



Geo++ Absolute Multi-Frequency GNSS Antenna Calibration

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Abstract



The transition to rigorous multi-GNSS positioning requires a consistent transition to multi-frequency PCV antenna corrections for ground and satellite GNSS antennas. Geo++ provides absolute GNSS antenna calibration services since 2000. The majority of the dual frequency GPS and GLONASS PCV corrections of the IGS model igs14.atx have been determined by the Geo++ robot-based antenna calibration method.

Since the beginning of 2019 Geo++ provides robot-based antenna calibrations for all GNSS frequencies and signals. Over several years GNSS raw measurements were recorded during regular real-time GNSS antenna calibration procedures including e.g. the GPS/Galileo L5/E5 frequency. A post-processing of the collected GNSS data is currently in progress to provide multi-frequency PCV corrections for about 100 different GNSS antenna types. This post-processing work has been finished for most antenna types in use on IGS and EPN stations to be applied for the IGS REPRO-3 campaign.

An overview of the absolute multi-frequency GNSS calibration and the PCV corrections determined in the Geo++ absolute multi-frequency antenna calibration post-processing is presented.

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- IGS/EUREF GNSS Antenna Priority List – IGS igsR3.atx
- Example: JAVRINGANT_DM___NONE
- GNSS Antenna Group Delay Variations
- Example: LEIAR25.R4_____LEIT
- ANTEX Format
- Summary/Outlook



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- **Absolute Robot-based GNSS Antenna Calibration**
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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

ife
SenB
GSA

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



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

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



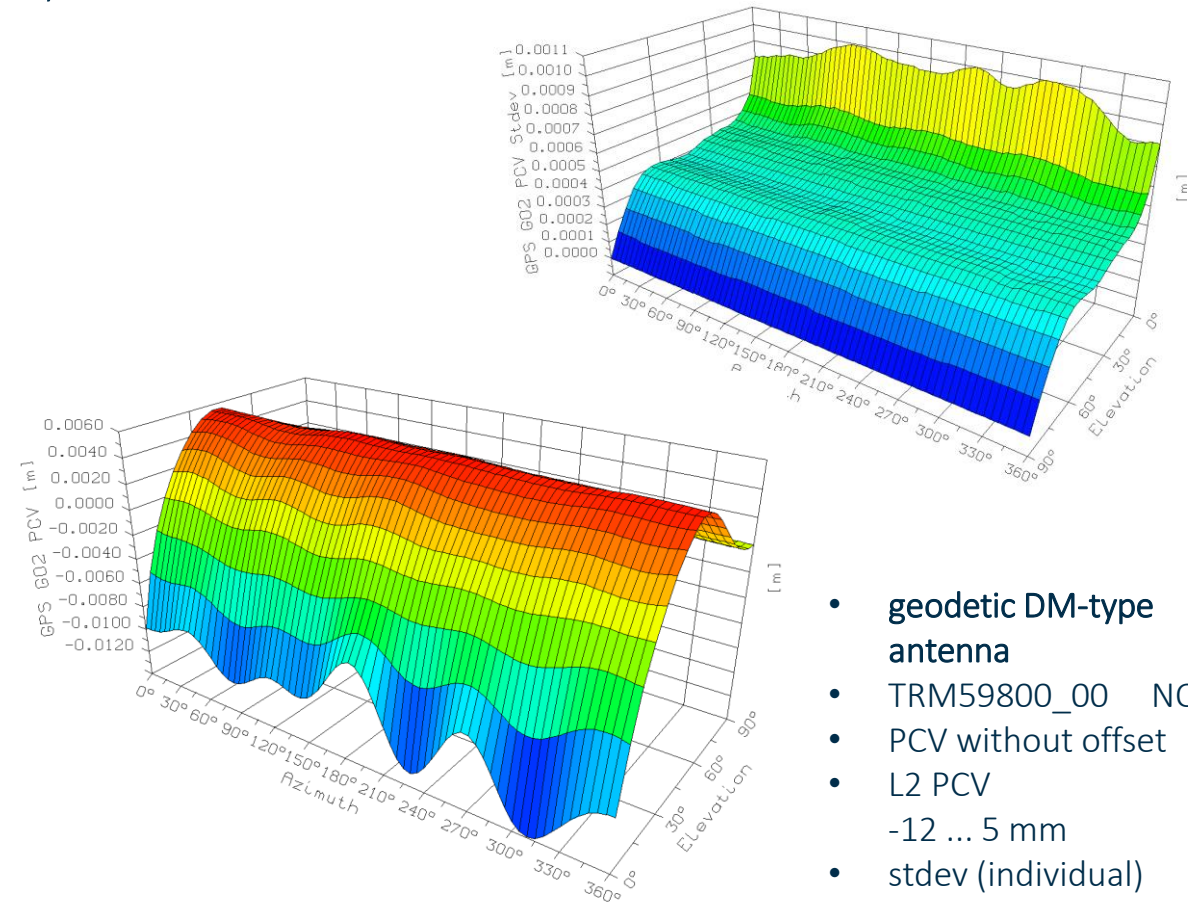
* without impact of a reference antenna

Geo++ robot with GNSS antenna TPSPN_A5 NONE

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 system accuracy through repeated calibrations



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



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Absolute Robot-based GNSS Antenna Calibration



- status 2019 at Geo++
- **extension of** existing absolute robot-based GNSS calibration system
- absolute **GNSS antenna calibration** in 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)
- **pre-requisites** for absolute robot-based field calibration
 - frequency in space
 - frequency tracked

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
A

M

Geo++ (R) Robot Antenna Calibration

Calibration Patterns are provided once per Frequency with one of the corresponding frequency codes and can be applied to other frequency codes according to following table:

Freq. [MHz]	Freq. Codes
1602.000	R01 R04
1575.420	G01 E01 J01 S01 C01
1561.098	C02
1278.750	E06 J06
1268.520	C06
1246.000	R02 R06
1227.600	G02
1207.140	E07 C07
1202.025	R03
1191.795	E08 C08
1176.450	G05 E05 J05 C05 S05 I05

ANTEX VERSION / SYST
PCV TYPE / REFANT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
COMMENT
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 signals)
- **GPS L5 always tracked**, availability of other signals and GNSS differs with data set
- **individual post-processing** of calibration **data** may have **not always best coverage** for new GNSS, but **type mean** of several individual antennas will have **sufficient coverage**
- about 100 antenna types available
- **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 in 2020
- 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
- calibration data sets with **best GNSS receiver technology** used
 - no combination with existing GPS/GLO L1/L2 type mean corrections



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IGS/EUREF GNSS Antenna Priority List – (1)



- priority list of GNSS antenna types used in network (status 2019-03-20)
 - IGS/MGEX
 - EUREF/EPN
- criteria: stations tracking Galileo
- initial check for availability of GNSS data for antenna type mean post-processing

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	

IGS/EUREF GNSS Antenna Priority List – (2)



- priority list of GNSS antenna types used in network (status 2019-03-20)
 - IGS/MGEX
 - EUREF/EPN
- criteria: stations tracking Galileo
- initial check for availability of GNSS data for antenna type mean post-processing

red : no GNSS data for post-processing

 : GPS L5/GNSS

		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		57 0	
JNSCR_C146-22-1	OSOD	1		--	
LEIAT504	NONE	1		107 0	
NOV750.R4	NOVS	1		--	
SEPCHOKE_B3E6	NONE	1		57 0	
SEPCHOKE_MC	SPKE	1		--	
TPSCR.G5C	NONE	1		57 0	
TPSCR3_GGD	CONE	1		--	
		268			
TRM59900.00	SCIS	--	<10	31/23	
LEIAT504GG	LEIS	--	<10	--	
TRM29659.00	NONE	--	<10	1/0	

IGS/EUREF GNSS Antenna Priority List



- in between **focus on missing antenna types**
- additional multi-frequency **GNSS calibration** conducted since May
- **new antenna types**
 - ASH700936D_M SCIS
 - ASH701945E_M SCIT
 - JAV_GRANT-G3T NONE
 - TPSCR.G3 NONE
 - TPSCR.G3 SCIS
- potential **alternate** for some antenna type (“COPY FROM”)
 - ASH701945E_M SCIS
- **additional data** from SenB, Berlin, Germany
 - LEIAR25.R3 LEIT

IGS/EUREF GNSS Antenna Priority List



- **IGS/MGEX** priority list (status 2019-10-14)
- contains 268 **GNSS antenna on stations**
 - for 228 antenna GNSS raw data for **multi-frequency PCV** available 85%
 - for 40 antennas no raw data 15%
- contains 47 different **GNSS antenna types**
 - for 31 antenna types GNSS raw data for multi-frequency PCV available 65%
 - for 16 antenna types no GNSS raw data 35%
- **EUREF/EPN** priority list (status 2019-10-14)
- contains 19 different **GNSS antenna types**
 - for 15 types GNSS raw data for **multi-frequency PCV** available 79%
(shared with IGS/MGEX list)
 - for 4 antenna types no GNSS raw data 21%

GNSS PCV Antenna Corrections – IGS igsR3.atx – (1)



- multi-frequency GNSS PCV antenna corrections provided (status 2019-05-25)
- igsR3.atx for IGS REPRO-3
- 36 antenna types
 - antenna type
 - frequencies
 - number of frequencies #FRQ
 - max number of antennas #ANT

Freq. [MHz]	Freq. Codes
1602.000	R01 R04
1575.420	G01 E01 J01 S01 C01
1561.098	C02
1278.750	E06 J06
1268.520	C06
1246.000	R02 R06
1227.600	G02
1207.140	E07 C07
1202.025	R03
1191.795	E08 C08
1176.450	G05 E05 J05 C05 S05 I05

antenna type	PCV	G01	G02	G05	R01	R02	R03	E06	E07	E08	C02	C06	#FRQ	#ANT
ASH700936D_M	SCIS	1	1	1	1	1	0	1	1	1	1	1	010	002
ASH701945C_M	NONE	1	1	1	1	1	0	0	0	0	0	0	005	001
ASH701945E_M	NONE	1	1	1	1	1	0	0	0	0	0	0	005	001
ASH701945E_M	SCIS	1	1	1	1	1	0	1	1	1	1	1	010	001
ASH701945E_M	SCIT	1	1	1	1	1	0	1	1	1	1	1	010	001
CHCC220GR2	CHCD	1	1	1	1	1	0	0	0	0	0	0	005	005
GPPNULLANTENNA	NONE	1	1	1	1	1	1	1	1	1	1	1	011	001
JAV_GRANT-G3T	NONE	1	1	1	1	1	0	1	1	1	1	1	010	002
JAVRINGANT_DM	NONE	1	1	1	1	1	0	1	1	1	1	1	010	001
JAVRINGANT_DM	SCIS	1	1	1	1	1	0	1	1	0	1	1	009	022
JAVRINGANT_G5T	JAVC	1	1	1	1	1	0	1	1	1	1	1	010	010
JAVRINGANT_G5T	NONE	1	1	1	1	1	0	0	0	0	0	0	005	006
LEIAR10	NONE	1	1	1	1	1	0	0	0	0	0	0	005	003
LEIAR20	LEIM	1	1	1	1	1	0	1	1	1	1	1	010	064
LEIAR20	NONE	1	1	1	1	1	0	1	1	1	1	1	010	008
LEIAR25.R22	NONE	1	1	1	1	1	0	0	0	0	0	0	005	001
LEIAR25.R3	LEIT	1	1	1	1	1	0	1	1	1	1	1	010	003
LEIAR25.R3	NONE	1	1	1	1	1	0	1	1	0	1	1	009	005
LEIAR25.R4	LEIT	1	1	1	1	1	0	1	1	1	1	1	010	037
LEIAR25.R4	NONE	1	1	1	1	1	0	1	1	1	1	1	010	003
LEIAT504	NONE	1	1	1	1	1	0	0	0	0	0	0	005	001
LEIAT504GG	NONE	1	1	1	1	1	0	1	1	1	1	1	010	020
SEPCHOKE_B3E6	NONE	1	1	1	1	1	0	0	0	0	0	0	005	005
SEPCHOKE_B3E6	SPKE	1	1	1	1	1	0	1	1	1	1	1	010	006

GNSS PCV Antenna Corrections – IGS igsR3.atx – (2)



- multi-frequency GNSS PCV antenna corrections provided (status 2019-05-25)
- igsR3.atx for IGS REPRO-3
- 36 antenna types
 - antenna type
 - frequencies
 - number of frequencies #FRQ
 - max number of antennas #ANT

antenna	type	PCV	G01	G02	G05	R01	R02	R03	E06	E07	E08	C02	C06	#FRQ	#ANT
TPSCR.G3	NONE		1	1	1	1	1	0	1	1	1	1	1	010	001
TPSCR.G3	SCIS		1	1	1	1	1	0	1	1	1	1	1	010	001
TPSCR.G3	TPSH		1	1	1	1	1	0	1	1	0	1	0	008	001
TPSCR.G5	TPSH		1	1	1	1	1	0	1	1	1	1	1	010	029
TPSCR.G5C	NONE		1	1	1	1	1	0	0	0	0	0	0	005	005
TRM115000.00	NONE		1	1	1	1	1	0	1	1	1	1	1	010	020
TRM29659.00	NONE		1	1	1	1	1	0	0	0	0	0	0	005	001
TRM55971.00	TZGD		1	1	1	1	1	0	0	1	0	1	0	007	001
TRM57971.00	NONE		1	1	1	1	1	0	1	1	1	1	1	010	025
TRM57971.00	TZGD		1	1	1	1	1	0	0	0	0	0	0	005	001
TRM59800.00	NONE		1	1	1	1	1	0	1	1	1	1	1	010	005
TRM59800.00	SCIS		1	1	1	1	1	0	1	1	1	1	1	010	006
TRM59900.00	SCIS		1	1	1	1	1	0	0	0	0	0	0	005	021

