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GNSS Absolute Antenna Calibration at the National Geodetic Survey

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Background

What is GNSS Antenna Calibration?

Antenna calibration = measurement of the antenna phase center (the apparent point of phase signal reception for a GNSS antenna)

Antenna phase center:
- Differs between antenna models and manufacturers
- Is affected by antenna radome and antenna mount

Why Do I Need Antenna Calibration?

To account for range errors introduced by the antenna element and hardware

Calibrations are a required input for many GNSS data processing software

Omitting calibrations leads to estimation errors:
- Long baselines
- Combining multiple antenna models
- Height errors

A full calibration is the sum of **two different components:**
- **PCO (phase center offset)**
  - Point in space relative to physical, easily ID'ed and accessible ARP
  - Given as NEU in antenna frame
- **PCV (phase center variations)**
  - Relative to PCO
  - Depends on direction of incoming satellite signal

Calibration values are given relative to a reference surface, typically the ARP

- **ARP (antenna reference point)**
  - Typically antenna mount point
  - Defined by calibration facility

Relative vs. Absolute Calibration?

Advantages of absolute calibrations:
- Better/fuller description of phase behavior
  - Depends only on calibrated antenna (reference-free)
  - Includes 0-10° elevation coverage
  - Captures azimuthal variations
  - Multipath removed/negated
- The way of the future
  - International GNSS Service (IGS) standard
  - Used in OPUS
  - Used in CORS multiyear [IGS08 epoch 2005.0 and NAD 83(2011) epoch 2010.0]
- Compatible with absolute calibrations from any IGS-sanctioned facility

	Relative	Absolute
Calibration values	Relative to a reference antenna (JPL chokering D/M_T)	Independent of reference antenna
Method	Stationary antennas	Test antenna moves
Advantages	Straightforward math	Sample full hemisphere and low elevation angles; independent of source
Limitations	Cannot sample full pattern; source-dependent	Requires robot and rigorous accounting of angles & rotations

Do not combine relative and absolute calibrations!

NGS Absolute Calibration Motivation and Goals

Serve high precision needs of U.S. surveying and geodesy communities
- Multi-frequency, multi-GNSS calibrations
- 2-D (elevation, azimuth) phase center patterns
- Free calibration service with quick turn-around *(antenna providers pay shipping)*
- Calibration values publicly distributed via Internet http://www.ngs.noaa.gov/ANTCAL/
- Compatible with IGS ANTEX values

Method

Calibration Setup

The NGS calibration facility is located in Corbin, VA.

- Antenna ARP ~ 50 cm above concrete pad (zero tilt)
- **10 cm Sokkia extension** used to separate test antenna from robot

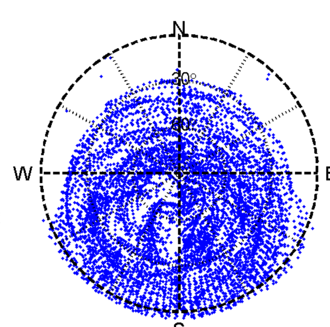
- **Flat field & concrete pad** = well-behaved multipath environment
- **5 meter baseline** (N-S orientation)
  - precise baseline from survey
  - baseline orientation used to fix robot reference frame

- **Robot**
  - 2-axis pan and tilt unit
  - rotation arm = 10.77 cm
  - coincident origins for pan and tilt systems
  - arm length and pan/tilt axis origin precisely measured with Total Station observations over range of robot pan/tilt angles

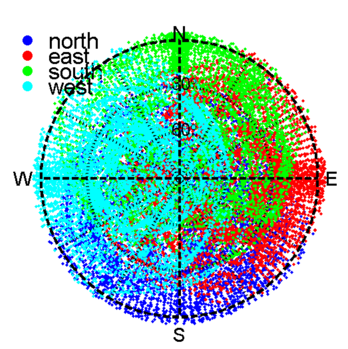
The 2-axis robot lacks the third degree of freedom necessary to fully sample the PCV pattern. Collecting data with the antenna in 4 different orientations on the robot circumvents this limitation.

