



Relative spring-gravimeter:
Scintrex Autograv CG5 #1151

Can vertical gravity gradients monitor local soil moisture dynamics?

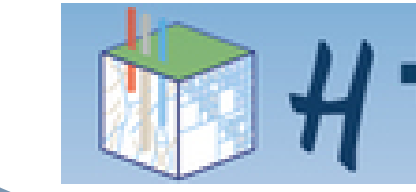
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Introduction

- 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

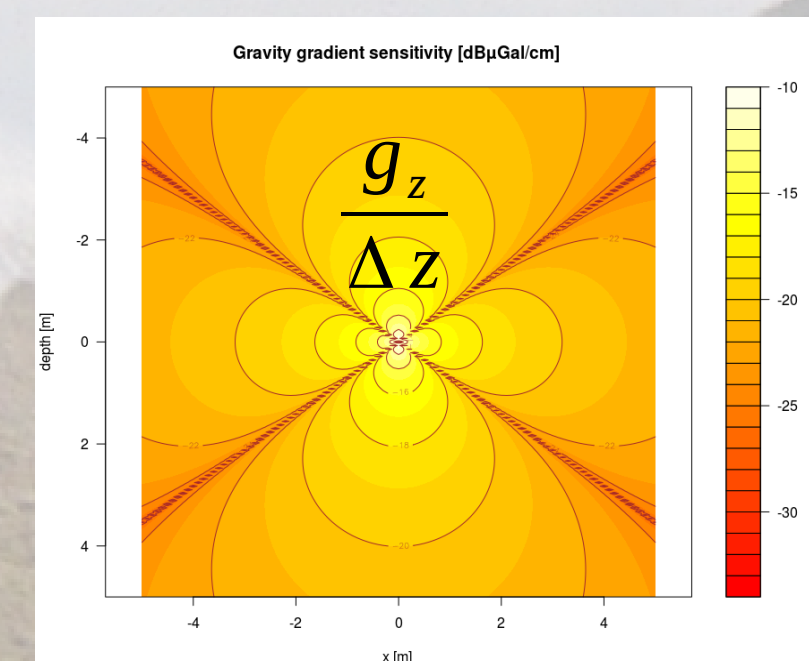
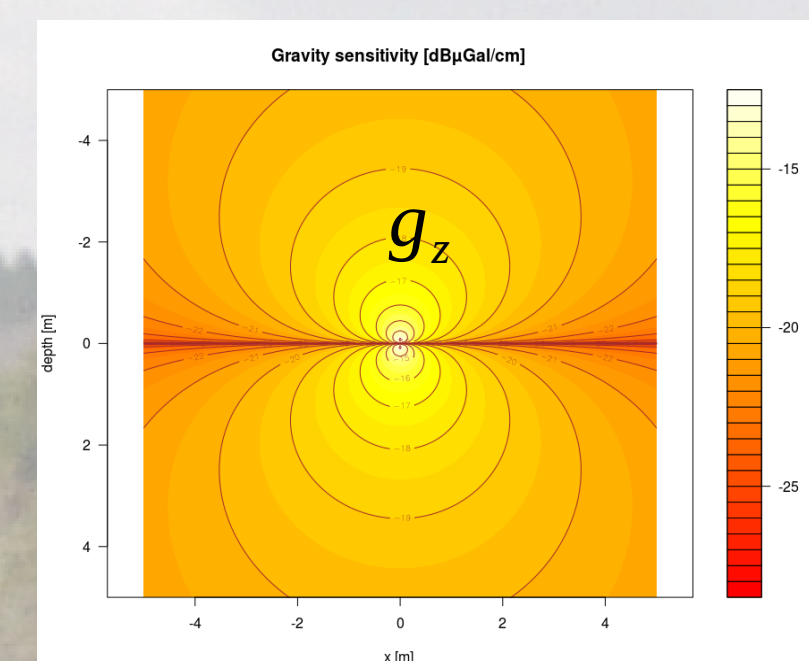


