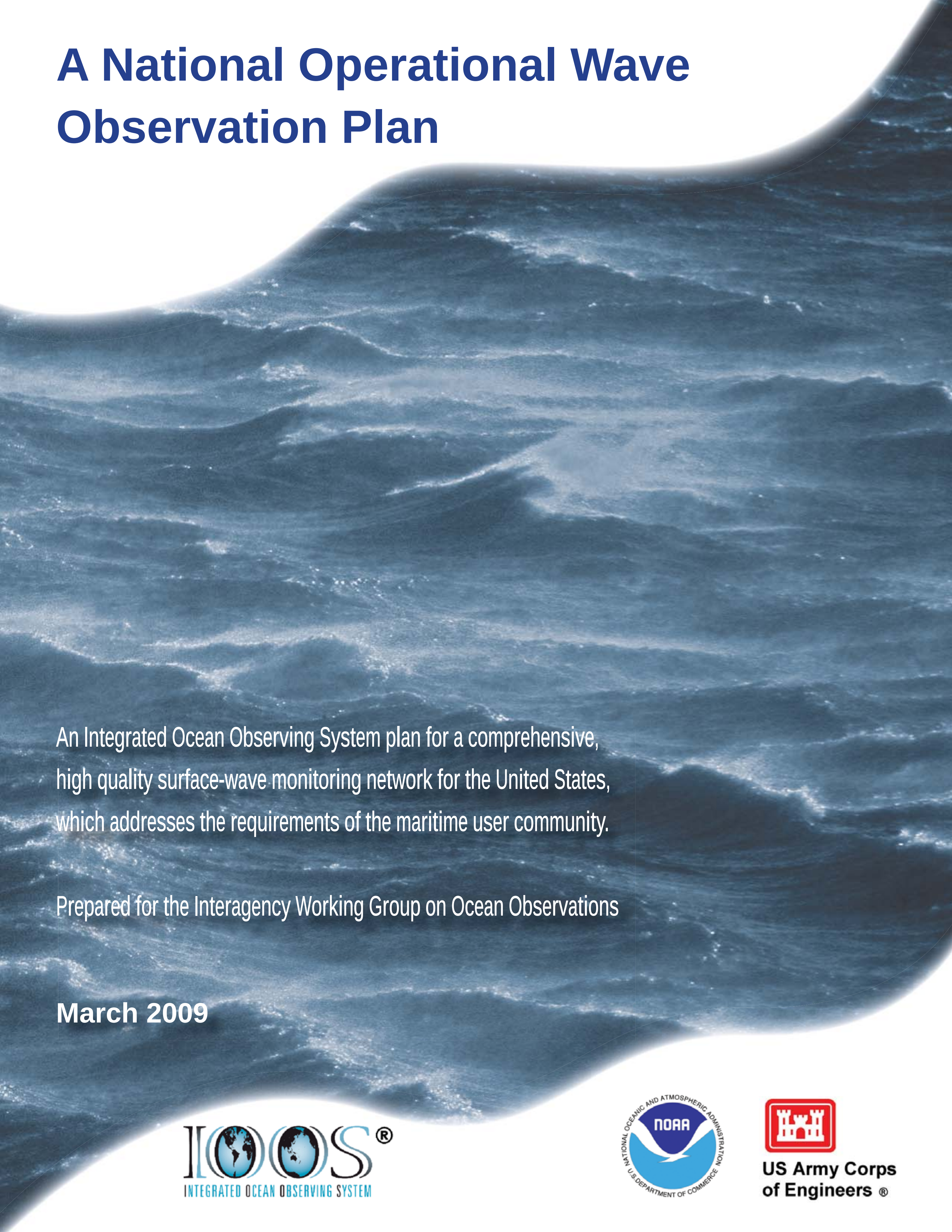
# A National Operational Wave Observation Plan



An Integrated Ocean Observing System plan for a comprehensive, high quality surface-wave monitoring network for the United States, which addresses the requirements of the maritime user community.

