Improved Models of the GPS Satellite Antenna Phase- and Group-Delay Variations Using Data from Low-Earth Orbiters

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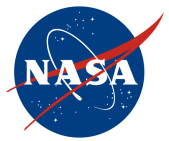

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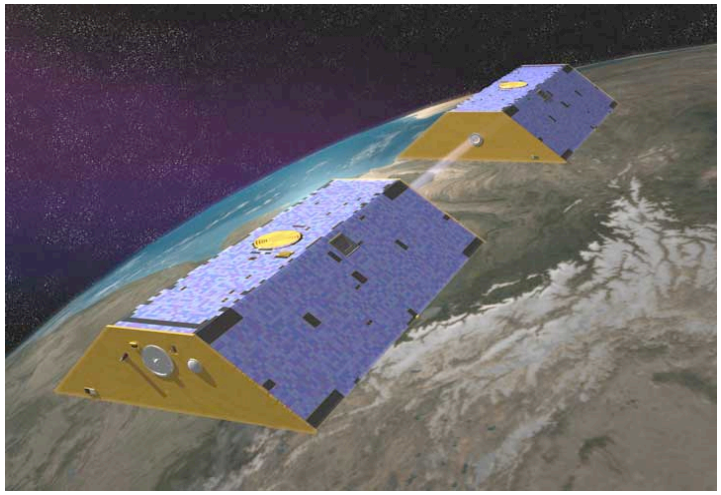
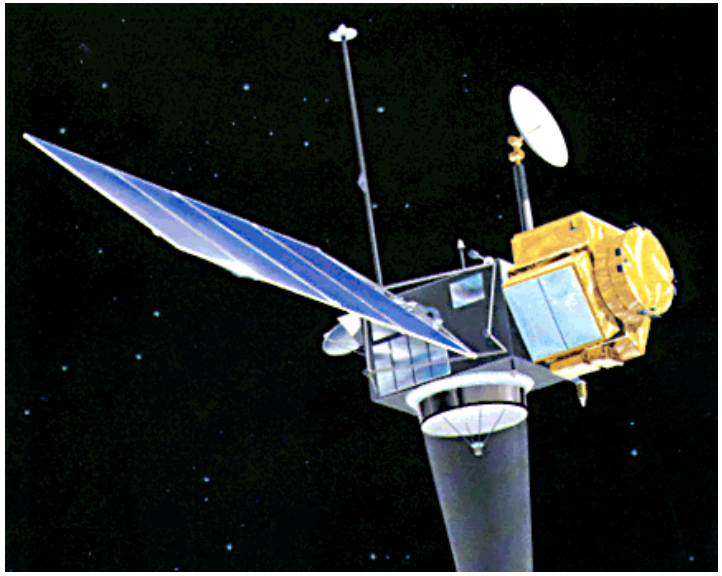
Outline

- Introduction
- New estimates of GPS transmitter antenna patterns
  - From GRACE tandem mission
  - Both phase- and group-delay variations
- Impact on realizing the Terrestrial Reference Frame
  - GPS-Based TRF vs. ITRF2008/IGS08
- Preliminary results from TOPEX/Poseidon & GRACE
  - Updated antenna phase variations for GPS transmitters
- Summary and Conclusions

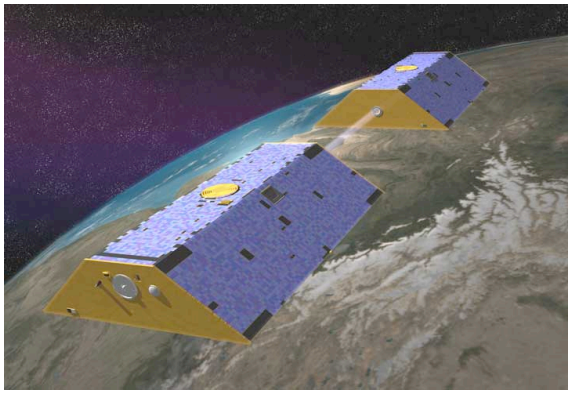
LEO-Based Calibrations of GPS Transmit Antennas

- Treat LEO as “reference antenna in space”
- Choose candidate missions to minimize multipath
  - GRACE (2002–pr.)
  - TOPEX/POSEIDON (1992–2005)
- Use Precise Orbit Determination (POD) to provide constraints
  - Scale constraint from dynamics (GM)
  - No a-priori constraint to TRF (use fiducial-free GPS s/c products)
  - No troposphere
- Derive *a priori* LEO antenna model from pre-launch measurements
  - e.g., anechoic, antenna test range

