



WROCLAW UNIVERSITY
OF ENVIRONMENTAL
AND LIFE SCIENCES

Applications and limitations of low-cost GNSS receivers

Možnosti využití a omezení nízkonákladových GNSS přijímačů

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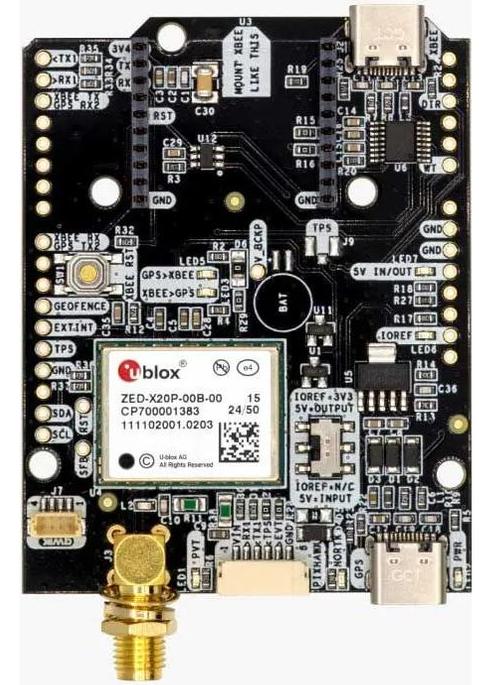
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Theoretical Introduction – Low-Cost Receivers

Type	Receiver	Price [€]	GNSS Supported	Use Case
Low-Cost	u-blox ZED-F9P	120 - 170	GPS, GLONASS, Galileo, BeiDou, QZSS	RTK, UAV, surveying
	ChipCraft CCNV2	190	GPS, GLONASS, Galileo, BeiDou, QZSS, NavIC, SBAS	Multi-band navigation, research, IoT
	u-blox ZED-X20P	150-180	GPS, GLONASS, Galileo, BeiDou, NavIC, QZSS	Surveying, UAV, autonomous systems
Professional	Trimble R780	15 000 -18 000	GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS, NavIC	Professional surveying, RTK
	Leica GS18T	20 000-25 000	GPS, GLONASS, Galileo, BeiDou, QZSS	Professional surveying, RTK
	Javad TRIUMPH-1M Plus	30 000	GPS, GLONASS, Galileo, BeiDou, QZSS	Professional surveying, RTK



AS-RTK4-X20P-L1256-NH-00

Cost: 225 €

<https://www.ardusimple.com/product/simplertk4-optimum-zed-x20p/>

Theoretical Introduction – Low-Cost Antenna

Type	Antenna	Price [€]	GNSS Supported	Use Case
Low-Cost	u-blox GNSS Multiband ANN-MB-00	54	GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS	Budget option, compact, basic coverage
	ArduSimple Calibrated Survey Multiband	200	GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS	Budget option, compact, basic coverage
	Septentrio Mosaic-G5 Smart Antenna	500-600	GPS, GLONASS, Galileo, BeiDou, QZSS, NavIC, SBAS	Budget option, compact, basic coverage
Professional	Trimble Zephyr 3 Base	2,200-2,500	GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS	Sub-mm phase center repeatability, multipath rejection
	Leica AR25 3D Choke Ring	10,800-14,000	GPS, GLONASS, Galileo, BeiDou, QZSS, NavIC	professional reference stations
	Javad RingAnt-DMT Choke Ring	5,000-8,000	GPS, GLONASS, Galileo, BeiDou, QZSS, IRNSS, SBAS	professional reference stations



AS-ANT3B-CAL-L1256-SMATNC-01

Cost: 199 €

<https://www.ardusimple.com/product/calibrated-survey-gnss-quadband-antenna-ip67/>



mosaic-G5 ultraLight RTK GNSS Smart Antenna

Cost: 552 €

<https://gnss.store/products/elt0757?srsId=AfmB0oqGJMMDa7Qxhw5bWtBJgo5kzXSXrEg5tgluzTXkHHra0IQ9i1U>

Description of Low-Cost set



Software:

- Microservices as Docker containers
- Written in Rust
- Independent from u-center
- Managed by BalenaOS and openBalena

Hardware:

- Running on Raspberry Pi 4B
- Uses u-blox
- IP67 aluminium case

Antenna:

- ArduSimple Calibrated Survey Tripleband GNSS Antenna (AS-ANT3B-CAL)
- Individual calibration model used (from Leibniz Universitaet Hannover)

Construction of a receiver network

Status as of 5 February 2026

Number of receivers

29 field receivers (32 to end of February)

