Absolute Robot-Based GNSS Antenna Calibration – Features and Findings –

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Outline

- Absolute Robot-Based GNSS Antenna Calibration
  - Overview
  - Insight Through Series of GNSS Antenna Calibrations
  - Features
- Analysis of GNSS Antenna and Station Errors
  - Near-field Multipath
  - Susceptibility of Antennas to Rain
  - Group Delay Variations (GDV)
  - Calibration of GNSS Satellite Antenna
- Summary

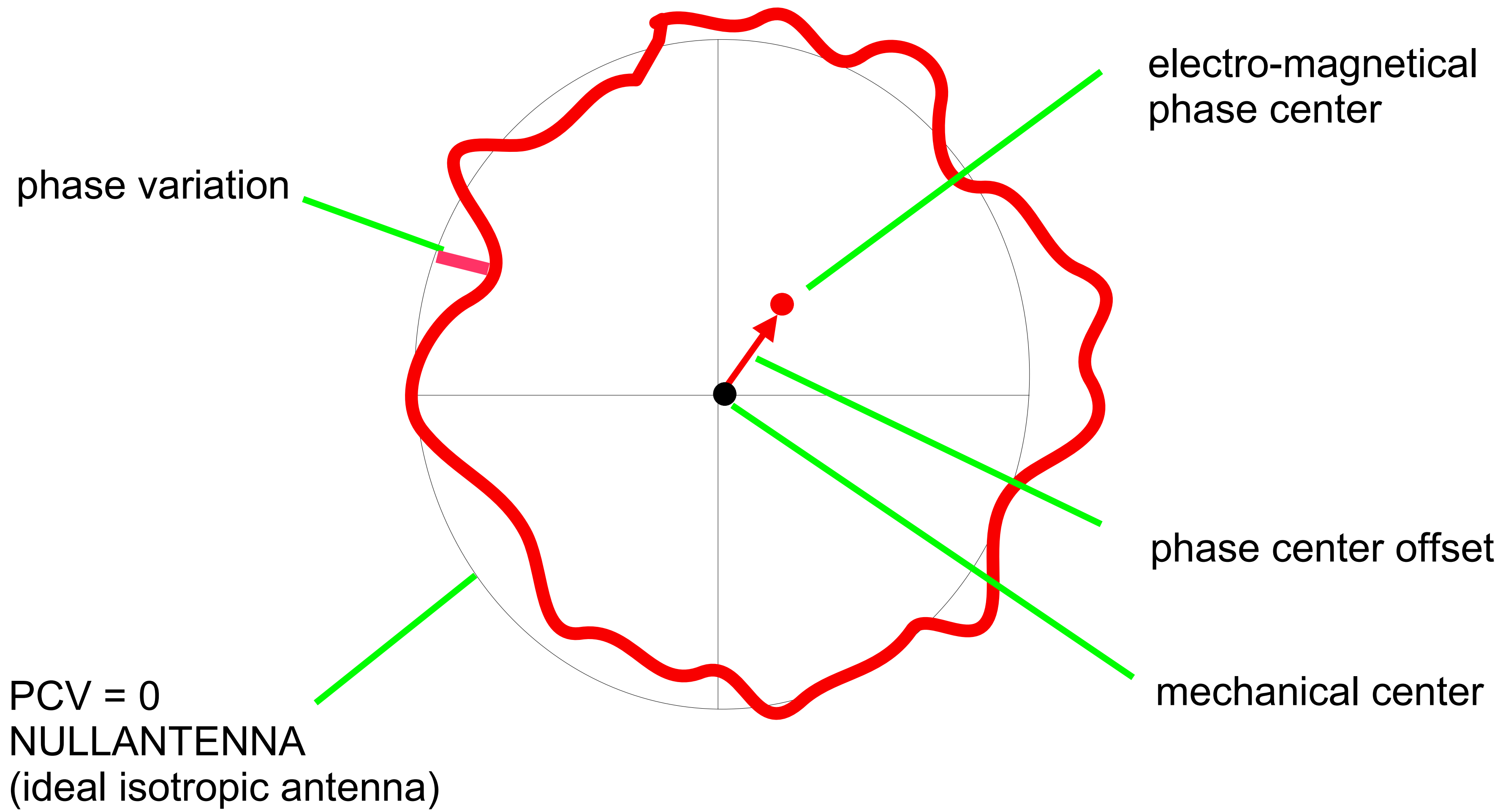
Absolute Robot-Based GNSS Antenna Calibration

- main task
  - determination of absolute*
    phase center offsets and variations (PCV)
- required for
  - any mixed antenna type GNSS applications
  - RTK networks
  - precise GNSS engineering tasks
  - global and scientific GNSS applications
- state-of-the-art antenna calibration technique
- recommended by International GNSS Service (IGS)

Geo++ robot with TPSCRG3_GGD PFAN

* without any influence from any reference antenna

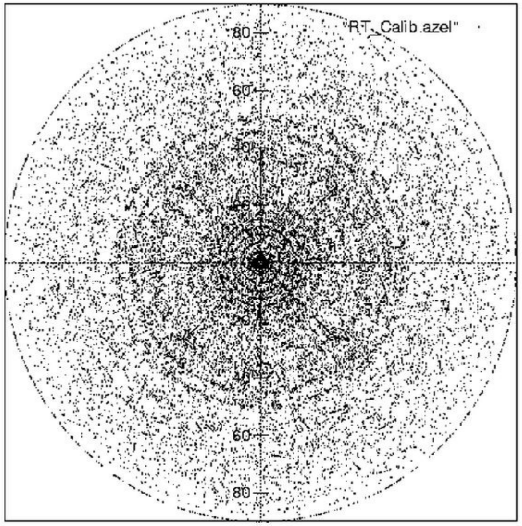
Antenna Phase Center Offset and Variations (PCV)



Absolute Robot-Based GNSS Antenna Calibration

overview method

- fast moving robot
- tilted and rotated GNSS antenna
- uses actual GNSS signals
- atmospheric and orbit errors cancel out using close-by reference station
- reference station antenna cancels out due to procedure
- far-field multipath
  - avoided through high elevation mask of 18°, dynamically adopted to tilted orientations
  - eliminated through modeling of high correlation between consecutive epochs (1-2 s)
- homogeneous coverage of hemisphere, even observations at negative elevations



typical antenna coverage
from robot-based calibration

Repeatability of Phase Phase Offsets and Variations

different robots

- repeatability of absolute PCV antenna calibration with robot
- three different GNPCV robots

robot	operated
Geo++	in Garbsen
ife	in Hannover
Berlin	tested in Garbsen

- individual ASH700936D_M antenna calibrated on

robot	date of PCV calibration
Geo++	2005-08-08
Berlin	2006-02-15
ife	2006-01-14

ife Institut für Erdmessung, Universität Hannover, Germany
Berlin Senatsverwaltung für Stadtentwicklung Berlin, Germany

