# 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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- 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

- 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

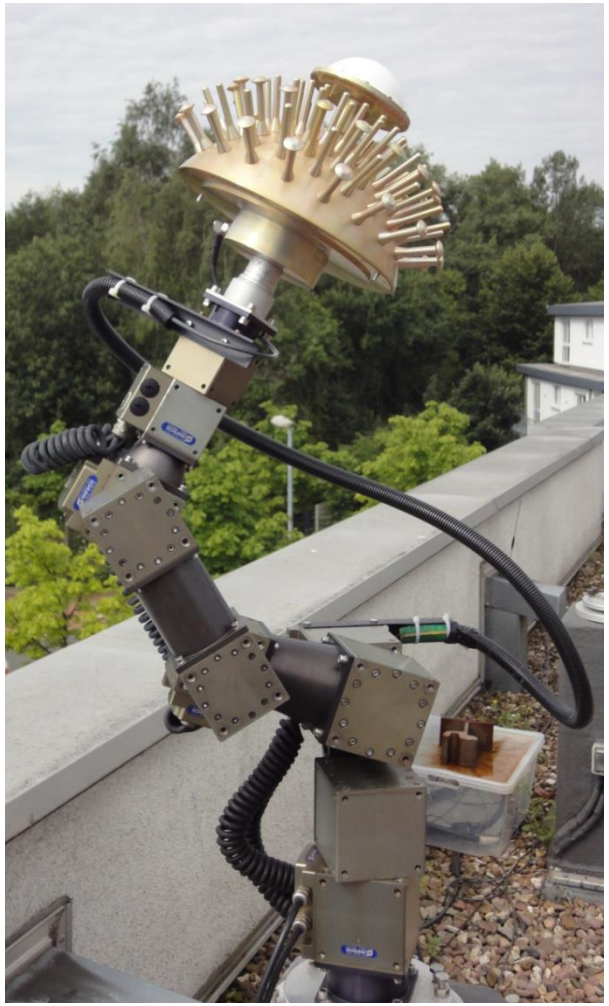
  - 2000 Geo++, **Garbsen** , Germany (retired)
  - **2000** ife, **Hannover** , Germany
  - 2005 SenB, Berlin, Germany (retired)
  - **2009** Geo++, **Garbsen** , Germany
  - **2012** GSA, Canberra, **Australia**
  - **2013** SenB, **Berlin** , Germany
  - **2019** Geo++, **Garbsen** , Germany


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

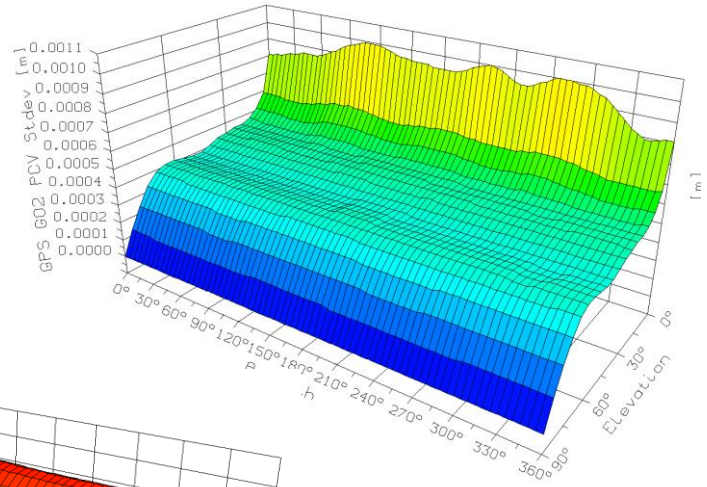


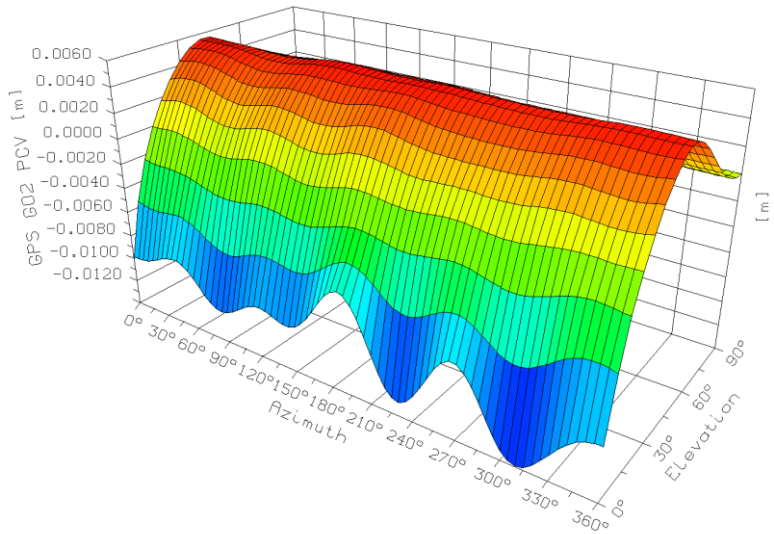
Geo++ robot with GNSS antenna TPSPN_A5 NONE

* 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 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                 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
                                                                     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**
- data sets for 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 | | 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 | |

# 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 antennas 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 (shared with IGS/MGEX list) **79%**
  - 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

| 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 |

| 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 |

# 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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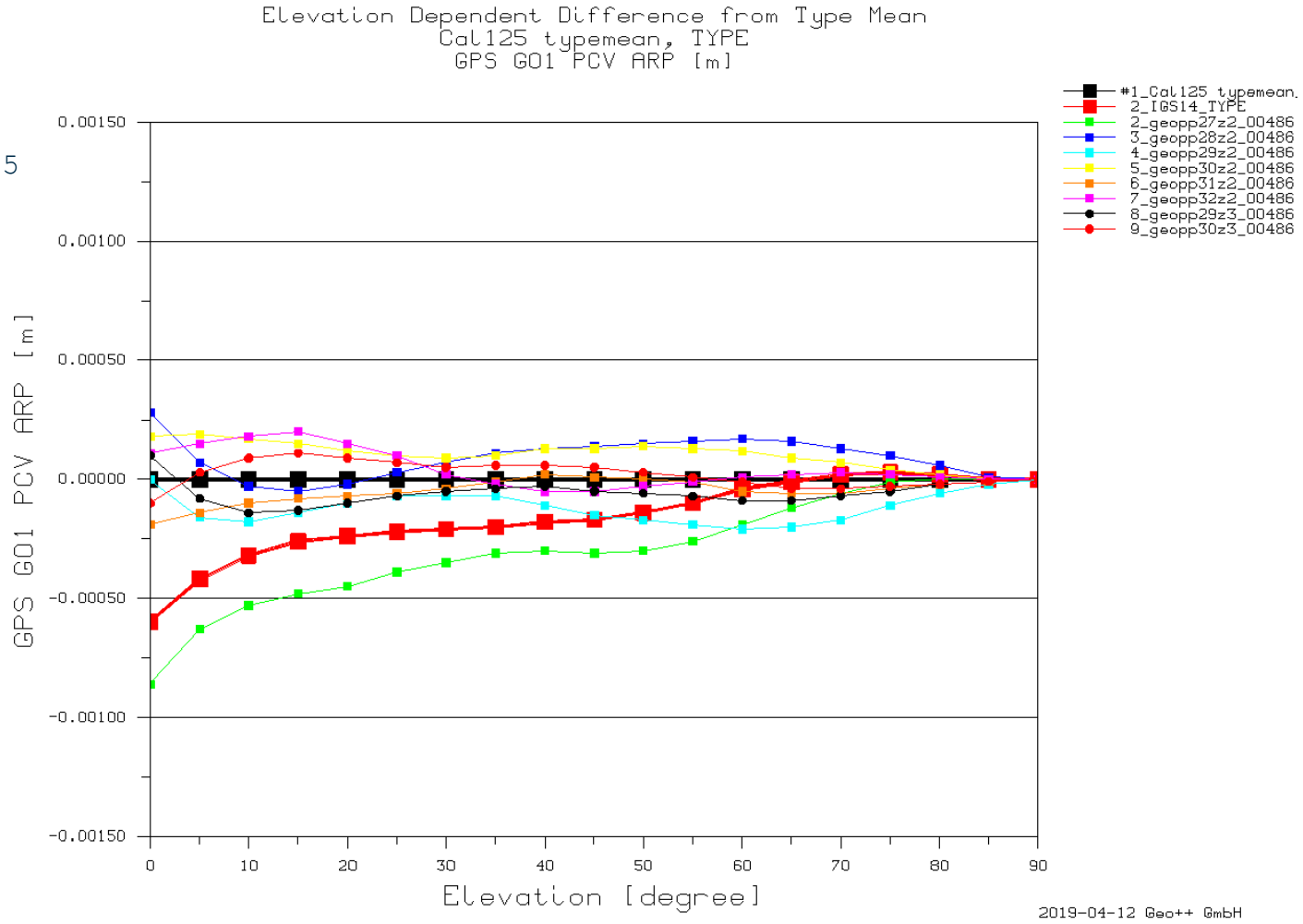
# GNSS Antenna Calibration – Individual Comparisons

- 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
```

- agreement with IGS14.atx

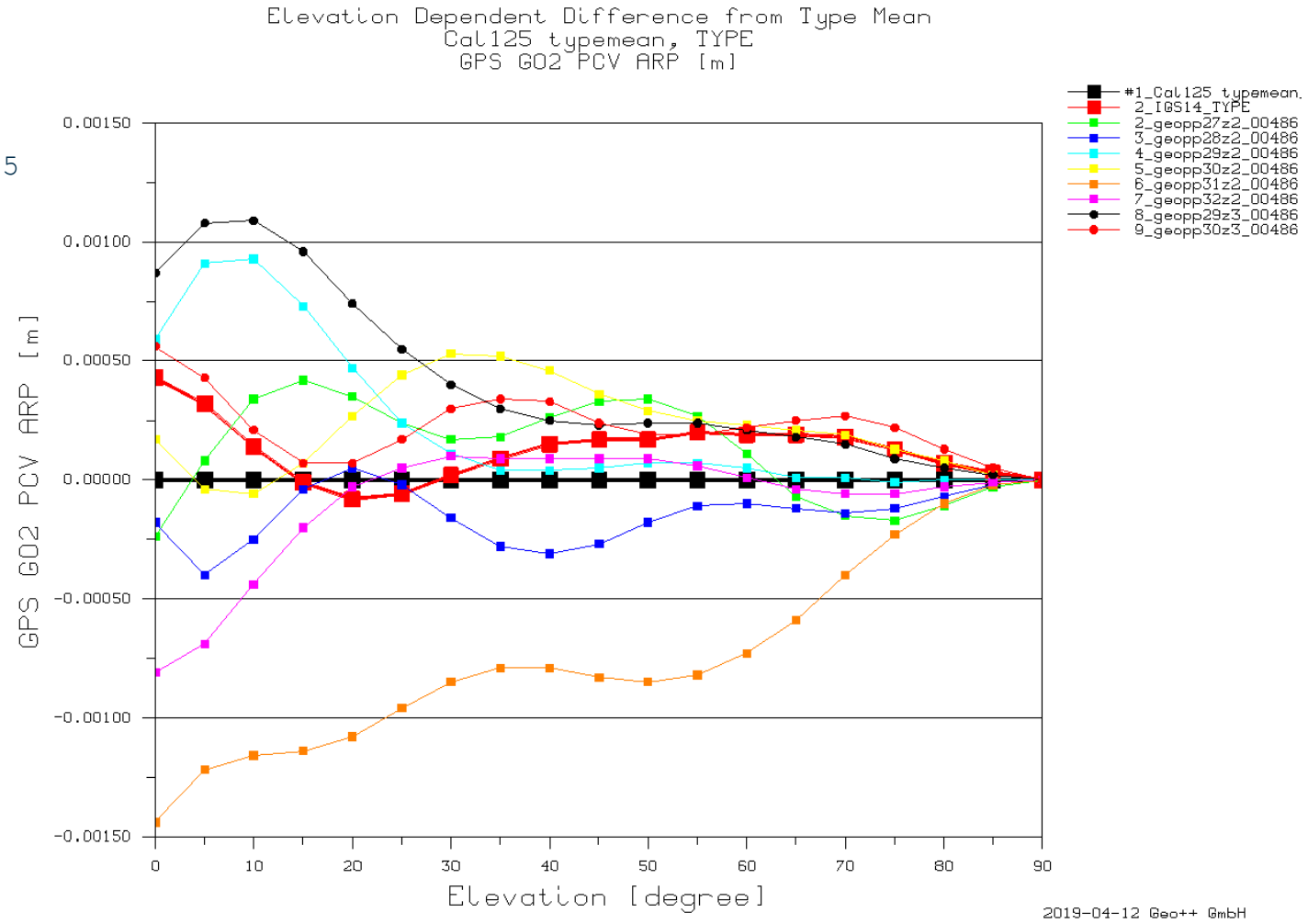



#a antenna #c calibration #s sets

# 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
```

