The Harvest Experiment: Calibration of the Climate 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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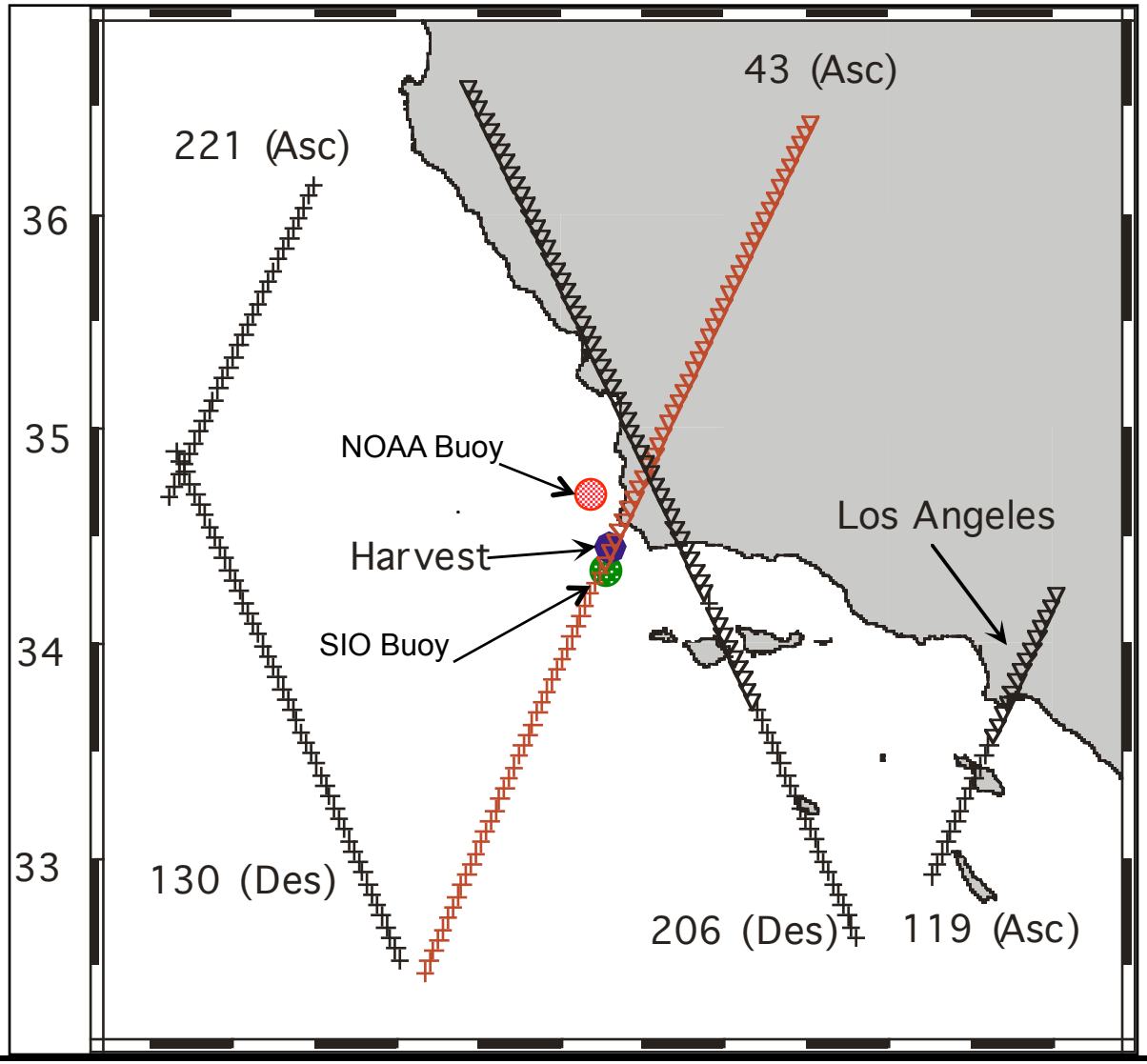
Harvest Platform

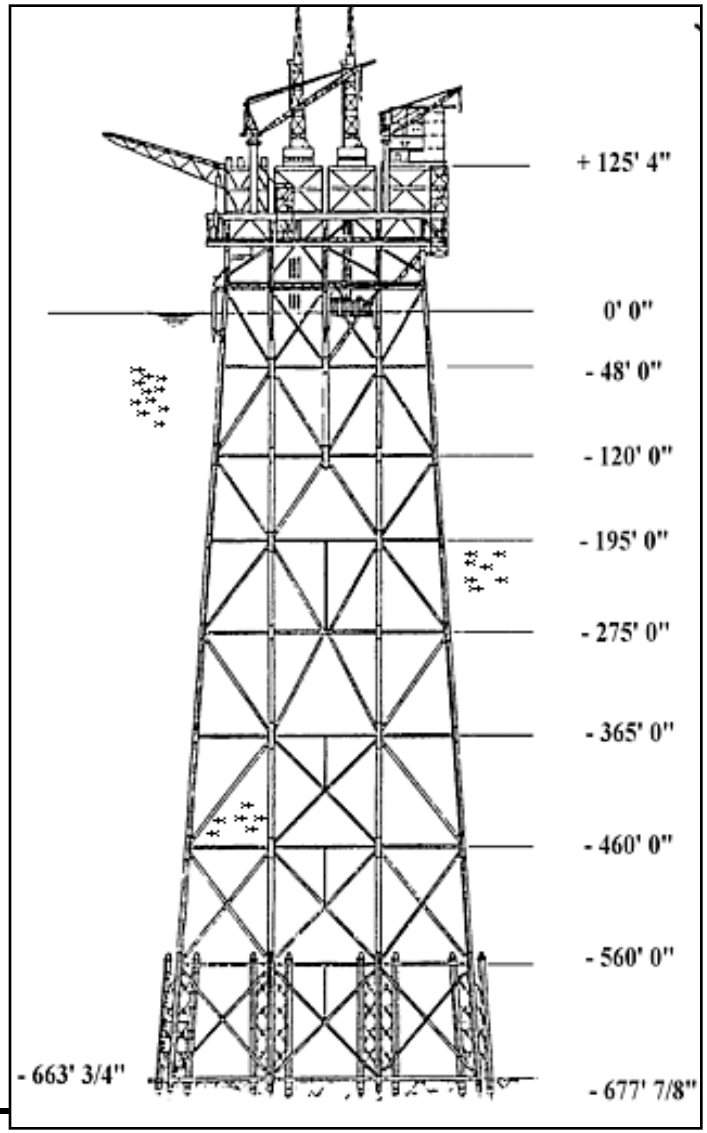
Owned by Plains Exploration and Production (PXP)

NASA Prime Verification Site for High-Accuracy (Jason-class) Altimetry: T/P (1992–2005), Jason-1 (2001–) and OSTM/Jason-2 (2008–).

