Geo++ Absolute GNSS Antenna Calibration

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- Summary/Outlook

Absolute Robot-based GNSS Antenna Calibration

- Geo++ GNPCV systems
- robot-based absolute GNSS antenna field calibration
- development by **Geo++** in cooperation with Institut für Erdmessung, **Universität, Hannover**, Germany
- **enhancements/new developments** and marketing through **Geo++** since 2000
- in total five working Geo++ GNPCV systems

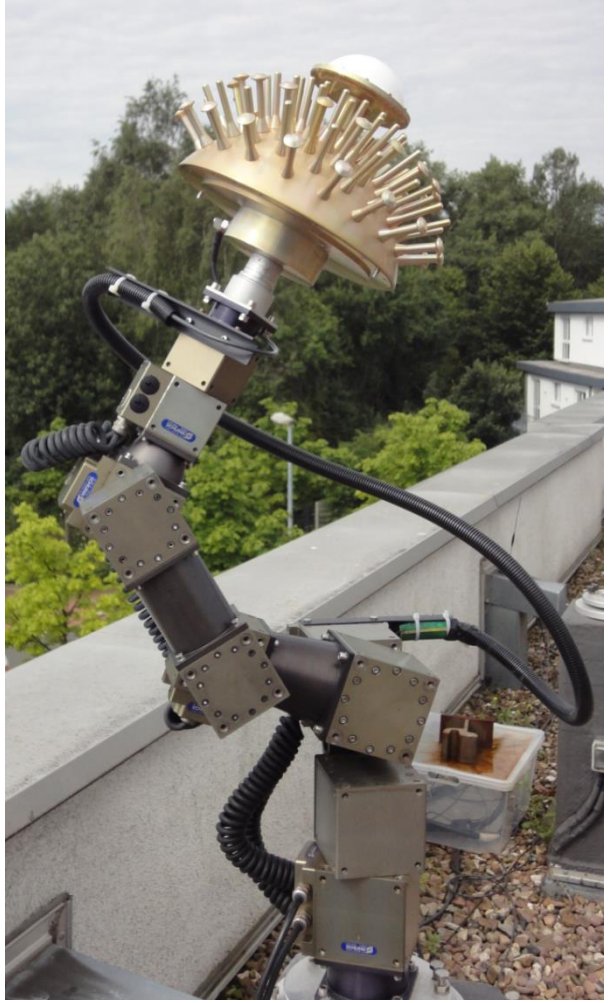
  - 2000 Geo++, **Garbsen** , Germany (retired)
  - 2000 ife, **Hannover** , Germany
  - 2005 SenB, Berlin, Germany (retired)
  - 2009 Geo++, **Garbsen** , Germany
  - 2012 GSA, Canberra, **Australia**
  - 2013 SenB, **Berlin** , Germany
  - 2019 Geo++, **Garbsen** , Germany

three robot-test, Mai 2012, Geo++ Garbsen

ife	Institut für Erdmessung, Universität Hannover, Germany
SenB	Senatsverwaltung für Stadtentwicklung Berlin, Germany
GSA	Geoscience Australia, Canberra, Australia

Absolute Robot-based GNSS Antenna Calibration

- characteristics/primary task of GNPCV service
  - absolute* **phase center** and **-variation** (PCV)
- antenna calibration provides (since 2000)
  - GPS + GLO L1 and L2 phase variations **PCV** (DeltaPCV for GLO)
  - GPS + GLO P1 and P2 group delay variations **GDV**
  - GPS + GLO S1 and S2 carrier-to-noise pattern **CNV**
- robot excellent instrument to determine additional parameters
  - **Group Delay Variations** (GDV)/Code calibration
  - **near-field impact** on antenna
  - **signal strength** (carrier-to-noise, CN0)
- separation of multipath in near-field and far-field effects
  - absolute **station calibration** of multipath

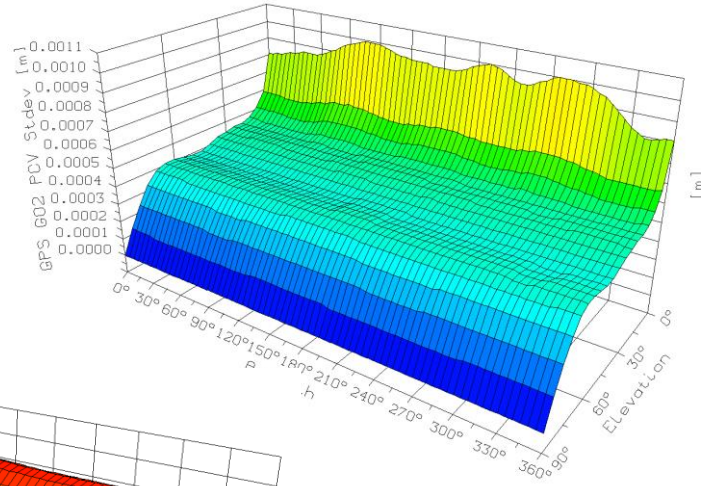


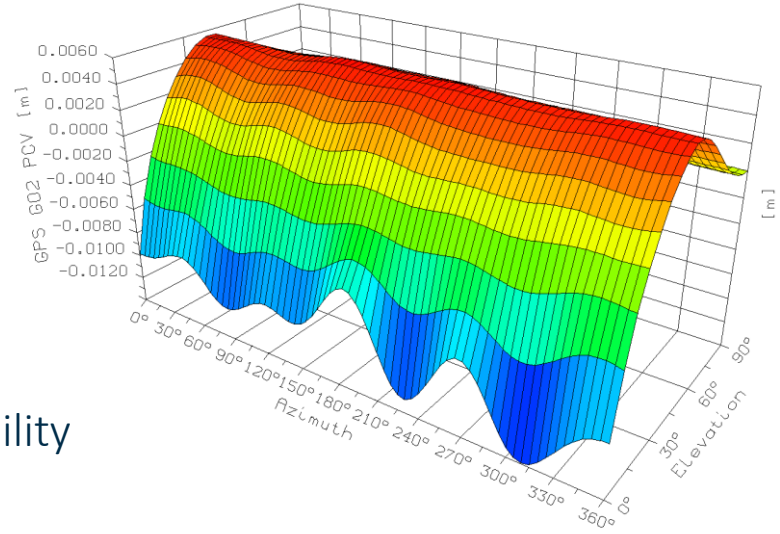
Geo++ robot with GNSS antenna TPSPN_A5 NONE

* without impact of a reference antenna

Characteristic of Absolute PCV Field Calibration

- absolute **3D offset** (derived from spherical harmonics)
- absolute **PCV**
  - PCV from (<) 0° to 90° elevation
  - 0° to 360° azimuthal PCV
- with **high resolution and precision**
  - free of multipath influence
  - site and location independent
- at least two independent calibrations
  - duration of several hours for one calibration
- **standard deviation 0.2 - 0.4 mm** (1 sigma) for complete PCV (offset plus PCV)
  - continuous verification of accuracy through repeatability





- **geodetic DM-type antenna**
- TRM59800_00 NONE
- PCV without offset
- L2 PCV
  -12 ... 5 mm
- stdev (individual)
  0.1 ... 0.4 mm

