The GeoMetre project: large-scale dimensional measurements for geodesy

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for the **GeoMetre Consortium**

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Metrology – another hidden service to society…

- The scientific study of measurements
- National metrology institutes (NMI) in each country
- Organized internationally through the BIPM and regional metrology organizations (e.g., EURAMET)
- Ensuring international equivalence of measurements
- Conducting comparisons in accordance with the Metre convention and the CIPM MRA
- Providing quality assured measurements, metrologically traceable to the SI definitions through unbroken calibration chains to the *Mise en Pratique*

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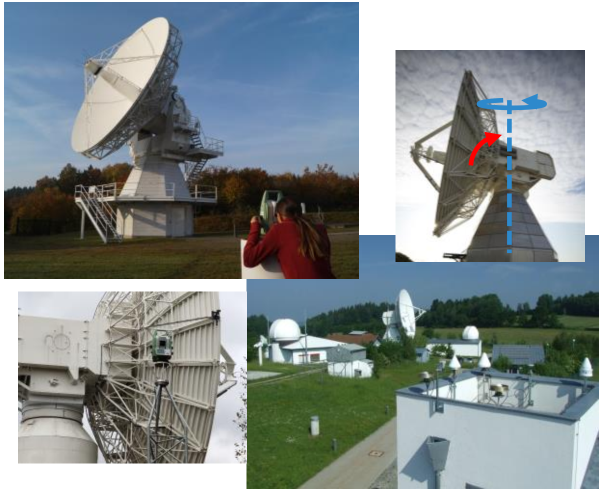
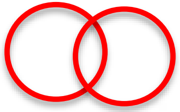
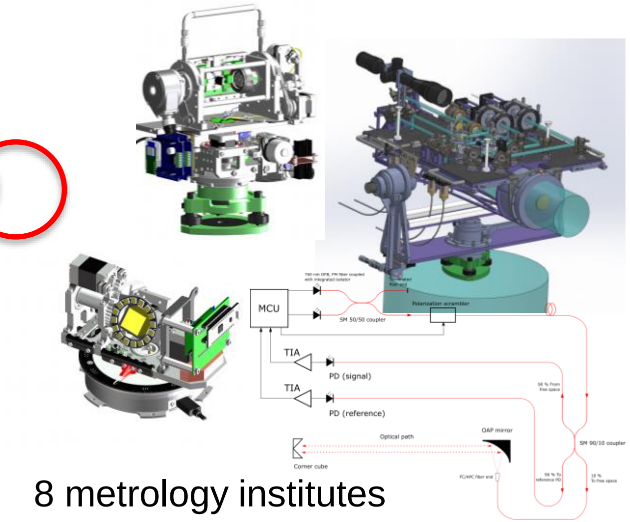
Motivation for the GeoMetre project



8 geodetic institutes





8 metrology institutes

The GeoMetre project united geodesists and metrologists tackling:

- Can advance in instrumentation and measurement strategy improve local tie metrology?
- Can traceability to the SI definition of the metre for reference frames be tightened?

GeoMetre

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Objectives

To improve the complex traceability chain in geodetic length metrology.
Specifically, to develop:

1. Field-capable primary or transfer standards to disseminate the unit metre to reference baselines over distances up to 5 km.

2. 3D capable measurement device for 50 m outdoor range with targeted measurement uncertainty better than 1 µm / m

3. technologies, methods and uncertainty assessment for an SI-traceable verification of space-geodetic technologies over at least 5 km with uncertainties 1 mm or better, and their implementation in a European reference standard.

4. To reduce uncertainty of local tie between co-located space-geodetic techniques at GGOS-CS to 1 mm over 200 m in real time tracking.

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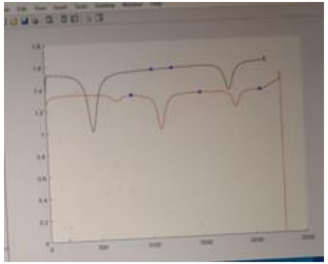
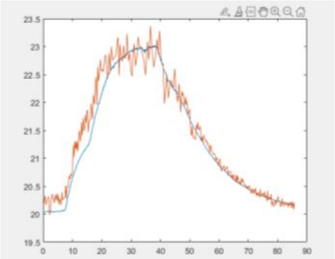
Length metrology: in-situ refractivity compensation

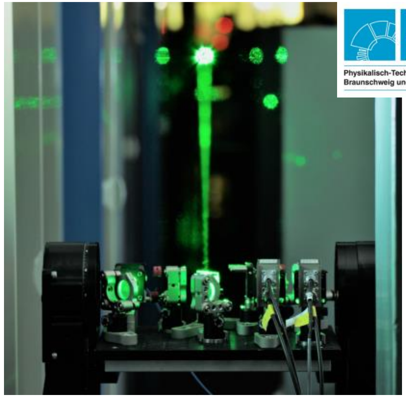
1. Spectroscopic temperature measurement