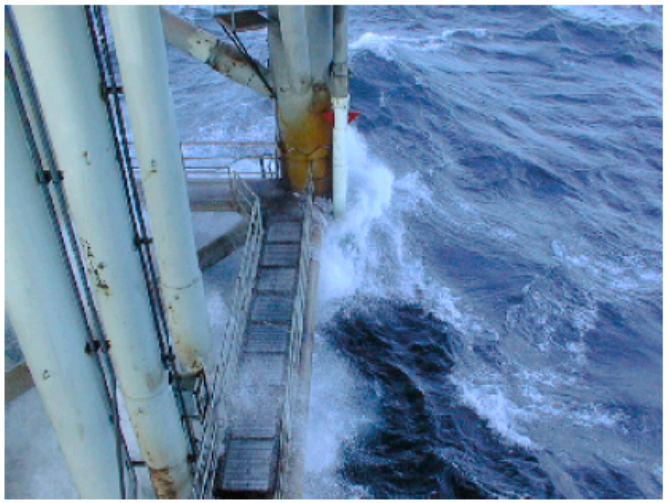
- **Open-ocean verification site located 10-km off coast of central California**
- **Ground track passes directly through this location by design (T/P heritage)**
- **Rich in-situ data set representing 17 years of continuous monitoring**
- **365 T/P overflights spanning 10 years**
  - 22 in formation 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
- **35 Jason-2 overflights and counting…**
  - Nearly one year of monitoring
- **Nominal experiment operations status**
  - Routine underwater maintenance this summer
  - GPS upgrade forthcoming (receiver, radome)

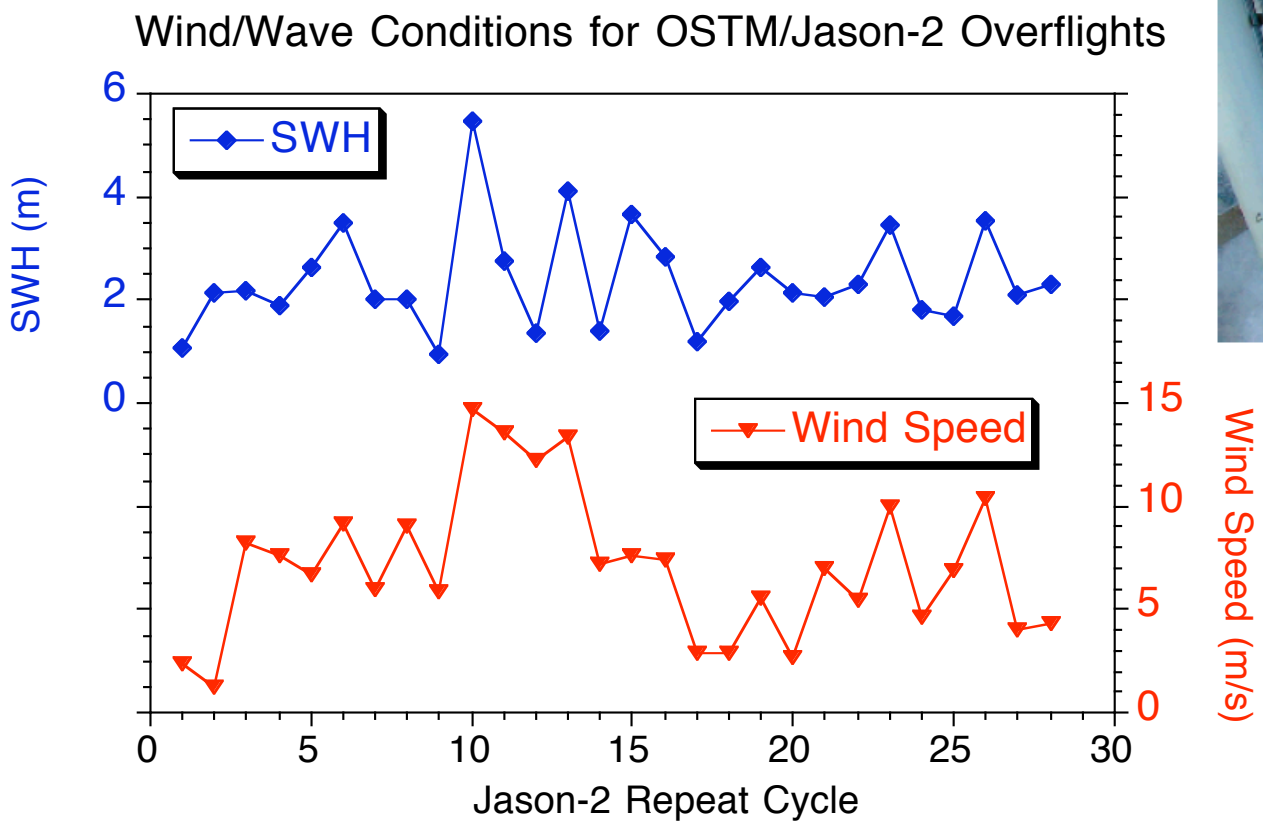
Map of Harvest Vicinity



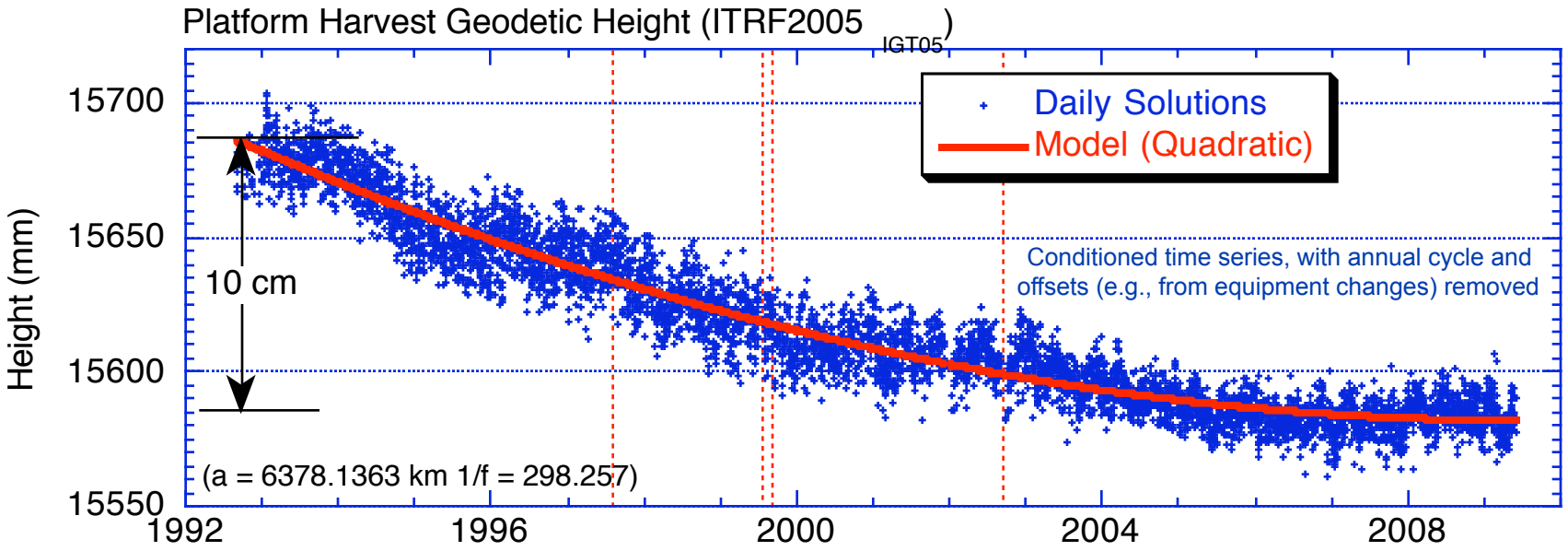


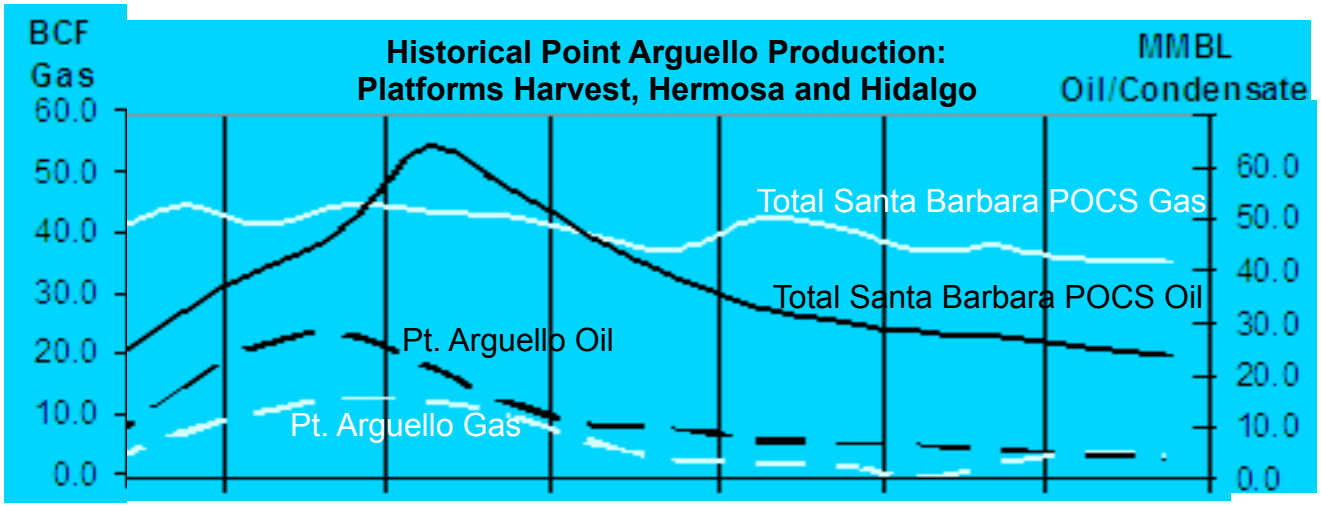
Wind/Wave Conditions for Jason-2 Overflights: Typical of Open Ocean





