Institut für Erdmessung

Federal Ministry of Education and Research

Leibniz Universität Hannover

# Geodetic-geophysical Monitoring of Sinkhole Instabilities - Results of SIMULTAN Campaigns from 2015 to 2017

- **Geodetic Week 2017** -

*Session - Environmental Monitoring and Remote Sensing*

SIMULTAN Research Group

***T. Kersten***[1], **L. Timmen**[1], **S. Schön**[1]
**A. Weise**[2], **G. Gabriel**[2], **D. Vogel**[2]

[1] Institut für Erdmessung, Leibniz Universität Hannover
[2] Leibniz Institut für Angewandte Geophysik (LIAG)

# Motivation - Research on Sinkholes / Subrosion Events

Schmalkalden 2010 © TULG

Nordhausen 2016 © MDR/Robert Müller

## Sinkhole Events in Germany

- sinkhole events mostly in depths of 100-150 m, diameters approx. 30 m and 50 m deep
- soluble rocks, subsidence and dissolution of gypsum and anhydrite
- no predictable processes (complex interaction of different factors)
- example Thuringia: approx. 30-40 events annually, (200 since 2016)

# SIMULTAN - Multi-Disciplinary Joint Research Project

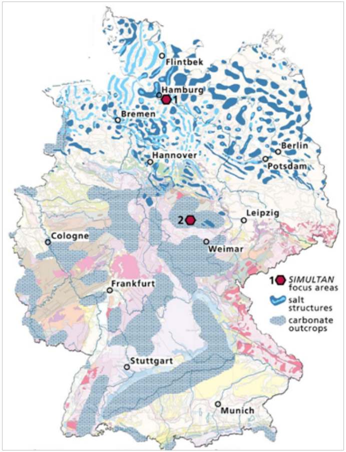
**SIMULTAN**

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

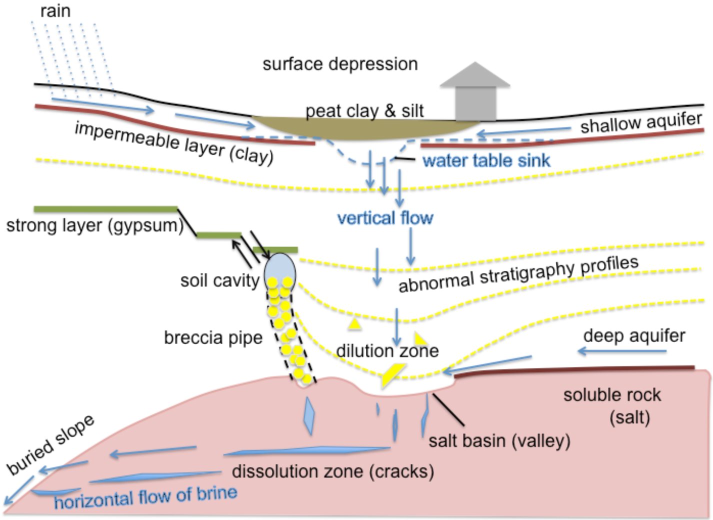
GFZ IAG UH GGL Leibniz Universität Hannover HELMHOLTZ CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

## Key-Parameter

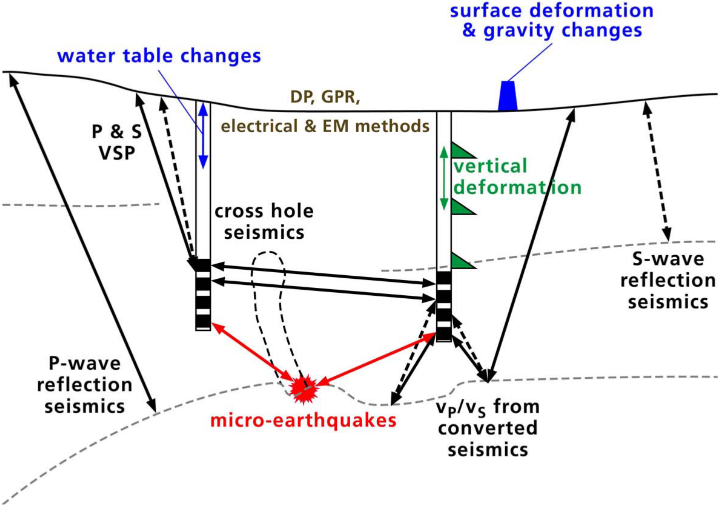
- **early recognition** concept (different scales: time, lateral extent and depth)
- **rigorous combination** of geodetic and geophysical techniques and data sets
- **integrated data sets** of subsurface mechanics and surface deformations by collocated and co-located stations
- **innovative** methods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