2. Acoustic temperature measurement

3. Dispersion
(2-colour) compensation



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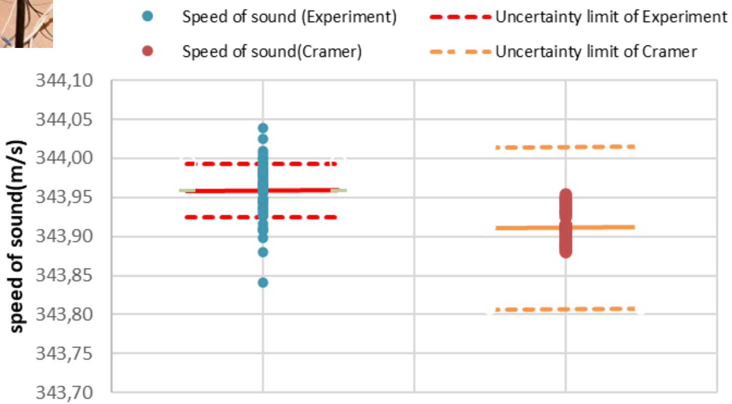
Results on two fundamental equations

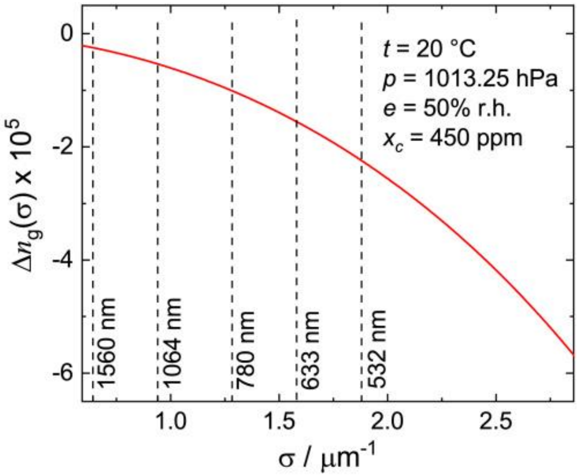
Cramer equation for speed of sound in air

- Temperature correlation at uncertainty of 300 ppm lowered to 100 ppm level for 10 – 30 °C; path temperature determined with uncertainty 0.06 °C

Pisani et al., to be published



Group index of refraction in air



Pollinger, Appl. Opt. 59 9771 (2020)

- Dispersive error in IAG-recommended standard compensation formula by Ciddor & Hill corrected at several ppm

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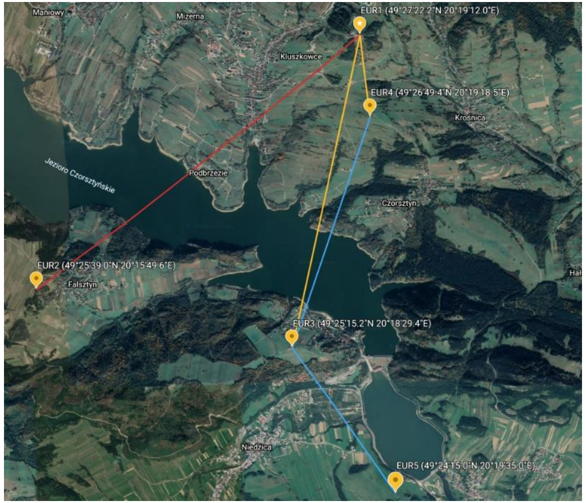
Establishment of long-distance baseline

- A new European reference baseline of up to 5 km length to study GNSS over medium distance ranges
- Located in the Pieniny Klippen Belt
- Area geodynamically monitored for over 60 years
- 5 new baselines established with visibility lines
- Measurable by GNSS and terrestrial measurement instruments
- Reference coordinates and uncertainties were derived within the GeoMetre project with uncertaintity < 1 mm



