The Harvest Experiment: Salient Results from 2017–2020

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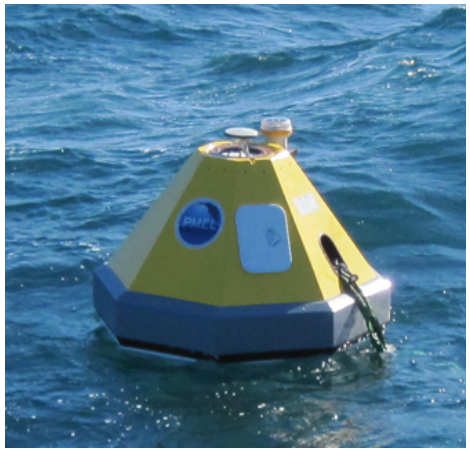
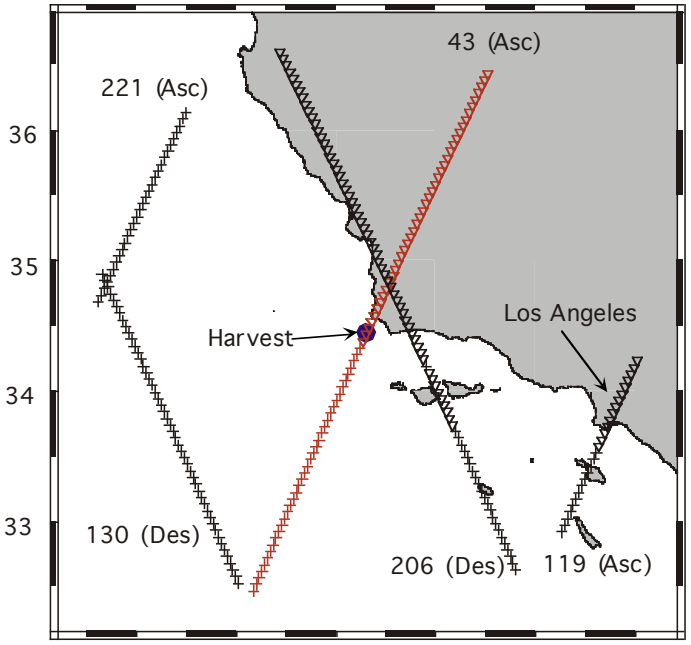
Virtual Forum

Harvest Platform: Status

- **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
  - Continuous support of TOPEX, Jason-1, -2 and -3
- **Provides independent measure of geocentric sea level.**
  - Precise GPS receivers (3 with 2 separate antenna mounts)
  - Redundant tide gauges: bubbler (1), radar (2) and lidar (1)
- **Platform to be decommissioned.**
  - Exact schedule uncertain, but long multi-year process
  - Regular tide gauge & sensor maintenance activities continue.
  - Risk reduction activities underway
- **Advanced buoy with GPS and Prawler (profiler) deployed.**
  - Demonstrated in multiple campaigns, including Harvest (2018–19)
  - Results competitive with Harvest
  - Moored near platform Oct. 5, 2020
  - Start of planned permanent occupation.





Highlights

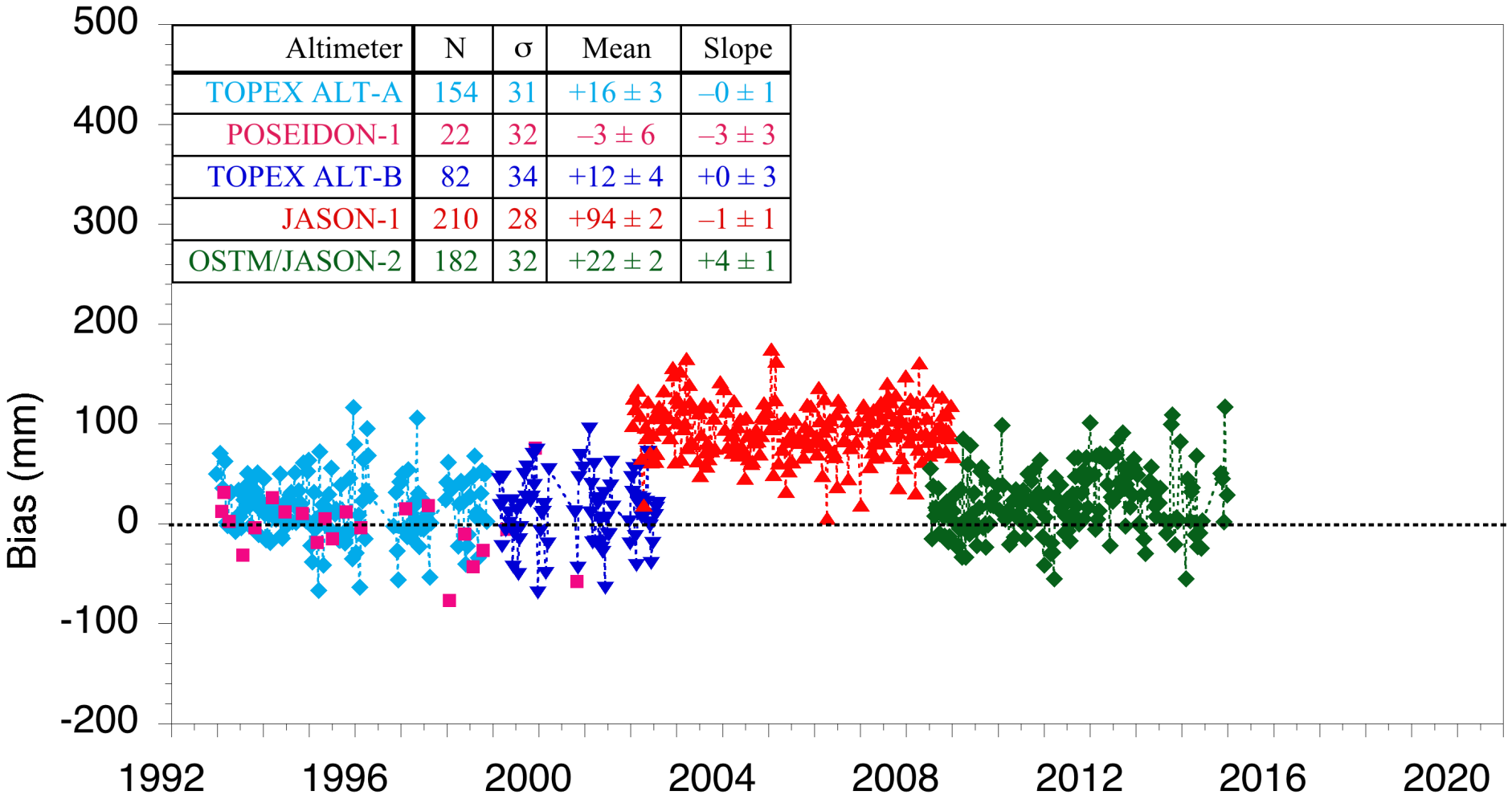
- **Evolution of Harvest SSH Time Series**
- Advances in Monitoring Vertical Seafloor Motion
- Advances in Tide Gauge Measurements
- Geographically Correlated Errors
- New Regional Observing Systems

Harvest Long-Term SSH Calibration Record

On Eve of Jason-3 Launch

Circa 2015 Time Series:

