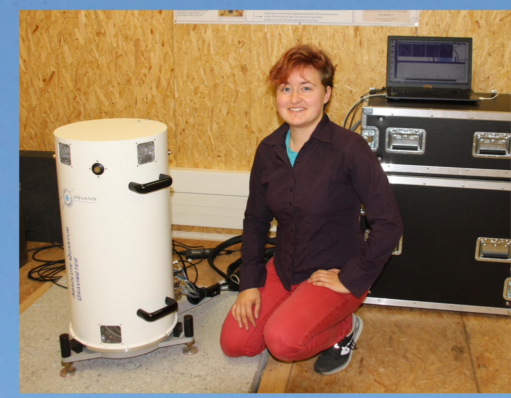
Relative spring-gravimeter:
Scintrex Autograv CG5 #1151

Can vertical gravity gradients monitor local soil moisture dynamics?



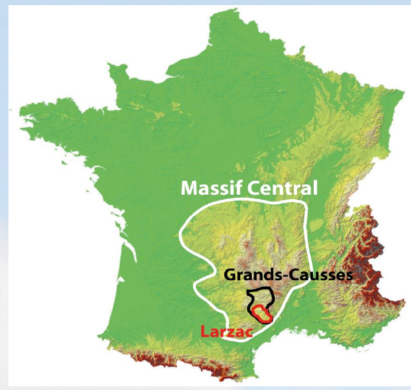
Anne-Karin Cooke (1,2), C. Champollion (1), C. Janvier (2), P. Vermeulen (2), N. Le Moigne (1) and S. Merlet (3)
(1) UM / CNRS, Géosciences Montpellier, Montpellier, France,
(2) Muquans, Talence, France,
(3) LNE-SYRTE, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC, Univ. Paris, France

ENIGMA ITN has received funding from European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie Grant Agreement N°722028.

(anne-karin.cooke@umontpellier.fr)

Introduction

- Gravimetry applied in hydro-geophysical studies
- Gravity signal vertically integrated
- Non-uniqueness of spatial mass distribution
- Vertical gravity gradient more sensitive to local mass changes than gravity



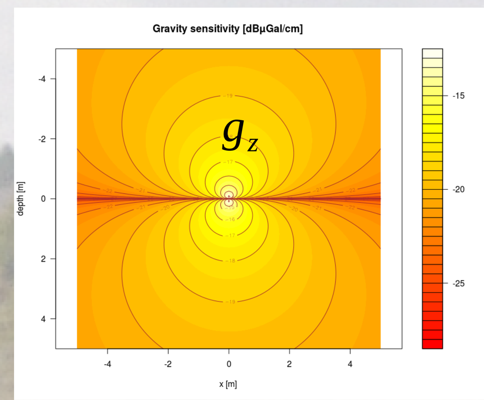
Fores, 2016, after BRGM

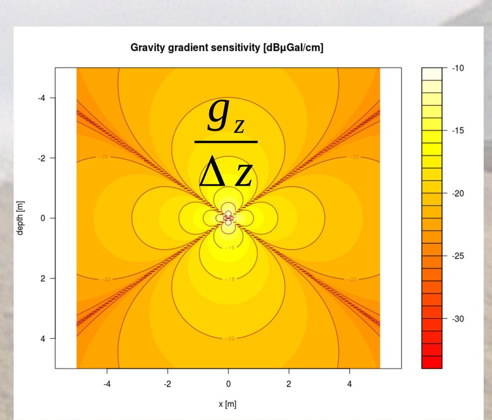
Objectives

- Developing time-lapse gravimetry and gradiometry surveys to detect filling and emptying of reservoirs → spatial localisation of mass changes
- Investigation of small-scale **vertical** gravity **gradient** data
- Preliminary comparison with spatio-temporal variations of **soil moisture**
- Coupled development of model and observations

Hypothesis

Temporal vertical gravity gradients caused by hydrological mass changes (soil moisture)





Soil moisture as **homogeneous**, infinite Bouguer-plate → **vertical gradient constant**

Heterogeneous soil moisture distribution visible in vertical gradient

Strategy

Observation

- Hydro-geophysical & meteorological monitoring on site
- Gravity surveys and vertical gradient estimation