Freq. [MHz]	Freq. Codes
1602.000	R01 R04
1575.420	G01 E01 J01 S01 C01
1561.098	C02
1278.750	E06 J06
1268.520	C06
1246.000	R02 R06
1227.600	G02
1207.140	E07 C07
1202.025	R03
1191.795	E08 C08
1176.450	G05 E05 J05 C05 S05 I05



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GNSS Antenna Calibration – Individual Comparisons



- example
- **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



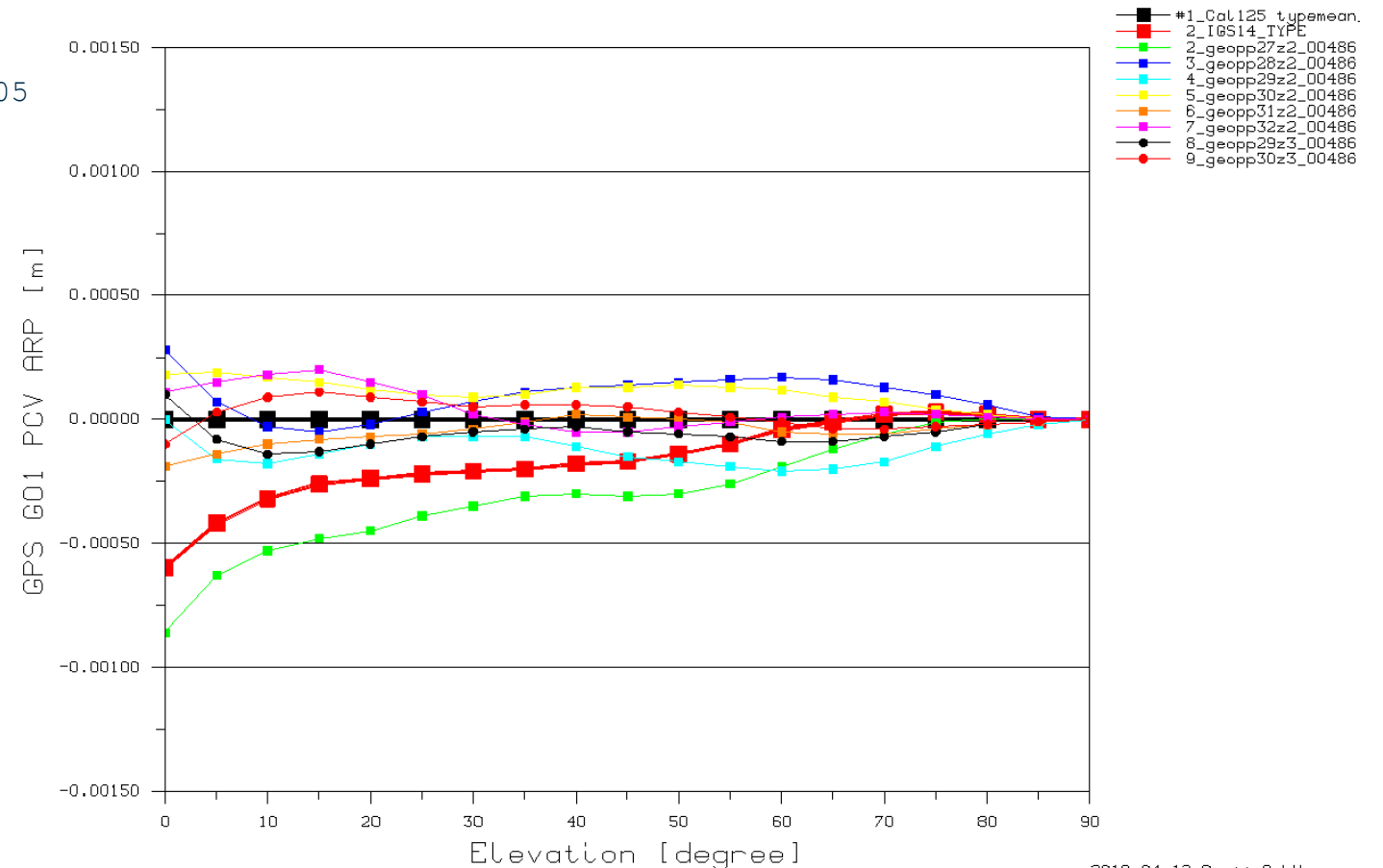
Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 I05
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```

Elevation Dependent Difference from Type Mean
Cal125 typemean, TYPE
GPS G01 PCV ARP [m]



- agreement with IGS14.atx

#a antenna #c calibration #s sets

2019-04-12 Geo++ GmbH

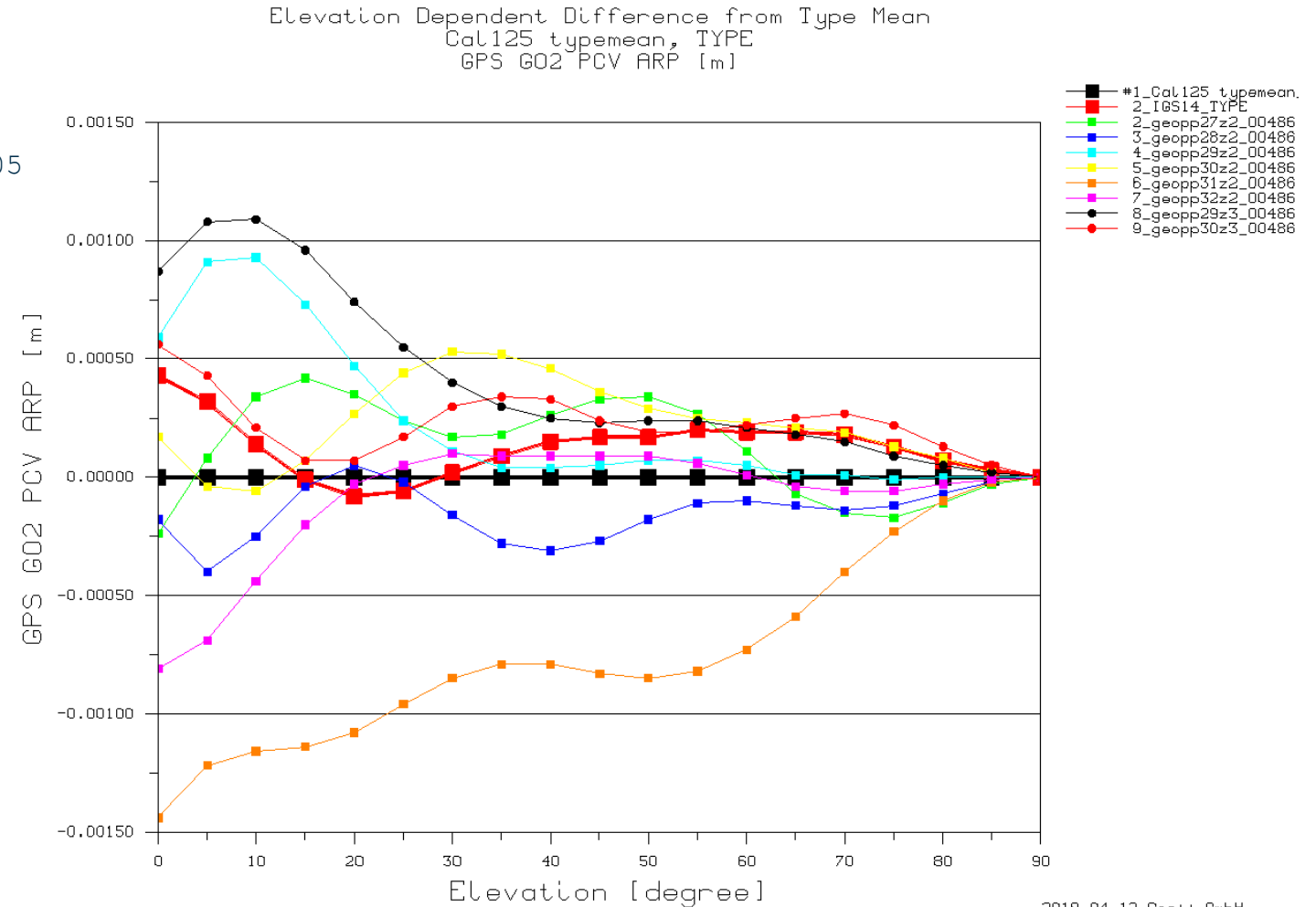
Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 I05
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```

- agreement with IGS14.atx

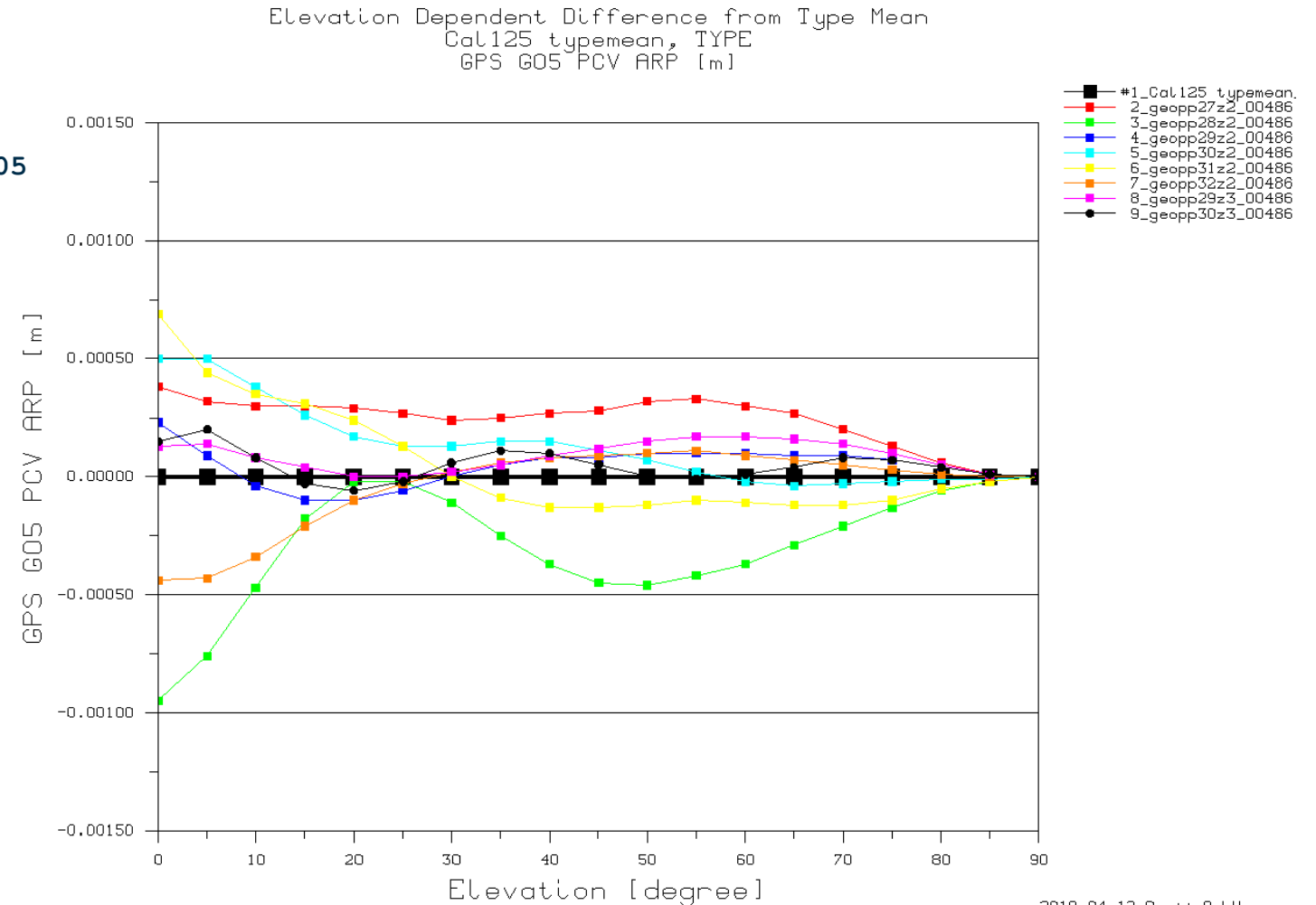


Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 I05
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```



