Institut für Erdmessung

Federal Ministry of Education and Research

Leibniz Universität Hannover

On Integrated Geodetic Monitoring for Sinkhole-Induced Surface Deformation and Mass Dislocation

- **JISDM2016 - Joint International Symposium on Deformation Monitoring** -

Session - Multi-Sensor-Systems for Deformation Monitoring

SIMULTAN Research Group

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Motivation - Research on Sinkholes / Subrosion Events

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May 30st, 2010: Sinkhole Event in Guatemala City

- tropical storm
- swallows three-storey building

Motivation - Research on Sinkholes / Subrosion Events

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February 21st, 2016: Sinkhole Event in Nordhausen

- sinkhole event in a depth of 100-150 m
- soluble rocks and subsidence of gypsum and anhydrite
- ≈ 70 000 tons of ground soil moved
- geometry: 30 m diameter and 50 m deep

SIMULTAN - A Multi-Disciplinary Joint Research Project and Group I

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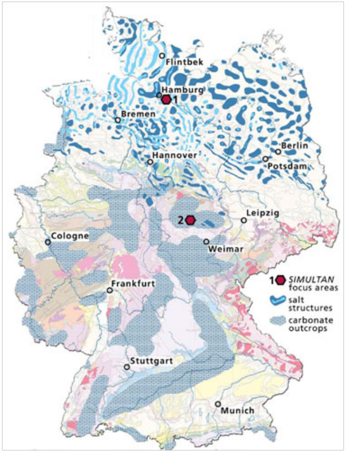
Sinkhole Instability: **I**ntegrated **MULT**i-scale Monitoring and **AN**alysis

GFZ | IAG | UH | GGL | TU Berlin | Leibniz Universität Hannover | HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

Key-Parameter

- **early recognition** concept (different scales: time, lateral extent and depth)
- **rigorous combination** of geodetic and geophysical techniques and data sets
- **integrated data sets** of subsurface mechanics and surface deformations by collocated and co-located stations
- **innovative** methods of urban geodetic/geophysical monitoring strategies



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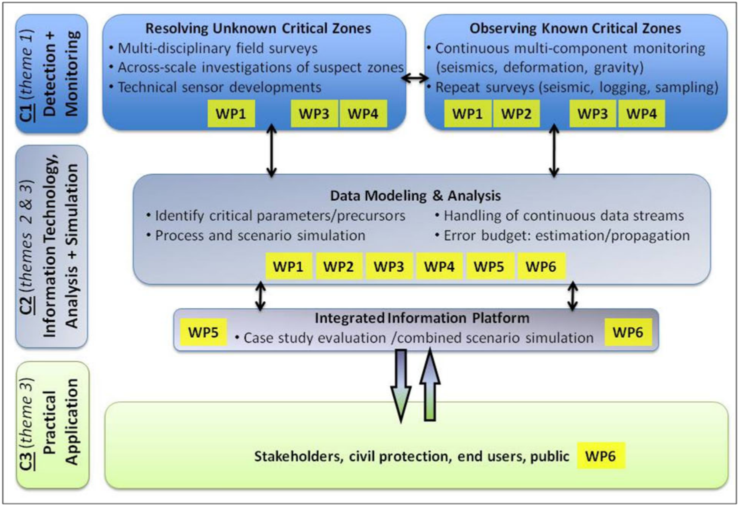

SIMULTAN - Combined Methods and Scales

Work Packages and Research Areas

- WP1: critical zones in sinkholes (LIAG)
- WP2: seismic monitoring and characterisation (UHH, GFZ, LIAG)
- WP3: surface deformation and mass dislocation (LUH, GGL, LIAG)
- WP4: rock soil water interaction in sinkhole formation (TU Berlin, UFZ)
- WP5: sub-surface cavity and collapse sinkhole evolution (GFZ, FU Berlin)
- WP6: protocols and decision process (geological surveys LLUR)

