Absolute GNSS Antenna Calibration with a Robot: Repeatability of Phase Variations, Calibration of GLONASS and Determination of Carrier-to-Noise Pattern

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- introduction
- repeatability of absolute phase variations (PCV)
- calibration of GLONASS PCV
- determination of carrier-to-noise (CN0)
- summary and conclusion

Introduction

- robot calibration
  - GPS phase center and variations (PCV)
- excellent tool to determine additional parameters
  - GLONASS PCV
  - carrier-to-noise (CN0) pattern
  - near-field effects of antenna
    - separation of multipath in near-field and far-field effects
  - absolute multipath with absolute station calibration
- robot calibration determines
  - GPS + GLO L1 and L2 PCV
  - GPS + GLO S1 and S2 PCV

Repeatability of Phase Variations

Different Robots

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

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

- individual ASH700936D_M antenna calibrated at dates

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

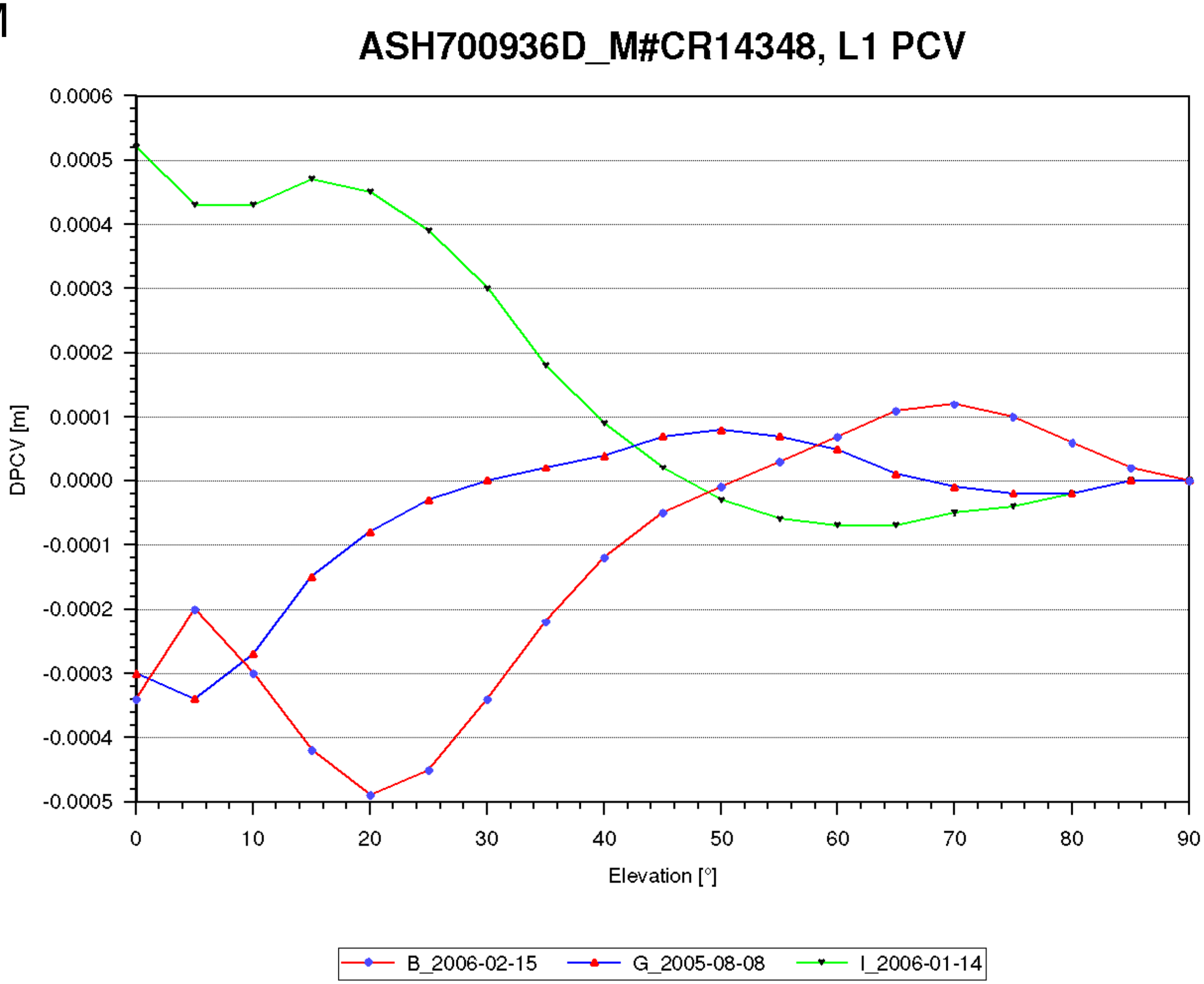
Repeatability of Phase Variations

L1 dPCV

- individual ASH700936D_M antenna
- three different robots
- magnitude PCV differences

L1 < 0.5 mm

Elevation Dependent Difference from Type Mean



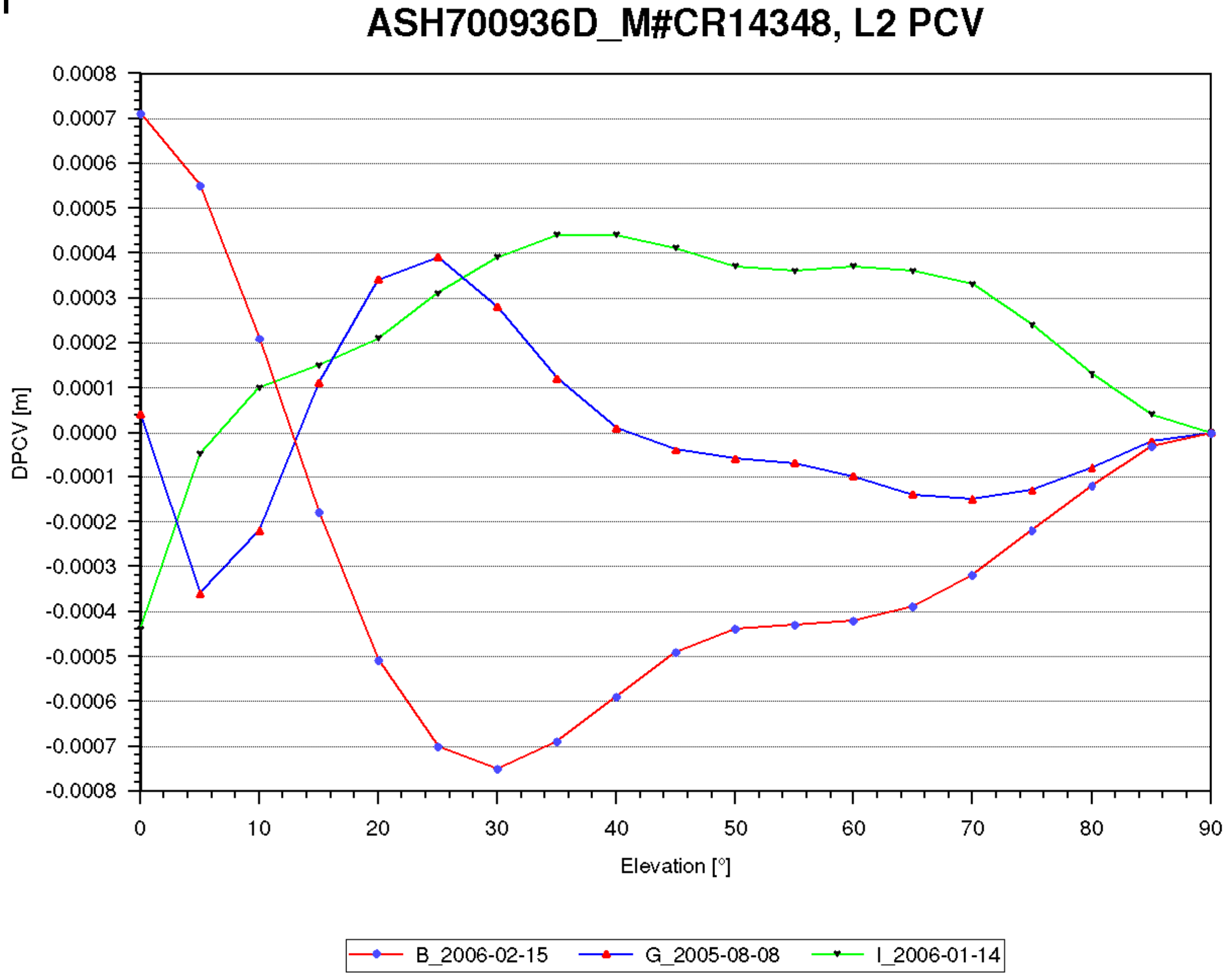
Repeatability of Phase Variations

L2 dPCV

- individual ASH700936D_M antenna
- three different robots
- magnitude PCV differences

