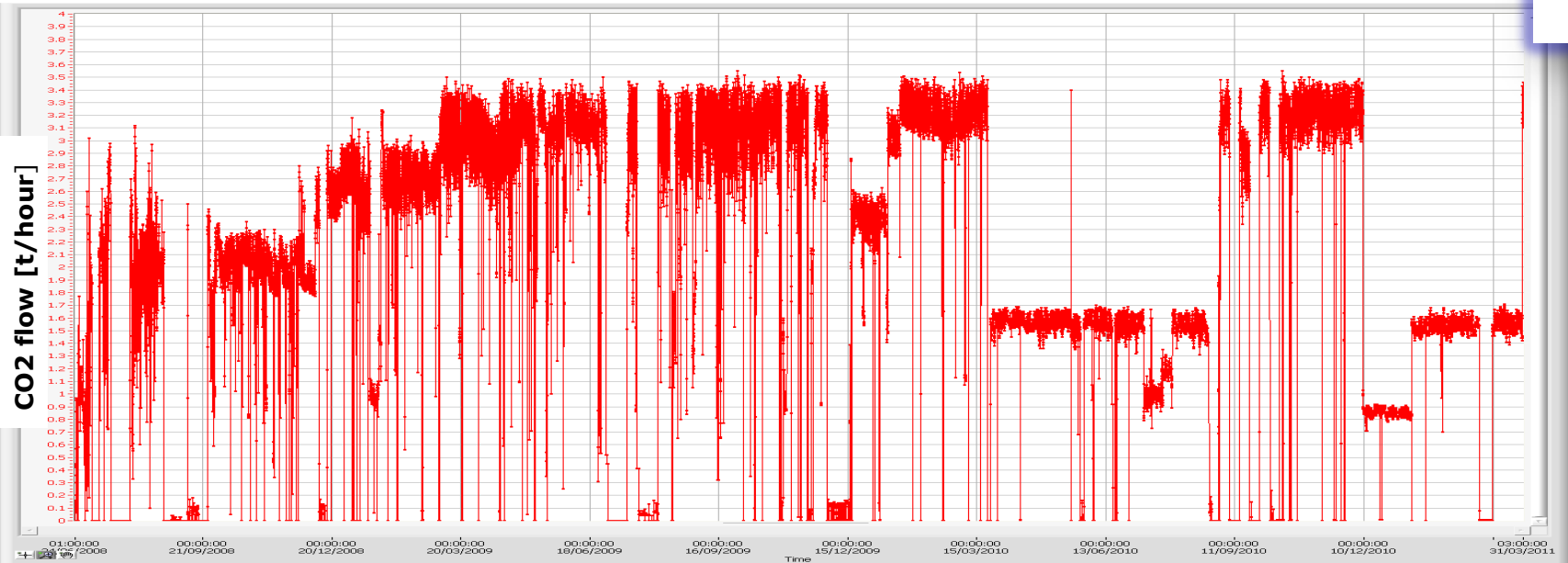
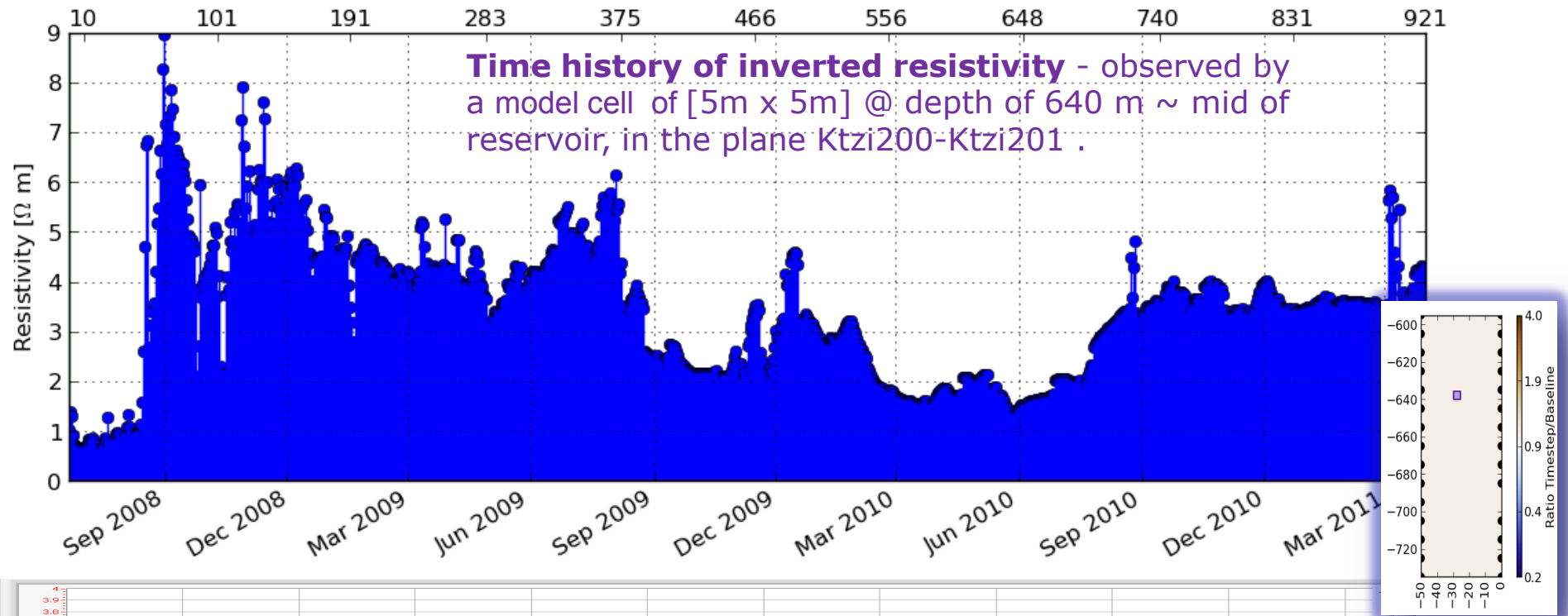
2D Time-lapse Results