# Complex Process Models Require Integrated Methods



# Complex Process Models Require Integrated Methods




© Krawczyk and Dahm 2014

## GNSS Network Processing - Hamburg, Groß Flottbek (HHX)

**Geodetic Datum (for all Working packages)**

- SA*POS*® 2016 (December 1st, 2016) with **GCG2016** for consistent combination of mathematical and physical heights (consistent combination of GNSS, gravimetry and levelling)

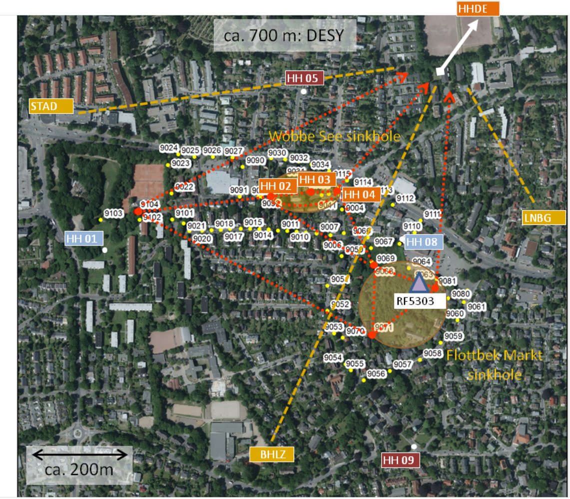
**Continuous GNSS (GPS/GLONASS) campaigns (09/2015 - 09/2017), star-like network**

- local reference: DESY (HHDE), fixed - controlled by several (3) SA*POS*® stations (ionosphere free linear combination)
- five campaigns (finished 09/2017), processed as L1-solution

**Investigations and related studies on GNSS processing**

- Galileo at challenging urban environments [Kersten und Schön, 2017a]
- Dynamic & adaptive elevation masks to improve challenging satellite geometry *dynMask* ( [Kersten und Schön, 2017b]
- Permanent high-sensitive and low-cost units in urban environments (street furniture, smart cities, ...)

# Multi-Technique Monitoring Network in Hamburg Groß-Flottbek




Legend

- all methods
- GNSS + levelling
- only GNSS
- STD2 SAPOS® GNSS stations
- gravimetry + levelling
- levelling
- gravity difference

© LIAG & IfE, (Weise et al. 2017)

# Multi-Technique Monitoring Network in Hamburg Groß-Flottbek

## GNSS Network

- Repeatability of individual sessions (L1 solution):
  - North/East: 0.8 - 1.5 mm,
  - Up: 0.8 - 3.5 mm
- Local reference stable (L3 solution)

## Levelling Network

- Precision: < 1 mm in 7 campaigns

## Gravity Network

- 13 gravity differences out of 8 stations
- $\pm 35 - 50\,nm/s^2$

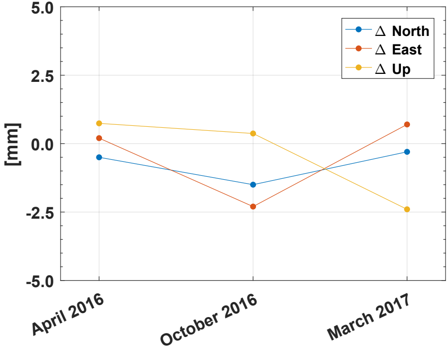
## Absolute Gravimetry

- annually, control network stability
- precision: $\pm 16\,nm/s^2$


© LIAG, IfE 2017

© LIAG, 2017

## Stability of Local Reference and Repeatability of Network Points



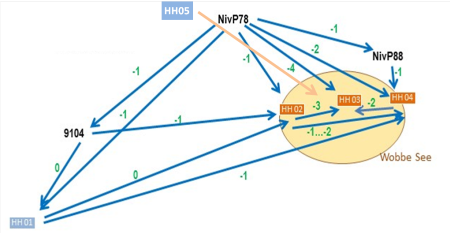

### Epoch Comparison and Validation

- new SA*POS*® Datum on Dec 1st, 2016: offsets in height component of up to 20 mm
- Epoch comparisons confirm very robust consistency of $< \pm 2$ mm in horizontal and up component (common Datum: DHHN2016)