L2 < 1 mm

Elevation Dependent Difference from Type Mean



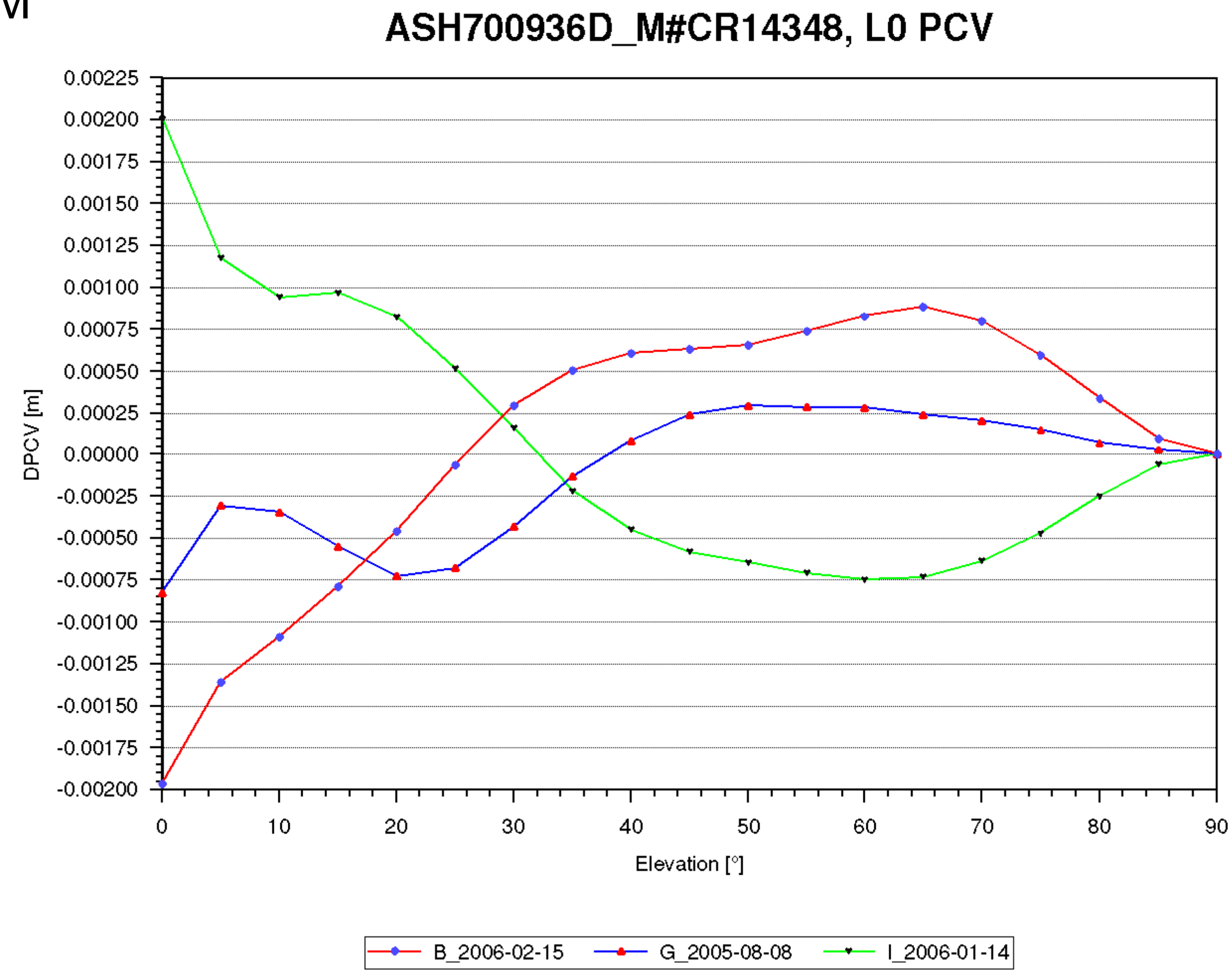
Repeatability of Phase Variations

L0 dPCV

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

L0 < 1 mm
above 10 deg

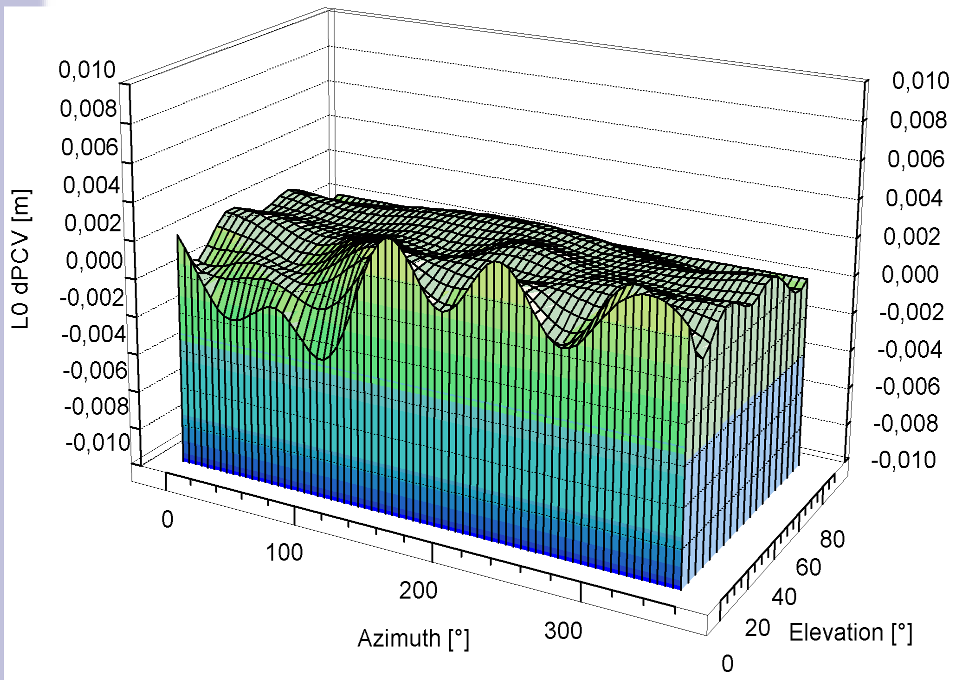
Elevation Dependent Difference from Type Mean