EURO5000, Pieniny mountains, PL

GeoMetre

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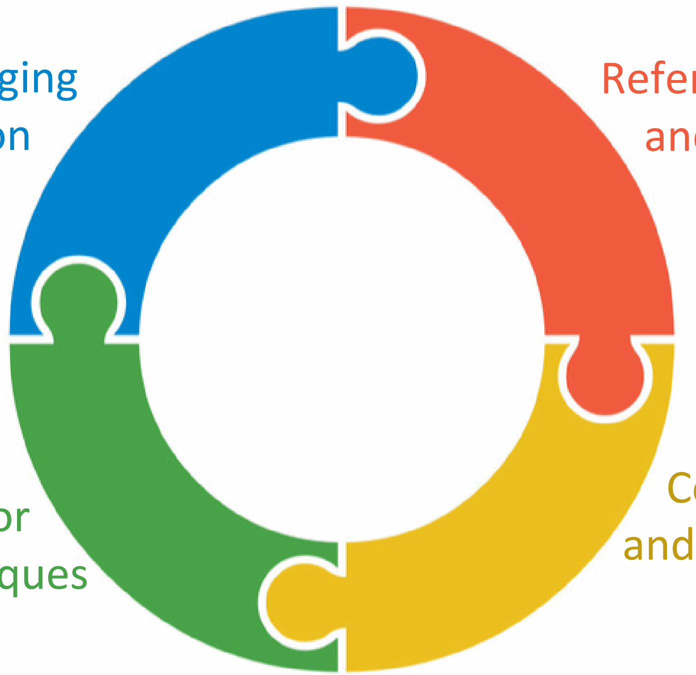
Local Tie Metrology: Multi-angle approach



High-accuracy ranging for scale definition

Reference point monitoring and index of refraction

Low uncertainty ground truth for space-geodetic techniques

Combination of terrestrial and GNSS observations

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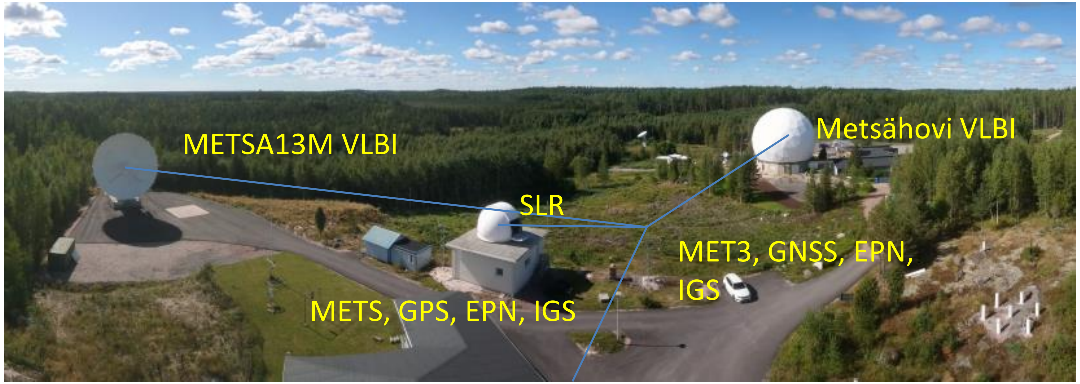
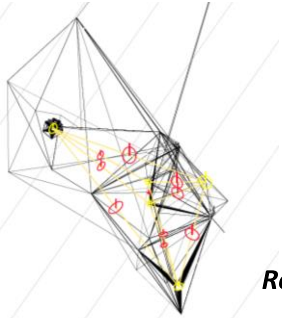
Modern local tie network: core-site Metsähovi

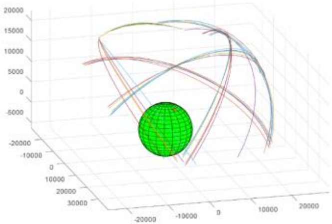
SI-traceable scale
from Nummela Standard Baseline

Local survey and monitoring
measurements in tachymeter system



Instrument orientation in global frame: geoid model

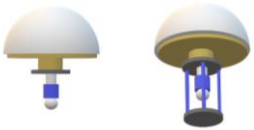




Rotation

Global orientation of the network

***Translation**: Coordinates in ITRF for MET3, IGS and EPN GNSS point*



*Accurate **micro-local-tie** between GNSS ARPs and prisms*

℗ 3D network adjustment directly in global frame
Observation equations in global geodetic system

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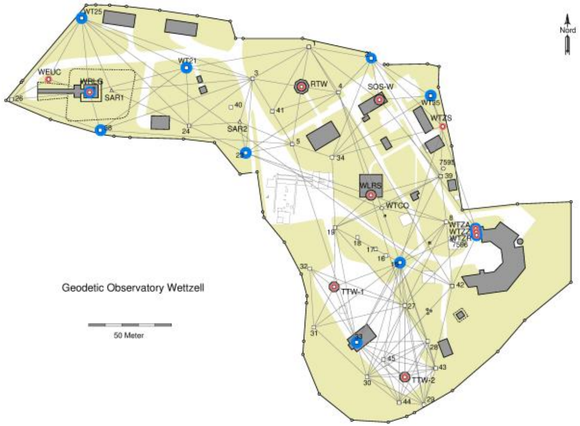
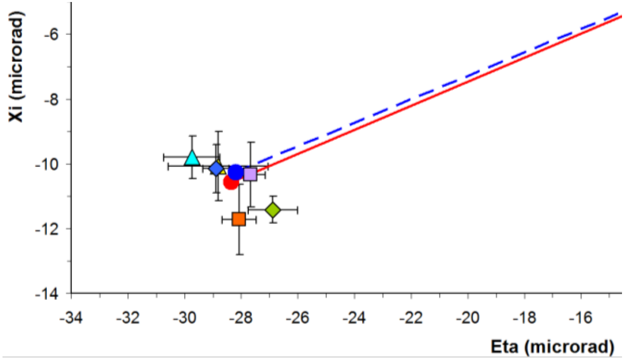
Transformation-free approach: core-site Wettzell

