EPISODIC WAVE DATA CAPTURE WITH MINIATURIZED INSTRUMENTATION

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Abstract- Obtaining ocean wave data has traditionally been an expensive undertaking. Deployments are often open-ended, because extreme conditions are usually the most important to measure. Advances in electronic miniaturization have produced wave instrumentation with impressive memory and telemetry capabilities that are very small and inexpensive. Descriptions of miniature wave gages and logistics for this new approach are provided. Benefits and costs of past and potential applications are analyzed to determine the value of this new wave measurement methodology.

I. INTRODUCTION

Obtaining ocean wave data has traditionally been an expensive undertaking. Deployments are often open-ended, because extreme conditions are usually the most important to measure. While a long term, continuous wave data set is almost always useful and often necessary, capture of a relatively few number of specific events will frequently satisfy the needs of a project. But such events are rare and may not occur in the first year, or even first few years, of a wave study. In addition, robust validation of wave models requires measurements of a wide range of conditions (e.g., various directions and periods as well as heights) that may take years to accumulate. With potential costs running several hundred thousand dollars, many, if not most, coastal engineering projects are designed without the benefit of site-specific measurements.

There are several reasons for such expenses in today's wave measurement programs, but the major factor is the circular nature of the design and logistics constraints. Gages are often deployed and operated for a year or longer only so they will be in place and operating when and if the event of interest occurs. Large, robust gages (e.g. buoys) are required to have sufficient electrical power (batteries and sometimes solar panels) for long deployments. Large instrument systems require large vessels, crews, and equipment, and relatively calm conditions to safely deploy, so instruments must be deployed far in advance of the conditions of most interest for engineering applications.

Advances in electronic miniaturization have produced wave instrumentation with impressive memory and telemetry capabilities that are very small and inexpensive. For example, all of the electronics for a non-directional wave buoy can be less than the size of a soda can. Battery technology has not kept pace. A battery pack with year-long operation capability still weighs hundreds of kg. Thus, small instruments with small battery packs are constrained to short-term deployments. Rapid, event-triggered deployment methods, including air-deployment, deployment from small vessels of opportunity (e.g., jet skis), cast-out and reel-back from platforms, or even an expendable release are required to realize the potential cost savings of miniature wave gages. If capture of extreme event data will satisfy a project's requirements, system and logistic costs can be decreased by an order of magnitude.

II. PRIOR ART

A. Stationary Wave Gages

Wave gages measure water surface displacement over time. Fixed-mount gages measure the surface directly (e.g., staff gages) or indirectly (e.g., pressure or velocity gages) from a rigidly-mounted sensor. Fig. 1 is typical of a state-of-the-art fixed-mount wave gage. It is the DWG-1 developed at the US Army Engineer Coastal and Hydraulics Laboratory (CHL). It consists of 3 pressure sensors in an array and a central electronics and battery module. The batteries are sufficient to enable the gage to sample and store hourly wave and water level observations for over one year. It is mounted in a steel hexapod, trawler-resistant frame that is pinned to the sea floor by divers using steel pipe pilings. The frame and instrument weigh about 500 kg. Installation from a vessel requires a dive team plus vessel with crew and takes about a day, once the vessel is moored on station. Mild sea states (less than 1-m waves) are required not only for placing the frame over the side and on positioning it correctly on the bottom but for the safety of the dive team.

Fig. 1. DWG-1 gage deployment.