Absolute Robot-based GNSS Antenna Calibration

- status 2019 at Geo++

- **extension of** existing absolute robot-based GNSS **calibration system**
- **processing-software** GNSMART **for multi-frequency GNSS**
  ready since January 2019
- **multi-frequency** absolute GNSS antenna **calibration** software **provides**
  - PCV for up to 11 GNSS frequencies
  - GDV for any signals
  - CNV for all signals (under preparation)

GNSS Antenna Calibration - Frequencies

- **multi-frequency** GNSS antenna **calibration**
- **same frequencies** from **different GNSS** are **combined** for PCV correction
- **frequencies with minor frequencies** differences are **combined**
  - R01 and R04
  - R02 and R06
- insufficient constellation for
  - R03 (will be tackled in real-time calibration)

```
 1.4            M                                       ANTEX VERSION / SYST
A                                                           PCV TYPE / REFANT
                                                            COMMENT
  Geo++ (R) Robot Antenna Calibration                       COMMENT
                                                            COMMENT
   Calibration Patterns are provided once per Frequency     COMMENT
   with one of the corresponding frequency codes and can    COMMENT
   be applied to other frequency codes according to         COMMENT
   following table:                                         COMMENT
                                                            COMMENT
  ______________________________________                    COMMENT
  | Freq.[MHz] | Freq. Codes             |                  COMMENT
  |------------------------------------|                    COMMENT
  |   1602.000 | R01 R04                 |                  COMMENT
  |   1575.420 | G01 E01 J01 S01 C01     |                  COMMENT
  |   1561.098 | C02                     |                  COMMENT
  |   1278.750 | E06 J06                 |                  COMMENT
  |   1268.520 | C06                     |                  COMMENT
  |   1246.000 | R02 R06                 |                  COMMENT
  |   1227.600 | G02                     |                  COMMENT
  |   1207.140 | E07 C07                 |                  COMMENT
  |   1202.025 | R03                     |                  COMMENT
  |   1191.795 | E08 C08                 |                  COMMENT
  |   1176.450 | G05 E05 J05 C05 S05 I05 |                  COMMENT
  |____________________________________|                    COMMENT
                                                            COMMENT
                                                            END OF HEADER
```

GNSS Antenna Calibration - Post-Processing

- status 2019 at Geo++

- **GNSS raw data** recorded **during real-time** antenna **calibration since 2014**
- real-time antenna calibration **optimizes coverage** of the antenna hemisphere with GNSS observations (generally for GPS L2)
- different GNSS receiver with **different tracking capabilities** have been used (e.g. GPS L5-only, full GNSS with Gal and BDS)
- **GPS L5 always tracked**, availability of other signals and GNSS differs
- **individual post-processing** calibration **data** may have **not always best coverage** for new GNSS, but **type mean** of several individual antennas will have **good coverage**
- **post-processing** calibration is **equivalent to real-time** antenna **calibration**

GNSS Antenna Calibration - Real-Time

- status 2019 at Geo++

- **extension to real-time real-time multi-frequency** absolute antenna calibration system scheduled
- mainly **enhancement** of **robot guidance** required
- **optimized coverage** of antenna hemisphere **for all frequencies**
- planed to be operational mid of 2019
- in between post-processing GNSS calibration option

GNSS Antenna Calibration – Type Mean

- computation of type mean

- **rigorous type mean** taking complete **variance-covariance** of individual GNSS antenna calibrations into account
- **consistent PCV corrections** for all GNSS frequencies from different GNSS

GNSS Antenna Priority List – IGS/EUREF – (1)

- priority list of GNSS antenna types for
  - IGS/MGEX
  - EUREF/EPN
- criteria: stations tracking Galileo

red : no GNSS data for post-processing

: GPS L5/GNSS

		IGS/MGEX	EUREF/EPN	Geo++ #ant G125+R/*+EC	Remarks
TRM59800.00	NONE	27	>10	27/6	
LEIAR25.R4	LEIT	25	>10	61/34	
LEIAR25.R3	LEIT	22	>10	2/1	
TRM59800.00	SCIS	22	<10	27/6	
TRM57971.00	NONE	19	>10	48/27	
JAVRINGANT_DM	NONE	18	<10	2/1	
JAVRINGANT_DM	SCIS	14	>10	35/22	
JAV_RINGANT_G3T	NONE	14	<10	--	
LEIAR25.R4	NONE	8	<10	19/3	
TRM115000.00	NONE	8		26/20	
JAVRINGANT_G5T	NONE	7		6/0	
LEIAR10	NONE	6	>10	11/4	
ASH701945C_M	NONE	5		1/0	
ASH701945E_M	NONE	5		1/0	
LEIAR25.R3	NONE	5	<10	6/5	
SEPCHOKE_MC	NONE	5	<10	--	
TPSCR.G3	NONE	5		--	
LEIAR20	LEIM	4	<10	71/29	
LEIAR20	NONE	4	<10	14/8	
TPSCR.G3	SCIS	4		--	
TRM55971.00	NONE	4	<10	--	
SEPCHOKE_B3E6	SPKE	3		11/6	

GNSS Antenna Priority List – IGS/EUREF – (2)

- page 1
- priority list of GNSS antenna types for
  - IGS/MGEX
  - EUREF/EPN
- criteria: stations tracking Galileo

		IGS/MGEX	EUREF/EPN	Geo++ #ant G125+R/*+EC	Remarks
TPSCR.G5	TPSH	3		57/29	
ASH701945E_M	SNOW	2		--	
ASH701945G_M	NONE	2		--	
JAV_GRANT-G3T	NONE	2		--	
LEIAR25	LEIT	2			Mix AR25.R2x
LEIAR25	NONE	2	<10	1/1	LEIAR25.R22 NONE
TPSCR.G3	TPSH	2		1/1	
TRM57971.00	TZGD	2		2/1	
ASH700936D_M	SCIS	1		--	
ASH701945B_M	JPLA	1		--	
ASH701945B_M	SCIS	1		--	
ASH701945B_M	SCIT	1		--	
ASH701945C_M	SCIS	1		--	
ASH701945C_M	SCIT	1		--	
ASH701945E_M	SCIT	1		--	
ASH701945G_M	JPLA	1		--	
ASH701945G_M	SCIT	1		--	
CHCC220GR2	CHCD	1		5/0	
JNSCR_C146-22-1	OSOD	1		--	
LEIAT504	NONE	1		10/0	
NOV750.R4	NOVS	1		--	
SEPCHOKE_B3E6	NONE	1		5/0	
SEPCHOKE_MC	SPKE	1		--	
TPSCR.G5C	NONE	1		5/0	
TPSCR3_GGD	CONE	1		--	
		268			
TRM59900.00	SCIS	--	<10	31/23	
LEIAT504GG	LEIS	--	<10	--	
TRM29659.00	NONE	--	<10	1/0	

