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Subsidence & Sinkholes – Current Research and Perspectives

Presentation for SubRISK+ final workshop.

27th of Feb. 2026

Applied Near-Surface Geophysics and Remote Sensing (AGRS)

Institute for Earth System Science and Remote Sensing | Talstraße 35, 04103 Leipzig, Germany

Expertise:

- Hydro- & Archaeogeophysics
- GIS & Satellite Image Analysis
- Photogrammetry & InSAR
- Geophysical Inversion & Numerical Modelling (FEM, DEM)
- AI-based Analysis of Earth Surface Deformation

Equipment:

- Geoelectrics, Self-Potential
- Georadar, EM34
- Magnetics
- Seismics, Seismometers
- DGPS, Drone
- SLAM LiDAR

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Outline

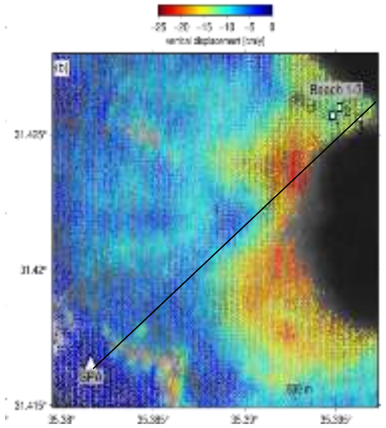
1. Short Background – scales of subsidence/sinkhole formation
2. Trends – Methods to assess subsidence - a case study from Germany
3. Perspectives – towards a generalized subsidence warning system
4. Conclusions
5. Questions

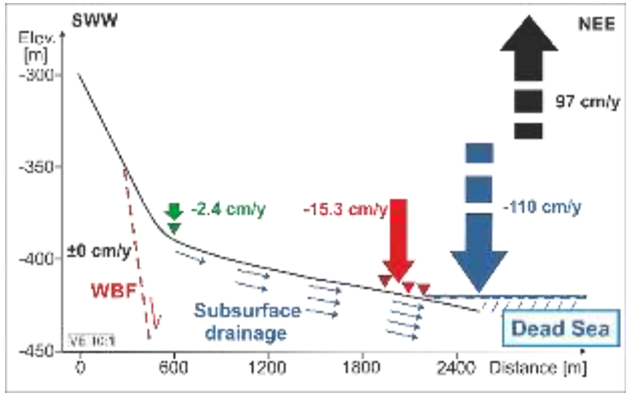
Subsidence & Sinkholes – Current Research and Perspectives

Background

Subsidence exists on many spatio-temporal scales.

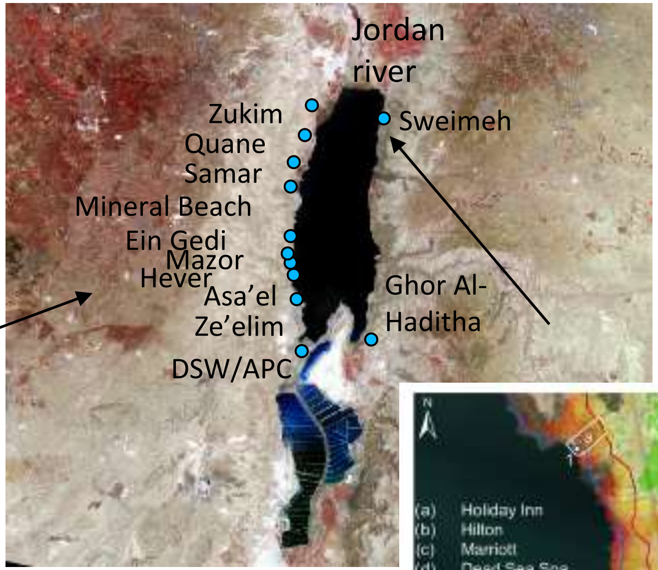
Subsidence scale (I) – widespread ground sinking along the shore





Vey et al., 2021

- time-lag 2 months
- primary & secondary consolidation



Abou Karaki et al., 2019

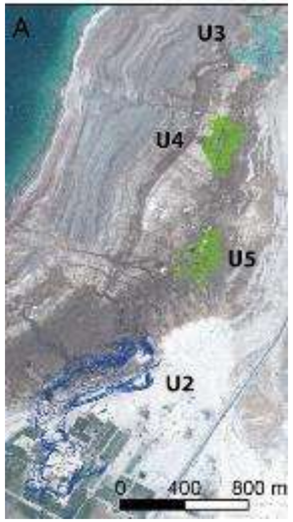
Subsidence & Sinkholes – Current Research and Perspectives

Background

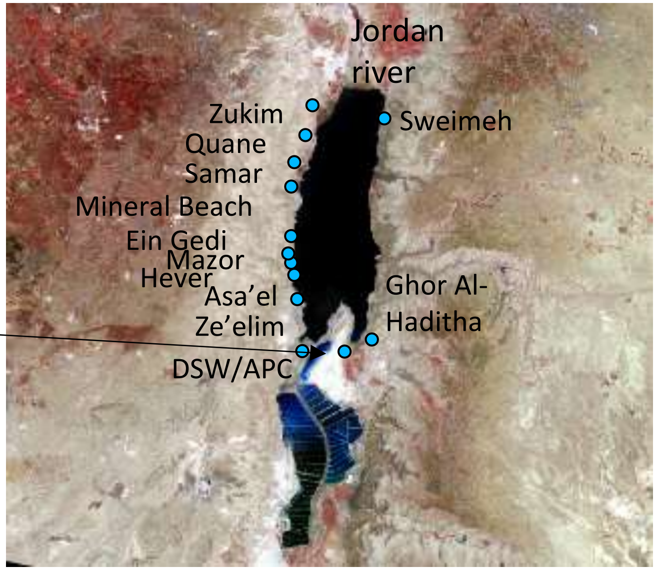
Subsidence exists on many spatio-temporal scales.

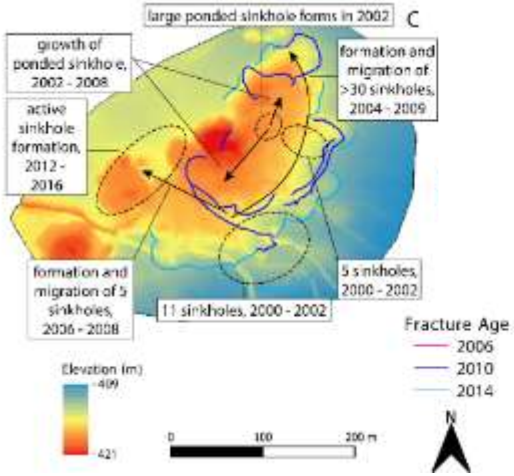
Subsidence scale (II) – large-scale depression formation

- uvala-formation = large-scale karstic depressions
- subrosion = distributed underground erosion



