The Harvest Experiment:
Updates from the Platform and Regional Campaigns

Bruce Haines and Shailen Desai
Jet Propulsion Laboratory, California Inst. of Tech., Pasadena USA
Adam Dodge and Bob Leben
Colorado Center for Astrodynamics Research, University of Colorado, Boulder USA
Christian Meinig and Scott Stalin
NOAA Pacific Marine Environmental Laboratory, Seattle USA

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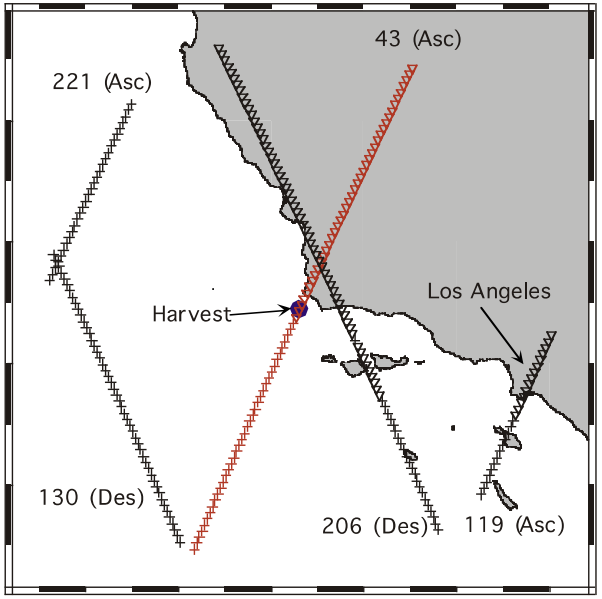
Harvest Platform

- **NASA Prime Verification Site for High-Accuracy Jason-class Altimetry (est. 1992)**
  - Open-ocean location along 10-d repeat track
  - 10-km off coast of central California
- **Provides independent measure of local geocentric sea level**
  - Precise GPS receivers
  - Redundant tide gauges (Bubbler, radar, lidar)
  - Local survey
- **Yields absolute SSH bias**
  - Also provides for monitoring of ancillary parameters (e.g., wet troposphere delay)
- **Supports collection of rich in-situ data set representing over 26 yr of continuous monitoring**
  - 365 T/P overflights spanning 10 years (1992–2002)
  - 259 Jason-1 overflights spanning 7 years (2002–2009)
  - 303 Jason-2 overflights spanning 8 years (2008–2016)
  - 96 Jason-3 overflights and counting (2016–)
- **Platform production remains on hold**
  - Future of platform not assured
  - Risk reduction activities underway

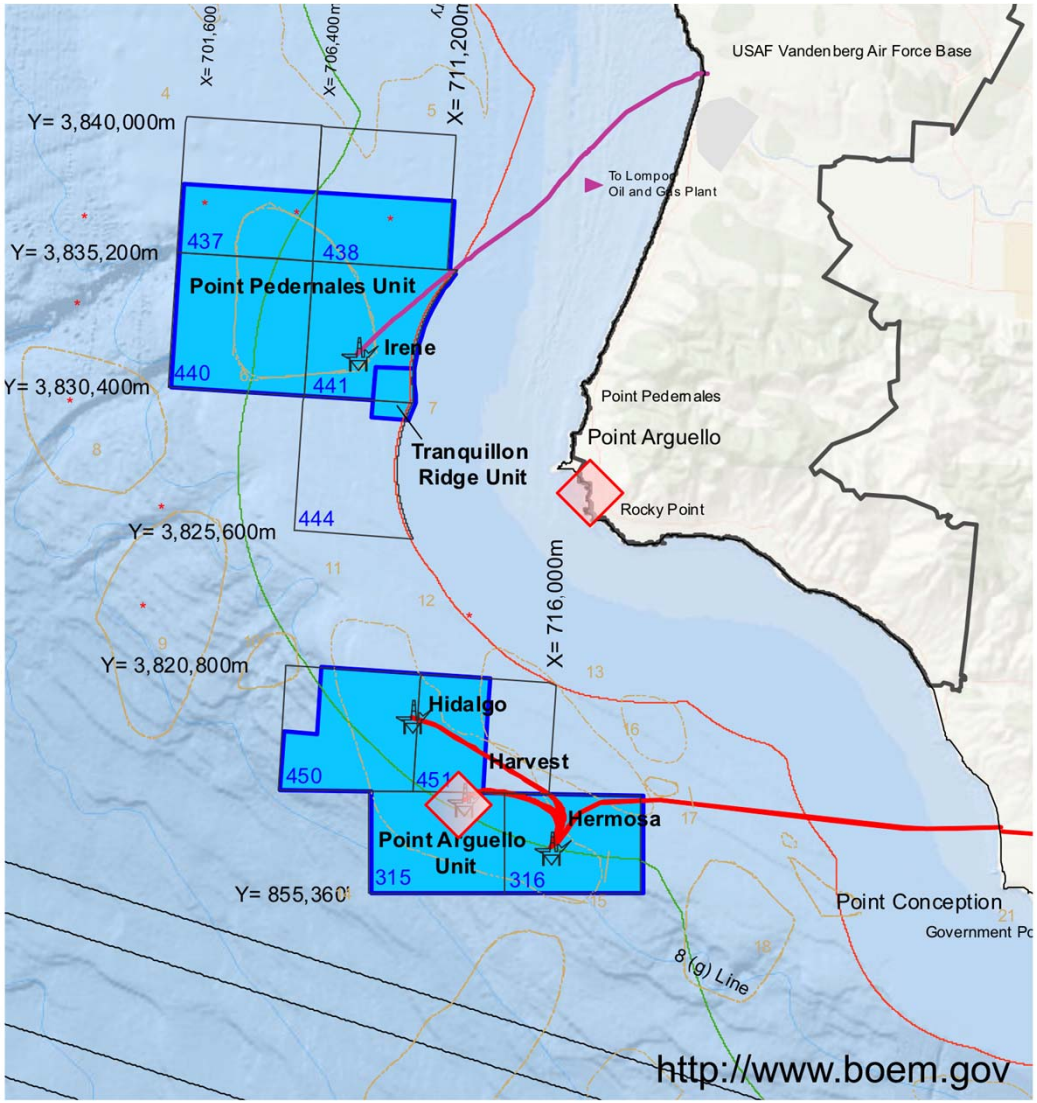


Highlights

- **Major Update to Model of Vertical Seafloor Motion**
- **New Tide-Gauge Technologies: Improving Prospects**
- **Updated Calibration Results for Sea-Surface Height and Path Delay Results: 26 Years**
- **Future of Harvest; Expanding the Calibration Footprint**
  - **GPS buoy campaign underway**
  - **New land-based tide gauges**