Platform Harvest Geodetic Height From 17 Years of Continuous GPS Monitoring



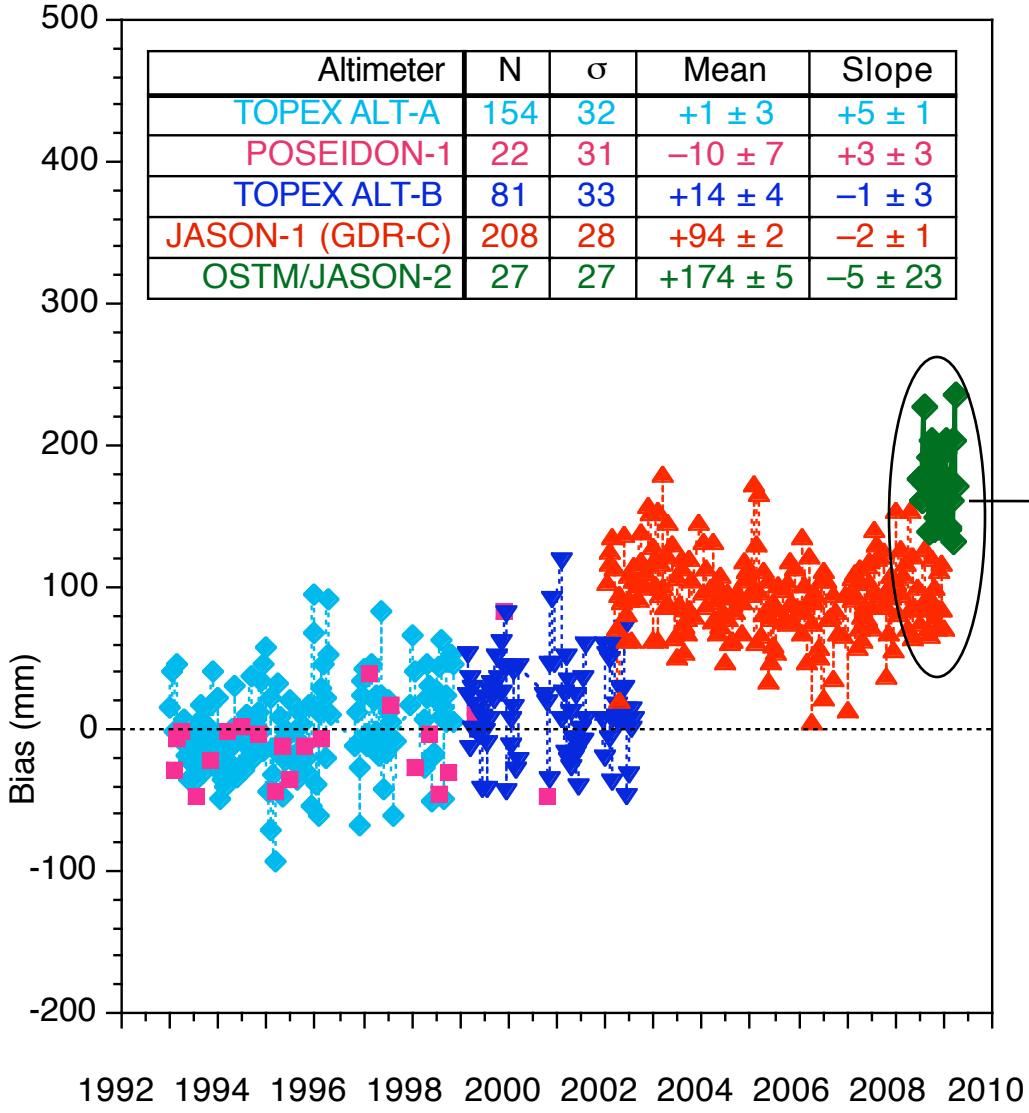


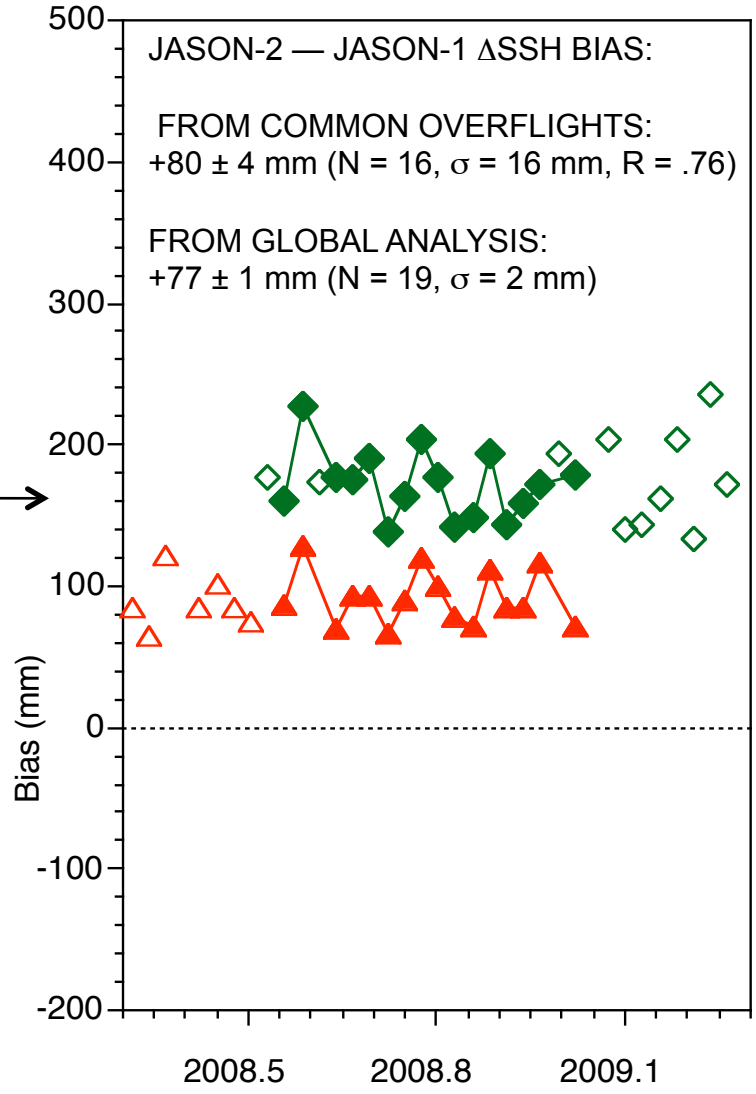
Oil/Gas Production from 1992–2005
California Division of Oil, Gas and Geothermal Resources; Minerals Management Services