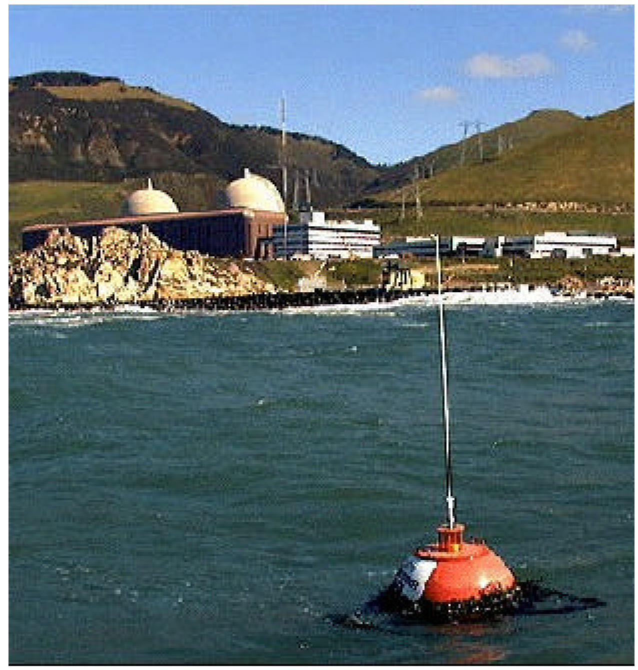


Fig. 3. Waverider (TM) buoy at Diablo Canyon, CA.

Floating gages measure displacements indirectly from the accelerations (and tilt, if directional) of a surface-following or particle-following) buoy that is moored to a stationary anchor. Perhaps the most well-known floating gage is incorporated into the familiar "weather buoy" operated by the National Data Buoy Center. Mid ocean buoys are 6 to 10m in diam. Fig. 2 shows one of the smallest operated by NDBC: the 3-m-diam. discuss buoy. The 3-m buoy measures meteorological parameters as well as directional wave information for up to 18 months using a combination of solar and battery power. It weighs about 1000 kg, not counting the anchor and mooring assembly. NDBC buoys are usually installed with US Coast Guard buoy tenders or cutters. Actual deployment can take less than an hour, once the cutter is on station, but steaming to the deployment site can take days.

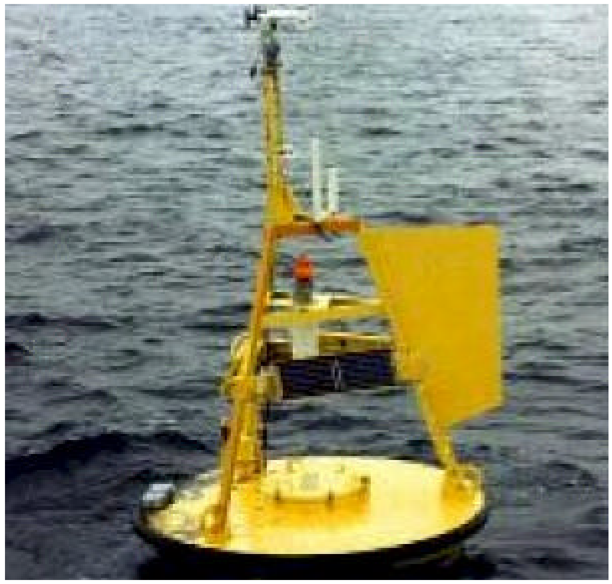


Fig. 2. NDBC 3-m discuss buoy.

One of the more commonly used wave gages is the Waverider (TM), manufactured by Datawell. The 1-m-diam. Spherical buoy weighs about 300 kg and can operate for over a year on its internal batteries. The Scripps Institution of Oceanography (SIO) operates a network of 20 or more Waveriders, and has recently developed a streamlined deployment method using a trailerable 10-m boat and a crew of two. Actual release of the system may only take minutes, but again, steaming time to the site takes hours. Deployments can take place in mild to moderately rough conditions, but not in waves over about 2m.

B. High Wave Deployment of Stationary Gages

The US Army Engineer Filed Wave Gaging Program (FWGP) and the SIO pioneered the use of helicopters for placing stationary wave gages. Both Waveriders and pressure arrays have been placed using the US Army Chinook CH-47 helicopter. When placing a Waverider, the buoy and its anchor are slung under the helicopter while the mooring is coiled inside. Once on station, the buoy is released and allowed to drift downwind while the mooring is paid out the stern cargo ramp. The anchor is released last. When placing pressure arrays, the array is slung from the helicopters central cargo hook (Fig. 4). Typically, an armored communication cable is laid from the gage to the beach (1-2 km) on the same flight. The cable is on a reel inside the helicopter and leads out the stern cargo ramp. The heavy-lift Chinook helicopter with its rear-opening cargo entrance is considered essential for these operations.

