DANISH NATIONAL SPACE CENTER

Gravity measurements in Denmark in 2005

Survey and processing report by

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Danish National Space Center
Technical report No. 6, 2006
May 2006

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Copenhagen, 2006

ISBN 978-78-91694-08-0

ISBN 87-91694-08-6

www.spacecenter.dk

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1. Introduction

The present report describes the relative gravity measurements in Denmark by the Department of Geodynamics of the Danish National Space Center, DNSC, and the absolute gravity measurements by the Institut für Erdmessung, Hannover. This work fulfills in part DNSC's contract obligations (resultatkontrakt) for 2005 for National Survey and Cadastre, KMS (Kort- og Matrikelstyrelsen).

2. The absolute gravity measurements in 2005

In 2005, DNSC committed itself to provide absolute gravity measurements on 2 permanent GPS stations in Denmark, Suldrup and Smidstrup. The measurements were performed by the Institut für Erdmessung, IfE, University of Hannover, with their FG5 instrument # 220, as a part of an ongoing field campaign in Scandinavia. The results of processing by IfE presented here are only temporary. An official publication on the absolute gravity measurements in Denmark in recent years is planned. Additionally, three other gravity stations were measured in Denmark in 2005: the repeated absolute gravity measurement in Vestvolden (Copenhagen) and Helsingør; and the establishment of a new absolute gravity station in the Rockefeller Komplekset (University of Copenhagen). Table 1 shows the period of occupation of different absolute gravity stations in Denmark in 2005.

Table 1. Period of occupation of different absolute gravity stations in Denmark in 2005

station	arrival	Departure
Smidstrup GPS antenna	june 9, 2005	june 13, 2005
Suldrup GPS antenna	june 13, 2005	june 17, 2005
Helsingør	june 17, 2005	june 21, 2005
Copenghagen Vestvolden	october 12, 2005	october 16, 2005
Copenhagen University	october 16, 2005	october 18, 2005

2.1 The measurement conditions and the field experience in 2005

For Smidstrup- and Suldrup gravity stations a new experience was gained. For the first time in Denmark the absolute gravity was measured in a weatherport (a thermally insulated tent used for the work in the Arctic). Due to the land ownership regulations it was not easy to obtain a permission to build a hut around the specially build absolute gravity pillar located close to the GPS antenna. (The existing hut for operating the GPS-antenna could not be extended. However, an external power outlet was built in the existing hut, providing a power supply to the gravimeter.) Normally, an FG5 absolute gravity meter requires indoor conditions. Especially, the temperature around the gravimeter must be stable during the measurements. As a compromise, it was decided to use a special Canadian-made weatherport with aluminum doors. Also, a special wooden floor for the tent was designed and constructed. The floor was built in segments, which were light enough to be carried by 2 persons, and which were mounted on iron girders detached from the pillar. The construction proved to be adequate but far from perfect. Fixing the floor to the girders required some skill. The frame of the tent was fastened to the floor by cramps.

In practice, the biggest problem was, the transportation. The wooden floor filled the whole DNSC's institute car (a minibus VW Caravelle T4 TDI) and there was no place left for the tent. Fortunately, and in order to guard the expensive equipment inside the tent, it was decided to rent a motorhome and to stay close to the antenna; practically, to camp just outside the tent. The additional vehicle (a motorhome) had just enough space for the tent. Another very practical problem was the transfer from Smidstrup to Suldrup on June 13, 2005. On this day it was raining. The danger was, once the inside of the tent and the wooden floor got wet, to wait with the measurements until the tent was dry. Considering the tight measurement program, the motorhome rental, … etc, this was not the option. Thus, it was decided to wait with dismantling the tent until it cleared-up, risking a delay. Luckily, it cleared up around noon, but there was still a problem in the other end, the Suldrup GPS-antenna, where it was raining. Altogether, the tent was moved and erected as planed, but the timing was very tight. Also, there were only 3 persons to do the job. Fortunately and by pure chance, a colleague from KMS, Bo Hansen, was in Suldrup to fix the GPS-antenna. He helped us with the tent. The experience that was gained from the project is that it is safer to move out with 2 tents and with two sets of wooden floor rather than one. It requires, of course, more vehicles and more people to set the tents up, but the campaign schedule would not be at risk.

Another problem concerned the measurements. Smidstrup station is very windy. Opening of a tent door could create conditions not suitable for the measurements, e.g. a sudden and strong gust of wind. This problem was overcome using plastic sheets to screen the instrument from the direct wind. In other words, a tent out of plastic was built within a tent. The measurements in these conditions were of acceptable quality and comparable to the noisy stations in Scandinavia. Also, the proximity of the highway with heavy traffic increased the set-scatter. Figure 1 shows some details.

Concerning the condition of other stations, the station in Helsingør is located indoor, in the entrance hall of a busy school (10klasses Skole, Helsingør). The station lies on a 56°N-gravity line, which was established by Nordiska Komissionen för Geodäsi to monitor the Scandinavian land uplift. The absolute measurements in Helsingør were timed during the weekend and in the beginning of the summer holidays, when the measurements would not be disturbed by pupils.

The station in Copenhagen Vestvolden is located inside an old military building – a part of Copenhagen fortification line from 1890s. The conditions there are quite good, even though it is not far away from a busy highway. The absolute gravity point in Vestvolden serves as a temporary fundamental gravity point for the Danish precise gravity network since DNSC has no access any more to the fundamental gravity point in Buddinge, Copenhagen.

