The Harvest Experiment: Calibration of the 16-yr Climate Date Record from TOPEX/Poseidon, Jason-1 and OSTM

Bruce Haines and Shailen Desai
Jet Propulsion Laboratory, California Inst. of Tech., Pasadena CA

George Born
University of Colorado, Boulder

Steve Gill
NOAA National Ocean Service, Silver Spring MD

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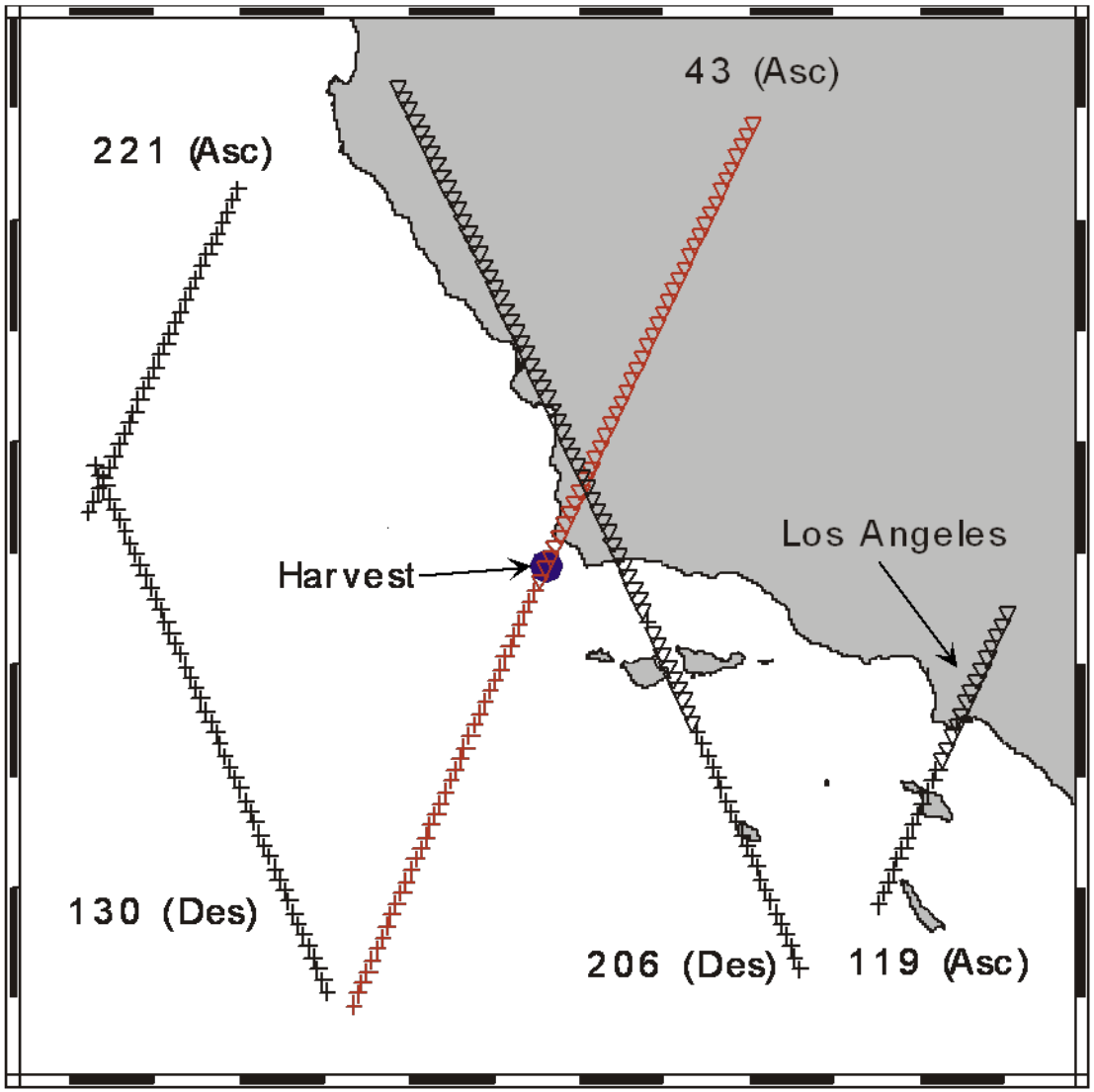
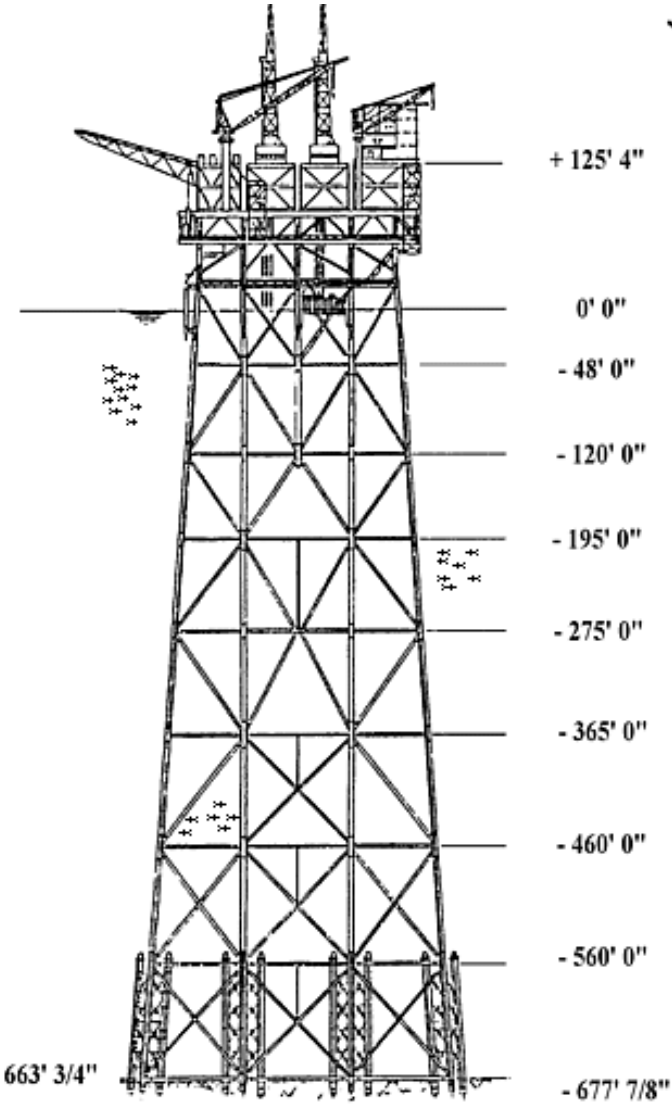
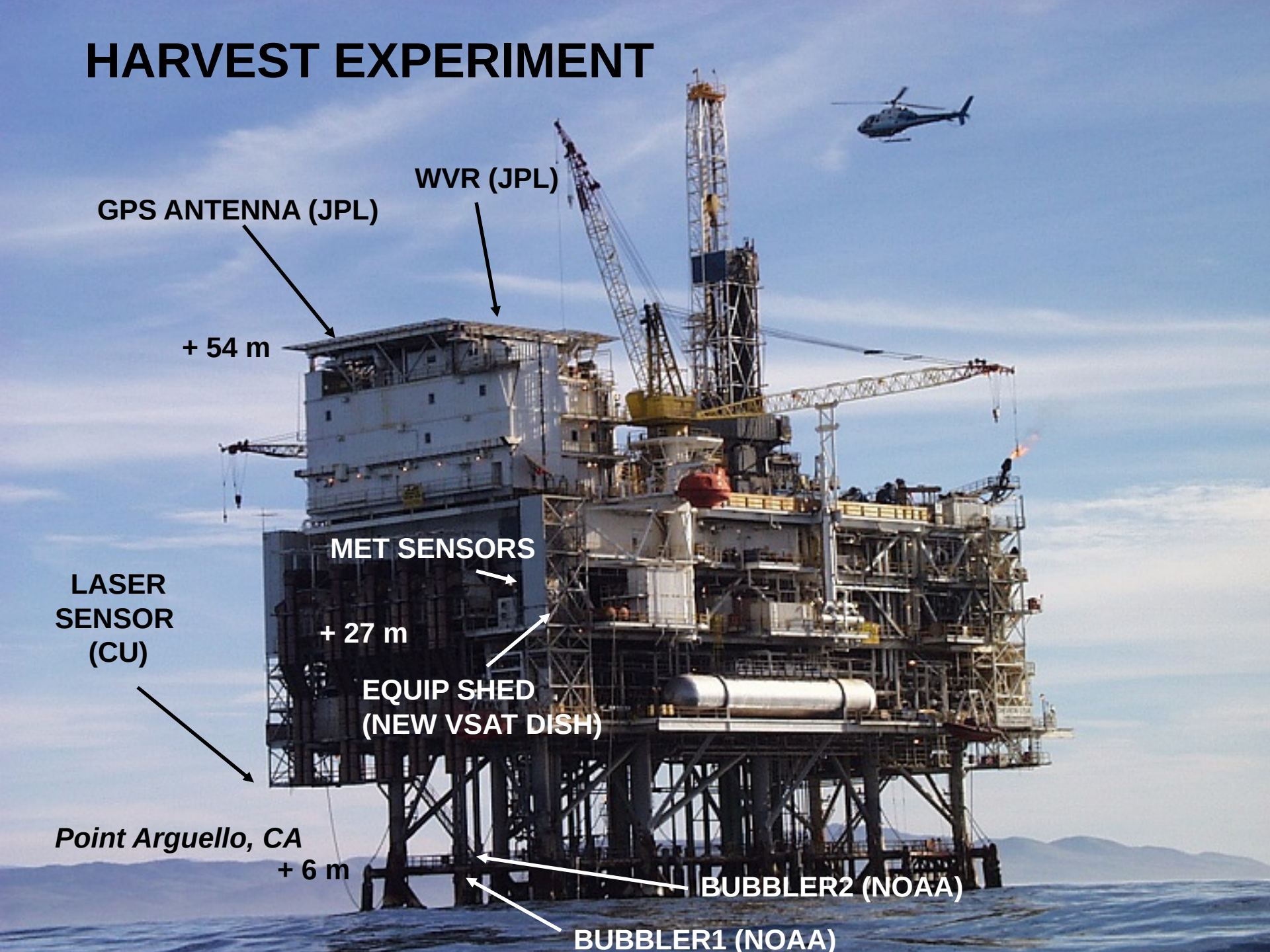
Ocean Surface Topography Science Team Meeting
Nice, France