The principal incentive for developing these methods was to enable stationary gage deployment under higher wave conditions than could be safely accomplished from vessels. In some regions, such as the Pacific Northwest, waves can exceed safe operating thresholds for months at a time. When continuous records are desired, waiting for calm conditions is not always an option. Deployments in this category took place in spite of high waves, not because of them. However, there are times when measurements under extreme conditions are the study's only objective.

Fig. 4. Chinook with DWG-1.

C. Roving Gages

CHL conducted a study in which current measurements were required during high wave conditions in the immediate vicinity of the jetties at the Siuslaw River Entrance. It was too dangerous to position vessels that close to the rocks, so a US Coast Guard-supplied helicopter was used to lower an InterOcean S-4 meter at numerous positions around the structure [1]. The helicopter lowered the instrument on a side-mounted winch, and remained on station in a hover for several minutes while the current measurements were made.

Another CHL study required wave, water level, and current profiles at multiple stations on top of the Columbia River Bar during a typical winter storm. This is considered one of the most treacherous bodies of water in the world, and extreme conditions can persist for months at a time. Simply passing through the channel in a vessel is risky in the winter; an over-side operation in the surf zone was not an option. An instrument package could be deployed in the summer, but significant scour and deposition rates make recovery of a fixed instrument the following year doubtful.

The technique used at Siuslaw was considered, but was impractical. The instrument package was significantly heavier, and required over 1200 kg of lead weights to insure stability during the measurements. This could be accommodated by a heavy-lift helicopter, such as the Chinook. However, wave measurements require the gage to be stationary for longer periods - typically 18 minutes. Stationary hovering for that long a period is extremely challenging for the pilot, and is nearly impossible over open water, without fixed visual targets in the near field of view. This demanded the helicopter to place, release, and recover the instrument repeatedly. The method is illustrated in Fig, 5 and described in Reference [2].

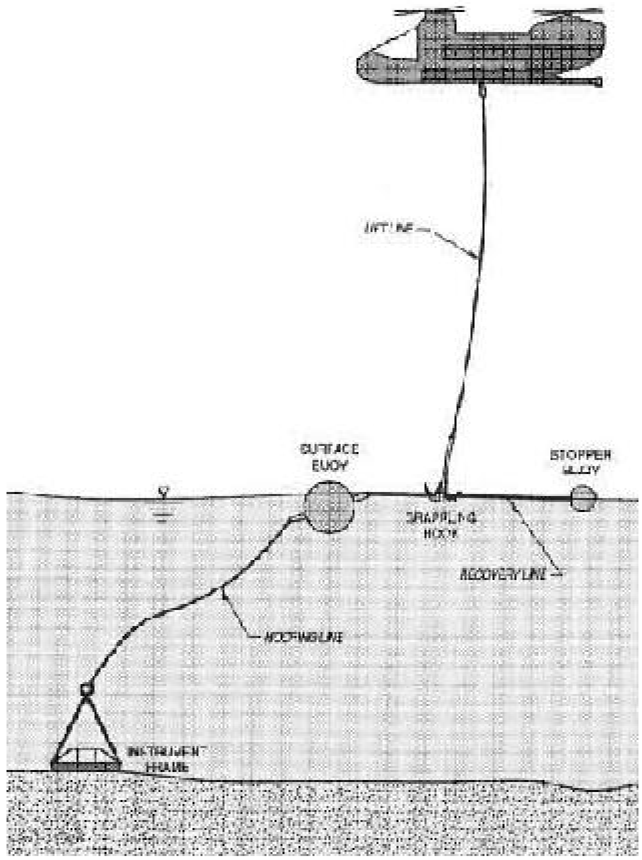


Fig. 5. Release and recovery of instruments with Chinook

While these two methods could be called event-deployed, the planning, preparation, and staging time, not to mention the cost, is significant and they are not likely to be widely utilized. In addition, most events of interest provide little advance warning - perhaps a few days at best, often just hours. A practical event-deployed gage must inherently be a rapidly-deployed gage.

