Multipath characteristics of GPS signals as determined from the Antenna and Multipath Calibration System (AMCS): Preliminary results

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Overview

- Description of the AMCS
- Some Preliminary Results
- Conclusions and Future Work

Park et al., (in preparation)

AMCS Accuracy Goal and Method

- **Goal**: Develop an *in situ* method for absolute calibration of site-dependent GPS phase-measurement errors such as scattering, multipath and unmodeled antenna phase variations ("SMA effects") with an accuracy of 1 mm (each frequency).

- **Method**: Form single phase differences between a GPS receiver connected to a GPS antenna to be calibrated and a second GPS receiver connected to an antenna free of SMA effects.

Components of the AMCS

- High-gain, multipath-free, 3-m diameter parabolic antenna
- GPS test antenna to be calibrated
- Two GPS receivers

Unique Strengths of the AMCS Method

- Current multipath reduction/calibration methods used include microwave absorber, relative field calibrations, anechoic chamber, mechanical robot, and data filtering.

- The AMCS enables us to accomplish three types of studies that are not possible with any other method:

  – In situ, absolute site calibration

  – Understand the sources of SMA effects, their dependence on weather and environment, and their time variability

  – Development and testing of improved antennas and understanding of site effects

Block diagram of the AMCS

Test GPS Antenna

High-gain, Multipath-free, 3-m diameter parabolic antenna

splitter

Switch

RF Amplifier

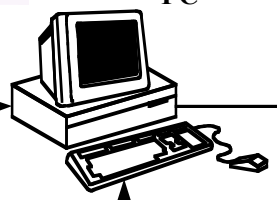
1 GHz Highpass Filter

DC Block

GPS Receiver #2

GPS Receiver #1

PC



H Maser (5 MHz)