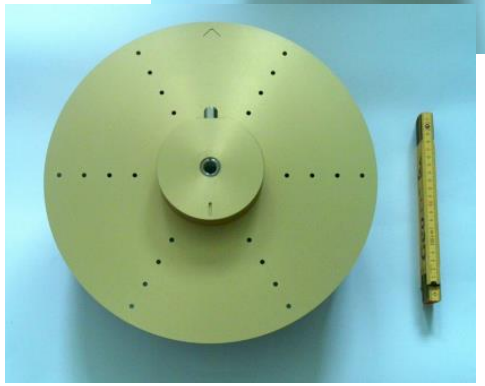
GNSS Antenna Priority List – IGS/EUREF

- **IGS/MGEX** priority list
- contains **268 GNSS antenna**
  - for 215 antenna GNSS raw data for **multi-frequency PCV** available **80%**
  - for 53 antennas no raw data **20%**
- contains 47 different GNSS antenna types
  - for 26 antenna types GNSS raw data for multi-frequency PCV available 55%
  - for 21 antenna types no GNSS raw data 45%

- **EUREF/EPN** priority list
- contains **19** different **GNSS antenna types**
  - for 15 types GNSS raw data for **multi-frequency PCV** available (shared with IGS/MGEX list) **79%**
  - for 4 antenna types no GNSS raw data 21%

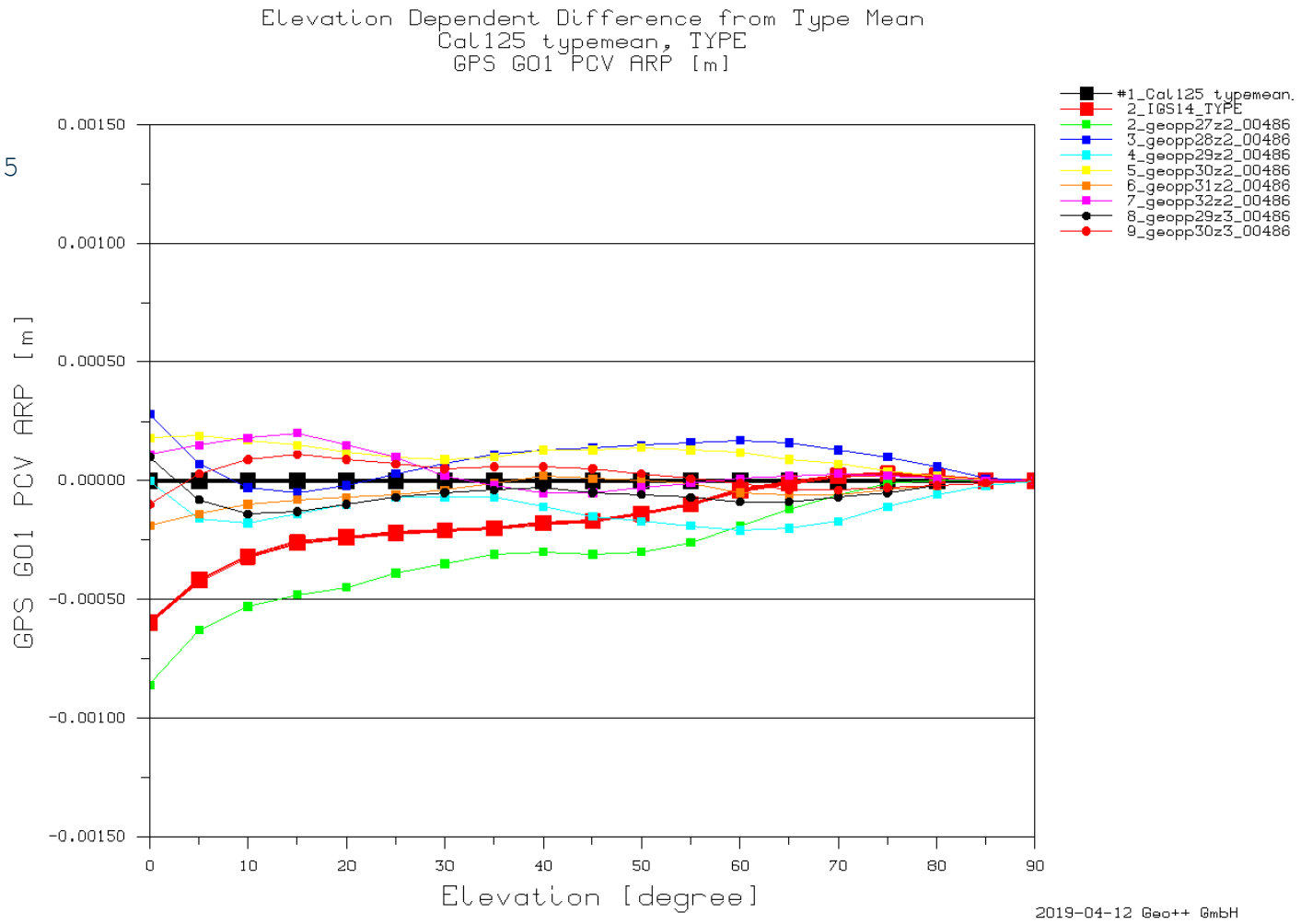
GNSS Antenna Calibration - Comparisons

- examples
- **individual** JAVRINGANT_DM___NONE **antenna**
  - several calibrations available
  - **multi-frequency post-processing**
  - data from 2016, 2017, 2018
  - optimized coverage for GPS L2 during real-time calibration
  - **only calibrations with new GNSS and sufficient coverage** for the respective frequencies are **shown** (counts refer to Cal125 type mean)
- **repeatability** of PCV
  - agreement between **individual multi-frequency** and former dual frequency absolute robot-based GNSS antenna calibration
  - agreement between multi-frequency PCV type means with GPS/GLO L1/L2 **IGS14 model igs14.atx**



Repeatability JAVRINGANT_DM___NONE

```
JAVRINGANT_DM   NONE 00486
 #a 001 #c 036 #p 047  | G01 E01 J01 S01 C01
 #a 001 #c 025 #p 026  | G02 J02
 #a 001 #c 036 #p 047  | G05 E05 J05 C05 S05 I05
 #a 001 #c 022 #p 026  | R01 R04
 #a 001 #c 022 #p 026  | R02 R06
 #a --- #c --- #p ---  | R03
 #a 001 #c 015 #p 021  | E06 J06
 #a 001 #c 019 #p 042  | E07 C07
 #a 001 #c 009 #p 013  | E08 C08
 #a 001 #c 009 #p 013  | C02
 #a 001 #c 015 #p 021  | C06
```



