Twenty Years of Altimeter Calibration from an Offshore Platform: An Update from the Harvest Experiment

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Harvest Platform

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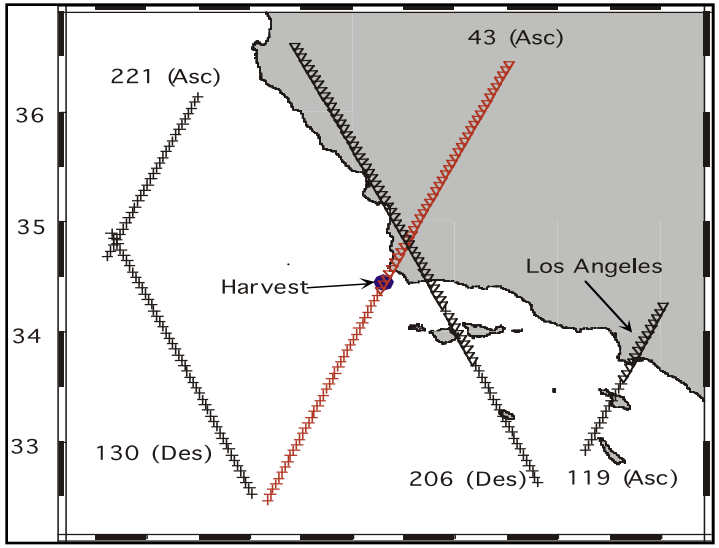
- **NASA Prime Verification Site for High-Accuracy (Jason-class) Altimetry**
  - Open-ocean location along 10-d repeat track (by design)
  - 10-km off coast of central California
- **Continuous monitoring for 20 years**
- **365 T/P overflights spanning 10 years**
  - 22 in formation with Jason-1 (2002)
  - Final overflight on August 13, 2002
- **259 Jason-1 overflights spanning 7 years**
  - 20 in formation with Jason-2 (2008–2009)
  - Final overflight on January 18, 2009
- **155 Jason-2 overflights and counting…**
  - Over four years of monitoring
- **Experiment operations status**
  - Primary NOAA water level system slipped deeper in March 2012 and now inoperable.
    - Corrosion of brass orifice suspected
    - Divers to replace orifice (underway)
  - Backup NOAA system (on separate riser) normal
  - CU Lidar upgrade: 9/2011



Harvest Closure Analysis: Assumptions for Altimeter Leg

MODEL	NOMINAL "Legacy"			UPDATE 1 "Quasi GDR-D"		UPDATE 2 J2 GDR-D
	TOPEX/Poseidon	Jason-1	OSTM/ Jason-2	Jason-1	OSTM/ Jason-2	OSTM/ Jason-2
Orbital Height	GSFC std0905 (Lemoine et al., 2010)	GDR-C	GDR-T	GDR-C	GDR-T	GDR-D
Altimeter Range	Ku (MGDR)			Corrected GDR-C*	Corrected GDR-T*	
Wet troposphere	Repro (Brown et al., 2009)			JMR EPD (Brown)	GDR-D (AMR EPD)	
Dry troposphere	MGDR			GDR-C	GDR-T	
Ionosphere	MGDR: Ku (ALT), DORIS (POS-1)			GDR-C	GDR-T + 5 mm	
Sea-state bias	MGDR			MLE4 from J2	GDR-D (MLE4)	

* Corrects for errors in antenna reference point and altimeter characterization (*Desjonquères and Picot, 2011)*

Recent Updates to Geophysical Data Products Reflected in the 20-Year Harvest Calibration Record

