Solid Earth Discuss.,
https://doi.org/10.5194/se-2018-115-RC2, 2018

Solid Earth
Discussions

Interactive comment on "Time-lapse gravity and levelling surveys reveal mass loss and ongoing subsidence in the urban subrosion prone area of Bad Frankenhausen/Germany" *by* Martin Kobe et al.

Braitenberg (Referee)

berg@units.it

Received and published: 30 December 2018

The working hypothesis of this fine example of repeated gravity measurements is, that the mass loss accompanying the formation of cavities is measurable. The measurement campaign is carried out over four years (2014-2018) in a karst area in Germany affected by the formation of sinkholes and active ground subsidence. These bear a hazard to the buildings and infrastructure, as suddenly the roof of the cavities can collapse creating a hole of many meters depth and bringing down buildings or streets located above the cave. The subsidence is documented by a precise repeat levelling

network. The repeated gravity campaign over the same network should determine the gravity change, which corrected for the height change and ambient factors, documents a subsurface mass loss. The mass loss is expected if the eroded or dissolved material is carried away by an underground water flow. In absence of a hydrologic flow the eroded material will remain in place without a mass loss. This shows that the subsurface hydrology is an important component of the active karst system. The manuscript documents in detail the levelling and gravity campaigns which were carried out with great care using traditional instrumentation. For gravity, the instrumentation consisted in a set of four different relative spring gravimeters, for levelling a digital level was used. The authors distinguish the locally subsiding areas from the surrounding stable areas with the levelling, finding subsidence up to 30.4 mm/yr, and finding a gravity decrease of up to 2 mm/yr partly for the subsiding areas, and stability outside. The important concurring mass variation stems from hydrology, and this is particularly relevant in karstic areas, where the underground water flows are an important part of the evolutionary process. The authors claim lack of local montoring in wells, which is the reason why they use the global GLDAS soil moisture model for correcting the gravity changes. In fact the soil moisture is found to anticorrelate with the gravity changes for the two years 2016-2018, and after applying a local regression factor the variability of the gravity loss and the negative rate are both reduced. Before 2016, for the years 2014-2015 the GLDAS has the greatest signal of the sequence which is though uncorrelated with the gravity. Applying the GLDAS correction over the entire interval 2014-2018 thus increases variability on gravity in 2015, introducing an artifact signal, as noticed also by the authors. I wonder whether the hydrologic modeling could be verified and improved by using rainfall observations, from which an integrated water storage could be simulated. I wonder also whether flow measurements of springs or a river are available which could be a proxy for the underground storage system, also if tens of km distant from the gravity campaign site. The geodetic observations of gravity (Champollion et al, 2018; Van Camp et al. 2006) and of tilt (Grillo et al. 2018, Tenze et al. 2012 , Devoti et al. 2015) in different karstic areas showed good correlation to rainfall, springs

and river, as these last drain the karstic storage and thus are a proxy for the hydrologic mass variations. Since the hydrologic mass variation is crucial in the estimate of the anticipated subsoil erosion, this point could be investigated further in the manuscript. The authors mention a groundwater gauge hundreds of meters distant that does not correlate to the gravity- it would be interesting to see the variation together with the rainfall and springs, if existing, and to see how this signal relates to the GLDAS.

The authors conclude that an observed gravity decrease of 6.5 microGal could be explained by the erosion of 1m of cavity roof in about four years. Apart from the ambiguity in the model, it would be interesting to read a comparison of this value to erosion rates known from literature, and a critical discussion of how realistic such an erosion rate is. In limestone the erosion rate is proposed to be in the order of 0.1 mm/yr (Waltham et al. 2005,p.6; Gabrovsek and Stepišnik, 2005), so much lower. In gypsum rates are higher, and have been proposed to reach 0.5m to 1 m wall retreat of phreatic caves under favourable river flow conditions (Waltham et al. 2005,p. 20). I propose these numbers should be included in the discussion.

The above comments regard the final interpretation of the obserevd gravity decrease, which is of general interest on ist own and well described in the manuscript.

Minor specific comments:

Page 2, L. 21: not clear what is intended with "projects in problematic karst regions“. Please give an explanatory sentence.