Vertical Land Motion from GPS

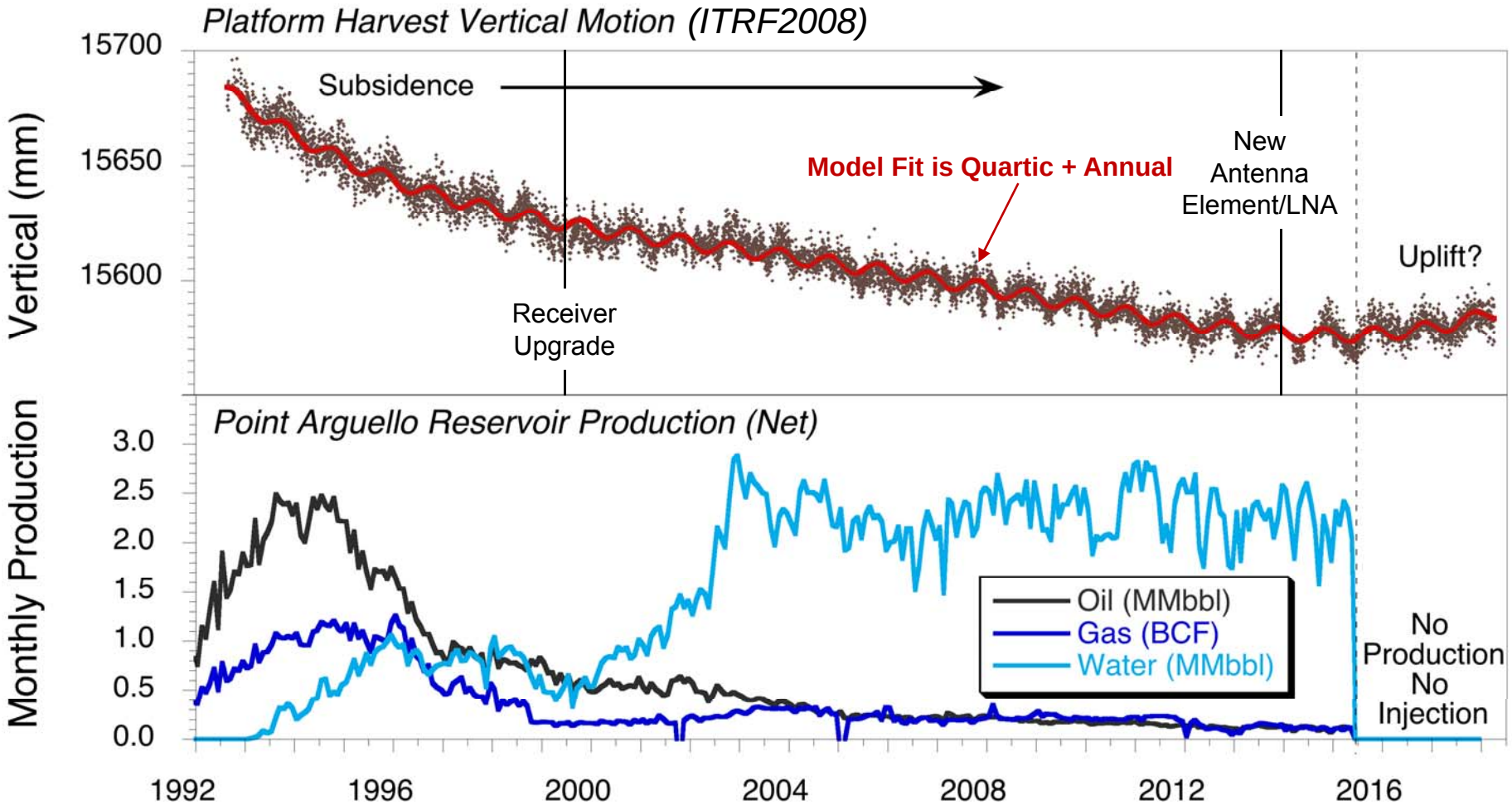
- Harvest (est. 1985) is the central of three oil platforms located over the Point Arguello offshore reservoir.
- Production began in 1991, peaked in 1994, and halted in 2015.
- Continuous GPS since 1992: one of the oldest GPS/tide gauge co-locations in the world.
- GPS at nearby Vandenberg AFB (est. 1992) provides onshore fiducial point away from reservoir subsidence bowl.
- Non-linear seafloor motions present significant challenge for altimeter calibration.



◇ GPS Receivers

New Estimate of Vertical Seafloor Motion from GPS

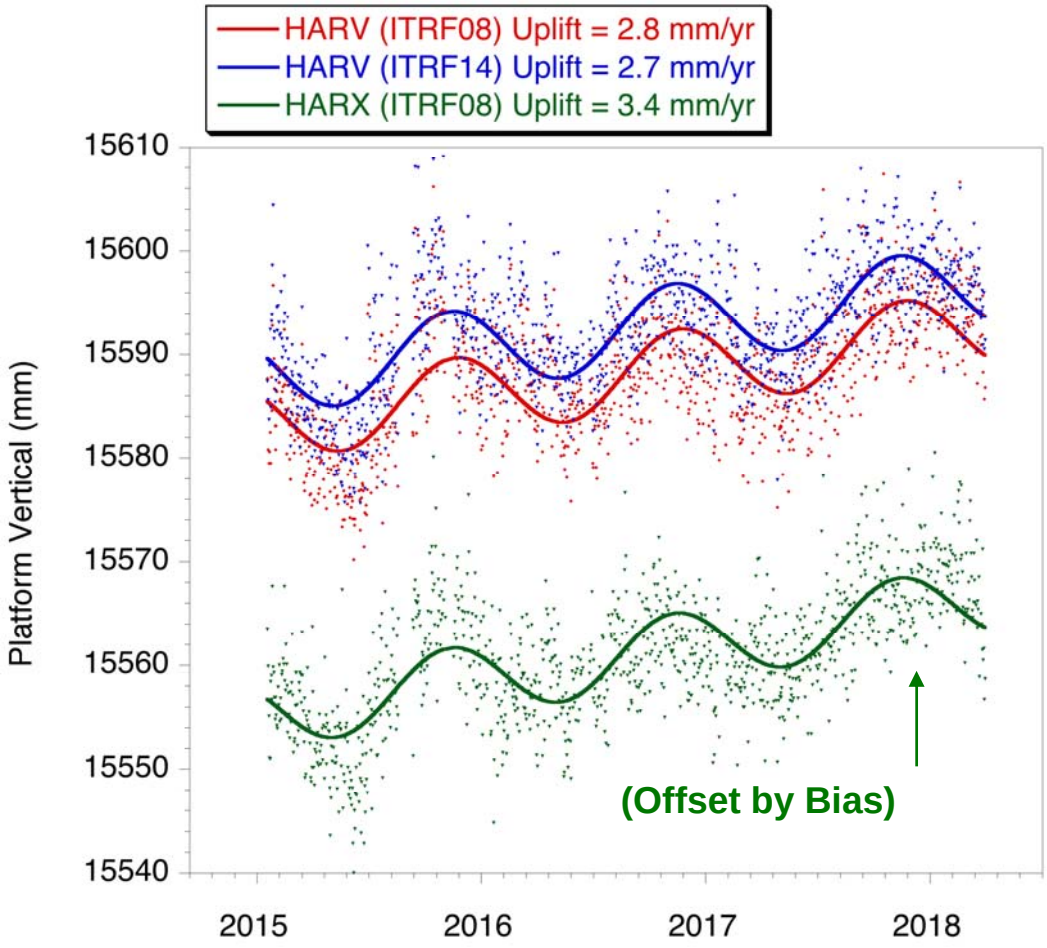
Complex Pattern of Subsidence and Rebound



