GNSS Antenna Calibration – Current Status

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Outline

- GNSS Antenna Calibration - Overview
- Absolute Robot-based GNSS Antenna Calibration
- GNSS Antenna Group Delay Variation
- ANTEX Format Status
- Summary/Outlook

- **GNSS Antenna Calibration - Overview**
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GNSS Antenna Calibration - Overview

- motivation and goals
- status late **1990s**
  - **problems** with antenna corretions from existing relative **field calibration** methods
  - **problems** with antenna corretions from absolute **chamber** calibration
  - **PCV** corretions urgently **needed for** GPS (and later for GLONASS) applications with **mixed antenna types** (eg Network RTK, precise engeneering tasks, …)
- **requirements** specified for an GNSS antenna calibration method
  - **separation of** phase center and variationen (PCV) and **multipath effects** (MP)
  - **absolute PCV** (independent from any reference antenna)
  - **high** resolution and **accuracy** of determined PCV
  - **independent from station and location** (eg MP and geographic latitude)
  - **field calibration** method

GNSS Antenna Calibration - Overview

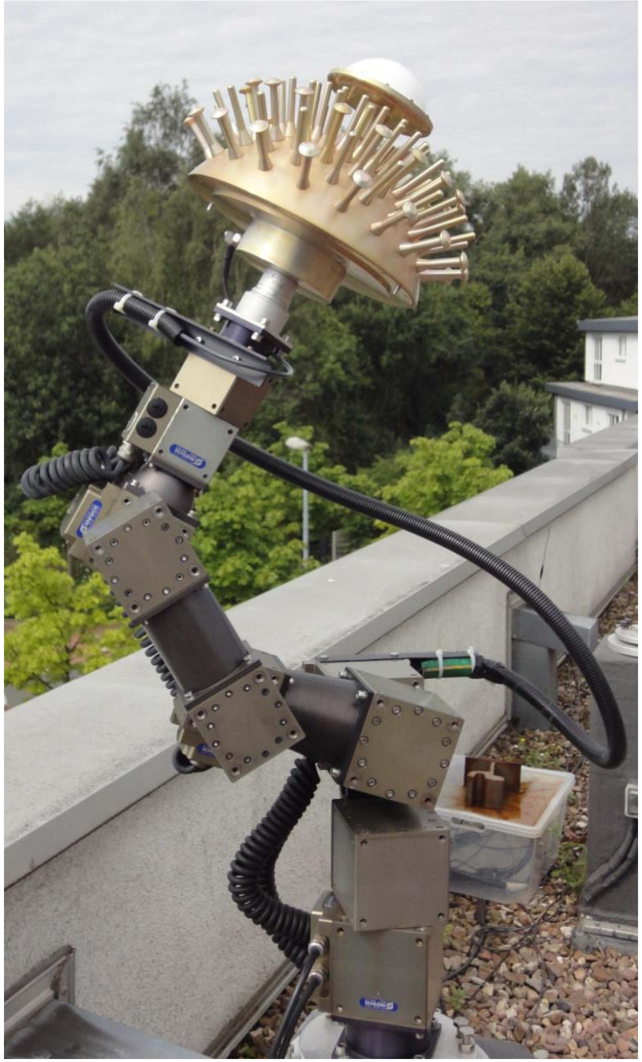
- motivation and goals today (2018)

- urgent **need for**
  - antenna corretions of **new frequencies** and GNSS (eg GPS L5, Galileo E6, GLONASS L3, …)
  - **satellite antenna** corretions
  - group delay variations (**GDV**)

- **requirements** to resolve issues
  - **consistency**
    - with existing PCV pattern
    - of PCV and GDV pattern
    - of satellite and receiver antenna pattern
  - extension of **absolute robot-based** GNSS antenna field **calibration**
  - **update** of ANTEX exchange **format**

Absolute Robot-based GNSS Antenna Calibration

- charactistics of GNPCV service
- primary task of calibration
  - absolute*
    phase center and **-variationen** (PCV)
- robot excellent instrument
  to determine additional parameters
  - **signal strength** (carrier-to-noise, CN0)
  - **Group Delay Variations** (GDV)/
    Code calibration
  - **near-field impact** on antenna
- separation of multipath
  in near-field and far-field effects
  - absolute s**tation calibration** of multipath
- antenna calibration provides (since 2013)
  - GPS + GLO L1 and L2 PCV
  - GPS + GLO S1 and S2 CNV
  - GPS + GLO P1 and P2 GDV



