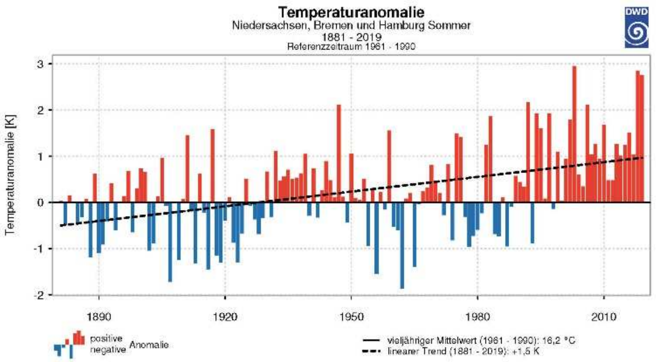
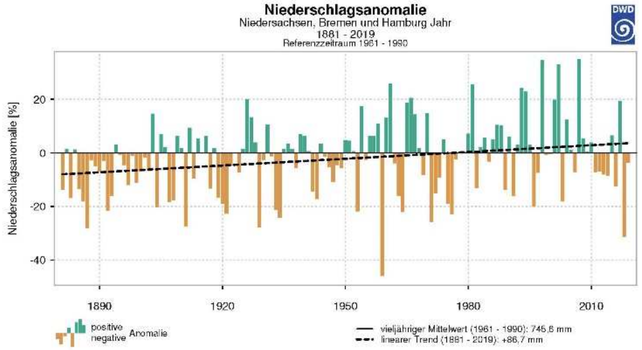
Heterogeneity of unsaturated flow measured in the dry summer of 2018 in Germany recorded by the combination of ERT and soil data

S. Stadler[1], O. Fishkis[2], U. Noell[1] and the TOPSOIL Team

[1]Federal Institute for Geosciences and Natural Resources, Hannover/Berlin, Germany (BGR)
[2]Institute of Sugar Beet Research, Göttingen, Germany

In 2018 the weather in Germany was extreme: The highest temperatures since 1881 (= start of regular weather recording) were observed during the months of April – August (temperature anomaly of +3.6 K) and the second lowest precipitation amounts (anomaly of -150 mm).





Summer temperature and annual precipitation anomalies in lower Saxony (data and figures: German Weather Service, DWD)

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Research questions:

Blöschl et al. (2019) have pointed out as one of the 23 unsolved questions in hydrology (**Twenty-three unsolved problems in hydrology (UPH) – a community perspective, Hydrological Sciences Journal, 64:10, 1141-1158, DOI: 10.1080/02626667.2019.1620507**):
:

‘5. What causes spatial heterogeneity and homogeneity in runoff, evaporation, subsurface water and material fluxes ….?’

In our experiment we aim at identifying these heterogeneities and

- observe high spatial and temporal variability of the water content at cm-, dm- and m-scale in a maize field under natural conditions
- find evidence for small scale variability of the water retention function
- detect locally highly variable nitrate content in the seepage water

although the observation area is located in very homogeneous sandy soil with no marked difference in clay and silt contents

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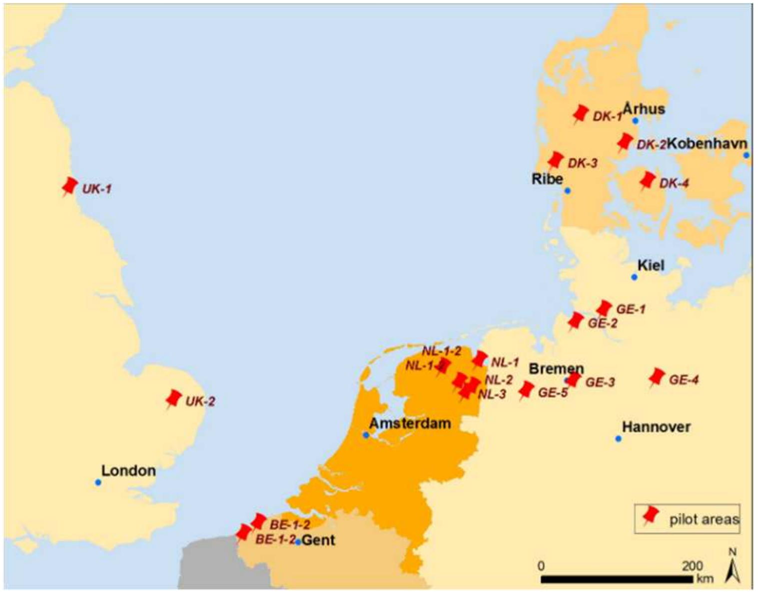

