Requirements for a Nearshore Wave Observation Capability within the National Ocean Service Center for Operational Oceanographic Products and Services

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U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

Center for Operational Oceanographic Products and Services
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

The National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) provides the National infrastructure, science, and technical expertise to collect and distribute observations and predictions of water levels and currents to ensure safe, efficient and environmentally sound maritime commerce. The Center provides the set of water level and tidal current products required to support NOS' Strategic Plan mission requirements, and to assist in providing operational oceanographic data/products required by NOAA's other Strategic Plan themes. For example, CO-OPS provides data and products required by the National Weather Service to meet its flood and tsunami warning responsibilities. The Center manages the National Water Level Observation Network (NWLON), a national network of Physical Oceanographic Real-Time Systems (PORTS®) in major U. S. harbors, and the National Current Observation Program consisting of current surveys in near shore and coastal areas utilizing bottom mounted platforms, subsurface buoys, horizontal sensors and quick response real time buoys. The Center: establishes standards for the collection and processing of water level and current data; collects and documents user requirements, which serve as the foundation for all resulting program activities; designs new and/or improved oceanographic observing systems; designs software to improve CO-OPS' data processing capabilities; maintains and operates oceanographic observing systems; performs operational data analysis/quality control; and produces/disseminates oceanographic products.

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NOTICE

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

A lack of sustained wave observations in coastal and estuarine environments along all United States coastlines is a known gap in operational oceanography. Less than 10% of all real-time wave observations collected in the United States (about 20 stations total) are shallow-water or nearshore areas. Yet, nearshore wave observations are critical for a wide range of uses and applications—including assisting with marine navigation, developing hydrodynamic models, predicting coastal hazards (such as rip currents), forecasting coastal change, and understanding and predicting coastal inundation. The National Ocean Service Center for Operational Oceanographic Products and Services (CO-OPS) is well positioned to collect nearshore wave observations as part of its standard suite of physical oceanographic observations. However, a robust assessment of partner and end-user needs was required prior to developing technical requirements to ensure the capability of meeting the operational needs for this information.

CO-OPS identified and documented top-level requirements to support establishment of a national nearshore waves observation program in 2020 through an internal assessment, literature review, and engagement with key navigation, weather, and academic partners. CO-OPS staff designed and administered a survey with the primary goal of gathering feedback on nearshore wave observations as well as specific wave measurement parameters, products, observation locations, and use-cases.

The group surveyed 37 federal, non-federal, academic, and maritime community partners and stakeholders. Nearly all respondents were extremely interested in wave observations co-located with existing CO-OPS water level stations. The two most important wave variables to observe were significant wave height and wave period, with wave direction deemed beneficial but not essential. Respondents indicated that real-time wave observations are vital; however, there was still some value for historical or non-real-time data. It was clear that at least a basic level of visual wave products on the CO-OPS website is needed. Further, access to data via a variety of web and data services is essential to better enable integration into other internal and external products and processes. Respondents identified use cases for wave observations such as model validation, improving forecasts, safe marine navigation, and monitoring and understanding wave processes.

Establishing requirements is an important step to determine if and how a nearshore wave observational capability will be implemented. CO-OPS will work with partners to develop a nearshore wave observation strategic plan to outline co-developed goals and objectives of a waves observation program. Additional paths forward to meet these objectives include budgeting and a resource requirements assessment. Once resource and strategic direction is in place, CO-OPS will begin developing technical requirements and a phased implementation plan, working closely with partners to progress the capability forward.

1.0 OBJECTIVE

The Center for Operational Oceanographic Products and Services (CO-OPS) has identified two objectives to ensure a nearshore capability for its wave observations: (1) Define top level requirements for CO-OPS wave measurement systems, disseminated data, and analysis products based on existing, well-established wave measurement observatory systems, user requests, and internal knowledge, and (2) identify wave measurements and products which support the greatest range of user requests and are most feasible given CO-OPS priorities and resource availability.

These requirements will drive the implementation of the strategy, partnerships, and technical details associated with:

- Design and development of wave measurement systems
- Wave sensor configuration settings
- Supporting IT infrastructure
- Research & development (R&D) of wave related products and services

2.0 MOTIVATION

Significant gaps in sustained in-situ wave measurements and products exist across all U.S. open coast and estuarine environments. Currently, wave observations include 245 stations nationwide, transmitting in real-time through the National Data Buoy Center (NDBC), the Coastal Data Information Program (CDIP), and/or the U.S. Army Corps of Engineers (USACE) (Figure 1). Of these measurements, less than 10% (20/245) are in shallow water nearshore areas (≤10 m, as defined by IOOS [1]; Figure 1). Wave direction is reported only from roughly half of these 245 stations. Long-term time series are relatively short (44 years for deep water buoys in the Gulf of Alaska and Coos Bay, Oregon [1]) compared to other oceanographic observation time series like tide records (e.g., 163-year tidal record in San Francisco).

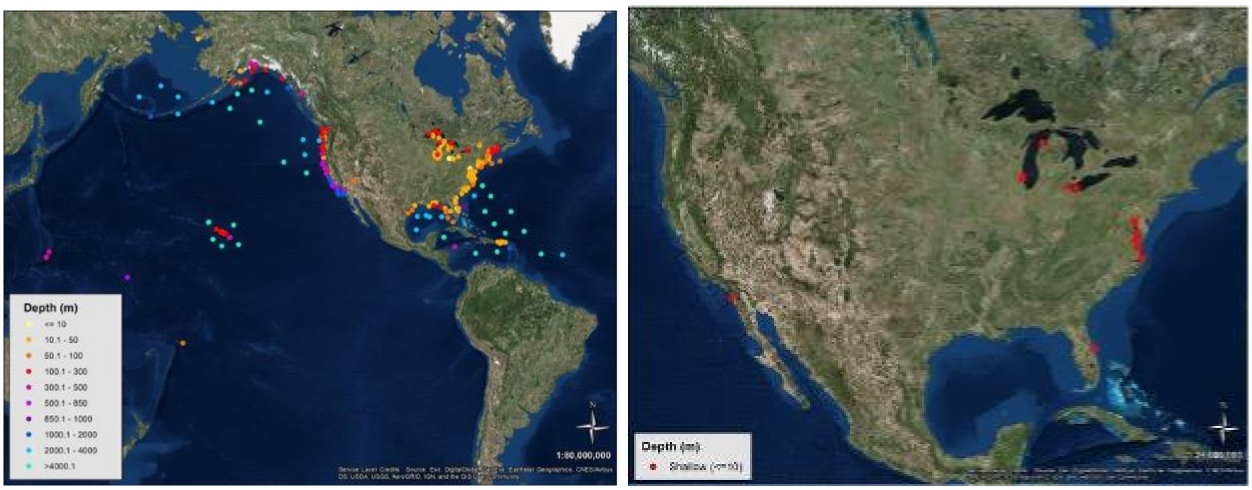

Figure 1. (Left) Real-time wave observation stations color coded by the station depth (m). The total number of stations is 245 and the data are available across multiple agencies and organizations. (Right) Of the 245 total stations, 20 (red dot) are in shallow water (≤10 m).

Expansion of real-time wave measurements to the CO-OPS observing network has been considered for several years in response to National Oceanic and Atmospheric Administration (NOAA) Integrated Ocean Observing System (IOOS®) National Operational Wave Observation Plan [2], which identifies that there is a critical need to increase spatial coverage of national nearshore wave observations. Currently, NOAA CO-OPS does not maintain a suite of wave measurement systems. Wave information disseminated via NOAA's Physical Oceanographic Real-Time Systems (PORTS®) is pulled in via web services from Scripps Institution of Oceanography (SIO) CDIP. Wave information from these Datawell buoys is integrated with other observations of the nearby PORTS.

Consistent wave height measurements at multiple National Water Level Observation Network (NWLON) stations along the coast of the U.S. would be useful to a wide array of users including ports and shipping managers, ocean modelers, weather forecasters, and others in the transportation, city management, and scientific communities. To begin to investigate the possibility of establishing a long-term wave measurement system and associated development and dissemination of wave products, CO-OPS outlined concepts through a white paper in 2018 [3]. To affirm the concept outlined in the white paper, an assessment of user needs and requirement gathering was proposed. This document is a critical first step in establishing a solid foundation for a wave measurement program and ensuring it is directly tied to NOAA’s mission and external customer needs.