The new station in the basement of the Rockefeller Building, University of Copenhagen, was established to provide an easy access to the absolute gravity point for the relative measurements. In the future, the relative gravity campaigns in Denmark of DNSC in Denmark can start and end indoor in the basement. Figure 2. shows the location of the absolute gravity stations measured in 2005. Figure 3 illustrates the quality of the typical absolute gravity measurements with an FG5 by showing some details from the 2005 absolute gravity measurements in Helsingør.

Figure 1. The absolute gravity campaign in Denmark 2005. (top left) Suldrup absolute gravity station: fixing the iron girders outside the hut to support the wooden floor of the tent; (top right) Smidstrup absolute gravity station: the wheatherport; (bottom left) Smidstrup absolute gravity station: FG5 # 220 of the Institut für Erdmessung, Hannover, inside the tent; (bottom left) Smidstrup absolute gravity station: eccenter point at the foot of GPS-antenna measured using Scintrex CG3 of IfE.

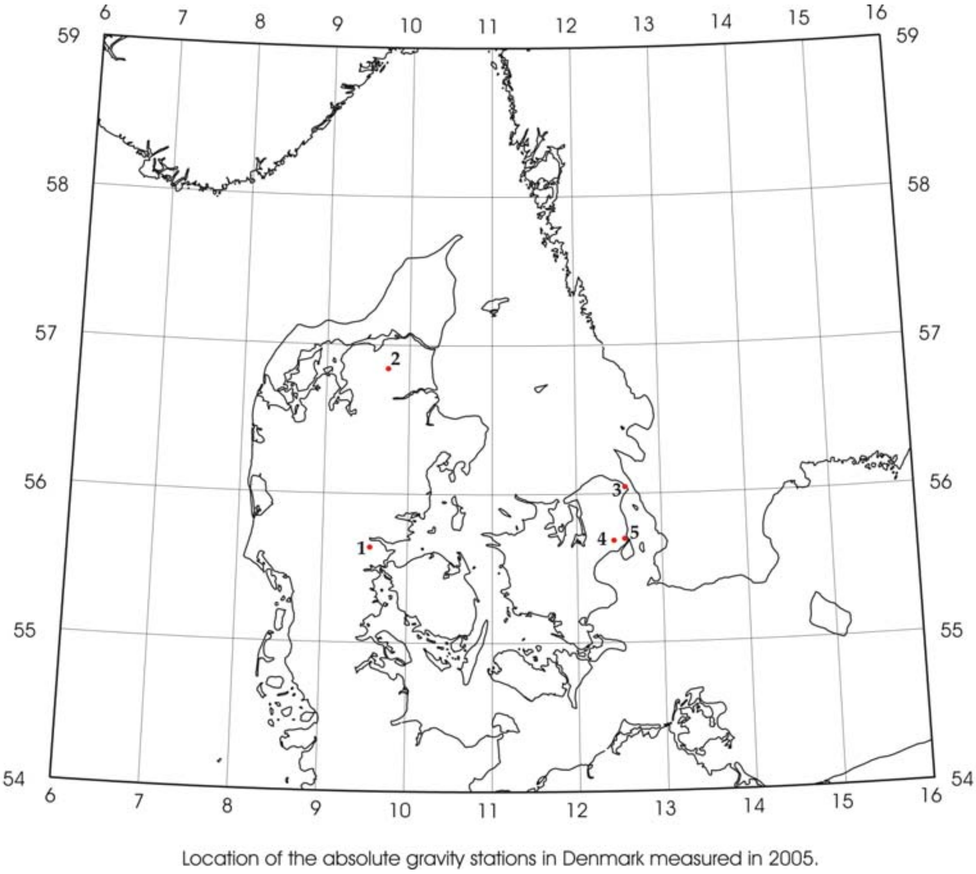

Figure 2. Location of the absolute gravity stations in Denmark measured in 2005: 1: Smidstrup GPS-antenna; 2: Suldrup GPS antenna; 3: Helsingør; 4: Copenhagen Vestvolden; 5: Copenhagen University.

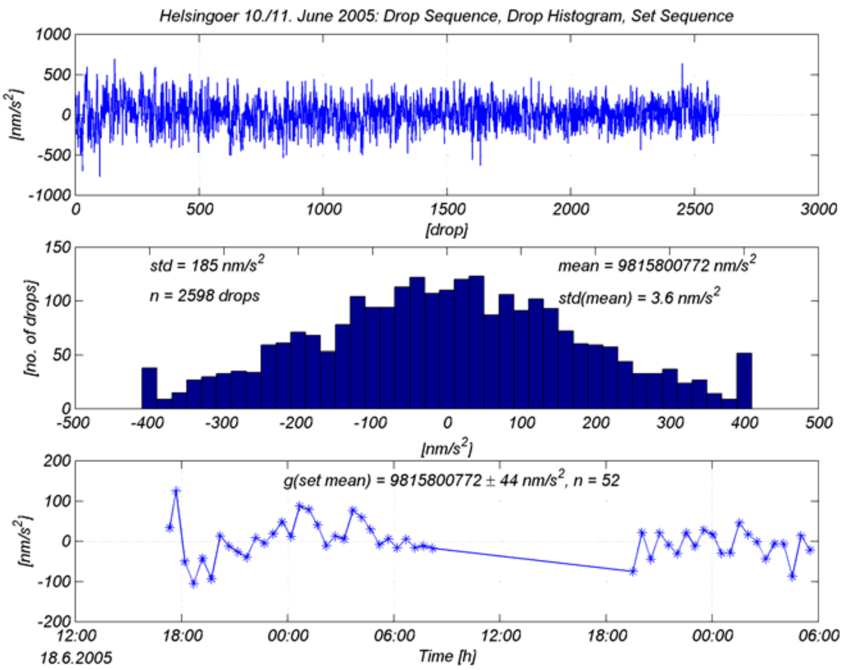

Figure 3. Some details concerning the 2005 gravity measurements in Helsingør. (1 set=50 drops).

