GNSS Absolute Antenna Calibration at the National Geodetic Survey

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Serve high precision needs of surveying and geodesy communities

- Calibration of any geodetic-grade receiving antennas (from chokerings to rovers)
- Multi-frequency, multi-GNSS calibrations
- 2-D (elevation, azimuth) phase center patterns
- Free calibration service with quick turn-around
- Calibration values publicly distributed via Internet http://www.ngs.noaa.gov/ANTCAL/
- Compatible with IGS ANTEX values

NGS Absolute Calibration

Motivation and Goals

Calibration Setup

Robot

- 2-axis pan and tilt unit produced by Directed Perception
- rotation arm = 10.77 cm mounting bracket + 10.0 cm Sokkia extension
- 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

Calibration Baseline

The NGS calibration facility is located in Corbin, VA.

o **5 meter baseline** (N-S orientation)

- precise baseline length and orientation from survey
- baseline orientation used to fix robot reference frame

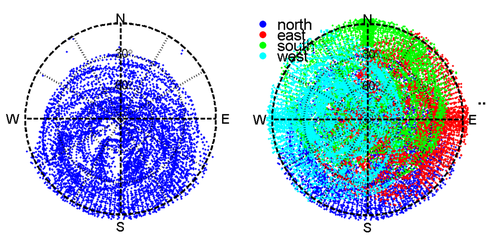
o **Flat field & concrete pad** = well-behaved multipath environment

o **Variable PCO height**

- highest ARP ~ 50 cm above concrete pad
- PCO height controlled by robot tilt
- other robot heights tested, but robot height had no effect on calibration results

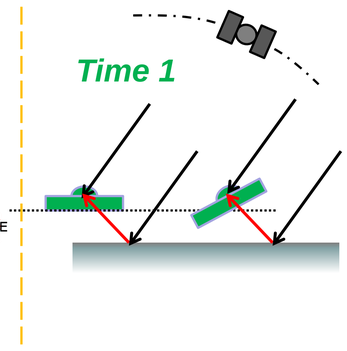
Data Collection

North only *Four Directions*



Four-orientation Antenna Mount: Mounting the antenna in one orientation (North) on robot cannot sample all directions*. Data are collected with antenna mounted in four different positions (N,S,E,W).

** Limitation of 2-axis robot and motor housing*



Between two closely spaced times:

- Robot moves test antenna through large angular change
- Reference antenna remains fixed
- Satellite moves negligible amount

When the two times are differenced:

- PCO/PCV of test antenna at two angles is combined
- PCO/PCV at reference antenna is removed
- Multipath at reference also removed

Solution Methodology

Data Reduction

Data Collection (all four directions) → Pre-Edit Phase
- Geometric range
- Satellite XYZ/velocity calcs (for windup)
- Omit data during motion

→ 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

Solution

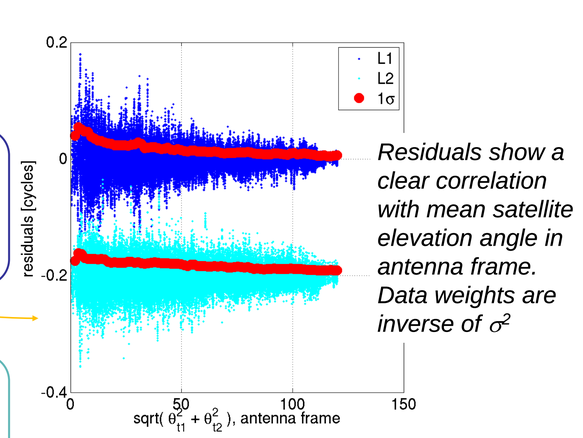
Build matricies
- Design (geometry)
  - Horizontal PCO (east, north)
  - Spherical harmonics (degree 1-8, order 0-5)
- Weights

SVD and PCA
- Singular value decomposition (SVD) inverts normal equations (pseudoinverse)
- Principal component analysis (PCA) identifies insensitive harmonics

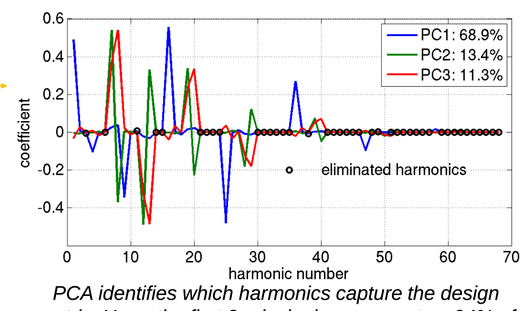
Solve 1: big features
- Weighted least squares
- Horizontal PCO
- Solve and sum M=0 harmonics (elevation-dependent PCV)

