Observing Absolute Gravity Acceleration in the Fennoscandian Land Uplift Area

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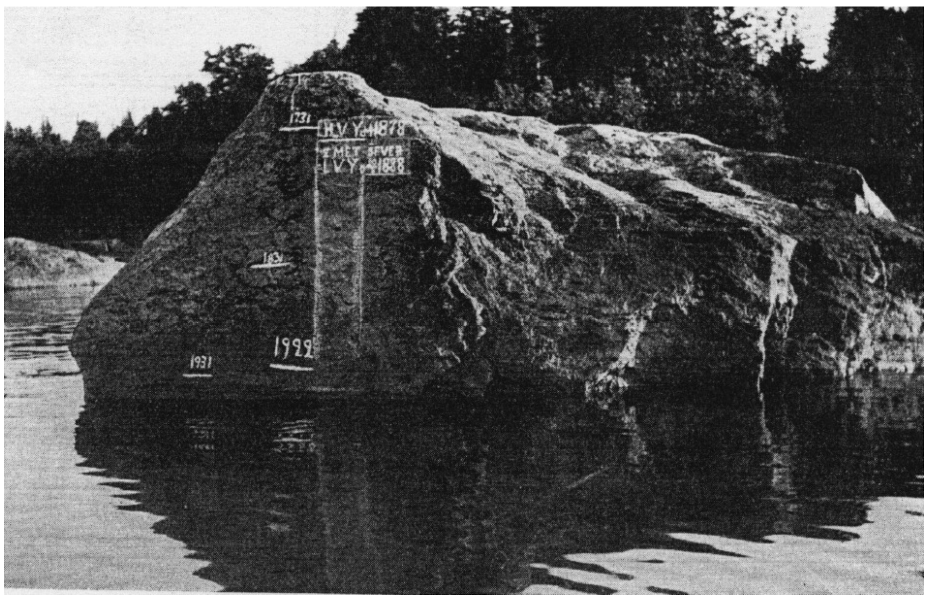
Anders Celsius 1743: 13 mm/year decrease of sea level since 1731; evaporation or a hole in the bottom.

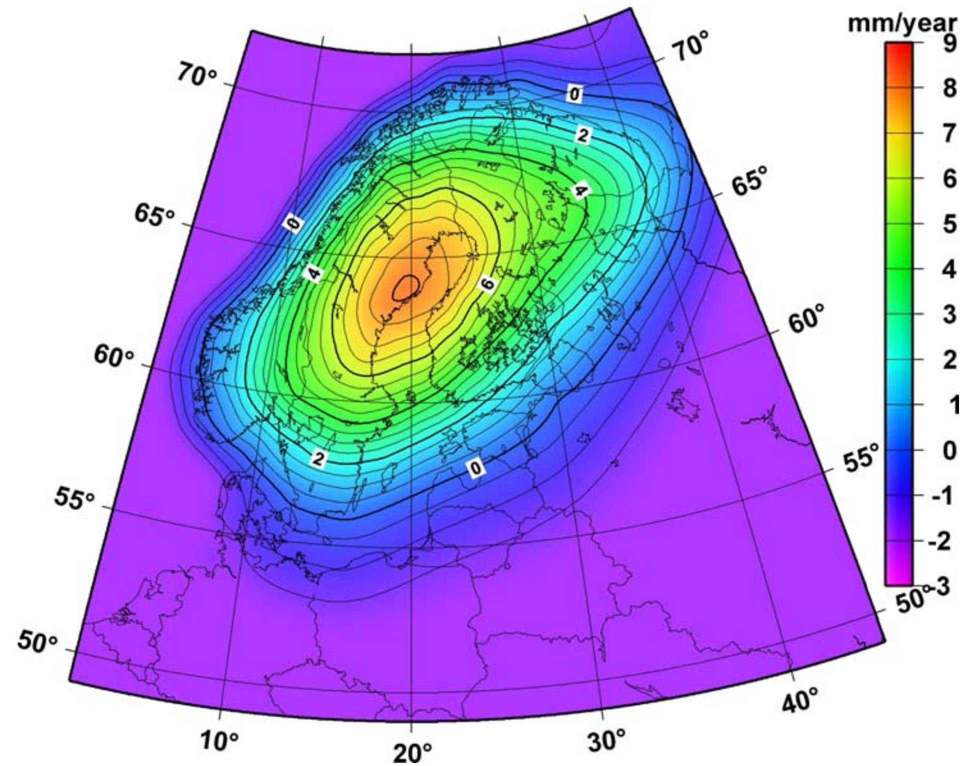


The Celsius seal rock with water level marks

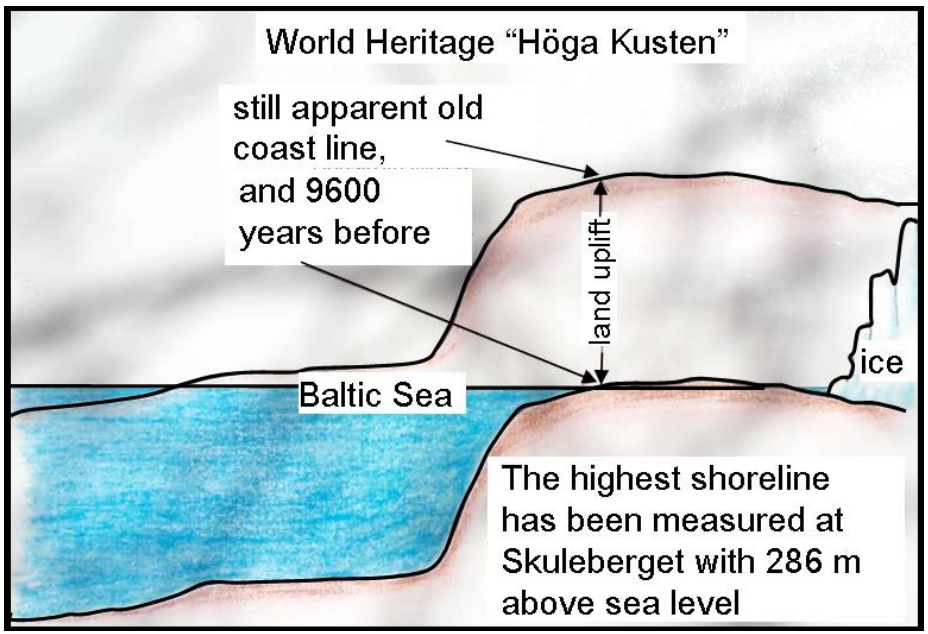
1. Gravimetric Determination of the Fennoscandian Uplift
2. Absolute Gravimetry
3. The Current Project
4. Summary / Conclusion

Gravimetric Determination of the Fennoscandian Land Uplift
- approaches in Geophysics and Geodesy -

- isostatic uplift since the glacial maximum (18 ka BP);
- geophysical modeling with unknowns (geometry of ice sheets, Earth model parameters, lateral rheological variations);
- for recent land uplift: complementary data from geodesy and oceanography.



