Analysis of Measurements from a Lidar Instrument for Sea Level and Sea State Studies

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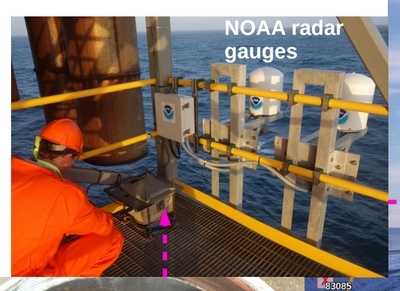
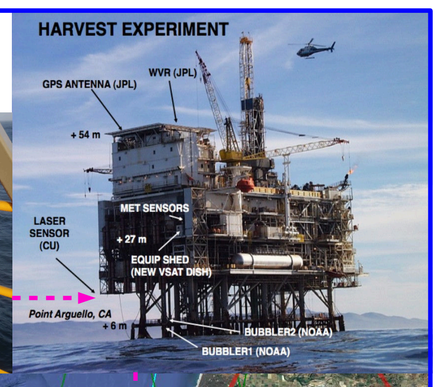
Since the TOPEX-Poseidon mission, the University of Colorado and JPL have operated a lidar laser ranging instrument on the Harvest Platform in support of altimeter calibration and validation. The instrument is a small, COTS device that continuously estimates the vertical range to the sea surface from a lower deck of the oil platform. The lidar collects measurements coincident with the reference altimeter and in concert with a suite of other tide gauge instruments mounted on the Harvest Platform: two nitrogen bubblers and two radar ranging units operated by NOAA. Although the nitrogen bubbler systems are used as the main reference for altimetry cal/val studies at the Harvest Platform [Haines et al, 2016], the lidar has provided redundancy and insight into effects of sea state on the in situ sea level measurements [Washburn et al., 2011]. Past work has shown that the in situ measurements are sensitive to the sea state conditions and experience effects similar to the satellite radar altimeter sea state bias (SSB) correction. Therefore, the lidar measurements or other future measurements of sea state at Harvest Platform may yield insight into improving the SSB correction. Here we report on recent lidar data collected at the Harvest Platform and an analysis of these data for sea level estimates and their sensitivity to sea state conditions. We also report on a new deployment of the lidar instrument at the USC Wrigley Marine Science Center near Two Harbors, CA on the island of Catalina. This new lidar deployment at Two Harbors is on a Jason-3 ascending track and is an experiment to determine the feasibility of future altimeter cal/val studies in the San Pedro Channel between Catalina and Los Angeles, CA.

Harvest Platform Cal/Val Site

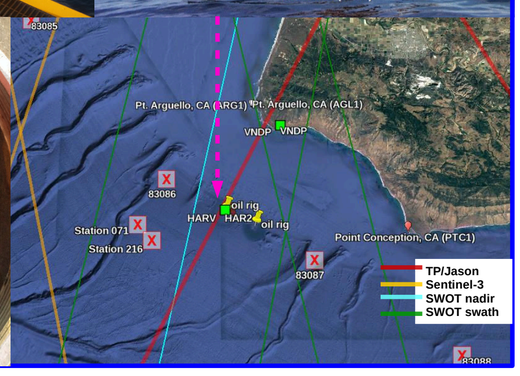
The Harvest Oil Platform (owned by Freeport-McMoran), located 12 km from Pt. Arguello, CA on a TP/Jason ascending ground track, hosts a suite of sensors for absolute cal/val of the altimeters (GPS (HARV, UNAVCO), bubbler & radar tide gauges (NOAA)). Directional wave state is measured nearby by two Waverider CDIP buoys (071 & 216).





