Gravimetry for monitoring water movements: the Classical Karst as a natural laboratory

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Motivation/Objectives

GENERAL PURPOSES

- Study the sensitivity of gravimetry for tracking water mass movements in the Classical Karst
- Assess the contribution of gravimetry in order to depict the water dynamics with respect to the most classical water monitoring systems

STUDY OBJECTIVES

- Produce a realisitic model of the water mass variations due to flooding events inside the Škocjan cave
- Model the gravity field temporal variations due to typical events
- Identify the best locations for placing a continuous recording gravity meter in the Škocjan caves area

1) The Classical Karst area

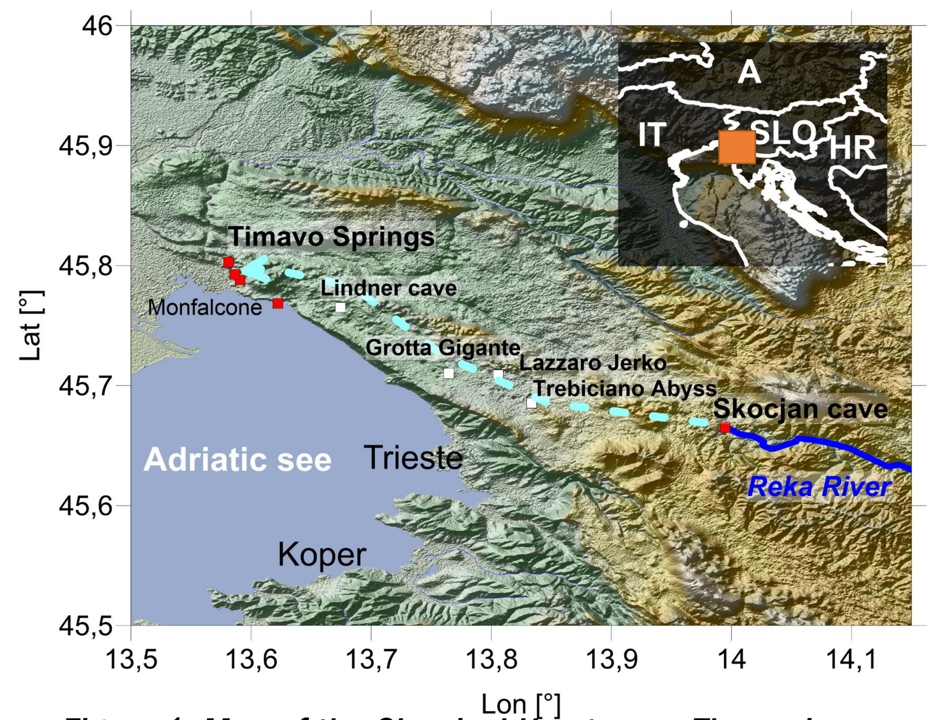

Figure 1: Map of the Classical Karst area. The main caves along the underground stream (cyan dotted line) of the Reka river are reported with white squares. Red squares show the location of the Škocjan cave and the Timavo Springs

- An area of 750km^2 shared between IT/SLO
- Well developed and complex karst system [1,2]
- Water is supplied by two main contributors

Rain infiltration — Reka River

- Reka river sinks in the Škocjan caves, flows underground and emerges at Timavo springs (fig. 1)
- In Škocjan area the water paths are shallow and well known
- Downstream the water dynamics become more unclear
- We focus on the Škocjan area to test the sensitivity of the gravity method because here the geometry of the cave is very well known and the water level variations due to flood events are continuously monitored [3]

