Absolute und relative gravity measurements at ILL Grenoble with the Hannover absolute gravity meter FG5X-220 (Oct. 2021) and the relative meters Scintrex CG-3#4493 and CG-6#171 (Aug. and Oct. 2021)

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Before, during and after the experiment 3-14-415 (PF2 UCN) "Weak Equivalence Principle Test with Neutrons" at ILL Grenoble, gravimetric measurements were performed. The PF2 experiment lasted from 24th of August to 13th of October 2021.
With the financial and man-power support of the Institute Laue-Langevin, Grenoble (ILL Grenoble), the Institute of Geodesy (Institut für Erdmessung, IfE), Gottfried Wilhelm Leibniz Universität Hannover (LUH), was able to perform absolute gravimetric measurements with a free-fall gravimeter after the experiment, which is the datum reference (gravimetric level) for the relative network established in August and completed in October.
The following tables, figures and the appendix are documenting the achieved work with the results.
During the whole duration of the neutrons experiment, a stationary recording with acquired 1-minute values supplemented the experiment. Please read carefully the captions of the tables and figures. Further remarks about the procedures of the Hannover gravimetry group and about the deployed absolute and relative gravimeters can be found in the cited literature.

Remarks about the absolute gravity determination with FG5X-220

The vertical gravity gradient along the plump line was determined by relative gravimetry. Here, the vertical gravity gradient is assumed as a constant along the plumb line. To avoid or minimize any deterioration of the absolute gravimetric result (g-value) caused by uncertainties in the assumption of the vertical gradient, which is actually not a constant, the final absolute result is transferred to the reference sensor height h = 1.250 m which is very close to the actual sensor height of FG5X-220. Here, the influence of the gradient becomes almost zero ("effective instrumental height" of the FG5, see e.g. *Timmen 2003*). Thus, the vertical gradient is only needed to transfer the g-value from the sensor height of about 1.26 m to the reference height of 1.250 m over the small distance of 1 cm only. In this way, the station time series (history) of the gravimeter point can be used best to investigate a secular gravity change over years to decades. A gravity value close to floor level can be useful to connect relative gravimetric networks with the absolute point serving as a datum point.

For most applications in geodynamics the observation of temporal gravity variations is important and a constant measuring offset to the true value of g can be accepted. For the reproducibility of the instruments measurement a stable offset to the true value of g over several years is a necessity. Otherwise, an unknown change of the offset might be interpreted as a geophysical signal. A rigorous control of the absolute accuracy with respect to a true gravity value at the moment of an absolute gravity measurement is not possible. The real g-value with a superior accuracy is not known, and a standard absolute gravimeter which is superior to the state-of-the-art FG5 meters does not exist. Therefore, international key comparisons are organized periodically with absolute gravimeters as primary standards maintained by national metrology institutes or designated institutes (key gravimeters), and with additional participants from the geo-scientific field. The key gravimeters define official reference values within the traceability chain of SI for all sites occupied by the key instruments and are provided to the other participating gravity meters. In addition, two or more gravimeters may be combined within a geodynamics project, and the offsets between the instruments are controlled by episodic comparisons during the project live time outside of the official traceability chain. For more detailed information, please refer to *Schilling and Timmen (2016)*, *Pálinkáš et al.* (2021) and *Timmen et al. (2021)* for the latest summarizing of international comparisons with FG5X-220.

The accuracy of final g-results of station determinations with FG5X-220 are estimated with an uncertainty of 20 nm/s^2 (long-term reproducibility of FG5(X)-220 and discrepancy to reference values of international comparisons). This overall estimate has been derived empirically as an average root mean square (r.m.s.) discrepancy from comparisons with other absolute gravimeter over the whole lifetime of the Hannover instrument (*Timmen et al. 2021*). Nevertheless, discrepancies between the single epoch results can be caused not only by instrumental errors but also by real gravity variations. E.g., local hydrological variations (groundwater change) may induce several 0.01 μm/s^2.

References

Pálinkáš, V.; Wziontek, H.; Vaľko, M.; Křen, P.; Falk, R. Evaluation of comparisons of absolute gravimeters using correlated quantities - reprocessing and analyses of recent comparisons. J Geodesy. 2021, 95, https://link.springer.com/article/10.1007%2Fs00190-020-01435-y.

Schilling, M., Timmen, L.: Traceability of the Hannover FG5X-220 to the SI units, International Association of Geodesy Symposia, doi: 10.1007/1345_2016_226, 2016.

Timmen, L.: Precise definition of the effective measurement height of free-fall absolute gravimeters. Metrologia 40, 62-65, https://doi.org/10.1088/0026-1394/40/2/310, 2003.