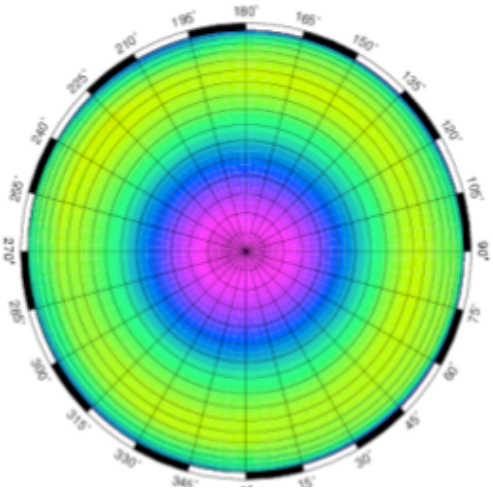




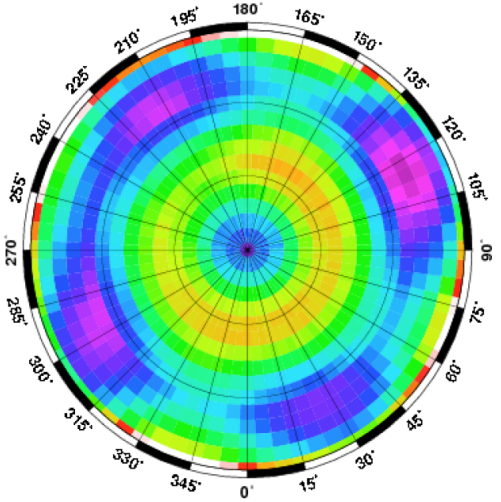
New GRACE-Based GPS Antenna Calibration



- From stacked post-fit POD residuals
- Iterative approach
- A priori GRACE antenna model from pre-launch anechoic measurements
- Estimates for all PRNs flying Oct. 2006–Nov. 2009
- Includes group delay (Ionosphere-free pseudorange, *PC*)



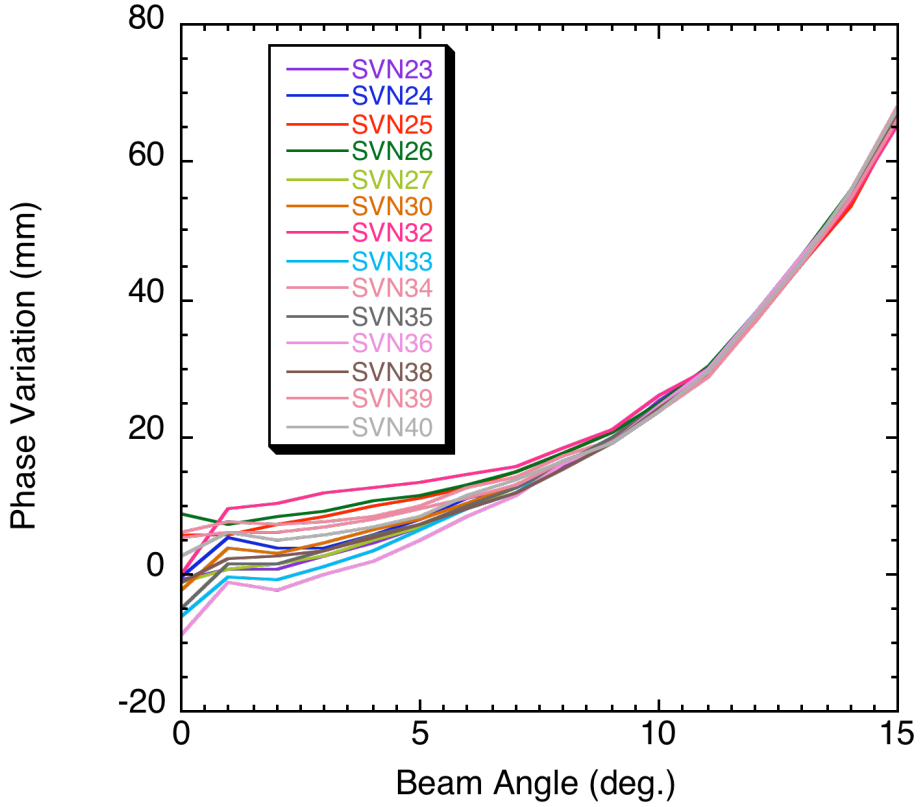
GRACE APV (LC) FROM ANECHOIC MEASUREMENTS