- agreement with IGS14.atx

#a antenna #c calibration #p pattern

Repeatability JAVRINGANT_DM___NONE

```
JAVRINGANT_DM   NONE 00486
 #a 001 #c 036 #p 047  | G01 E01 J01 S01 C01
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 #a --- #c --- #p ---  | R03
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 #a 001 #c 019 #p 042  | E07 C07
 #a 001 #c 009 #p 013  | E08 C08
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 #a 001 #c 015 #p 021  | C06
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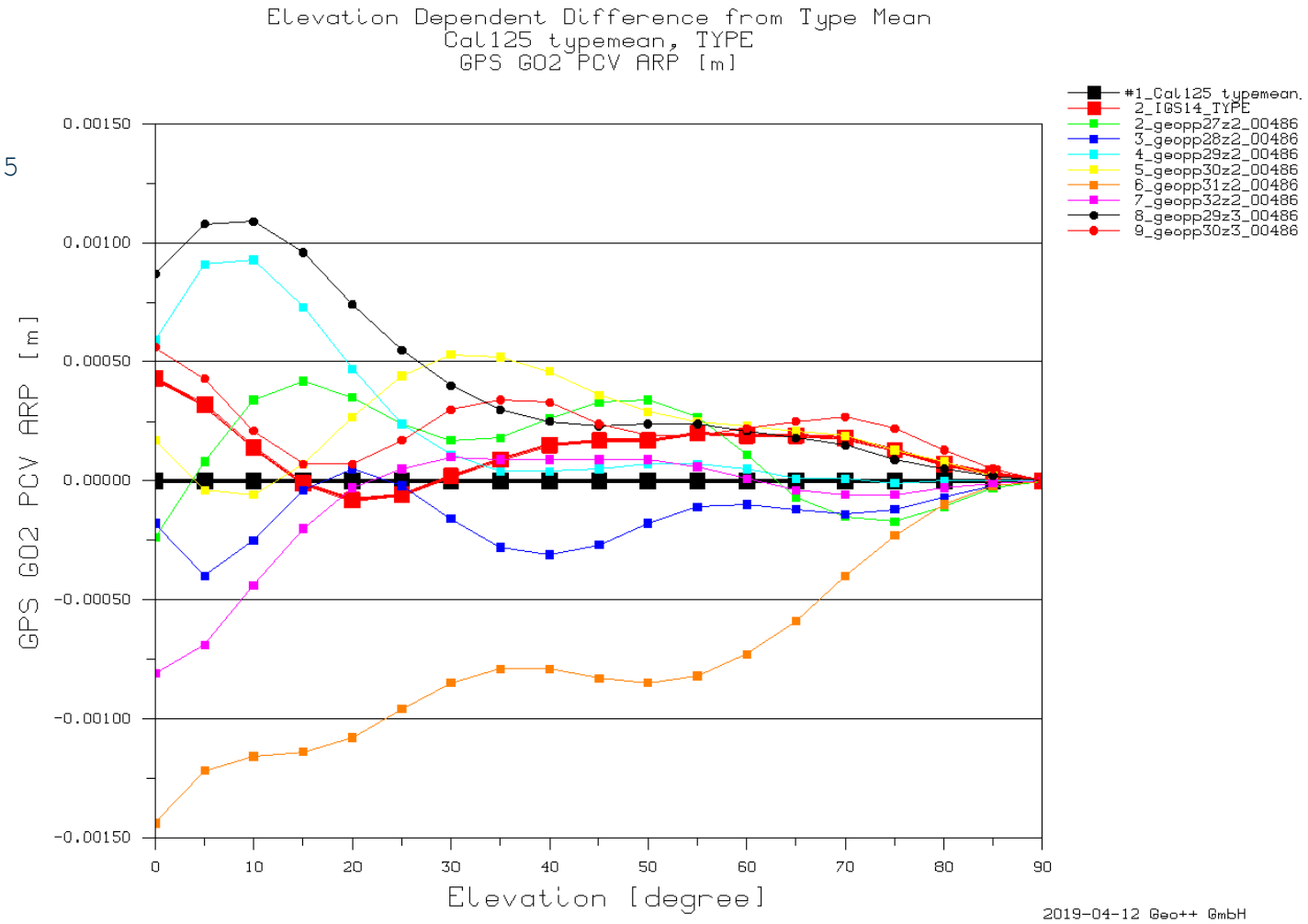

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 #a 001 #c 022 #p 026  | R01 R04
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 #a 001 #c 019 #p 042  | E07 C07
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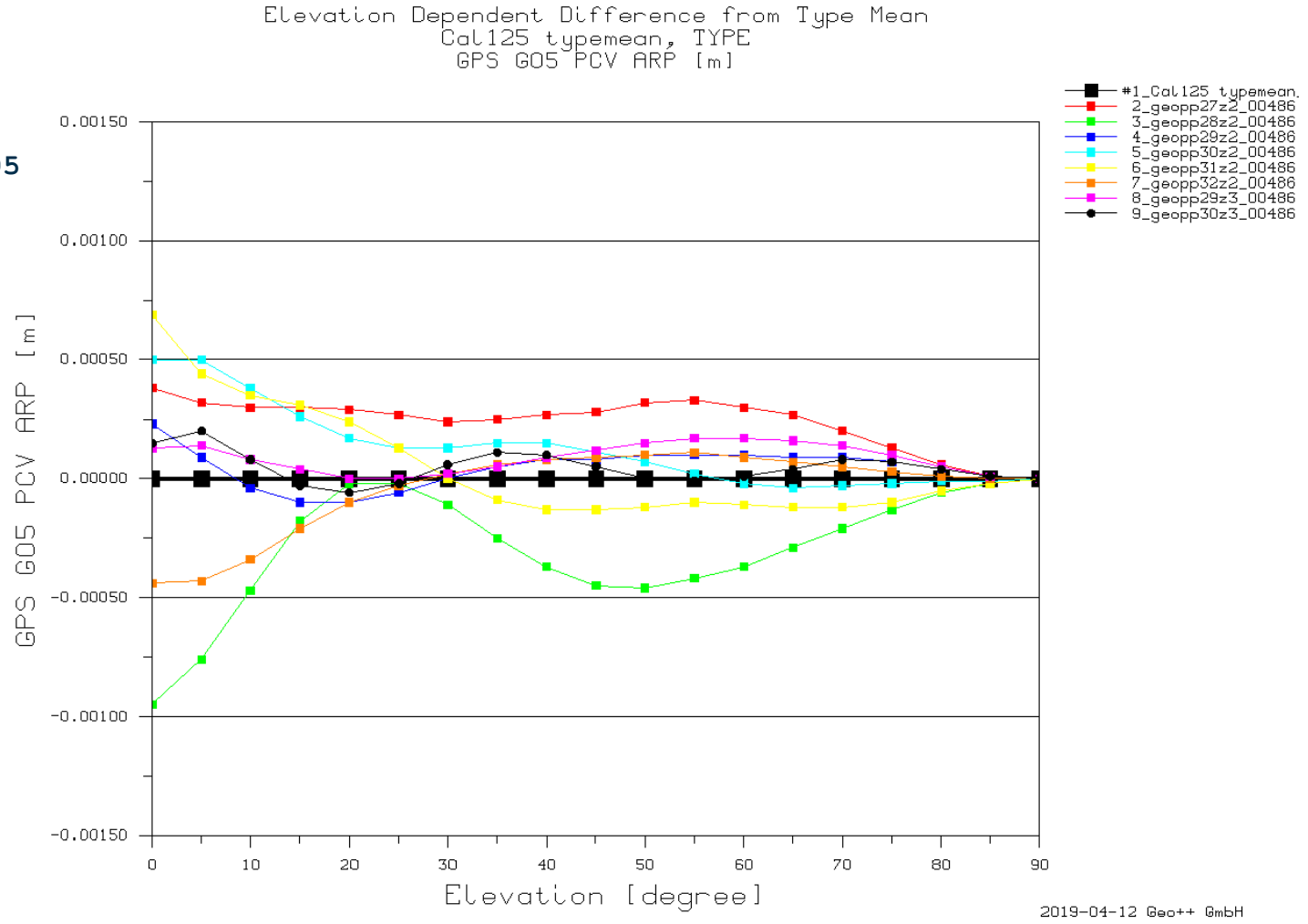
 #a 001 #c 009 #p 013  | C02
 #a 001 #c 015 #p 021  | C06
```