Map of Harvest Vicinity

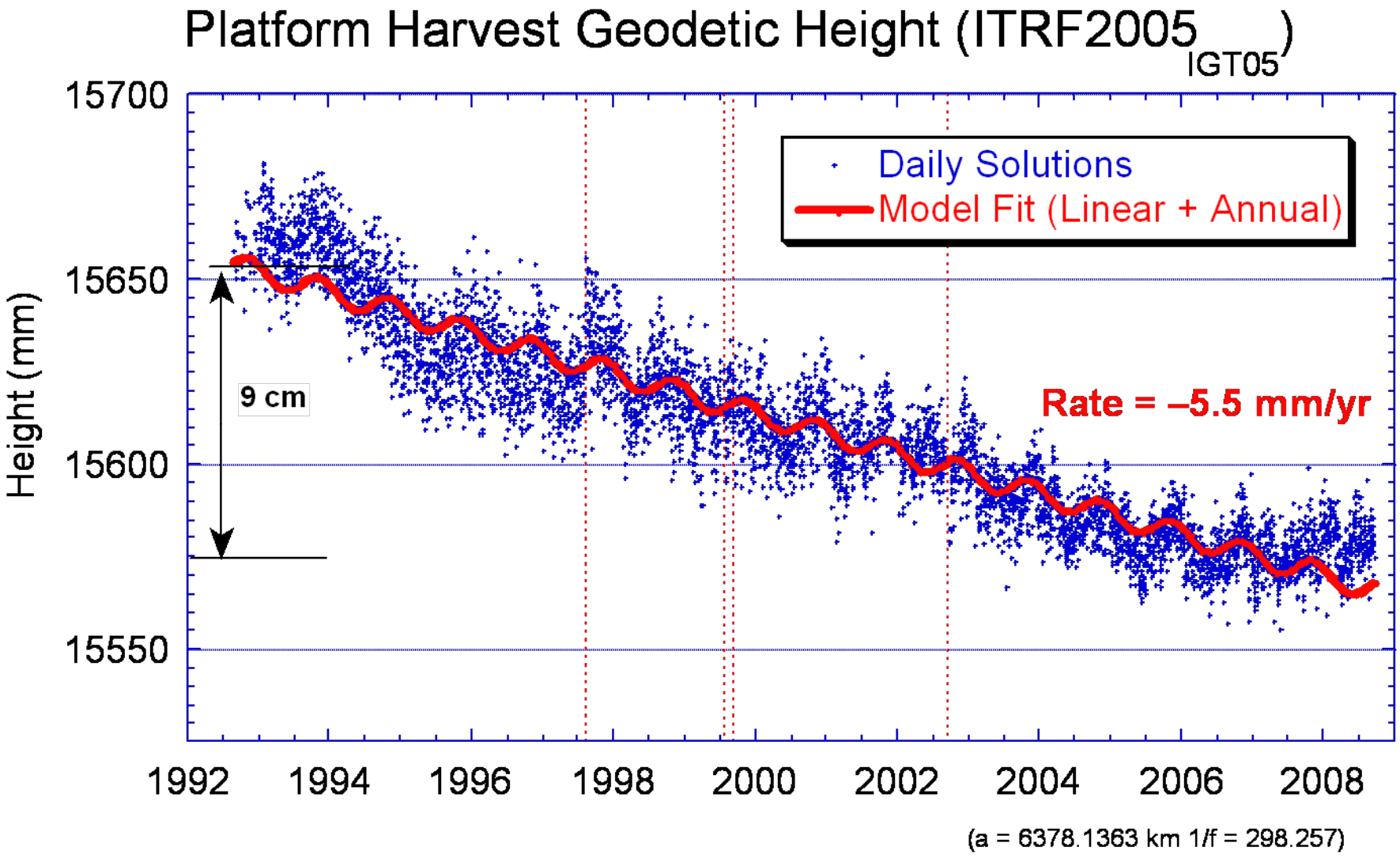




HARVEST EXPERIMENT



16 Years of Continuous GPS Monitoring



Conditions for Tandem Overflights

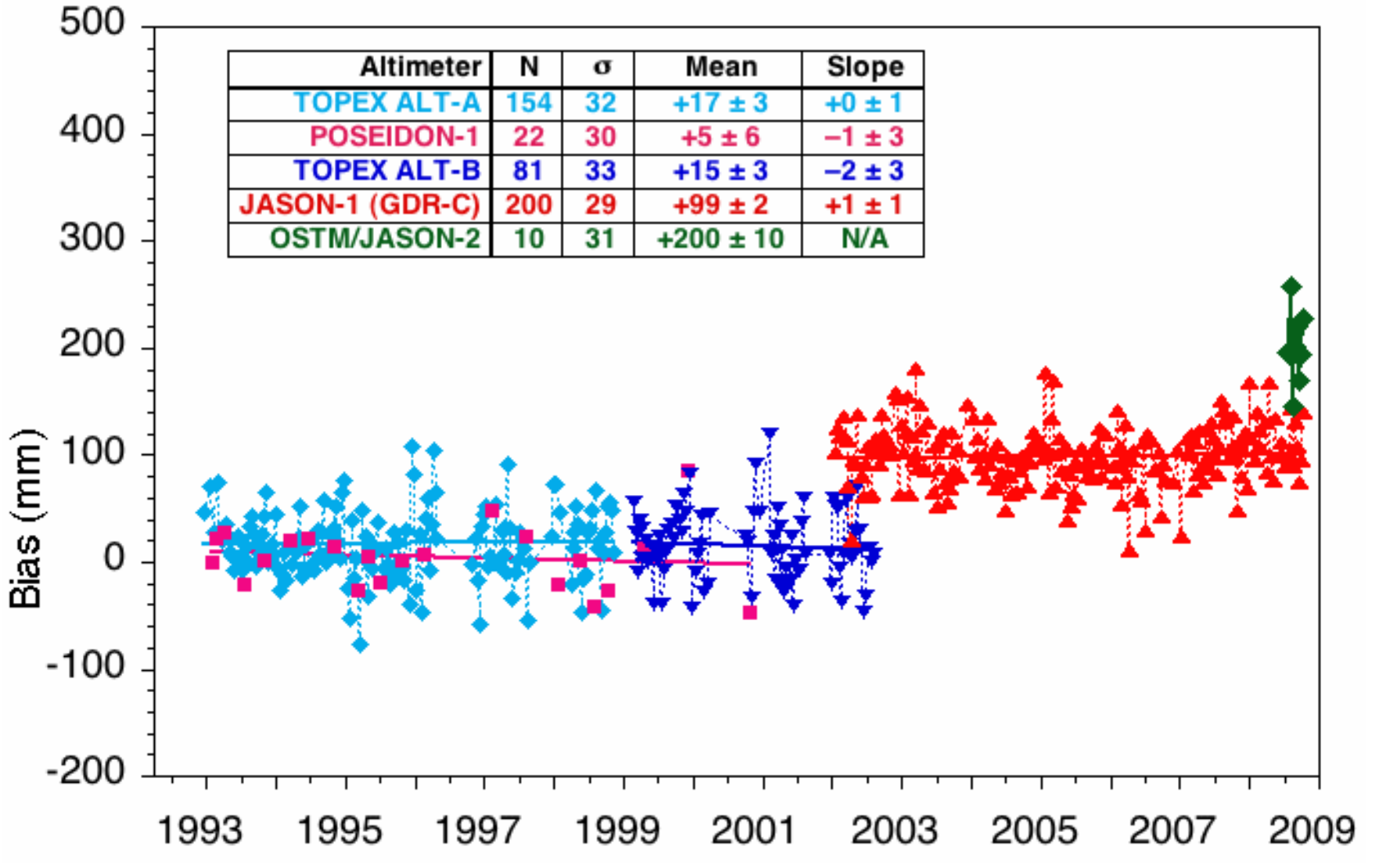
Jason-2 Cycle	Jason-1 Cycle	UTC Date	Local Time	SWH (m)	Wind (m/s)	POS-3 Mode	Comments
1	240	13-Jul-2008	10:21	1.1	2.4	SGT	Poor ALT quality
2	241	23-Jul-2008	08:20	2.1	1.2	Median	
3	242	02-Aug-2008	06:18	2.2	8.2	DIODE/DEM	
4	243	12-Aug-2008	04:17	1.9	8.0	Median	Jason-1 safehold
5	244	22-Aug-2008	02:15	2.7	6.7	DIODE/DEM	
6	245	01-Sep-2008	00:13	3.5	9.2	Median	
7	246	10-Sep-2008	22:13	2.0	6.0	DIODE/DEM	
8	247	20-Sep-2008	20:11	2.0	9.0	Median	
9	248	30-Sep-2008	18:09	1.0	6.0	Median	
10	249	10-Oct-2008	16:08	5.5	15.0	Median	
11	250	20-Oct-2008	14:06	2.4	10.9	Median	
12	251	30-Oct-2008	12:04	1.2	9.8	Median	