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

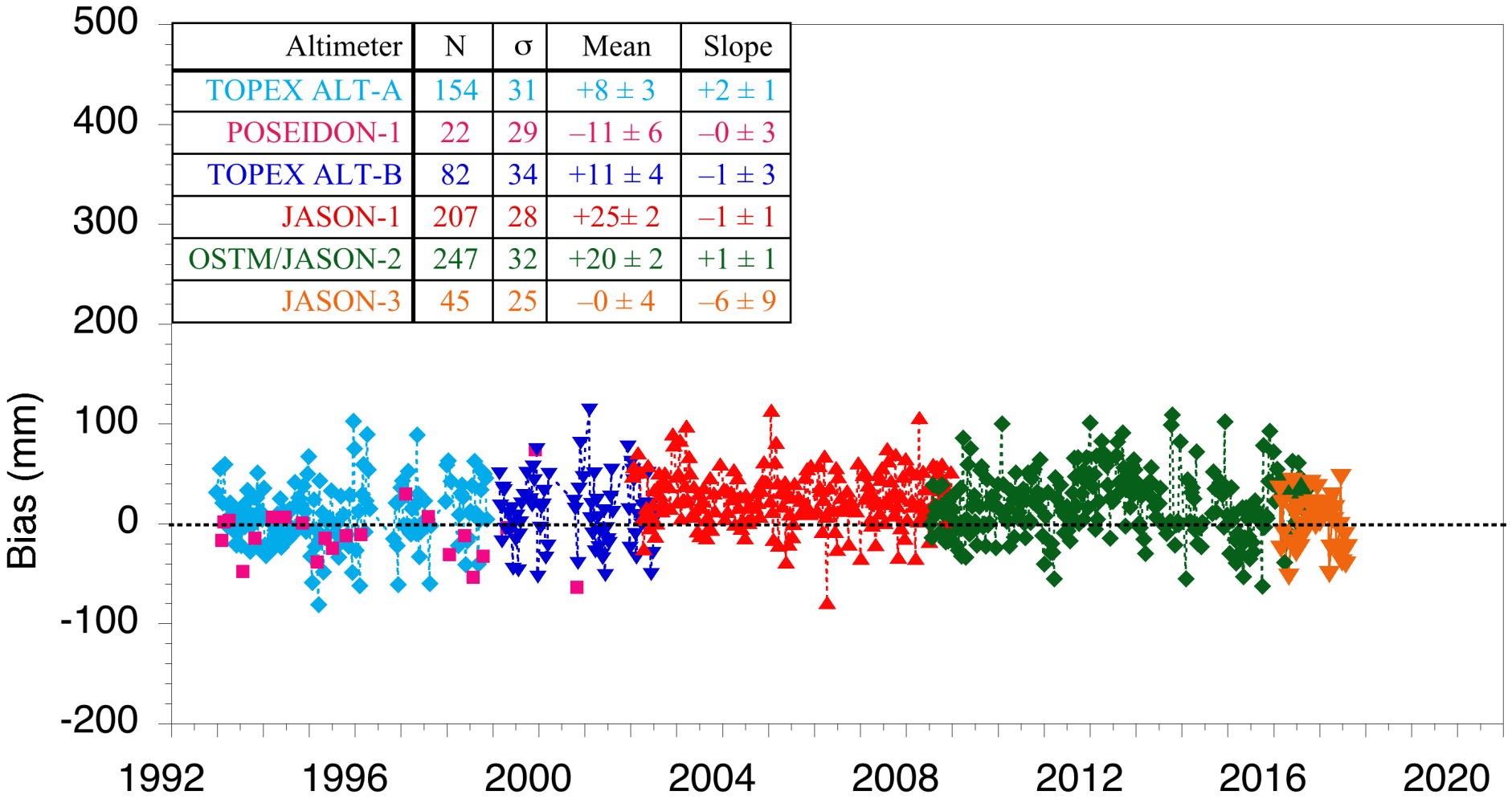


Harvest Long-Term SSH Calibration Record

Early Jason-3 Results

Circa 2017 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-T



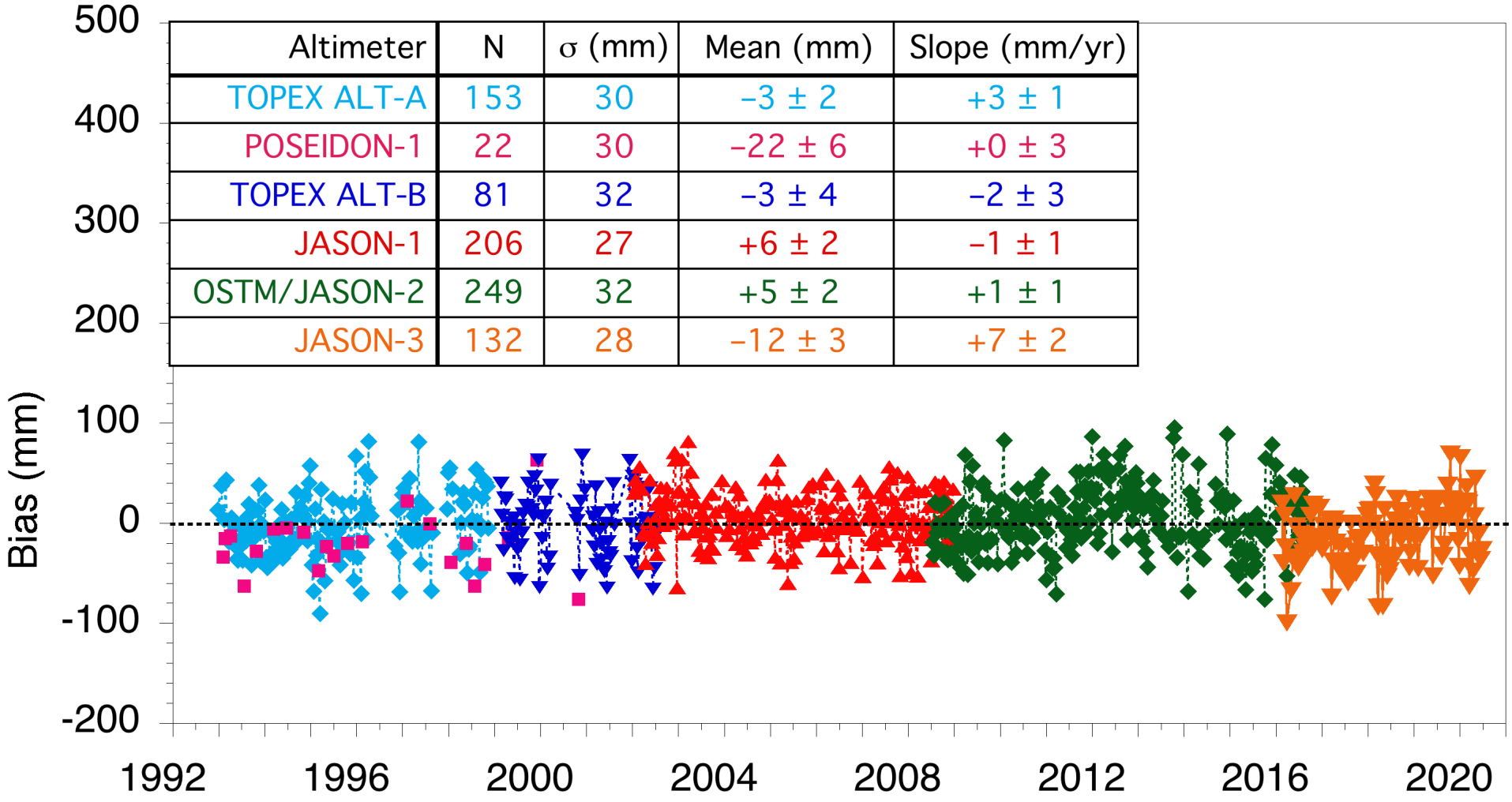
Harvest Long-Term SSH Calibration Record

On Eve of Sentinel-6 Launch

Current (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-D

Altimeter	N	σ (mm)	Mean (mm)	Slope (mm/yr)
TOPEX ALT-A	153	30	−3 ± 2	+3 ± 1
POSEIDON-1	22	30	−22 ± 6	+0 ± 3
TOPEX ALT-B	81	32	−3 ± 4	−2 ± 3
JASON-1	206	27	+6 ± 2	−1 ± 1
OSTM/JASON-2	249	32	+5 ± 2	+1 ± 1
JASON-3	132	28	−12 ± 3	+7 ± 2



