GPS Block II/IIA Antenna Calibration with the Geo++ Robot

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Geo++ Robot-Based Antenna Calibration

- absolute field calibration of GNSS antenna phase center offsets and variations (PCV) (since 2000)
  - calibration with real GNSS signals
  - elevation and azimuth dependent PCV
  - PCV down to 0° elevation (and below)
  - free of site dependent errors (eg multipath) or reference antenna
- calibration system determines
  - PCV
  - carrier-to-noise pattern (CNO)
  - group delay variation (GDV) (recently implemented)
- independent approach confirmed absolute chamber calibrations

Antenna Description
GPS Block II/IIA

- two concentric rings of elements
- inner quad: four equally spaced helical elements
- outer ring: eight elements octagonal array
- antenna pattern
  - 180° phase shift between inner and outer ring
  - ratio of L-band power supplied for Block II/IIA array
    - 90% inner four elements
    - 10% outer elements
- transmitting cone of 15° covers Earth

Geo++ Test Facility

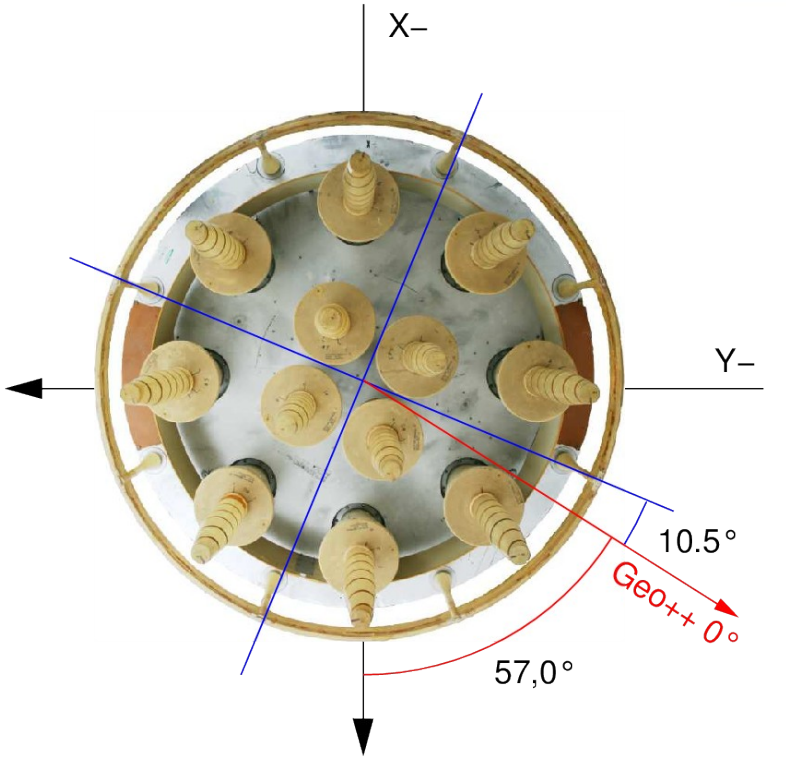
- testing environment Geo++ roof
- setup different Block II/IIA testing
  - static
  - single drive (rotations)
  - robot (tilts and rotations)
- data collection
  - tracking of different GNSS receivers
  - testing of real time calibration
  - post-processing analysis

Test Setup and Methodology
Mounting and Robot

- Block II/IIA antenna
  - 14.4 kg, Ø 1.34 m
- custom-made mount based on carbon elements and fiber optimized
  - momentum and acting forces
  - weight, dimensions of mount
  - mounting height
- robot guidance
  - modifications of actual control of robot modules
  - changes in procedure to decide on orientation

