Calibration of the BEV geodetic baseline

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Geodetic baseline

- a measurement standard for length measurements in geodesy
  - typically a set of observation pillars in line; in field conditions; number of pillars from a few to more than ten; pillars at varying distances, the total length from tens of metres to one kilometre or more
- lengths are traceable to the definition of the metre
  - *metrological traceability is a property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty (BIPM JCGM 200:2008)*
  - *metrological traceability chain is a sequence of measurement standards and calibrations that is used to relate a measurement result to a reference (BIPM JCGM 200:2008)*
- applications:
  - in calibration of electronic distance measurement (EDM) instruments
  - in testing and validation of new absolute distance measurement (ADM) instruments
  - in scale transfer measurements to (and comparisons with) other geodetic baselines and test fields for calibration of surveying instruments
  - to determine the scale in local tie measurements at co-located fundamental geodetic stations (VLBI, SLR, GNSS etc.)
  - to verify the scale in local geodynamical monitoring networks for crustal deformations
  - the traditional use was in triangulation to determine the scale for surveying and mapping (calibration of invar wires for field baselines)

Motivation of the work

- objectives set by the European Metrology Research Programme (EMRP) Joint Research Project "Absolute long distance measurement in air"
  - development and validation of new techniques and instruments for long distance measurements (up to a few km) in air beyond the state of the art, with targeted accuracy level 10^{-7}
  - nine European metrological institutes participating
  - proper testing and validation facilities in field conditions needed
- new results from interference measurements in 2005 and 2007 are available for the Nummela Standard Baseline of the Finnish Geodetic Institute (FGI)
  - this baseline is widely known as the longest, most accurate and stable measurement standard in the world for traceable geodetic length measurements, with almost 80-years history
  - measurements with the unique Väisälä interference comparator and traceability through a unique quartz gauge system, with obtained accuracy 10^{-7}
- a very different baseline of the BEV in Innsbruck is available for the project
  - differences in length, design, environment, climate, accessibility, centring method ...
- to improve facilities for testing and validation of new instruments a scale transfer from the FGI baseline to the BEV baseline was performed
  - the most accurate existing EDM instrument used as a transfer standard
  - projection measurements and calibrations of the transfer standard at the Nummela Standard Baseline before and after the measurements at the BEV geodetic baseline

The Nummela Standard Baseline of the FGI

- 6 underground and 6 aboveground pillars at 0, 24, 72, 216, 432 and 864 metres; difference in altitude 4 m
- location on a forested non-frozen sandy ridge
- established 1933, Standard Baseline since 1947
- during last ten years the traceable scale has been transferred from Nummela to about 20 baselines or test fields in about 10 countries

The BEV Geodetic Baseline in Innsbruck

- 7 pillars at 0, 30, 120, 270, 480, 750 and 1 080 metres; difference in altitude 2 m
- location on a riverbank between a high mountain and a busy motorway
- established 2006 with high precision EDM
- environmental conditions similar to many typical surveying tasks

Method and traceability chain of scale transfer

1) definition of the metre

- the SI unit as a starting point: *<u>the metre</u> is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second (CGPM 1983)*
- realization of the definition of the metre is performed at National Metrology Institutes, where iodine-stabilized lasers are used as primary national standards

2 a) absolute calibrations of 1-m-long quartz gauges using gauge block interferometers

- standard uncertainty about 35 nm
- at MIKES, Finland, and PTB, Germany

2 b) relative comparisons of quartz gauges in maintaining the quartz metre system

- interferometrical methods again
- standard uncertainty a few nm
- by FGI and UTu, at Tuorla Observatory, University of Turku, Finland

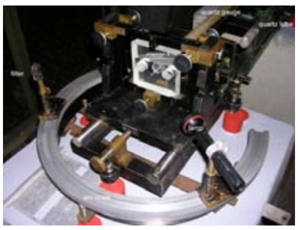
Method and traceability chain of scale transfer

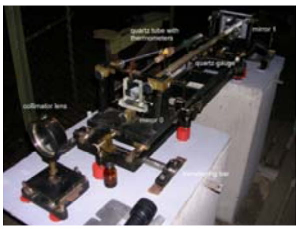
3) measurement of a standard baseline by multiplying the length of a quartz gauge in the Väisälä interference comparator

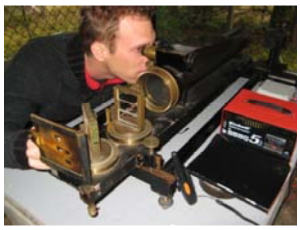
- standard uncertainties from 20 µm to 90 µm
- Nummela Standard Baseline section lengths from interference measurements, the results in 2007 with standard uncertainties and differences from the results in 1996:

24 033.218 mm ±0.034 mm	–0.19 mm
72 014.949 mm ±0.022 mm	+0.08 mm
216 053.128 mm ±0.028 mm	–0.08 mm
432 095.284 mm ±0.045 mm	+0.05 mm
864 122.865 mm ±0.074 mm	+0.11 mm