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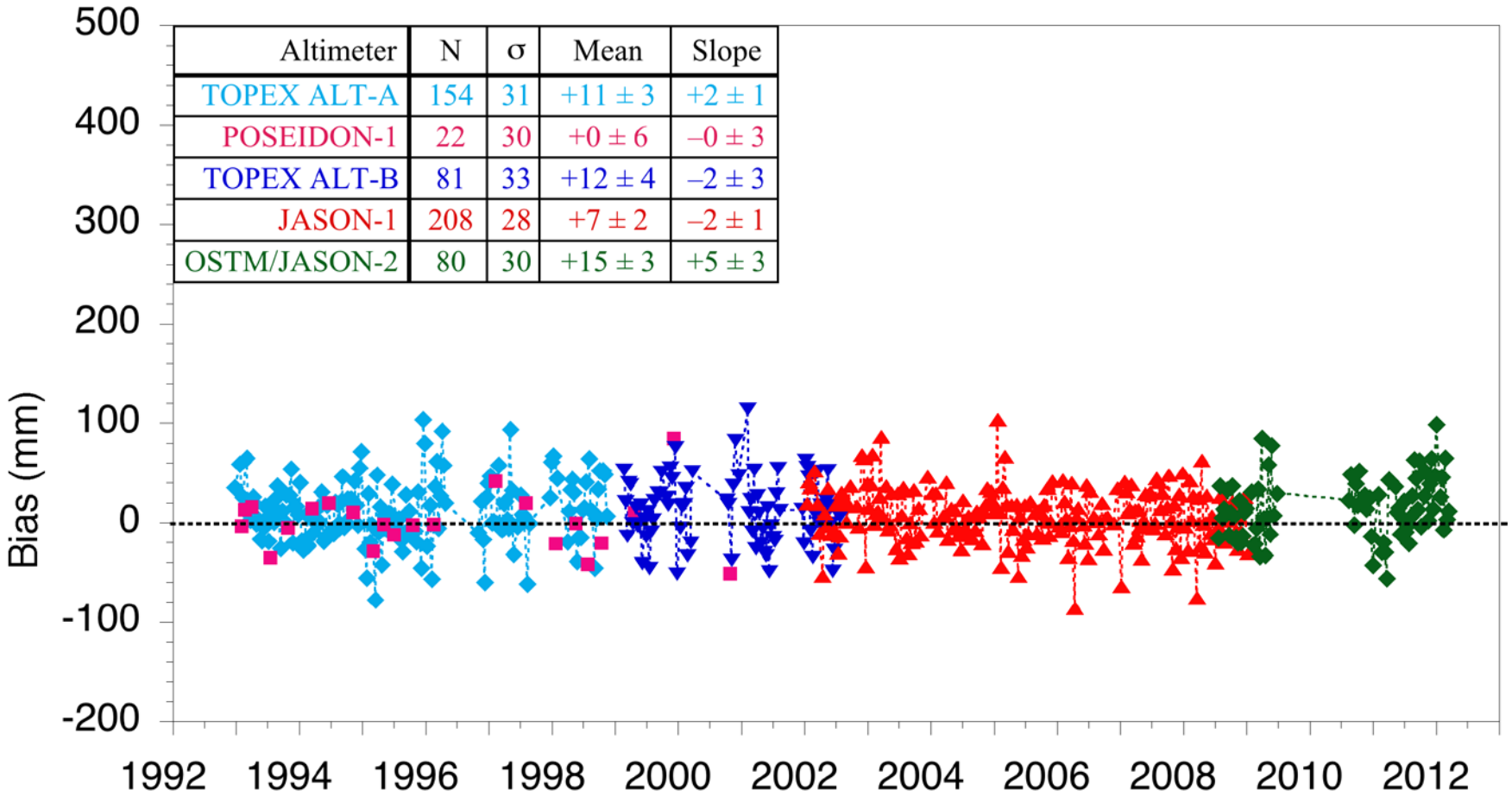
Update 2 (Jason-2 GDR-D):

Replace Jason-2 “quasi GDR-D” with real GDR-D.