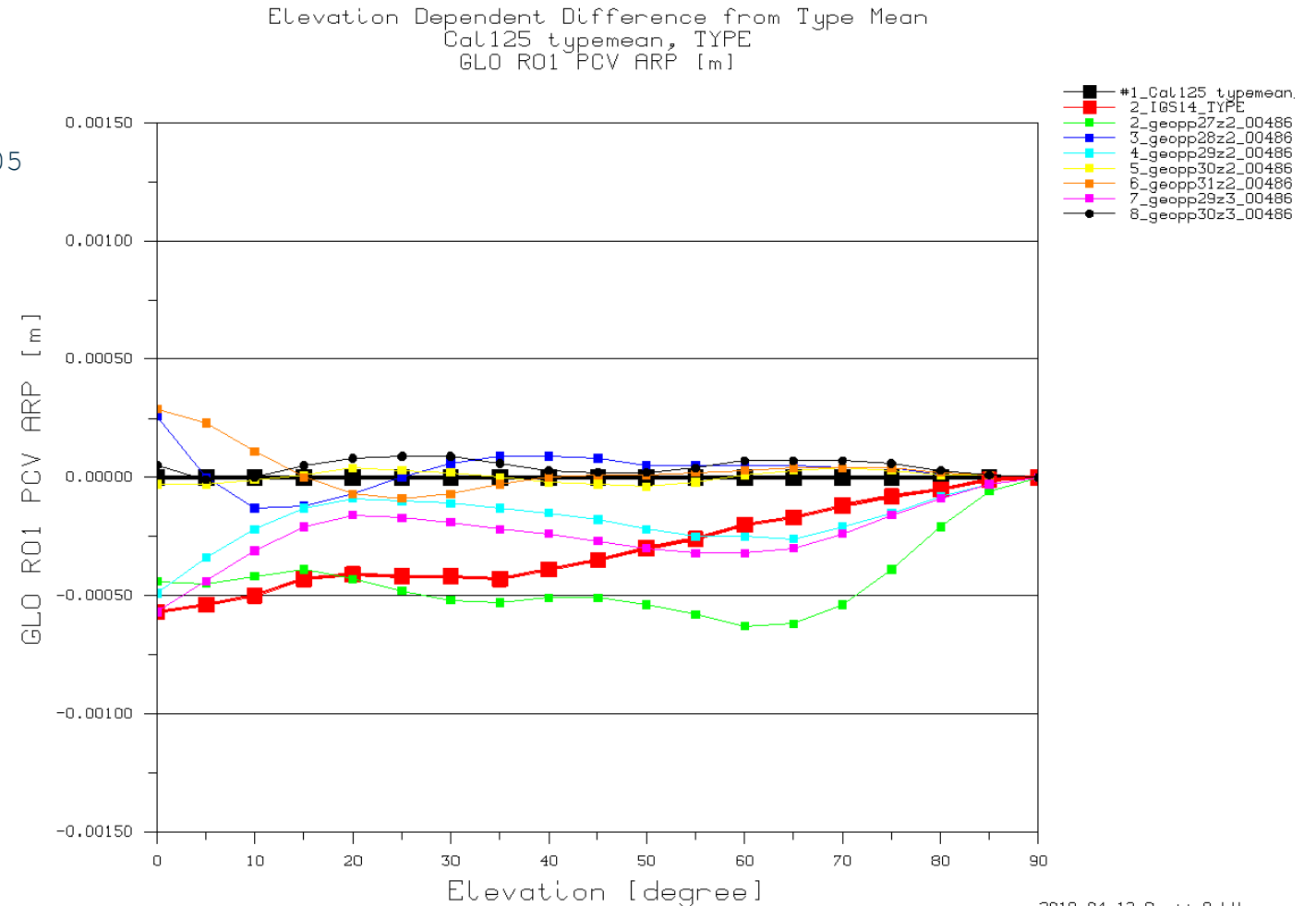
Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 I05
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```

- agreement with IGS14.atx



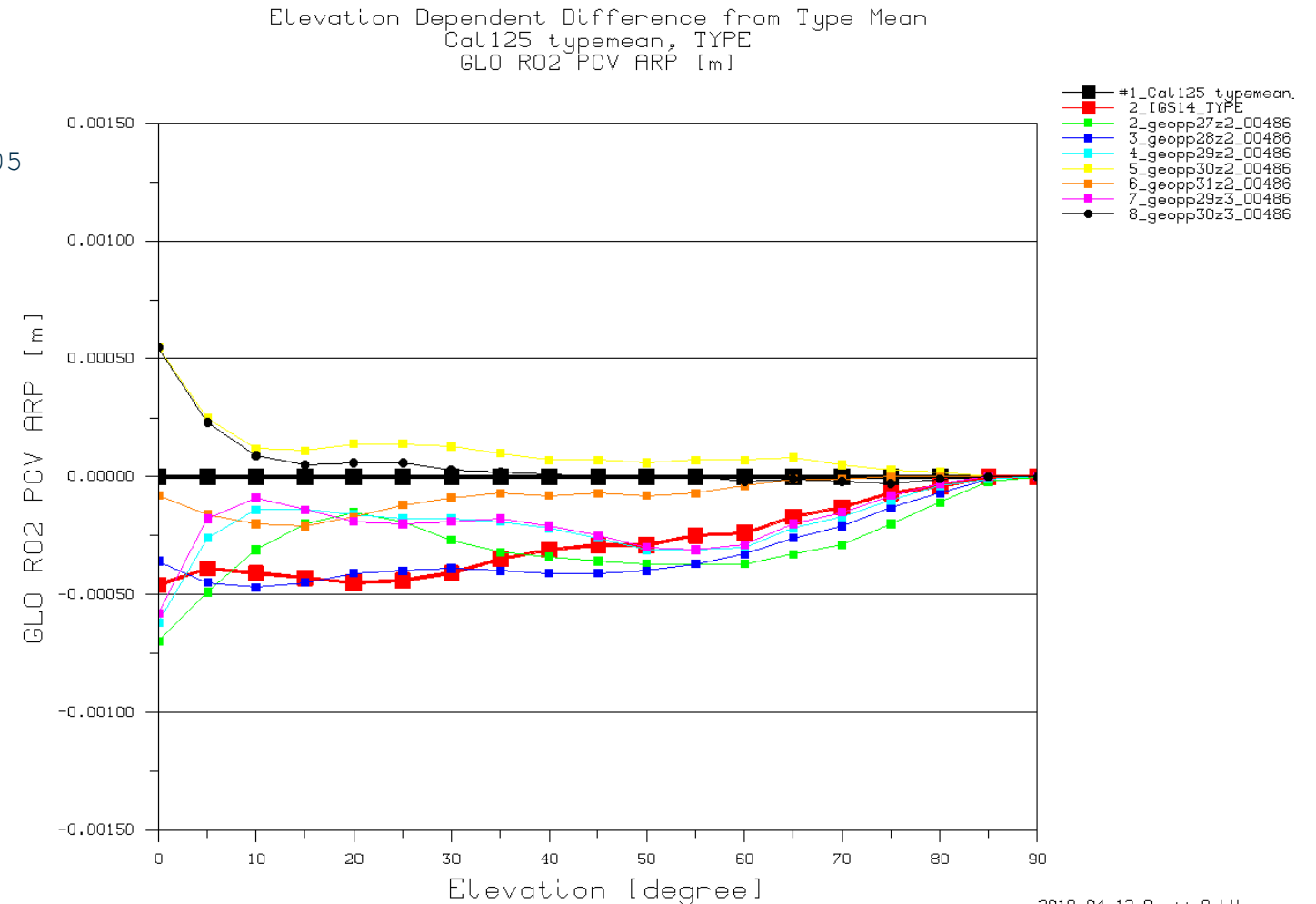
Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 I05
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```

- agreement with IGS14.atx



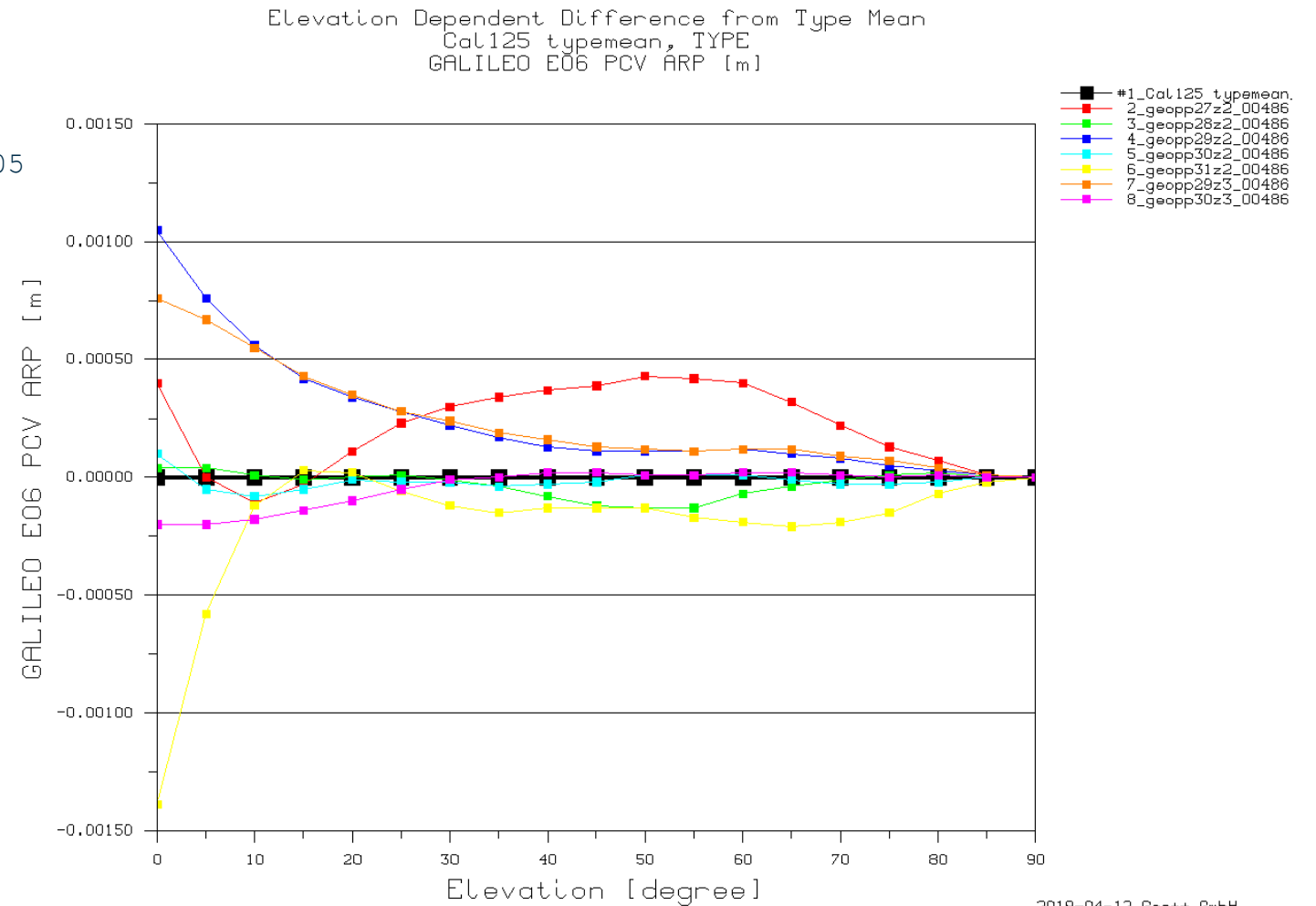
2019-04-12 Geo++ GmbH

Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 I05
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```