Harvest Closure Analysis: Assumptions for Altimeter Leg

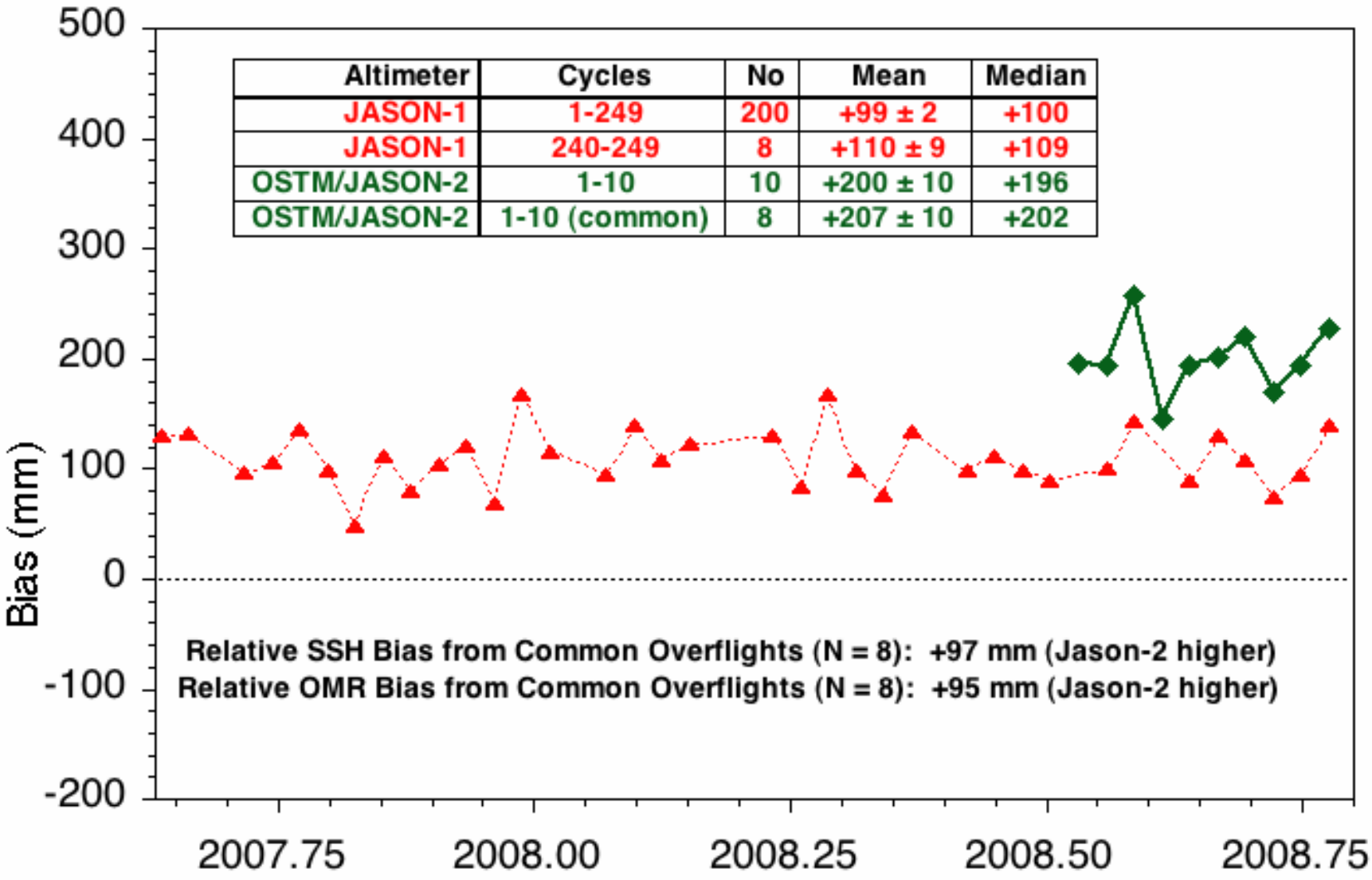
Model	TOPEX/Poseidon	Jason-1†	OSTM/ Jason-2
Orbital Height	GSFC TVG ITRF2005p	I/GDR-C	IGDR
Altimeter Range	Ku (MGDR)	Ku (GDR-B/C)	Ku (IGDR)
Wet troposphere	Brown et al. repro (for RGDR)	GDR-C	IGDR
Dry troposphere	MGDR	GDR-B/C	IGDR
Ionosphere	MGDR: Ku (ALT), DORIS (POS-1)	GDR-B/C	IGDR
Sea-state bias	MGDR	GDR-C table (but corrected SWH)	IGDR

† Jason-1: GDR used through cycle 240 (IGDR afterwards)

Current Harvest Time Series: First SSH Calibration Results from OSTM

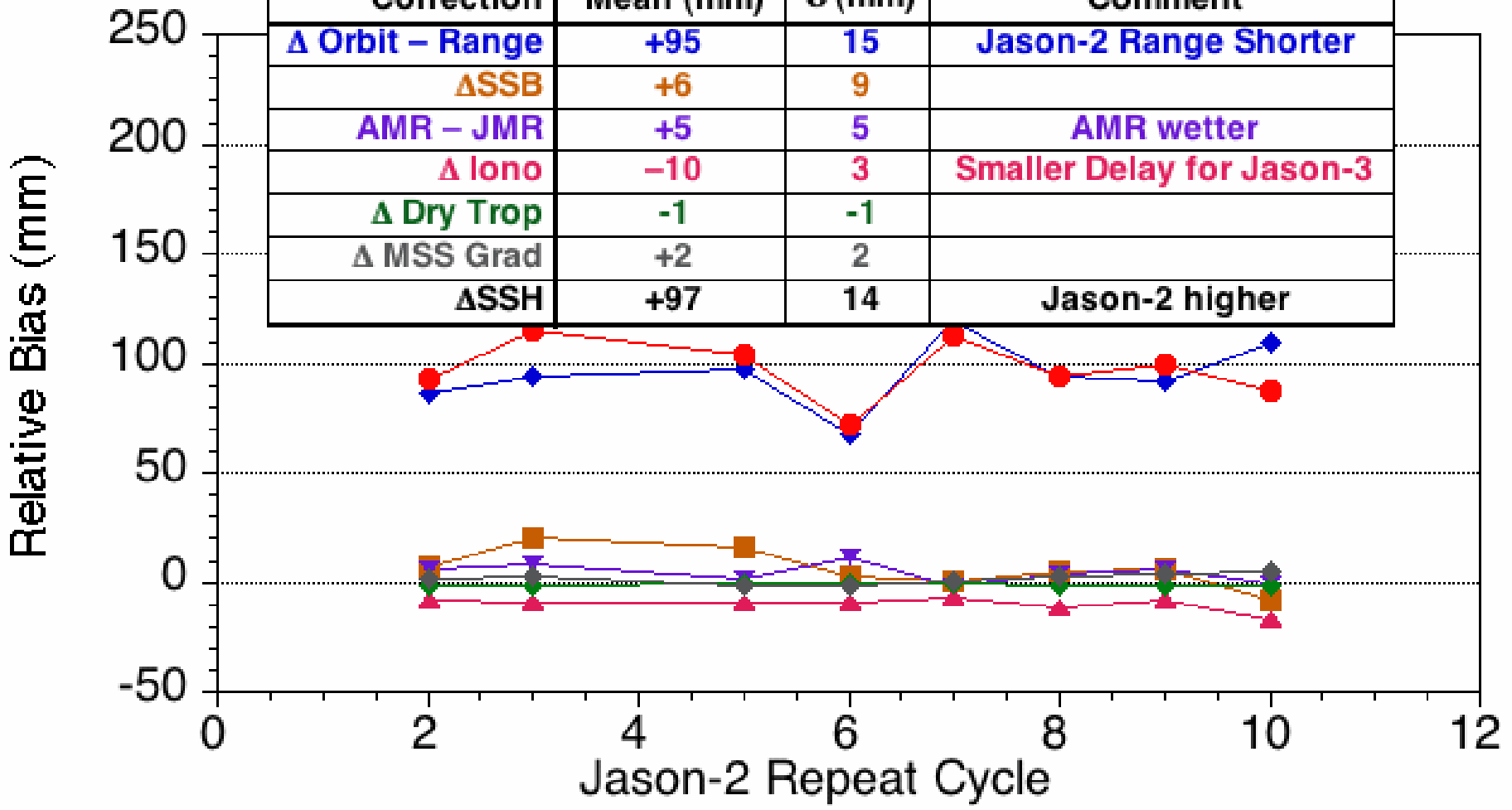


Sea-Surface Height Bias Time Series With First OSTM/Jason-2 Results



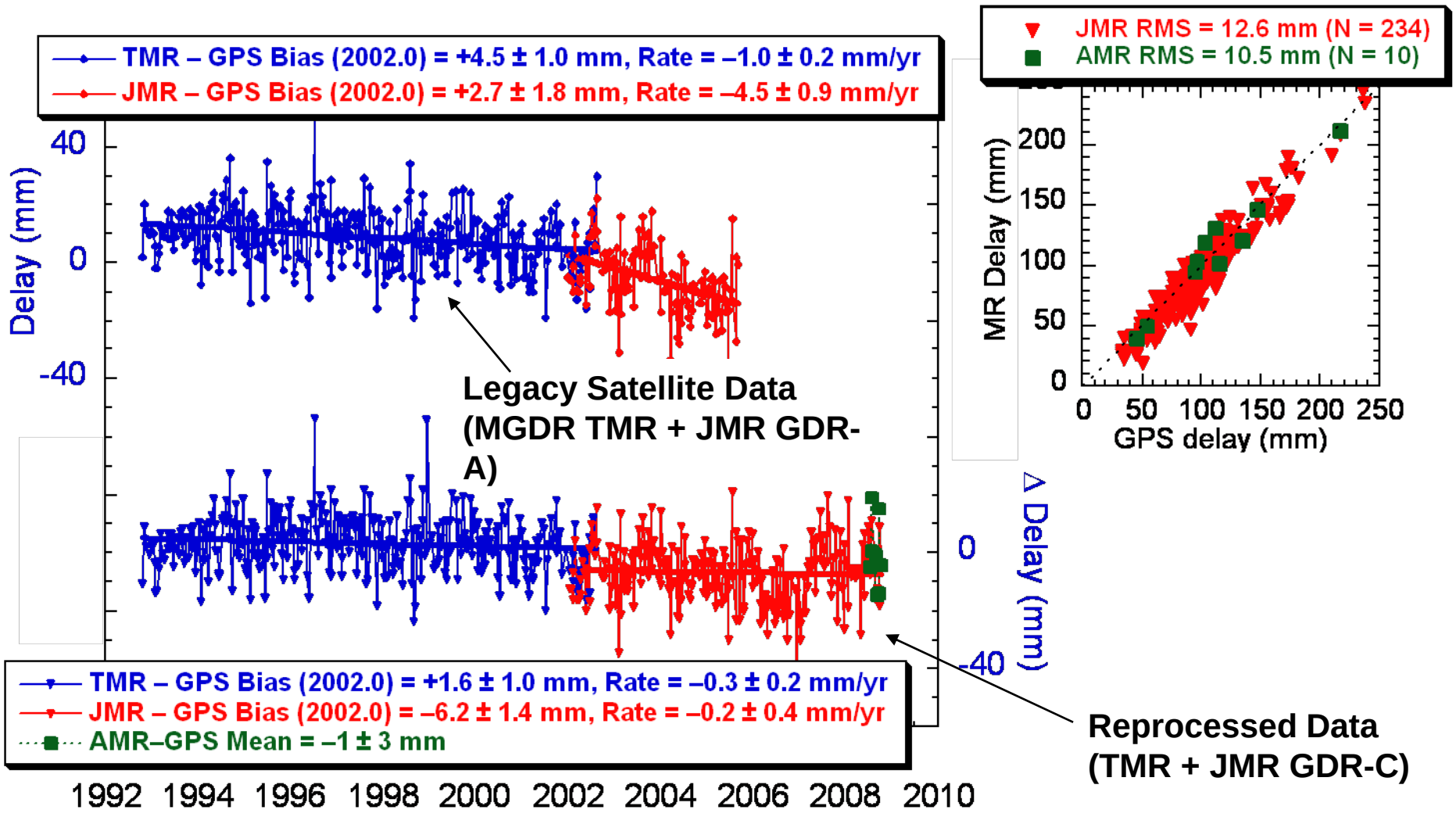
Jason 1/2 Tandem Overflights of Harvest: Comparison of Correction Terms