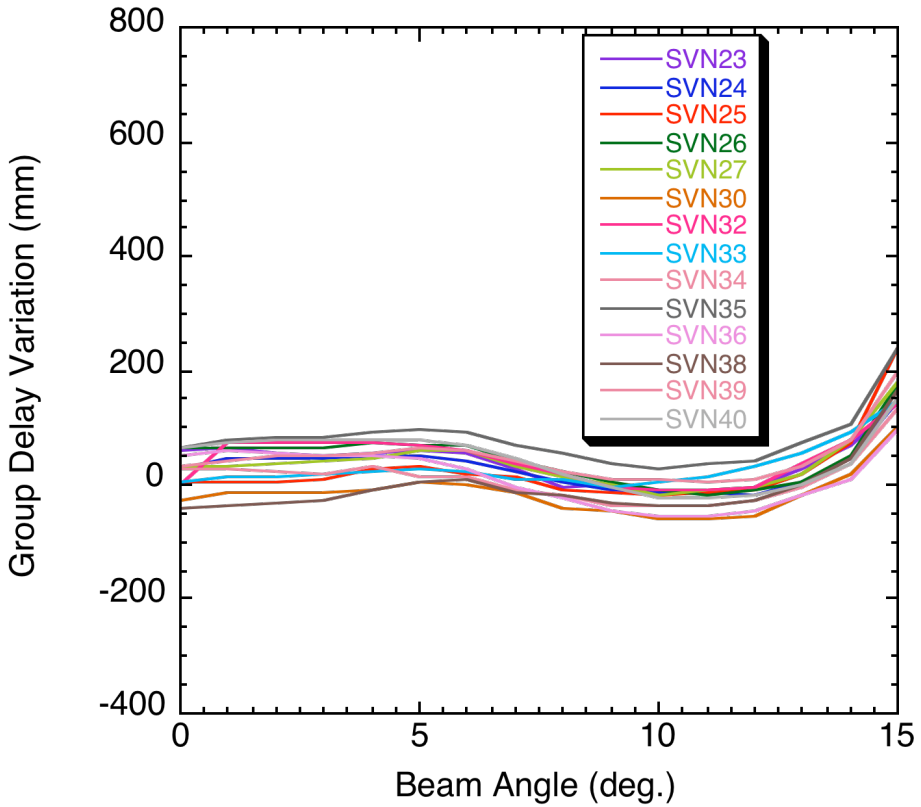
TYPICAL GPS APV (LC) FROM STACKED RESIDUAL APPROACH

Legacy (Block IIA) Antennas
Total Variation Relative to S/C Center of Mass

PHASE (LC)



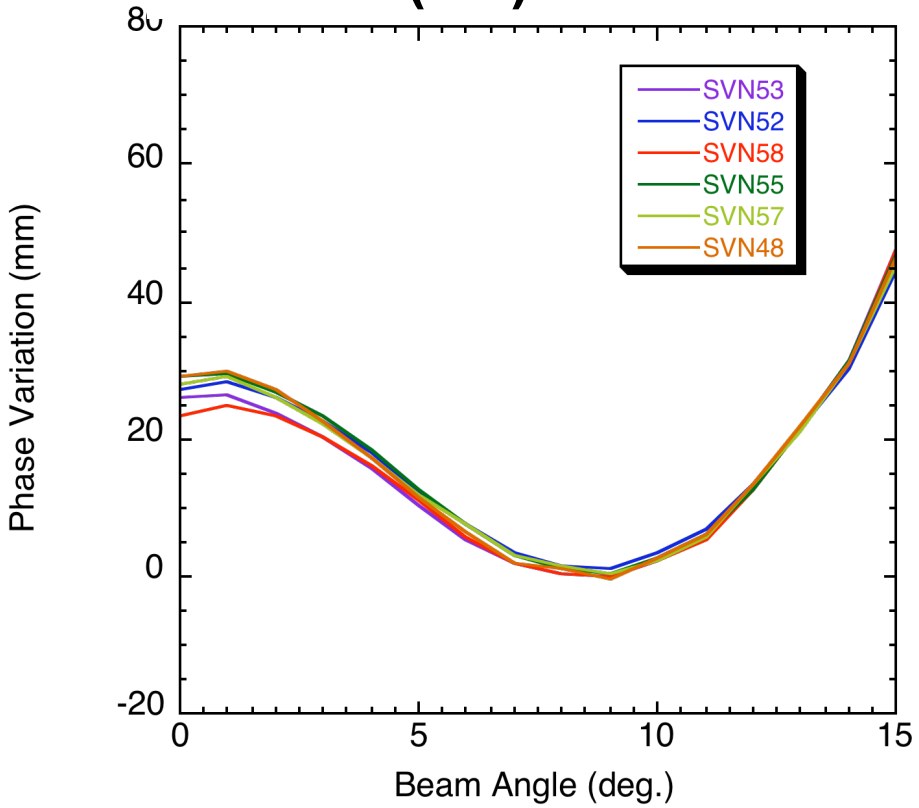
PSEUDORANGE (PC)