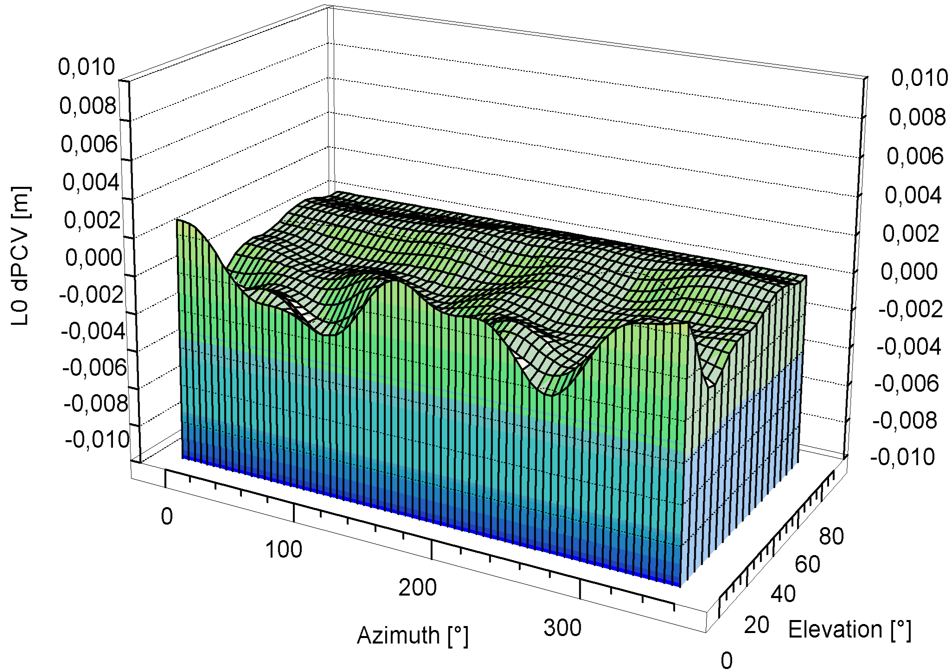
Repeatability Individual Antenna

Repeatability after 2 Years

- geodetic antenna ASH700936D_M SNOW
- differences L0 PCV: average 1-2 mm
- maximum at horizon about 4 mm



after 2 month



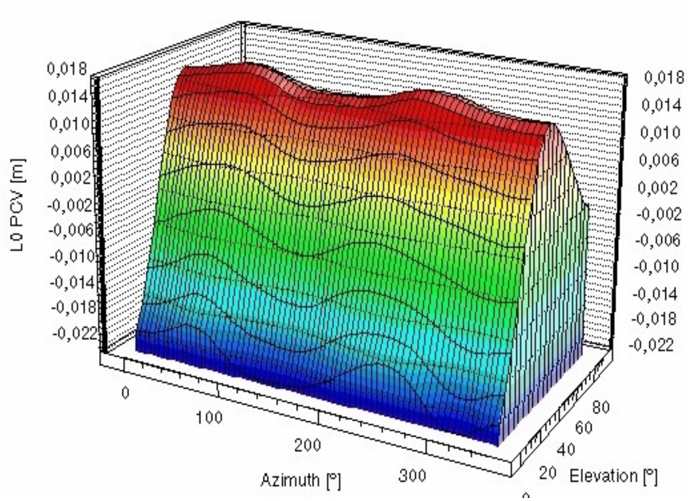
after 26 month

Repeatability of Azimuthal PCV

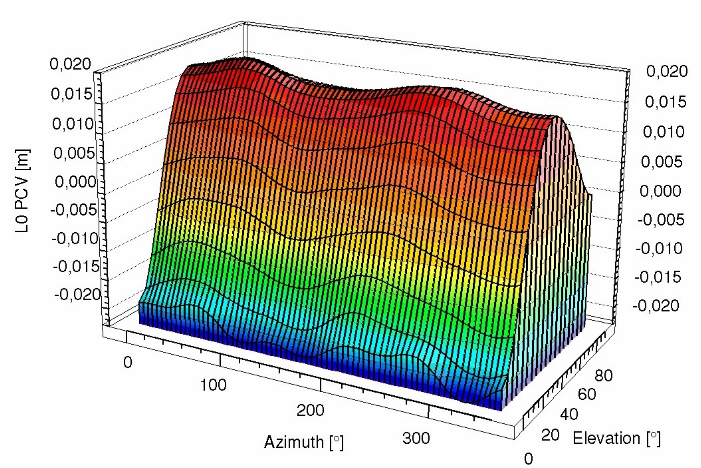
Significance of Azimuthal PCV

- repeatability and standard deviation of azimuthal PCV from robot calibration document stability
- example TPSCR3_GGD CONE
  - choke ring antenna
  - similar PCV pattern as DM-type choke ring antennas
  - type mean consists 132 antennas and 318 calibrations
  - randomly selected individual antenna shows high correlation of 2 mm azimuthal variation
  - remark: also individual differences present

TPSCR3_GGD CONE
Antenna Type PCV L0: 132 Ant, 318 Cal



TPSCR3_GGD CONE
Individual PCV L0: 1 Ant, 2 Cal



Geo++ GNPCVDB Database

Absolute PCV Type Mean

- type means computed from calibrated antennas performed with robot
- rigorous adjustment using complete variance-covariance matrix of individual calibrations
- April 2006

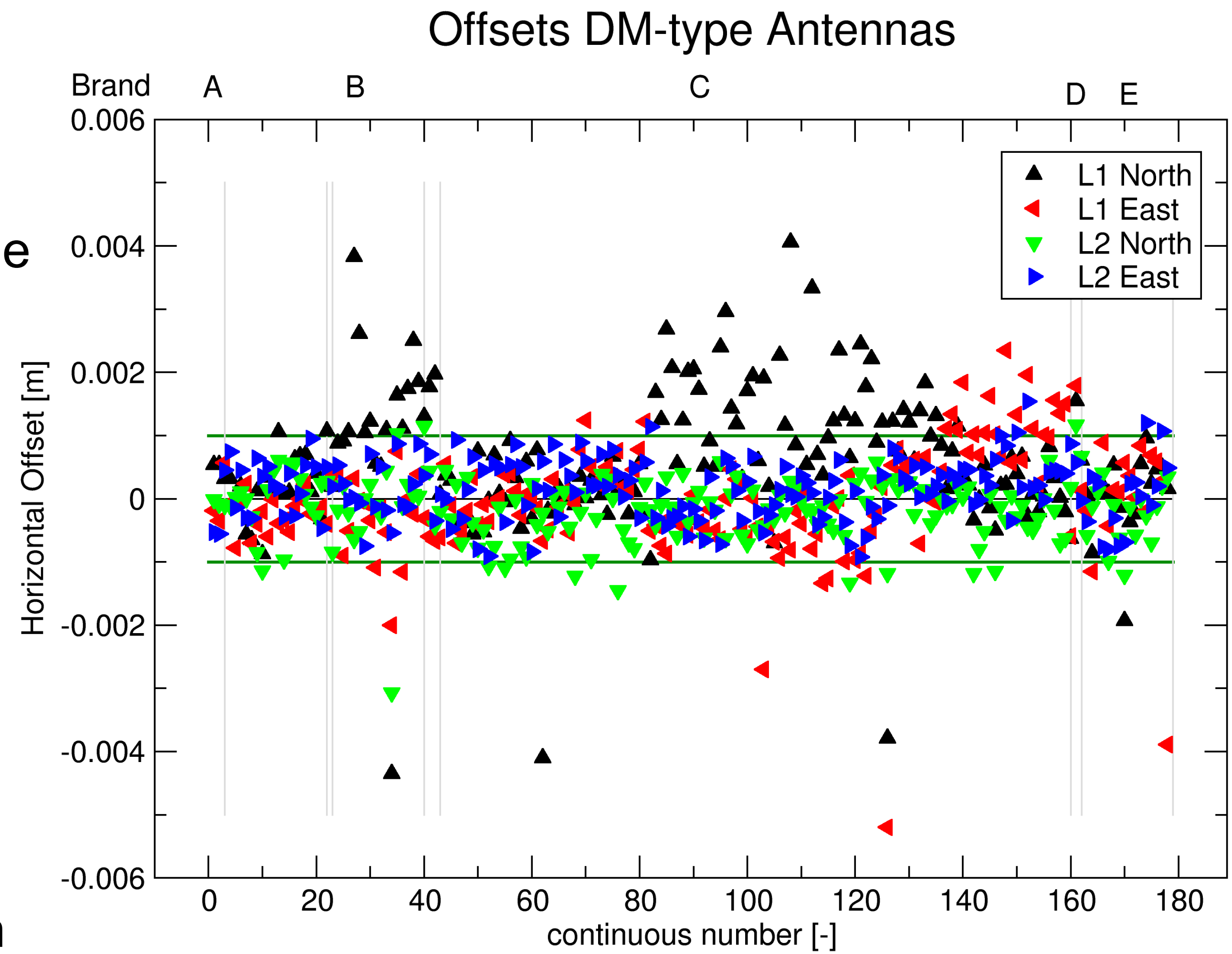
about	125	different antenna types
	957	individual calibrated antennas
	3748	individual calibrations