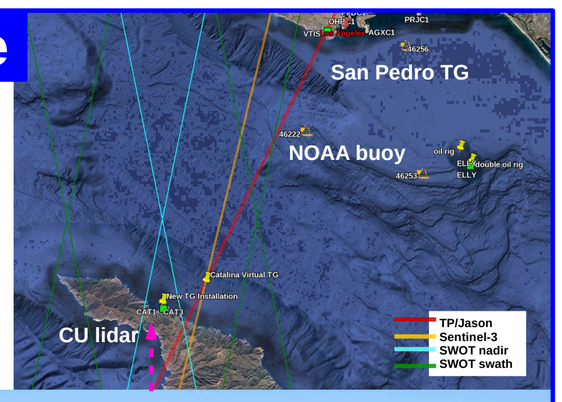
CU Lidar Instrument

- ULS 905 nm laser ranger
- 2 cm precision
- 500 single shot range & amplitude meas/sec
- ~12 m to MSL (Harv), ~1.5 m to MSL (Cata)
- Raspberry Pi data logger
- Temperature sensor
- Enclosed aluminum housing (Harv), PVC housing (Cata)



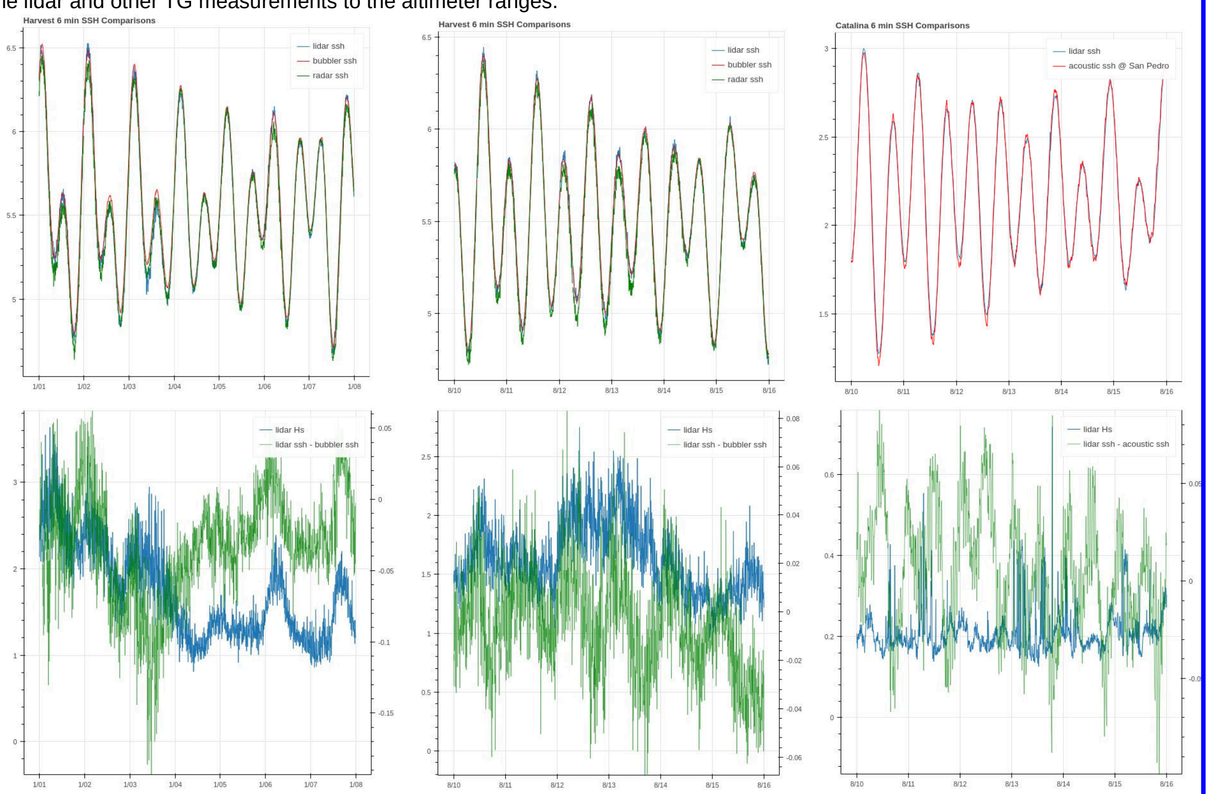
Catalina Island Cal/Val Site

The new Catalina lidar site is mounted on a concrete pier at the USC Wrigley Marine Science Center (WMSC) near Two Harbors, CA on Catalina Island located ~3 km north of a TP/Jason ascending ground track and 34 km from San Pedro, CA. VLM estimates are available from the CAT3 GPS site (UNAVCO) at the WMSC facility. A NOAA tide gauge operates on the east side of the channel at San Pedro, and a NOAA directional wave buoy (46222) near the TP ground track. Due to land contamination of the altimeter at the lidar location, a "virtual tide gauge" location needs to be estimated on the ground track away from the land surface.



Lidar and TG SSH Comparisons

The lidar was redeployed at Harvest in April, 2016, while the new Catalina site was installed in June, 2017. At Harvest, two redundant pairs of tide gauge measurements (bubbler and radar) from NOAA are available for comparison. The bubbler is considered the reference and used as the main altimeter cal/val source. Both the lidar and radar gauges suffer sea state effects and have comparable data quality/noise characteristics. The closest tide tide gauge to Catalina is 35km across the channel at San Pedro, CA. Future work will compare the lidar and other TG measurements to the altimeter ranges.



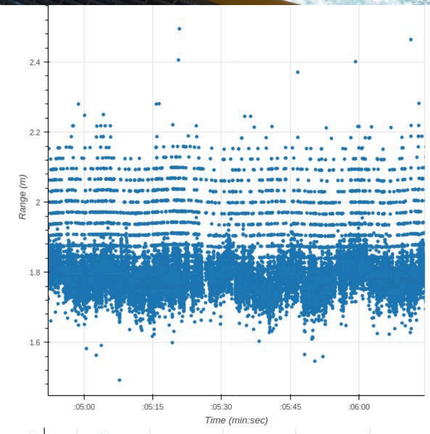