Network utilization

Troposphere analysis

Analysis of the impact of the averaged model

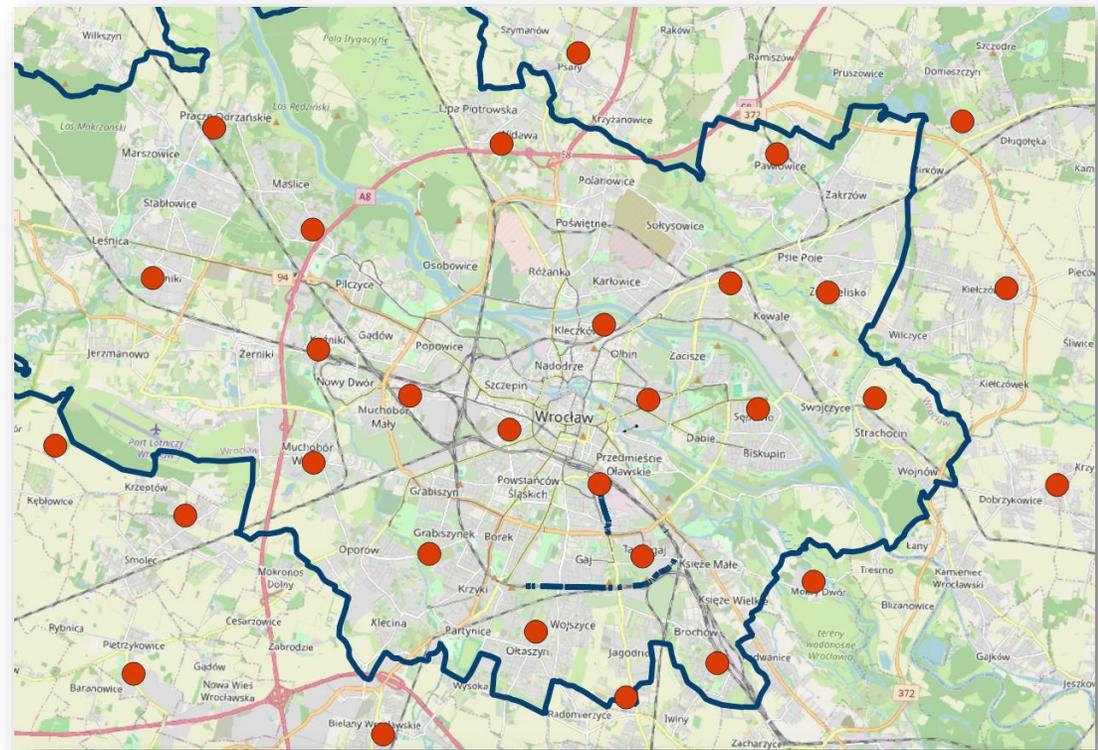
Possibility online to set the measurement interval and time range of the file

Data

Transfer of files from the receiver to the sftp server for each time range

Files download in near real time

if you are interested, please contact me 😊



Discussion of ANTEX calibration files

Why calibrate?

- Each antenna has unique PCO/PCV characteristics
- Factory models \neq real behavior

What calibration gives:

- Precise PCO & PCV values for this specific antenna
- Eliminates manufacturing/assembly asymmetries

How it's done:

- Test field \rightarrow antenna rotated in multiple orientations
- Multi-satellite observations \rightarrow compute individual phase pattern

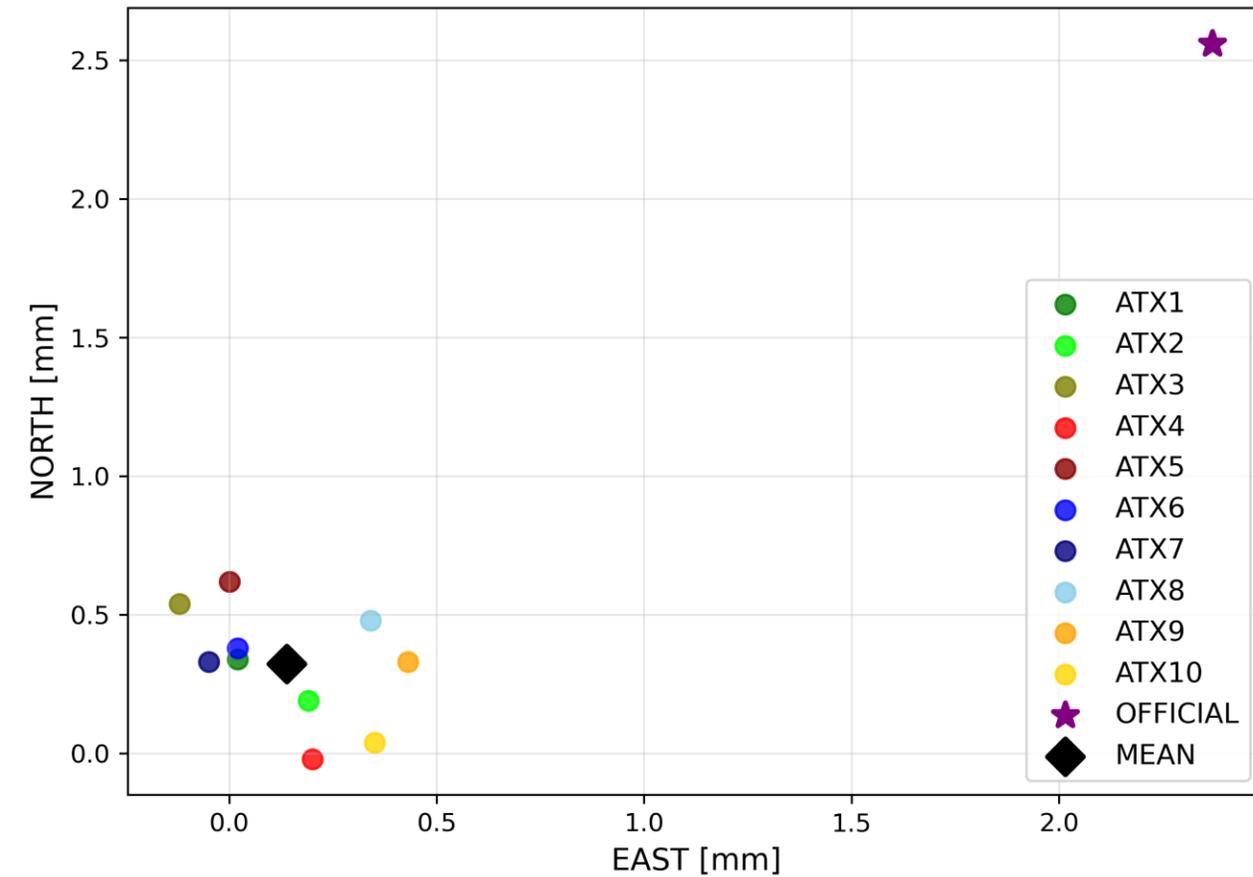


Tupek, A., Zrinjski, M., Švaco, M., & Barković, Đ. (2023). GNSS Receiver Antenna Absolute Field Calibration System Development: Testing and Preliminary Results. *Remote Sensing*, 15(18), 4622. <https://doi.org/10.3390/rs15184622>