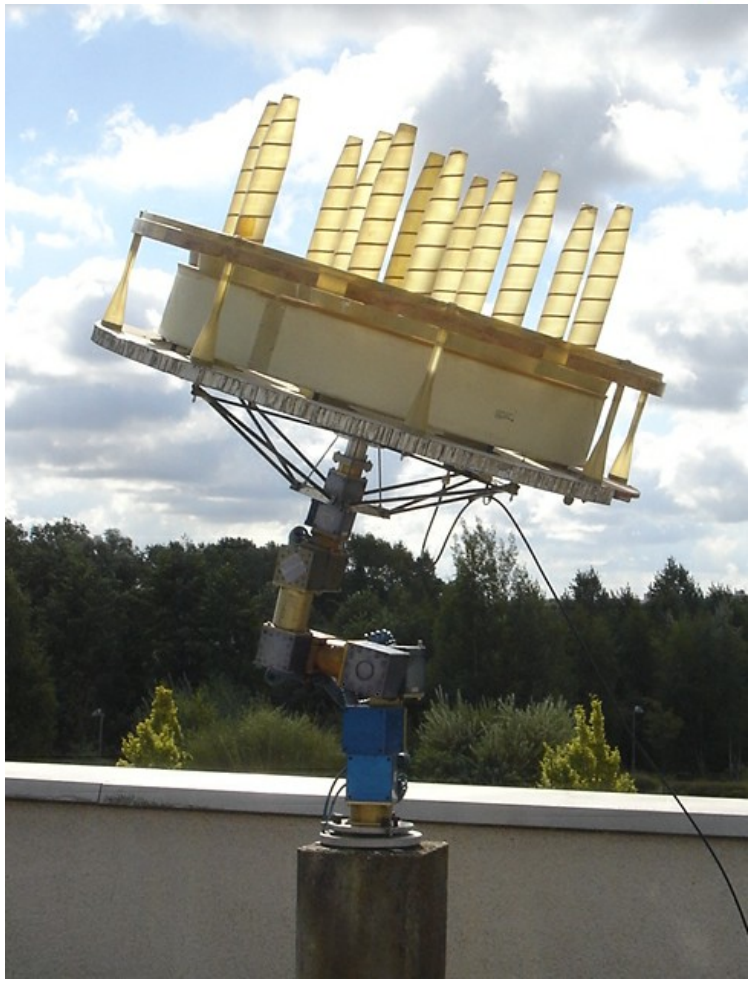
Test Setup and Methodology Definitions

- definition of orientation and height reference during robot calibration
- north orientation
  - currently defined by mount o
  - not aligned to marked axis on antenna (X- Y-) o
  - not aligned to symmetry of antenna feed o
- ARP, antenna reference point
  - top of groundplane
  - can be referenced to center of mass (CM)
- sign of PCV according to Geo++ convention



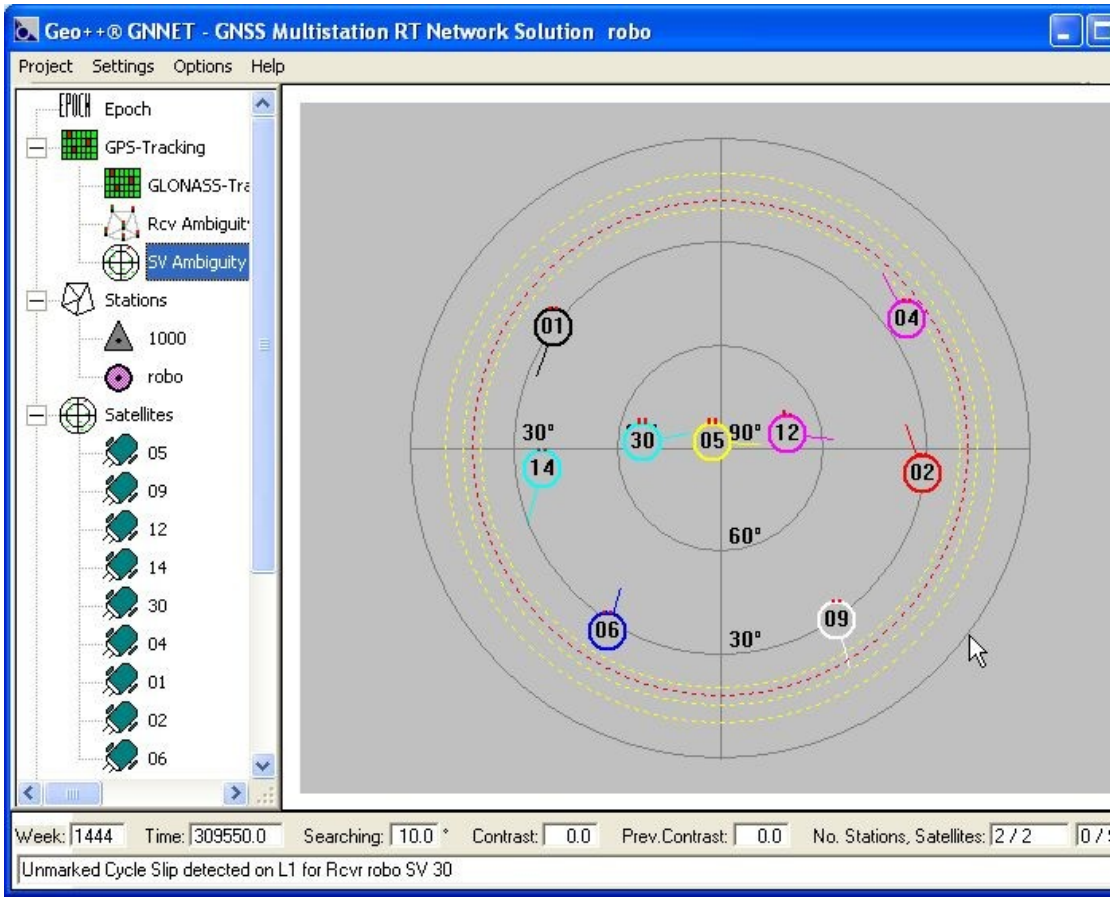
Test Setup and Methodology
Absolute Calibration and Advantages

- real time antenna calibration with Geo++ GNSMART software
- use of undifferenced observable
- small area of interest (15° cone), but data >30° used in GNSS
- 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
- estimation of L1 and L2 CN0 pattern (carrier-to-noise)
- spherical harmonics to model PCV (including offsets)