Objectives

- 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)

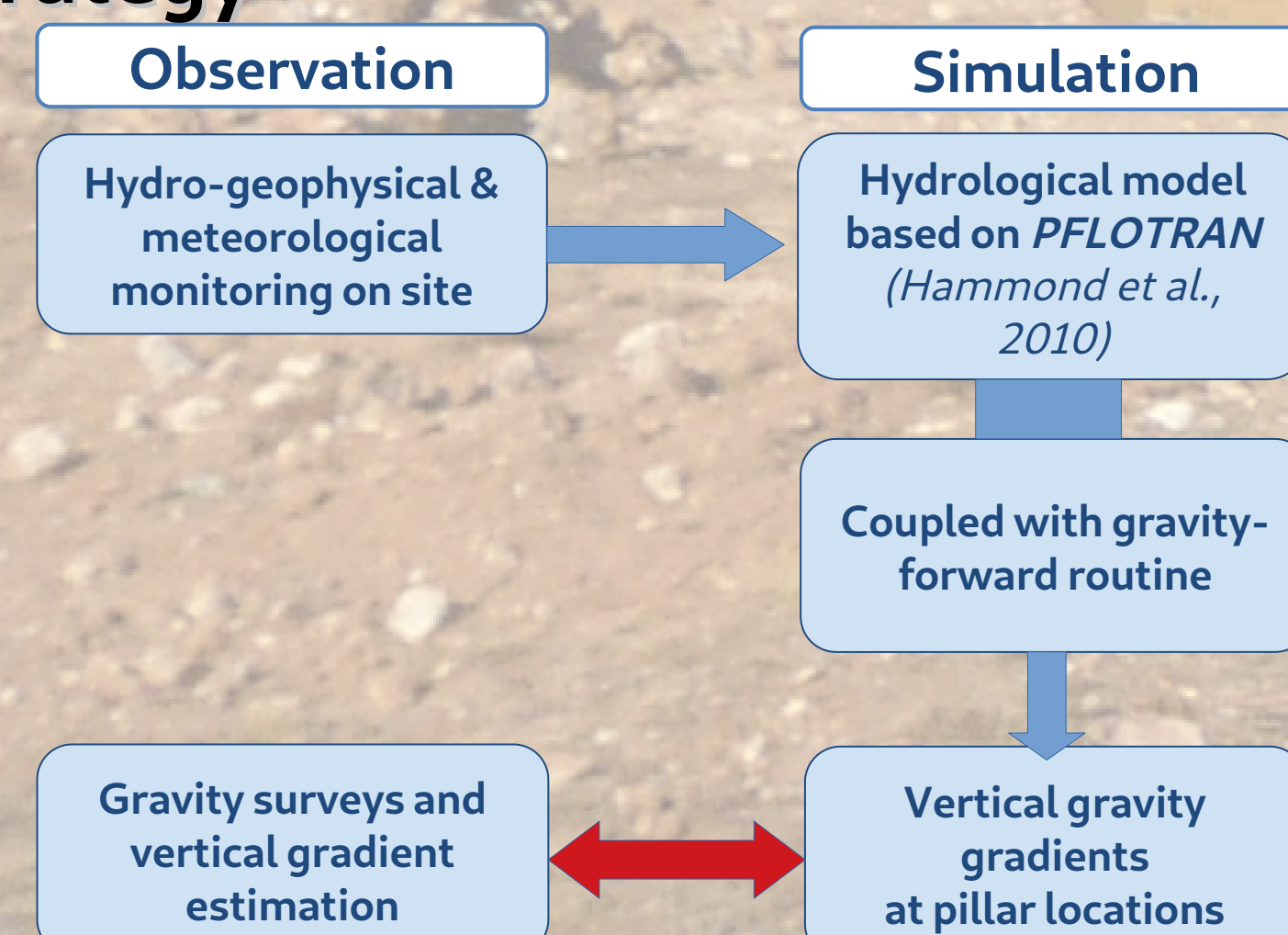


Soil moisture as homogeneous, infinite Bouguer-plate
→ vertical gradient **constant**