http://www.countyofsb.org/energy/projects/arguello.asp

Harvest SSH Calibration Time Series

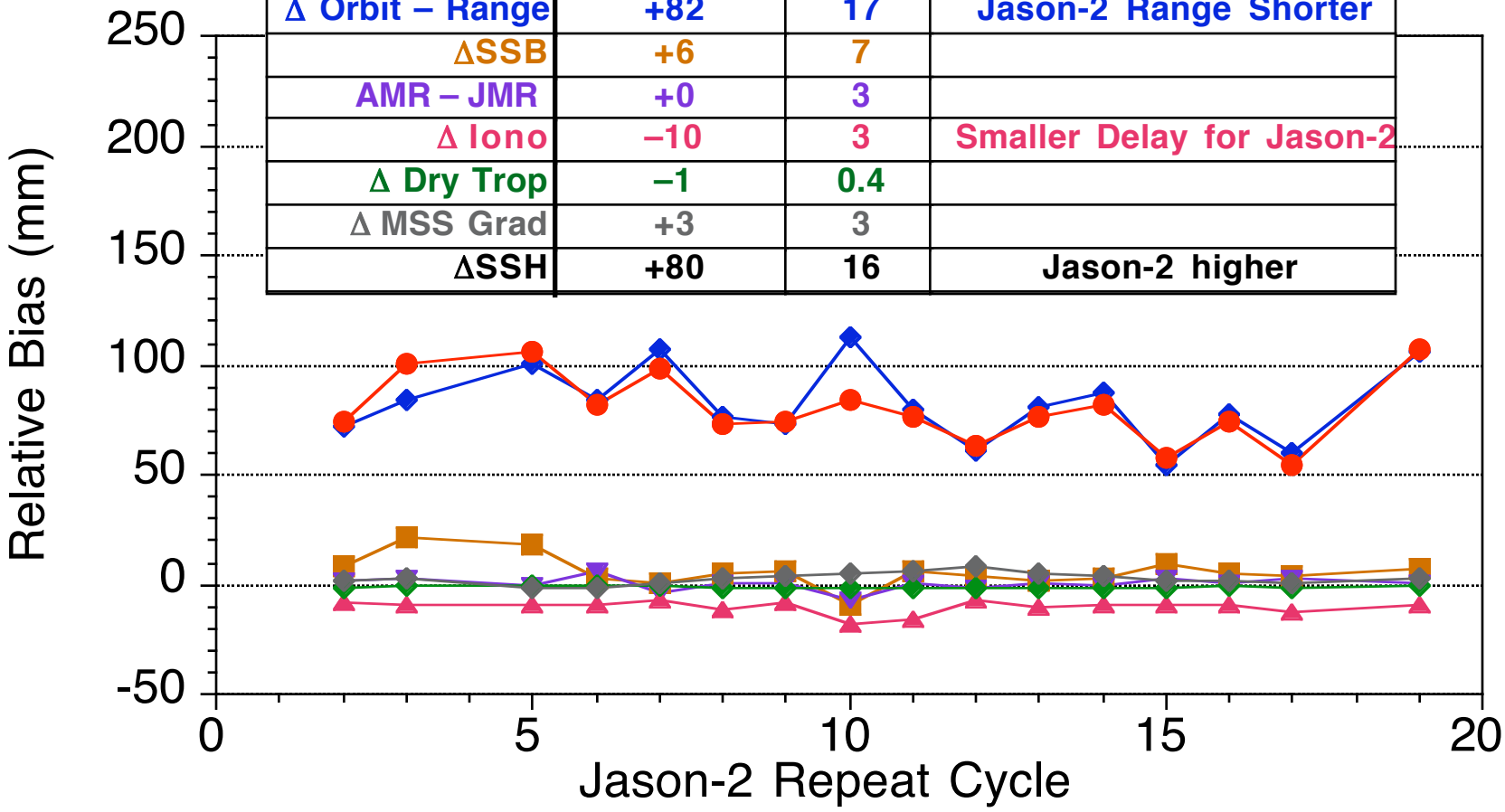
Altimeter	N	σ	Mean	Slope
TOPEX ALT-A	154	32	+1 ± 3	+5 ± 1
POSEIDON-1	22	31	−10 ± 7	+3 ± 3
TOPEX ALT-B	81	33	+14 ± 4	−1 ± 3
JASON-1 (GDR-C)	208	28	+94 ± 2	−2 ± 1
OSTM/JASON-2	27	27	+174 ± 5	−5 ± 23





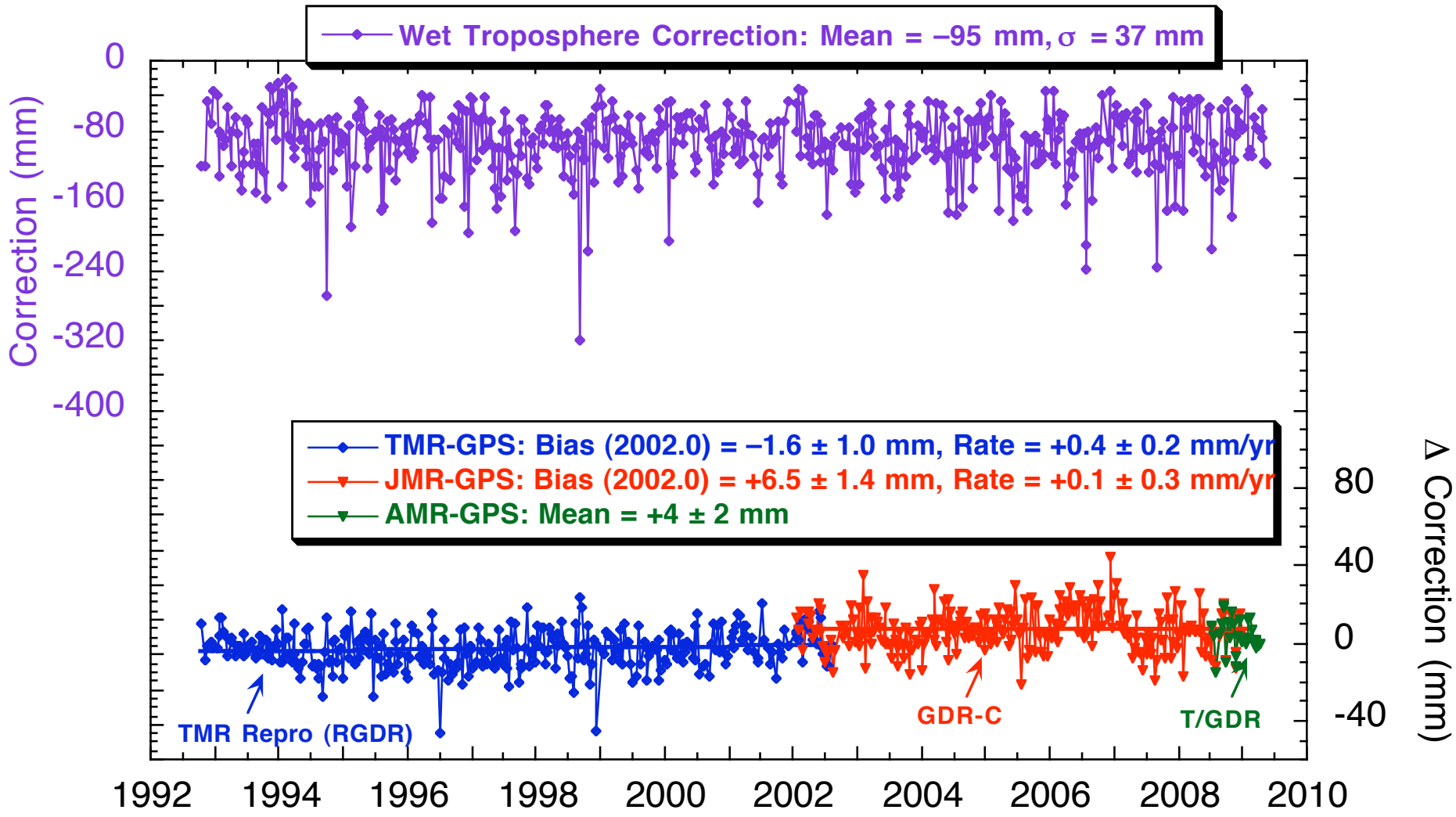
Jason 1/2 Tandem Overflights of Harvest: Comparison of Correction Terms