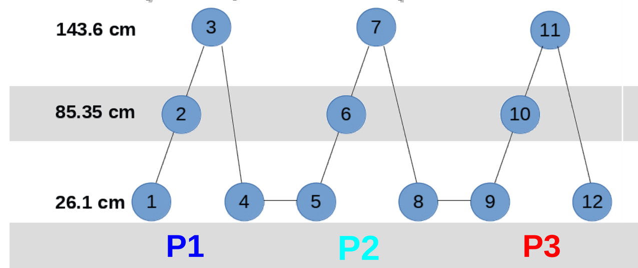
Simulation

- Hydrological model based on *PFLOTRAN* (*Hammond et al., 2010*)
- Coupled with gravity-forward routine
- Vertical gravity gradients at pillar locations

Study Site

- GEK-observatory (Géodésie en Environnement Karstique),
- a highly instrumented hydro-geophysical study site
- Durzon karstic basin (~110 km²) on the Larzac plateau with dolomite/limestone Karst system, deep unsaturated zone

Gravity acquisition protocol



Methods

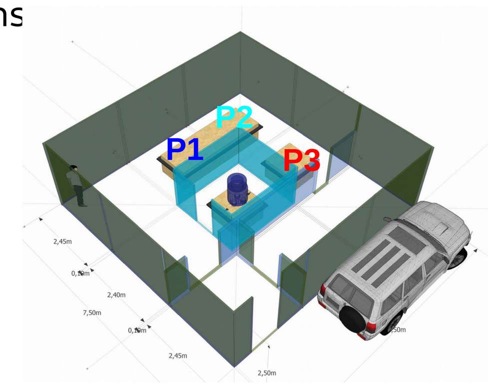
1. Gravity survey

- 3 loops on each concrete pillar with *Scintrex CG5* relative gravimeter
- Monthly surveys 11/2017 – 11/2018
- Post-processing in *pyGrav* software (*Hector and Hinderer, 2016)*
- Site-specific parameters available for: Solid Earth Tides and Ocean Tides corrections atmospheric pressure correction

After N. Le Moigne, 2011

Vertical gradient estimation

- Gradient estimation per pillar and loop as linear drift with height

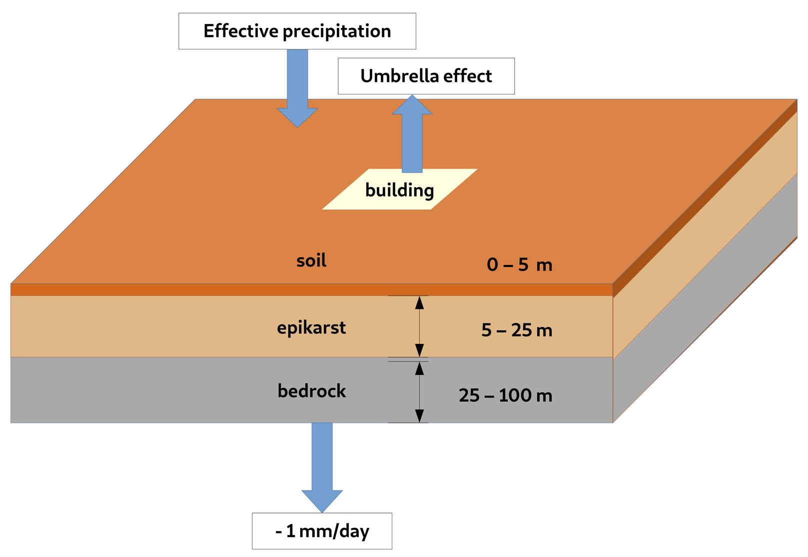


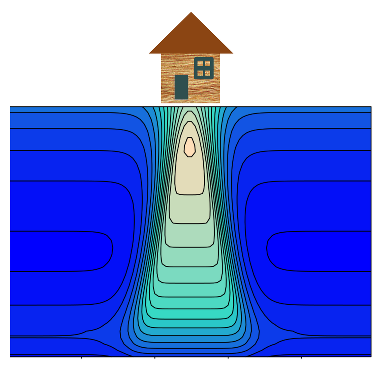
After N. Le Moigne, 2011

2. Hydro-gravimetrical modelling

- Hydrological model based on PFLOTRAN (*Hammond et al., 2010*), an open source, parallel subsurface flow and reactive transport code
- Coupled with FORTRAN-based gravity forward routine (based on *Okabe, 1979*)
- Gravity changes caused by mass changes (changes in water saturation) calculated for pillar locations