Apparent land uplift model NKG2005LU according to Ågren& Svensson 2006 (geodetic levelling, mareographs, rel.gravimetry, GPS + geophys. modelling)

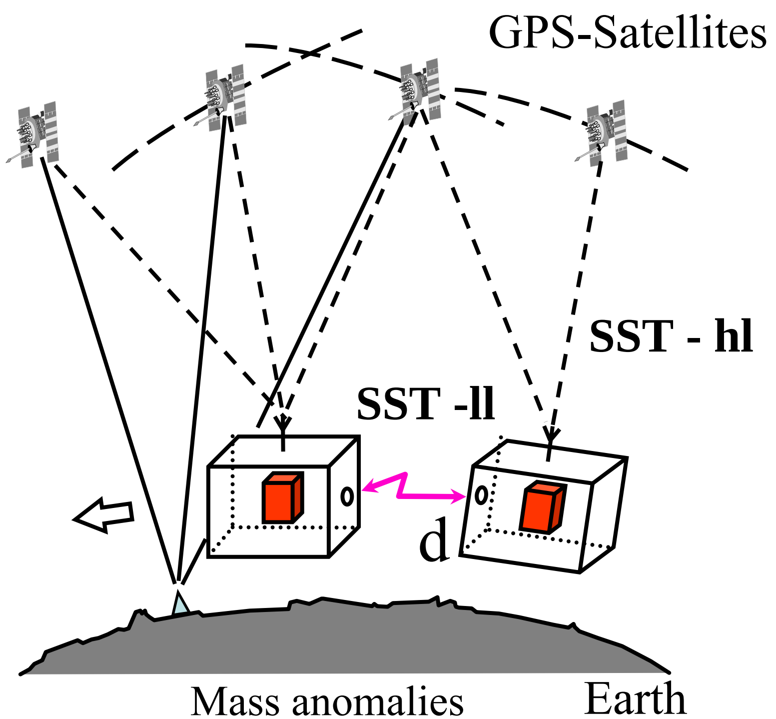


$\dot{H}_a \approx 9.0\ mm/yr$	(Ekman 1996)
$\dot{H}_e \approx 1.2\ mm/yr$	(Nakiboglu & Lambeck 1991)
$\dot{g}/\dot{h} \approx -0.2\ \mu Gal/mm$	(Ekman & Mäkinen 1996)
$\dot{N}_0 \approx 0.6\ mm/yr$	"
$\dot{h}_0 \approx 10.8\ mm/yr$	"
$\dot{g} \approx -2.0\ \mu Gal/yr$	

Gravimetric Determination of the Fennoscandian Land Uplift
- GRACE: satellite gravimetry with area measurements -

GRACE

- temporal geoid change: ±2 to 3 mm for a phenomenon of 600 km extension (Tapley et al. 2004).



Synergy with terrestrial methods:

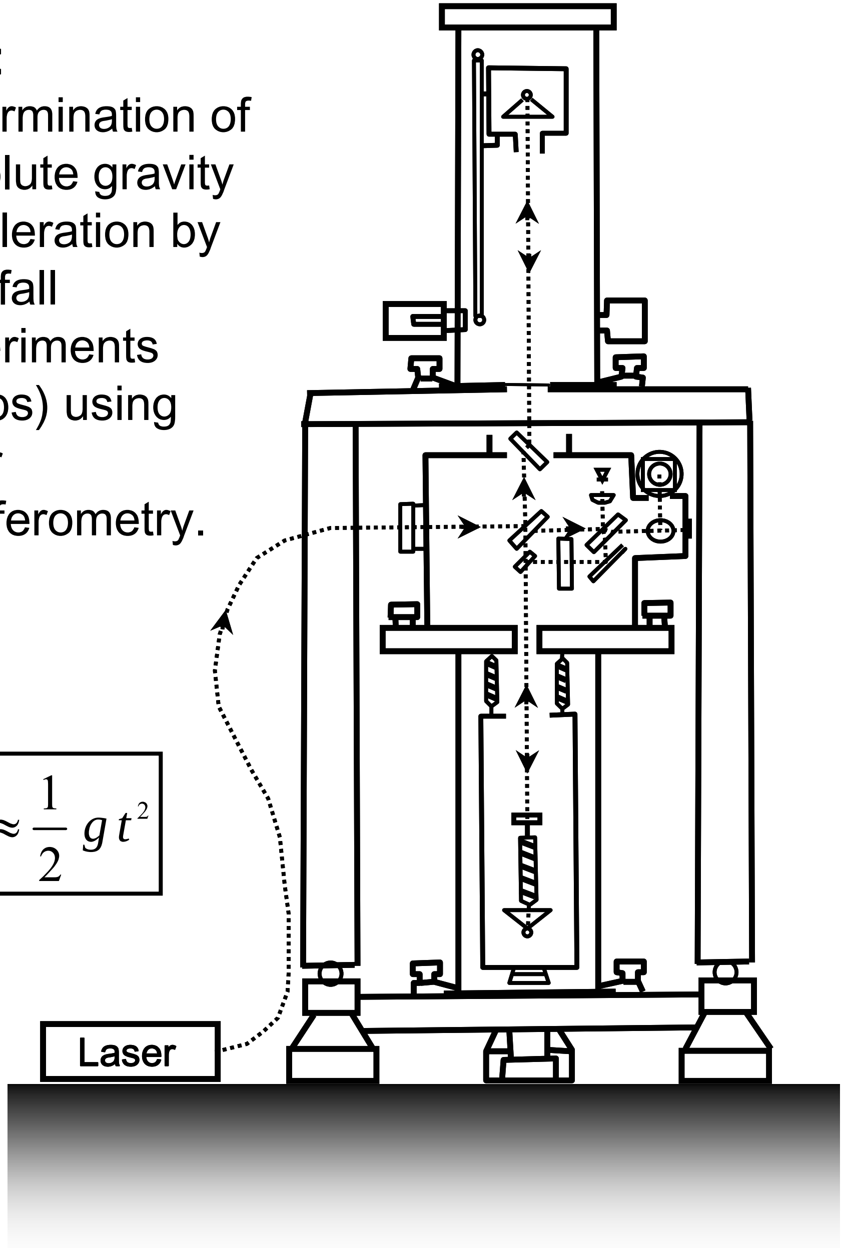
- Fennoscandian land uplift is a measurable signal for GRACE;
- interference with mass variations due to oceanography, land hydrology and atmospheric processes;
- combination with hydrological, atmospheric and geodetic measurements are inevitable.