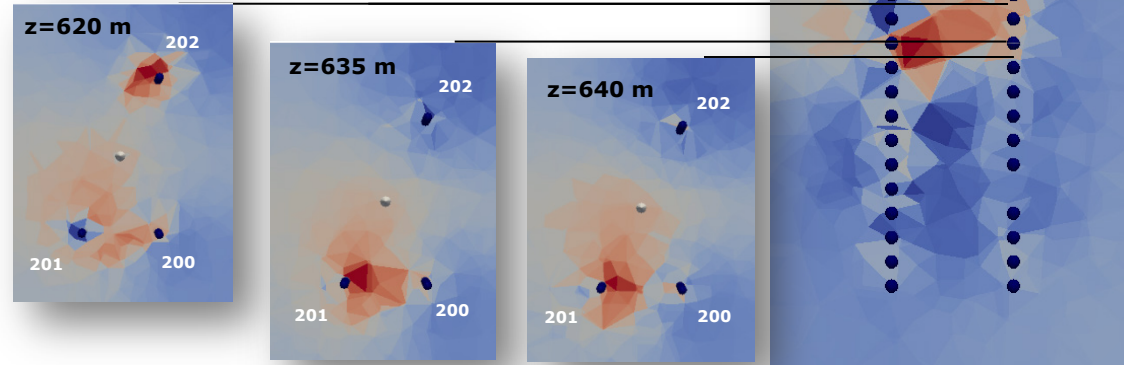
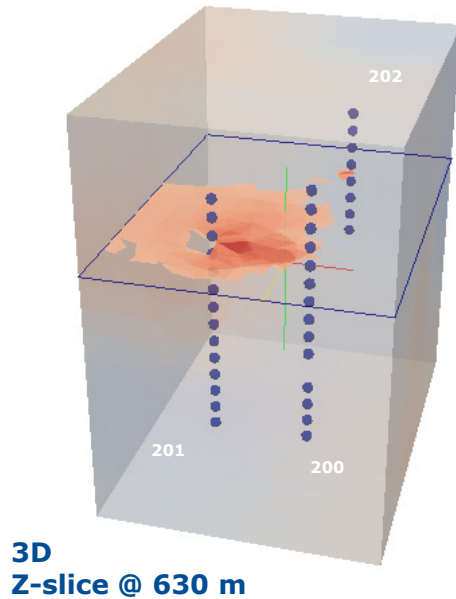
- Gravity driven upward migration (funnel-like shape) was observed since middle of August 2008.

