Interference measurements at the Nummela Standard Baseline in 2024 for maintenance of a world-class length measurement standard

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SUMMARY

The Nummela Standard Baseline is a national length measurement standard for geodetic measurements in Finland. Its long history, unique measurement method, stability and accuracy have brought it international fame and customers from around the world. The baseline is used for calibration of the most accurate electronic distance meters and in research and development and new measuring projects. The Finnish Geospatial Research Institute of the National Land Survey of Finland remeasured the baseline in 2024, which resulted in the smallest measurement uncertainty in the baseline's history. This article presents an overview of the results.

The 864-metre baseline was measured using the Väisälä Interference Comparator for the first time in 1947. Since then, the baseline has been measured 17 times, the latest campaign being in 2024. The Väisälä method, based on multiplication of the length of a quartz gauge using white-light interferometry, is now used exclusively on the Nummela Standard Baseline. The metrological traceability to the Väisälä method comes from the quartz metre, which is calibrated in the laboratory of the National Metrology Institute VTT MIKES. Throughout the history of the baseline, the variation of lengths from 24 m to 864 m have mostly remained within tenths of a millimeter, and standard uncertainties of measurements smaller than 0.1 mm. The remeasured length of the entire baseline is 864 122.96 mm ± 0.05 mm.

The lengths of the baseline from the interference measurements are projected from the aboveground pillars to the underground markers, which are more stable and safer for storing the lengths. When using the baseline for calibration purposes the lengths are projected back to the aboveground pillars with better than 0.2 mm standard uncertainty. Such high accuracy is needed for a reliable determination of the scale correction and the additive constant of the most accurate electronic distance measurement instruments. The results of the latest interference measurements are expected to keep the baseline usable well into the next decade.

In European metrology research projects, the baseline is used as a testing and validation ground for novel absolute distance measurement instruments in field conditions. Within the Finnish Geospatial Research Institute's activities, calibrated instruments are employed for various measurements, including determining and monitoring the positions of reference points for major geodetic measurement systems, such as geodetic VLBI, satellite laser ranging, and satellite positioning, at the Metsähovi Geodetic Research Station.

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1. INTRODUCTION

The International System of Units, SI, is the world's most widely used system of measurement. The metre, the unit of length, is one of the seven base units of the SI. National Metrology Institutes (NMI), Designated Institutes (DI) and National Standards Laboratories (NSL) maintain the SI in each country. In Finland, The Finnish Geospatial Research Institute (FGI) of the National Land Survey of Finland (NLS) is a DI and the NSL for two quantities, length (geodetic measurements) and acceleration of free fall (gravity measurements).

The areas of expertise in the length metrology at the FGI are calibrations of electronic distance measurement (EDM) instruments in field conditions up to approximately 1 km, system calibration of precision levelling instruments for height measurements, and local dimensional metrology of space and satellite geodetic measurement systems. In Finland, the most accurate EDM instruments are calibrated at the Nummela Standard Baseline.

The 864-m-long Nummela Standard Baseline is one of the FGI's national measurement standards, with known traceable lengths and measurement uncertainty relative to the SI definition of the metre. Originally, geodetic baselines were established for the determination of the scale for the geodetic networks that were the basis in surveying and mapping. For this purpose, invar wires and EDM instruments were calibrated at geodetic baselines. Today, calibrated EDM instruments are needed in the most demanding scientific or engineering applications. The FGI serves customers worldwide in the EDM instrument calibrations, as well as in the traceable scale transfers to other geodetic baselines and test fields.

The FGI remeasured the world-class length standard, the Nummela Standard Baseline, using the Väisälä Interference Comparator in 2024. The measurements, computation procedure and results are shortly presented here. In section 2, the development of the Nummela Standard Baseline is described. In sections 3 and 4, the methodology and the results of the latest measurement in 2024 are presented. Section 5 describes the use of the baseline for the EDM instrument calibrations and scale transfers to other baselines around the world. Finally, section 6 presents the latest scientific metrology projects for which the Nummela Standard Baseline results have been used for.