- Accuracy of measured deflection of vertical about 1 μrad (astronomical and gravimetric)
- GNSS accuracy:
  - Short baselines: substantial vertical orientation error ($3\ \mathrm{mm}\ @\ 100\ \mathrm{m} \approx 30\ \mu\mathrm{rad}$ error)
  - Long baselines: (L1/L2 direct) problematic, L3 less accurate
- Terrestrial measurement:
  - First velocity correction (distance)
  - Beam bending (zenith angle)

℗ Recommendation:
  - Horizontal orientation by distant targets (GNSS/terrestrial)
  - Vertical orientation by using ellipsoidal coordinates plus correction for deflection of vertical





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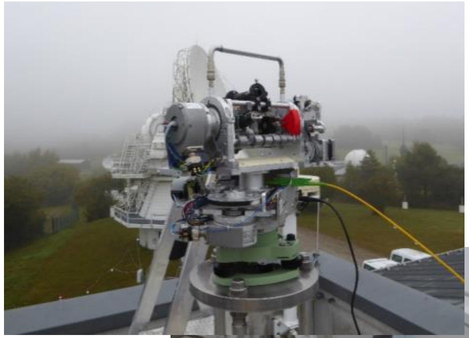
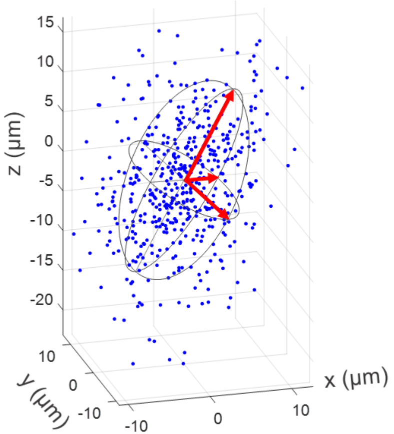
Multilateral VLBI reference point determination

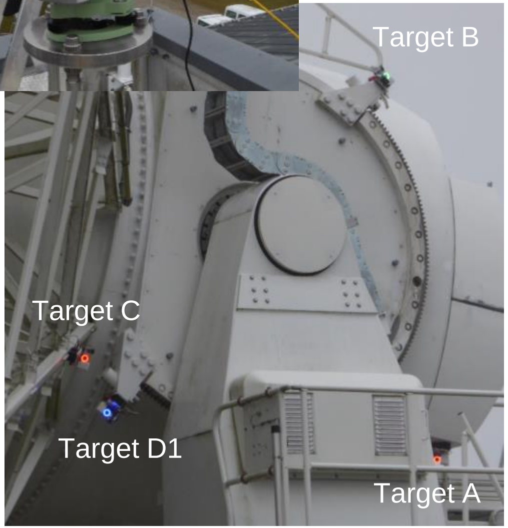
le cnam

DistriMetre:

- Robust ranging technique based on a RF modulated optical signal
- One optical telemetric source with four fiber-optic output ports
- Four compact optical heads
- MU $< 5\ \mu\mathrm{m}$ in 1D and MU $< 22\ \mu\mathrm{m}$ in 3D (confidence regions of 68% probability, indoors in controlled environments)
- VLBI reference point determination at VGOS antenna in Wettzell