- public information on PCV pattern (graphics, ARP and North definition, etc)
- selected antennas provided to IGS
- license for use of absolute PCV (actual access to numeric PCV)
- http://gnpcvdb.geopp.de/

Offset Analysis DM-type Choke Ring Antennas

Horizontal Offsets

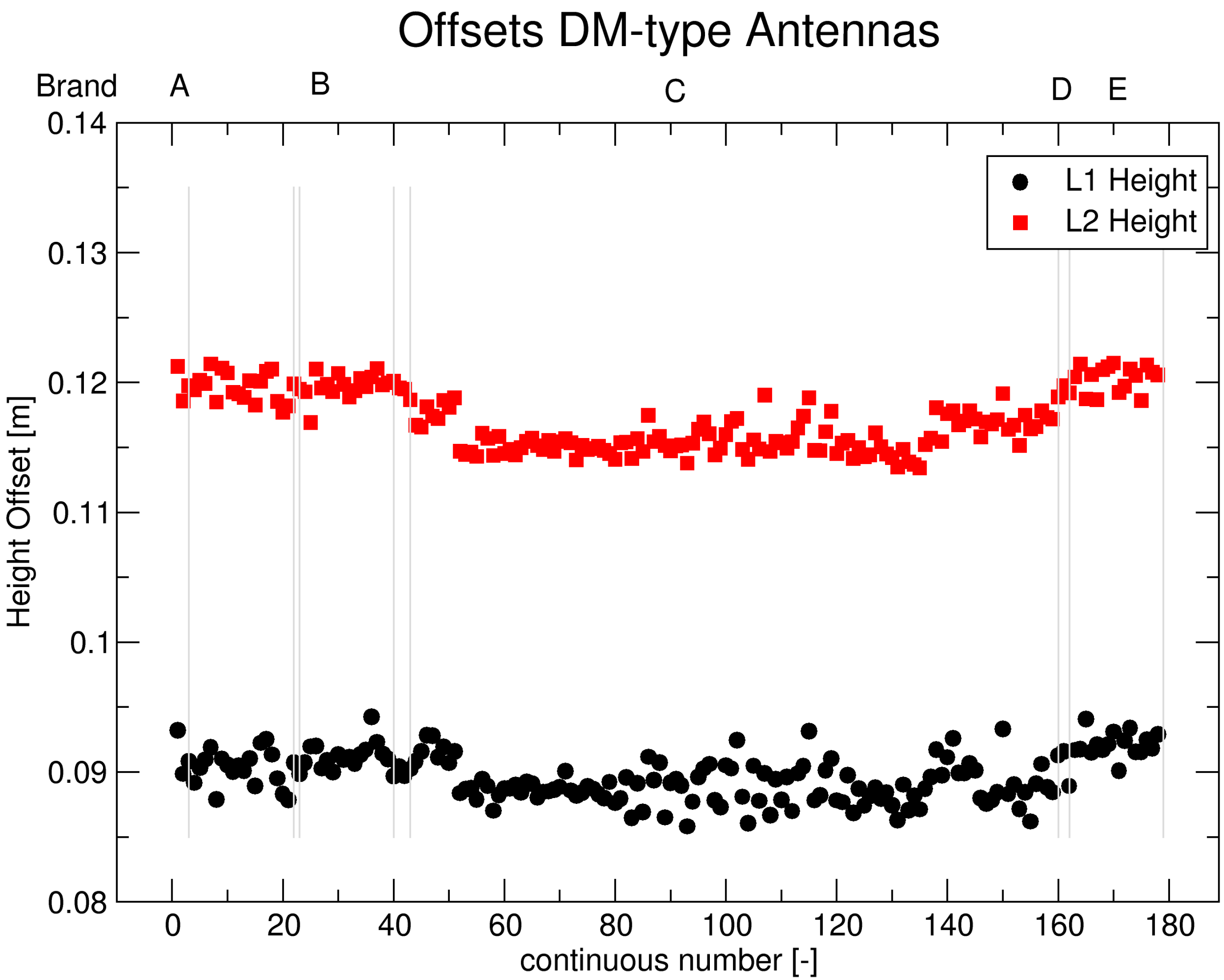
- 5 different brands
- 8 DM-type antennas
- with or without radome not distinguished
- offsets not suited to describe PCV
- however, offsets are also azimuthal PCV
- outliers
- significant changes in model series



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 level for different model types

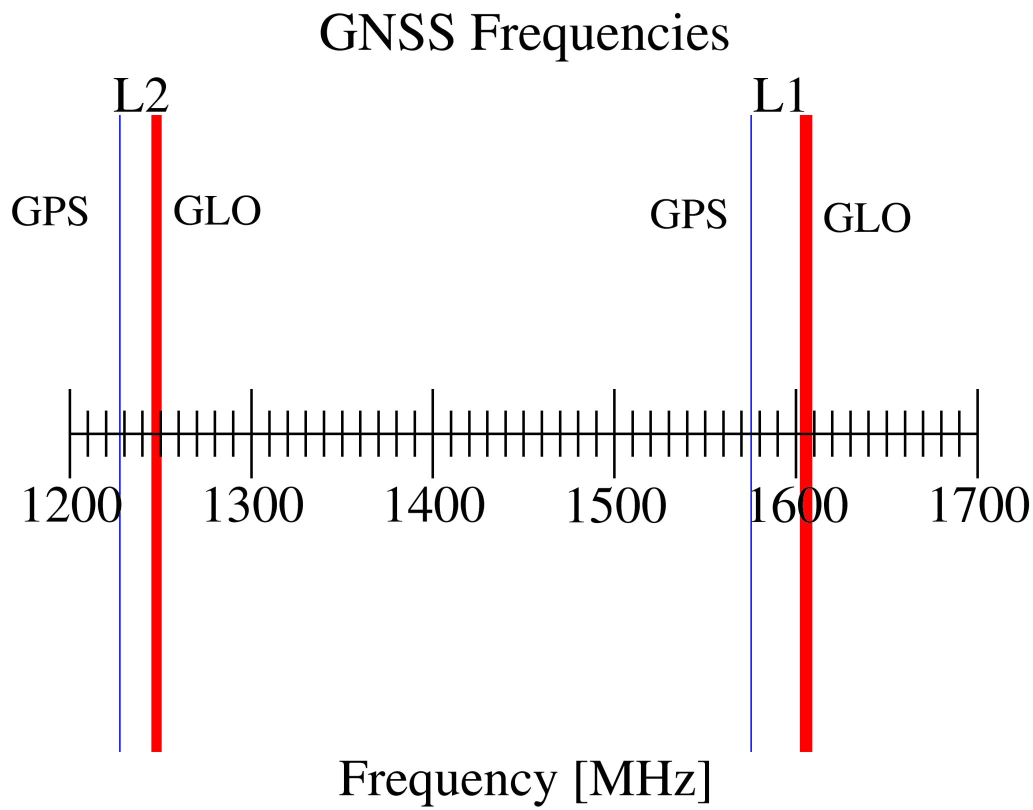


Calibration of GLONASS PCV

Current Status

- differences to GPS
  - different frequencies
  - mixture of frequencies used in field calibration
  - for a long time no sufficient constellation
- GPS PCV used for GLO PCV

- GPS PCV representative**?** / GLONASS calibration necessary**?**
- frequency dependent calibration possible for GLONASS**?** / necessary for GLONASS**?**