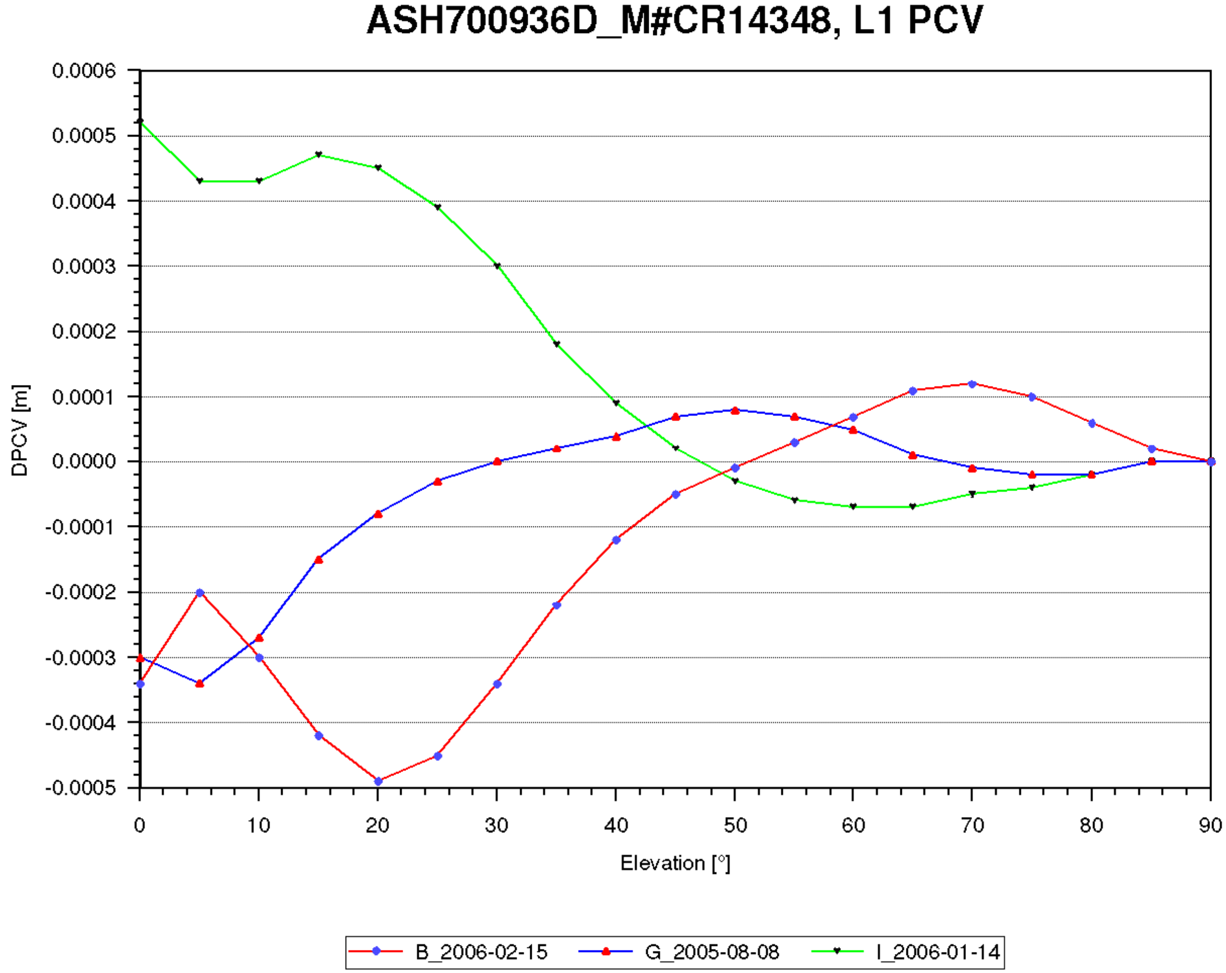
Repeatability of Phase Offsets and Variations

L1 GPS dPCV

- individual ASH700936D_M antenna
- three different robots
- GPS L1 signal
- magnitude PCV differences

L1 < 0.5 mm

Elevation Dependent Difference from Type Mean



Repeatability of Phase Offsets and Variations

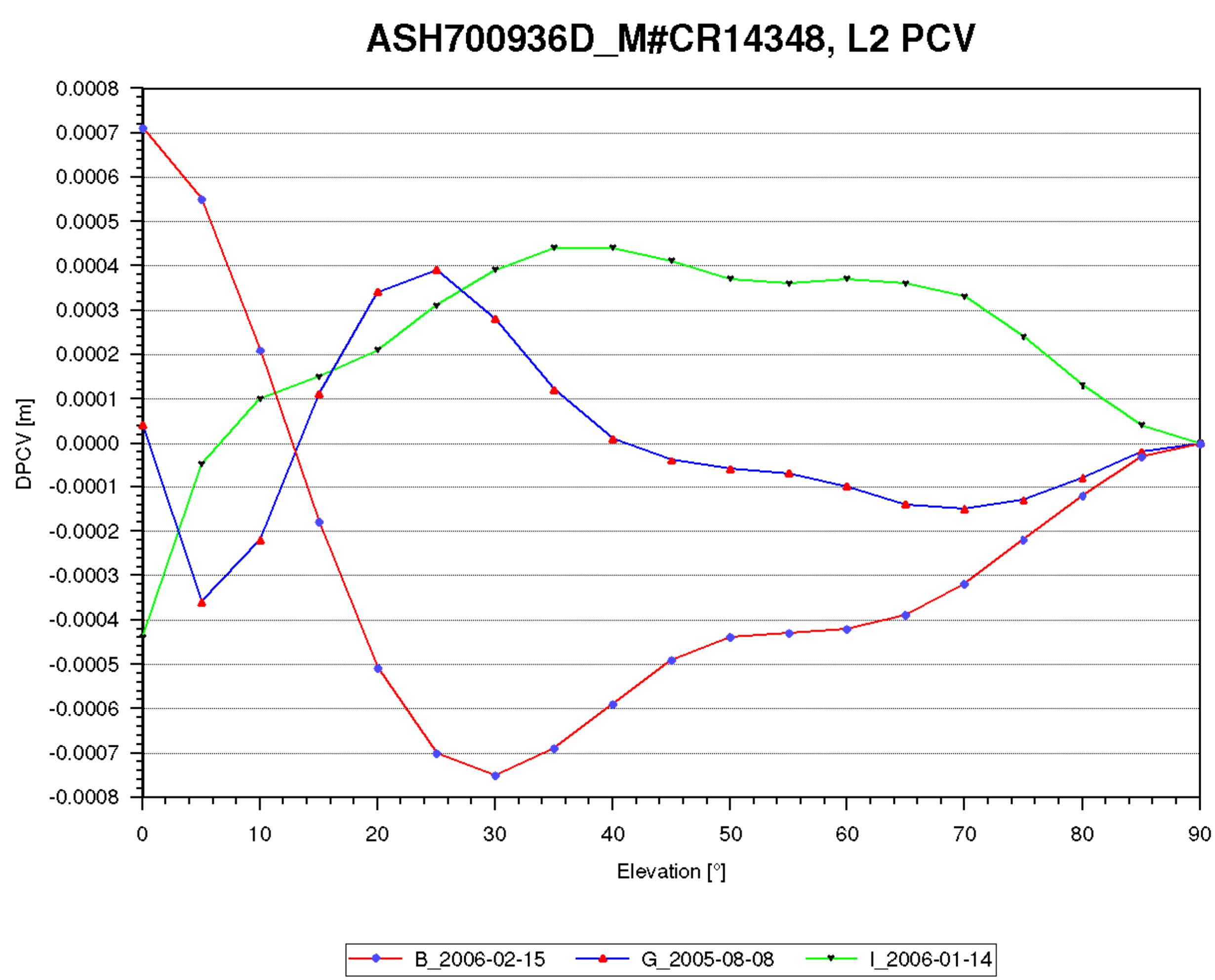
L2 GPS dPCV

- individual ASH700936D_M antenna
- three different robots
- GPS L2 signal
- magnitude PCV differences

