DTU Space: Marine Gravity Measurements in Denmark, Greenland and beyond

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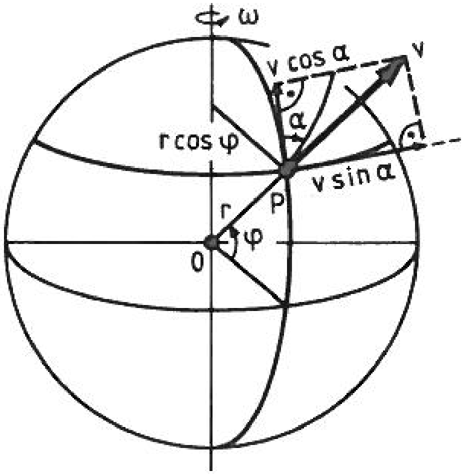
- **Theory: moving platform gravimetry (air, sea)**
- **Instrumentation (LCR, Chekan)**
- **DTU Space sea-/air gravimetry: historical overview**

  [calibration (harbour ties), navigation, processing software, surveys and (some) results]

- **I will say nothing about ”examples of use of the marine gravity data in connection with a new geoid of Denmark and Greenland”**



Theory (Torge, ”Gravimetry”, 1989, sec. 7.2.4)

Assume a spherical rotating Earth and a stationary point on the surface ($v = 0$):

$$g = \frac{GM}{r^2} - \omega^2 r \cos^2 \varphi$$

Assume that the platform is not stationary but moves with a (constant) speed v on the surface of the rotating Earth:

$$g^* = \frac{GM}{r^2} - \left(\omega + \frac{v \sin \alpha}{r \cos \varphi} \right)^2 r \cos^2 \varphi - \left(\frac{v \cos \alpha}{r} \right)^2 r$$

Eotvös correction (spherical approx., marine gravimetry)

$$\delta g_{Eöt} \equiv g - g^* = 2\omega v \cos \varphi \sin \alpha + \frac{v^2}{r}$$

Marine gravimetry (r=R=6371 km):

$$\delta g_{Eöt} = 40 v \cos \varphi \sin \alpha + 0.012 v^2, \quad \mu m s^2$$

Theory (Torge, "Gravimetry", 1989, sec. 7.2.4) cont.

Eotvös correction (ellipsoidal approx., airborne gravimetry)

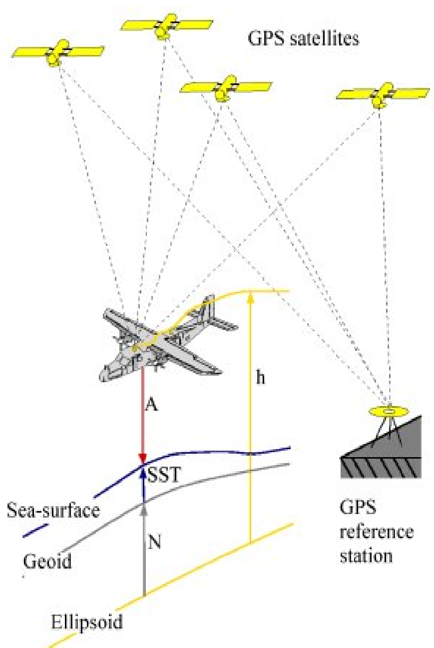
$$\delta g_{E\ddot{o}t} \equiv g - g^{*} = \left(1 + \frac{h}{a}\right)\left(2\omega v \cos\varphi \sin\alpha + \frac{v^{2}}{r}\right) - f\,\frac{v^{2}}{a}\left(1 - \cos^{2}\varphi\left(3 - 2\sin^{2}\alpha\right)\right)$$

Moving-platform gravimetry: Airborne Gravimetry

Sea-Air gravimeters: gyro-stabilized

Basic principle:

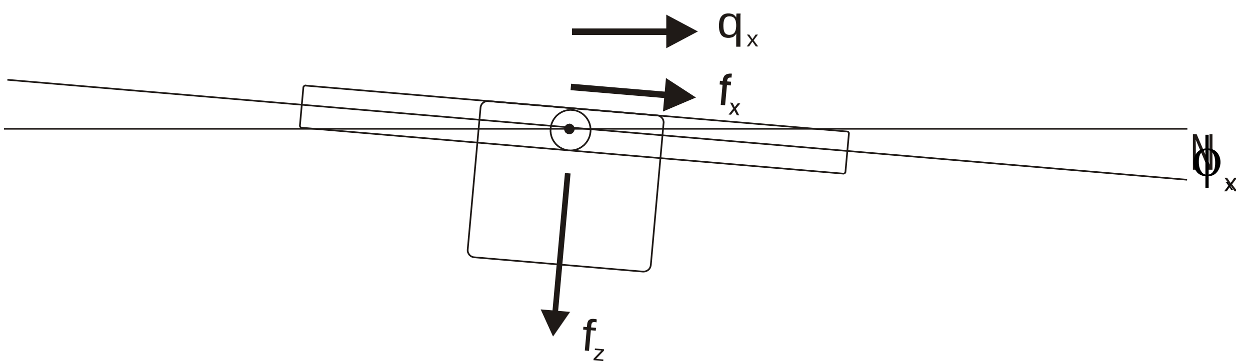
$$\Delta g = y - h'' - \delta g_{eotvos} - \delta g_{tilt} - y_0 + g_0 - \gamma_0 + 0.3086\,(h - N)$$



y: measured acceleration (gravimeter or INS)
h'': acceleration from GPS
y_0: airport base reading
g_0: airport reference gravity
h : GPS height
δg_{eotvos}: Eotvos correction
δg_{tilt}: Gravimeter instrument corr.

Current accuracy: 2-3 mGal

Tilt correction (aerogravity)



Traditional approach: $\delta g_{tilt} \approx f^2 - q^2$

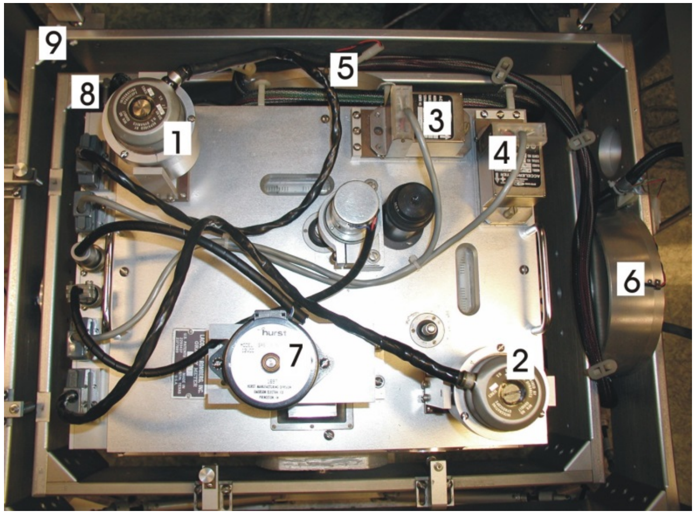
Modeling approach:

$$\delta g_{tilt} = (1 - \cos\phi_x \cdot \cos\phi_y) \cdot f_z + \sin\phi_x \cdot f_x + \sin\phi_y \cdot f_y$$

