A Low-Cost, Structure-Mounted Wave and Water Level Gauge for Real-Time Nearshore Coastal Monitoring

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***Abstract*—Nearshore wave conditions at coastal structures and shorelines remain among the least-observed parameters in the U.S. ocean observing enterprise. No operational system provides simultaneous, real-time wave and water level (WWL) measurements at the coast: offshore buoys and nearshore models supply wave information and sparse tide-gauge networks supply water level, but the two are rarely co-located and referenced to a common datum. We present a low-cost, structure-mounted gauge that measures sea-surface elevation with a single downward-looking acoustic sensor. The device samples at 5 Hz with centimeter vertical precision, yielding datum-referenced water level and wave parameters from one deployment on existing infrastructure. Because the high-frequency wave signal and still water level share a common datum, the gauge produces a continuous, wave-resolved water level record at the point of impact. To date, a prototype deployed at the Santa Cruz Municipal Wharf (~7 m depth) since December 2025 has produced over seven months of continuous data and nearly 2.5 million individually resolved waves. Bulk parameter data correlate with regional buoy and model references, and a structure-referenced overtopping analysis yields empirical critical-elevation thresholds previously unavailable to wharf operators.**

Keywords — nearshore waves, coastal water level, acoustic sensor, ocean observing systems, QA/QC, wave overtopping, flooding, low-cost sensors.

I. Introduction

Coastal hazards are an increasingly costly challenge. High-tide flooding alone imposes nearly $1.5 billion in annual costs to U.S. road networks and is projected to grow to $28–37 billion by 2050 [1]. The most impactful events (including infrastructure overtopping and damage, hazardous nearshore conditions, and storm-driven evacuations) are not driven by sea level alone, but by the combined effect of high wave action arriving on top of elevated water levels. Wave runup often dominates the total water level signal during damaging storm events [2] and has been shown to contribute an average of 73% to total water level during dune erosion events along the U.S. Atlantic and Gulf coastlines [3]. Surf-zone hazards such as rip currents, which form and strengthen with breaking-wave conditions, are estimated to cause more than 100 deaths a year [4]. Acting on these hazards requires observing waves and water level together at the structures and shorelines where impacts occur.

Despite this need, few operational systems provide real-time, co-located wave and water level observations at the coast. Wave information typically comes from offshore buoys (e.g. NDBC) and nearshore models (e.g. CDIP Monitoring and Prediction (MOP)), while coastal water level often comes from sparse tide-gauge networks (e.g. NOAA CO-OPS NWLON network). These systems operate independently: wave buoys do not measure water level relative to a vertical datum and are difficult to deploy in shallow water; tide gauges do not resolve wave motion; and operational models often fail to capture how individual waves transform across the surf zone. This observational gap has been formally documented at the federal level: NOAA CO-OPS reported that fewer than 10% of U.S. real-time wave observations lie in shallow (<10 m) nearshore water, and showed near-universal demand across federal, academic, and maritime partners for real-time, co-located wave and water level observations [5].

Fixed-structure sensing offers an effective alternative around the marine-operations burden of floating platforms. Acoustic and microwave sensors on tide-station infrastructure have been shown to recover wave height alongside water level [6][7], and recent work has measured storm waves and water level from a fixed structure using rapidly deployable radar [8].

Building on this direction, we present a low-cost, structure-mounted gauge that measures both datum-referenced water level and a suite of wave parameters from a single downward-looking acoustic sensor, and we characterize the performance of a continuously operating prototype at the Santa Cruz Municipal Wharf against regional buoy and model references.

II. Gauge Description

Hohonu builds low-cost gauges on a standardized, sensor-agnostic hardware platform that supports non-contact acoustic and microwave-radar observation of the water surface below. The units are compact, watertight, and are designed for rapid

mounting on existing infrastructure (wharves, piers, jetties, seawalls) with low-maintenance service. Compared to traditional wave monitoring platforms, cost is reduced primarily from eliminating the marine operations that dominate the life-cycle expense of a water-based platform (vessel time for deployment and recovery, mooring hardware and biofouling management, permitting, or drift-and-loss exposure). The wave and water level (WWL) platform underlies Hohonu's operational fleet of nearly 200 water level gauges across 18 U.S. states [9][10].