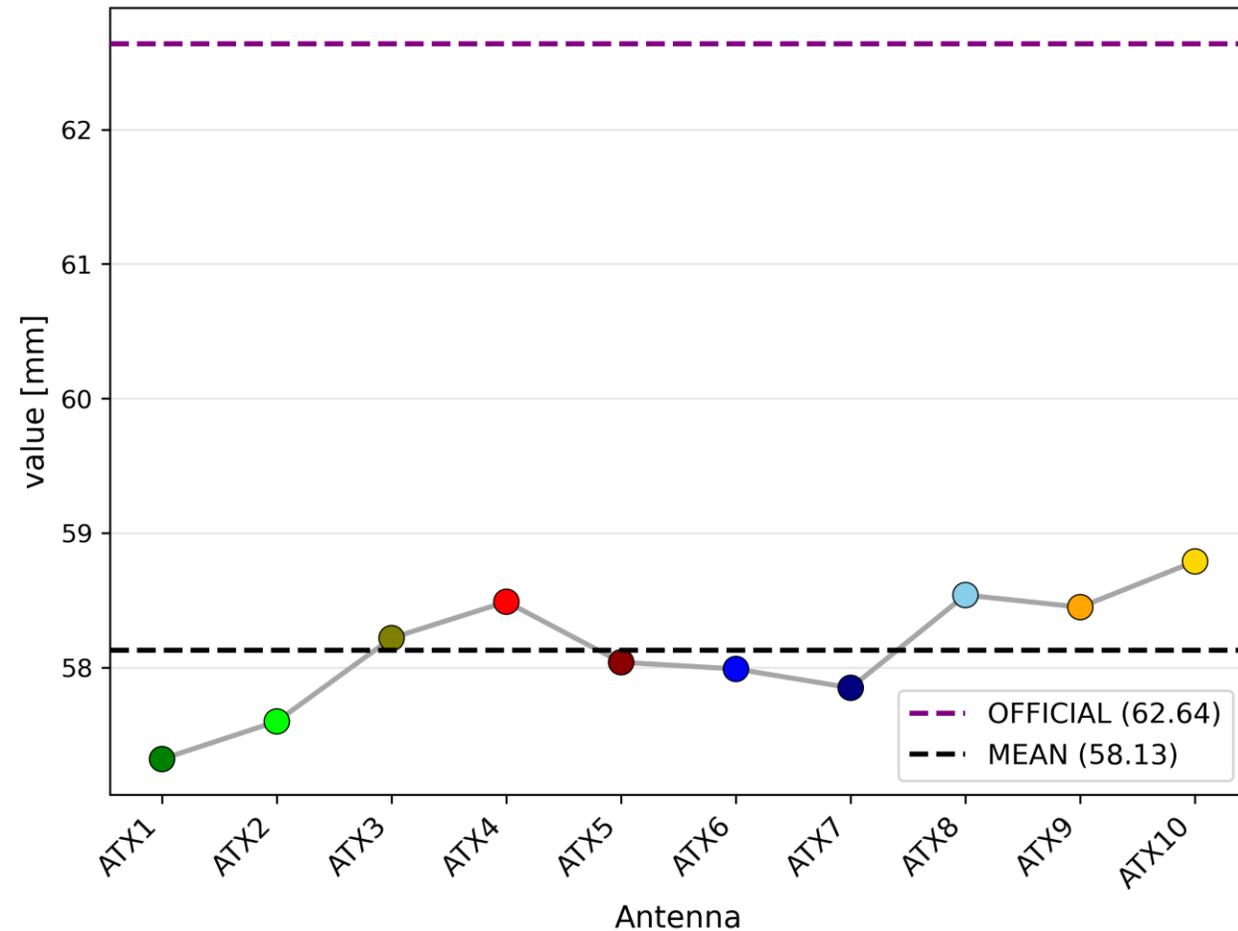
Construction of the mean model - comparison with official ArduSimple model - PCO