3.0 APPROACH

In accordance with proposed plans laid out in the 2018 reference [3], a CO-OPS working group was formed, consisting of members across multiple divisions and staff, to lead the requirements definition process. Input and information used to drive requirements defined here can be classified into three categories:

1. Working group discussions regarding CO-OPS operational needs.
2. Measurement specifications and data products of well known, existing wave observing systems
3. A questionnaire that was developed and distributed to individuals representing a wide range of potential end user organizations.

A CO-OPS working group identified operational needs based on personal experiences with oceanographic and coastal engineering research efforts, measurement systems and field operations, and interactions with CO-OPS end users. A questionnaire was drafted to assess the interest and need for the establishment of long-term nearshore wave measurement systems by CO-OPS and to solicit external input on measurement systems, as well as data and product requirements. The working group collaborated to design and develop a specific set of questions to optimize the information gathering process in support of the requirements objectives. The questionnaire can be found in Appendix A.

Wave measurement specifications and data products of both NOAA National Weather Service (NWS) NDBC and the University of California San Diego CDIP were considered and discussed, representing examples of two extensive and well-established wave measurement programs. Based on available wave measurement system types, measurement and data requirements are grouped into two categories: 1) non-directional and 2) directional wave measurements. Requirements cover details associated with measured and derived parameters, as well as sample rates, metadata, data access, and visual products.

4.0 STAKEHOLDERS

The following partners were considered and contacted when determining requirements. A list of specific people who filled out the questionnaire can be found in Appendix B.

- NOAA - NWS
  - National Center for Environmental Prediction (NCEP)
  - Analyze, Forecast, and Support Office (AFS)
  - Weather Forecast Offices (WFO)
- United States Geological Survey (USGS)
  - MD-DE-DC Water Science Center
  - Coastal-Marine Hazards and Resources Program
  - St. Petersburg Coastal and Marine Science Center
  - Woods Hole Coastal and Marine Science Center
- USACE
  - Coastal and Hydraulics Laboratory
- Academic partners
  - SIO CDIP
  - University of North Carolina Wilmington
  - University of South Alabama
  - Texas A&M Corpus Christi
  - University of Washington Applied Physics Lab
- IOOS regional associations
- PORTS maritime partners
- Various end users (recreational users, city managers, coastal engineers)

5.0 SUMMARY OF SURVEY RESULTS

A total of 37 participants took the survey and overall answered affirmatively to increased availability of wave observations with a preference for real-time and directional wave data. To view the survey questions and results, see Appendices B and C.

Nearly all respondents were extremely interested in wave observations co-located with existing CO-OPS water level stations.

When participants were asked to rate their interest in real-time wave observations co-located with CO-OPS existing water level observations (Question 2), all the respondents answered from moderate (3) to high interest (5) with 84% of respondents (31/37) answering the highest level of interest (5).

Significant wave height and wave period are the two most important variables to provide, while wave direction is beneficial but not essential.

Respondents were surveyed on the utility of wave parameters to their work and identified significant wave height (97%), dominant (peak) wave period (92%), and mean wave direction (81%) as the most useful. Respondents (70–72%) indicated spectral energy density, average wave period, principal (peak) wave direction, and maximum wave height as having moderate utility to their work; 54% indicate steepness to be useful, while little utility (one respondent) was identified for 9-band component height/direction, swell period, and height parameters. Many respondents also indicated that associated metadata should be provided with wave measurements, specifically the spectral method and sampling schemata.

Real-time wave observations are vital and should be updated at least every 60 minutes (min).

Participants demonstrated a preference for real-time over non-real time wave measurements. Overall, respondents indicated greater importance for real-time wave measurements, with all 37 respondents indicating moderate importance (3) to high importance (5) and 73% of respondents (27/37) indicating that real-time measurements have high importance (5). When asked to define how often real-time data measurements should be updated, 51% preferred updates every 20 min, 29% indicated preference for 30 min, and another 29% indicated preference for 60-min updates. Regarding non-real time and historical wave data, three respondents found no or little importance, while 46% of respondents (17/37) indicated high importance of non-real-time wave data.

Directional wave observations are useful, but nearly all respondents would value wave observations <u>without</u> wave direction.

Most questionnaire respondents stated that they would find directional measurements to be very useful, but also answered that they would still want the non-directional wave measurements if that was the only option. When asked how important directional wave observations were, 25/37 respondents answered with the highest level of interest (5), 11 answered (4) and one answered (1). If directional measurements were unavailable, 16/37 respondents replied they would have the highest level of interest (5) in non-directional measurements, 10/37 respondents selected an interest level of (4), and 5/37 respondents selected (3). Three respondents said they would not find them useful (three selected (2) and one selected (1-not useful).

Respondents desire at least a basic level of visual wave products on the CO-OPS website and want to access data via a variety of web services.

Participants were asked to list any visual products they would like to see on the CO-OPS site. Responses included time series, spectra, climatologies, monthly box plots, and wave roses. When surveyed on how users preferred to access wave data beyond the CO-OPS website or API, respondents indicated a preference for access through Advanced Weather Information Processing System or AWIPS (27%), and map services (19%).

Wave observations are essential for model validation, improving forecasts, safe marine navigation and monitoring, and understanding wave processes.

Respondents provided a large number of use cases for additional nearshore wave observations. The absolute dearth of wave observations presently along much of the U.S. coastline was highlighted repeatedly, as was the present lack of wave observations for validation and tuning of numerical wave models. Several respondents mentioned the need for wave observations in areas of frequent marine navigation. There was also a need for wave observations to support scientific research and monitoring the nearshore environment. Specific responses identified the following benefits:

<u>NWS</u>

- validation of nearshore wave forecasts for surf advisories
- validation of Nearshore Wave Prediction System
- initial conditions for storm surge, tide, and wave model
- produce data-dominated products
- represent smaller (sub-100 m) spatial scales
- increase observations and safety along coastlines with minimal or no observations
- enhance marine forecasts
- improve weather forecasting skills
- resolve anomalous wave runup
- enhance Decision Support Services (DSS) efforts.

<u>USGS</u>

- strengthen the value of analysis of coastal evolution and coastal change hazards
- provide spatial variability in wave/flood simulations
- input and validation for the Total Water Level and Coastal Change Forecast (TWL)
- improved understanding of nearshore hydrodynamics under varying conditions to be linked with onshore and topographic measurements.

<u>Pilots and Harbormasters</u>

- increase safety in seaports and harbors

- ensure pilot boarding and disembarkation safety

Research and Academics

- model forcing and validation
- short-term inundation predictions
- coordination of threatened sea turtle nesting related tasks
- beach infrastructure management
- erosion control and sand management.

6.0 WAVE MEASUREMENT AND PRODUCT REQUIREMENTS

The following measurements and products were chosen as requirements based on user needs identified in the questionnaire, as well as industry standards from similar organizations such as CDIP and NDBC.

6.1 Measured Parameters

Measured parameters are those observations measured directly from instruments and are primarily sea surface height displacement, as well as three-dimensional (3-D) motion from acoustic Doppler current profilers (ADCPs) or buoys. Wave observations can either be non-directional or directional (Table 1). The type of measurement available at a station depends on the sensor type. In order to provide a directional wave observation, the measured parameters must be two-dimensional (2-D) from a single source, or an array. Wave spectra computed from historical water level measurements or from microwave radars and single point pressure sensors will be non-directional.

Table 1. Measured Parameters

Non-Directional Wave Measurements	Directional Wave Measurements
Sea surface height (displacement)	Sea surface height (displacement)
	Near surface orbital motion (ADCP)
	Buoy motion

6.2 Derived Parameters

The derived parameters are those computed from the measured parameters (Table 2). Derived parameters, including significant wave height and peak wave period, are computed through a statistical analysis of the measured parameters. The most commonly used method to compute wave parameters is spectral analysis, though wave train analysis is also used.

Table 2. Derived Parameters

	Non-Directional	Directional
Significant wave height	X	X
Maximum wave height	X	X
Dominant/Peak wave period	X	X
Average wave period	X	X
Spectra (energy density)	X	X

	Non-Directional	Directional
Steepness	X	X
Mean wave direction		X
Dominant/Peak wave direction		X
Fourier coefficients (A1, B1, A2, B2)		X
M2/N2 band centered Fourier coefficients		X
Standard deviation of sea surface height	X	

6.3 Metadata

Table 3 shows the metadata that CDIP uses and that they request from external users. While some end users, particularly pilots, harbormasters, and recreators need only location, most users require information related to sampling and wave analysis.

