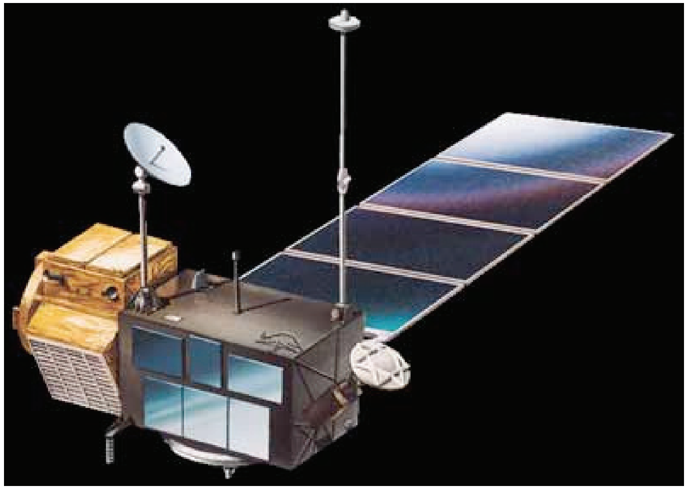
20-Years of Precision Orbit Determination For Altimetry With GPS

Willy Bertiger, **Shailen Desai**, **Angie Dorsey**, **Miquel Fernandez**, **Bruce Haines**, **Tim Munson**, **Christina Selle**, **Jan Weiss**, **Wenwen Lu**, **Larry Young**

Jet Propulsion Laboratory, Calif. Inst. of Tech., Pasadena CA USA

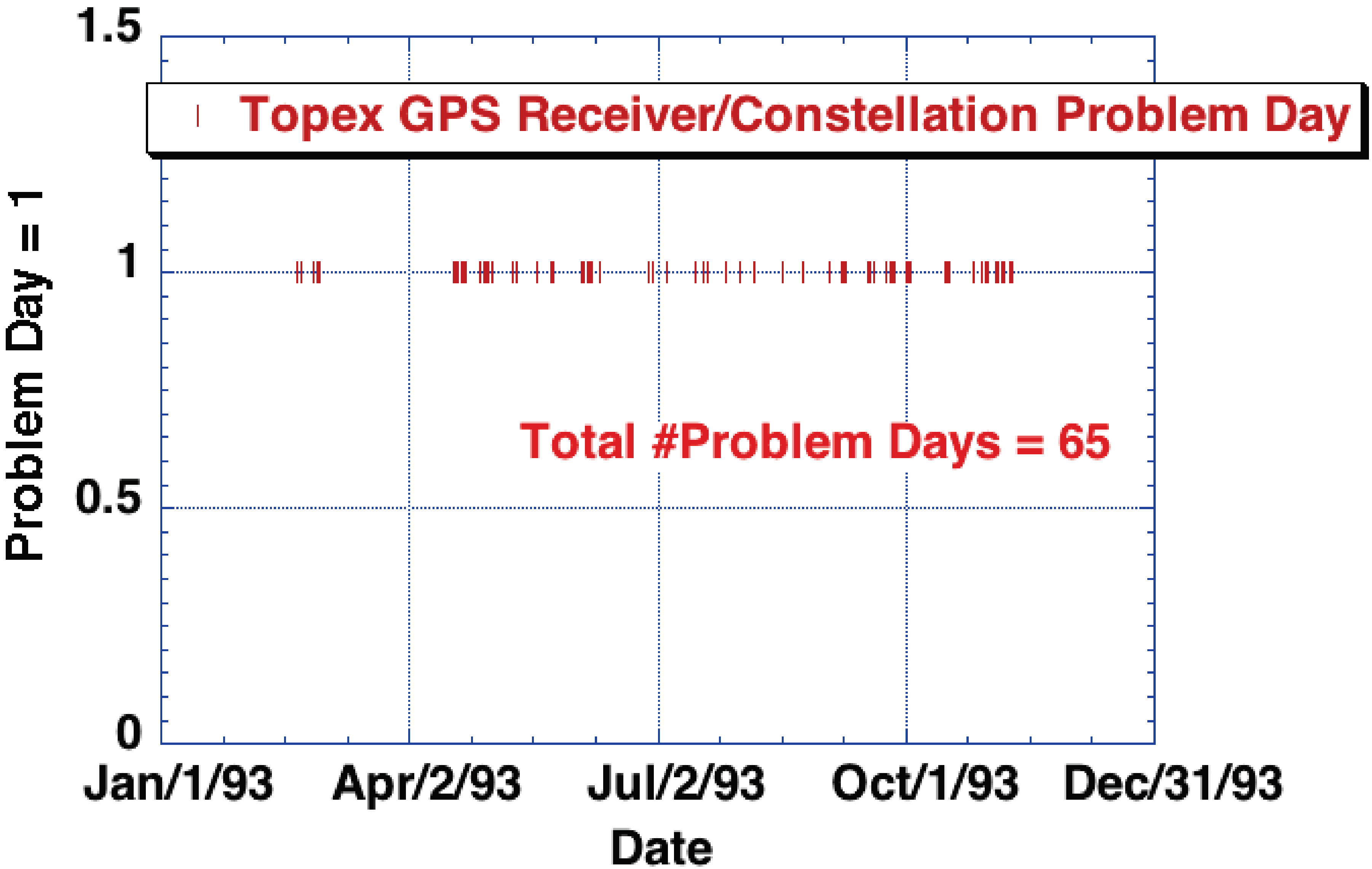
TOPEX/POSEIDON GPS Data Reminders

- **Launched in August 1992 with experimental GPS system**
- **T/P GPS Demonstration Receiver (Motorola Monarch)**
  - 12 channels supported tracking of 6 satellites on two frequencies
  - Dual Frequency data collected only when Anti-Spoofing off
  - ASIC Error on P2 (~25 cm): elevation dependent
    - Compromises use in widelane ambiguity resolution
  - Half Cycle Slips with probability of 50% in L1 or L2
    - Some hope of resolving half cycles, but small
- **1993 - GPS Constellation is not operational**
  - Anti-Spoofing testing
  - Individual GPS satellite tests
  - System bugs
  - 23-24 GPS satellites
  - 30-50 ground stations



All these problems were known prior to launch. None compromised the goals of the experiment. Quite different from the Jason1/2 era.