Harvest SSH Calibration Time Series: GDR-D vs. GDR-T

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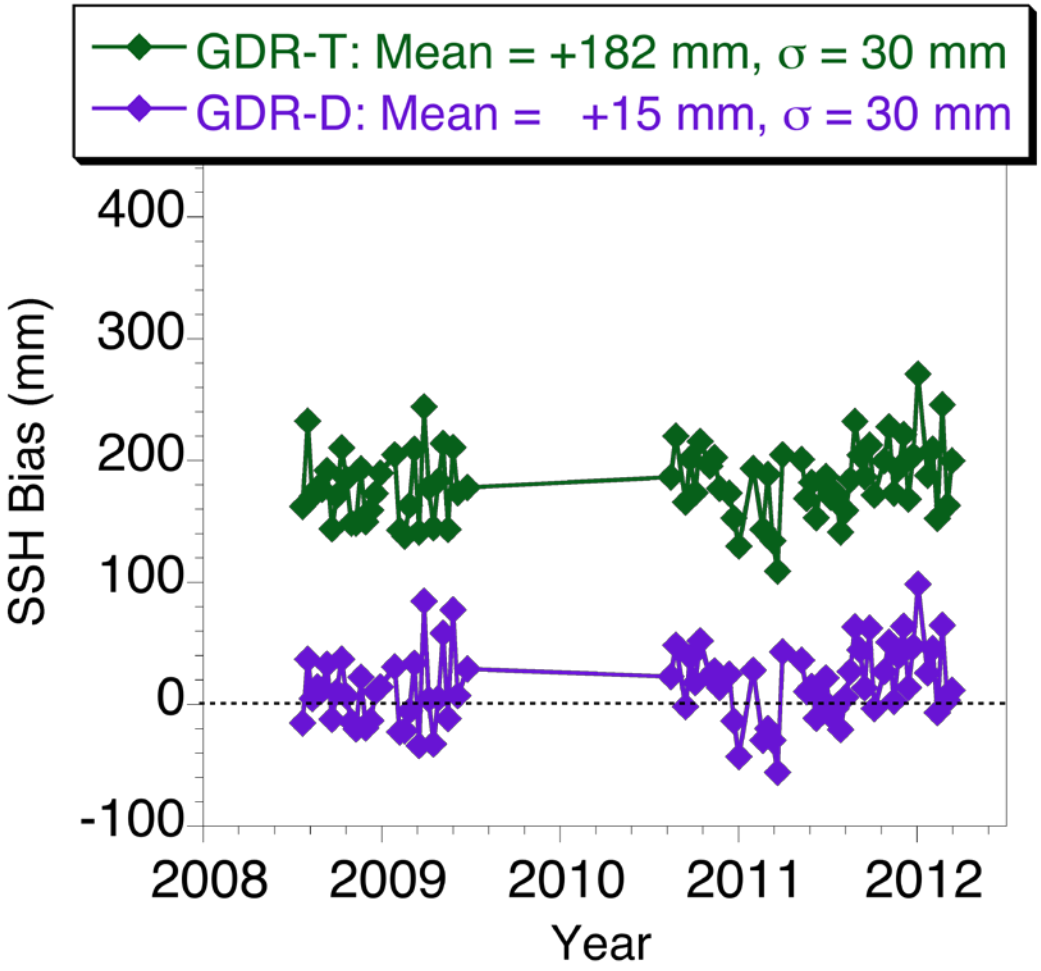
Comparison of GDR-D and GDR-T for Common Cycles (N = 80)



Source of ΔSSH Bias (GDR-T to GDR-D):

Parameter	Bias (mm)	σ (mm)
ΔRange_Ku*	–151	1
ΔSSB_Ku	–31	4
ΔIono_Ku	+6	1
ΔWet_Rad	+5	6
ΔOrbit	+4	5
TOTAL	**–167**	**11**

* ΔRange_C = –149 mm

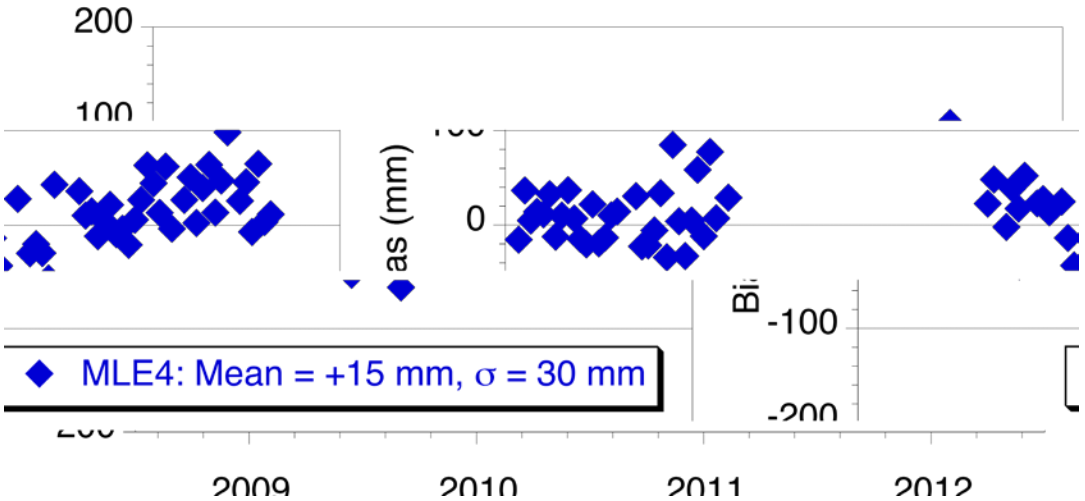
Alternative Retracking on Jason-2 GDR-D

- **GDR-D contains both MLE3 and MLE4 retracked data.**
  - MLE4 is nominal
- **MLE3 data increase scatter of SSH bias estimates**
  - Due mainly to Ku range
- **MLE3 data shift SSH bias upward**
  - Due mainly to SSB

