Long-Term Evaluation of Precise Point Positioning with Single Receiver Phase Ambiguity Resolution using JPL's GPS Products

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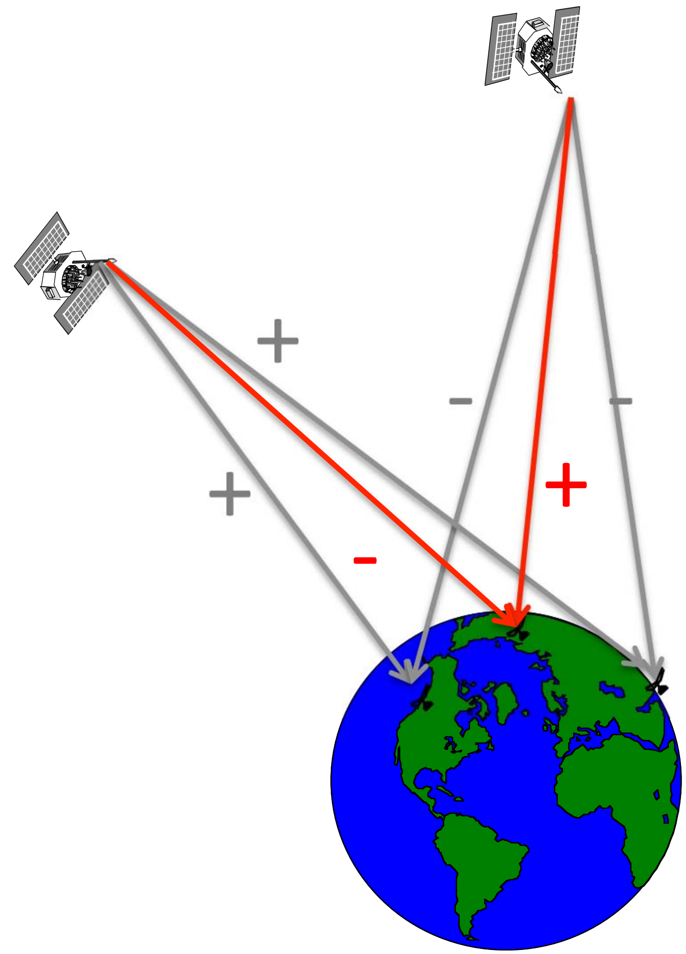
Introduction

- Approach to perform single receiver GPS-based positioning with ambiguity resolution described by Bertiger et al. [2010].
  - Evaluated with >200 stations and 6 months
- **OBJECTIVE: Evaluate Bertiger et al. approach using 16 stations, 4-years of GPS data, 2006-2009.**
- GNSS satellites provide two observables:
  - Pseudorange (e.g., P1, P2), with accuracy of 30-100 cm
  - Carrier phase (e.g., L1, L2), with accuracy of ~1cm or better.
    - ≈Range biased by an unknown integer number of cycles, i.e., phase biases.
- Precision geodetic GNSS-based positioning leverages phase measurement accuracy.
  - Single-receiver positioning typically estimates phase biases as real values.
- Improved positioning accuracy realized through "ambiguity resolution":
  - Resolving the integer number of cycles in the phase measurements.
  - Traditionally, performed using double differences of measurements:
    - Two receivers with two commonly viewed GNSS satellites (Blewitt [1989]).

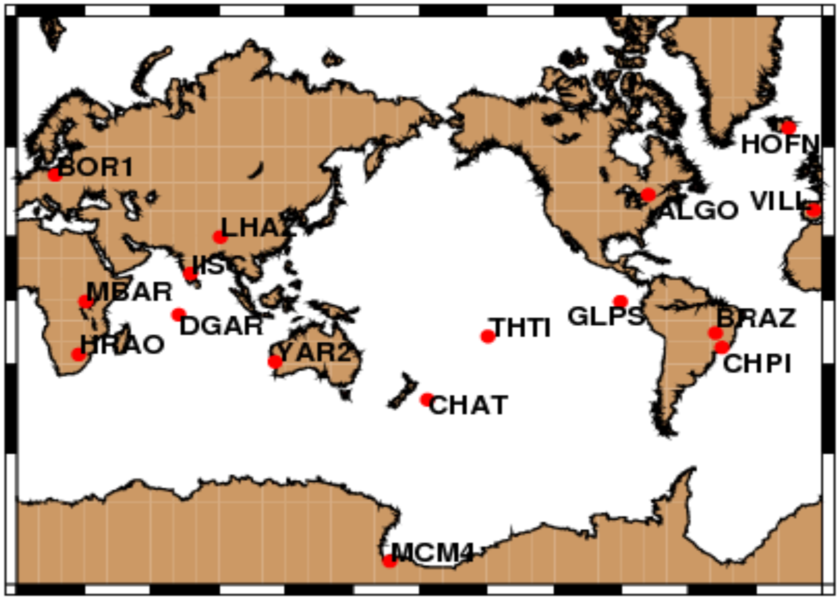
Single Receiver Ambiguity Resolution Approach