T/P GPSDR: 1993 Problem Days



T/P GPSDR: Past Experiences at JPL

- **Comprehensive evaluation of performance provided by Bertiger et al. (1994)***
  - 4-5 cm accuracy (radial RMS)
  - 1-cm orbit overlaps (radial RMS)
  - 5-mm ionosphere-free phase (LC) residuals
  - Apparent 5-cm bias in antenna height of unknown origin.
- **Early efforts predated the emergence of precise point positioning (PPP)**
  - POD was based on simultaneous (network) solution for T/P, GPS constellation and ground stations.
- **Routine near-real time POD began in 1995**
  - Next-day solutions, based on single-frequency data (A/S on January 1994)
  - Sponsored by U. S. Navy
  - Supported operational oceanography, forecasting.
  - Continued until demise of satellite in 2005.
- **First major re-analysis of dual-frequency data in 2006**
  - Dynamic solutions, to test new models of GPS satellite antenna phase variations (APV).
  - Demonstrated 5-cm antenna offset due to mis-modeling of GPS APV (Haines et al., 2006)

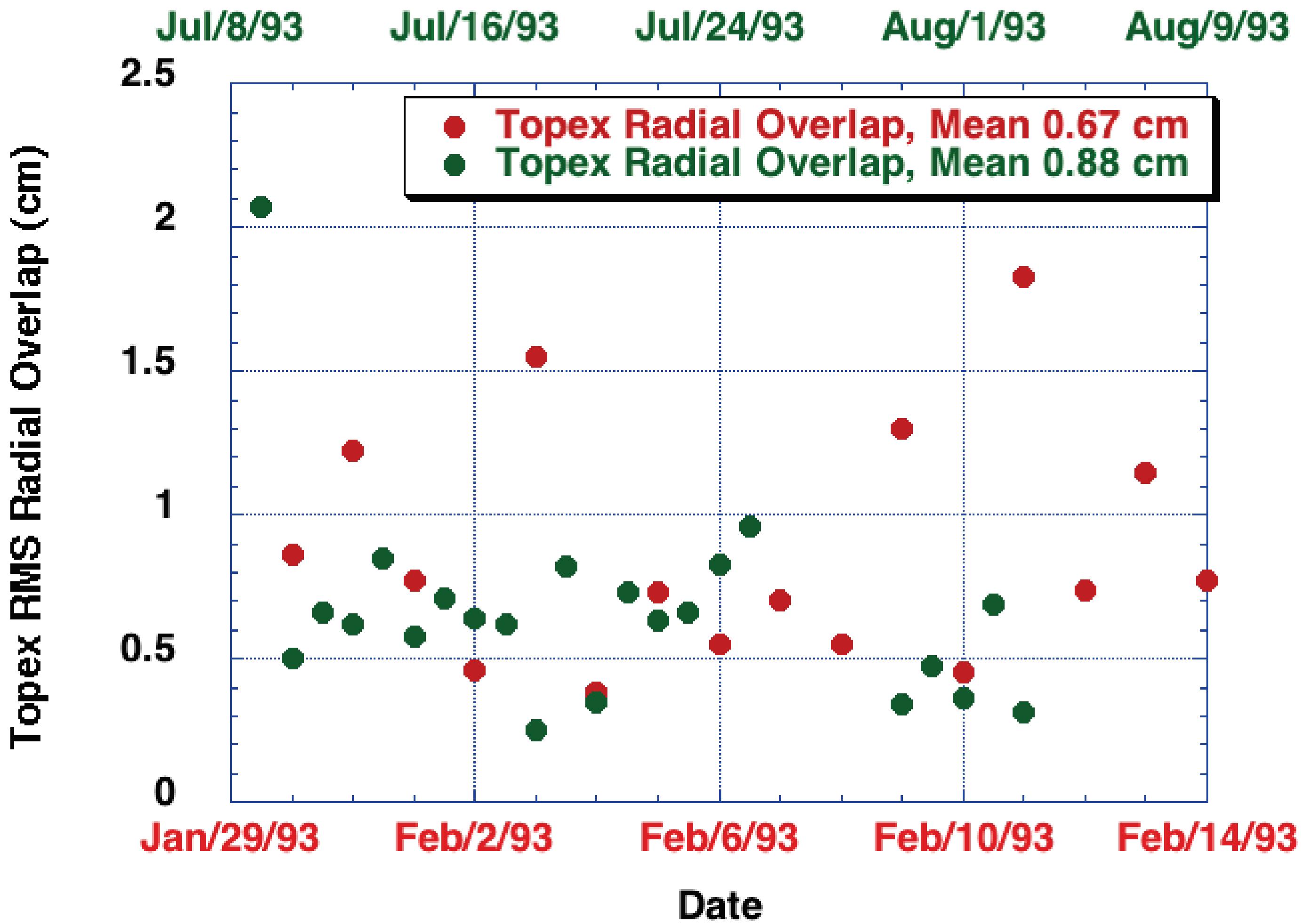
* J. Geophys. Res., 1st special issue on TOPEX/Poseidon, 1994

Revisiting T/P POD: New GPS-Based Solution Strategies

- **Use dual-frequency data from 1993**
  - Focus on repeat cycles 14–15, 30–32 (good GPSDR + constellation performance).
- **Use current static gravity model (GRACE)**
- **Use IGS08 terrestrial reference frame and IERS2010 standards**
- **Apply GPS Antenna Calibrations**
  - IGS08 standard for both ground station and satellites
- **Perform controlled test of PPP vs. Network Approach:**
  - Fixed GPS orbit and clock states (PPP)
  - Simultaneous solution for T/P and GPS constellation using fiducial approach (ground stations fixed to IGS08).

Precision of GPS-based T/P Orbit Solutions

Repeat Cycles 14-15 and Repeat Cycles 30–32



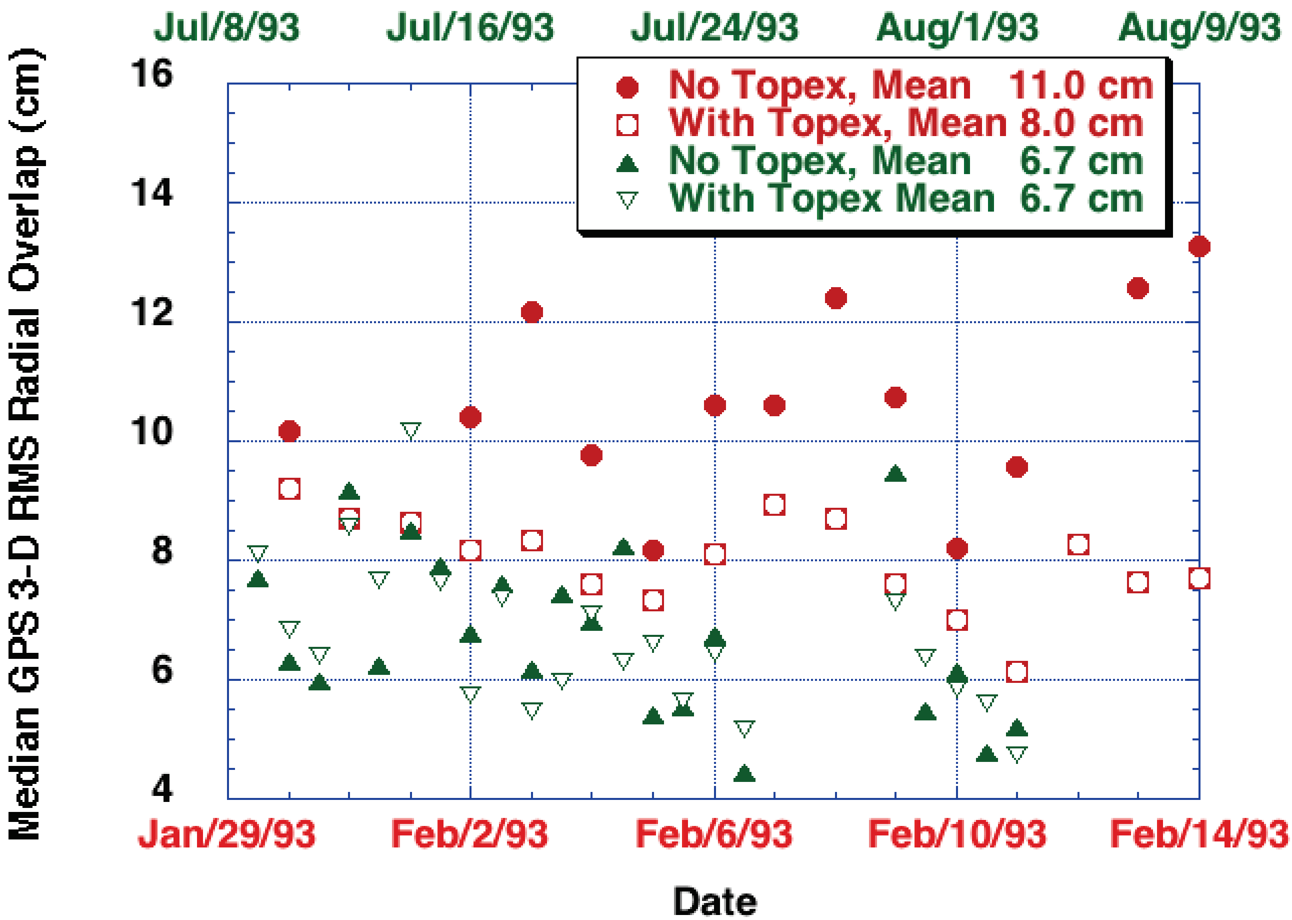
- Network approach yields best overlap precision (vs. PPP solution)
- Re-analysis results (7–8 mm) improve on original (1994) result (10–12 mm)