PCO values for G01

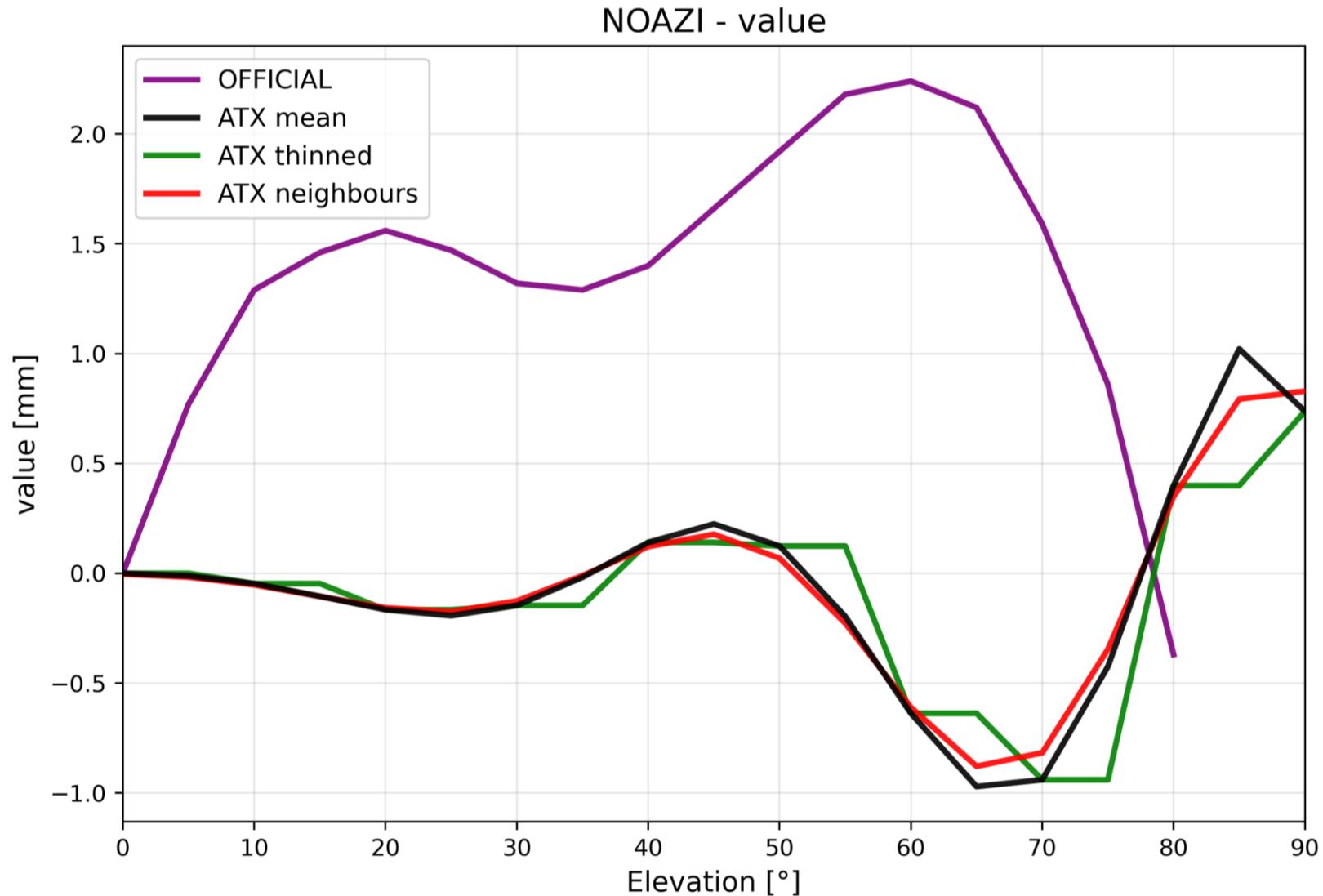
NORTH / EAST