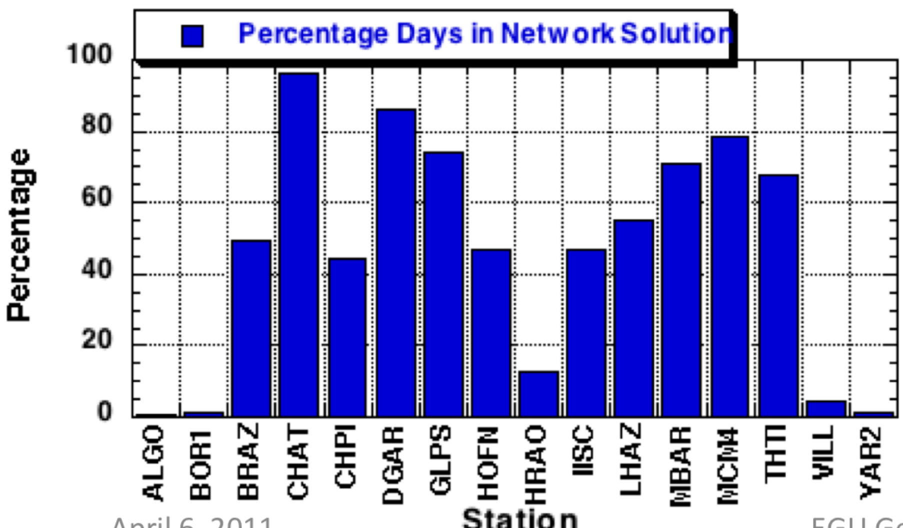
- Determine orbit and clock states of GPS satellites using global network of ground stations.
  - Resolves integer ambiguities using double differences of data from ground network/GPS satellites.
    - Includes determining wide-lane and phase biases for each station/satellite pair.
      - » Wide-lane=Dual frequency (L1/L2, P1/P2) data combination with long wavelength.
- Published products from network solution include:
  - Orbits and clocks of GPS satellites.
  - **Wide-lane and phase bias estimates for each receiver/satellite continuous phase arc.**

– Single receiver ambiguity-resolved positioning:
  - Use published orbits and clocks of GPS satellites.
    - As usual for single receiver positioning.
  - Estimate wide-lane and phase biases for receiver.
  - Resolve ambiguities using **double differences of wide-lane and phase biases estimates:**
    - Single receiver w.r.t. all available stations from network solution with common satellites in view. (>> 2).