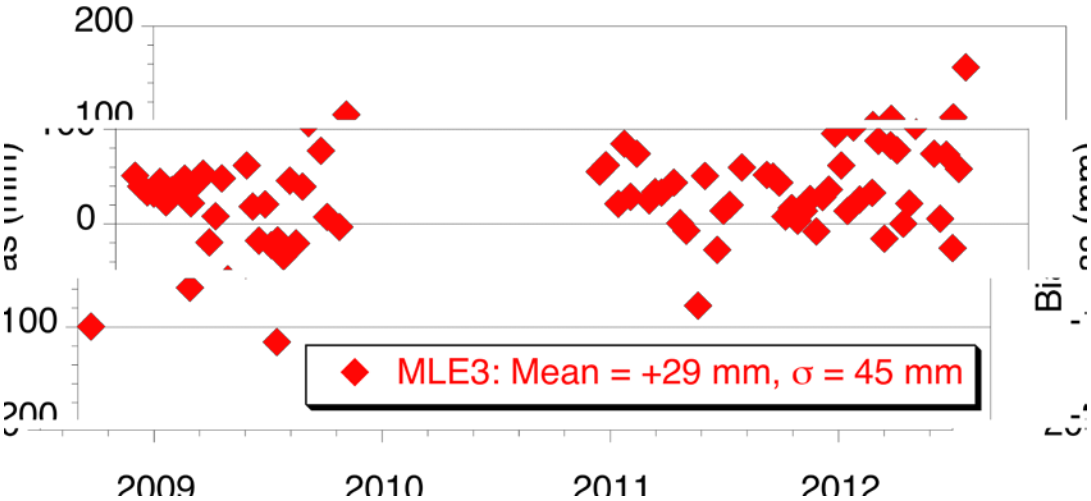
Source of ΔSSH Bias (MLE-4 to MLE-3):

Parameter	Bias (mm)	σ (mm)
ΔRange_Ku	–9	32
ΔSSB_Ku	+31	4
ΔIono_Ku	–6	6
TOTAL	**+16**	**35**

SSH Calibration Time Series with MLE4



SSH Calibration Time Series with MLE3



Absolute Ku- and C-Band SSH Bias/Drift

- **Begin with uncorrected Ku- and C-Band Ranges**
  - Compensate for troposphere using standard (GDR) approach
  - Use GDR-D range for Jason-2 (Jason-1 range corrected for ARP and characterization).
- **Estimate SSH bias, drift and local SSB & iono. on each frequency simultaneously**
  - SSB model (local to Harvest) is a simple percentage of SWH from nearby buoy ("BM1")
  - Ionosphere is a scaling of TECU from GIM (GPS-based): theoretical values are 2.2 (Ku) and 14.3 (C).

	Jason-1 Ku-Band	Jason-1 C-Band	Jason-2 Ku-Band	Jason-2 C-Band
SSH Bias (mm)	+22 ± 6	+7 ± 10	+22 ± 12	+34 ± 23
SSH Drift (mm/yr)	–2 ± 1	–2 ± 2	+2 ± 3	+8 ± 6
Local SSB (%)	3.5 ± 0.2	4.4 ± 0.3	3.7 ± 0.4	3.7 ± 0.7
Iono. (mm/TECU)	2.1 ± 0.2	12.0 ± 0.3	1.6 ± 0.5	13.0 ± 0.9
Number	207	203	62	60
Postfit σ (mm)	30	47	27	53