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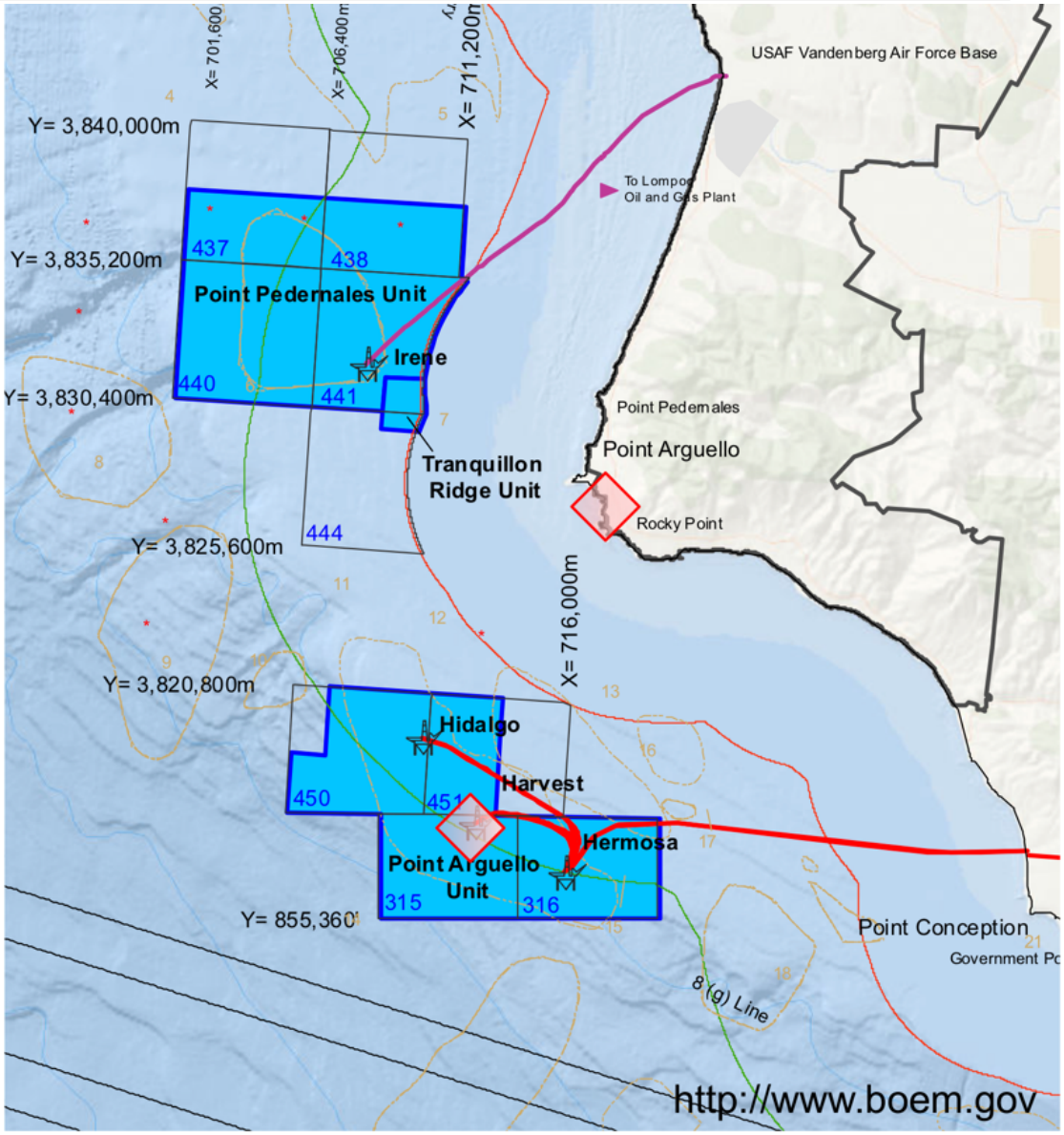
Vertical Land Motion from GPS

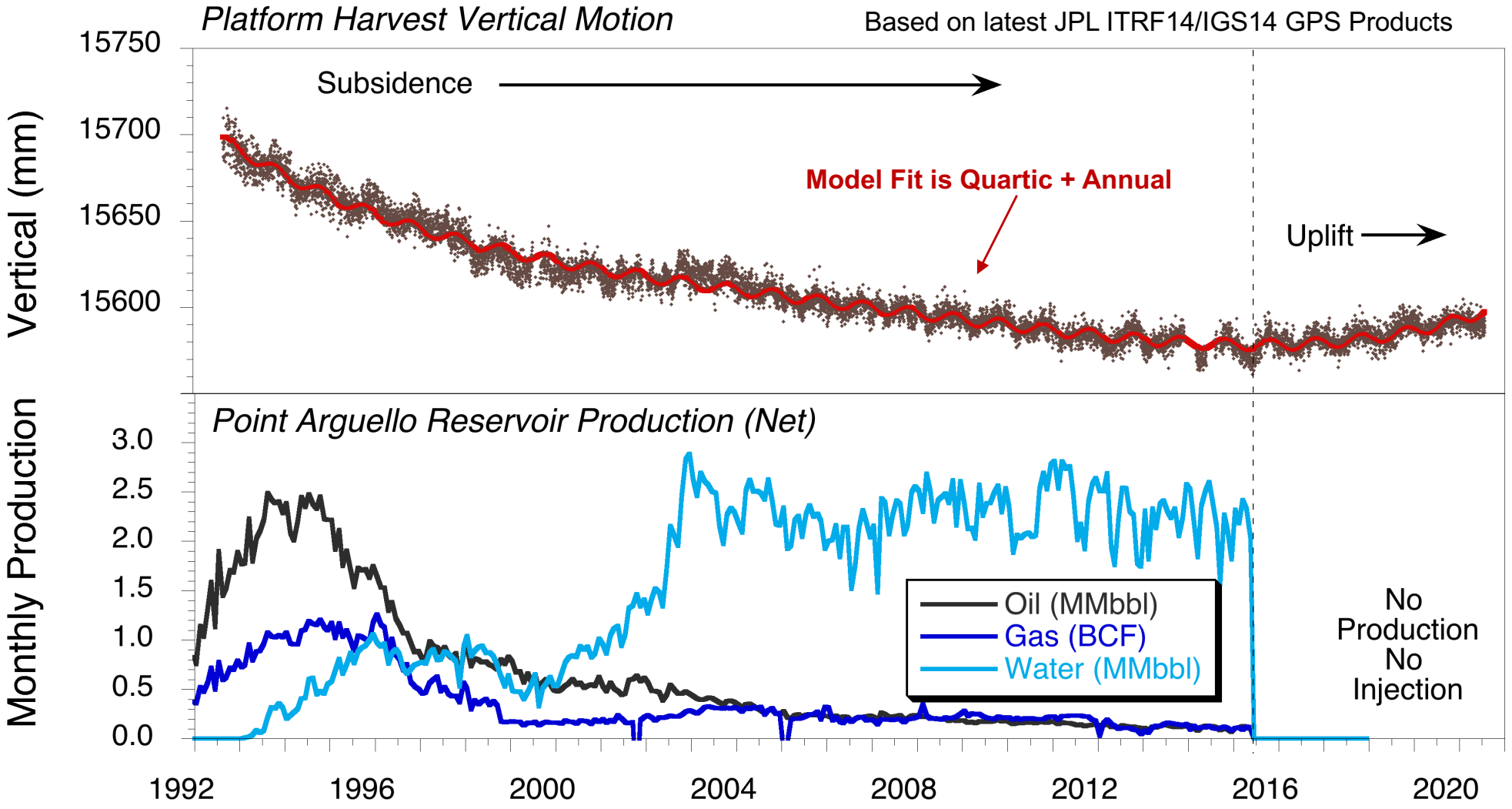
- Harvest (est. 1985) is the central of three oil platforms located over the Point Arguello offshore reservoir.
- Production began in 1991, peaked in 1994, and halted in 2015.
- Continuous GPS since 1992: one of the oldest GPS/tide gauge co-locations in the world.
- GPS at nearby Vandenberg AFB (est. 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