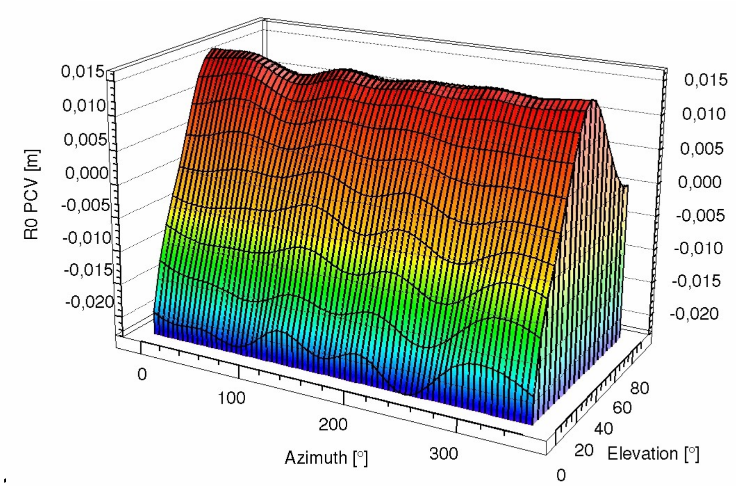
Calibration of GLONASS PCV

Absolute PCV Robot Calibration

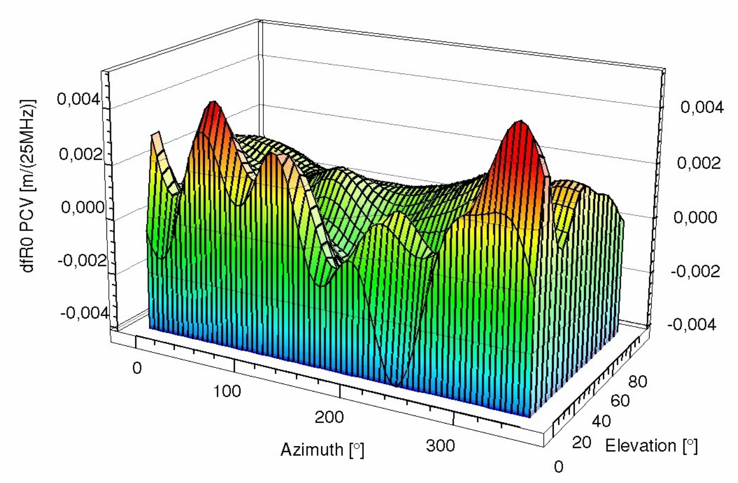
- estimates GLO L1 and L2
  - mixture of observed GLONASS frequencies (constellation)
- frequency dependent GLONASS PCV
  - assumes linearity of PCV changes for GPS/GLO, GLO/GLO frequencies
    (compliant with Schupler, Clark, GPS World, 200[illegible])
  - reference signal GPS L1 and L2
  - estimates Delta PCV per 25.0 MHz
  - easy to handle scaling based on approximate mean difference between GPS and GLO frequencies

    (mean both freq. (k = -7 ... 6) ~ 22 MHz
    mean both freq. (k = -7 ... 12) ~ 24 MHZ)

ASH700936D_M SNOW
GLO L0 PCV: Mixed GLO Calibration



ASH700936D_M SNOW
GLO L0 Delta PCV



Calibration of GLONASS PCV

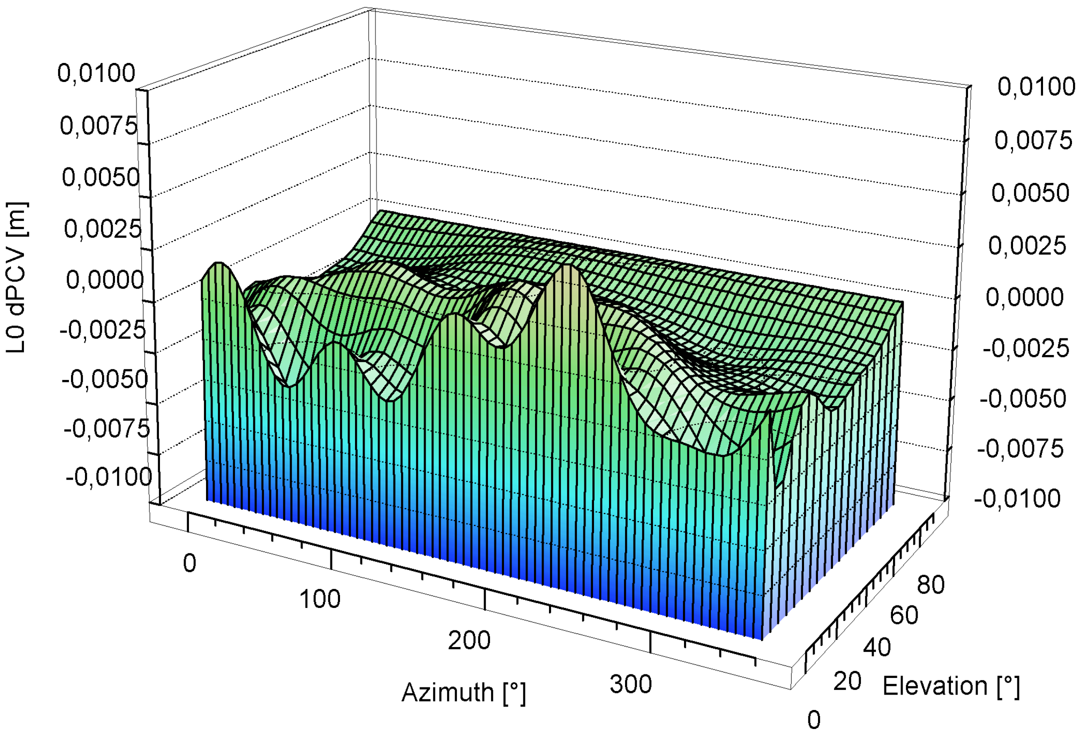
PCV Difference between GPS and GLONASS

- current situation
  GPS PCV == GLO PCV
- k=4 mean frequency channel for current GLONASS constellation
- ASH700936D_M antenna
- simultaneous calibration
- mean difference GPS and GLO L0 PCV
- magnitude PCV differences

  L0 mean 2 mm
  maximum over 5 mm

ASH700936D_M SNOW

Difference_GPS/GLO_(k=4)

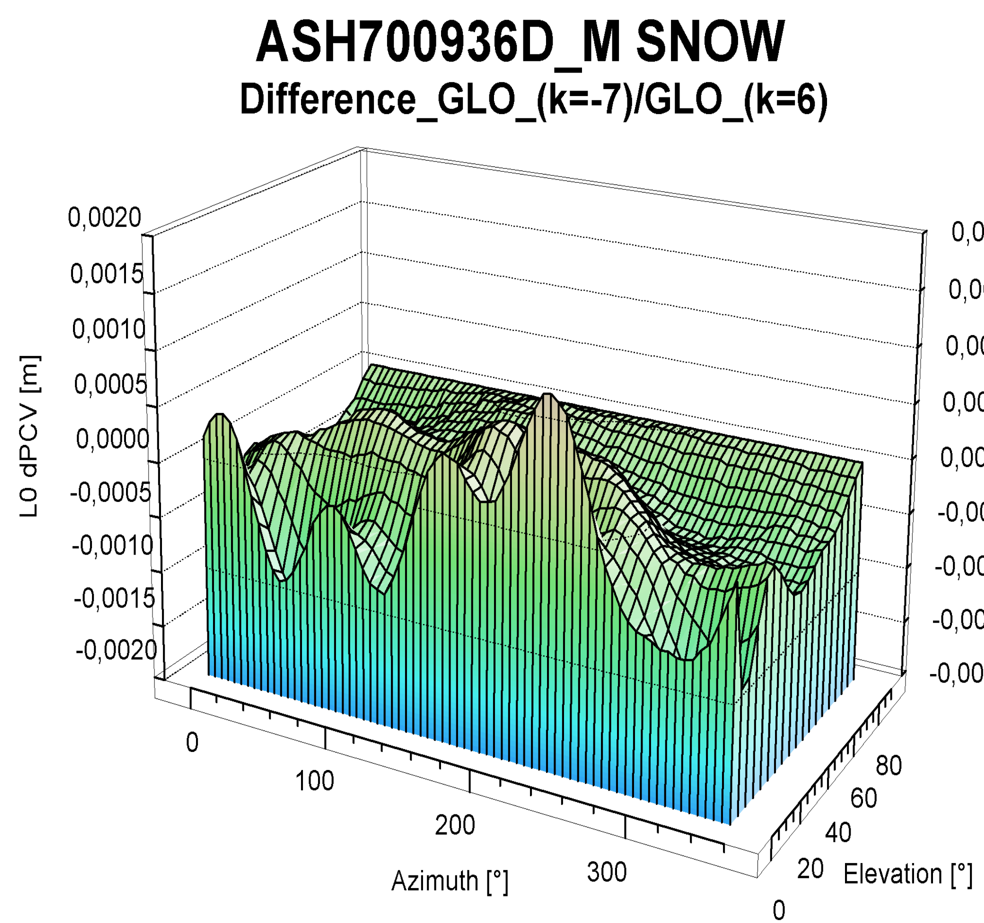


Calibration of GLONASS PCV

Difference between GLONASS frequencies

- GLONASS frequencies beyond 2005
  frequency channels
  k = -7 ... +6
  - largest frequency difference
    k=-7 and k=6
- ASH700936D_M antenna
- magnitude PCV differences