Correction	Mean (mm)	σ (mm)	Comment
Δ Orbit – Range	+95	15	Jason-2 Range Shorter
ΔSSB	+6	9	
AMR – JMR	+5	5	AMR wetter
Δ Iono	–10	3	Smaller Delay for Jason-3
Δ Dry Trop	-1	-1	
Δ MSS Grad	+2	2	
ΔSSH	+97	14	Jason-2 higher

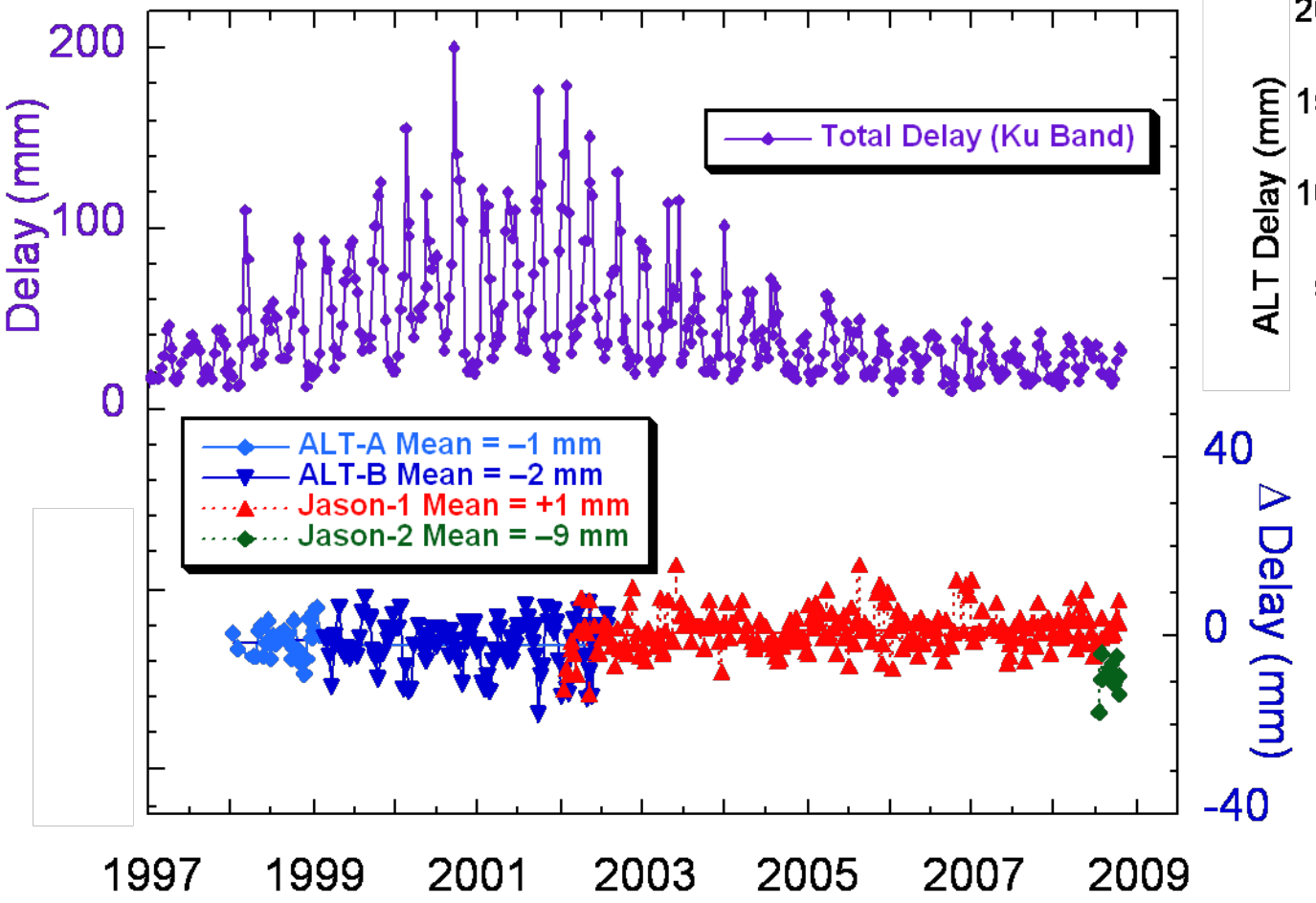


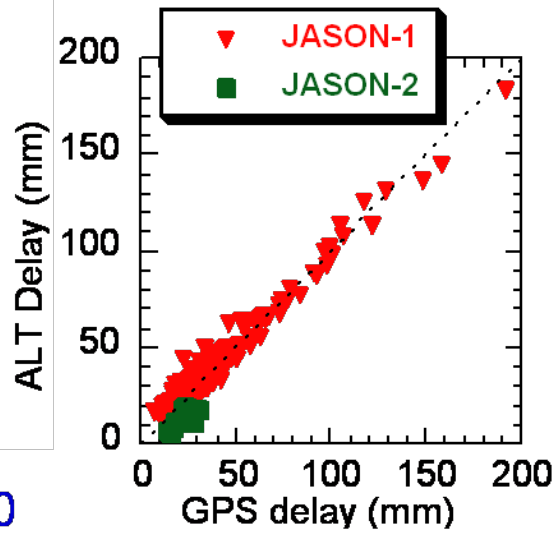
Jason-2 Orbit: Radial Difference (GPS — IGDR/MOE): RMS = 11 mm, Mean = –2 mm (N = 10)

Platform Harvest GPS: Radiometer Calibration (TMR, JMR, AMR)