III. MINIATURE GAGES

A. Hardware

An event-deployed measurement plan is possible with a new-generation of miniature wave gages developed by Neptune Sciences, Inc (NSI). The largest model is the Wave Sentry Buoy (Fig. 6). It is made from aluminum, PVC, and urethane foam and weighs 19 kg; the foam floatation collar is 75 cm in diam. It measures buoy motions with solid state sensors and an on-board micro processor calculates directional wave spectra. Typical wave parameters, such as significant wave height, peak wave period, and dominant wave direction, are automatically calculated from the spectra. Power comes from 27 alkaline D-cell batteries. Operating life is a function of the programmable sampling scheme; it will last about 1 month taking hourly, 17-min samples.

Fig. 6. NSI Wave Sentry Buoy

Fig. 7. Two NSI Mini Sentry Buoys

The next smaller model, the Mini Sentry Buoy, is a hand-held floating wave gage (Fig. 7). It is 9 cm in diam. by 58 cm tall, not counting the 40 cm antenna, and weighs 3.6 kg. The Mini Sentry measures non-directional wave spectra. The battery pack accounts for most of its mass, and will last about one week taking hourly wave measurements.

The smallest model from NSI is the Micro Sentry buoy. It measures 6 by 47 cm and weighs a little over ½ kg (see Fig. 8). It has essentially the same electronics as the Mini Sentry but only holds enough batteries for about 1 day of operation. Like all of the Sentry buoys, the sampling scheme is programmable, so increasing the sampling interval to say, two hours would double the operating period. This is truly a hand-held, "hand-tossable" instrument. It is based on the original model designed for the US Navy that is air-deployed and free-falls to the surface, so it is extremely rugged.

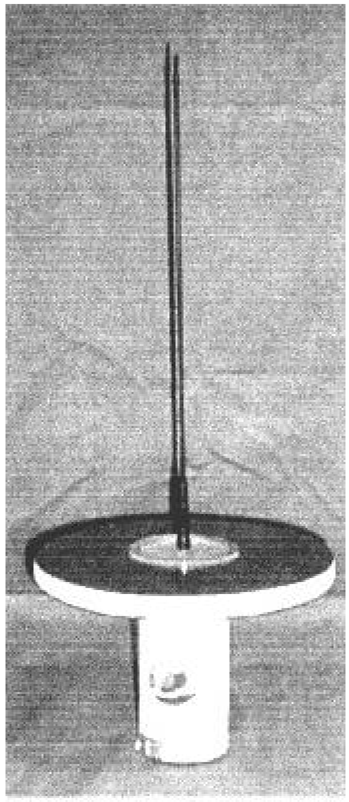


Fig. 8. NSI Micro Sentry Buoy

B. Operation

Measured data are both stored internally on solid state memory and transmitted in near real-time via spread spectrum UHF telemetry to a plane overhead, to a nearby vessel, to shore, or to an ARGOS satellite. Horizontal telemetry range is approximately 10 km, depending upon receiving antenna height. The receiving station consists of a UHF transceiver, a radio modem, and a PC. Even if the data are not required as soon as they are measured, telemetry offers valuable redundancy for capturing the measurements.

The buoys can be either free floating or moored. An onboard GPS receiver tracks the buoy and its position is included in the telemetry stream. Not only does this allow recovery if visual tracking is lost, but turns the buoy into a trackable drifter that provides surface current measurements as well as waves.