# Levelling and GNSS

## Levelling network

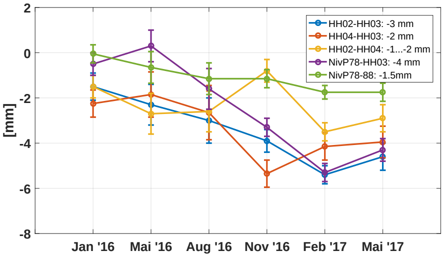
- Subsidence at Flottbek Markt (confirmed by benchmark RF5303) and Wobbe See, change: -1 mm/a
- Seasonal variations, further surveys required




Levelling network & deformation rates

## Comparison to GNSS

- Consistent trend of subsidence for HH05-HH03 (first epoch comparisons, not significant)
- Seasonal variations detectable, further investigations required to separate superimposed signals
- Further steps: integrated data model

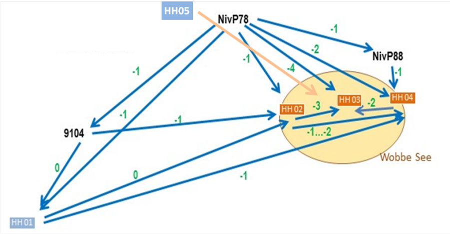



First epoch differences by levelling

# Levelling and GNSS

## Levelling network

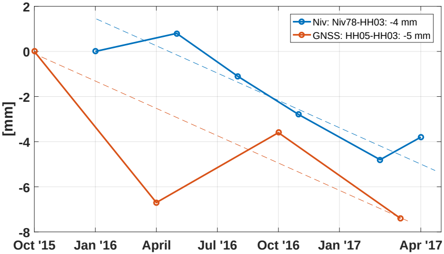
- Subsidence at Flottbek Markt (confirmed by benchmark RF5303) and Wobbe See, change: -1 mm/a
- Seasonal variations, further surveys required




Levelling network & deformation rates

## Comparison to GNSS

- Consistent trend of subsidence for HH05-HH03 (first epoch comparisons, not significant)
- Seasonal variations detectable, further investigations required to separate superimposed signals
- Further steps: integrated data model




First epoch differences between levelling and GNSS

# Absolute and Relative Gravimetry

## Absolute Gravimetry

- FG5X-220 ($s \approx 0.02\ \mu m/s^2$) to control and confirm gravity level Datum
- Reducing earth tides and air pressure gravity changes

## Relative Gravimetry

- Gravimeter instruments used in campaigns
  - Scintrex CG3, CG5
  - LaCoste & Romberg
- *Step method* to control drift of spring gravimeters

gravity local tie measurement

levelling mark to gravity tie

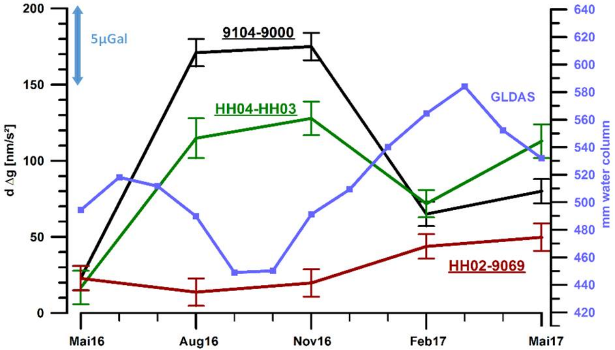
**Findings: Absolute Gravimetry**

- Increase of gravity: $50\,\text{nm/s}^2 \pm 22\,\text{nm/s}^2$
- Consistent with effects in observed gravity differences
- Induced by hydrological variations at subsurface station DESY