2.2 Some comments concerning the definition and the use of gravity for geodetic purposes.

Modern absolute gravity meter like FG5 is able to measure gravity with an accuracy of 1-5 μGal (1 μGal = 10^{-8} ms^{-2}). The principle is the simultaneous recording of the time and position of a test mass in free fall inside the vacuum chamber. (The vacuum chamber of a FG5 is some 60 cm long). A theoretical relation of the free-fall is used to obtain a value of the absolute gravity at some specific point inside the vacuum chamber. The theoretical relation includes a gravity model, which changes linearly with height. At the Earth's surface, the gravity change with height is some -300 μGal/m outdoor (and some –250 to -280 μGal/m inside a building), which is quite significant at the μGal level of accuracy. This corresponds to approximately 3 μGal change for a 1 cm height difference and some 0.3 μGal for 1 mm height difference. Consequently, the gravity is measured accurately, but at a point in space related to the position of the instrument for this particular set-up.

When using the absolute gravity measurements in practice, e.g. for the relative gravity field campaigns, the user refers to the gravity value at some physical point on the terrain, e.g. a marker. For the geodynamic studies, e.g. in order to monitor the small gravity change with time for some location, the gravity value must be referred to a specific height above the marker on the ground. This is done using the vertical gradient to extrapolate/interpolate the physical measurement to the standard height. Such extrapolation/interpolation is always related to the loss of accuracy - the smaller the extrapolation distance, the smaller the loss of accuracy. Thus, the abstract concept of a virtual gravity point (a physical point in the air at a standard height above the physical marker), which is commonly familiar to the researchers measuring the absolute gravity, is used to detect the week geodynamic signals in repeated gravity measurements over many epochs. For example, a standard height of 1.20 m above the physical marker is used for the FG5, which is quite close to (but not exactly) the instrument height for each set-up.

To minimize the extrapolation error, the standard field procedure of IfE is to measure the in-situ vertical gravity gradient as an integrated part of the absolute gravity measurement. (The alternative is to use for the interpolation a standard vertical gradient value, e.g. the free-air gradient of -308.6 μGal/m, at the expense of the increased extrapolation error.) In practice, IfE measures the in-situ vertical gradient using two relative gravity meters (usually one LaCoste and Romberg and one Scintrex-CG3), where one instrument is placed on a platform at the instrument height of some 1.20 m above the ground, and the other directly above the point. The gravity difference for this fixed height difference is measured 10 times by changing the instruments.

For reasons explained above (the geodynamic studies) and for the purpose of the direct use in Danish gravity networks, it was decided that the measured absolute gravity value at certain height above the point is extrapolated to the standard height ΔH , ΔH *=1.20 m,* above the top of the marker, and to the top of the marker itself, i.e. ΔH *=0.00 m,* using the vertical gravity gradient.

In Denmark a 5D-network of sub-terrain geodetic points was constructed, see sec. 3. For these points a similar concept of the virtual gravity points should perhaps be considered. The reason for making the sub-terrain geodetic points is to protect the marker from the public for the future measurements. From the gravimetric point of view, the use of the sub-terrain points is problematic. The influence of the near-point terrain effect of the hole in the ground is measurable at the μGal level, especially, if the gravity is measured inside the masses, e.g. directly on the point. A possible virtual gravity point can be defined relative to a 5D-point as a point vertically above the marker at a standard height of e.g. *1.20 m*. The virtual point is defined relative to the physical point. Thus, it moves in the vertical with the marker, and by the same amount. Consequently, the height difference between the two markers is the same as the height difference between the corresponding virtual points. However, if the height difference is expressed in geopotential units, g.p.u., see [2], the interpolated gravity value to the virtual point, as compared to the true gravity value, is more accurate than the one interpolated to the top of the marker.

Appendix A contains the recommendation (in German) of Ludger Timmen, IfE, to the German authorities for a similar type of the sub-terrain gravity points. The author deals with the gravity effect of the near point mass distribution. The main recommendation is to use a virtual gravity point at some standard height above the physical sub-terrain point for the corresponding gravity point, e.g. at the height of 40 cm above the Earth's surface (110 cm above the point) or more.

2.3 The absolute gravity measurements in Denmark in 2005. The temporary results

The results of the absolute campaign in Denmark in 2005 shown in Table 2 are temporary. An official publication about all measurements conducted in recent years is on the way.

Table2. The temporary results of the absolute gravity campaign in Denmark in 2005 with measurement precision (standard deviation) at standard heights $\Delta H = 0.000m$ and $\Delta H = 1.200\ m$ above the physical marker. DVR90 heights for most of these stations are not yet available. **Smid:** Smidstrup GPS antenna; **Suld:** Suldrup GPS antenna; **Hel:** Helsingør; **Cph Vestv:** Copenhagen Vestvolden; **Cph Univ:** University of Copenhagen.

