The Harvest Experiment:
New Results and Status on the Eve of Sentinel-6 Launch

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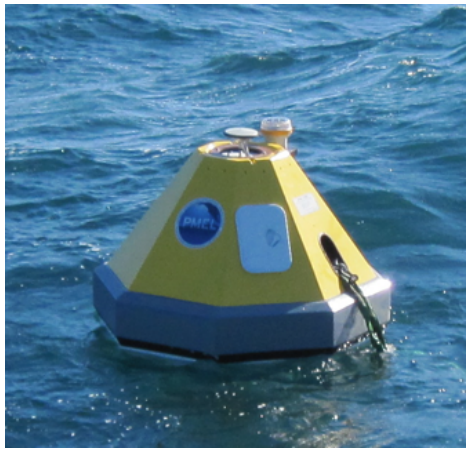
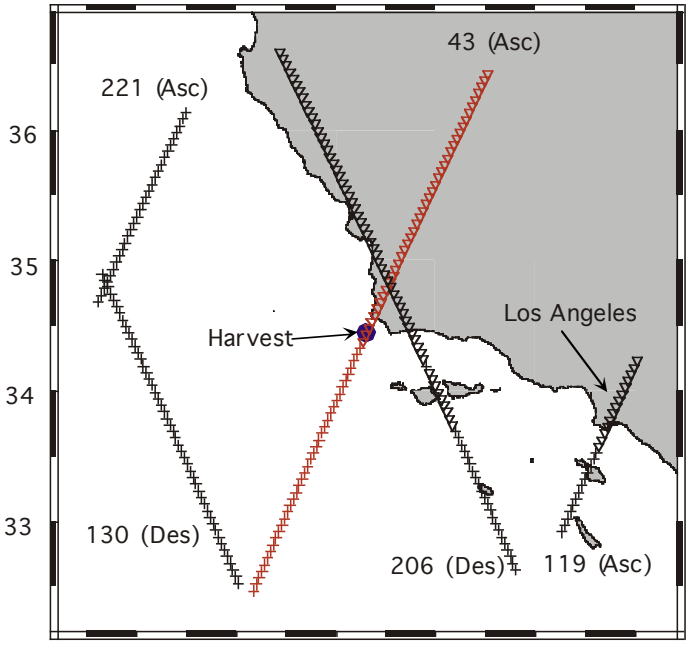
Harvest Platform: Status

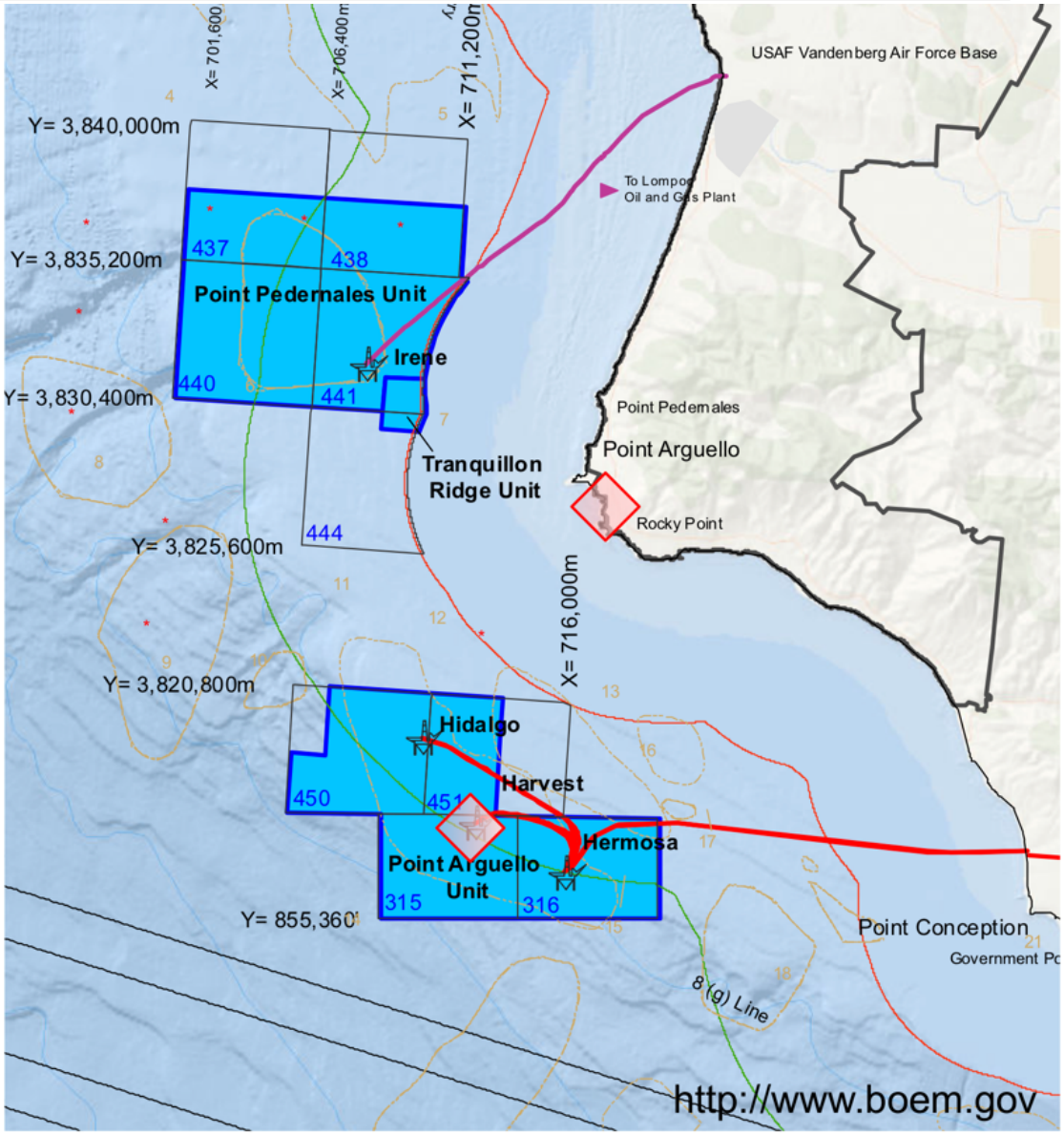
- **NASA prime verification site for high-accuracy Jason-class altimetry (est. 1992)**
  - Open-ocean location along 10-d repeat track
  - 10-km off coast of central California
  - Continuous support of TOPEX, Jason-1, -2 and -3
- **Provides independent measure of geocentric sea level.**
  - Precise 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.





