

On the potential of vertical gravity gradient monitoring for hydrological signal detection

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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

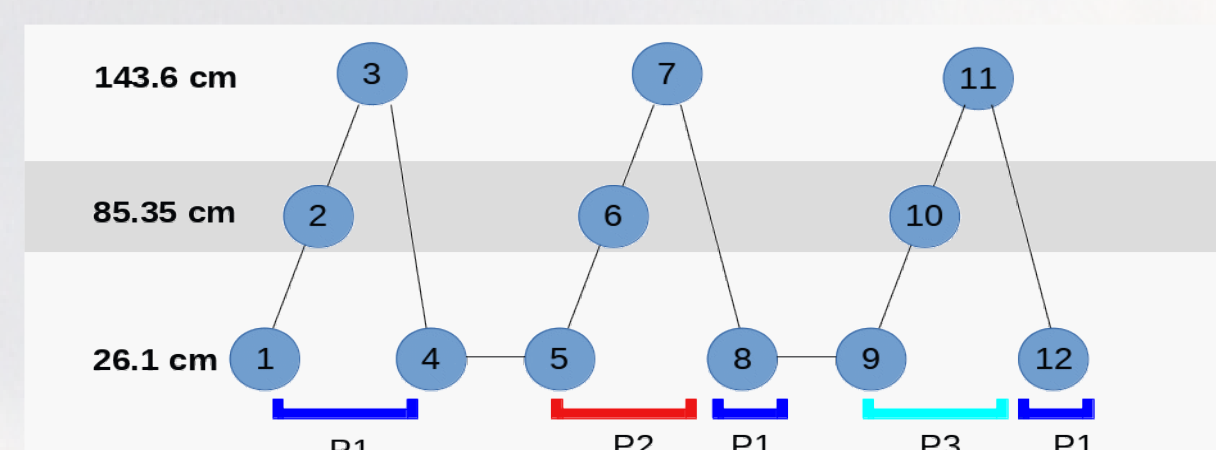
Objectives

- Developing time-lapse gravimetry gradiometry surveys to enhance spatial localisation of mass changes
- Investigation of small-scale **vertical gravity gradient** data
- Preliminary comparison with spatio-temporal variations of **soil moisture**