https://www.data.boem.gov/Main/PacificProduction.aspx

Current Estimate of Vertical Seafloor Motion from GPS
Is Recent Uplift Real?

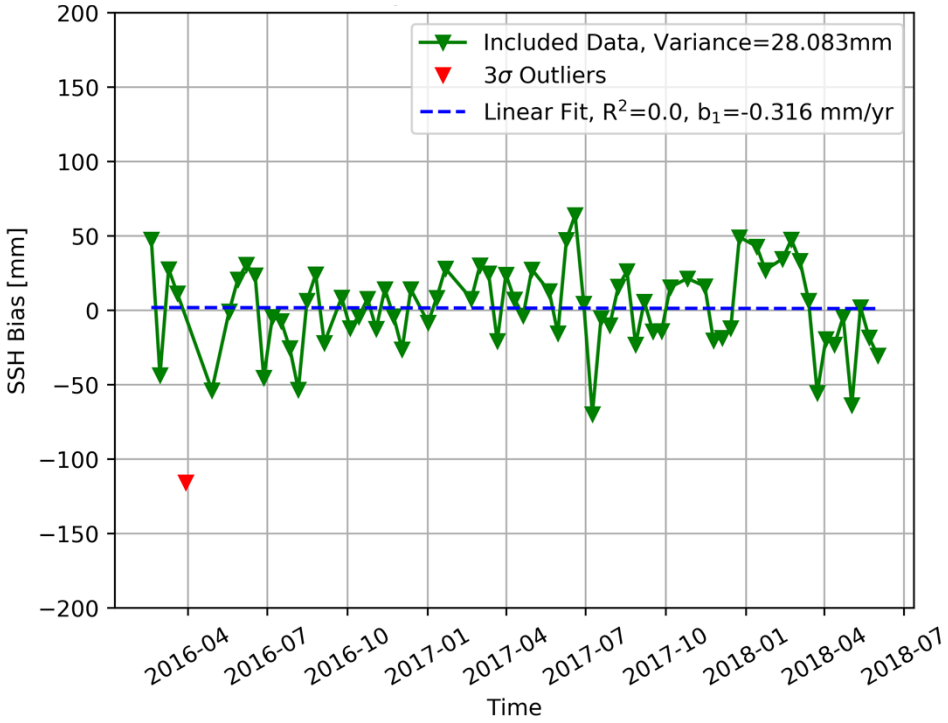
Application of New JPL GPS Orbit/Clock Products (in ITRF2014) and Use of Data from Independent Station* Show Similar Uplift (~3 mm/yr) since 2015



*Independent GPS system (receiver + antenna) installed in 2015 for monitoring purposes.

Platform Water Level from Tide Gauges
Update on Tide Gauge Performance in Heavy Seas

Jason-3 SSH Bias Using Radar Gauge



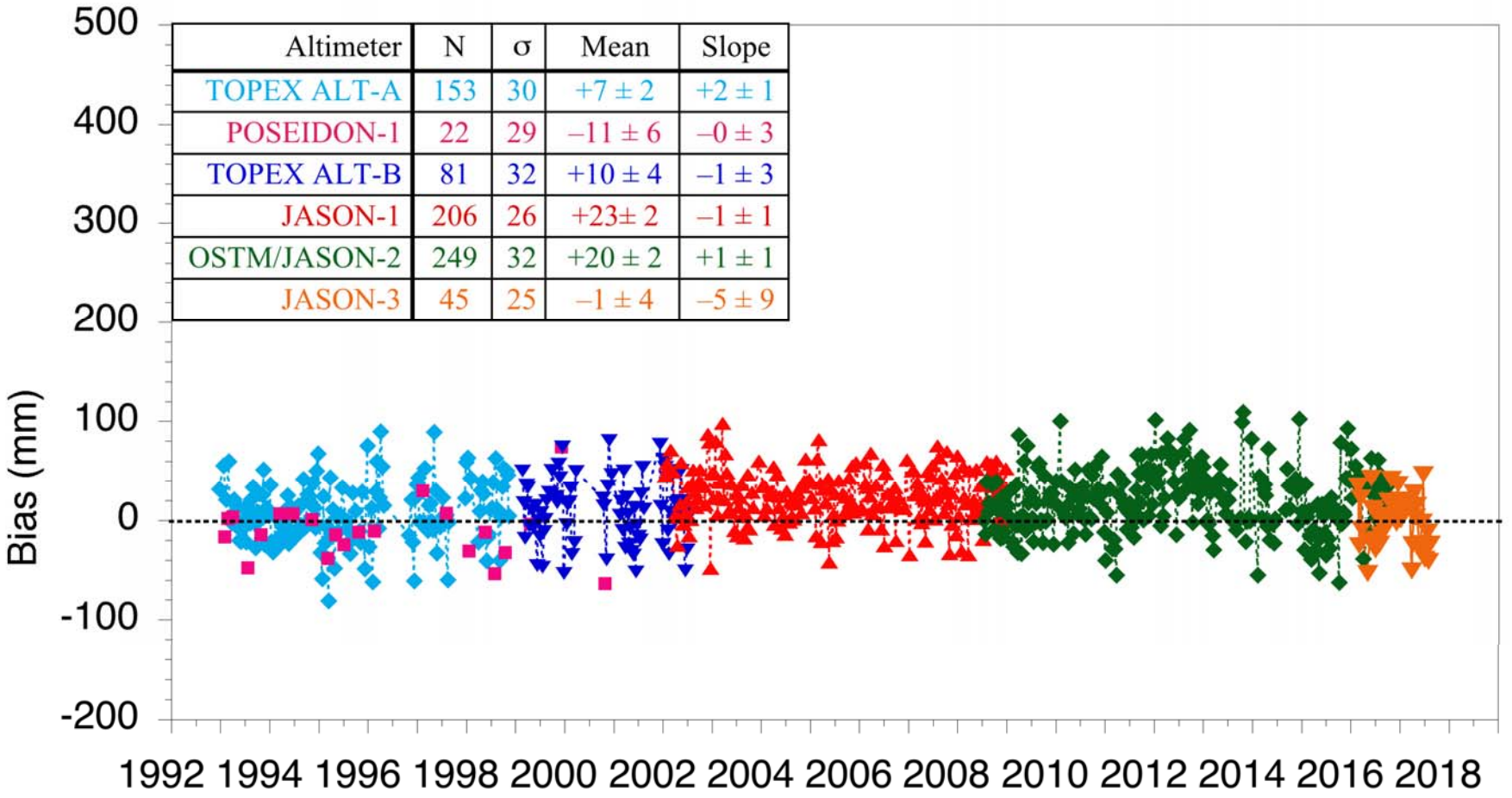
- Pressure (Bubbler) gauge has served as the standard at Harvest for many years, but has significant sea-state dependence and presents maintenance challenges.
- Radar gauges stable, accurate, and easy to maintain: gradually replacing submerged systems in NOAA network.
- Studies are ongoing to characterize remaining systematic errors from, e.g. wind waves, swell, sea spray and spume.
- Plan is to maintain pressure (Bubbler), radar and lidar systems operating simultaneously as long as practical.