Wet Path Delay: Radiometer vs. GPS

Impact of Enhanced (Brown) Path Delay Products

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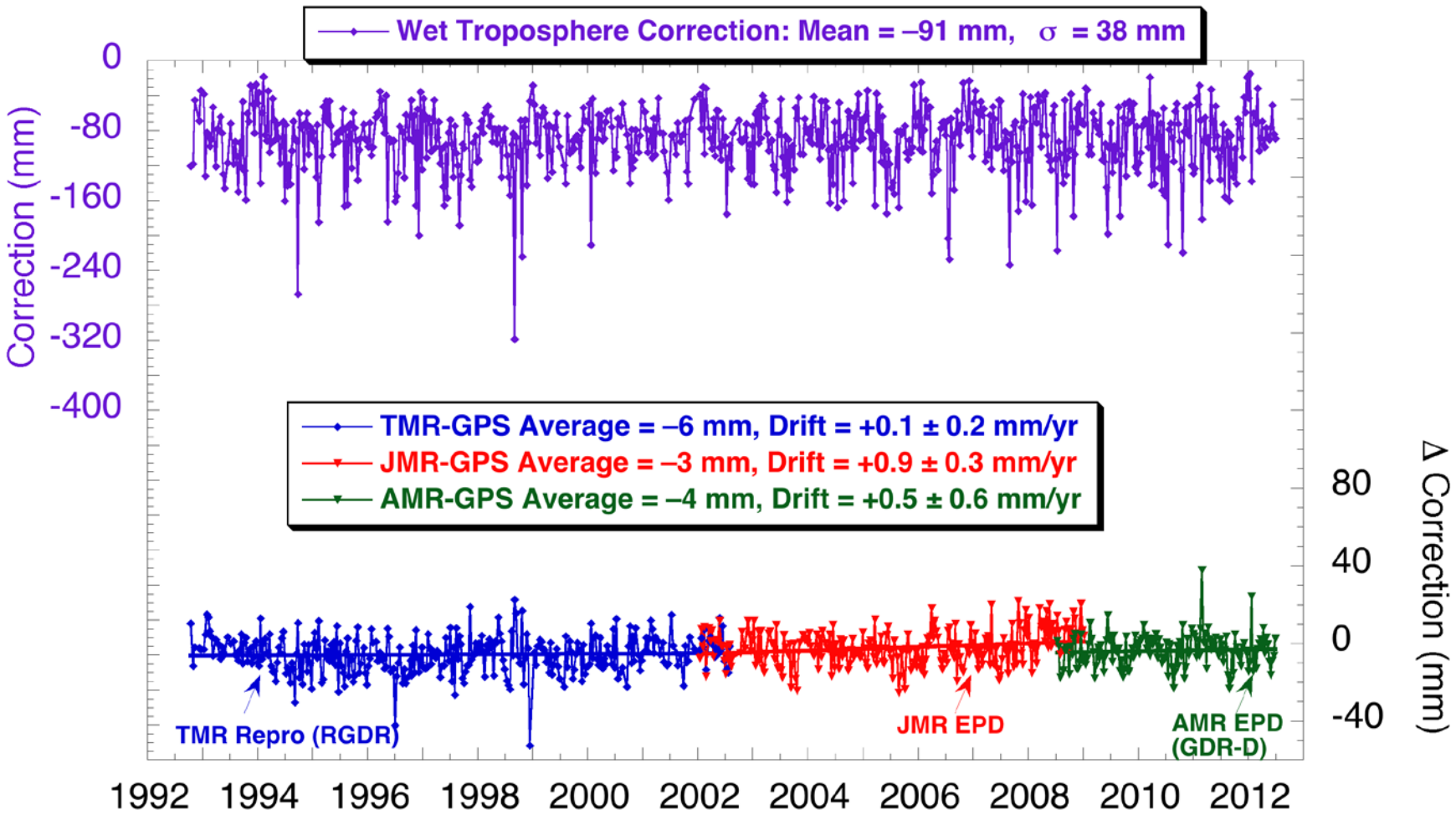

EPD correction interpolated directly to platform TCA (vs. t–5 s for std. correction)