Top row: Example time series of lidar SSH measurements taken at Harvest Platform (1st and 2nd columns) and Catalina (3rd column) and compared with the collocated traditional bubbler tide gauge and radar tide gauge SSH measurements.

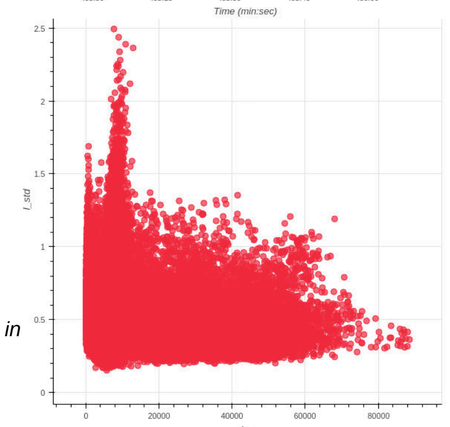
Bottom row: The estimated significant wave height (Hs) derived from the lidar data (left axis, blue) along with the residuals between the lidar SSH and the bubbler SSH (right axis, green). At Harvest, the lidar data will require estimation of a sea state bias (SSB).

Sea State Potential

The Harvest Platform is unique among altimetry cal/val sites since it experiences open ocean conditions and periodically very high wind wave and swell conditions. Currently, two nearby Waverider buoys provide directional wave spectra, but potential exists to measure higher frequency wave spectra using either arrays of lidar scanners or stereo imaging techniques. The goal would be to further characterize altimeter biases (range and SWH) in varying sea state conditions at the same location as the in situ SSH cal/val.

Below: Example raw 500Hz lidar range measurements from July 3, 2017, measured at Harvest Platform showing individual wind waves and swell. Note the lidar (like the altimeter) only reflects from specular facets on the surface and therefore has periods of missing returns.





Top Right: Example raw 500Hz lidar range measurements from July 3, 2017, measured at the Catalina site showing a much calmer wave state in Fisherman's Cove. Note the lidar at Catalina shows evidence of the discrete range bins and penetration below the water surface.
Bottom right: the 6-min lidar range std dev versus the number of return shots showing specular reflection selectivity.