L0 mean	> 1 mm
maximum	1.5 mm

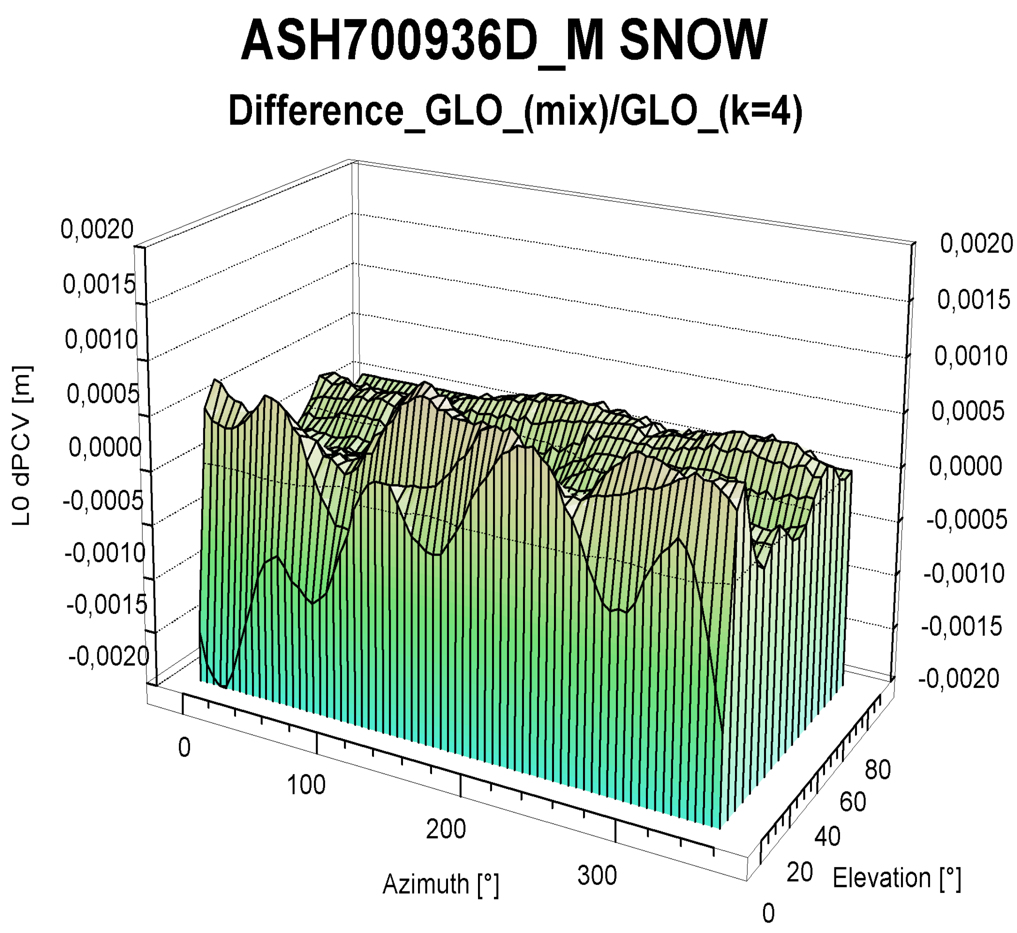


Calibration of GLONASS PCV

Difference between mixed and frequency dependent calibration

- constellation dependent mix of GLONASS frequencies
- k=4 mean frequency channel for current GLONASS constellation
- ASH700936D_M antenna
- simultaneous calibration
- magnitude PCV differences

L0 mean	<1 mm
maximum	2 mm

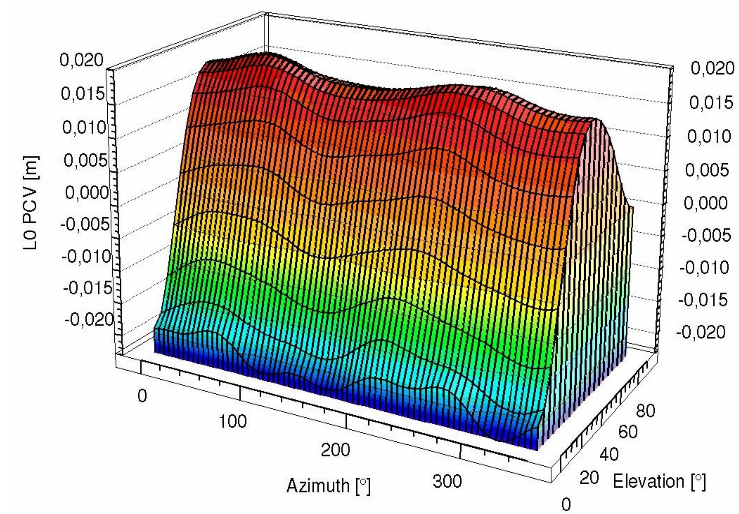


Calibration of GLONASS PCV

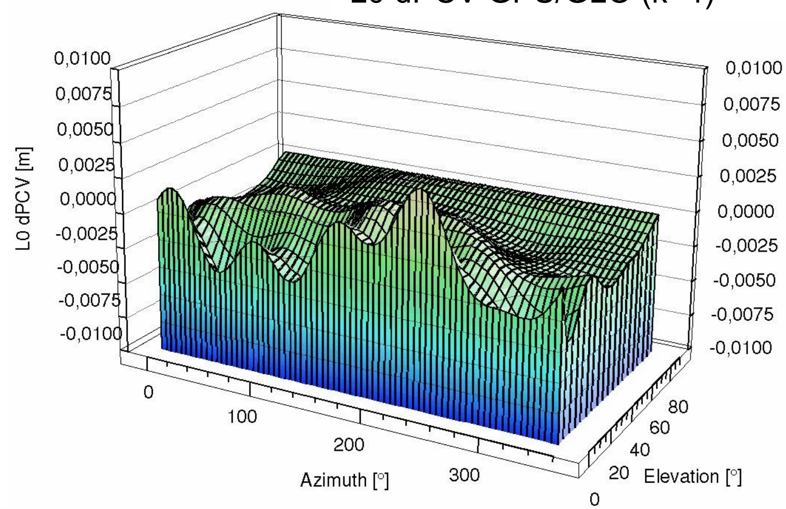
TPSCR3_GGD CONE

- similar PCV pattern as ASH700936D_M choke ring antenna
- different constellation during calibration
- high correlation in L0 PCV difference GPS/GLO (k=4)
- supports independently significance and magnitude of PCV differences between GPS and GLO