9.5/9.1/11.6

Harvest: Ku-Band Ionosphere Calibration Using JPL GPS Ionosphere Maps

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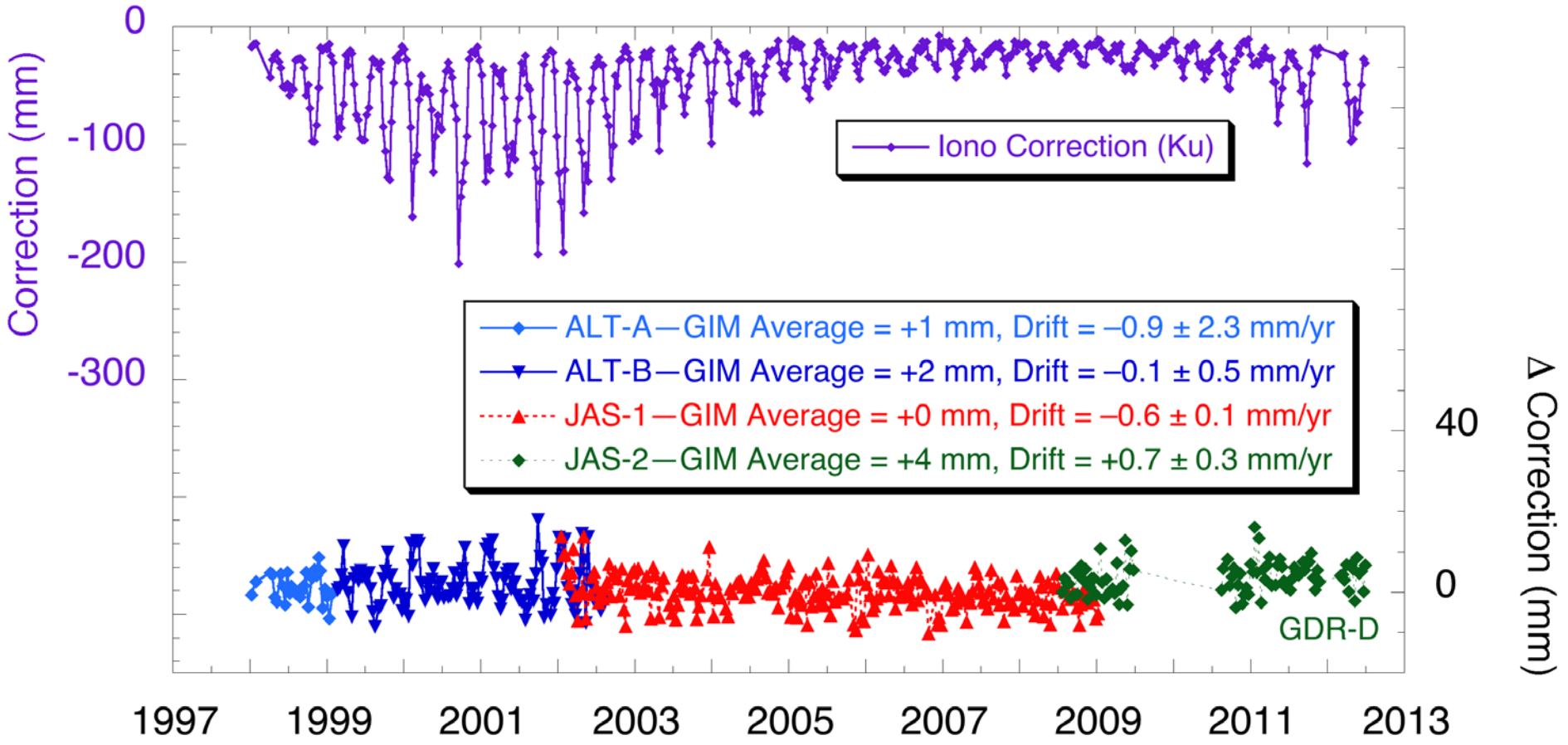

Platform Harvest Geodetic Height From 20 Years of Continuous GPS Monitoring

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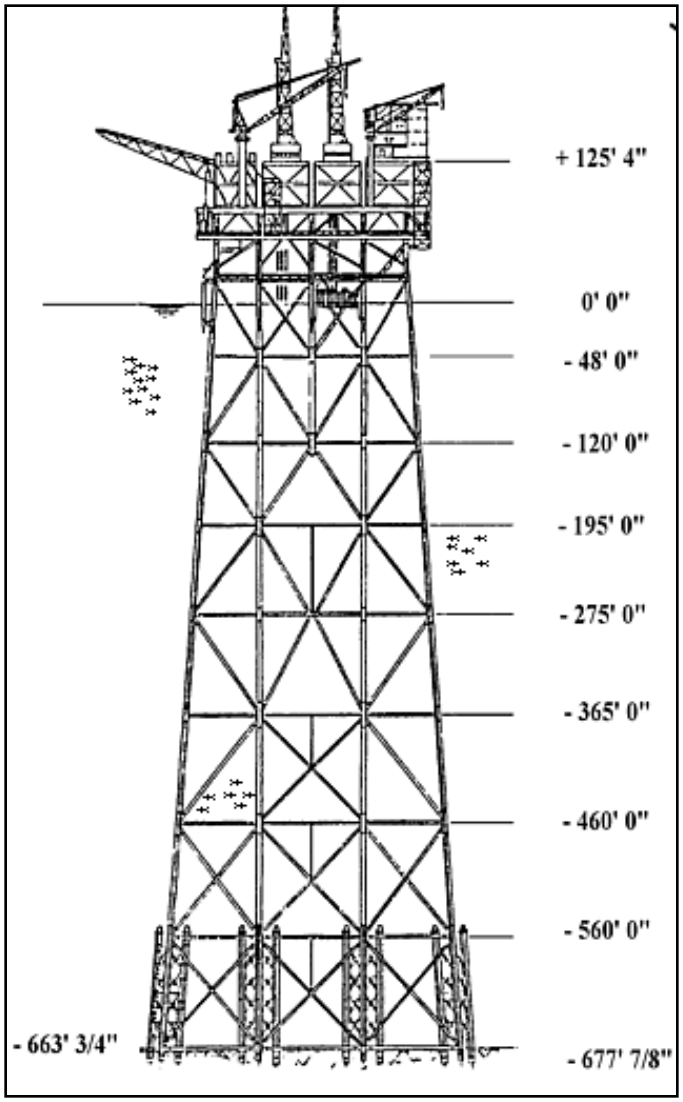