Timmen, L.: Absolute and relative Gravimetry (2010): In: Guochang Xu (ed.), Sciences of Geodesy-I, Advances and Future Directions, 1-48, 10.1007/978-3-642-11741-1_1, Springer Berlin Heidelberg. http://link.springer.com/chapter/10.1007/978-3-642-11741-1_1#page-1

Timmen, L.; Gerlach, C.; Rehm, T.; Völksen, C.; Voigt, C.: Geodetic-Gravimetric Monitoring of Mountain Uplift and Hydrological Variations at Zugspitze and Wank Mountains (Bavarian Alps, Germany). Remote Sens. 2021, 13, 918. https://doi.org/10.3390/rs13050918.

Timmen, L., Wenzel, H.-G.: Worldwide synthetic gravity tide parameters. In: H. Sünkel and I. Marson (Eds.), Gravity and Geoid, Proceed. IAG Symp. No. 113, 92-101, DOI: 10.1007/978-3-642-79721-7_11, Springer-Verlag Berlin Heidelberg New York, 1995.

Wziontek, H.; Bonvalot, S.; Falk, R.; Gabalda, G.; Mäkinen, J.; Pálinkáš, V.; Rülke, A.; Vitushkin, L. Status of the International Gravity Reference System and Frame. J. Geod. 2021, 95, 7.

Table 1. Coordinates of the absolute gravity site occupied by the Hannover FG5X-220 in 2021. Latitude and longitude were picked off the online map of Google Earth Pro. The height (above sea level) of point 1000, basement of ILL1, is referred to the Earth's surface height (210.5 m), as given by Google Earth Pro.

Station	Reg. No.	φ [deg]	λ [deg]	H [m NN]	Description
Grenoble ILL1	1000	45.2057	5.6949	209	station in the basement of ILL1, room S60

Table 2: Absolute gravity values of the FG5X-220 measurements on point Grenoble ILL1 (facility of the Institute Laue-Langevin) defined at the reference height h=1.250 m above floor level. The gradient insensitive sensor height ("effective instrumental height", e.g. Wziontek et al. 2021) varies with the gravimeter setup and is about 1.263 m above floor level for these setups at ILL Grenoble. To calculate the weighted mean g-values, the different numbers of drops have been used for weighing. The standard uncertainty std.u of FG5X-220 (long-term stability and deviations from international datum references) are estimated to 0.02 µm/s² (statistical level of confidence of 68.3%, corresponding to classical definition of standard deviation (1-σ estimates)).

Site **Grenoble ILL1**	Measurement run (orientation)	Date in 2021	Drops	δg/δh [µm/s² / m]	$g_{h=1.250\ m}$ [µm/s²]
Run 1/setup1	20211019a (SW)	19. Oct.	100	-2.583	9804972.359
Run 2/setup1	20211019b (SW)	19. Oct.	447	-2.583	9804972.361
Run 3/setup1	20211019c (SW)	19. Oct.	999	-2.583	9804972.369
Run 4/setup2	20211020a (NE)	20. Oct.	600	-2.583	9804972.402
Run 5/setup2	20211020b (NE)	20. Oct.	798	-2.583	9804972.394
Run 6/setup3	20211021a (SW)	21. Oct.	400	-2.583	9804972.349
Average	(weighted mean SW)		1946		9804972.362
Average	(weighted mean NE)		1398		9804972.397
Total Average	(arithm. mean SW,NE)		3344		**9804972.380**

g-value at effective position: $g_{h=1.263\ m}$ = 9804972.346 µm/s², std.u = 0.02 µm/s²

g-value at floor level: $g_{h=0.000\ m}$ = 9804975.609 µm/s², std.u = 0.03 µm/s²

Table 3. Adjusted gravity values of relative points at ILL Grenoble. They are connected to the absolute point, which was determined by FG5X-220 just after the PF2 experiment in October 2021. The heights (above sea level) are referred to the Earth's surface height (210.5 m), as given by Google Earth Pro. As an empirical accuracy estimate, the extended uncertainty (95% confidence interval) of all relative points can be assumed better than 0.1µm/s^2. The adjustment precision (standard deviation) of the observed differences vary within a few 0.01 µm/s^2, which is too optimistic.