Harvest Long-Term SSH Calibration Record

Circa October 2017 (Miami OSTST)

Nominal Time Series:

T/P: MGDR + reprocessed orbits (*Lemoine et al.*, 2010) and wet trop. (*Brown et al.*, 2009); **Jason-1:** GDR-E; **Jason-2**: GDR-D; **Jason-3**: GDR-E

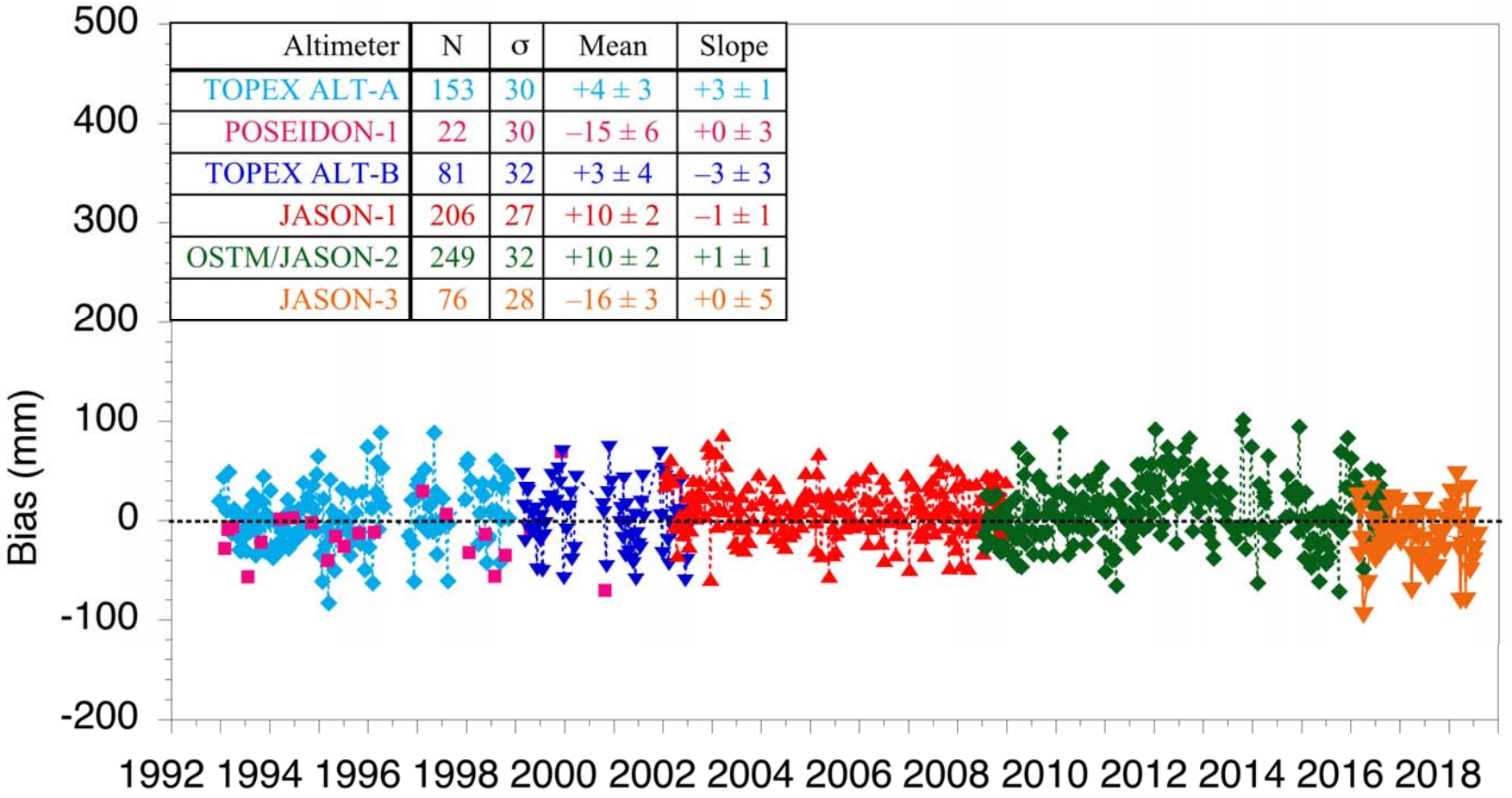


Harvest Long-Term SSH Calibration Record

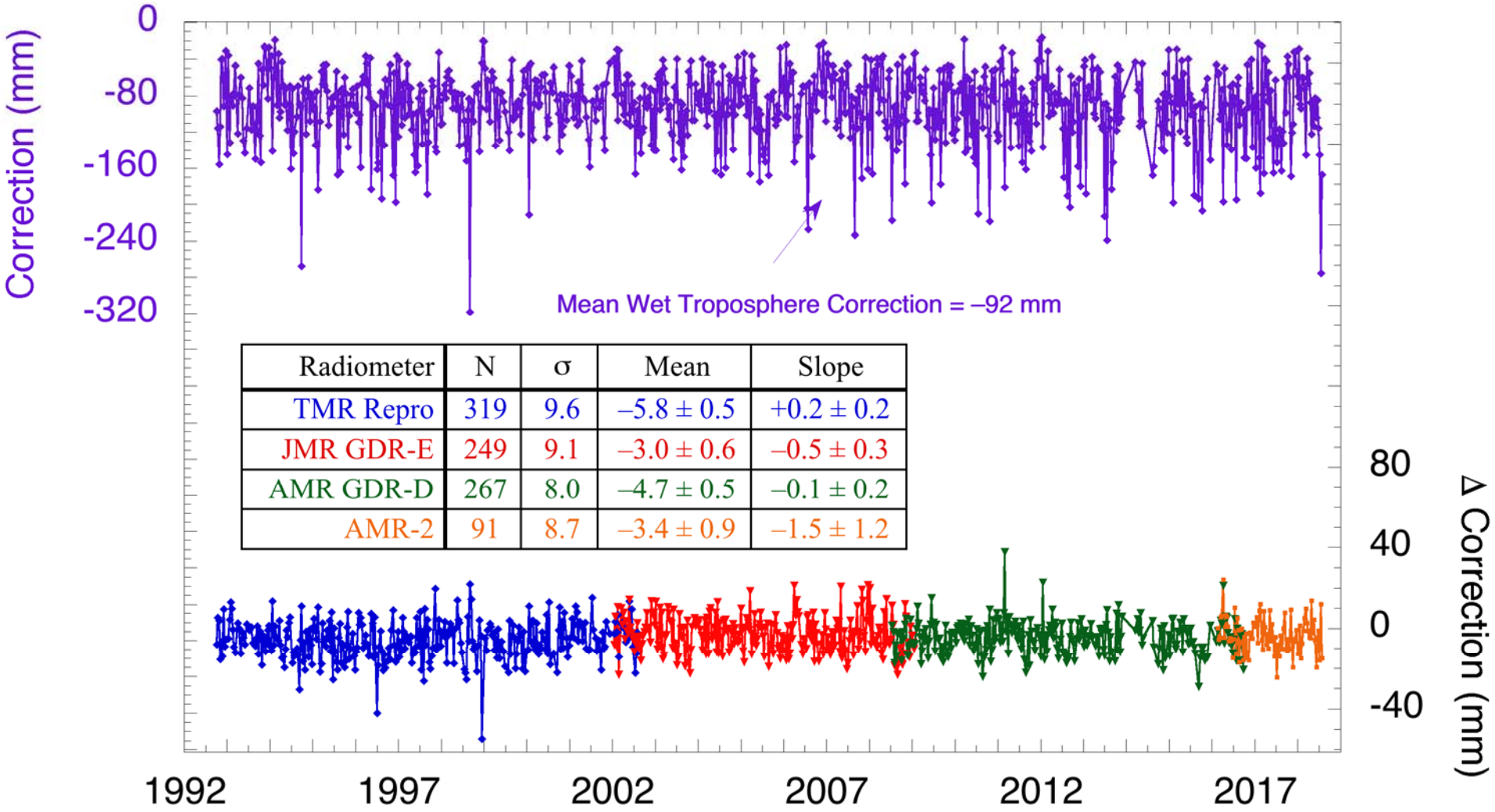
Current Best Estimate (Using New Estimate of Seafloor Motion)

Nominal Time Series:

T/P: MGDR + reprocessed orbits (*Lemoine et al.*, 2010) and wet trop. (*Brown et al.*, 2009); **Jason-1:** GDR-E; **Jason-2**: GDR-D; **Jason-3**: GDR-E