Heterogeneous soil moisture distribution visible in vertical gradient



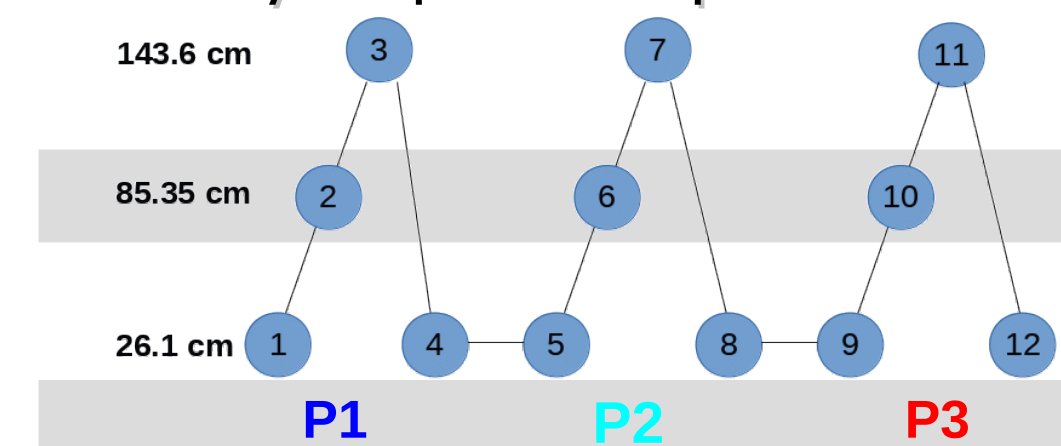
Strategy



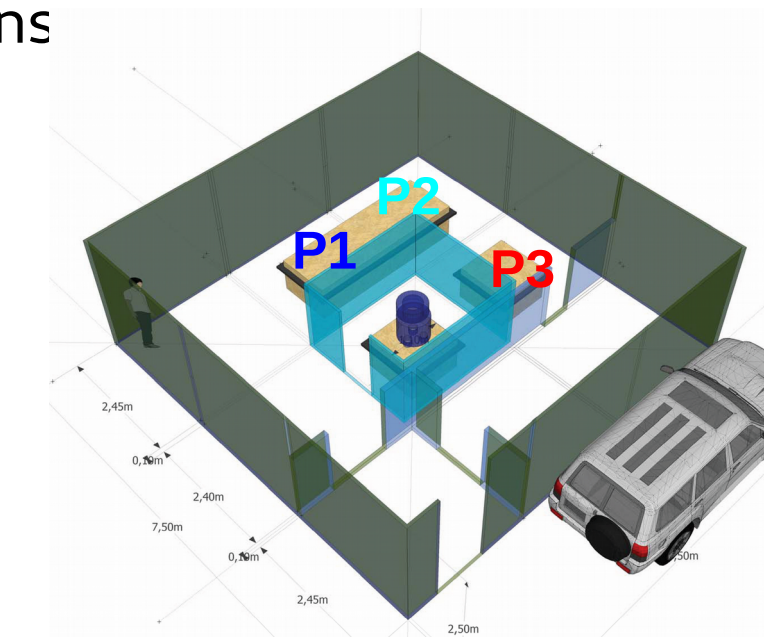
Study Site

- 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