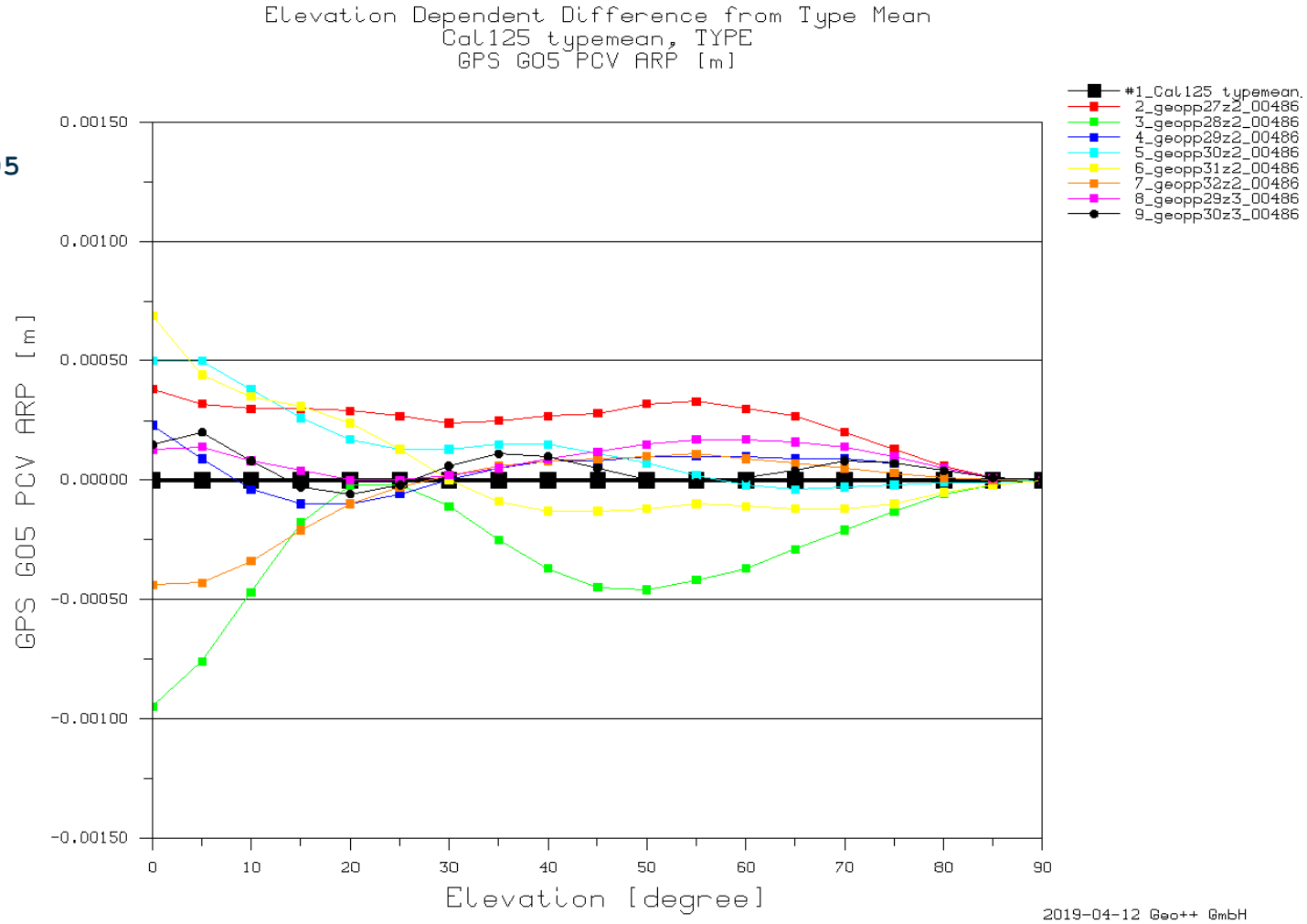
- agreement with IGS14.atx



# Repeatability JAVRINGANT_DM___NONE

**JAVRINGANT_DM NONE 00486**

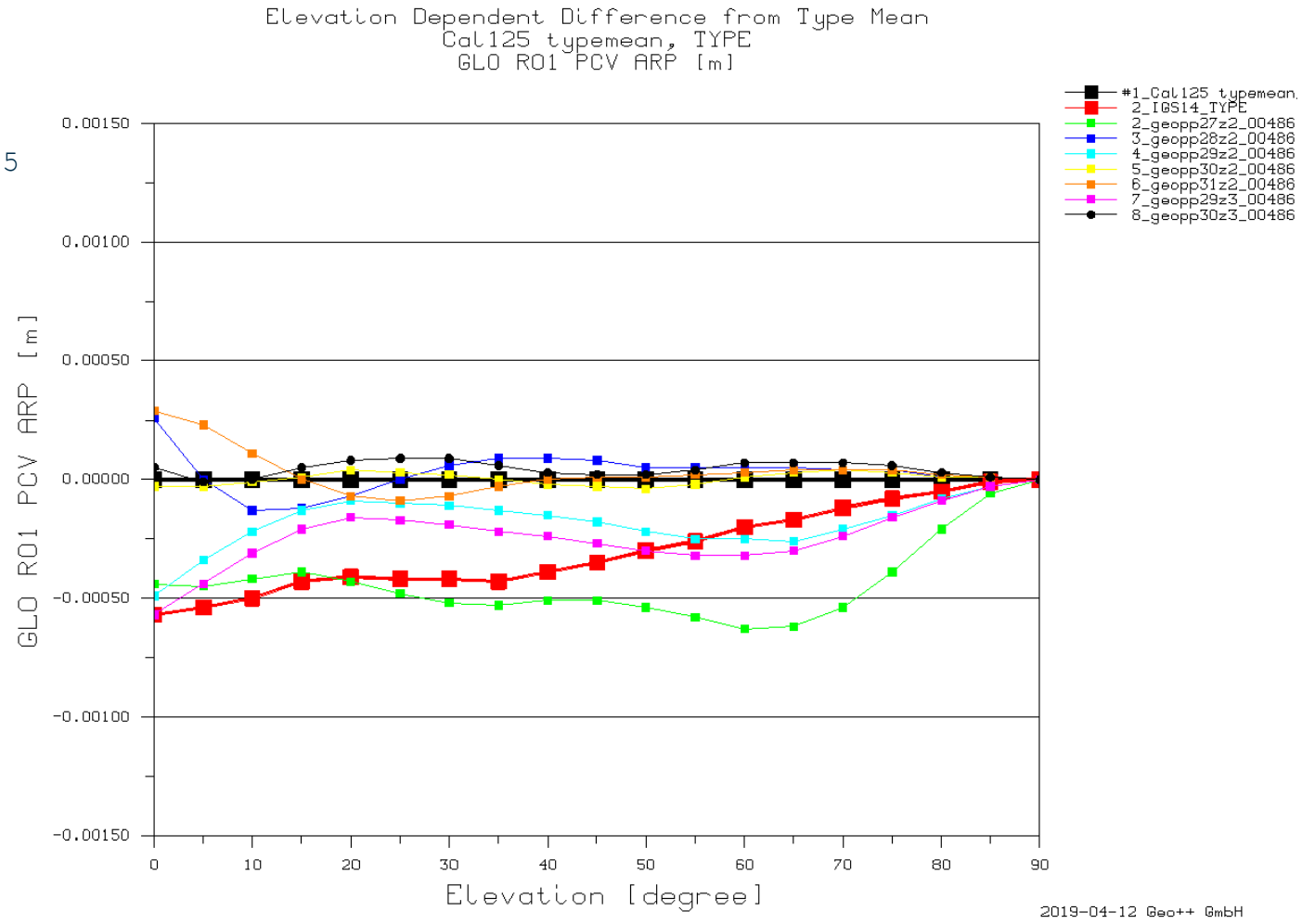
```
 #a 001 #c 036 #s 047  | G01 E01 J01 S01 C01
 #a 001 #c 025 #s 026  | G02 J02
 #a 001 #c 036 #s 047  | G05 E05 J05 C05 S05 I05
 #a 001 #c 022 #s 026  | R01 R04
 #a 001 #c 022 #s 026  | R02 R06
 #a --- #c --- #s ---  | R03
 #a 001 #c 015 #s 021  | E06 J06
 #a 001 #c 019 #s 042  | E07 C07
 #a 001 #c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

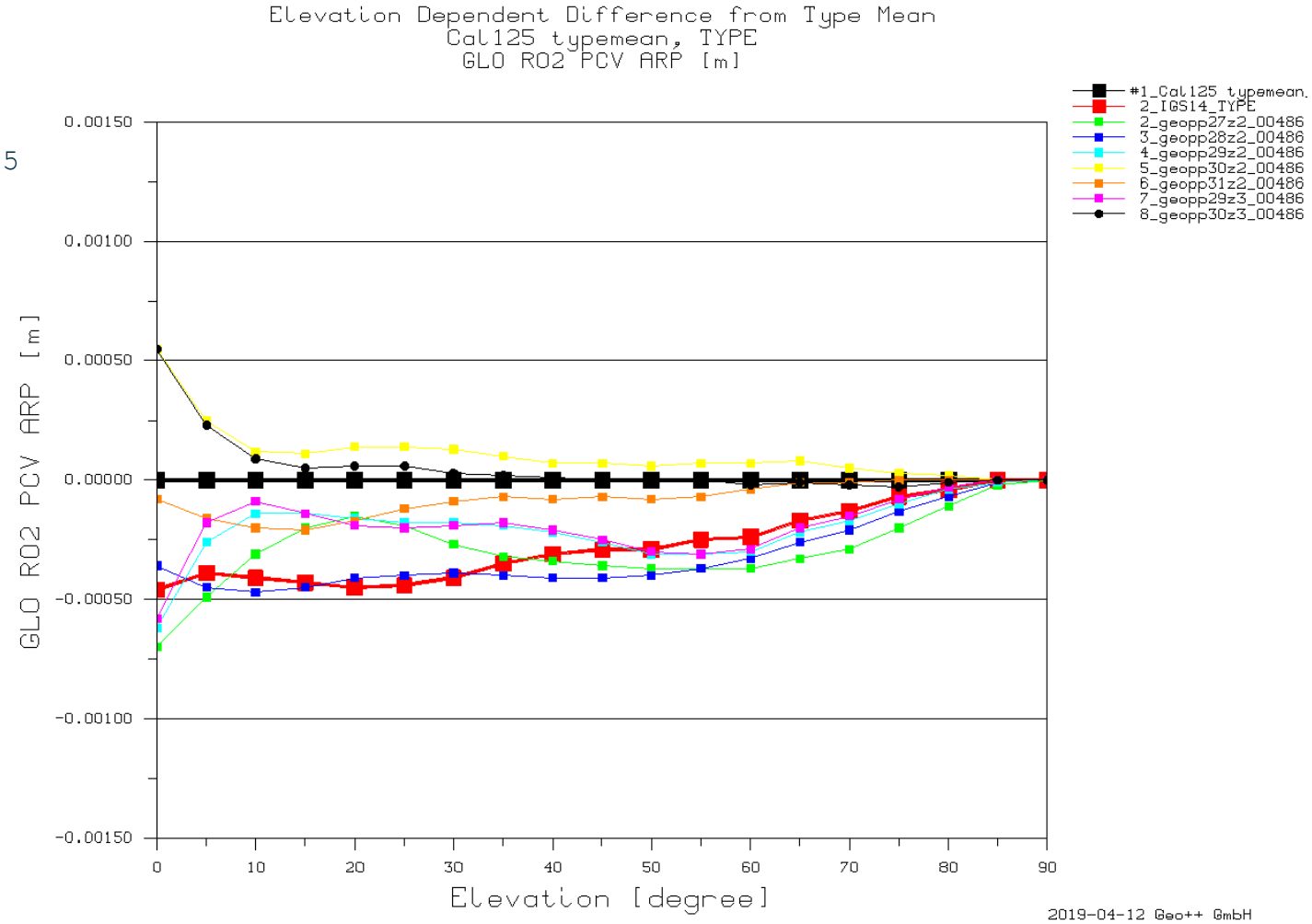
- agreement with IGS14.atx



# Repeatability JAVRINGANT_DM___NONE

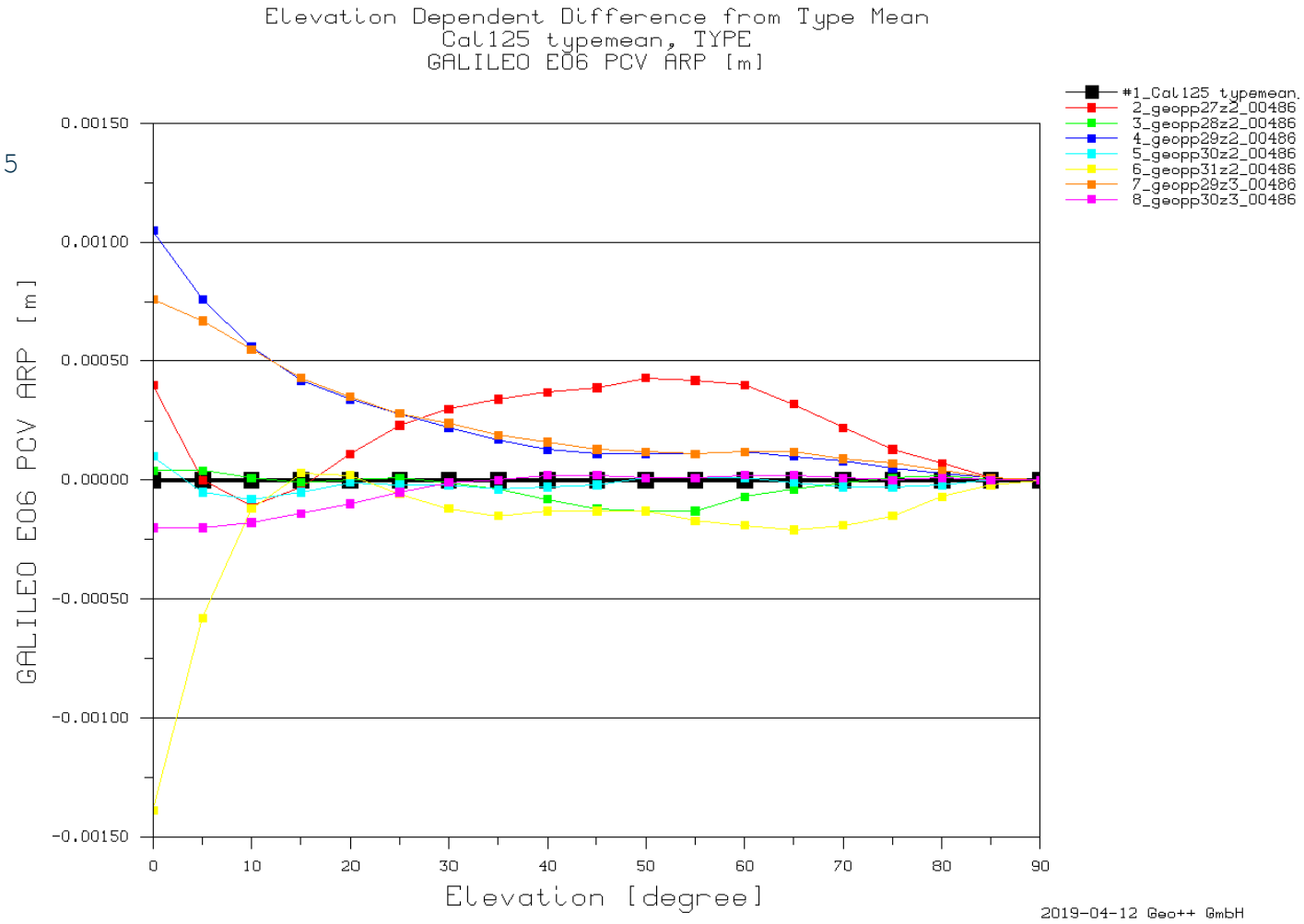
```
JAVRINGANT_DM    NONE 00486
 #a 001 #c 036 #s 047   | G01 E01 J01 S01 C01
 #a 001 #c 025 #s 026   | G02 J02
 #a 001 #c 036 #s 047   | G05 E05 J05 C05 S05 I05
 #a 001 #c 022 #s 026   | R01 R04
 #a 001 #c 022 #s 026   | R02 R06
 #a --- #c --- #s ---   | R03
 #a 001 #c 015 #s 021   | E06 J06
 #a 001 #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