GeoMetre

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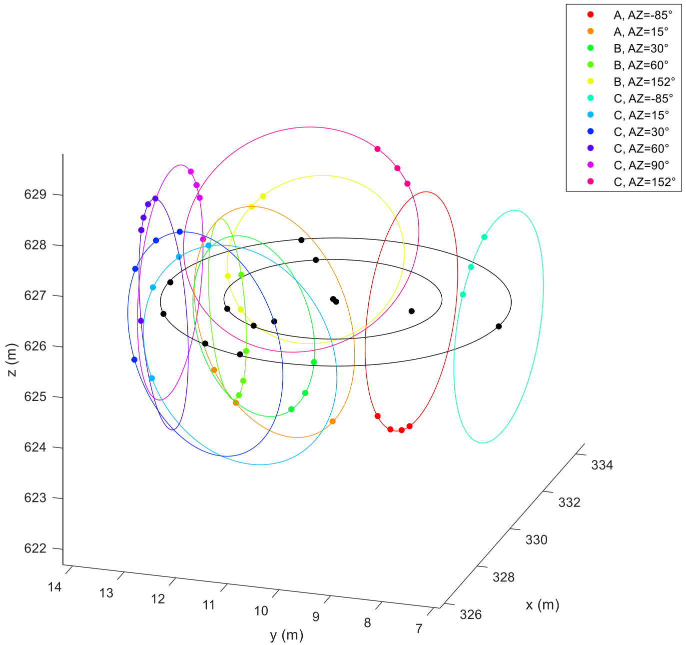
Multilateration: preliminary results

le cnam

- Standard deviation of the error of the multilateration algorithm of 23 μm.
- Position uncertainties between 70 μm and 304 μm for the targets installed on the radio telescope, depending on uncertainties of the distance measurements, target visibility, and the positions of the targets relatively to the heads.
- Analysis in combination with polar observations jointly measured with Frankfurt UAS

Ⓟ Pre-analysis: Variance component estimation indicates multilateration distances being three times better



Graphical representation of the raw data of multilateration

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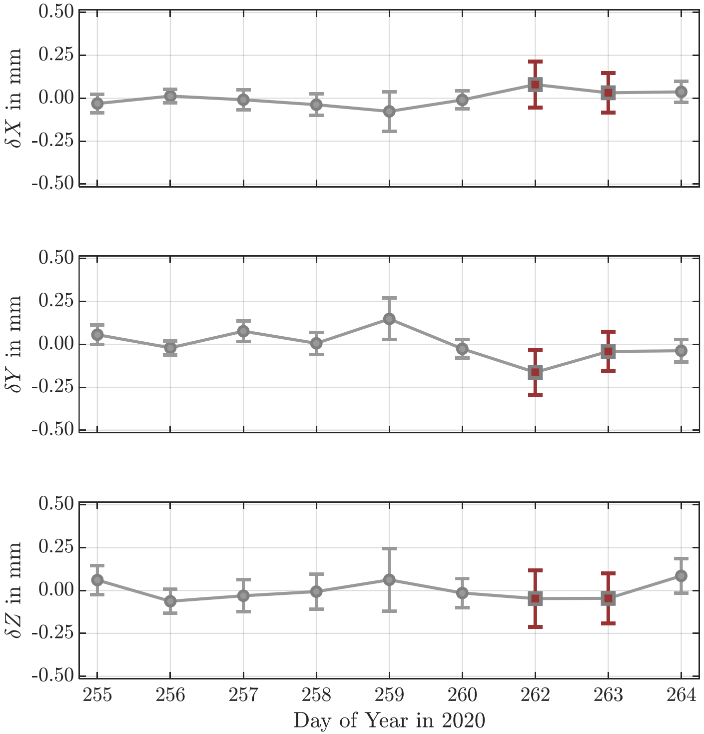
Advancing SLR/VLBI Reference Point Determination

- Improved model for in-process reference point determination
- Evaluation of close range photogrammetry at SLR telescope Wettzell using
  - Traditional multi-image analysis (grey dots)
  - Concatenated transformation (red squares)
- Development of bundle-adjustment software package for rigorous data analysis

Ⓟ More details at GGOS/IERS Unified Analysis Workshop



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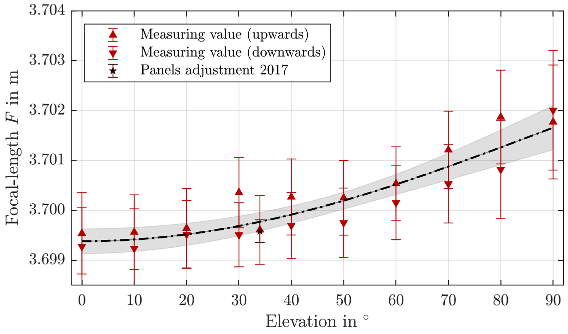
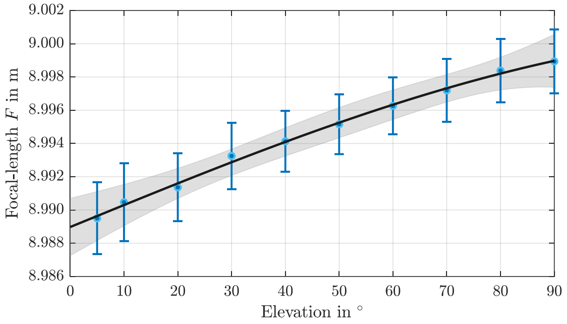
Deformation of VLBI receiving unit