Table 3. Metadata

Metadata Source	Metadata Details
Station	Platform type Location Water depth
Sensor	Type Manufacturer & Model Vertical position (height above mean sea level or depth below mean sea level)
Observation frequency	
Sampling	Sampling period start Sampling frequency Sampling period Number of frequency bins Minimum - maximum frequency range Directional resolution
Wave analysis	Technique FFT parameters (NFFT, window, overlap)

6.4 Analysis and Visual Products

There are a variety of possible products that can be created based on the wave observations. The questionnaire respondents were asked to name any visual products that they would like to see on the CO-OPS website. The following list shows those commonly available from other organizations and most requested by respondents.

Primary

- Time series plots - basic times series plots of main wave parameters (significant wave height, period, direction)
- Spectra - 2-D or polar wave energy

Historical Analysis

- Sigma - computation of significant wave height derived from the standard deviation of 6-min water level observations.
- Climatologies - monthly box plots, yearly/seasonal extrema
- Dynamic Water Level - mean water level ±2 × sigma

Additional

- Gerling-Hanson Plots - individually tracked wave systems
- Wave rose - polar plot of wave heights
- Swell components - computation of swell and wind wave components or indication of swell or wind dominance
- Model comparison - comparison to Wave Watch 3
- 9-band plots - special data format for energy and direction used by USACE.
- User defined plotting capabilities

6.5 General Technical Requirements

Several questions in the questionnaire (Appendix A) were related to technical details of wave measurements and data products. The needs of users, industry standards, as well as instrumentation capabilities were considered when determining the following technical requirements.

Sampling Rate: - No less frequent than 1 Hz
The highest frequency wave that can be resolved with a sample rate of 1 Hz is 0.5 Hz. This is sufficient for any surface gravity waves.

Observation Period: - 20 min
Respondents were asked how often they would like wave observations. Most (19) requested 20 min (11 chose 30 min and 11 chose 60 min). This is a feasible observation period with a 1 Hz sampling rate.

Data Latency: not to exceed 30 min for real-time data
All respondents said that having the availability of wave measurements in real-time was important (27/37 chose [5-very important], 7/37 chose [4], and 3 chose [3]). In order for wave observations to be useful for safety and as model and forecast inputs, it is vital for them to be as current as possible. Latency should not exceed 30 min for real-time measurements.

Respondents were also asked whether non-real-time or historical measurements would be useful in instances when real-time data were unavailable (e.g., post-analysis on historical data, non-real-time short deployments). Many would still find this type of measurement useful (17/37 chose (5-very useful), 8 chose (4), 9 chose (3), 1 chose (2), and 2 chose (1-not useful)). Non-real-time waves computations should be considered on a case-by-case basis.

Accuracy and Precision:
Accuracy and precision of wave measurements is highly dependent on the instrumentation type. CO-OPS should maintain accuracy and precision documentation for each instrument, setup, and wave computation type.

6.6 Data Management Requirements

The data management of waves data covers several areas:

- Data transmission
- Data ingestion
- Database (tables and other objects)
- Data retention and archival
- Quality control tools
- APIs, web services, and products
- Tides and Currents website (TAC)

Data transmission
A new method for computing, logging, encoding, and transmitting wave observations would need to be implemented on field measurement systems. For most prospective CO-OPS applications, this will involve modified software capabilities on the standard data logger/controller component of an NWLON and PORTS station and most likely an encoding scheme that can support real-time transmission via current data telemetry systems (GOES, Iridium, LTE wireless gateway). Although real-time computing and logging details will vary with each wave sensor type, a standard encoding scheme for all wave measurement stations must be designed and implemented to support development of an automated, streamlined decode and ingestion system. Existing encoding standards and previously developed capabilities common across COTS data loggers could possibly be investigated and leveraged for new CO-OPS applications.

Data Ingestion:
New product pathways will need to be developed within data ingestion to acquire, decode, and perform initial quality control (QC) of waves data. This may involve entirely new software, depending on the data pathway (GOES, polling, etc.) data format, transmission frequency, etc. Decisions regarding data frequency should be made as early as possible, as a higher frequency (i.e., *N*-second data as opposed to 30-min data) can have a large impact on design considerations.

Database:
New database tables will need to be designed and developed; associated stored procedures for data insertion and retrieval will need to be written. New tables and fields are needed for both the observational data and any associated station metadata. Depending on the frequency, entirely

separate databases may need to be developed in order to manage the potentially larger amounts of data. Similarly as for data ingestion, decisions regarding data frequency should be made as early as possible as a higher frequency (i.e., *N*-second data as opposed to 30-min data) can have a large impact on design considerations.

Data Retention and Archival

CO-OPS should also consider retaining 1 Hz observations when feasible. Most questionnaire respondents said that they would find such data useful (20/37 yes, 15/37 maybe).

When this CO-OPS operational wave data product is implemented, the transition will include a full data management plan with the pertinent data management information from this document, along with other elements (e.g., how much wave data should be retained in the CO-OPS operational database, data archiving requirements, and formal metadata documentation needs).

Quality Control:

Quality control checks on wave observations will be conducted in accordance with NOAA\IOOS latest edition waves manual [4] and associated QA\QC flags will be archived and available with data records.

If waves are treated as a fully operational product, various quality control and monitoring tools will need to be updated to manage waves data. These may include Diagtool (to plot raw data), Continuously Operating Real-Time Monitoring System (CORMS) QC (to monitor real-time data and turn dissemination on/off) and possibly analysis tools such as WALI (to better understand raw waves data and possibly reprocess or verify).

A series of automated flags may be set, and then data will be subsequently placed into CO-OPS Database Management System (DMS). Once in DMS, all real-time data is monitored by CORMS, which includes human observers who monitor data 24 hours a day, 7 days a week. When CORMS staff detects a data QC issue, public data dissemination is immediately stopped, and an internal request is submitted to commence troubleshooting and repair.

Application Programming Interfaces (APIs), Web Services and Products:

CO-OPS APIs and web services need to be updated to be able to disseminate waves data. Changes include updating the Metadata API to serve station listings with waves data and associated info. The CO-OPS Data API will need to be updated to retrieve waves data. Finally, other services such as IOOS-DIF-SOS, SOAP AXIS, and ERDDAP need to be updated. We may also wish to update our AIS BBM web service so the U.S. Coast Guard can transmit wave data via their AIS transmitters. Engagement and technical support should be provided for data integration into NWS operations, particularly through AWIPS. In addition, SHEF and CREX bulletins will likely need to be developed for wave data.

Tides and Currents Website (TAC)

The TAC website would need to be updated to create a landing page for waves related station listings, plotting waves data, and integrating waves data into our PORTS product pages. Integration should occur into other specific applications such as the Coastal Inundation Dashboard and should be assessed when project planning is undertaken.

6.7 Locations

In the future, nearshore wave observation locations may include current CO-OPS water level stations, as well as new stations that are highly requested by users. It may also be possible to include wave measurements based on archived data at historical and/or temporary stations, such as those occupied during a National Current Observation Program survey.

Questionnaire respondents were asked to identify current CO-OPS stations at which they would benefit from wave observations. They were also asked to specify any locations that do not currently have existing CO-OPS measurements. While the responses are highly dependent on the respondent's work and work location, the results show what types of locations will be most useful and desired in the future (Table 4).

Recommended areas include port and harbor entrances, high population centers, areas with recreational fishing, and estuaries and bays. Several specific locations requested were stretches of coastline with gaps in both wave observations and water level observations, such as the Gulf side coastline of Texas, the eastern coast of Florida, and U.S. territories in the western Pacific. A map of requested locations along the contiguous U.S. can be seen below (Figure 2).

Location selection will also depend on physical qualities of the site and sensor availability. Some locales will require wave buoys, while others may be suitable for the standard deviation of water level (sigma) analysis or spectral calculations from microwave radars.

A full list of responses can be found in Appendix C, Questions 4 and 5.