geodetic "Ground-Truth" is required

Gravimetric Determination of the Fennoscandian Land Uplift
- absolute gravimetry: terrestrial point measurements -

FG5:
Determination of absolute gravity acceleration by free-fall experiments (drops) using laser interferometry.

$$\boxed{z \approx \frac{1}{2} g\, t^2}$$



instrumental errors
gravitational "noise" $\Rightarrow$ s(AG)

<u>Assumption:</u>
single error sources

- setup uncertainty and small temporary offsets of absolute gravimeter,
- soil moisture / ground water,
- atmosphere (residual effect),
- ocean and Baltic Sea (residual eff.)

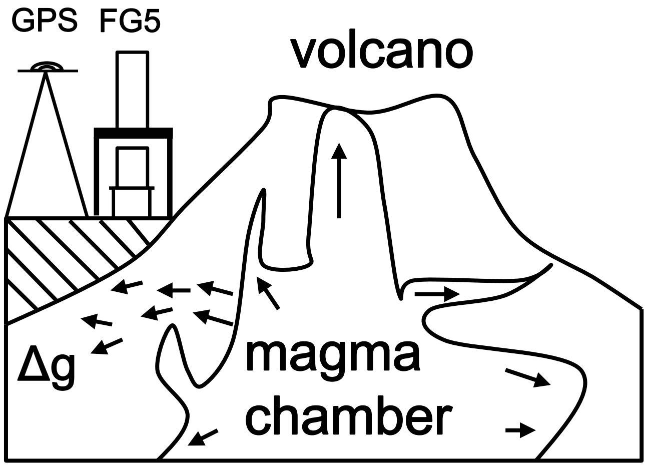
effect the final result (linear trend) after many station determinations only randomly
(→ averaging effect).

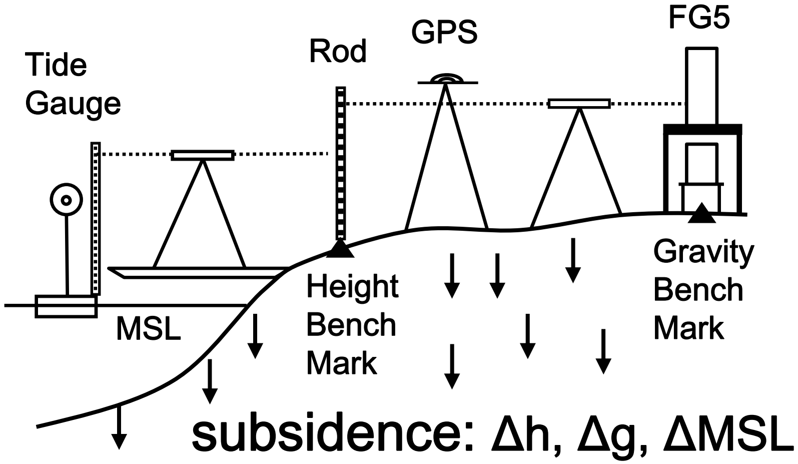
$\Downarrow$

project idea: since 2003, yearly occupations of the stations

goal: s($\dot{g}$) = < ±2 μGal for a 5 years time span

Absolute Gravimetry
- advantages -





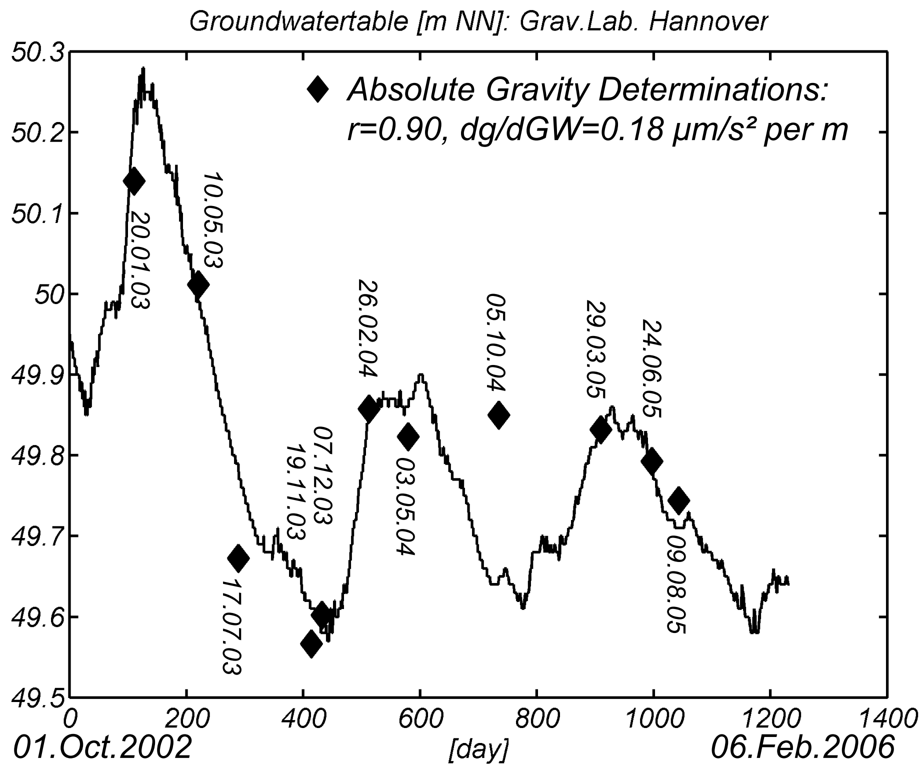
In addition and complementary to other geodetic measurements, terrestrial absolute gravimetry has the following positive characteristics:

- monitoring of gravity changes caused by subsurface mass redistributions or by vertical displacements;
- accuracy of absolute gravity net is independent of geographical extension and of scale of gravity range;
- independent validation method for GPS, VLBI, SLR, and superconducting gravimetry;
- combined with geometrical methods, vertical surface deformations and subsurface mass movements can be separated.