- Joint measurement campaigns with Bochum UAS
- Unmanned Aerial Vehicle (UAV) based data acquisition
  - VGOS antennas at Onsala and Wettzell
  - Legacy VLBI antenna at Wettzell
- Derivation of elevation-dependent
  - Focal-length deformations
  - Sub-reflector variations
  - Vertex shifts

℗ Elevation dependent correction of signal path variations



VGOS antenna at Onsala published in 2019



Legacy VLBI antenna at Wettzell published in 2022

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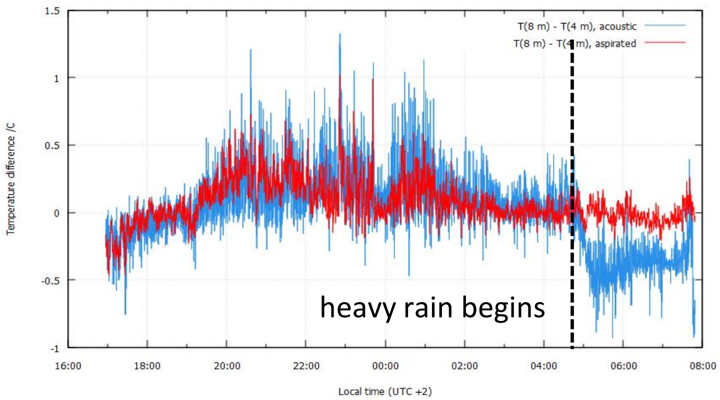
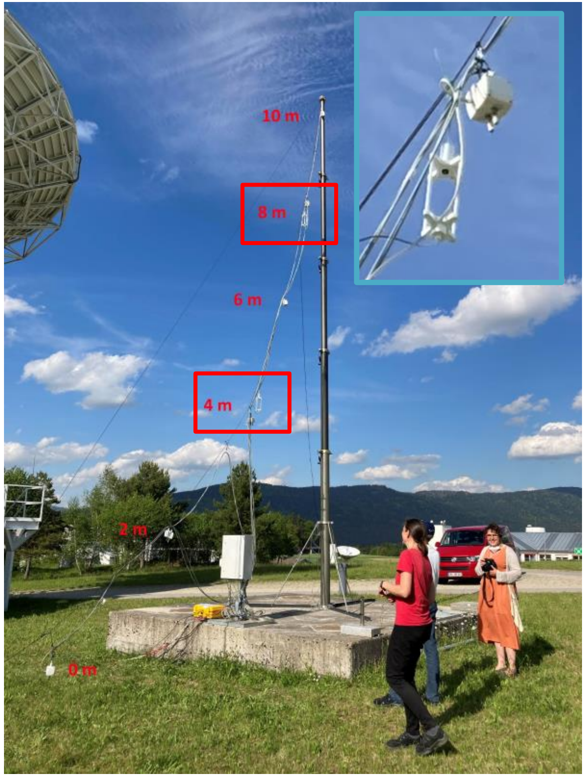
Refractive beam bending correction

- Measurement of vertical temperature gradients
- Comparison of passive and aspirated Pt1000 sensors and ultrasound-based thermometers mounted on 10 m mast close to VGOS antennas at Wettzell



℗ Gradients of ultrasound and aspirated sensors agree well:
Pt1000s: 0.091 °C ATGSM: 0.103 °C



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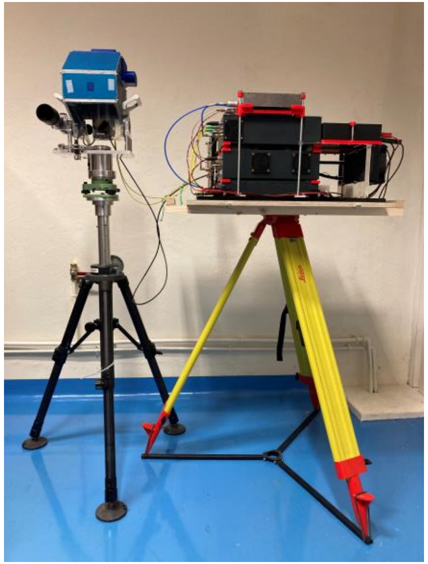
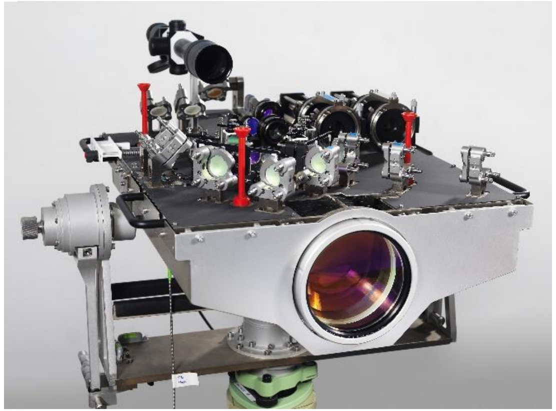
Scale definition: new long distance meters