Correction	Mean (mm)	σ (mm)	Comment
Δ Orbit – Range	+82	17	Jason-2 Range Shorter
ΔSSB	+6	7	
AMR – JMR	+0	3	
Δ Iono	–10	3	Smaller Delay for Jason-2
Δ Dry Trop	–1	0.4	
Δ MSS Grad	+3	3	
ΔSSH	+80	16	Jason-2 higher



Jason-2: RMS Radial Orbit Difference (POE vs GPS) = 6 mm (N = 28)

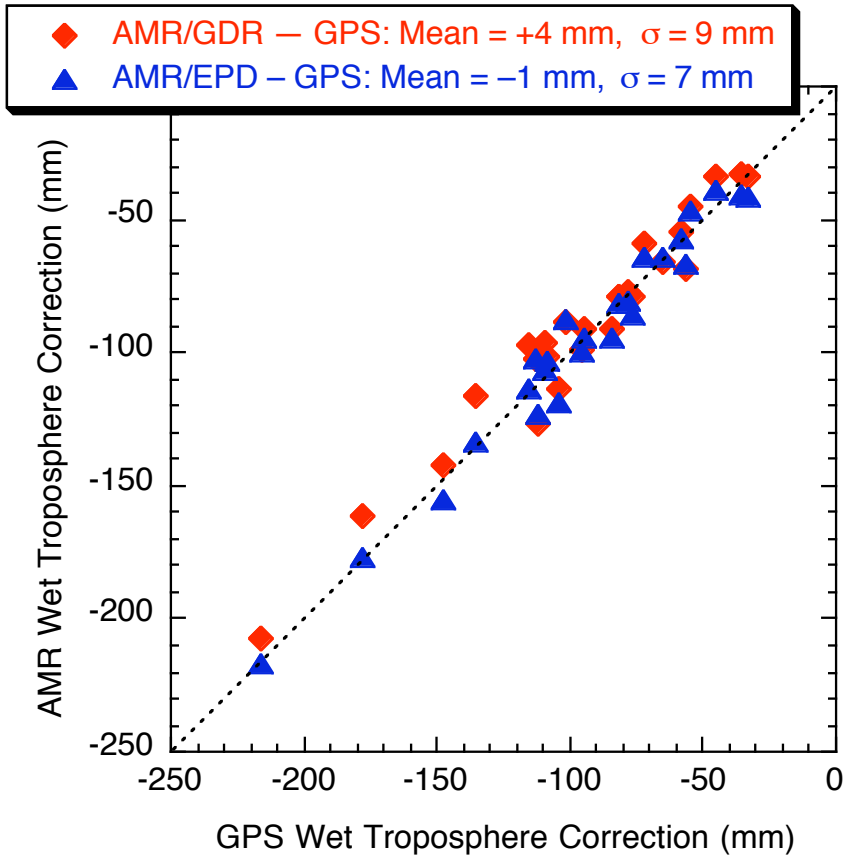
Harvest: Long-term (Legacy) Radiometer Wet Path Delay Correction from GPS



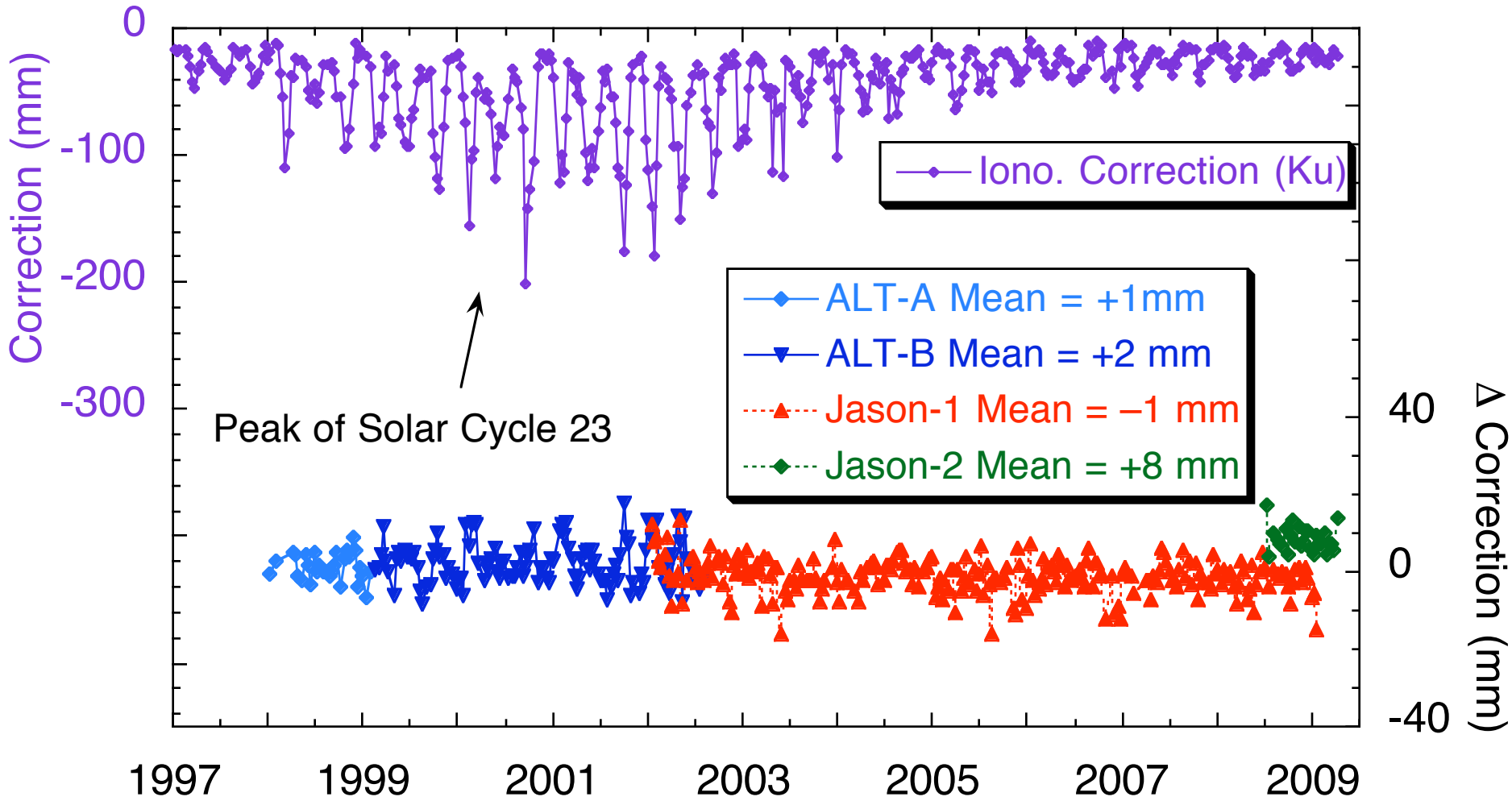
Radiometer Land Contamination: Performance of AMR/EPD Product at Harvest

- Use std. fit procedure for AMR GDR correction on approach to Harvest
  - Linear fit over 10-s terminating 5-s before platform overflight.
  - Avoids land contamination (e.g., Christensen et al., 1994).
- Use new fit procedure for AMR EPD
  - Linear fit over 10-s terminating at TCA.
  - Harvest ~10 km from land along pass 43
- AMR/EPD reduces both scatter and bias with respect to GPS
  - Caveat: bias value from GPS may not be trustworthy at few mm level (e.g, radome)
- AMR/EPD suggests troposphere over platform slightly wetter vs. 30 km offshore.
  - Would increase Jason-2 SSH bias by 5 mm.

