GNSS Absolute Antenna Calibration at the National Geodetic Survey

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GOAL: 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 from other calibration facilities

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

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

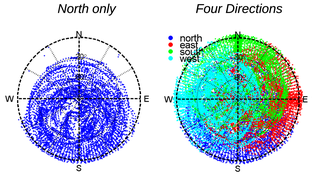
- precise baseline length and orientation from survey
- baseline orientation used to fix robot reference frame

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

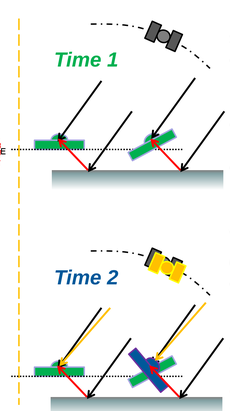
Data Collection

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 → Calculation of Angles → Single Difference Phase → Time Difference of Single Difference Phase Pairs

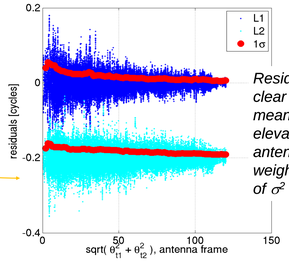
Pre-Edit Phase
- Geometric range
- Satellite XYZ/velocity calcs (for windup)
- Omit data during motion

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

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

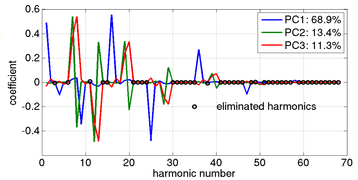
Solution

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



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

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



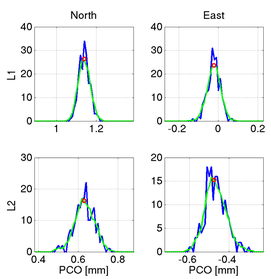
PCA identifies which harmonics capture the design matrix. Here, the first 3 principal components = 94% of variance, eliminating 41 harmonic components. Eliminating harmonics prevents over-fitting.

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)

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.



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

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.

New Developments

In 2012, several models of geodetic antennas were individually calibrated at NGS (field), Geo++ (rooftop) and Bonn (anechoic chamber).

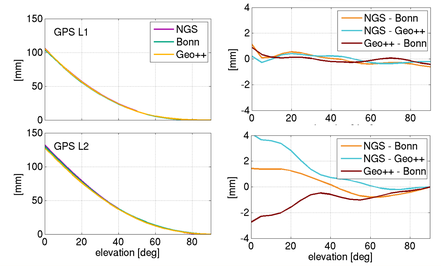
Equipment used at each facility varies (see table below).

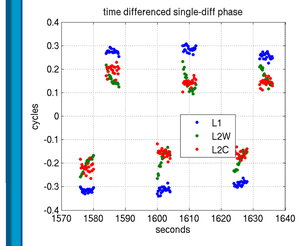
GPS L1 results were within 1-2 mm tolerances of "good agreement".

For antennas such as the TRM59800.00, L2 results disagreed by several mm. [This level of disagreement can create **mm-cm positioning differences**, see talk G13C-04 this afternoon]

Multi-Method Antenna Comparison

Trimble GNSS chokering (TRM59800.00)





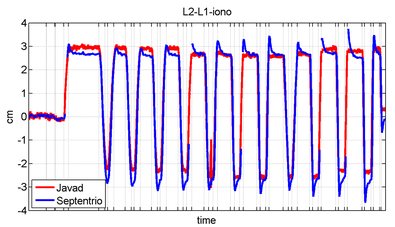
*Poor L2 results are attributable to L2W/L2P tracking loop behavior, specifically L1 aiding of L2P loops, which creates apparent (erroneous) motion in **L2P TDSD**. Note how the **L1** and **L2C** TDSD (left) do not drift.*

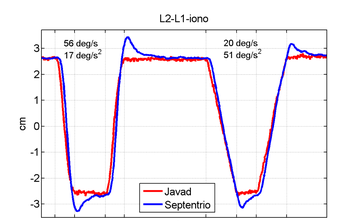
Receiver and Tracking Loop Testing

L2P carrier phase is highly dependent upon
- Antenna dynamics (speed and acceleration)
- Tracking loop bandwidth
- Dwell time after antenna stops moving

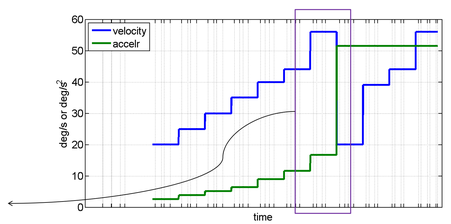
A calibration system must be tuned to optimize tracking loops, antenna motion, and time spacing between motions.

	Septentrio AsteRx2eH	Javad Delta
L1 PLL Bandwidth	0.1 Hz	25.0 Hz
L2 PLL Bandwidth	0.1 Hz	3.0 Hz
Used by	NGS	Geo++





Zoomed section to show detail of phase lag by Septentrio receiver relative to Javad, caused by low tracking lower bandwidth. The tighter bandwidth also results in phase smoothing and phase lag relative to start/stop of motion.



Phase difference (L2-L1, in cm) after removing Motion start/stop times are indicated by vertical gridlines. Purple box denotes section in zoomed plot at left.

Conclusions

- Reliable antenna testing facility and capabilities are place at NGS
- Detailed methodology paper in progress, for distribution and discussion in IGS AWG
- Aspects of methodology (dwell time between motions, data weights, PTU speed) will be tweaked following conclusion of receiver and tracking loop tests.

Next Steps

- Determine optimal tracking loop settings and antenna dynamics to maintain time-difference single-difference assumptions
- Work with the IGS Antenna Working Group to finalize approval of NGS methods
- Set permanent piers for calibration baseline
- Add capabilities to software:
  - Integrated antenna + receiver units
  - GLONASS
- Port production code to Java