Geo++ robot withTPSPN_A5 NONE

* without impact of a reference antenna

Absolute Robot-based GNSS Antenna Calibration

- Geo++ GNPCV systems
- robot-based absolute
  GNSS antenna field calibrationen
- development by **Geo++** in cooperation with
  Institut für Erdmessung, **Universität, Hannover**
- **marketing and enhancement/development**
  through Geo++ since 2000

- 2000 Geo++, **Garbsen** , Germany (to be retired)
- 2000 ife, **Hannover** , Germany
- 2005 SenB, Berlin, Germany (retired)
- 2009 Geo++, **Garbsen** , Germany
- 2012 GSA, Canberra, **Australia**
- 2013 SenB, **Berlin** , Germany
- 2018 Geo++, **Garbsen** , Germany

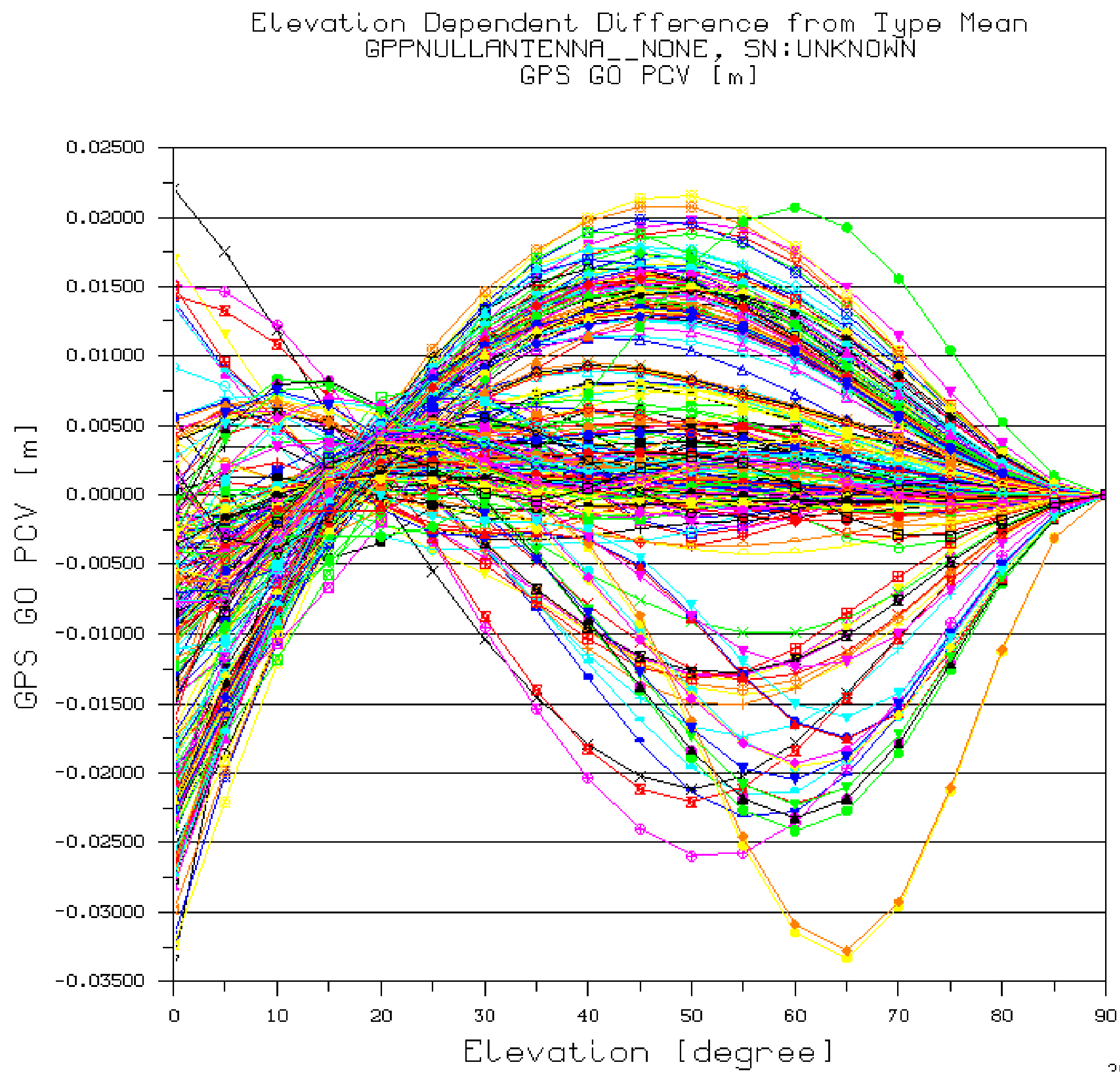
- in total there are currently six
  working Geo++ GNPCV systems