Ku-Band Ionosphere Calibration from GIM

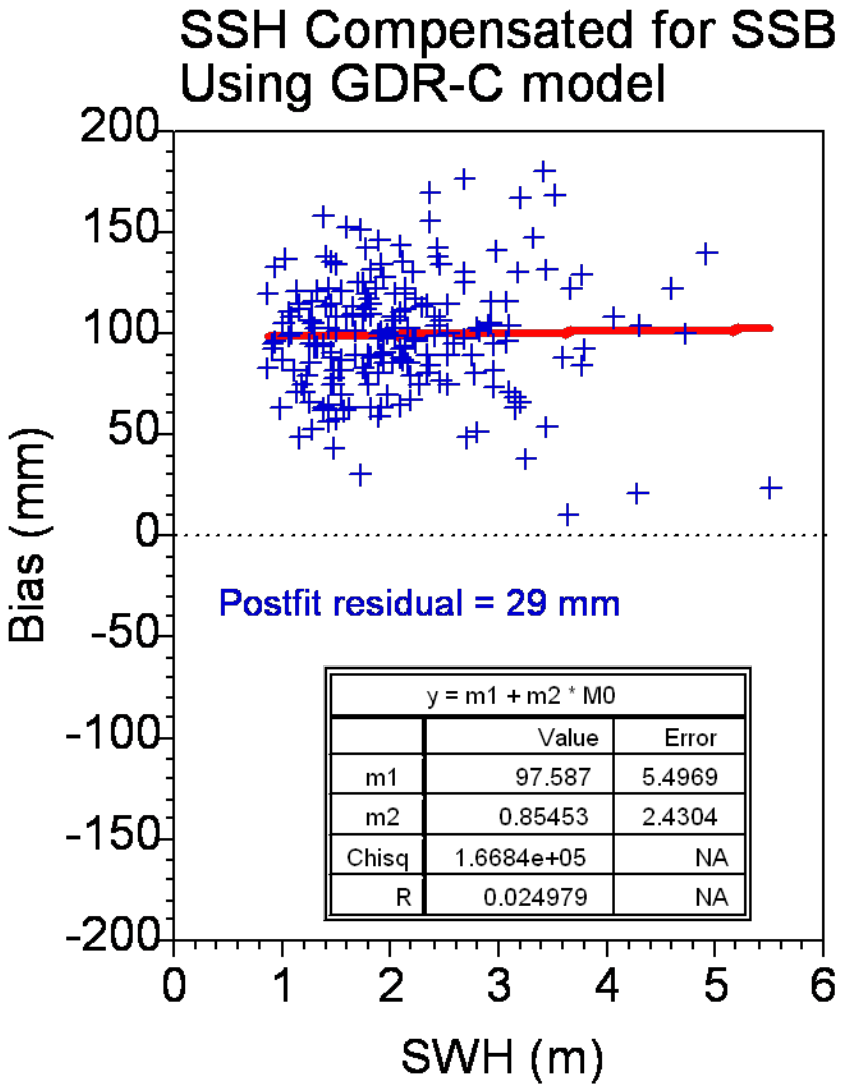


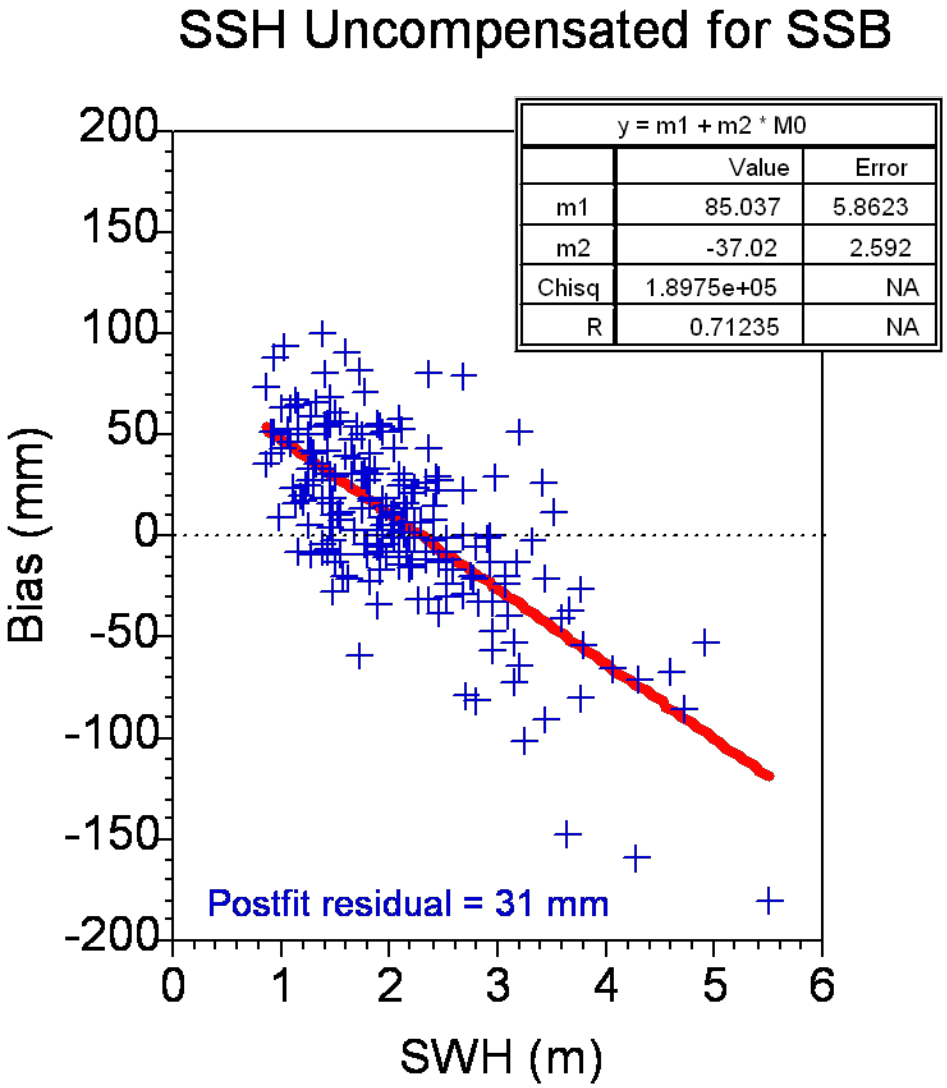


Summary of Harvest Findings

- **Both Jason-1 and Jason-2 are reading SSH too high, by +10 and +20 cm respectively**
  - OSTM/Jason-2: +200 ± 10 mm (N = 10, σ = 31 mm)
  - Jason-1: +99 ± 2 mm (N = 200, σ = 29 mm)
- **TOPEX/Poseidon systems unbiased (< 2 cm)**
  - T/P ALT-B: +15 ± 3 mm (N= 81, σ = 33 mm)
  - T/P ALT-A: +17 ± 3 mm (N = 154, σ = 32 mm)
  - T/P POS: +5 ± 6 mm (N = 22, σ = 30 mm)
- **Relative SSH Bias (from Common Overflights) consistent with absolute estimates.**
  - Jason-2 — Jason-1 +97 ± 5 mm (N = 8, σ = 13 mm)
  - Jason-1 — T/P ALT-B +78 ± 8 mm (N = 16, σ = 32 mm)
- **SSH drift estimates for all 5 altimeter systems statistically indistinguishable from zero.**
  - Large drift (~1 cm/yr) seen in early (A) versions of Jason-1 GDR data absent in GDR-C
- **Primary source of Jason-1 and Jason-2 biases is altimeter**
  - Mean effect of orbit, ionosphere, wet/dry troposphere at 1-cm level or smaller
  - Consistent with “Orbit-Range” figures from common overflights
  - Evolution of SSB correction (e.g., from GDR-B to GDR-C) has large (~ 4 cm) impact on SSH bias
- **AMR slightly wetter (~5 mm) than JMR, but with questionable statistical significance**
- **Poseidon-3 Ku-ionosphere delay smaller (~10 mm) than Poseidon-2**
  - Poseidon-2 agrees better with GPS (GIM)
- **Role of geographically correlated errors under investigation**
  - 1-cm discrepancy between Δ “Orbit–Range” for Harvest (+95 mm) and global (+84 mm) analyses.

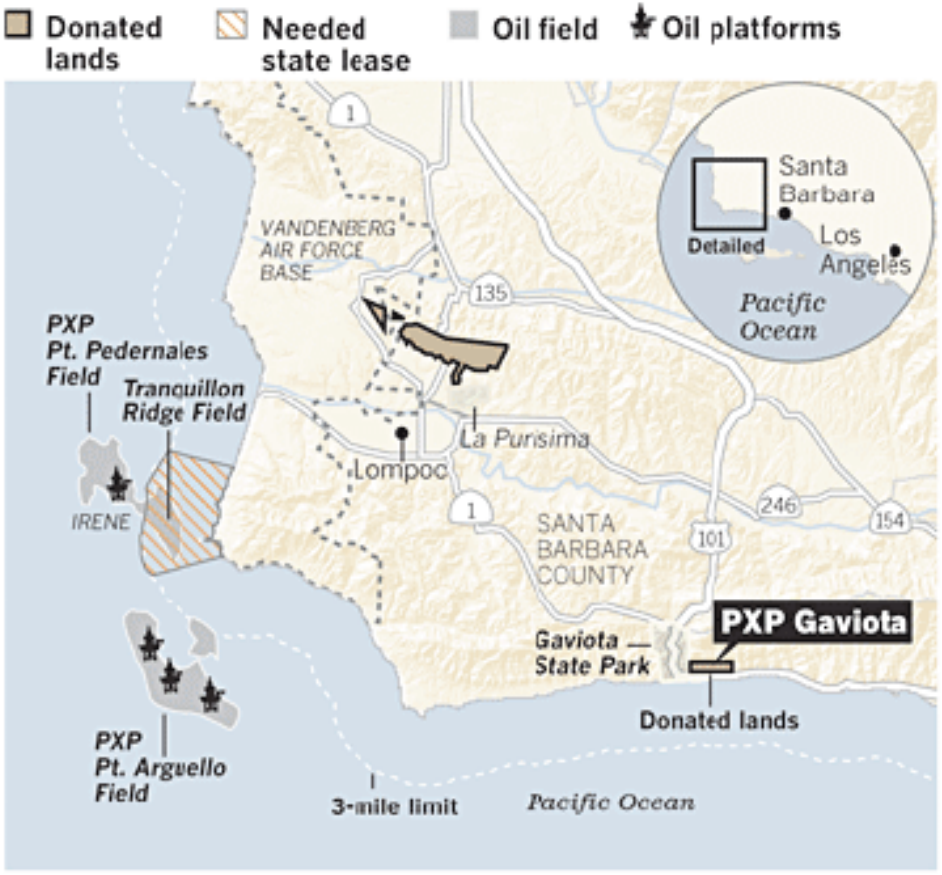
Jason-1 SSH Bias ~ Mean SSB Correction

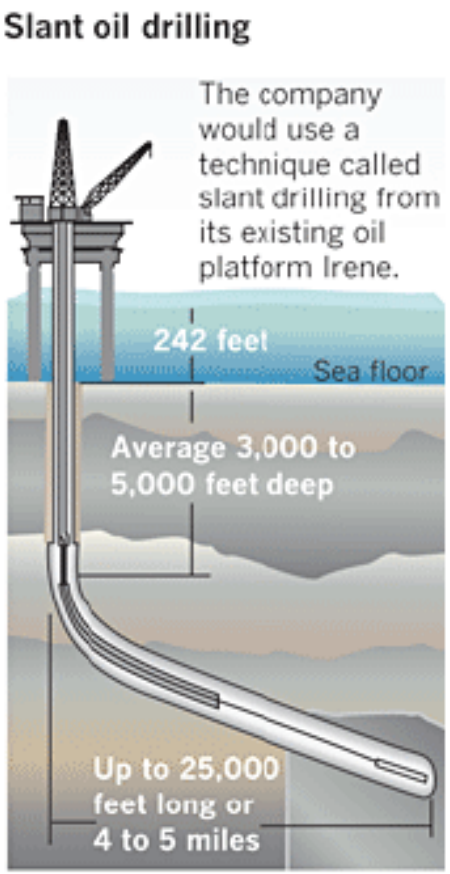




Offshore oil deal

An oil company known as PXP has agreed to shut down four platforms off the Santa Barbara coast by 2022 and to donate about 3,900 acres of land for public parks in exchange for permission to tap an undeveloped oil field beneath state waters.