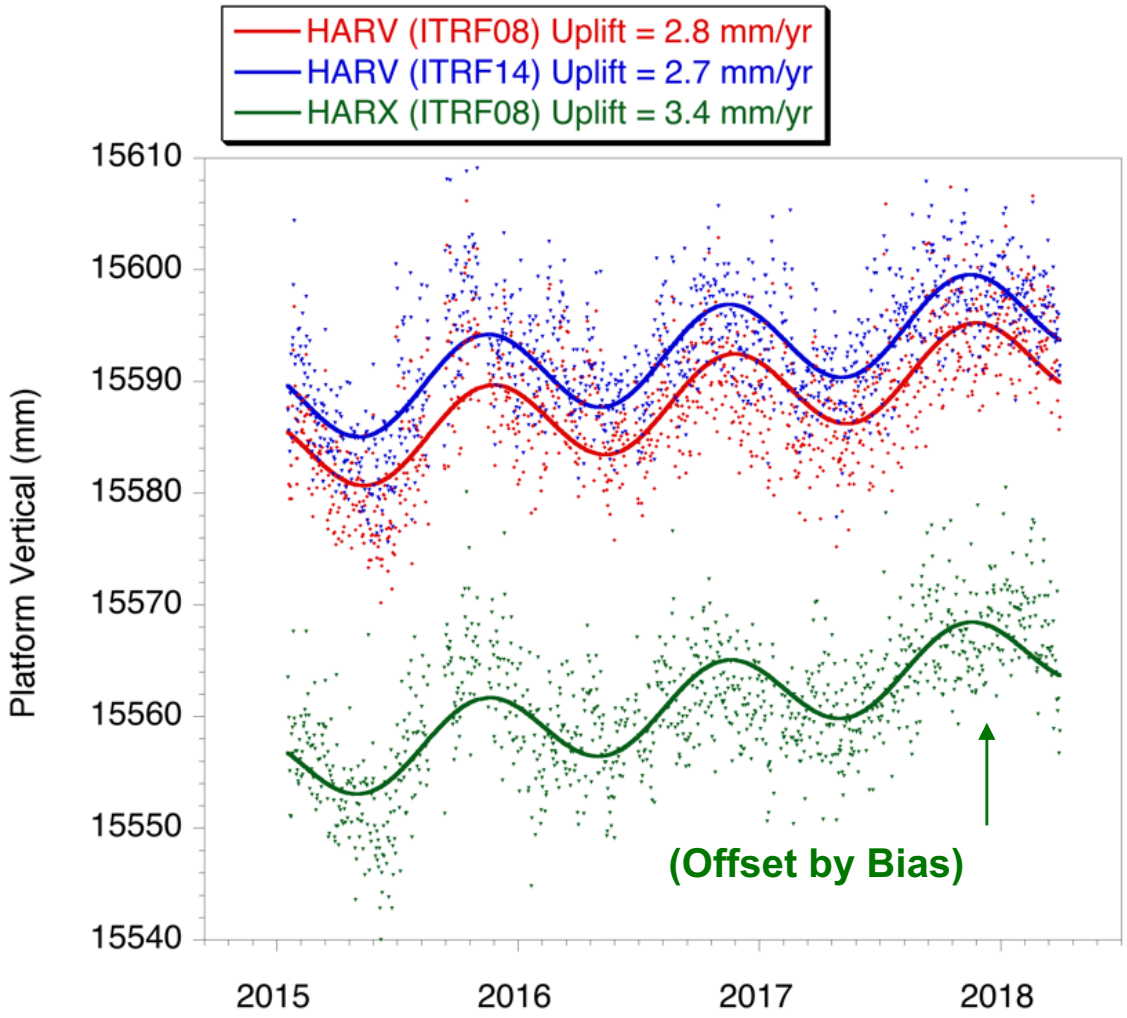
Complex Pattern of Subsidence and Rebound



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

Current Estimate of Vertical Seafloor Motion from GPS
Is Recent Uplift Real? (from 2018 OSTST Meeting)

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.

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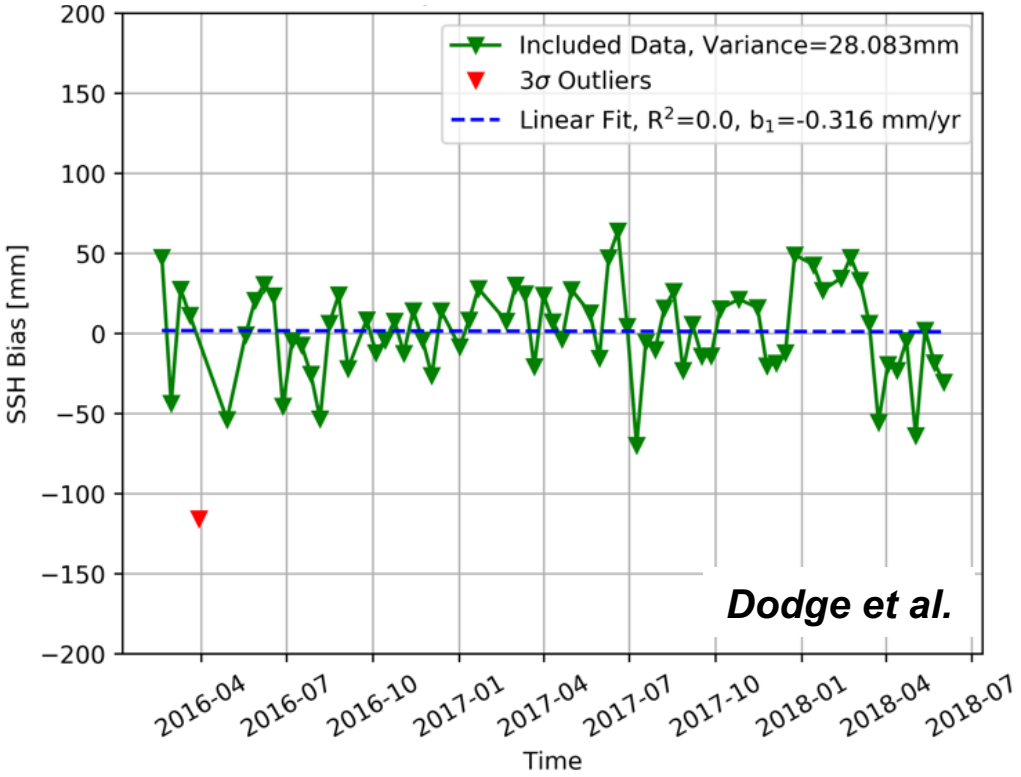
Platform Water Level from Tide Gauges
Update on Tide Gauge Performance in Heavy Seas

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, leveraging lidar systems.
- Plan is to maintain pressure (Bubbler), radar and lidar systems operating simultaneously as long as practical.