Page 3, L.2-5: here different geophysical methods that are useful to define morphology of cavities and sinkhole fills are mentioned, but the gavity method is lacking. Please include it, for instance with Braitenberg et al. 2016, and Pivetta et al.2015.

Page 3, L. 19-23: for hydrologic monitoring in karst I suggest to include the recent paper of Campollion et al 2018 and the work of Van Camp et al. 2006.

Page 5, L. 6:“ Karst Trail“. Not clear what is meant: is it a touristic trail or you mean

something else? Please reformulate or add a few words.

Page 5, L.10:“ structures regional scattered“: check Grammar.

Page 15: Least Square Adjustment of Network: it would be of interest to see the mathematical equations of the process. Maybe you could add it to the Appendix.

Page 17, L.1: GLDAS produces artifacts before February 2016. Do you know whether the data assimilated in the model have changed in 2016? How does the GLDAS series compare to the groundwater measurements in the well you have? Please also show the groundwater well that exists. Show also the rainfall and an integrated rainfall function. Discuss whether it is useful for the observed gravity changes.

Page 18, L. 5: “add up to 0.1..”: units missing?

Page 18, L. 7: "It is not mandatory that gravity values on installed benchmarks are stable over time”: please add a few words, to make this point clearer.

REFERENCES

Braitenberg C., Sampietro D., Pivetta T., Zuliani D., Barbagallo A., Fabris P., Rossi L., Fabbri J., Mansi A. H. (2016). Gravity for detecting caves: Airborne and terrestrial simulations based on a comprehensive karstic cave benchmark. Pure and Applied Geophysics, doi: 10.1007/s00024-015-1182-y, 1-22

Champollion, C., Deville, S., Chéry, J., Doerflinger, E., Le Moigne, N., Bayer, R., Vernant, P., and Mazzilli, N.: Estimating epikarst water storage by time-lapse surface-to-depth gravity measurements, Hydrol. Earth Syst. Sci., 22, 3825-3839, https://doi.org/10.5194/hess-22-3825-2018, 2018.

Devoti R., Zuliani D., Braitenberg C., Fabris P., Grillo B. (2015). Hydrologically induced slope deformations detected by GPS and clinometric surveys in the Cansiglio Plateau, southern Alps. Earth and Planetary Science Letters, 419, 134-142, doi:10.1016/j.epsl.2015.03.023,

Gabrovšek F., Stepišnik U. (2011) On the formation of collapse dolines: A modelling perspective, Geomorphology, 134, 23-31,ISSN 0169-555X, https://doi.org/10.1016/j.geomorph.2011.06.007.

Grillo B., Braitenberg C., Nagy I., Devoti R., Zuliani D., Fabris P. (2018). Cansiglio Karst-Plateau: 10 years of geodetic-hydrological observations in seismically active northeast Italy. Pure and Applied Geophysics, 175, 1765-1781, doi:10.1007/s00024-018-1860-7

Pivetta T., Braitenberg C. (2015). Laser-scan and gravity joint investigation for subsurface cavity exploration - The Grotta Gigante benchmark. Geophysics, Vol. 80, No. 4, (July - August 2015), B83 - B94, doi: 10.1190/GEO2014-0601.1

Tenze D., Braitenberg C., Nagy I. (2012). Karst deformations due to environmental factors: evidences from the horizontal pendulums of Grotta Gigante, Italy. Bollettino di Geofisica Teorica ed Applicata, 53, 331-345, doi:10.4430/bgta0049,

Van Camp, M., P. Meus, Y. Quinif, O. Kaufman, M. Van Ruymbeke, M. Vandiepenbeeck, and T. Camelbeek (2006), Karst aquifer investigation using absolute gravity, Eos Trans. AGU, 87(30), 298, doi:10.1029/2006EO300005.

Waltham, T., Bell, F. G., Culshaw, M. G. (2005) Sinkholes and Subsidence - Karst and Cavernous Rocks in Engineering and Construction, Springer, Berlin, Heidelberg, https://doi.org/10.1007/b138363.

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2018-115, 2018.