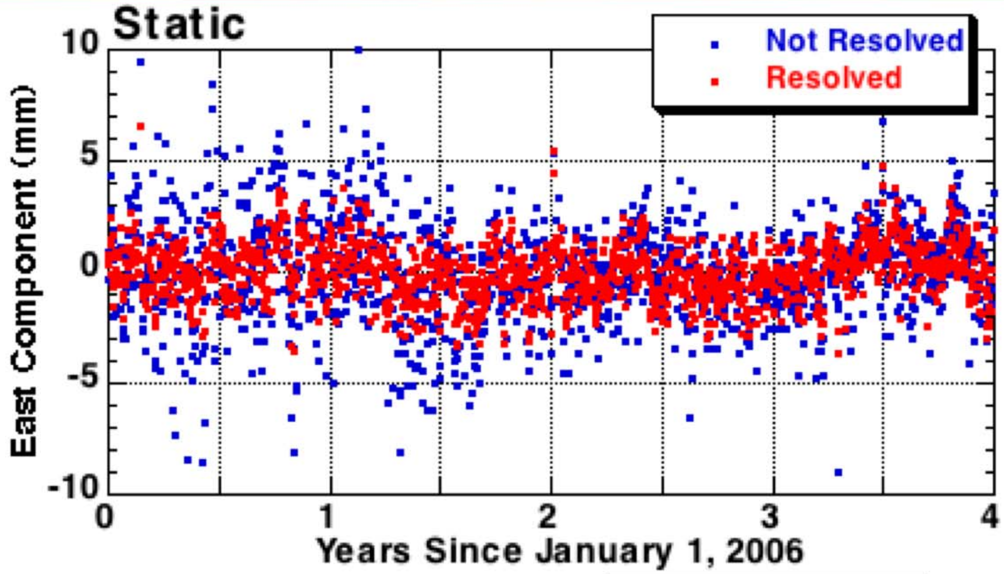
Point Positioning Evaluation Approach

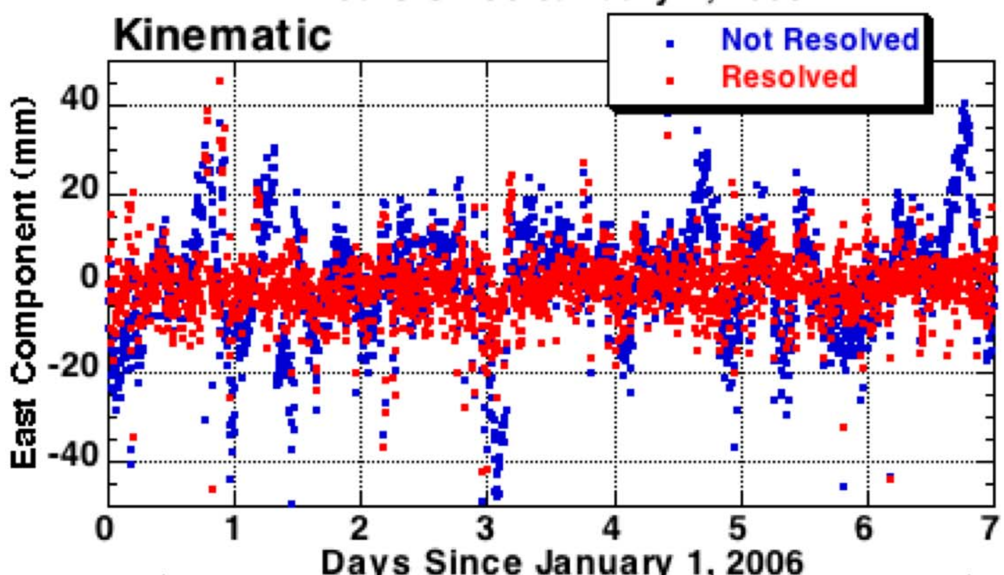




- Selected 16 GPS stations:
  - Global coverage and 2006-2009 occupation history.
- Perform single receiver static and kinematic point positioning:
  - Static: 1 position/day
  - Kinematic: 1 position/5 minutes
    - White noise, unconstrained.
  - JPL's GIPSY/OASIS software.
  - JPL's Reprocessed GPS orbits/ clocks spanning 2006-2009.
    - Includes wide-lane and phase bias estimates from network solution.
  - Compare station repeatability with and without ambiguity resolution.
    - After removing discontinuities, drift, and seasonal.
    - Outlier detection/removal.