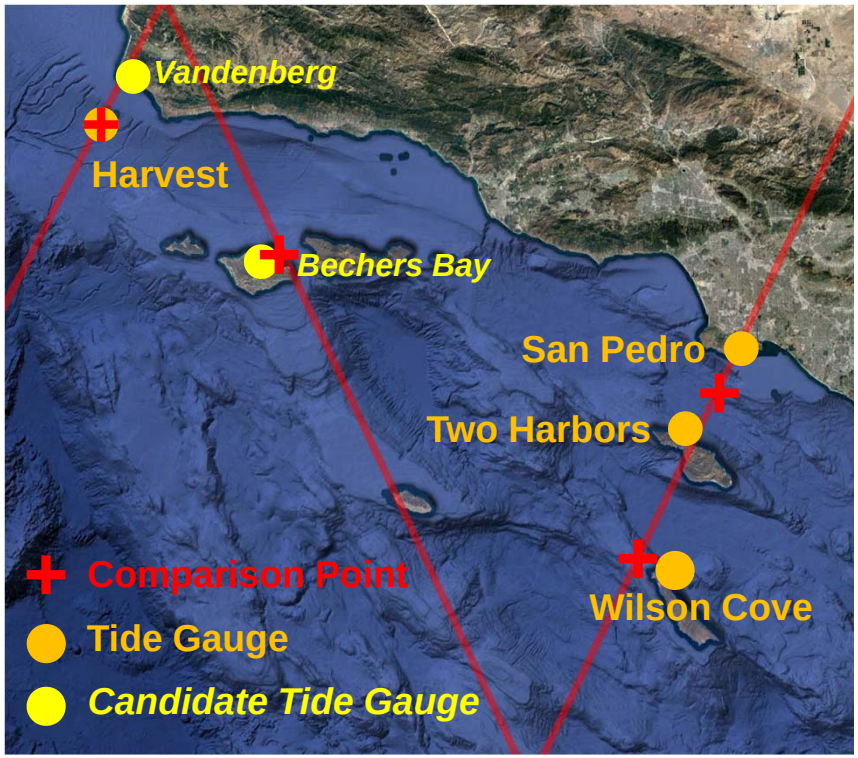


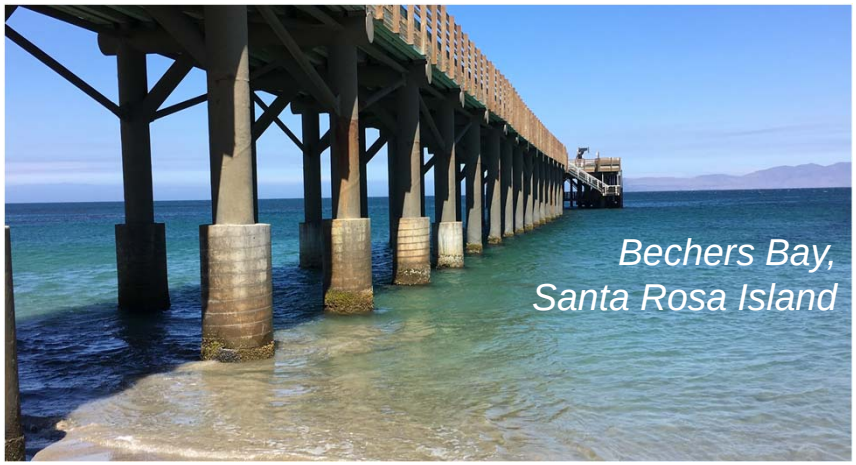
Wet Troposphere: Radiometer vs. GPS



Towards a Permanent Regional Network:
Provisional Tide Gauge Sites

- **Lidar tide gauge (TG) installed 6/2016 on Catalina Island**
  - USC Wrigley Inst. for Environmental Studies near Two Harbors.
  - ~20 km (along Jason pass 119) to center of San Pedro Channel.
- **First altimeter vs. TG comparisons show promise**
  - 30-mm repeatability (N = 14 overflights) for comparison point in San Pedro channel.
  - But 45% of overflight opportunities eliminated on account of high backscatter (low winds).
- **Radar gauge installed 3/2017 on San Clemente Island**
  - NOAA/NOS COOPS sensor in Wilson Cove for 90 days
  - Comparison point is along unobstructed open-ocean approach.
  - Wind/wave conditions are intermediate: more active than San Pedro Channel, but less active than Harvest.
  - 24-mm repeatability (N = 9 overflights)
- **Two Additional Sites Under Consideration**
  - Vandenberg boat dock, close to primary (Harvest) Track, and permanent GPS at US Air Force Base (est. 1992).
  - Bechers Bay on Santa Rosa Island (adjacent descending pass).





GPS Buoy Project

- Joint NASA JPL, NOAA PMEL and U. Washington project funded through NASA ROSES call (Physical Oceanography)*

OBJECTIVES:

- Design, build and test a modular, low-power, robust, high-accuracy GNSS measurement system for long-term, continuous and autonomous operations on ocean- and cryosphere-observing platforms.
