High-resolution 4D GPR data acquisition strategy to monitor fast and small-scale subsurface flow processes

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Motivation

- Understanding fast (minutes) and small scale (mm-cm) subsurface flow processes demands for measurement techniques with high temporal and spatial resolution

- Ground-penetrating radar (GPR) considered as a suitable non/invasice geophysical tool for efficiently monitoring such flow processes in 4D (repeated 3D surveys)

- Although case studies indicate the potential of 4D GPR, little is known regarding the resolution and repeatability limits

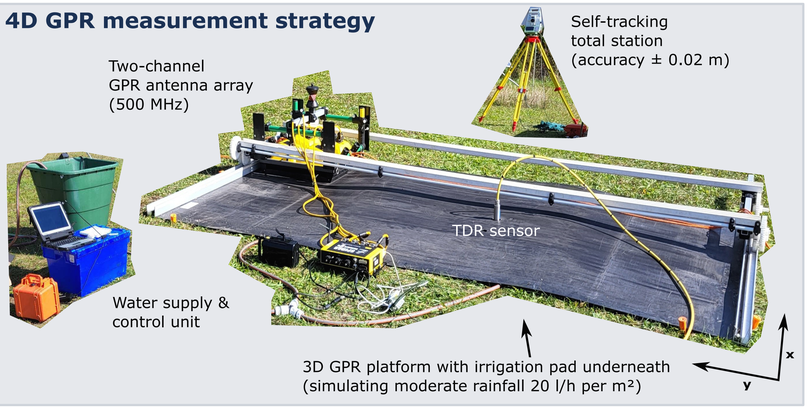
- We present systematic irrigation experiments to investigate and quantify these limits

Systematic irrigation experiments monitored with GPR

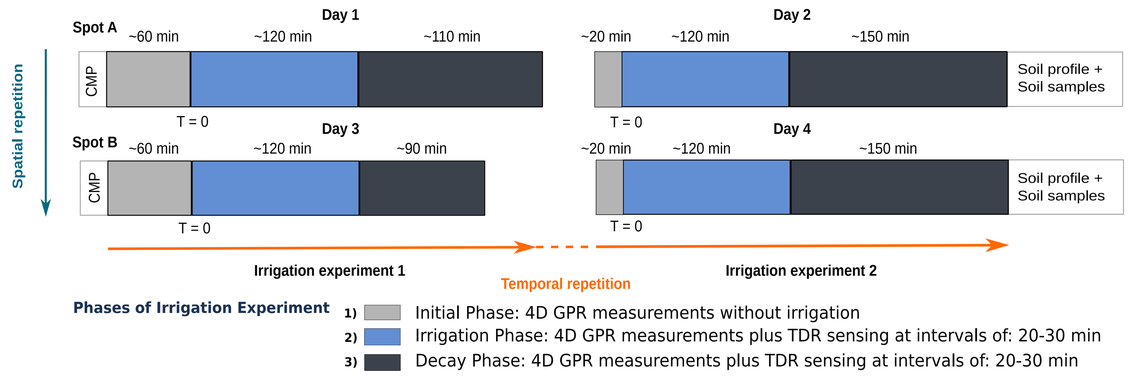
Field location

- Field plot (seperated into two areas (spot A, B) at the Fieldlab for Digital Agriculture of the Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) in Potsdam, Germany
- At each spot, **two recurrent irrigation experiments** monitored with repeated 3D GPR measurements (4D GPR)

4D GPR measurement strategy



Time schedule of experiment



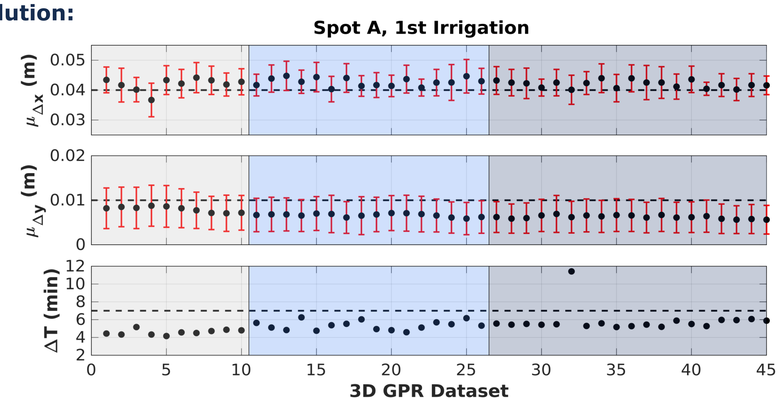
Evaluation of 4D GPR data

Continuity of data acquisition, resolution:

- Evaluating accuracy in positioning, consistent crossline (Δx) and inline (Δy), consistent temporal interval (ΔT) between individual 3D data sets

Target values for resolution (dashed black lines in figure):
- spatial: Δx, Δy < 1/4 λ (< 0.04 m at our field site)
- temporal: ΔT < 10 min

Experimental values for resolution:
- spatial: Δx, Δy < 0.04 m
- temporal: ΔT < 7 min

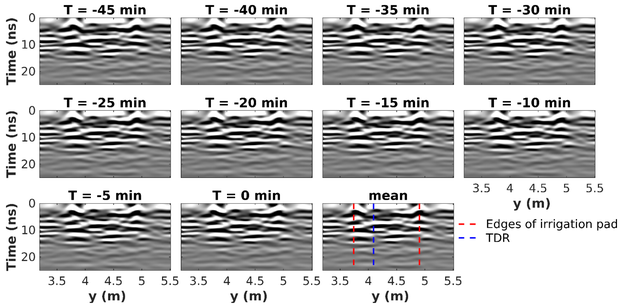


μ(Δx) - mean crossline trace spacing within single 3D GPR data set

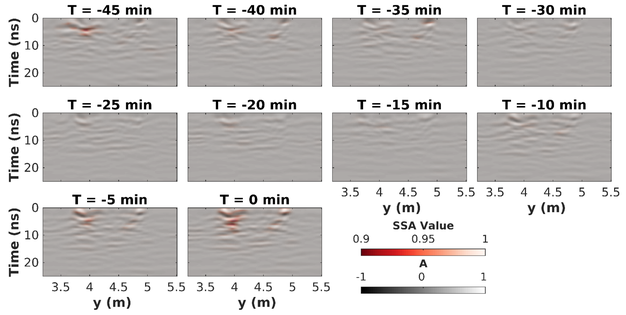
μ(Δy) - mean inline trace spacing within single 3D GPR data set

Background variations, repeatability:

- Evaluating data recorded in initial phase using
  1) **amplitude differences** between mean 3D data set and single 3D data sets
  2) attribute-analysis using the **structural similarity attribute (SSA)**, which is sensitive to traveltime changes
- Small amplitude differences and little shifts in traveltime (high SSA values): **high 4D GPR data repeatability**
- **Experiment specific SSA threshold**: SSA values < 0.9 indicate changes induced by water infiltration



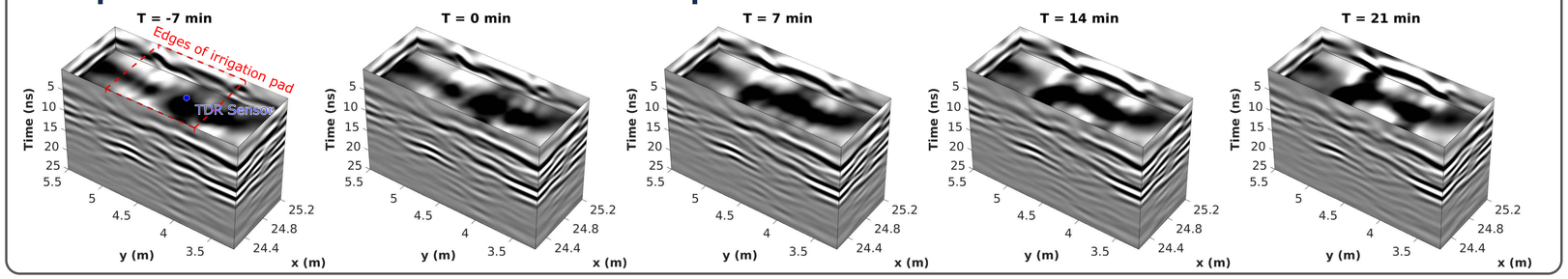
Selected profile extracted from 3D GPR data sets recorded during initial phase at spot A compared to corresponding mean profile



Selected profile of amplitude differences (gray) and structural similarity attribute (SSA) (red) between mean and selected profiles from initial phase at spot A

Snapshot of 3D GPR data sets recorded at spot A

Total amount of recorded data:189 3D GPR data sets in 4 days!



Summary

- 4D GPR measurement strategy and analysis with structural similarity attribute (SSA) provides information about small scale, near-surface flow processes with:
  high repeatablility (SSA < 0.9, mean amplitude difference of ~1%)
  so far unreached temporal and spatial resolution of ~7 min and ~0.03 m

- Monitoring of initial conditions important for analyzing data quality and defining SSA threshold for later data analysis and interpretation