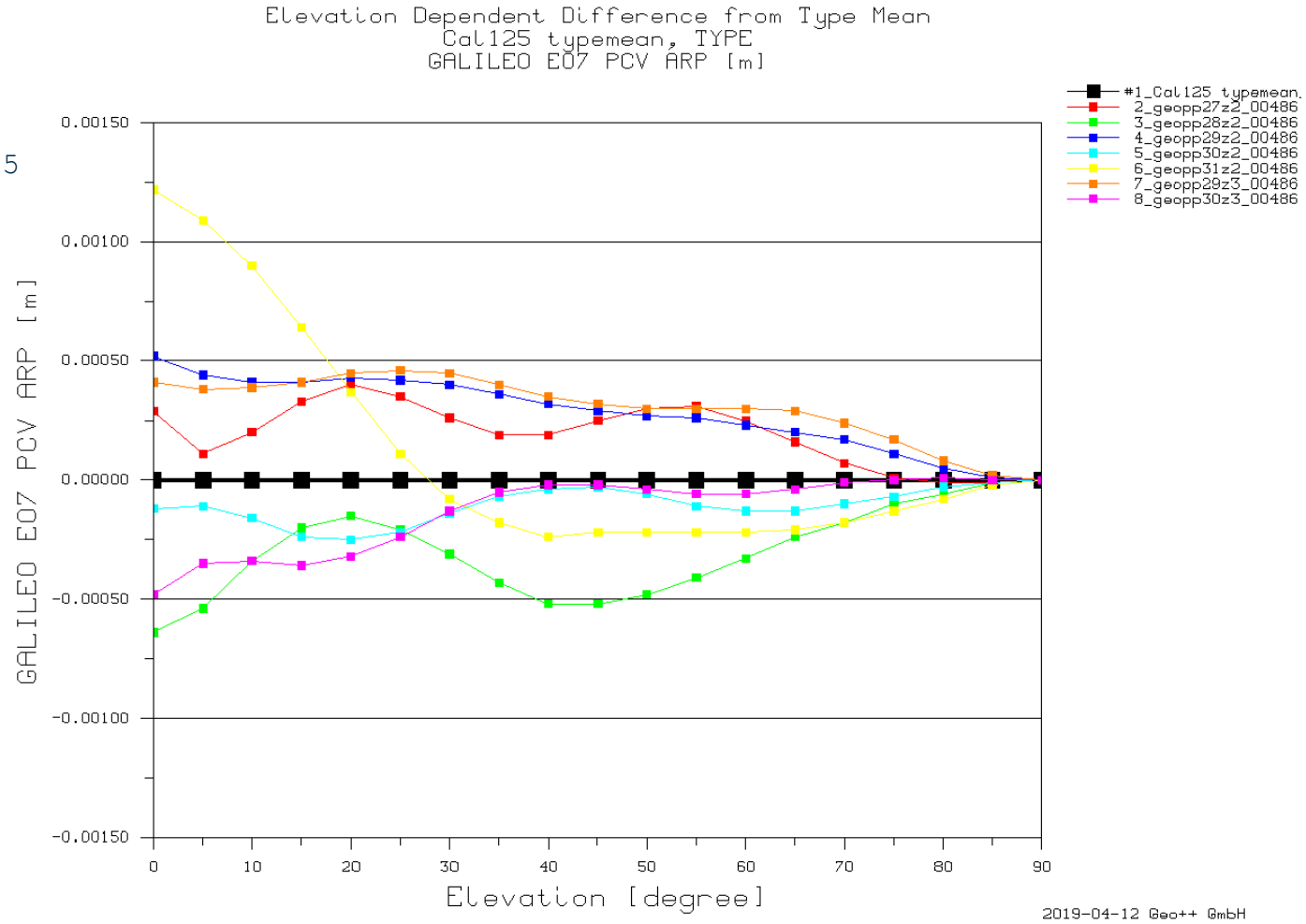
# Repeatability JAVRINGANT_DM___NONE

```
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
```