Watson et al., 2019



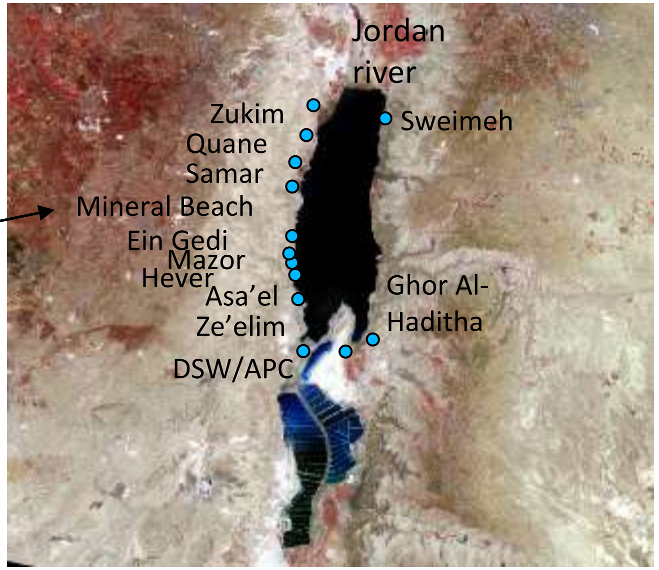


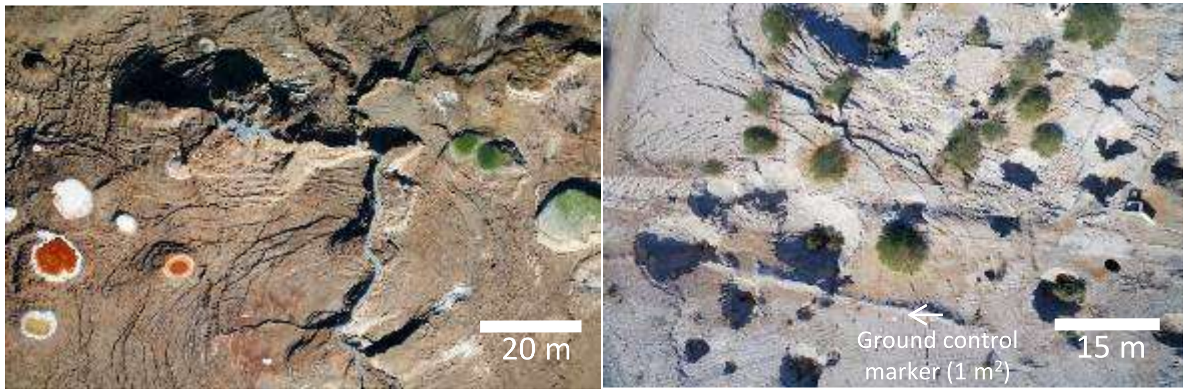
Background

Subsidence exists on many spatio-temporal scales.

Subsidence scale (III) – sinkholes

Nof et al., 2019



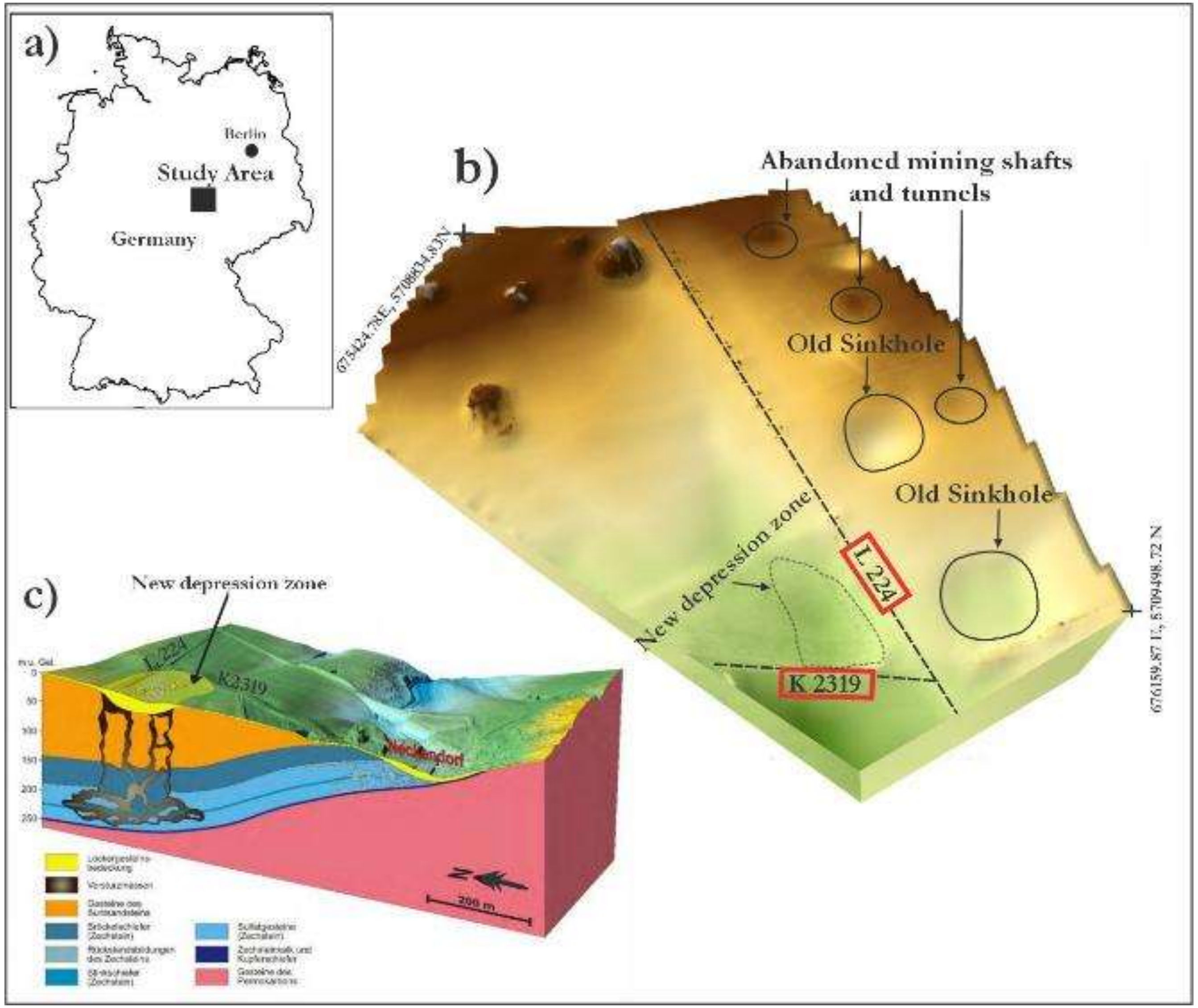


Al-Halbouni et al., 2017

Trends – example case study

The Mansfelder Land lies within the Central European copper belt, famed for its sediment-hosted copper slate deposits that fuelled regional industry for over eight centuries.

Geologically relevant are the deep lying and inclined Zechstein evaporite beds - gypsum, anhydrite, halite and dolomite which are highly susceptible to natural dissolution.



Subsidence & Sinkholes – Current Research and Perspectives

Trends – example case study

New sinkholes and large-scale subsidence has appeared since the stopping of the mining in the 1970s.

Road, farm and garden closures are the consequences.

In 2022/23 the rate of deformation at the road was 1,5 mm /day.

Nowadays smaller but new cracks appear/widen.

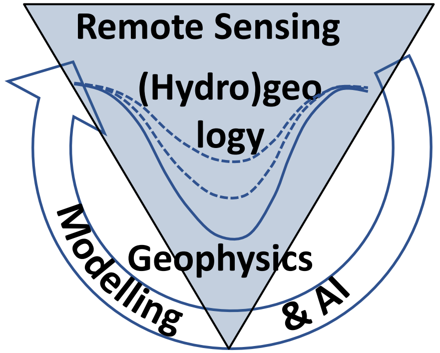
Trends – example case study

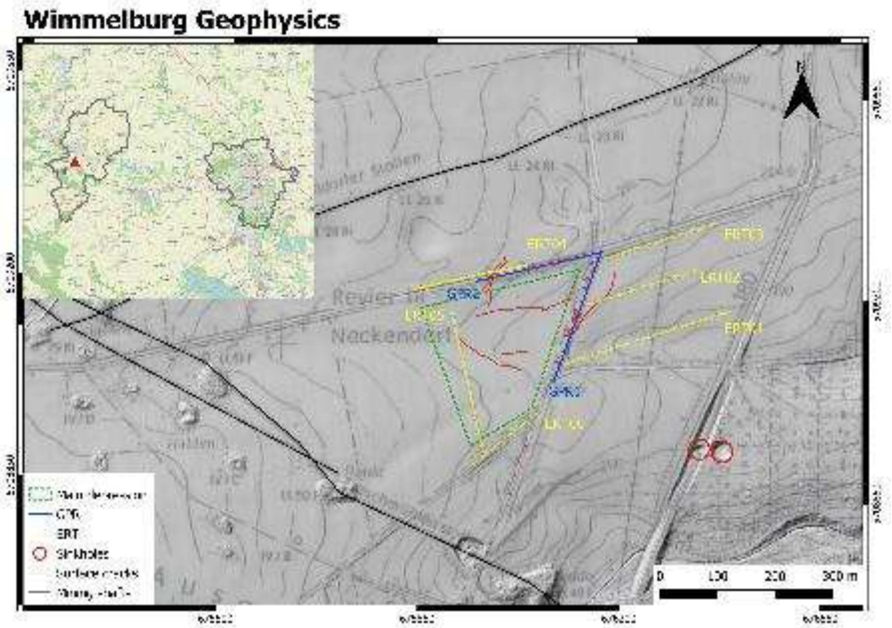
We used an integrated approach ranging from remote sensing – over ground-based measurements to subsurface measurements in mines.