TOPEX/POSEIDON Crossovers
Repeat Cycle 14

Solution	Tracking Data	N Xover	σ (mm)	$\Delta\sigma^2$ (mm^2)	Mean (mm)
MGDR-B	SLR+DORIS	486	54.69	—	–3.4
GSFC std0905	SLR+DORIS	486	54.78	+10	–10.4
JPL PPP	GPS	486	56.48	+199	+5.0
JPL Network	GPS	486	54.59	+10	+2.0

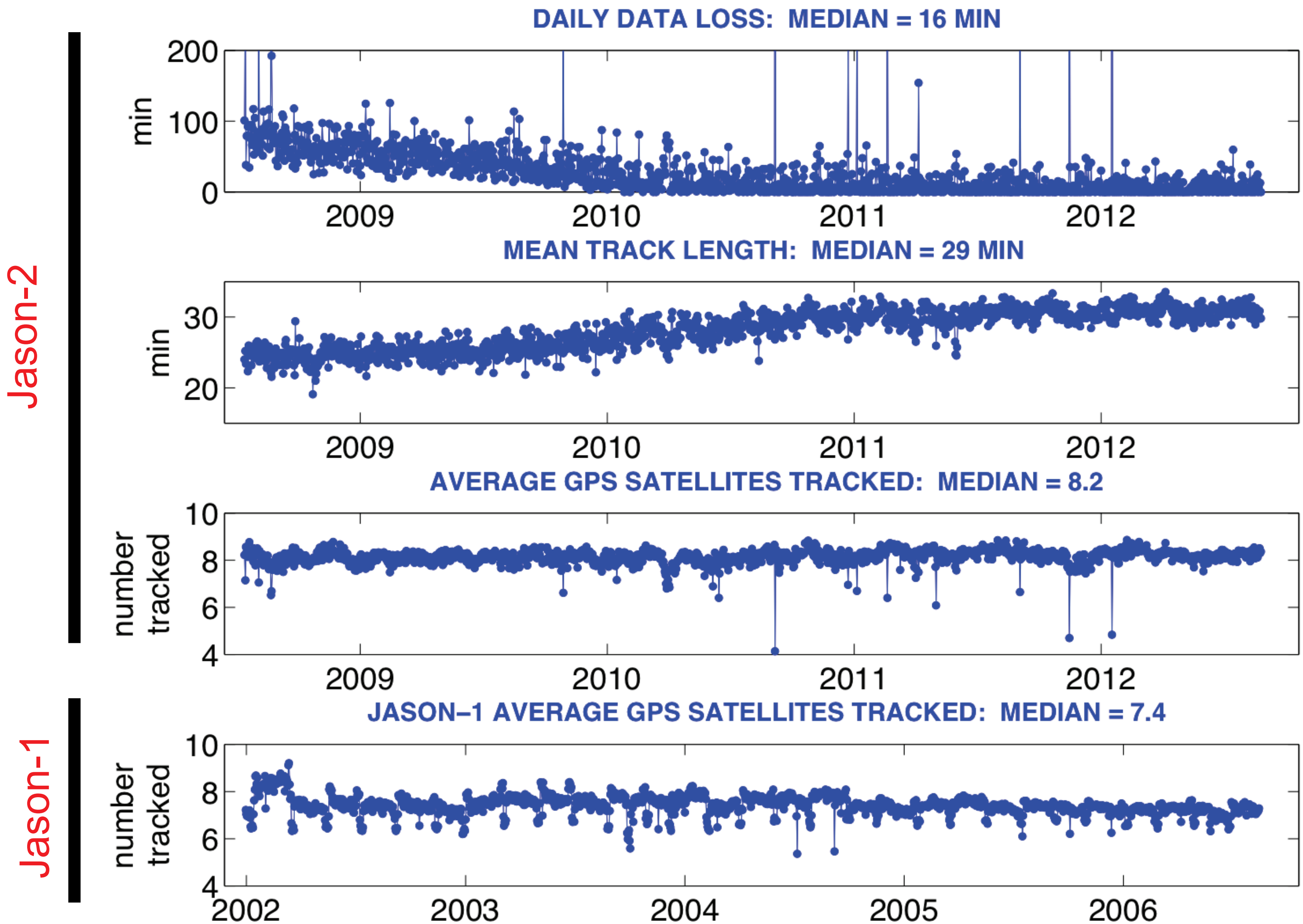
- **Limited data set (from Cycle 14 only)**
- **Superedited crossovers yield 5–6 cm RMS agreement**
- **MGDR-B, GSFC std0905 and JPL Network Orbits nearly indistinguishable**
- **JPL PPP solution inferior**

GPS Satellite POD Precision from 3D Overlap Test: Repeat Cycles 14-15 and Repeat Cycles 30–32