Typical effect: 0.5 to 1 mGal under normal conditions

LCR marine/air gravimeter (S-38,S-99)

S-99 marine gravimeter updated to airborne use, owned by UIB



Kept dynamically leveled in-flight Post-flight level correction needed

CHEKAN (made in Russia)

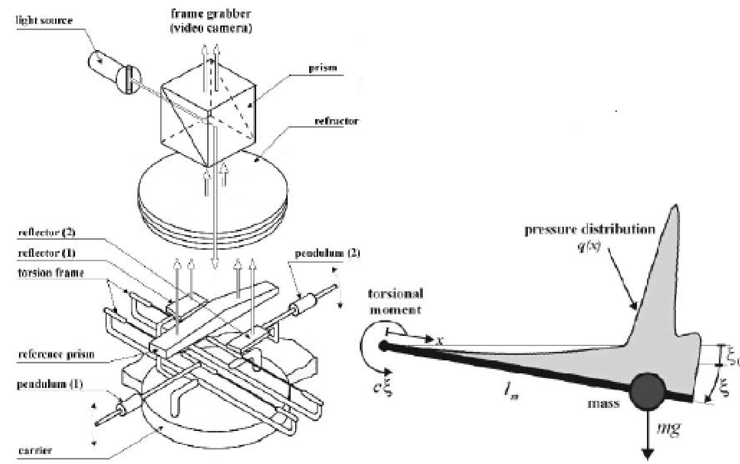


Fig. 3 Construction and modelling of the gravity sensor

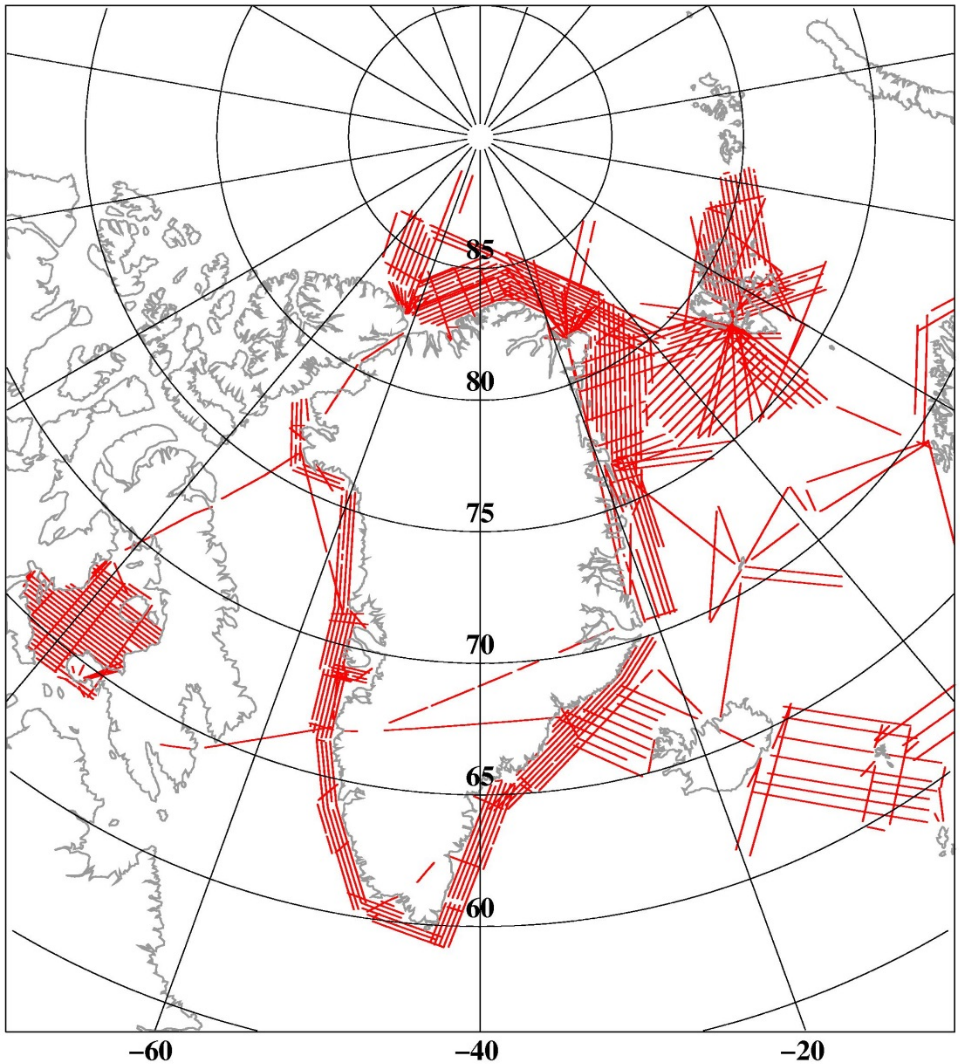
CHEKAN principle:

Two pre-stressed, identical and inversly arranged torsion frames (a double quartz elastic system). A pendulum mounted on each torsion frame.

To attenuate the vibrations of the pendulums the system is submerged in a viscous fluid.

Gyro-stabilised platform

Greenland aerogravity measurement (1998-2002) after GAP (1991-1992)



- **logistic challenge**
- **long DGPS baselines**
- **active ionosphere**
- **diverse flight conditions**

Arctic surveys

Crossover statistics (mgal)

Data set	# X's	RMS
1998	86	1.8
1999	74	2.5
2000	96	2.8
2001	66	2.6
2002	101	2.6
2003	46	2.1
All years	670	2.5

2.5 mgal indicates 1.8 mgal noise
1.8 mgal - - 1.3 mgal - -

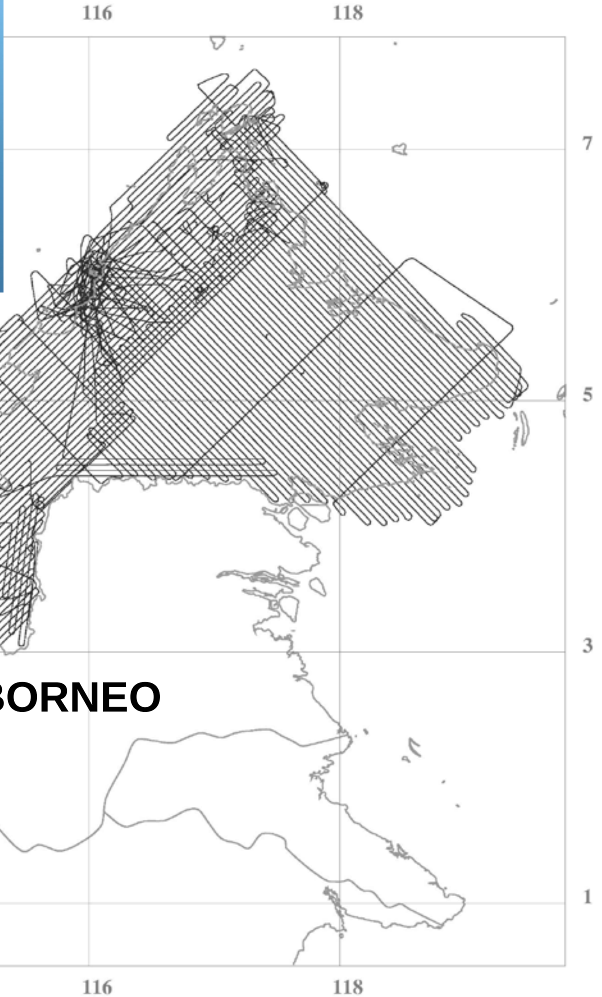
IMPORTANT
no crossover adjustment
INDICATES
healthy reduction scheme no bias problems
MEANS
fewer crossing lines
cost-effective system
single lines can be utilized