Resilient soil and water resources, understanding the water beneath your feet.

The five shared challenges are:

1. **Flooding in towns and agricultural areas.**
2. **Saltwater intrusion into freshwater reserves.**
3. **The need for a groundwater buffer to store water in periods of excess rainfall.**
4. **Better knowledge and management of soil conditions.**
5. **The capacity to break down nutrients and other environmentally hazardous pollutants.**

financed by the EU-Interreg North Sea Programme (https://northsearegion.eu/topsoil/)

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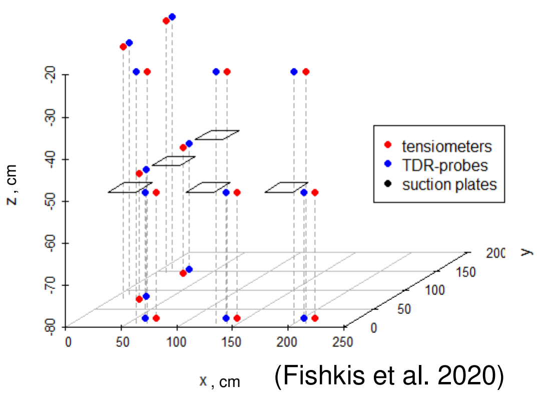
Material and methods

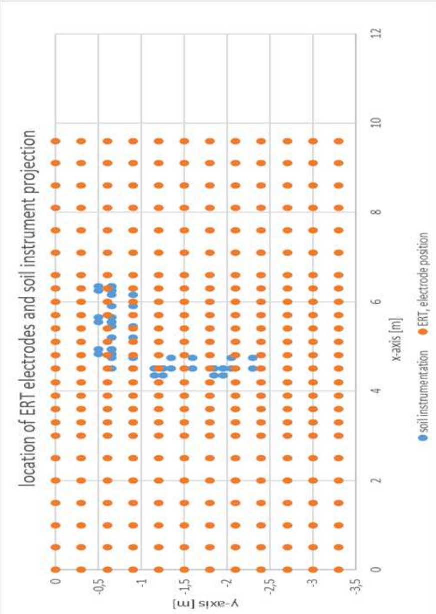
Soil conditions were measured (soil water tension, water content, electrical resistivity, temperature, seepage water at suction plates) in a maize field in Northern Germany continuously down to a depth of about 1.5 m using a combined geophysical and soil scientific small-scale instrumentation array.

Location of soil instruments



(Fishkis et al. 2020)

A rain gauge was installed a few meters away and water was collected **biweekly.**



Position of ERT electrodes and projection of the soil instruments.

Post-harvest view of the installation.

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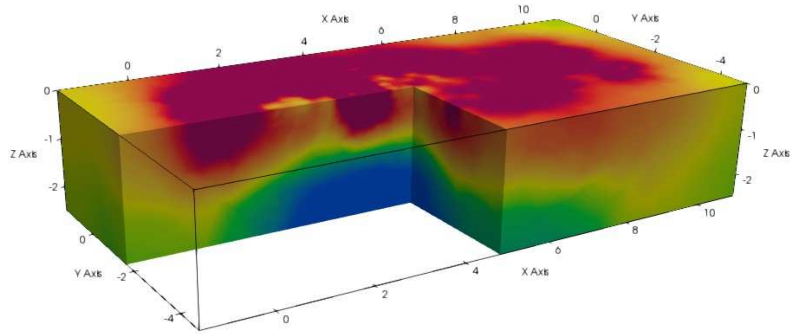
Material and methods