Absolute station	φ [°]	λ [°]	H_{DVR90} [m]	$\partial g/\partial H$ [μGal/m]	drops	g(h=1.200m) [μGal]	g(h=0.000m) [μGal]	Set-to-set scatter [μGal]
Smid	55.6406	9.5593	-	-322.0	2650	981556878±0.1	981557264.4	7
Suld	56.8418	9.7421	-	-319.4	3200	981638310±0.1	981638693.3	8
Hel	56.0453	12.5797	-	-262.0	2600	981580077±0.1	981580391.4	4
Cph Vestv	55.6869	12.435	-	-284.0	2700	981547278±0.1	981547619.0	4
Cph Univ	55.6976	12.5626	-	-245.0	1850	981546301±0.1	981546595.0	4

In Table 2 the precision of the mean (±0.1 μGal) denotes the standard deviation of the deviation from the mean for all drops. The set-to-set scatter is a measure of the variation of the set mean values (1 set = 50 drops). Figure 3 illustrates these concepts.

The accuracy of the temporary gravity values is assumed to be about ±3 to5 μGal (empirical estimate). A quantitative estimation of the site stability and the instrument's stability is given by the drop and set sequences and the corresponding drop-to-drop and set-to-set scatters, see Figure 3. But such contemplation does not immediately reveal floor instabilities and the instrument's set up, resulting in floor recoil effects. These effects include a systematic part, triggered by the dropping procedure. The resulting vibration disturbs the gravity acceleration - the effect thoroughly investigated in [4] and [5], and it may cause errors of up to a few μGal for FG5 gravimeters.

For the absolute gravity stations in Smidstrup, Suldrup and Helsingør the eccentric stations were measured at the end of the campaign using the relative instruments. Table 3 lists the results. The gravity difference measured by different instruments is adopted as the gravity difference between the top of the marker and the top of the eccenter point (except for the sub-terrain points 117-05-00808 and 61-10-00805 where it is the top of the circular cover of the well containing the marker).

Table3. The eccentric stations for the absolute gravity stations. The height of the absolute gravity point (the top of the marker) is H_a. The gravity value at height H_a is g_a. The height and the corresponding gravity value of the eccentric point is H and g. For the sub-terrain points 117-05-00808 and 61-10-00805, H denotes the vertical level of the top of the circular cover of the well. $\Delta g \equiv g(H) - g_a(H_a)$. The suspicious results are in brackets.

Absolute gravity station	Eccentric station	$\Delta g = g - g_a$ [μGal]	comments
Smidstrup GPS antenna	117-05-00808	268±1	Measured with CG3-4492 of IfE
	117-05-00808	(314±14)	Measured with DNSCs LCR-G867 and LCR-G466
	117-05-09060	212±1	Measured with CG3-4492 of IfE
	117-05-09060	(188±16)	Measured with DNSCs LCR LCR-G867 and LCR-G466
Suldrup GPS antenna	61-10-00805	-524±1	Measured with CG3-4492 of IfE
Helsingør	Vestervang Kirke gravity station #251 , see [1]	-1338±2	Measured with CG3-4492 of IfE
		-1334±3	Measured with LCR-G079 of IfE

For 117-05-00808, located some 14.98 m away from the absolute gravity point, the top of the cover was at a height of some 0.500 m above the top of the marker, and the height difference between the top of the sub-terrain point and the top of the marker of the absolute gravity point is some –1.485 m.

For 61-10-00805, located some 30.17 m away from the absolute gravity point, the top of the cover was at a height of some 0.542 m above the top of the marker, and the height difference between the top of the sub-terrain point and the top of the marker of the absolute gravity point is some 1.690 m. In principle, the 4 relative instruments used [CG3-4492 and LCR-G079 of IfE, and LCR-G466 and LCR-G867 of DNSC] measure in different heights and, thus, the gravity difference in these heights should be slightly different. This is, however, a minor effect.

As seen from Table 3, there is an unacceptable discrepancy between the measurements of IfE with CG3 and the two instruments from DNSC (the numbers in the brackets). A detailed inspection of the results obtained by the two DNSC instruments (4-6 repetitions with each instrument of the relative measurement over a short distance and a short time span) shows, that while each of the two instruments is internally consistent, and while the two instruments disagree systematically by some 10-30 μGal (G-466 measures a higher value than G-867), the IfE results lie systematically outside the range of DNSC measurements. On the other hand, the quality of IfE measurements with both instruments can be seen for the eccentric station in Helsingør. The agreement is quite impressive (some 4 μGal). Thus, it was decided in 2006 to repeat the above measurements by DNSC.

3. The relative campaigns in 2005 – 5D points

The activities in 2005 included the gravity surveys on the so-called 5D-points – a cost efficient geodetic network for the future use. The reason behind the establishment of this network – while the geodesy as a whole moves away from the physical points on the ground, and into the remote-sensing techniques – is to preserve some kind of the ground truth control. The network consists of markers - iron rods screwed some 1.20 m into the ground - in wells. Ideally, the depth of the well should be larger than 60 cm – which is sufficient for ensuring that the benchmark will not be affected by the freezing of the soil. In practice, few wells are shallower. The well is empty (i.e. filled with air not soil) and has a concrete circular cover approximately 40 cm in diameter. In principle, these benchmarks are sub-terrain points (even though they are shallow).

