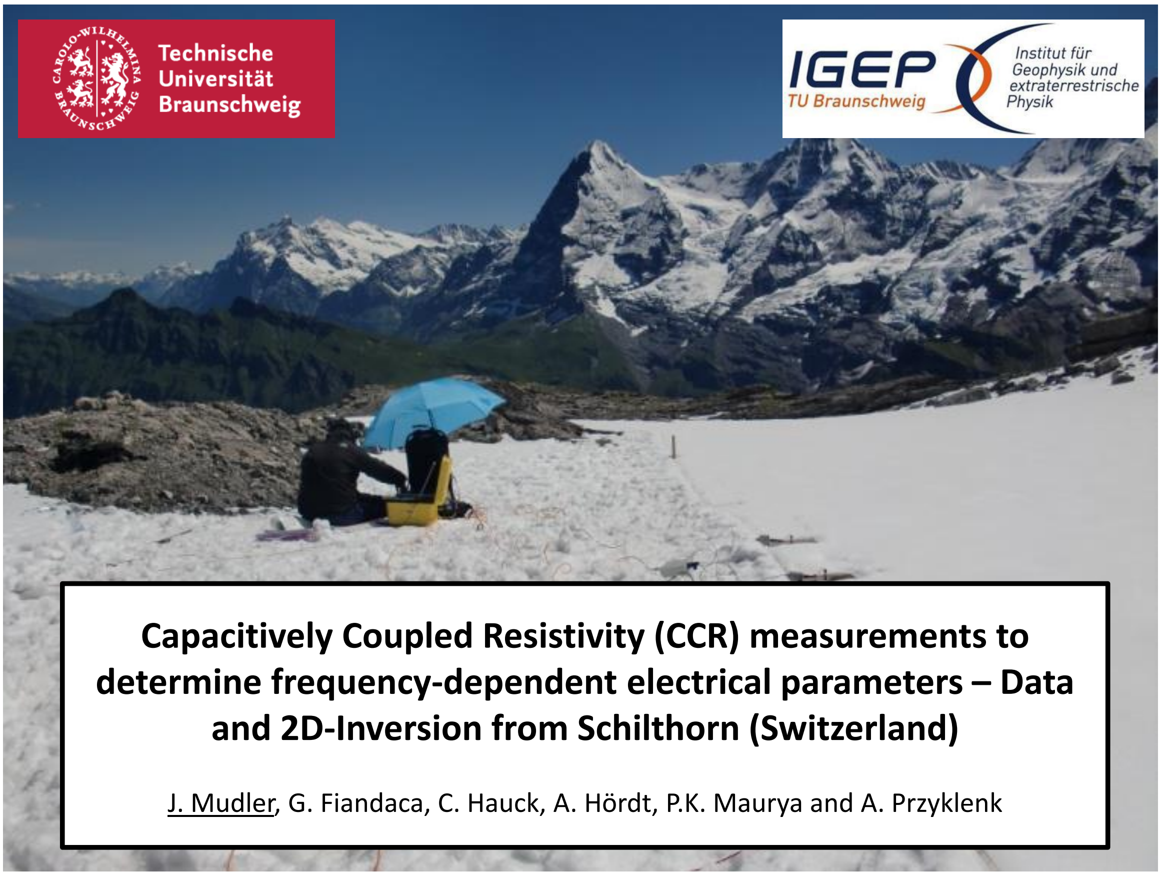
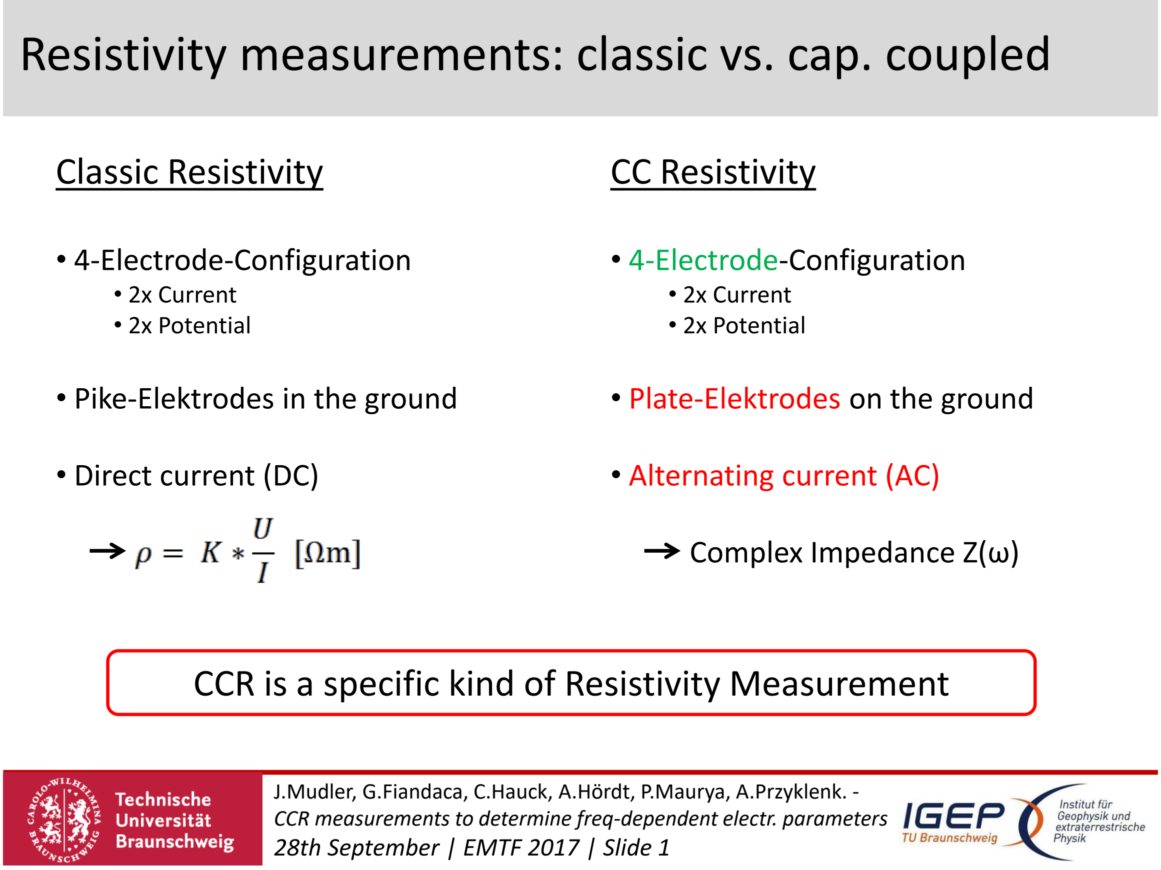


Capacitively Coupled Resistivity (CCR) measurements to determine frequency-dependent electrical parameters – Data and 2D-Inversion from Schilthorn (Switzerland)

J. Mudler, G. Fiandaca, C. Hauck, A. Hördt, P.K. Maurya and A. Przyklenk



Resistivity measurements: classic vs. cap. coupled

Classic Resistivity

- 4-Electrode-Configuration
  - 2x Current
  - 2x Potential
- Pike-Elektrodes in the ground
- Direct current (DC)