SIMULTAN - Combined Methods and Scales

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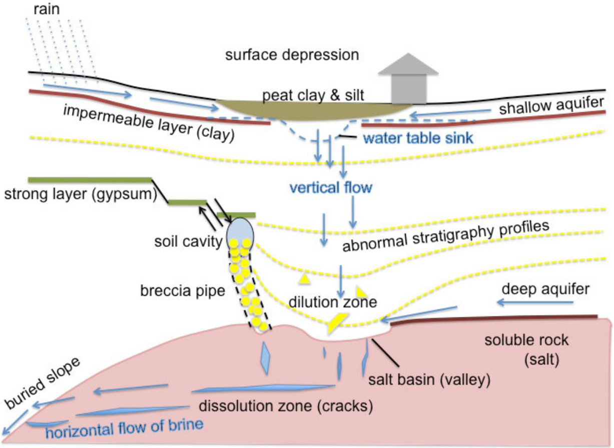

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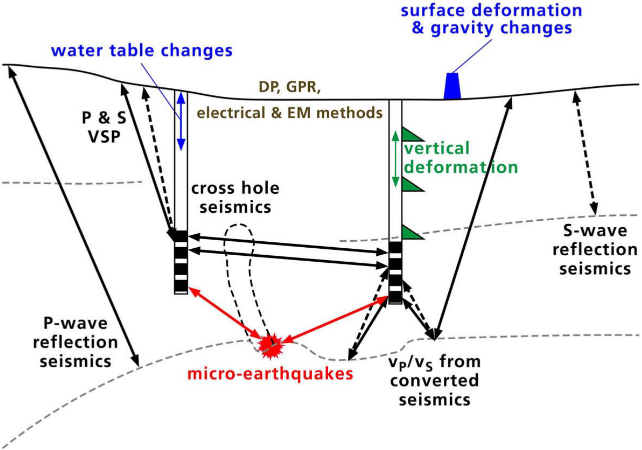
SIMULTAN - Combined Methods and Scales

Work Packages and Research Areas



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Multi-scale Observing Techniques (geodetic & geophysical)

- Levelling (3-monthly) LIAG
- relative Gravimetry (3-monthly), LIAG
- micro-Gravimetry, GGL
- GNSS-Monitoring (6-monthly), LUH
- absolute Gravimetry (yearly), LUH

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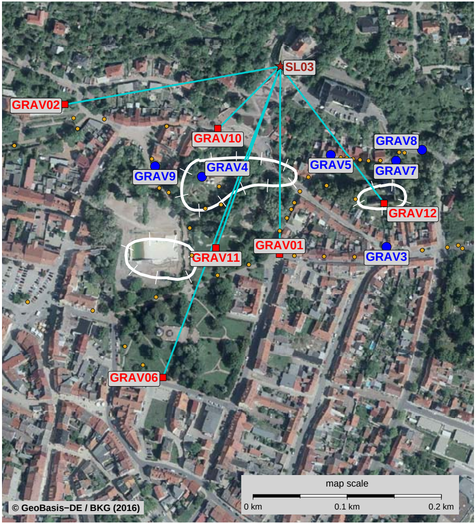
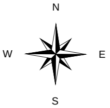
Multi-Technique Geo-Monitoring Network (Collocated and Co-located Sites)



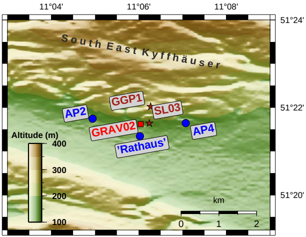
Bad Frankenhausen

(Thuringia, Germany)



Legend

- GNSS / Levelling / Gravimetry
- Levelling / Gravimetry
- GNSS only
- GNSS baselines
- Levelling only (between AP2 and AP4)



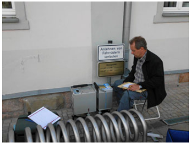
Multi-Technique Geo-Monitoring Network (Collocated and Co-located Sites)

Design of the Monitoring Network

- **120 levelling** points
- **13** (out of 120) sites for **relative gravimetry** (collocated) + 2 distal references
- **1** (of 13) site for **absolute gravimetry** (co-located by local tie to levelling mark)
- **6** (of 13) **GNSS** sites (collocated) + 2 pure GNSS points (incl. a geodetic fundamental point - GGP)