L2 < 1 mm

- L2 generally worse due to different signal tracking

Elevation Dependent Difference from Type Mean



Repeatability of Phase Offsets and Variations

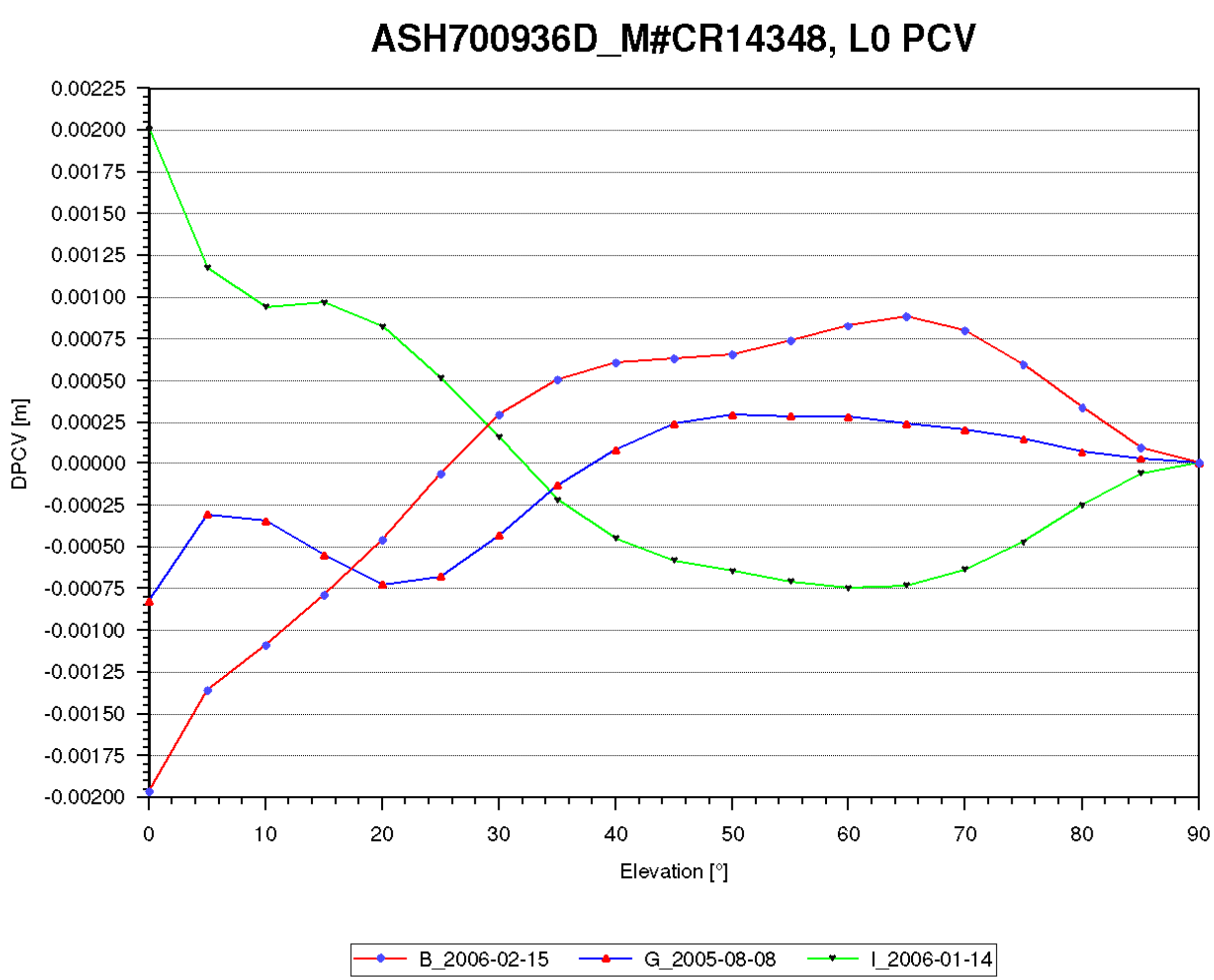
L0 GPS dPCV

- individual ASH700936D_M antenna
- three different robots
- ionospheric free signal
- magnitude PCV differences

L0 < 1 mm
above 10 deg

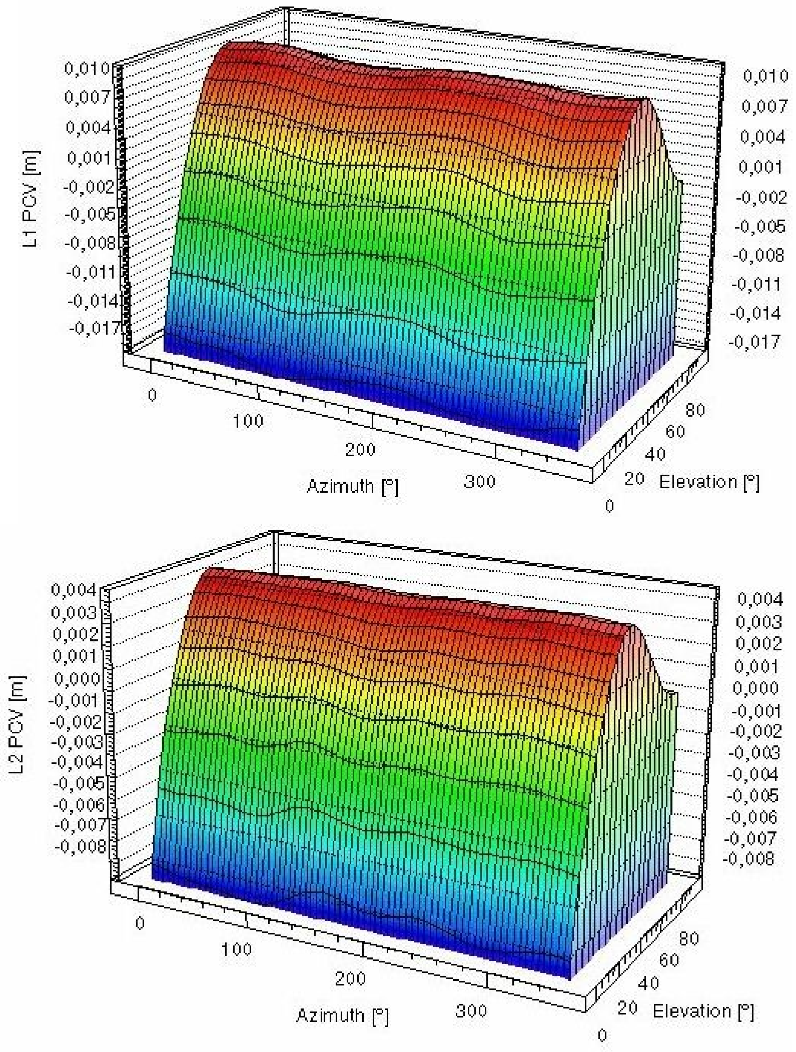
- rule-of-thumb:
factor 3 worse than original signal

Elevation Dependent Difference from Type Mean



Findings from Robot-Based GNSS Antenna Calibration

- absolute 3D offset
  (magnitude mm ... cm)
- absolute phase variation
  (magnitude mm ... cm)
- PCV from (<) 0° to 90° elevation
- 0° to 360° azimuthal PCV
- simultaneous L1, L2
  GPS and GLONASS PCV
- standard deviation
  0.2 ... 0.3 mm (1 sigma)
  for complete PCV (offset plus variation)
- verification of accuracy through
  repeatability
- free of multipath influence
- site and location independent



GPS L1 and L2 PCV TPSCR.G3 TPSH

Insight Through Series of GNSS Antenna Calibrations

Geo++ **GNPCVDB Database** of PCV Type Mean

- PCV type means computed from robot-based antenna calibrations
- rigorous adjustment using complete variance-covariance matrices of individual calibrations
- November 2008 status consists of

154	different antenna types
1151	individually calibrated antennas
4139	individual calibrations

- public information on PCV pattern (graphics, ARP and North definition, etc)
- license for use of absolute PCV (actual access to numeric PCV)
- www.gnpcvdb.geopp.de
- antenna types used within IGS and EPN network published for scientific use (ANTEX file igs05.atx)

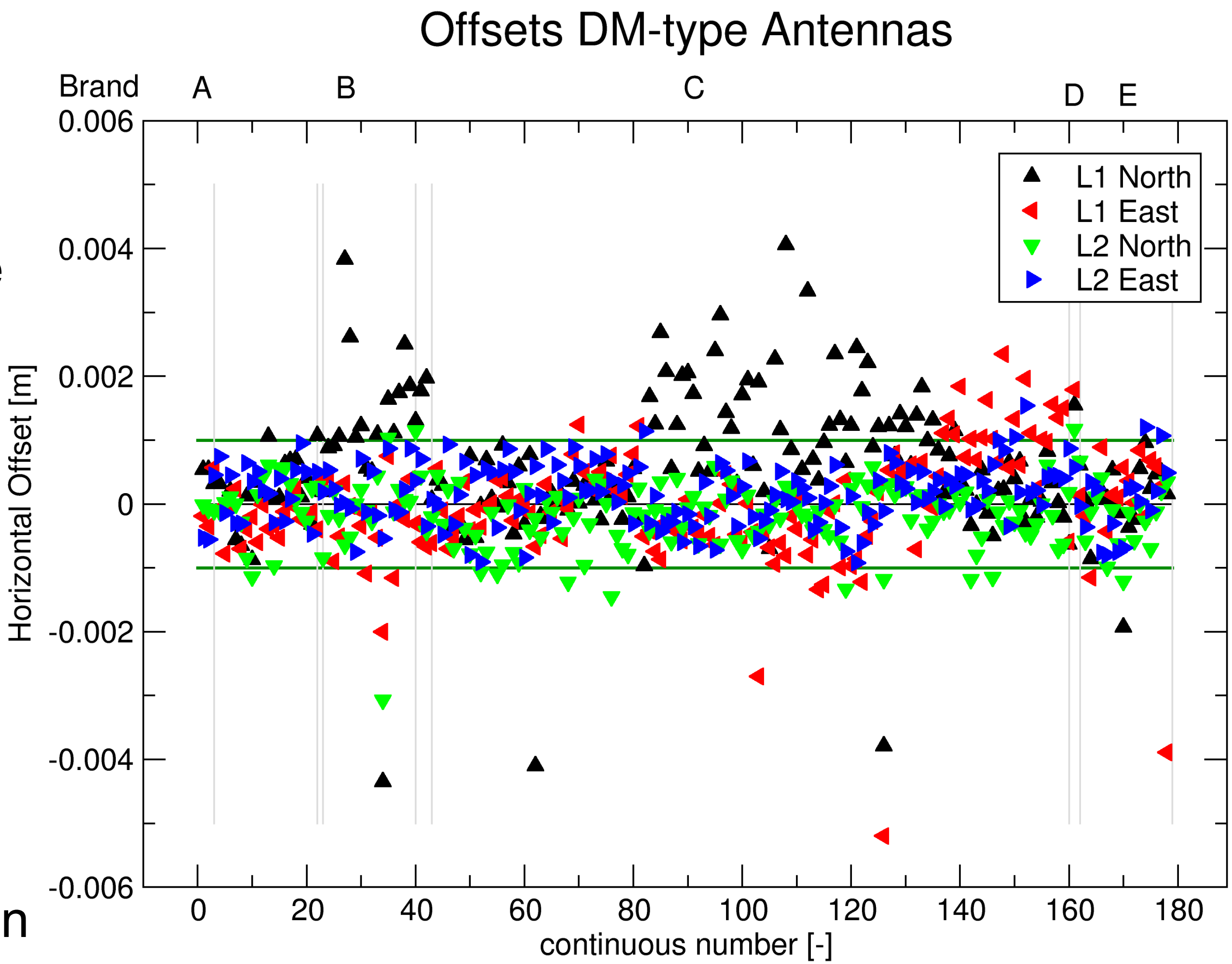
Offset Analysis DM-type Choke Ring Antennas