Vertical Land Motion from GPS

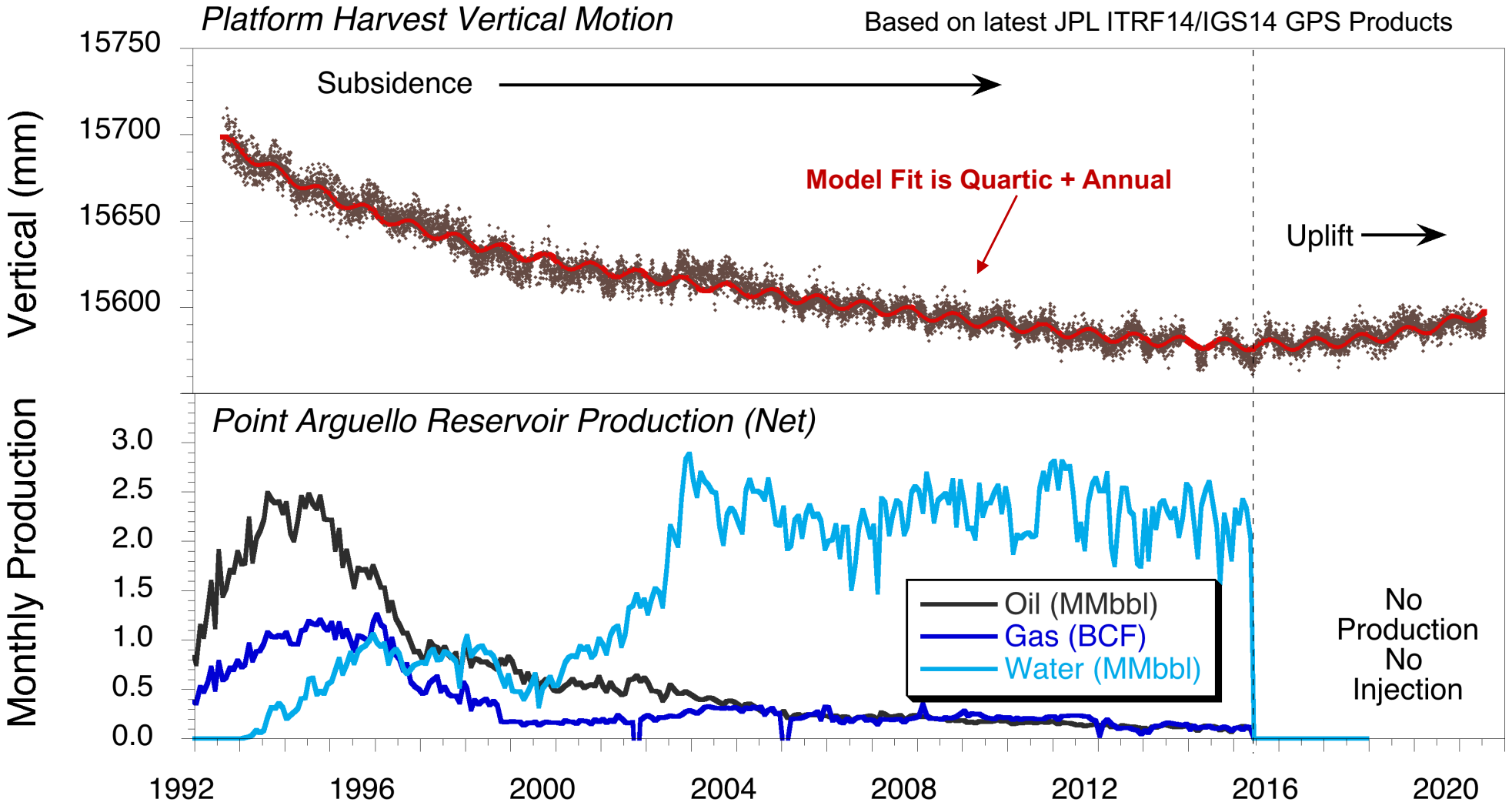
- Harvest (est. 1985) is the central of three oil platforms located over the Point Arguello offshore reservoir.
- Production began in 1991, peaked in 1994, and halted in 2015.
- Continuous GPS since 1992: one of the oldest GPS/tide gauge co-locations in the world.
- GPS at nearby Vandenberg AFB (est.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