Test Setup and Methodology
Satellite Availability

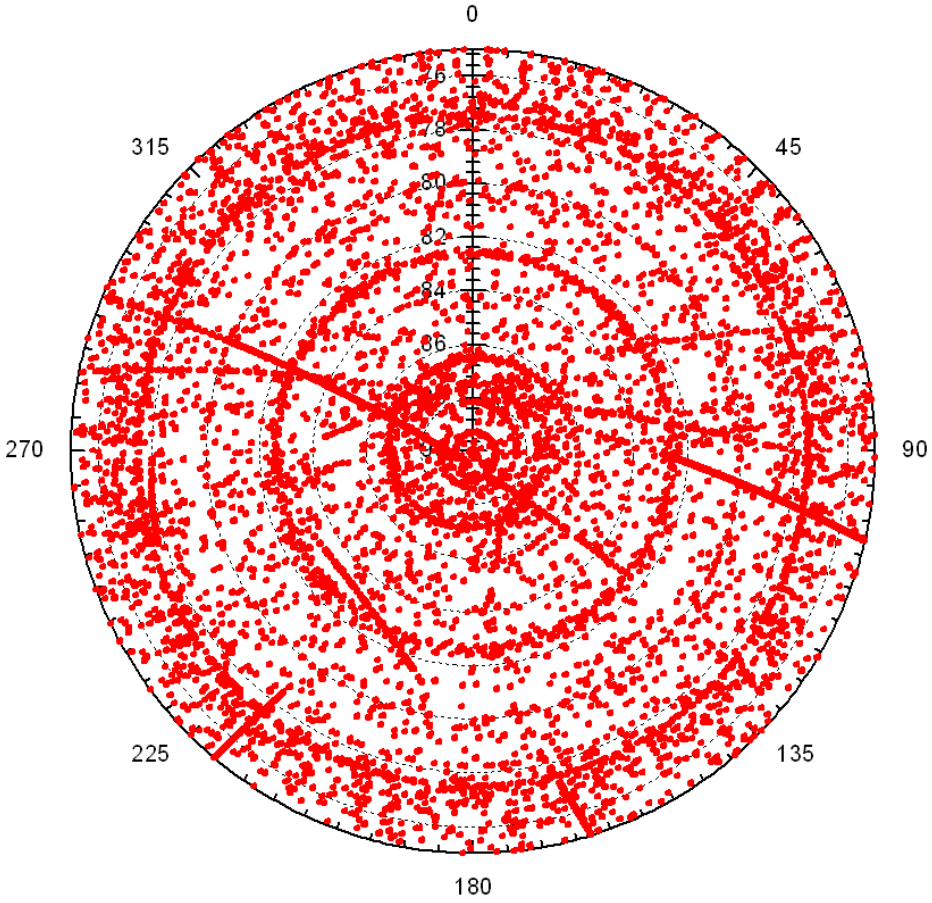
- Block II/IIA calibration
  - requires sufficient number of satellites in narrow reception cone
- GPS constellation offered satellites in same orbital plane and close slots
  - twin of GPS satellites
  - triplet of GPS satellites
- example
  - triplet PRN 30-05-12



Test Setup and Methodology
Details on Testing

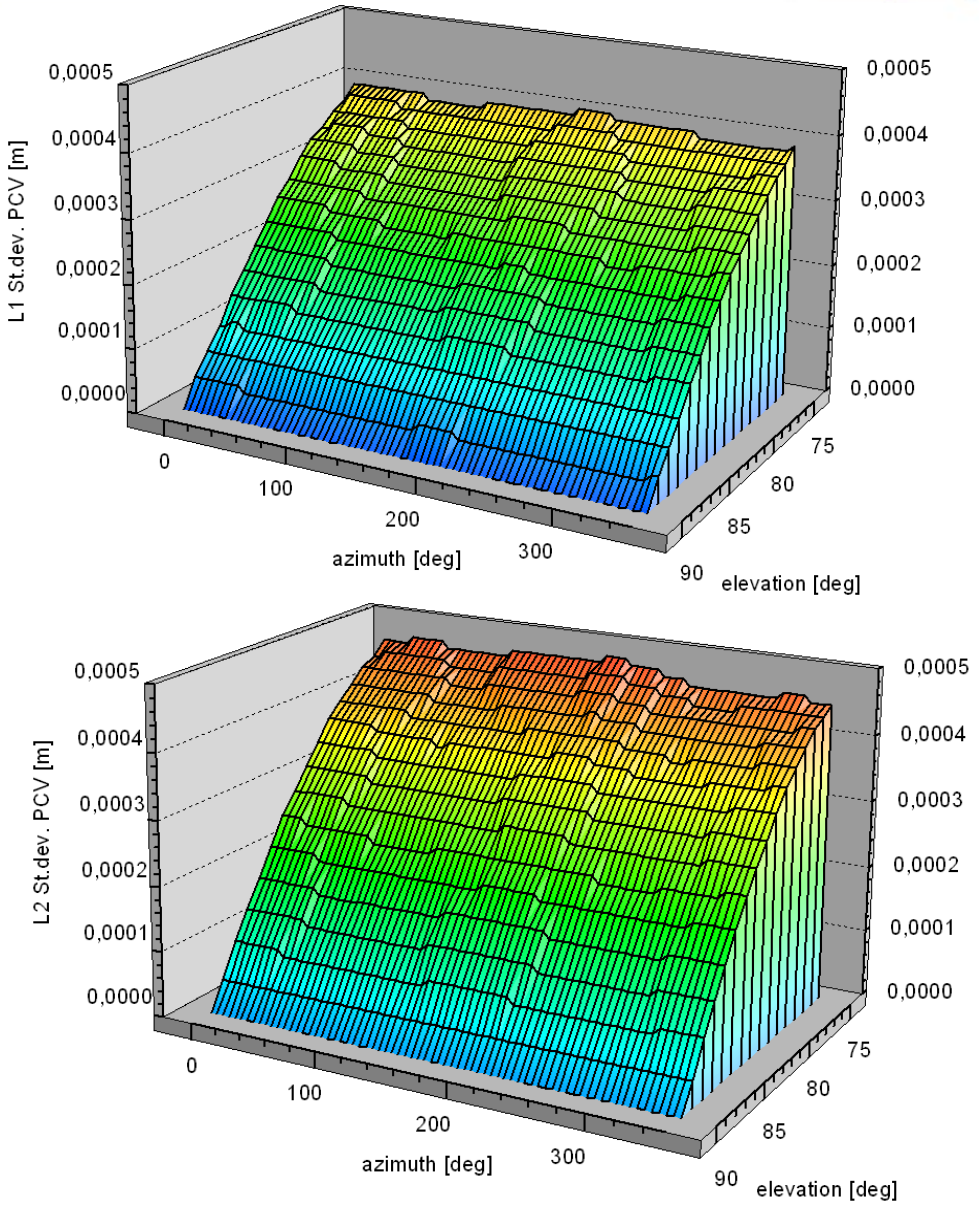
- observation four consecutive days on Sept. 11 to 14, 2007
- JPS LEGACY receiver
- combination of daily results with rigorous adjustment using complete variance-covariance information
- about 21 h observations
- over 24650 robot positions
- in average every 3 seconds a orientation change
- good coverage of 75° to 90° elevation