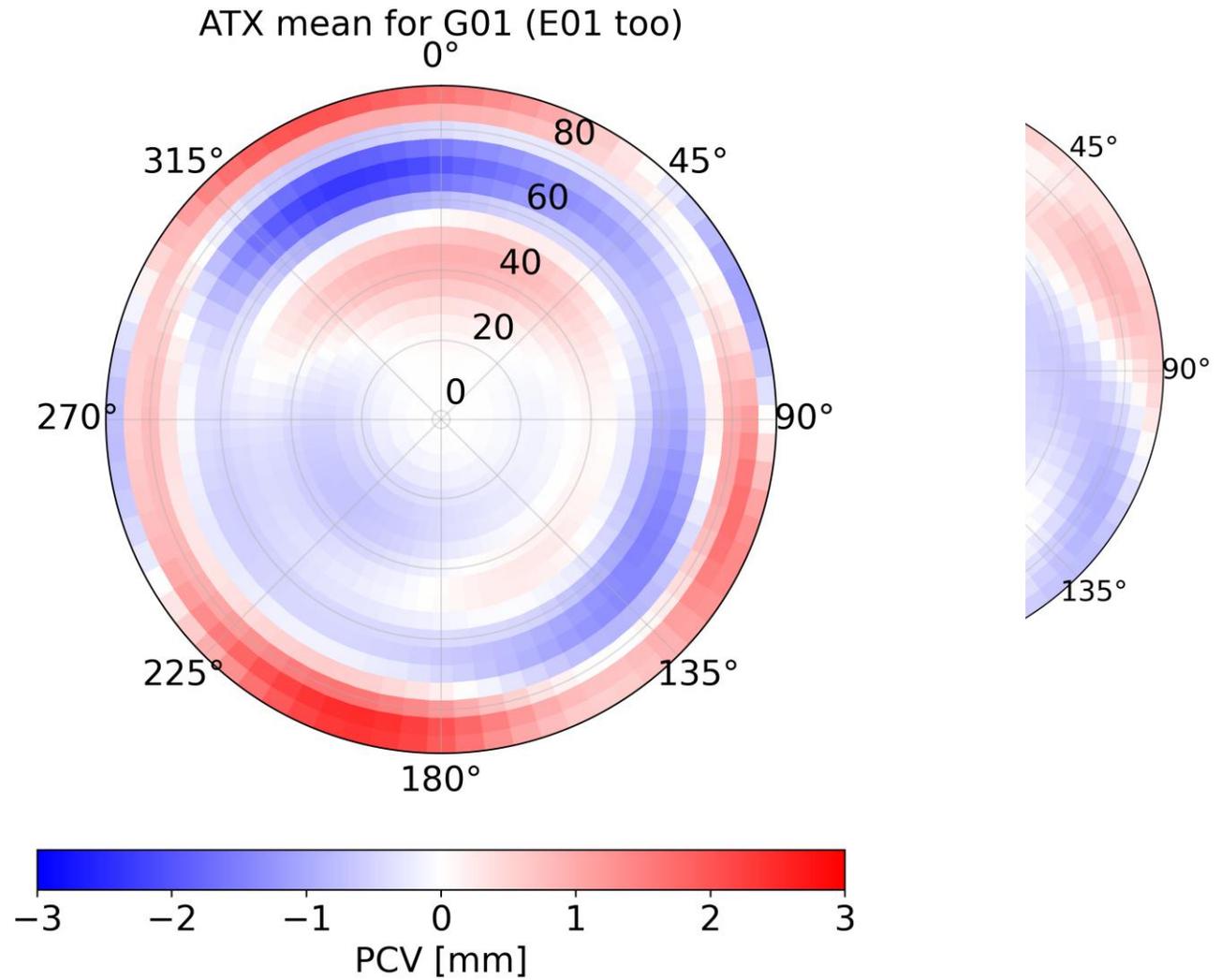
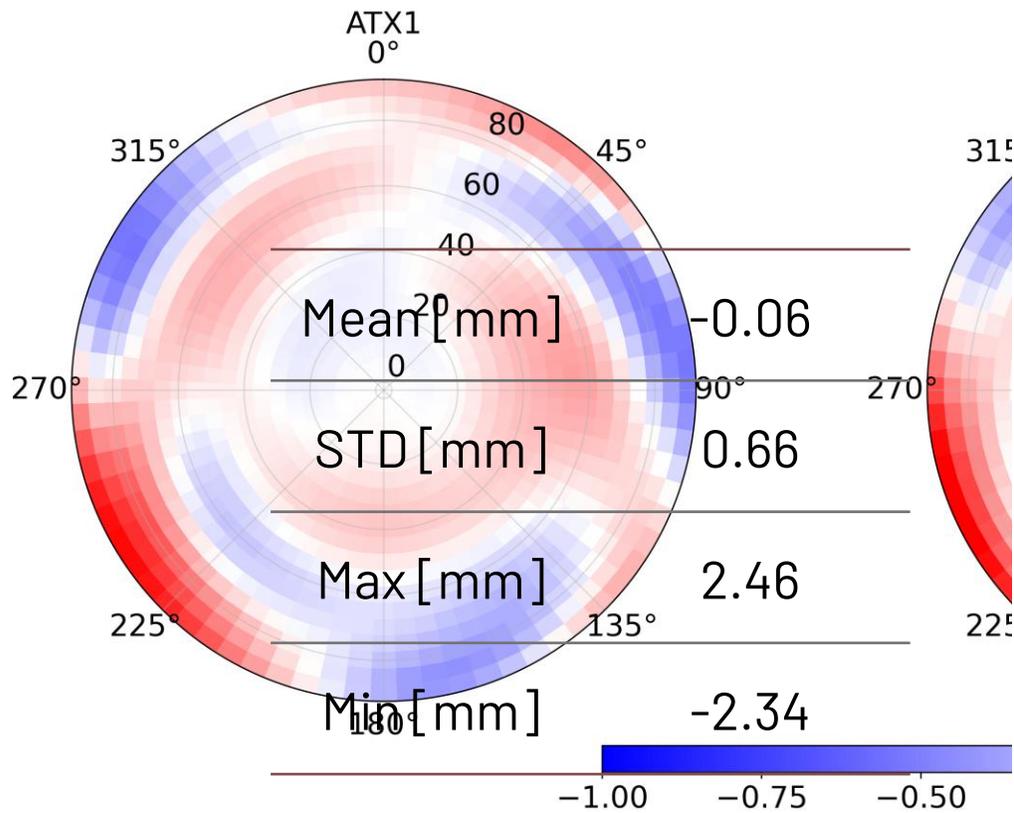
UP