Conceptual model

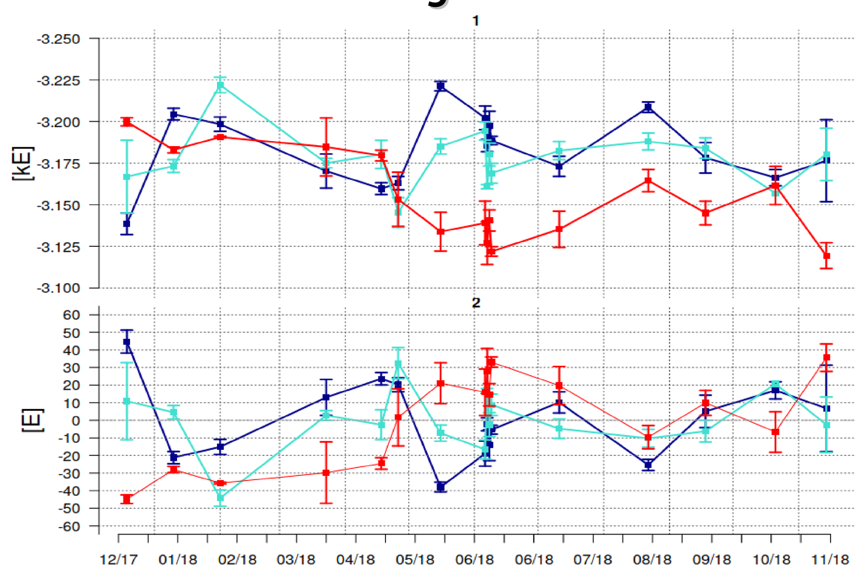




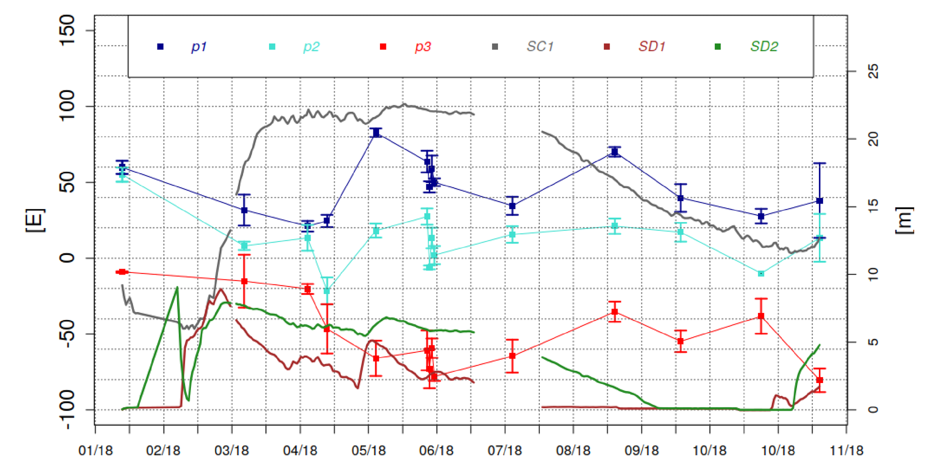
- Impact of buildings on local gravity measurements known as "umbrella effect" due to shielding from precipitation (e.g. *Creutzfeldt et al., 2010; Deville et al., 2013*)
- Effect found for the Larzac site (*Fores et al., 2016*), up to 80% gravity reduction compared to Bouguer slab equivalent **Does the umbrella effect explain observed vertical gravity gradient variations?**

Results

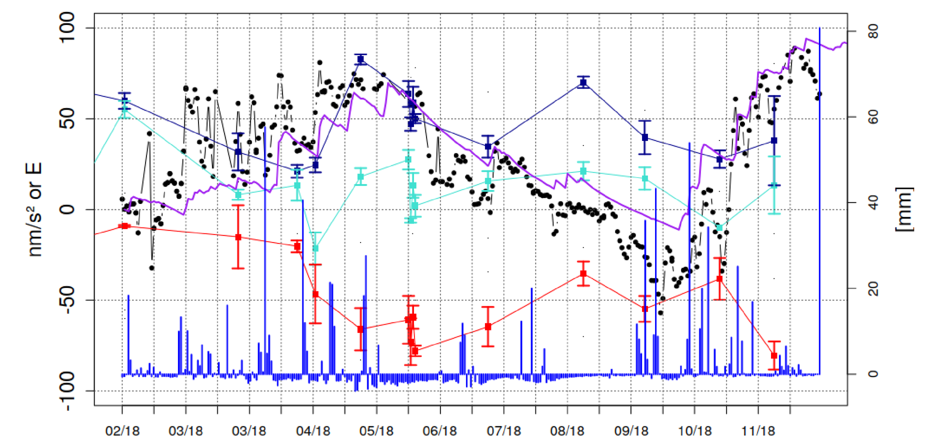
1. Observed vertical gradients



Panel 1: Estimated vertical gravity gradients (VGG) for p1,p2,p3 in kilo Eotvos [μGal cm⁻¹], corrected for differences caused by concrete pillar masses
Panel 2: VGG residuals in Eotvos