- **Noisy measurements**
- **Sensor modeling**
- **Filtering**
- **Resolution ~5 km**

Aircraft used:

Twin-Otter
Antonov 38
Dornier 228
CASA 212
Fokker 27

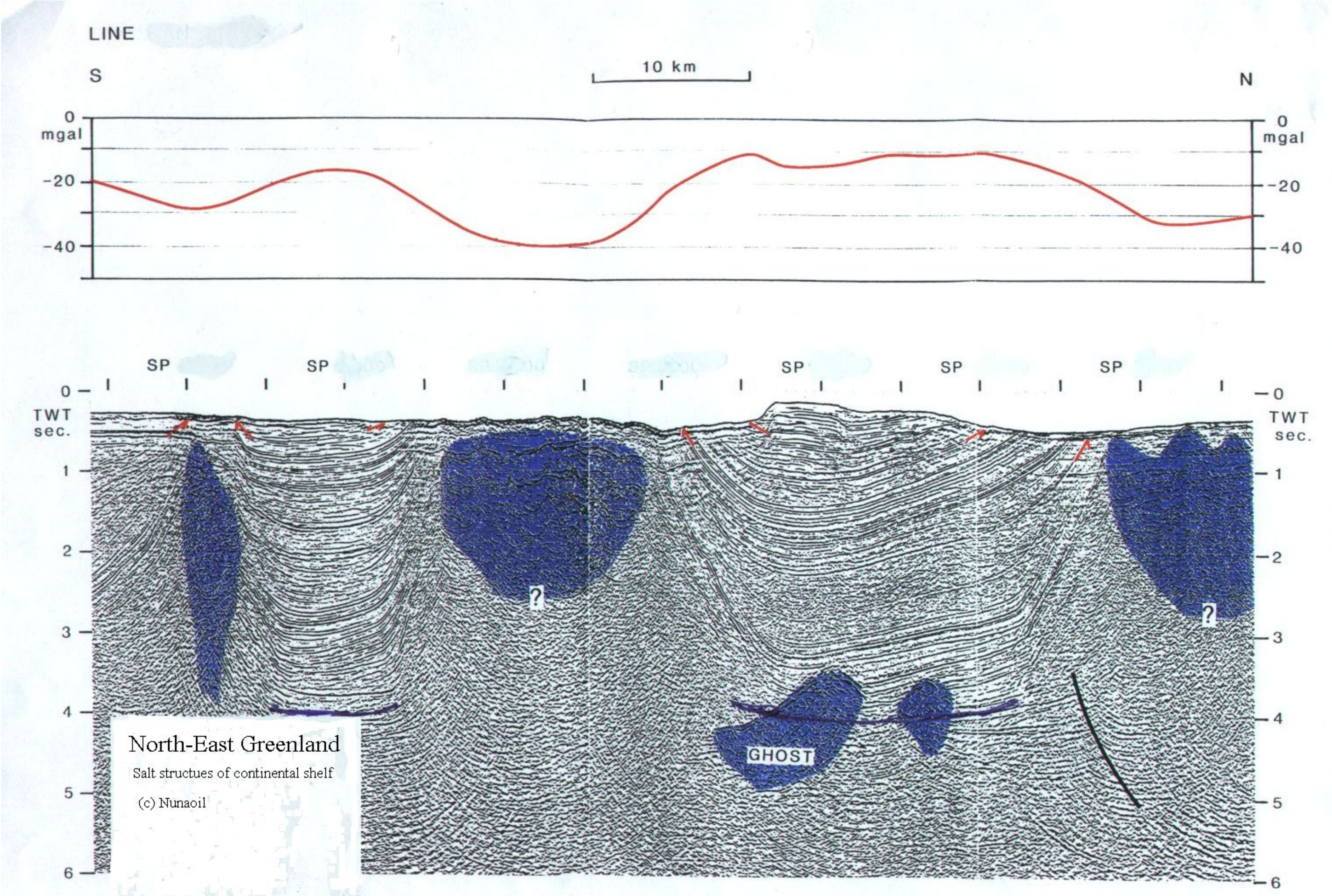
Malaysia Airborne Gravity and Geoid Project (2005)