The prototype WWL configuration reported here uses a downward-looking acoustic sensor sampling sea-surface elevation at 5 Hz, with an effective vertical precision of ±1 cm at the maximum detection distance of 10 m. Specifically, the sensor is a MaxBotix MB7388 with a parylene coating for corrosion resistance. Hardware-side quality assurance, developed and validated across Hohonu's operational fleet, covers power monitoring, sensor diagnostic flags, and seal-integrity testing. Gauges are bench-calibrated against fixed reference targets prior to deployment.

The raw data output is a 5 Hz time series of distance to a surface. At the device's 2.5 Hz Nyquist frequency, the shortest resolvable period is 0.4 s which spans the wind-wave band (~2–10 s) and vessel-wake energy (~1–2 s) with margin. The resulting data record is a continuous time series (as opposed to fixed-length bursts), allowing simultaneously for water level estimation, spectral parameters, and continuous individual wave statistics.

The prototype is plugged into 120 V AC wall power, and the full 5 Hz raw series is manually retrieved for server-side spectral and individual-wave processing. Full-stream telemetry of the high-frequency series and solar/battery-based power are operational design targets included in the sustained-operations effort described below.

Fig. 1. Left: Map indicating the location of the wave and water level (WWL) gauge relative to the MOP SC-142 model node and the CDIP 156p1 offshore buoy. Right: The installed WWL gauge above the target area underneath the municipal wharf.

III. Deployment and Analysis

A prototype has operated continuously on the Santa Cruz Municipal Wharf since 17 December 2025 (Fig. 1). The coastline at the site is south-facing and partially shadowed from north winds and swell by a nearby headland. The sensor is mounted on the wharf approximately 275 m from shore at a sensor-face height of 11.03 m above the seabed or 3.26 m above mean higher high water (MHHW), with the vertical datum established using a depth measurement at the time of installation (~7 m) and cross-referencing the still water level signal from a nearby tidal gauge also mounted to the wharf.

Data QC for the prototype deployment extends Hohonu's operational, QARTOD-aligned procedures [11] to wave parameters. Individual QC tests include 'no target' (i.e. was a valid measurement observed), spike, gross range, and rate-of-change tests. QC flags were applied sequentially in that order followed by linear interpolation across gaps of 1 second or less. To date, 99.5% of raw samples (N=94 million) have been retained after QC. The majority of gaps in the time series are brief, with the median gap being 0.6 s. The longest gap is approximately 7.7 hours, due to a power outage at the municipal wharf during which the gauge was temporarily offline.

Each valid distance measurement is converted to a water-surface elevation relative to MHHW, so that both the still water level and the wave-band fluctuations are captured by a single instrument on one datum. Still water level is computed by running a 4th order Butterworth filter with a 5 minute cutoff. Non-directional energy density spectra are estimated from 30-minute subsets of the 5 Hz data using Welch's method with a

Hann window, 1024 sample segment length, and 50% overlap. Significant wave height (H_s) is computed spectrally as $4\sqrt{m_0}$; peak period T_p is taken at the spectral peak; mean period T_a is reported as m_0/m_1, where m_0 and m_1 are the zeroth and first spectral moments.

Individual wave heights and periods are extracted directly from the detrended 5 Hz series by zero-crossing analysis (Fig. 2), yielding distributions of maximum wave height (H_{max}) and peak period and per-wave crest elevations referenced to the datum. To filter surface chop from the analysis, waves in the signal with crest elevation < 0.025 m and period < 1 s were omitted. To assess threshold overtopping, the still water level is combined with the individual wave-crest elevations to give the 'wave-resolved water level', or the elevation reached by individual crests at the wharf referenced to datum. We note that wave-resolved water level as reported here is a directly observed quantity at the structure and is distinct from 'total water level' that includes the extent of wave runup relative to land [3], which this fixed-elevation sensor does not directly measure.