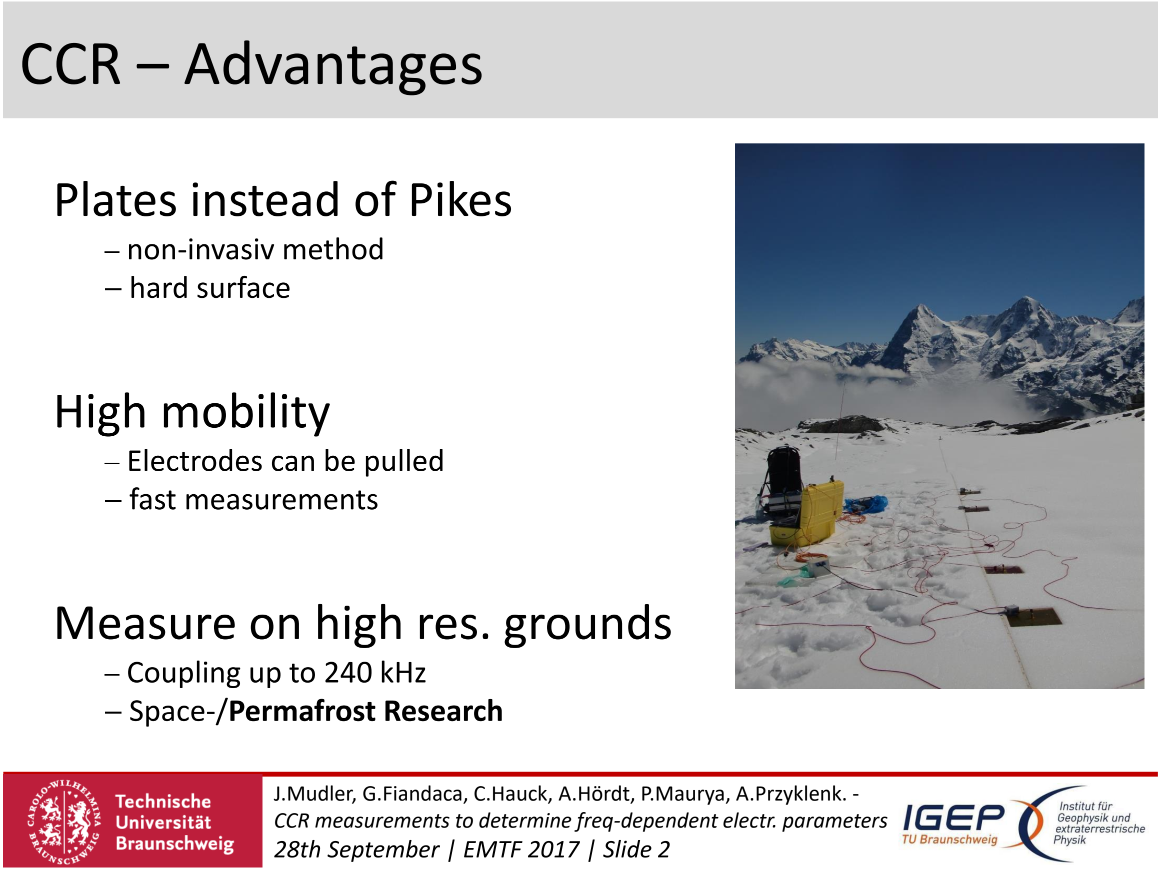
→ $\rho = K * \frac{U}{I}$ [Ωm]

CC Resistivity

- 4-Electrode-Configuration
  - 2x Current
  - 2x Potential
- Plate-Elektrodes on the ground
- Alternating current (AC)

→ Complex Impedance Z(ω)

CCR is a specific kind of Resistivity Measurement



CCR – Advantages

Plates instead of Pikes

- non-invasiv method
- hard surface

High mobility

- Electrodes can be pulled
- fast measurements

Measure on high res. grounds

- Coupling up to 240 kHz
- Space-/**Permafrost Research**

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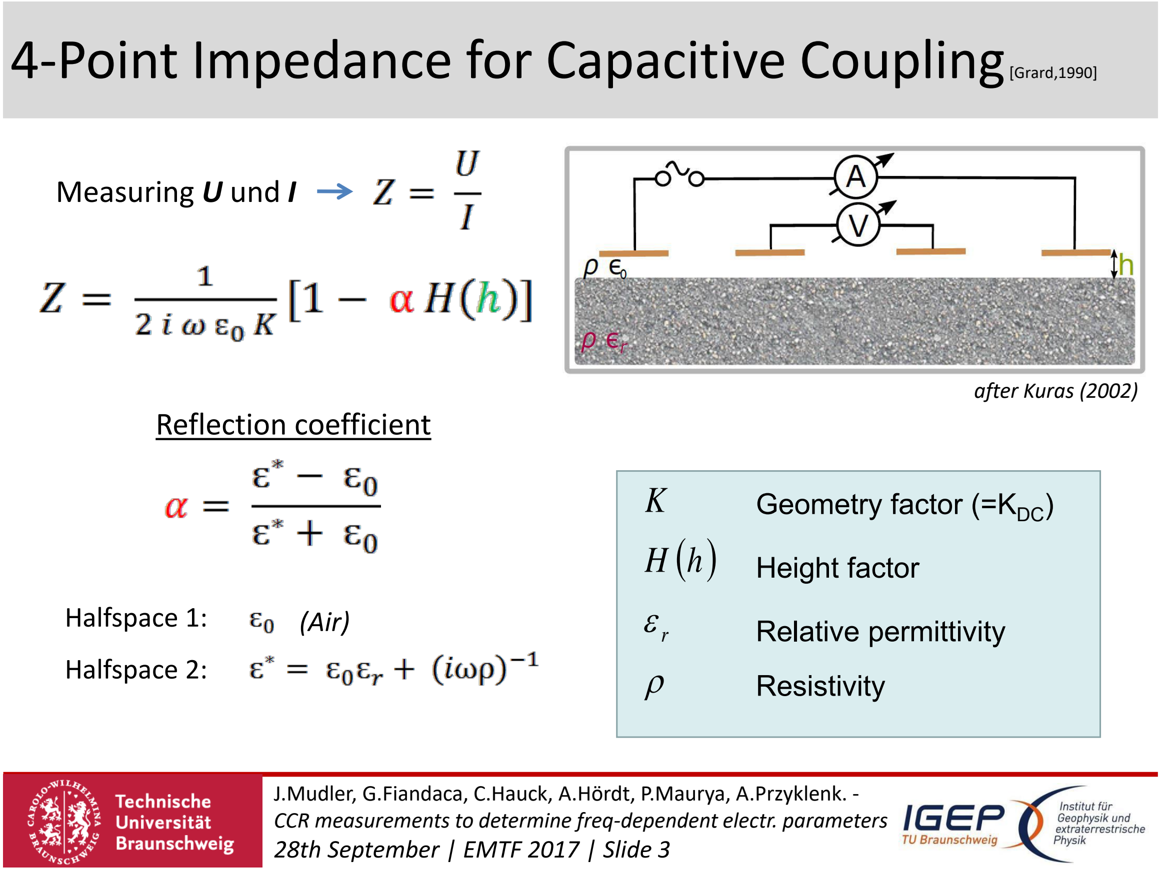

4-Point Impedance for Capacitive Coupling [Grard,1990]

Measuring ***U*** und ***I*** → $Z = \frac{U}{I}$

$$Z = \frac{1}{2\, i\, \omega\, \varepsilon_0\, K}\left[1 - \alpha\, H(h)\right]$$

after Kuras (2002)

Reflection coefficient

$$\alpha = \frac{\varepsilon^* - \varepsilon_0}{\varepsilon^* + \varepsilon_0}$$

Halfspace 1: ε_0 *(Air)*

Halfspace 2: $\varepsilon^* = \varepsilon_0 \varepsilon_r + (i\omega\rho)^{-1}$

K	Geometry factor (=K_{DC})
$H(h)$	Height factor
ε_r	Relative permittivity
ρ	Resistivity