Target: reduction of uncertainty of scale and orientation of surveillance network
- Development of SI-traceable long distance range meters with low uncertainty
- Exploiting intrinsic refractivity compensation



Arpent system:
- RF modulation
- 780 nm and 1560 nm
- All-fibred design
- Flexible in use, well portable

TeleYAG-II system:
- Absolute interferometry
- 532 nm and 1064 nm
- Complex set-up



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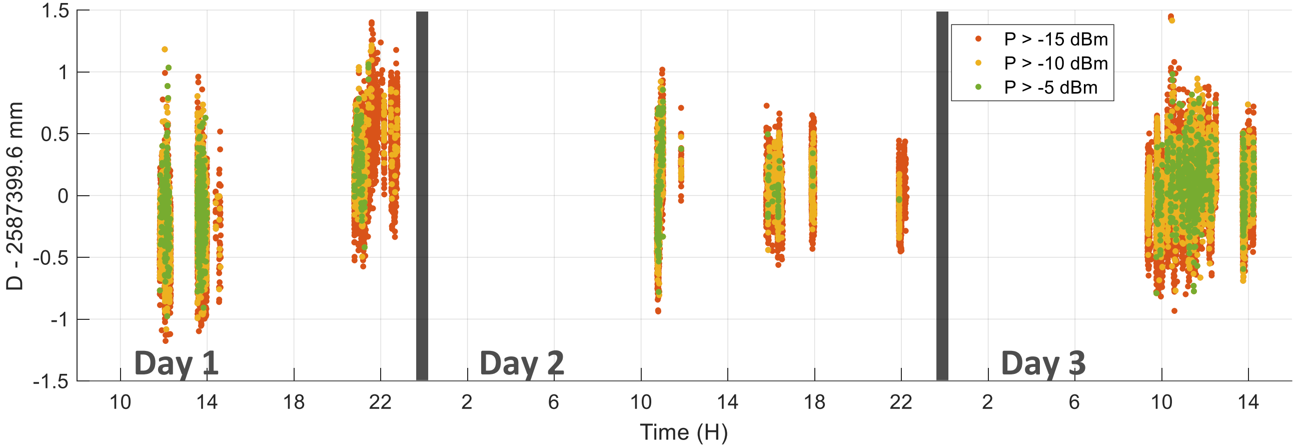
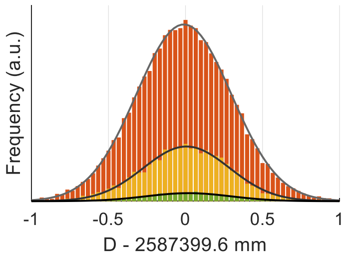
Verification of SLR versus Arpent/EDM

le cnam

Comparison of the distance difference between two corner cubes separated by about 2.6 km

- Two-colour ADM Arpent from CNAM, at 780 nm and 1560 nm
- Two-colour SLR from Observatoire de la Côte d'Azur, at 532 nm and 1064 nm
- Data analysis of the measurements of the Two-colour SLR is still ongoing





normal distribution
with $\sigma \sim 300\ \mu m$

Ⓟ Result of the 2-colour ADM from CNAM: average distance of $2\ 587\ 399.6\ mm \pm 0.3\ mm$

GeoMetre

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Conclusions

- GeoMetre project developed novel instrumentation and methods for long-distance measurements, with a strong focus on local tie metrology

- Scope included
  - Identification of possible angles for improvement
  - Novel measurement and analysis strategies
  - Development of novel instrumentation designed for these approaches

- SINEX Contribution to ITRF2020 for Metsähovi and Wettzell

- Analysis of many experiments is still ongoing

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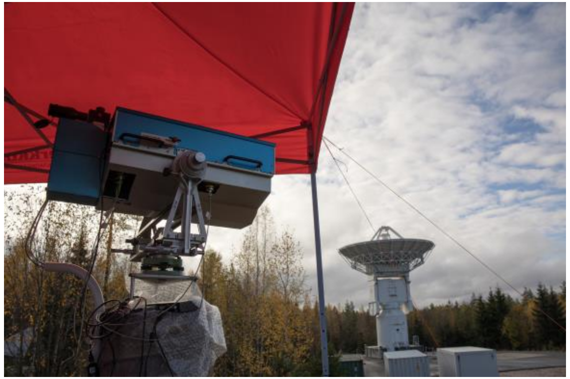
Measurement campaigns



Targets:

- Network measurements
- System verification
- “Metrologist” calibration to measurement environment
- Sometimes systems were not mature enough

℗ The work will be continued!