Antenna Controller

Antenna Interface Unit

Az/El Motors

Az/El Encoders

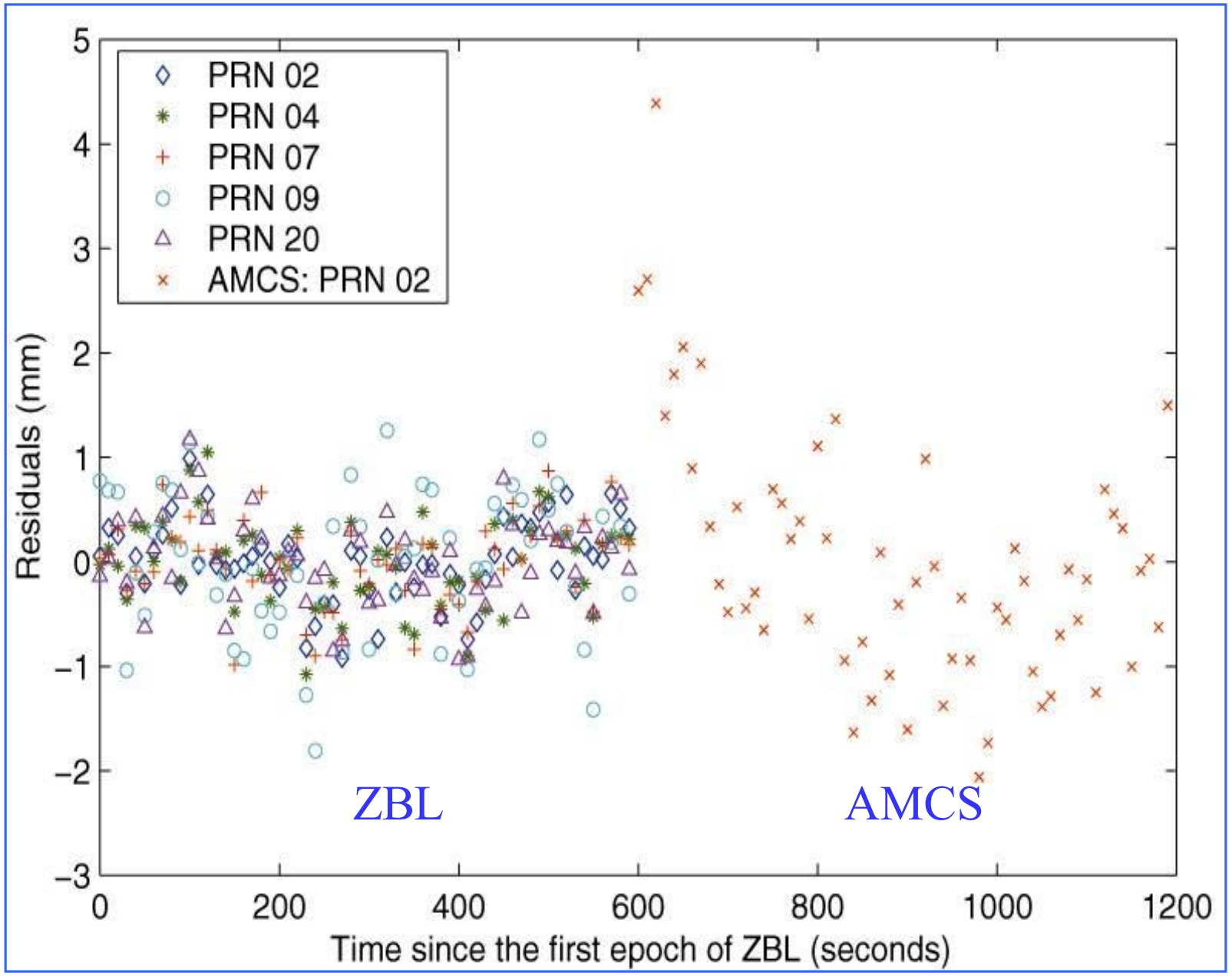
Limit Switches

Modes of Operation

- Zero-Baseline (ZBL) Calibration Mode
  - Both receivers collect data from the GPS test antenna
  - ZBL-mode data is processed to estimate a clock synchronization error and a phase offset of each satellite, which will be used in AMCS-mode data processing as fixed parameters

- AMCS Mode
  - **Static** (Calibration)
    - The parabolic antenna is stationary, pointing toward a certain direction, and the target GPS satellite drifts in and out of the antenna main beam
  - **Tracking**
    - The parabolic antenna tracks the target GPS satellite and its pointing direction is updated at each observation epoch

L_1 Phase Residuals (ZBL/AMCS-static)



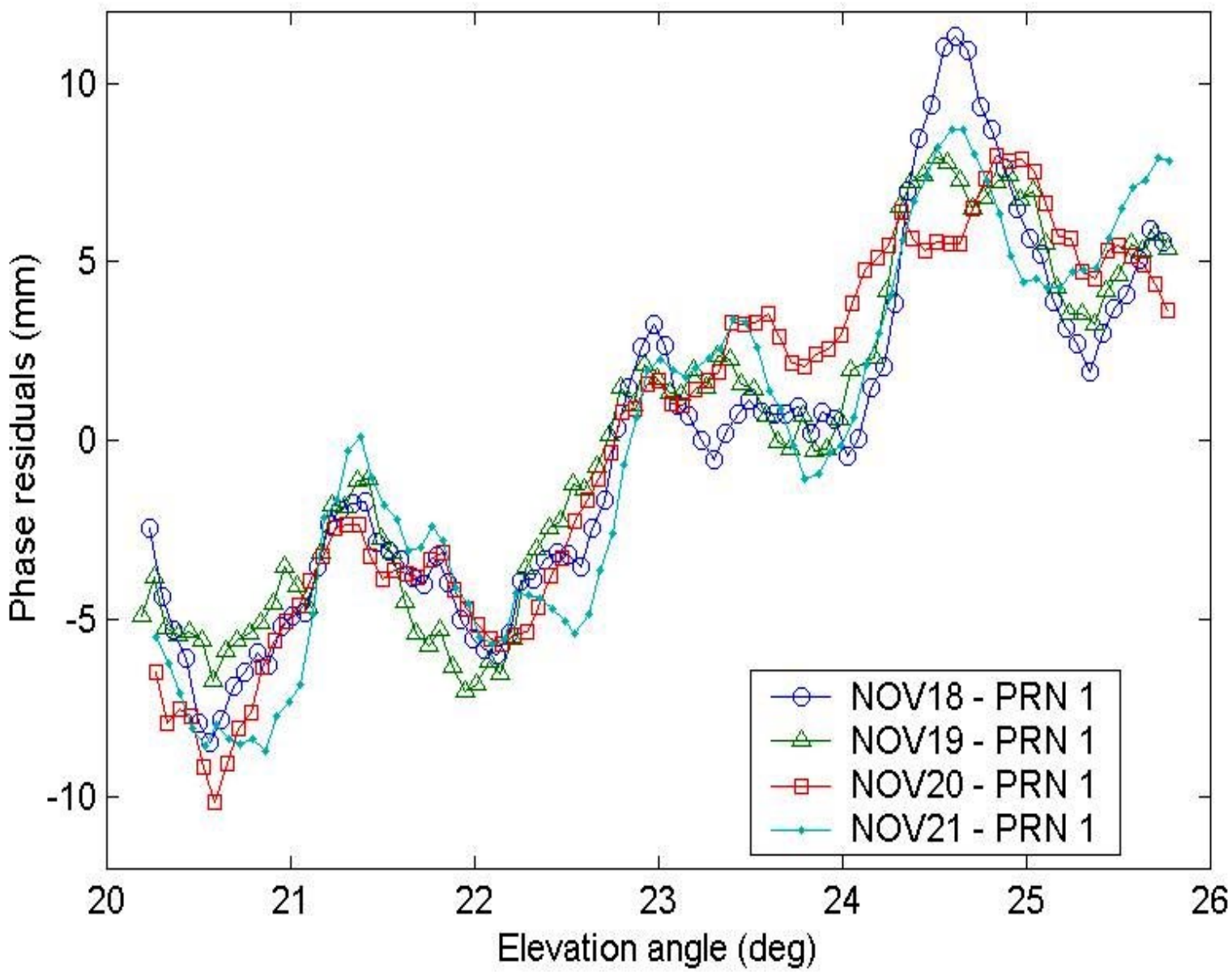
Analysis of Residuals (ZBL/AMCS-static)