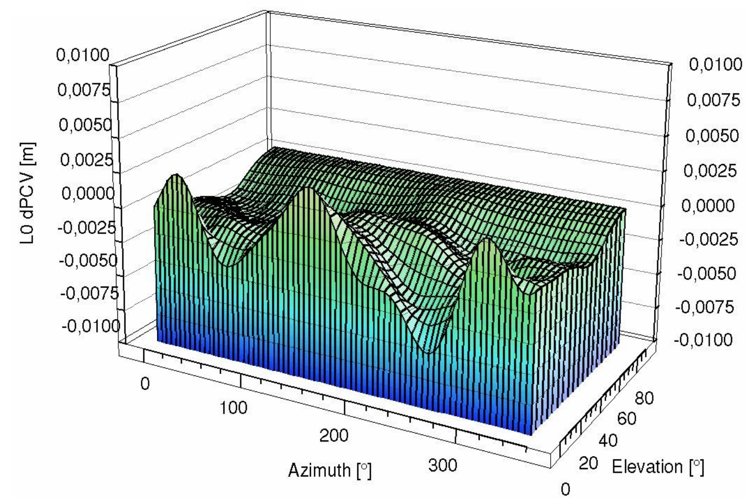
TPSCR3_GGD CONE
GPS L0 PCV



ASH700936D_M
L0 dPCV GPS/GLO (k=4)



TPSCR3_GGD CONE
L0 dPCV GPS/GLO (k=4)



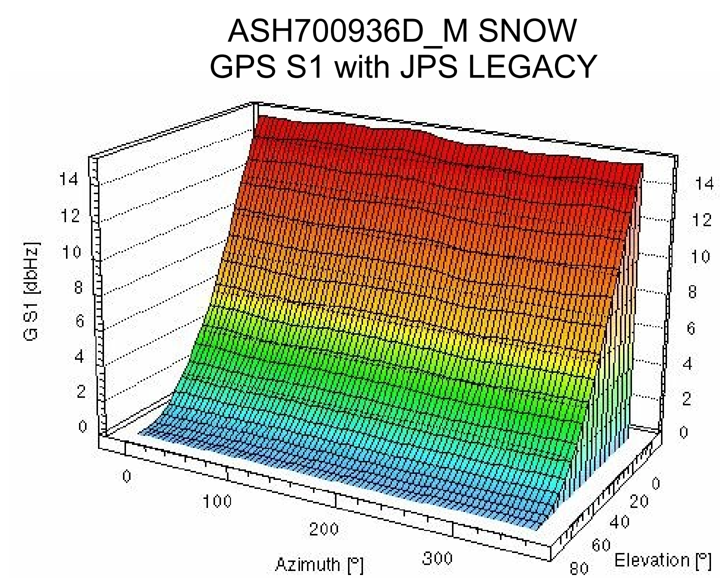
Determination of Carrier-to-Noise Pattern

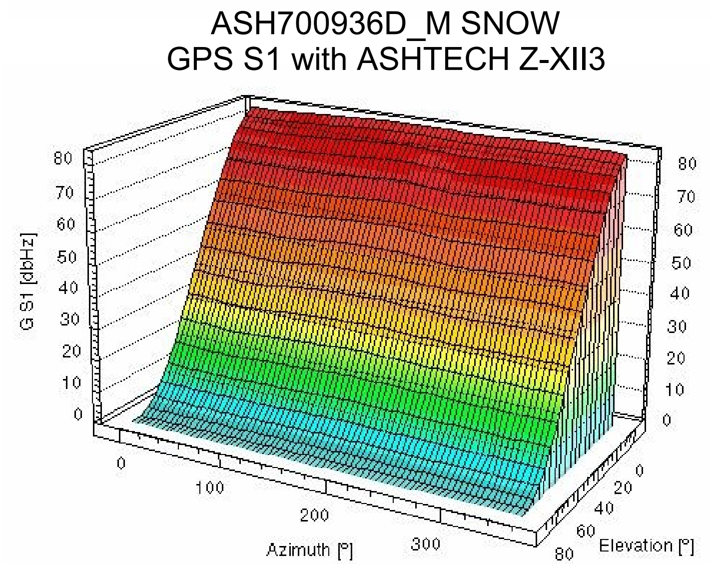
CN0 Robot Calibration

- modeling with spherical harmonics (degree and order as for PCV)
- CN0 for zenith set to zero, hence result is CN0 decrease
- absolute information also stored and accessible
- example

  individual ASH700936D_M SNOW

receiver type	L1 CN0 decrease
JPS Legacy	14 dBHz
ASHTECH Z-XII3	80 units





Determination of Carrier-to-Noise Pattern

How to Use CN0 Decrease Function?

- effective use of CN0 observable requires standardization
  - determination of equipment dependent effects
    - antenna „gain pattern“
    - cable attenuation
    - receiver dependencies
      (hardware and firmware version, parameter settings)
      - mapping function to convert to dBHz CN0 observable
      - mapping function to get comparable CN0 observable between receivers
  - mapping-function for atmospheric effects (inclusive space loss)
  - calibration of satellites using global observations

Determination of Carrier-to-Noise Pattern

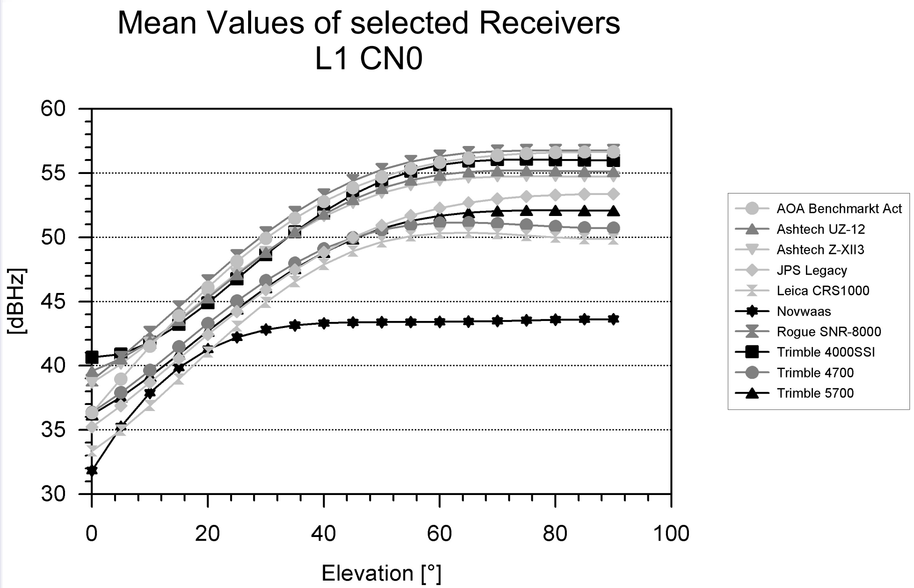
Applied CN0 Standardization Procedure

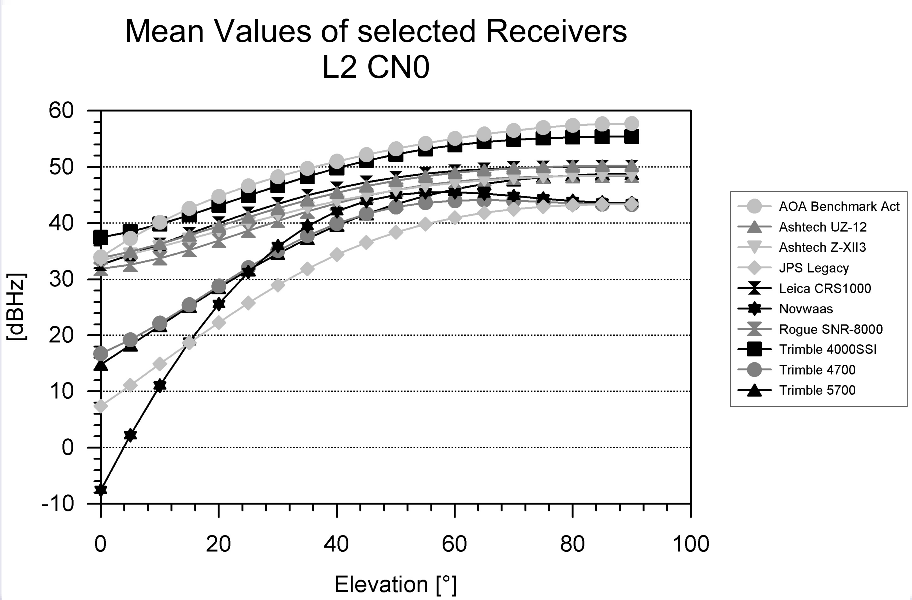
- several conversions and corrections applied to initial CN0 observable