Prepared for the Interagency Working Group on Ocean Observations

**March 2009**

IOOS®
INTEGRATED OCEAN OBSERVING SYSTEM

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

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*This report was funded by the NOAA Integrated Ocean Observing System (IOOS®) Program and the USACE Coastal Field Data Collection Program and developed by the NOAA National Data Buoy Center and USACE Engineering Research and Development Center, with support from the Alliance for Costal Technologies (ACT) and the wave observing community.*

# Preface

Nationwide, accurate, and sustainable wave observations have long been the goal of the U.S. Army Corps of Engineers (USACE), the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS) and National Weather Service (NWS), along with other Federal and state agencies, universities, local/commercial interests, and emergency/resource managers. This document presents a National Operational Wave Observation Plan, which was developed as an interagency effort coordinated by the NOAA Integrated Ocean Observing (IOOS®) Program and the USACE. The USACE worked in close partnership with NOAA's National Weather Service (NWS) National Data Buoy Center (NDBC) in developing the plan. The Alliance for Coastal Technologies (ACT) contributed to the plan and facilitated the development process. The plan was written by a steering committee of authors.

Work on the plan began in March 2007. At the core of the plan is an inventory and assessment of existing assets and community requirements followed by a gap analysis. This assessment included the use of the IOOS Observations Registry, the Ocean.US 2007 inventory of US Ocean Observing Systems and surveys of the IOOS Regional Associations (RA). An Expert Review Panel was convened August 20-22, 2007 to critique and review the draft plan and to identify roles and responsibilities. The draft plan was amended, refined, and endorsed by the Expert Review Panel. The plan was reviewed by the National Federation of Regional Associations (NFRA), NOAA's Councils and numerous other panels. This final document is a synthesis of over 500 comments and suggestions.

The panel would like to acknowledge the support of Zdenka Willis of the NOAA IOOS Program, Charley Chesnutt of USACE, Paul Moersdorf of NDBC, and Margaret Davidson of NOAA's Coastal Services Center (CSC). In addition the panel would also like to thank Lorrie Easterling (NDBC); Jim Boyd (CSC); Sherryl Gilbert, Michelle McIntyre, Ali Hudon, and Sue Sligh (ACT) for their help and hard work in facilitating the development of the plan.

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# List of Acronyms

ACT: Alliance for Coastal Technologies
ADCP: Acoustic Doppler Current Profiler
AOOS: Alaska Ocean Observing System
ASAR: Advanced Synthetic Aperture Radar
ASIS: Air-Sea Interaction Spar
AWCP: Acoustic Wave And Current Profiler
CaRA: Caribbean Regional Association
CDIP: Coastal Data Information Program
CeNCOOS: Central California Ocean Observing System
CF: Climate and Forecast
CMAN: Coastal Marine Automated Network
CSC: Coastal Services Center
CO-OPS: Center for Operational Oceanographic Products and Services
DAC: Data Assembly Center
DART®: Deep-ocean Assessment and Reporting of Tsunamis
DIF: Data Integration Framework
DMAC: Data Management and Communications
DODS: Distributed Ocean Data System
FGDC: Federal Geographic Data Committee
FRF: Field Research Facility
GCOOS: Gulf of Mexico Coastal Ocean Observing System
GEOSS: Global Earth Observation System of Systems
GOOS: Global Ocean Observing System
GLOS: Great Lakes Observing System
GoMOOS: Gulf of Maine Ocean Observing System
GPS: Global Positioning System
GTS: Global Telecommunications System
HF: High Frequency
IOC: Intergovernmental Ocean Commission
IOOS®: Integrated Ocean Observing System
ISO: International Organization for Standardization
IWGOO: Interagency Working Group on Ocean Observations
JCOMM: Joint Technical Commission for Oceanography and Marine Meteorology
MACOORA: Mid-Atlantic Coastal Ocean Observing System
NANOOS: Northwest Association of Networked Ocean Observing Systems
NCDC: National Climatic Data Center
NDBC: National Data Buoy Center
NERACOOS: Northeastern Regional Association of Coastal Ocean Observing Systems
netCDF: Network Common Data Form
NOAA: National Oceanic & Atmospheric Administration
NOAAPort: The National Oceanic & Atmospheric Administration's Broadcast System
NODC: National Oceanographic Data Center
NOMAD: Navy Oceanographic Meteorological Automatic Device
NOS: National Ocean Service
NSRS: NOAA Spatial Reference System
NWS: National Weather Service
NWSTG: National Weather Service Telecommunications Gateway
OPeNDAP: Open Source Project for a Network Data Access Protocol
PacIOOS: Pacific Islands Integrated Ocean Observing System
PORTS: Physical Oceanographic Real-Time System
PPBES: Program Planning Budget & Execution System
RACCOONS: Regional Association Coordinators for Coastal Ocean Observation Networks
QA/QC: Quality Assurance / Quality Control
QARTOD: Quality Assurance of Real-Time Oceanographic Data
R&D: Research and Development
RA: Regional Association
RCOOS: Regional Coastal Ocean Observing System
SAR: Synthetic Aperture Radar
SBIR: Small Business Innovation Research Program
SCCOOS: Southern California Coastal Ocean Observing System
SECOORA: Southeast Atlantic Coastal Ocean Observing System Regional Association
SIO: Scripps Institution of Oceanography
UNFCCC: United Nations Framework Convention on Climate Change
UNOLS: University-National Oceanographic Laboratory System
USACE: United States Army Corps of Engineers
USGS: United States Geologic Survey
WMO: World Meteorological Organization