75° to 90° elevation



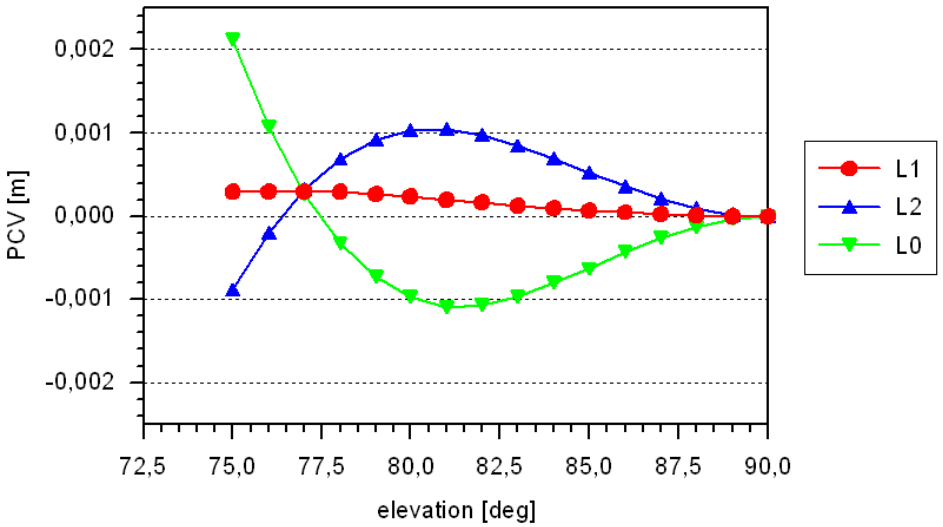
Testing Results
PCV Standard Deviation

- standard deviation (1 sigma)
- valid for complete PCV estimation
- offsets from spherical harmonics
  - horizontal offsets extracted (lower coefficients)
  - height offsets computed (using elevation mask)
- L1 and L2 frequency
- magnitude of 0.4 mm at 15° zenith distance



Testing Results
Pure Elevation Dependent PCV and Offsets

- L1, L2, L0 PCV
  - offset removed
  - small magnitude of a few mm
  - however
    - small beam width
    - offset of certain relevance