- "true" values for the calibration of EDM instruments
- the Nummela Standard Baseline is nowadays the almost only geodetic baseline, which is maintained with regular interference measurements (15 times 1947 – 2007)







Method and traceability chain of scale transfer

4) projection measurements in maintaining a standard baseline
- the high-accuracy link between the interference measurements and calibrations
- several times every year with smaller than 0.1 mm standard uncertainty

5) calibration of a transfer standard at the Nummela Standard Baseline
- a high-precision EDM equipment Kern ME5000 was calibrated four times before and four times after the measurements at the BEV geodetic baseline
  - August 28 – September 3 and October 31 – November 6, 2008
- altogether 2 x 4 x 6 x 5 = 240 distances ranging from 24 m to 864 m were measured
- weather data for velocity corrections obtained with classical instruments
- determination of the scale correction with smaller than 0.1 mm uncertainty
- the method is independent on frequency calibrations

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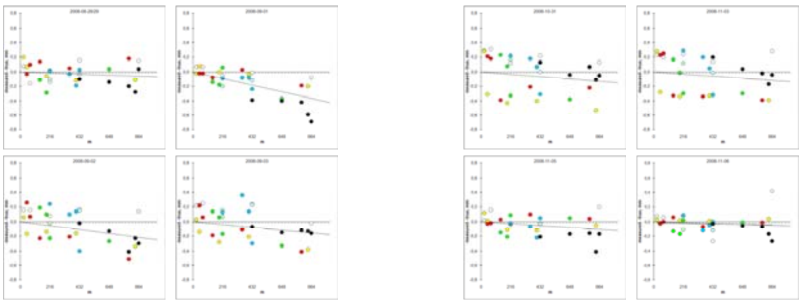
Method and traceability chain of scale transfer

Calibration of the transfer standard, Kern ME5000



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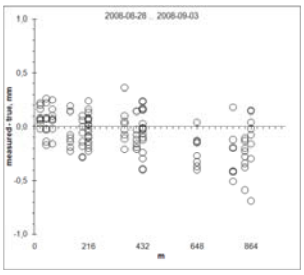

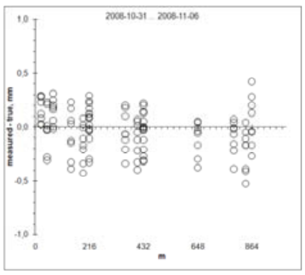

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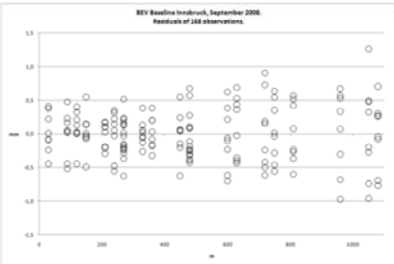
Method and traceability chain of scale transfer

6) measurements at the BEV geodetic baseline in Innsbruck

- four calibrations, double observations from all 7 pillars to other 6 pillars in each
- altogether 4 × 7 × 6 = 168 distances ranging from 30 m to 1 080 m were measured
  - September 16 – 22, 2008
- about equal temperature conditions at the both baselines, from 6.5 °C to 16.2 °C
  - weather conditions more unfavourable in Innsbruck than in Nummela
- scale correction +0.151 mm/km ±0.049 mm/km used for the transfer standard, as determined from the eight calibrations in Nummela
  - additive constant +0.079 mm ±0.014 mm
- computation of baseline section lengths with least-squares adjustments, weights reversely proportional to distances; rather large residuals:



Estimation of uncertainty of measurement

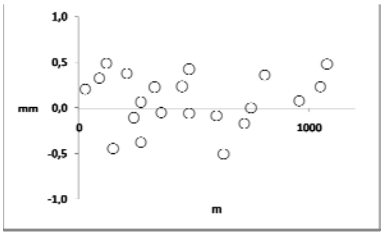
Type of uncer-tainty	Description	Quantity x_i	Standard uncertainty $u(x_i)$	Sensitivity coefficient c_i	Standard uncertainty, fixed component (mm)	Standard uncertainty, proportional component (µm × L, L in m)
A	21 distances from the adjustments (including centring and levelling)	from 30 m to 1080 m	from 0.068 mm to 0.163 mm	1	from 0.068 to 0.163	0.000
B	scale from Nummela	1.000000000	0.000000086	L	0.000	0.086
B	projection measurements	0 mm	0.070 mm	1	0.070	0.000
B	EDM scale correction	1.000000151	0.000000049	L	0.000	0.049
B	EDM additive constant	0.079 mm	0.014 mm	1	0.014	0.000
B	temperature observations	from 279.8 K to 289.4 K	0.30 K	1×10^{-6} K^{-1} L	0.000	0.300
B	temperature instruments	0 K	0.11 K	1×10^{-6} K^{-1} L	0.000	0.110
B	pressure observations	from 94.62 kPa to 95.32 kPa	20 Pa	3×10^{-9} Pa^{-1} L	0.000	0.060
B	pressure instruments	0 Pa	10 Pa	3×10^{-9} Pa^{-1} L	0.000	0.030
B	humidity observations	from 42 % to 92 %	2 %	1×10^{-8} %$^{-1}$ L	0.000	0.020
	Total standard uncertainty				**from 0.098 to 0.178**	**0.343**