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

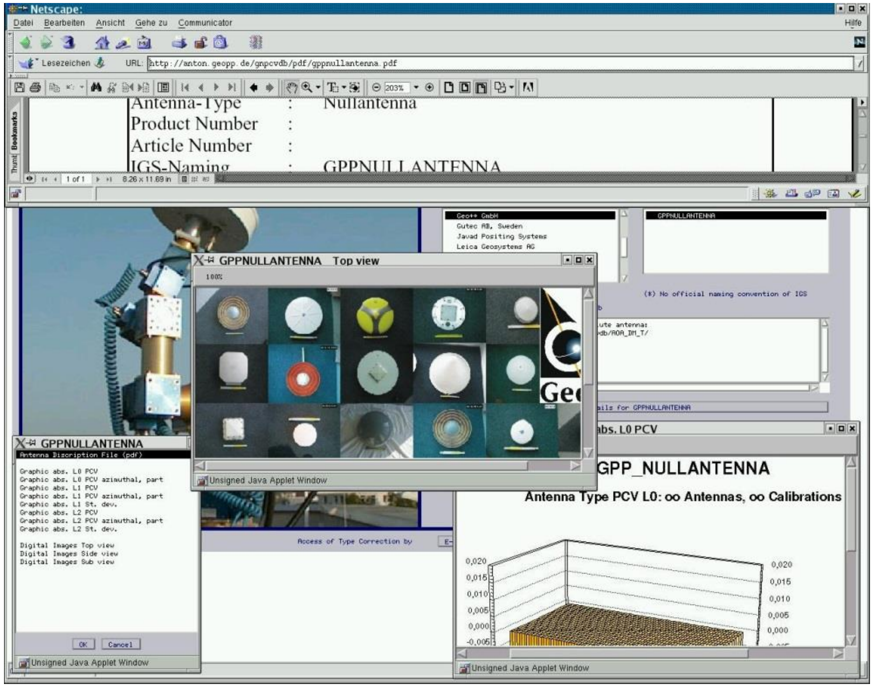
Absolute Robot-based GNSS Antenna Calibration

- **phase variation** (PCV without offset) for different antenna types
- **266 antenna types**
- Geo++ **GNPCVDB** database
- **GPS L0** signal
- PCV **difference to GPPNULLANTENNA**
- **magnitude** of PCV
  - **up to several cm**
  - in high elevations



L0 ionospheric free signal rule-of thumb
L0 effects larger by factor of 3 than original signals (L, L2)

Geo++ GNPCVDB Database



- **absolute PCV type means**
- **type means** computed from several individuallly robot-based calibrated antennas
- rigorous adjustement uing the complete variance-covariance matrix of individual calibrations
- **November 2018**
  - **334** different **antenna types**
  - 2705 individual GPS antennas
  - **7718** individual GPS **calibrations**
  - 1316 individual GPS+GLO antennas
  - **3679** individual GPS+GLO **calibrations**
- **free access to information** on PCV pattern (graphics, **ARP**- und **NRP** definition, etc.)
- certain type means are provided to IGS/EPN (see eg **IGS igs14.atx**)
- licence for actual access to absolute PCV (numerical values of PCV)
- http://gnpcvdb.geopp.de/

Absolute Robot-based GNSS Antenna Calibration

GNSS carrier phase frequencies

Frequency [MHz]	GPS	GLONASS	Galileo	BDS	QZSS	SBAS	IRNSS
2492.028							S
1602+k*9/16 (k=-7…+12)		G1					
1600.995		G1 CDMA					
1575.42	L1		E1		L1	L1	
1561.098				B1			
1278.75			E6		L6 (LEX)		
1268.52				B3			
1268.06		G2 CDMA					
1246+k*7/16 (k=-7…+12)		G2					
1227.60	L2				L2		
1207.140			E5b	B2			
1202.025		G3, CDMA					
1191.795			E5a+E5b				
1176.45	L5		E5a		L5	L5	L5