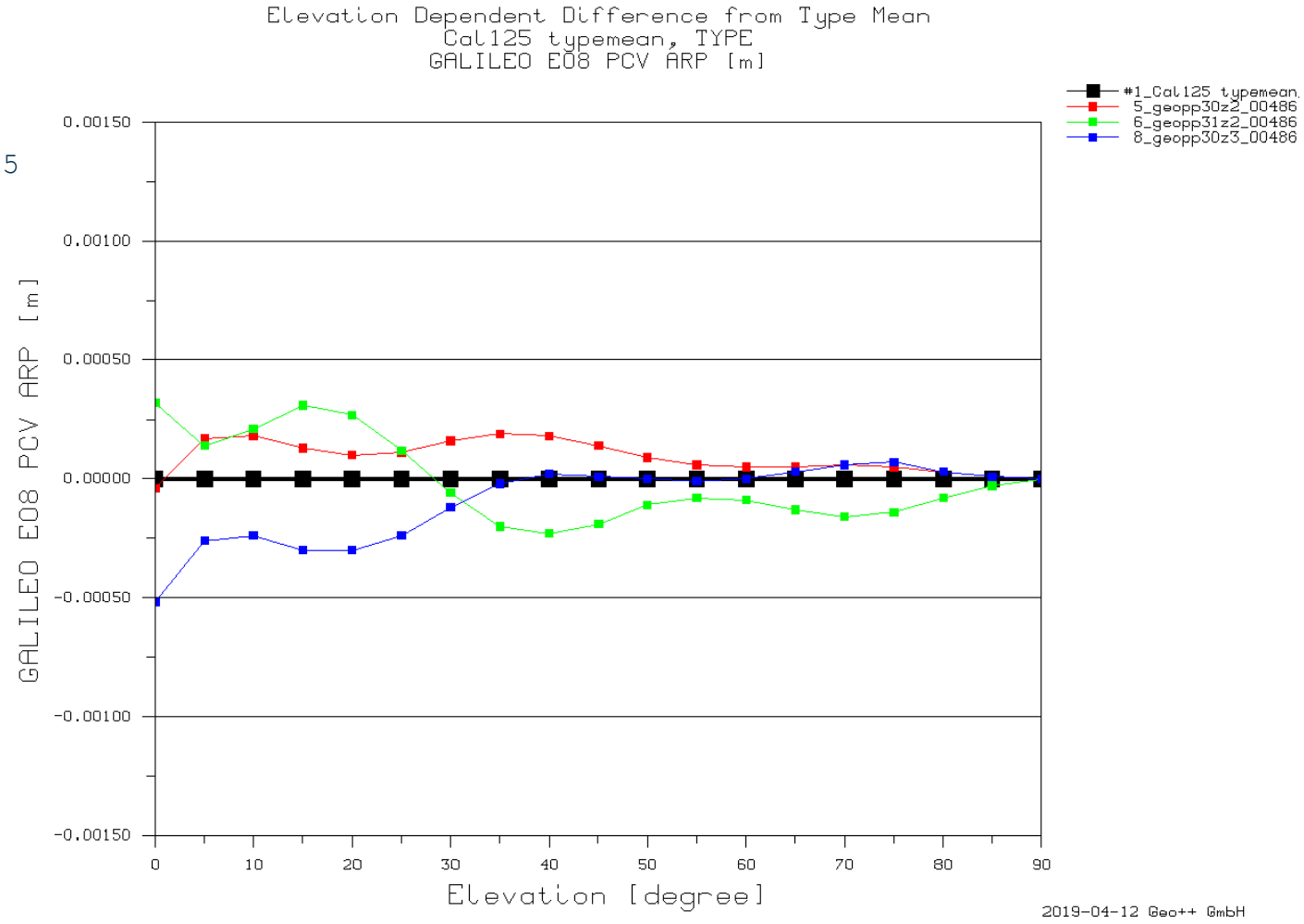
# Repeatability JAVRINGANT_DM___NONE

```
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
```



# Repeatability JAVRINGANT_DM___NONE

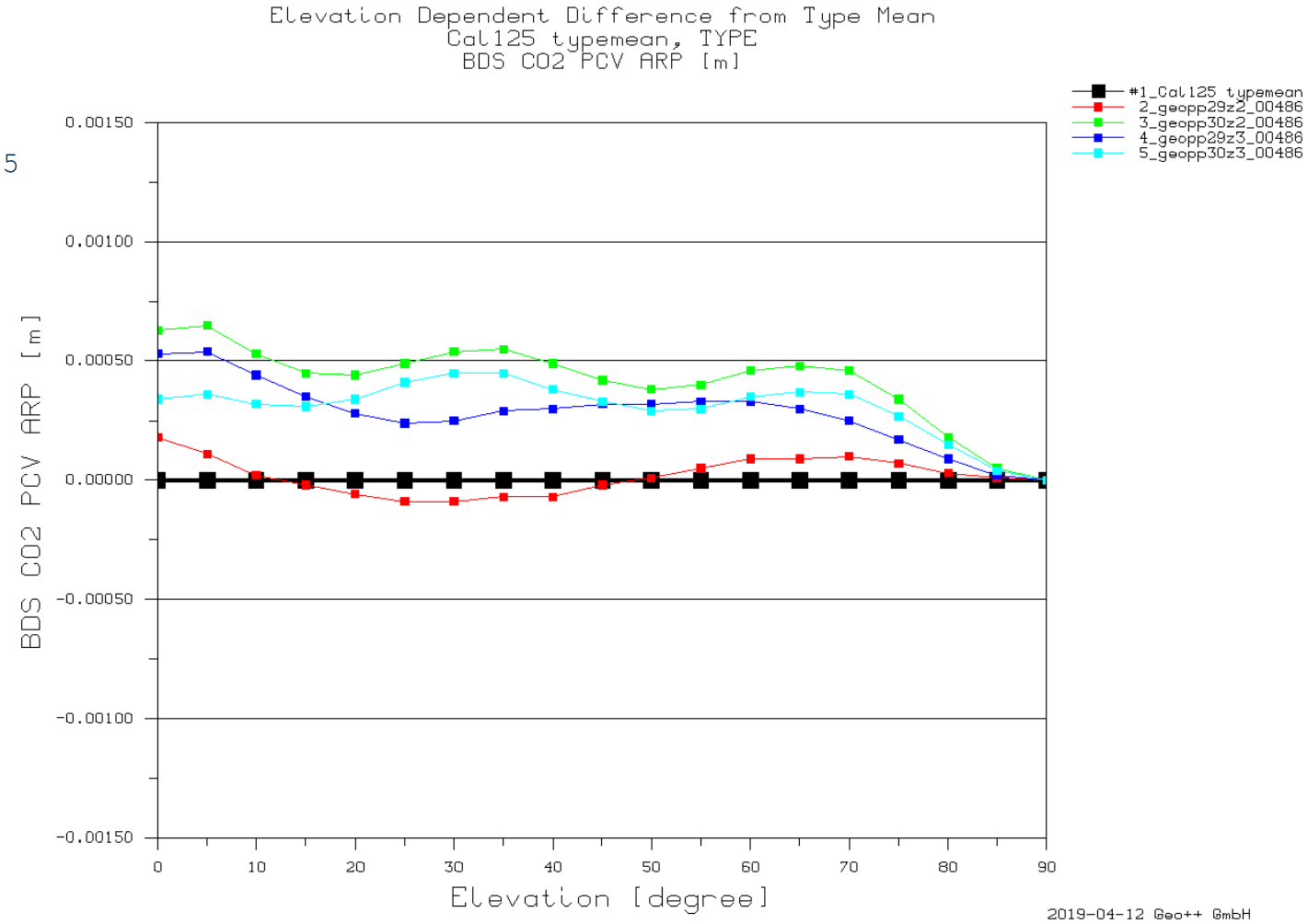
```
JAVRINGANT_DM    NONE 00486
 #a 001 #c 036 #s 047   | G01 E01 J01 S01 C01
 #a 001 #c 025 #s 026   | G02 J02
 #a 001 #c 036 #s 047   | G05 E05 J05 C05 S05 I05
 #a 001 #c 022 #s 026   | R01 R04
 #a 001 #c 022 #s 026   | R02 R06
 #a --- #c --- #s ---   | R03
 #a 001 #c 015 #s 021   | E06 J06
 #a 001 #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

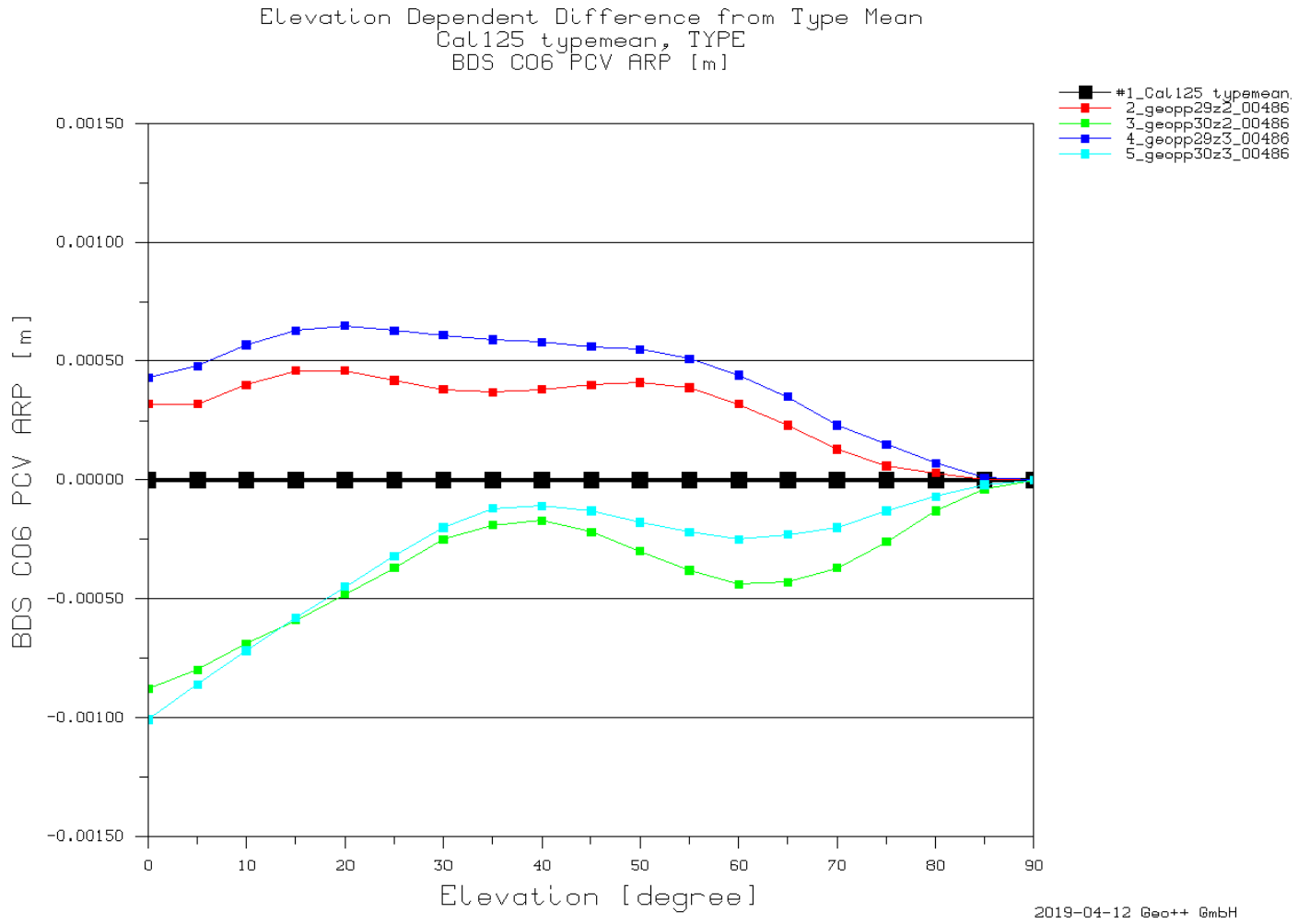
**JAVRINGANT_DM  NONE 00486**

```
 #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
```



# 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 I0
 #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
```