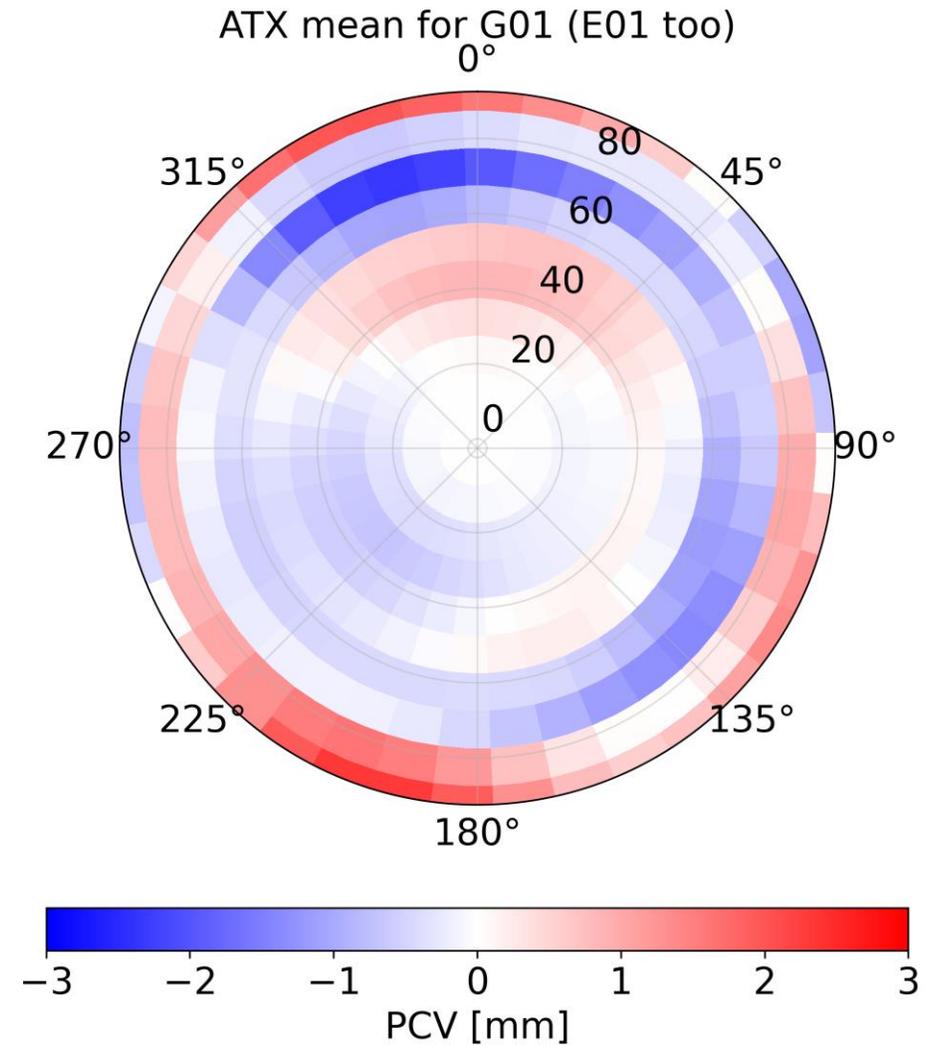
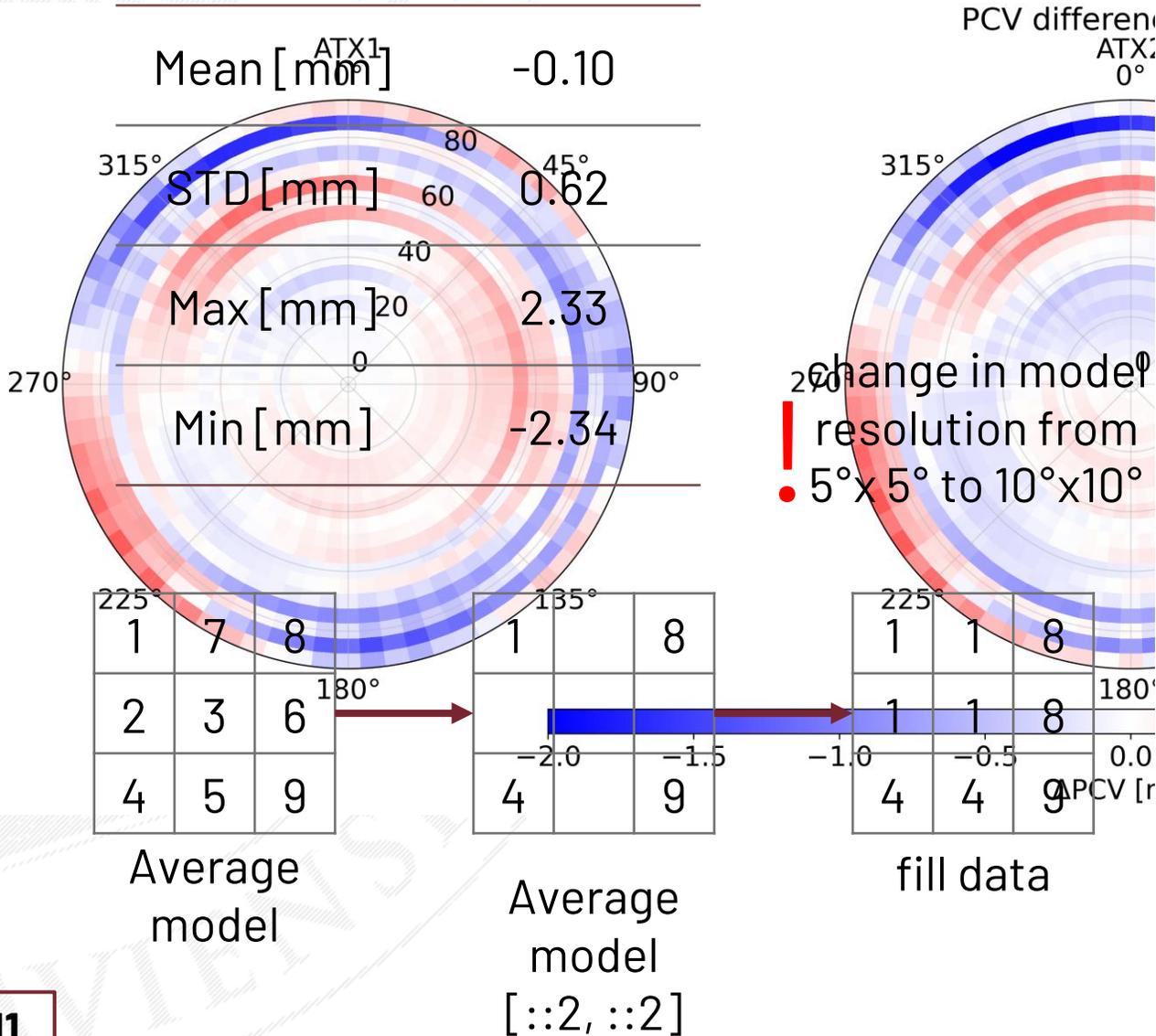
Construction of the mean model - comparison with official ArduSimple model - NOAZI