# Executive Summary

The deployment of an Ocean Observing System is one of three central science and technology elements of the Ocean Research Priority Plan issued by the Joint Subcommittee on Ocean Science and Technology in January 2007. In support of this goal, this document presents a national plan for observing waves, one of the most important ocean variables. The plan is part of the national Integrated Ocean Observing System (IOOS®) and is the result of an interagency effort coordinated by the NOAA IOOS Program and the US Army Corps of Engineers (USACE). The USACE worked in close partnership with NOAA's National Weather Service (NWS) National Data Buoy Center (NDBC) in developing the plan. The Alliance for Coastal Technologies (ACT) contributed to the plan and facilitated the development process.

Surface gravity waves (wave period range from 1.0 to 30.0 seconds) entering and crossing the nation's waters, whether generated by a distant Pacific storm, local sea breeze, or a Category 5 hurricane, have a profound impact on navigation, offshore operations, recreation, safety, and the economic vitality of the nation's maritime and coastal communities. Although waves are a critical oceanographic variable and measurement assets exist, there are only 181 observation sites nationwide, leaving significant gaps in coverage. Just over half of these wave instruments have the capability to estimate directional waves, though their directional accuracy varies. Moreover, existing locations were placed based on local requirements, resulting in a useful, but ad hoc wave network with limited integration of the observations into user products. The proposed system will increase the wave observation spatial coverage along and across the US coasts; and will serve as a stimulus for wave modeling activities in verification/validation, improvements, data fusion and assimilation. The wave observation data and metadata will meet national and international standards to ensure interoperability and seamless integration of data. The design will complement existing and future remote sensing programs (land- and satellite-based systems) and will coordinate with and leverage related international efforts, such as the Global Earth Observation System of Systems (GEOSS).

The plan is comprehensive in that it defines a level of measurement accuracy that will serve the requirements of the broadest range of wave information users. It identifies existing wave observation assets, presents a comprehensive integrated system design and then makes specific recommendations to: (1) upgrade existing sensors; (2) add additional observations in critical "gap" locations; (3) implement a continuous technology testing and evaluation program; (4) support the Quality Assurance / Quality Control (QA/QC) and data integration of wave observations from a large number of IOOS operators; (5) support the operation and maintenance requirements of the system; (6) include the training and education of IOOS wave operators; and (7) promote the development of new sensors and measurement techniques.

The design of the network is based on establishing four along-coast observational subnets. These include:

- Offshore Subnet: deep ocean outpost stations that observe approaching waves, prior to their passage into coastal boundary currents;
- Outer-Shelf Subnet: an array of stations along the deepwater edge of the continental shelf-break where waves begin to transition from deep to shallow water behavior;
- Inner-Shelf Subnet: on wide continental shelves (notably the Atlantic and Gulf of Mexico coasts), an array of shallow water stations to monitor cross-shelf bottom dissipation and wind generation of waves;
- Coastal Subnet: shallow coastal wave observations, which provide local, site-specific information.