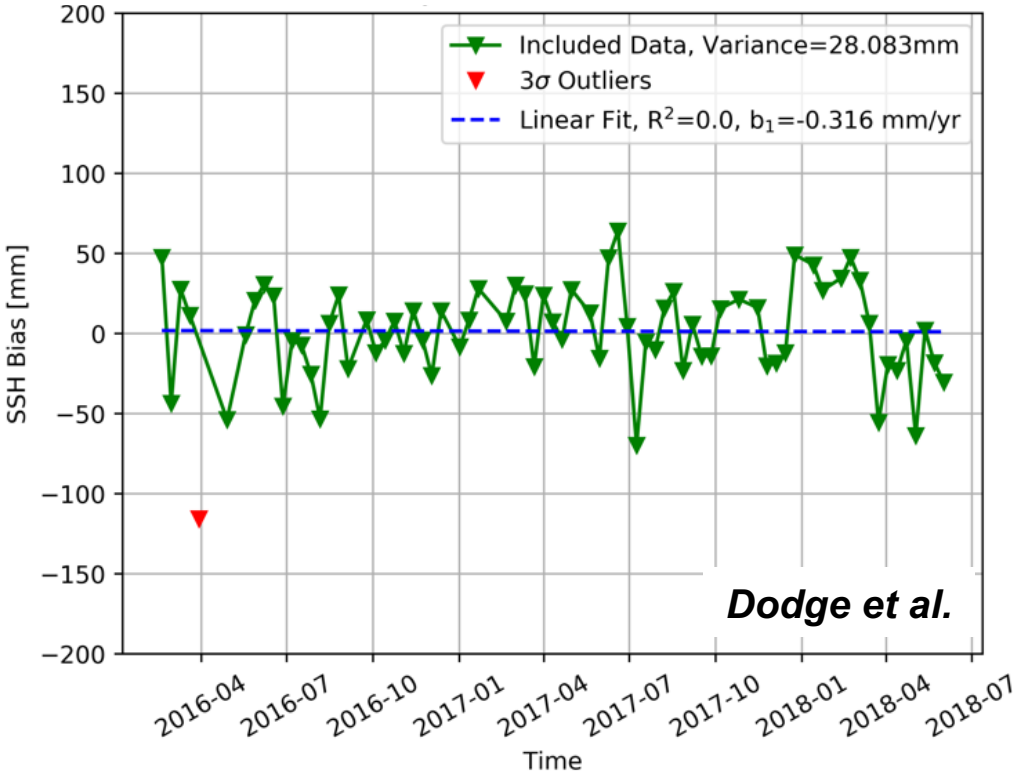
Complex Pattern of Subsidence and Rebound



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

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.