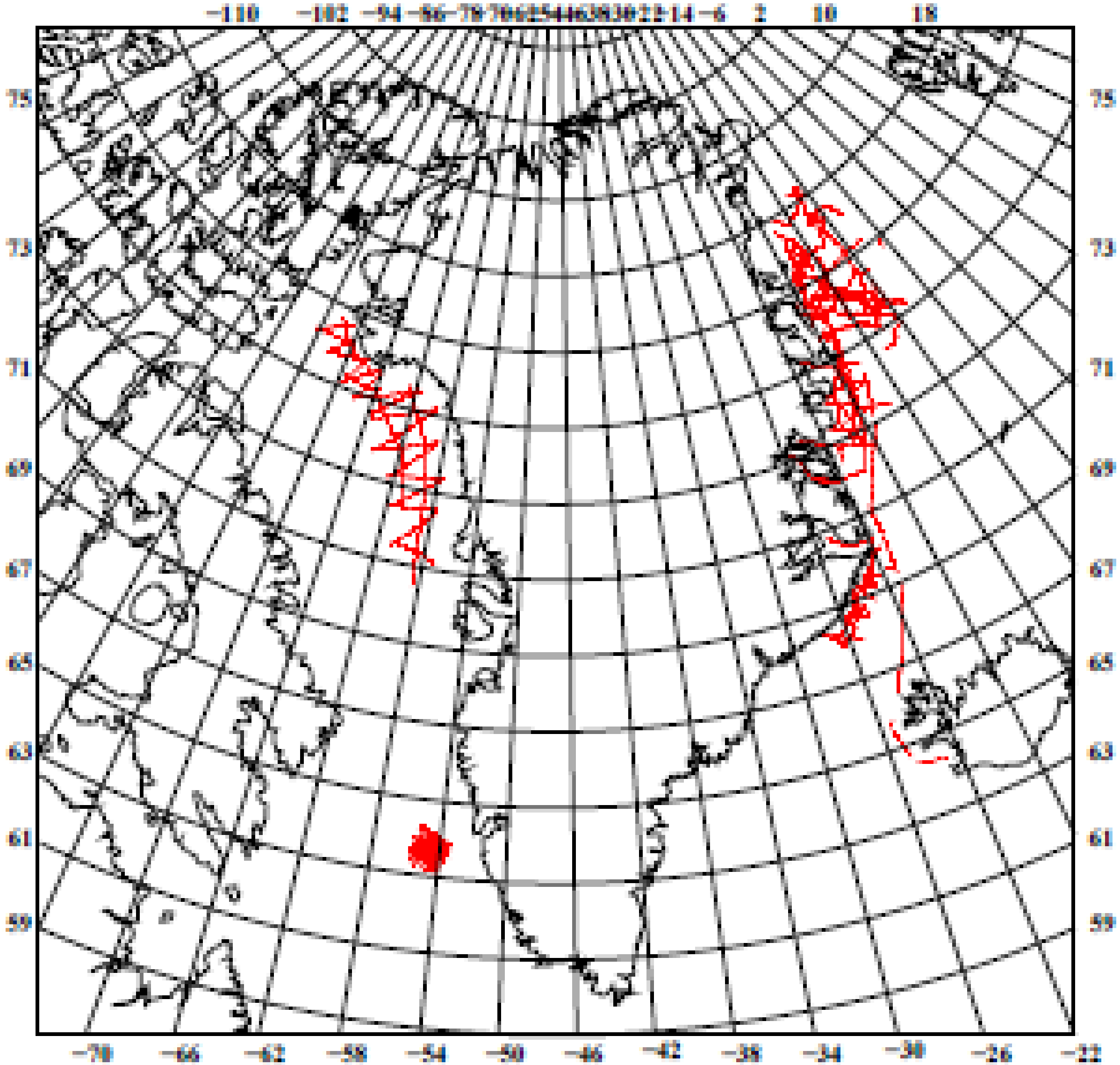


KANUMAS projects (1991-1995)

”Thetis” danish navy inspection vessel seismic surveys

Motivation:
Example NE-Greenland: correlation between the gravity profiles and seismic structures

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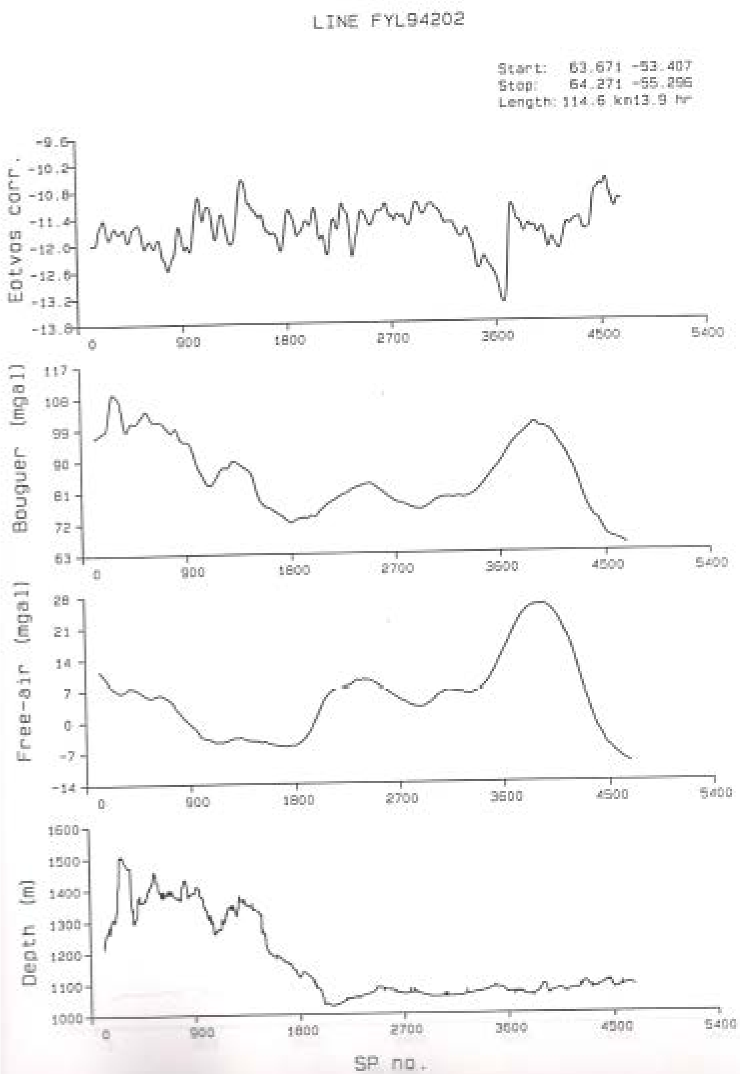
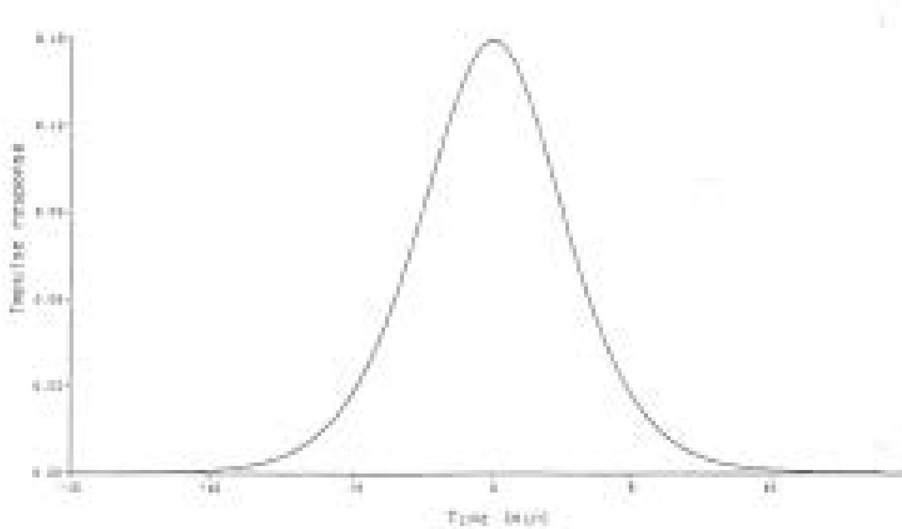




digital filter:

”5-min RC-filter”: 5 x 1min RC-filter (similar to filtering of LCR gravimeter)