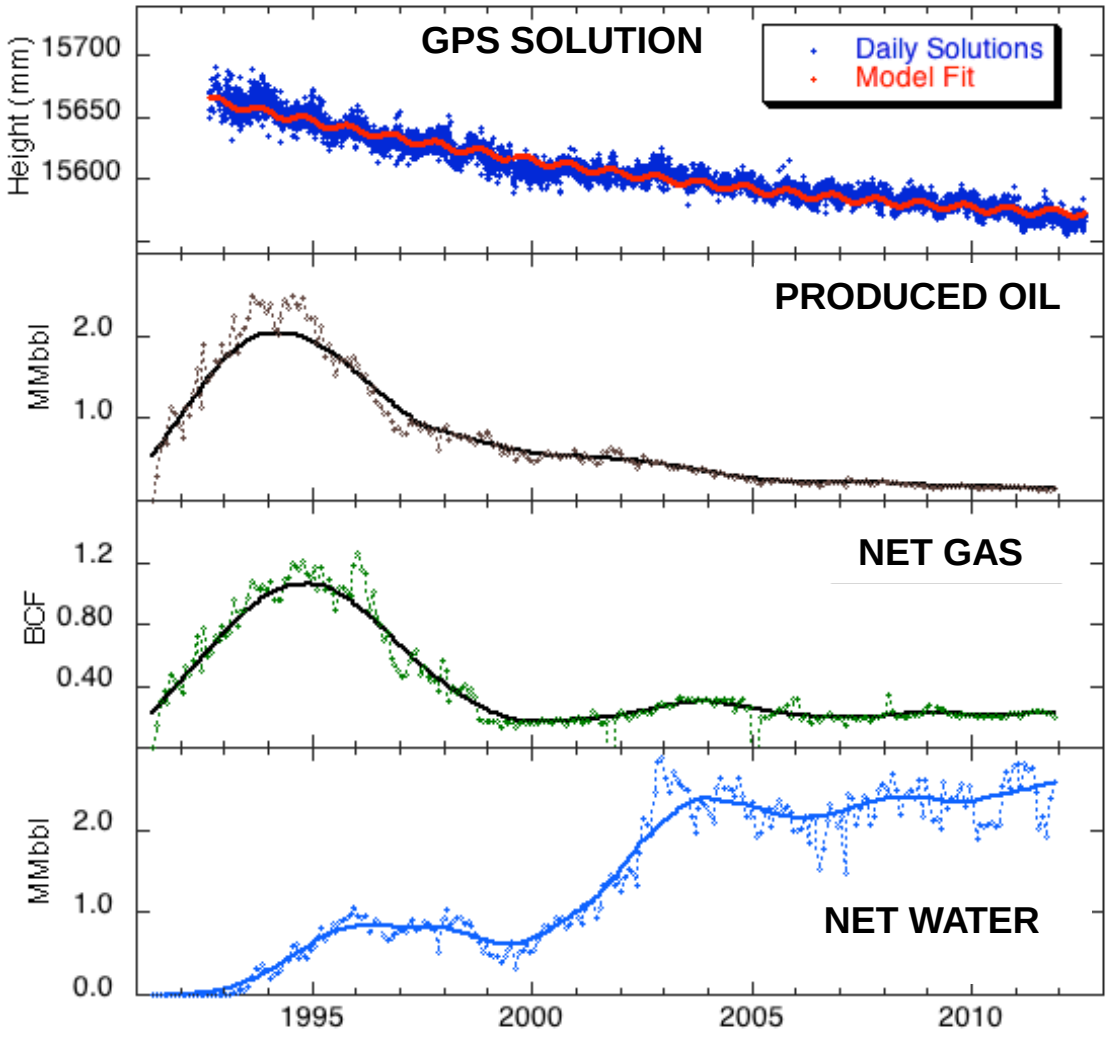

Production Statistics for Pt. Arguello Field from http://www.boem.gov

Error Budget: Accommodating Uncertainty in the Platform Position

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- **Uncertainty in platform height and vertical (seafloor) motion among limiting error sources in the Harvest closure exercise.**
- **New analysis develops error budget from competing GPS solutions & fit strategies.**
- **Overall error budget for SSH bias and drift now includes this systematic error source.**
  - The SSH estimates for all systems are statistically indistinguishable from zero (at ~15 mm level).
  - The uncertainty in the SSH drift estimate for Jason-1 is approaching 1 mm yr^{-1}