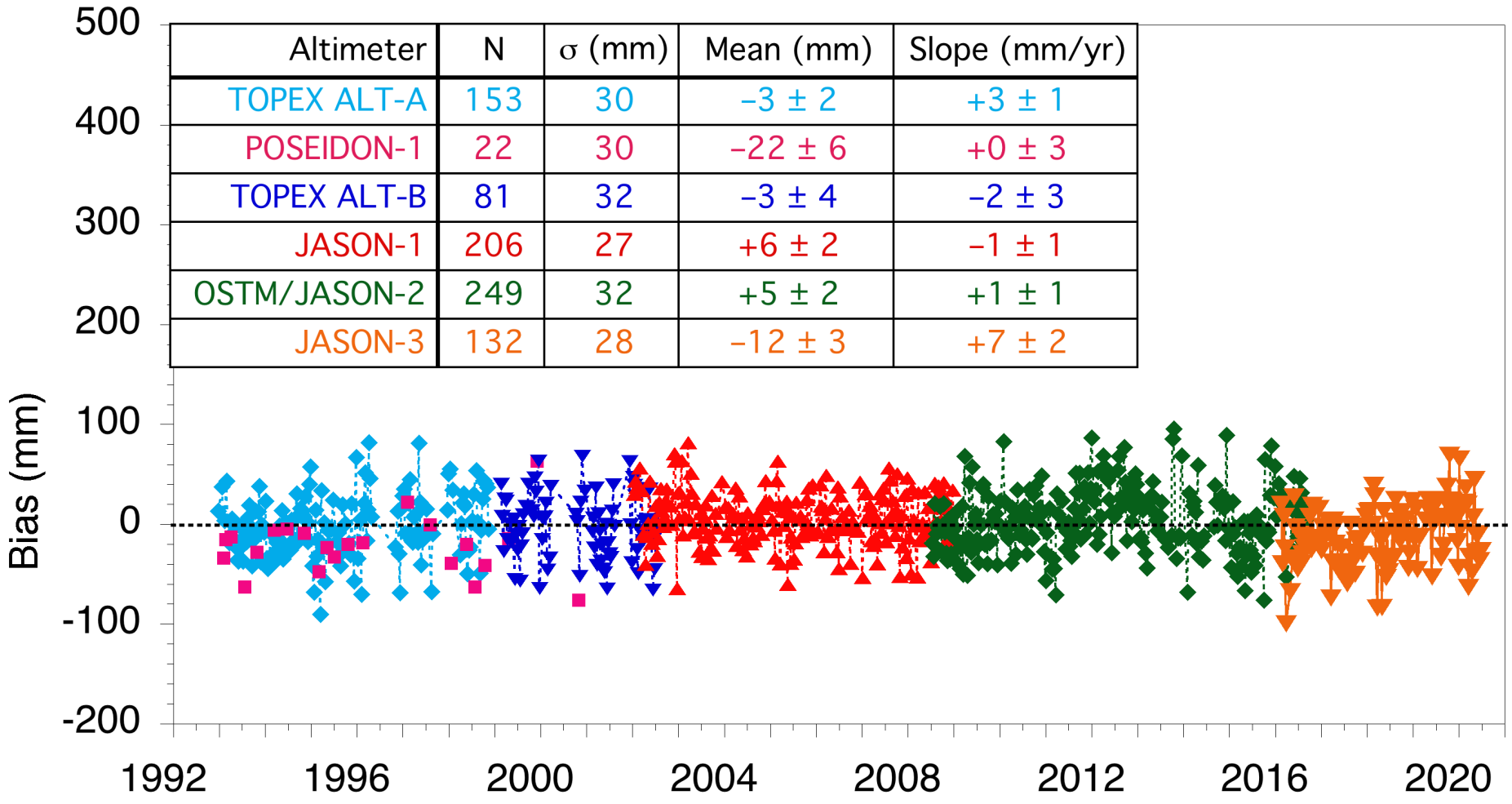
Harvest Long-Term SSH Calibration Record

Updated to Reflect Current Jason-3 Results 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