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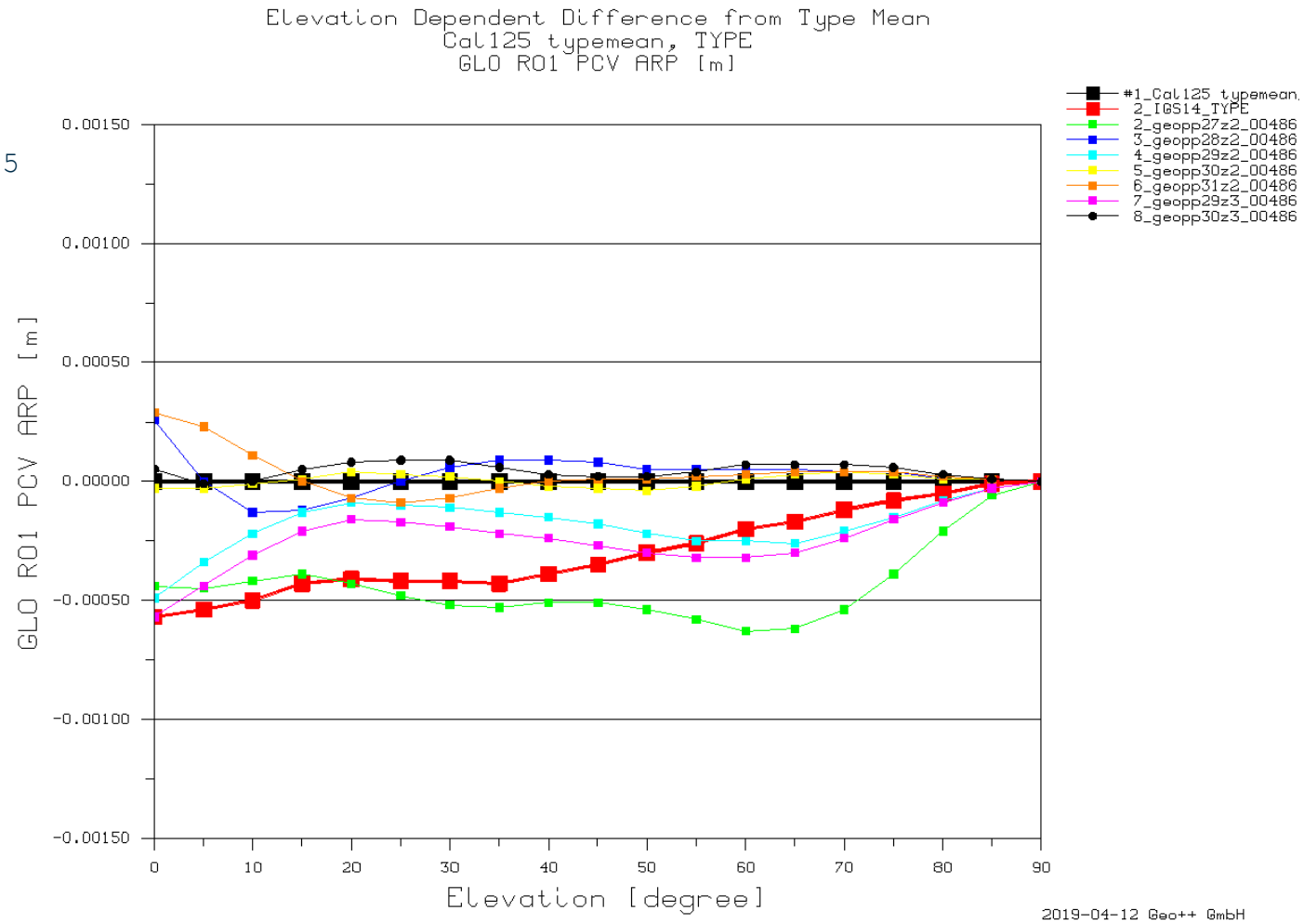

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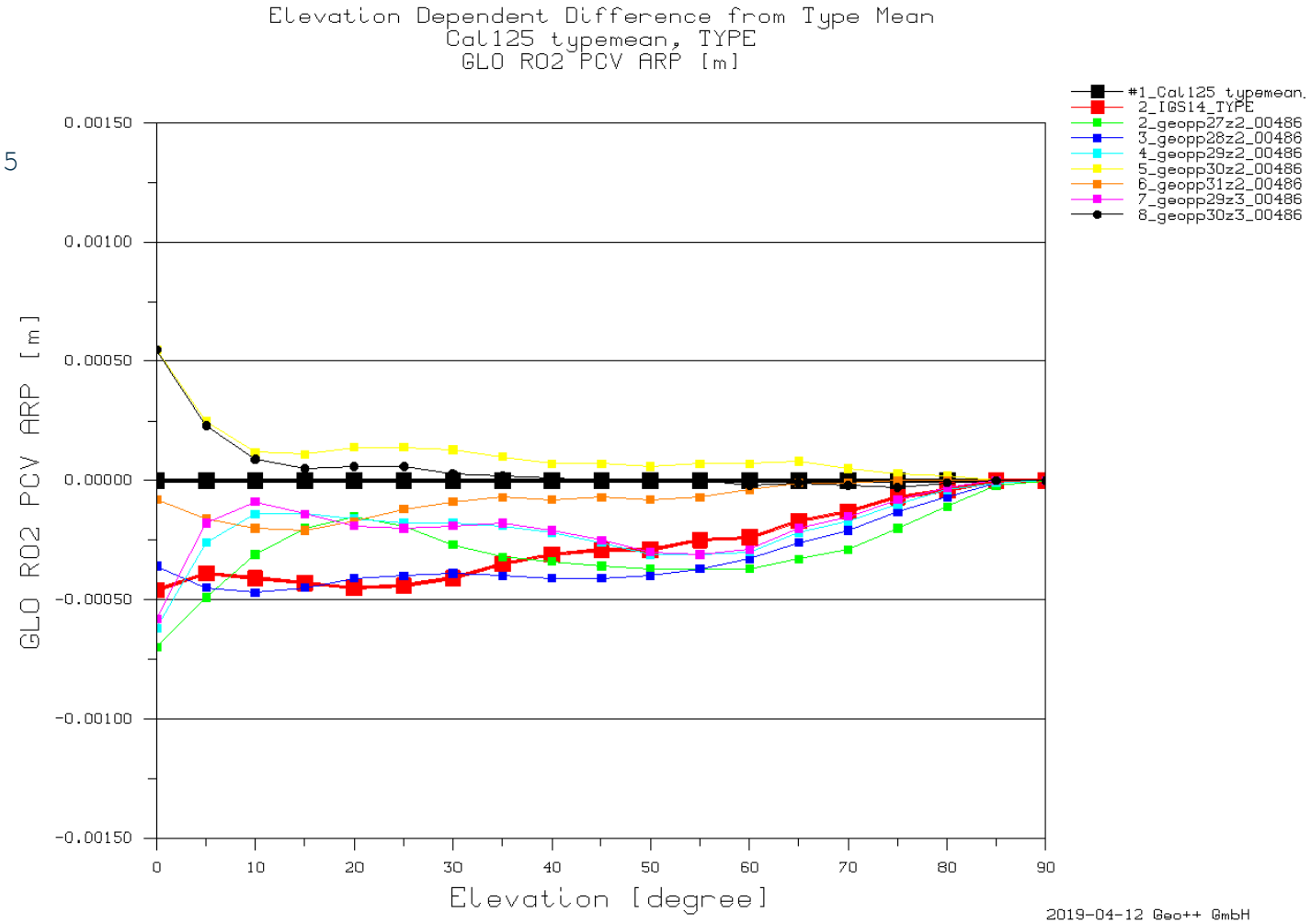