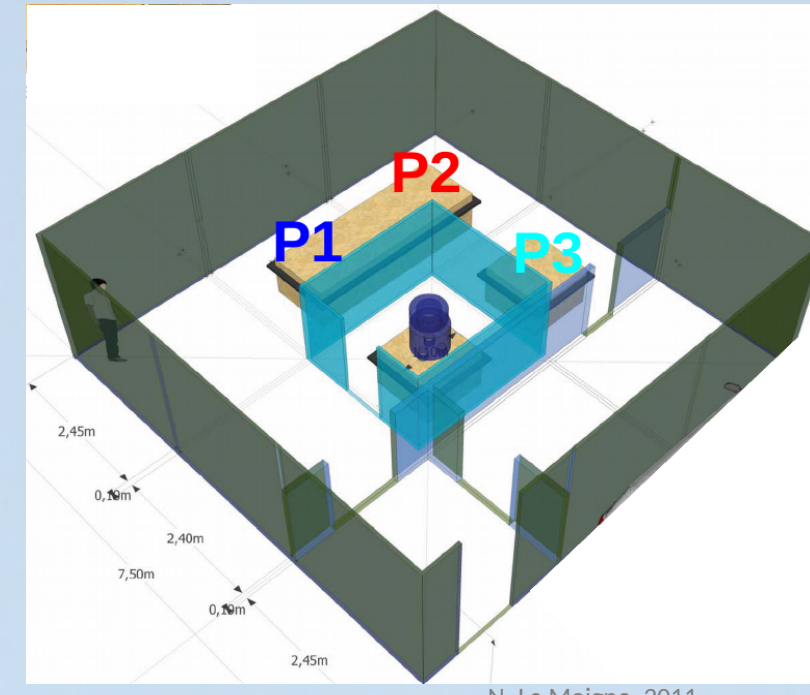
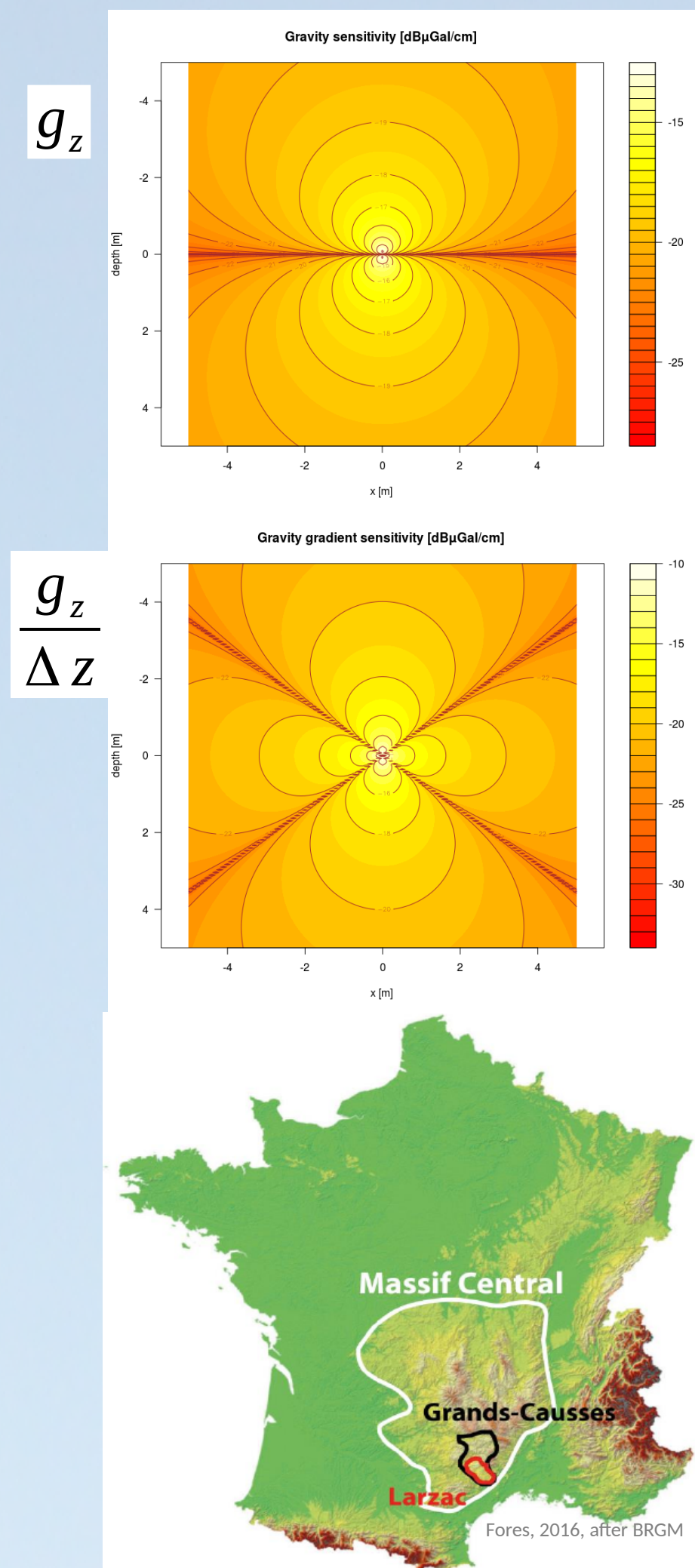
Study Site

- GEK-observatory (Géodésie en Environnement Karstique)
- a highly instrumented hydro-geophysical study site
- Durzon karstic basin (~110 km²) on the Larzac plateau
- Dolomite/Limestone Karst
- System, deep unsaturated zone ~ 150 m
- Water storage in the epikarst

Gravity survey



- 3 loops on each concrete pillar
- Monthly surveys 11/2017 – 06/2018



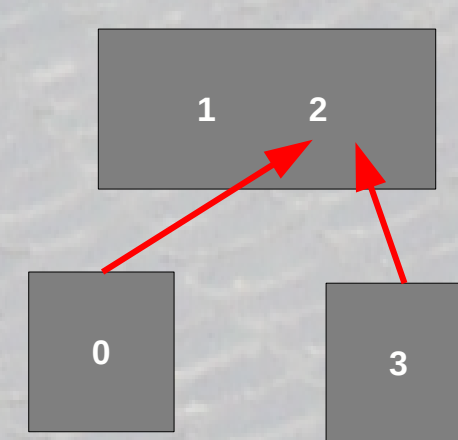
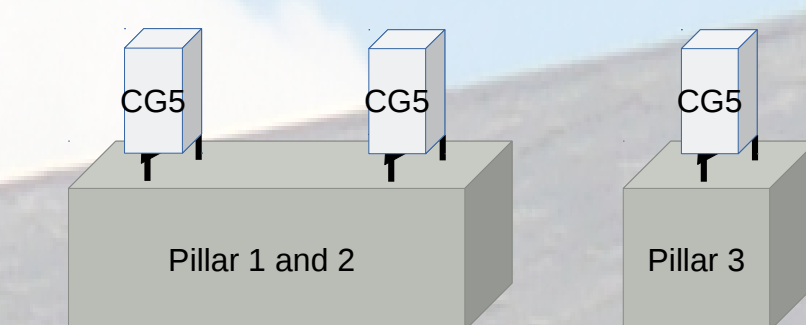
Forward- modelling