Wet Troposphere Correction
AMR Enhanced Path Delay Product vs. GPS



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

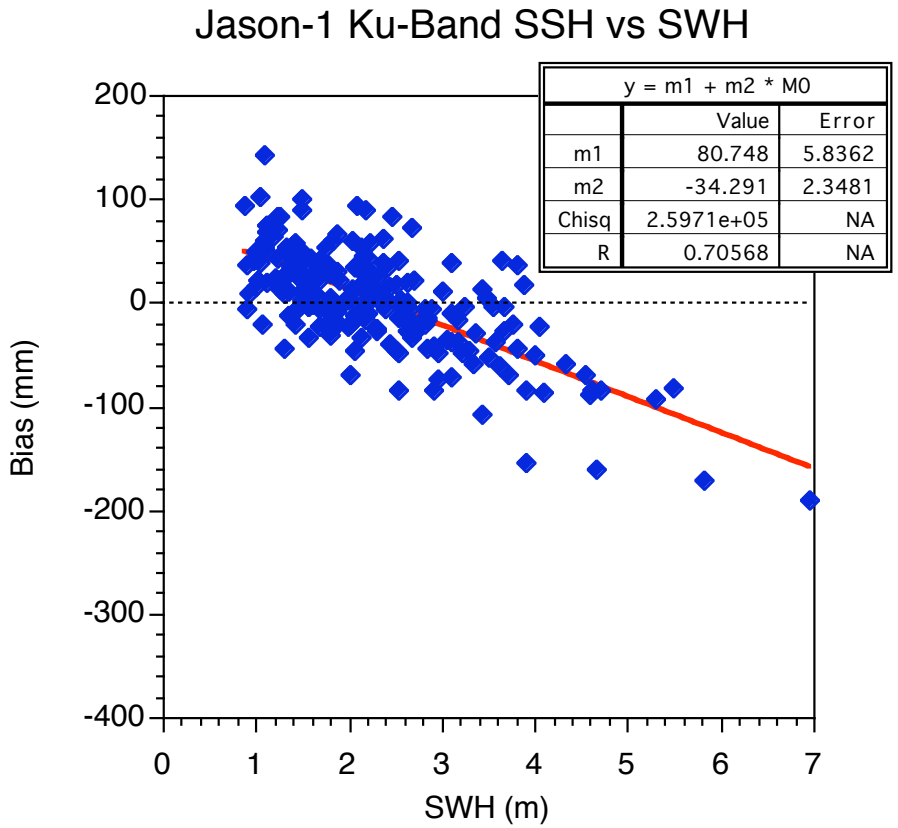


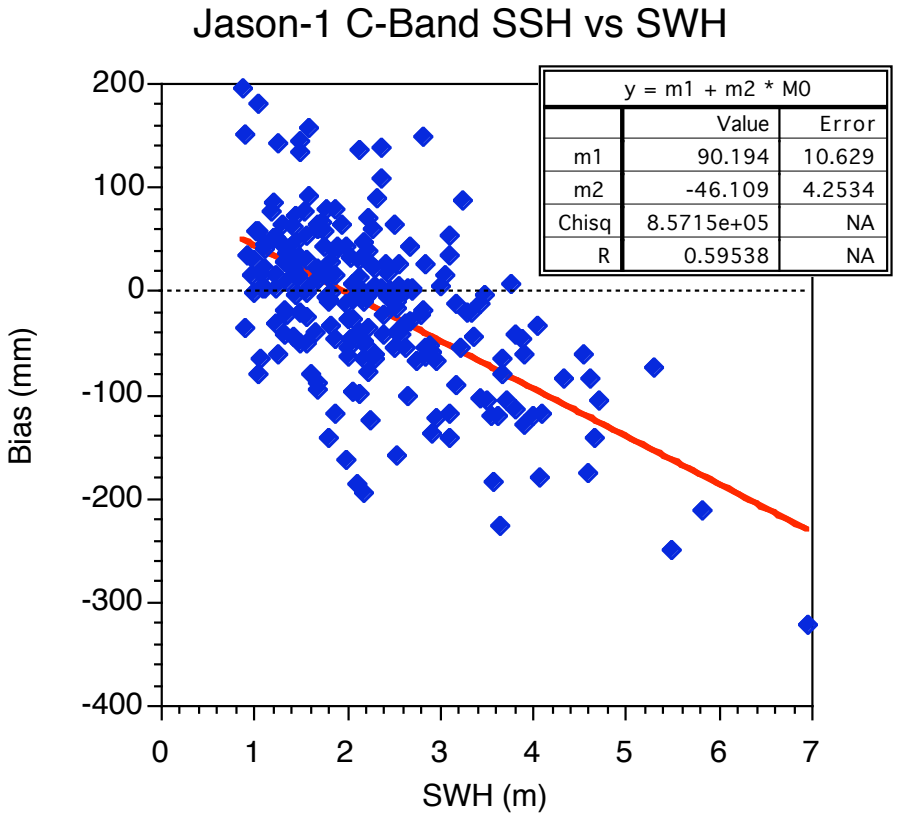
Absolute Ku- and C-Band SSH Biases: A New Approach

- **Begin with uncorrected Ku- and C-Band Ranges**
- **Compensate for troposphere using standard (GDR) approach**
  - Model dry troposphere
  - AMR/JMR wet troposphere
- **Compensate for ionosphere using independent measure**
  - GPS-based correction (JPL GIM; Mannucci et al.)
  - Ensure independence of potential inter-frequency altimeter bias (Ku-C) and ionosphere correction.
- **Do not compensate for sea-state bias (SSB)**
- **Do linear regression of SSH bias against SWH**
  - Use measurements from nearby buoy (Scripps) at Harvest.
- **Estimate SSH bias and local SSB simultaneously**
  - SSB model (local to Harvest) is a simple percentage of SWH.
  - Iterative 3-sigma edit (no other QC on closure data).
  - SSH Bias is intersection of model with SWH = 0.