Point Positioning Example: BOR1 – East Component



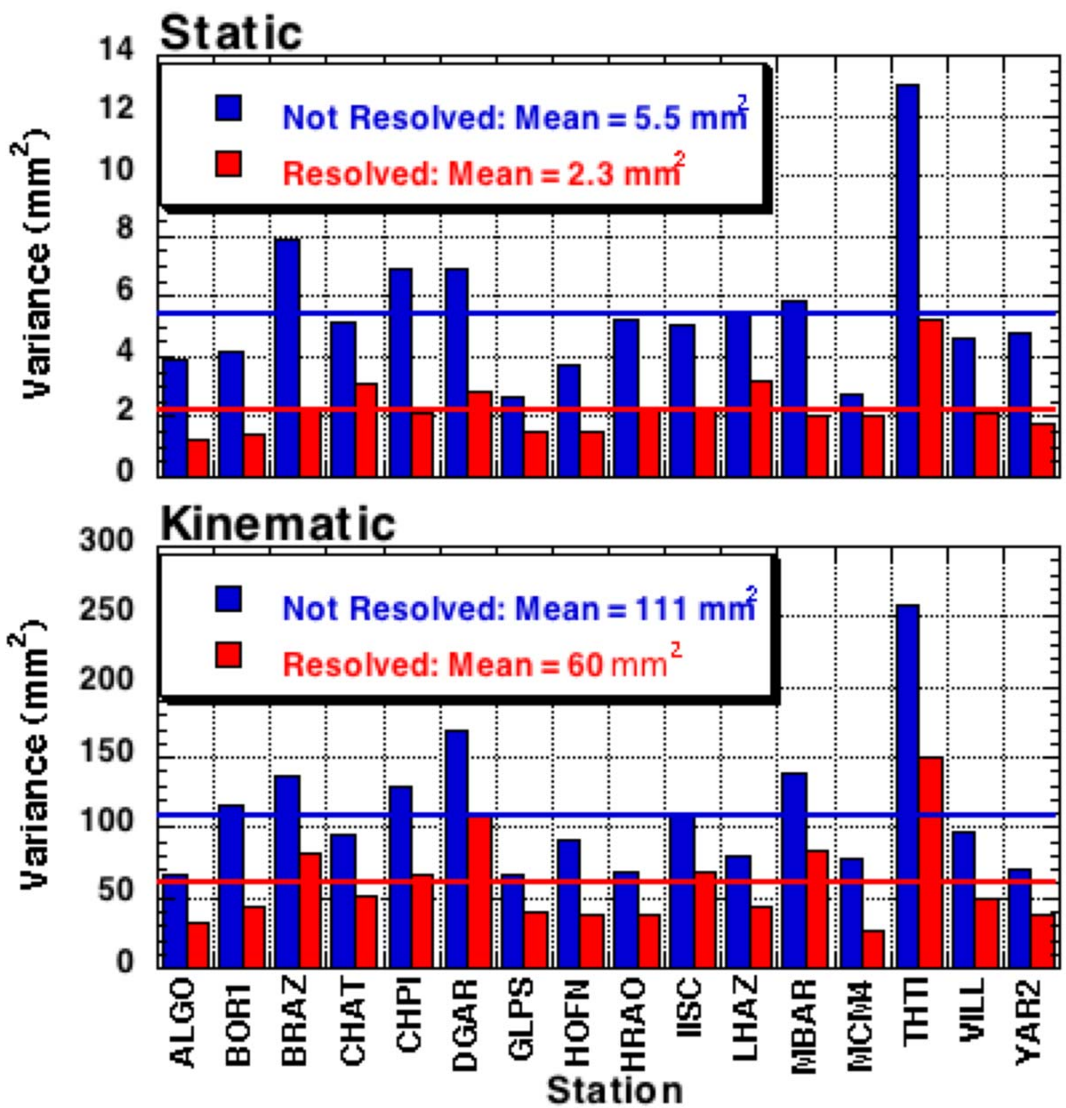


- BOR1: Borowiec, Poland
- Ambiguity resolution especially effective for East component.
- Kinematic scatter ~ 6 times larger than static.
  - When estimated as white noise process.
- Single receiver technique improves station repeatability in static and kinematic positioning.

RMS of 4-year Scatter - East (mm)