- as usual in EDM, the determination of the environmental conditions for the velocity correction is a major source of uncertainty of measurement
- the refractive index of air is also an essential topic for research and development in the present joint research project

The results – baseline lengths with expanded uncertainties (2-σ)

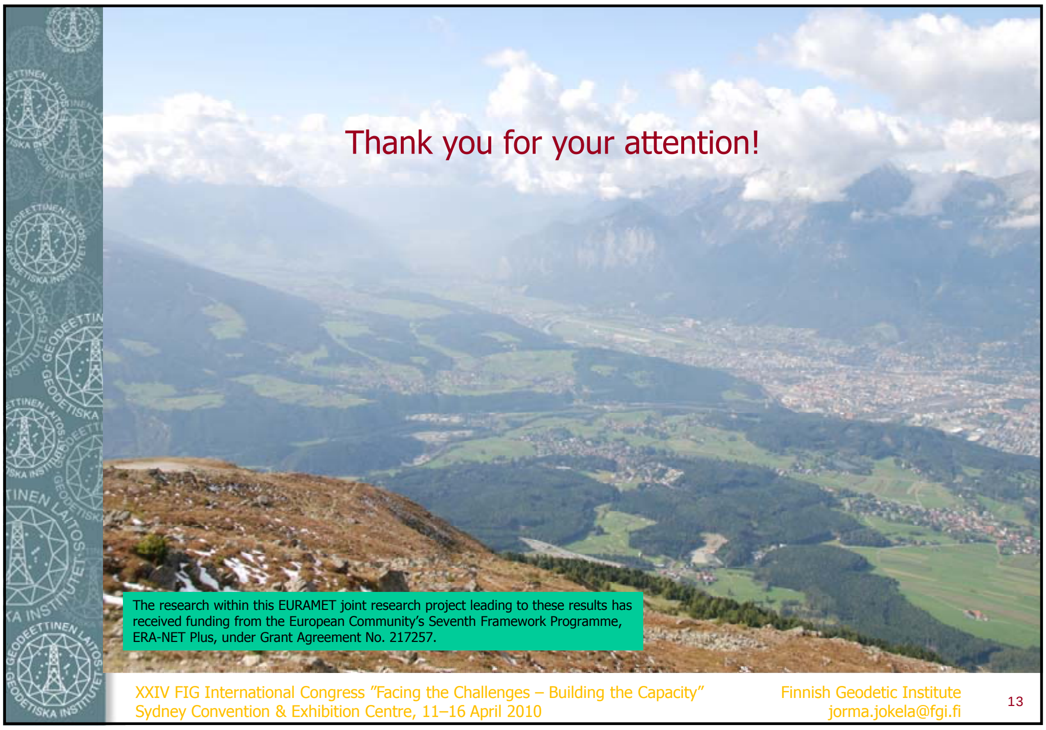
Interval	Distance (mm)	Interval	Distance (mm)
1 2	30 038.63 ±0.21	3 4	149 971.99 ±0.22
1 3	120 036.12 ±0.21	3 5	359 953.18 ±0.32
1 4	270 008.10 ±0.28	3 6	629 956.42 ±0.48
1 5	479 989.28 ±0.38	3 7	960 005.73 ±0.75
1 6	749 992.50 ±0.56	4 5	209 981.40 ±0.25
1 7	1 080 041.18 ±0.81	4 6	479 984.48 ±0.39
2 3	89 997.56 ±0.21	4 7	810 035.19 ±0.64
2 4	239 969.55 ±0.26	5 6	270 003.85 ±0.30
2 5	449 950.69 ±0.37	5 7	600 054.80 ±0.50
2 6	719 953.97 ±0.54	6 7	330 063.22 ±0.36
2 7	1 050 002.60 ±0.79		

- difference 2006 -> 2008 :



Conclusion

- a topical example of the best current practice and state-of-the-art in scale transfer for geodetic baselines is presented
- 7.5×10^{-7} uncertainty was reached
  - in favourable weather conditions 5×10^{-7} uncertainty would be achievable
- differences in comparison with the preliminary measurement in 2006 are small
  - good stability
  - no scale difference
- the location is not optimal for a baseline, but the circumstances correspond to many practical surveying tasks, and the results give a realistic estimate of the accuracy to be obtained with a proper method in average conditions
- the new results are directly usable in calibration of EDM instruments
- the new results also meet the needs for validation of new instruments
  - availability of a set of different kinds of baselines indoors and especially outdoors is advantageous for length metrology
  - international comparisons of geodetic length metrology ahead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