Further steps will include hydromechanical numerical modelling and AI analysis of subsidence structures.

Methodological approach

- **Photogrammetric surveys and (In)SAR**
- **Field observation & GPS**
- **Hydrogeophysics: Electrical Resistivity Tomography, GPR and Self-Potential**
- **Mine (LiDAR) surveys**
- **Numerical Modelling & AI analysis (to come)**





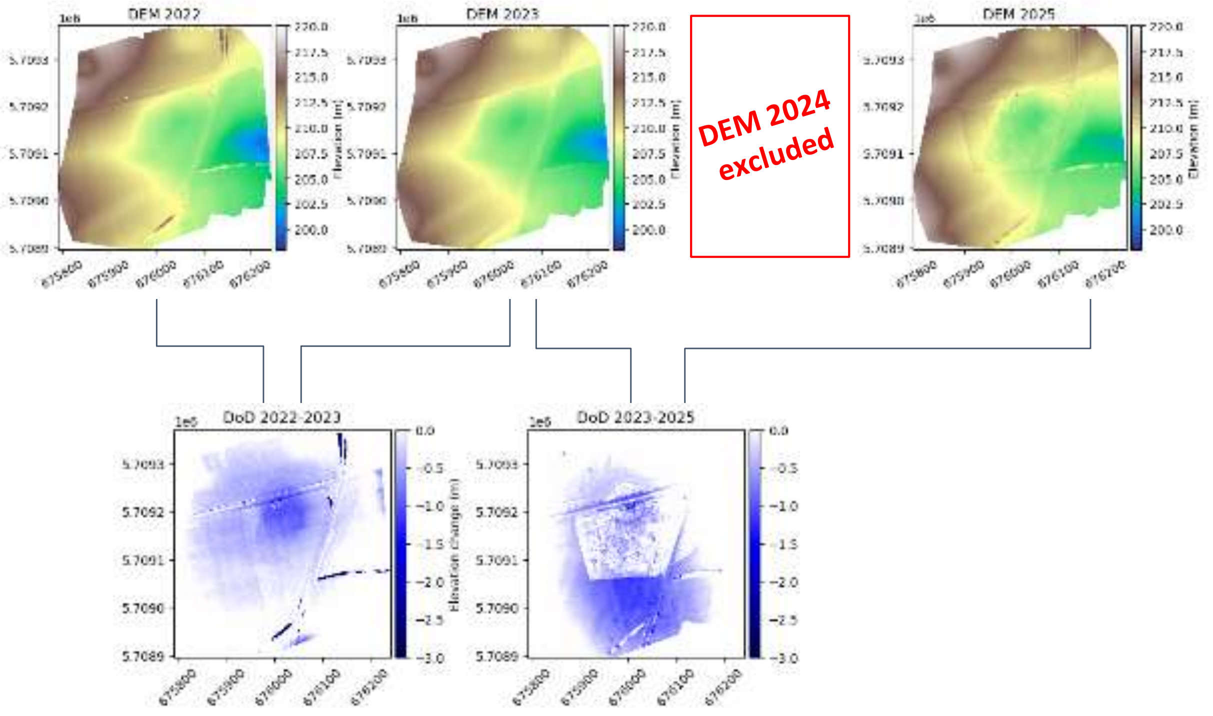
Subsidence & Sinkholes – Current Research and Perspectives

Trends – example case study

DEM alignment:
- ➔ grid resolution
- ➔ CRS
- ➔ extent

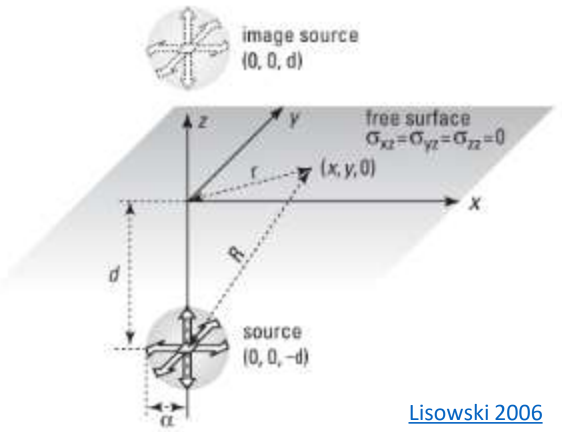
DEM Differencing → DoD

DoD preparation:
- ➔ clip to main subsidence zone
- ➔ median filter (noise, vegetation)
- ➔ filter for subsidence only



Remote Sensing & Source Modelling

Mogi deformation source model inversion (for vertical displacement) using least squares grid search



Lisowski 2006

$$u_z = \frac{(1-\nu)V}{\pi} \frac{f}{(r^2+d^2)^{3/2}}$$

Trends – example case study

Mogi deformation source model inversion (for vertical displacement) using least squares grid search

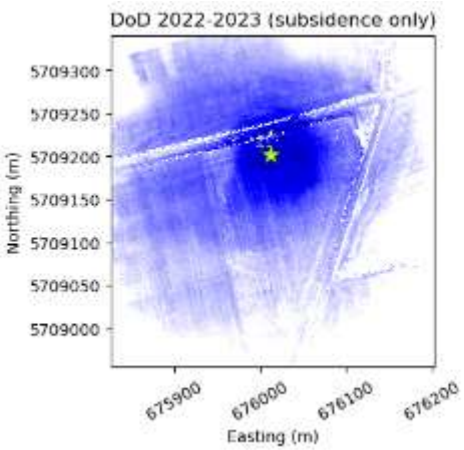
u_z - vertical surface displacement → *DoD subsidence values*
r - horizontal radial distance between observations and source → *calculated from estimated source location*
ν - Poisson's ratio → *0.27 (estimated from literature)*

to be optimized:
f - deformation source depth [m]
→ grid: 0.5 - 250 m
V - volume change [m³]
→ grid: -234 000 - -5000 m³

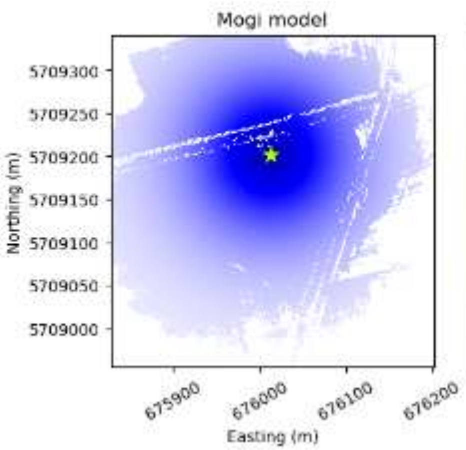
results:
f - source depth: 101.4 m
V - volume change: -42793 m³
a - radius: 21.7 m