Sources: PXP, Santa Barbara County Energy Division, Environmental Defense Center, Trust for Public Land, ESRI, TeleAtlas, USGS, BLM, Department of the Interior

LESLIE CARLSON *Los Angeles Times*

Acknowledgements

- **Eric Lindstrom (NASA Physical Oceanography Program)**
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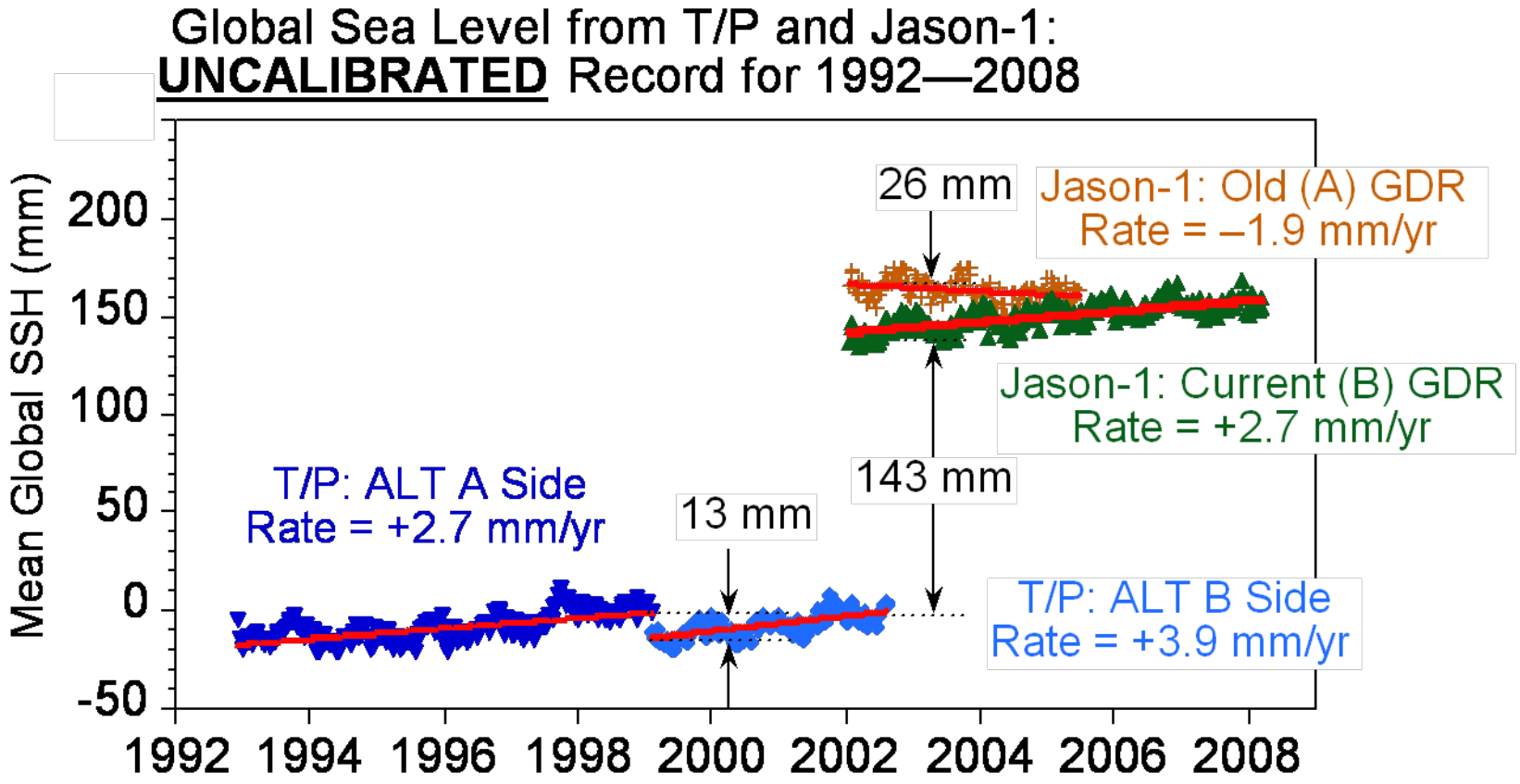
- **Chuck Fowler, Jacob Gilman, Chris Ellerhorst, Dave Miller (CCAR/CU)**
- **Dan Kubitschek (Lockheed Martin, ex. CU/JPL)**
- **UNAVCO (see poster by Andreatta et al.)**
- **Plains Exploration and Production (PXP)**
- **Divecon**

- **Dedications:**

- Yves Menard
- Edward J. “Chris” Christensen

Backup Material

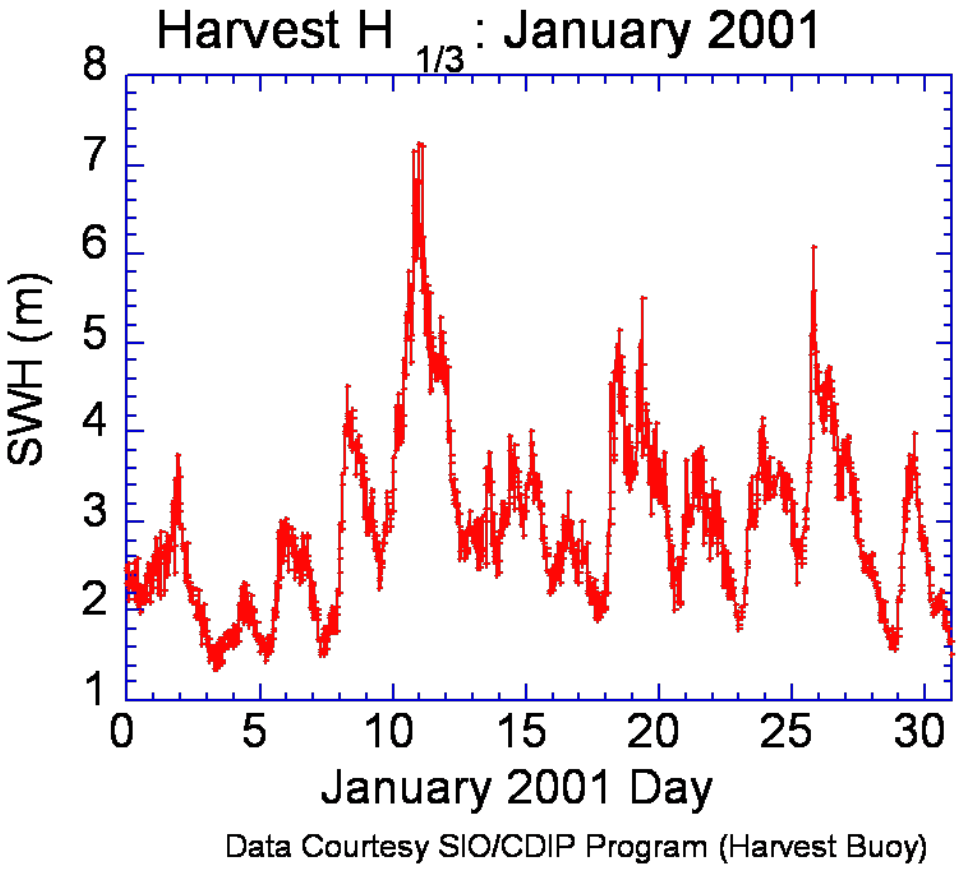
Motivation



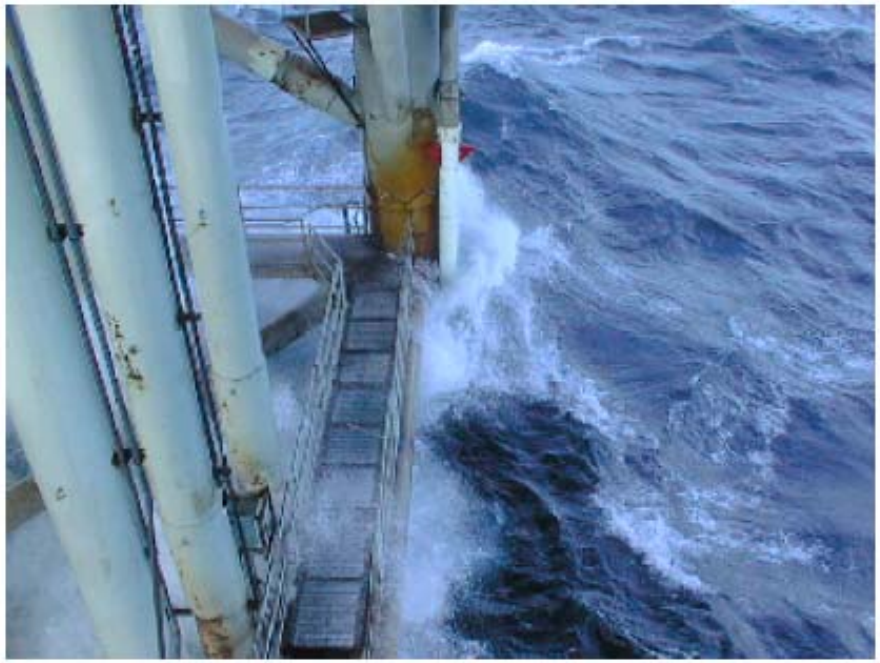
- **How do we best calibrate sea-level record at the 1 mm/level?**
  - Geographically correlated errors in both the bias and rate
- **What are the sources of the errors?**

Harvest Conditions Typical of Open Ocean

Provides for Direct Monitoring of Altimeter Measurement Systems Under Normal Operating Conditions