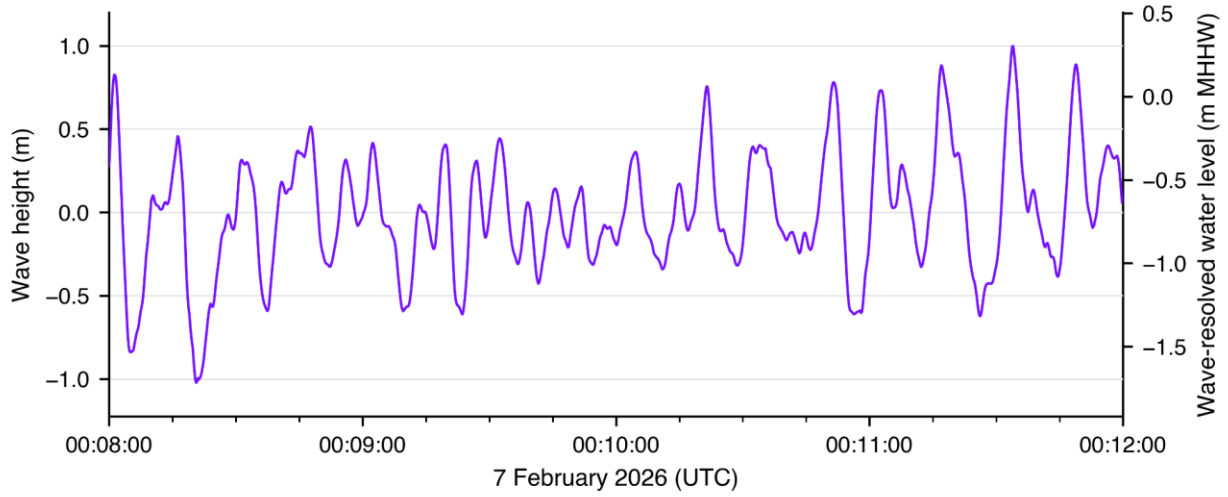

Fig. 2. A four-minute segment of the 5 Hz time series exhibits distinct individual wave profiles unavailable from low frequency sampling. Axes show wave height and wave-resolved water level (relative to MHHW).

Two nearby reference products were used to assess gauge agreement: the CDIP MOP SC-142 nearshore model node (~15 m depth, ~1.5 km offshore, hourly cadence) [12] and CDIP Station 156p1, a directional Datawell buoy (~150 m depth, ~23 km offshore, 30-min cadence). Reference bulk parameters were matched to the WWL gauge's 30-min window timestamps by nearest-neighbor assignment with a maximum permitted offset of 1 h, without interpolation or correction for swell propagation time between the offshore buoy and the gauge. Because MOP output is hourly, each model value was matched to two consecutive gauge windows; reported n for MOP therefore reflects gauge windows rather than independent model samples.

IV. Results

As of July 22, 2026, the deployment has produced 217 days of continuous observation. Maximum and mean significant wave height were measured as 1.55 m (December 24, 2025) and 0.43 m, respectively. Maximum and mean peak period were measured as 24.8 s (March 10, 2026) and 14.6 s, respectively.