A Wave Sentry or Mini Sentry (and its mooring if desired) can be deployed in a few minutes from a small craft by two people (Fig. 9). The Micro Sentry can be tossed out from an airplane, a small boat, or even a personal watercraft by one person, without even reducing speed.

The low cost (see next section), ruggedness, and ease of deployment of these gages open an entirely new way to capture design wave information In one scenario one or more buoys would be stored in secure locations near sites where wave data are desired (harbors, airports, field offices, on board a dredge, etc.). When weather forecasts predict an event of interest, local trained personnel would.

Fig. 9. Two Wave Sentry Buoys ready for Installation.

deploy the buoy(s). In many cases, these would be volunteers with an intimate knowledge of the region and its weather and a personal or organizational stake in the wave information - harbor pilots, marine police, US Coast Guard search and rescue patrols, and lifeguards are all candidates for potential deployment teams. Access to real-time output by these organizations will more than compensate for the minimal investment in time. After adequate data are obtained, the buoy is recovered and readied for the next event or immediately redeployed at another site.

IV. COST COMPARISON

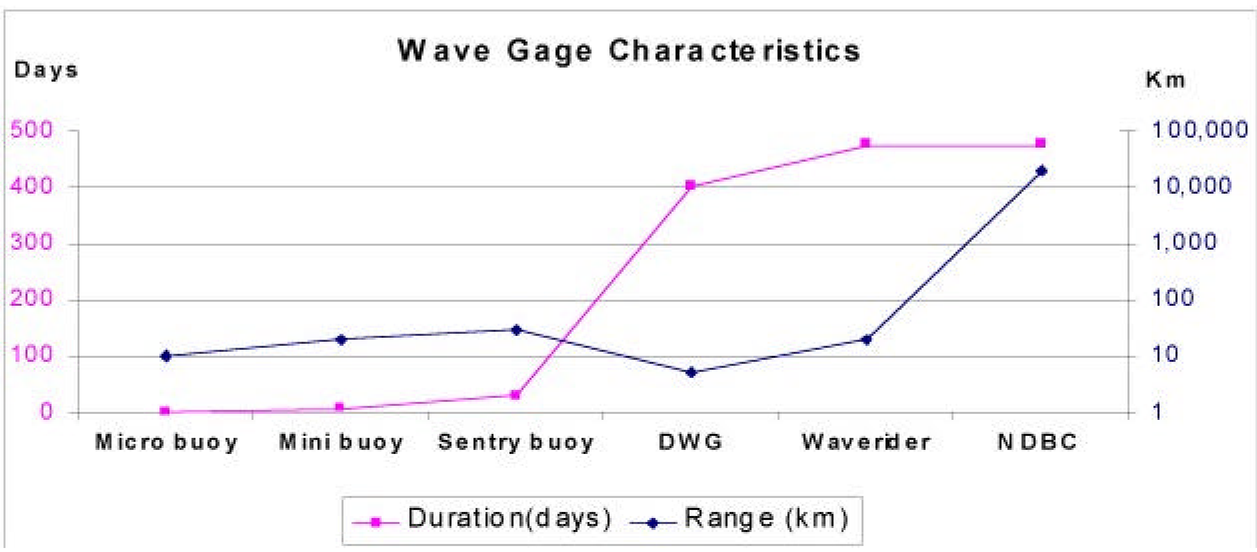
The principal costs of acquiring wave data are the hardware (gage and associated mooring or mount and shoreside electronics) operations (installation, repairs, and recovery), and data management (analysis, QC/QA, reporting, distribution, and archiving). Often, it is assumed the instrumentation is the major cost, but for the typical stationary gage, each of these three categories account for approximately equal shares of the total project cost.