Precision GPS Buoy System

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)*

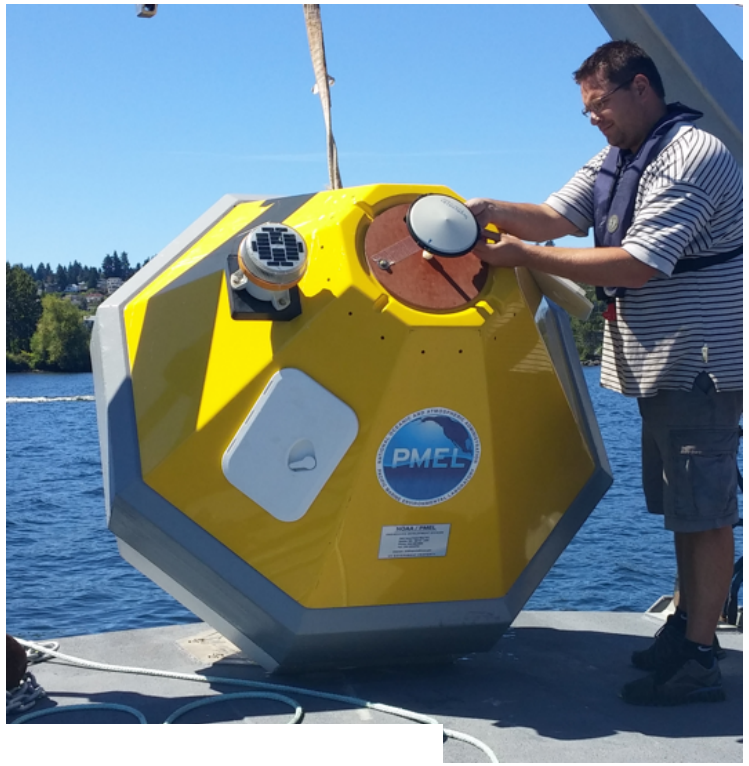
✓ *Puget Sound (2015)*

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

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

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

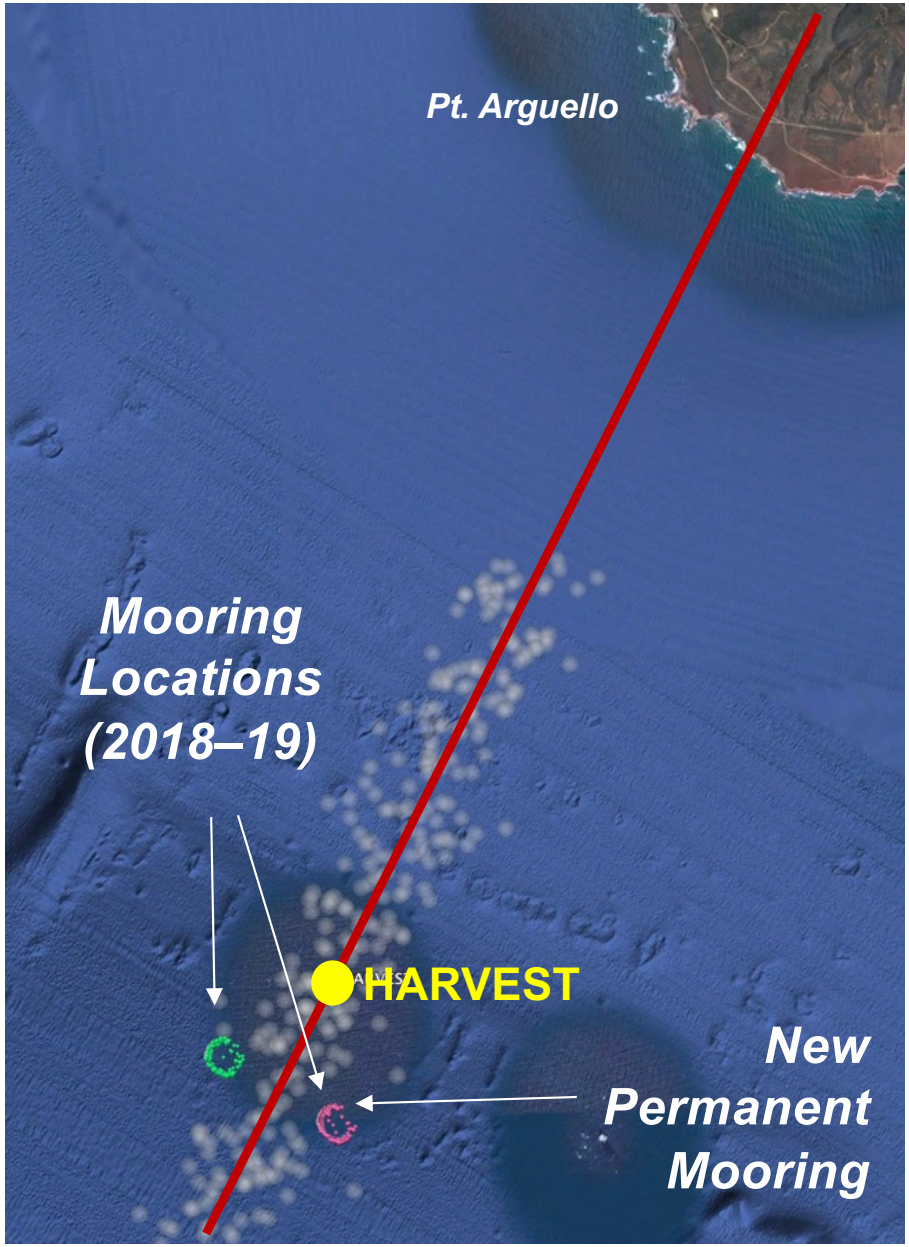
✓ *SWOT Prelaunch Campaign (2019): see Wang et al. presentation, this meeting.*