This plan divides the US coastline into seven primary regions: the Atlantic, Gulf of Mexico, Pacific, Alaska, Hawaii-South Pacific Islands, Great Lakes, and the Caribbean Sea. Existing wave observation assets, and requests for additional assets from the IOOS® Regional Associations (and partners), were incorporated into the subnet design structure. This resulted in a network, that when completed, will include a total of 296 sensors: 56 in the Offshore, 60 Outer-Shelf, 47 Inner-Shelf, and 133 Coastal. Of these, 115 are new. Directional upgrades are required at 128 locations.

All observation data supported by this plan will flow through the IOOS Data Assembly Center (DAC) operated by NDBC and through the USACE/Coastal Data Information Program (CDIP) data center at Scripps Institution of Oceanography (SIO), using IOOS Data Integration Framework (DIF) compliant standards and metadata. Use of DIF standards with controlled vocabulary identification and documentation will enable wave data to be easily found through an open data discovery process. To insure that deployed sensors meet the accuracy requirements of the plan, a significant effort to test and evaluate existing and new sensor/platform combinations is included, as are provisions to support and encourage the development of new wave observation technology.

The proposed Year-1 cost estimate is approximately $14M, increasing to about $17M per year thereafter, with capital investment costs being gradually replaced with operation and maintenance costs.

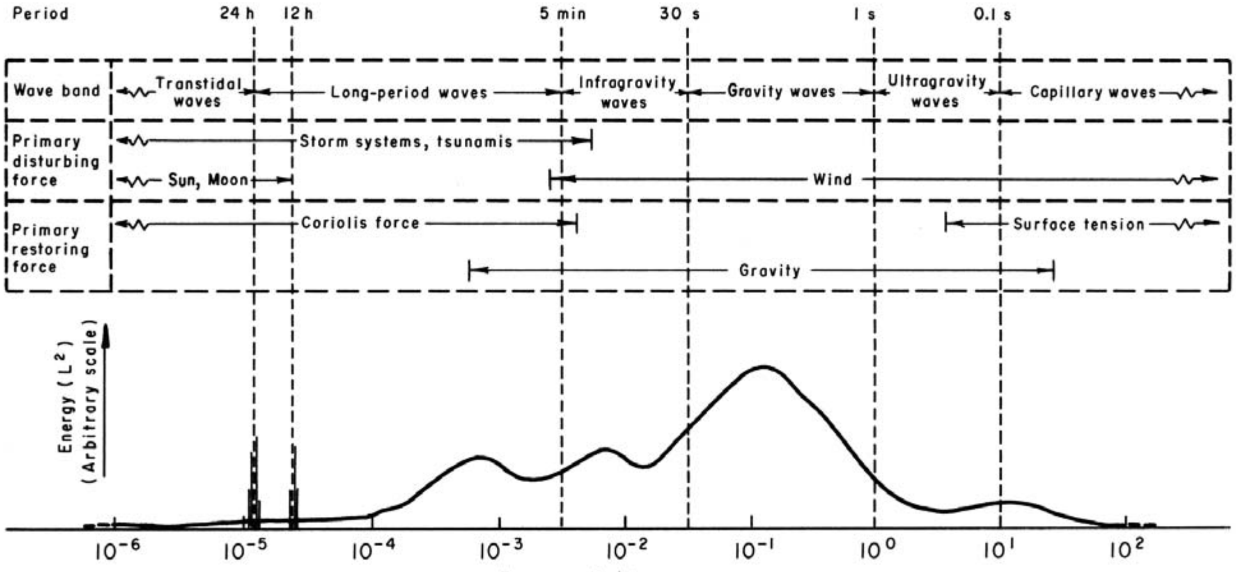
The establishment and maintenance of an effective and efficient wave measurement system requires a partnership between federal agencies, state and local agencies, the private sector, Regional Associations and Regional Coastal Ocean Observing Systems (RCOOS). Because of the diversity of observers, funding sources, and deployed instruments, the USACE and NOAA will work closely with IOOS partner agencies to encourage compliance with and adoption of the plan.

In August 2007, a draft of this plan was reviewed by a panel of wave data collection and application experts. Their numerous suggestions have been incorporated into this document, and they unanimously support both the need for a National Operational Wave Observation Plan and the proposed design.