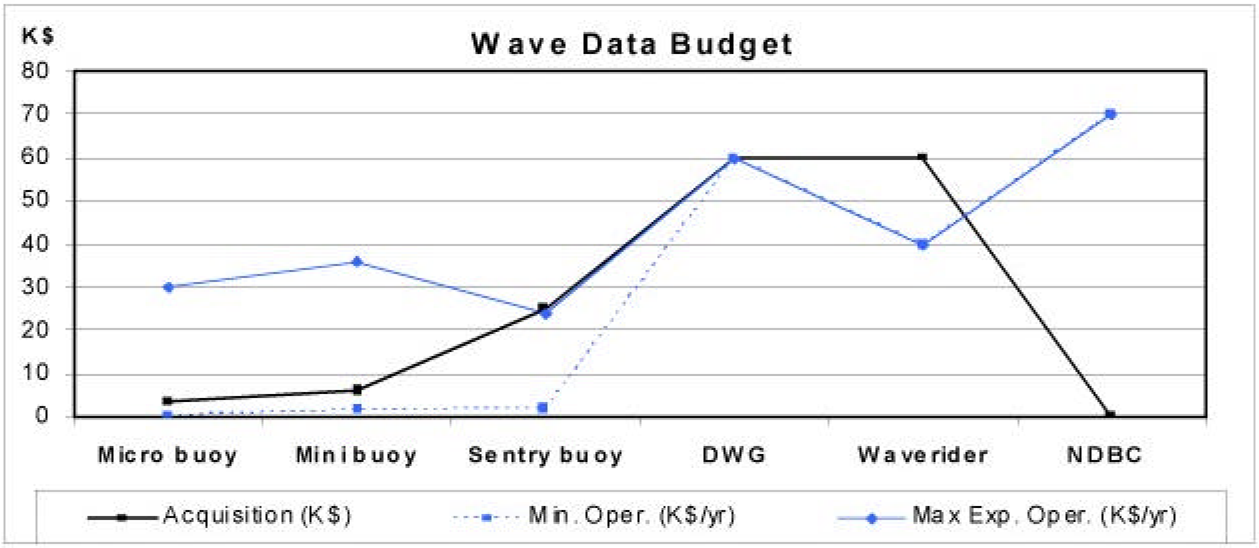
Costs are compared for the three models of Sentry gages, a Waverider, a DWG-1, and an NDBC 3-m discuss buoy. Acquisition costs for the first three gages are firm, but operational costs are projections based upon typical labor and travel costs, since there is little field experience available. For the latter three gages, cost estimates are based upon the principal author's twelve years of experience managing the FWGP between 1986 and 1998. During those years, the FWGP operated the world's largest network of stationary ocean wave gages, including nearshore coastal stations and deep water buoys. While it is understood that a streamlined private company may realize a more efficient operation than the government, it would not have the benefit of the economy of scale attained from operating a network approaching 100 gages for multiple years. Occasionally a "problem" site would cost considerably more than average to maintain in some years. However, the only way to realize significant savings was by neglecting maintenance. The overall data recovery rate for the FWGP was 90 %. Thus, these are considered conservative estimates applicable to a project that maintains the gage to assure capture of events of interest.

Fig. 10 (top) compares some basic operating characteristics of the 6 gages. "Duration" is the operating time for the gage using its internal batteries. As a fixed-mount gage, the DWG-1 is usually installed with a power and signal cable connecting it to a shore station. It could theoretically operate indefinitely on shore power. In practice, other considerations usually required approximately annual service trips. "Range" is the maximum distance it can send data in real-time. For the DWG, this is the maximum a signal can be sent on the cable without using in-line amplifiers. For the Sentry and Waverider, it is the line-of-sight radio range without using extraordinary receiving antenna height. Since the NDBC buoy uses the GOES satellite network for telemetry, its range is global. Thus, from a site selection standpoint, only the NDBC buoy offers access to real-time data across oceanic scales. If access to the data can wait until the gage is discovered, the Sentry buoys can also be deployed without concern for distance to a receiver. While the DWG can also store data internally, its pressure sensors limit the deployment depth for measuring wind waves to about 20m, so it is effectively a nearshore gage.