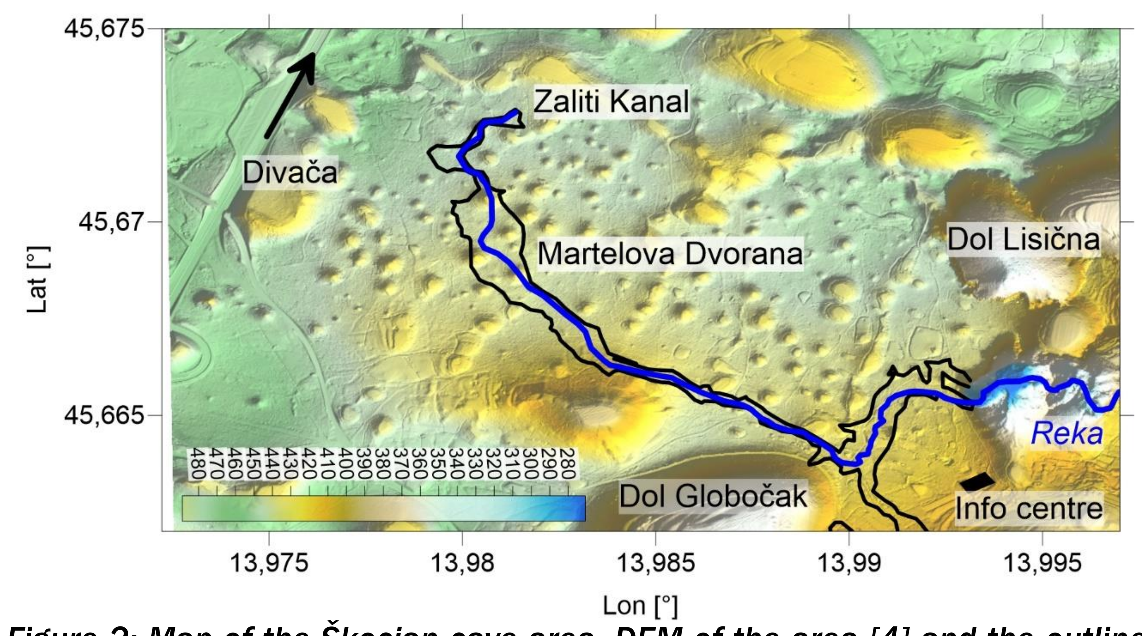

Figure 2: Map of the Škocjan cave area. DEM of the area [4] and the outline of the cave (black line). Martelova Dvorana is a big hall inside the cave; Zaliti kanal is the final small tunnel of the cave that drains the water out from the Škocjan caves system. The info center is reported as it could be a good site for placing a continuous recording gravimeter

2) Škocjan cave: a) Hydrology

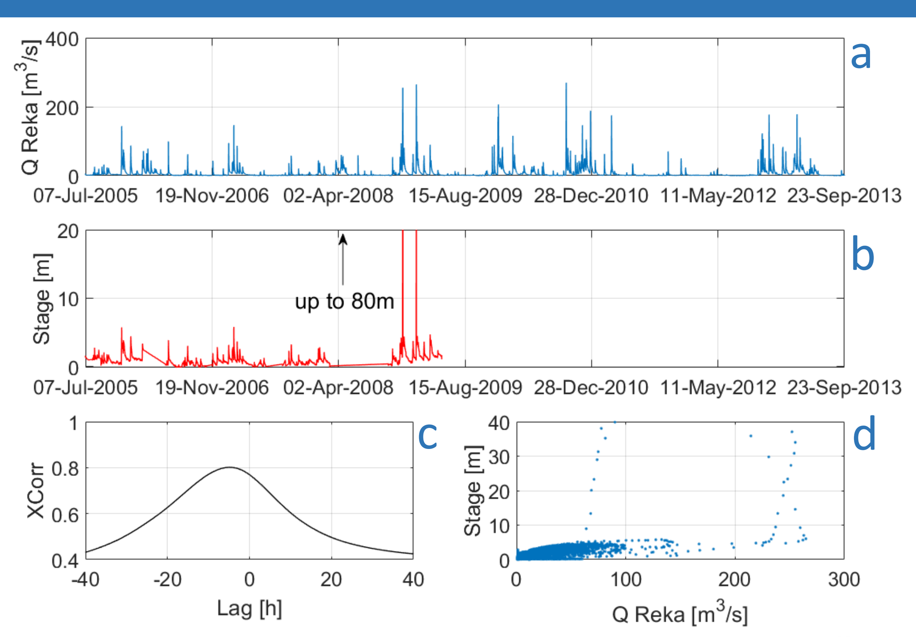

Figure 3: Analysis of the hydrologic timeseries in the Škocjan caves. a) water discharge of the Reka river before the immission in Škocjan cave system (Cerkvenikov Mlin). b) water level variation recorded at the Martelova Dvorana. c) Crosscorrelation between the two timeseries. d) Discharge of the Reka vs. level at Martelova Dvorana