GLONASS FDMA G1 1598.0625 … 1608.75 MHz
G2 1242.9375 … 1251.25 MHz

FDMA Frequency Devision Multiple Access
CDMA Code Devision Multiple Access

Absolute Robot-based GNSS Antenna Calibration

- Extension of absolute robot-based GNSS antenna calibrations for new GNSS and signals
  - Robot calibration starts with GNSMART 2
  - suitable GNSS receivers for calibration with all frequencies and signals are selected and recently delivered, testing is ongoing
  - operational calibration to start in December 2017
  - **detailed analysis** of already existing logged data pending
  - **no full constellation or signal availability** for several GNSS
    - adjusted modeling (**single signal in space** approach)
    - effect on calibration **duration** to be verified
    - **type mean correction** for some new frequencies for an **interim** period
  - GNSS **biases**
    - separation of antenna effects requires
    - proper handling of phase and code receiver biases

Absolute Robot-based GNSS Antenna Calibration

- Other biases to be considered and/or calibrated

  - significant receiver tracking biases in codes and phases exist depending on
    - receiver type
    - firmware version
    - settings (smoothing, multipath mitigation)
    - signal tracking modes
    - station/satellite combination
    - all this is to be part of another talk …

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GNSS Antenna Group Delay Variations

- **DM-type** geodetic chokering antennas
- `TRM159800.00     SCIS (Geodetic Choke)`
- `TRM159800.00     NONE (Geodetic Choke)`
- `TRM59800.00      NONE (Geodetic Choke)`
- `JAVRINGANT_DM    SCIS (Geodetic Choke)`

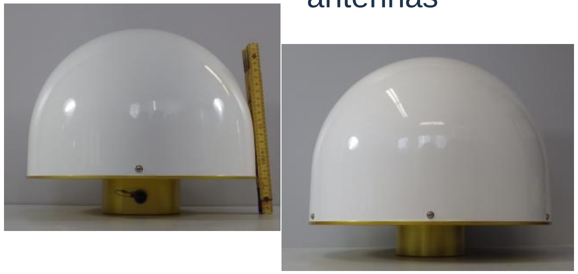
- **geodetic** chokering antennas
- `HXCCGX601A       HXCS (Geodetic Choke)`
- `HXCCG7601A       HXCG (Geodetic Choke)`

- **geodetic** antenna
- `TRM41249.00      SCIT (Geodetic)`

- **rover** antenna
- `SOKGCX3          NONE (Rover)`
- `IGAIG8           NONE (Rover)`

