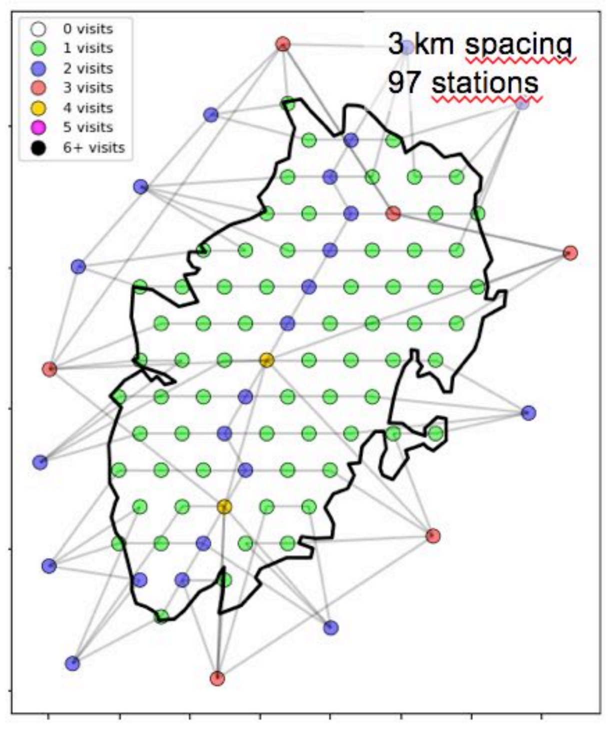
Experiences with relative microgravity surveying

Ola Eiken, Quad Geometrics

Measurement techniques



Example of grid of stations, in map view.

High-precision aerial gravity surveys can be carried out by relative spring meters. For time-lapse studies, the grid can be tied to stable reference stations or absolute measurements. Instrument drift is controlled by station repeats and repeatability of 1-2 μGal has been common both onshore and offshore. Free-fall gravimeters are heavier and costlier but provide absolute values and are immune to drift. Superconducting gravimeters are stationary and provide sub-μGal resolution over days and weeks, while drift uncertainty can build up to several μGal over years. Cold atom gravimeters are under development and may provide yet another survey alternative in the future.

Stability of measurement platforms is required for high time-lapse precision and can be achieved by geodetic monuments. Surface subsidence or uplift requires sub-cm precision which can be obtained by optical leveling, InSAR, GPS or water pressure. For optimal monitoring of a producing oil, gas or geothermal field, a water reservoir or a volcano, a grid of stations with spacing smaller than the overburden thickness is required.