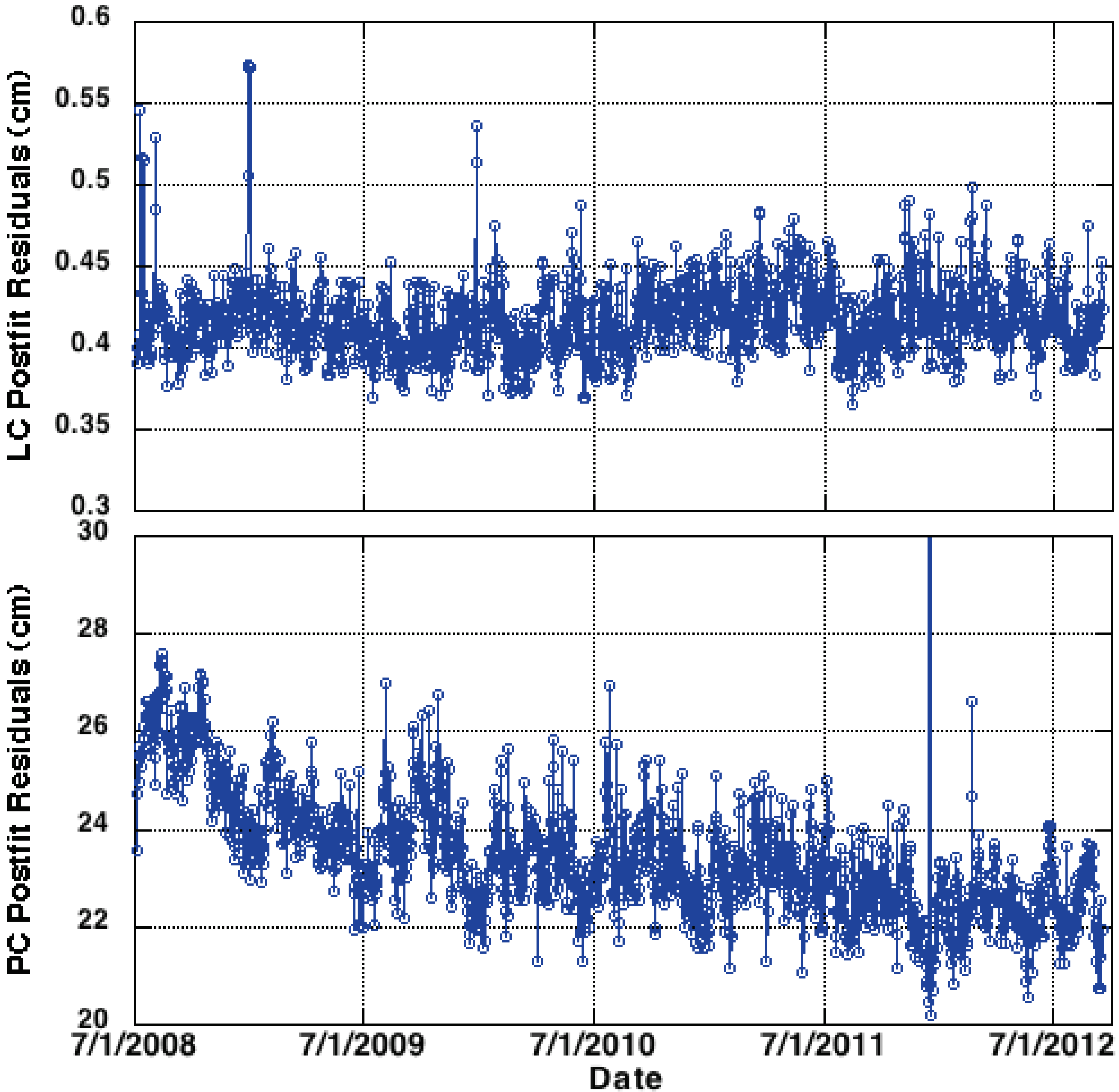


- Including T/P in network solution helps considerably in February, 1993.
- In July–August, 1993, no obvious impact of including T/P (larger ground network)