- The high values of the cross correlation (fig. 3c) testifies the similarity between the two time-series (a and b). The lag is 5 hours that corresponds to the travel time of the flood pulse from the Cerkvenikov Mlin to the Martelova Dvorana.
- Fig. 5d testifies a strong non linear response of the water level in the Martelova Dvorana when huge events occur (Q_{peak} >200m^3/s). During these events the Martelova Dvorana is flooded and is almost completely filled by water

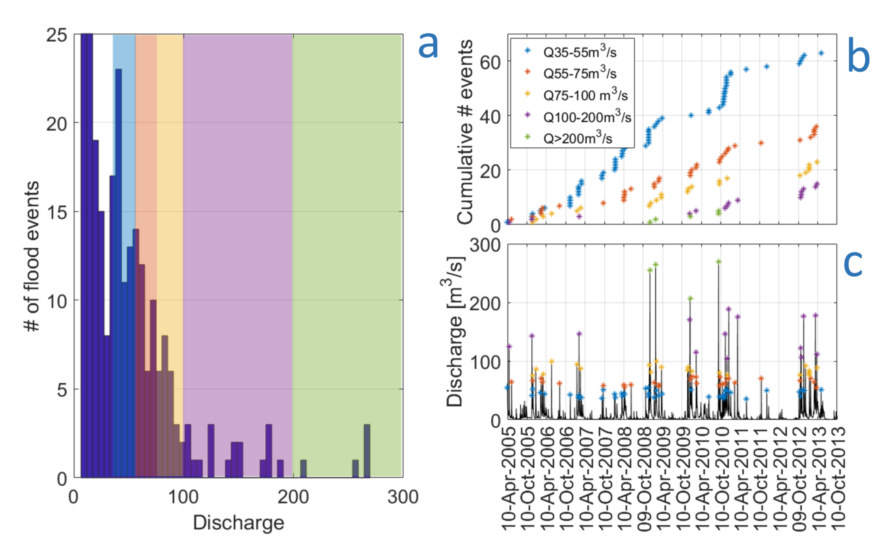

Figure 4: Analysis of the recurrence od flooding events a) frequency distribution of the peak discharge events the colors divide the distribution into 5 classes. b) cumulative curve of the events for the five different classes. c) the timeseries with the peaks coloured according to the discharge classes.

From the recurrence analysis (fig.4) we find:

- Events with Q_{peak} 50-75m^3/s occur typically 7 times/year and prevalently occur in the autumn Spring period
- Events >100m^3/s have a 1.5 years recurrence time
- Events > 200m^3/s are sporadic with recurrence time > 2 years

b) Hydraulic model

- SWMM [5] is a software that models the unsteady flow in conduits and pipes by numerically solving the Saint-Venant equations
- We used the SWMM software to produce a 4D hydraulic model of the water variations inside the cave
- We simulate the karst system of the Škocjan caves with 4 conduits (fig. 5)
- We injected the water hydrograph at the node j4. The input is the discharge timeseries from Cerkvenikov Mlin