The results presented complement the previous review of the use of the Nummela Standard Baseline in present-day European metrology, presented by Jokela and Häkli, 2006, and Jokela, 2017.

2. DEVELOPMENT OF THE HISTORICAL NATIONAL LENGTH STANDARD TO A MODERN INTERNATIONAL METROLOGICAL RESOURCE

The Finnish Geodetic Institute (FGI, 1918–2014) established a national comparison baseline for length measurements in 1933 in Nummela, Finland (40 km NW of Helsinki). During the first decades, the baseline was mainly used for the invar wire length comparisons for the national surveying and mapping work.

The history of the Nummela Standard Baseline began in 1947 when the FGI measured the baseline using the Väisälä interference comparator (Väisälä, 1923) for the first time (Honkasalo 1950). In the 1950s, during the most active time of the national triangulation, both the International Association of Geodesy (IAG) and the International Union of Geodesy and Geophysics (IUGG) promoted the establishment of geodetic standard baselines and the use of the Väisälä method for assuring a uniform scale in each country. From the 1950s to the 1990s, the FGI performed nearly 40 measurements at 14 baselines around the world with the Väisälä comparator.

With the advent of satellite positioning, the demand of EDM calibrations for national geodetic works decreased rapidly. Although the original purpose has somewhat changed, there are many scientific and engineering measurements that require the highest measurement accuracy and metrological traceability to the SI system of units. Since the late 1990s, the FGI has used the Väisälä comparator only at Nummela and used a calibrated Kern Mekometer ME5000 as the scale transfer standard for other baselines. Since that, the FGI has transferred the scale from Nummela to more than ten countries/baselines and participated in several international metrology projects.

With the long history and exceptional accuracy, the Nummela Standard Baseline has retained its significance as a world-class length measurement standard for calibrating the most accurate EDM instruments. Additionally, it's an optimal place for testing the newly developed instruments in field conditions.

3. WORK PROCEDURE IN THE INTERFERENCE MEASUREMENTS

The successor of the old FGI, the Finnish Geospatial Research Institute (also FGI, 2015–) of the National Land Survey of Finland (NLS) continues the operation of the National Standards Laboratory for the two quantities, length (geodetic measurements) an acceleration of free fall (gravity measurements). The FGI has long been the only metrology institute in the world that utilizes the original Väisälä method for maintaining a national length standard for long distance measurements in field conditions. Reason for this is that the method is very laborious and extremely dependent on weather conditions. On the other hand, the method provides still the best accuracy in the field conditions. The work steps that are needed are briefly listed here. For a more comprehensive description, see Kukkamäki, 1969, and Jokela, 2014.

3.1 Principle of the Väisälä interference comparator

The Väisälä method is based on the white-light interferometry, in which the interference fringes are visible only when the phase difference of the interfering light rays is only a few wavelengths (Väisälä, 1923, 1930). In the Väisälä interference comparator this phenomenon is utilized for multiplying distances using three mirrors at the same time. The 1-m-long quartz gauge, calibrated in laboratory conditions, brings the traceable scale for the Väisälä interference comparator. The quartz gauge is placed between the comparator mirrors at 0 m and 1 m. A point-like source of white light (< 1 mm) is placed in the focal point of a collimator lens, which forms a parallel beam of light. A part of the light travels to the rear mirror (at 6 m in Nummela) and reflects to the telescope. The other part reflects between mirrors 0 and 1 six times before reflecting to the telescope. The idea is to adjust the three mirrors into a position, in which the travelled paths of the two beams are equal within 1.3 micrometres (Honkasalo, 1950). In such a position, the interference fringes can be seen in the observation telescope. Compensator glass plates, in front of the telescope, are used in delaying one of the beams, as absolute adjustment of the mirrors with such an accuracy is not possible.

When the correct position of the mirror at 6 m is known (exact multiple of the quartz gauge length), the mirror interval 0–6 can be used as the scale for the next multiplication to 24 m. The geometry and principle of the Väisälä method is presented in the Figure 1. Using the principle, multiplications can be continued to 72 m, 216 m, 432 m and, to the final length of the Nummela Standard Baseline, 864 m.