- TDR devices for water content, temperature and conductivity hourly (15 devices at depths of 0.2, 0.5, and 0.8 m)
- tensiometers for hourly suction recording (15 devices at depths of 0.2, 0.5, and 0.8 m in direct vicinity to the TDR devices)
- ERT array monitoring (300 electrodes, electrode distances of 0.5 and 1.0 m, 2012 quadrupole measurements, combination of dipole-dipole and Schlumberger configuration, array measurements every 8 hours)
- five suction plates at 0.5 m depth, samples collected biweekly
- daily precipitation data from nearby station of the German weather service (DWD), local rain gage collected biweekly
- inversion of ERT data using the code BERT (**Günther, T., Rücker, C., 2005-2015. Boundless Electrical Resistivity Tomography (BERT) — user tutorial. URL: http://www.resistivity.net.**)
- analysis of water conductivity and hydrochemistry at BGR laboratory.

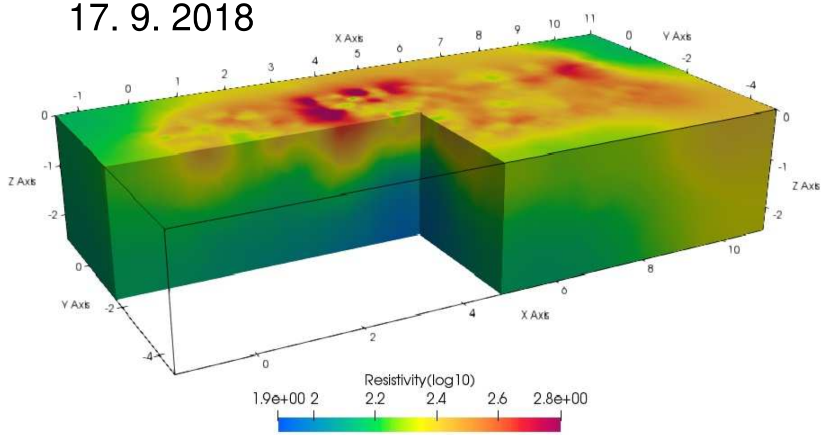
ERT evidence for deep dryness and heterogeneous water distribution after winter rain

After the very dry summer of September 2018 the monitored area showed increased resistivity down to a depth of about 1 m indicating very low water content.



17. 9. 2018

After the winter rains of 2018/2019 resistivity decreased leaving a heterogeneous pattern of higher and lower resistivity indicating small scale water content differences.