- ZBL-mode residuals: RMS ~0.5 mm
- AMCS-mode (static) residuals: RMS 1 - 3 mm
  - *Highly systematic variations*
    - Parabolic antenna pointing offset errors
    - Baseline error
    - Parabolic beam pattern errors
    - Low Signal-to-Noise Ratio (SNR) in the AMCS-mode data collection

AMCS-tracking Analysis

- Observing schedule:
  - 10-minute ZBL-mode
  - 10-minute AMCS-mode
  - Steer the parabolic antenna every 10 seconds
- Track the same satellite for several consecutive days
- Track different GPS satellites
  - Elevation angle: high, medium, and low
  - Azimuth angle: extensive coverage

L_1 Phase Residuals (AMCS-tracking)



Results of AMCS-tracking Analysis

- Effects are low-amplitude (~5 mm)
- Effects vary extremely rapidly in elevation angle
  - periodicity with variations of $\sim 1^{o}$ of elevation angle
  - periodicity is not very regular
- Effects are fairly repeatable from day to day

  but they can also vary by amounts large with respect to the AMCS measurement uncertainty of 1mm
- Effects are very sensitive to azimuth and time of day

  perhaps due to moisture on reflecting surfaces, temperature, or both.
- Amplitude variations of multipath effects are typically larger at lower elevation angles