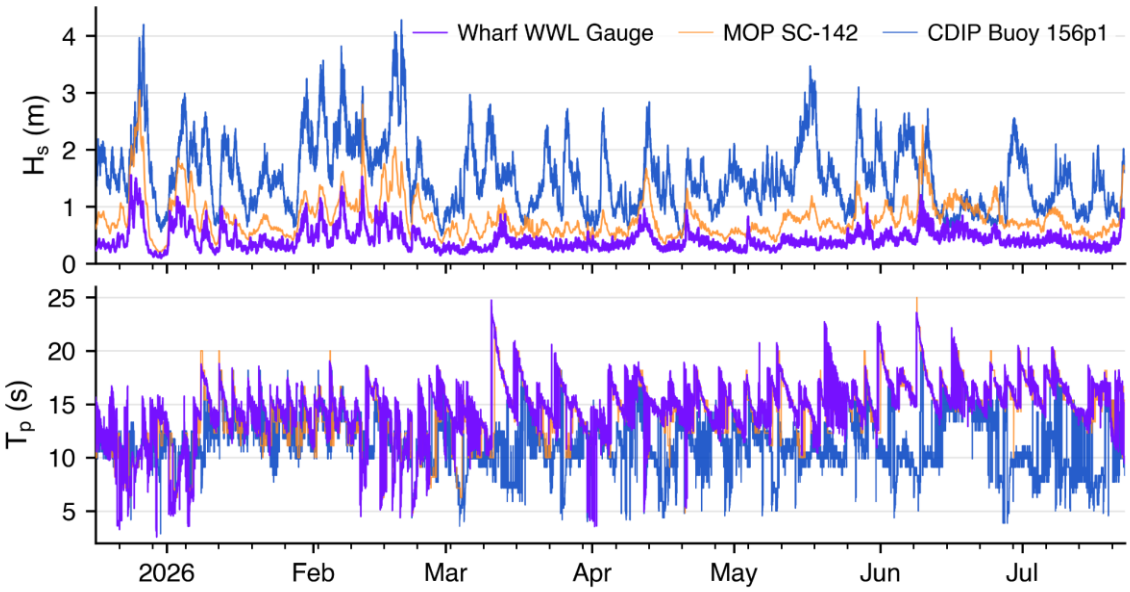

Fig. 3. Time series of significant wave height (Hs, upper), and peak wave period (Tp, lower) measured at the WWL gauge vs the reference stations.

H_s measured at the gauge tracks the nearshore model node MOP SC-142 closely (r=0.85, n=10,399), but the offshore buoy CDIP 156p1 weakly (r=0.45) (Fig. 3). Agreement with MOP decreases as offshore wave height increases, from r = 0.85 across all conditions to r = 0.50 for MOP $H_s \geq 2$ m. Mean H_s differs systematically among the three locations, with the wharf gauge reading lower than MOP by 0.38 m (RMSE 0.43 m) and lower than the CDIP buoy by 1.10 m (RMSE 1.23 m). T_p shows moderate agreement with MOP SC-142 (r = 0.65) and weak agreement with CDIP 156p1 (r = 0.08). The poor correlation with the offshore buoy may indicate that coastal shadowing and directional filtering at the wharf represents a different wave system from the one arriving at the buoy.

Zero-crossing analysis resolves individual wave heights and periods directly at the structure (Fig 2). To date, 2,452,191 individual waves were measured, and the maximum individual wave height was 2.23 m (December 24, 2025). Over the study period, there were 3,377 individual waves (over 32 days) in which wave-resolved water level exceeded 1 m MHHW, a typical elevation where moderate to major coastal flooding becomes a likely [13]. The maximum individual wave height of 2.23 m corresponded to a wave-resolved water level of 1.26 m MHHW, while the maximum wave-resolved water level on record was 1.70 m MHHW (January 3, 2026), occurring due to a 1.24 m wave on top of high tide. These results help define empirical critical-elevation exceedance statistics for the structure (Fig. 4). For additional results, visit https://sc-waves.streamlit.app/.