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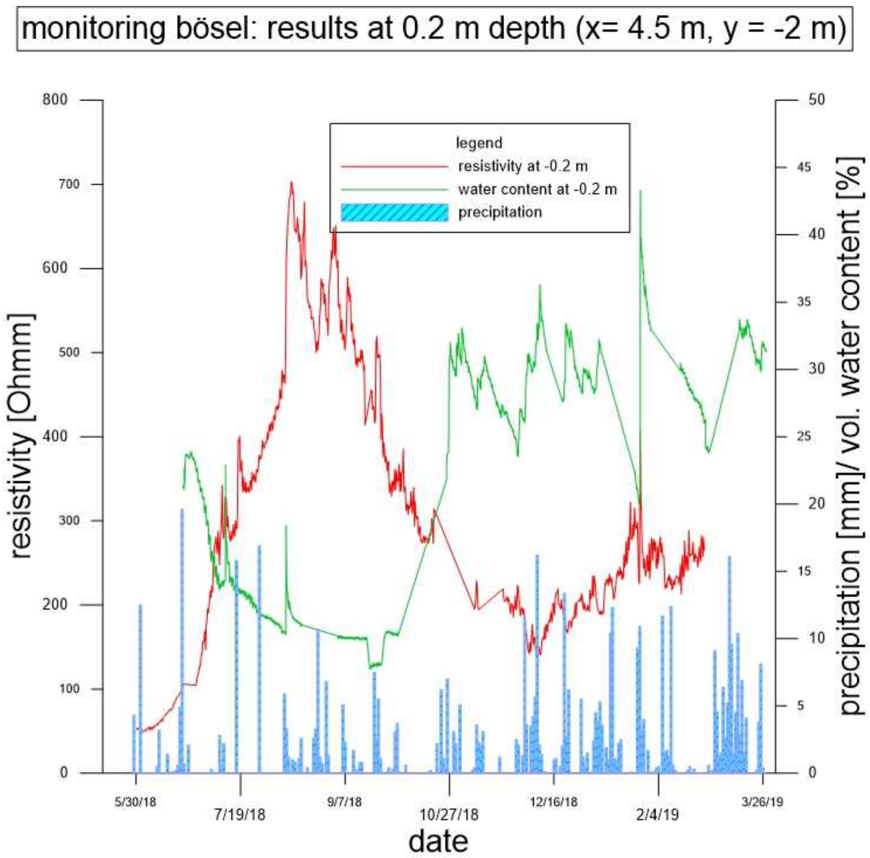
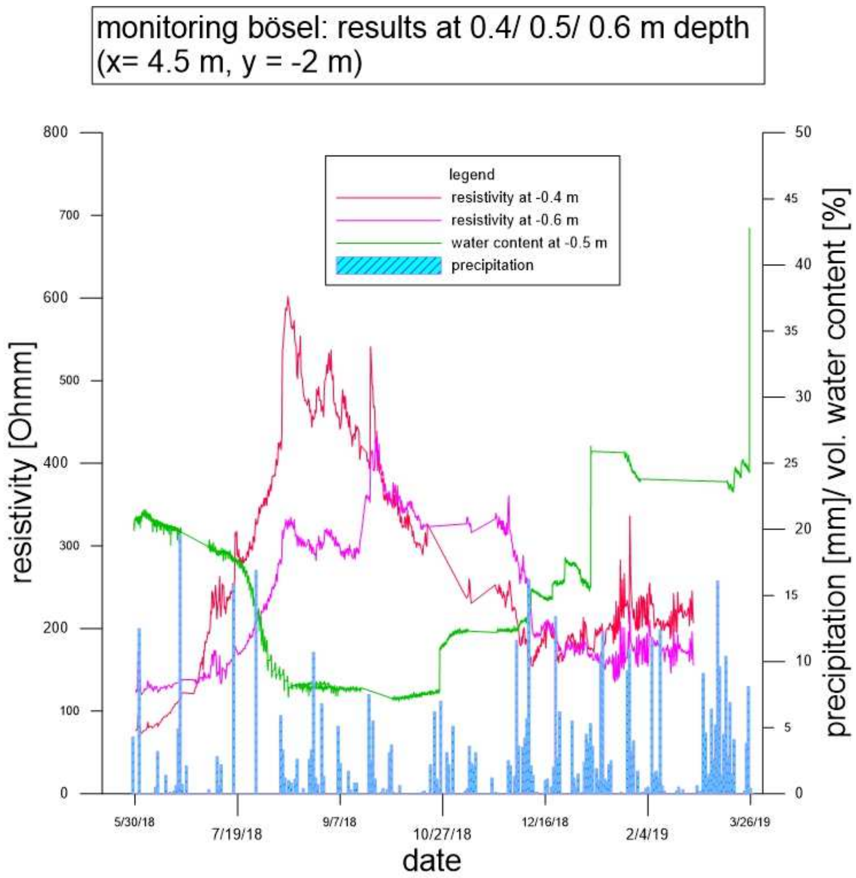
Development of resistivity and water content with time at different depths