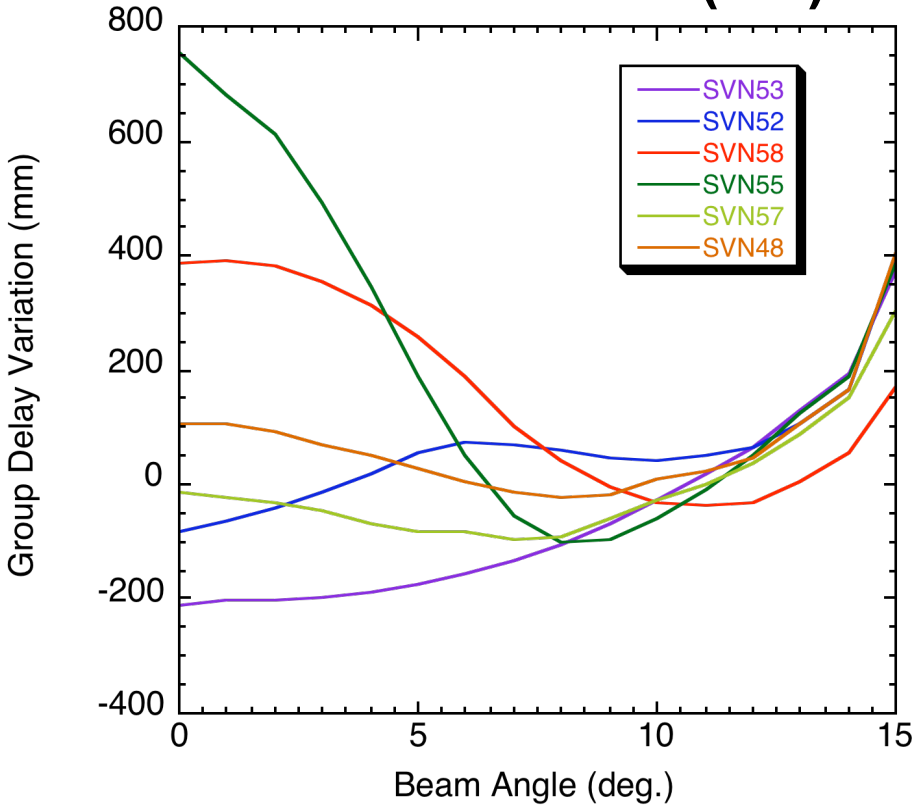


- Good consistency among individual PRNs for both phase and group delay

Modernized (Block IIR-M) Antennas

Total Variation Relative to S/C Center of Mass



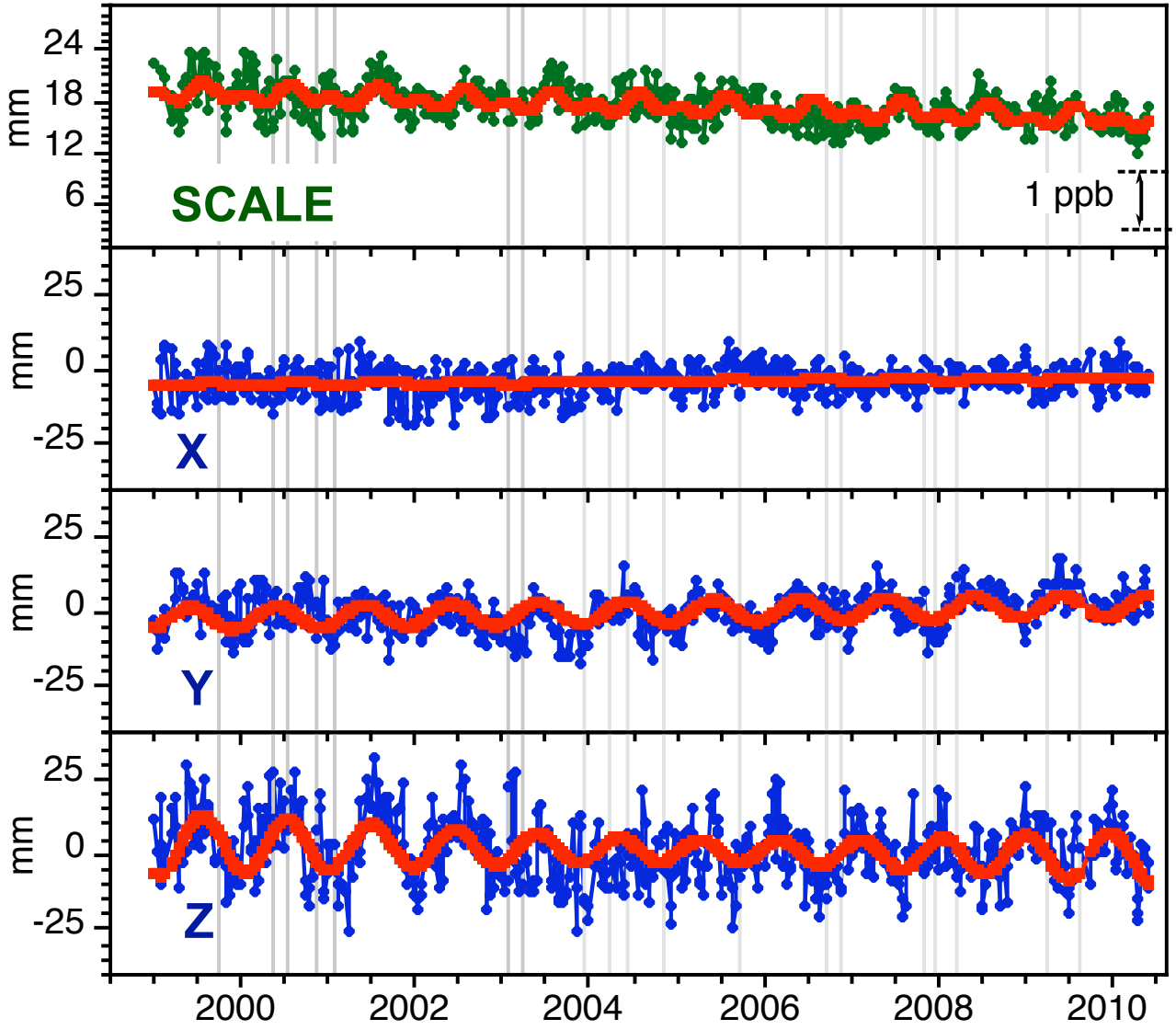


- Good consistency among individual PRNs for phase (left)
- Significant discrepancies for group delay (right)
- Similar-sized discrepancies observed for Legacy Block IIR (IIR-A) and IIR-B

Realizing the TRF from a Global GPS Network Solution: Elements of a New Strategy

- Use GPS s/c antenna phase variation (APV) and group-delay models from GRACE
- Use 40 well-distributed stations with choke-ring antennas
  - TurboRogue-inspired design (with Dorne-Margolin Element) common in global geodetic network
  - Improves homogeneity among GPS stations for TRF realization
  - Use choke-ring APV model from JPL test range (Dunn and Young, 1992)
- Use long-arc solutions to better capitalize on dynamical constraints
  - 9 days centered on each GPS week
  - Overlap of 2 days with neighboring solutions
- Estimate empirical accelerations at orbit-error resonance
  - Estimating accelerations once and twice per revolution (“1 cpr”, “2 cpr”)
  - Expressed in solar (UW) coordinates (U points from s/c to sun)
  - Estimated as random walk (updated every 12 hr, 6 hr, respectively)
- Use fiducial-free network/POD strategy (Heflin et al., 1992)
  - Loose (1-m) a priori constraint on all stations
  - Internal (GPS) TRF compared to ITRF2008(IGS08) via 7 parameter transformation

Terrestrial Reference Frame From GPS Alone
COMPARED TO ITRF2008/IGS08



Bias (2005)	**+17 mm**	(+2.7 ppb)
Trend	**–0.3 mm/yr**	(–0.04 ppb/yr)
Annual	**1 mm**	(0.1 ppb)
Semi Ann	**1 mm**	(0.1 ppb)
RMS Res	**2 mm**	(0.3 ppb)