Remote Sensing & Source Modelling

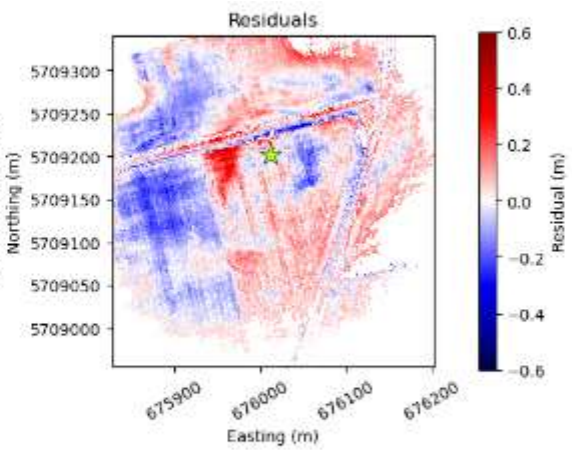
Observed subsidence



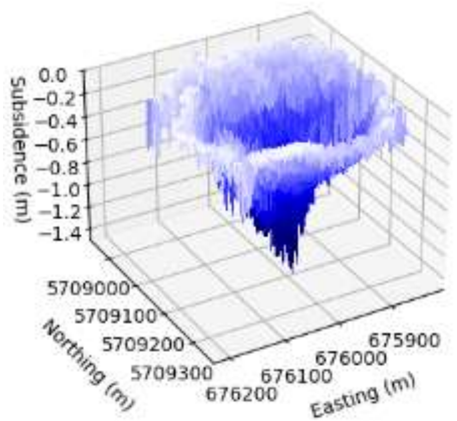
Mogi model prediction

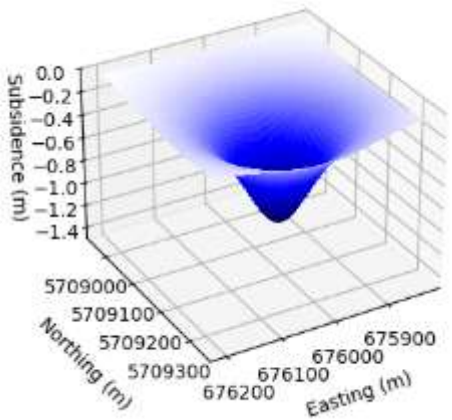


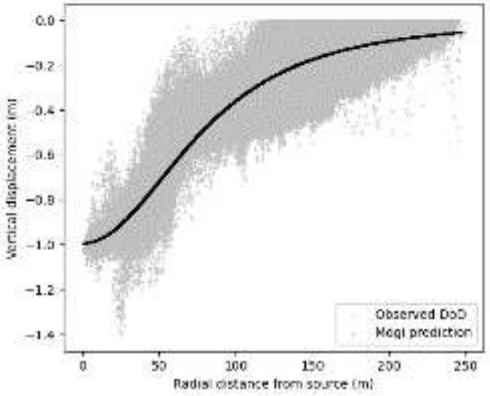
Model error



RMSE: 0.097 m
MAE: 0.076 m







Trends – example case study

SAR drone (GFZ Potsdam
resolution 1-5 m
1st survey: 08.10.2025
2nd survey: 24.02.2026

objectives:
vegetation height assessment
(C-band - P-band)
interferometry (on helical data)

P-band

C-band

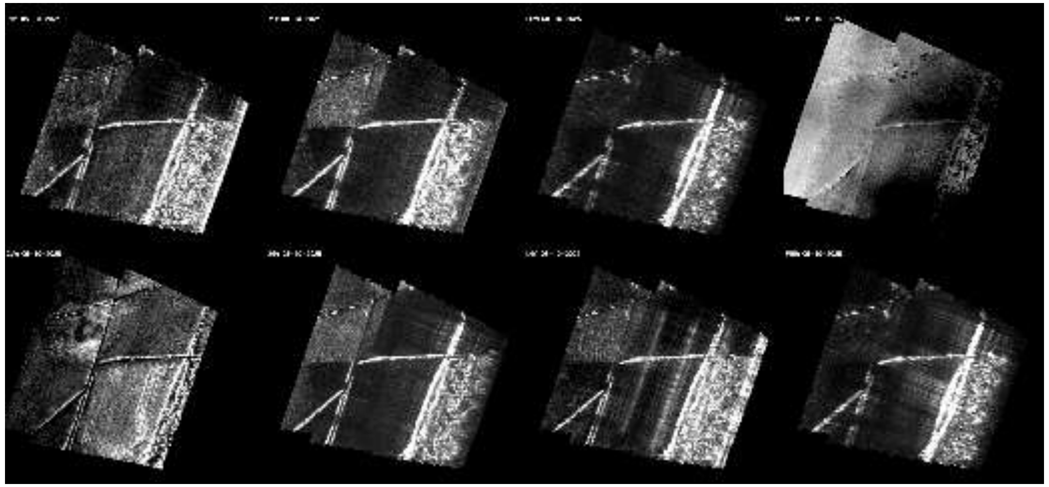
L-band

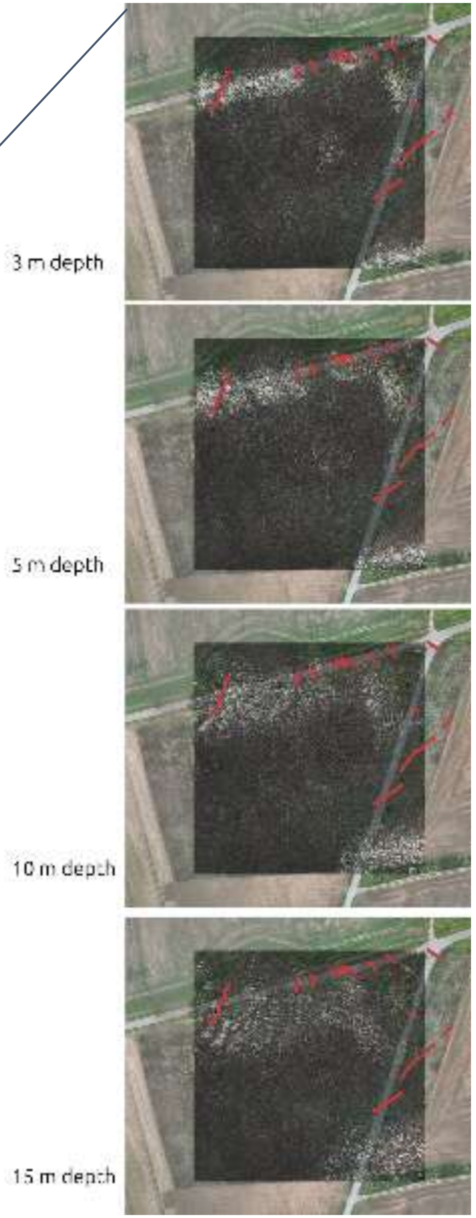
SAR Drone

helical flight mode for ground penetration
backscatter intensity at different depths
(flight height 200 m; resolution 0.2 m)

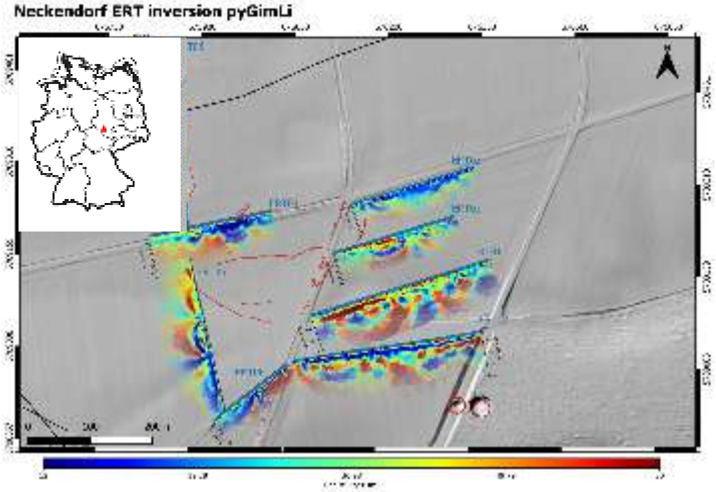
cavities should appear dark
bright → high reflectivity, likely noise due to trees and their roots

linear flight mode results (amplitude)