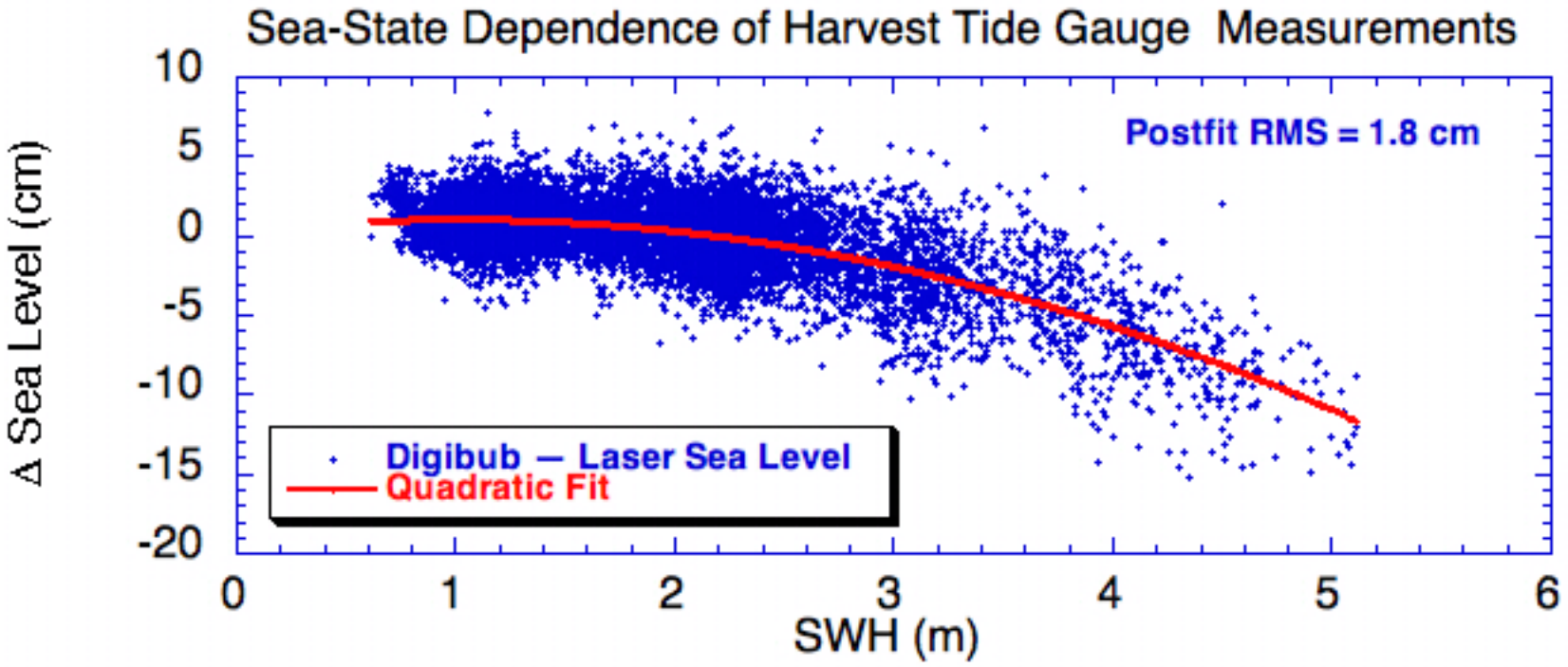


Data Courtesy SIO/CDIP Program (Harvest Buoy)

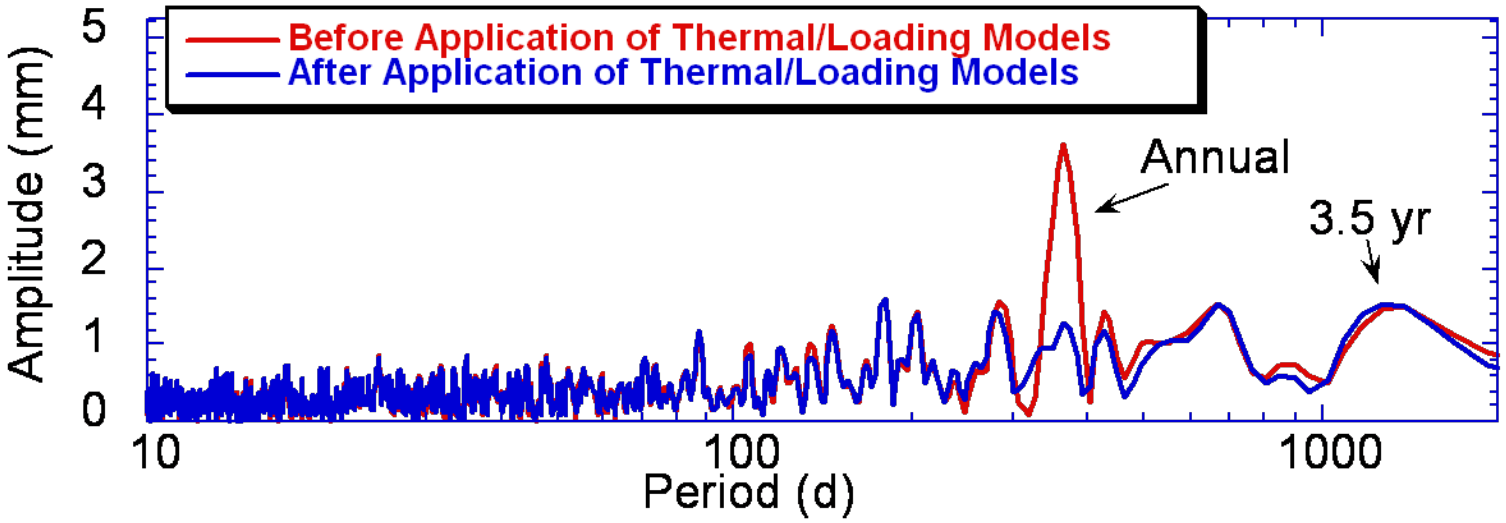


High Sea States Impact Tide-Gauge Data

- **Two systems for measuring water level**
  - NOAA Digibub (N_2 Bubbler, submerged)
  - CU optical laser system (down-looking from 12-m sump deck)
- **Differenced data show strong sea-state dependence**
  - Up to 15 cm for SWH > 5 m.
  - Largest sensitivity seen in Bubbler data (e.g., Parke and Gill, 1995)



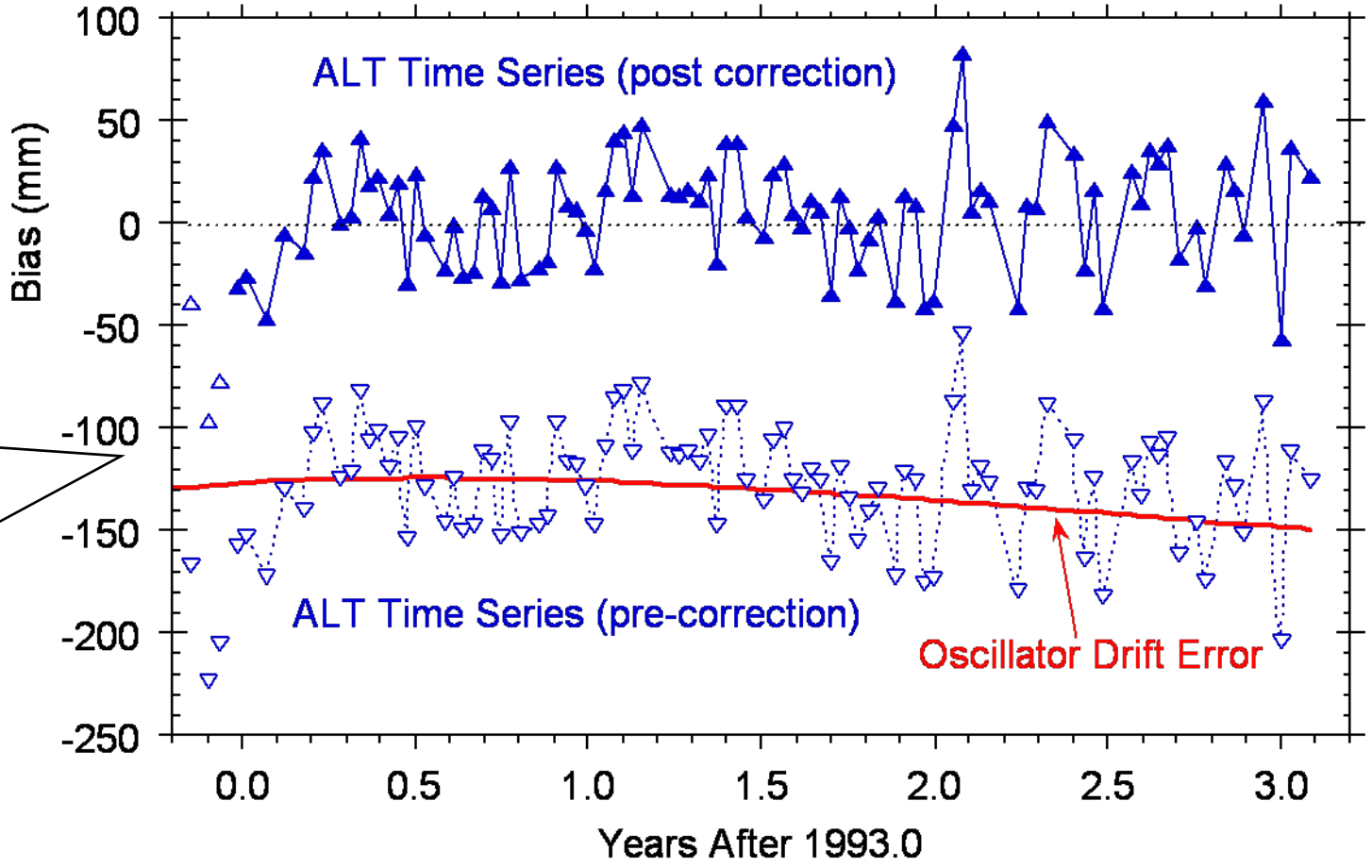
Periodicities in the Platform Height



Annual Signal	*Amp. (mm)*	*Peak*	*Source*
Thermal (below water)	1.8	Nov.	200 m steel (λ = 1.2 x 10^{-5}/°C), Temperature climatology from hydrographic station 80.55 (http://www.calcofi.org)
Thermal (above water)	1.3	Sep.	52 m steel (λ = 1.2 x 10^{-5}/°C) Temperature variations from platform thermometer.
Soil moisture load	1.2	Sep.	NCEP/DOE AMIP II reanalysis (Dong et al., 2002)
Non-tidal ocean load	0.8	Mar.	T/P altimeter – WOA-94 steric (Dong et al., 2002)
Snow/ice load	0.3	Apr.	NCEP/DOE AMIP II reanalysis (Dong et al., 2002)
Atmosphere load	0.2	Feb.	NCEP reanalysis (Dong et al., 2002)

Harvest: A Legacy of Important Contributions to Satellite Altimetry

TOPEX (ALT–A) Oscillator Drift Error (discovered 1996 by Zanife et al.)