GPS Data, Jason Missions



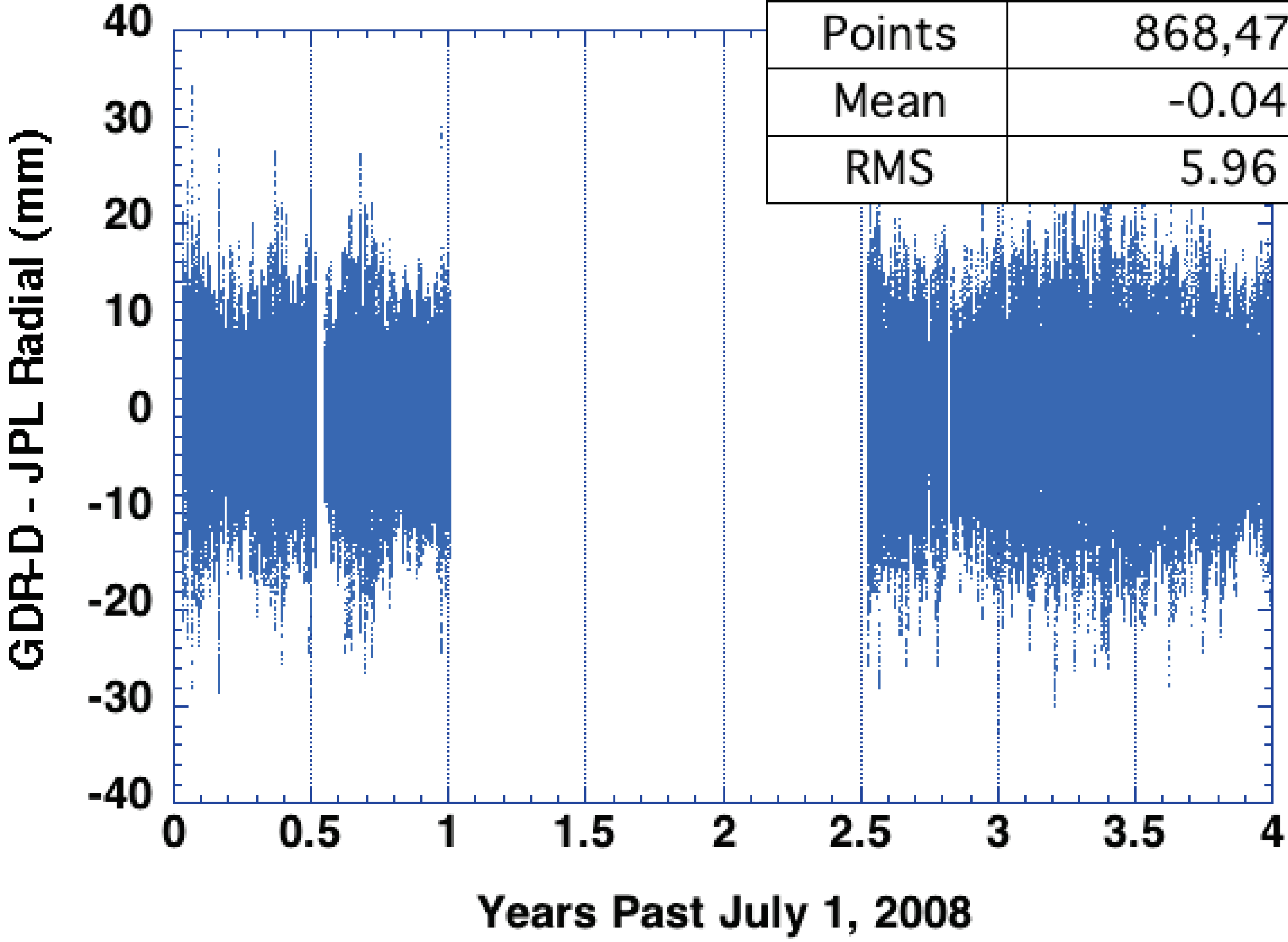
Jason-2 GPS Postfit Residuals



- **Excluding maneuver days.**
- **Median:**
  - LC: 0.42 cm
  - PC: 23.3 cm

Radial Differences GDR-D

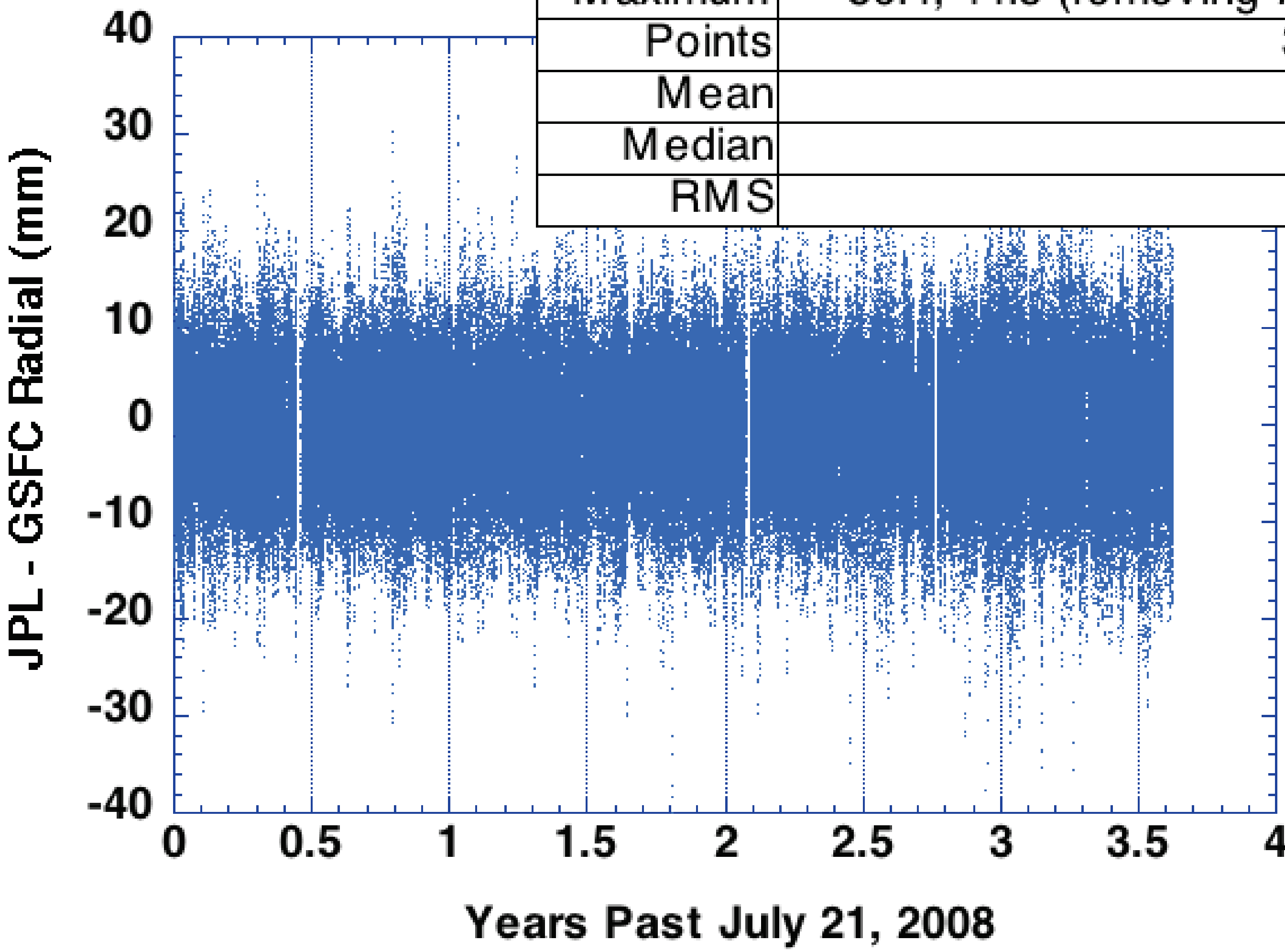
	GDR-D - JPL (mm)
Minimum	-36.5
Maximum	34.1
Points	868,473
Mean	-0.04
RMS	5.96



JPL – GSFC SLR/DORIS Reduced Dynamic TVG4x4

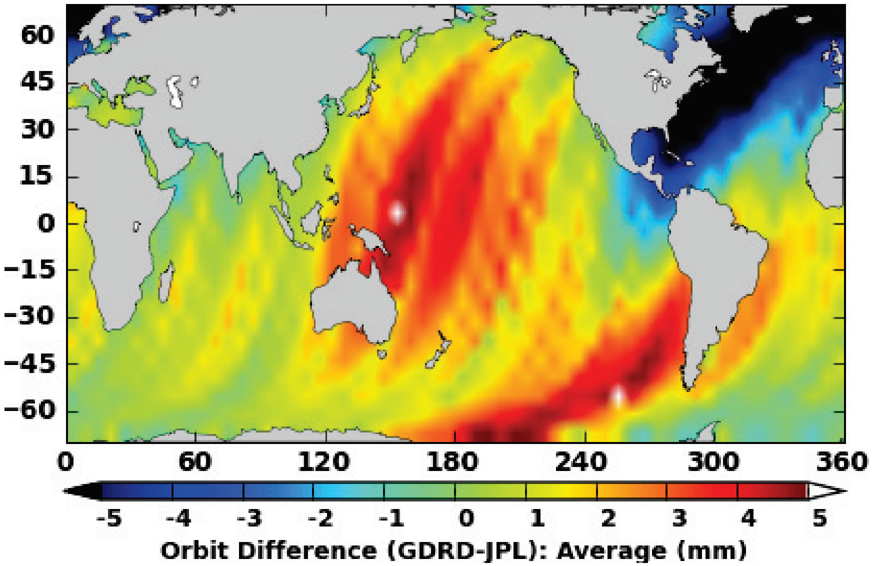
Min/Max (-99,86) in 7 hour window July 4, 2011

	JPL - GSFC Radial (mm)
Minimum	-99.0, -40.2 (removing 7 hours)
Maximum	86.4, 44.5 (removing 7 hours)
Points	362,516
Mean	-0.45
Median	-0.40
RMS	6.3