Jason-1 SSH Bias (Ku, C) vs SWH at Harvest

SSH uncompensated for sea-state bias





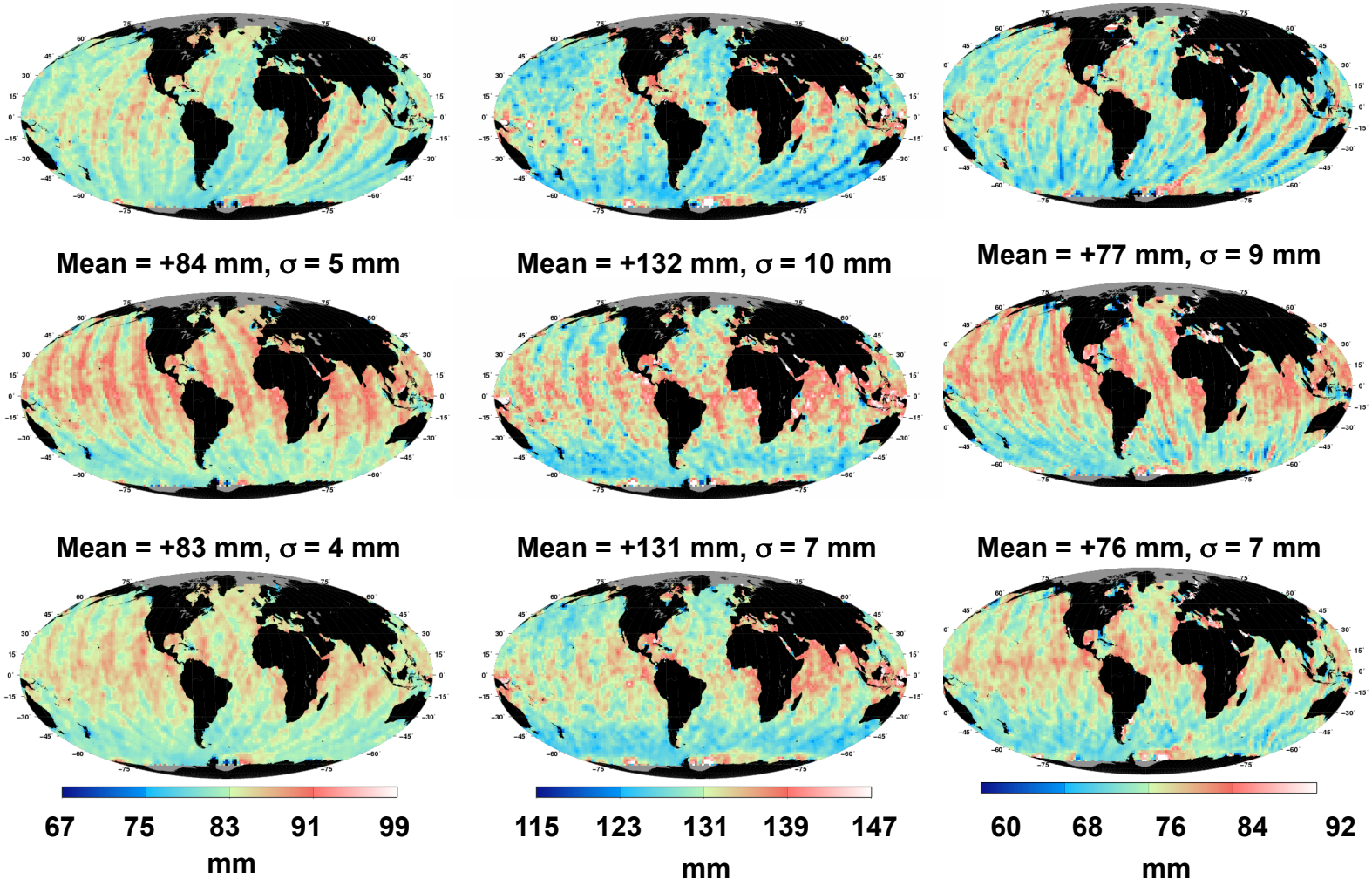
Absolute Ku- and C-Band SSH Biases

	Jason-1 Ku-Band	Jason-1 C-Band	Jason-2 Ku-Band	Jason-2 C-Band
SSH Bias	+81 ± 6 mm	+90 ± 11 mm	+164 ± 13 mm	**+213 ± 18 mm**
Local SSB	3.4 ± 0.2 %	4.6 ± 0.4 %	3.4 ± 0.5 %	4.6 ± 0.7 %
Number of Overflights	217	216	28	25
Postfit σ	35 mm	63 mm	26 mm	37 mm

- **Jason-1 Ku- and C-Band SSH biases agree well (i.e., to better than 1 cm).**
  - Also agree well with estimate (+94 mm) from traditional closure exercise.
- **Jason-2 Ku- and C-Band SSH biases disagree by 5 cm**
  - C-band SSH bias higher than corresponding Ku-band estimate
  - Ku-band SSH bias agrees well with estimate (+174 mm) from traditional closure exercise
  - More overflights needed to increase confidence (small number of samples vs Jason-1).
- **Lends insight on results from global analysis (see deCarvalho *et al.* poster)**
  - Discrepancy of ~5-cm between Ku- and C-Band Δ "Orbit–Range" (J2–J1)
  - Relative bias of ~1 cm between Jason-1 and Jason-2 ionosphere corrections
- **Local (Harvest) SSB model shows higher sensitivity of C band to SWH**

Jason-2 – Jason-1 Geographically Correlated Errors From Tandem Calibration Phase (J2 Cycles 8–20)

	K-Band ΔOMR	C-Band ΔOMR	ΔSSH
Ascending	Mean = +82 mm, σ = 5 mm	Mean = +129 mm, σ = 10 mm	Mean = +75 mm, σ = 9 mm
Descending	Mean = +84 mm, σ = 5 mm	Mean = +132 mm, σ = 10 mm	Mean = +77 mm, σ = 9 mm
All Tracks	Mean = +83 mm, σ = 4 mm	Mean = +131 mm, σ = 7 mm	Mean = +76 mm, σ = 7 mm