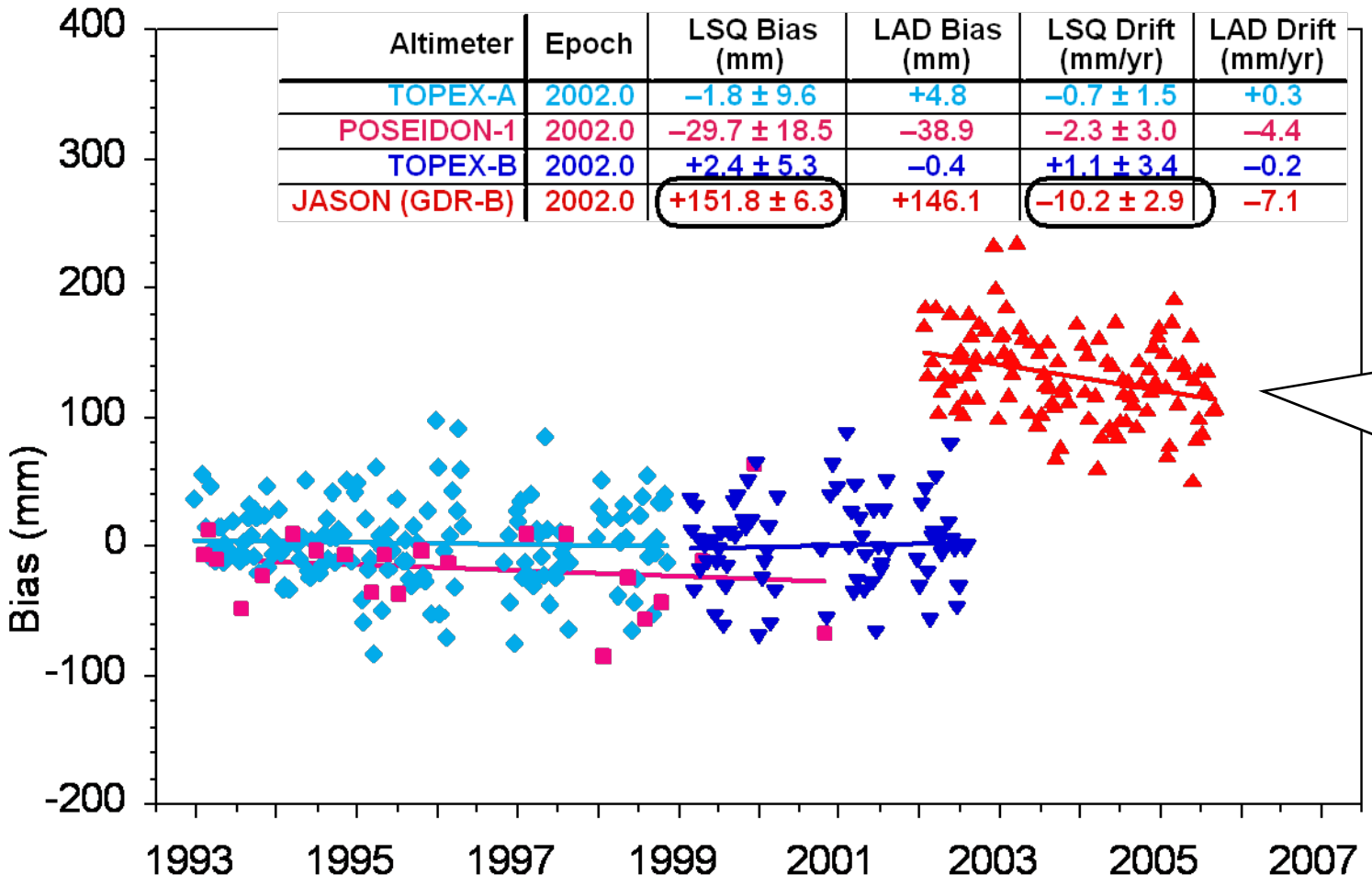


Effects of Undetected s/w Error Seen in TOPEX SSH Bias Estimates Shortly After 1992 Launch

Harvest: A Legacy of Important Contributions to Satellite Altimetry

Long-term Calibration Record Puts Jason-1 SSH Bias/Drift in Context:

Altimeter	Epoch	LSQ Bias (mm)	LAD Bias (mm)	LSQ Drift (mm/yr)	LAD Drift (mm/yr)
TOPEX-A	2002.0	–1.8 ± 9.6	+4.8	–0.7 ± 1.5	+0.3
POSEIDON-1	2002.0	–29.7 ± 18.5	–38.9	–2.3 ± 3.0	–4.4
TOPEX-B	2002.0	+2.4 ± 5.3	–0.4	+1.1 ± 3.4	–0.2
JASON (GDR-B)	2002.0	+151.8 ± 6.3	+146.1	–10.2 ± 2.9	–7.1



Large SSH bias and drift With Early (A) Version of Jason-1 GDR

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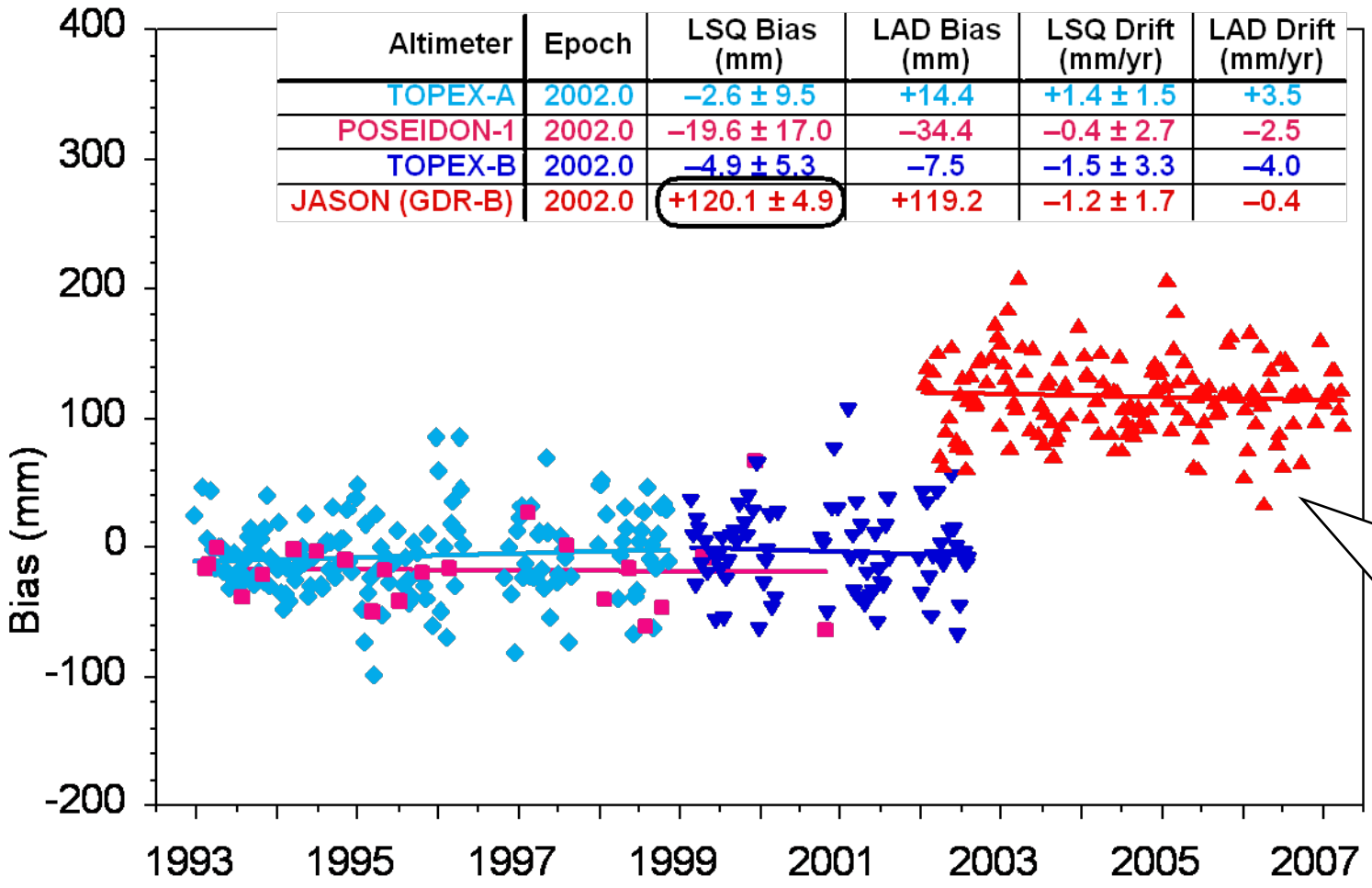
Altimeter	Epoch	LSQ Bias (mm)	LAD Bias (mm)	LSQ Drift (mm/yr)	LAD Drift (mm/yr)
TOPEX-A	2002.0	–2.6 ± 9.5	+14.4	+1.4 ± 1.5	+3.5
POSEIDON-1	2002.0	–19.6 ± 17.0	–34.4	–0.4 ± 2.7	–2.5
TOPEX-B	2002.0	–4.9 ± 5.3	–7.5	–1.5 ± 3.3	–4.0
JASON (GDR-B)	2002.0	+120.1 ± 4.9	+119.2	–1.2 ± 1.7	–0.4



Drift Absent In Updated (B) Version of Jason-1 GDR (Bias Persists)

Harvest Contributions

Existing 16+ year record, direct overflight geometry and collocation of tide gauges, GPS, WVR, buoys and ancillary sensors make Harvest a unique international resource for measuring sea level from space.

- **Precise and long-term tie with global terrestrial reference frame.**
- **Coincident observations of satellites in formation flight (T/P + Jason-1, and Jason-1 + OSTM).**
- **Excellent characterization of systematic errors from long-term observation and redundant measurements.**
- **Segregation of various potential contributors to drift (e.g., Altimeter, Radiometer)**
- **Open-ocean environment tests measurement system in typical operating conditions.**
- **Important contributor to the growing network of active, dedicated calibration sites serving Jason/OSTM and oriented along the original TOPEX ground track:**
  - Corsica, Bass Strait, Gavdos, Ibiza….