Fig. 10 (middle) shows the acquisition and annual operating costs for each gage. Acquisition costs include telemetry and shoreside receiving electronics. If operated in internal storage mode only, about $2,500 could be deducted from the Sentry gages and about $10,000, depending upon cable length, from the DWG. A single Micro Sentry costs $1500. NDBC does not sell its gages to clients; it charges a fee for operation including, presumably, an amortized hardware cost. Because the principal mission of NDBC is to collect and disseminate weather (including wave) observations, outside clients usually benefit from a significant government subsidy.

Operating costs for the Sentry buoys are linearly dependent upon the number of deployments, so a range between the minimum and the maximum expected operating costs is presented. The minimum cost represents one deployment and recovery. The maximum expected cost represents a 50 % duty cycle. That would be two one-day deployments a week for the Micro, two one-week deployments per month for the Mini, and six one-month deployments for the Wave Sentry Buoy. If a continuous record is required, a long-term gage is preferable.





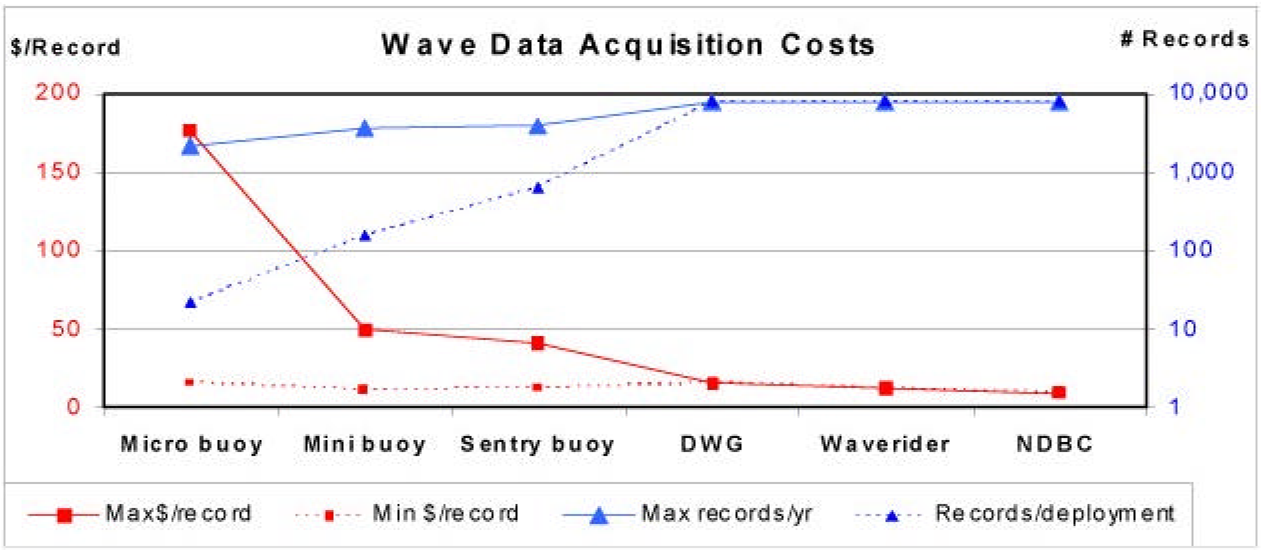


Fig. 10. Gage Performance (top), Acquisition and Operating Costs (middle) and Wave Record Costs (bottom).

Fig. 10 (bottom) recognizes that the desired product is the data, not the hardware. It plots the number of wave records measured in a year by each gage, assuming 90% successful data recovery. Finally, the unit cost of each wave record recovered is plotted. For the Sentry gages, the minima and maxima are shown, as described above; minimum costs per record comes form maximizing usage. Note that per-record cost for the Sentry gages is comparable to the long-term gages if it is fully utilized. Maximum cost per record means using the gage for only one deployment. Obviously, buying a Micro Sentry and throwing it away after one day results in the highest cost per wave record. But if those 24 measurements fulfill the study requirements, it is still the lowest cost option.