	Static	Kinematic
Not Resolved	2.0	10.7
Resolved	1.2	6.6

Point Positioning Repeatability: East Component

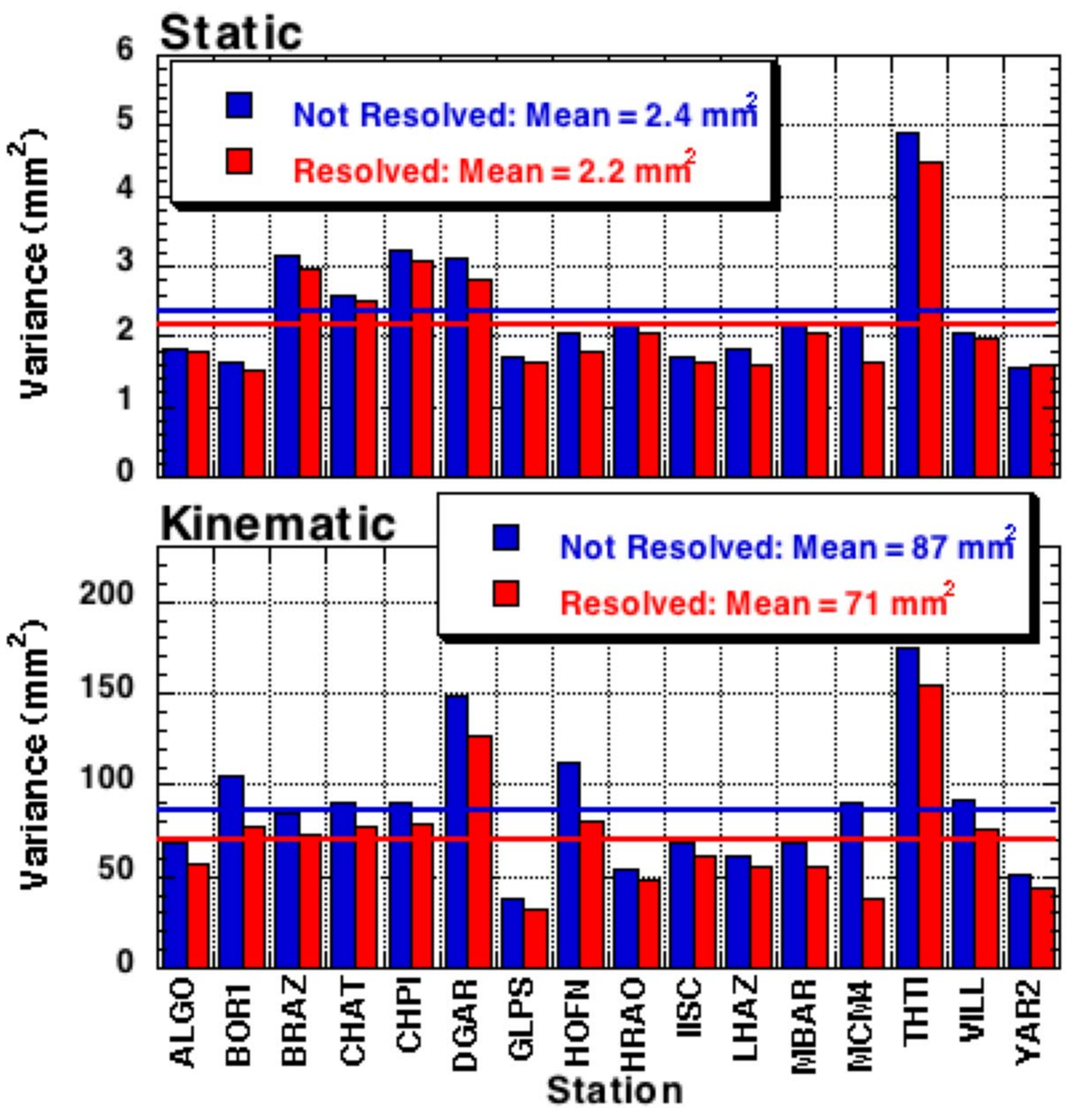


Variance Reduction: %

	Static	Kinematic
Minimum	**28**	**35**
Maximum	**71**	**66**
Average	**56**	**46**

- Improved repeatability for all 16 stations:
  - Static:
    - 2.3 to 1.5 mm
  - Kinematic:
    - 10.5 to 7.7 mm
    - White noise estimates.