Absolute Gravimetry
- accuracy and precision -

FG5-220 (Univ. Hannover)

Repeatability control at station Hannover



Instrumental offset control by comparisons

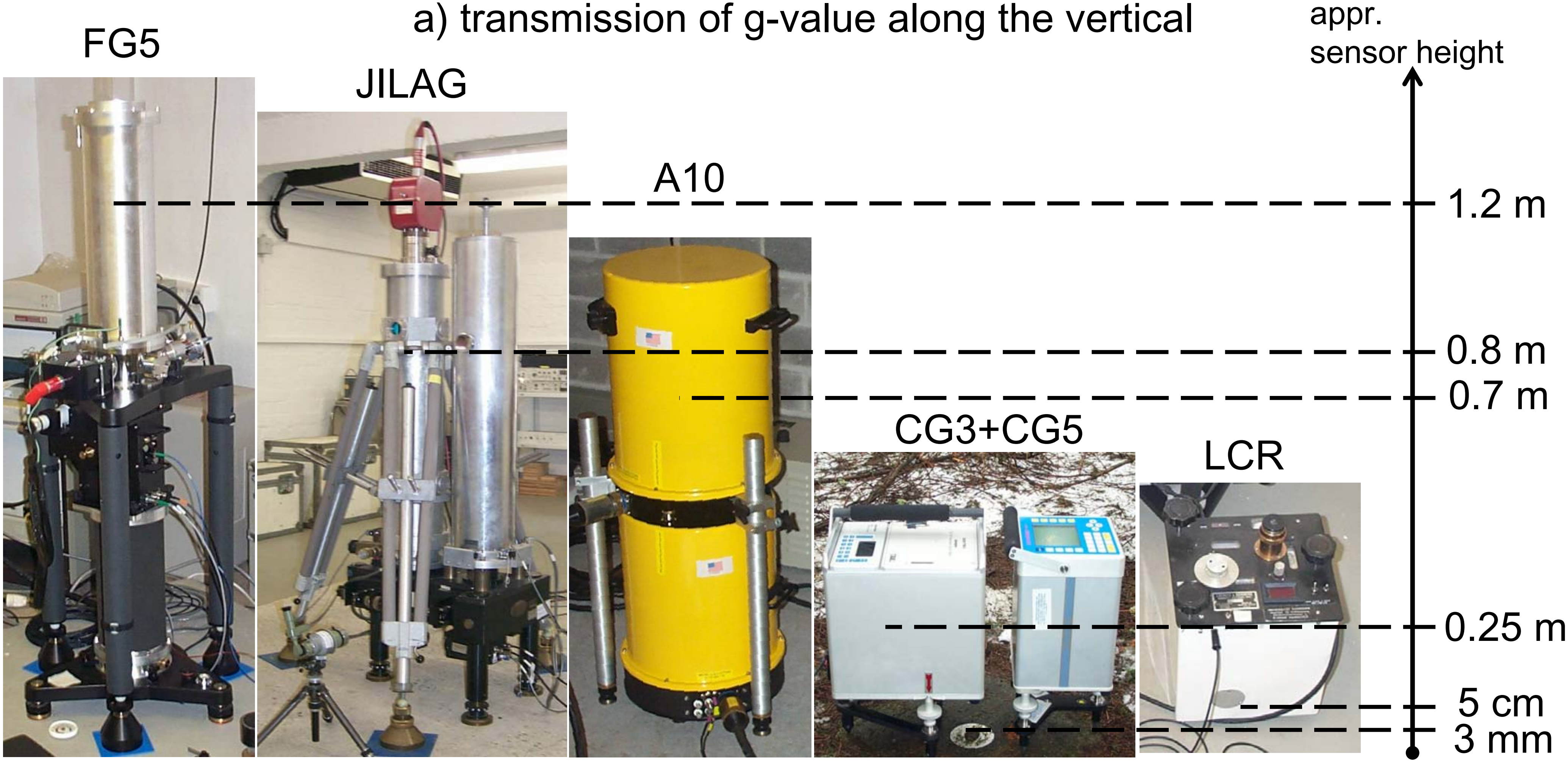
Date	Station	FG5-220 compared with	Diff. [nm/s²]	Remark
Nov 03	Bad Homburg (BH)	mean	-10	
April 05	"	"	2	
April 06	"	"	8	
Mar+Apr04	Ås	FG5-226	22	
May 04	Vaasa AB	FG5-221	14	Simult.
May 04	Metsäh. AB	FG5-221	-3	Simult.
May 04	Metsäh. AC	FG5-221	44	Simult.
Oct 04	Onsala AS	FG5-226	-23	Simult.
Oct 04	Onsala AS	FG5-221	3	Simult.
Oct 04	Onsala AN	FG5-226	-14	Simult.
Oct 04	Onsala AN	FG5-221	15	Simult.
		mean (excl. BH)	7	
		r.m.s.	±21	

Int. Comparison of Absolute Gravimeters in Walferdange (Luxemb.), Nov. 2003:
dg (FG5-220 − mean(15 instr.)) = -19 nm/s² (Francis et al. 2006)