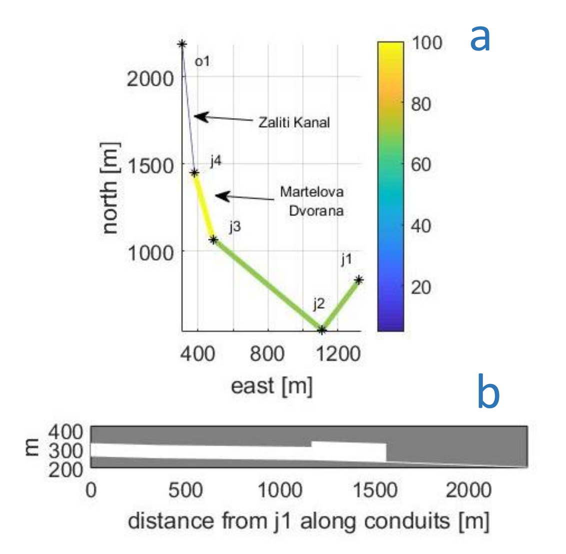

Figure 5: Model Geometry for the simulation a) plan view of the geometry of the conduits. Color scale reports the height of each conduit b) cross section along the conduits; note the big hall Martelova Dvorana and the restriction of the Zaliti Kanal

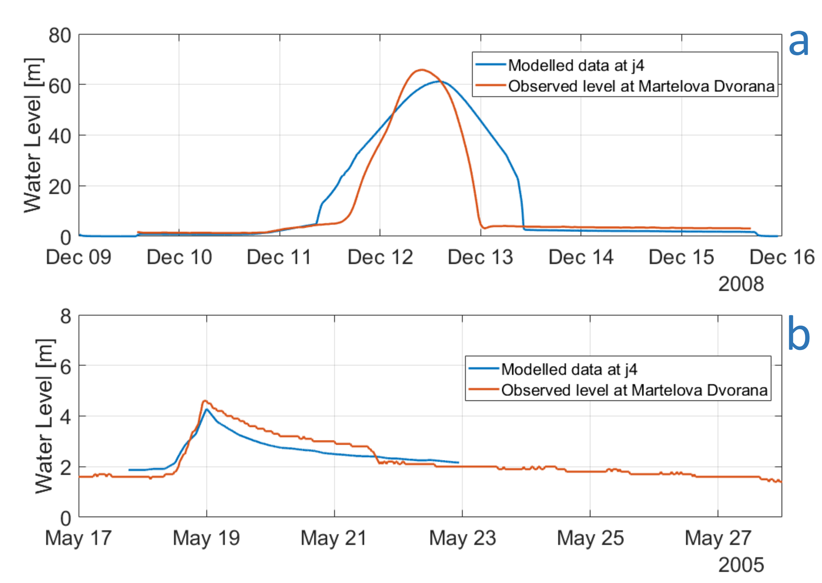

Figure 6: Hydraulic simulations in the Škocjan cave. a) modelling of a rare event with Q_{peak}>250m^3/s; b) modelling of a typical seasonal event (Q_{peak}=60m^3/s)

- Two events were considered: a yearly typical event (fig. 6b) and a more rare event (fig. 6a)
- Figure 6 shows the modelled and observed time-series of the water variations. The temporal resolution of our model is 15minutes
- Our model reproduces well both the events in terms of magnitude. The duration of the event in figure 6a seems to be a bit overestimated.