In practice, the measurement of gravity on such points initiates each time with measuring the height of the edge of the well above the top of the marker. Subsequently, the thickness of the concrete cover is measured and added to the measured height. This combined height is, thus, the height of the top of the cover above the top of the marker. The gravimeter is then placed on the circular cover and the instrument height refers to the top of such cover.

In sec. 2.2. and in Appendix A some remarks were made about these sub-terrain 5D-points. Another issue, which needs to be discussed, is how accurately the gravity should be measured. The future use of such measurements is, of course, not known. At the present, the measurements are done for the sake of completeness, i.e. in order to provide the 5D-stations with a complete set of information for the present time epoch. The main purpose is to be able to convert the height differences between the stations into the geopotential numbers, i.e. according to the modern definition of heights, see [2]. For this purpose, the gravity value must not be very accurate (10-30 microgal accuracy is sufficient). Another possible application would be to measure the accumulated gravity change caused by the land uplift, e.g. over 100 years. If the purpose is to monitor the gravity change it would require a microgal- or less accuracy, which is not achievable with the relative instruments at the present. In fact, such microgravity surveys were conducted over the years in Scandinavia where the rate of the land uplift is known to be quite large, see [3]. Even for such strong uplift signal, the results are at the limit of what is achievable. The uplift signal is at the level of noise over 40 years.

In 2005, the relative gravity campaigns on 5D-points were conducted in two short campaigns: 24-25 november 2005 and 8-12 december 2005. The campaigns initiated and finished at The University of Copenhagen building (Rockefeller Komplekset) in Copenhagen on the newly established absolute gravity point, see sec 2. Whenever possible, the campaigns were connected to the newly established absolute gravity points in Jutland (Smidstrup- and Suldrup GPS antenna), but also verified against the stations of the precise gravity network, see [1], in churches in Denmark. Table 4 shows the station coordinates of the 5D-points (the geographical latitude and longitude in EUREF89 and the height in the Danish height system DVR90). The point in Skagen has no DVR90 height yet. This information about the absolute heights is not important for the gravity measurements as the gravity measurements are conducted in heights related to the physical points. (Putting it differently, the knowledge of the DVR90 height of the 5D-station will not change the gravity result.)

Figure 4 shows the location of 5D-stations measured in 2005. Table 5 shows the results of the relative campaign on 5D points. Table 6 shows the connection misfit to the established absolute gravity stations and the stations of the precision gravity network, see [1]. Appendix B lists the observation files of the 2 campaigns.

Table 6 shows some rather big misfits to the known points of the precision gravity network. It can perhaps be explained in part by the transportation. For example, the Maribo Domkirke was measured after a long drive from Copenhagen and prior to the ferry-boat transfer to Langeland and with no control-points in between. However, even for a relatively well-constrained survey in Jutland, i.e. many measurements and ties to the absolute gravity stations, the results from Måbjerg Kirke show some rather big misfits. Combined with the problems in sec. 2 with the eccentric points in Smidstrup, this indicates that we should perhaps check the instruments. However, for the present day purpose of the relative gravity surveys on 5D-points, see above, the accuracy of the results is probably sufficient.