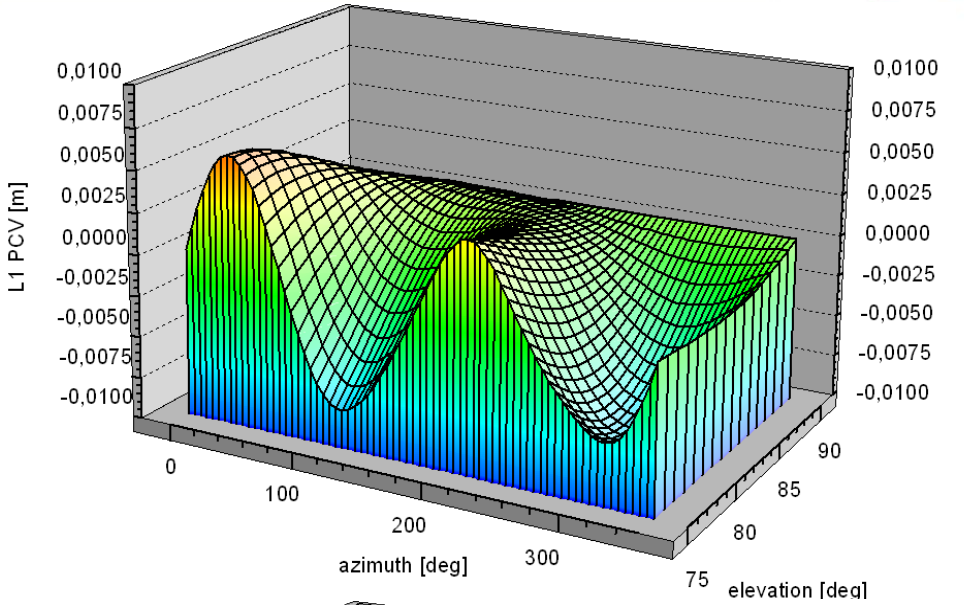


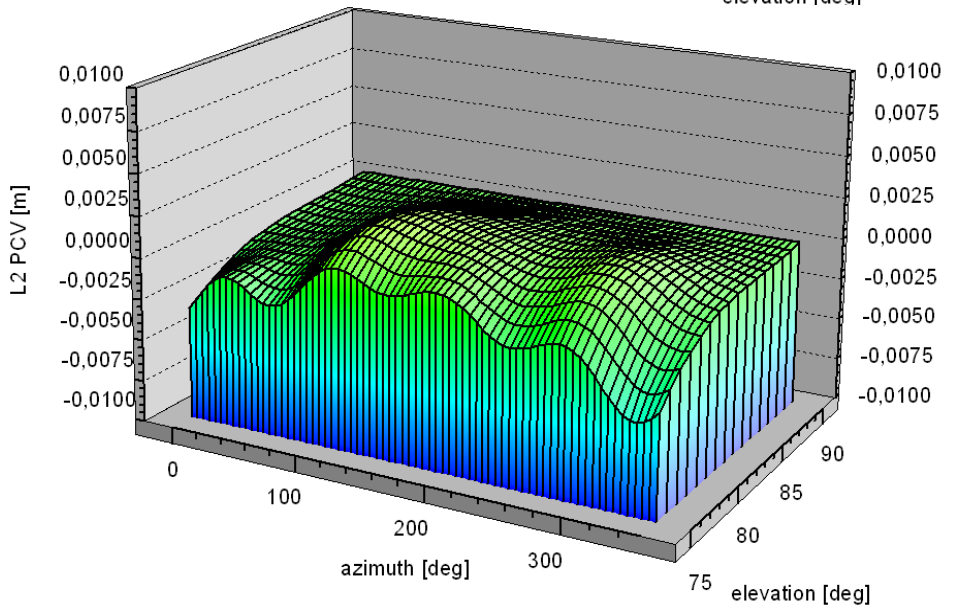
Frequency	North* [m]	East* [m]	Up [m]
L1	+0.00195	-0.01079	+0.26867
L2	+0.00291	+0.00020	-0.18817
L0			+0.97481

L0 ionospheric free linear combination
* depends on mounting

Testing Results
Elevation and Azimuth Dependent L1, L2 PCV

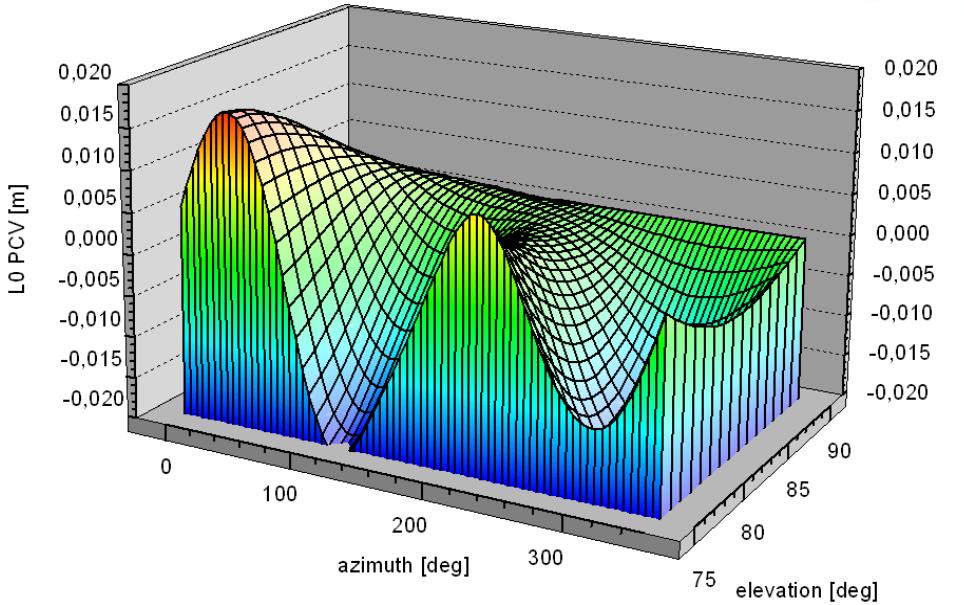
- L1 PCV
  - offset removed
  - range from -8 mm to +6 mm (at 15° zenith distance)
  - two significant maximums
- L2 PCV
  - offset removed
  - range from -4 mm to +2 mm (at 15° zenith distance)
  - four maximums, which correspond to four center elements of antenna array