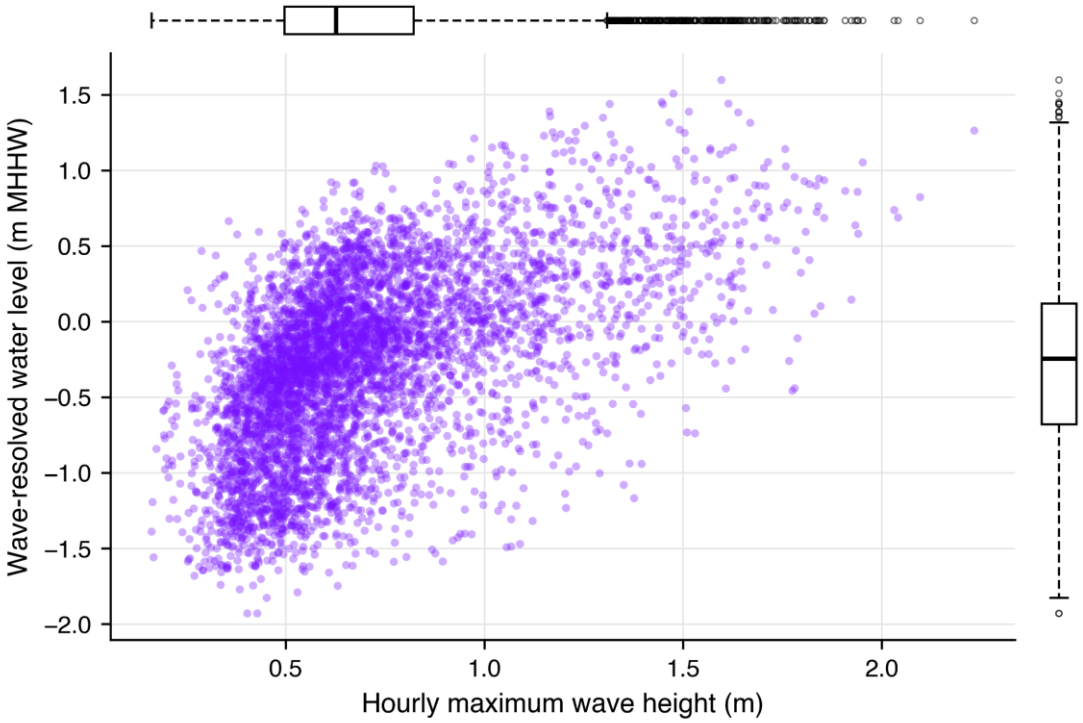

Fig 4. Distribution of maximum hourly wave height vs. wave-resolved water level (relative to MHHW). Boxplots summarize the 5,205 hourly maxima shown in the scatter: the box spans the interquartile range, the interior line shows the median, whiskers extend 1.5 × IQR, and open circles are the values beyond them.

V. Limitations and Applications

There are several limitations to note about the WWL gauge and the deployment results described above. While not observed during the prototype deployment, acoustic gauges are sensitive to air-gap temperature gradients and to wind and spray, which can degrade signal quality during important periods of measurements (e.g. storms). The gauge configuration is non-directional, and any wave direction must be inferred from reference sources (e.g. the CDIP offshore buoy) or gathered using multiple, time-synchronized installations. Future work looks to install additional gauges along the wharf transect to infer directional information. Sampling at 5 Hz bounds the resolvable band at 0.4 s. Capillary wave energy distinctly falls outside of the gauge limits, and while vessel wake is resolvable at this sampling rate, certainty around wake estimates would be improved with a higher sampling rate. Finally, we note that there is no absolute ground truth available for nearshore waves at the structure. The model node and offshore buoy are themselves estimates at different depths and locations, so any comparison is a characterization of agreement and not a validation. Co-located gauges from independent sources (e.g. a USGS or NOAA CO-OPS gauge) and camera-based wave estimates [14] could be used for more rigorous validation.

Work to advance the WWL gauge prototype and data pipeline toward an operational system is presently underway. An integrated solar and battery system will support continuous, unattended operation of the device. In place of manual retrieval, cellular telemetry will enable a continuous, real-time stream of the high-frequency record for data users. A cloud pipeline will ingest, process, quality-control, and disseminate the high-frequency wave record and its derived products through public dashboards and API endpoints. Making WWL datasets continuously accessible enables actionable decision-support products (such as structure-referenced overtopping thresholds).

Results of the prototype deployment have been used for engagement with the City of Santa Cruz, USGS and USACE researchers, emergency managers, and coastal-engineering consultants. These conversations surfaced a number of concrete use cases, including post-storm damage assessment, wave overtopping and flood thresholds, infragravity wave monitoring, and integration into municipal emergency operations. Moreover, this technology may better inform wave model forecasting for climate and coastal resilience of critical infrastructure along the coast; along with understanding erosion events and rates of shoreline change. We note that datum-referenced, wave-resolved water levels observed at the point of impact – rather than an estimate merged from instruments separated by kilometers – underpin all of these applications.