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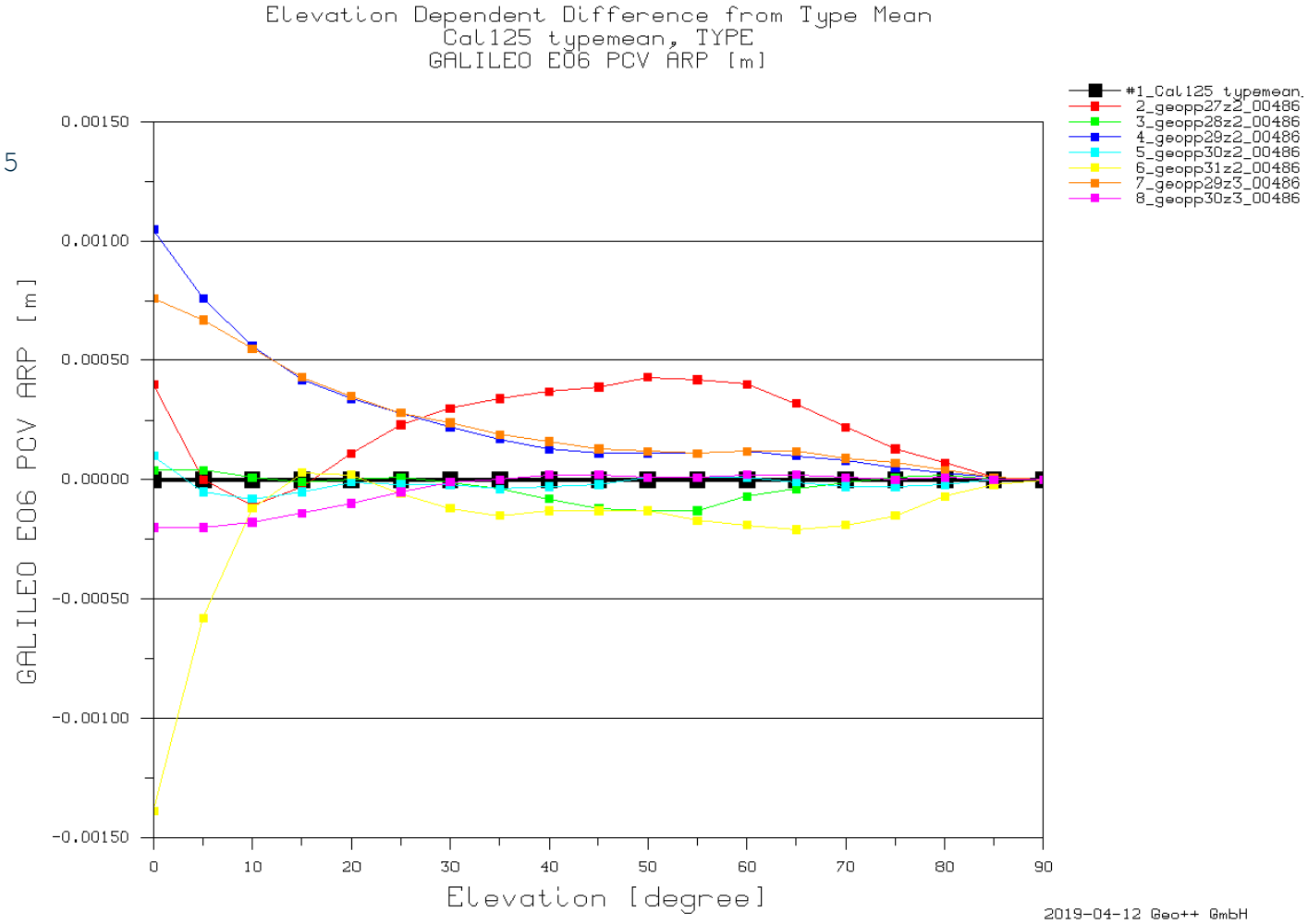

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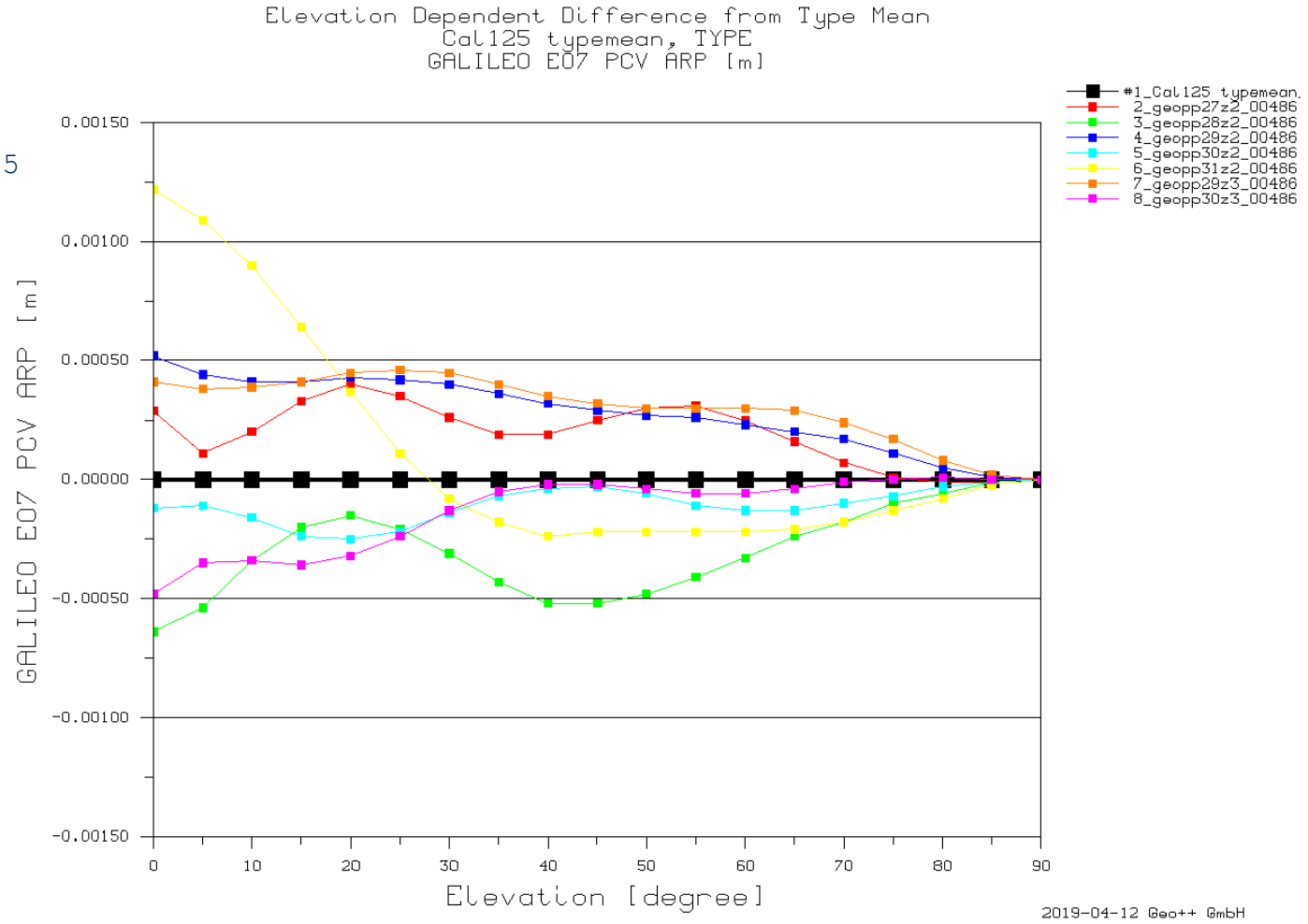