Testing Results
Elevation and Azimuth Dependent L0 PCV

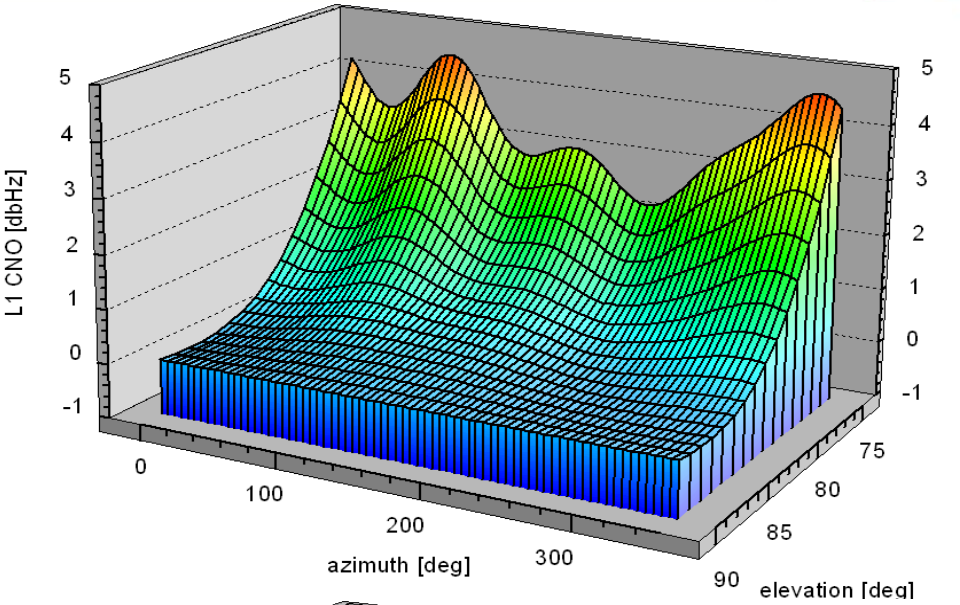
- L0 PCV
- offset removed
- range from -21 mm and +17 mm (at 15° zenith distance)
- two maximums
  - L1 PCV pattern dominating
  - L2 PCV pattern not significantly visible
- compared with pure elevation dependency
  - elevation dependent L0 PCV factor 4 ... 5 smaller
  - elevation dependent L0 PCV account only for 10%

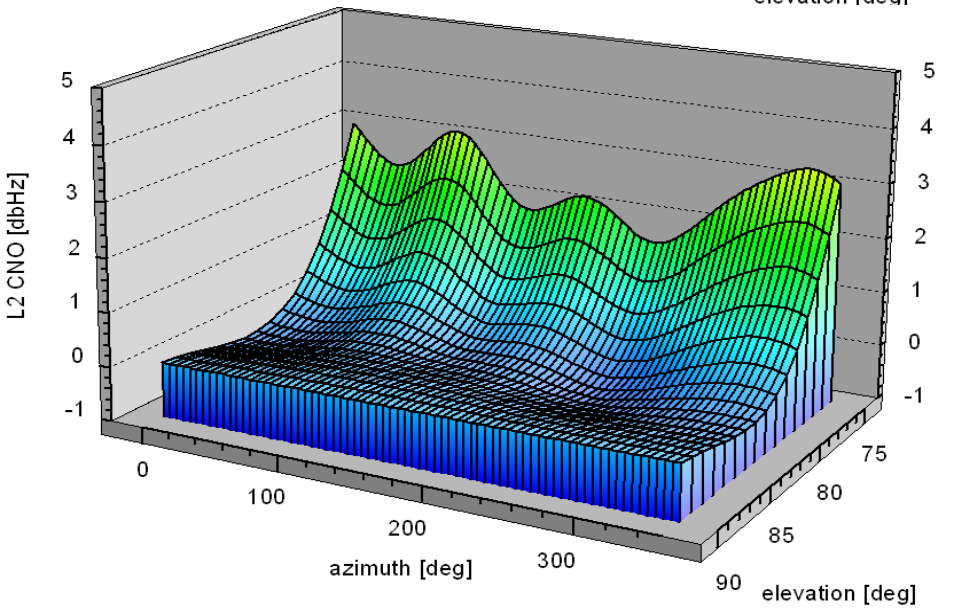


L0 ionospheric free linear combination

Testing Results
CN0 Decrease Function

- decrease function
  - CN0 value for zenith set to null
  - eliminates hardware setup or changes affecting CN0 pattern
- from 75° to 90° elevation
  - CN0 decrease about 3 dbHz for both frequencies
  - slightly less for L2
  - maximums resemble symmetry of four center elements
  - only small part slightly higher values than zenith