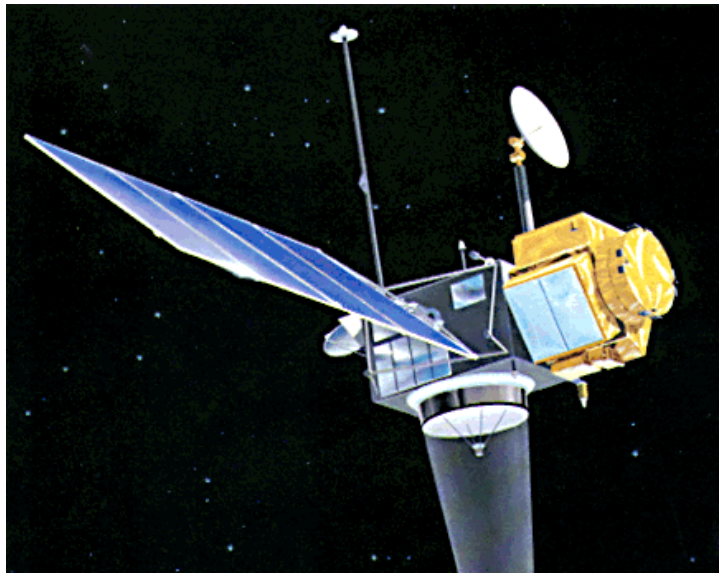
Bias (2005)	**–4 mm**
Trend	**+0.2 mm/yr**
Annual	**1 mm**
RMS Res.	**5 mm**

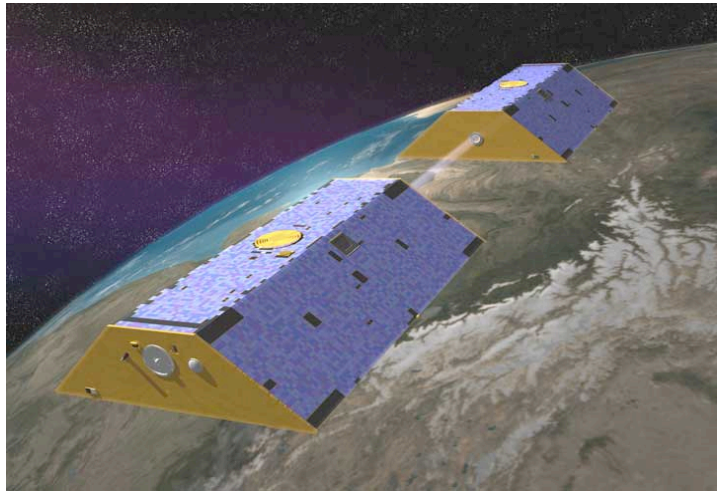
Bias (2005)	**+0 mm**
Trend	**+0.4 mm/yr**
Annual	**4 mm**
RMS Res.	**5 mm**

Bias (2005)	**+1 mm**
Trend	**–0.4 mm/yr**
Draconitic	**9 mm**
Annual	**5 mm**
RMS Res.	**10 mm**