⇨ **FG5-220 accuracy: ±2 . . . ±3 µGal**

Absolute Gravimetry
- merge with relative gravimetry -

a) transmission of g-value along the vertical



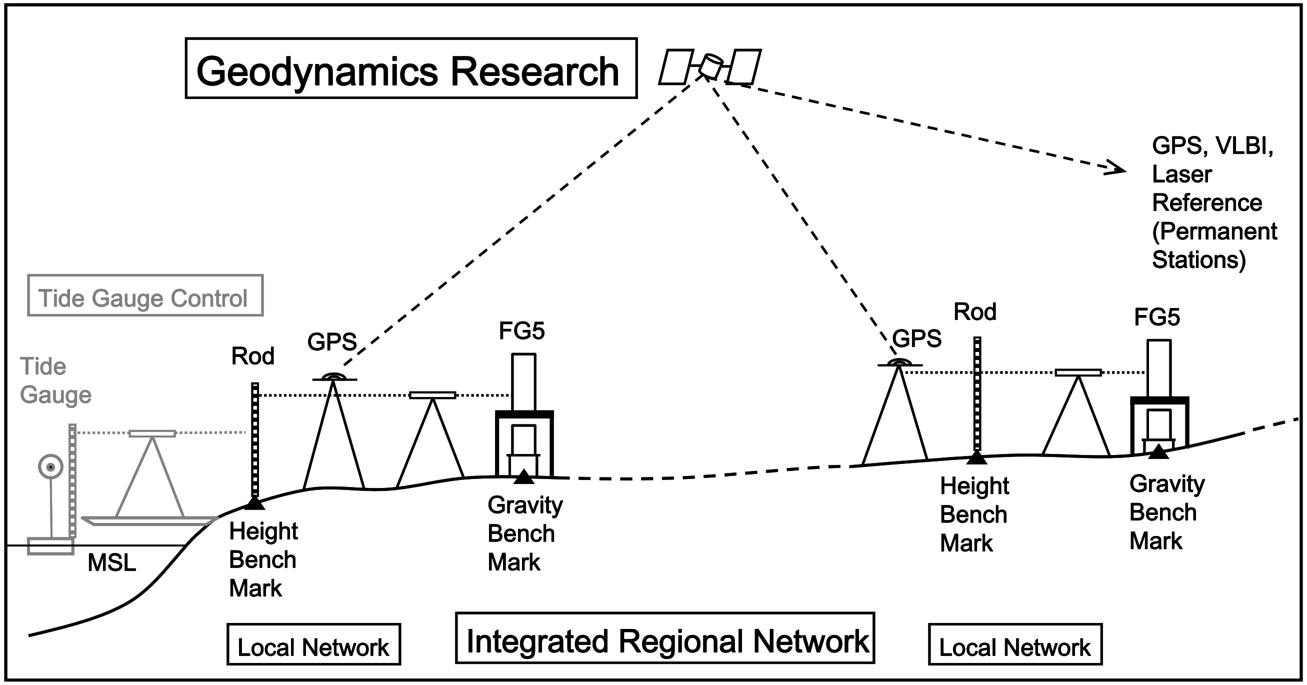
b) connecting safety points

c) measuring the effect of human-caused mass redistributions, e.g. building conversion

±1 . . . ±2 µGal

(for differences of up to 10 mGal)

The Current Project
- project realization -



Keys:

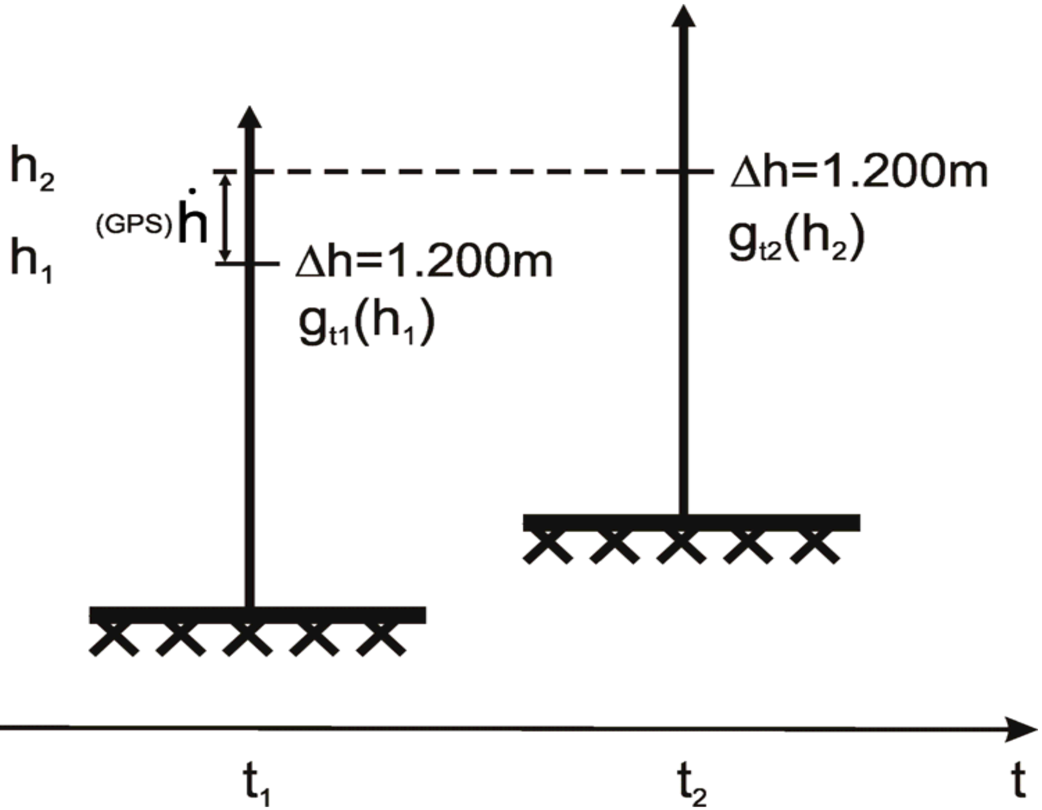
- planning panel: NKG working group "Geodynamics"
- annual abs. gravity surveys over 6 years (2003: 22 stat., 2004: 24 stat., 2005: 30 stat.);
- close cooperation between four FG5-expert teams (2003: BKG, FGI, IfE, since 2004: FGI, IfE, UMB);
- continuous GPS at almost all stations (BIFROST);
- geod. levelling between abs.gravity points and eccenters (control of local variations, direct connection to GPS);
- integration of already existing geodetic data sets (e.g. Wilmes et al. 2004, Kuo et al. 2004);
- comparison with GRACE.