horizontal offsets

- 5 different brands
- 8 DM-type antennas
- with or without radome not distinguished

- offsets not suited to describe PCV, however, offsets are also azimuthal PCV

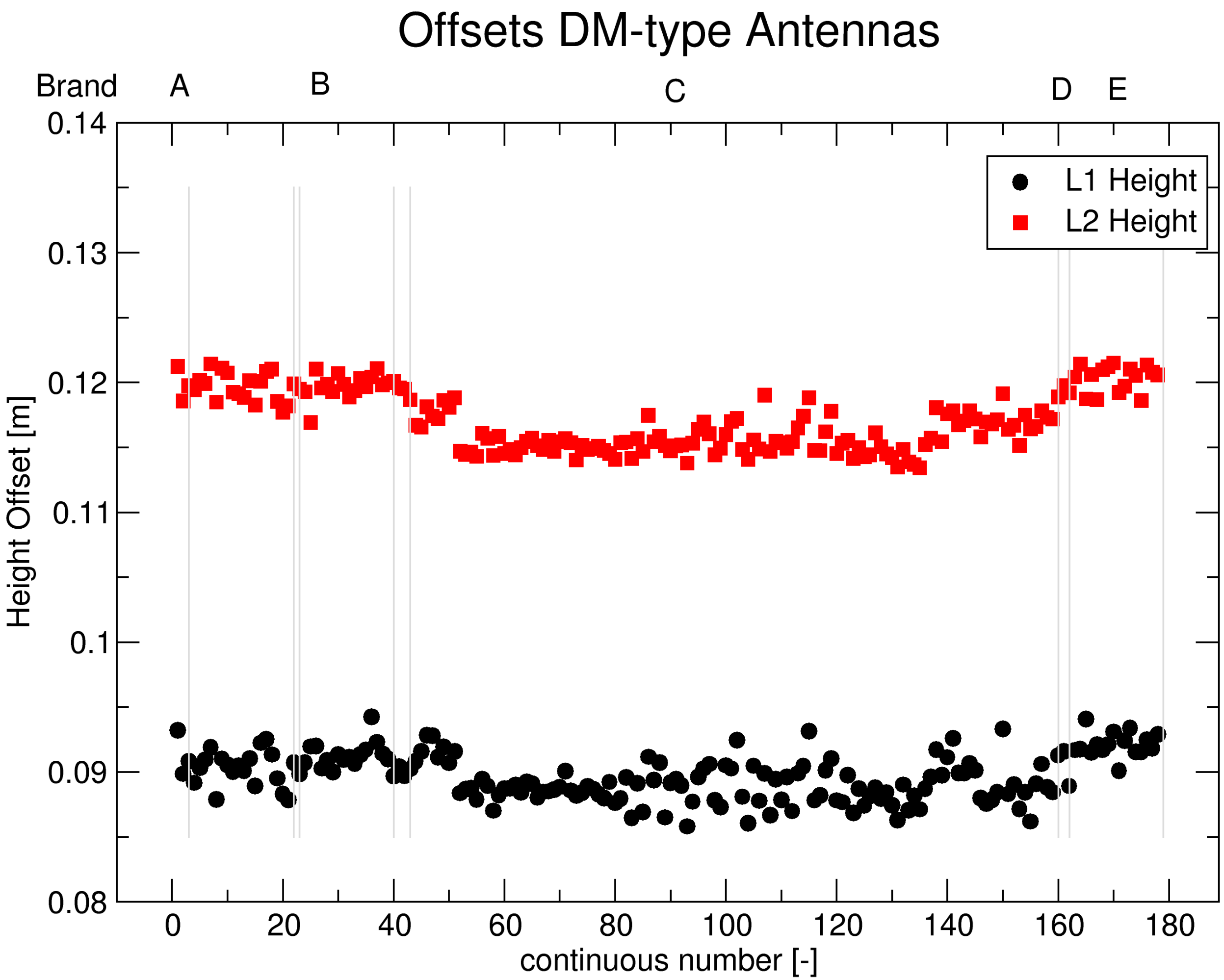
- obviously
  - outliers
  - significant changes in model series



Offset Analysis DM-type Choke Ring Antennas

height offset

- dimension of antenna basically identical
- height offset much weaker than horizontal offsets
- standard deviation over all antennas about 2 mm
- different height level for different model types



Findings from Series of GNSS Antenna Calibrations

- experiences from numerous antenna calibration
- one can observe
  - individual characteristics of antenna
  - outliers compared to type mean
  - changes in model series
  - modification of antenna model
  - assembling errors
- recommendation for precise application
  - individual calibration of antenna

Features of Robot-Based GNSS Antenna Calibration

- robot-based antenna calibration regularly provides
  - GPS phase center and variations (PCV)
  - GLONASS PCV (frequency dependent)
- but, sophisticated method for analysis of complex antenna and station errors
  - far-field multipath for a single station with randomized motions enabling absolute station calibration
  - near-field multipath impact on antenna
  - carrier-to-noise (CN0) pattern
  - environmental impact on antenna reception
  - antenna`s group delay variations (GDV)
  - satellite transmission antenna PCV

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near-field multipath impact on antenna