→ steady-state situation reached in December 2008.

- Attenuated resistivity profiles in the observation plane Ktzi200-Ktzi201 for phases of significant reduced injection rate (March – August 2010).
- Good coverage of the injection start phase by frequently measured data sets given.

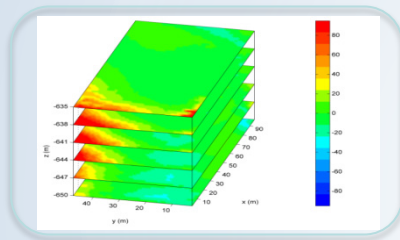


3D Time-lapse Results



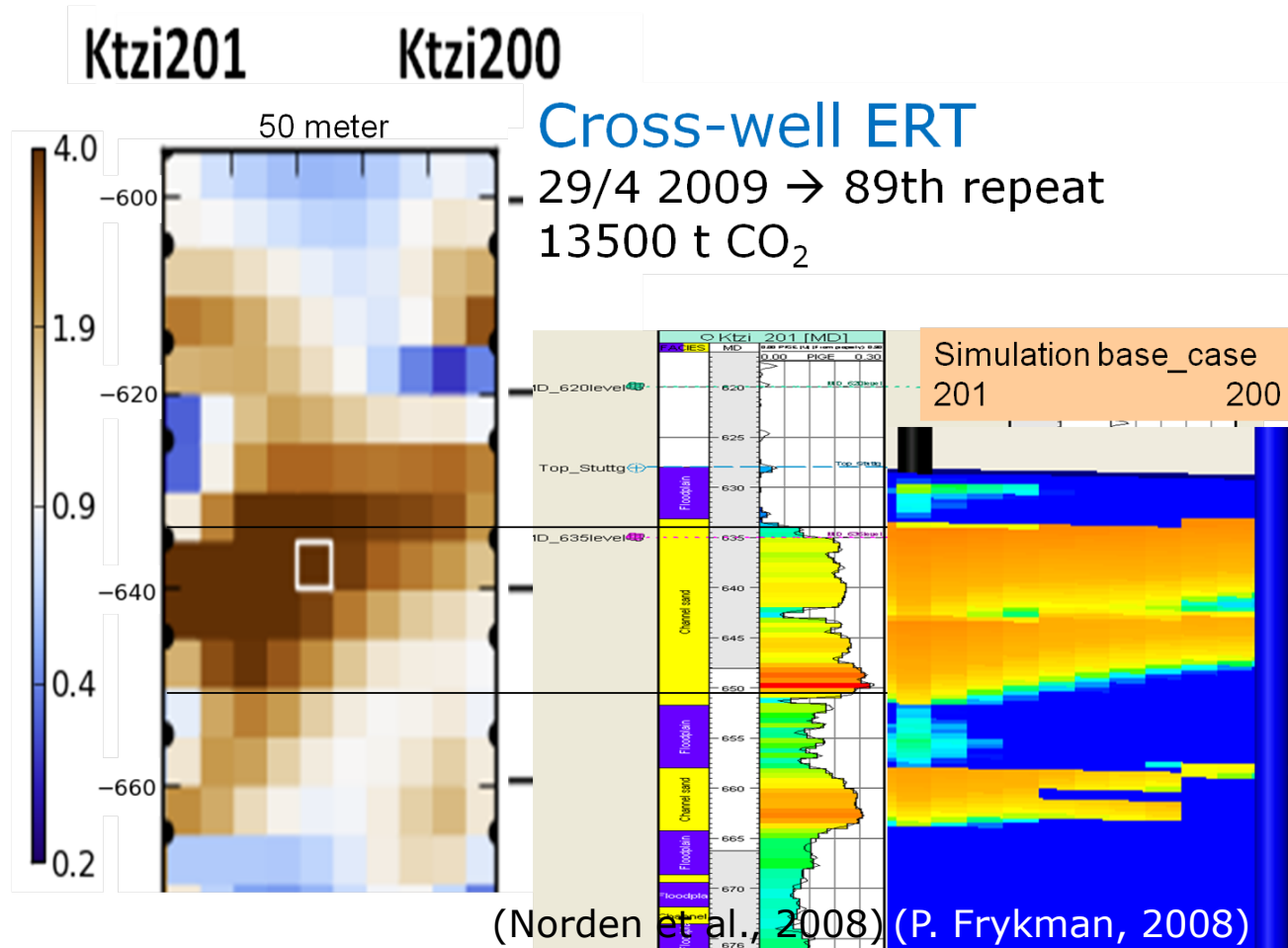
Data set from July 2010

- **Consistent results** in the planes Ktzi200-Ktzi201, and Ktzi200-Ktzi202 obtained by separate 2D calculations. Consistency exists also between the Crosshole and Surface-Downhole evaluation.
- **Significant CO₂ effect** necessary in order to detect the arrival at both observation wells (Ktzi200 / Ktzi202) in the inverted data (true volume effect 1-2 months later).