- Probe the limits of new kinematic precise-point positioning (PPP) techniques for accurately determining sea-surface height, and recovering neutral and charged atmosphere characteristics.
- Explore potential scientific benefits—in the fields of physical oceanography, weather and space weather—of accurate GNSS observations from a global ocean network of floating platforms.

**Extending the Reach of the Global GNSS Network to the World's Oceans: A Prototype Buoy for Monitoring Sea Surface Height, Troposphere and Space Weather*, B. Haines, S. Brown, S. Desai, A. Komjathy, R. Kwok, D. Stowers, C. Meinig and J. Morison.

Prototype Precision GPS Buoy

FEATURES

- Integrated low-power (~1 W), dual-frequency GPS system (Septentrio)
- Miniaturized digital compass/accelerometer.
- Iridium communications (presently used for basic heartbeat information).
- Adaptable to multiple floating platforms (e.g., buoys, wave gliders).
- Enables geodetic quality solutions without nearby reference stations.

DEVELOPMENT AND TESTING

- Buoy tested successfully under progressively more challenging conditions:

✓ *Lake Washington (Aug. 7–12, 2015).*

✓ *Puget Sound (Nov. 10 to Dec. 14, 2015).*

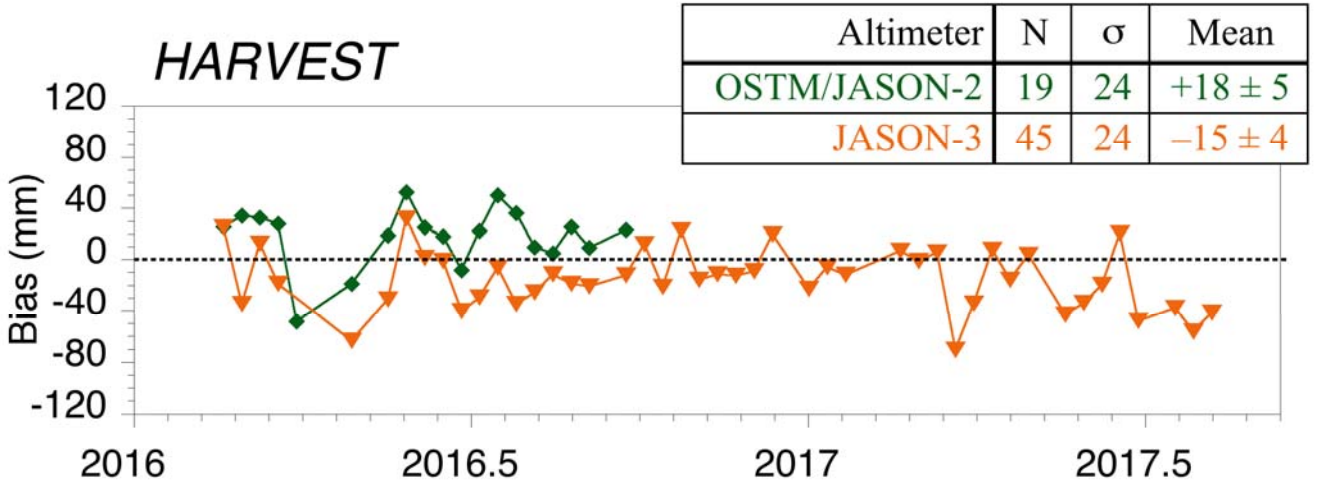
✓ *Daisy Bank: open ocean Jason crossover location (May 11 to Sep. 8, 2016).*

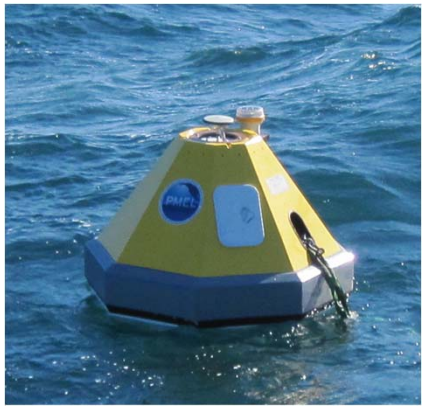
✓ *Monterey Bay: SWOT Pilot Experiment (June 22 to September 7, 2017).*