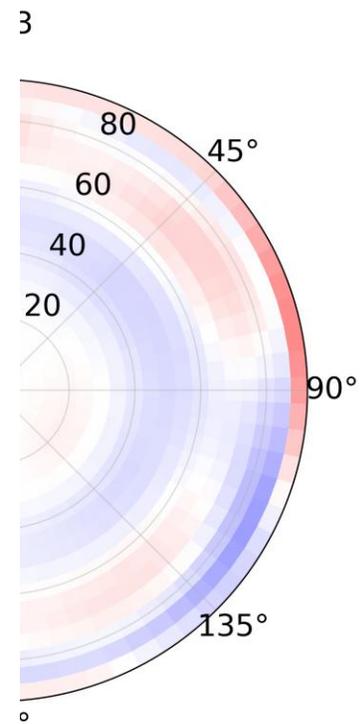
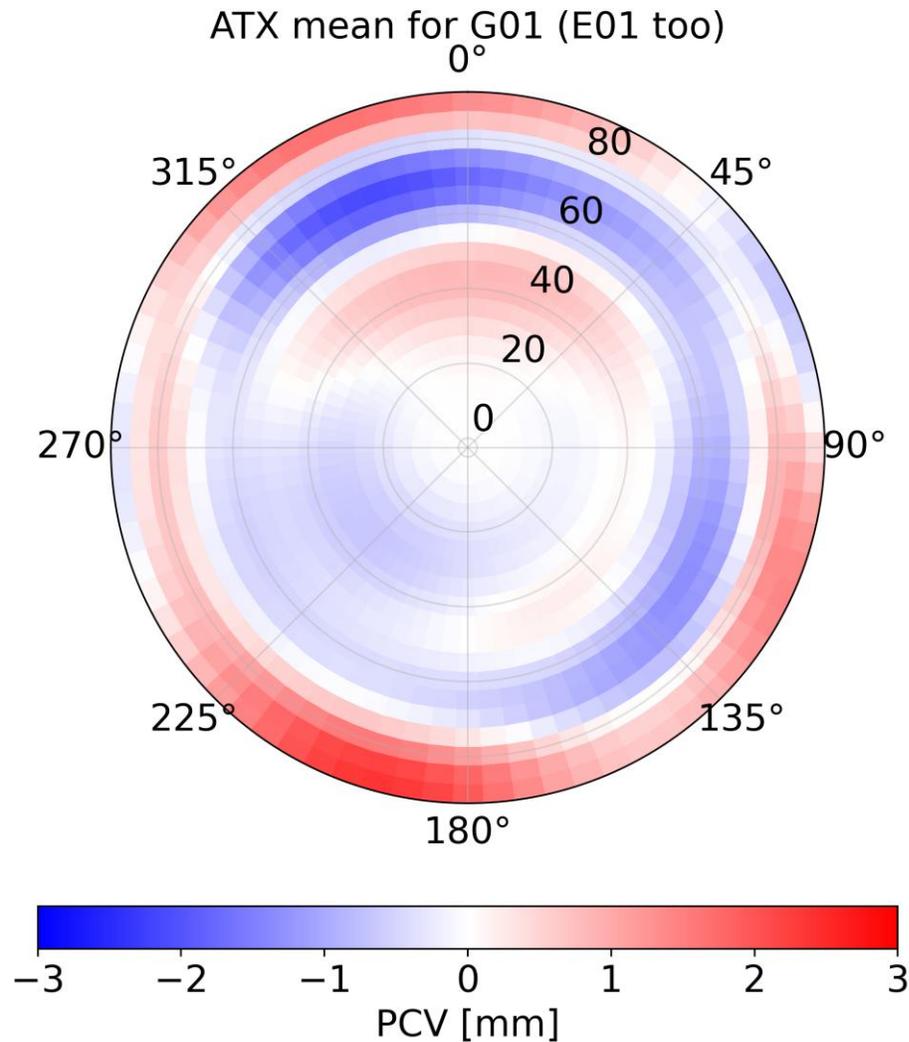
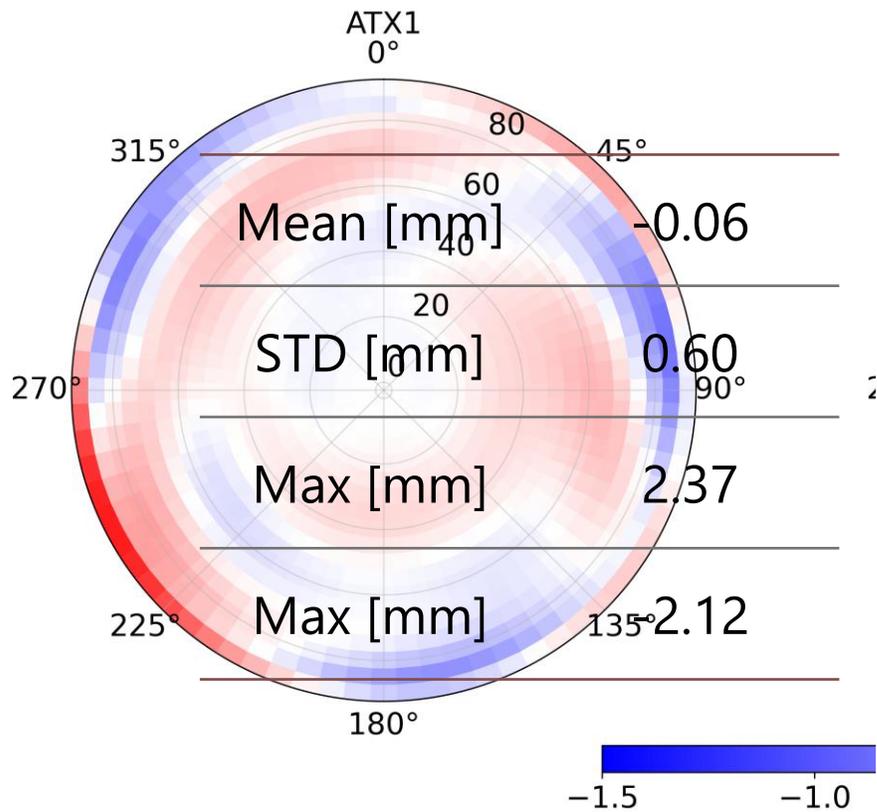
Construction of the mean model - average of 10 antex