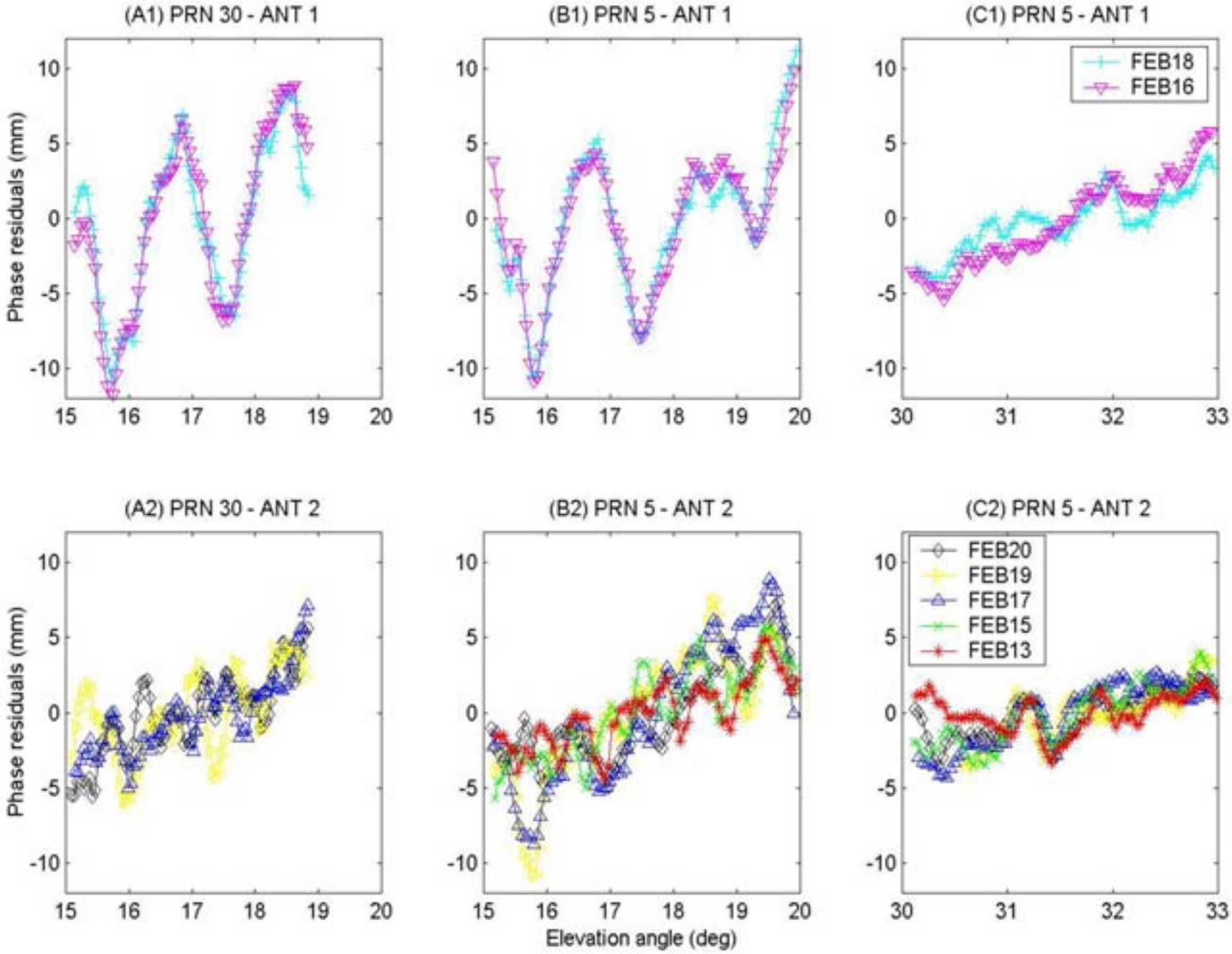
Second GPS Test Antenna

- Objective: are the observed effects due to multipath?

- Installed a second GPS antenna
  - Same antenna type and hardware
  - Reduced multipath environment
  - Microwave absorber

- Observations: 10 days in February 2002

- Compare phase residuals between GPS antennas


(A1) PRN 30 - ANT 1
(B1) PRN 5 - ANT 1
(C1) PRN 5 - ANT 1
FEB18
FEB16
(A2) PRN 30 - ANT 2
(B2) PRN 5 - ANT 2
(C2) PRN 5 - ANT 2
FEB20
FEB19
FEB17
FEB15
FEB13
Phase residuals (mm)
Elevation angle (deg)

Second Test Antenna (cont'd)

- GPS antenna in **higher multipath** environment
  - Residuals are more repeatable from day to day
  - Larger amplitude variations
  - Larger signal amplitude at low elevation

- GPS antenna in **lower multipath** environment
  - Residuals are less repeatable from day to day
  - Smaller amplitude variations
  - Amplitude rather independent of elevation angle

Summary and Conclusions

- Description of AMCS
- ZBL-mode phase residuals are ~0.5 mm (RMS)
- AMCS-mode phase residuals
  - Measured absolute SMA effects
  - High spatial resolution (sub-degree)
  - Accuracy is ~1 mm
  - SMA effects are:
    - Low-amplitude (~5 mm)
    - High-frequency (periodicity with variations of 1^{o} elevation angle)
    - Fairly repeatable from day to day
    - Very sensitive to azimuth angle and time of day

Future Research and Calibration

- **Open questions**:
  - How dependent are these effects on environmental conditions?
  - Can an accurate and standard set of calibrations be obtained for a GPS site?
  - What is the ultimate limitations that these effects place on the accuracy of (geodetic and geophysical) estimates obtained from GPS data?

- **Quantitative answers:**
  - Construct a second, field deployable AMCS:
    - Side-by-side tests for accuracy assessment
    - Characterization of SMA effects at various GPS test sites
    - Deliberate introduction of SMA effects for model applicability
    - Time-series analysis of GPS analyses with/without SMA corrections