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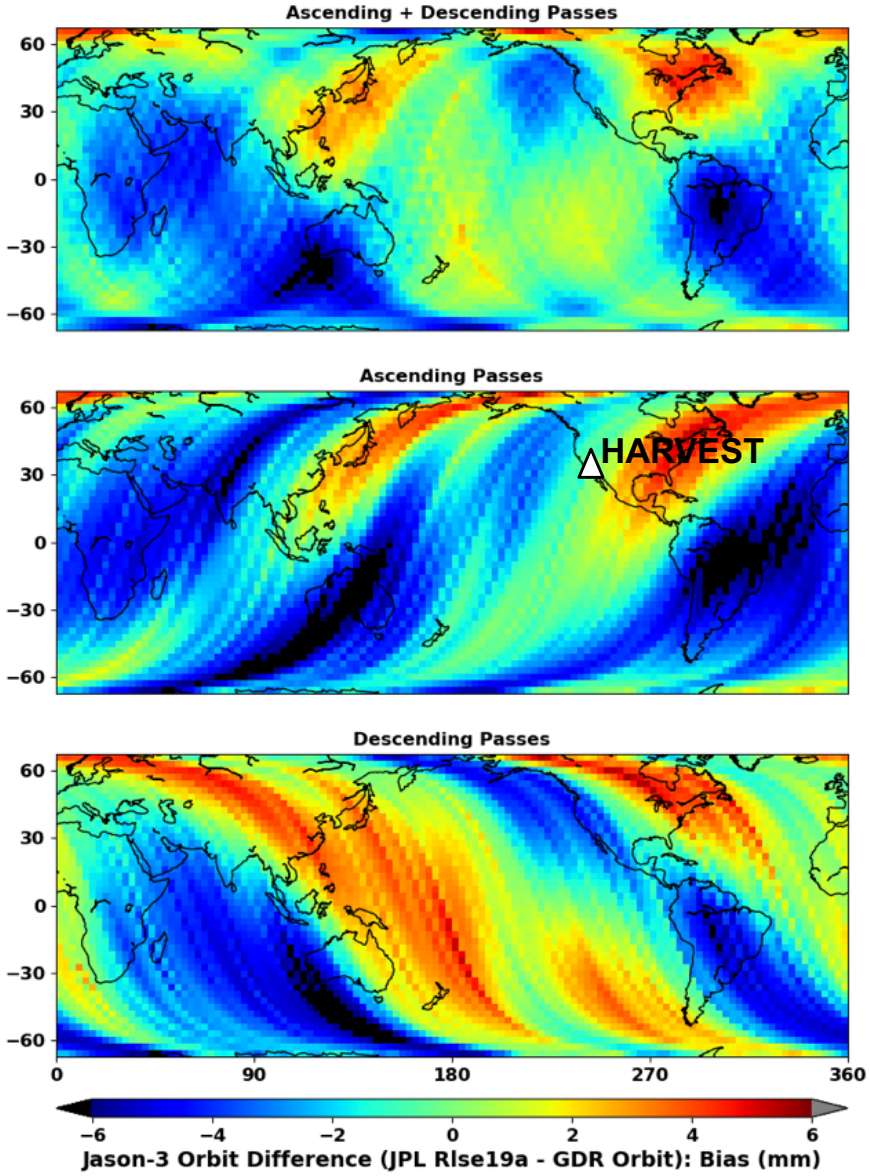
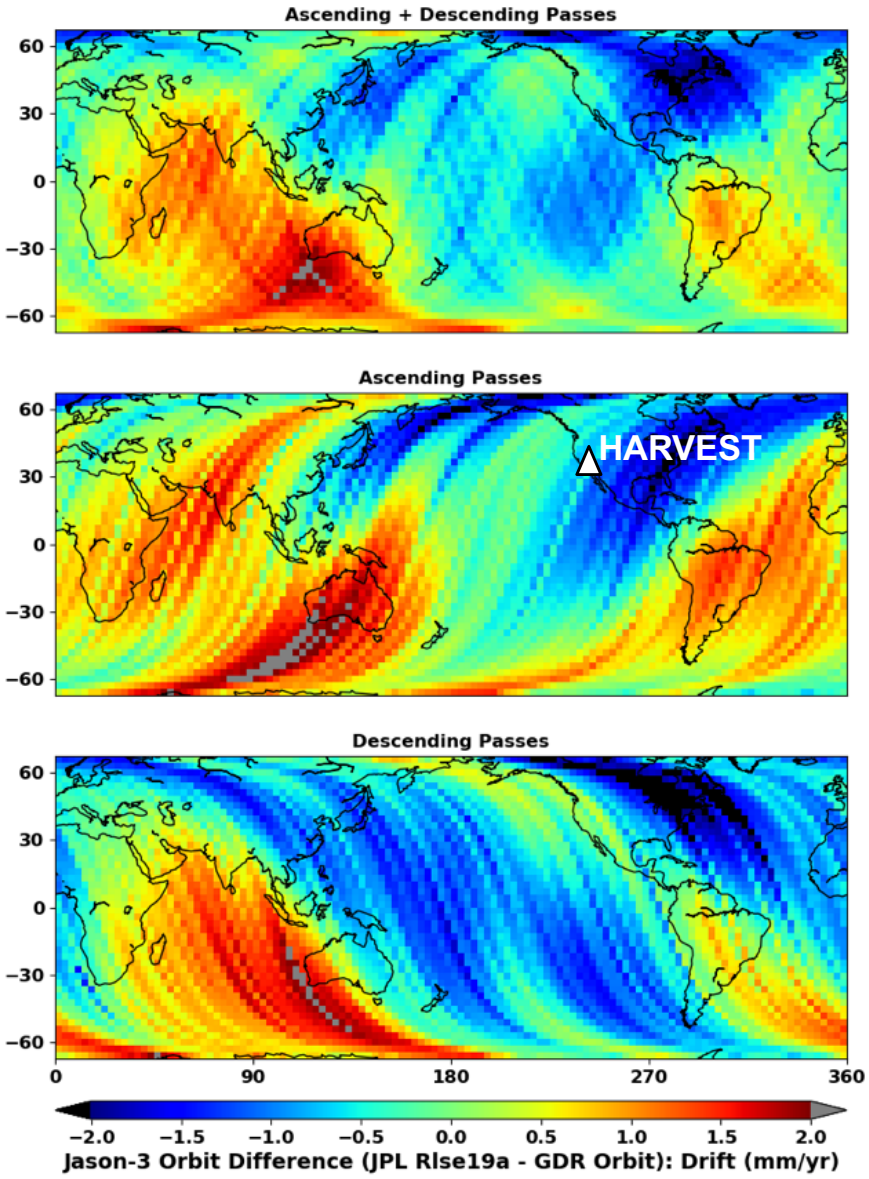
GPS Reduced Dynamic Orbit Solutions for Jason-3 Reveal Geographically Correlated Errors (JPL GPS RLS19a vs. GDR)

Mean (–2 mm at Harvest)



Drift (–0.8 mm/yr at Harvest)