After N. Le Moigne, 2011



After N. Le Moigne, 2011

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

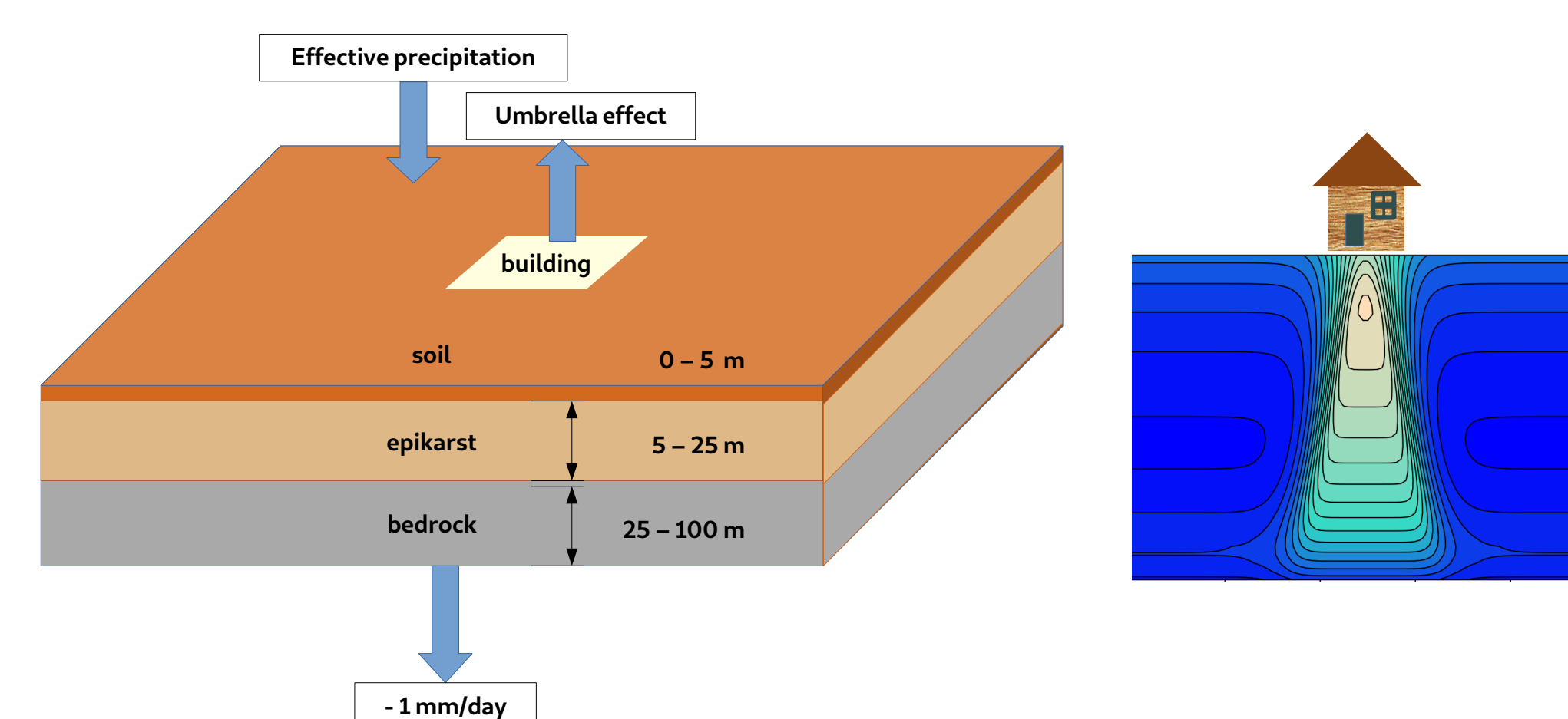
Vertical gradient estimation

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