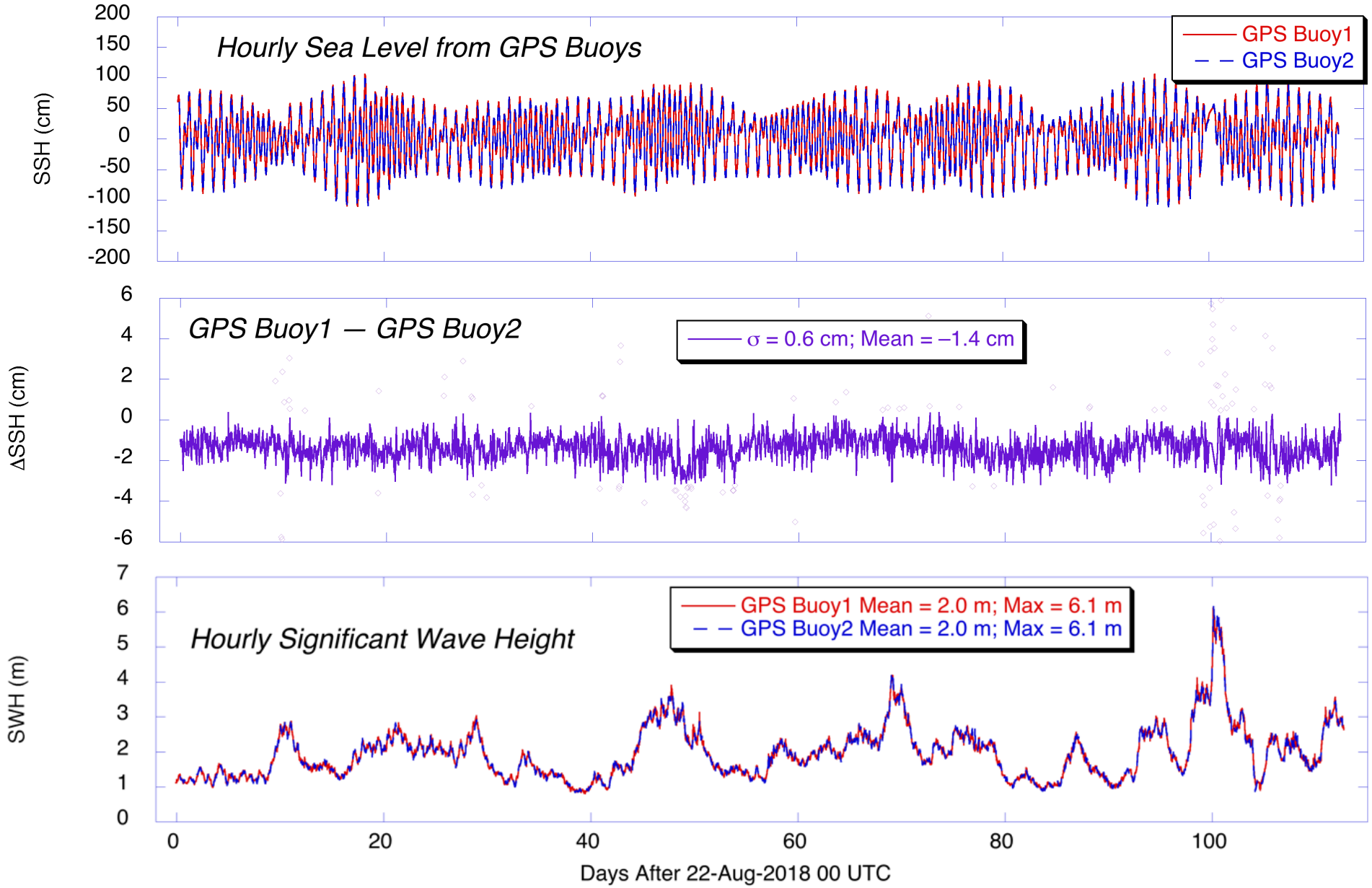
Nearly 1000 successful buoy days in the water.
New endurance record of 400 days (@ SWOT ocean CALVAL site).

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.).