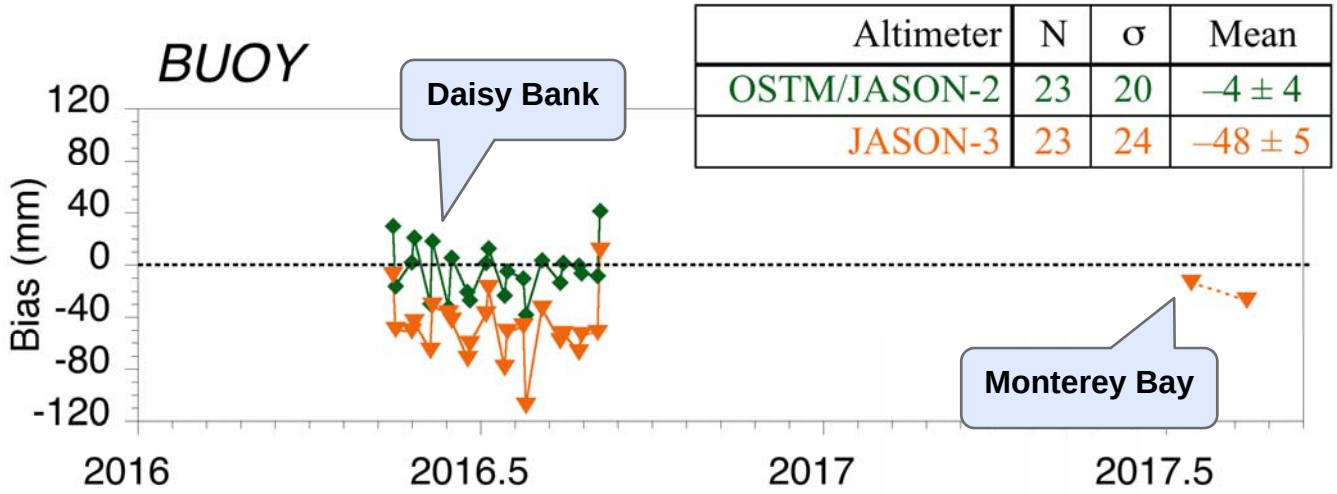
⇨ **Total of 236 days in the water** (20 days of data from Monterey Bay data lost due to failed USB drive).

Verification of Altimeter Sea Surface Height:
Harvest vs. Buoy (Daisy Bank + Monterey)

Comparable Results for the Jason-3 Era

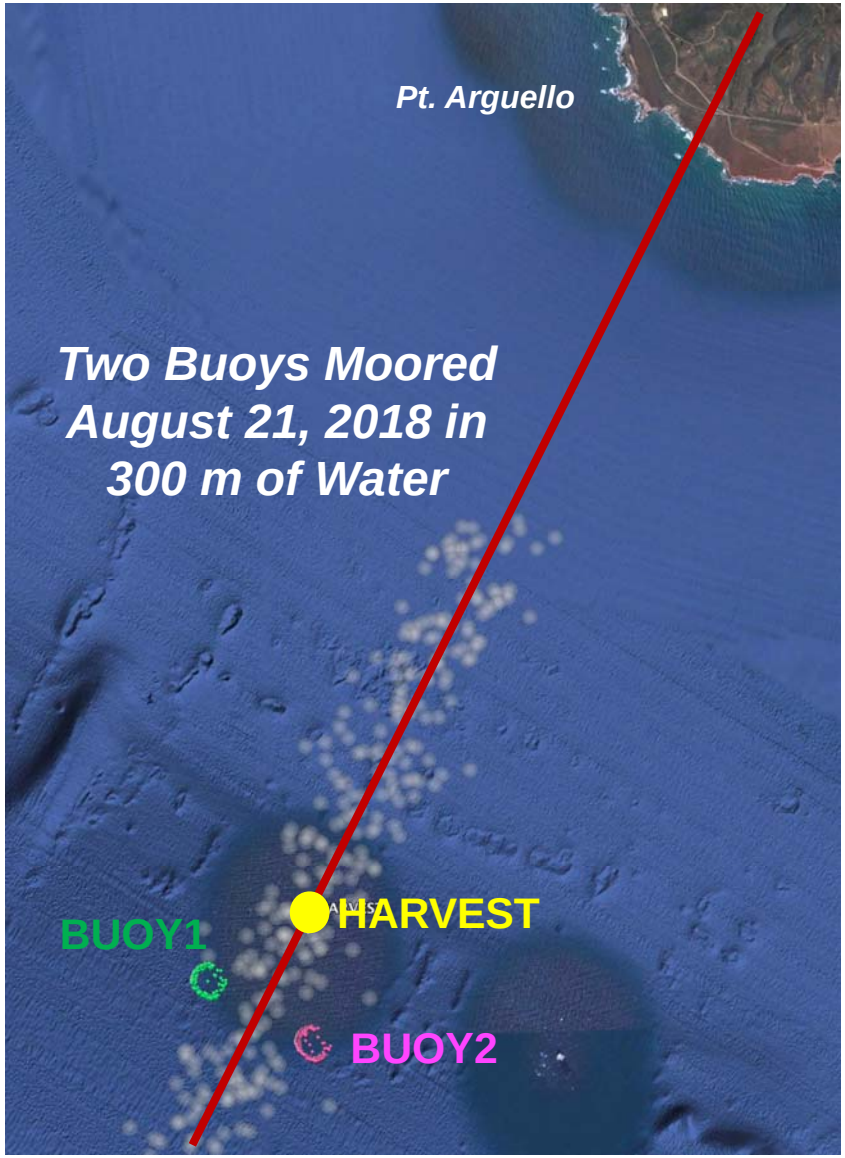






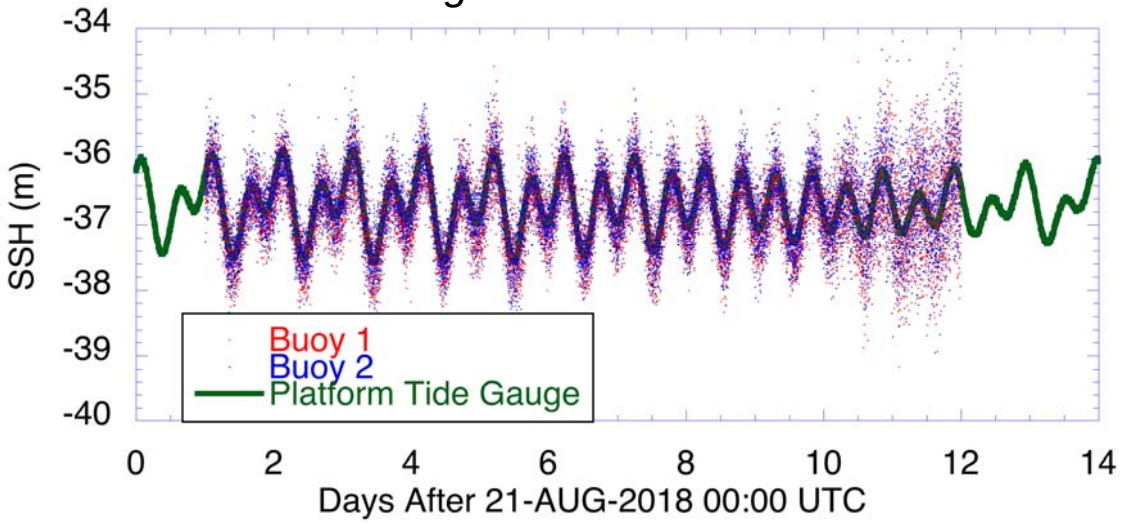
Harvest Buoy Campaign: Aug. 2018 – Jan. 2019