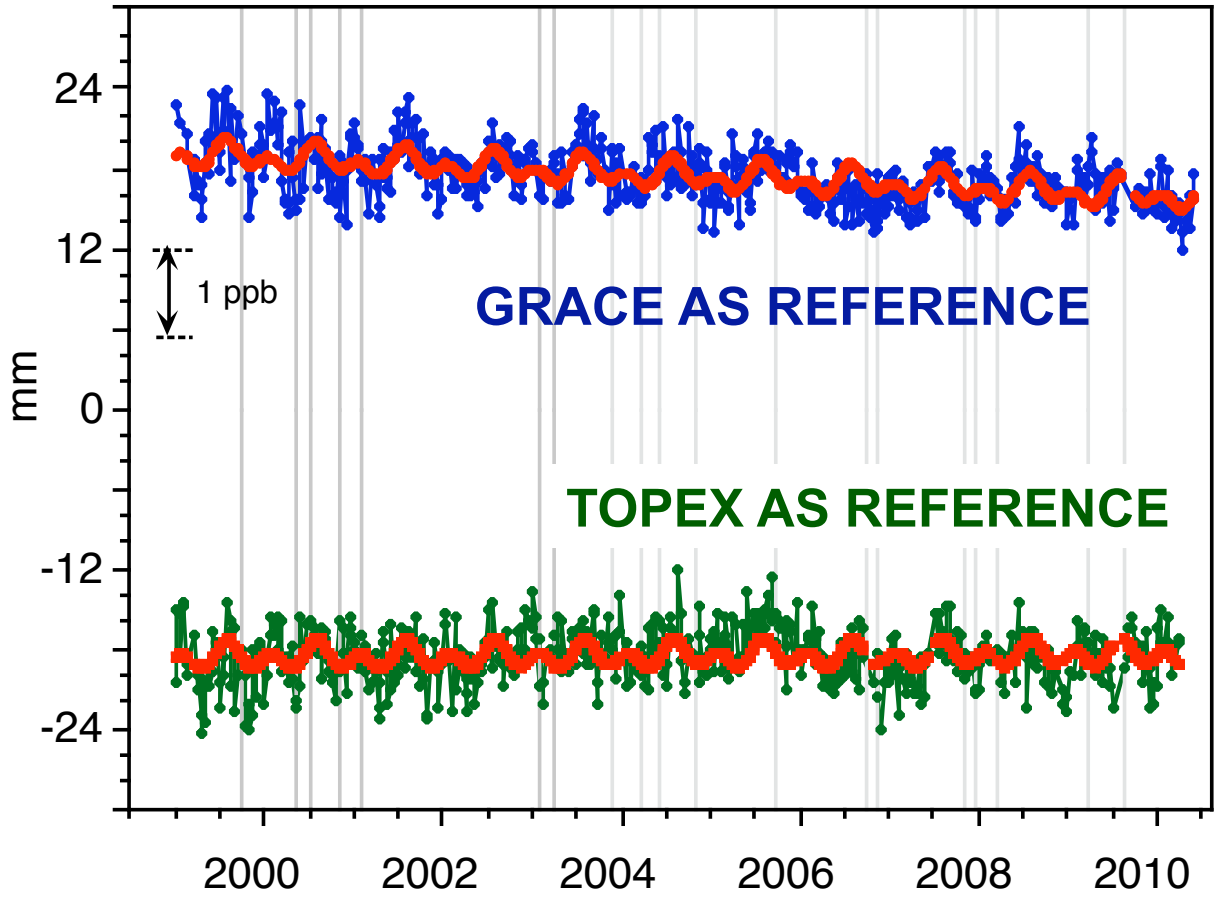
GPS Transmitter Antenna Phase Variations (APV) from TOPEX/POSEIDON and GRACE: Preliminary Results

- Combine results from T/P (1993) and GRACE (2003–2008)
  - Perform daily dynamical POD using carrier phase (LC) only
  - Save off normal equations and combine after-the-fact
  - Estimate APV for each GPS block simultaneously
- Treat T/P as reference antenna
  - Capitalize on low multipath (choke ring on 4-m boom)
  - Use test-range measurements (Dunn and Young, 1992) as *a priori*.
  - Adjustment to T/P APV constrained to zero mean in each elevation band.
  - Lend insight on remaining scale bias





Terrestrial Reference Frame Scale From GPS (vs. ITRF2008)
TOPEX vs. GRACE as Reference Antenna