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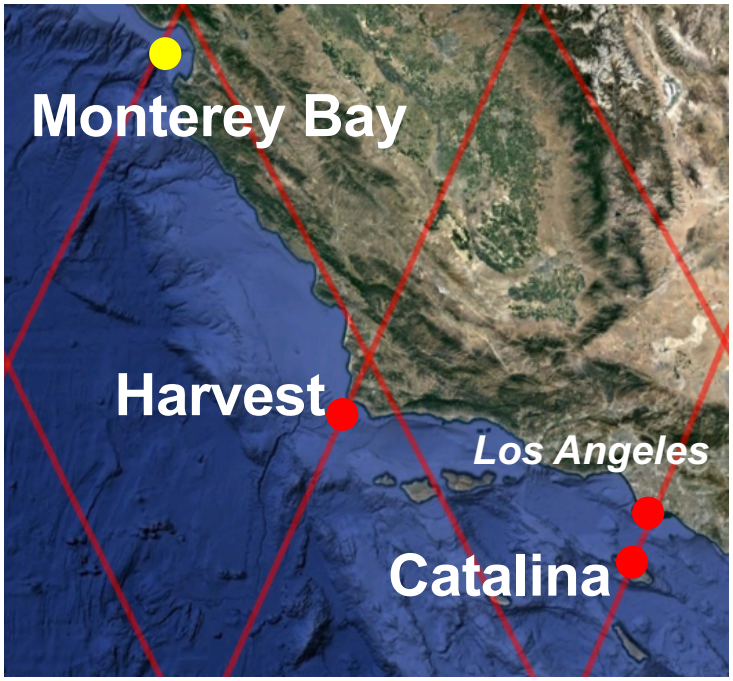
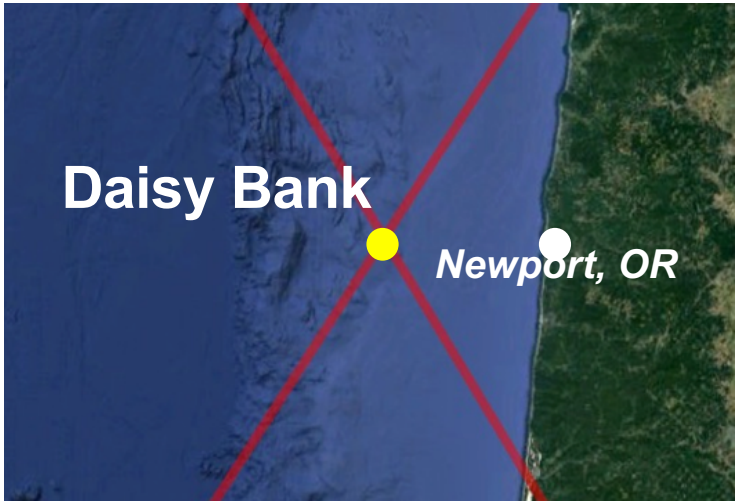
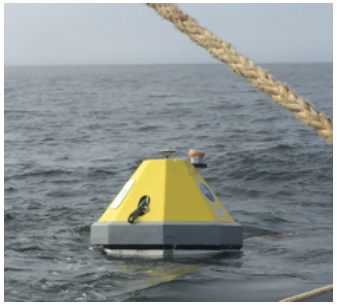
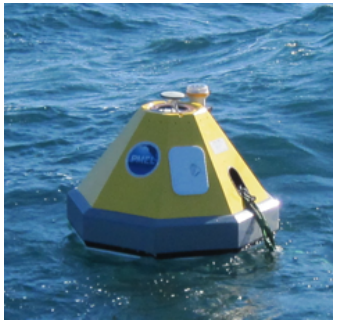
Regional Campaigns: Expanding the Calibration Footprint









Monterey Bay

Summer 2017 GPS Buoy Campaign for SWOT (but also near Jason pass).

Harvest

NASA Prime Verification Site for High-Accuracy (Jason-class) Altimetry.

Stable and Accurate Calibration Record Spanning 25 Years.

Catalina Island

Provisional calibration site est. 6/17 (lidar tide gauge + existing GPS).

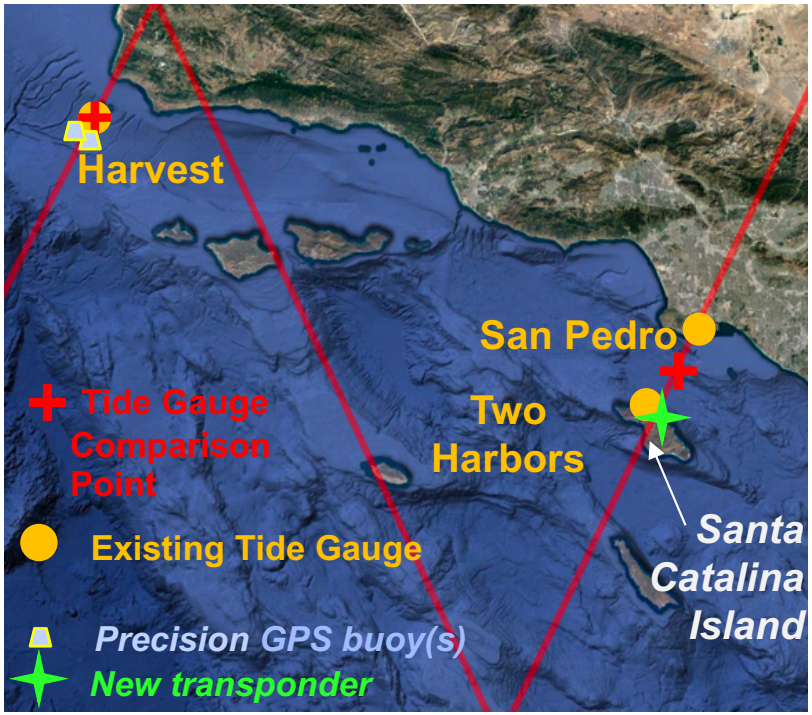
Daisy Bank

Summer 2016 GPS Buoy Campaign at Jason Crossover Location

Santa Catalina Island Cal/Val Site:

Tide Gauges and Transponder on Adjacent Ascending Track

- **Test facility for new, low-cost tide-gauge technologies**
  - Pier at Big Fisherman's Cove (University of Southern California Wrigley Marine Science Center)
  - Two lidar systems + 1 radar system (to be installed)
  - Comparisons to altimetry at center of San Pedro channel (~20 km) yield ~3 cm repeatability when seas are sufficiently active (~50% of passes)
  - Provide connection to Harvest and planned transponder.
- **Leverages nearby permanent GPS (CAT3)**
- **New radar transponder to be installed in high backcountry nearby.**



Precision GPS Buoy System

Partnership with NOAA/PMEL (Meinig et al.)

FEATURES

- Integrated low-power (~1 W), dual-frequency GNSS
- Miniaturized digital compass/accelerometer
- Iridium communications
- Load cell (for modeling water line displacement)
- Enables geodetic quality solutions without nearby reference stations.

DEVELOPMENT AND TESTING

- Buoy system design evolves under progressively more challenging conditions:

✓ *Lake Washington (2015)*

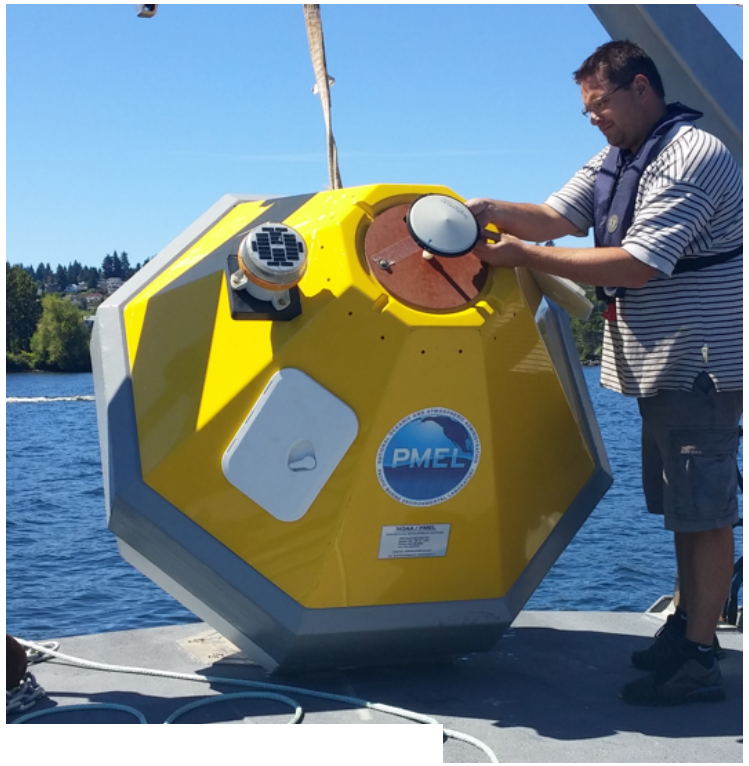
✓ *Puget Sound (2015)*

✓ *Daisy Bank: open-ocean Jason satellite crossover location off coast of Oregon (2016)*