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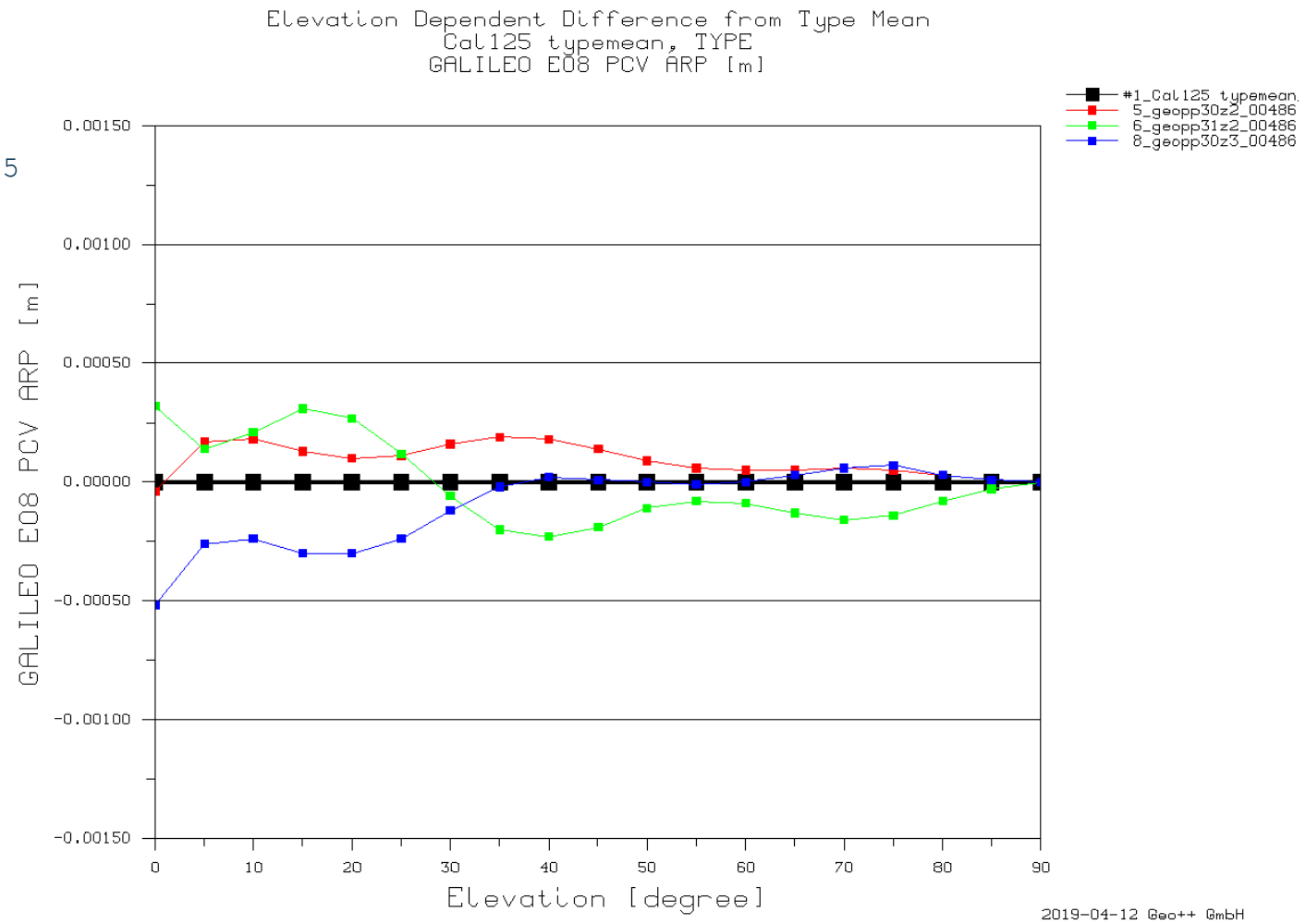