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Thank you for your attention!

First progress meeting in Paris, 2020

Contact via https://www.ptb.de/empir2019/geometre/home/
and florian.pollinger@ptb.de

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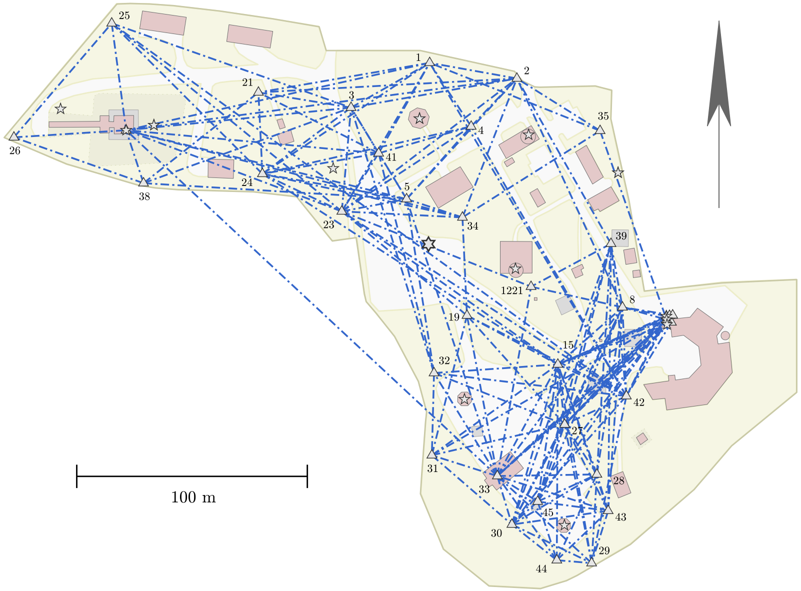
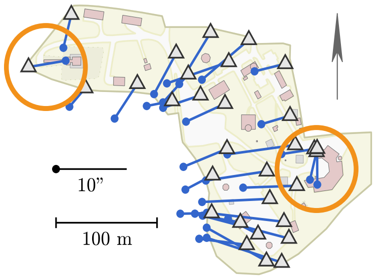
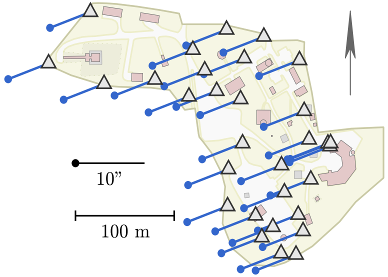
Operator-Software Impact

FRANKFURT UNIVERSITY OF APPLIED SCIENCES

- Joint measurement campaign with CNAM at Wettzell
- Study for consideration of vertical deflections in local tie networks treating deflections as
  - Deterministic parameters
  - Or parameters to be estimated
- Strong dependence on network datum
  - Network tilting
  - Network bending







℗ Vertical deviations of about $0.5 - 2.5$ mm caused by Operator-software impact

GeoMetre

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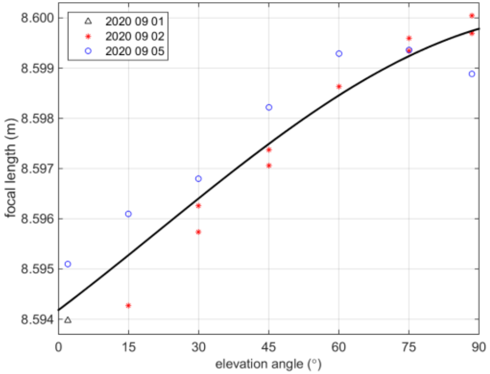
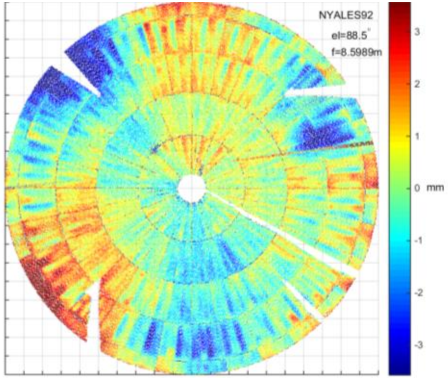
Deformation of VLBI receiving unit

- 3D scanning of 20 m dish of legacy VLBI antenna at Ny-Ålesund (receiver in primary focus)
  - 3D scanner mounted on one of the upper beams
  - Interferometer laser ranger mounted in telescope center for distance vertex-receiver as function of elevation and temperature
- Analysis by least square fitting to parabola
- Deformation curve derived





℗ Results included in ITRF2020

GeoMetre

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