Problem: phase shift. Cure: corresponding inverse time RC-filter

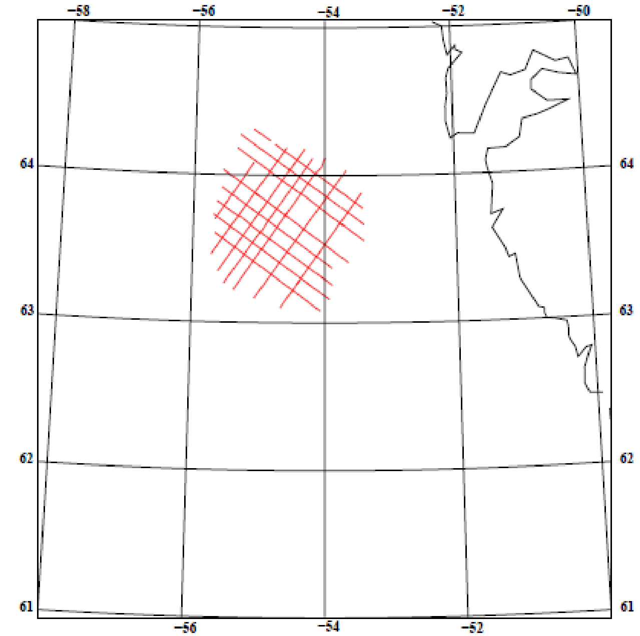
In total: zero-phase filtering

Total width at half-amplitude: 6 min
Corresponds to 740 m at 4 knots (=7.4 km/h)

Example:

Harbour ties 1994-survey

Nuuk	**JUL 21**	**13810.0**	**982192.3**
Reykyavik V	**AUG 17**	**13882.0**	**982266.7**



Survey navigation:

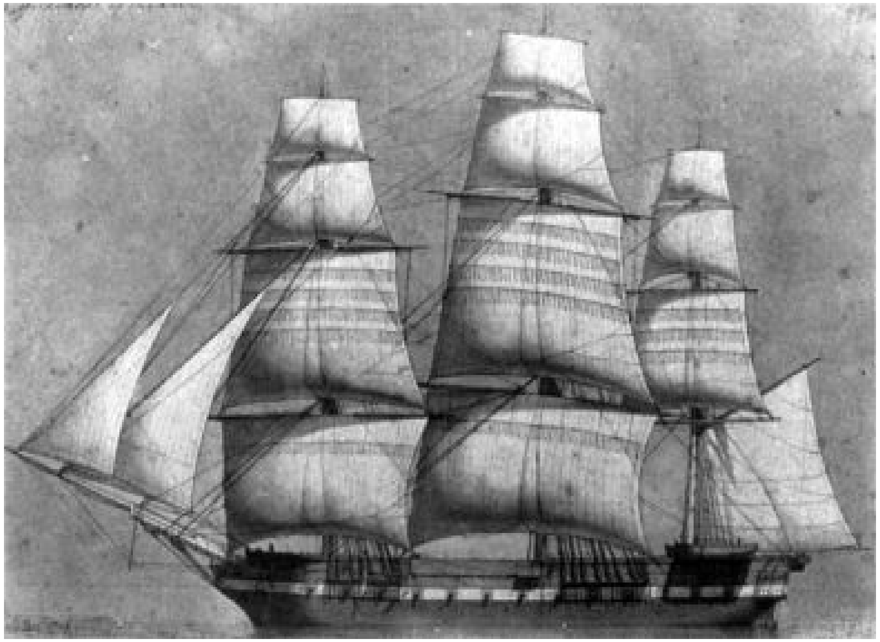
lines
constant low speed (seismic survey, streamers)

Intra-survey consistency at 57 cross-over points

mean	rms	min.	max.	(in mGals):
-0.34	0.88	-2.56	2.67	(prior to adjustment)
-0.01	0.64	-1.16	2.16	(after x-over adjustment)

Comparison to older Canadian data (interpolated) is better than 1 mGal.

Galathea expeditions



Galathea 1, 1845 – 1847. Expedition initiated by King Christian VIII. The purpose was to make scientific investigations and to promote trade with the East.

Galathea 2, 1950 – 1952. Planned in a cooperation between a journalist and a scientist. Primary goal was to investigate The deep ocean and as a follow up on the results of Galathea 1 expedition.

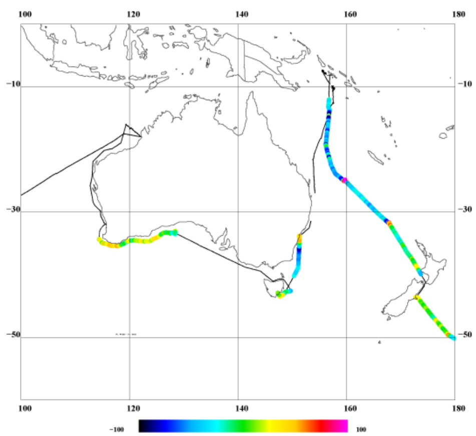
Galathea-3 expedition (14/8/2006->24/4/2007)

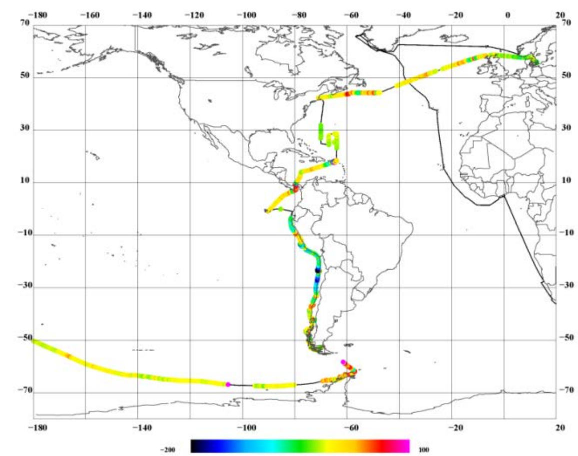
Installation in Freemantle (Western Australia)