relative spring (land)
CG-6

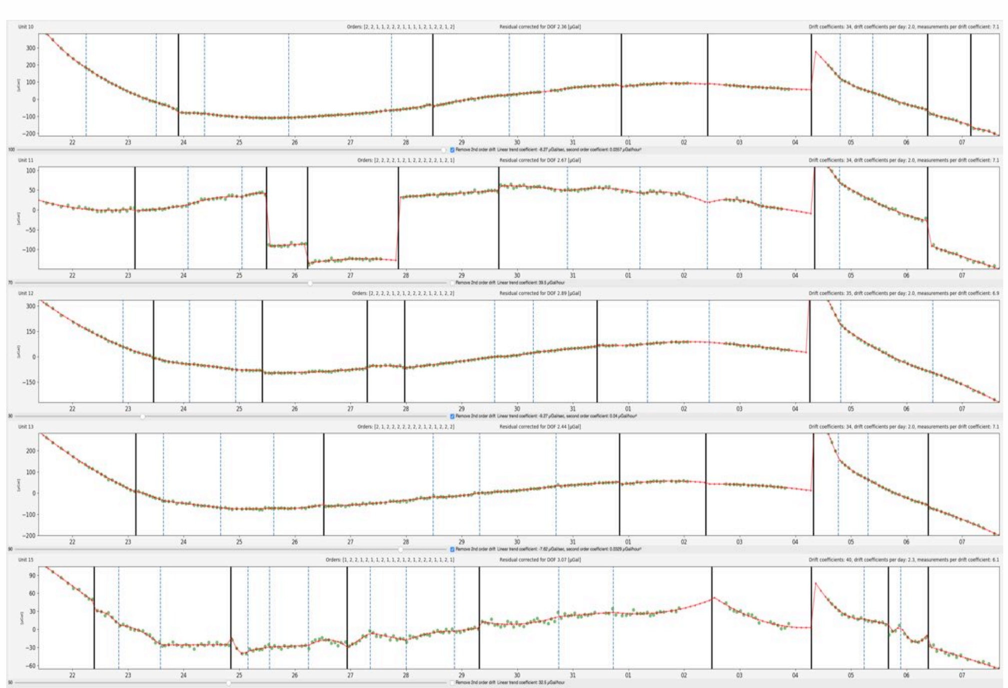
relative spring (seafloor)
ROVDOG III.5

free-fall absolute
A-10

Superconducting
iGrav

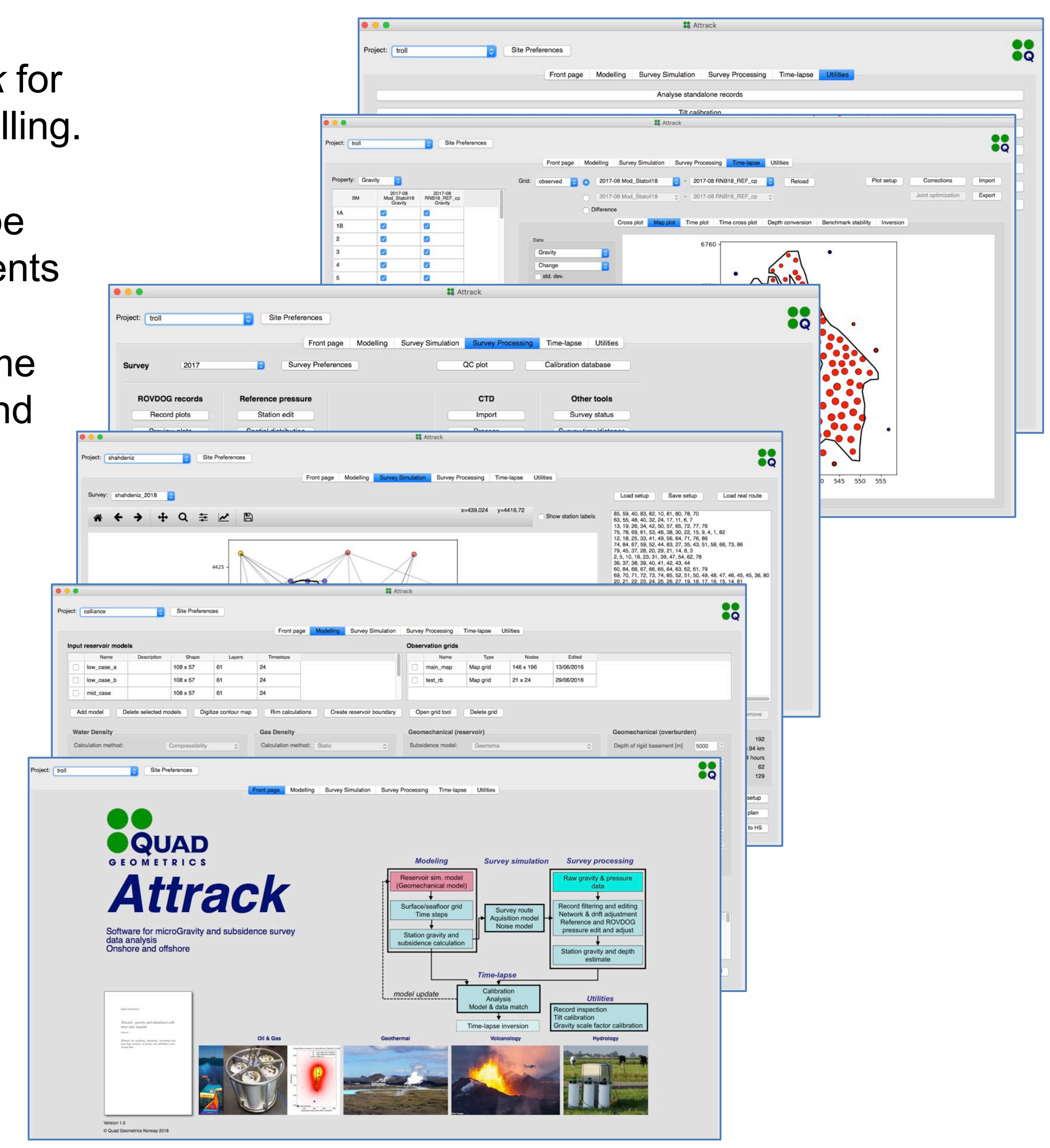
absolute quantum
(atom interferometry)