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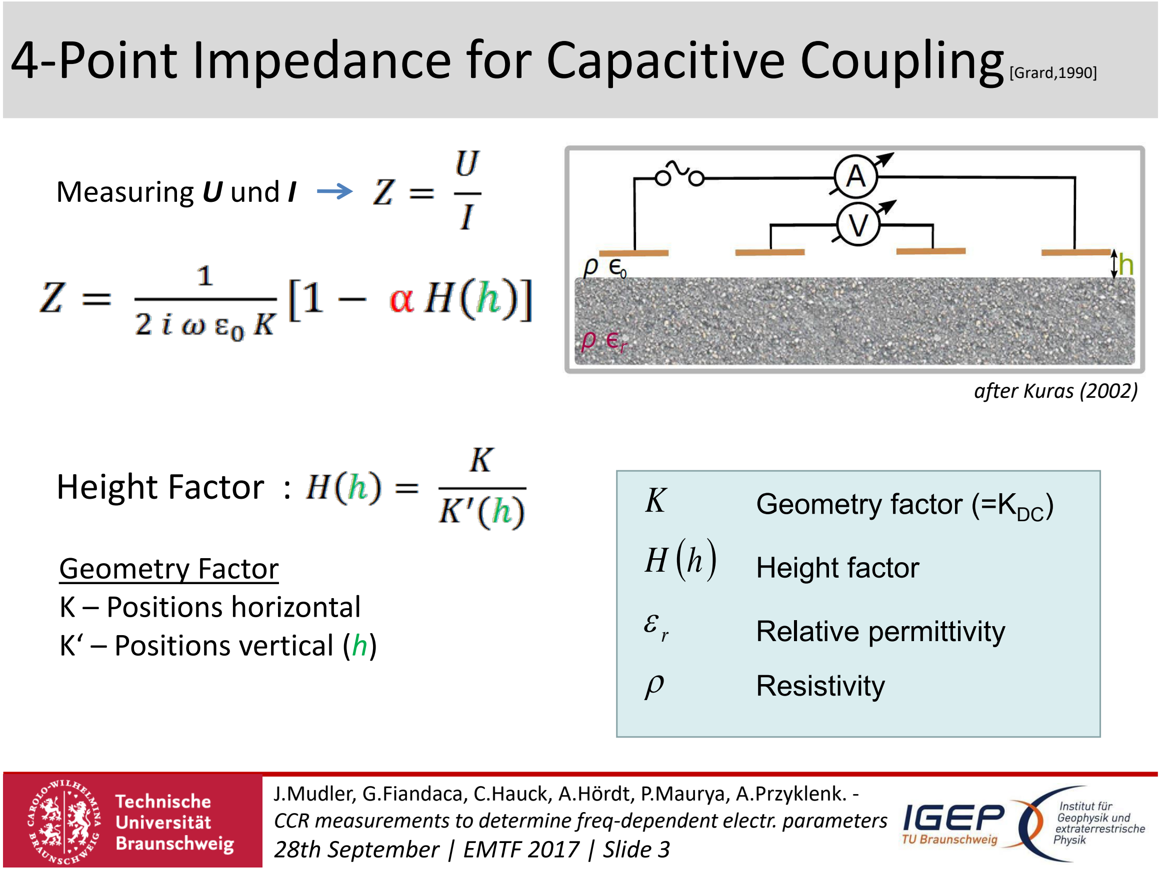

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after Kuras (2002)

Height Factor : $H(h) = \frac{K}{K'(h)}$

Geometry Factor

K – Positions horizontal

K' – Positions vertical (h)

K	Geometry factor (=K_{DC})
$H(h)$	Height factor
ε_r	Relative permittivity
ρ	Resistivity

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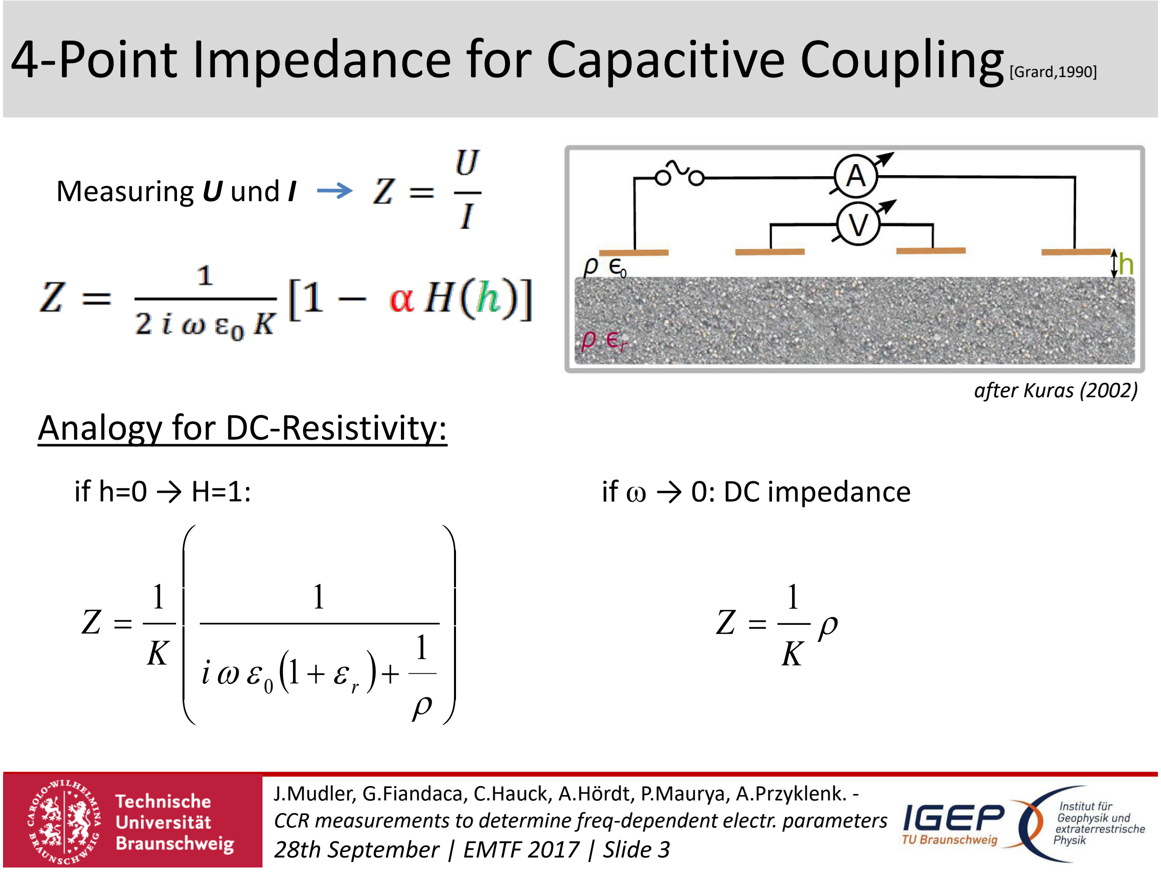

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after Kuras (2002)

Analogy for DC-Resistivity:

if h=0 → H=1:

$$Z = \frac{1}{K}\left(\frac{1}{i\,\omega\,\varepsilon_0(1+\varepsilon_r)+\frac{1}{\rho}}\right)$$

if ω → 0: DC impedance

$$Z = \frac{1}{K}\rho$$

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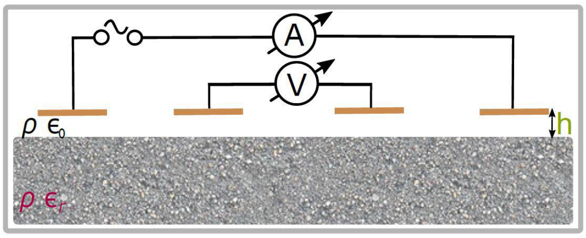
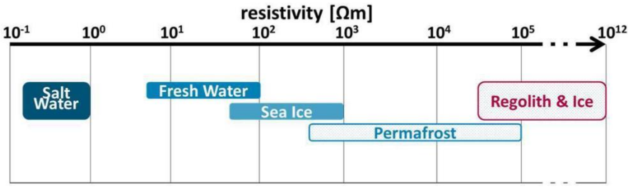


after Kuras (2002)

Conventionel CCR determines just the Resistivity ρ with fix Frequency

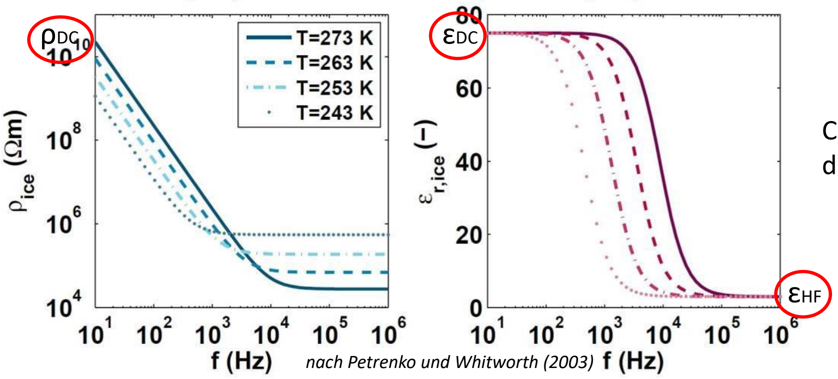
<u>Our Goal</u>: Spectral Measurements and Determination of **ρ(f) and ε_r(f)**