Reg. No.	Height [m NN]	g-value [µm/s^2]	Description
1000	209	9804975.61	absolute site at floor level, basement of ILL1, room S60
1001	211	9804971.61	outdoor point of ILL1
1002	228	9804924.69	ILL5, level D, 3.15 m below PF2 experiment
1003	231	9804916.47	ILL5, above level D, about 0.5 m below centre of PF2
1010	211	9804963.16	ILL7, instr. S18 (neutrons interferometer)
1011	211	9804962.56	ILL7, experimental zone PF1b, 1 m above floor
1012	210	9804964.84	ILL7, experimental zone PF1b, floor level

Table 4: Applied Earth tide data set with amplitude factors and phase shifts. The parameter of the partial tides with daily and shorter wavelengths are derived from the 69 days registration at ILL Grenoble during the experiment from August to October 2021. The parameter for the long wavelengths (fortnight, monthly, etc.) are from a synthetic model (*Timmen and Wenzel 1995*)

Frequency [cpd] Start	End	Ampl. factor	Phase lead [°]	Tide symbol
0.000000	0.000000	1.0000	0.0000	DC
0.000100	0.249951	1.1875	0.3958	Long
0.501370	0.911390	1.14444	0.1368	Q1
0.911391	0.947991	1.15275	-0.1379	O1
0.947992	0.981854	1.13682	0.7982	M1
0.981855	1.023622	1.13914	-0.3531	P1S1
1.023623	1.057485	1.19893	-0.0293	J1
1.057486	1.470243	1.13747	1.7974	OO1
1.470244	1.880264	1.13070	-2.9271	2N2
1.880265	1.914128	1.16881	3.7271	N2
1.914129	1.950419	1.18570	2.1119	M2
1.950420	1.984282	1.20660	-0.8589	L2
1.984283	2.451943	1.19688	0.7228	S2K2
2.451944	3.381478	0.99767	-2.3194	M3
3.381379	7.000000	3.12233	-47.2098	M4M5

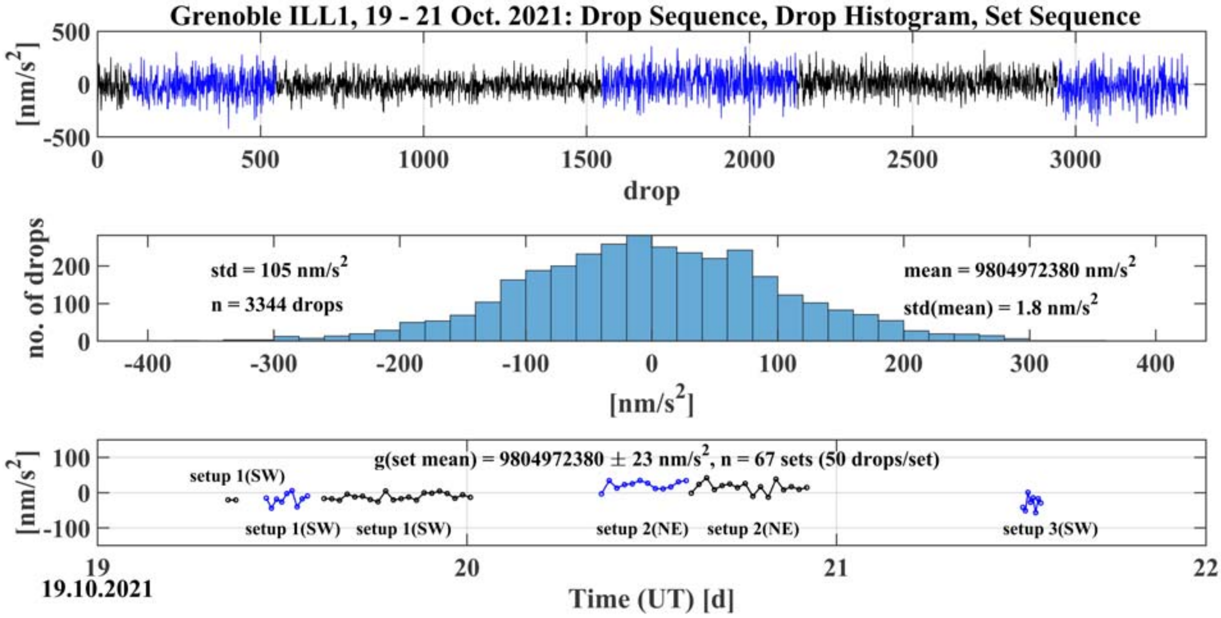


Figure 1: Statistical compilation of the station determination with the Hannover FG5X-220 absolute gravimeter at ILL Grenoble in October 2021