Microgravity data processing



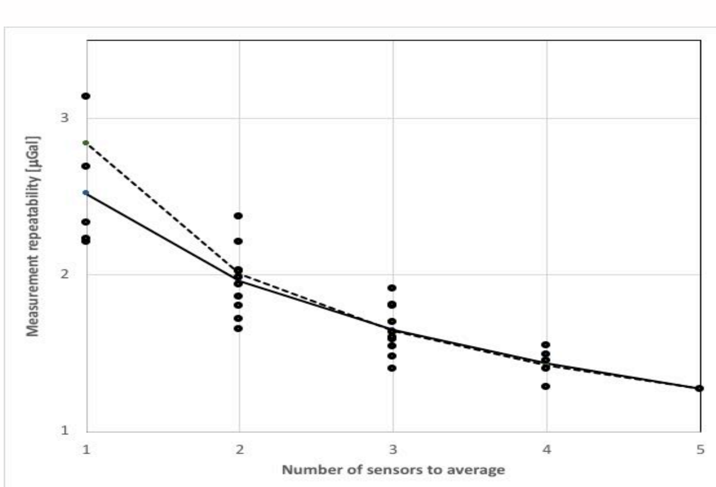
Example of gravity drift residuals for 5 sensors measuring in parallel.

Quad Geometrics has developed the software package *Attrack* for survey data processing, time-lapse analysis and forward modelling. The common corrections such as tilt, temperature, earth tide, ocean loading and scale factor are included. Time-series can be edited, and whole records omitted. Redundancy of measurements and sensors allows for finding an optimal drift solution using all sensors simultaneously, and estimate station values at the same time. It further allows in-situ re-calibration of tilt, temperature and scale factor parameters by minimizing residuals.



User interface of the Attrack microgravity software.

Accuracy



Repeatability vs. number of sensors used in parallel.

Station repeatability is a robust accuracy measure for relative surveys with multiple occupations of each station. When more sensors are used in parallel, the redundancy provide good statistics. Further, time-lapse precision can be judged at stations with minimal or known subsurface changes.

Using multiple sensors and repeats are effective ways of improving survey precision, as much of the noise has random properties and reduce as $\sqrt{N}$. This holds also for the sensor drift residuals. A transparent and reproducible processing software is an integral part of exploiting the redundancy.