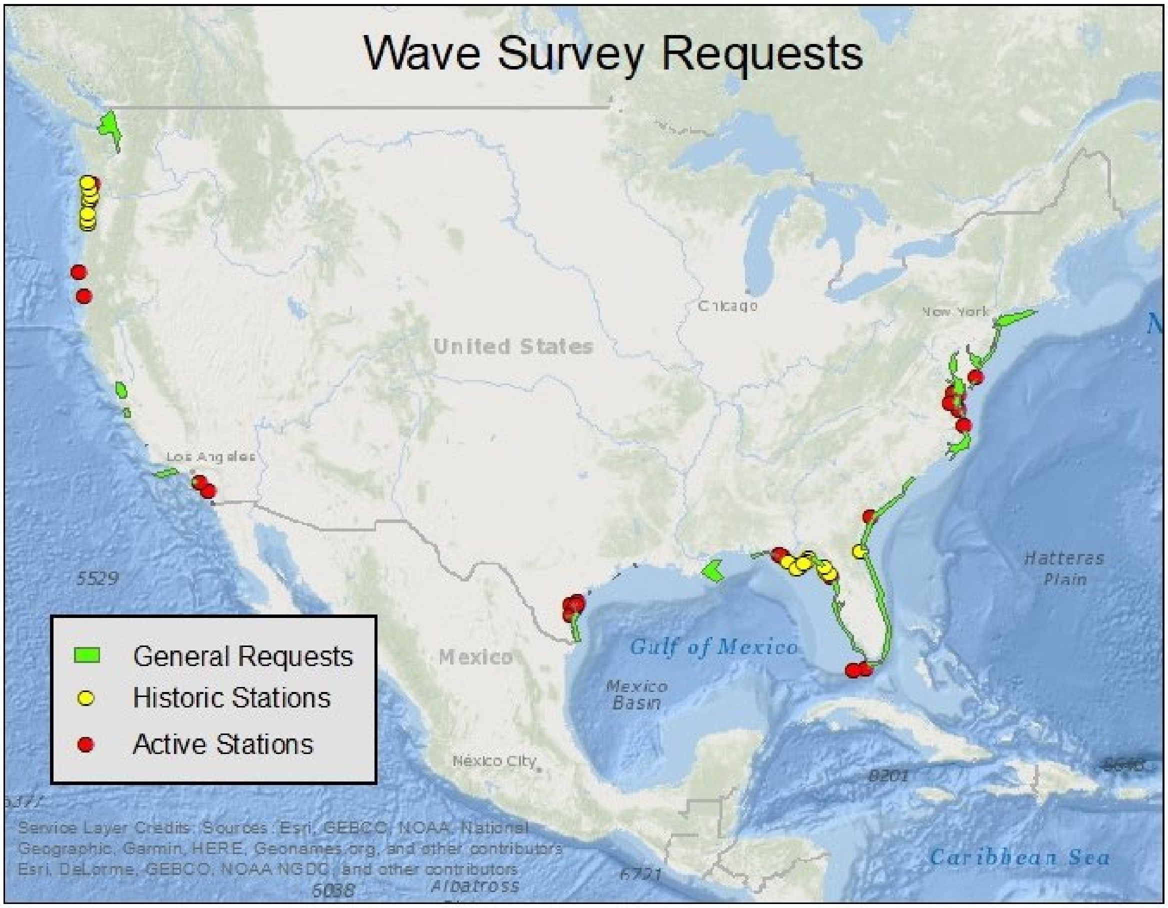

Figure 2. Map of requested wave observation station locations along the continental U.S.

Table 4. Selection of requested stations

Active Open Ocean	Active Other	Historic Open Ocean	Historic Other
8651370 Duck, NC	8632837 Rappahannock, VA	8720214 Degaussing Structure, FL	8727558 Suwannee River Entrance, FL
8723979 Vaca Key, FL	8638901 CBBT, VA	8727648 Horseshoe Point, FL	8727695 Steinhatchee, FL
8724580 Key West, FL	8638999 Cape Henry, VA	8728229 Shell Point, FL	8728548 St. George Island East End, FL
8727520 Cedar Key, FL	8728690 Apalachicola, FL	8728288 Alligator Point, FL	8728669 Sikes Cut - St. George Island, FL
8775241 Aransas Pass, TX	8729108 Panama City, FL	8728995 Mexico Beach, FL	8728408 Dog Island East End, FL
8775870 Bob Hall Pier, TX	8729210 Panama City Beach, FL		9435385 Yaquina USCG Newport, OR
9431647 Port Orford, OR	8774770 Rockport, TX		9435827 Depoe Bay, OR
1770000 Pago Pago, American Samoa	8775296 USS Lexington, TX		9436381 Cascade Head Salmon River, OR
	8775792 Packery Channel, TX		9437585 North Jetty Tillamook Bay, OR
	8776604 Baffin Bay, TX		9437954 North Fork, OR
	9435380 South Beach, OR		9438478 Seaside, OR
	9437540 Garibaldi, OR		9440572 Jetty A Columbia River, OR
	8775237 Port Aransas, TX		
	9410396 Oceanside Harbor, CA		
	9410580 Newport Beach, CA		
	9419750 Crescent City, CA		
	8570283 Ocean City, MD		
	8636580 Windmill Pt, VA		
	8720218 Mayport Bar Pilots Dock, FL		
	9439040 Astoria, OR		
	9440581 Cape Disappointment, WA		
	8670870 Fort Pulaski, GA		
	8637689 USCG Training Center, VA		

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NDBC:

https://www.ndbc.noaa.gov/rsa.shtml
https://www.ndbc.noaa.gov/wave.shtml
NDBC Technical Document 03-02 Handbook of Automated Data Quality Control Checks and Procedures of the National Data Buoy Center, vol. 54, 2003:

CDIP:

http://cdip.ucsd.edu/themes/cdip?pb=1&d2=p103&u2=p_desc:sp_format
http://cdip.ucsd.edu/documents/index/product_docs/qc_summaries/waves/waves_table.php

APPENDIX A. QUESTIONNAIRE

As NOAA CO-OPS investigates the establishment of long-term wave measurement systems and the development and dissemination of wave products, we are reaching out to our partners and stakeholders to determine user needs to help shape potential wave data products.

Here "nearshore" is defined as wave observations in estuarine areas or along the coast out to about 10 m depth.

Please fill out the following questionnaire on your use of wave measurements and let us know how you would benefit from nearshore wave observations. This survey should take about 10 minutes to complete.

1. How (if at all) are you and your organization presently using nearshore wave observations?
2. How interested are you in having nearshore waves observations at the CO-OPS real-time water level stations? (scale 1-5)
3. How would you and others in your organization benefit from new or additional nearshore wave observations?
4. Are there any specific CO-OPS NWLON/PORTS® locations where you would like to see waves measurements added? See map of existing stations here: https://tidesandcurrents.noaa.gov/stations.html
5. Are there any additional locations where you'd like to see nearshore wave observations? See map of existing stations here: https://tidesandcurrents.noaa.gov/stations.html
6. What wave parameters would you find useful? significant wave height, maximum wave height, dominant (peak) wave period, average wave period, steepness, spectral energy density, mean wave direction, principal (peak) wave direction, other
7. Are you and your organization interested in the metadata associated with spectra and bulk parameter estimation methods? If yes, please list what parameters/metadata would you request (i.e., sensor type, spectral method).
8. How important is having the wave measurements be available in real-time? (scale 1-5)
9. If real-time measurements are important, how often would you like the data to be updated? 20 min, 30 min, 60 min, other
10. How useful would non-real-time or historical wave data be to your organization? (i.e., at a short-term deployment or existing water level station) (scale 1-5)
11. How important are DIRECTIONAL wave observations to your work and organization? (scale 1-5)
12. If directional wave observations are unavailable, how useful would you find non-directional observations? (scale 1-5)
13. Other than by direct download from the CO-OPS website (tidesandcurrents.gov) or through the CO-OPS API, through what services would you like to access these data (e.g., map services, cloud)?
14. What visual products (if any) would you like to see on the CO-OPS site (e.g., polar spectra, monthly wave height box plots)?

15. Would you use high frequency sea surface height time series (offered in non-real-time)?
16. Do you have any questions, comments, or suggestions regarding nearshore wave observation products?