# A National Operational Wave Observation Plan

## 1. Introduction

On any given day, the ocean surface is occupied by surface wave patterns that are derived by different mechanisms. A good way to characterize one wave form from another is based on the wave period (defined as the time between successive wave crests). Kinsman (1965) identified waves, from short capillary waves, to long tidal motion in terms of their relative wave period and their disturbing and restoring forces (Figure 1). This National Operational Wave Observation Plan focuses on wind-generated gravity waves as other national programs already focus on the measurement of tides (NOAA's National Water Level Observation Network), and tsunamis (NOAA's Deep-ocean Assessment and Reporting of Tsunamis, DART® program).



(after Kinsman, 1965)

*Figure 1. Approximate distribution of wave energy for various types of ocean surface waves.*

The waves entering and crossing the nation's waters, whether generated by a distant Pacific storm, local sea breeze, or a hurricane in the Gulf of Mexico, have a profound impact on navigation, offshore operations, recreation, safety, and the economic vitality of the nation's maritime and coastal communities. User requirements for short-term wave information differ: commercial fisherman want the wave conditions at their fishing grounds, as well as a forecast for the length of their trip; ship captains on the Columbia River want to know if they will be able to safely clear the waves breaking on the dangerous outer bar before they leave port; surfers look for large swell while recreational fisherman and divers seek calm waters; lifeguards want to know if the high surf warnings of yesterday will be needed today; marine engineers

AP Photo/Michael Dwyer

require continuous wave measurements in order to identify extreme waves; and Navy and commercial ship captains require wave information for safe and efficient ship routing to reduce fuel usage. Long-term wave records are also important for studies of climate change and the development of climate information for the design of coastal and offshore structures and facilities.

The total number of in situ real-time wave observations number only 181 nationwide, and of those, only 110 report some measure of wave direction. Considering the nation's approximate 17,000 mile-long coastline, waves are under-sampled and significant spatial gaps exist. Moreover, the existing measurements are not well integrated in terms of location, data formats, access, and user products. One consequence of this situation was the lack of wave observations in critical locations during the 2004 and 2005 hurricane seasons, which adversely affected the preparations, forecast, response, and post-storm forensic analysis of these events, including Hurricane Katrina. Although some additions have been made, this situation still exists today. It is the intent of this document to correct that by defining a national wave measurement program that directly supports the goals and objectives of the Integrated Ocean Observing System (IOOS®) and which contributes to the deployment of an ocean wave observing system, one of three central science and technology elements of the Ocean Research Priority Plan issued by the Joint Subcommittee on Ocean Science and Technology in January 2007.

Specifically, this plan supports the seven IOOS societal benefits (Ocean.US, 2006); serves end-user requirements; promotes standardization and interoperability; supports modeling, and includes elements of observations, analysis, and communications. Of the seven benefits, waves are specifically important to:

- Predict climate change and weather and their effects
- Conduct safe and efficient marine navigation
- Mitigate the effects of natural hazards
- Ensure national and homeland security
- Reduce public health risks

This plan also addresses the stated international requirement by the World Meteorological Organization (WMO) and Intergovernmental Oceanographic Commission (IOC) for additional directional wave measurements* and represents a significant national contribution to the Global Earth Observation System of Systems (GEOSS).

This plan was developed as an interagency effort coordinated by the NOAA IOOS Program and the US Army Corps of Engineers (USACE). The USACE worked in close partnership with NOAA's National Weather Service (NWS) National Data Buoy Center (NDBC), and with input from other interested agencies of the Interagency Working Group on Ocean Observations (IWGOO). This plan extends the NOAA IOOS Data Integration Framework (DIF) to include waves as an integrated variable.

The plan focuses on real-time, in situ, directional wave sensors required to create a national perimeter-backbone for deep ocean, shelf, mid-shelf and coastal observations. This is the responsibility of the federal agencies and is of fundamental importance to every IOOS region and to wave modeling and forecasting. The relationship between a region's wave observations, models, and societal goals is shown in Figure 2. Because observations are necessarily point measurements, they provide information on past and present wave conditions, and can serve as input to predictive models that can be used to fill gaps between the observations; to forecast future conditions; and to address user products and requirements. As one moves from offshore to the beach, the observational technology changes as does the sophistication of the models, the range of user application, and the accuracy requirements of the wave observations.