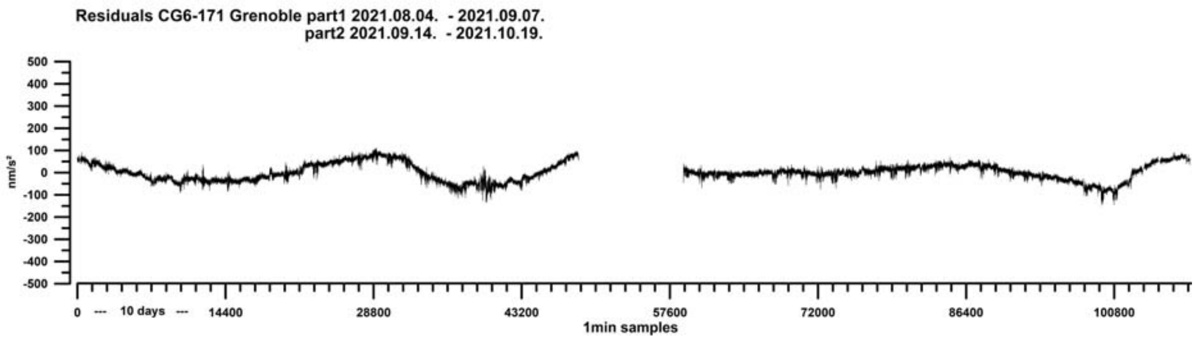
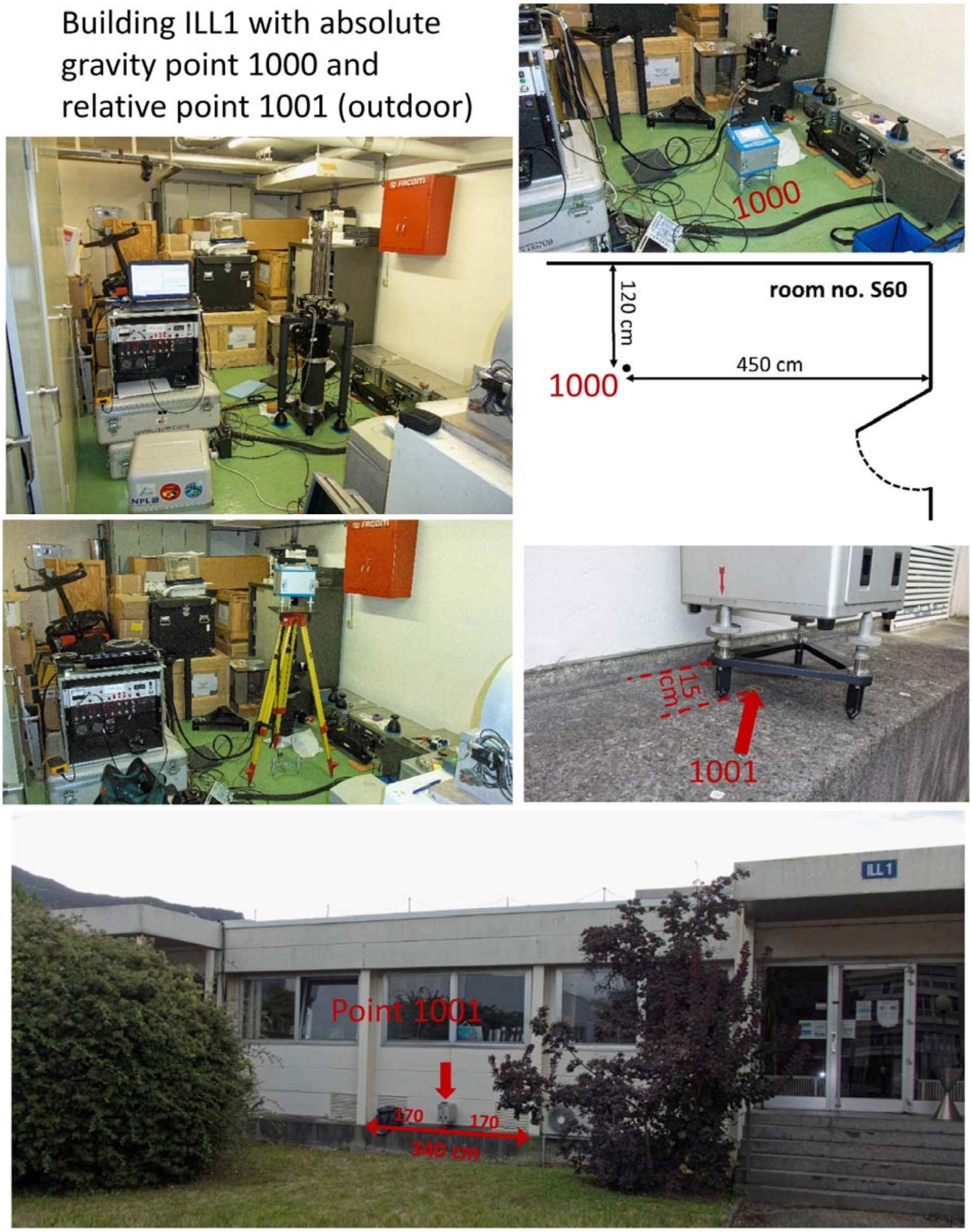