Data Reduction and Solution

Samples collected with antenna mounted in north orientation



Composite sampling after all four directions



Data Collection (all 4 directions)

Pre-Edit Phase
- Geometric range
- Satellite XYZ/velocity calcs (for windup)

Calculation of Angles
- Angles in local frame
- Angles in antenna frame

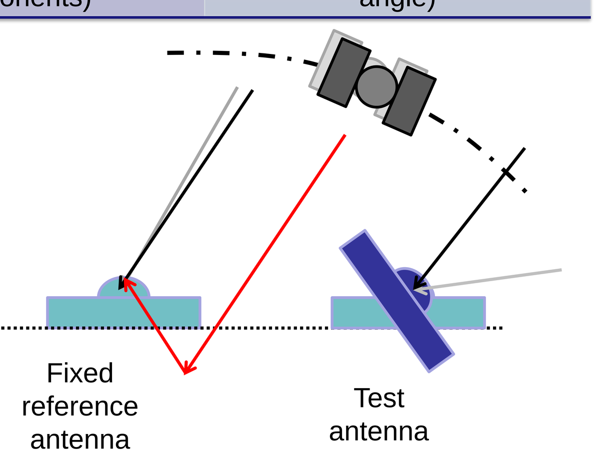
Single Difference Phase
- Cycle slip editing
- Phase windup
- PTU tilt arm

Time Difference of Single Difference Phase Pairs

Form / Solve Normal Equations
- PCO (east, north, up components)
- PCV (elevation and azimuth angle)

Solution method:
1. Solve for PCO
2. Remove PCO from data, solve for PCV using spherical harmonic fit
   - NOAZIM PCV = degree 8, order 0
   - Full PCV = degree 8, order 5

The robot moves the test antenna between two closely spaced times. During that time interval the satellite has moved a negligible amount. Therefore multipath and PCO/PCV at the reference antenna are unchanged, and drop out when observations at the two times are differenced.



Results

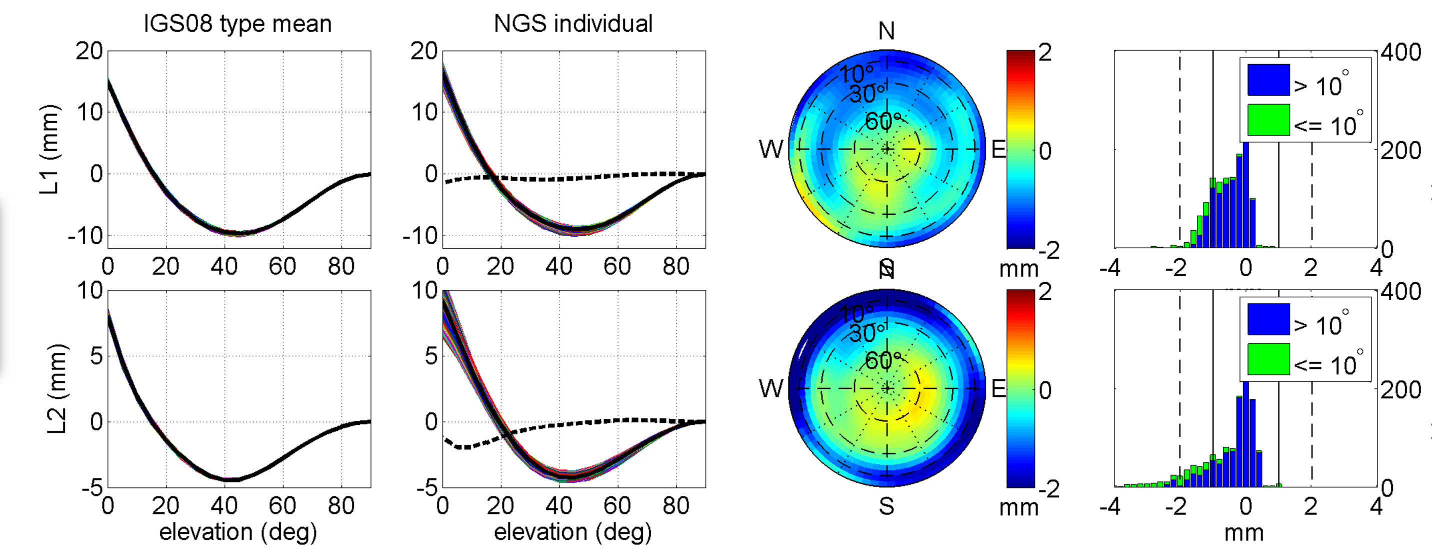
... individual NGS calibrations versus the IGS08 published type mean for the antenna model