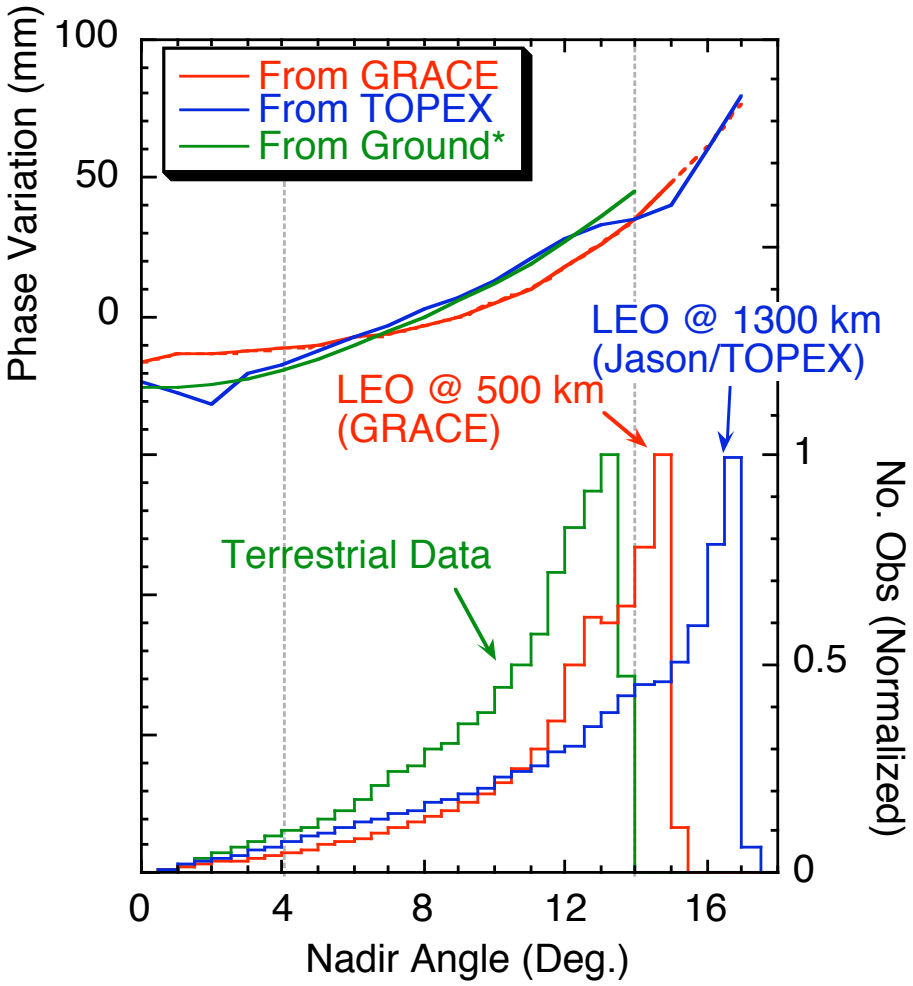


Bias (2005)	**+17 mm**	(+2.7 ppb)
Trend	**–0.3 mm/yr**	(–0.04 ppb/yr)
Annual	**1 mm**	(0.1 ppb)
Semi Ann.	**1 mm**	(0.1 ppb)
RMS Res.	**2 mm**	(0.3 ppb)

Bias (2005)	**–19 mm**	(–2.9 ppb)
Trend	**+0.0 mm/yr**	(+0.00 ppb/yr)
Annual	**1 mm**	(0.1 ppb)
Semi Ann.	**1 mm**	(0.1 ppb)
RMS Res.	**2 mm**	(0.3 ppb)

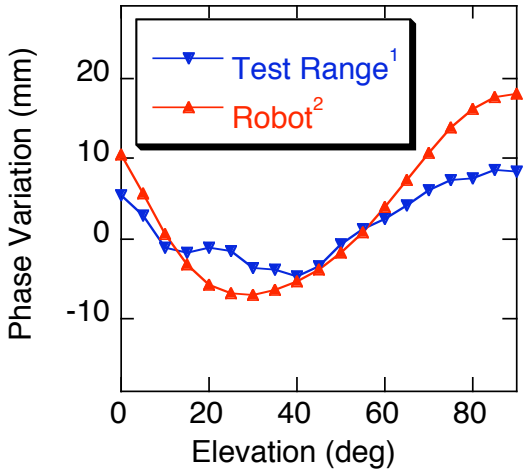
Sensitivity of Scale Bias to Antenna Phase Variation (APV) Models: GRACE or TOPEX as Reference Antenna?

TRANSMITTER: BLOCK IIA APV



* Block IIA average, from igs05.atx (Schmid et al., 2005)

RECEIVER: CHOKE RING APV



vs. ITRF2008

Transmit Ant. Model	Ground Ant. Model	ΔScale (ppb)
Grace-based	Test Range[1]	+2.7
TOPEX-based	Test Range[1]	–2.9
Grace-based	Robot[2]	+7.1
TOPEX-based	Robot[2]	+1.6
IGS (igs05.atx)	*Robot[2]*	*+1.2*

Uses ITRF2000(IGb00)

1 Dunn and Young (1992)
2 Wübbena et al. (2000)

Summary and Conclusions

- New GRACE-based estimates of the GPS satellite antenna phase- and group-delay variations
  - Group-delay (pseudorange) estimates show important satellite-to-satellite differences for Block IIR vehicles.
- New realization of the TRF from GPS alone.
  - 9-day network solutions for the period 1999–2010.
  - Uses new GRACE-based calibrations for GPS s/c antenna.
  - Agreement with ITRF2008/IGS08:
    - Scale offset and rate of 17 mm (2.7 ppb) and 0.3 mm/yr (0.04 ppb/yr)
    - Origin offset and rate (3D) of 4 mm and 0.6 mm/yr respectively
- Preliminary estimates of GPS satellite antenna phase variations (APV) from TOPEX/POSEIDON and GRACE
  - Directly estimate APV calibration (vs. residual stacking).
  - Lend insight on potential sources of remaining scale bias.
  - T/P provides unique visibility into GPS satellite APV at large nadir angles.