GNSS at collocated point
© LUH

absolute gravimetry
© LUH



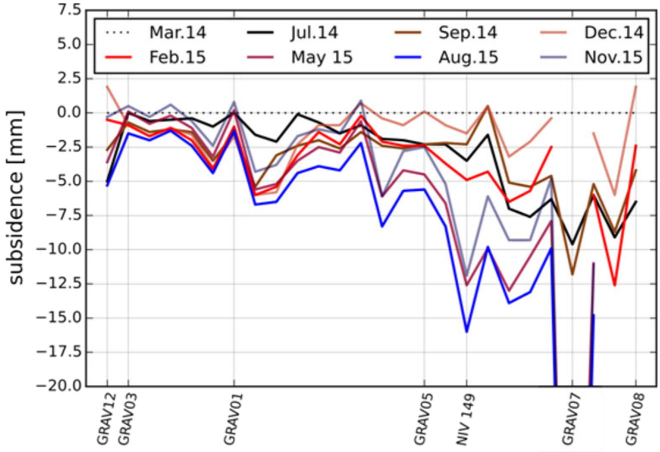
local gravimetry tie
© LUH

relative gravimetry
© LIAG

collocated point
© LIAG

Levelling Campaigns

- Leica Geosystems digital level DNA03 ($\sigma_0 : \pm 0.3\,mm$) and bar code invar staffs
- std. deviation of levelling: $\leq 1.5\,mm$
- eight campaigns since march 2014



Levelling Campaigns (LIAG)

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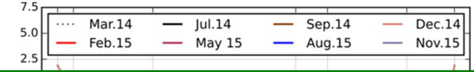


Subsidence Rates - Bad Frankenhausen (Thuringia)

- verified maximum subsidence rates of 4-5 mm/yr since march 2014
- higher values for GRAV05 and GRAV08 (possibly due to extensive construction work nearby)
- time needed to separate / evaluate these effects from subrosion-induced processes

Gravimetry Campaigns - absolute and relative (LUH, LIAG)

Absolute Gravimetry

- FG5X-220 ($s \approx 0.02 \mu m/s^2$) to control gravity level (datum)
- reducing earth tides and air pressure gravity changes
- gravity tie obtained with Scintrex CG3M ($s_{\Delta g} = 0.015\, \mu m/s^2$)

Relative Gravimetry

- gravimeter instruments used in campaigns
  - Scintrex CG3, CG5 ($s \approx 0.02\, \mu m/s^2$)
  - LaCoste & Romberg ($s \approx 0.05 - 0.07\, \mu m/s^2$)
- *step method* for drift control (spring gravimeters)

gravity tie measurement, © LUH

levelling mark to gravity tie © LUH

Gravimetry Network - Bad Frankenhausen (Thuringia)

- gravity level (datum) observed yearly by absolute gravimetry
- max. gravity difference: $44.5\, \mu m/s^2$ (calibration accuracy < $0.0445\, \mu m/s^2$)
- combined adjustment of relative gravity network: $\leq 0.015\, \mu m/s^2$

GNSS Campaigns - Overview (LUH)

GNSS-Equipment

- **Receiver**: Leica GRX1200+GNSS, GX1230GG and GRX1200GG Pro
- **Antennas**: Leica AR25.R3 NONE and JPS GrAnt G3T NONE (individual robot calibration @LUH)
- GNSS adaptor FG-ANA100B for precise GNSS-height determination
- atmospheric data (height differences $\geq 100\,m$)

Session setup

- star like network (**SL03** reliable reference station)
- 6 sessions, 4 hours observation duration
- 8 GNSS-sites, 5 employees, 3 days
- GPS only and GPS/GLONASS combined network solution (final solution: **GPS/GLO combined**)

collocated point, © LUH

reference @SL03 © LUH

mock-up for calibration © LUH

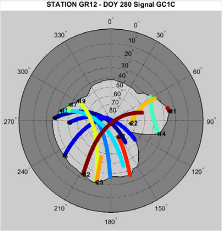
GNSS Campaign - Preparation and Challenges

Challenges for urban Monitoring Networks (GNSS)