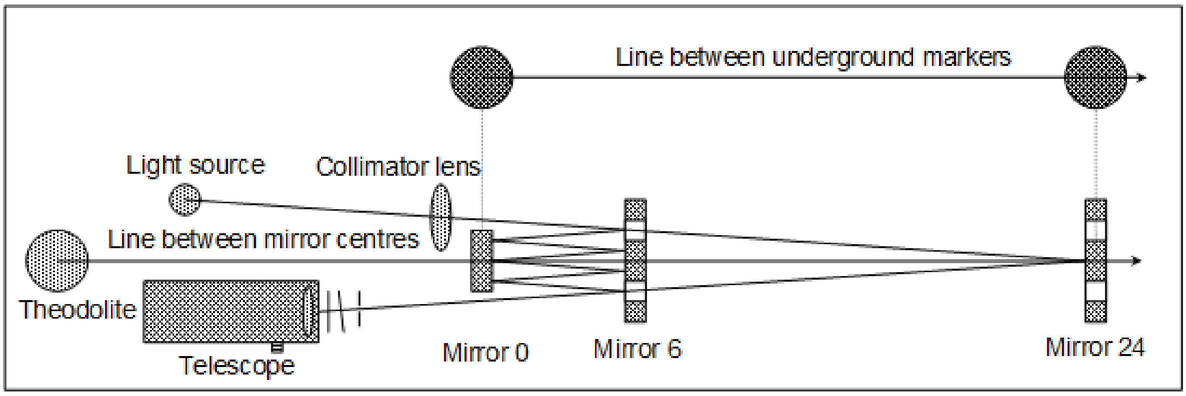

Figure 1. The principle of the Väisälä interference comparator and the geometry of the 0–6–24-interference (Jokela, 2014; not drawn to scale).

After the interference measurement, the centres of the mirrors in the interference positions are transferred to the permanently fixed transferring bars on the observation pillars. Yet, these are further projected from the aboveground observation pillars to the lengths between the permanent underground markers. These are used as known lengths later in the calibration measurements.

3.2 Preparations and installing of the comparator

The 864-m-long baseline has ten aboveground observation pillars for the interference measurements and six underground markers to preserve the lengths of the baseline. First, the heights of the underground markers and the observation pillars are determined with precise levelling. Curvature of the Earth must be considered. Mirror rails, mirror stands and mirrors are installed on eight observation pillars, first approximately, and then using the most accurate theodolite available. At Nummela, the Kern DKM3 theodolite has been used for this purpose. Mirror centres must be in the same line in space, with heights and horizontal positions determined with an accuracy of 1 mm. In the baseline direction, approximate distances of the mirrors from the 0-mirror are determined using a tachymeter, or, as in Nummela, utilizing data from the previous interference measurements.

Next, equipment on the observation pillars 0 and 1 and on the telescope pillar is measured and installed symmetrically to the baseline: a point-like source of white light, collimator lens, quartz gauge stand, arc instrument at pillar 1, and telescope, all within 1 mm in the horizontal and vertical directions with the correct distances. Stands for the 30 calibrated thermometers are measured next to the mirror line to cover the whole baseline. Finally, the mirror surfaces are directed exactly perpendicular to the baseline to reflect the beam from the light source back to the telescope. An autocollimator at the theodolite on the tenth pillar (behind the baseline) is used for the adjustment of the mirror surfaces.

The preparations for the interference measurements were started already in September 2022. First six projection measurements between the underground markers and observation pillars were performed in the beginning of October 2022. The search for the interferences was started successfully and three measurements up to 432 m were performed by the mid-November 2022. The 864 m interference was not found in the autumn of 2022, due to the early arrival of winter. In addition, a recently done floor renovation in the comparator house was found out to be problematic as it caused micrometre-level movements to the pillars 0 and 1 (depending on where the observers were standing during the measurements). Such small movements could not be found before the interference observations, but discovered to be disastrous for the measurements, and even the three performed measurements had to be rejected afterwards.