✓ *Monterey Bay: SWOT Pilot Experiment (2017)*

✓ ***Harvest Platform Tandem Campaign (2018)***

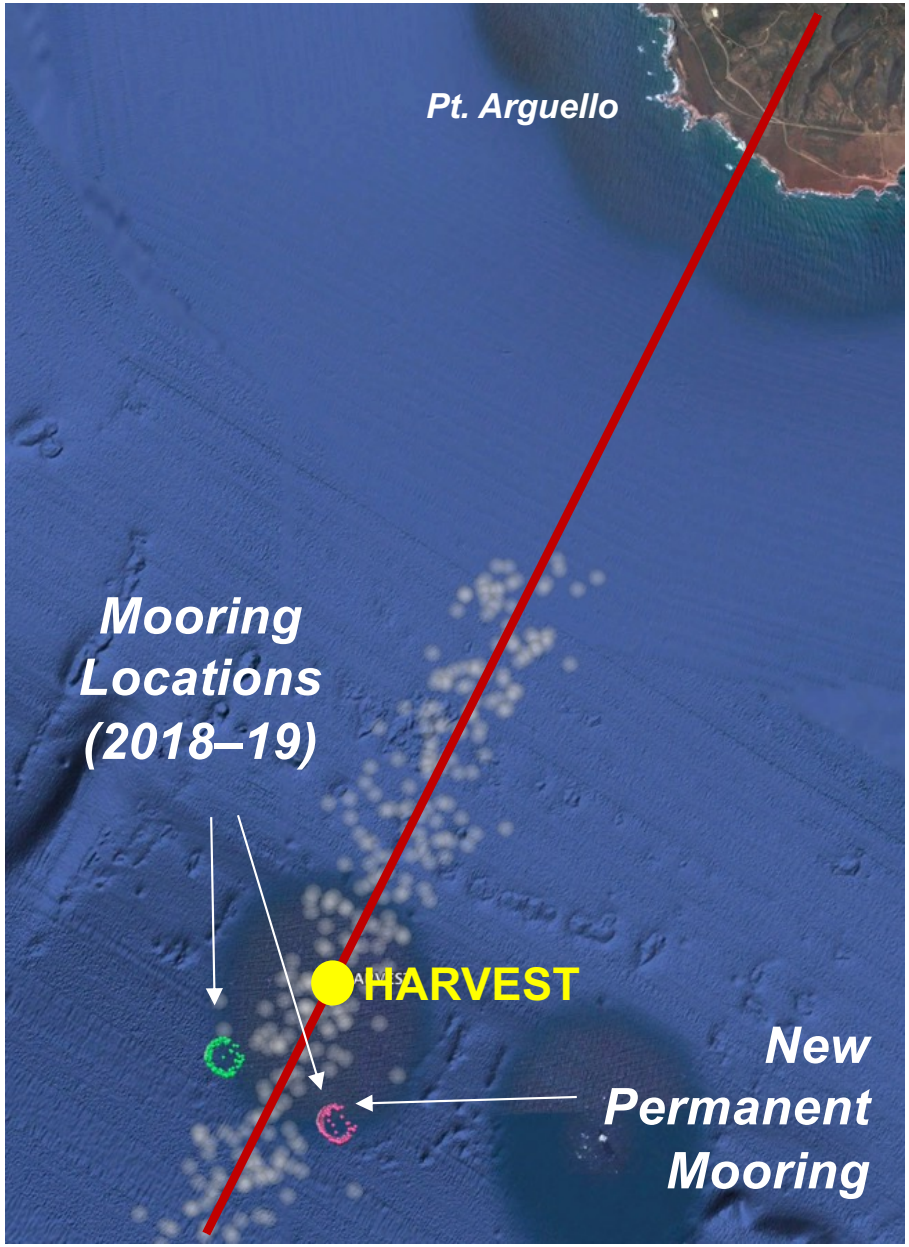
✓ *SWOT Prelaunch Campaign (2019): see Wang et al. presentation, this meeting.*



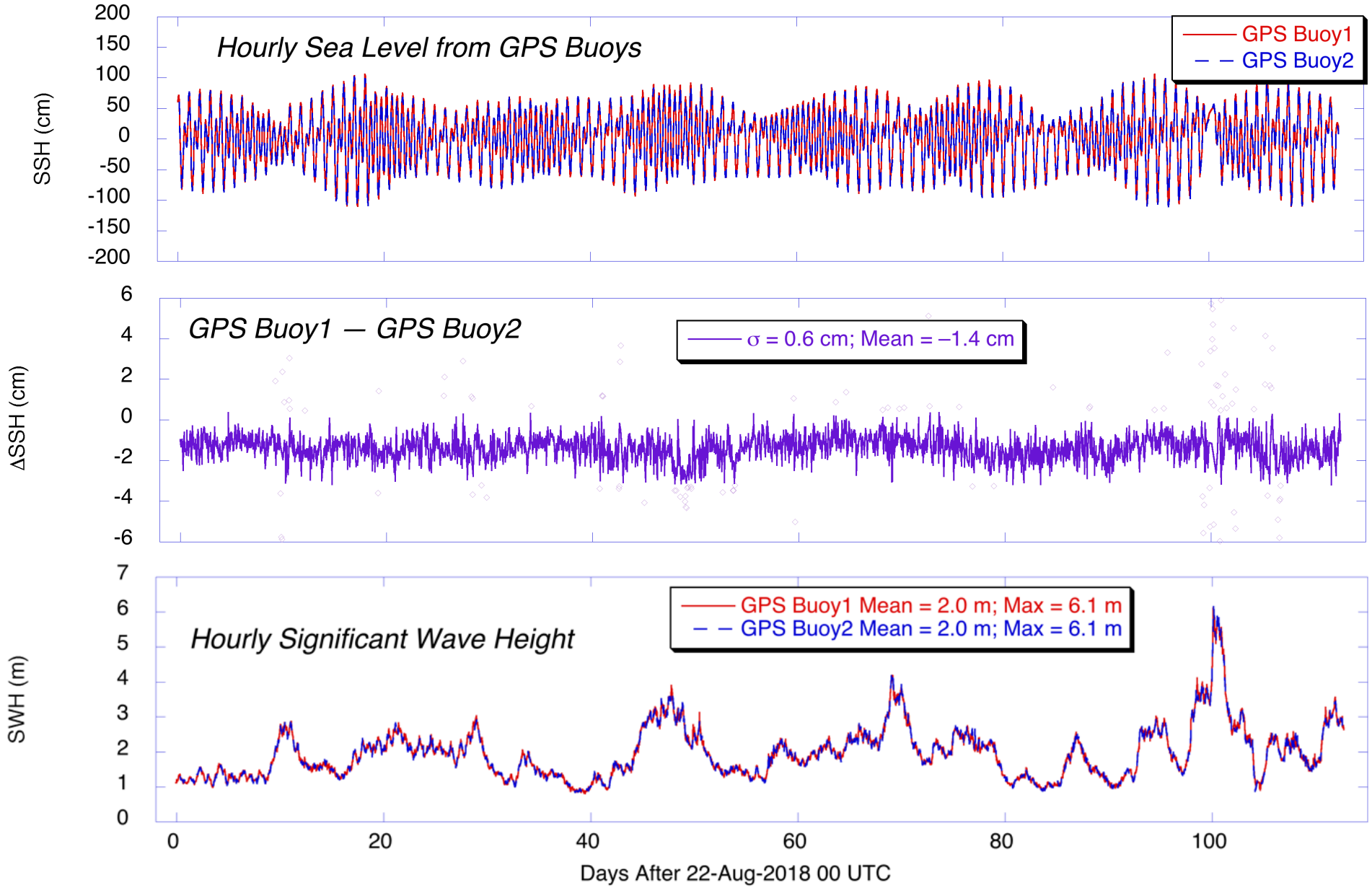
Nearly 1000 successful buoy days in the water.
New endurance record of 400 days (@ SWOT ocean CALVAL site).