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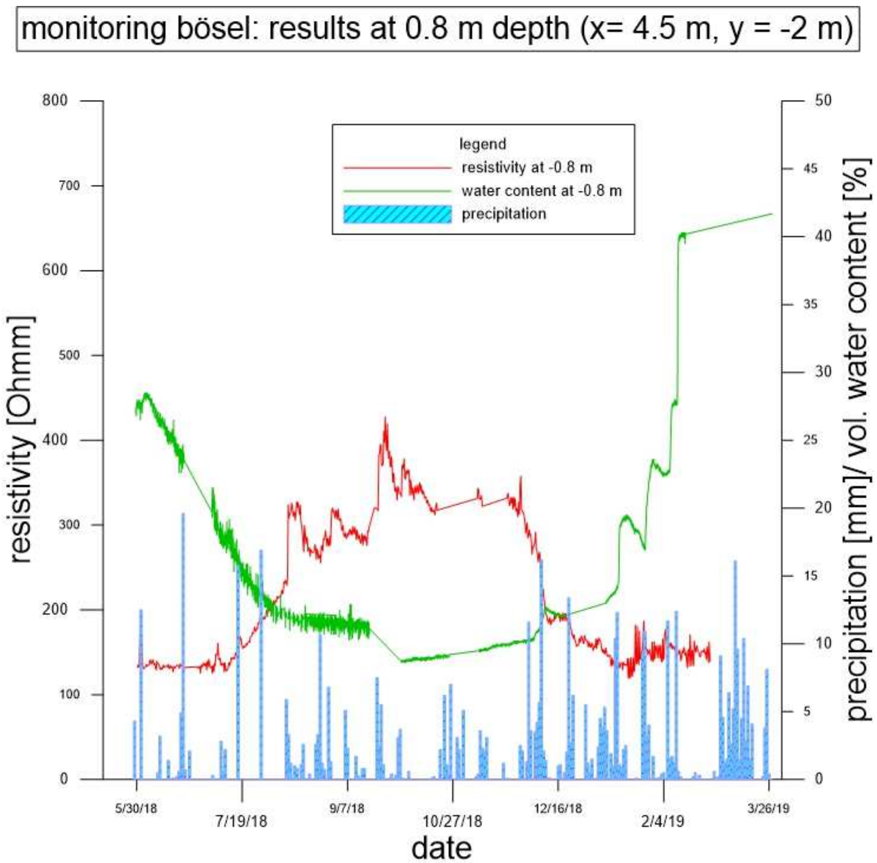

Resistivity changes generally reflect the water content changes

but

there are time shifts between resistivity and water content minima and maxima, which differ at different depths.

The TDR devices measure local values while ERT yields smoothed averaged values.

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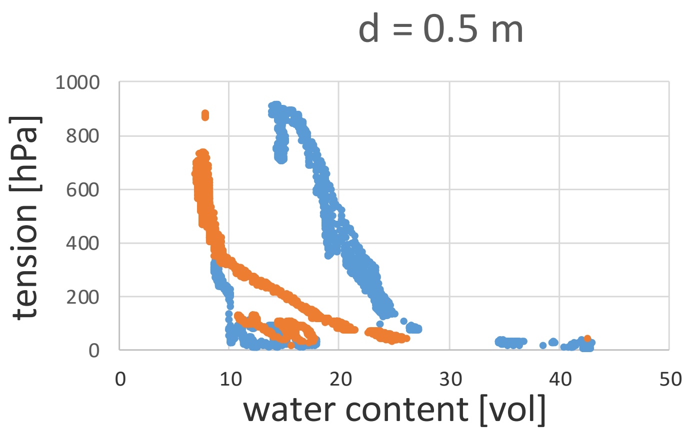
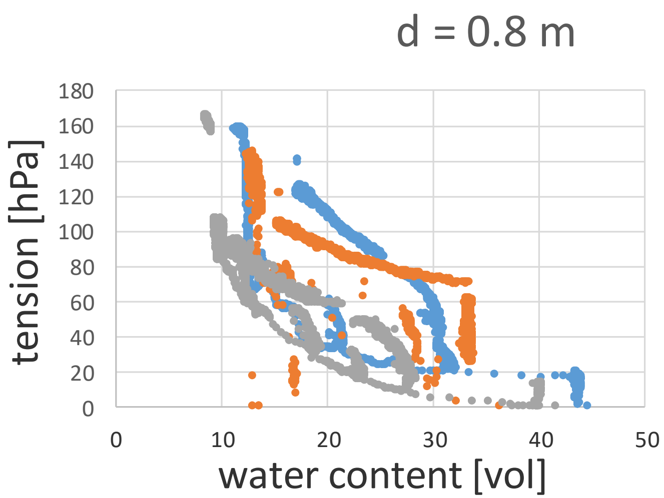
Evidence for locally different water retention functions