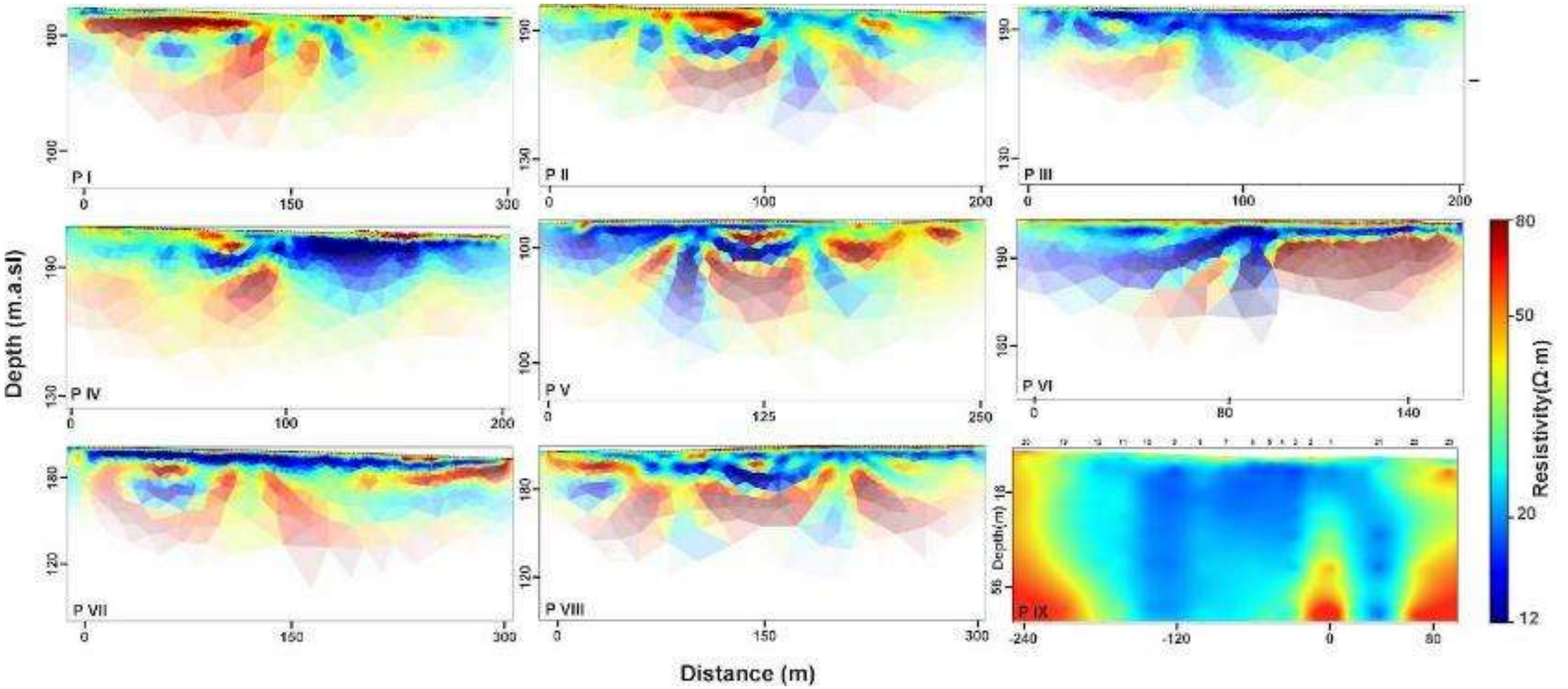


Trends – example case study



Study area of Wimmelburg with location of ERT profiles.

Electrical Resistivity Tomography



(P I to PVIII): Eight ERT profiles with the classical inversion. (P IX): The ninth ERT profile, measured and processed by the LAGB Saxony-Anhalt.

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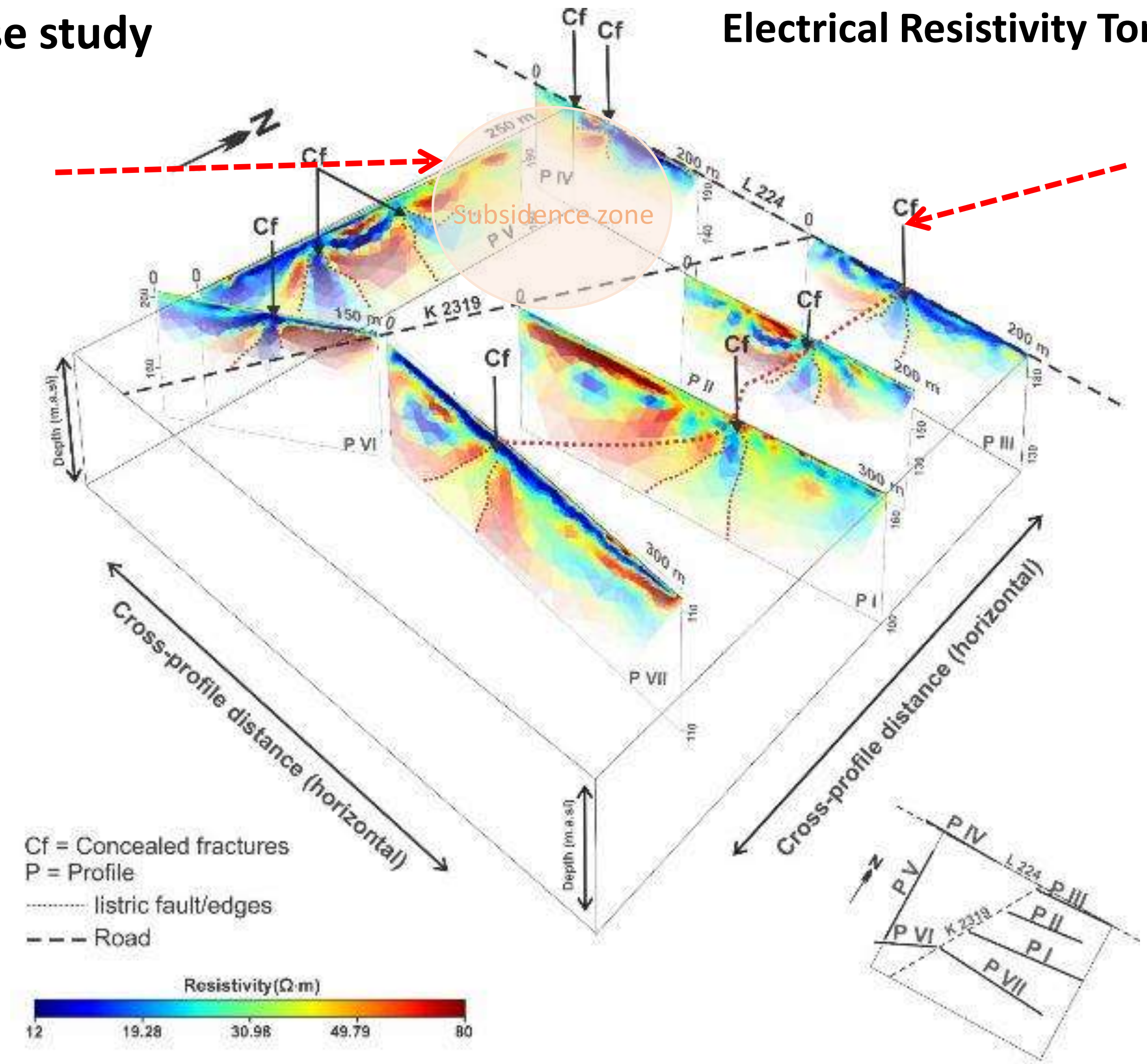
Trends – example case study