- 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

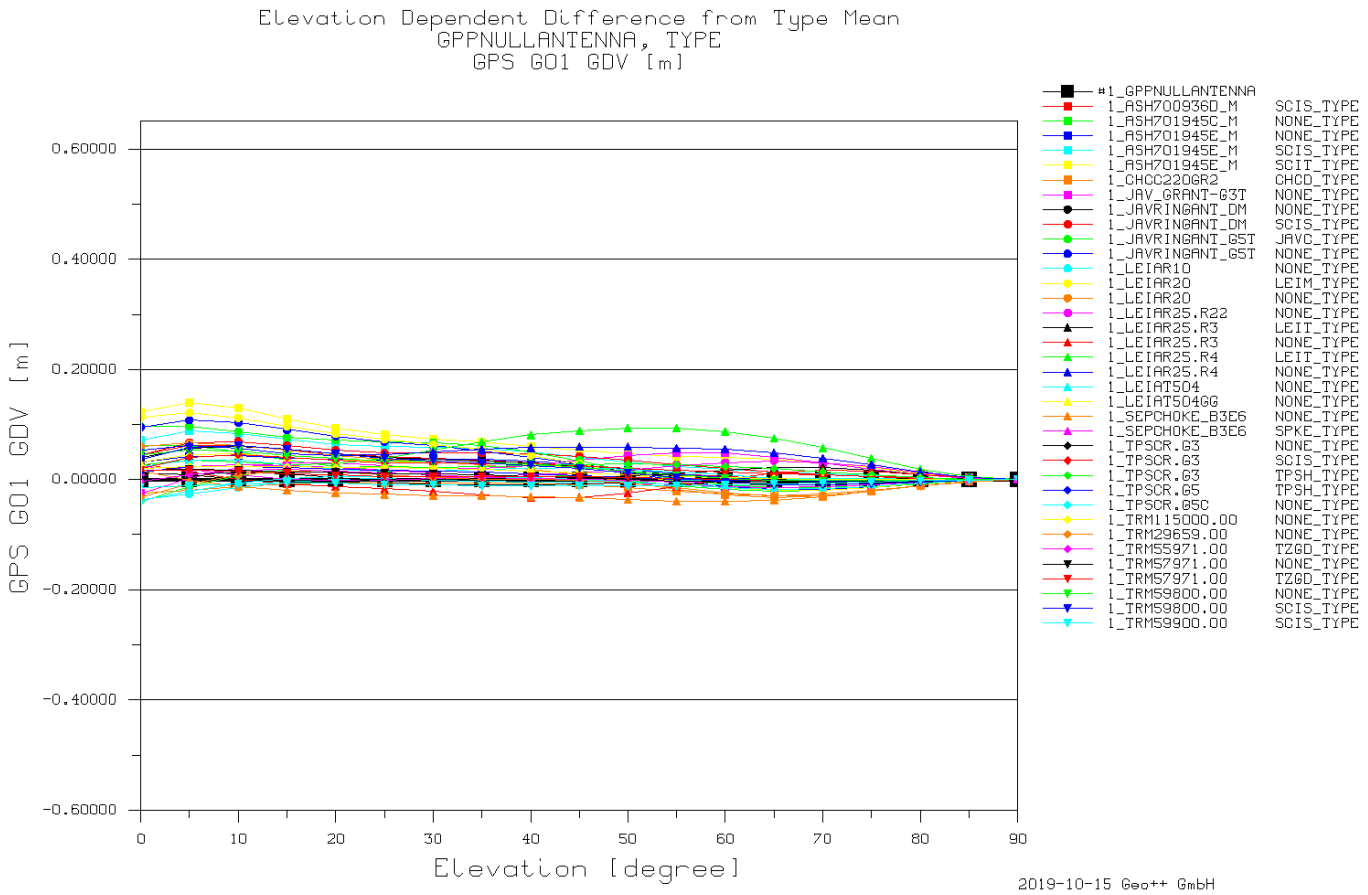
# GNSS Antenna Group Delay Variations

- **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**
  - **…**

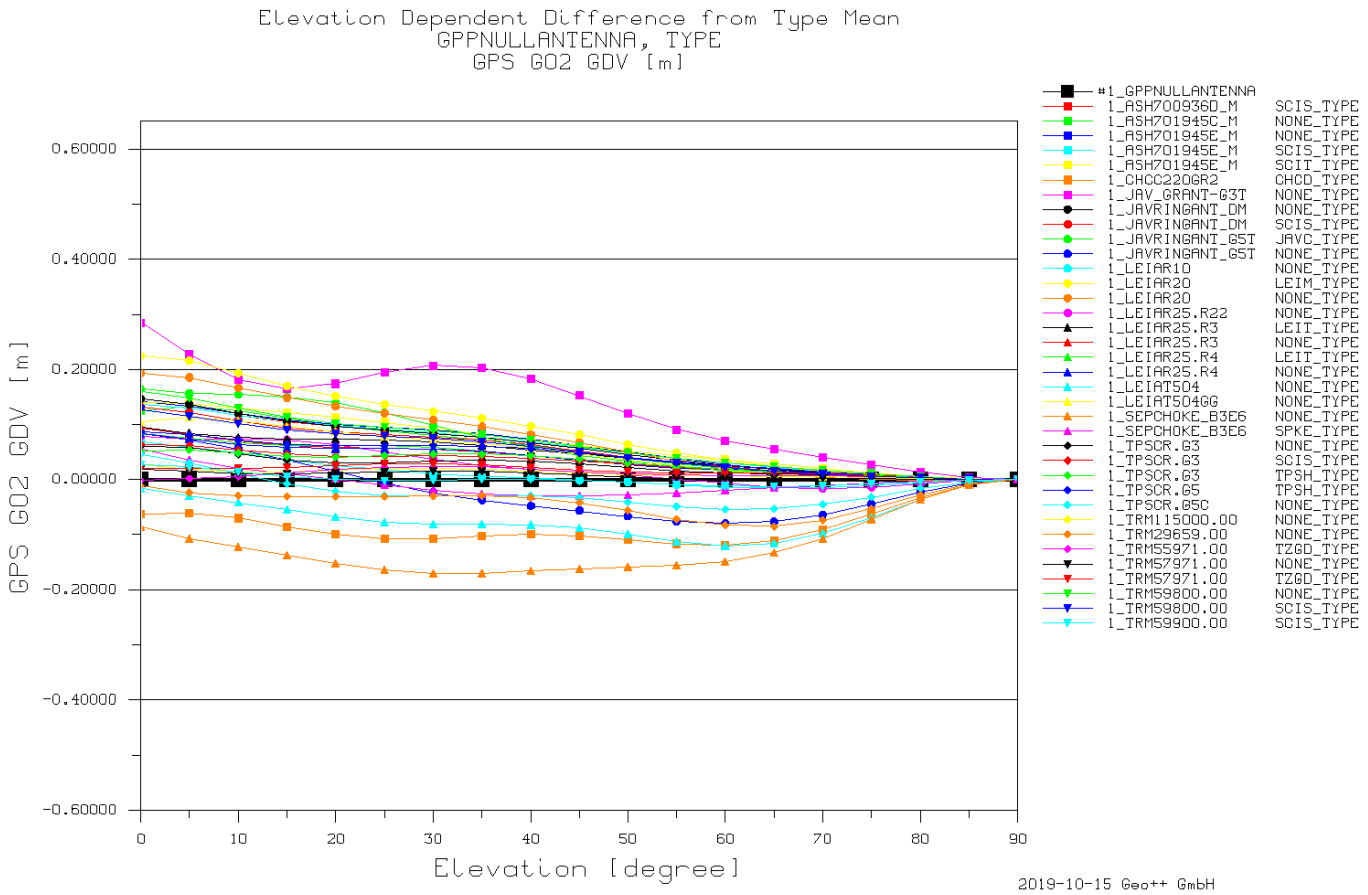
# GNSS Antenna Group Delay Variations

- **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



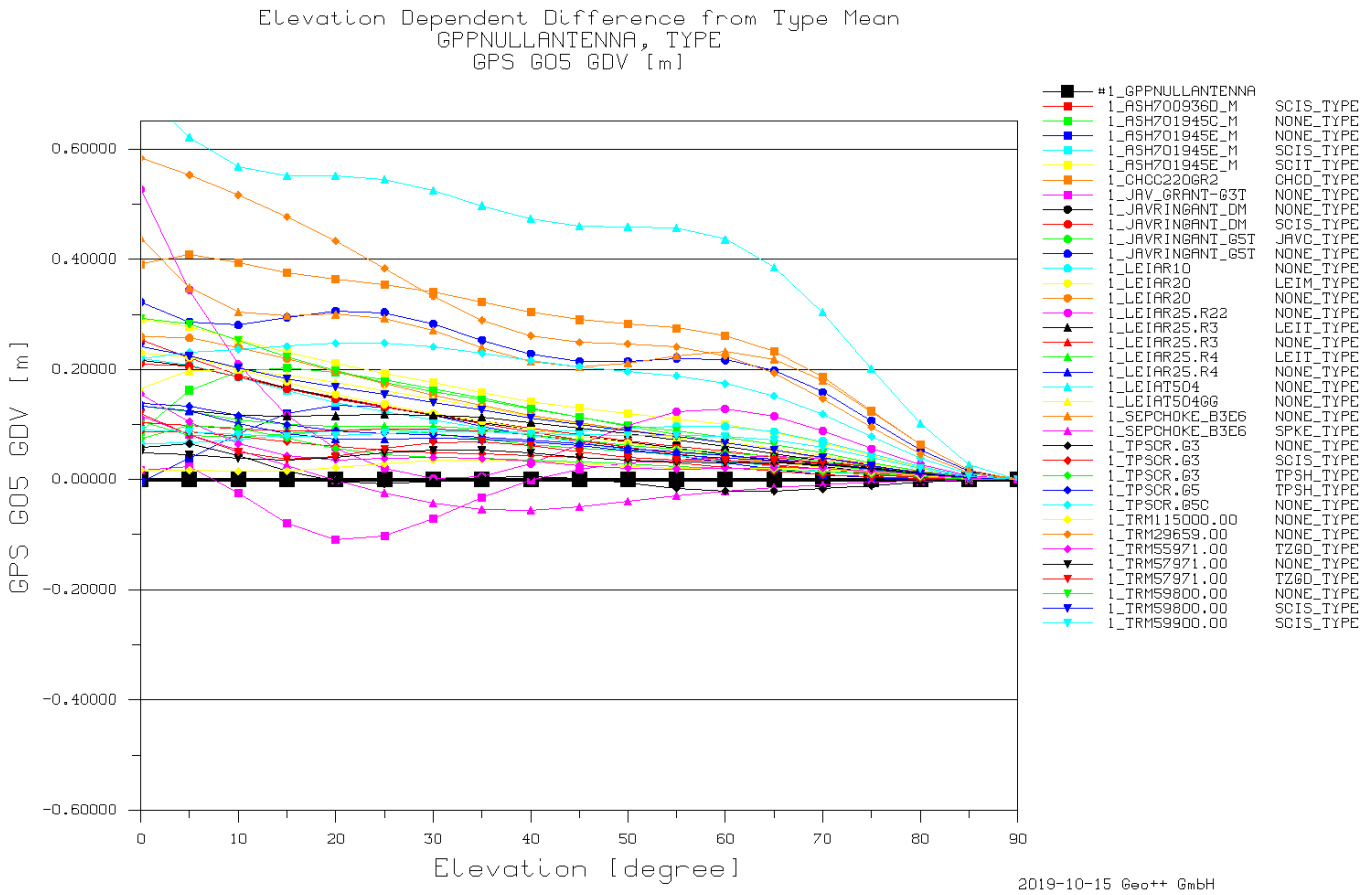
# GNSS Antenna Group Delay Variations

- GDV antenna **type mean** correction
- G02 GDV



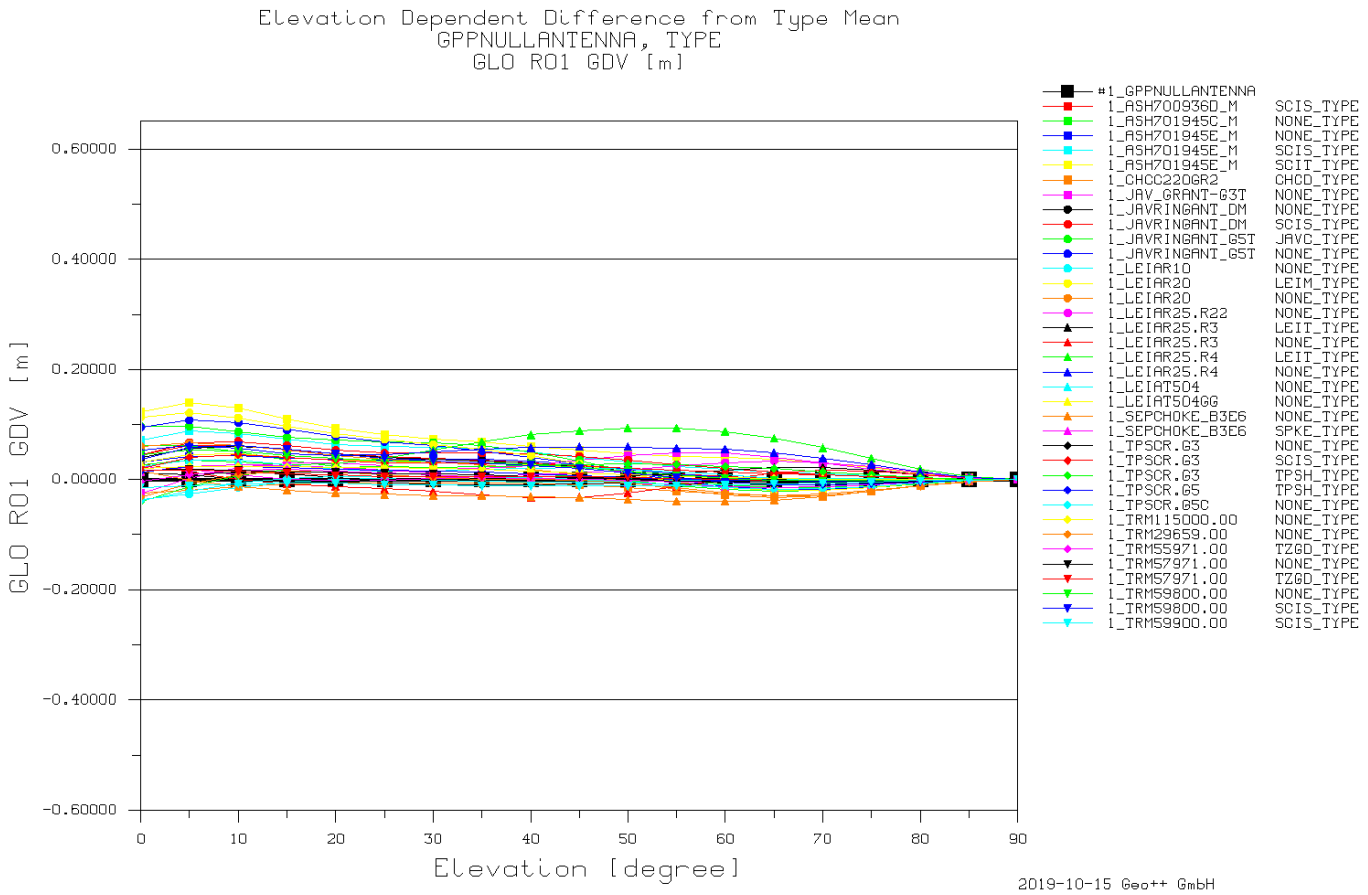
# GNSS Antenna Group Delay Variations

- GDV antenna **type mean** correction