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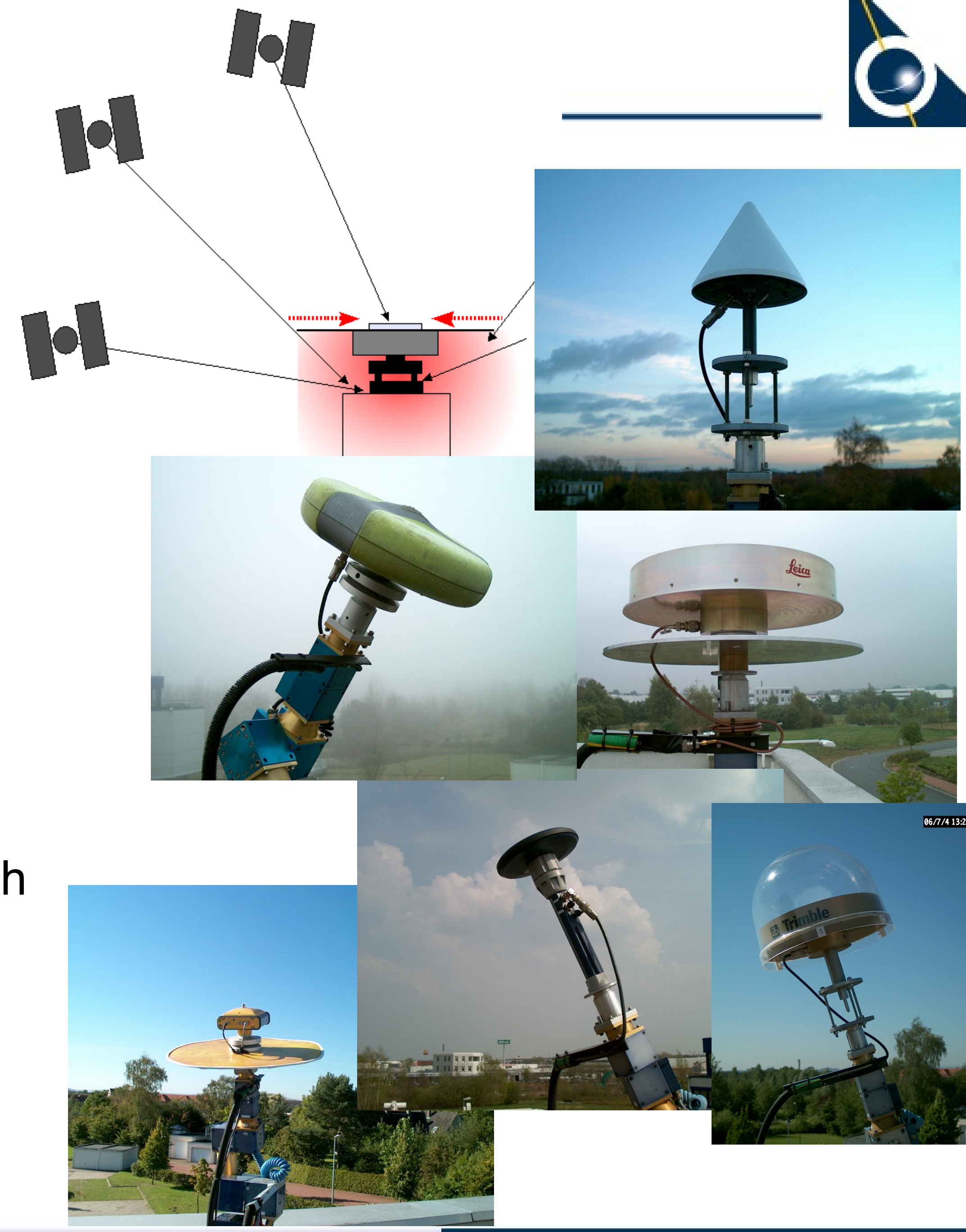
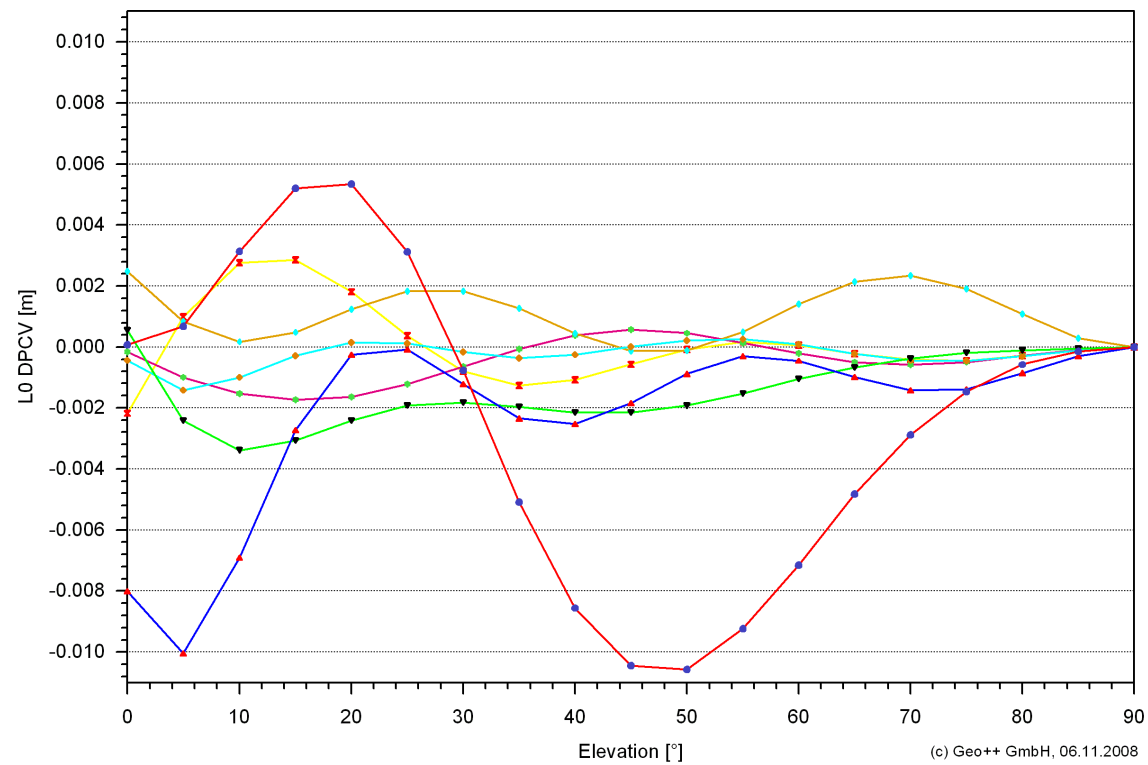
Near-Field Multipath

- representative near-field environment during calibration required
- unprecise boundary of near-field/far-field (dm ... m)
- boundery depends on wavelength and dimension of antenna
- constant geometric relation between antenna/near-field despite movements of antenna
- calibration provides PCV including near-field multipath
- separation obtained through difference of calibration with/without near-field environment



Near-Field Multipath Results

- mm ... cm PCV changes
- but, amplification and dependency on
  - linear combination (L0)
  - tropospheric modeling
  - satellite constellation
  - elevation mask
  - ...
- effect in position domain (height) much higher



examples of geodetic and rover antennas
dPCV L0 GPS standard/near-field calibration

1	TPSPG_A1+GP+M	CONE
2	TPSLEGANT2_E+TM	NONE
3	TPSCR3_GGD+OUB	CONE
4	TRM29659.00+PS	TZGD
5	TPSCR3_GGD+ADF	CONE
6	LEIAT504GG+DFB	NONE
7	LEIAT504GG+SFD	NONE

1 2 3 4 5 6 7

Findings from Near-Field Multipath Analysis

- near-field multipath
  - average of near-field effects not zero
  - no reduction through long observation time
  - causes systematic error in coordinates
  - influence on positioning is location and time dependent
- recommendation for precise applications
  - very careful selection of site, setup and equipment

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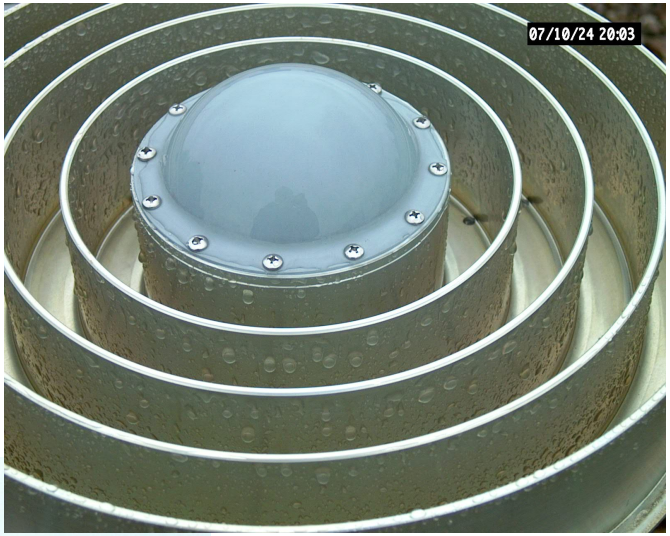
environmental impact on antenna reception

  - antenna`s group delay variations (GDV)
  - satellite transmission antenna PCV

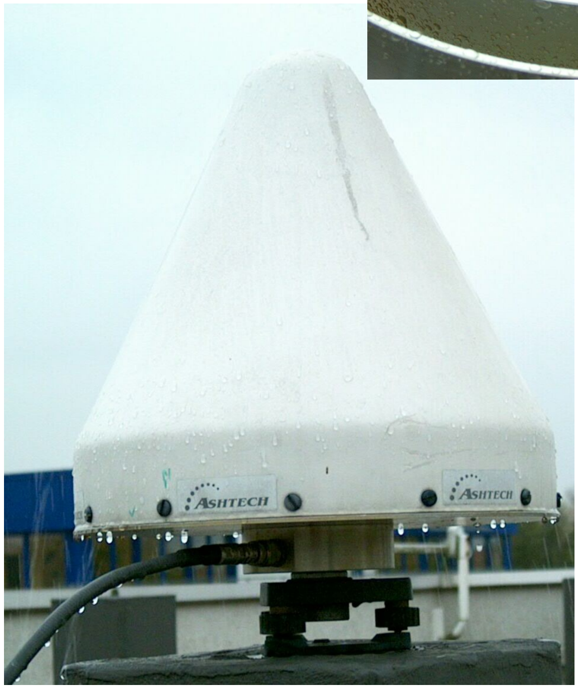
Susceptibility of Antennas to Rain

- Dorne Margolin type GNSS chokering antenna
- considered best choice for precise GNSS applications



what about rainfall
and radome or none?