Spectral Information



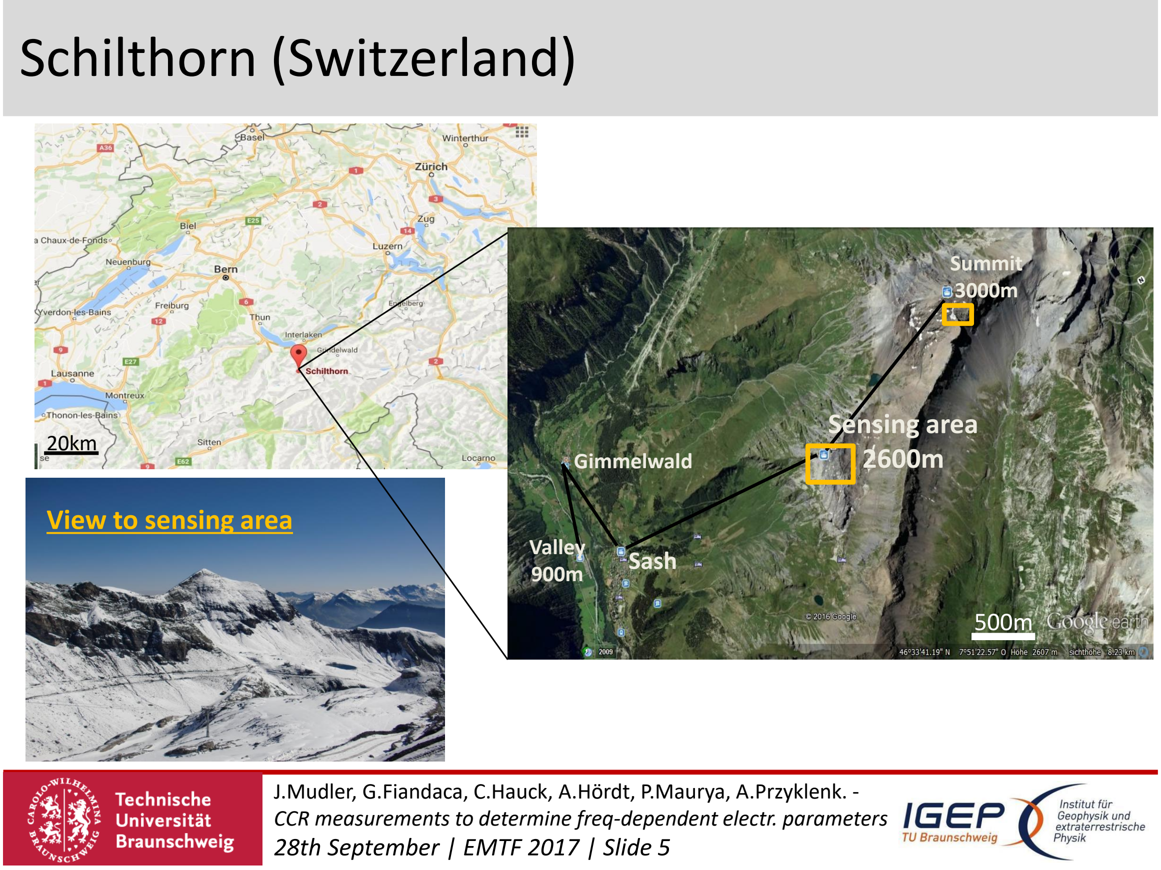
nach Palacky (1988)

Over resistive ground:
both ρ and ε are relevant



nach Petrenko und Whitworth (2003)

Characteristic frequency dependence



Schilthorn (Switzerland)

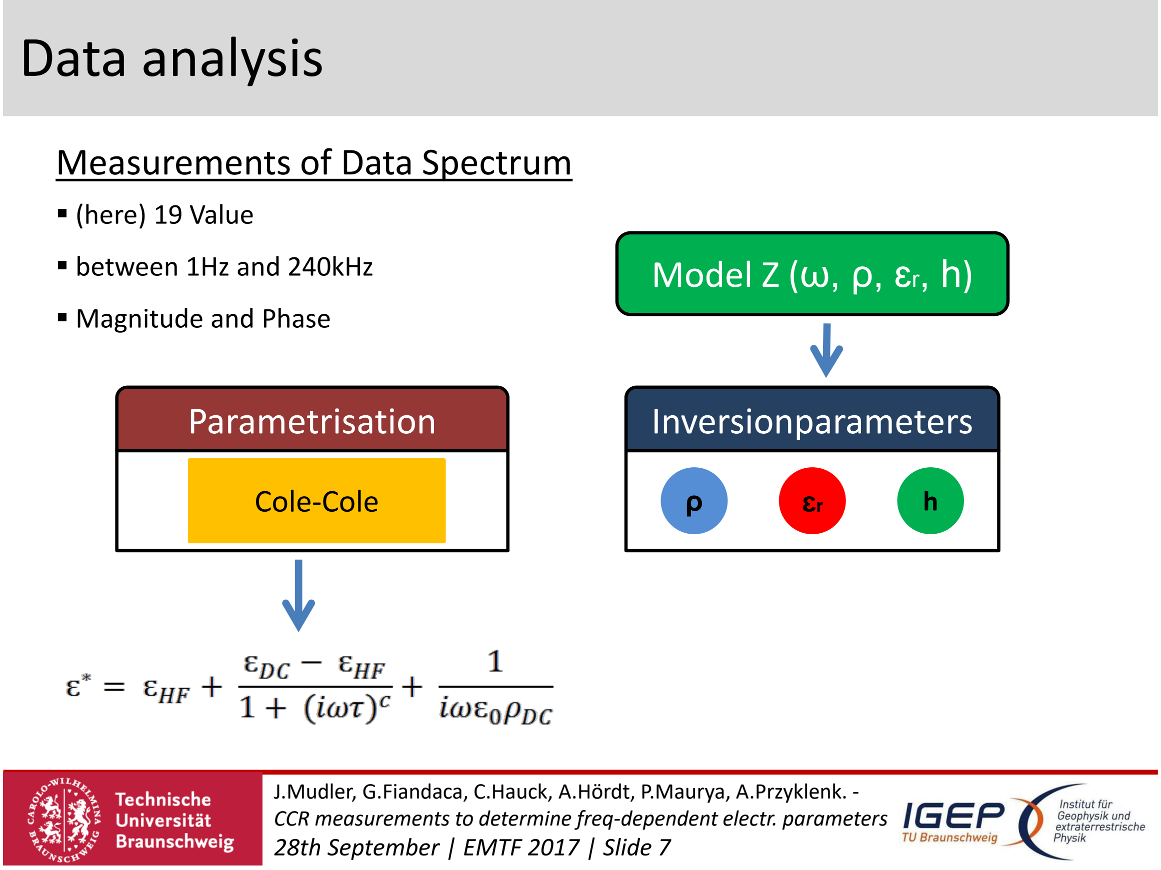
View to sensing area

Measurements

- Summer 2016 and 2017
- Measured on Ice-/Snowsurface
- Additionally: Snowdepth

System from *Radic Research*

- Electrodes isolated with capton
- Galvanically decoupled
- Frequnecy range 1 Hz – 240 kHz



Data analysis

Measurements of Data Spectrum

- (here) 19 Value
- between 1Hz and 240kHz
- Magnitude and Phase

Model Z (ω, ρ, ε_r, h)

Parametrisation

Cole-Cole

Inversionparameters

ρ ε_r h

$$\varepsilon^* = \varepsilon_{HF} + \frac{\varepsilon_{DC} - \varepsilon_{HF}}{1 + (i\omega\tau)^c} + \frac{1}{i\omega\varepsilon_0\rho_{DC}}$$