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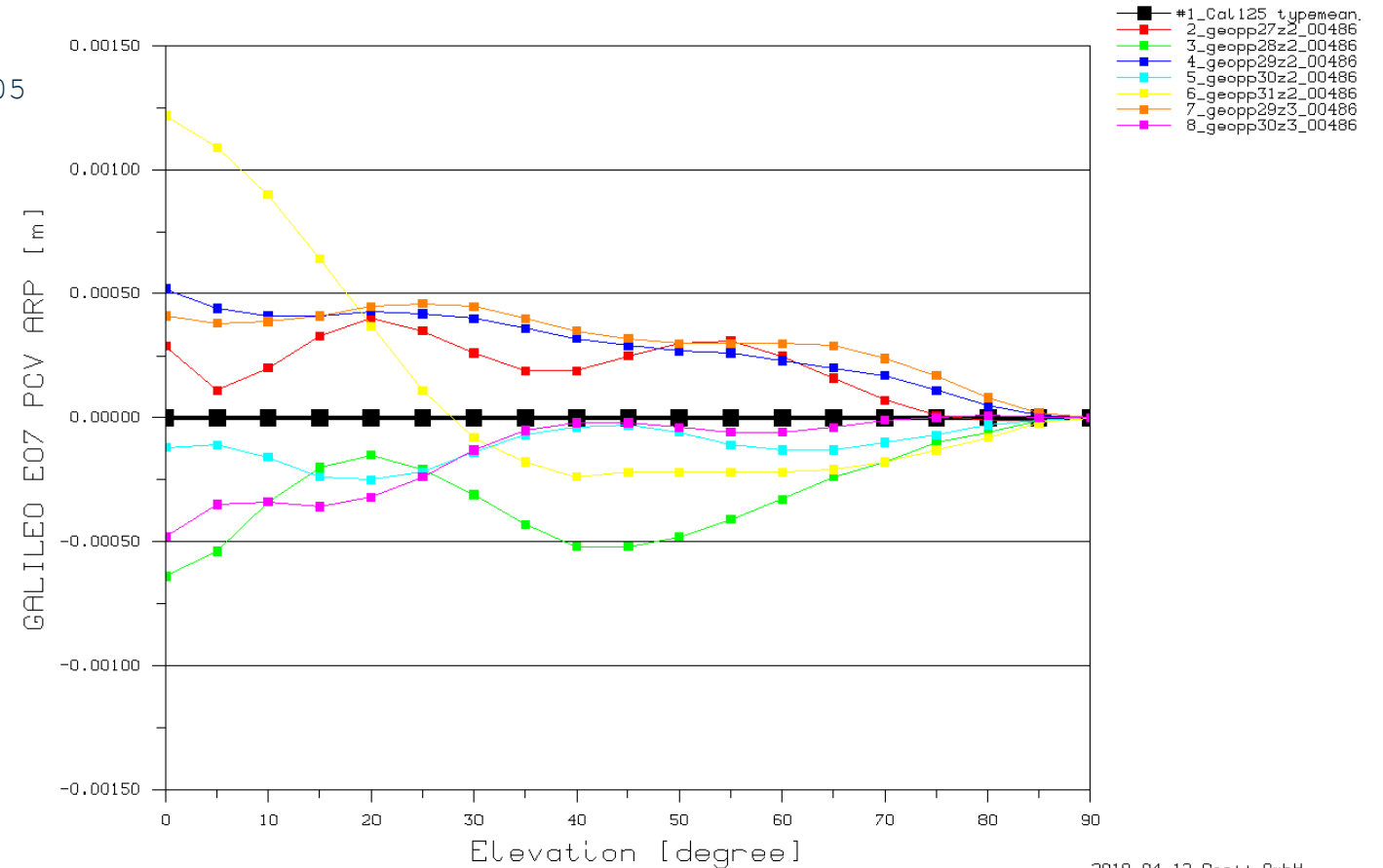
Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 I05
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```

Elevation Dependent Difference from Type Mean
Cal125 typemean, TYPE
GALILEO E07 PCV ARP [m]



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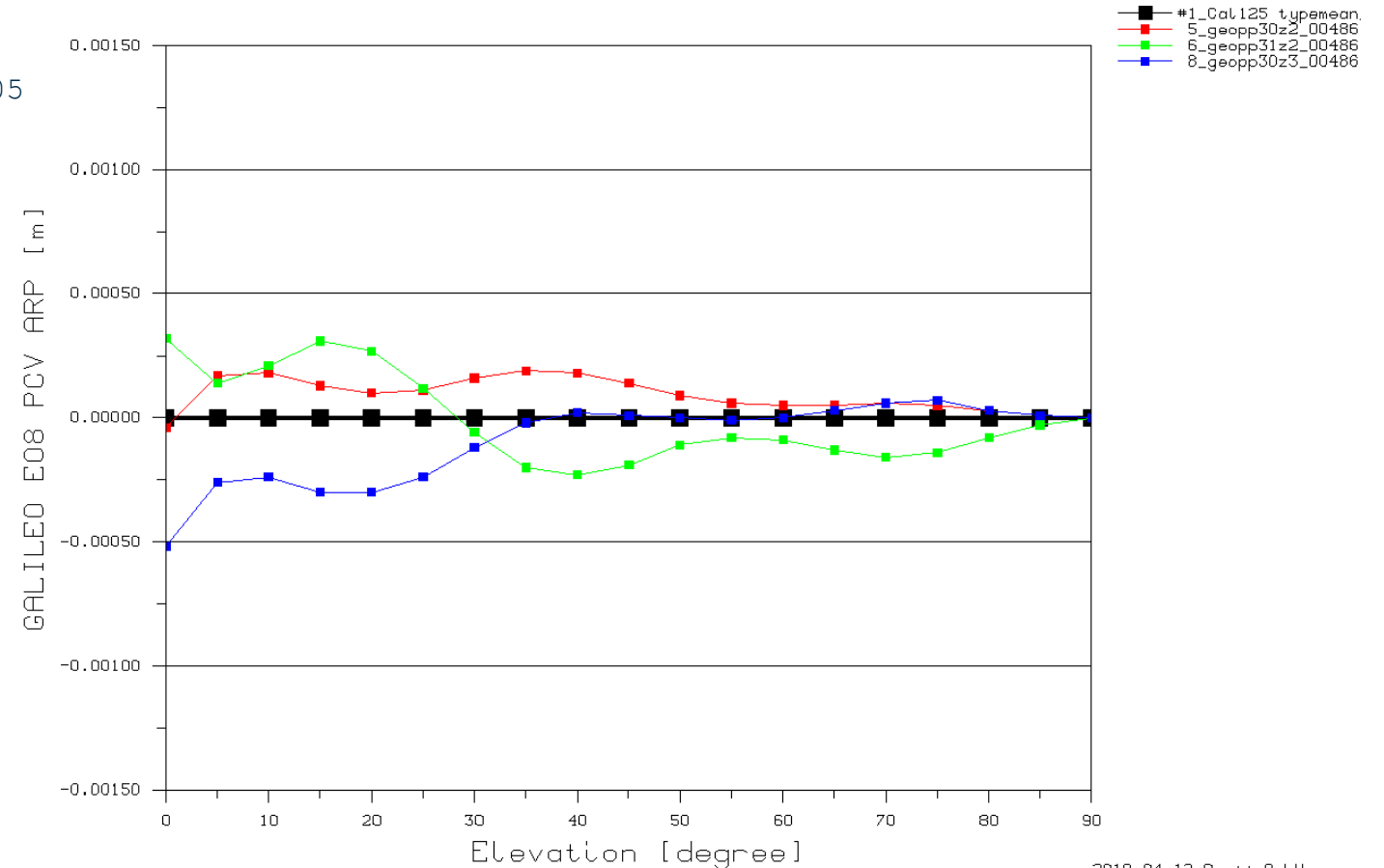
Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 I05
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```

Elevation Dependent Difference from Type Mean
Cal125 typemean, TYPE
GALILEO E08 PCV ARP [m]

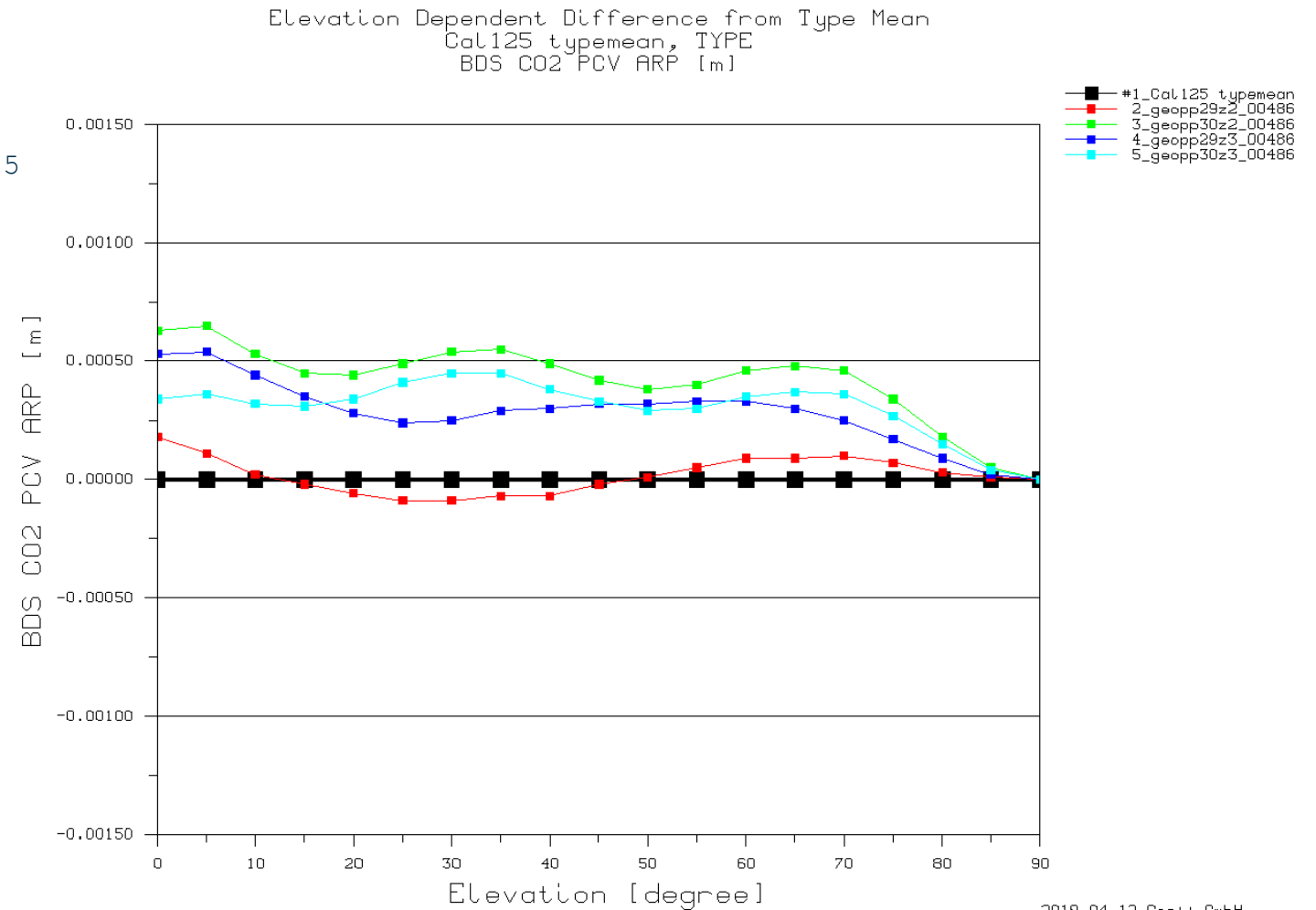


Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 I05
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```



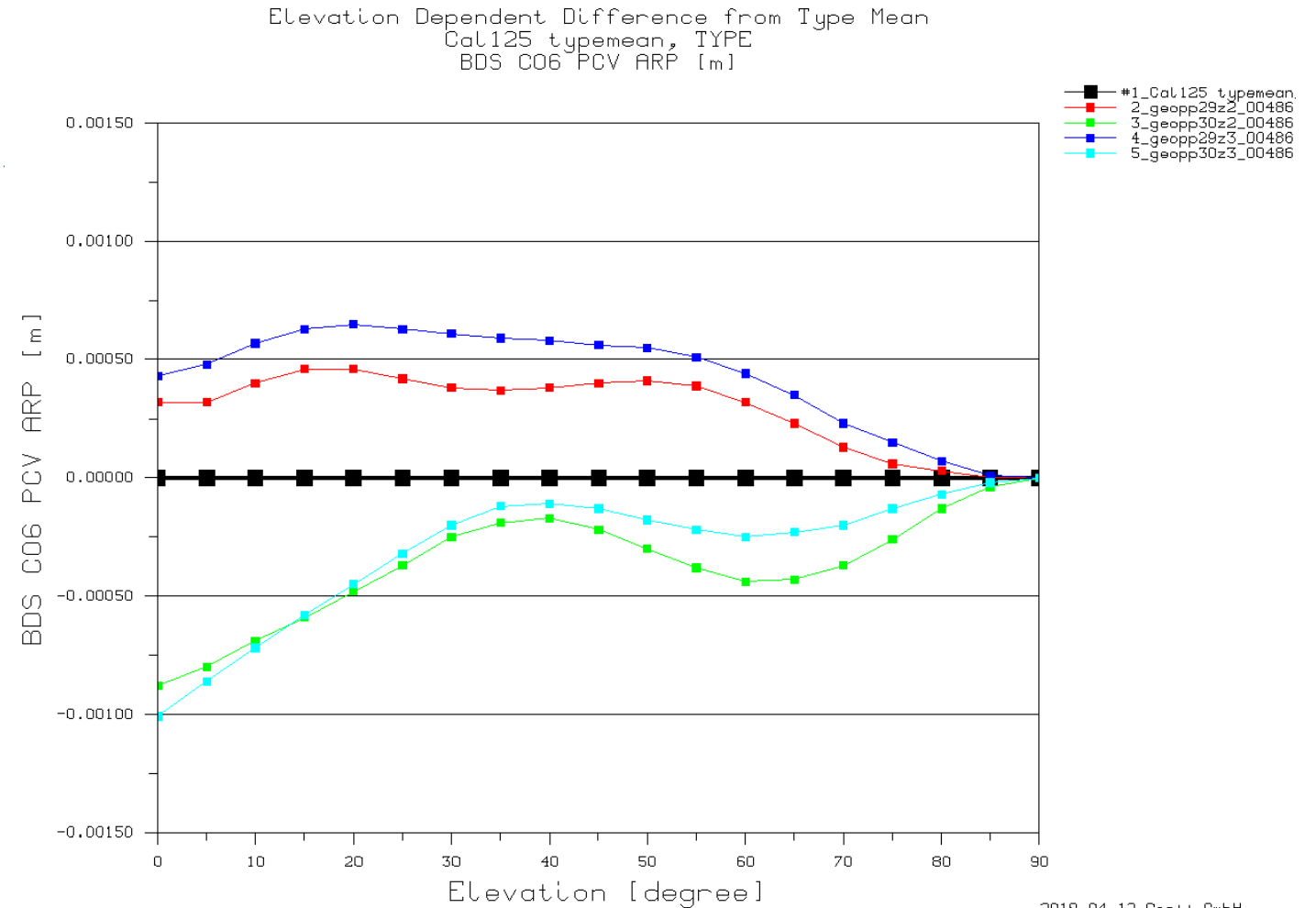
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Repeatability JAVRINGANT_DM__NONE