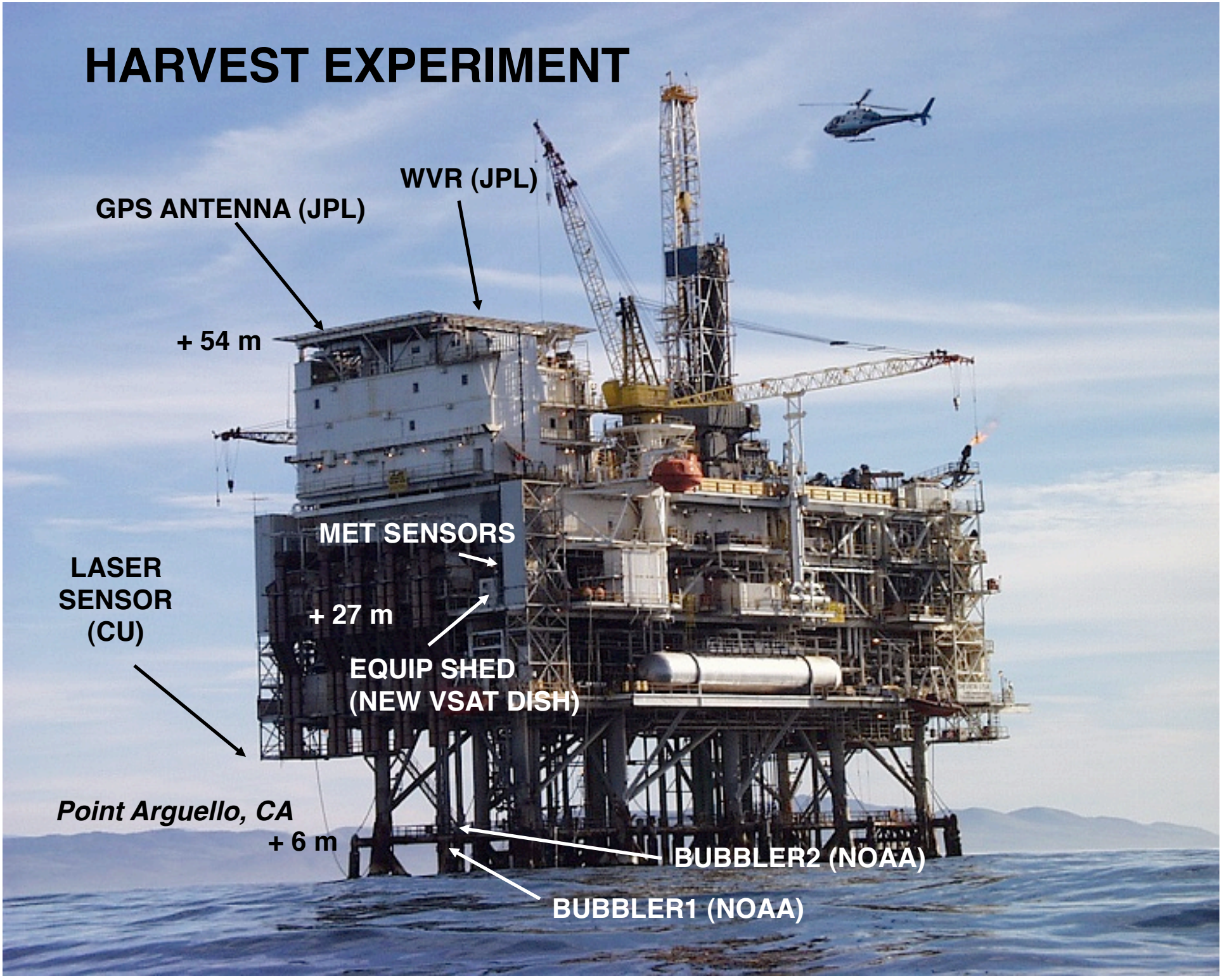
Summary of Harvest Findings

- **Both Jason-2 and Jason-1 reading SSH too high, by +17 and +9 cm respectively**
  - OSTM/Jason-2: +174 ± 5 mm (N = 27, σ = 27 mm)
  - Jason-1: +94 ± 2 mm (N = 208, σ = 28 mm)
- **TOPEX/Poseidon systems unbiased (< 2 cm)**
  - T/P ALT-B: +14 ± 4 mm (N= 81, σ = 33 mm)
  - T/P ALT-A: +1 ± 3 mm (N = 154, σ = 32 mm)
  - T/P POS: –10 ± 7 mm (N = 22, σ = 31 mm)
- **Excellent agreement between Harvest & global estimates of relative (J2 – J1) SSH bias**
  - +80 ± 4 mm from 16 common overflights of Harvest
  - +77 ± 1 mm from global cycle-by-cycle comparisons
- **Jason-1 and OSTM/Jason-2 exhibit common behavior**
  - High correlation of bias estimates (R = 0.76)
  - 16-mm scatter (1σ) of individual relative bias estimates
  - Testifies to common heritage of measurement systems
- **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
  - Poseidon-2 agrees better with GPS (GIM)
- **SSH drift estimates altered by new model for platform subsidence**
  - Drift estimates for ALT-B, POS-2, Jason-1 and Jason-2 all statistically indistinguishable from zero
  - ALT-A drift estimate (5 mm/yr) consistent in sign with PTR degradation, but larger.

Summary of Harvest Findings (cont.)

- **Excellent agreement between AMR and JMR for common overflights**
  - 3 mm scatter (1σ) with negligible bias for open ocean (30 km offshore) comparison point
- **New AMR enhanced path delay (EPD) product yields promising results**
  - Enables use of AMR data at platform location (~10 km from shore)
  - Improves agreement with independent GPS-derived PD estimates
- **Poseidon-3 Ku-ionosphere delay smaller (~10 mm) than Poseidon-2**
  - Poseidon-2 agrees better with GPS (GIM)
- **Quadratic model for platform vertical motion now preferred**
  - Lower rate of subsidence consistent with decreased production from Arguello Field
- **Influence of radome to be revisited in upcoming campaign**
- **New approach to SSH bias computation lends insight on individual Ku, C contributions**
  - Jason-1 C- and Ku-band SSH biases agree at ~1 cm level
  - Jason-2 C SSH bias ~5 cm larger than corresponding Ku SSH bias.

Backup Slides


HARVEST EXPERIMENT
WVR (JPL)
GPS ANTENNA (JPL)
+ 54 m
MET SENSORS
LASER
SENSOR
(CU)
+ 27 m
EQUIP SHED
(NEW VSAT DISH)
Point Arguello, CA
+ 6 m
BUBBLER2 (NOAA)
BUBBLER1 (NOAA)

Press Release Source: Environmental Defense Center

Environmental Groups Announce Landmark Agreement to Limit Oil Development and Protect Lands in Santa Barbara County

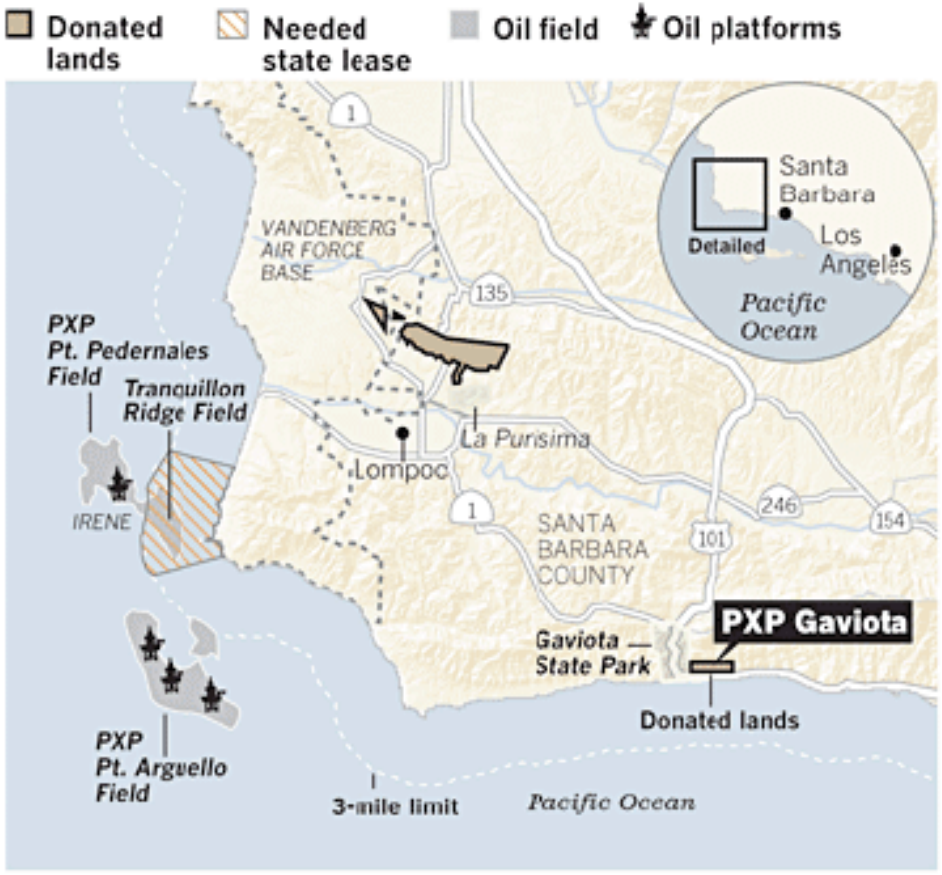
Thursday April 10, 3:40 pm ET

SANTA BARBARA, Calif., April 10 /PRNewswire-FirstCall/ -- The Environmental Defense Center (EDC), Get Oil Out! (GOO!), and Citizens Planning Association of Santa Barbara (CPA) announced today that they have signed an historic and unprecedented agreement that will allow for development by Plains Exploration & Production Company (PXP) of the Tranquillon Ridge Oil and Gas Field off Lompoc, while curtailing the life of existing oil and gas operations offshore Lompoc and the Gaviota Coast. The agreement further requires PXP to reduce greenhouse gas emissions and protect significant lands in the County. (See Fact Sheet and Maps.)

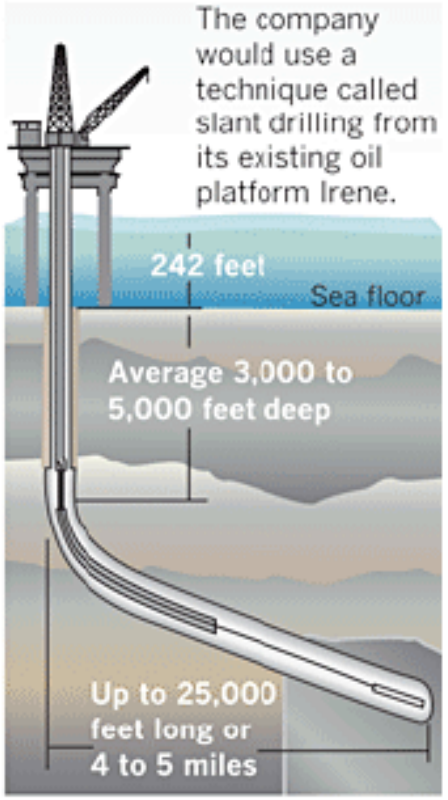
In an attempt to obtain support from the environmental groups, PXP offered to shut down its entire operation (both existing and new development) in 2022, when the existing Pt. Pedernales Project is slated, but not required, to end. PXP has also agreed that the 2022 end date will apply to its existing Lompoc Onshore Oil Fields and has committed to terminate its Gaviota Coast operations, i.e., the Pt. Arguello Project, comprised of Platforms Hidalgo, Harvest and Hermosa, and the Gaviota processing site, by 2017.

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.



Slant oil drilling



Drawing not to scale

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*