- NONE
  - drop forming
  - solid water at bottom of chokerings
- SNOW radome
  - dry reception element and chokering from direct rain
  - drop forming
  - water layer (or moisture) on radome



Controlled Rainfall during Absolute Antenna Calibration

- antenna calibration
  - under dry weather conditions
  - wet weather conditions using lawn sprinkler

- approximate rainfall intensity 10 ... 20 mm/h during calibration

- rainfall intensity Germany

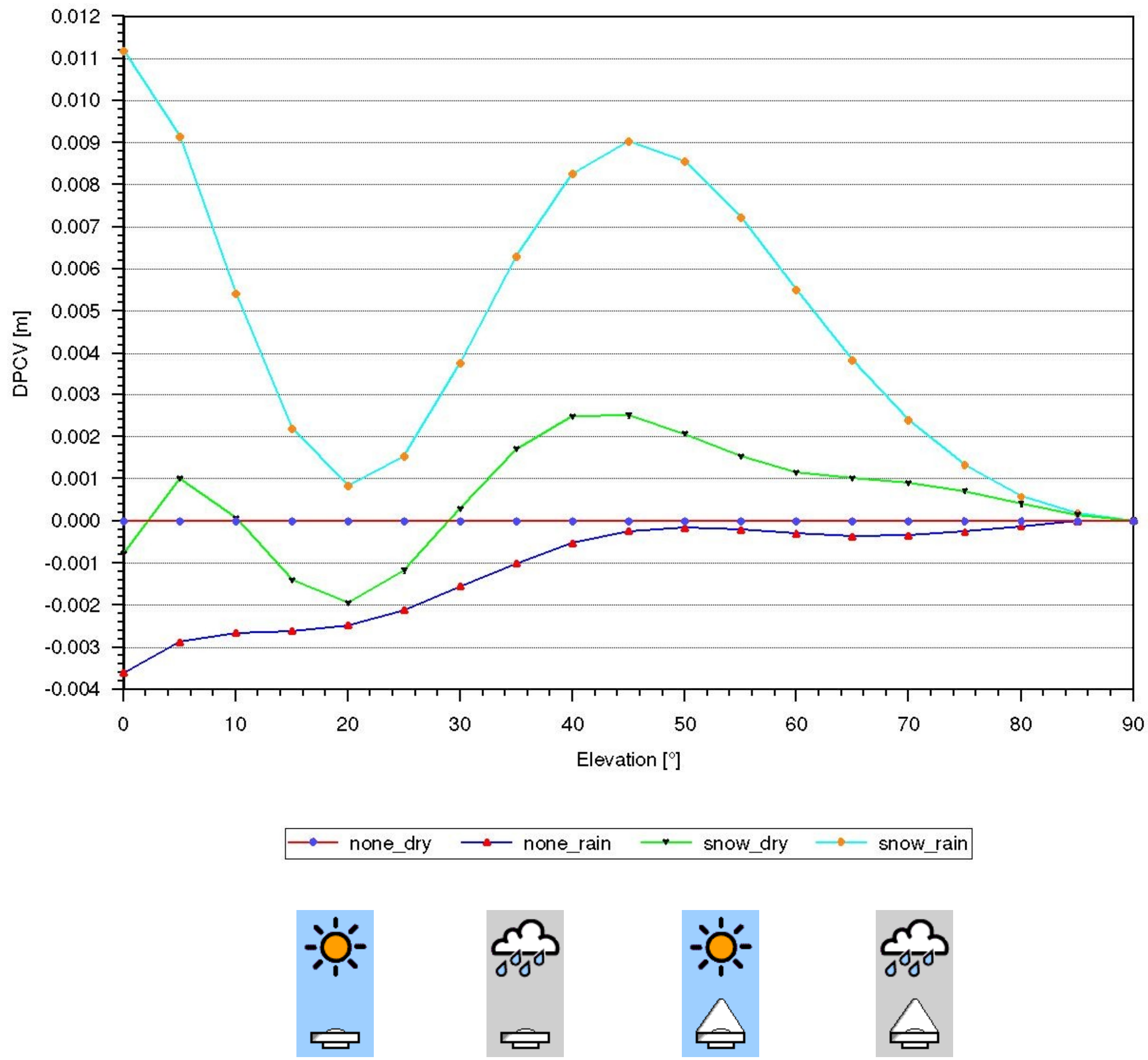
  moderate rainfall 5 mm/h
  heavy rain 30 mm/h
  violent storm > 50 mm/h

Sprinkling of ASH700936D_M SNOW during antenna calibration

Sprinkling of ASH700936D_M NONE during antenna calibration

Susceptibility of Antennas to Rain

- PCV changes due to rainfall for ASH700936D_M
  - NONE GPS L0 < 3 mm
  - SNOW GPS L0 > 10 mm
- significant compared to repeatability of individual antenna
- chokering antenna with radome more affected



L0 ionospheric free signal

Findings from Controlled Rainfall

- PCV changes due to rainfall
- systematic effects in precise height determination
- coordinates changes under changing weather conditions
- reception characteristics will be superimposed by multipath
- needs further analysis with different antenna types

verification using static, short baseline experiment supports results of antenna calibration;
3 to 4 mm height changes due to heavy rain while using investigated antenna model ASH700936D_M SNOW

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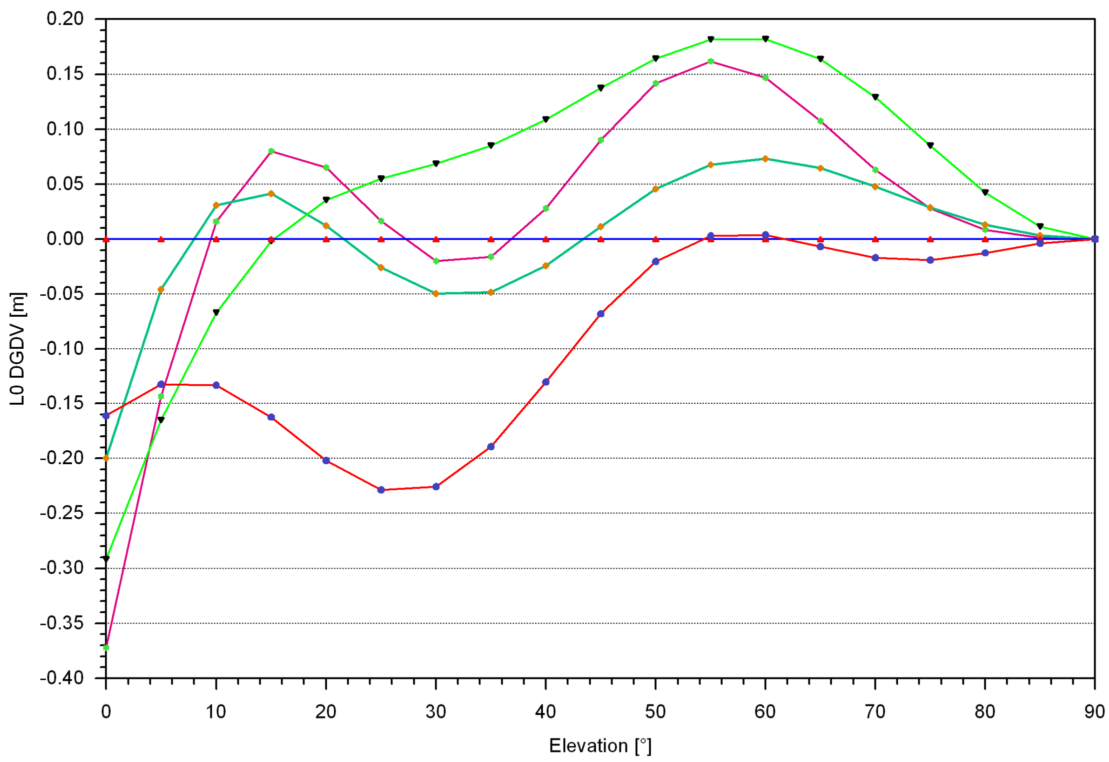
antenna`s group delay variations (GDV)

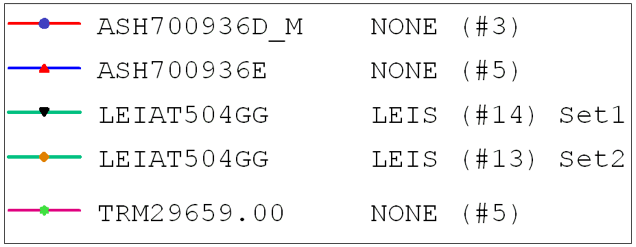
  - satellite transmission antenna PCV

Absolute Group Delay Variations (GDV)