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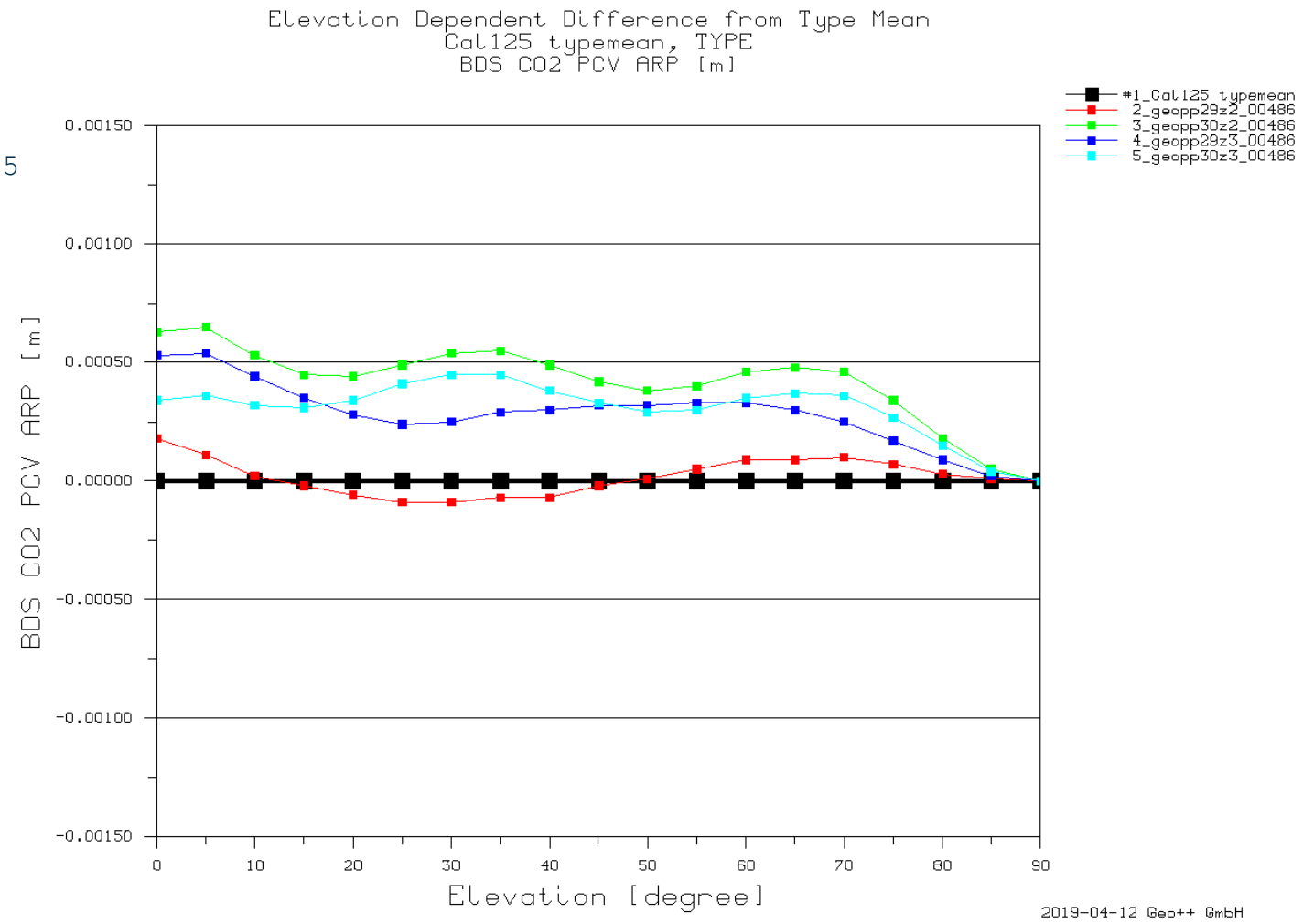

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 #a 001 #c 022 #p 026  | R01 R04
 #a 001 #c 022 #p 026  | R02 R06
 #a --- #c --- #p ---  | R03
 #a 001 #c 015 #p 021  | E06 J06
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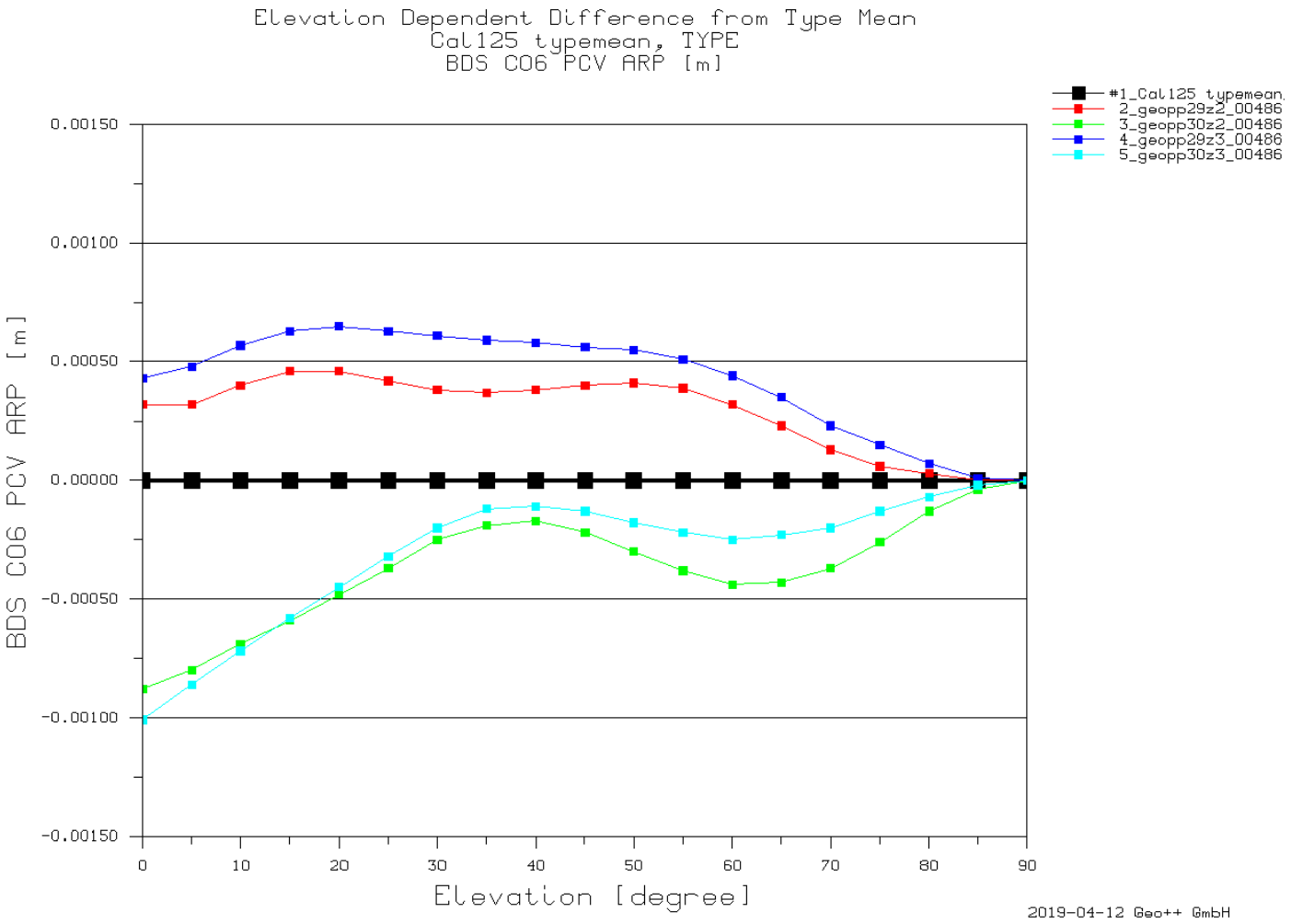
```



Summary/Outlook

- **multi-frequency** absolute robot-based **GNSS antenna calibration** available since **January 2019**
  - **consistent** with former dual frequency absolute robot-based antenna calibration
  - provides consistent **PCV for up to 11 frequencies**
- GNSS raw data from antenna calibration
  - available for antenna calibrations at Geo++ since 2014
- GNSS raw data for **majority of IGS/EUREF antenna types** available
  - first iteration of post-processing executed for new GNSS calibrations
  - combination with additional calibrations pending
- **real-time multi-frequency** absolute robot-based **GNSS antenna calibration**
  - scheduled for mid 2019
  - allows for optimized antenna coverage for all frequency

Thanks for your Attention

Geo++®
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