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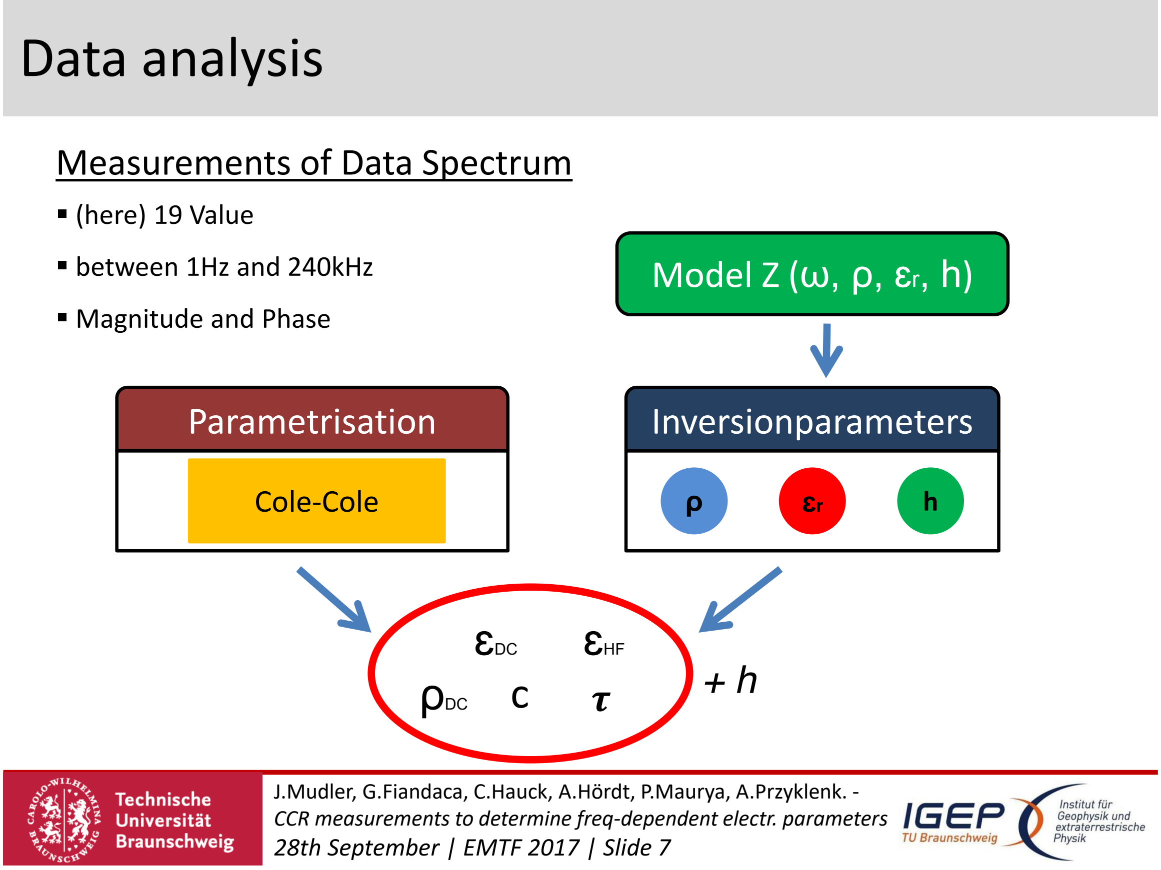

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Cole-Cole

Inversionparameters

ρ ε_r h

ε_{DC} ε_{HF}

ρ_{DC} c τ

$+ h$

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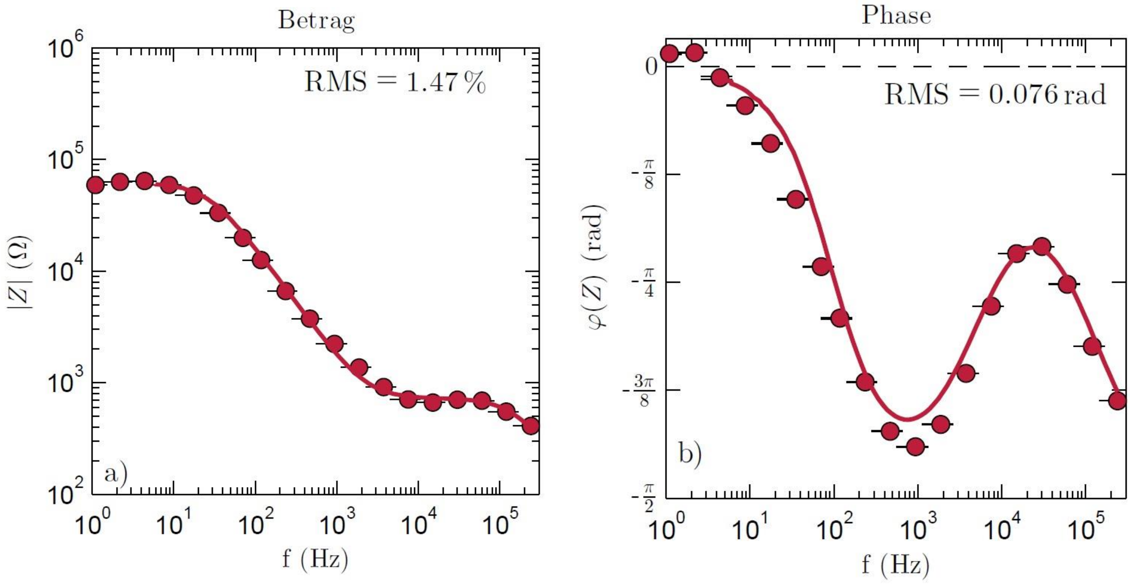
Results – Spectra



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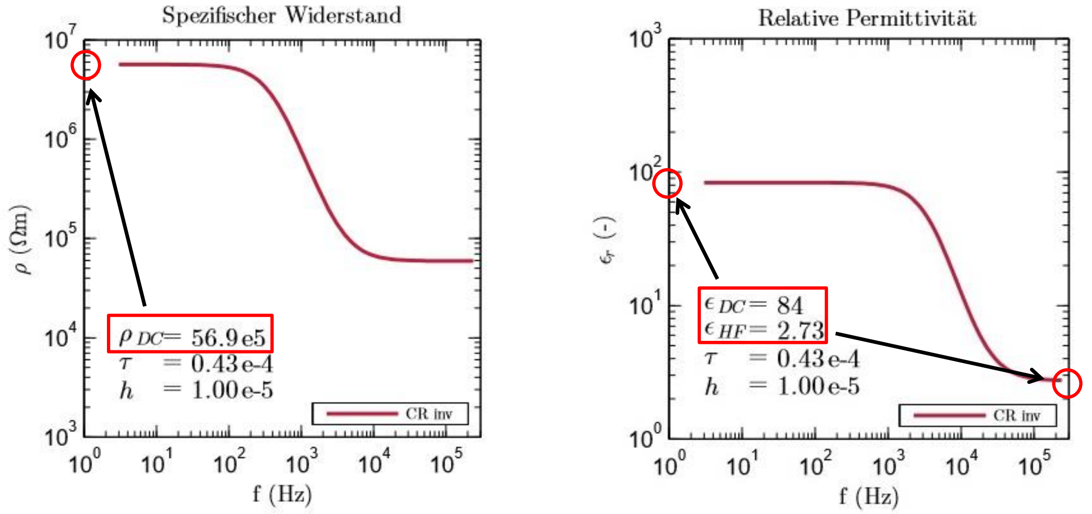
Results – Spectra



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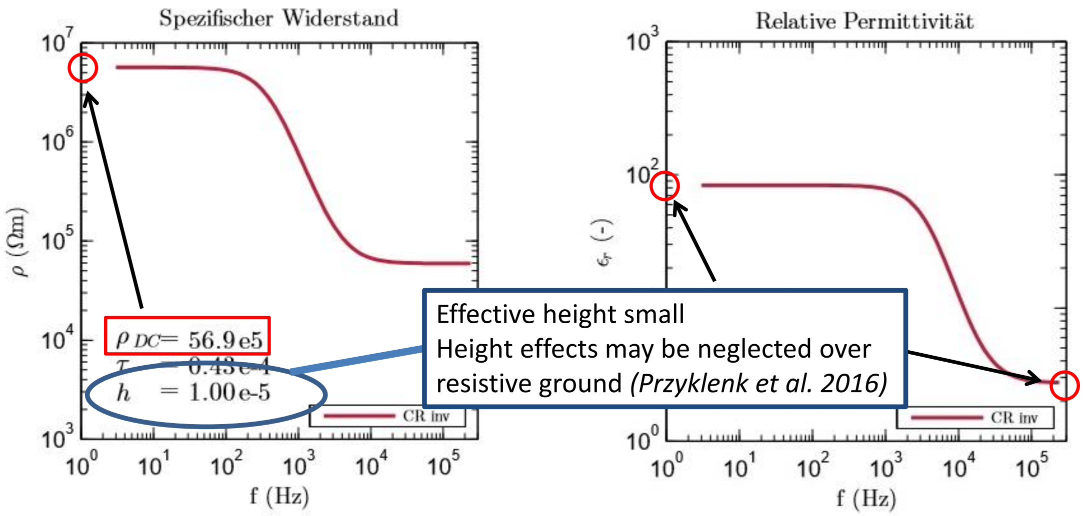

Effective height small
Height effects may be neglected over resistive ground *(Przyklenk et al. 2016)*

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Inversion of the Data

Variant 1: Isolated Inversion of all Measured Points/Spectra

- homogeneous Halfspace
- presented as Pseudosection

Variant 2: 2D-Inversion AarhusInv

- Inversiontool from the Hydrogeophysics Group, University of Aarhus for several geophysical Methods
- combined Inversion of all measured Spectra
- Implemented Cole-Cole-Model
- Two-dimensional distribution of the modelparameters ρ_{DC}, ε_{DC}, ε_{HF}, τ, c