2. Hydro-gravimetric 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

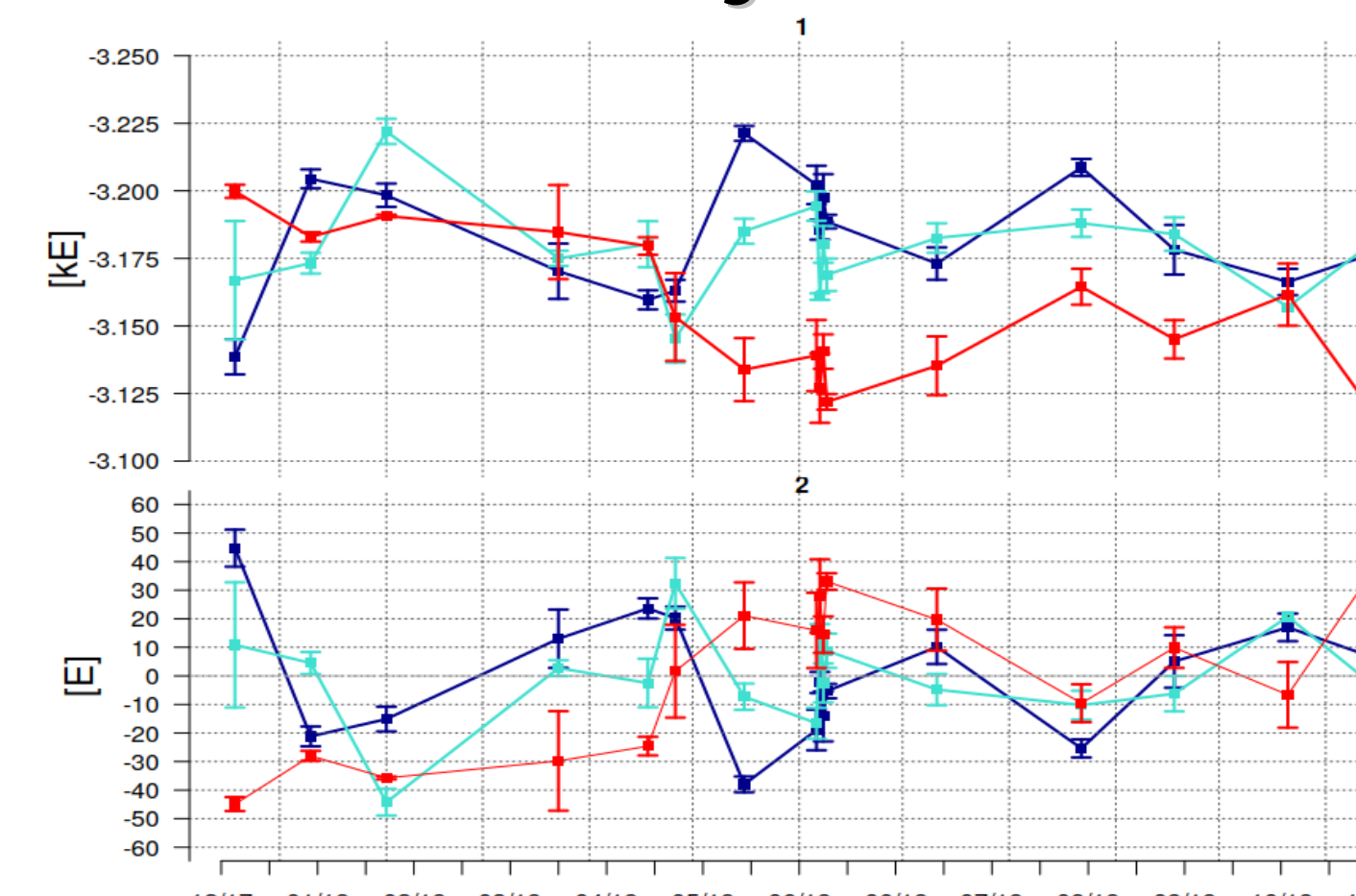
Conceptual model



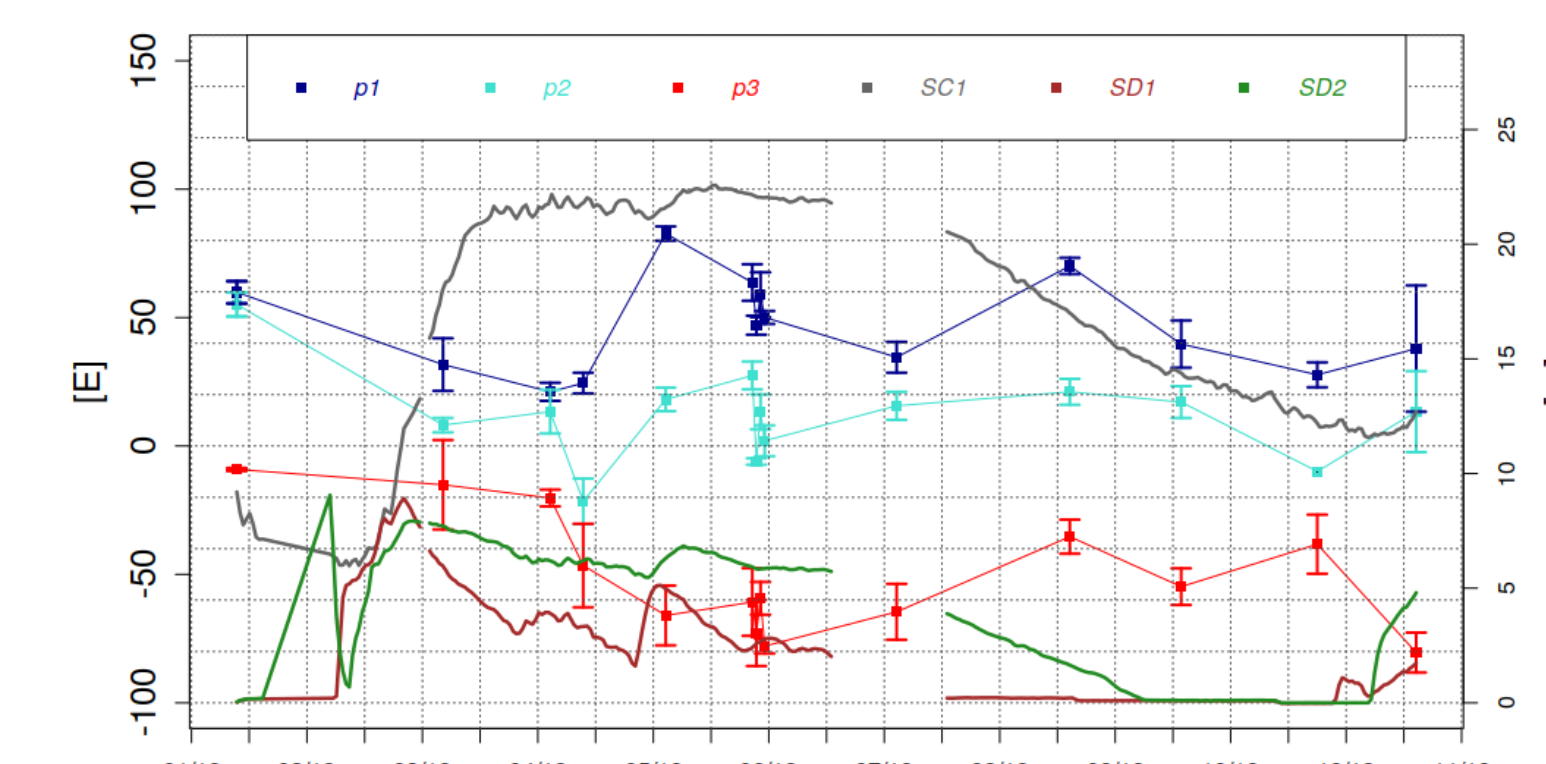
- Impact of buildings on local gravity measurements known as "umbrella effect" due to shielding from precipitation (e.g. Creutzfeldt et al., 2010; Deville et al., 2013)
- Effect found for the Larzac site (Fores et al., 2016), up to 80% gravity reduction compared to Bouguer slab equivalent
- Does the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