Sensitivity of gradients derived at different heights

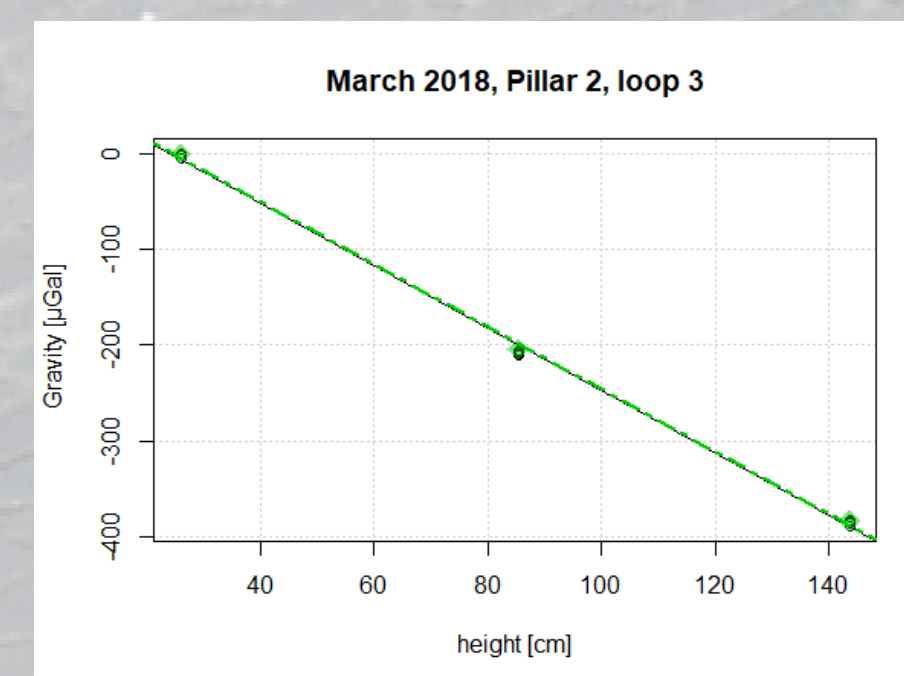
Simulation
influence of pillars 3 and 0 on pillar 2, terrestrial vertical gradient of 3.089 kE added



Relative spring-gravimeter: Scriptrix Autograv CG5 #1151



Numerical approximation of Prisms' gravity (after Okabe, 1979)



Post-processing

software: pyGrav "a multi-platform, open-source Python-based software for processing relative gravity data" (Hector and Hinderer, 2016)

Solid Earth Tides and Ocean Tides corrections

- tidal model function PREDICT from ETERNA program package (Wenzel, 1996)
- combined earth and ocean tide parameters specifically obtained for the Larzac site

Atmospheric pressure correction

- 2.71574 nm/s²/hPa
- Flux tower data from OSU-OREME

Drift adjustment

- Least-squares inversion drift estimation (based on Beilin, 2006; Hwang et al., 2002)