Electrical Resistivity Tomography

Superficial cracks at the surface relate show higher-resistivity

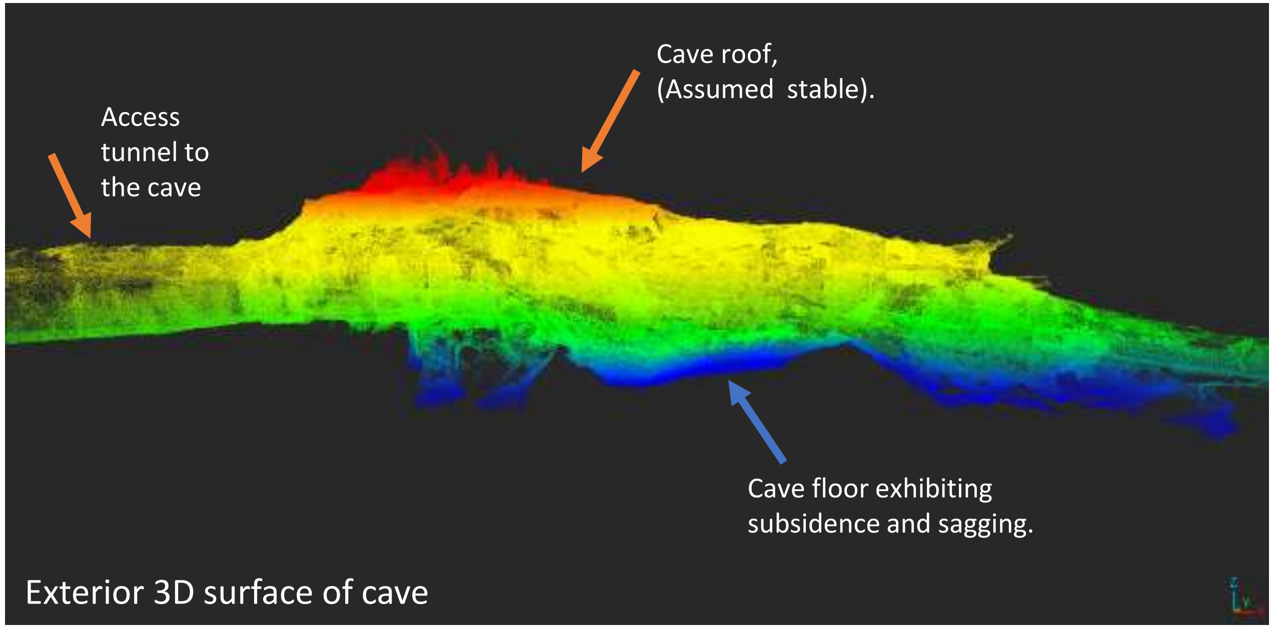
The repeated presence of near-vertical low-resistivity anomalies presenting concealed fractures as preferential water flow paths



A block structure is visible dividing the zone into high and low resistivity patches

Composite image from 2D classical inversion geoelectrical sections.

Trends – example case study



Exterior 3D surface of cave

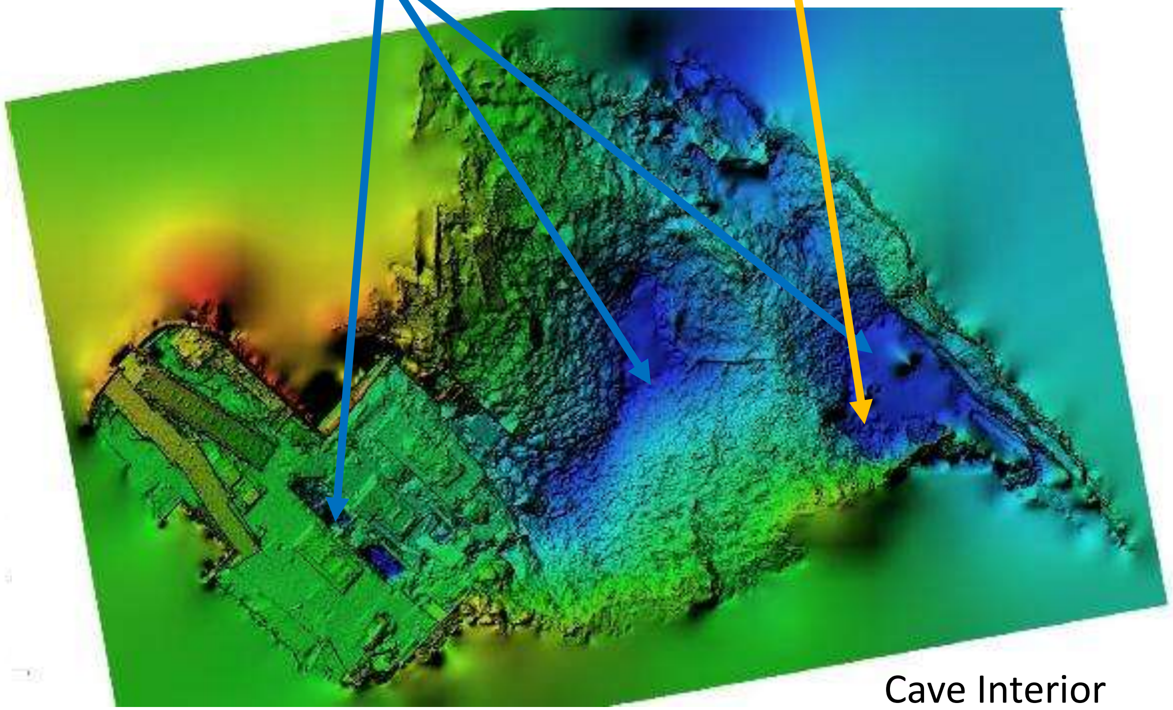
- Scanned with FJD Trion P1 SLAM LiDAR mounted with external RGB Camera.
- High Capture Rate (200,000 pts/sec) and spatial accuracy of up to 2 cm.
- **Challenges**: No natural light, limited artificial lighting, numerous hanging objects from the roof, and restricted access due to safety protocols.
- Dataset:111,698,399 points in 21.98 minutes

LiDAR

- **Location**: **Anhydrite** cave - historically used as a Pumping station for mine water management.

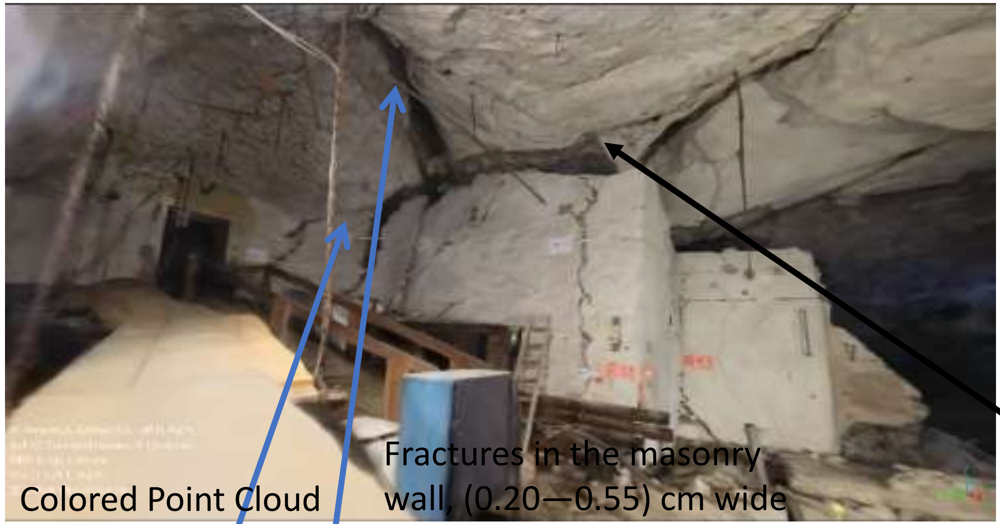
Lower-elevation subsidence features (blue) include depressions that are water-filled.

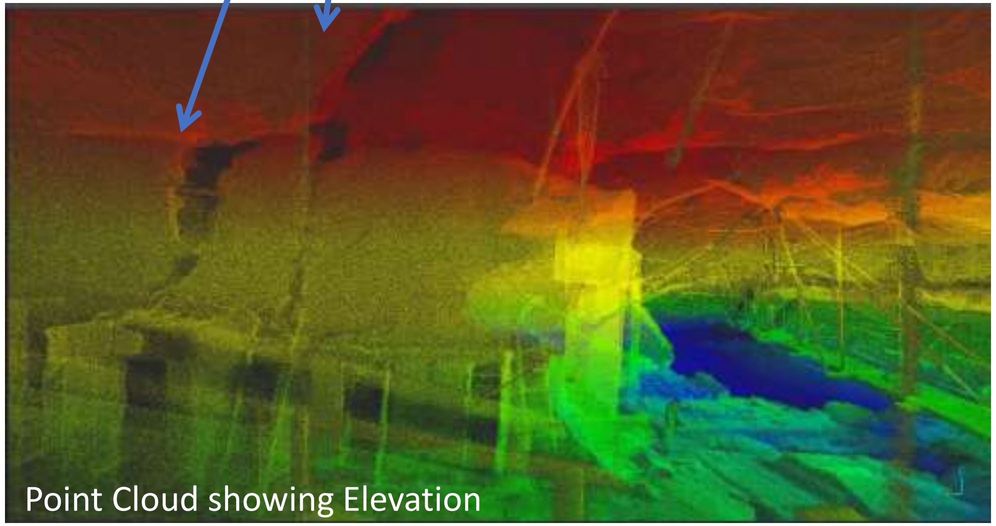
Suspension bridge that was used to walk and scan the cave