Moving-platform gravimetry: marine gravity surveys

S-38 LC&R gravity meter

Harbour tie in Valparaiso, Chile



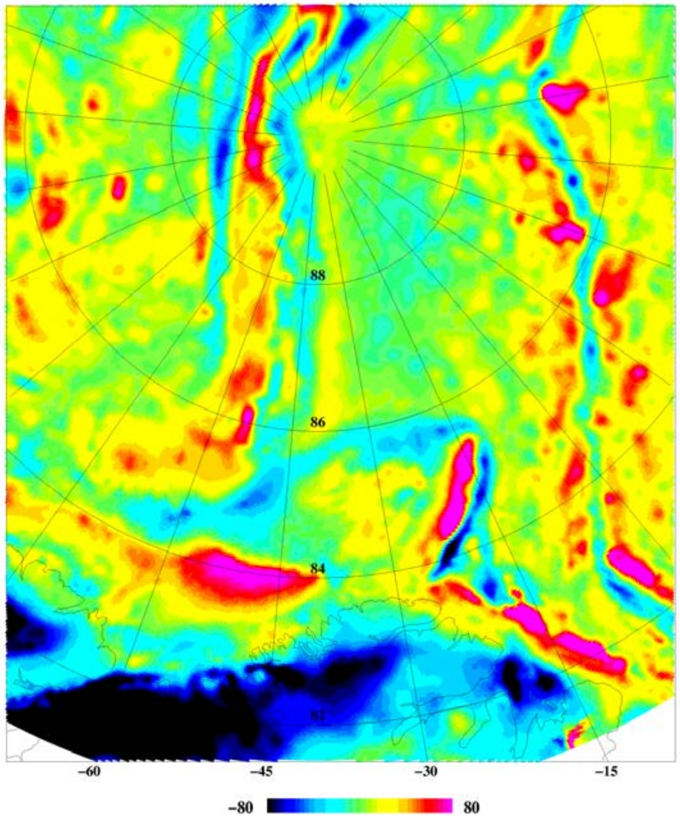


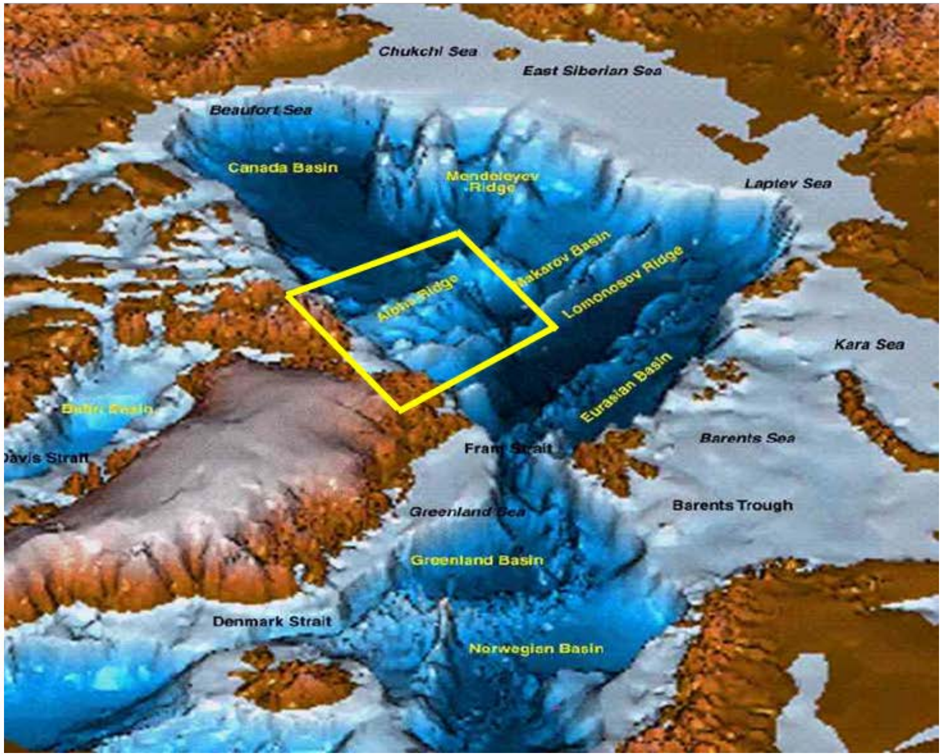
Free-air gravity anomalies (mgal)

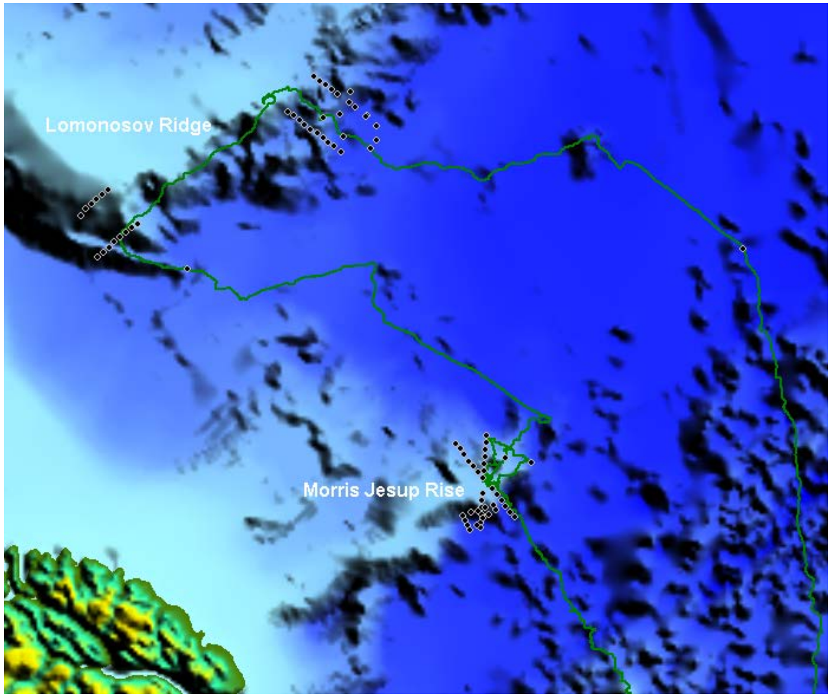
Lomrog 1 (2007)
Lomrog 2 (2009)
Lomrog 3 (2012)

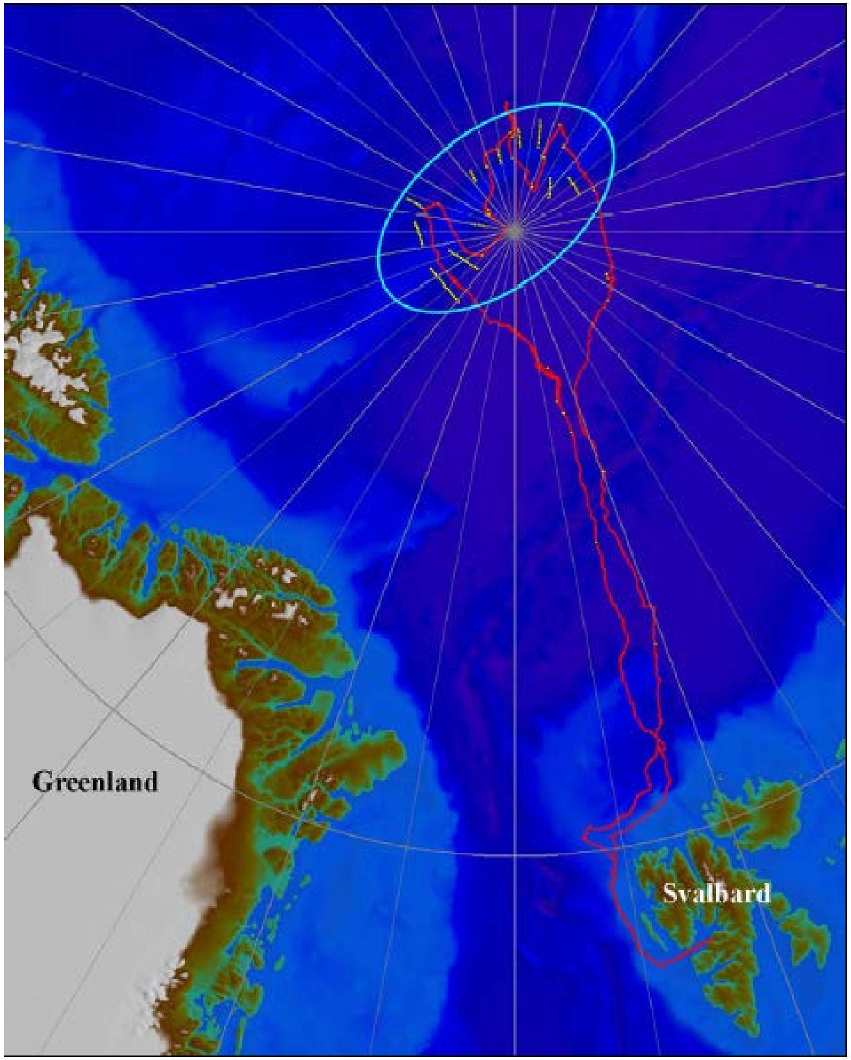
Swedish ice-breaker ”Oden”