The work continued in the autumn of 2024, now with a completely renovated comparator house floor. The preparations and installations made in the autumn of 2022 enabled a significantly easier start for the autumn of 2024, as only the fine tuning of mirrors and other instruments had to be done again.

3.3 Traceable scale for the measurement

A quartz metre between the mirrors 0 and 1 provides the traceable scale in the Väisälä Interference Comparator (Figure 2). The quartz metre no. VIII was calibrated in the length laboratory of VTT MIKES, the Finnish NMI, using the equipment for calibrating long gauge blocks (Lassila et al., 2003). Before the year 2000 the German NMI, Physikalisch-Technische Bundesanstalt (PTB), performed the calibration of the quartz metres.

The quartz metre was calibrated in two positions, up and down, as it is not absolutely straight and thus used in both positions during the Väisälä measurements. At the calibration in May 2025, the length of the quartz gauge was 1 000.151 610 mm in the standard conditions (t = 20 °C, p = 1 013.25 hPa). There was a 19 nm difference between the two positions. The results were documented in the VTT MIKES certificate of calibration no. M-25L106.

The new length of the quartz gauge is 68 nm longer than in the previous calibration made in February 2015, due to the properties of the manufacturing material. This is in good agreement with the previous lengthening estimate of 5 nm per year. The expanded uncertainty of measurement in both calibrations is 72 nm.

3.4 Performing of the measurements

Finding interference fringes in the observation telescope is possible, when the mirrors are adjusted properly and are exactly at the right distances. Fine tuning of the mirrors is needed every evening. Search of the interferences starts from the shorter distances, and if 432 m or 864 m can be found, the interference observations begin immediately. In such a case, the measurements often take all night. After the interference measurement, the exact positions of the mirrors are stored to the permanently fixed transferring bars on the observation pillars. This is done by measuring the distance between the centres of the mirrors and the transferring bars using a mechanical transferring device with approximately 0.001 mm uncertainty.

After the preparations, the campaign started with six projection measurements between the underground markers and observation pillars in the beginning of October 2024. The 24 m interference (with mirrors at 0 m, 6 m, and 24 m) is the easiest to find and was found on 1st of October. The 72 m interference was found on 5th of October. During the next night, the 6 m interference was found. Thus, the mirrors 0, 1, 6, 24 and 72 could be placed at their almost final positions by installing the quartz metre to transfer the scale between mirrors 0 and 1. The 216 m and 432 m interferences were found on 11th of October. The first observations to 432 m were taken at the first possible opportunity regarding the weather conditions on 14th and 26th of October. Cloudy nights with minimal temperature differences are needed, especially for the longest distances. The 864 m interference was found and measured on 3rd of November. However, the extremely troublesome work in wintry weather conditions produced inconsistent results and they had to be rejected from the final calculations. Fortunately, the next week was successful and observations to 864 m were made during three nights: 6th, 9th, and 11th of November. The campaign was concluded with the second set of the projection measurements later in November.

Figure 2. After two months of arduous but successful measurements Jorma Jokela is removing the quartz metre no. VIII from the Väisälä interference comparator at the Nummela Standard Baseline in December 2024. Photo: T. Saari, FGI.

Figure 3. For EDM calibrations, Nummela Standard Baseline has six observation pillars with centring plates at 0, 24, 72, 216, 432 and 864 metres. The actual baseline (with the known lengths from the interference measurements) is preserved between the six underground markers two metres apart from the observation pillar line. The connection between the two lines is annually checked with the theodolite-based projection measurements with up to 0.2 mm standard uncertainty. Photo: J. Jokela, FGI.

3.5 Computation

The basis of the calculation is the length of the quartz meter. Its length, known from the laboratory measurements, is multiplied step by step to the longer distances between the mirror surfaces: 2 x 2 x 3 x 3 x 4 x 6 x 1 m = 864 m. Computation of the final lengths include several corrections.