JAVRINGANT_DM NONE 00486

```
#a 001 #c 036 #s 047 | G01 E01 J01 S01 C01
#a 001 #c 025 #s 026 | G02 J02
#a 001 #c 036 #s 047 | G05 E05 J05 C05 S05 IO.
#a 001 #c 022 #s 026 | R01 R04
#a 001 #c 022 #s 026 | R02 R06
#a --- #c --- #s --- | R03
#a 001 #c 015 #s 021 | E06 J06
#a 001 #c 019 #s 042 | E07 C07
#a 001 #c 009 #s 013 | E08 C08
#a 001 #c 009 #s 013 | C02
#a 001 #c 015 #s 021 | C06
```



2019-04-12 Geo++ GmbH



-
- Absolute Robot-based GNSS Antenna Calibration
 - Multi-Frequency GNSS Antenna Calibration – Status
 - IGS/EUREF GNSS Antenna Priority List – IGS igsR3.atx
 - Example: JAVRINGANT_DM___NONE
 - **GNSS Antenna Group Delay Variations**
 - Example: LEIAR25.R4_____LEIT
 - ANTEX Format
 - Summary/Outlook

GNSS Antenna Group Delay Variations

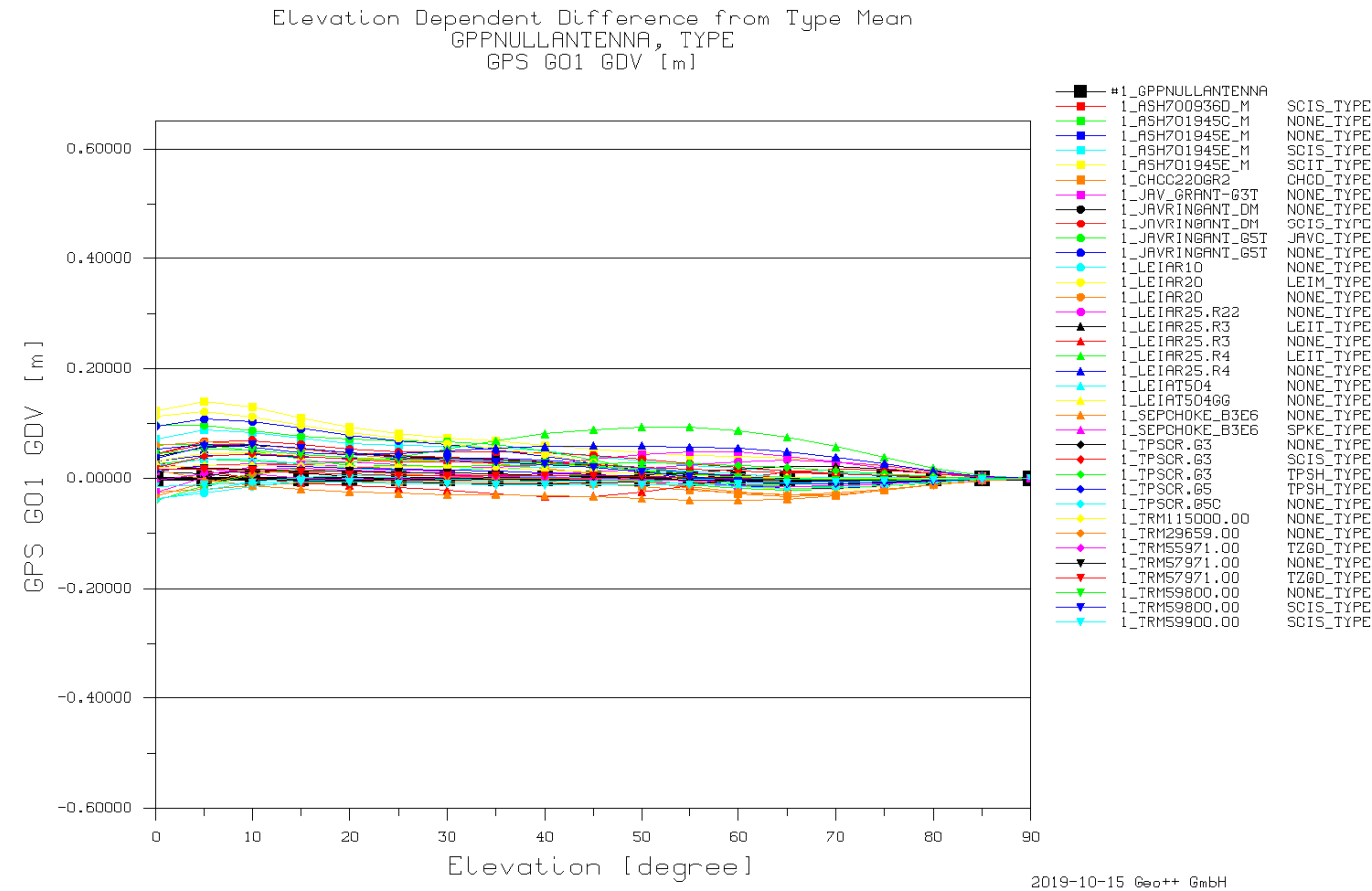


- **multi-frequency** absolute GNSS antenna **calibration** software provides
 - PCV for up to 11 GNSS frequencies
 - **GDV for any signals**
 - CNV for all signals (under preparation)
- code observable getting more important
- antenna **type mean GDV** correction required for
 - **code based** GNSS **positioning** applications
 - **code sensitive** GNSS **applications**
(e.g. PPP utilizing Melbourne-Wübbena linear combination)
 - receiver GDV antenna correction required **to determine satellite GDV**
 - ...

GNSS Antenna Group Delay Variations



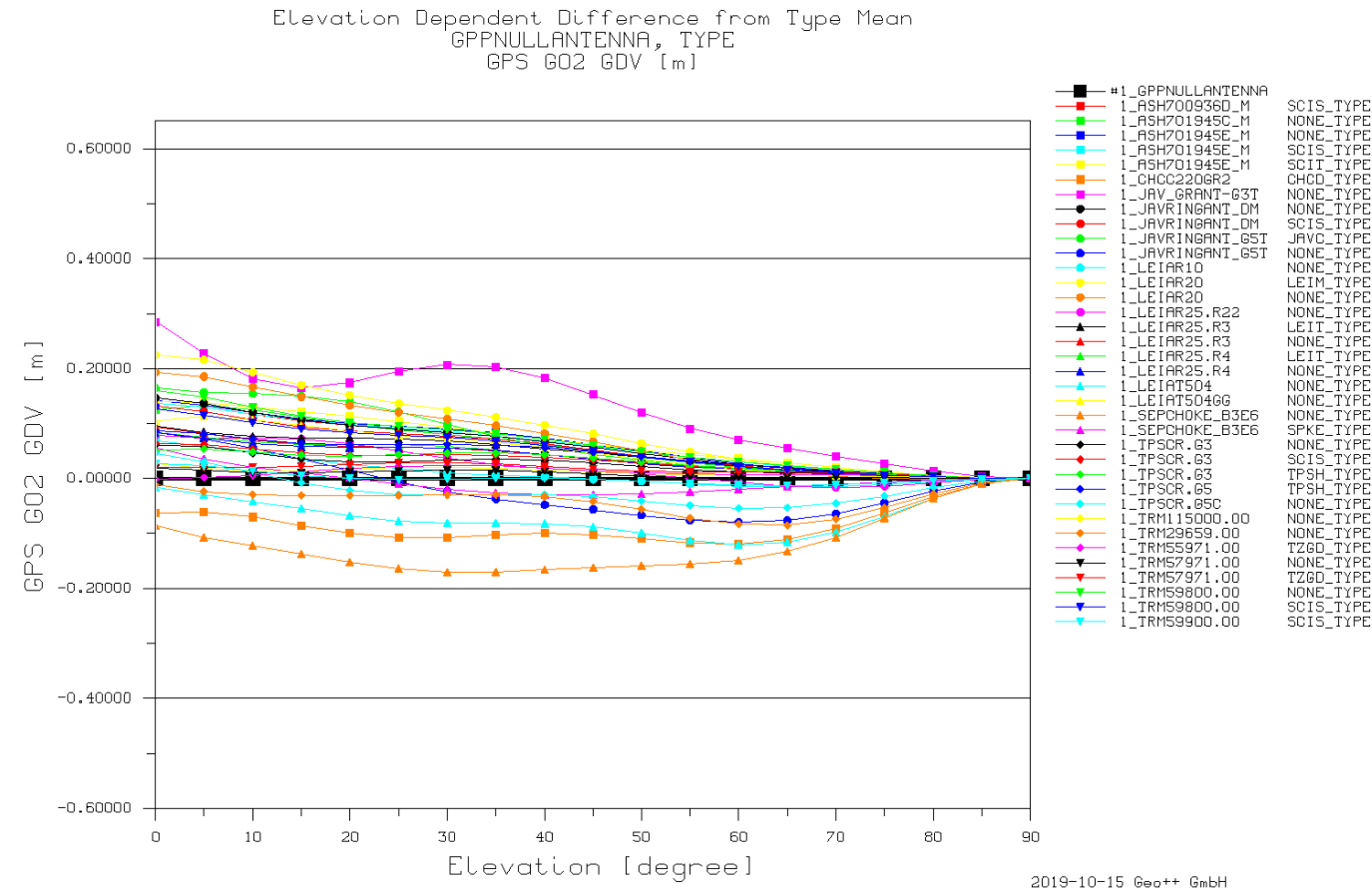
- **GDV antenna type mean correction**
- **pattern of 36 antenna types** corresponding to igsR3.atx
- **G01 GDV**
 - GDV related to a nominal PCV offset
 - difference to GPPNULLANTENNA, i.e. absolute GDV



GNSS Antenna Group Delay Variations



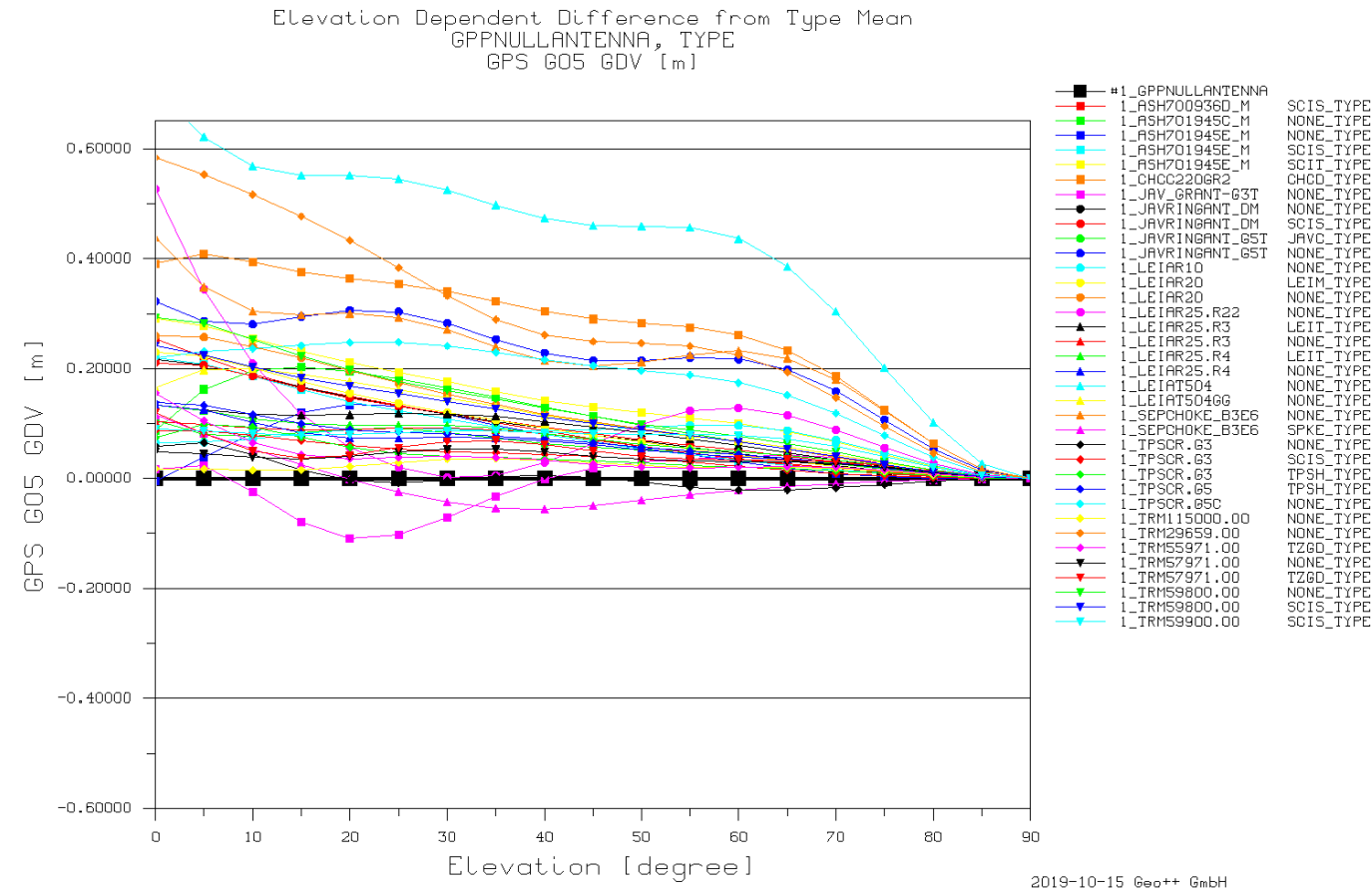
- GDV antenna type mean correction
- G02 GDV