Products:

1. temporal changes of gravity and **the gravity disturbances** at the measurement locations,
2. area model for gravity disturbances and for geoid changes.

Conversion of gravity and height changes

Change of gravity disturbance:



$$g_{t1}(h_2) = g_{t1}(h_1) + \frac{\partial g}{\partial h}\dot{h}$$

$$\dot{\delta g} = g_{t2}(h_2) - g_{t1}(h_2)$$

Example:

$$\dot{h} = 1.0\ cm$$

$$g_{t2}(h_2) - g_{t1}(h_1) = -2.0\ \mu Gal$$

$$\frac{\partial g}{\partial h} = -3.0\ \frac{\mu Gal}{cm}$$

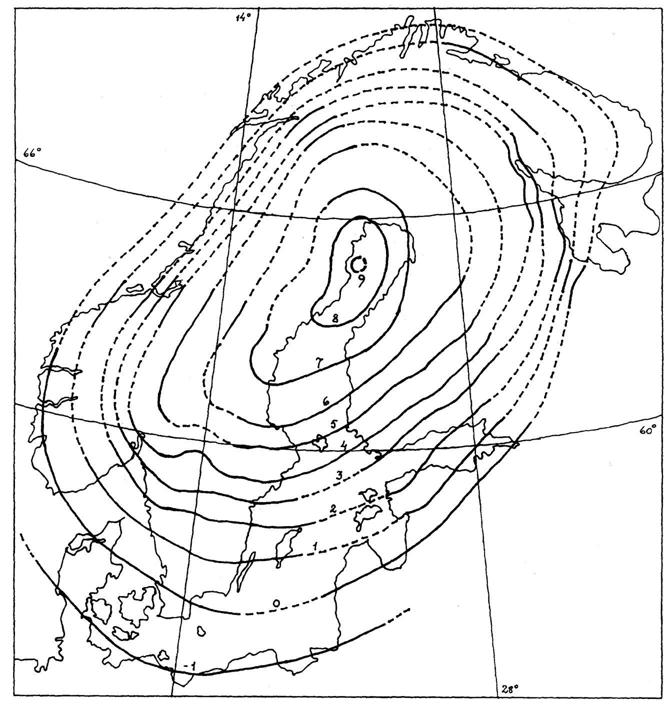
$$\dot{\delta g} = +1.0\ \mu Gal\,/\,\Delta t$$

Geoid change:

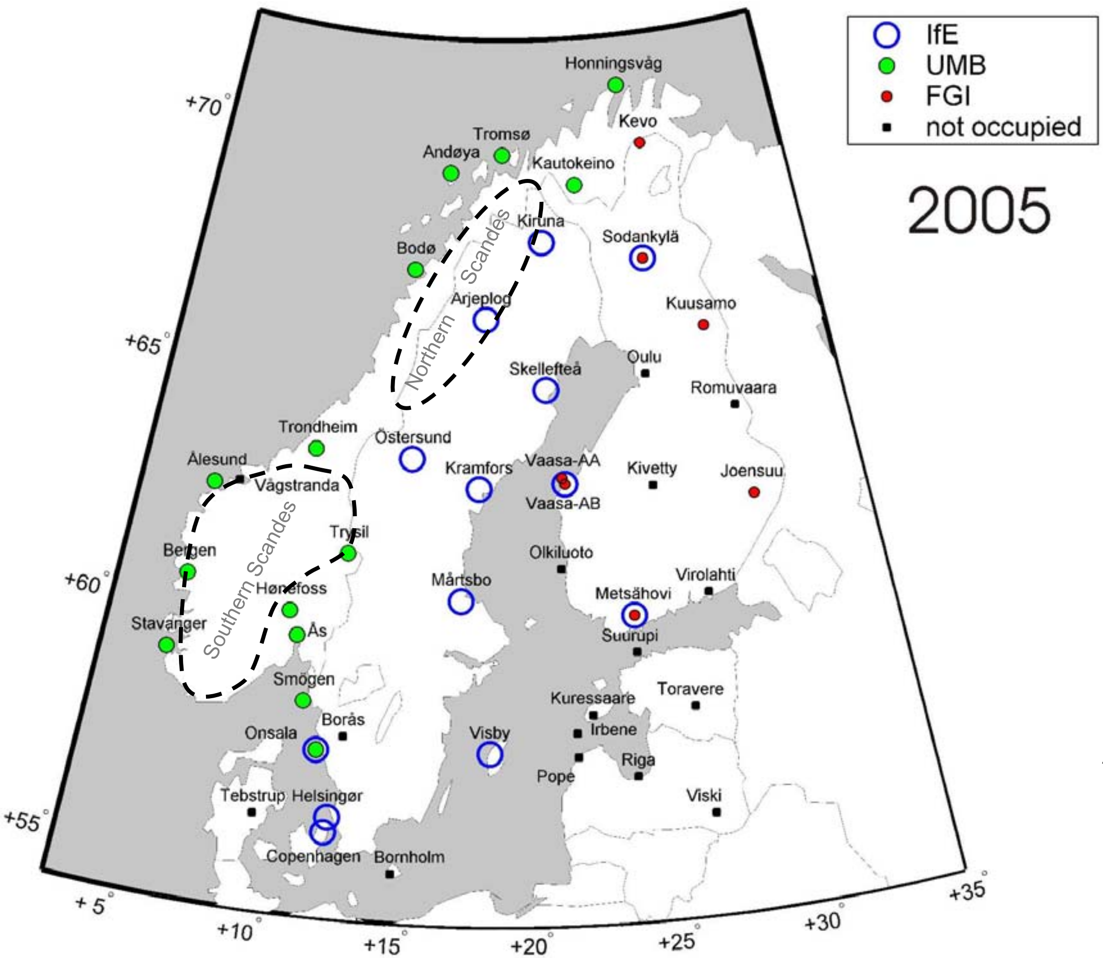
$$\dot{N} = \frac{R}{4\pi\gamma}\iint_{\sigma} H(\psi)\left(\dot{g} + \frac{2\gamma}{r}\dot{h}\right)d\sigma$$