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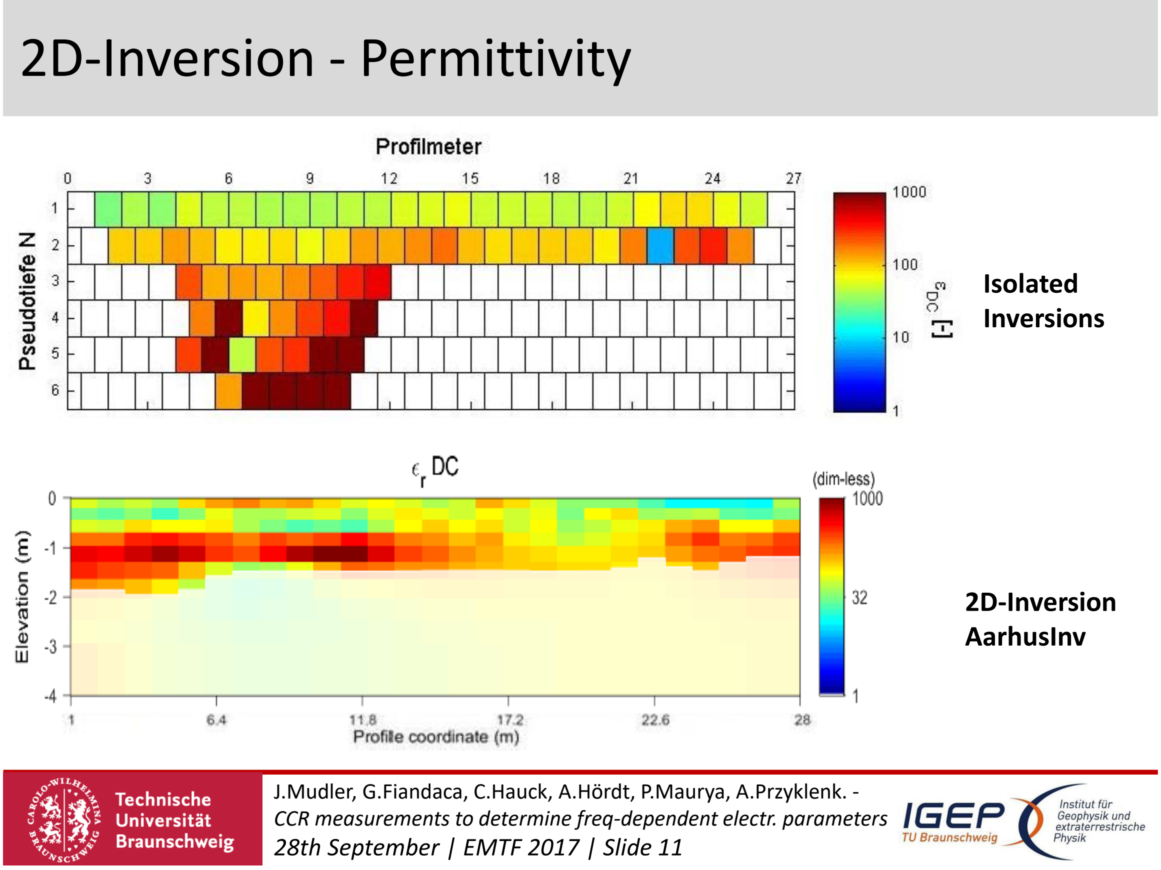

2D-Inversion - Permittivity

Isolated Inversions

2D-Inversion AarhusInv

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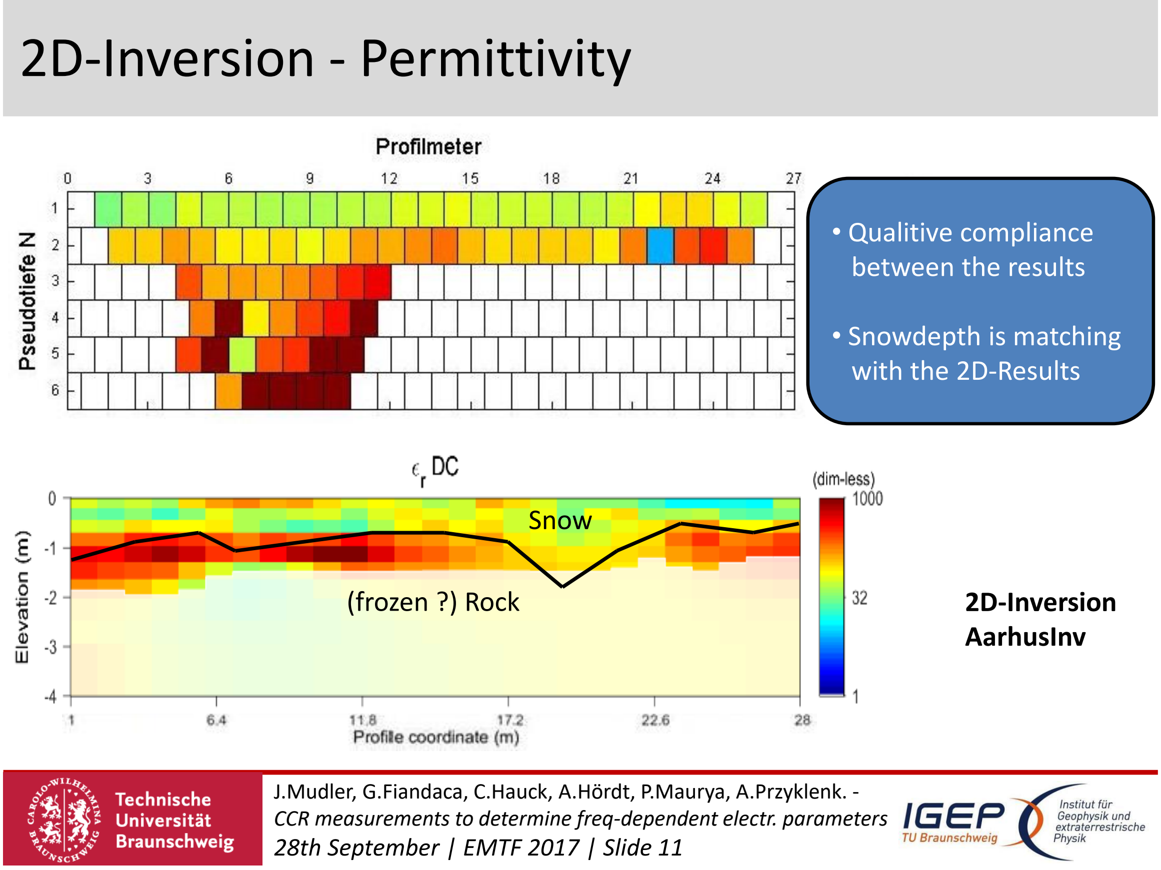

2D-Inversion - Permittivity

- Qualitive compliance between the results
- Snowdepth is matching with the 2D-Results