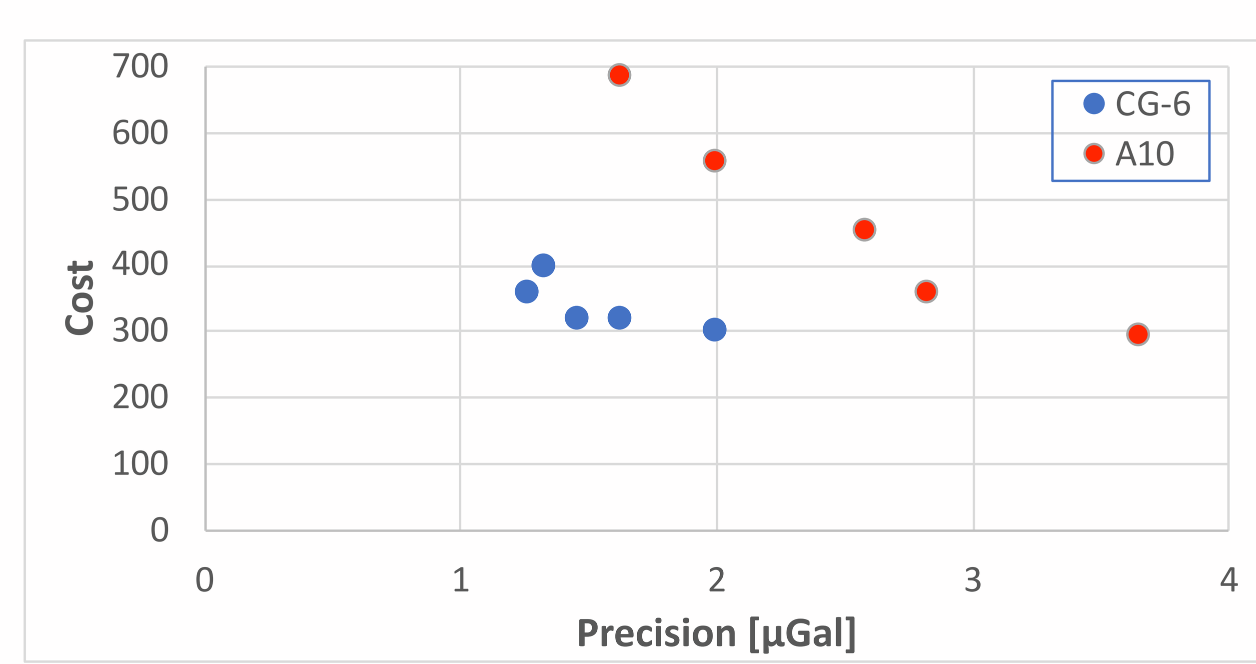
Efficiency and cost

Most microgravity projects have been carried out in a research or development setting, using one sensor, few station repeats and often capital and personnel cost is covered by different budgets. In an industrial setting with use of more instruments and measurements, personnel and mobilization portion of the cost will likely reduce. Precision/cost tradeoffs and value of data will anyhow determine the economics of a project.

A simple formula for precision (uncertainty, $\sigma_{station}$) by redundancy is as shown to the right. Further, a cost model is split in terms for mob/demob, equipment depreciation and daily cost of surveying. When cross-plotting cost and precision with reasonable input value, relative spring sensors generally come out better than absolute free-fall instruments; either lower in cost or better in precision. This is mainly due to a crew's ability to run multiple sensors and the lower cost of the spring sensors compared to absolute gravimeters.

$$\sigma_{station} = \frac{\sigma_{measurement}}{\sqrt{\#\ of\ sensors \cdot visits\ per\ station}}$$

$$cost = mob/demob + equipment\ depreciation + k \cdot days$$



Cost vs. precision for surveys with relative and absolute instruments and various number of sensors and repeats.

Conclusions

Current survey repeatabilities of 1-2 μGal are well proven and have become commonplace for microgravity surveys using relative gravimeters. This can widen the range of applications and reduce monitoring intervals. Further instrument developments may lower the noise threshold.

Obtaining such precision requires not only good instruments, but also multiple sensors and repeats, and comprehensive data processing.

Similar precision can be obtained with absolute gravimeters, but likely at a higher survey cost.

QUAD
GEOMETRICS