Conclusions & Future Work

Ideas for Cal/Val Beyond Harvest Platform

Goals:

- Maintain open ocean cal/val, climate data record quality
- Maintain a direct calibration site (i.e., on reference ground track)
- Expand to indirect calibration sites (i.e., extrapolate from TG to PCA) [Cancet, 2013; Watson, 2011]
- Plan for other altimeter tracks & distributed, regional measurements for SWOT

Harvest Platform Issues

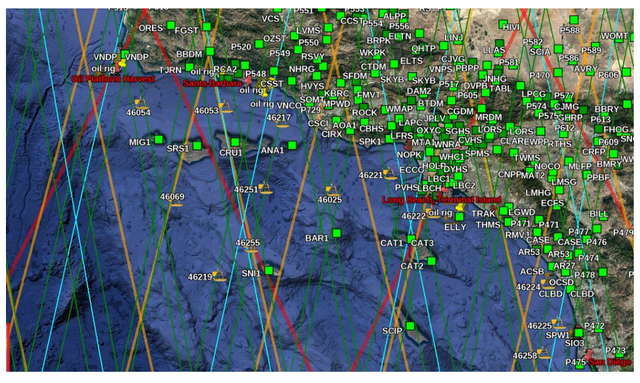
- Benefits: direct calibration; long-term record, open ocean conditions
- Freeport-McMoran has sold all oil/gas assets except CA offshore platforms
- Extraction most likely finished unless pipeline repaired and price of oil rises
- What is the potential for NASA/NOAA to assume ownership (much less expensive than partial removal)?
- Expansion of Harvest capabilities (sea state, wave measurements, other instrument cal/val)

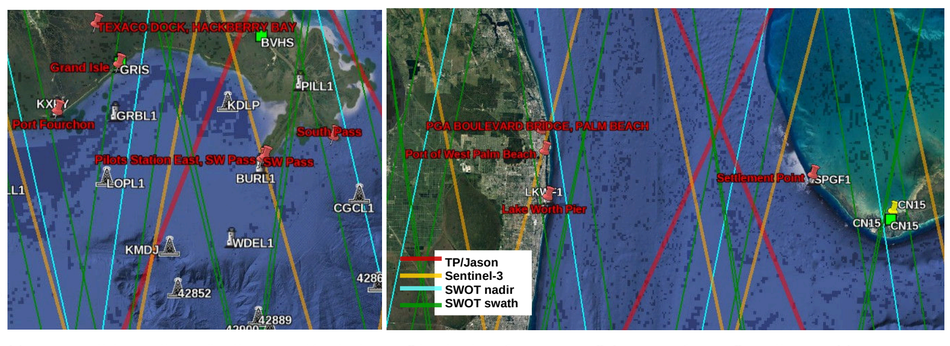
Expanded, Distributed Altimeter Cal/Val Options

- Direct cal on reference ground track requires a static platform. Harvest is only option on West Coast of CONUS. Other oil platforms in Gulf of Mexico could be considered.
- Candidate new in situ TG/wave instruments to give SSH and wave state:
- Hokuyo UXM-30LX-EW laser scanner:
  1 cm precision; 0.25 deg scan res.; 270 deg FOV)
- Leddartech IS16 (16 angle lidar rangefinder)

Next Steps

- Maintain Harvest Platform functionality & pursue NASA/NOAA interest in acquiring platform
- Enhance SSB studies via wave spectrum measurements using TLS, stereo imaging techniques
- Study Swell/wave effects on SAR altimeters and SWOT
- Pursue direct cal/val site on Gulf of Mexico oil platforms
- Continue GPS buoy development with NOAA
- Plan a distributed network (all of the above and future GPS buoys) for SWOT cal/val





New candidate direct/indirect cal/val sites. Clockwise from top: CA coast from Catalina to Harvest Platform, West Palm Beach, FL, and Gulf of Mexico oil platforms near TP tracks and crossover sites.

Acknowledgments

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