geodetic chokering antennas DM-type

geodetic chokering antennas



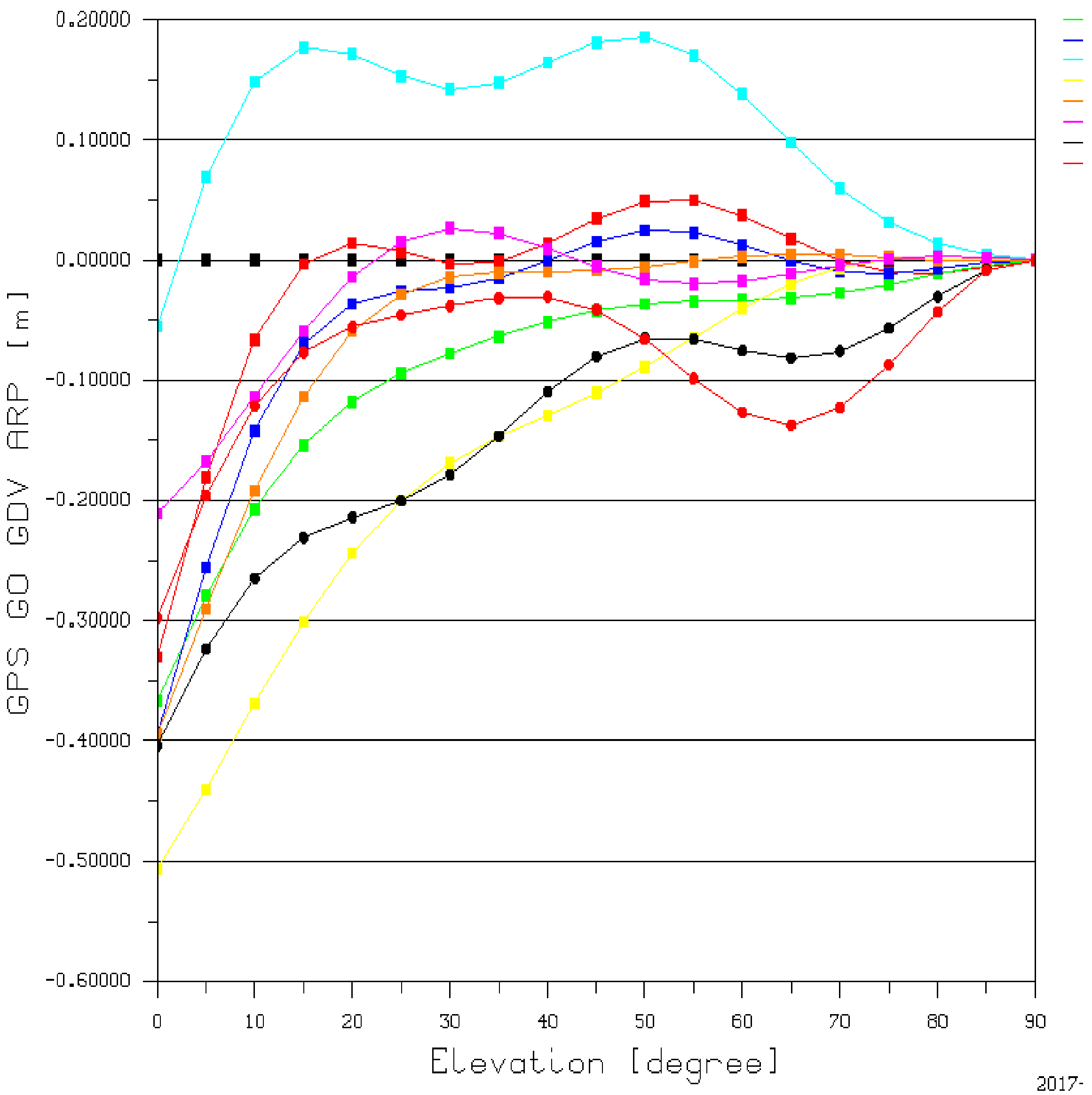
geodetic antenna with SCIT

rover antennas

DM Dorne Margolin element

GNSS Antenna Group Delay Variations

- **examples** of some **GDV** pattern
  - **geodetic choke ring** antennas with and without **radome**
  - **geodetic antenna** with radome
  - **rover antennas**
  - **significant effects for code** sensitive applications (e.g. PPP utilizing Melbourne-Wübbena linear combination)



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ANTEX Format Status

- **ANTEX 1.4** supports
  - all GNSS systems (except IRNSS)
  - all 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 of offset and/or PCV

CM center of mass
ARP antenna reference point

ANTEX Format Update Discussion

- **IGS antenna working group** (chaired by Arturo Villiger) is currently discusssing (IGS Workshop 2017, Paris)
  - **fast** update of **ANTEX 1.5**
  - **rigorous** update **ANTEX 2.x** later (basic changes)

- initial proposal of ANTEX 1.5 modifications
  - optional satellite antenna related to **SRP**
  - optional **GDV** and GDV RMS section
  - multiple identifiers for identical frequencies used by different GNSS on one line
  - optional **signal code**
  - **clarification** of the FREQ RMS section content
  - integration of **IRNSS**
  - controversial dissussion on
    - optional **CNR** and CNR RMS section

SRP satellite reference point

ANTEX Format Update

- **major benefits** of update of ANTEX format
  - GNSS application
    - corrections for group delay variations (**GDV**)
      - essential for PPP applications
  - GNSS service provider
    - flexible handling of center of mass (**CM**) and satellite antenna pattern (**PCV**, GDV) using satellite reference point (**SRP**)

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Summary/Outlook

- **modernization and new GNSS**
- **impact** on absolute **GNSS antenna calibration**
  - **more** carrier **frequencies** (PCV)
  - **more signals** (GDV)
  - **different satellite** payloads (PCV and GDV, CM issue)
- consequently **need** for
  - sohisticated **PCV and GDV** correction **model and format** for **GNSS receiver and satellite antenna**
- **benefits** for GNSS service provider and user with respect to **GNSS positioning accuracy**