Point Positioning Repeatability: North Component

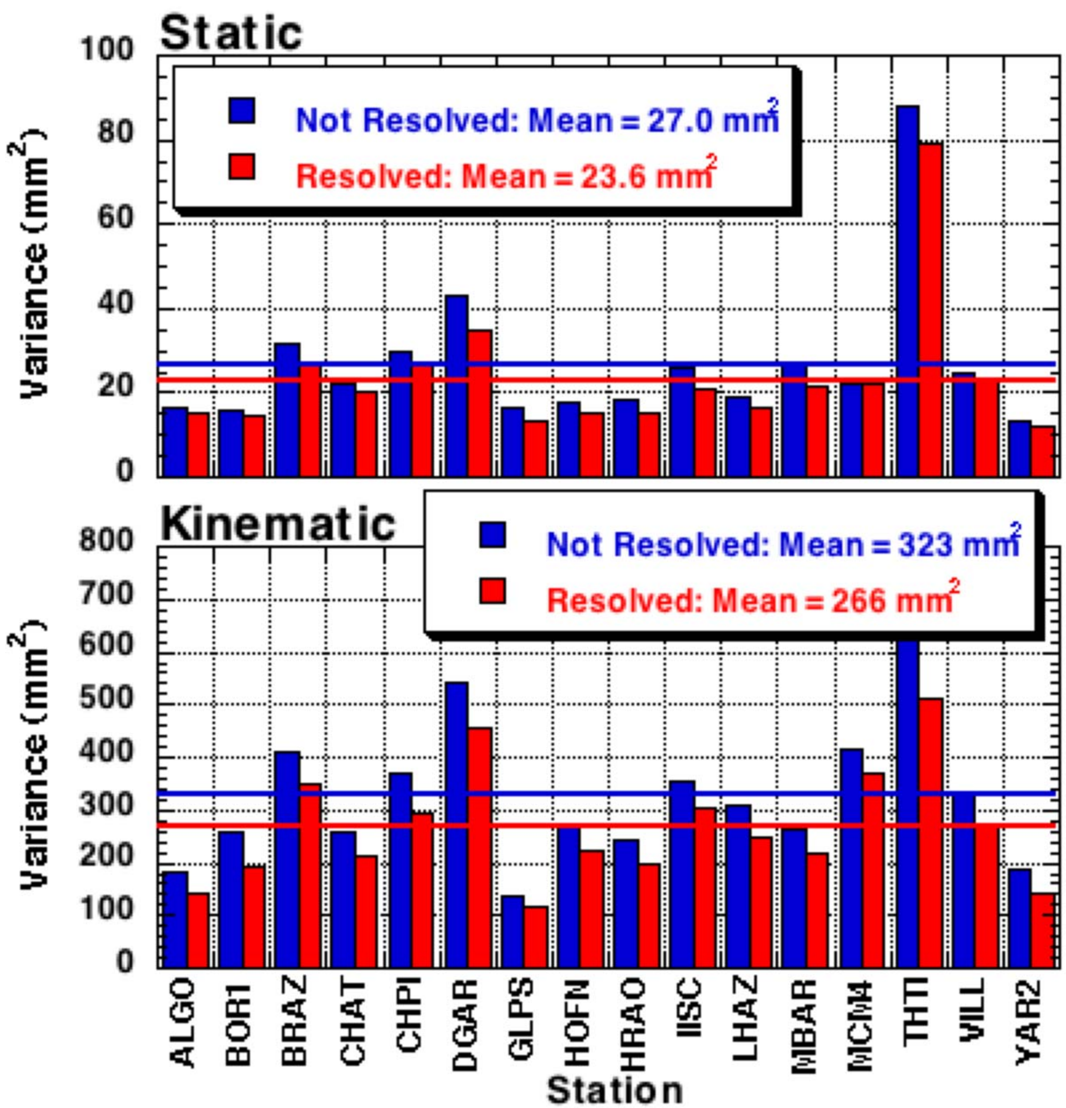


Variance Reduction: %

	Static	Kinematic
Minimum	**-3**	**11**
Maximum	**23**	**58**
Average	**7**	**18**

- Improved repeatability:
  - Static:
    - 15 of 16 stations.
    - 1.6 to 1.5 mm
  - Kinematic:
    - All 16 stations
    - 9.3 to 8.4 mm
- **North and east components very similar with ambiguity resolution.**
  - Without ambiguity resolution east is 50% higher than north.