- basically use of code instead of phase signal
- repeatability of individual GDV calibration not sufficient
- significance of GDV only from large sample, eg
  - LEIAT504GG NONE
  - Set1 #14 antennas, Set2 #13 antennas
  - agreement at ~ 5 cm for L1 and L2 GDV
- different DM-type antennas
  - agree better than +/- 20 cm for L0 GDV

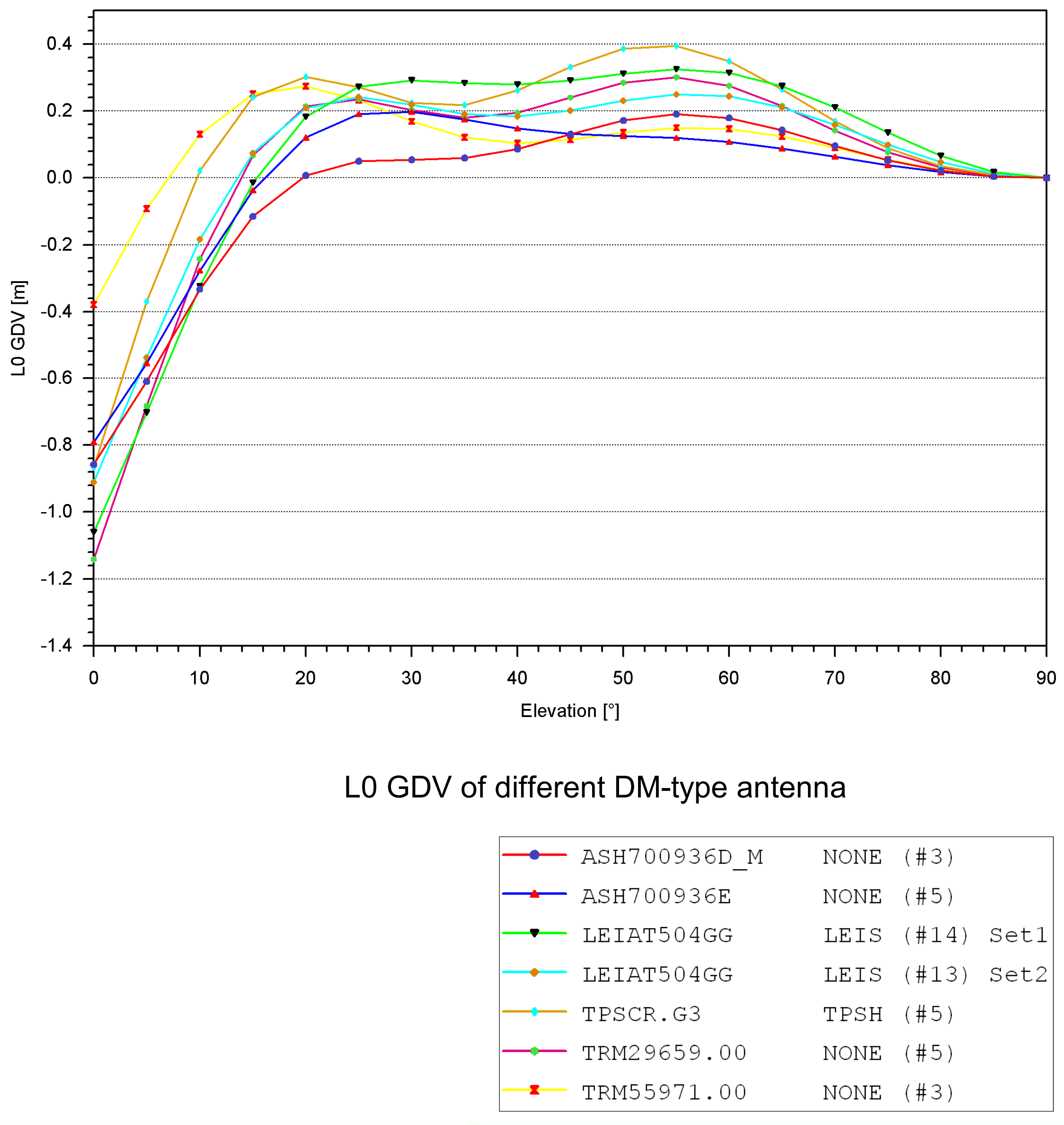


L0 dGDV of different DM-type antenna compared to ASH700936E NONE



Absolute Group Delay Variations (GDV)

- absolute L0 GDV
- different geodetic antennas analyzed
- samples from #3 to #14 antennas
- up to 1 m L0 GDV at low elevations

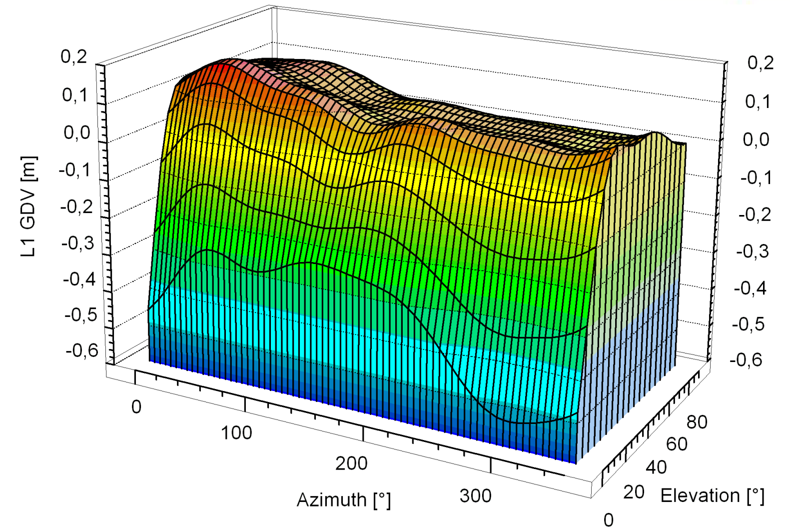


L0 GDV of different DM-type antenna

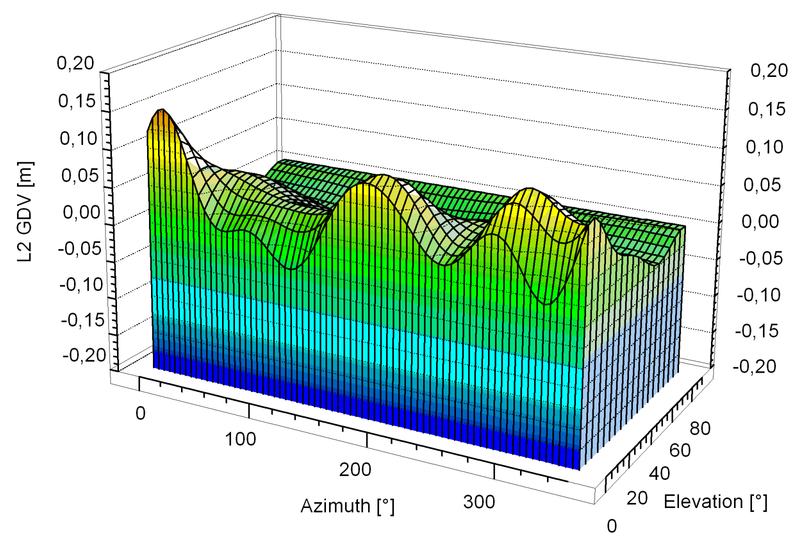
L0 ionospheric free signal

Findings from Absolute Group Delay Variations (GDV)

- large GPS GDV
  for geodetic GNSS antennas
- no sufficient GDV repeatability from individual calibration
- large samples of GDV calibrations give significant type mean
- up to 1 m L0 GDV for elevations
  below 30 deg
- required for
  - precise time transfer
  - precision approach/landing systems
  - ambiguity resolution
    (code/carrier comparison techniques)
- needs further investigations



L1 GDV LEIAT504GG LEIS



L2 GDV LEIAT504GG LEIS

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satellite transmission antenna PCV

Calibration of GNSS Satellite Antenna

why are satellite PCV of importance?