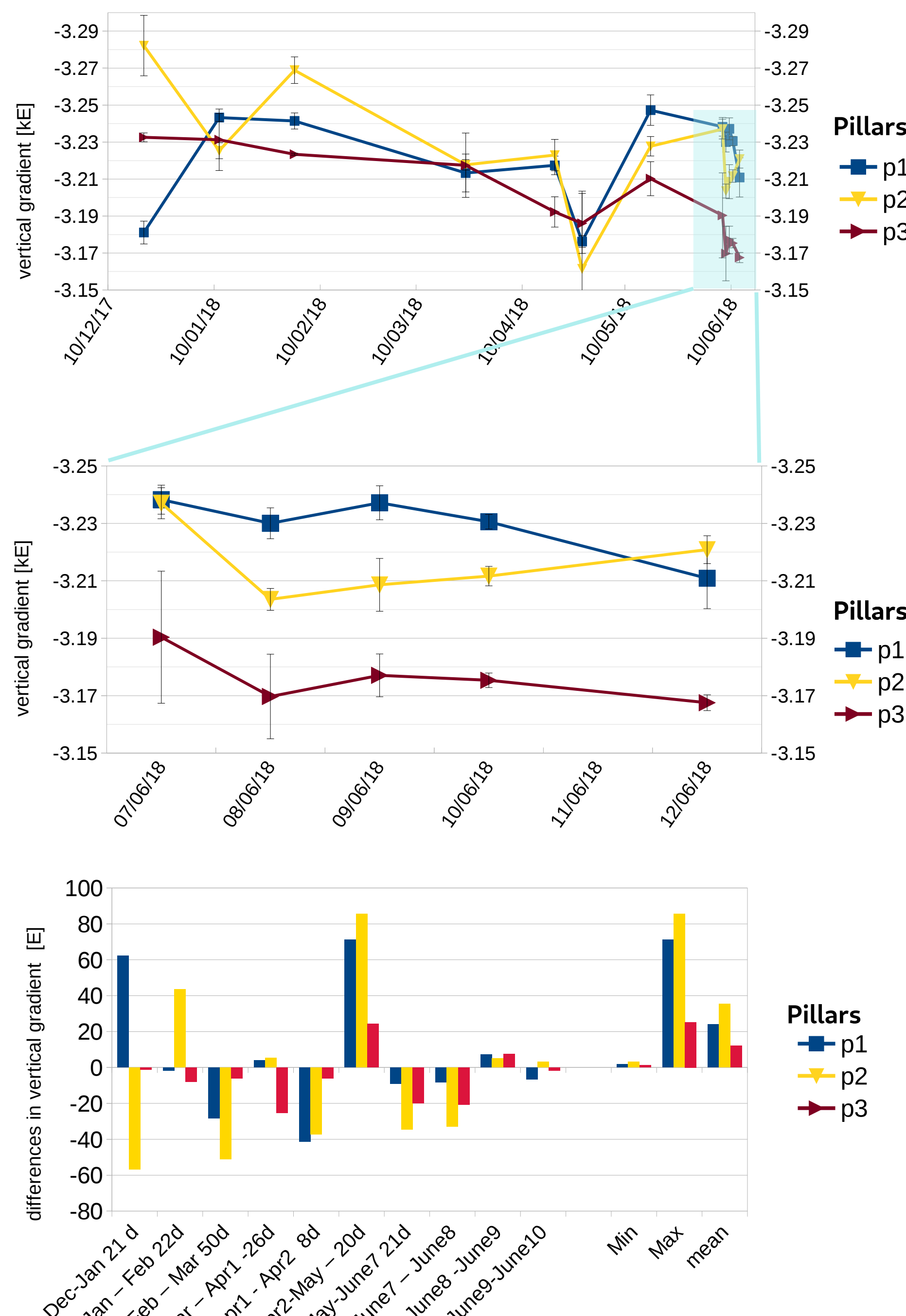
Vertical gradient estimation

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

Simple and double differences

- Simple diff.: A posteriori covariance matrix in reference to fixed gravity value
- Double diff.: base station, comparison with different loops (here: pillar 1, revisited in between changing the pillars)

Results



Discussion

Signal or noise?

- Spatial differences** → structure → simulation of concrete pillars supports found differences in gradient per height
- Temporal differences** → hydrological mass changes?
- Soil moisture only significant mass change at this site
- Repeatability tests in June show that observed monthly changes are larger than noise level
- Unusually wet spring, larger moisture differences expected for end of summer

Limitations:

- Instrument: drift and tares of CG5, non-linearities
- Noise introduced by frequent instrument movement

Conclusion

Short term:

- Uncertainty reduction necessary, longer time-series
- Refined simulations needed to improve understanding

- Next steps: **improved gradient measurements**
- Mid term : **utilization of Absolute Quantum Gravimeter for absolute gravity measurements**
- Longer term : **utilization of quantum gravity gradiometer with an expected stability ~ 1 E**

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

Heterogeneous soil moisture distribution
visible in vertical gradient



Outlook

Simulation with Pflotran (Hommand et al., 2014)

- Conceptual model around GEK
- Soil moisture saturation with depth, unsaturated flow using Richards equation

→ Transform saturation of mesh cells into gravity and gradient changes on the pillars

- Available hydrological, meteorological and hydrochemical data as model constraints

- Coupled development of model and observations

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