V. APPLICATIONS

Low cost, miniature instrumentation is not a low-cost replacement for traditional gages in all situations. For example, they will not serve NDBC's primary mission to monitor weather conditions. It is just as important for a mariner to know with certainty when the waves are less than his safe operational threshold as when they are above it. Neither are they suited to obtaining climactic statistics directly from measurements. They are not suited for sediment transport studies or structural fatigue studies, where the integrated effect over time of all loading is required. They also are more susceptible to two common hazards faced by gages in unprotected locations - accidental collisions with vessels and deliberate theft or vandalism. However, there are situations where they can replace conventional gages, and others new applications where wave measurements have not been considered.

Damage Threshold Measurements: In structural stability/integrity studies, the threshold of conditions that cause damage or failure is critical information. For example, the (INSERT HARBOR NAME HERE) breakwater failed unexpectedly under conditions that were estimated to be much lower than the damage threshold predicted by the physical model used for design. However, no gage was in place at the project site to provide a detailed measurement of the incident conditions. Knowledge of the incident wave spectrum that caused the damage would not only help design an adequate repair, but allow better understanding and improvement of a tool used to design hundreds of coastal structures.

Episodic Events: The US Army Engineer District, New Orleans, is using four Mini Sentry gages to capture hurricane wave conditions on Lake Pontchartrain to study potential for overtopping of the levees surrounding New Orleans [3]. Many years could pass before the gages are needed; when they are required, warning time could be a few days or less. The low cost and rapid deployment capability allow them to obtain the desired data at multiple sites for much less than the cost of a single long-term gage.

Emergency Response: The optimal tool for responding to an oil spill depends on the wave conditions. Rapid deployment of a gage directly into a spill would prevent managers from mobilizing resources (e.g., booms) when conditions preclude their use. Search and rescue missions are most effective when the right vessel for the conditions is dispatched. Air deployment of a gage could prevent the rescue crew from becoming victims themselves. Hurricane evacuation routes on bridges or causeways may become impassable when wave conditions become excessive. Real-time monitoring could allow civil defense authorities to reroute traffic before lives were lost.

Wave Model Validation: Calibration and verification of numerical and physical wave models is expensive but necessary. Usually, one gage is deployed for a year, and the model validated for whatever conditions occur during that time. Questions can remain about unusual conditions that weren't measured - not only high energy events, but unusually long periods or crossing wave trains. If the model domain includes widely varying boundaries, selecting the one site for calibration is a compromise. If a large number of sites could be measured during these unusual events, confidence in the model would be greatly enhanced. Once a deployment crew is mobilized, additional gages could be deployed at negligible additional operational cost

Small Projects: Budgets for smaller structures or harbors rarely have several hundred thousand dollars for obtaining site specific data. If data collection cost several tens of thousands or less, managers of smaller projects could afford to design a safer, more efficient project. Examples include low-cost shore protection projects, small boat harbors, lakes and reservoirs.

Operations: Most construction contracts include provisions for weather delays. Claims and disputes over the wave conditions can become a major burden to both parties. A contractor could document the exact conditions at any time using a $1500 instrument, a fishing pole and line to deploy it, and 15 minutes of non-skilled labor.

VI. CONCLUSIONS

New miniaturized wave gages provide a low-cost alternative to traditional, long-term stationary gages. Battery capacity, and thus operational life, is much reduced compared to larger gages, and they face greater risk from accidental and deliberate encounters with mariners. However, in those applications where it is critical to capture specific events, savings of more than an order of magnitude can be realized. The lowest overall cost is realized by minimizing the number of deployments. On the other hand, if a miniature gage is utilized to its maximum practical capacity, the cost per wave record collected costs can is actually less than for traditional long-term gages.

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