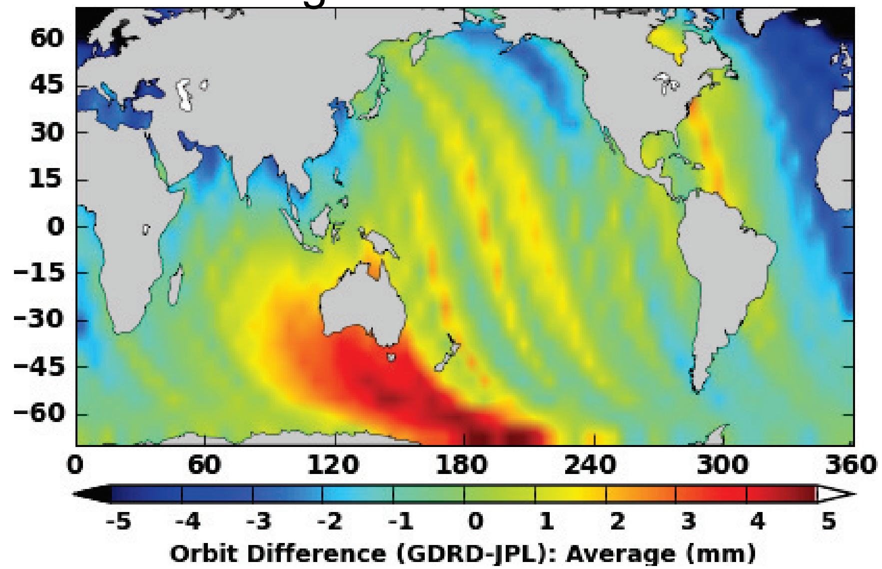


Geographically Correlated Differences: Average: GDRD-JPL

Ascending Passes RMS = 2.7 mm

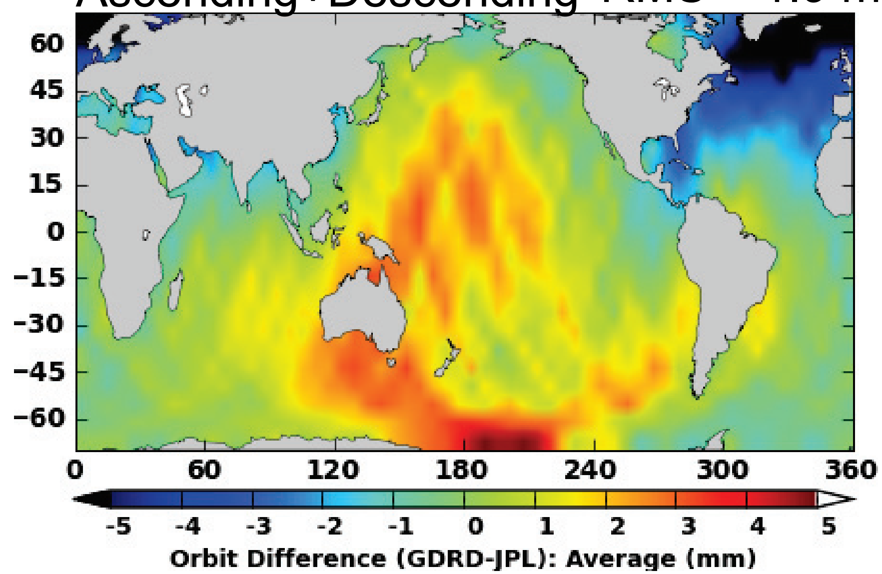


Descending Passes RMS = 1.9 mm



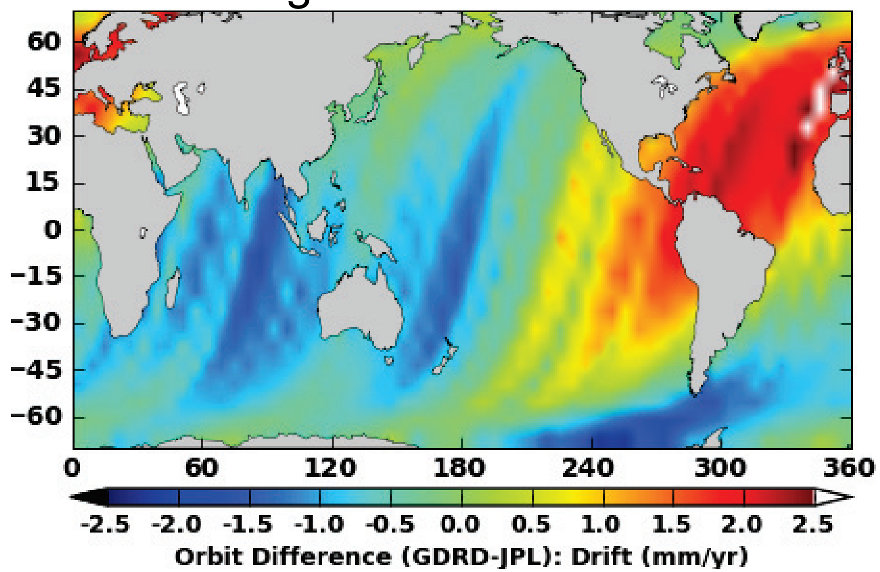
- Use GDRD-JPL GPS orbit differences to determine:
  - Bias
  - Drift
  - Annual
- 103 repeat cycles from 1-145:
  - Excluding 19, 37-76, 80.