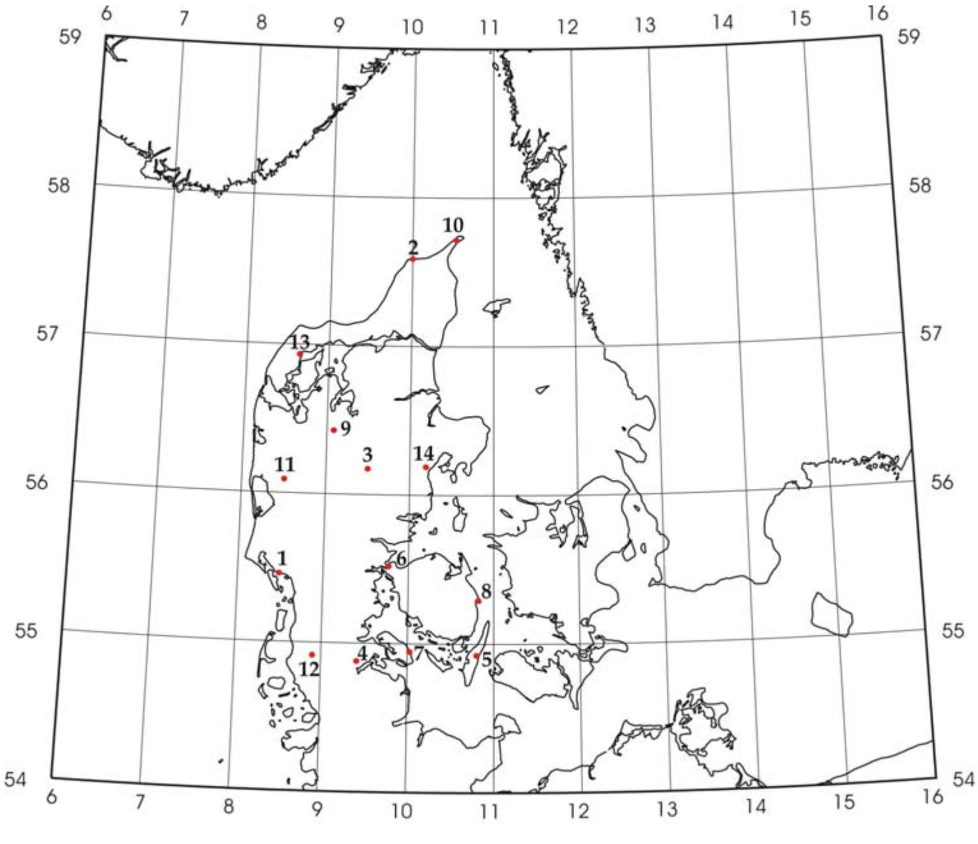

Figure 4. Location of the 5D-stations measured in 2005: **1:** K-75-00957 Esbjerg; **2:** 54-05-00832 Hirtshals; **3:** 81-01-00816 Hvinningedal Kirke; **4:** 153-05-00837 Kelstrup Kro; **5:** 46-05-00814 Longelse Kirke, Langeland; **6:** 40-19-00830 Middelfart; **7:** 155-05-00833 Mommark, Als; **8:** K-41-00995 Nyborg; **9:** 82-18-00812 Sjørup; **10:** K-48-00921 Skagen; **11:** 118-01-00836 Spjald; **12:** 149-04-00808 Sæd; **13:** 70-11-00811 Thisted; **14:** K-63-00909 Århus.

Table 4. The geographical coordinates of the Danish 5D-stations measured in 2005.

	Station number	φ	λ	H_{DVR90}
Esbjerg, Jutland	K-75-00957	55° 27’ 51.612’’	08° 26’ 49.117’’	16.387 m
Hirtshals, Jutland	54-05-00832	57° 35’ 03.687’’	09° 56’ 31.898’’	26.881 m
Hvinningedal Kirke, Jutland	81-01-00816	56° 10’ 23.541’’	09° 29’ 45.950’’	119.523 m
Kelstrup Kro, Jutland	153-05-00837	54° 52’ 42.035’’	09° 24’ 51.199’’	35.431 m
Longelse Kirke, Langeland	46-05-00814	54° 55’ 26.022’’	10° 48’ 02.519’’	19.437 m
Middelfart, Fyn	40-19-00830	55° 30’ 48.264’’	09° 46’ 03.368’’	33.999 m
Mommark, Als	155-05-00833	54° 55’ 36.019’’	10° 02’ 29.554’’	17.217 m
Nyborg, Fyn	K-41-00995	55° 18’ 20.447’’	10° 48’ 21.709’’	3.823 m
Sjørup, Jutland	82-18-00812	56° 25’ 34.566’’	09° 04’ 44.710’’	47.214 m
Skagen, Jutland	K-48-00921	57° 43’ 04.387’’	10° 32’ 22.474’’	unknown
Spjald, Jutland	118-01-00836	56° 05’ 26.859’’	08° 30’ 20.539’’	66.251 m
Sæd, Jutland	149-04-00808	54° 54’ 51.577’’	08° 54’ 00.995’’	0.440 m
Thisted, Jutland	70-11-00811	56° 55’ 54.802’’	08° 38’ 27.079’’	43.104 m
Århus, Jutland	K-63-00909	56° 11’ 20.789’’	10° 11’ 24.540’’	85.181 m

Table 5. Results of the gravity measurements on 5D points in 2005. $g_{measured}$ is the adjusted gravity value at the top of the circular cover of the 5D-point in height $\Delta H_{measured}$ above the top of the marker. For convenience, standard free-air gradient of -308.6μGal/m is used to transform the measured gravity value to standard heights: ΔH=0m and ΔH=1.20m.

$\Delta g_{\Delta H=0m} \equiv g(\Delta H = 0) - g_{measured} \approx 308.6 \cdot \Delta H_{measured}$

$\Delta g_{\Delta H=1.20m} \equiv g(\Delta H = 1.20m) - g_{measured} \approx -308.6 \cdot (1.20m - \Delta H_{measured})$

location	Station number	$g_{measured}$ [μGal]	$\Delta H_{measured}$ [m]	$\Delta g_{\Delta H=0m}$ [μGal]	$\Delta g_{\Delta H=1.20m}$ [μGal]
Esbjerg, Jutland	K-75-00957	981553035±27	0.228	70.4	-300.0
Hirtshals, Jutland	54-05-00832	981718831±28	0.312	96.3	-274.0
Hvinningedal Kirke, Jutland	81-01-00816	981622133±31	0.540	166.6	-203.7
Kruså, Jutland	153-05-00837	981497009±36	0.421	129.9	-240.4
Longelse Kirke, Langeland	46-05-00814	981506312±34	0.370	114.2	-256.1
Middelfart, Fyn	40-19-00830	981561136±32	0.460	142.0	-228.4
Mommark, Als	155-05-00833	981509511±35	0.465	143.5	-226.8
Nyborg, Fyn	K-41-00995	981541499±32	0.470	145.0	-225.3
Sjørup, Jutland	82-18-00812	981614191±32	0.370	114.2	-256.1
Skagen, Jutland	K-48-00921	981731755±21	0.463	142.9	-227.4
Spjald, Jutland	118-01-00836	981596422±28	0.512	158.0	-212.3
Sæd, Jutland	149-04-00808	981501011±36	0.431	133.0	-237.3
Thisted, Jutland	70-11-00811	981667382±30	0.432	133.3	-237.0
Århus, Jutland	K-63-00909	981604992±29	0.523	161.4	-208.9

Table 6. Comparison of the results of the gravity measurements on 5D points in 2005 to published results, see [1].

location	Station number, see [1]	g [μGal]	$g-g_{published}$ [μGal]
Maribo Domkirke, Lolland	240	981487560±35	-62
Måbjerg Kirke, Jutland	235	981622215±29	-39
Tolne Kirke, Jutland	246	981709417±28	-14

4. Results and Conclusions

The present report summarizes the activities by DNSC and partners on the relative and absolute gravity measurements in Denmark in 2005. The contract requirements with KMS for 2005 were fulfilled.