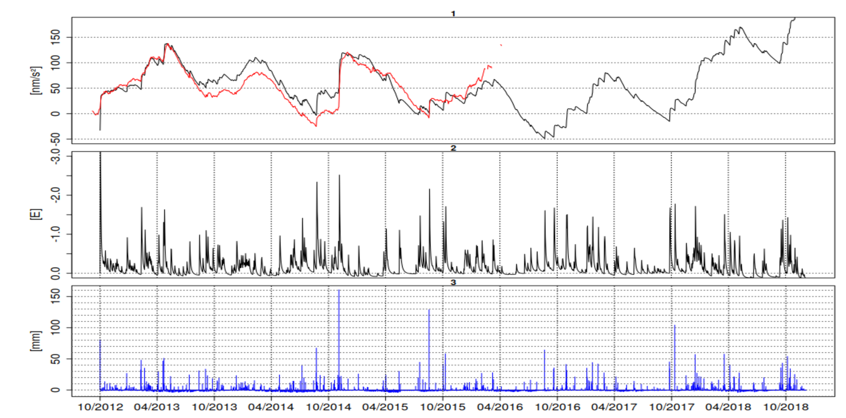


VGG residuals in Eotvos; SD1/SD2 20m deep borehole water level, SC1 50 m deep. All boreholes within 20 m distance to observatory



VGG residuals in Eotvos; daily gravity residuals (iGrav, GWR) in nm/s² (black), Bouger slab equivalent (purple) in nm/s². Daily effective precipitation in mm.

2. Simulated vertical gravity gradients (VGG)



Panel 1: Simulated and measured (red) gravity residuals
Panel 2: Simulated vertical gravity gradients in Eotvos. Simulations start with homogeneous initial soil moisture conditions, run with effective rainfall (panel 3).

Discussion

1. Vertical gradient estimation

- VGG on p1/p2 stable over time; VGG p3 shows significant trend over time and significantly different from p1/p2
- VGG p3 residuals show temporal correlation with borehole water levels
- Differences between pillars appear to be reduced in dry period and increased in wet periods

Limitations: VGG estimation wth CG5 ~ 20 Eotvoes

2. Hydro-gravimetrical simulation

- Simulations reproduce observed gravity residuals
- Simulated VGG respond to rainfall events
- Simulated VGG only a few Eotvoes, differences between pillars negligible
- Order of magnitude of umbrella effect was not reproduced by model; simulated VGG only a few Eotvoes
- More information on soil properties needed surrounding the observatory → realistic saturation difference between and outside "umbrella" required
- Order of magnitude of observed VGG suggest stronger, unknown subsurface spatial heterogeneity

Perspectives

Next step: **Stochastic simulations** of subsurface heterogeneity:

- nearby **borehole water level changes** (local saturated Karst "pockets")
- Soil property variability
- Possibilities: **Soil water saturation** monitoring below building; ERT survey

References

Creutzfeldt, B., Güntner, A., Thoss, H., Merz, B., & Wziontek, H. (**2010**). Measuring the effect of local water storage changes on in situ gravity observations: Case study of the Geodetic Observatory Wettzell, Germany. Water Resources Research, 46(8).
Deville, S., Jacob, T., Chery, J., & Champollion, C. (**2012**). On the impact of topography and building mask on time varying gravity due to local hydrology. Geophysical Journal International, 192(1), 82-93.
Fores, B., Champollion, C., Moigne, N. L., Bayer, R., & Chery, J. (**2016**). Assessing the precision of the iGravsuperconducting gravimeter for hydrological models and karstic hydrological process identification. Geophysical Journal International, ggw396.
Fores, B. (**2016**). Gravimétrie et surveillance sismique pour la modélisation hydrologique e n milieu karstique: application au bassin du Durzon (Larzac, France) (Doctoral dissertation, Université Montpellier).
Hammond, G. E., & Lichtner, P. C. (**2010**). Field-scale model for the natural attenuation of uranium at the Hanford 300 Area using high-performance computing. Water Resources Research, 46(9).
Hector, B., & **Hinderer**, J. (**2016**). pyGrav, a Python-based program for handling and processing relative gravity data. Computers & Geosciences, 91, 90-97.
Okabe, M. (**1979**). Analytical expressions for gravity anomalies due to homogeneous polyhedral bodies and translations into magnetic anomalies. Geophysics, 44(4), 730-741.