PCO | PCV | residuals | statistics

Topcon CR-G3 (TPSCR.G3)

	N	E	U [mm]
IGS08	-0.16	0.30	88.41
NGS	-0.23	1.50	88.76

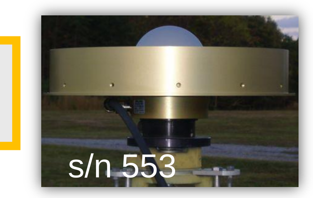
	N	E	U [mm]
IGS08	0.26	-0.03	119.38
NGS	0.26	0.83	119.20



92% < 1mm @ >10°
94% < 2mm @ ≤10°

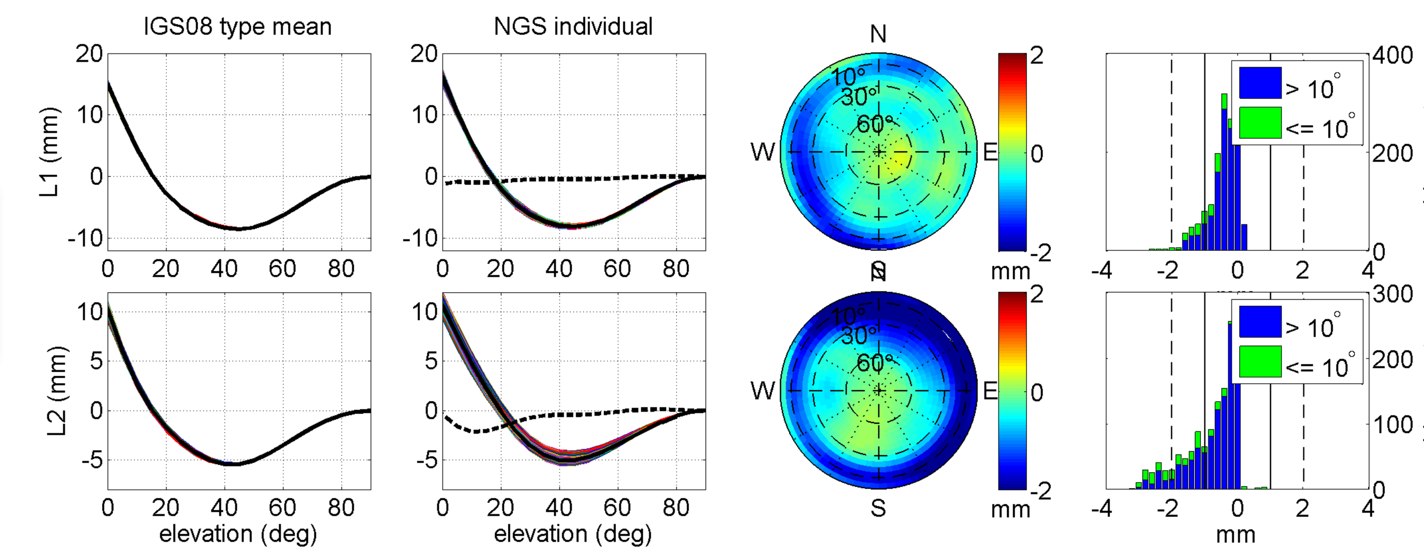
89% < 1mm @ >10°
69% < 2mm @ ≤10°

Javad RingAnt-DM (JAVRINGANT_DM)