- G05 GDV



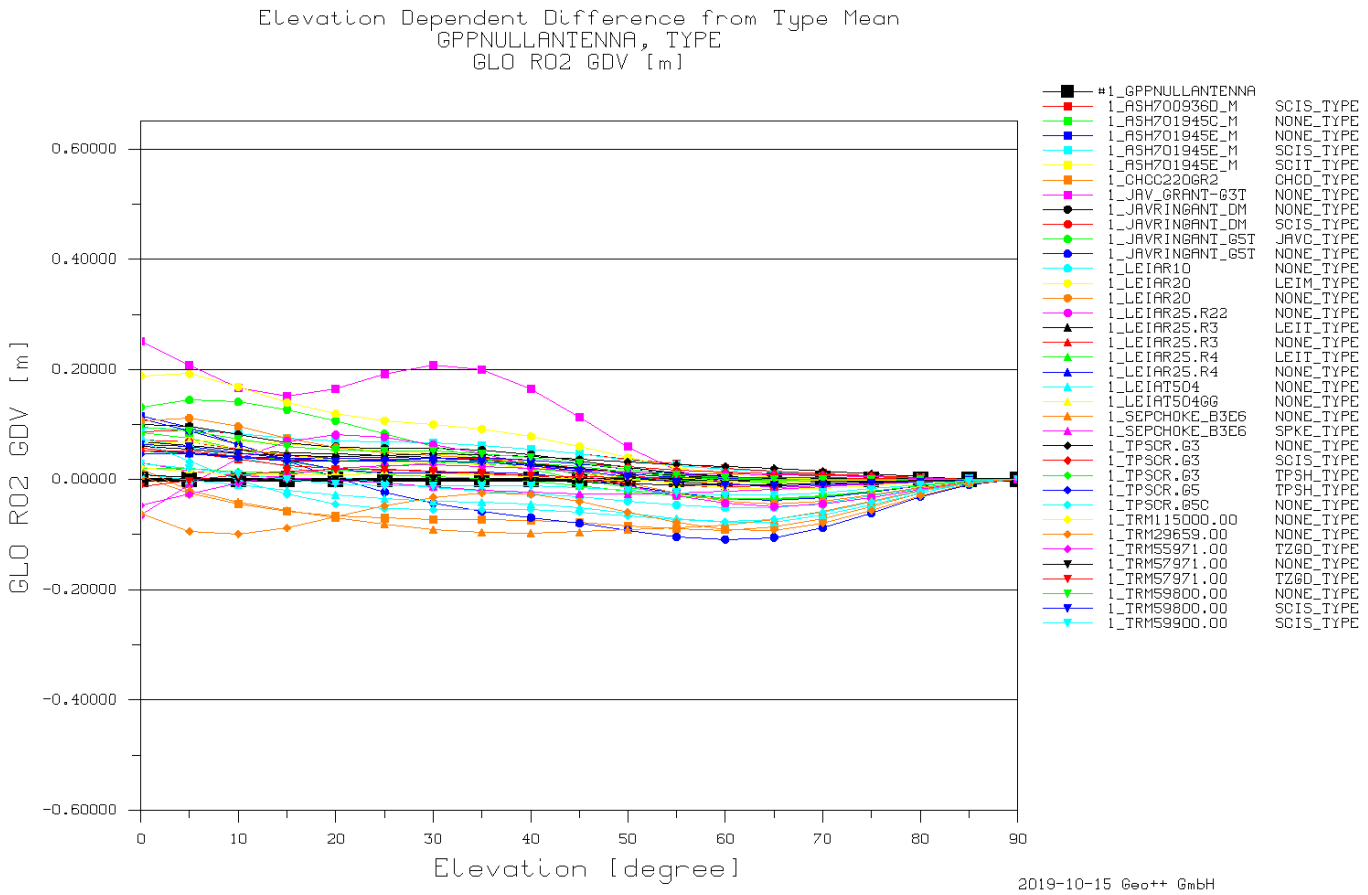
# GNSS Antenna Group Delay Variations

- GDV antenna **type mean** correction
- R01 GDV



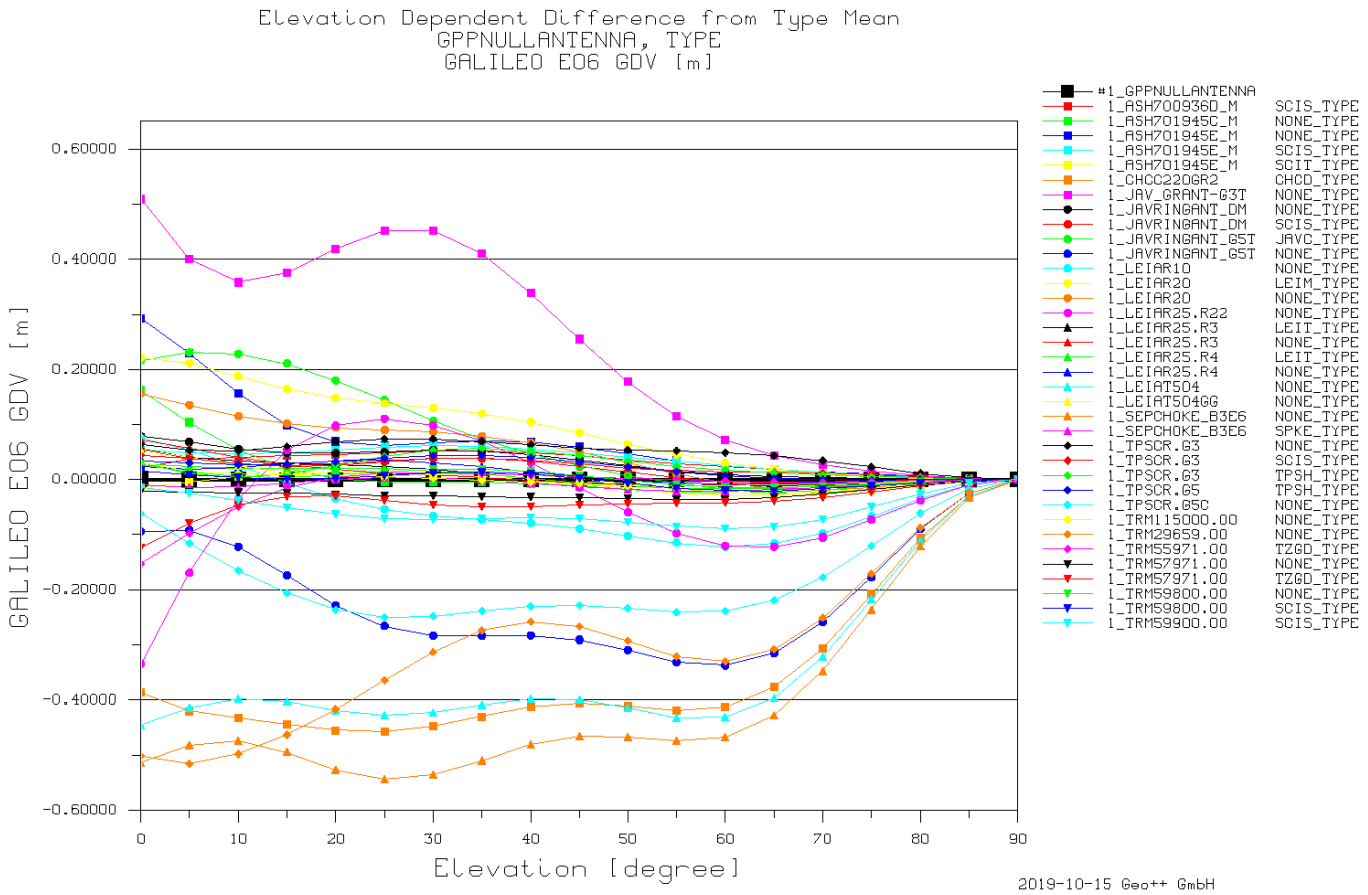
# GNSS Antenna Group Delay Variations

- GDV antenna **type mean** correction
- R02 GDV



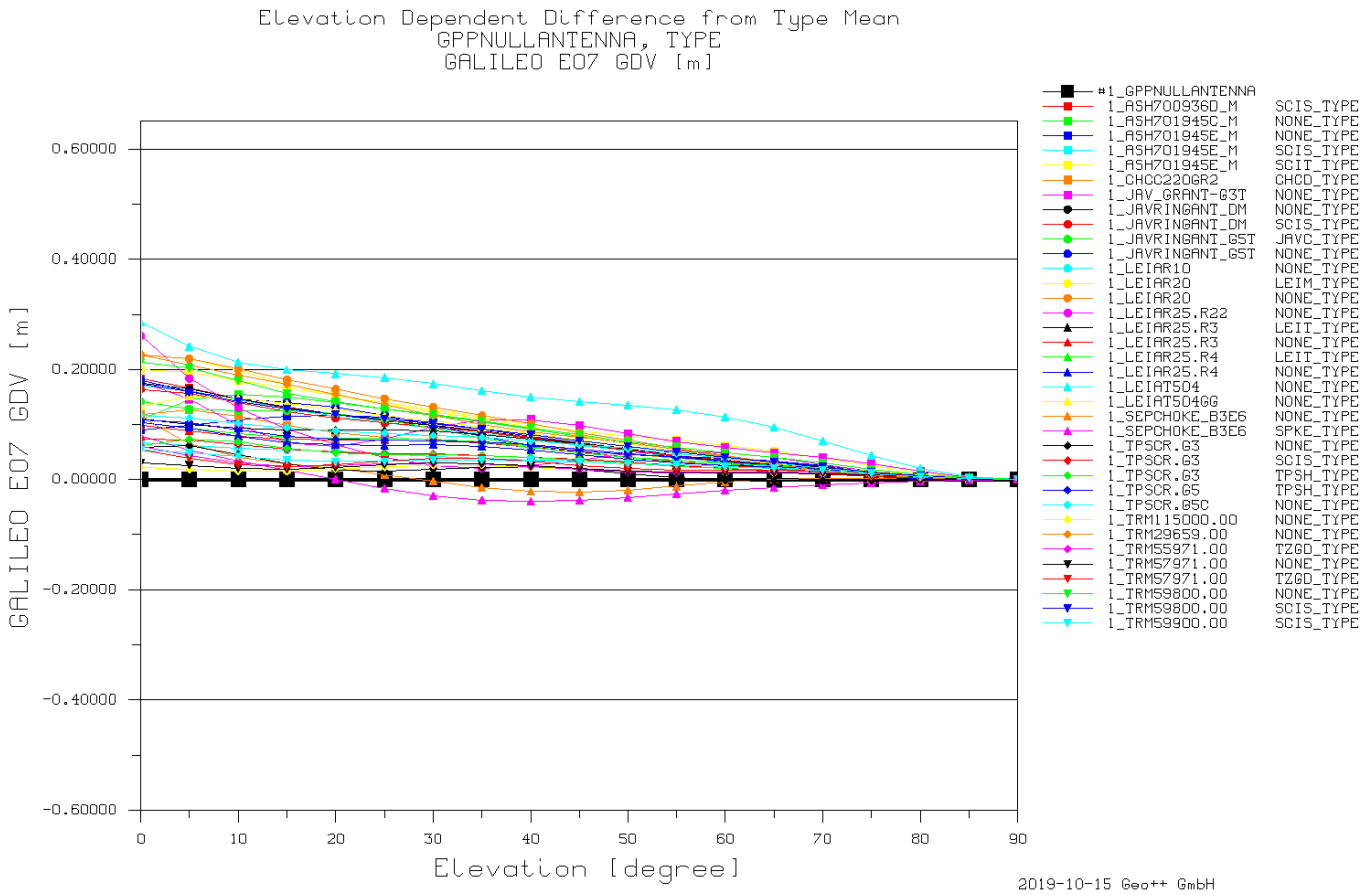
# GNSS Antenna Group Delay Variations

- GDV antenna **type mean** correction
- E06 GDV



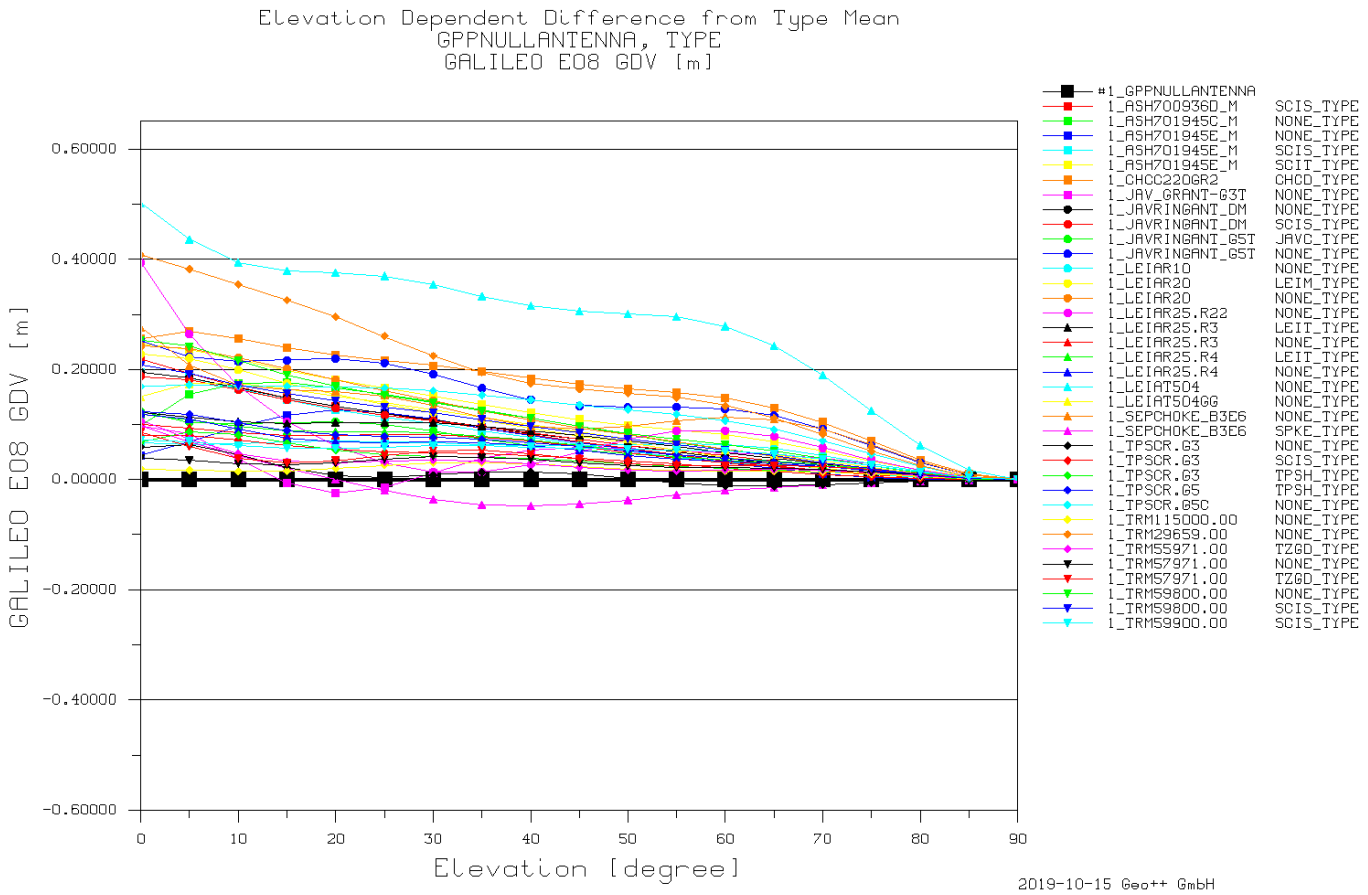
# GNSS Antenna Group Delay Variations

- GDV antenna **type mean** correction
- E07 GDV