Point Positioning Repeatability: Vertical Component

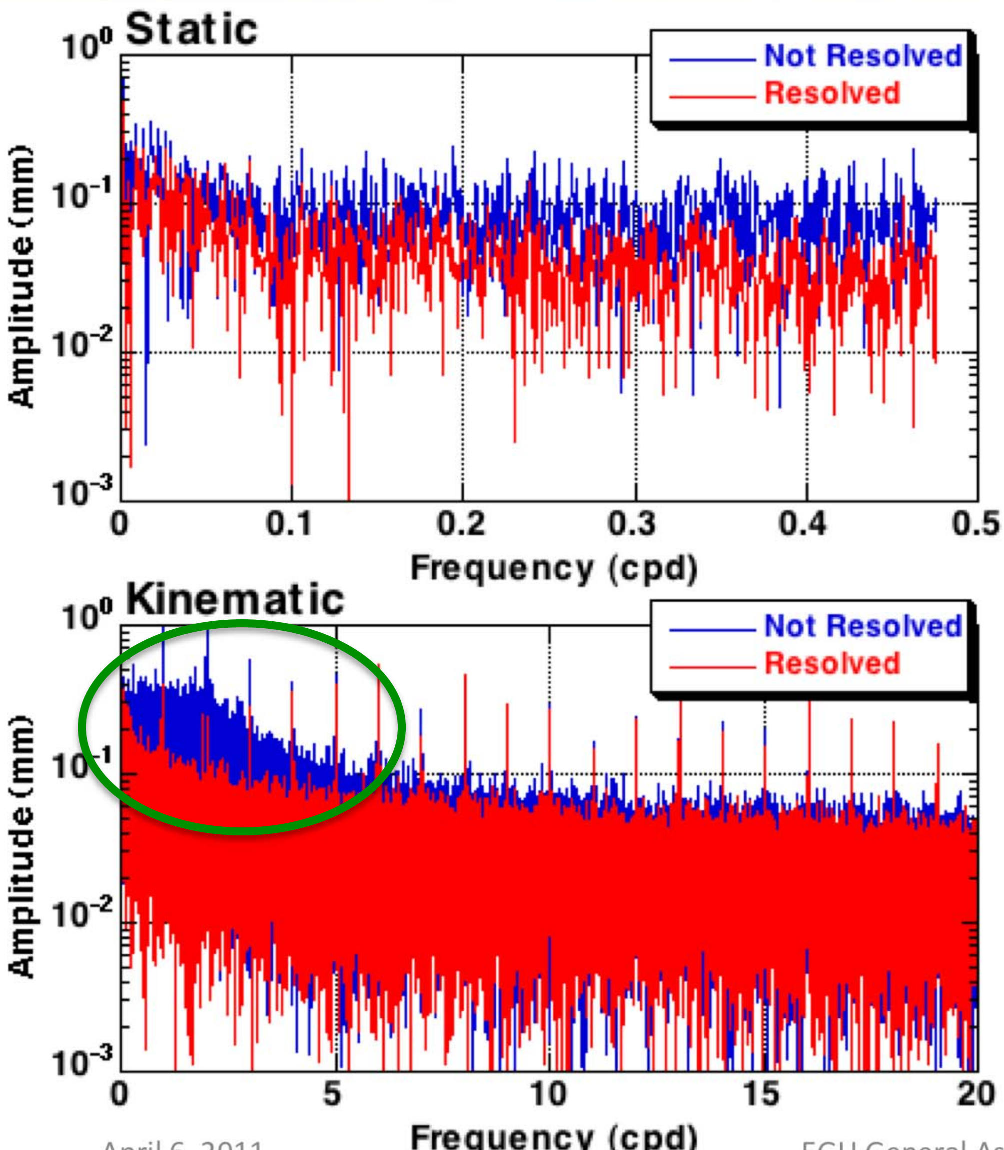


Variance Reduction: %

	Static	Kinematic
Minimum	**-0.2**	**12**
Maximum	**20**	**26**
Average	**13**	**18**