Refraction corrections are based on the temperature observations along the baseline during the interference observations. Two assistants, that walk and observe the temperature readings, are needed for this. The Kukkamäki formulas (Kukkamäki, 1969, p. 16–18) have been used to compute the temperature difference and refraction correction between the two mirror intervals (shorter, longer). Corrections remained smaller than 0.03 mm, as absolute value for the refraction is not needed in the Väisälä method, just the difference between the two intervals. In unfavourable weather conditions, with larger temperature differences and refraction corrections, the interference observations are not possible at all.

Adjusting the mirrors with the required micrometre-level accuracy to find the interference fringes in the telescope is not possible. Two rotating glass plates, one for each beam, are used in front of the telescope to delay one of the reflecting light beams. Based on the rotation angles, compensator corrections are computed. Careful adjustment of the mirrors decreases these corrections, which were 0.3 mm at maximum during the 2024 campaign.

Mirror positions (and their references on the observation pillars, the transferring bars) were projected to the line between the underground markers (fixed points on the underground concrete pillars) before and after the interference measurements. Optimal measurement geometry, a precise theodolite and two calibrated steel tapes were used in the projection measurements. The first set was measured from 2nd to 9th of October and the second set from 8th to 26th of November. An additional projection for the 0-pillar was made on 23rd of October. The measurements resulted in the projection corrections of −14 mm to +20 mm with 0.017 mm to 0.029 mm standard uncertainty. Other necessary corrections include corrections due to baseline geometry and mirror coatings.

4. RESULTS OF THE INTERFERENCE MEASUREMENTS

The main results of the interference measurements are summarized in Table 1 (lengths of the baseline) and Table 2 (the measurement uncertainties). The method for estimating the measurement uncertainty has been discussed more thoroughly in Jokela (2014) and is following the GUM (BIPM, 2008). The uncertainty of the interference observations and transfer readings includes the uncertainties of the refraction corrections and compensator corrections. Additional sources of error are included in the total uncertainty budget, see Table 2.

Table 1. Time series of the Nummela Standard Baseline sections from 17 interference measurements in 1947–2024. These are the lengths between the underground markers, reduced to the elevation of the underground marker at the pillar 0. The number after the symbol ± is the numerical value of the combined standard uncertainty. The underground markers 24, 72 and 216 were established after measurements in 1975. Quartz metre calibrations performed by VTT MIKES are used to determine the scale of the measurements in 2005–2024.

Epoch	**0 – 24** mm + 24 m	**0 – 72** mm + 72 m	**0 – 216** mm + 216 m	**0 – 432** mm + 432 m	**0 – 864** mm + 864 m
1947.7	—	—	—	95.46 ±0.04	122.78 ±0.07
1952.8	—	—	—	95.39 ±0.05	122.47 ±0.08
1955.4	—	—	—	95.31 ±0.05	122.41 ±0.09
1958.8	—	—	—	95.19 ±0.04	122.25 ±0.08
1961.8	—	—	—	95.21 ±0.04	122.33 ±0.08
1966.8	—	—	—	95.16 ±0.04	122.31 ±0.06
1968.8	—	—	—	95.18 ±0.04	122.37 ±0.07
1975.9	—	—	—	94.94 ±0.04	122.33 ±0.07
1977.8	33.28 ±0.02	15.78 ±0.02	54.31 ±0.02	95.10 ±0.05	122.70 ±0.08
1983.8	33.50 ±0.02	15.16 ±0.02	53.66 ±0.04	95.03 ±0.06	—
1984.8	33.29 ±0.03	15.01 ±0.03	53.58 ±0.05	94.93 ±0.06	122.40 ±0.09
1991.8	33.36 ±0.04	14.88 ±0.04	53.24 ±0.06	95.02 ±0.05	122.32 ±0.08
1996.9	33.41 ±0.03	14.87 ±0.04	53.21 ±0.04	95.23 ±0.04	122.75 ±0.07
2005.8	33.23 ±0.04	14.98 ±0.04	53.20 ±0.04	95.36 ±0.05	—
2007.8	33.22 ±0.03	14.95 ±0.02	53.13 ±0.03	95.28 ±0.04	122.86 ±0.07
2013.8	33.32 ±0.08	14.98 ±0.06	53.09 ±0.05	95.39 ±0.07	122.99 ±0.10
2024.9	32.92 ±0.03	14.72 ±0.02	52.80 ±0.03	95.09 ±0.05	122.96 ±0.05

Table 2. Standard uncertainty of measurements (µm) in the autumn 2024. The first two components are based on statistical analysis of a series of observations (Type A), and the values for other components are based on previous results and experiences (Type B).