APPENDIX B. QUESTIONNAIRE RESPONDENTS

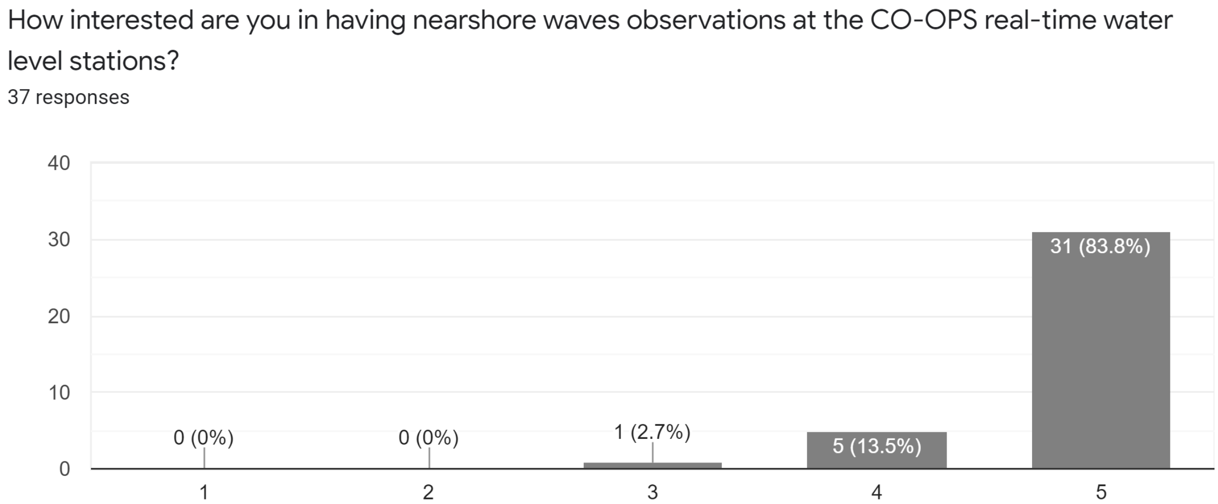
Organization
NOAA NWS National Hurricane Center
NOAA NWS NDBC
NOAA NWS Marine, Tropical, and Tsunami Services Branch
NOAA NWS Corpus Christi WFO
NOAA NWS Key West WFO
NOAA NWS Tallahassee WFO
NOAA NWS Melbourne WFO
NOAA NWS Corpus Christi WFO
NOAA NWS Wakefield VA WFO
NOAA NWS Charleston WFO
NOAA NWS Medford WFO
NOAA NWS Los Angeles WFO
NOAA NWS Wakefield VA WFO
NOAA NWS Guam WFO
NOAA NWS Samoa WFO
NOAA NWS Jacksonville WFO
NOAA NWS Puerto Rico WFO
NOAA NWS Honolulu WFO
NOAA NWS Tallahassee WFO
USGS MD-DE-DC Water Science Center
USGS Pacific Marine Science Center
USGS Woods Hole Coastal and Marine Science Center
USACE, FRF
University of California San Diego - Scripps
University of South Alabama - Civil Engineering
Texas A&M Corpus Christi, Conrad Blucher Institute
University of Washington - Applied Physics Lab
Mariners Advisory Committee of the Delaware River and Bay
Lake Charles Pilots
Ventura Harbor

APPENDIX C. QUESTIONNAIRE RESULTS SUMMARY

1. How (if at all) are you and your organization presently using nearshore wave observations?

    Observational research
    Support observations and measurements
    Nearshore wave modeling
    Nearshore wave forcing
    Dune erosion modeling
    Forcing and validation for numerical wave simulations in hindcasts and forecasts
    Development of wave climates for coastal evolution
    Inundation plots
    Planning
    Sea level tracking
    Marine forecasts and warnings
    Wind and wave forecasting
    Historical and storm event analysis
    Nearshore Wave Prediction System (NWPS)
    COASTAL Act Named Storm Event Model (NSEM)
    Coastal flooding potential and effects
    Rip current risks
    Surf risks
    Small craft risks
    Port and shipping vessel risk
    Search and rescue operations
    Coastal flood risk
    Beach hazard forecasting and warning
    Prediction and validation of damaging surf
    Recreational and commercial boating hazards

2. How interested are you in having nearshore waves observations at the CO-OPS real-time water level stations? (scale 1-5)



3. How would you and others in your organization benefit from new or additional nearshore wave observations?

Responses from those surveyed:
That sort of depends on the measurement locations. Since many CO-OPS locations are very close to shore and oftentimes in bays or sounds, the measurements would not be particularly helpful for our work. We are more interested in measurement locations across the inner shelf and also out in the middle of bays, sounds, and estuaries (as in, likely not at existing station locations).
It will strengthen the value of our analysis and provide a sound base for our study of coastal evolution and coastal change hazards.
The more observations the better.
Such observations are very valuable, but often limited to single stations. When approaching wave/flood simulations for regions, spatial variability is important, and additional observations provide invaluable data to illustrate such variability.
Model validation, model input (TWL model), improved understanding of nearshore hydrodynamics under varying conditions (to be linked with onshore and topographic measurements).
The Lake Charles Pilots would benefit from a wave buoy in the vicinity of the Calcasieu Ship by giving us real-time information on wave heights in our pilot boarding areas. We typically suspend pilot boardings when wave heights are too high, steep or have short wave periods. A buoy would give us reliable information when there are no vessels in the area to give us a visual report.
Frequently field and model studies are limited by lack of nearshore wave measurements
Nearshore wave observations would be used for short term inundation predictions that include runup. Very important as folks drive on the beach here, also for coordination of threatened sea turtles nesting related tasks and overall beach infrastructure management around inundations. Longer term time series (for these, real time is not needed) important for predictions in changes in inundation frequencies and with wave directions, important for erosion and sand management.
Good nearshore wave data could greatly enhance the safety of Pilot boarding/disembarkation operations in the

Responses from those surveyed:
Cape Henlopen Pilot Area. Further, with the coming construction and operations in the offshore wind areas that are contiguous with our sea lanes, better nearshore wave data will be critical.
They would offer additional observations to validate our Nearshore Wave Prediction System
Better initial water conditions for the (storm surge + tide + wave) model. Validation of the model.
Wave observation networks are not based on needs of data-dominated wave analyses. We can get away with this as wave models do not require a data assimilation step to constraint the models. With that, we literally never have enough data to produce data-dominated products, hence all new data is much appreciated. this is particularly true for coastal applications where representative spatial scales can be as small as sub-100m (compared to 1-10 km scales on the continental shelf)
It really depends where the water level instrument is located. If exposed to the open ocean, then yes, the data would be valuable. If the gauge is located inside an estuary or bay, then the wave gauge should address surge.
Utilize in addition to other offshore buoy obs for marine forecasts/updates.
NDBC already has a process in place to pull and distribute the NOS CO-OPS meteorological data. It would take some work to pull additional observations from the SOS server, but we already have the appropriate templates and distribution points in place that can be utilized.
We could have a more comprehensive view of our unique coastline. At this time, we primarily have one sensor to determine hazards. This may not be representative for other locations.
Nearshore wave observations are limited across the Florida Keys. New nearshore wave observations would be highly valuable to FWC, USCG, NOAA FKNMS, NOAA NWS, Navy, US Customs and Border Patrol, NOAA OLE, etc. for the protection of life and property.
We would for the first time ever be able to verify our nearshore wave forecasts in the CWF and point-n-click. This would also help with high surf advisories and warnings.
New or additional nearshore wave observations would allow for us to fill in the observation gaps along the South Texas coast for aforementioned partner support.
Better understanding and validation of near shore conditions for which we are forecasting and warning. This will increase situational awareness and validation improving services the NWS provides.
It will provide more data for monitoring and verification, improving both.
Having nearshore wave observations will be absolutely critical in better understanding the surf zone environment and how
It would improve forecasting skill, awareness of how swell disperses nearshore, improve user safety and decision making, help with wave modeling if this data is incorporated into model input, more data to verify wave models with, improve warning skill, help grow understanding of the relationship between open ocean swell and beach wave conditions (storm surge, sneaker wave, surf characteristics).
We only have two buoys with wave data in our waters, so any more observations would be greatly helpful.
We have a lack of wave observations overall, and having new observations, especially nearshore, will enhance our situational awareness, our forecast/warning process, and our DSS efforts, as the beaches and bar entrances are our primary hazard locations, and we have very few representative observations to monitor them.
Greatly improve our nearshore wave forecasts.
This would assist us in present and future planning as well as real time Public Safety decisions. We currently work with CAL OES, California Geological Survey, University of Southern California, National Tsunami Warning Center, and the Army Core of Engineers
Having more nearshore observations would help resolve anomalous wave runup. We never know what's actually happening near the beaches in which we are forecasting for.
New or additional nearshore wave observation stations at the Commonwealth of the Northern Mariana Islands, Republic of Palau, Federated States of Micronesia and Republic of the Marshall Islands will provide valuable data in our area of responsibility (AOR). Our AOR is huge but only a handful of observations are available right now.
Buoys that monitor waves are quite valuable but vary sparse in coverage for our 10,000,000 sq nm area of