DNSC was asked to provide 2 absolute gravity measurements on the permanent GPS-stations in Jutland (Smidstrup and Suldrup). The work included construction of special pillars for the gravimeter and the construction of a wooden floor for the tents. In 2005, and for the first time in Denmark, the absolute gravity measurements were done in a weatherport (a thermally insulated tent). In addition, three other absolute gravity measurements were done by the partners of DNSC (Institut für Erdmessung, IfE, Hannover, Germany). The temporary results of IfE are presented here. An official publication on the absolute gravity measurements in Denmark in recent years is planned in the near future.

2005 was the first year of the relative gravity measurements on the new geodetic 5D-network in Denmark. DNSC was obliged by the contract to measure on 10-15 points. 14 points were measured. The report contains the results as well as a description of the field experience gained. Furthermore, some considerations about the theoretical as well as practical aspects are given here. It will help in the future to better understand the objectives of the relative gravity campaigns on 5D-points.

The present report should be viewed as a work in progress. From the 2005-project, a number of outstanding issues remain:

- DNSC will in 2006 repeat the measurements using G-867 and G-466 on the eccentric points in Smidstrup (Table 3) to check whether there are problems with the instruments at the μGal level.

- All the absolute gravity stations in Denmark and 5D stations should have a height in the national height system DVR90, see Table 2 and Table 4. The leveling team from KMS is currently (april-may 2006) doing the job.

- The objective of gravity measurements on 5D-stations, the field procedure and the accuracy requirements should be discussed and refined.

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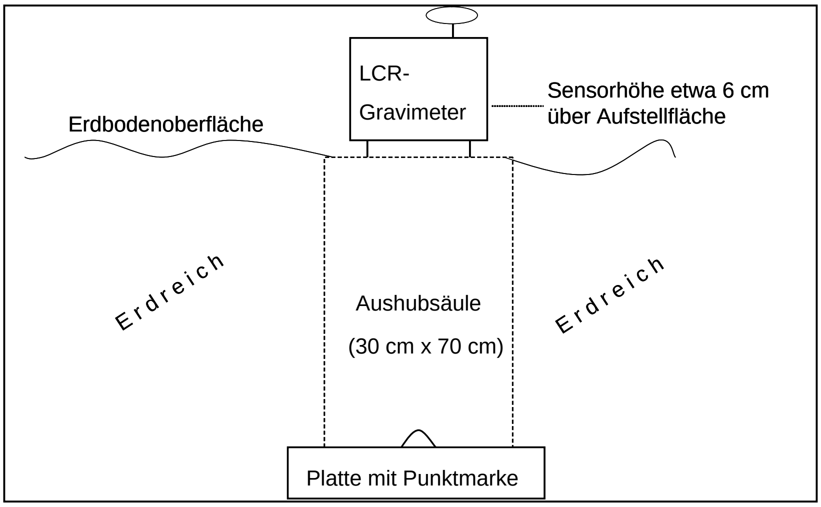
Appendix A. Ludger Timmen, IfE: A note on gravity measurements for sub-terrain points.

Schweremessungen mit Bezug zu unterirdischen Vermarkungen (Grundlagenpunkte der Landesvermessung): Abschätzungen und Empfehlung

Annahme zur Situation:



angenommene Dichte: 2 g/cm^3,

Sensorhöhe über Säule [cm]	Schwerewirkung der Säule auf Sensor [µGal]
10	6.6
40	1.8
50	1.3

Angenommenes Genauigkeitsziel für Schwerebestimmung: 10 µGal (beinhaltet alle Einzelfehler).

- Bei einer Sensorhöhe von ca. 40 cm über Erdboden kann der Erdaushub über der Platte als vernachlässigbar betrachtet werden. Die Messung kann mit oder ohne Grabung vorgenommen werden.
- Ist der Aushubbereich während der relativgravimetrischen Messungen bei beiden Verbindungspunkten entweder gefüllt oder leer, so hebt sich durch die Differenzbildung dieser kleine Masseneffekt weitestgehend heraus.
- Für die Reduktion einer Messung auf eine bestimmte Höhe über Punktmarke wird der vertikale Schweregradient benötigt. Deshalb sollte die Sensorhöhe nicht in unmittelbarer Bodennähe sein, sondern sich 30 cm oder höher über Boden befinden, so dass der Freiluftgradient verwendet werden kann.
- Die gravimetrisch zu reduzierende vertikale Schwereänderung auf eine definierte Höhe über Marke sollte nur für einen Höhenunterschied von weniger als 10 cm vorgenommen werden.
- Es ist vorteilhaft, bei gefülltem Zustand die Messungen vorzunehmen, weil dadurch vermieden wird, dass immer ein gleich großes Loch ausgehoben werden muss.

Empfehlung zur Vorgehensweise:

- Für jeden Punkt sollte eine auf 10 cm gerundete Höhe über Punktmarke definiert werden, auf dem sich der Schwerewert beziehen soll. Diese Höhe sollte mindesten ~40 cm über dem Bodenniveau liegen. Beispiel: 110 cm über Marke, ca. 40 cm über Boden.