Altimeter	*Years*	*N*	*Bias (mm)*			*Drift (mm yr^{-1})*		
			$\sigma_{\bar{x}}$	σ_v	*Estimate*	$\sigma_{\bar{x}}$	σ_v	*Estimate*
ALT-A	1992–1999	154	3	16	+11 ± 16	1.4	2.0	+1.7 ± 2.5
Poseidon	1992–2000	22	6	16	+0 ± 17	2.7	1.8	–0.2 ± 3.3
ALT-B	1999–2002	81	4	15	+12 ± 15	3.3	0.8	–1.6 ± 3.4
Jason-1	2002–2009	208	2	16	+7 ± 16	0.9	0.5	–2.1 ± 1.1
Jason-2	2008–2011	108	3	16	+5 ± 16	2.6	1.2	+1.0 ± 2.8

$\sigma_{\bar{x}}$: one standard error from least-squares fit (bias or linear) to time series of SSH biases.

σ_v : estimated error from uncertainty in vertical location and motion of seafloor (see text).

Estimate: estimate of bias or drift with total error (quadrature sum of $\sigma_{\bar{x}}$ and σ_v).

Haines et al., Adv. Space Research, submitted 2012

Evolution of Bias/Drift Estimates

BIAS (mm)	Nice 2008	Seattle 2009	*Mar. Geod.* 2010	Lisbon 2010	San Diego 2011	Venice 2012
Jason-2	+200	+174	+178	+176	+176	**+15**
Jason-1	+99	+94	+94	+87	+89	**+7**
ALT-B	+15	+14	+14	+10	+14	**+12**
Poseidon-1	+5	–10	–10	–5	+6	**+0**
ALT-A	+17	+1	+1	+7	+18	**+11**

DRIFT (mm/yr)	Nice 2008	Seattle 2009	*Mar. Geod.* 2010	Lisbon 2010	San Diego 2011	Venice 2012
Jason-2	n/a	–5	+15	+8	+2	**+5**
Jason-1	+1	–2	–2	–2	–2	**–2**
ALT-B	–2	–1	–1	–3	–4	**–2**
Poseidon-1	–1	+3	+3	+1	–0	**–0**
ALT-A	+0	+5	+5	+4	+2	**+2**

- Impact of improved models for platform subsidence (from GPS measurements) is significant.
- Tide-gauge errors also contribute

Summary

- **Current (GDR-D) Jason-2 SSH unbiased.**
  - +15 ± 16 mm, including error in platform vertical
- **Current (GDR-C) Jason-1 SSH biased high.**
  - +94 ± 16 mm, including systematic error from platform vertical.
  - Upgrades for next (GDR-D) product expected to reduce bias to 1-cm level.
- **TOPEX/Poseidon systems unbiased.**
  - T/P ALT-B: +12 ± 15 mm
  - T/P ALT-A: +11 ± 16 mm
  - T/P POS: +0 ± 17 mm
- **Uncertainty in SSH bas estimates dominated by error (> 1 cm) in platform vertical.**
- **Nominal (MLE4) retracking approach for GDR-D yields best results at Harvest.**
  - MLE3 (K_U range) significantly degrades repeatability of SSH bias estimates.
  - MLE3 (K_U SSB) significantly increases average of SSH bias estimates.
- **Jason-2 Ku-ionosphere remains slightly small.**
  - 4 mm for nominal (MLE4) GDR-D vs. ~1 cm for MLE3 (same level as GDR-C)
- **Enhanced path delay (EPD) product continues to yield promising results.**
  - Enables use of JMR/ AMR data at platform location (~10 km from shore)
  - Improves agreement with independent GPS-derived PD estimates
  - Slight (< 1 mm/yr) drifts between EPD and GPS will be monitored
- **No signs of significant instabilities in SSH calibration time series.**
  - Estimated uncertainties in drift estimate range from 1 mm/yr (Jason-1) to 3 mm/yr (Jason-2)
  - Recent increase in Jason-2 SSH biases warrants further investigation (in situ error?).