## Absolute and Relative Gravimetry

### Relative Gravity Network

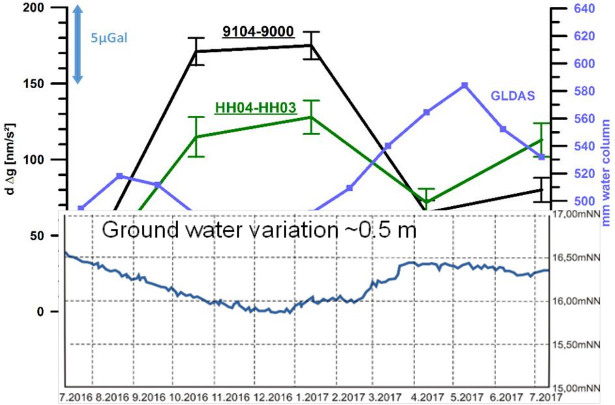
- Precision of network: $\pm 10\,\mathrm{nm/s^2}$
- Temporal variations of gravity differences (up to $120\,\mathrm{nm/s^2}$)
- Correlation of seasonal and local hydrological variations: soil water (GLDAS) and ground water ($\approx$0.5 m water column), partly due to topography/subsurface station



## Absolute and Relative Gravimetry

### Relative Gravity Network

- Precision of network: $\pm 10\,\mathrm{nm/s^2}$
- Temporal variations of gravity differences (up to $120\,\mathrm{nm/s^2}$)
- Correlation of seasonal and local hydrological variations: soil water (GLDAS) and ground water ($\approx$0.5 m water column), partly due to topography/subsurface station



# Summary and Outlook

**Integrated multi-technique monitoring network**

- Ongoing campaigns observe and monitor focus areas (levelling and gravimetry)
- Quantitative interpretation of gravity changes and deformations
- Combination of GNSS and levelling confirm subsidence processes

**Challenges and further work**

- Integrating of data sets (gravimetric, GNSS, levelling, borehole extensometer, seismic)
- Separating significant signals from noise requires longer time series
- Re-processing historical levelling data
- Surface deformation by imaging methods (e.g. InSAR, DInSAR)
- Re-processing of monitoring networks with Galileo

**Tobias Kersten**
**Institut für Erdmessung**
Schneiderberg 50
D-30167 Hannover, Germany

| | |
|---|---|
| phone | + 49 - 511 - 762 5711 |
| fax | + 49 - 511 - 762 4006 |
| web | http://www.ife.uni-hannover.de |
| mail | kersten@ife.uni-hannover.de |


SIMULTAN
Research Group

**Acknowledgement**

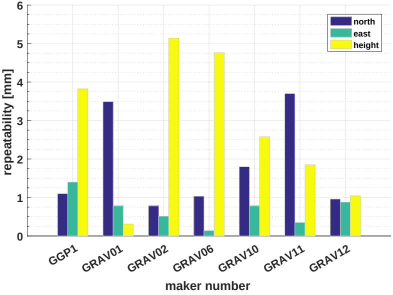
This work was funded through the Ministry of Education and Research (grant 03G0843D).

## References

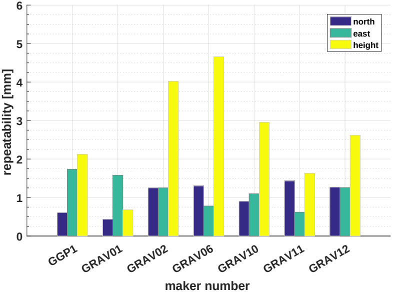
Kersten, T. und Schön, S. (2017a). Galileo for GNSS-Monitoring Networks in Urban Environments. In *Proceedings of Ingenieurgeodäsie 17 - 18 Internationaler Ingenieurvermessungskurs, April 25.-29., Graz, Austria*. DOI: 10.13140/RG.2.2.23052.10887.

Kersten, T. und Schön, S. (2017b). GNSS Monitoring of Surface Displacements in Urban Environments. In Lienhardt, W. (Hrsg.), *Ingenieurvermessung '17. Beiträge zum 18. Internationalen Ingenieurvermessungskurs Graz*, Seiten 415–426. Wichmann Verlag, Berlin/Offenbach, Germany. ISBN: 978-3-87907-630-7.

# GNSS Campaign - L1-Solution of Monitoring Network




GPS only solution




GPS/GLONASS combined solution

## 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] | $\triangle$Levelling [m] | $\triangle$GNSS [m] | $\triangle$GNSS - $\triangle$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)