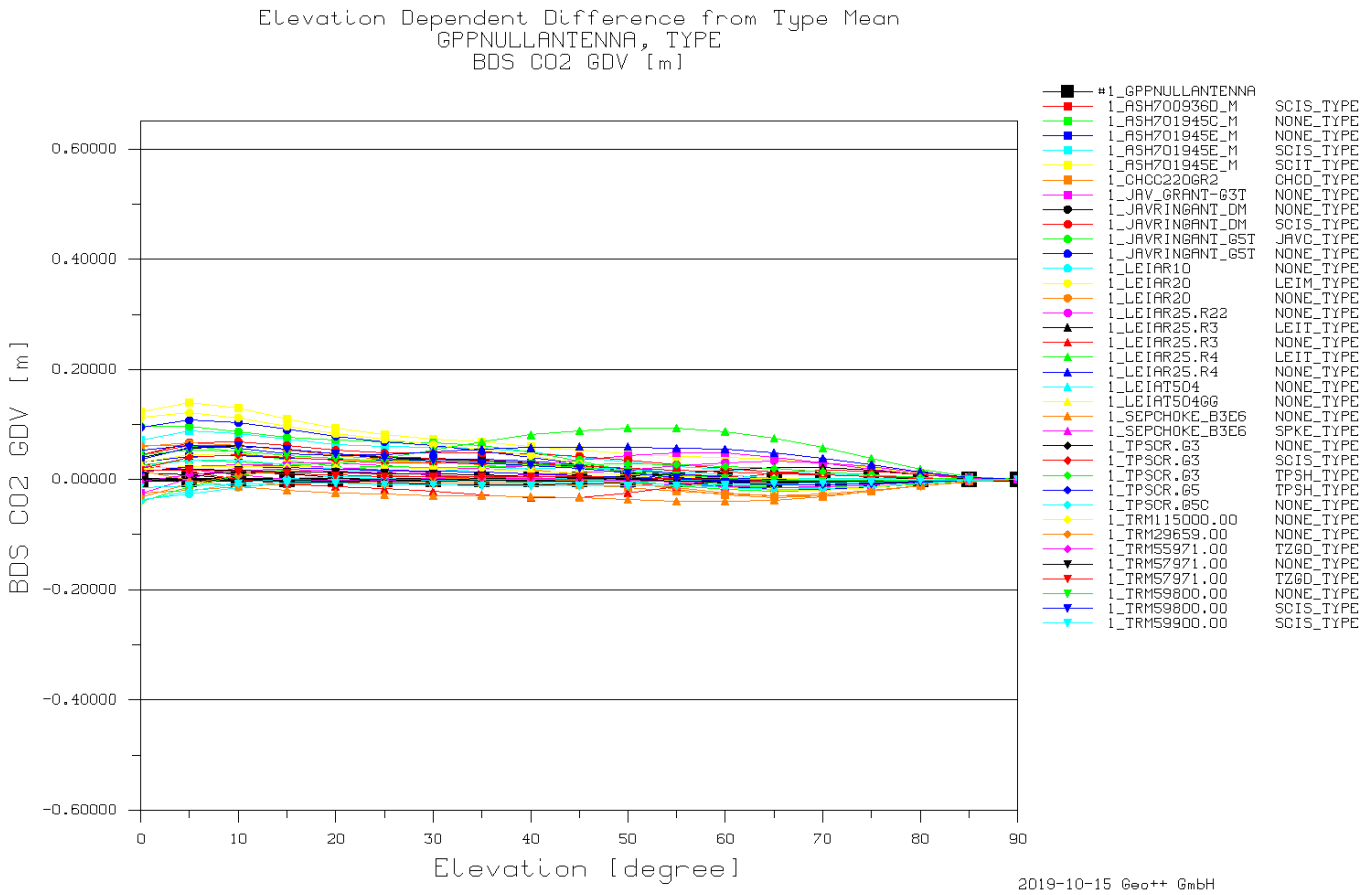
# GNSS Antenna Group Delay Variations

- GDV antenna **type mean** correction
- E06 GDV



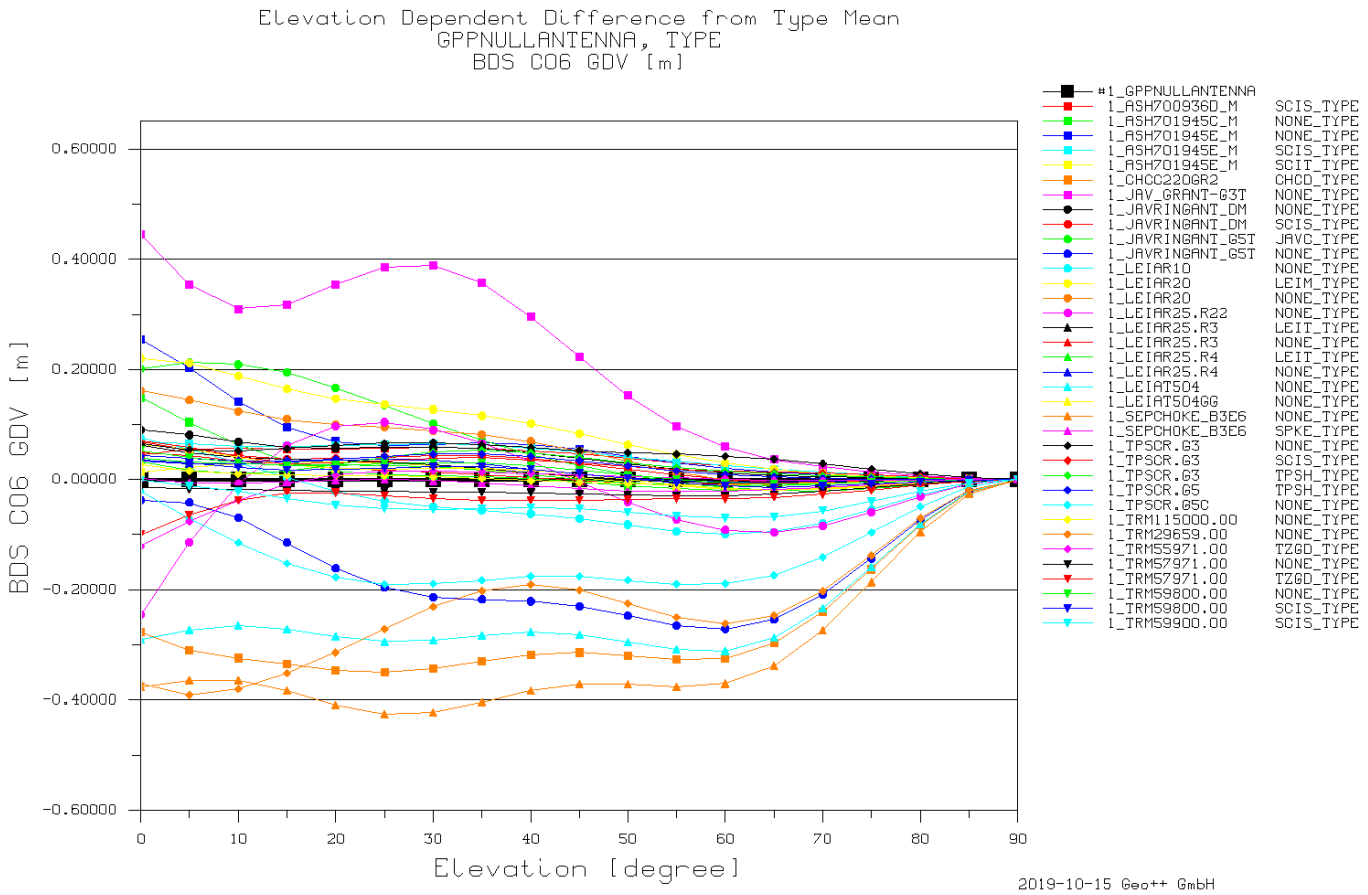
# GNSS Antenna Group Delay Variations

- GDV antenna **type mean** correction
- C02 GDV



# GNSS Antenna Group Delay Variations

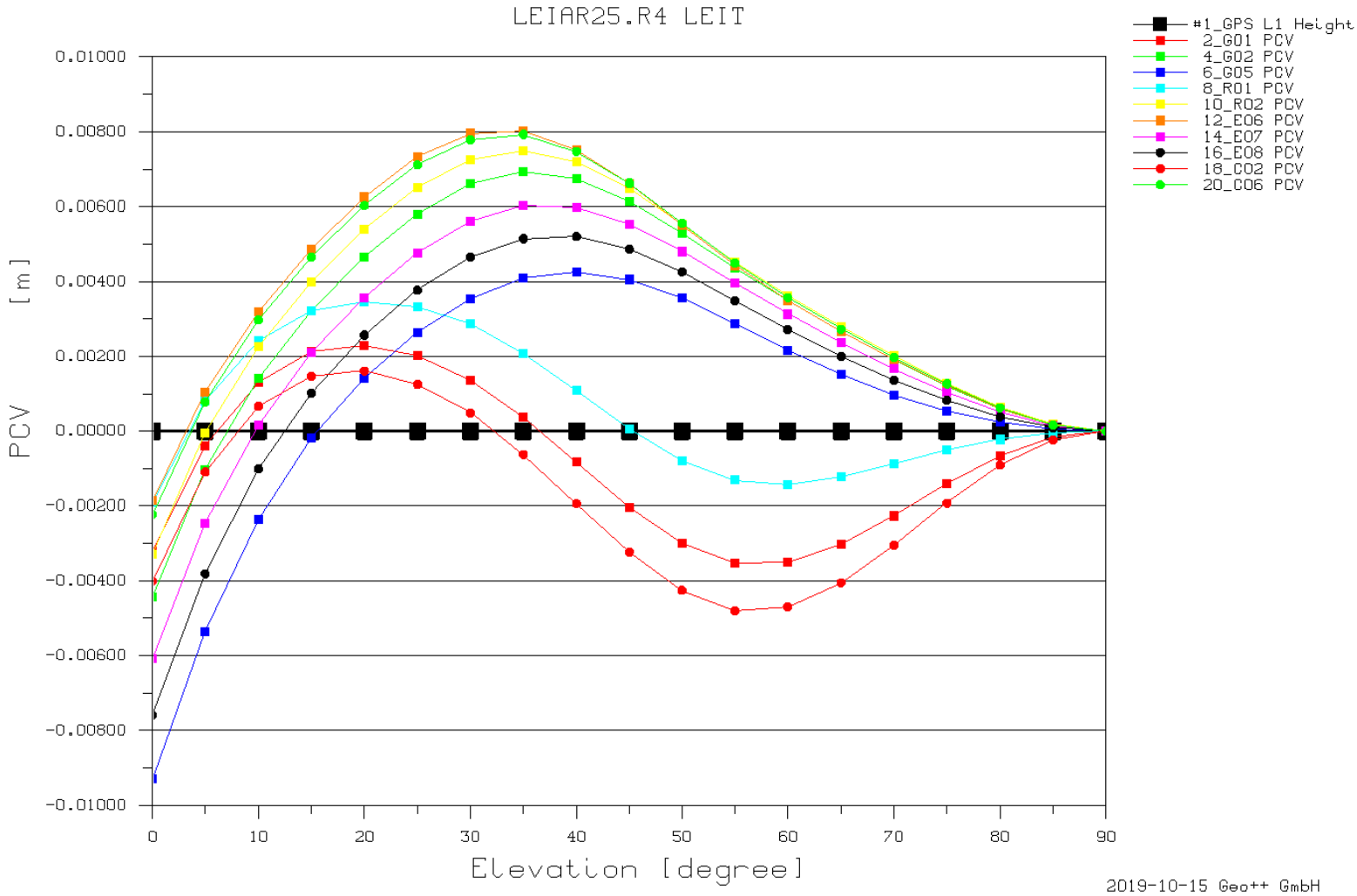
- GDV antenna **type mean** correction
- C02 GDV



- Absolute Robot-based GNSS Antenna Calibration
- Multi-Frequency GNSS Antenna Calibration – Status
- 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