- Main goal: examine potential of precision GPS buoy systems to replace NASA Harvest verification site.
  - Risk reduction exercise for Jason-3 and Sentinel-6.
  - Anticipates possible platform loss or abandonment.
  - Buoys close to platform (~1.5 km) to support comparisons with platform tide gauges and overhead altimetry from Jason-3.
- Secondary goal: probe limits of GPS-based relative sea-surface height determination in open ocean.
  - Features two identically equipped surface buoys (new buoy modeled after prototype).
  - Buoys separated by ~1.5 km.
  - Short baseline will lend further insight on potential of GPS array for SWOT CALVAL.
- Campaign enhancements
  - New longevity goal of 150 days: operate through higher (winter) sea states.
  - Buoys equipped with load cells to measure force on mooring (to study movement of buoy water line).
  - NOAA Prawler for taking CTD and dissolved oxygen measurements along mooring.
  - Telemetry upgrade: 1-min snapshots of GPS tracking data + Prawler, load cell and orientation data. (High-rate GPS data saved onboard for recovery with buoys.)

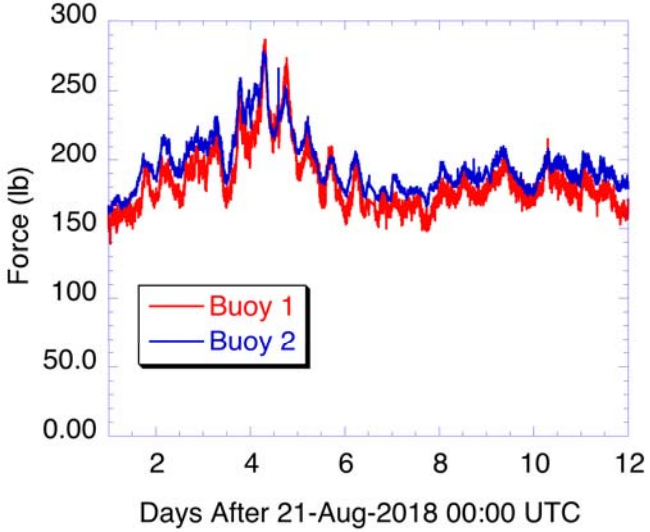


Early Results from the Harvest Buoy Campaign

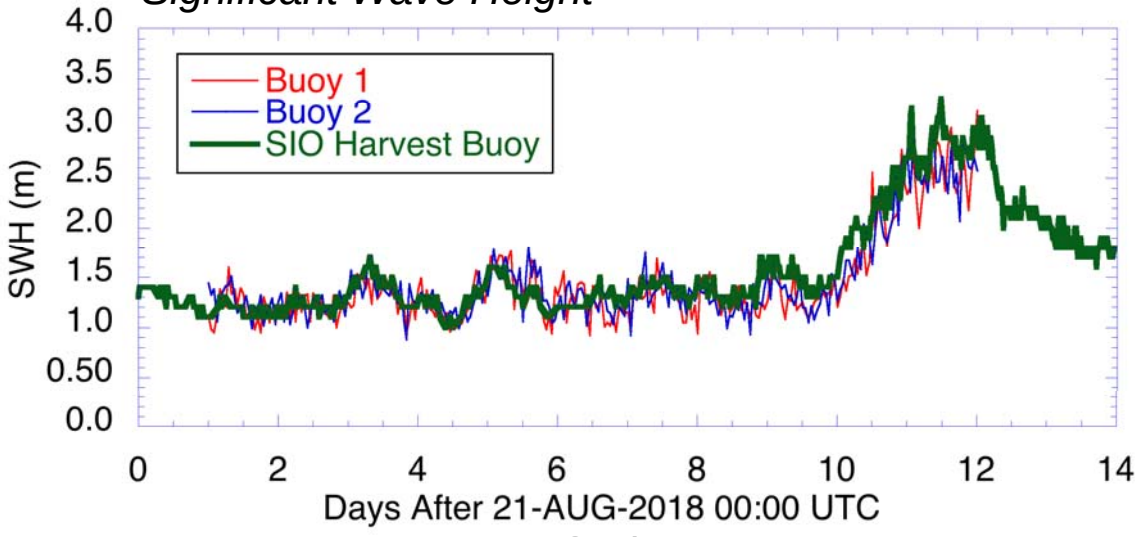
Sea Surface Height



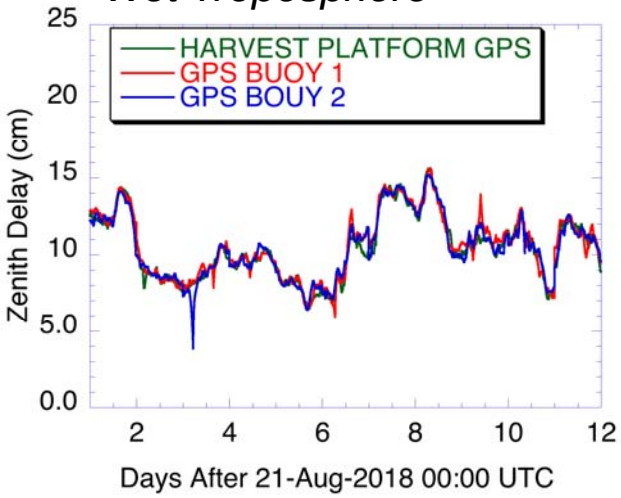
Load Cell



Significant Wave Height



Wet Troposphere



Summary

- **Absolute SSH bias from Harvest***
  - Jason-3: –16 ± 12 mm for GDR-E (thru Cycle 91 with N = 76)
  - Jason-2: +10 ± 10 mm for GDR-D (N = 249)
  - Jason-1: +10 ± 10 mm for GDR-E (N = 206)
  - ALT–B: +3 ± 10 mm for MGDR+ (N = 81)
  - ALT–A: +4 ± 12 mm for MGDR+ (N = 153)
  - POS–1: –15 ± 12 mm for MGDR+ (N = 22)
- **SSH drift at Harvest indistinguishable from zero for all systems**
  - ≤ 1 mm/yr for all systems except TOPEX (Side A).
- **Provisional tide gauges in Channel Islands**
  - Supplement Harvest for future missions (e.g., Sentinel-6, SWOT).
  - Provide some insurance against possible loss of platform.
- **Results from GPS buoy campaigns continue to show great promise**
  - Returned continuous, high accuracy data for Daisy Bank and Monterey Bay
  - Supported accurate retrievals of SSH, SWH, wet path delay and ionosphere.
  - Competitive with Harvest for all altimeter calibration metrics.
  - Harvest campaign underway with two buoys in platform vicinity.

** Error includes uncertainty in platform vertical*

Backup

Sample Harvest Prawler Data: Temperature Profiles