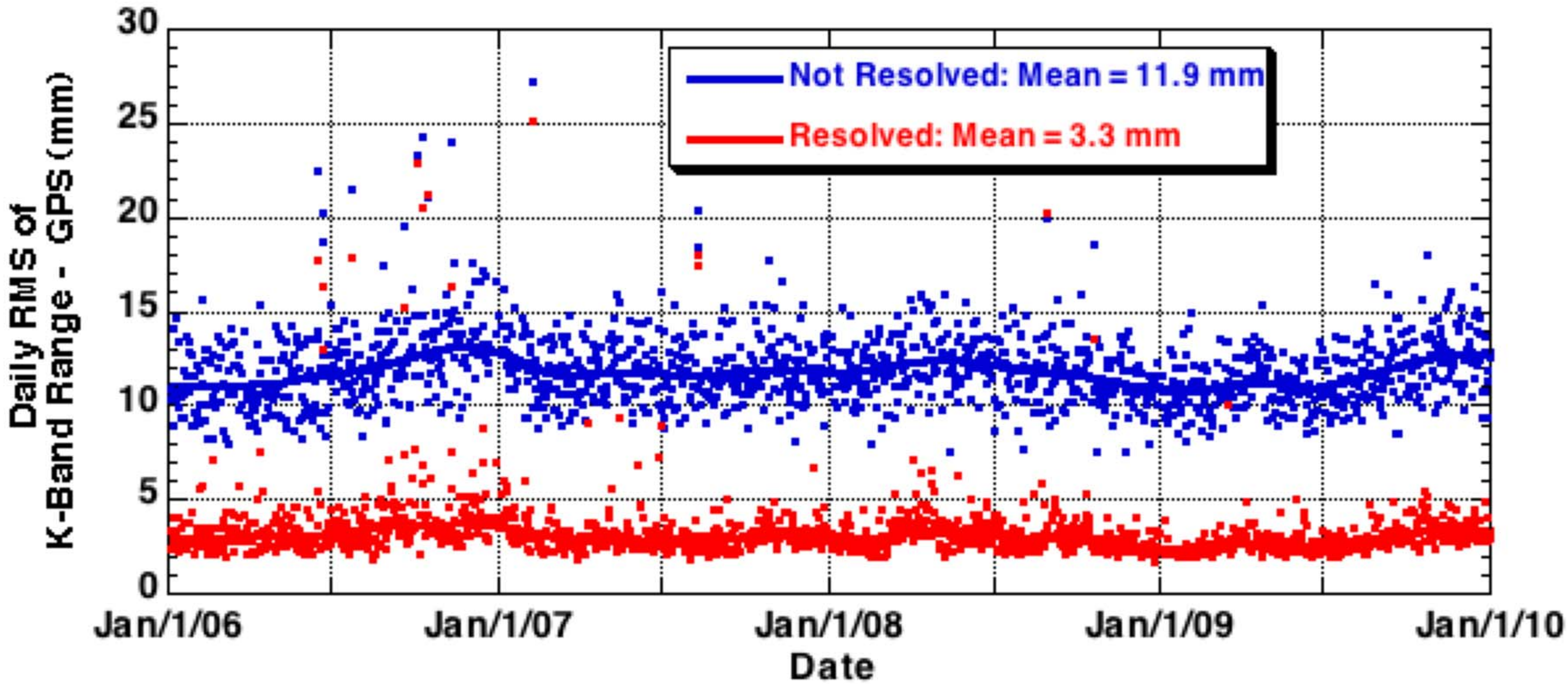
- Improved repeatability:
  - Static:
    - 15 of 16 stations.
    - 5.2 to 4.9 mm
  - Kinematic:
    - All 16 stations
    - 18.0 to 16.3 mm

Spectral Decomposition: BOR1 East Component



- Static Point Positioning:
  - 1 estimate/day
  - Ambiguity resolution reduces variance at all frequencies.
    - Especially >0.1 cycles per day (cpd).
- Kinematic Point Positioning:
  - 1 estimate/5 min.
  - Ambiguity resolution reduces variance primarily at frequencies < 6 cpd (> 4-hour periods).
    - Speculate related to typical continuous phase arc of ~3-4 hours for ground stations.
  - Spikes at integer multiples of 1 cpd due to independent kinematic solutions each day.
    - Exaggerated by unconstrained white noise estimation strategy.
    - Mitigation: constrained random walk with ambiguity resolution.

K-Band Residuals from Twin GRACE Satellites



- GRACE mission: Twin satellites at 500 km altitude, 200 km apart.
- GPS-based precise orbit determination for each satellite, **independently**.
- K-band biased ranging system between satellites, micron-level accuracy.
  - Provides independent measure of orbit accuracy.
  - Daily RMS computed after removing one K-band range bias per continuous arc.

– 5-minute GPS data used here. Additional improvement found when using 30-second data (e.g. Bertiger et al. [2010] show improvement from 4.1 to 2.9 mm)

Conclusion

- Single receiver ambiguity-resolved static and kinematic point positioning easily applied (plug-and-play) using:
  - JPL's GIPSY/OASIS Software
  - JPL's GPS orbit, clock, **AND wide-lane/phase bias products.**
    - **Wide-lane/phase bias products generated operationally since April 12, 2009.**
  - **Reprocessing underway to generate wide-lane/phase bias products for 1992-present.**
    - Applying IGS08 reference frame and IERS2010 standards.
    - Expect 1996-present to be available by August 2011.
- Results competitive with bias-fixing (double difference) approach.
  - Shown in Bertiger et al. [2010] paper.
- Variance reduction of repeatability in all components.
  - Most significant improvement observed in East component.
    - Likely due to north/south geometry of GPS satellite orbits.
- Alternative approach from Laurichesse et al. [2008].