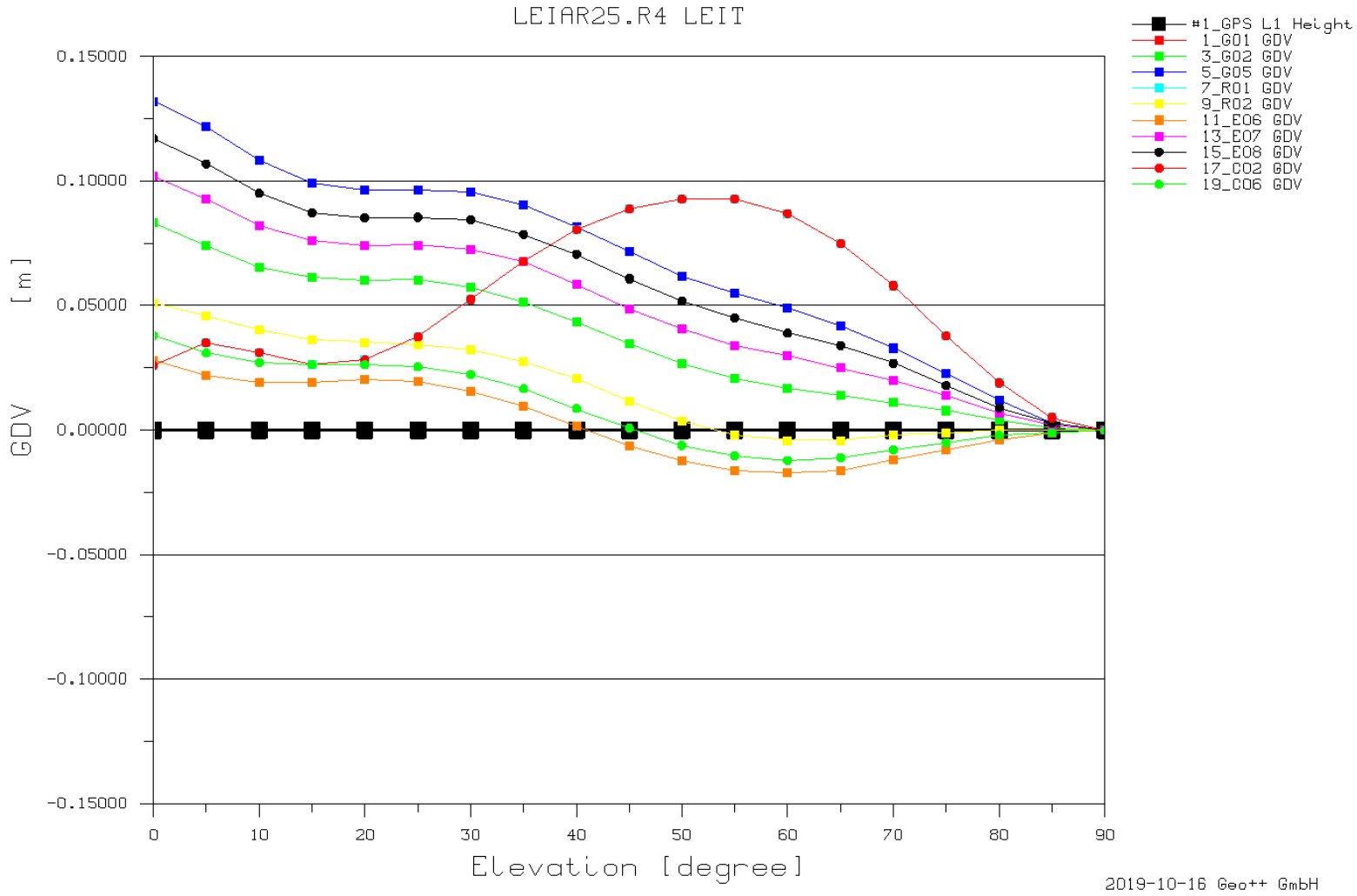
# Example: GNSS Antenna PCV for all Frequencies

- 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**



# 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**



- 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 | center of mass |
| ARP | antenna reference point |
| SRP | satellite reference point |

- 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
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- **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

**Geo++®**
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