Ascending+Descending RMS = 1.9 mm

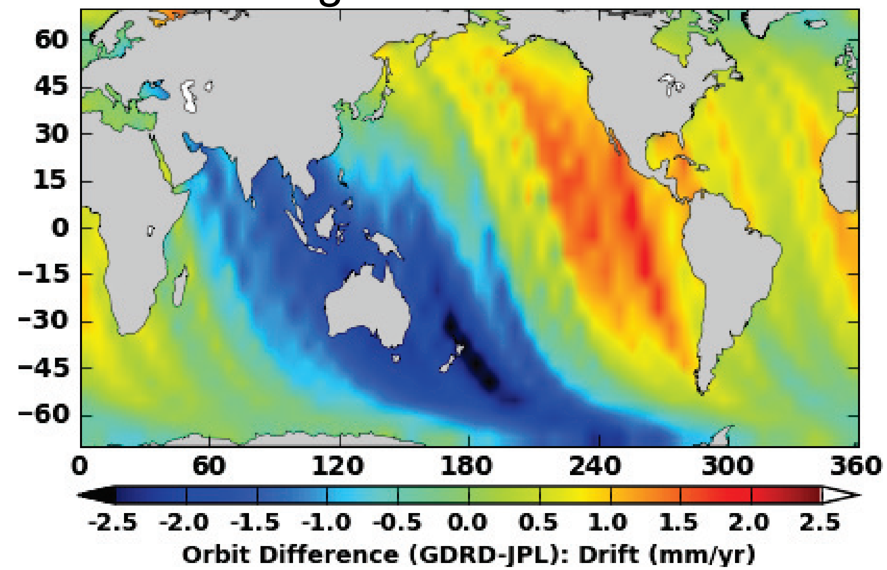


Geographically Correlated Differences: Drift: GDRD-JPL

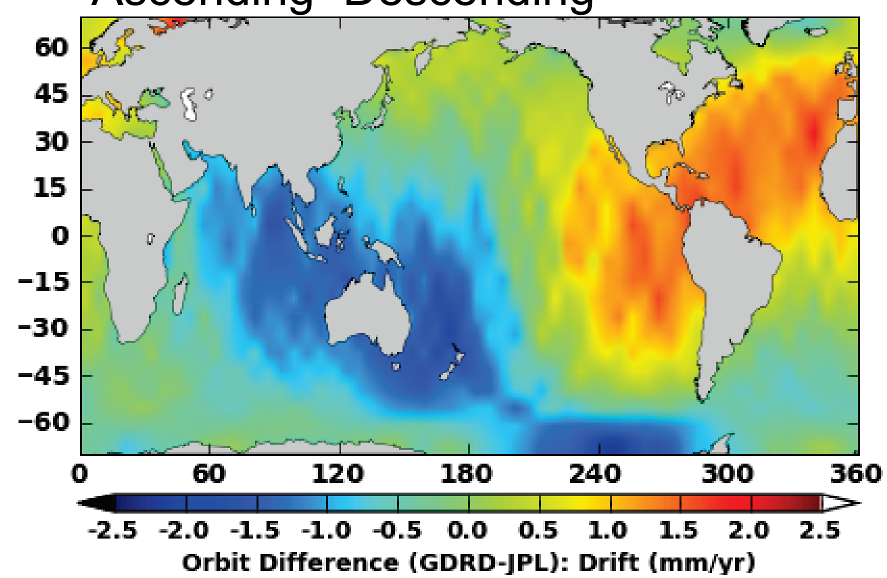
Ascending Passes



Descending Passes



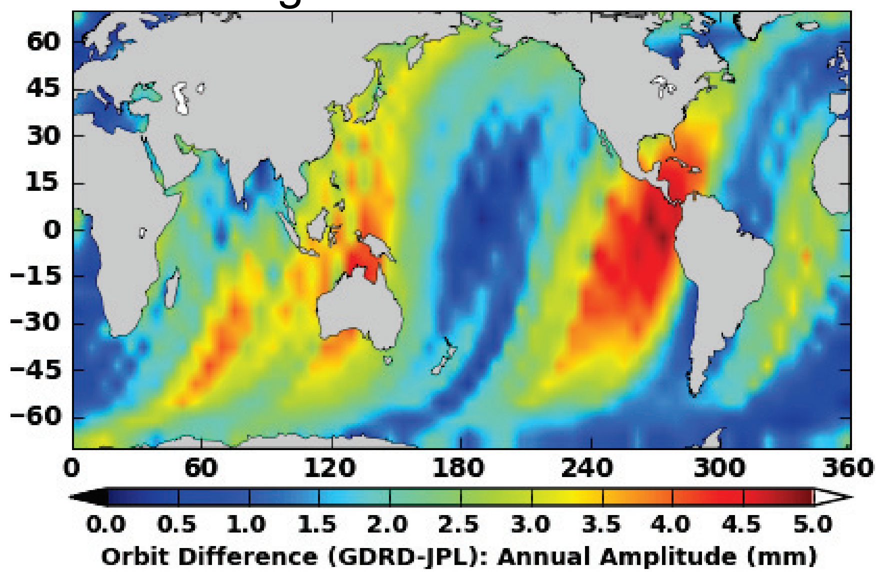
Ascending+Descending



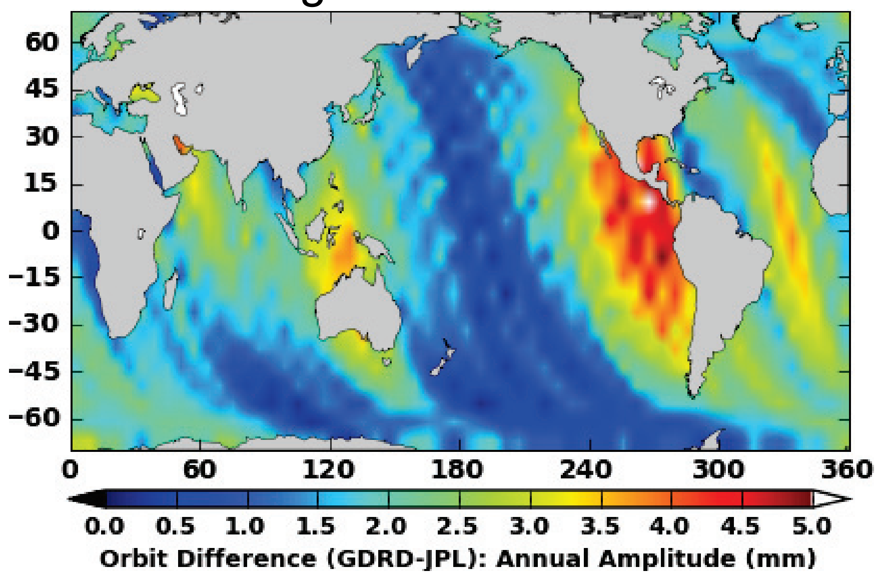
- RMS Ascending = 1.0 mm/yr
- RMS Descending = 1.0 mm/yr
- RMS Asc + Des = 0.9 mm/yr
- Global Average = –0.1 mm/yr