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* *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC, WMO/TD No. 1219, October 2004, World Meteorological Organization, Intergovernmental Oceanographic Commission, United Nations Environment Programme, and International Council for Science. http://www.wmo.int/pages/prog/gcos/Publications/gcos-92_GIP_ES.pdf*

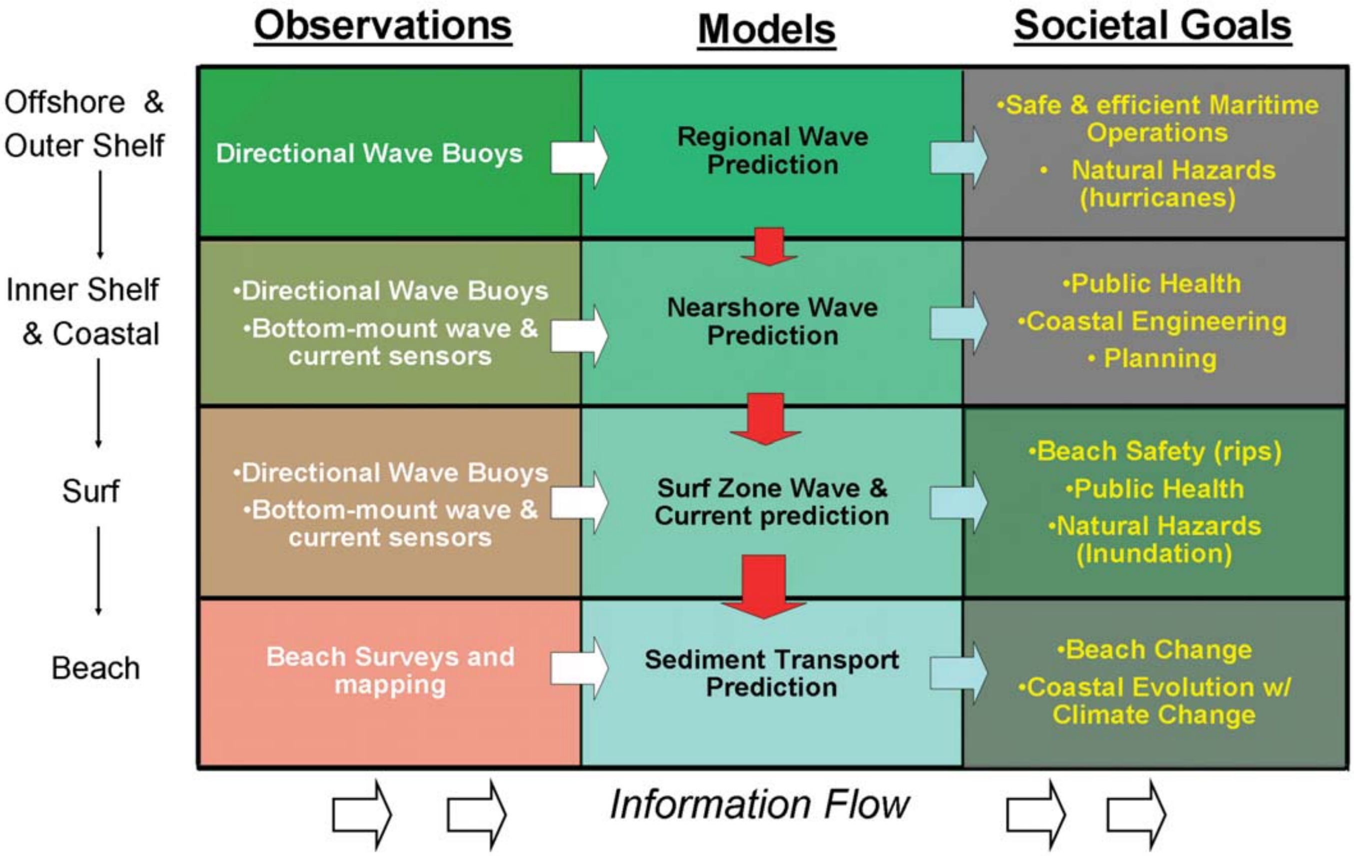


*Figure 2. Diagram showing the flow of wave observations through models to example societal goals for each applicable region.*

The plan is comprehensive in that it addresses the spatial coverage and accuracy requirements of the broadest range of wave information users. It identifies existing wave assets, presents a comprehensive system design, and formulates specific recommendations to: (1) upgrade existing sensors; (2) add additional observations in critical "gap" locations; (3) implement a continuous technology testing and evaluation program; (4) support the QA/QC and data integration of wave observations from a large number of IOOS operators; (5) support the operation and maintenance requirements of the system; (6) include the training and education of IOOS wave operators; and (7) promote the development of new sensors and measurement techniques.