Comparison Absolute and Relative Field Calibration

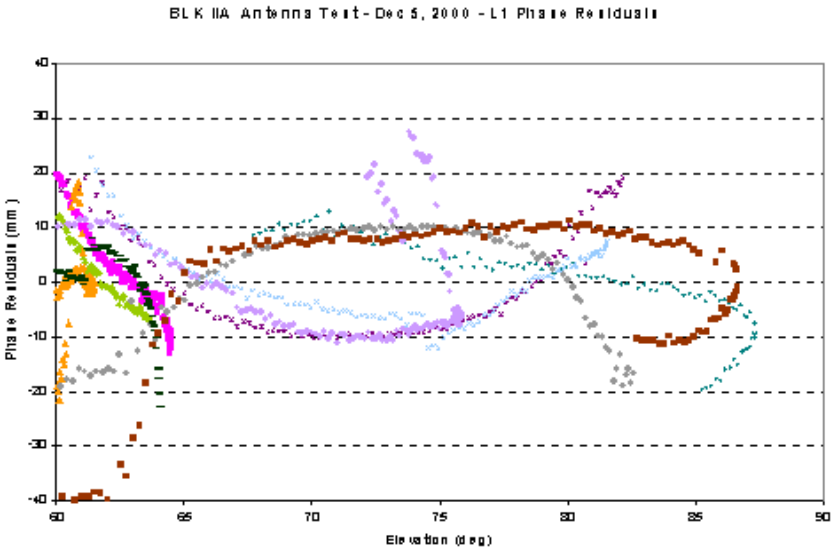
- same GPS Block II/IIA
- relative field calibration (Mader, Czopek 2001)
- absolute field calibration with different height offset computations (Wübbena et al. 2007, Geo++)

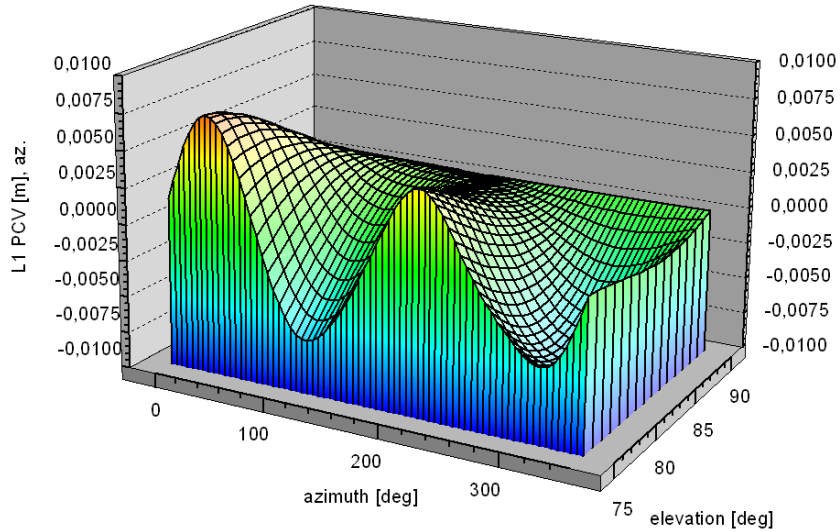
Computation	cut-off [°] elev/nadir	L1 Up [m]	L2 Up [m]	L0 Up [m]	L0 Up [m]	L1-L2 Up [m]
ARP		top GP	top GP	top GP	CM	
Wübbena et al.	75/15	+0.2687	-0.1882	+0.9748	+1.6931	+0.4568
Geo++	30/60	+0.3511	+0.0056	+0.8852	+1.6035	+0.3455
Geo++	60/30	+0.2983	-0.0135	+0.7804	+1.4987	+0.3119
Geo++	80/10	+0.2689	-0.2571	+1.0820	+1.8003	+0.5260
Mader, Czopek	60/30	+0.459	+0.149	+0.9382	+1.6563	+0.31

Comparison Absolute and Relative Field Calibration

- residuals from relative calibration Mader, Czopek 2001 ([mm])
- pure azimuthal PCV from robot calibration ([m])
- L1 residual vs L1 PCV