Advanced Harvest GPS Buoy System:
Successful Campaign Leads to Permanent Mooring

- Main campaign goal: examine potential of precision GPS buoys 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 J3 altimetry.
- Secondary goal: probe limits of GPS-based relative sea-surface height determination in open ocean.
  - Featured similarly equipped surface buoys (new buoy modeled after prototype, except adds Prawler system).
  - Buoys separated by ~1.5 km.
  - Short baseline lends insight on impacts of waves and on potential of GPS array for SWOT CALVAL.
  - Results suggest accuracies of <1 and < 2 cm for relative and absolute SSH, respectively.
- Features of buoy deployed October 2020:
  - Buoy equipped with load cells to measure force on mooring (to study movement of buoy water line).
  - Designed for 1 year endurance without maintenance.
  - NOAA Prawler for taking CTD and dissolved oxygen measurements along mooring.
  - Telemetry upgrade: 30-s snapshots of GPS tracking data + Prawler, load cell and orientation data.
  - Barometer: to support path delay and IB modeling (and aid comparisons with Prawler dynamic height data.).

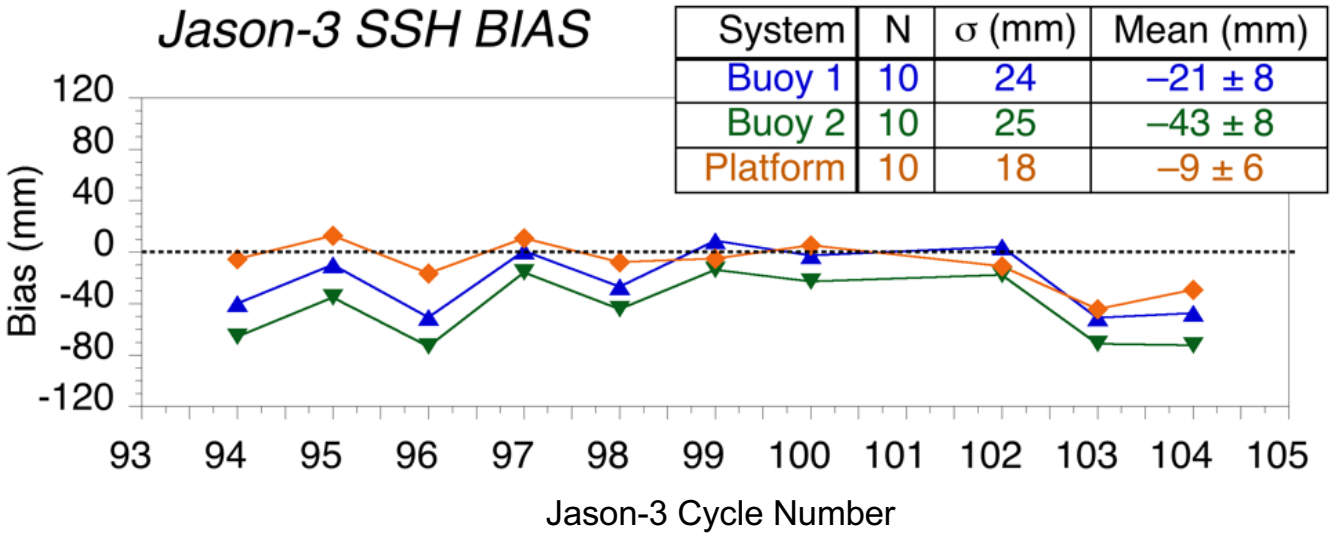


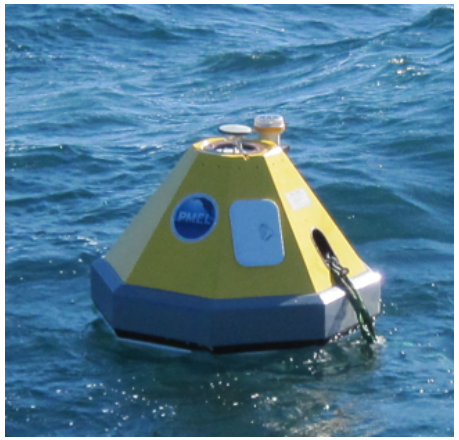
Sea Surface Height Time Series from Harvest Campaign: Comparing Two GPS Buoys Separated by 1.5 km

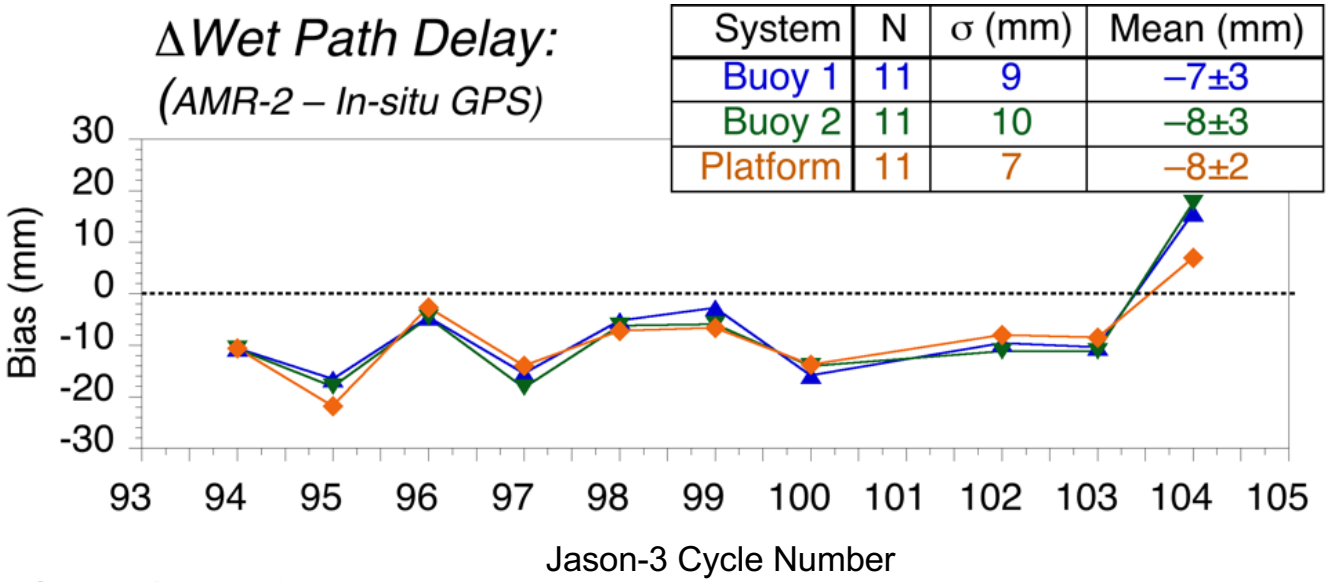


Verification of Altimeter Sea Surface Height and Wet Path Delay

Platform Harvest (Tide Gauge and Fixed GPS) vs. GPS Buoys







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A brief history of the Harvest experiment: 1989–2019

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Abstract

The Harvest Oil Platform, near Point Conception, California, has long served as the NASA prime verification site for the TOPEX/POSEIDON and Jason series of reference altimeter missions. In this brief review article, we provide a short history of the platform verification experiment dating to the site selection in 1989. We describe the evolution of the verification data record over the past three decades, and demonstrate how the results have informed the development of a stable and accurate climate data record of sea level change from satellite altimetry.

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