Gravity Anomalies – Lomonossov Ridge









Lomrog 1 (2007)

Lomrog 2 (2009)

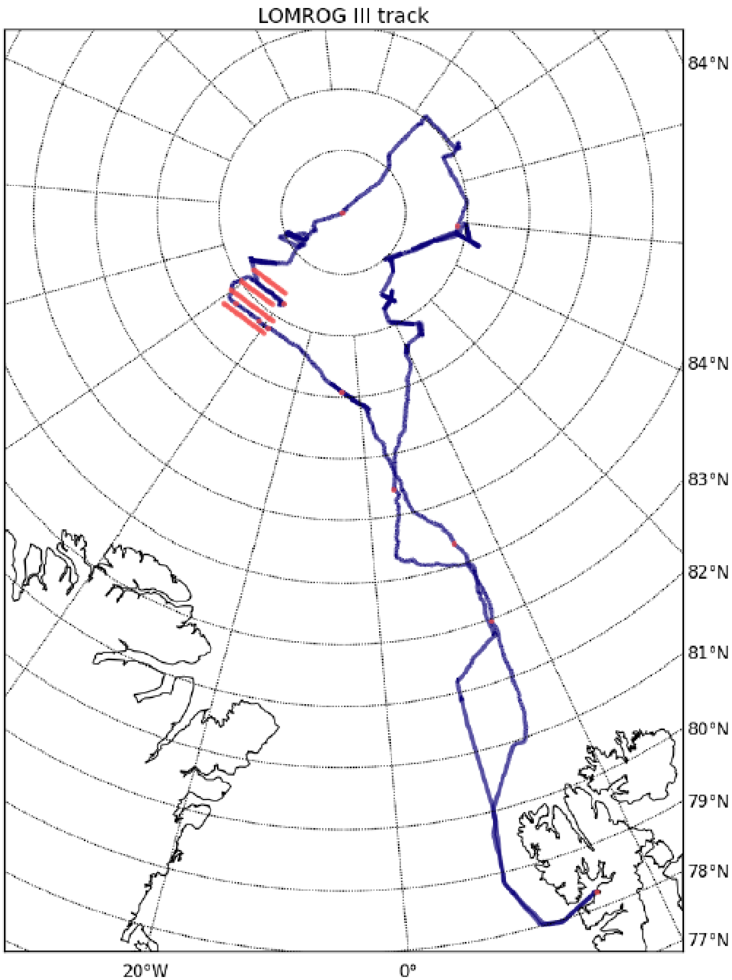
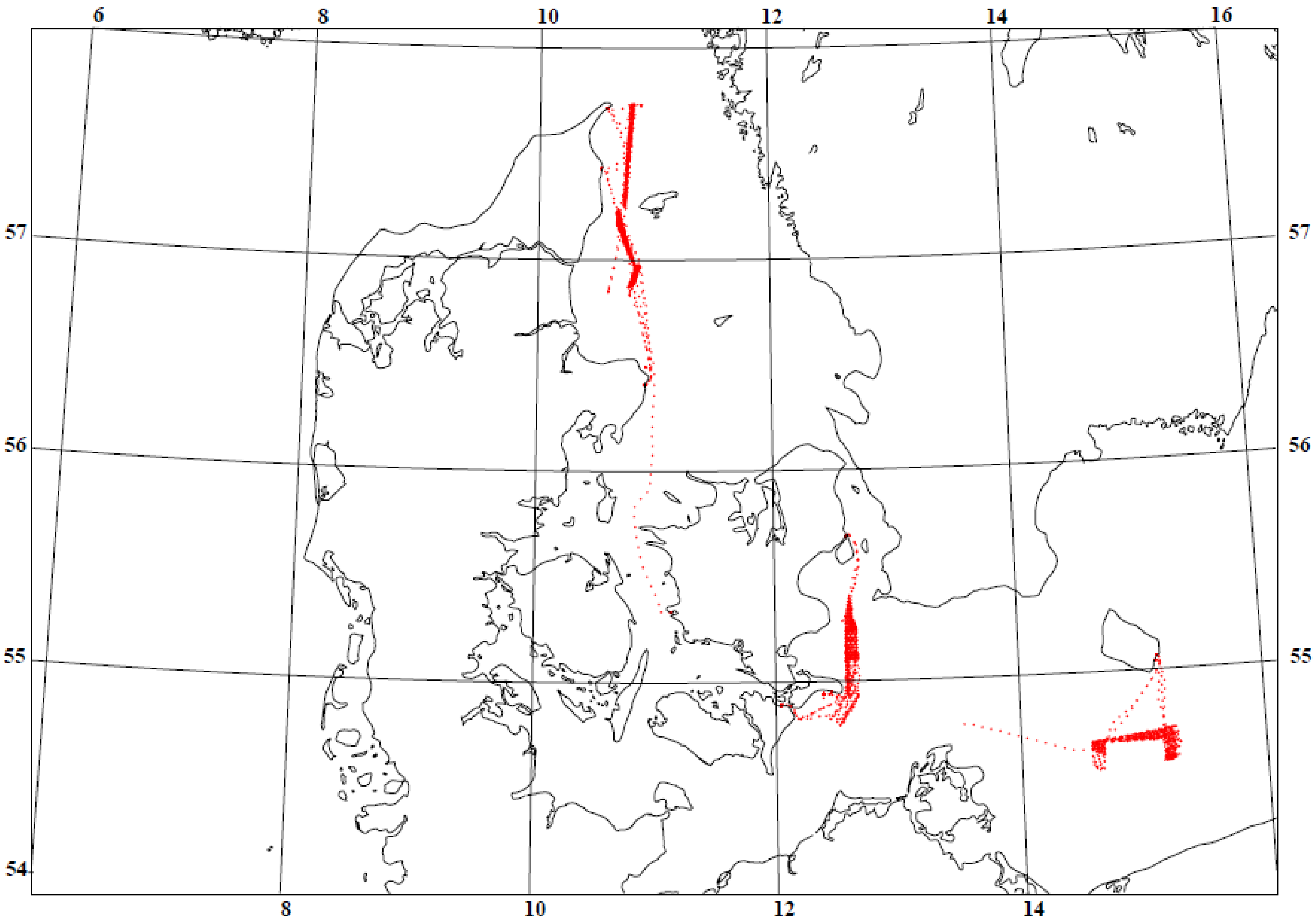