GNSS Antenna Group Delay Variations



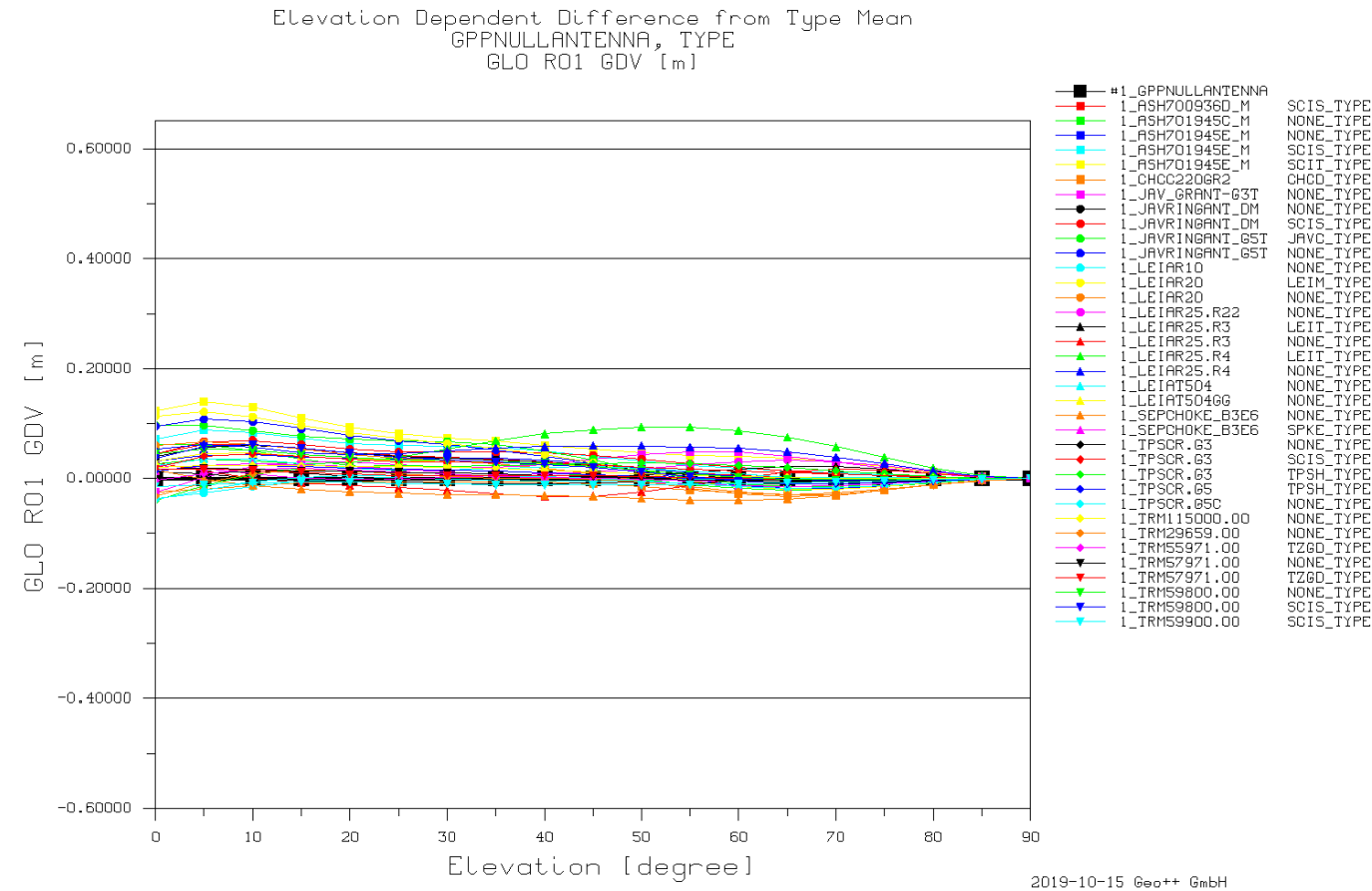
- GDV antenna type mean correction
- G05 GDV



GNSS Antenna Group Delay Variations



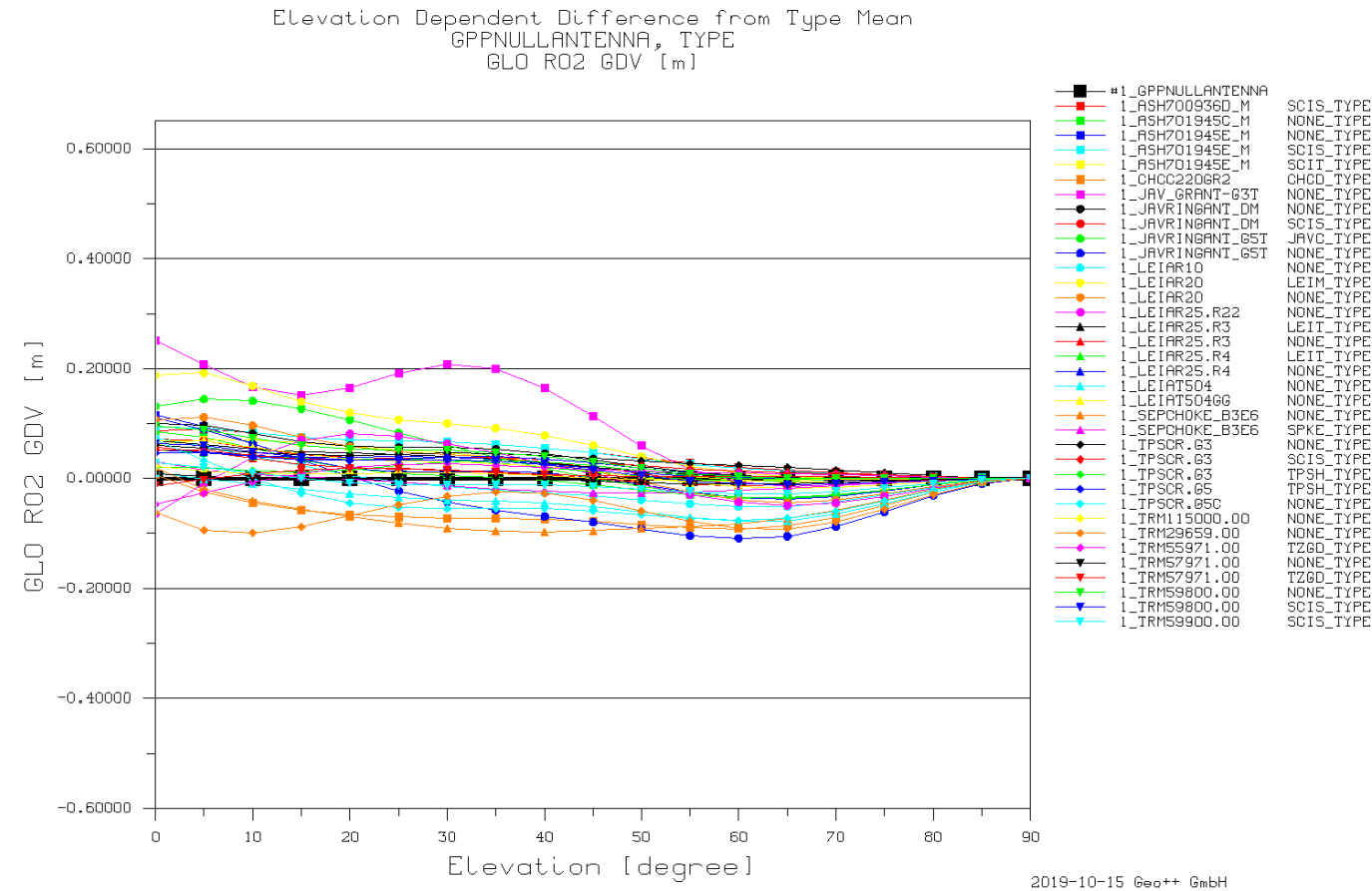
- GDV antenna type mean correction
- R01 GDV



GNSS Antenna Group Delay Variations



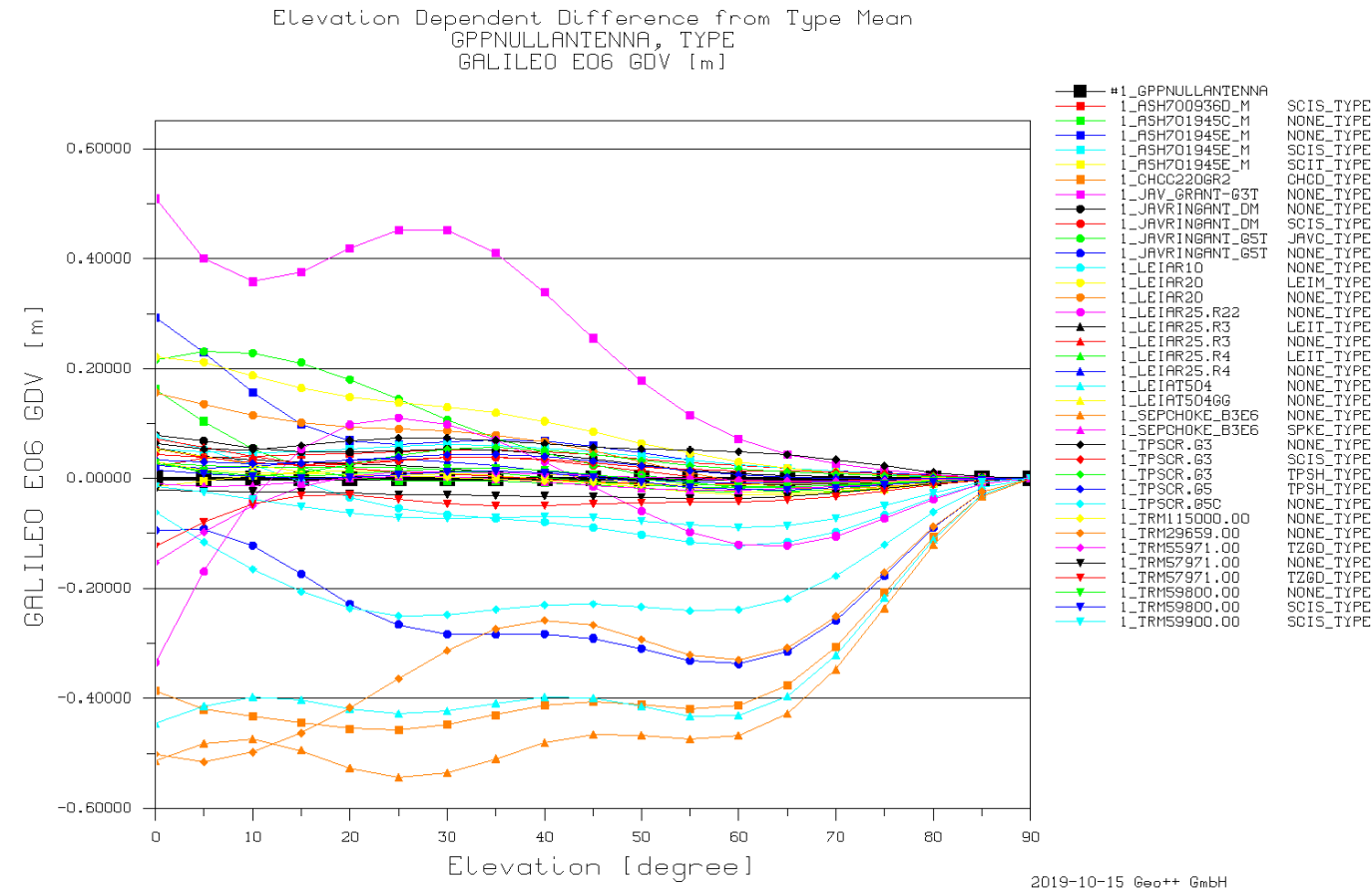
- GDV antenna type mean correction
- R02 GDV