gravity disturbance

Apparent land uplift [mm/yr], after Ekman 1996



The Current Project
- project realization -



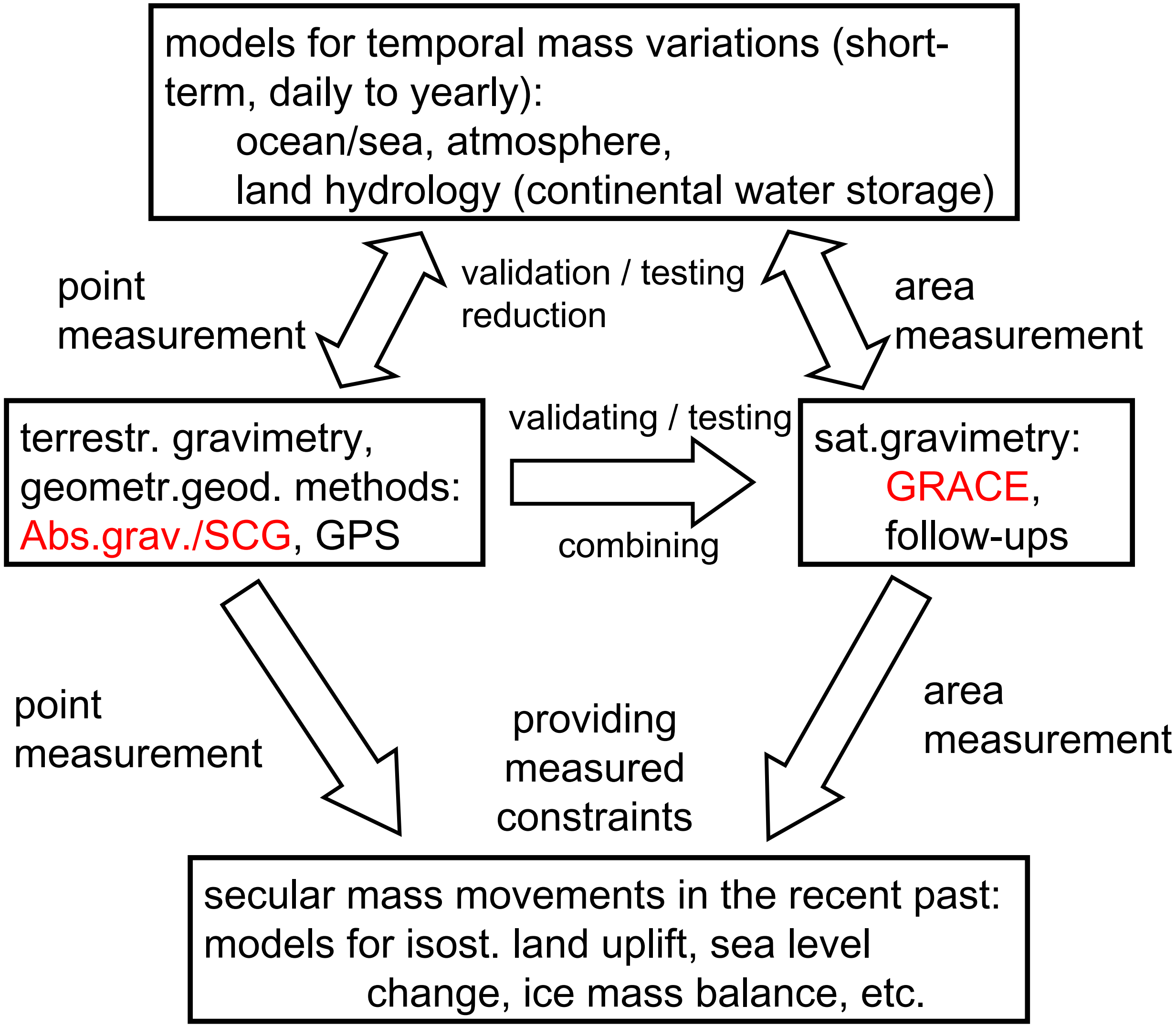
Station Skellefteå

Absolute gravimeter in Östersund

Due to lateral heterogeneous Earth's properties and other (minor) tectonic phenomena: no radial symmetrical uplift behaviour.

Absolute gravimetric observation system with a dense and regular station distribution.

Complementarity of Gravimetric Techniques



SCG stationary | FG5 transportable

determination of

short-term | long-term

gravity changes

Summary and Conclusions

- more than 30 absolute gravimetry stations in Fennoscandia recently observed;
- occupied stations: 22 (2003), 24 (2004), 30 (2005);
- four FG5 absolute gravimeter are employed to increase the reliability and accuracy of the whole network and to achieve a proper number of station occupations every year;
- accuracy of a single station determination: ±2 . . . ±3 μGal;
- with GRACE, a new appreciation of processes in the system Earth has arisen which requires the interaction with ground based measurement techniques;
- the absolute gravity net is designed as a long-term monitoring system;
- with the implementation of a long-term reference frame, future gravimetric datum problems can be avoided (establishment of a few reference stations with SCG, GPS, GW monitoring, frequent abs. grav. measurements by different groups).

Acknowledgments

Thank's to all involved colleagues from the project partners:

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Federal Agency for Cartography and Geodesy (BKG), Frankfurt