Responses from those surveyed:
responsibility. The more datapoints of wave heights will significantly improve our sea state analysis and wave forecasts.
I think local National Weather Service WFOs would benefit more than TAFB/NHC since we forecast more for the offshore areas. But still...these additional observations/data would be highly beneficial to the National Weather Service/NOAA.
Currently, WSO Pago Pago only has one wave-buoy. Due to the sparse data available for American Samoa coastal waters, any additional observations would greatly improve our forecast procedures and dissemination of advisory/warning products. Our ambassadors, especially marine users and beachgoers rely heavily on these for their daily operations, especially since our territory has witnessed losses of life and property at sea due to strong rip currents, rough seas, or high surfs. Hence, not only would additional nearshore wave observations benefit our forecasts; it would also contribute to the safety of our marine customers.
There remain numerous holes and gaps in coastal wave observations along the coast of North America and these obs would greatly help to fill in some of those gaps
Helping the office with surf and our core partners
A lot. More sensors that can estimate the wave height, direction, etc. is very useful when we are preparing the marine forecast
Increased observation density across our forecasting AOR.
1) Rip currents are arguably are #1 killer. The environment that is conducive to life threatening rip currents is very sensitive to wave heights, which can be as low as 2 feet in our area during a high risk of rip currents. The nearshore wave observations would allow us to better resolve the smaller wave heights during these situations, and would fill a data gap, given the current absence of nearshore wave observations in our area. Overall, this would lead to better rip current forecasts, and subsequent partner and public awareness of hazardous conditions. 2) There is no wave data currently available in our coastal waters, which extend out to 40 nautical miles from the shore. The nearshore wave observations would allow us to add value to our marine forecasts and better validate them. For example, if nearshore wave observations indicate heights are greater than our forecast and approaching hazardous levels, we can update our forecast to alert mariners, most of which operate small craft and are vulnerable. In the absence of wave data, this otherwise would not occur, and mariners could be met with conditions much more hazardous than they anticipated. It's not uncommon for wave height forecasts to be off a couple feet, which makes all the difference for mariners operating small craft. 3) Nearshore wave observations would assist with our partner decision support services. For example, this could involve briefing a federal agency on conditions relating to a search and rescue operation or advising a county/local government on changing conditions that could lead to life threatening rip currents at local beaches. While real-time measurements of wave heights would be great, we can also use non-real-time data to better fine tune our local tools and conceptual models.

4. Are there any specific CO-OPS NWLON/PORTS® locations where you would like to see waves measurements added? See map of existing stations here: https://tidesandcurrents.noaa.gov/stations.html

   Specific NWLON stations:

   8570283 Ocean City MD
   8632837 Rappahannock VA
   8636580 Windmill Pt VA
   8637689 USCG Training Center
   8638901 CBBT VA
   8638999 Cape Henry VA
   8651370 Duck NC
   8670870 Fort Pulaski GA

8720214 Degaussing Structure
8720218 Mayport Bar Pilots Dock FL
8723979 Vaca Key
8724580 Key West
8727520 Cedar Key
8728690 Apalachicola
8729108 Panama City
8729210 Panama City Beach (X2)
8774770 Rockport
8775237 Port Aransas
8775241 Aransas Pass
8775296 USS Lexington
8775792 Packery Channel
8775870 Bob Hall Pier (X2)
8776604 Baffin Bay
9410396 Oceanside Harbor CA
9410580 Newport Beach CA
9419750 Crescent City CA
9431647 Port Orford OR
9435380 South Beach OR (X2)
9437540 Garibaldi OR (X2)
9439040 Astoria
9440581 Cape Disappointment WA
1770000 Pago Pago

Specific historical stations:
9438478 Seaside OR (X2)
9437954 North Fork
9437585 North Jetty Tillamook Bay OR (X2)
9436381 Cascade Head Salmon River OR (X2)
9435827 Depoe Bay OR
9435385 Yaquina USCG Newport OR (X2)
9440572 Jetty A Columbia River
8728288 Alligator Point
8727648 Horseshoe Point
8728229 Shell Point
8728669 Sikes Cut - St. George Island
8728548 St. George Island East End
8727695 Steinhatchee
8727558 Suwannee River Entrance
8728728408 Dog Island East End
8728995 Mexico Beach

General locations:
San Francisco Bay
Puget Sound
San Diego Bay
Dana Point CA

Charleston, SC
Charleston OR
Los Angeles/San Pedro
Caribbean
Hawaii
Long Island
New Jersey
New York
Georgia
South Carolina
Port of Miami
Tampa Bay
Florida coast

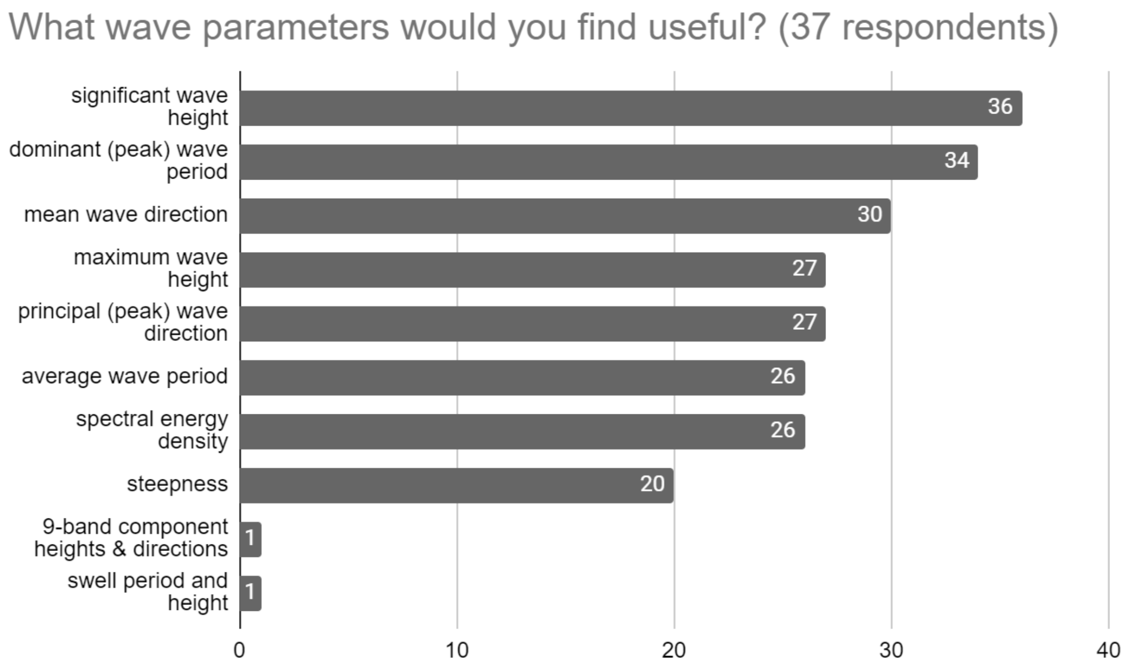
General:
Locations with old measurements
Areas with high instances of sheltering (at predominant or storm directions)
Harbor approach or where the pilots transfer.
High population centers
Areas with recreational fishing

5. Are there any additional locations where you'd like to see nearshore wave observations? See map of existing stations here: https://tidesandcurrents.noaa.gov/stations.html

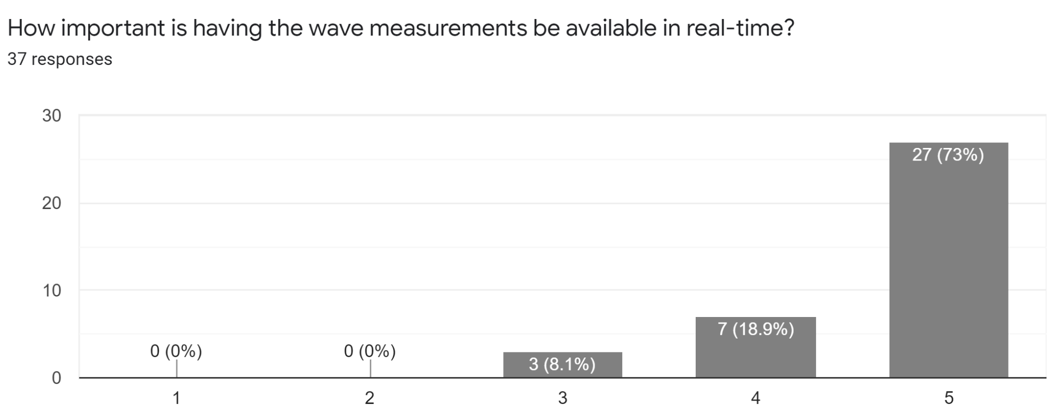
Estuaries and Bays
20m isobaths for total water level forecasts
Vicinity of the Calcasieu Ship Channel from CC Buoy to Buoys 27 & 28.
On the CH Buoy in the Cape Henlopen Pilot Area
On the "D" buoy at the end of the Delaware to Cape Henlopen traffic lane
Tropical/subtropical NE Pacific basin from 3.4N to 30N and eastward of 140W
Bar entrances
Major port entrances
Open Gulf of Mexico Stations
Pamlico Sound
Chesapeake Bay
Delaware Bay
Barnegat Bay
Great South Bay
Texas Bays (TCOON Stations)
Central east coast of Florida
Ingleside TX
Ventura Harbor
Koror, Palau
Chuuk, FSM
Kosrae, FSM
Monterey Bay
South Padre Island