Uncertainty component	**0 - 24**	**0 - 72**	**0 - 216**	**0 - 432**	**0 - 864**
Interference observations and transfer readings	13	5	16	29	15
Projection measurements	27	18	21	29	17
Absolute length of the quartz gauge	1	3	8	16	31
Absolute temperature of the quartz gauge	0	1	4	9	17
Thicknesses of mirror coatings	1	3	9	17	34
Levellings	0	1	2	2	4
Total standard uncertainty	**30**	**19**	**29**	**48**	**54**

The maximum variation in the Nummela Standard Baseline time series, using the Väisälä method since 1947, is 0.73 mm for the entire baseline (864 m). No other geodetic baseline can report such a good accuracy and stability over 80 years. Therefore, the results are considered good, when they are close to the values from the previous interference measurements. The lengths of the baseline in 2024 differed −0.40 mm to −0.02 mm from the previous results in 2013. Minor variations in the lengths of the baseline are considered normal movements and accounted for with the regularly repeated measurements.

The standard uncertainties of the measurement have varied from 0.02 mm to 0.12 mm for all the lengths from 24 m to 864 m. Without one exception in 2013, the standard uncertainties have always been below 0.10 mm. In 2013, the uncertainties are slightly exceeding the normal level, because of early winter conditions and frozen ground during the final projections. In 2024, the standard uncertainties of measurements are smaller than ever, from 0.02 mm to 0.05 mm.

5. ANNUAL MAINTENANCE AND USE OF THE NUMMELA STANDARD BASELINE

The results of the interference measurement are converted to the distances between the measurement platforms on the observation pillars with annual projection measurements. Usually, at least two series of projections are performed every year, in the beginning and in the end of every field work season from May to October. The baseline cannot be used in winter.

The resulting 15 known distances, from 24 metres to 864 metres, can be used for the calibrations and scale transfers. They are traceable to the definition of the metre with the standard uncertainties typically smaller than 0.2 mm. These distances provide the accurately known reference data for determining the scale correction and additive constant for the EDM instruments.

The FGI calibrates its tacheometers annually at the baseline. The calibrated instruments are used for local installation, control and monitoring at geodetic observation sites, e.g. at the Metsähovi Geodetic Research Station (MGRS). Additionally, instruments from customers worldwide are calibrated at the baseline. The FGI performs also scale transfer measurements to baselines abroad. For this, the most accurate EDM instrument for the field conditions, Kern Mekometer ME5000 is used (Figure 3).

During the first two decades of the 21st century, the FGI and its partners have performed calibrations for more than twenty international and bilateral metrology projects. The traceable scale of the Nummela Standard Baseline has been transferred to the geodetic baselines and test fields around the Europe and East Asia. Years 2020–2024 were quiet at the baseline, first due to the restrictions during the COVID-19 pandemic, then due to the delayed interference measurement. Now, the Nummela Standard Baseline is in use again, with smaller uncertainty of measurement than ever.

6. RESEARCH PROJECTS RELATED TO THE NUMMELA STANDARD BASELINE

The FGI has participated in several European metrology research projects that are closely related to geodesy and include the use of FGI's facilities, services and results at Nummela and Metsähovi:

- 2008–2011 Implementing Metrology in the European Research Area (iMERA-Plus) project ”Absolute long distance measurement in air”,
- 2013–2016 European Metrology Research Programme (EMRP) project ”Metrology for long distance surveying”,
- 2019–2022 European Metrology Programme for Innovation and Research (EMPIR) project “Large-scale dimensional measurements for geodesy” (PTB, 2019),
- 2025–2028 European Partnership on Metrology (EPM) project “Traceability for industrial 3D digitalization by advanced scanning systems”.