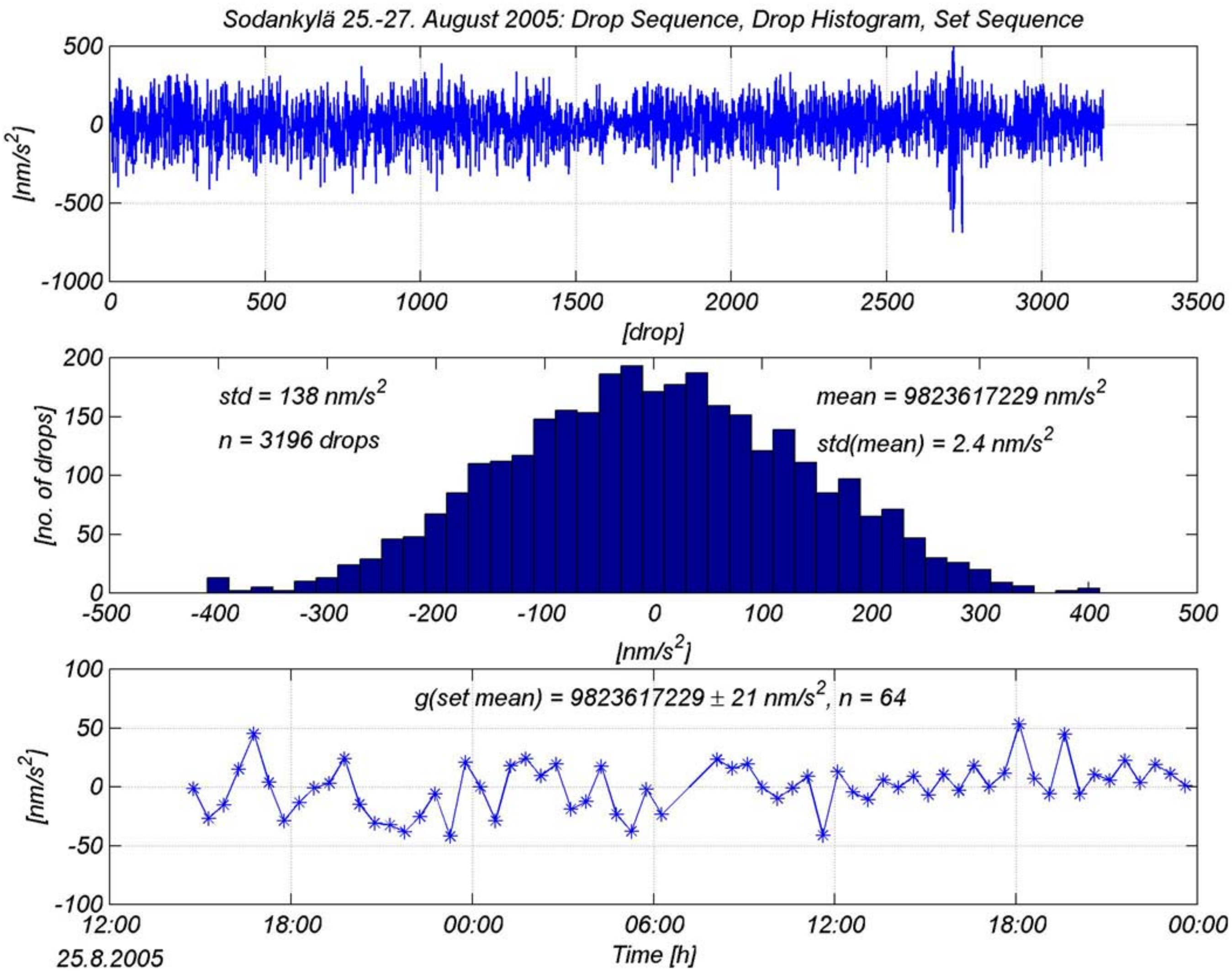
Finnish Geodetic Institute, Masala

Lantmäteriet, Gävle

Onsala Space Obs., Chalmers Univ. of Technology

Statens Kartverk, Hønefoss

Absolute Gravimetry
- accuracy and precision: site and instrument stability -



Quantitative estimation of the site stability and the instrument's stability

Systematic errors are not considered:

- instrumental offset,
- misaligned verticality,
- floor recoil,
- etc.

Absolute Gravimetry
- accuracy and precision: setup uncertainty -

gravity differences at ~120.0 cm height (sensor) between two points measured by **absolute** and **relative** gravimetry

Metsähovi	*Onsala*	*Bad Homburg*
AB-AC	*AS-AN*	*BA-AA*
dg (relative gravimetry) ±0.5 μGal		
1.9	*7.7*	*34.9*
comparison with absolute gravimetry dg(abs) – dg(rel)		
1.9 (2003)	*1.4 (2004)*	*-2.6 (2003)*
-1.6 (2004)	*1.1 (2005)*	*0.1 (2003)*
2.7 (2004)		*1.7 (2005)*
1.9 (2005)		*-0.3 (2006)*
0.2 (2005)		

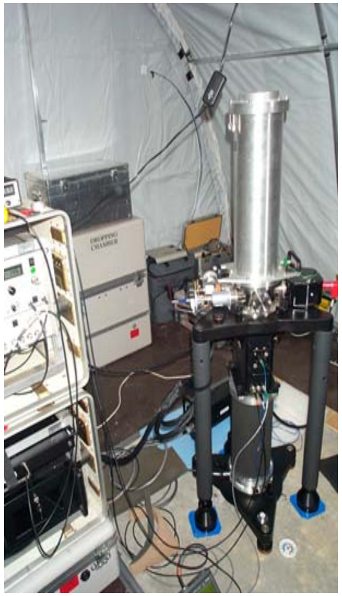
parallel registration in Bad Homburg / BKG

r.m.s. discrepancy:
±1.6 μGal
(setup uncertainty)

→ several setups during a station determination to minimize the instrumental setup uncertainties

(floor-recoil, azimuth dependency: Coriolis force / attrition, electrostatic, …)

The Current Project “Absolute Gravimetry to Observe the Fennoscandian Land Uplift” - project realization -



Denmark:
absolute gravimetry with measurement tent and camper

Finland:
gravimeter transportation with bars

Norway:
new station Ålesund

Gravimetric Determination of the Fennoscandian Land Uplift
- conversion of measured land uplift of geoid change -

From Hotine (1969): formula for the conversion of temporal gravity and height changes to geoid changes:

$$\dot{N} = \frac{R}{4\pi\gamma} \iint_{\sigma} H(\psi) \left(\dot{g} + \frac{2\gamma}{r} \dot{h} \right) d\sigma \,,$$

$$\text{mit} \quad H(\Psi) = \left(\sin \frac{\Psi}{2} \right)^{-1} - \ln \left(1 + \left(\sin \frac{\Psi}{2} \right)^{-1} \right).$$

$\dot{N}$: temporal geoid changes,

$\dot{h}$: ellipsoidal heigh changes,

$\dot{g}$: gravity changes,

γ: normal gravity,

R: mean Earth's radius,

r: radius of the computation point P,

Ψ: spherical distance between P and surface element $d\sigma$.

- combination of gravimetry and GPS is needed,
- accuracy of both measurement types should be in accordance to each other, e.g. ±2 µGal und ±1 cm.