Galveston Island
Sabine Pass
Bird Island
Port Mansfield
Baffin Bay
Corpus Christi Bay
Packers Channel
Naval Air Station TX
Port O'Connor
Rockport TX
Padre Island (South end)
Gulfside observations between Bob Hall Pier and SPI Brazos Santiago (several requests)
Florida Keys between Islamorada and Key Largo
Assateague Island
Virginia Beach
Sandbridge VA
Ocean View VA
Albemarle Sound
South Carolina coastline
Ventura
Morro Bay
Channel Islands
St Augustine Beach FL (SAUF1)
St Simons Island GA
Hanalai Bay
Kauau
Lanai (southside at barge and ferry terminal)
Saipan, North Mariana Islands
Pohnpei, FSM
Majuro, Marshall Islands
Mississippi River mouth
Panama Canal approach
Yucatan Channel
Gulf of California
Gulf of Tehuantepec
Gulf of Papagayo

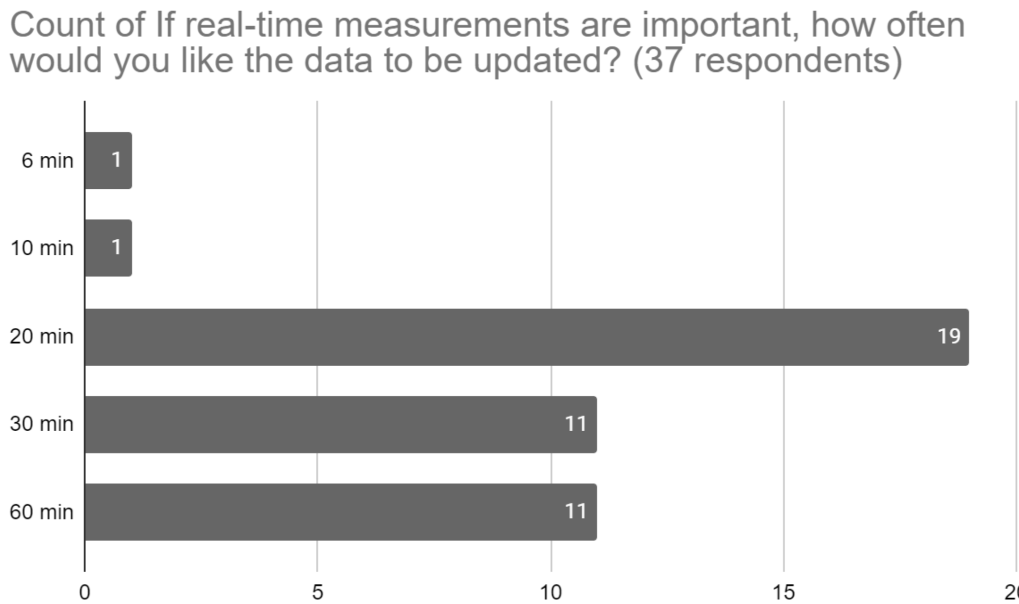
6. What wave parameters would you find useful? significant wave height, maximum wave height, dominant (peak) wave period, average wave period, steepness, spectral energy density, mean wave direction, principal (peak) wave direction, other



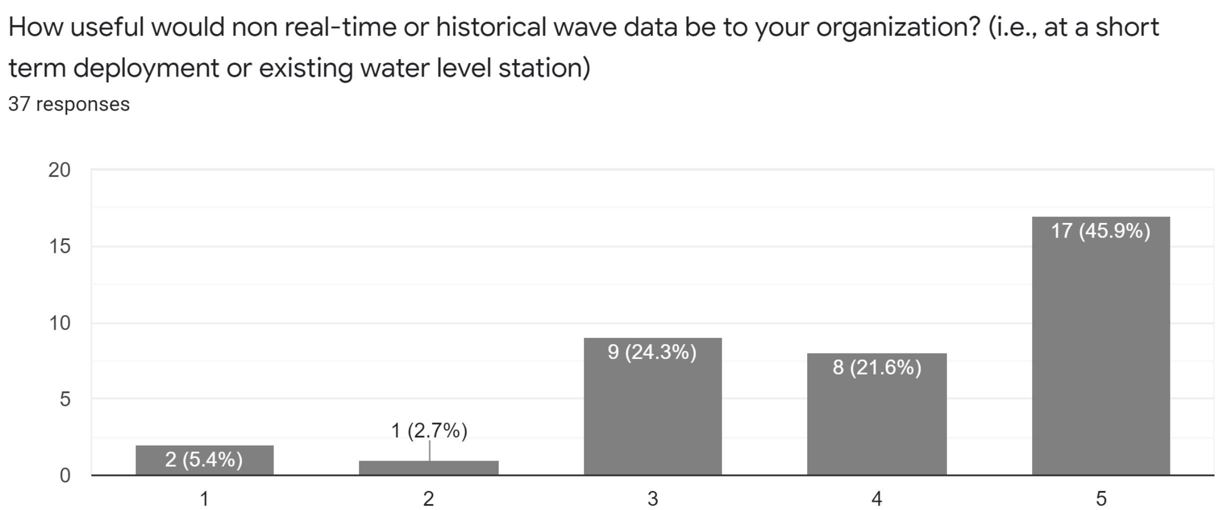
7. Are you and your organization interested in the metadata associated with spectra and bulk parameter estimation methods? If yes, please list what parameters/metadata would you request (i.e., sensor type, spectral method).
   Responses include sampling frequency, sampling scheme, sensor type, spectral method, frequency filtering, degrees of freedom for confidence intervals, water depth, instrumentation, length of input record, data on response function of instrument, same as CDIP,
8. How important is having the wave measurements be available in real-time? (scale 1-5)



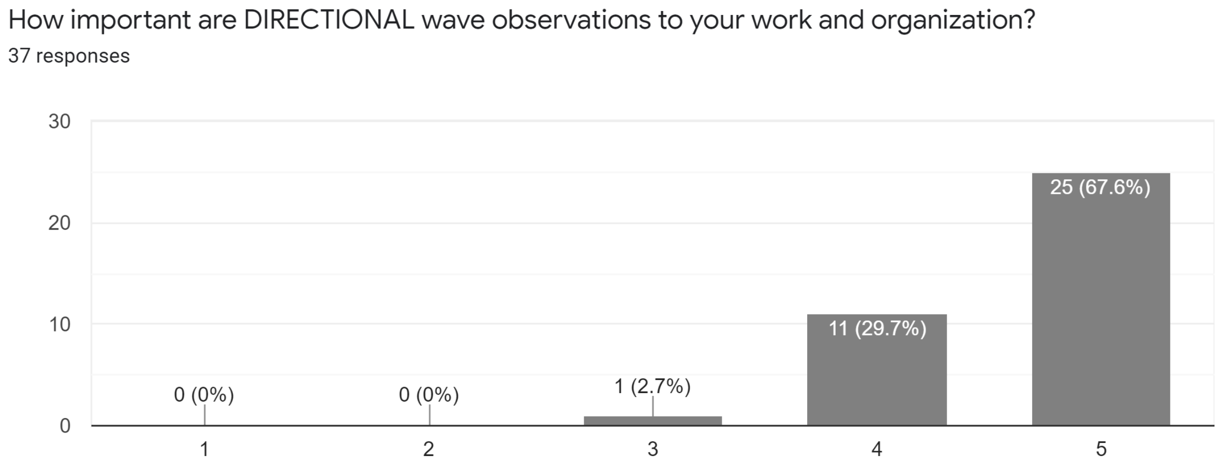
9. If real-time measurements are important, how often would you like the data to be updated? 20 min, 30 min, 60 min, Other