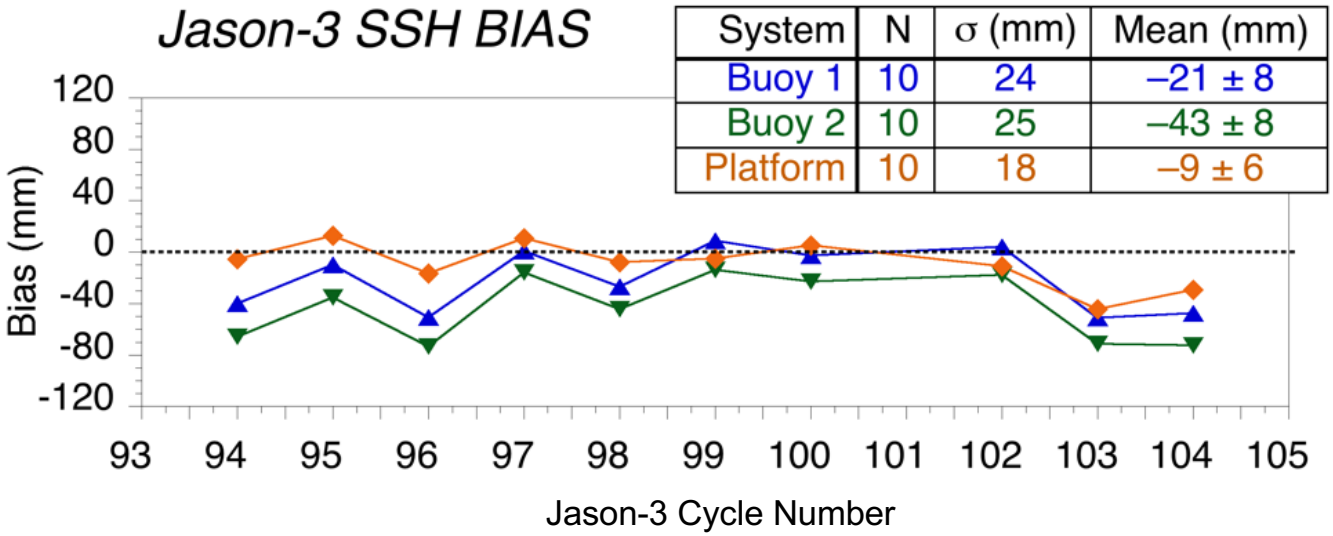


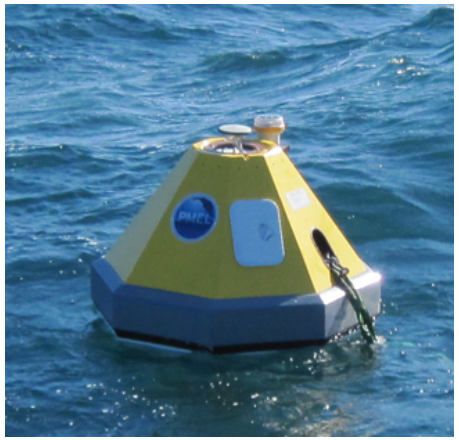
Sea Surface Height Time Series from Harvest Campaign: Comparing Two GPS Buoys Separated by 1.5 km