Solve 2: finer features
- Remove pre-solved parameters from data
- Weighted least squares
- Solve M>0 harmonics not eliminated by PCA (azimuthal PCV)

ANTEX
- Separate vertical PCO from PCV
- Sum harmonics
  - M=0 → elevation-dependent
  - M>=0 → full PCV
- Combine via geometric mean



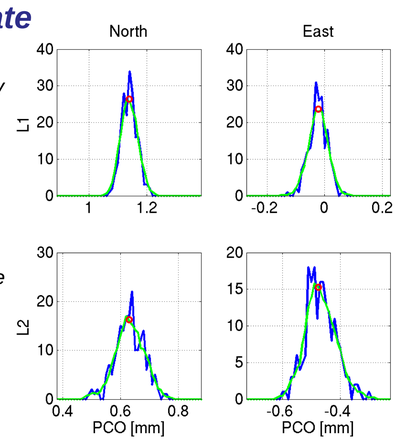
Residuals show a clear correlation with mean satellite elevation angle in antenna frame. Data weights are inverse of σ^2



PCA identifies which harmonics capture the design matrix. Here, the first 3 principal components = 94% of variance, eliminating 41 harmonic components. Eliminating harmonics prevents over-fitting.

iterate

Solution depends strongly on selection of noisy data points. Iteration with subsets of data points enables pinpointing best average estimate – here, horizontal PCO components after 200 iterations with ¼ of total data.

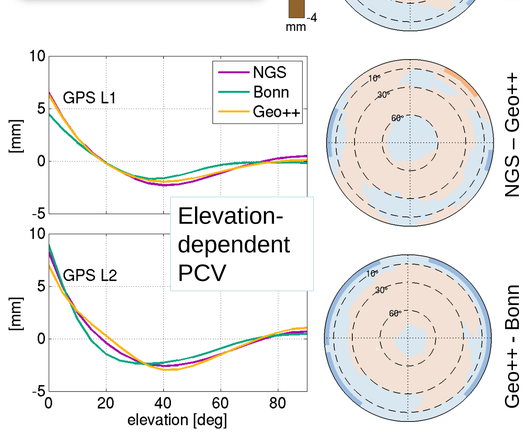


Results

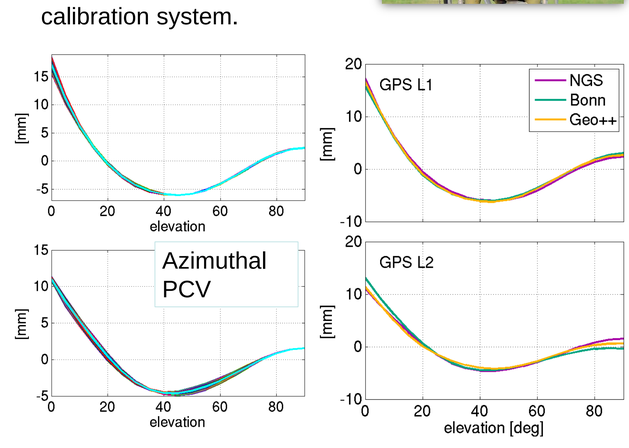
Trimble Zephyr Geodetic 2 (TRM55971.00)

Trimble GNSS chokering (TRM59800.00)

L1 PCV differences



These examples, taken from the Thursday plenary presentation on the three-method calibration test, demonstrate the capabilities of the NGS absolute antenna calibration system.



Policy and Procedures

Recently, NGS formally instituted documents covering policies and procedures for antenna calibration at NGS, to:

- Set clear policies which will help NGS maintain the high standards of accuracy expected for NGS calibrations
- Maintain consistency of calibrations appearing in the NGS calibration database

Policies and procedures of most interest to IGS:

- Production-ready antennas only (labels and markings for photo ID)
- "Clone" calibrations
  - NGS will not copy calibration values based only on manufacturer claims
  - verification through calibration (one or more sample)
- Require 3-5 antenna samples for type mean
- Antenna provider must submit high-quality engineering drawing

These documents are available at www.ngs.noaa.gov/ANTCAL

Conclusions

- Solid methodology and testing facility are in place at NGS
- Favorable comparison to other calibration methods (see Thursday plenary talk and included slides)
- NGS policies could be used/extended by IGS AWG

Next Steps

- Finalize agreement with IGS institutions, begin contributing calibrations
- 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.