Affecting CN0	*Abbr.*	*Correction*
satellite	Sat	ICD GPS "received power function"
atmosphere	Atm	ICD GPS "received power function"
antenna	Ant	robot calibration
cable/wiring	Cab	relative CN0 (CN0 decrease)
receiver	Rec	standardization (mapping function related to Ashtech Z-X)

- standardized CN0 =
  CN0 - ((Sat + Atm) + Cab + Ant + Rec) = MP + Diff + ε
- multipath and diffraction maintained
- usable for CN0 based observation weighting

Determination of Carrier-to-Noise Pattern





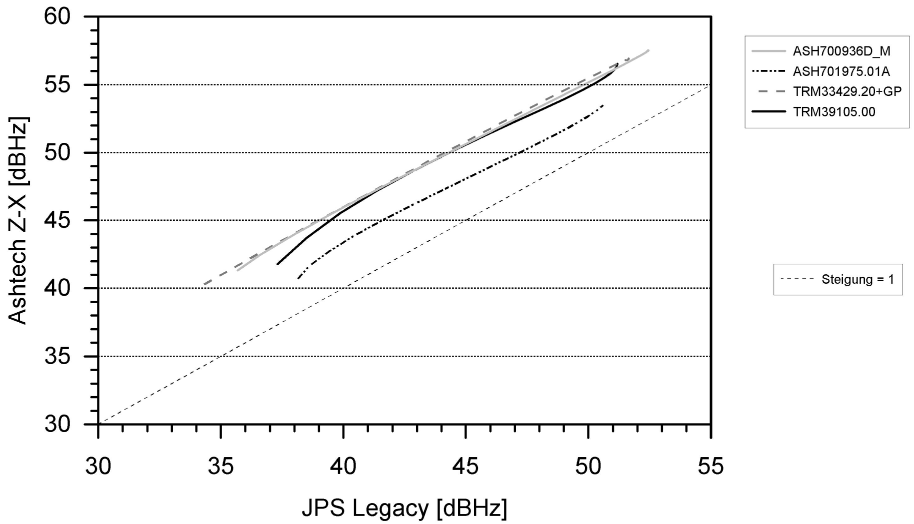
CN0 Differences between Receivers

- conversion signal-to-noise units to dbHz
- significant differences in shape of functions
- cable and receiver setups allow parallel shift of function

Determination of Carrier-to-Noise Pattern

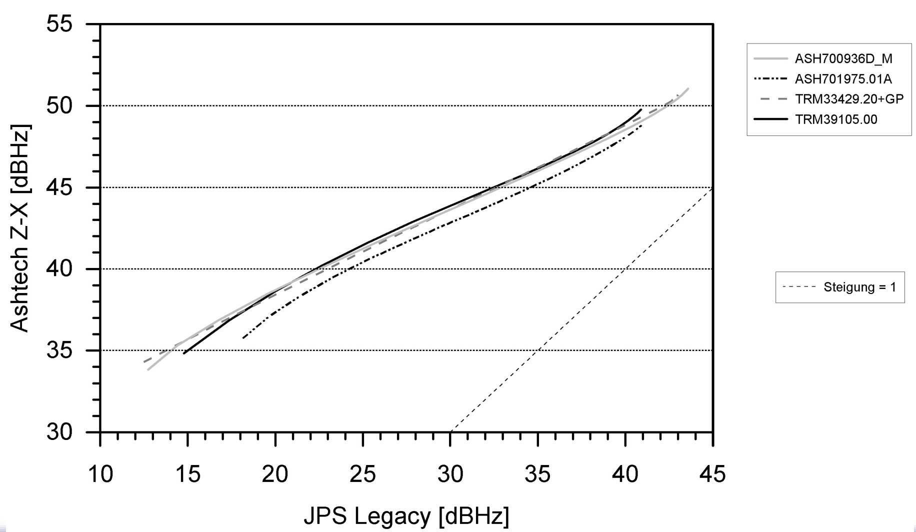
JPS Legacy

L1 function vs Ashtech Z-X



JPS Legacy

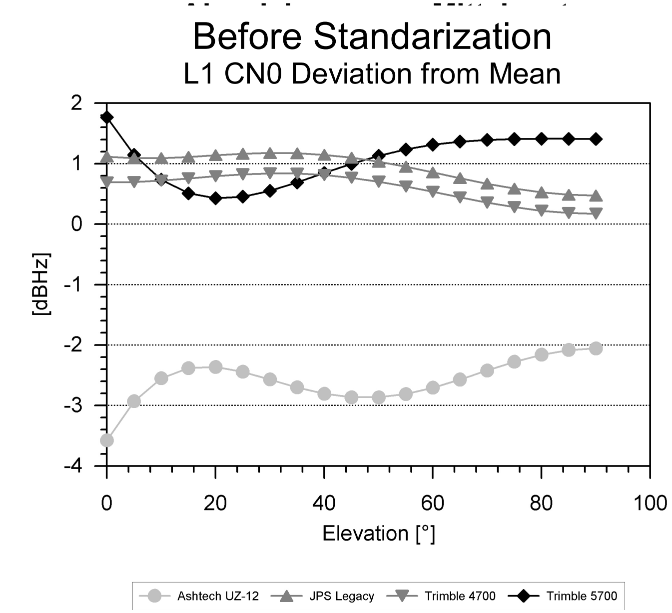
L2 function vs Ashtech Z-X

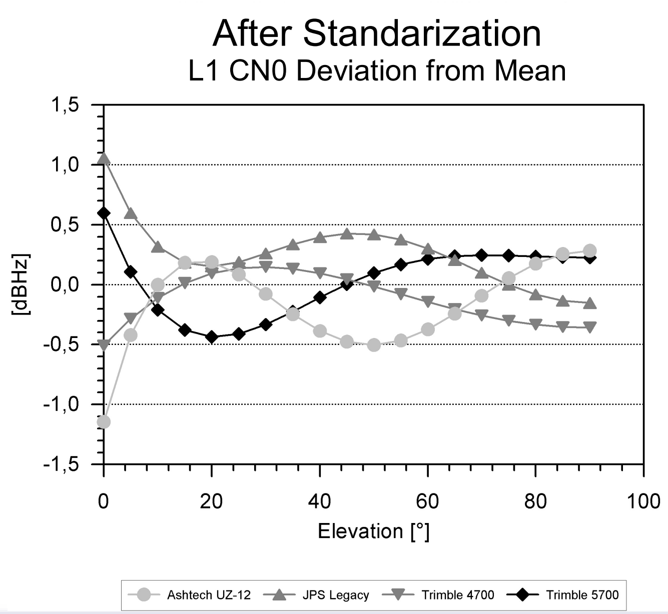


Mapping Function

- standardization using Ashtech Z-Xtreme as a reference
  - latest receiver technology during analysis (2004)
  - uses Z-tracking for L2
- 24 h data observed with identical antenna with different receivers
- example JPS Legacy with different antennas
- polynomial of 3rd degree as a mapping function on ASHTECH Z-X
- goal in graphs line with gradient 1 starting in defined origin

Determination of Carrier-to-Noise Pattern





Standardized CN0

- IGS stations with same receiver type
- influence of antenna, satellite and atmosphere corrected
- multipath averaging through number of stations
- deviation from mean value for several receivers
- magnitude of CN0 differences between receivers

L1 CN0 +/- 0.5 dbHz
(above 5 deg elevation)

- applying standardization gives improvement in absolute level

Summary and Conclusion

- robot calibration operational procedure since 2000 providing
  - GPS L1 and L2 PCV
  - GLO L1 and L2 PCV, frequency independent Delta PCV
  - GPS & GLO S1 S2 decrease functions
- GNPCVDB database in the future with GNSS PCV
- field calibration of GLONASS PCV possible
  - difference to GPS PCV
  - GLO PCV should be frequency dependent estimated and applied
- CN0 decrease functions available
  - standardization of CN0 is feasible
- IGS ANTEX (Antenna Exchange format) extension suggested
  - add Delta PCV for GLONASS
  - add CN0 pattern

thank you for your attention