Cave Interior

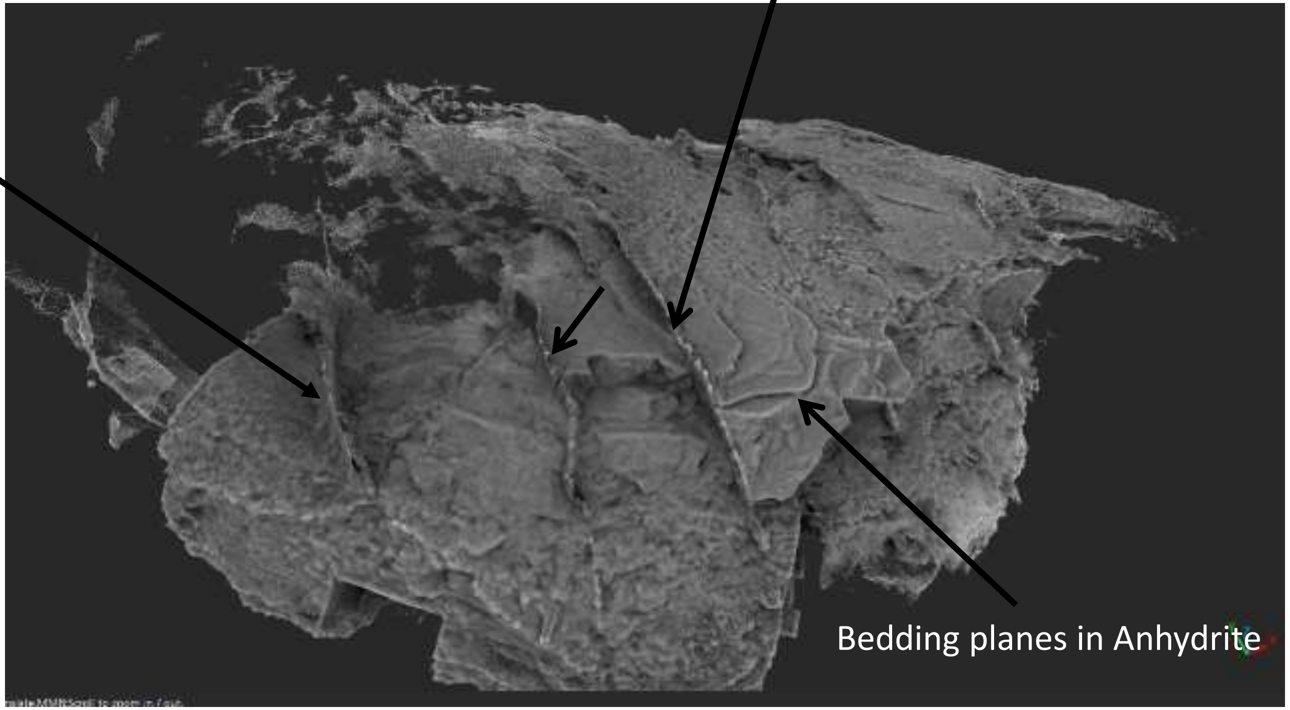
Trends – example case study





LiDAR

Distinct linear and parallel tectonic features are clearly visible in cutting across the rock mass.



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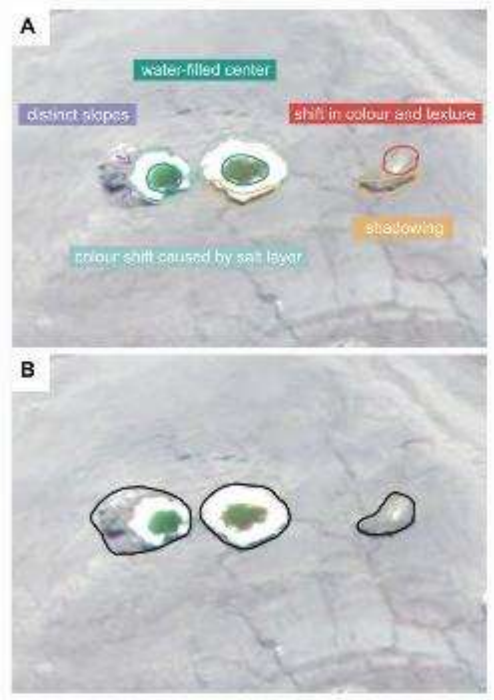
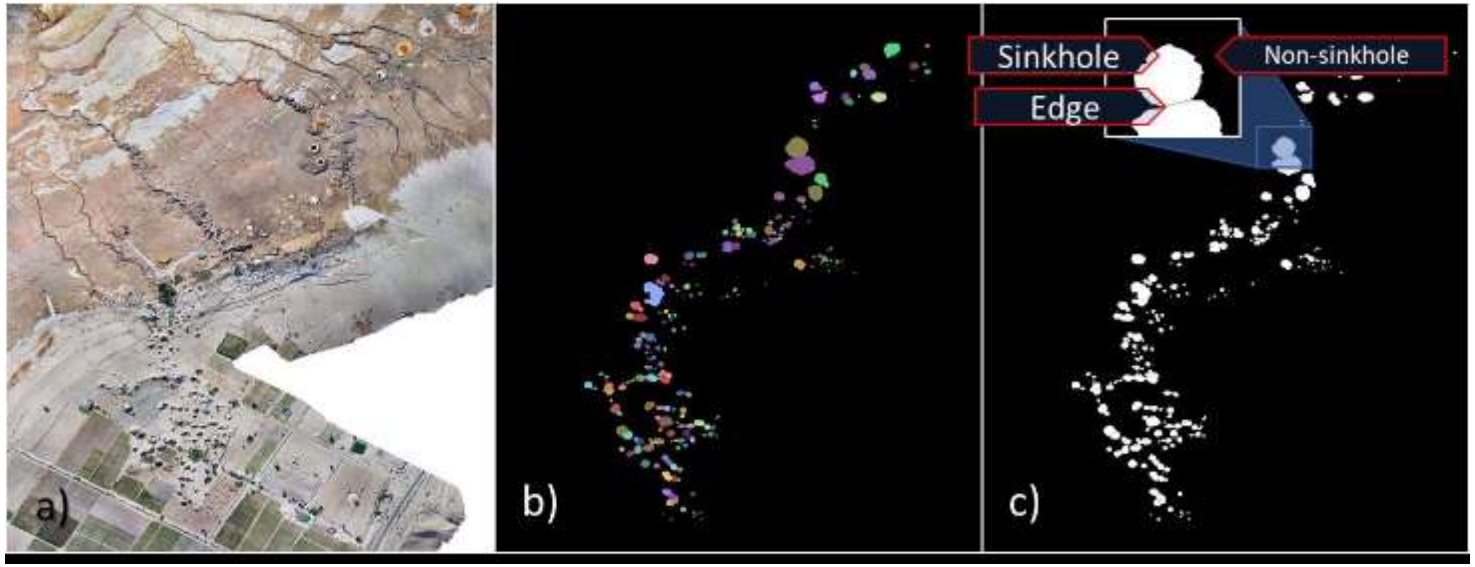
Perspectives

ML is revolutioning our capacity and accuracy of subsidence tracking.