- Die Höhe des Instrumentes über Punktmarke (Vorsicht, evtl. nicht gleich mit Plattenoberfläche) kann mit Hilfe einer Stabsonde ohne Grabung mit einer Genauigkeit von 1 cm bestimmt werden.
- Ein Stativ zum zentrischen Aufbau (± 10 cm) des Relativgravimeters über Punkt mit einer Höhe von ca. 40 cm über Bodenniveau ist erforderlich.

Hier wurde von flachem Gelände ausgegangen (keine Hanglage). Die obigen Ausführungen sollten auch noch mit einer zweiten Person „aus der Praxis" diskutiert werden.

Appendix B. The observation files of the two relative gravity campaigns in 2005 on 5D stations

```
# G-466 november 2005  time in  UT
 777 241105  6.35  5035.068 21.0
 888 241105  9.50  5045.354 26.2
 957 241105 11.20  5041.314 26.2 5Dpunkt Esbjerg flisetop over punktet 22.8 cm (inkl. 5 cm flise)
 836 241105 13.00  5082.455 26.0 5Dpunkt ved Spjald flisetop over punktet 51.2 cm (inkl. 8 cm flise)
 235 241105 14.20  5106.873 27.0
 811 241105 16.10  5149.694 27.2 5Dpunkt ved Thisted flisetop over punktet 43.2 cm (inkl. 5 cm flise)
 921 241105 19.30  5210.725 27.2 5Dpunkt ved Skagen flisetop over punktet 46.3 cm (inkl. 5 cm flise)
 921 251105  7.35  5210.725 27.3 5Dpunkt ved Skagen flisetop over punktet 46.3 cm (inkl. 5 cm flise)
 246 251105  8.30  5189.525 27.2
 832 251105  9.25  5198.488 27.3 5Dpunkt i Hirtshals flisetop over punktet 31.2 cm (inkl. 4 cm flise)
 999 251105 11.10  5122.540 27.5
 909 251105 12.30  5090.618 27.0 5Dpunkt i Århus flisetop over punktet 52.3 cm (inkl. 7 cm flise)
 888 251105 14.15  5045.358 26.5

# G-867 november 2005  time in  UT
 777 241105  6.01  4922.901 21.2  no dish optical reading only
 888 241105  9.57  4933.460 27.4  optical reading only
 888 241105 10.00  4933.446 27.4
 957 241105 11.25  4929.292 27.3 5Dpunkt Esbjerg flisetop over punktet 22.8 cm (inkl. 5 cm flise)
 836 241105 13.15  4972.077 27.2 5Dpunkt ved Spjald flisetop over punktet 51.2 cm (inkl. 8 cm flise)
 235 241105 14.27  4997.537 26.8
 811 241105 16.10  5042.000 27.2 5Dpunkt ved Thisted flisetop over punktet 43.2 cm (inkl. 5 cm flise)
 921 241105 19.15  5105.466 27.2 5Dpunkt ved Skagen flisetop over punktet 46.3 cm (inkl. 5 cm flise)
 921 251105  7.41  5105.398 26.8 5Dpunkt ved Skagen flisetop over punktet 46.3 cm (inkl. 5 cm flise)
 246 251105  8.30  5083.401 27.1
 832 251105  9.30  5092.691 26.9 5Dpunkt i Hirtshals flisetop over punktet 31.2 cm (inkl. 4 cm flise)
 999 251105 11.15  5013.683 27.2
 909 251105 12.39  4980.482 27.6 5Dpunkt i Århus flisetop over punktet 52.3 cm (inkl. 7 cm flise)
 888 251105 14.15  4933.443 27.2

# G-466 november 2005  time in  UT
 777  81205  5.46  5035.060 27.1 1014.8
 240  81205  8.26  4979.126 27.1 1015.6
 814  81205 11.00  4996.915 26.1 1016.0
 833  81205 15.20  4999.903 26.4 1020.7
 837  81205 16.46  4988.065 27.0 1020.2
 808  81205 17.55  4991.823 27.1 1025.5
 957  81205 19.25  5041.186 26.8 1025.9
 957  91205  8.36  5041.322 26.5 1040.0
 812  91205 10.17  5099.250 27.4 1033.9
 816  91205 11.58  5106.762 27.1 1029.8
 888  91205 13.40  5045.173 26.9 1029.9
 830  91205 14.47  5048.872 27.2 1040.0
 995  91205 16.06  5030.232 26.5 1040.0
 777  91205 18.22  5035.029 27.3 1040.0

# G-867 november 2005  time in  UT
 777  81205  5.58  4922.429 27.3 1014.8
 240  81205  8.17  4864.282 27.4 1015.6
 814  81205 10.46  4882.752 26.3 1016.0
 833  81205 15.29  4885.824 26.8 1020.7
 837  81205 16.35  4873.471 27.1 1020.2
 808  81205 17.46  4877.453 27.1 1025.5
```

957	81205	19.34	4928.775	27.1	1025.9
957	91205	7.25	4928.744	26.8	1040.0
812	91205	10.03	4989.041	27.3	1033.9
816	91205	11.50	4996.894	27.5	1029.8
888	91205	13.43	4932.948	27.6	1029.9
830	91205	14.53	4936.721	27.1	1040.0
995	91205	16.17	4917.391	27.1	1040.0
777	91205	18.20	4922.351	27.2	1040.0