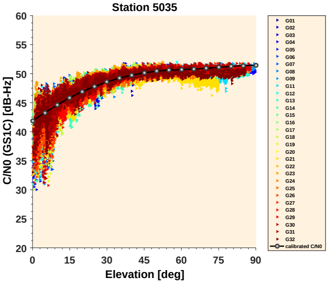
- obstruction at collocation sites due to urban reflectors
- C/N0 as quality indicator (zero baseline vs. field)
- knowledge of C/N0 reference curves (calibration)

Analysing Double Differences and C/N0s

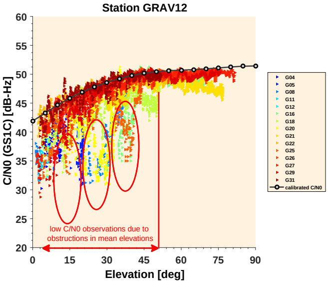
- typical phase noise: $\leq \pm 3.5\,mm$ (DD on zero-baseline)
- significant variations $\geq \pm 3.5\,mm$ (DD in the field)
- dynamic & adaptive elevation masks
- combination of GPS and GLONASS



obstruction mask for site GRAV12

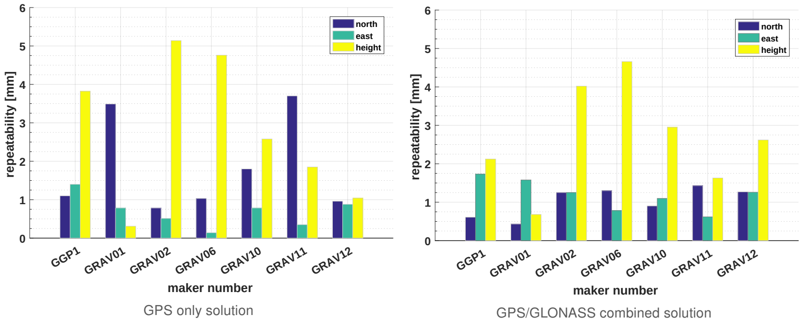


C/N0s on zero-baseline test @LUH



C/N0s in field @GRAV12

GNSS Campaign - L1-Solution of Monitoring Network



GNSS-Monitoring Network

- combined GPS/GLONASS solution optimal w.r.t. GPS only solution (L1-Solution)
- GLONASS improves observations under challenging sky distribution
- height component most challenging parameter - the effort of using FG-ANA100B and individual antenna calibrations is mandatory and justified

Comparison of GNSS and Levelling Heights

Cross-checks between GNSS-heights and Levelling

- proving GNSS-height determination using relative height differences (w.r.t. #GRAV10)
- comparing different measurement-techniques (Levelling vs. GNSS)
- validating ongoing data integration, combination and later modelling of subsurface processes

Number	Name	NHN92 Height [m]	GNSS Height [m]	△Levelling [m]	△GNSS [m]	△GNSS - △Levelling [mm]
1	GRAV01	140.2861	185.8377	-1.037	-1.039	**-1.34**
2	GRAV02	143.7469	189.2970	2.424	2.421	**-2.81**
3	GRAV06	132.7434	178.2935	-8.580	-8.583	**-2.89**
4	GRAV10	141.3234	186.8763	0.000	0.000	**0.00**
5	GRAV11	140.2651	185.8193	-1.058	-1.057	**1.28**
6	GRAV12	152.9325	198.4901	11.609	11.614	**4.66**

Cross-checks

- GNSS-heights correspond with $\pm 3\,mm$ to levelling heights
- GRAV12 shows significant variation in height component (challenging visibility and geometry at this marker)

Summary and Outlook

Integrated multi-technique monitoring network

- installation and first measurements for each technique obtained
- ongoing campaigns to observe and monitor focus areas (determine deformations)
- collecting and integrating of data sets of different kind (gravimetric, GNSS, levelling, borehole extensometer, seismic)

Challenges and further work

- urban environment challenging (levelling, gravimetry, seismic, GNSS) for Hamburg/Bad Frankenhausen
- time to separate significant signals from noise (station specific evaluation)
- evaluating deformations and modelling geophysical processes and rock-soil interaction

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