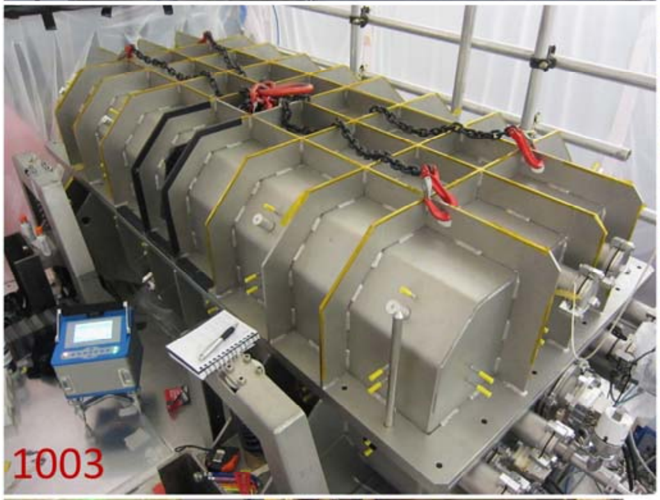
Figure 2: Time series of continuous gravity recording with relative gravimeter Scintrex CG-6#171 at ILL Grenoble (daily tick marks along the time axis). The Earth's tides as analyzed from the recording have been reduced. An air pressure reduction with the transfer factor -3 nm/s² per hPa has been applied as well. A quadratic polynomial, modelling the gravimeter spring drift, has been considered. Around minute 100800, the experiment 3-14-415 (PF2 UCN) was finished and the upcoming man made disturbances become visible in the changing drift direction. All long periodic signal variation should be assigned to the gravimeters drift. The many spikes are due to the noise environment caused by human activities in the building. The reason for the instrumental failure on the 7th of September cannot be explained.

Appendix

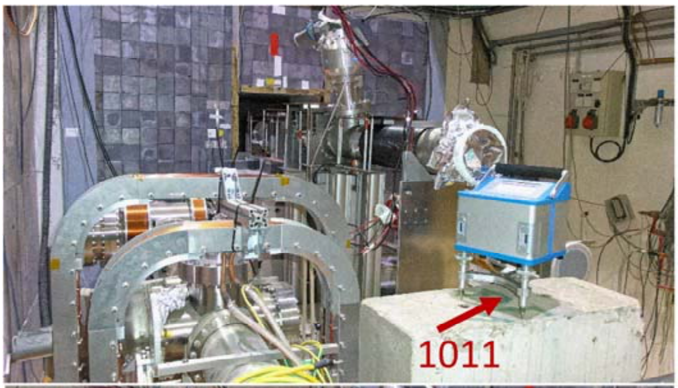
The measuring points at ILL Grenoble are shown and described.
The setup surfaces of the relative gravimeter are defining the reference heights of the g-values in Table 3.

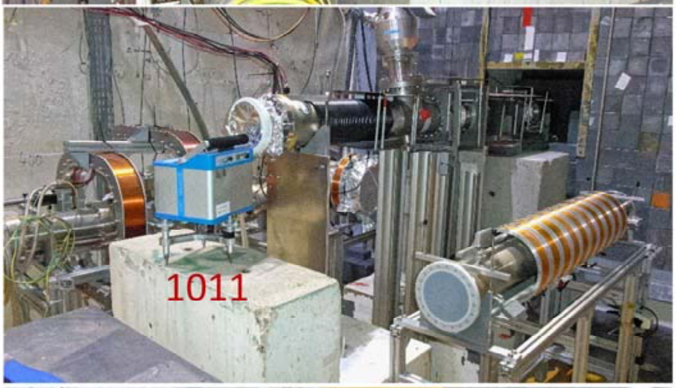


Building ILL5



At PF1B in building ILL7:
Direction: Z-beam 18 mrad;
position 1011: 2.35 m from casemate lead protection, 1 m above floor (placed on 2 concrete blocks 0.8x0.3x0.5 m^3);
Position 1012: 4.35 m from casemate lead protection, on floor;





S18 Neutrons Interferometer with Point No. 1010