VI. Conclusion

This work introduces a low-cost approach to a measurement problem traditionally requiring multiple separated and high-cost instruments. The WWL gauge is a structure-mounted acoustic gauge that recovers datum-referenced water level and a suite of wave parameters from a single deployment on existing infrastructure. A prototype deployment produced bulk parameters that track regional buoy and model references, individual-wave statistics resolved at the structure, and structure-referenced overtopping thresholds not previously

available to operators. The co-located WWL capability enables a new class of coastal analytics at a cost point compatible with municipal and federal operating budgets.

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REFERENCES

[1] C. Fant, J. M. Jacobs, P. Chinowsky, W. Sweet, N. Weiss, J. E. Sias, J. Martinich, and J. E. Neumann, "Mere nuisance or growing threat? The physical and economic impact of high tide flooding on US road networks," J. Infrastruct. Syst., vol. 27, no. 4, art. 04021044, 2021.

[2] C.-E. Hsu, K. A. Serafin, X. Yu, C. A. Hegermiller, J. C. Warner, and M. Olabarrieta, "Total water levels along the South Atlantic Bight during three along-shelf propagating tropical cyclones," Nat. Hazards Earth Syst. Sci., vol. 23, no. 12, pp. 3895–3912, 2023.

[3] H. F. Stockdon, J. W. Long, M. L. Palmsten, A. Van der Westhuysen, K. S. Doran, and R. J. Snell, "Operational forecasts of wave-driven water levels and coastal hazards for US Gulf and Atlantic coasts," Commun. Earth Environ., vol. 4, art. 169, 2023.

[4] B. C. Brewster, R. E. Gould, and R. W. Brander, "Estimations of rip current rescues and drowning in the United States," Nat. Hazards Earth Syst. Sci., vol. 19, no. 2, pp. 389–397, 2019.

[5] L. Fiorentino, K. Kirk, B. Heitsenrether, G. Dusek, A. Luscher, C. DiVeglio, C. Paternostro, C. Dean, and A. Pruessner, "Requirements for a nearshore wave observation capability within the National Ocean Service Center for Operational Oceanographic Products and Services," NOAA/NOS/CO-OPS, Silver Spring, MD, 2021.

[6] J. Park, R. Heitsenrether, and W. Sweet, "Water level and wave height estimates at NOAA tide stations from acoustic and microwave sensors," J. Atmos. Oceanic Technol., vol. 31, no. 10, pp. 2294–2308, 2014.

[7] L. A. Fiorentino, R. Heitsenrether, and W. Krug, "Wave measurements from radar tide gauges," Front. Mar. Sci., vol. 6, art. 586, 2019.

[8] J. Brown, B. J. McClenney, and P. Dickhudt, "Measuring storm waves and water levels from a fixed structure with a rapidly deployable oceanographic radar," in Coastal Dynamics 2025, Aveiro, Portugal, pp. 696–702.

[9] D. Hernandez et al., "Building resilience in vulnerable coastal communities with the Southeast Water Level Network initiative," Mar. Technol. Soc. J., vol. 59, no. 1, pp. 80–85, 2025.

[10] H. Baranes et al., "Supporting coastal flood forecasting and community-led adaptation with tide gauges, community science and youth engagement," Front. Climate, vol. 8, art. 1757212, 2026.

[11] U.S. IOOS, "Manual for Real-Time Quality Control of In-Situ Surface Wave Data (QARTOD), Version 2.1," 2019.

[12] W. C. O'Reilly, C. B. Olfe, J. Thomas, R. J. Seymour, and R. T. Guza, "The California coastal wave monitoring and prediction system," Coastal Eng., vol. 116, pp. 118–132, 2016.

[13] W. V. Sweet, G. Dusek, J. Obeysekera, and J. J. Marra, "Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold," NOAA, Silver Spring, MD, USA, NOAA Tech. Rep. NOS CO-OPS 086, Feb. 2018.

[14] D. Buscombe, R. J. Carini, S. R. Harrison, C. C. Chickadel, and J. A. Warrick, "Optical wave gauging using deep neural networks," Coastal Eng., vol. 155, art. 103593, 2020.