Clear hysteresis in the water retention function at all depths but less pronounced at deeper depths (0.8 m)

Occurrence of local preferential flow suggested by a drop of soil suction without simultaneous water content change.

For detailed underlying processes see
Vogel, H.-J., 2019, Scale Issues in Soil Hydrology, Vadose Zone J. 18:190001.
doi:10.2136/vjz2019.01.0001 and references therein.

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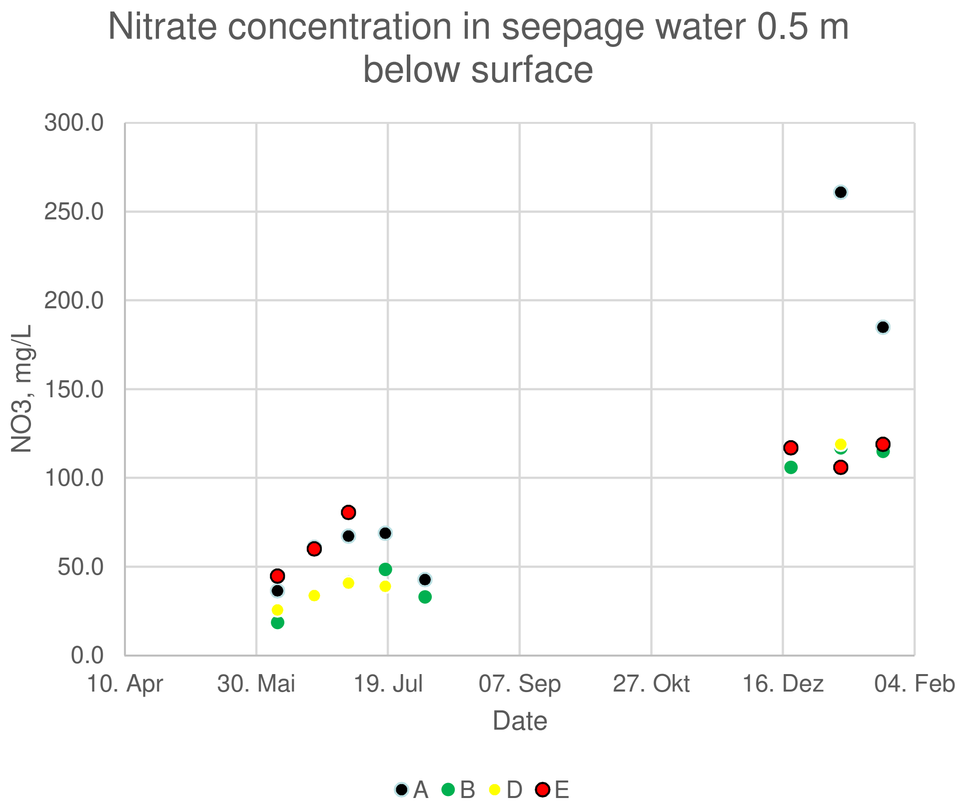
Evidence for locally different nitrate content



The nitrate concentration is around 50 mg/l throughout the observation period

but

after the dry summer exceptionally high nitrate values were detected, yet only locally.

Conclusions

- ERT is able to detect the variability of the water content at m- and dm-scale
- A combination of ERT and soil instruments (TDR and tensiometers) is necessary to relate resistivity quantitatively to water content
- Heterogeneities supported by recorded hydrochemistry variations and soil hydraulic data
- The effect of the maize plants (and their roots) on water content needs further attention beyond the scope of the current study

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