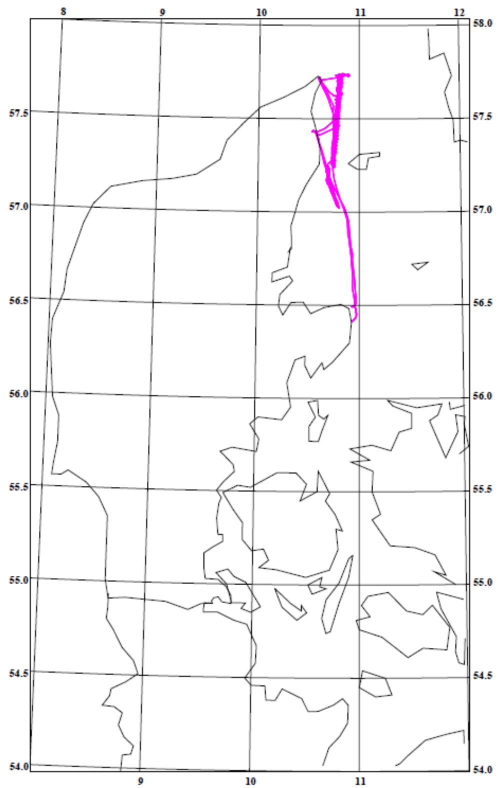
Figure 1: Lomrog III track. On-ice gravity measurements are representet as pink dots.

Figure 3 LaCoste and Romberg land gravimeter (left). Photo: Henriette Skourup. Gravity measurements on the sea ice (right). Photo: Adam Jeppesen.

Hydrographic survey vessel ”Jens Sørensen”

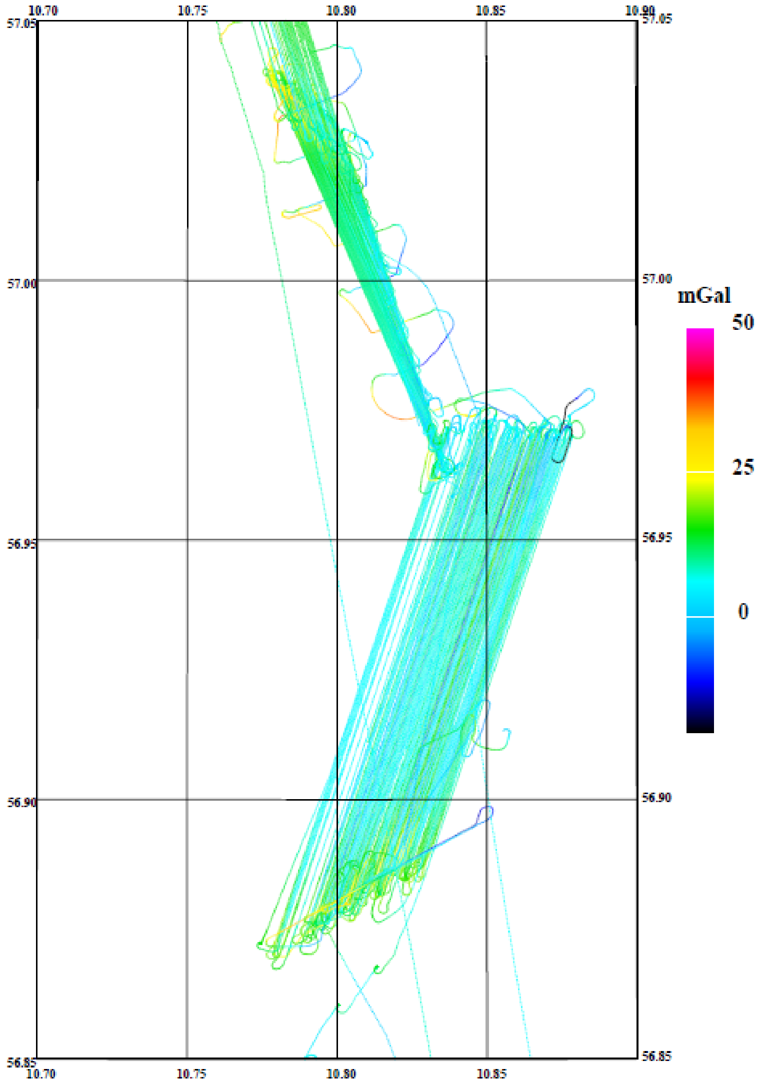


Gravity measured from ”Jens Sørensen” 2011-2013



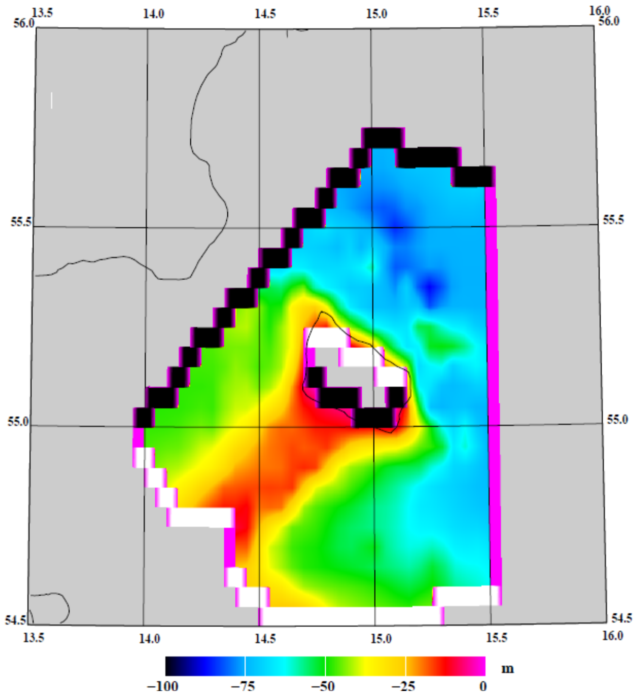
Harbour tie

S-38



"Process and cut-off"

- **FA**
- **Bathymetry from a detailed model**
- **BA**



In house processing software: EOTVOS7 (Fortran code)

Input:

- **GPS positions – time (enhanced with depths from the bathymetric grid)**
- **LCR gravity readings (pseudo-LCR gravity readings for Chekan)**
- **Harbour ties**

Processing:

Whole survey processed as one (no line structure)
Detection of holes in the data and interpolation
GPS time vs. UTC time (15 sec)
Filtering of bathymetry to achieve consistent with gravity information.

Output
Gravsoft point format: ST# LAT LON H FA BA