Results

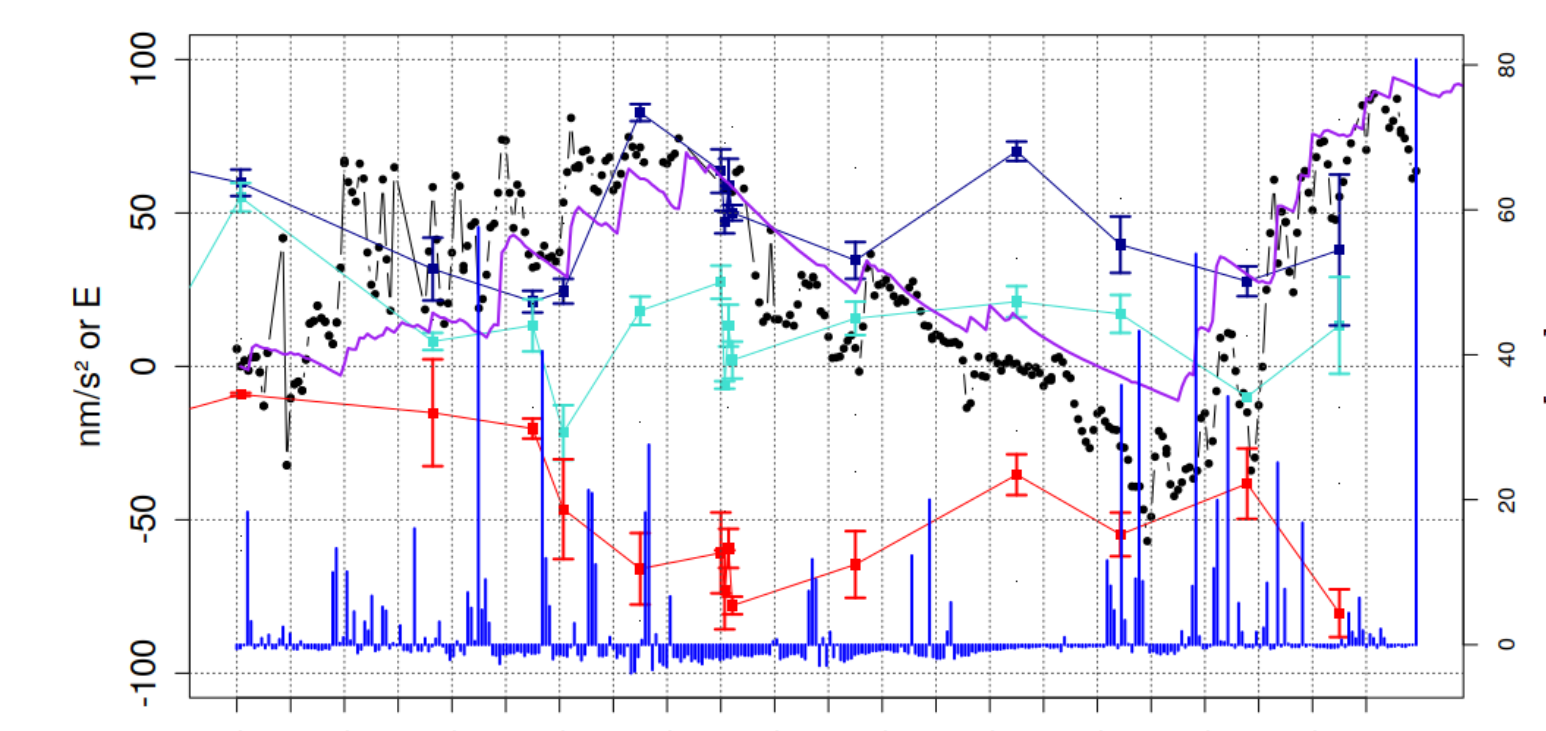
1. Observed vertical gradients



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

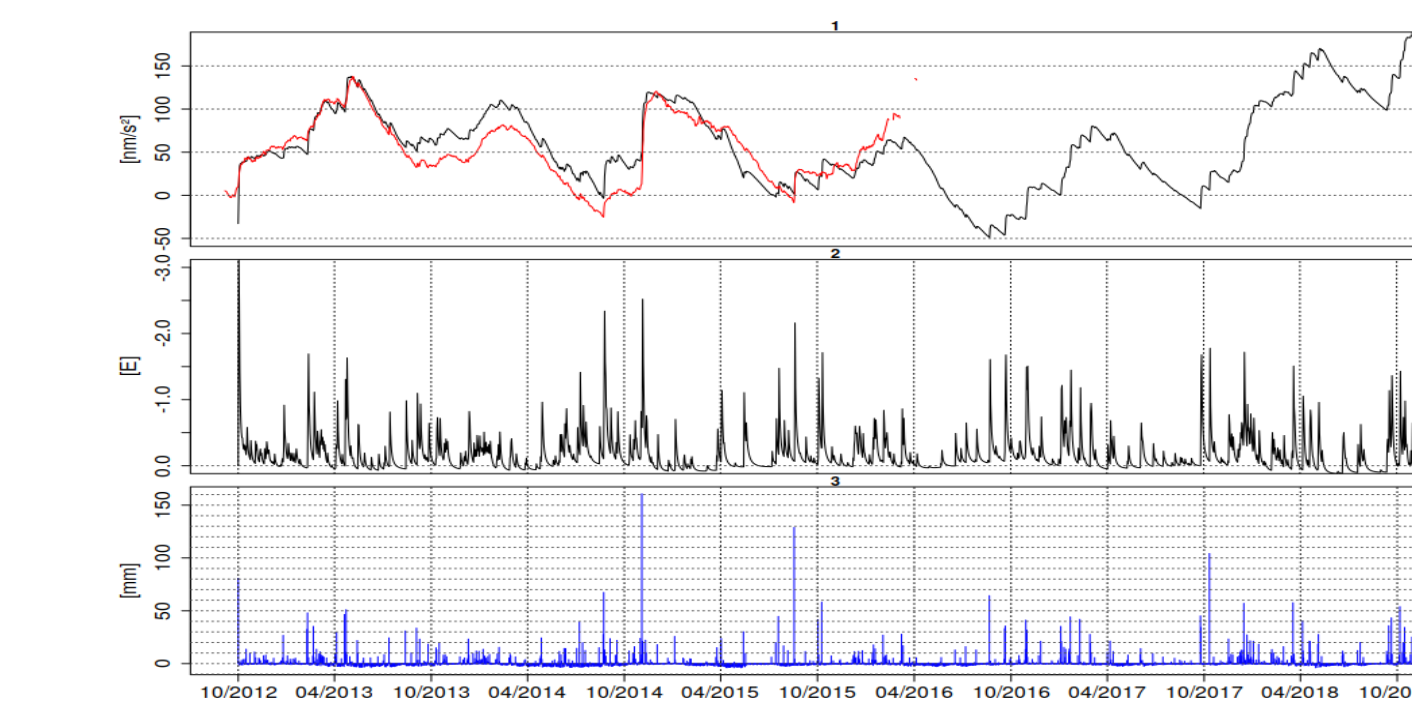


VGG residuals in Eotvos; SD1/SD2 20m deep borehole water level, SC1 50 m deep. All boreholes within 20 m distance to observatory



VGG residuals in Eotvos; daily gravity residuals (iGrav, GWR) in nm/s² (black), Bouguer 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 with CG5 ~ 20 Eotvos

2. Hydro-gravimetric simulation

- Simulations reproduce observed gravity residuals
- Simulated VGG respond to rainfall events
- Simulated VGG only a few Eotvos, differences between pillars negligible
- Order of magnitude of umbrella effect was not reproduced by model; simulated VGG only a few Eotvos
- 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

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