Construction of the mean model -thinned average model



Construction of the mean model -average of 4 neighbours



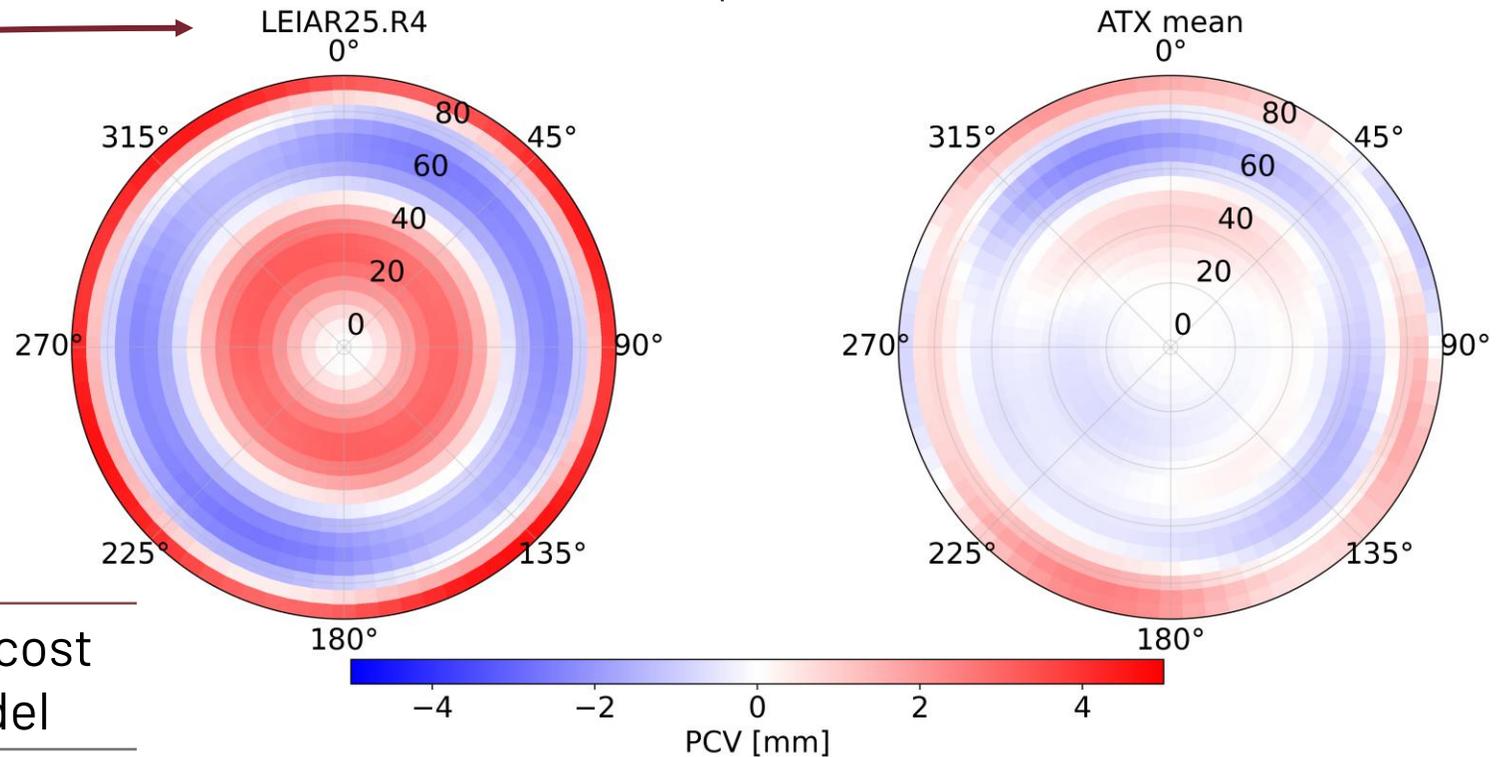
Construction of the mean model - comparison with professional model

Individual calibration model of the WROC station (frequency G1)

- higher values
- evenly distributed = independent of the direction of north

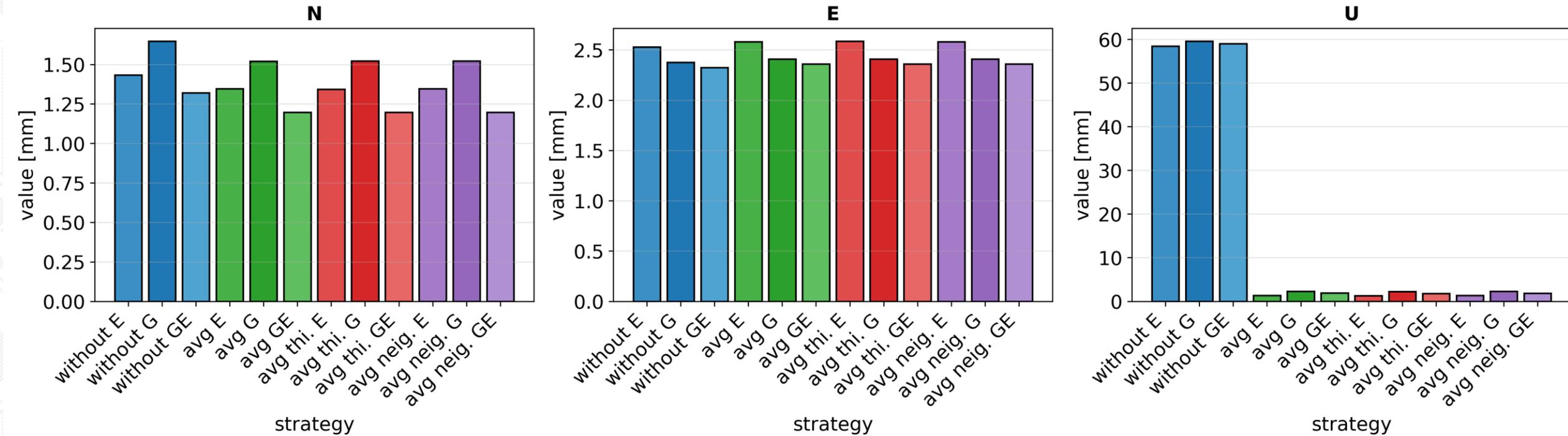
	LEIAR25. R4	Mean low-cost PCV model
Mean [mm]	0.73	-0.06
STD [mm]	1.80	0.66
RMSE [mm]	1.94	0.66
Max [mm]	4.67	2.46

PCV comparison - G01



Impact of ANTEX models on positioning results

Average differences relative to official model to GPS



of receivers

23

DOYs

274-280.2025

interwal

30s

Base station

WROC00POL

Avg distance

6.725 km

daily calculate (RTKLIB)

Summary

ANTEX:

- The average model demonstrates good representativeness for individual unit models.
- The thinned and neighborhood models do not obscure the overall distribution of values.
- Low-cost antennas, in comparison with professional antennas, do not exhibit regular symmetry in their characteristics.

Positioning:

- The use of the official model is not permissible when other satellite constellations are employed.
- The official model is characterized by significantly different PCO (Phase Center Offset) values compared to the Hanover model.
- The application of the averaged, thinned, and neighborhood models affects positioning results in a similar manner.





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Děkujeme za pozornost!



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