The European Union has partly funded these research programmes and projects. For example, National Metrology Institutes of Germany, PTB, and France, LNE-CNAM, have tested and validated absolute EDMs in Nummela and Metsähovi several times within these programmes. The instruments are based on the modern laser technology and being developed in work packages of the research programs.

At the MGRS, the FGI has developed local terrestrial measurements for the dimensional metrology, i.e. methods for determining and monitoring the positions of the reference points of the global geodetic observation systems (GeoVLBI, satellite laser ranging, and satellite positioning) with the uncertainty of measurement of tenths of a millimetre. The metrological traceability of the monitoring network scale originates from the instruments calibrated at the Nummela Standard Baseline. As a core station in the Global Geodetic Observing System (GGOS), MGRS relies on local tie vectors produced with these calibrated instruments, which are essential for integrating MGRS data into realizations of terrestrial reference frames. The results have been published in the doctoral dissertation (Kallio, 2023).

According to the Geodesy strategy in Finland, the highest order CORS (Continuously Operating Reference Station) network in Finland, FinnRef (Koivula et al., 2012), is used to connect the Finnish terrestrial, vertical and gravity reference frames together (Poutanen et al., 2017). Local geodetic measurements using precise angle and distance measurements are performed at the stations to transfer the levelled heights from the surrounding benchmarks to the GNSS antennas. With careful methodology and the instruments calibrated at the Nummela Standard Baseline, sub-mm relative positions (local ties) between the benchmarks and antennas can be obtained. Such stations with accurate GNSS-levelling observations are essential e.g. for fitting gravimetric geoid models to the national reference frames.

Similarly, the Finnish synthetic aperture radar (SAR) corner reflectors, co-located with the selected FinnRef stations, are tied to the national references. With the local geodetic measurements, and instruments calibrated at the baseline, the coordinates of the reference point and the azimuth of the corner reflector have been determined with respect to the surrounding benchmarks. As a result, the corner reflectors are tied to the national ETRS89 realization, but also to the Finnish first-order levelling network. Such SAR data, referenced to the corner reflectors and co-located with permanent GNSS stations, provide valuable information for various geodetic and ground motion monitoring applications including the European Ground Motion Service and its calibration in the future updates (European Ground Motion Service, 2025).

7. CONCLUSION

The results of the interference measurements at the Nummela Standard Baseline in the autumn 2024 ensure the baseline's usability for several years into the future. The new result of the absolute calibration of the quartz metre confirms metrological traceability to the definition of the SI unit metre. The new results and compatibility with the 80-year time series demonstrate excellent long-term accuracy and stability, the characteristics of the world-class measurement standard. With the smallest measurement uncertainty in its history, Nummela Standard Baseline is once again ready to serve as the venue for accurate EDM instrument calibrations and comparisons in new research and engineering projects. Additionally, the traceable scale can be transferred from Nummela to other geodetic baselines and test fields around the world.

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BIOGRAPHICAL NOTES

D.Sc. (Tech.) Jorma Jokela is a research manager and NSL Head, who has worked on geodetic measurements, calibrations and metrology for almost 40 years. His dissertation, "Length in Geodesy – On Metrological Traceability of a Geospatial Measurand", was published in 2014. Jokela will retire during year 2026.

M.Sc. (Tech.) Pasi Häkli is a senior research scientist, who has worked on reference frames, GNSS and metrological measurements for almost 25 years.

D.Sc. (Tech.) Timo Saari is a senior research scientist, who has worked on height, gravity and metrological measurements for more than 10 years. The national geoid model of Finland, published in 2024, is based on his doctoral thesis "Investigations of geoid models in Finland – Towards GNSS-related height system".

The three FGI experts performed the latest remeasurement of the Nummela Standard Baseline in autumn 2024.

CONTACTS

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