- **Assumption:** limited 3D effect since Nov 2009 (degradation detected by contact resistances) → handling of **critical electrodes**: some of them have to be excluded from interpretation, and some of them even from the inversion procedure.



Evaluation

Contribution to Data Integration



well	Effective Saturation S_{CO_2}
Ktzi201	60-80 %
Ktzi200	40-60%
Ktzi202	20-30 %

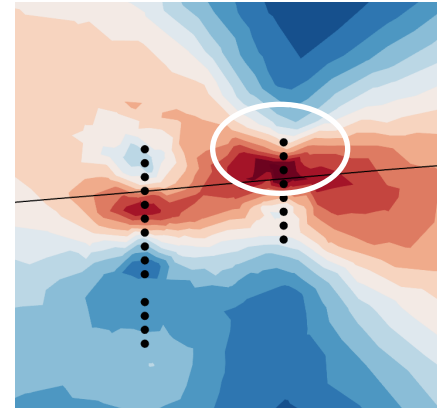
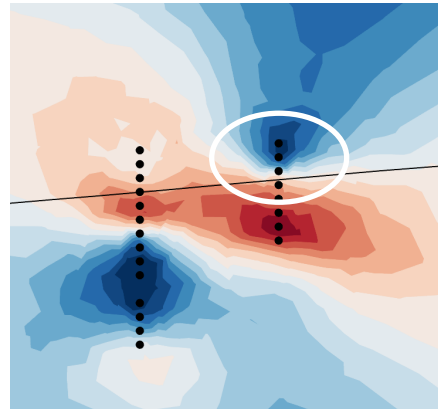
(Ivanova et al., 2011, accepted)

→ **Input into static and dynamic modeling** was started and has to be proven. Available data are on **different scales**, not easy to match them !