A variety of techniques have been used for over three decades for point measurement of surface gravity waves and those technologies continue to evolve. However, accurate spatial coverage of the wave field is also desirable and many cases may be preferable. Spatial wave observations are derived from present and next generation satellite remote sensing packages and ground based radar systems. While implementation of this plan does not specifically require new research and development, the plan includes and supports development of new and pre-operational technologies that would expand coverage and reduce capital and operational costs.

# 2. Background

Federal interest in wave observations date back to the early 1960's when congressional hearings into the devastation resulting from the "Ash Wednesday Storm," on the East Coast in 1962 resulted in the USACE initiating a wave measurement program. Similarly, NDBC started observing waves in 1973 in support of the NWS. Initially, both programs collected non-directional wave data; however, coastal engineering activities of the USACE required detailed directional wave information to support coastal project designs and emergency operations. To satisfy that requirement, in the early 1990's, cooperative agreements between the

USACE and NDBC supported the addition of directional wave sensors on NDBC buoys. That collaboration continues today and provides the foundation for this plan. As the IOOS® developed, it was recognized that a significantly expanded network of NDBC buoys would form the critical deepwater backbone of the observing system (First IOOS Development plan Ocean. US, 2006) and in 2005; NDBC began including a broad range of oceanographic sensors, including directional waves, into the buoy network.

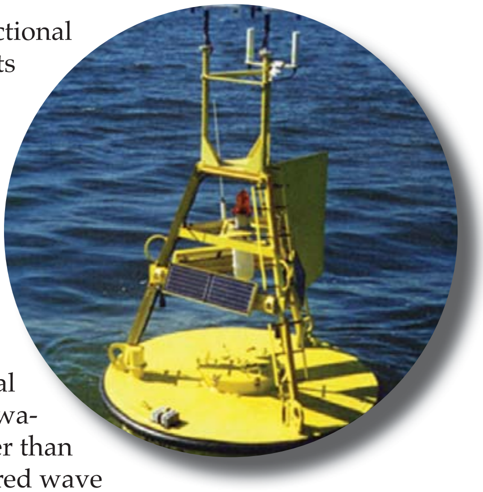
The growth of wave measurement assets along the US coastlines provides information to an ever-growing user community. The importance and interest in waves is relatively easy to demonstrate. Daily web hits for wave observations, just in Southern California, typically number upwards of 100,000/day and during a storm can exceed 600,000/day. The NDBC routinely receives nearly two (2) million web hits per day. However since NDBC data flow directly to the world's meteorological forecast community, actual data use is much greater. It is not a question of whether or not users require wave information, but a question of how best to meet user requirements.

The concepts describing a wave field at a specific location on the ocean surface dates back to the late 1930's (Kinsman, 1965). The techniques used are statistically based, employing time series analysis to quantify the wave characteristics. The wave field at any point on the ocean is a combination of passing "component" wave systems that are distinguished by their height, period, and direction. Locally generated seas are short in period and choppy, moving generally in the direction of the wind and crossing, or traveling with faster-moving, longer waves, or swell, generated by distant storm systems. An example of this is shown in Figure 3, where the swells are moving from left to right while the local wind-seas are moving from top to the bottom of the figure.

*Figure 3. Example of the ocean surface showing long-period swells traveling from left to right and local wind-seas (of short period) are moving from top to bottom.*

With each storm producing a separate and evolving wave system, the combined wave field at any location can be quite complex. This presents an observation challenge both for users and for measurement instruments, since available sensor systems often produce differing results. For example, some users are looking for simple measures, e.g., how high are the waves? Other users need to differentiate incoming swell from wind-sea, or measure a subtle change in wave direction that causes a once stable beach to erode. Measuring waves and providing products that suit the user community becomes a multi-dimensional problem. The basic principle stems from the wave properties of height, period and direction. The three quantities are the first order approximation to the wave field. These wave properties are derived from the estimation of the directional wave spectrum quantifying energy levels at discrete frequencies[*], for discrete direction bands. Because of this complexity, the measurement of waves is dependent on the capabilities of the specific sensor being used and is therefore unlike the measurement of other slowly changing oceanographic variables, such as ocean temperature, which is independent of the sensor used (excepting for measurement accuracy). This plan recognizes that in order to serve the full range of IOOS users, that a national wave observation network should accurately resolve the details of the directional spectral wave field. To achieve this requires that the observations satisfy a "First-5" standard.