Geographically Correlated Differences: Annual Amplitude: GDRD-JPL

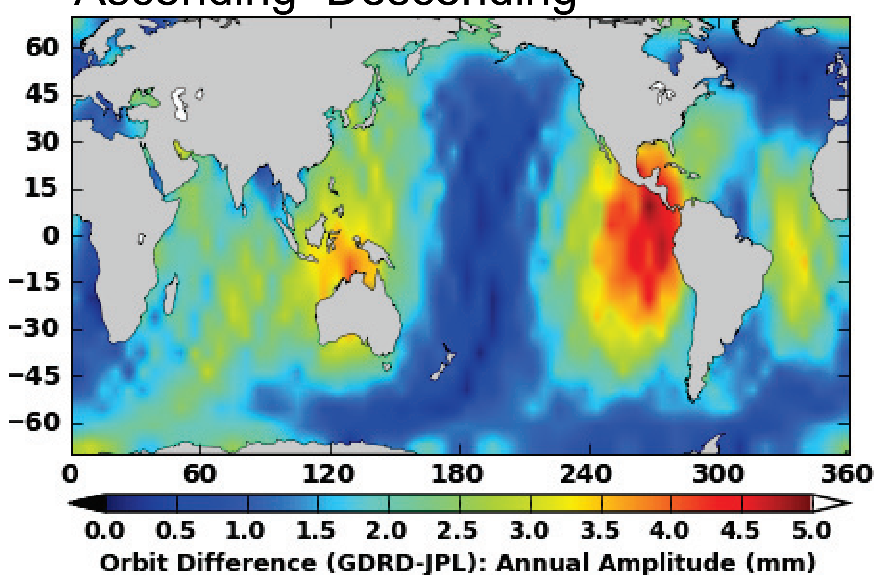
Ascending Passes



Descending Passes

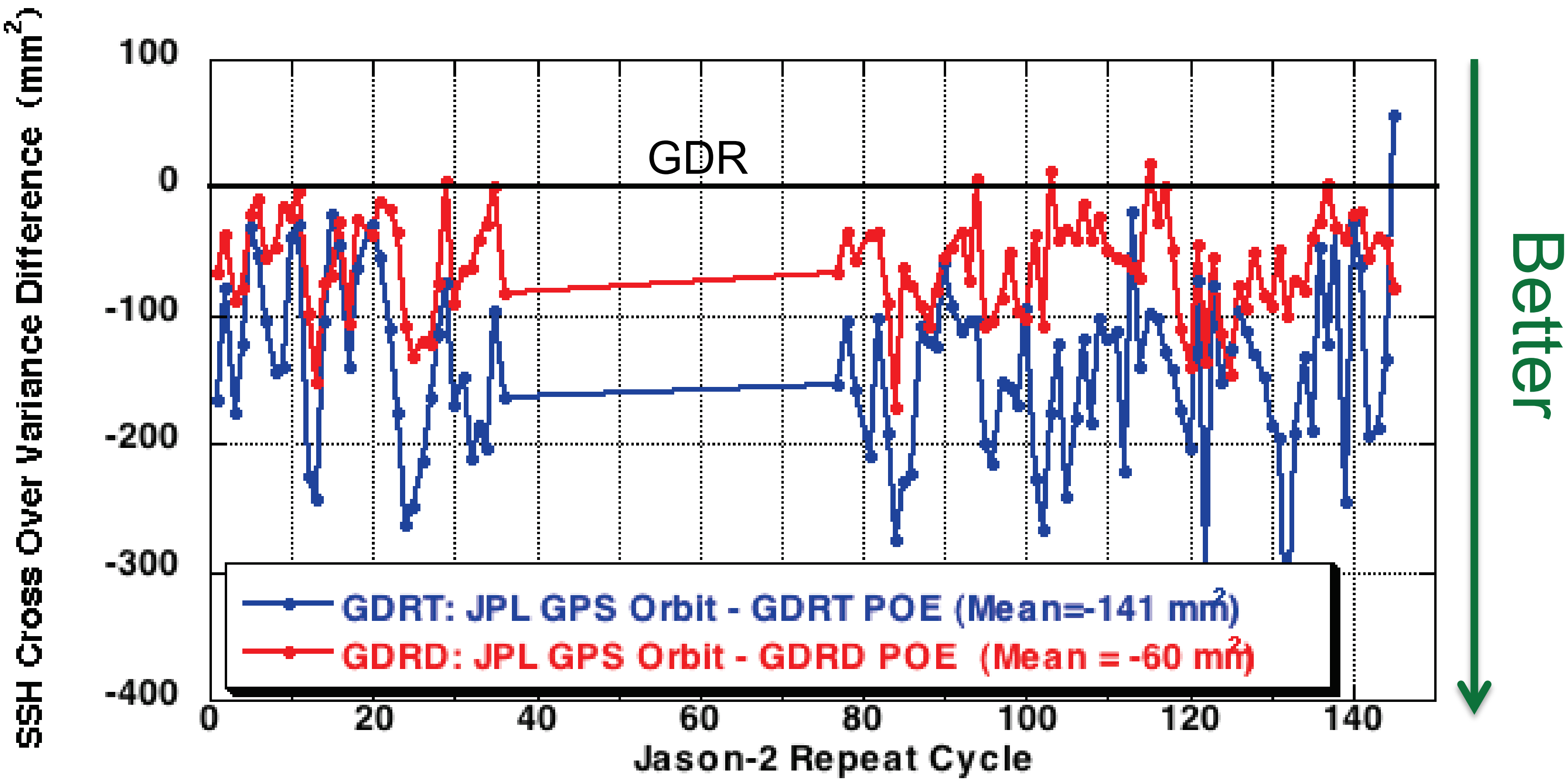


Ascending+Descending



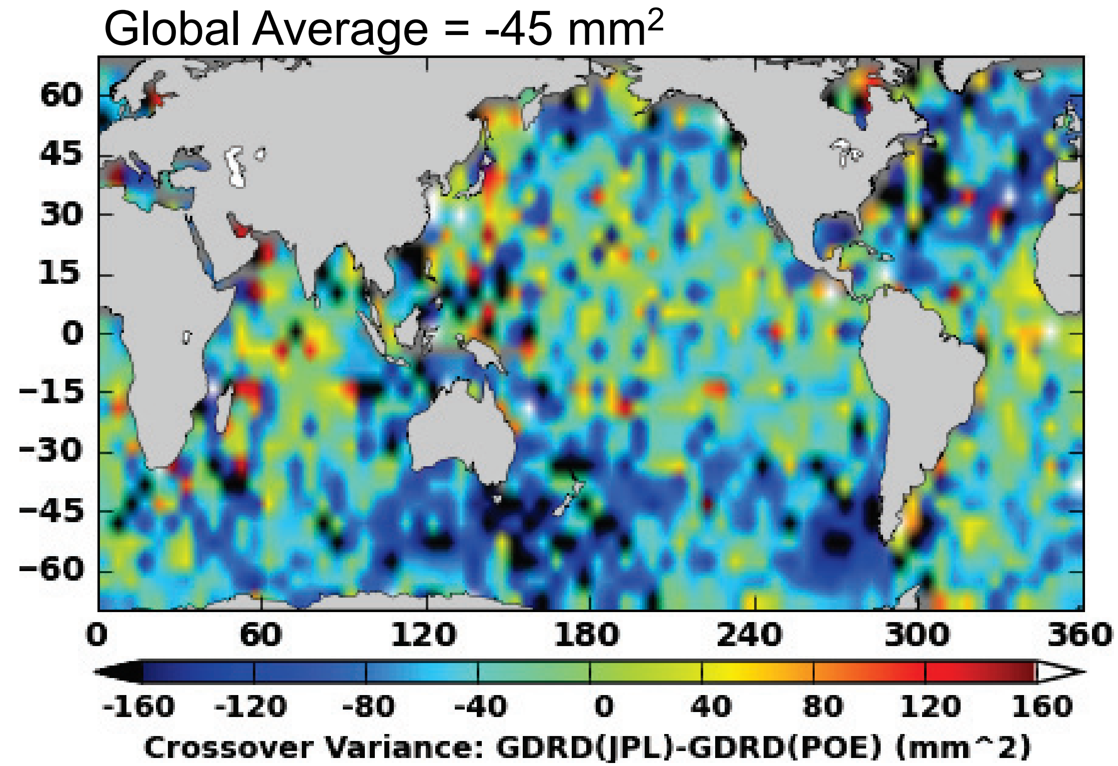
- RMS Ascending = 2.4 mm
- RMS Descending = 2.1 mm
- RMS Asc + Des = 2.0 mm

Jason-2 SSH Crossover Variance: JPL Orbit Relative to GDR POE



- **JPL GPS orbit has lower SSH crossover variance relative to POE on GDRT and GDRD.**
- **GDRD POE has closer agreement to JPL GPS orbit than GDRT POE.**

GDR SSH Crossover Variance: JPL Orbit Relative to GDRD POE



- **SSH crossover variance computed using 103 GDRD cycles.**
  - Cycle 1-145, excluding 19, 37-76, 80.

Summary

- Topex, 1993 GPS is harder than Willy remembered
- Preliminary Topex reprocessing shows significant improvements, but bias fixing may be very difficult
- Jason-2 GPS continues excellent performance
- JPL GPS Jason-2 agrees with GDR-D and GSFC DORIS/SLR at the 6 mm level
- Geographically correlated errors remain in GDR-D vs. GPS orbit differences.

Backups