Geoelectrical Large-Scale Measurements

November 2008
 → 2nd repeat ,
 4500 t CO₂

April 2009
 → 3rd repeat ,
 13500 t CO₂

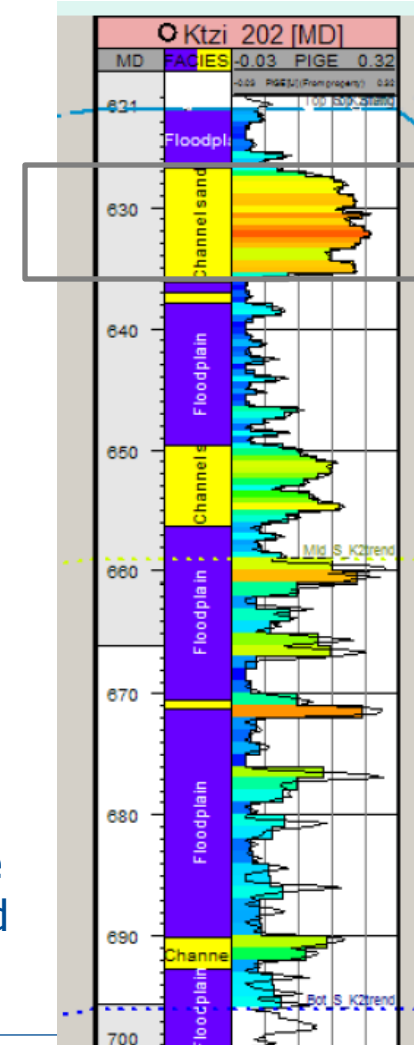


Ktzi200-Ktzi202 plane

Ktzi200-Ktzi202 plane

inversion realization (P. Bergmann, 2011)

- Geophysical monitoring can detect small amounts of CO₂ .
- Further data integration is necessary and can be done in iterative way
- Continued observation of reliability and long-term stability of the geoelectric array provides a valuable contribution to consolidated Performance Assessment (P.A.) work.



(Norden et al., 2008 /
 Frykman et al., 2008)

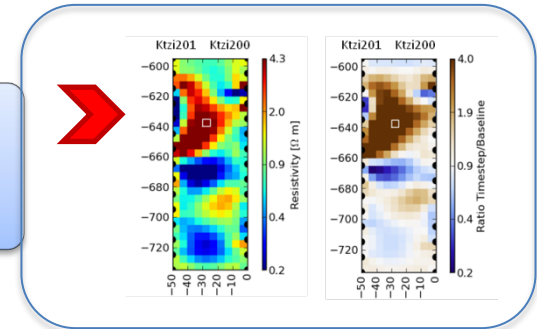
Evaluation & Outlook

- CO2 signature has been detected. Sufficient spatial resolution, but no detailed structural information is available.
- Data sets are consolidated now, updated petrophysical results are available.
- Operating range: extended wellbore area.

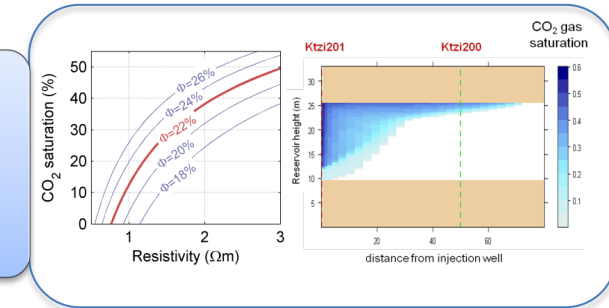


Necessary prerequisite for minimizing uncertainty in the planned quantification.

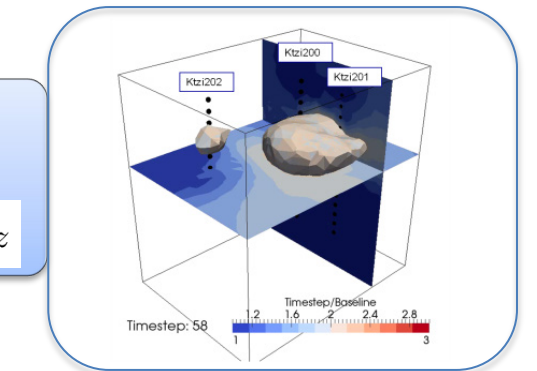
Resistivity Mapping



Petrophysical Conversion (inverse)



Quantification

$$Vol_{CO_2} = \Phi \cdot S_{CO_2} \cdot dx \cdot dy \cdot dz$$


Summary

- The present research work is based on three years of regular injection operation.
- Technology for ERT surface and downhole installation has been successfully site-proofed.
- Conditioning of field data by suitable pre-processing and by adaptation of the inversion module 3D-BERT has been achieved.
- The lowest detection threshold is still under evaluation.
- VERA system is a valuable interface for CSEM/MT measurements.

Objective: to deliver a *realistic and reliable specification* for the ERT-MMS, which can help regulators/operators to decide for this surveillance technique.

Acknowledgements

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We thank all involved persons of the Ketzin Team.

Thank you for your attention.