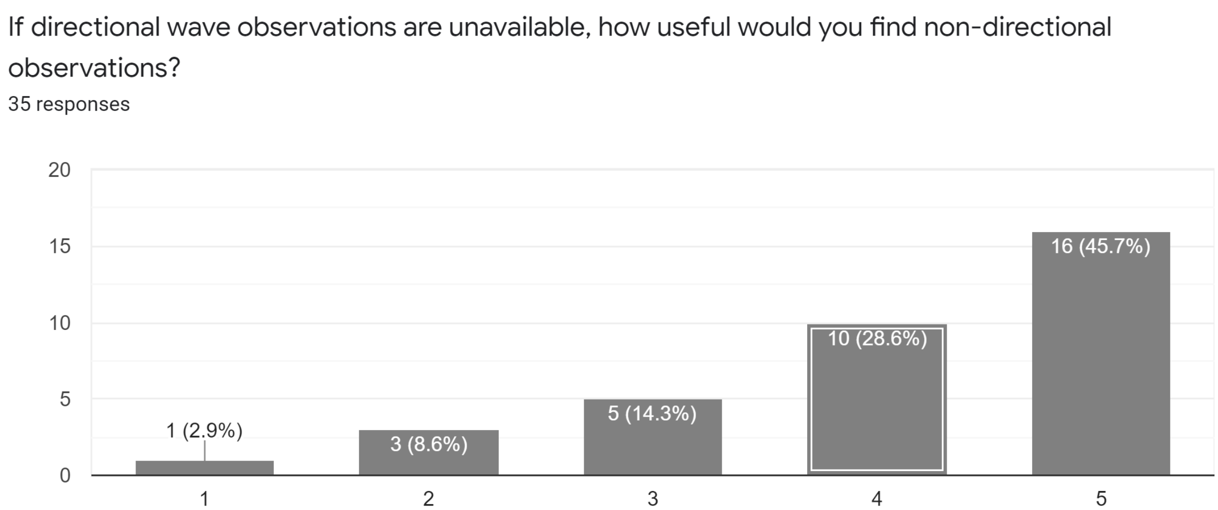
10. How useful would non-real-time or historical wave data be to your organization? (i.e., at a short-term deployment or existing water level station) (scale 1-5)



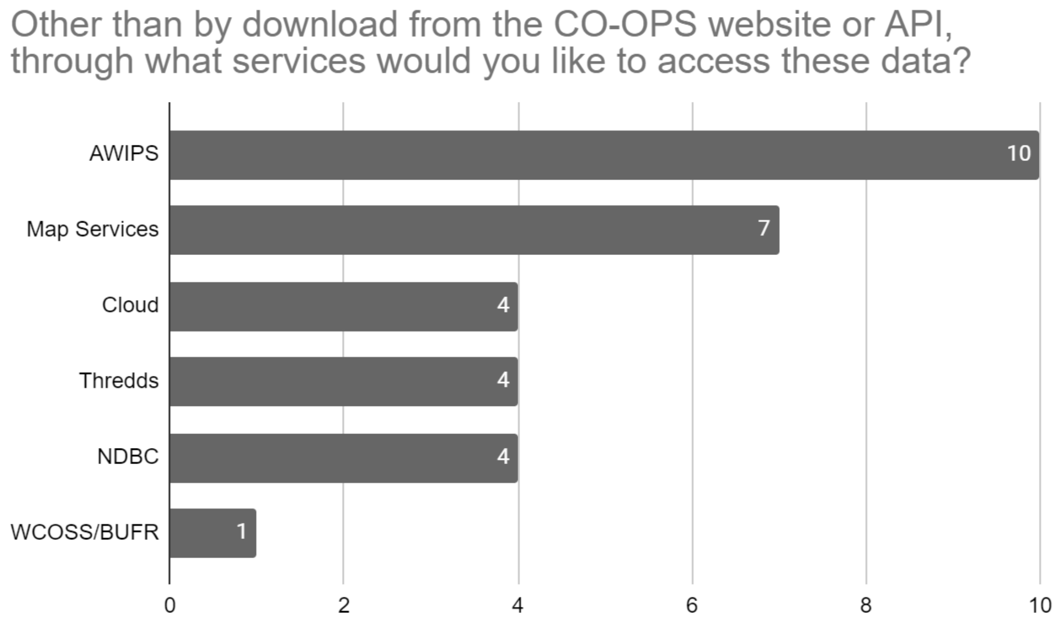
11. How important are DIRECTIONAL wave observations to your work and organization? (scale 1-5)



12. If directional wave observations are unavailable, how useful would you find non-directional observations? (scale 1-5)

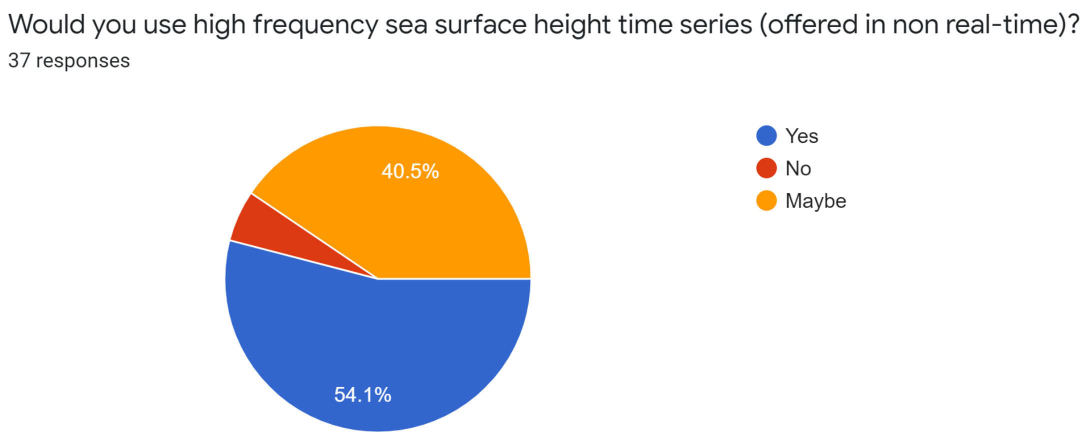


13. Other than by direct download from the CO-OPS website (tidesandcurrents.gov) or through the CO-OPS API, through what services would you like to access these data (e.g., map services, cloud)?



14. What visual products (if any) would you like to see on the CO-OPS site (e.g., polar spectra, monthly wave height box plots)?
Responses include wave rose, directional spectra, monthly/yearly plots (box plots of Hs or Taylor diagrams of extremes/median/min), time-series of last 7 days, and overlay with wind U/dir, Monthly wave height, direction, and period box plots would be very useful, Hanson plots, 9 band p\lot

15. Would you use high frequency sea surface height time series (offered in non-Real-time)?



16. Do you have any questions, comments, or suggestions regarding nearshore wave observation products?

Responses from those surveyed:
This is a worthwhile endeavor, but only if we put them in the right places. Location selection will be critical to success of the program.
Hopefully there is enough support to get a network going.
Exciting stuff!
Thank you for your service to the coastal research community!
Not at this time
Thanks for this needed effort.
Thank you for considering our needs.
Our primary uses would be for NWPS model verification but also for local beach forecasts.
What is meant by "high frequency sea surface height" in preceding question? Is that the total height of the waves/water column, or the height of the waves on top of a "still water" surface? Trying to determine if a near-shore analysis field of storm surge + tide could be estimated by averaging the "high frequency sea surface height".
Please make sure to look at the national wave observation plan published about a decade ago and be aware that a follow up meeting to discuss the next plan is scheduled in Europe for late this year or next year (JCOMM and its present continuation in WMO).
The usefulness of the wave direction question above really depends upon where the gauge is located. If the gauge is inside a harbor, it is really the surge information that is helpful. In the open ocean though, yes, wave direction if very helpful.
Only comment I have is to feel free to reach out to NDBC if you have any questions or just want to share knowledge.
Any platforms that can be added in the Apalachee Bay between Apalachicola and Cedar Key. This is the 2nd most vulnerable stretch of U.S. coastline to storm surge.
This would be absolutely critical to our improvement of nearshore marine and surf zone forecasts.
Thank you for the opportunity to provide this input, and in considering increasing the near-shore wave observations.
Thanks for looking into this.
Thanks!
We have a long history of collaborating with outside agencies and routinely use our resources to assist. We have had great success in Tsunami planning as our Harbor has been identified as prone to above average and prolonged Tsunami Surge activity.
Can WFO Guam be involved in the development/expansion of nearshore wave observation products in the future?
While wave models continue to improve, one frequently has "surprises" where the wave heights are significantly different (either higher or lower) than anticipated from WaveWatchIII when observations occur. Eventually, such observations will be assimilated into WaveWatchIII, which should improve the initial and forecast wave guidance.
I find it difficult to create useful time series plots of historical data from the NDBC web site and much prefer sites such as CDIP for plotting. Developing this would be very helpful for reports and documentation
Nearshore waves are important for coastal surf forecasts and for tropical landfall situations. Beach cameras systems can also be very helpful which costs less and may be effective for our needs.
None