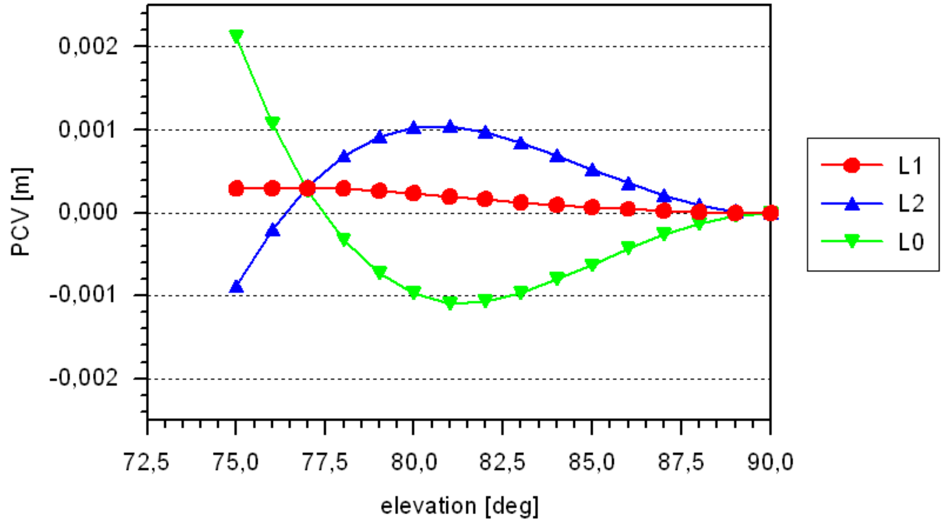
- demand for consistency of absolute receiver PCV and satellite PCV
- provides consistency with other space techniques
  - terrestrial scale
  - station coordinates
  - orbit parameters
  - troposphere
  - ...
- affect GNSS applications
  - eg International Terrestrial Reference Frame (ITRF)
- general GNSS performance improvement for certain applications

GPS Block II/IIA Satellite Antenna

- cooperative project of NGS, Boeing and Geo++
- GPS Block II/IIA antenna
  - 14.4 kg, Ø 1.34 m
- small area of interest (15° cone), but data >30° used
- improved coverage due to robot
- estimation of L1 and L2 PCV
- elevation and azimuth dependency
- not affected by GNSS errors (eg ionosphere, troposphere, etc) due to short baseline

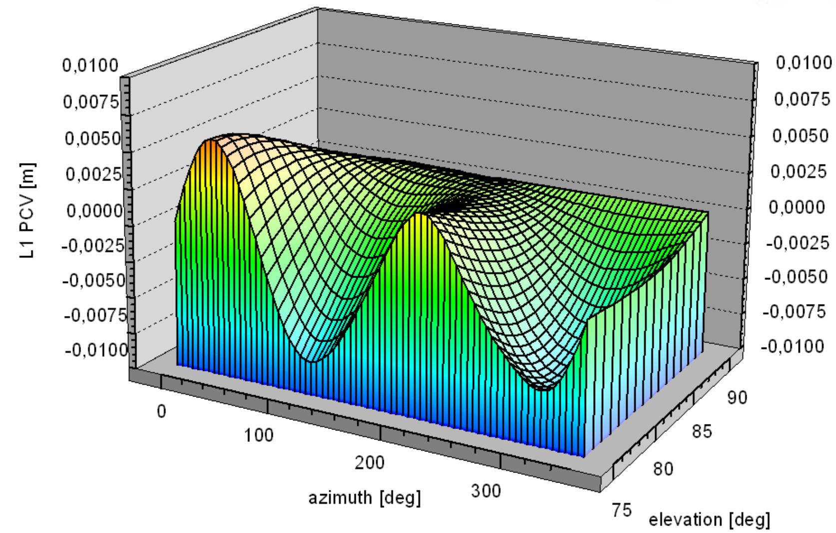
- currently offsets and pure elevation dependent PCV derived from global networks used

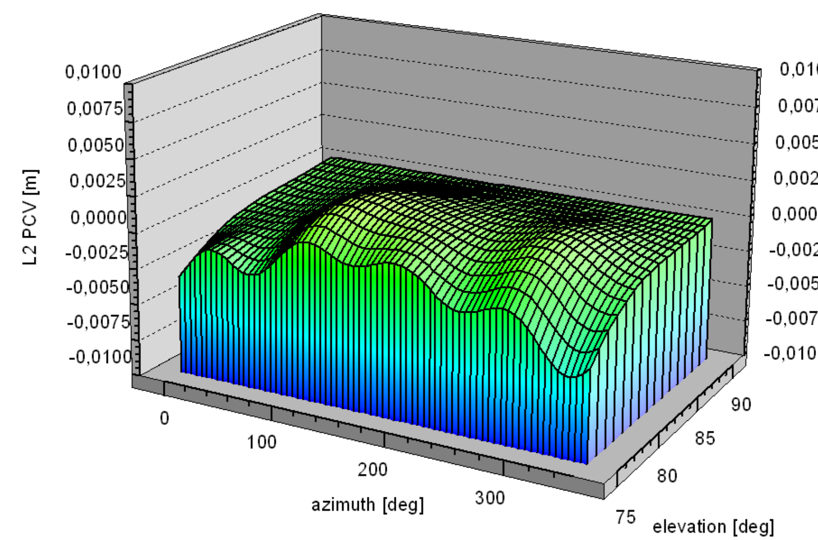
GPS Block II/IIA Satellite Antenna



pure elevation dependent PCV

- mm magnitude of pure elevation dependent PCV
- azimuthal PCV at 15° zenith distance range from
  - -8 ... +6 mm for L1
  - -4 ... +2 mm for L2

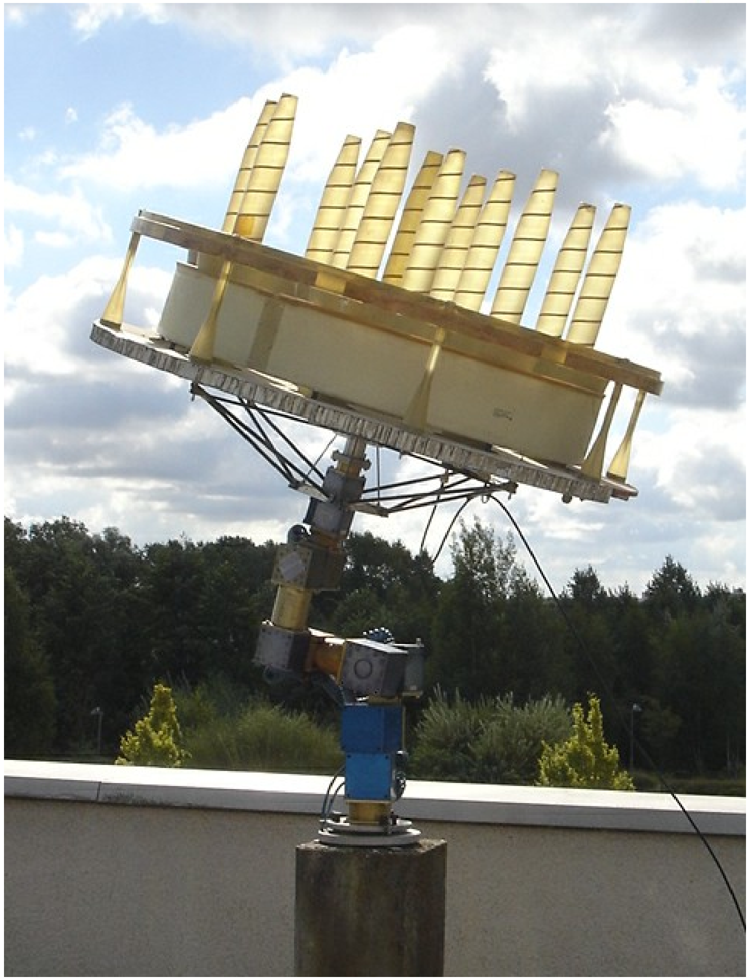




elevation and azimuth dependent PCV

Findings from GPS Block II/IIA Satellite Antenna

- successful absolute PCV field calibration of very heavy antenna
- determination of L1, L2 and L0 PCV
- azimuthal variations significantly larger than pure elevation dependent PCV
- pure elevation dependent PCV account only for 10% of PCV effect
- azimuthal satellite PCV required for further improvement GNSS performance



Summary

- robot-based GNSS antenna calibration operational since 2000
- features and functionalities have been extended
- standard calibrations provide
  - PCV, GDV and CN0 pattern
- sophisticated method for analysis of complex antenna and station errors
  - near-field impact on antenna
  - far-field multipath
  - environmental impact on antenna reception
- high precision of calibration system
- enables better understanding of GNSS error budget to improve GNSS positioning performance

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for further references refer to publications at www.geopp.de


thank you for your attention