2D-Inversion AarhusInv

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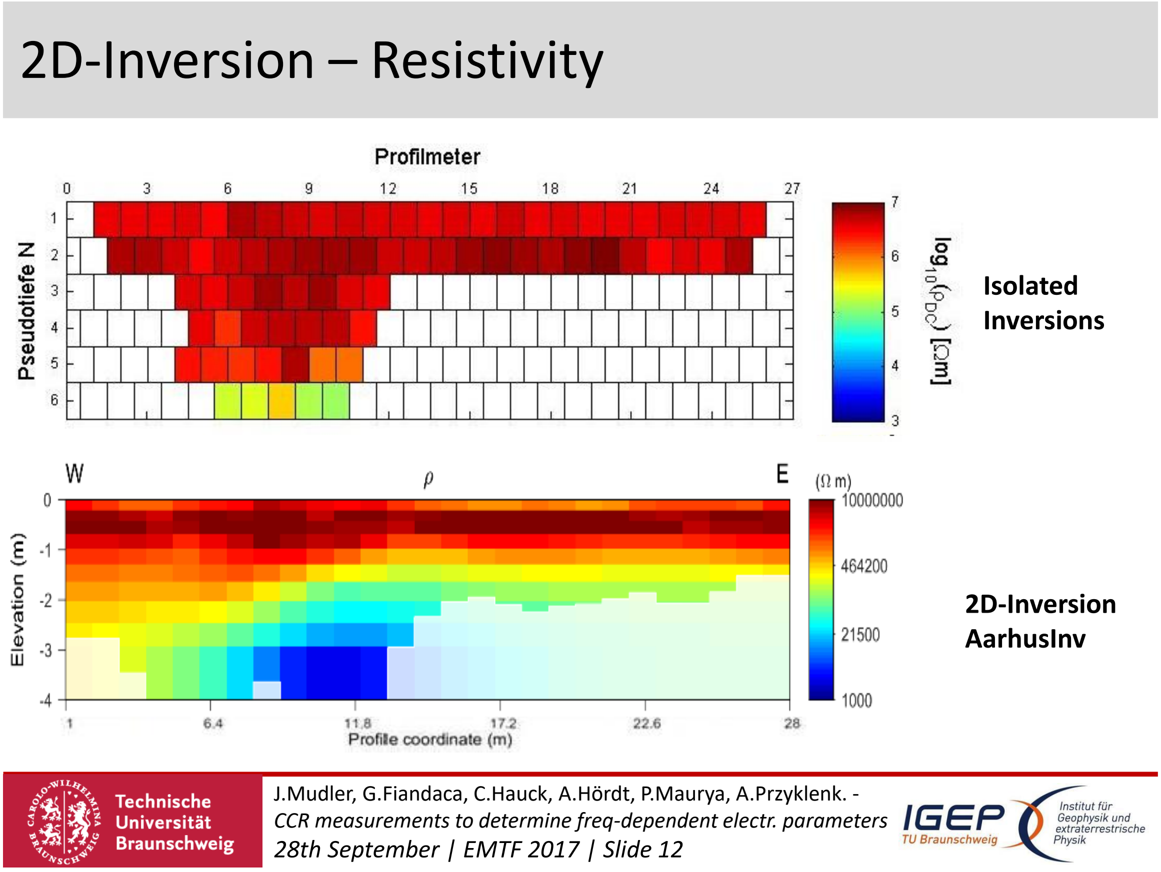

2D-Inversion – Resistivity

Isolated Inversions

2D-Inversion AarhusInv

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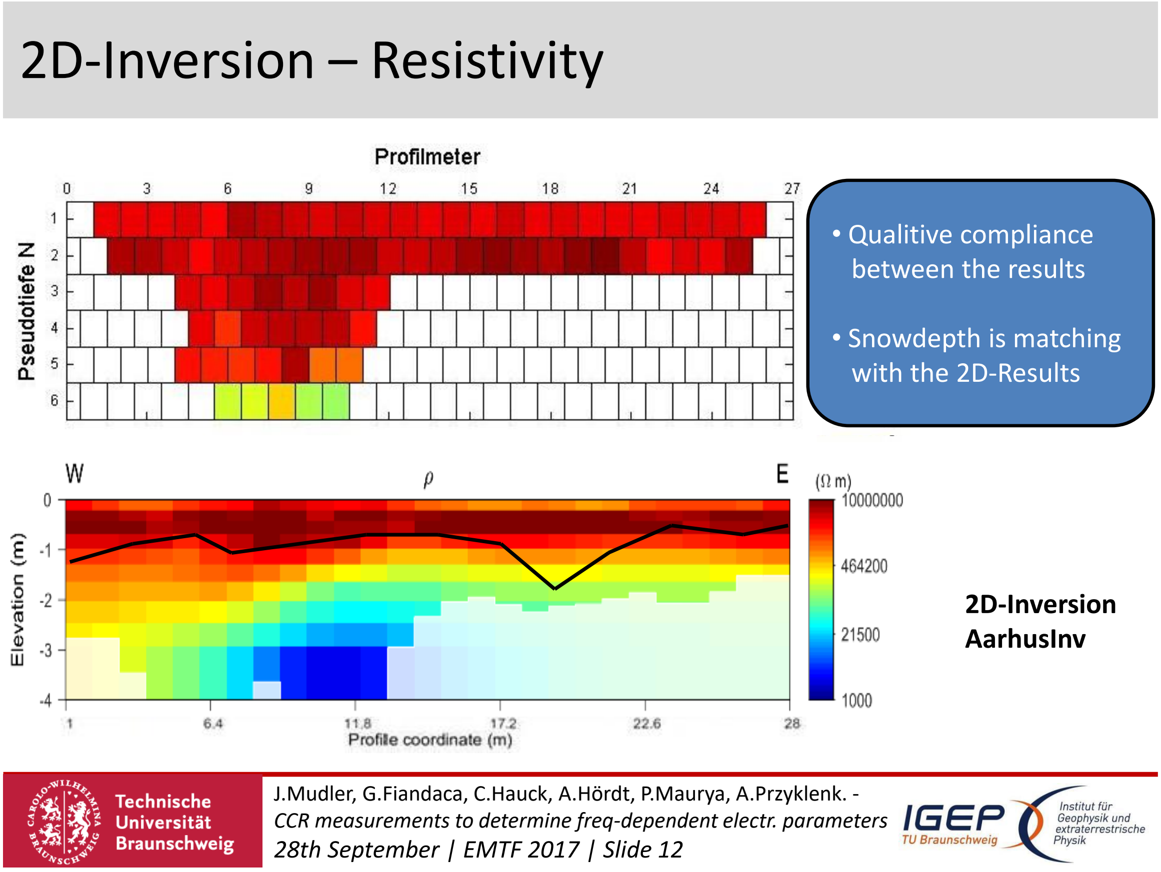

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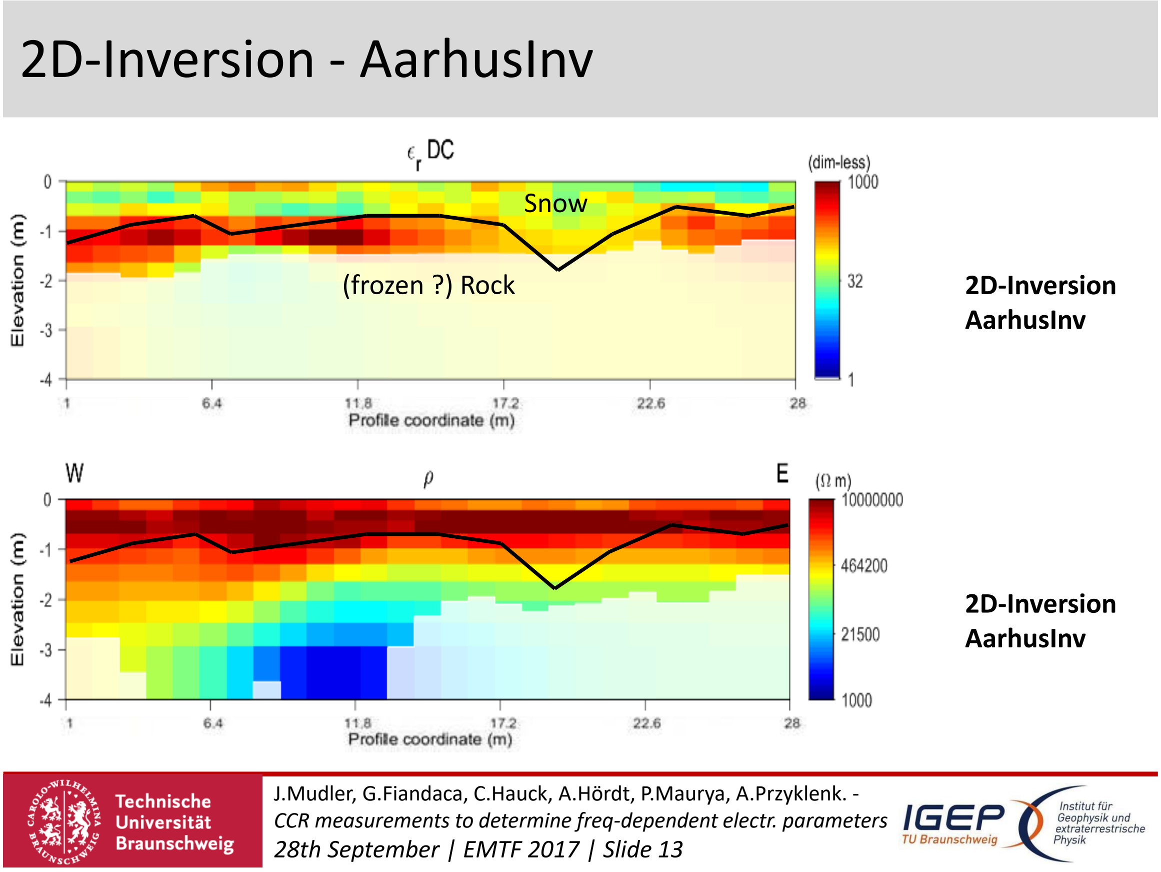