GNSS Antenna Group Delay Variations



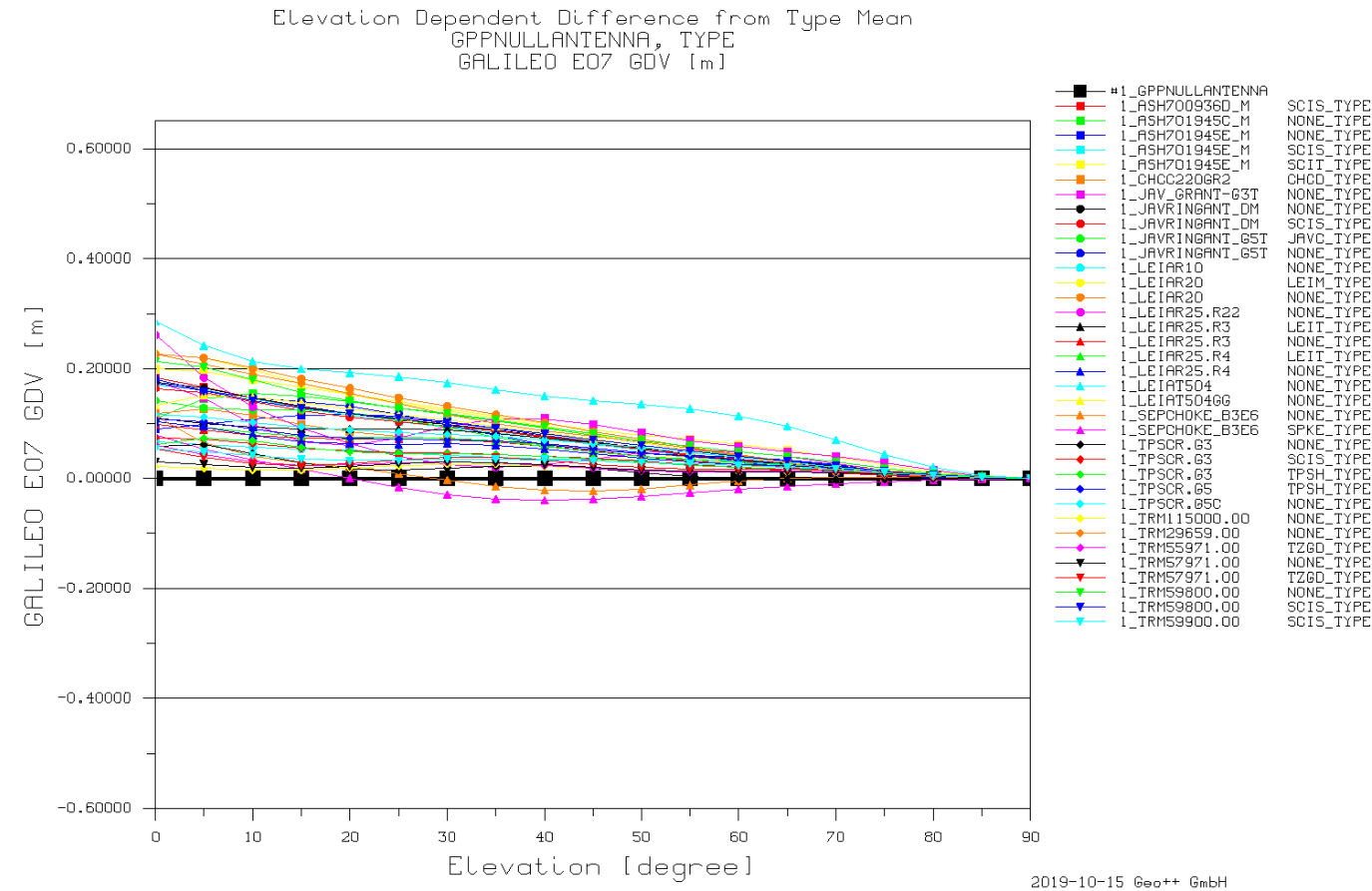
- GDV antenna type mean correction
- E06 GDV



GNSS Antenna Group Delay Variations



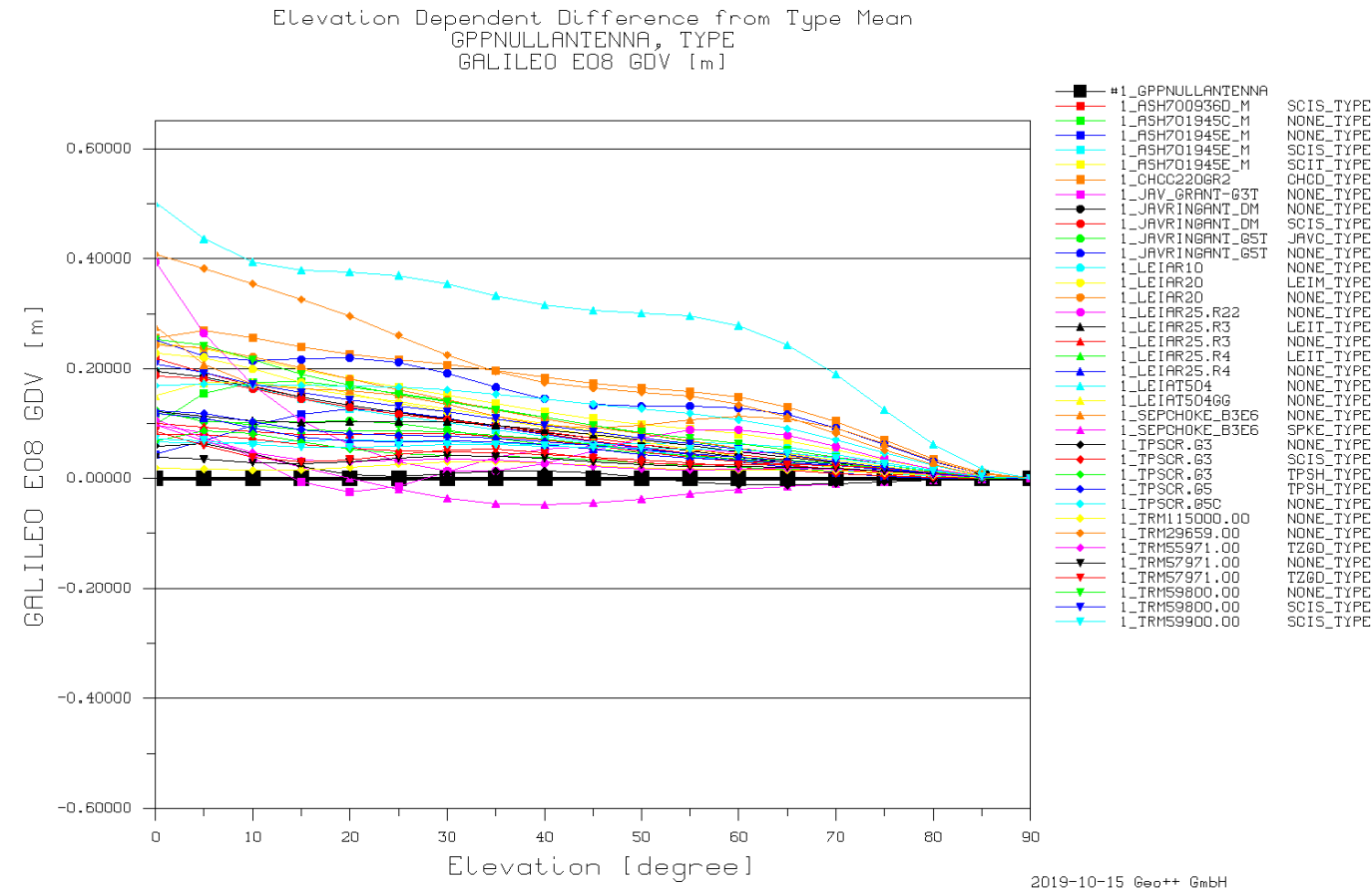
- GDV antenna type mean correction
- E07 GDV



GNSS Antenna Group Delay Variations



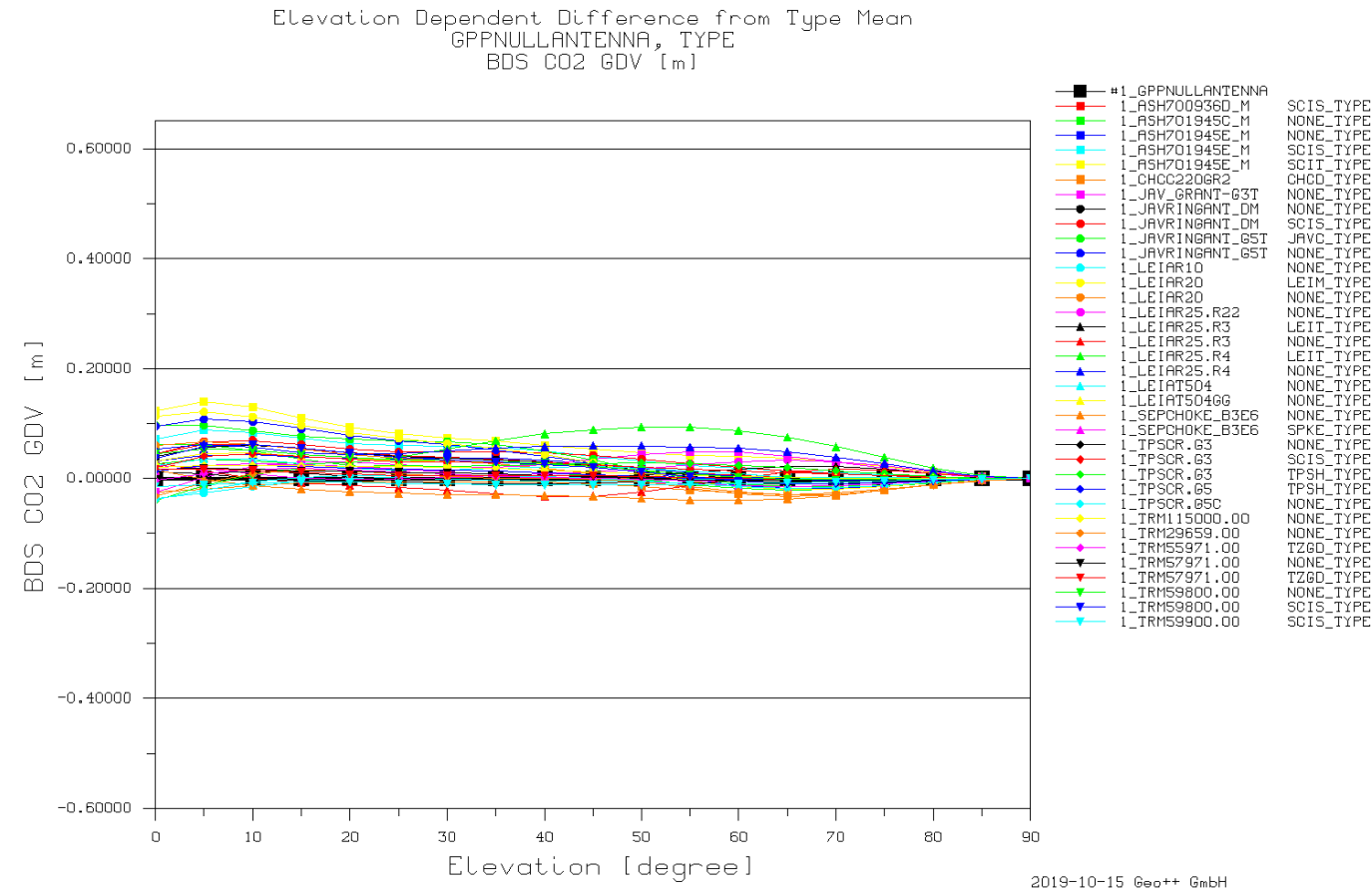
- GDV antenna type mean correction
- E06 GDV