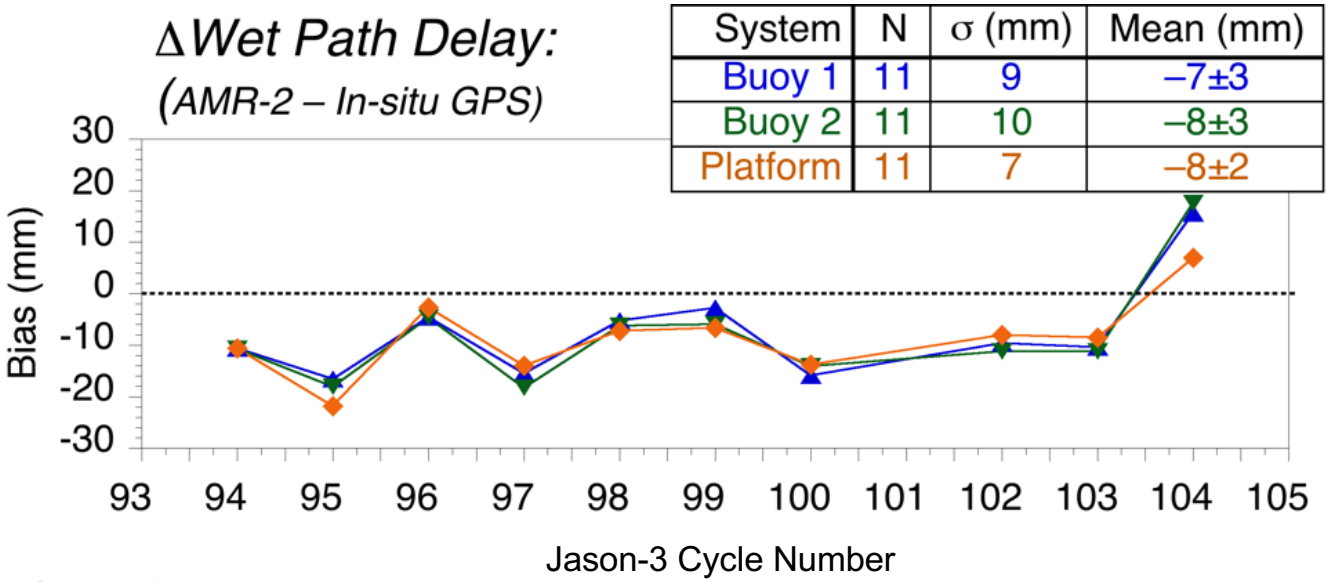


Verification of Altimeter Sea Surface Height and Wet Path Delay

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



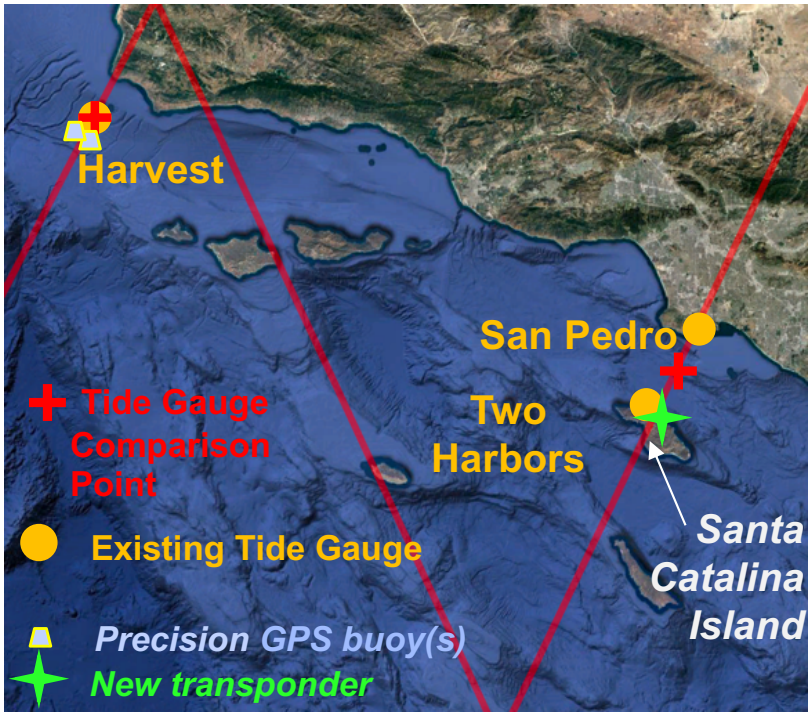




Santa Catalina Island Cal/Val Site:

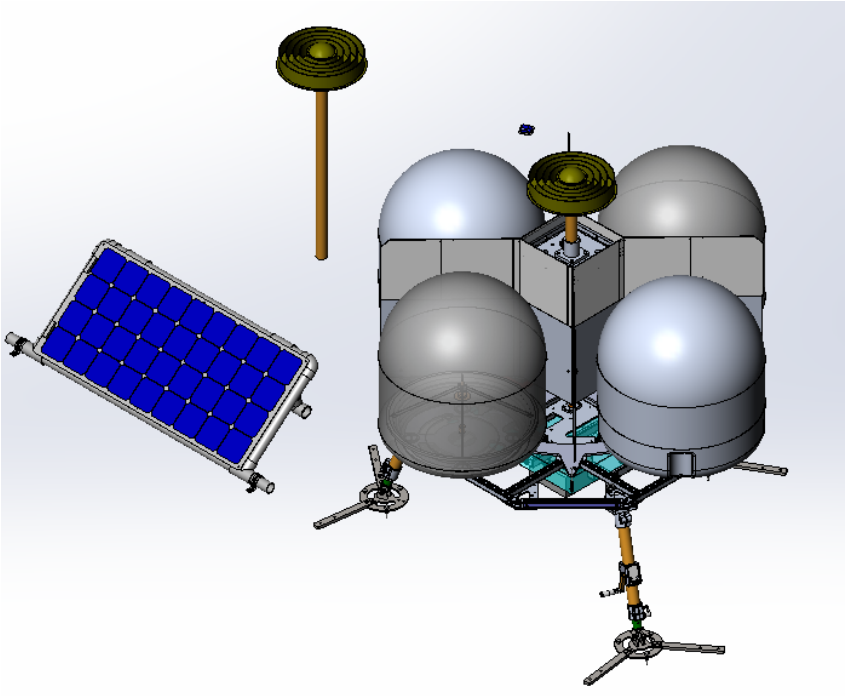
Tide Gauges and Transponder on Adjacent Ascending Track

- **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.**



Radar Transponder

- New Dual Frequency Transponder undergoing fabrication/test
- Scheduled for installation in December 2020.
- Planned deployment on Catalina Island, on top of steep bluff above secondary tide gauge/GPS collocation near Two Harbors.
- Will lend new important insights on S6 altimeter bias and stability in calibration region, without confounding effects of sea states.



Summary

- **Latest SSH bias estimates from Harvest***
  - Jason-3: –12 ± 12 mm for GDR-E
  - Jason-2: +5 ± 10 mm for GDR-D
  - Jason-1: +6 ± 10 mm for GDR-E
  - ALT–B: –3 ± 10 mm for MGDR+
  - ALT–A: –3 ± 12 mm for MGDR+
  - POS–1: –22 ± 12 mm for MGDR+
- **New era of continuous GPS buoy measurements at Harvest.**
  - Complements platform measurements.
  - Reduces risk from platform decommissioning.
- **Dual-frequency transponder to be deployed on Santa Catalina Island.**
  - Complemented nearby tide gauges and GPS.

⇨ **Ready for Sentinel-6**

** Error includes uncertainty in platform vertical*