Al-Rabayah et al., 2024

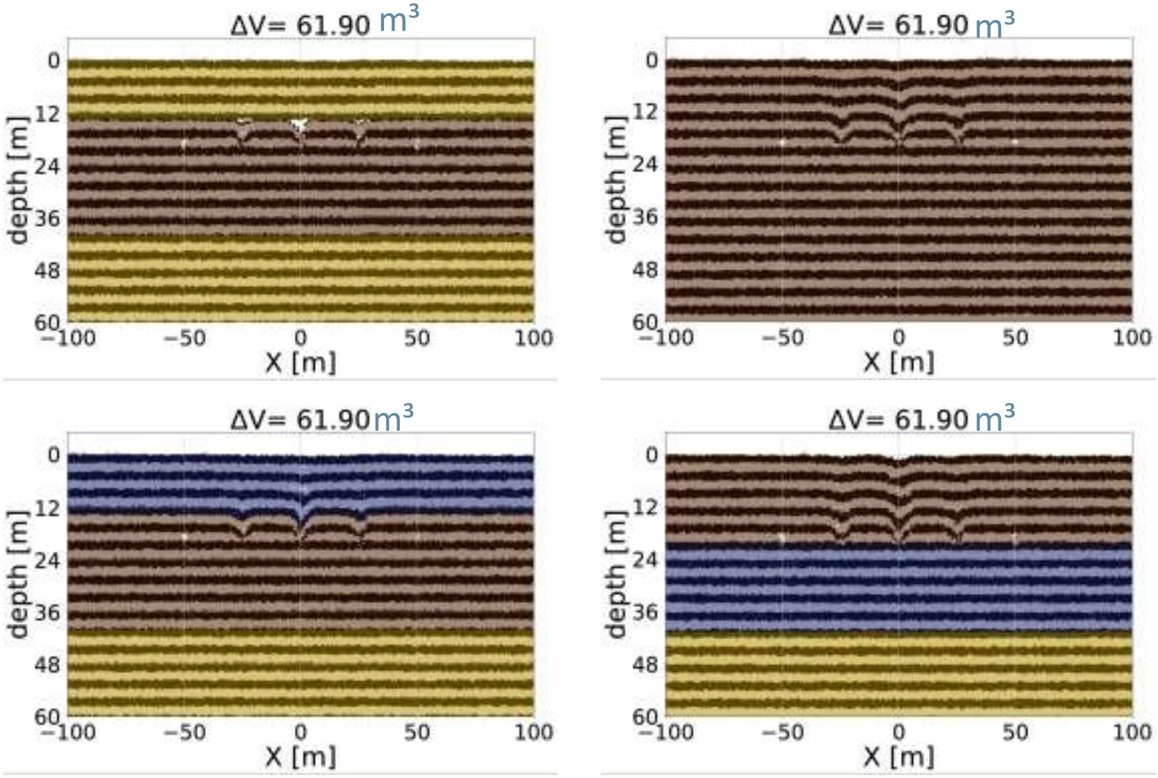
Deep-learning based semi-automatic sinkhole recognition.

Tested successfully for drone (5 cm/px) and via transfer learning for satellite image (30 cm/px).

Perspectives

Geomechanical numerical modelling needs to be coupled in near real-time with groundwater flow.

„Strong“ overburden　　„Weak“ overburden



Salt

Mud

Alluvium

Al-Halbouni et al., 2018 & 2019

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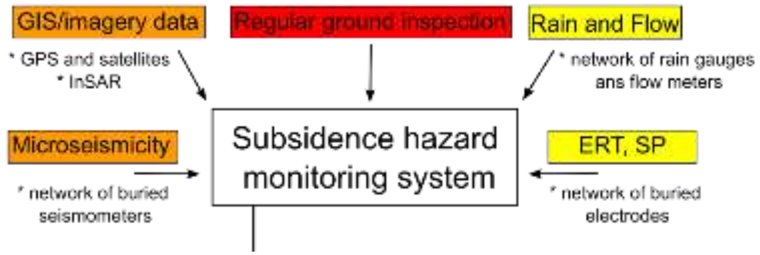
SubRISK+

Perspectives

We need to get towards a generalized subsidence hazard monitoring system.



Al-Halbouni et al., 2022 a & b

We would need change detection by semi-automatized:

- Remote Sensing (global and regional databases)
- Hydro(geo)logical measurements
- Geophysical measurements
- Geomorphological analysis

Is that enough for early warning?

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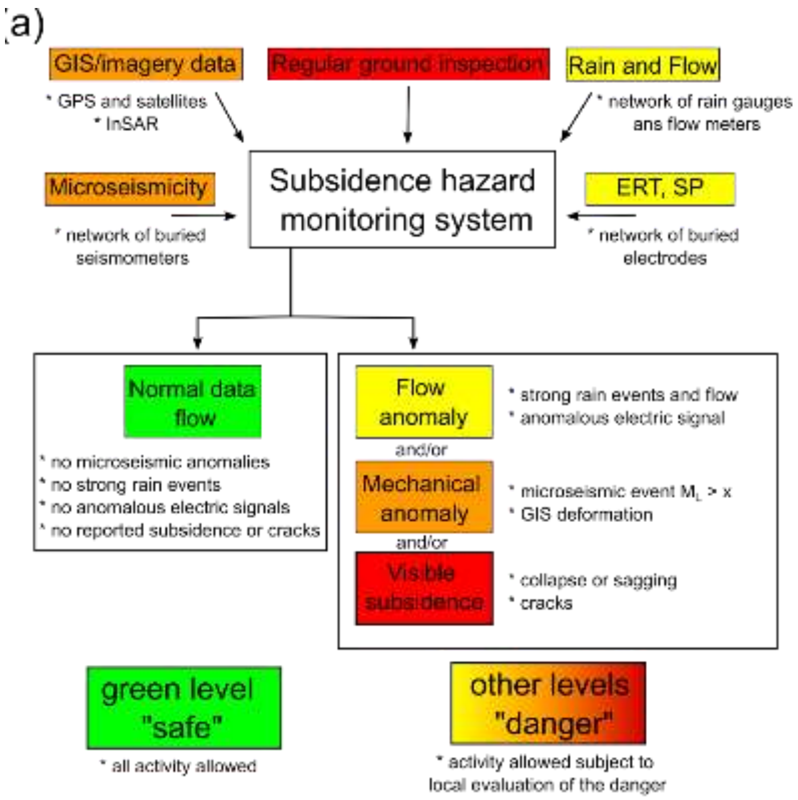
SubRISK+

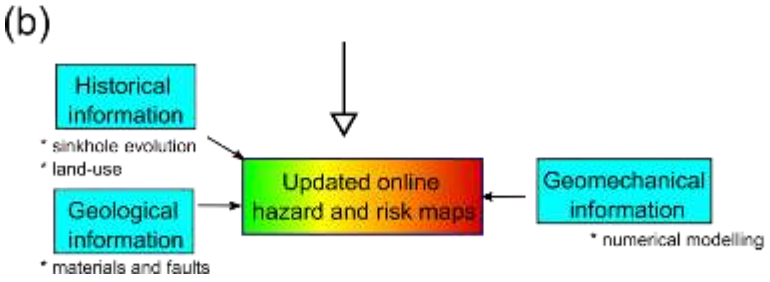
Perspectives

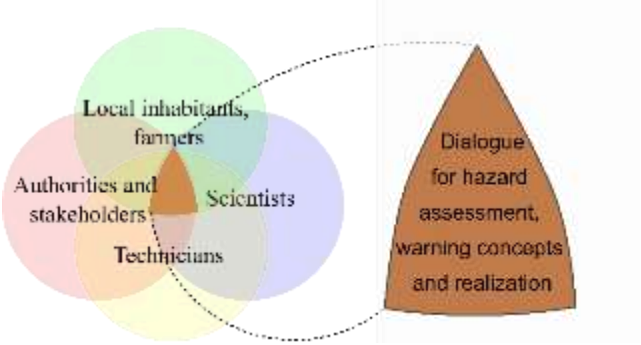
We need to get towards a generalized subsidence hazard monitoring system.

REACTIVE



We need expert knowledge, local experience and computer model databases to assess the danger!





PREVENTIVE

Al-Halbouni et al., 2022 a & b

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Conclusions

- Subsidence and especially sinkholes exhibit manifold scales, formation and trigger processes, and likewise manifold methods of different scales and resolution are needed for a proper investigation.

- In order to establish a reliable sinkhole monitoring system that works on different temporal and spatial scales, the combination of remote sensing, field and computer methods as well as expert analysis is necessary.

- Advances in modern technology, i.e. numerical modelling, satellite surveillance, ML algorithms and AI capabilities offer new possibilities for rapid data processing and analysis.

- However, all technology is not useful, all data accumulation useless, if no personnel is available to dedicate time & effort to develop and update sinkhole hazard & risk maps and inventories. SubRisk hereby made a large step forward with e.g. the online mapping system.

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Questions?

Thank you!