	N	E	U [mm]
IGS08	1.05	0.86	89.31
NGS	1.00	1.18	90.01

	N	E	U [mm]
IGS08	0.28	-0.07	119.64
NGS	-0.39	0.12	120.60



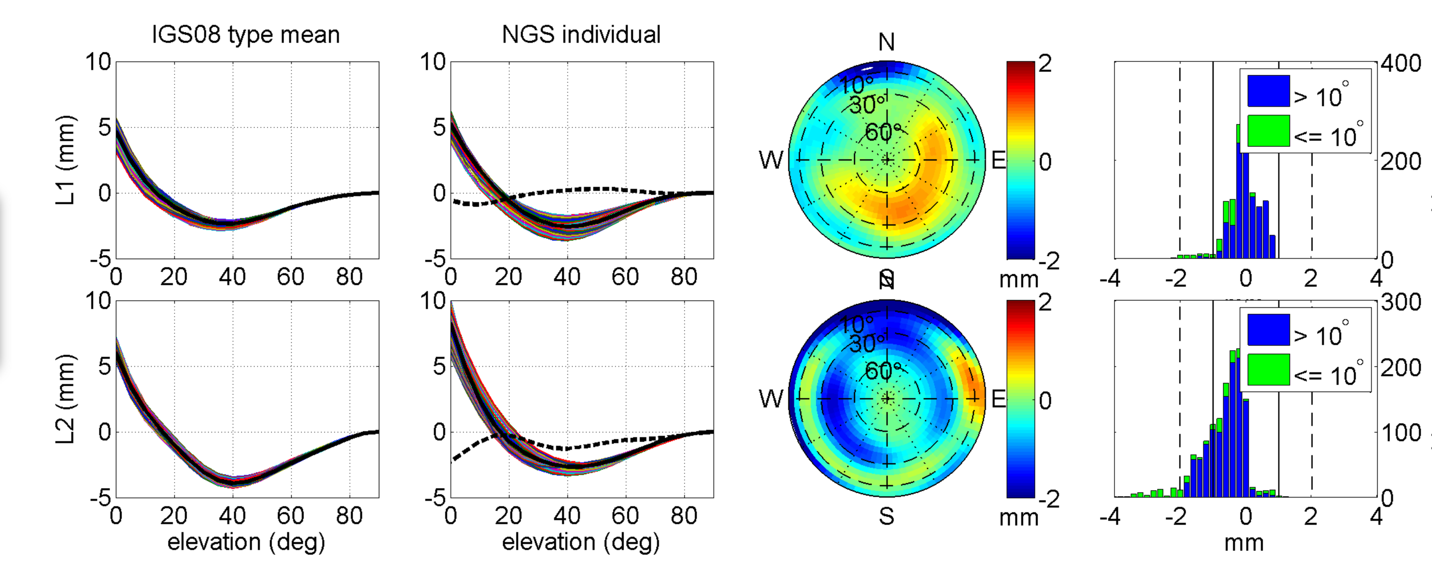
93% < 1mm @ >10°
96% < 2mm @ ≤10°

77% < 1mm @ >10°
69% < 2mm @ ≤10°

Trimble Zephyr 2 (TRM55971.00)

	N	E	U [mm]
IGS08	1.29	-0.19	66.73
NGS	0.48	0.40	65.99

	N	E	U [mm]
IGS08	0.38	0.61	57.69
NGS	0.12	0.71	57.84



99% < 1mm @ >10°
99% < 2mm @ ≤10°

81% < 1mm @ >10°
67% < 2mm @ ≤10°

We provide NGS PCO values from the individual calibration of the serial number shown on the photo, to demonstrate the NGS method's ability to correctly recover PCO. However, all further comparison (plots to right) are after shifting NGS values to use the published IGS PCO.

*Colored lines are azimuthal lines through full PCV pattern every 5°. **Heavy black line** is the NOAZIM elevation-only profile.*

*NGS solution is shifted to use IGS PCO. **Dashed black line** is the NOAZIM difference between IGS and NGS values..*

IGS minus NGS residuals, shown with respect to azimuth and elevation angle (lefthand circular plots) and as a histogram (righthand). Vertical bars in histogram denote 1mm and 2mm bounds for IGS AWG approval.

Percentage of NGS-IGS residuals which fall within 1mm and 2mm bounds.

Conclusions

- Solid methodology and testing facility are in place
- Able to compute type means from 3-5 samples *(not shown)*
- Favorable individual comparison to IGS published values: close PCO match; good statistics to residuals
- Small systematic discrepancies remain for all antenna models: residuals skew to negative; bulge ~ 10° elevation on L2

Next Steps

- Finalize IGS Antenna Working Group approval
  - 3-method comparison with Bonn chamber and Geo++ robot
  - remove residuals bulge and skew
- Set permanent piers for calibration baseline
- Add capabilities to software
  - Integrated antenna + receiver units
  - GLONASS

References & Acknowledgements

Bilich A and GL Mader, *GNSS Antenna Calibration at the National Geodetic Survey*, **Proceedings of ION GNSS 2010**, Portland, OR, September 2010, pp. 1369-1377.

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Please see our website at http://www.ngs.noaa.gov/ANTCAL for more information