GNSS Antenna Group Delay Variations



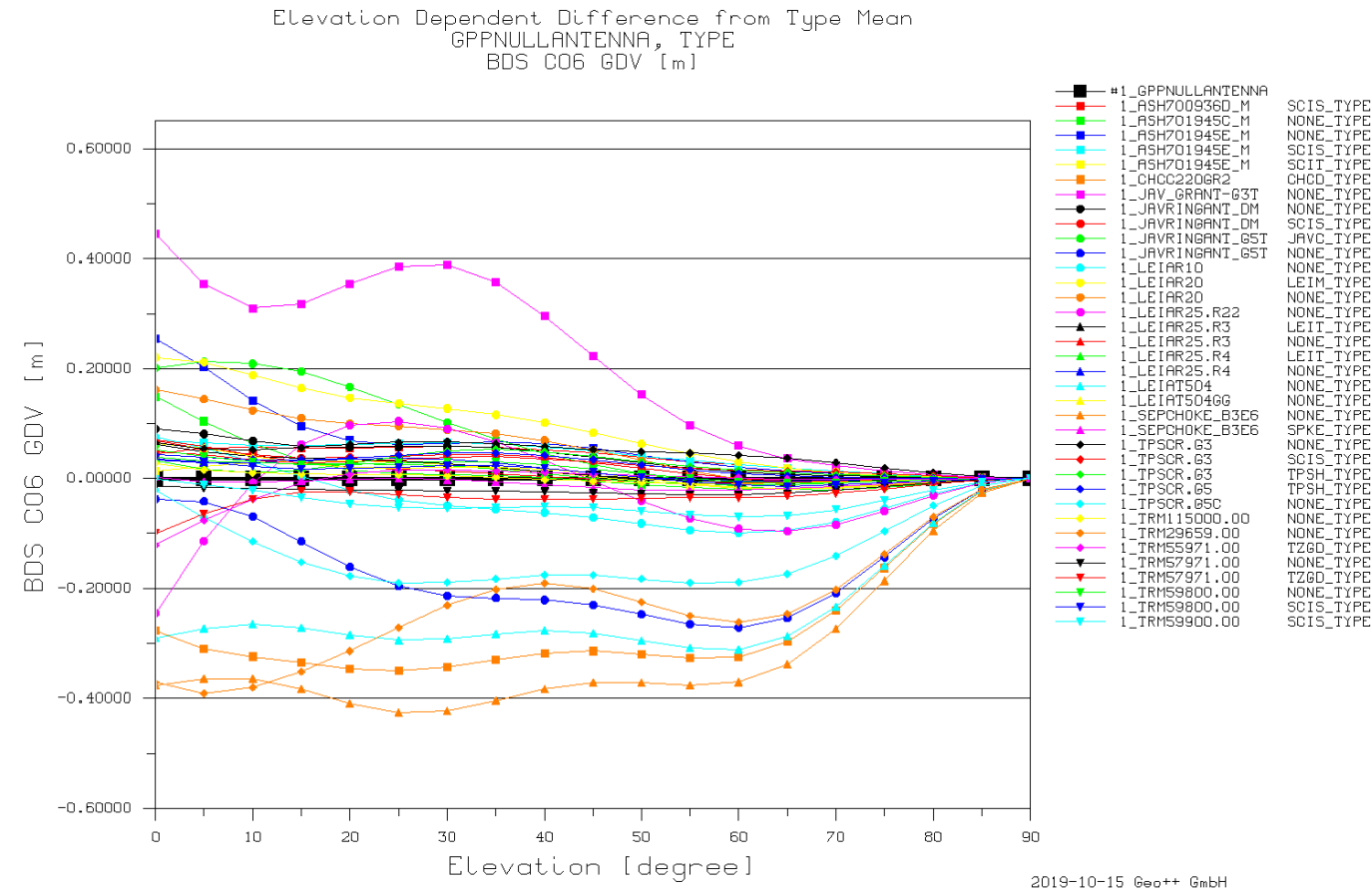
- GDV antenna type mean correction
- C02 GDV



GNSS Antenna Group Delay Variations



- GDV antenna type mean correction
- C02 GDV



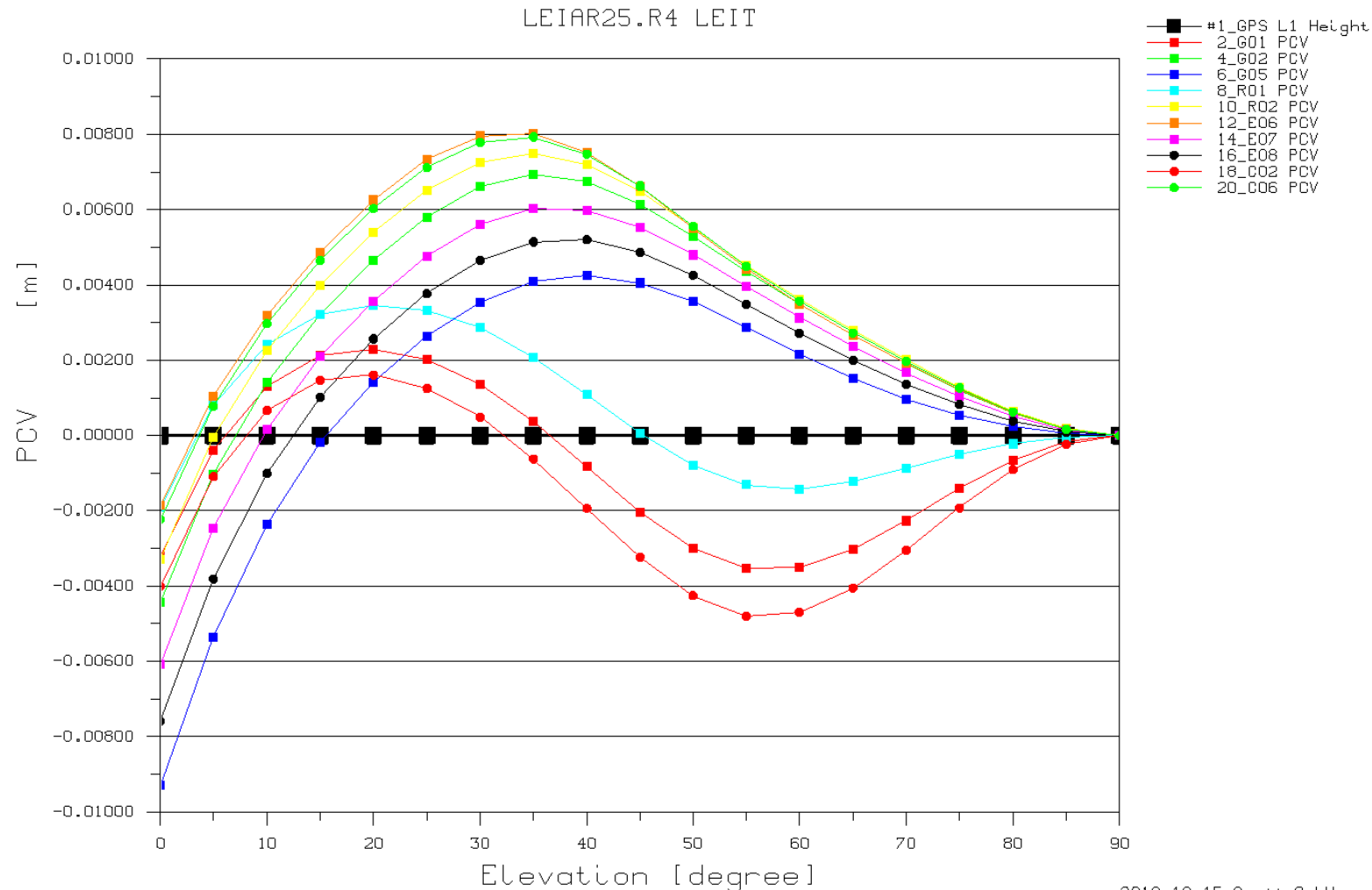


-
- Absolute Robot-based GNSS Antenna Calibration
 - Multi-Frequency GNSS Antenna Calibration – Status
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 - Example: JAVRINGANT_DM___NONE
 - GNSS Antenna Group Delay Variations
 - **Example: LEIAR25.R4_____LEIT**
 - ANTEX Format
 - Summary/Outlook

Example: GNSS Antenna PCV for all Frequencies



- example
- **PCV** LEIAR25.R4 LEIT
- antenna **type** mean correction
- **differences** to GPS L1 height offset impact (null line)
- PCV differences between all frequencies
- impact may **change** significantly for linear combinations

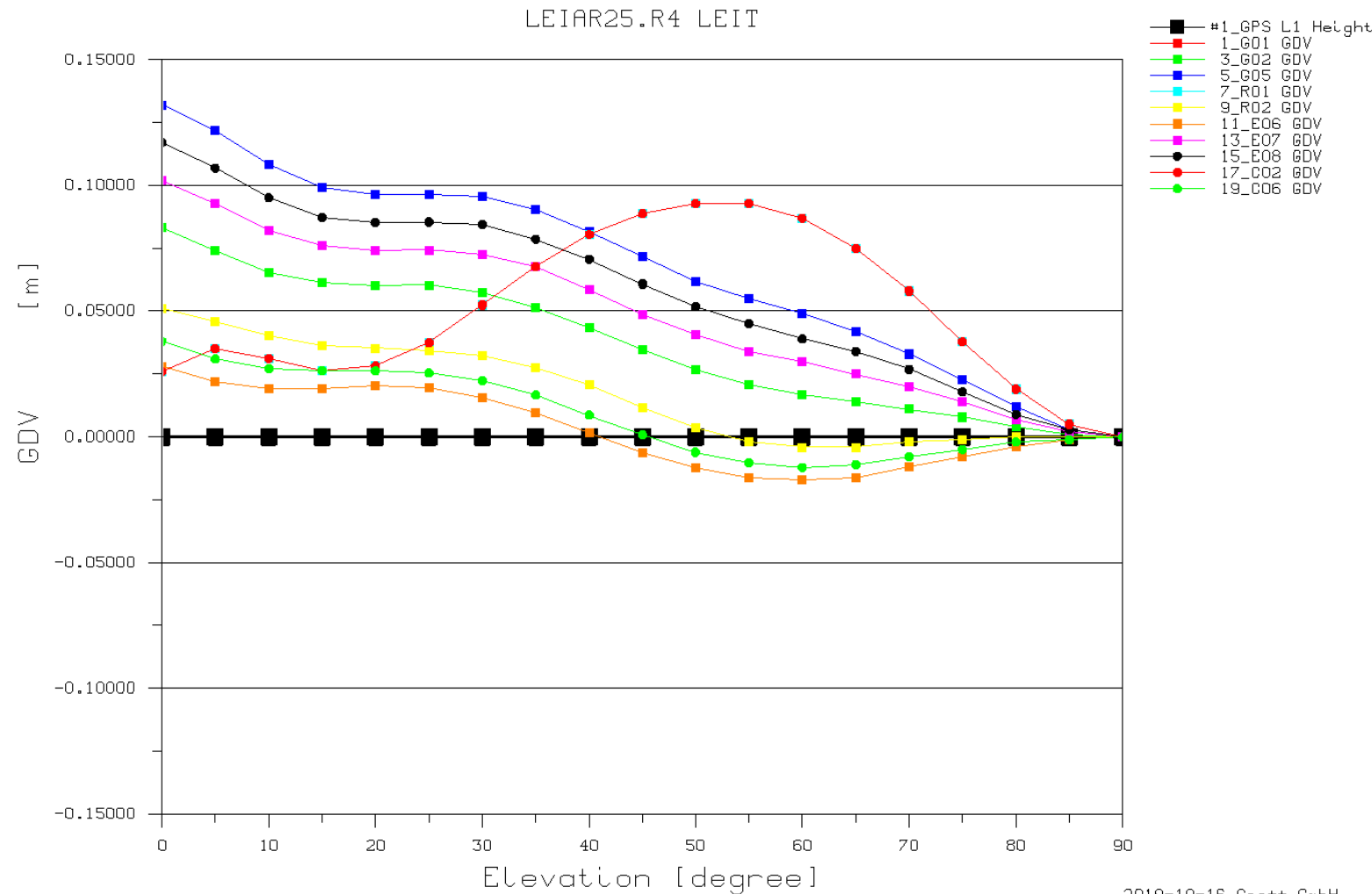


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Example: GNSS Antenna GDV for all Frequencies



- example
- **GDV** LEIAR25.R4 LEIT
- antenna **type** mean correction
- **differences** to GPS L1 height offset impact (null line)
- GDV differences between all frequencies
- impact may **change** significantly for linear combinations



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-
- Absolute Robot-based GNSS Antenna Calibration
 - Multi-Frequency GNSS Antenna Calibration – Status
 - IGS/EUREF GNSS Antenna Priority List – IGS igsR3.atx
 - Example: JAVRINGANT_DM___NONE
 - GNSS Antenna Group Delay Variations
 - Example: LEIAR25.R4_____LEIT
 - **ANTEX Format**
 - Summary/Outlook

ANTEX Format



- ANTEX 1.4 status
- all major GNSS systems (except IRNSS)
- all major PCV frequencies (except GLONASS G3 and L1+L2 CDMA)
- **satellite** antenna **PCV** (offset and variation)
 - definition of mean phase is
center position =
CM position + phase center offset vector
- **receiver** antenna **PCV** (offset and variation)
 - definition of mean phase is
center position =
ARP position + phase center offset vector
- **RMS** information for offset and/or PCV
- ANTEX update needed, which requires mainly support of
- group delay variations (**GDV**) **corrections** for **receiver and satellite antenna**
- **flexible handling** of center of mass (**CM**) and satellite antenna pattern (PCV, GDV) using **satellite reference point** (SRP)

CM
ARP
SRP

center of mass
antenna reference point
satellite reference point



-
- Absolute Robot-based GNSS Antenna Calibration
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 - Example: JAVRINGANT_DM___NONE
 - GNSS Antenna Group Delay Variations
 - ANTEX Format
 - Example: LEIAR25.R4_____LEIT
 - **Summary/Outlook**

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
 - post-processing executed for new GNSS multi-frequency corrections
- **GDV antenna corrections** are getting important
 - significant impact on code based GNSS applications
- **ANTEX format requires update**
 - to support GDV and flexible satellite reference point

Thanks for your Attention



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