2D-Inversion - AarhusInv

2D-Inversion AarhusInv

2D-Inversion AarhusInv

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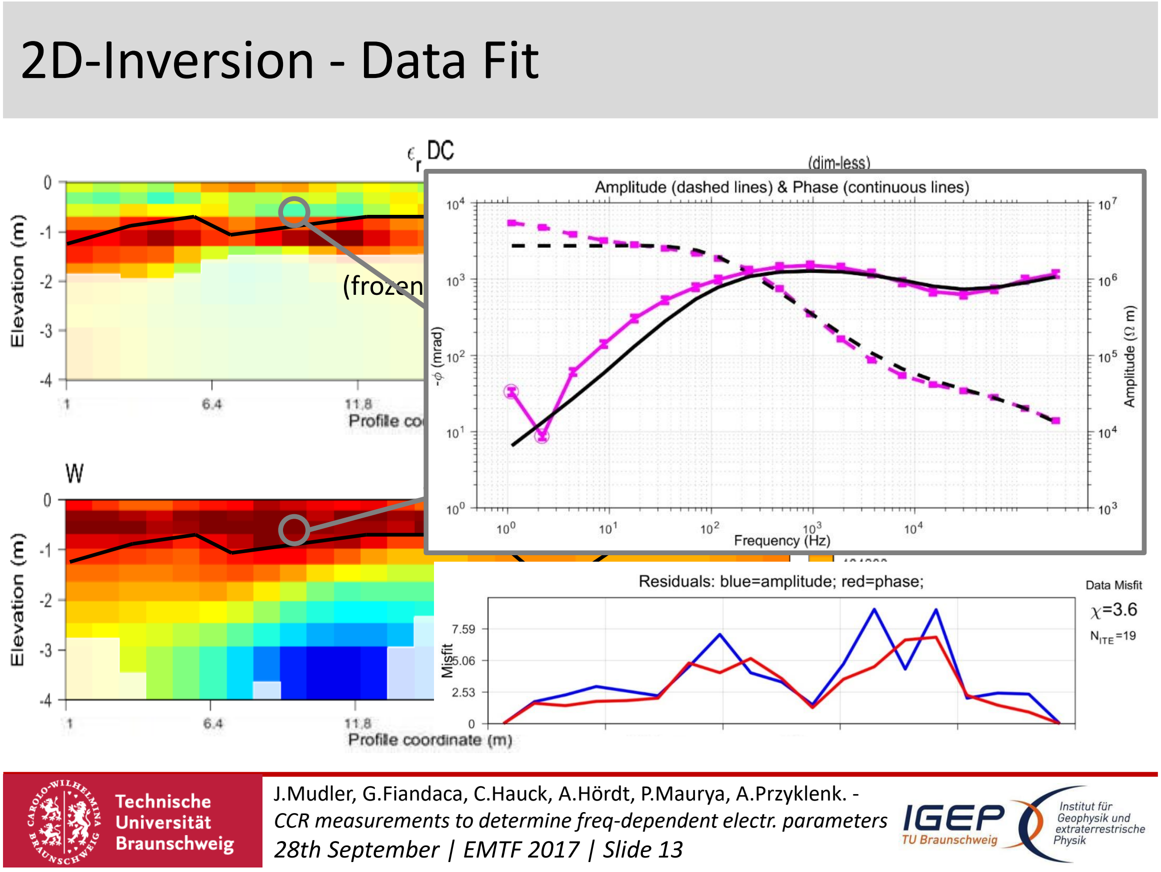

2D-Inversion - Data Fit

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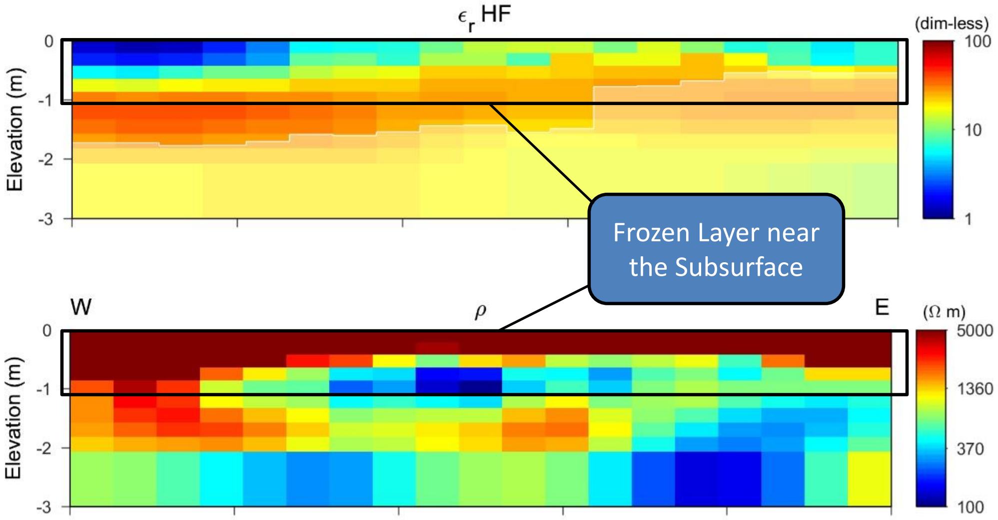
2D-Inversion - AarhusInv



Frozen Layer near the Subsurface

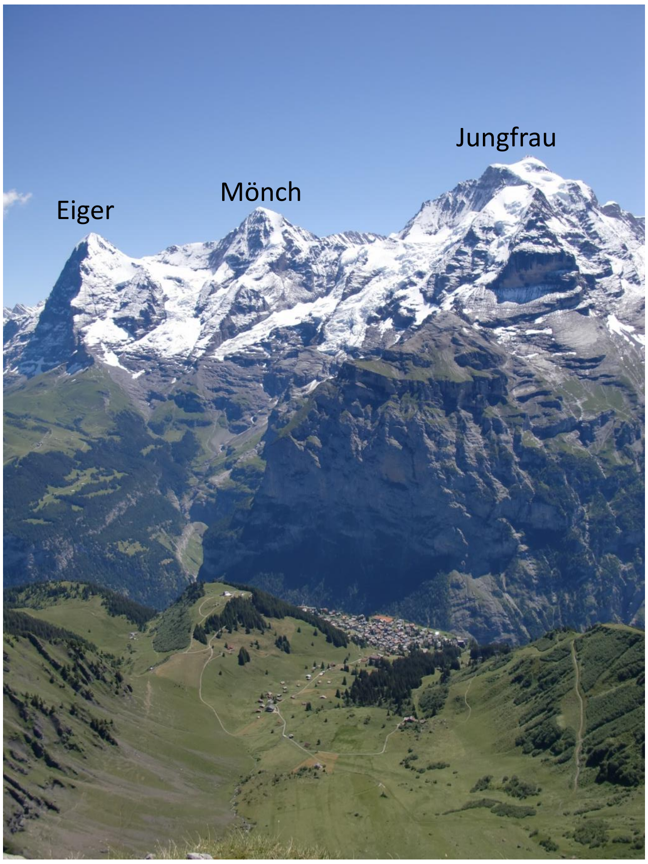
Conclusion

- Measurements of spectral complex impedance (*1 Hz – 240 kHz*) with Capacitively Coupled Resistivity method
- Determination of Resistivity ρ **and** Permittivity ε_r
- Good fit of the measured data using the cole-cole model
- Good results with the new 2D-Inversion

Outlook:

- Deeper Measurements in Subsurface; new device
- Investigation and Interpretation of the Permafrostlayer

Thank you for your Attention



Acknowledments

- DFG (Ho1506/23)
- Aarhus University
- Christian Kulüke and Hermann Stebner

SIP vs. CCR

Spectral Induced Polarization	Capacitively Coupled Resistivity
• 1mHz – 1kHz	• few Hz – 240kHz
• Phase in mrad	• Phase in rad
• IP-Effect	• Polarization
• Modell e.g. *Mashall & Madden*	• Ice/Water Dipolcharacter

⇨ Measured variables are the same, but Effects are different

„CCR = highfrequency SIP"

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