=> agreement of magnitude

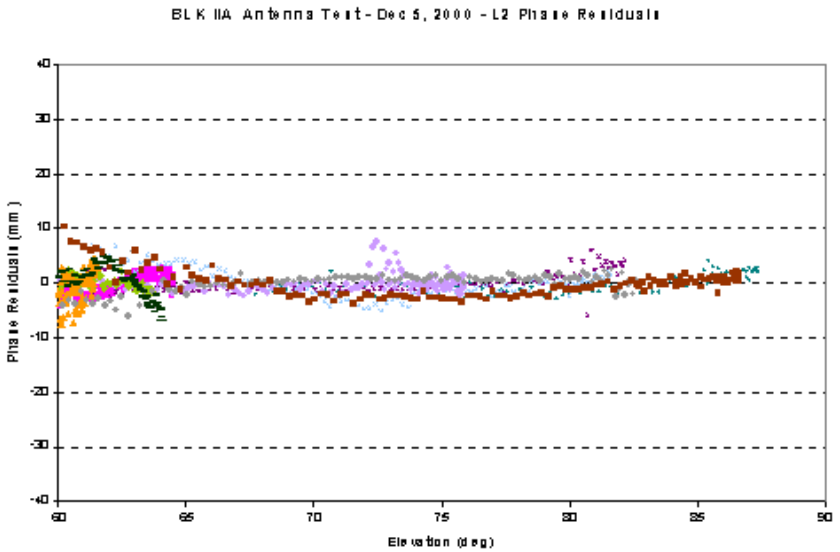


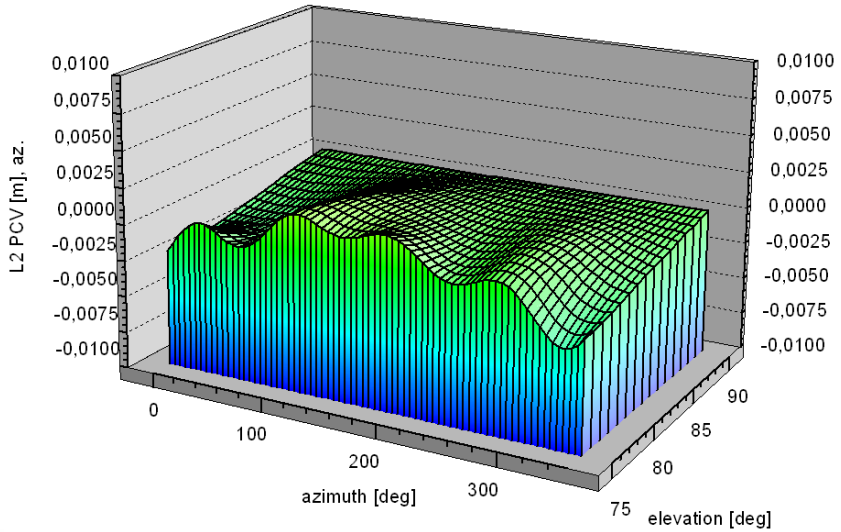


Comparison Absolute and Relative Field Calibration

- residuals from relative calibration Mader, Czopek 2001 [mm]
- pure azimuthal PCV from robot calibration ([m])
- L2 residual vs L2 PCV

=> agreement of magnitude

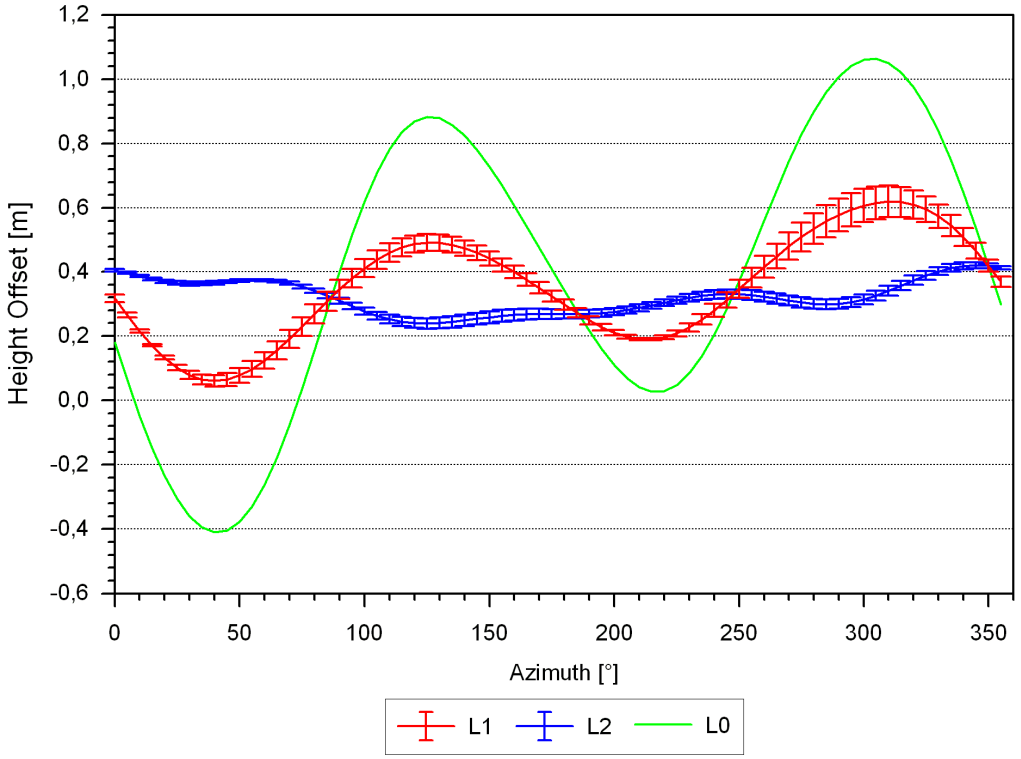




Comparing Height Offsets

- example offset effect
  - 0.5 m offset change in zenith direction results in 17 mm PCV change for 15° zenith distance
- variation of height offset
  - offset computed for every 5 deg azimuth direction
  - fitting PCV to get minimum RMS of residual PCV
  - large variations up to 1.4 m for L0

=> significant impact of azimuthal PCV on offset determination



Comparing Height Offsets

- “only a consistent set of offsets and PCV describes an antenna”
- from other research groups

Source	L0 Up [m]
ARP	CM
Wübbena et. al	+1.693
Mader, Czopek	+1.656
IGS*	+2.396
JPL*	+1.96
NGA*	+0.952

=> guess: differences may be attributed to azimuthal PCV

=> a wish: calibration of L1, L2 and new signals
and all GNSS before satellite launch

IGS International GNSS Service, Schmid et al. 2007
JPL Jet Jet Propulsion Laboratory, Bar-Sever et al. 2006
NGA National Geospatial-Intelligence Agency, from Schmid et al. 2007

Summary and Future Plans

- successful absolute PVC field calibration of GPS Block II/IIA with a robot
- 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 PCV required for further improvement
- ideal is calibration of satellite antenna before launch
- future plans
  - post-processing of collected calibration data
  - investigating estimation of group delay variations