3) Gravity variations due to floods

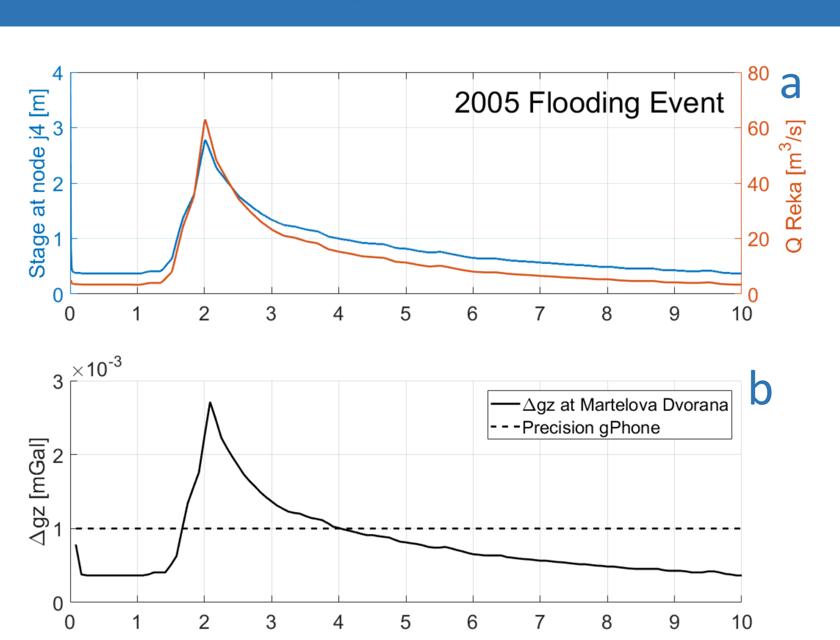

Figure 7: Simulations of the gravity variations due to the flooding event with Q_{peak}=60m^3/s. a) discharge rate time series and water level variation at node j4. b) gravity variation simulated above the Martelova Dvorana

- We calculated the gravity variations discretising the 4D simulated water variations with prisms
- We calculated the effect for the considered events in two locations: one above the Martelova Dvorana and the other in the info center (Fig. 2)

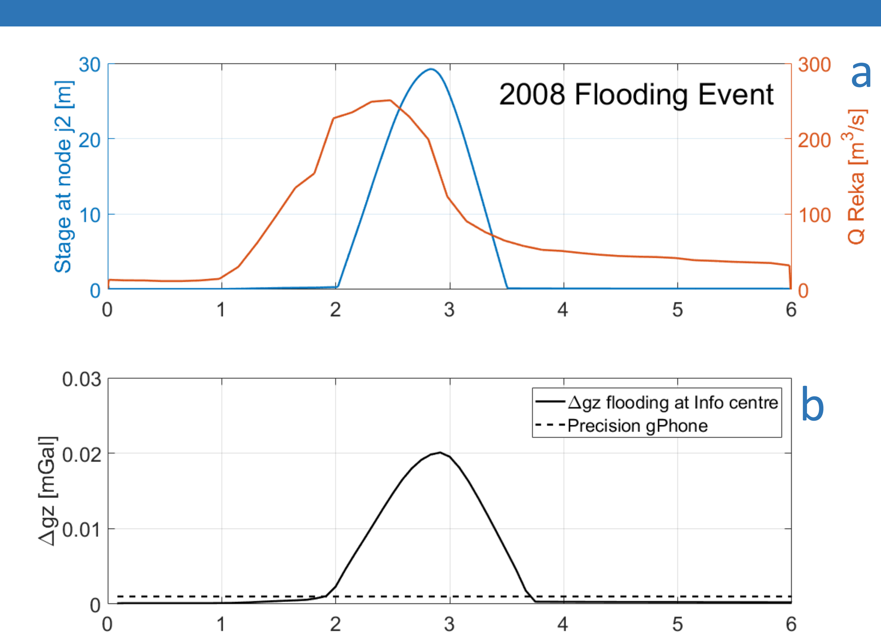

Figure 8: Simulations of the gravity variations due to the flooding event with Q_{peak}>250m^3/s. a) discharge rate time series and water level variation at node j2. b) gravity variation simulated above at the info center

From the simulations we found:

- Above the Martelova Dvorana the signal is maximized; both the events could be recorded by continuous recording gravity meters with precision of 1 µGal (fig. 7)
- For the event with Q>250m^3/s we estimate a gravity maximum anomaly above the Martelova Dvorana of 0.08mGal
- In the info center the biggest event is detectable (fig. 8); a 60m3/s event is slightly below the sensitivity of 1 µGal

4) Conclusions/perspectives

- Simulations showed that gravimetry could be useful to track water movements in the Classical Karst area
- The Škocjan cave could be an interesting test site to verify the sensitivity of the method. The biggest events should be recorded also in the info centre that is about 250m far from the caves
- Additional effects not yet modelled should be considered when a continuous gravity meter is placed in the Classical Karst area, in particular:
  1. Tectonic movements that deform the Karst plateau
  2. Newtonian and loading effects due to the Marine Tides of the Adriatic sea

References and Acknowledgments

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