Technically, First-5 refers to 5 defining variables at a particular wave frequency (or wave period). The first variable is the wave energy, which is related to the wave height, and the other four are the coefficients of the Fourier series that defines the directional distribution of that energy. At each frequency band, not only is the wave direction defined but the spread (second moment), skewness (third moment) and kurtosis (the fourth moment). The skewness resolves how the directional distribution is concentrated (to the left or right of the mean) and the kurtosis defines the peakedness of the distribution. Obtaining these three additional parameters (spread, skewness and kurtosis) for each frequency band yields an improved representation of the directional characteristics in the wave field. For example, high quality First-5 observations can be used to resolve two component wave systems at the same frequency, if they are at least 60 degrees apart; whereas other systems cannot. Why is this important? One component could be the eroding force on a beach while the other could be the restoring force. While there are more than five Fourier coefficients, the First-5 variables provide the minimum level of accuracy required for an IOOS wave observing system, as it covers both the basic information (the significant wave height, peak wave period, and the mean wave direction at the peak wave period) along with sufficient detail of the component wave systems to be used for the widest range of activities: navigation, maritime safety, rip current prediction, wave model development and verification, search and rescue, and hurricane research applications, etc.



While most directional wave instruments presently in use are able to resolve basic wave parameters; few are capable of satisfying the First-5 standard. In general, for all non-coastal applications (in water depths greater than 10-m) the preferred wave measurement platform is a buoy. These buoys are either spherical, discus, multi-spar, or boat-shaped hull. The buoy response and the payload estimating the free-surface waves vary; however they can be quantified into two types: translational (also referred to as particle-tracking) or slope-following (or pitch-roll) buoys. For both types, a variety of different sensor technologies are used to measure buoy motion. Teng and Bouchard (2005) noted: "because directional wave information is derived from buoy motions, the power transfer functions and phase responses associated with the buoy, mooring, and measurement systems play crucial roles in deriving wave data from buoys." This dependence is particularly important at low energy levels and at both short and long wave periods where the wave signal being measured is weak and potential for added signal contamination increases.

Wave measurements in shallow water (depths less than 10-m) are measured with buoys, bottom-mounted or less commonly, surface-piercing instruments (capacitance and resistance gauges). Surface-piercing instruments have to be mounted to a structure and are used close to shore or on offshore platforms and towers. Bottom-mounted sensors include pressure sensors and acoustic wave sensors which also measure currents. All of these systems (buoys, surface-piercing, or bottom-mount) base their directional estimators on the measurements of three concurrent time series which can be transformed into a description of the sea surface. These devices will provide good integral wave parameter estimates (height, peak period and mean direction at the peak period). However not all sensor systems have the capability of returning high quality First-5 estimates because of the inherent inability of the sensor to separate wave signal from electronic and buoy response noise.

Establishing the First-5 capability in directional wave measurements is critical to the success of this plan.

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[*] *"Wave frequency" is the inverse of, and interchangeable with wave period; the time interval between successive wave crests.*

The USACE standard for First-5 measurements in water depths greater than 10-m, is a translational (particle-tracking) buoy system with the order of centimeter accuracy (in terms of the sea surface vertical and two horizontal displacements) for surface gravity waves. This has proven sufficient for wave model applications used to drive demanding sediment transport computations, and is the recommended standard for the National Operational Wave Observation Plan.

## 2.1 Value of the National Operational Wave Observation Plan

While it is desirable to assign an economic value or positive cost/benefit ratio to this proposed plan, no such number yet exists. In fact no such number exists in support of the existing wave observation system as much of it supports the common-good, public mission of the NWS. This makes it even more difficult to clearly identify the added benefits of expanding and improving the existing network. However, considerable anecdotal and supportive statistics do exist and will be presented in this section.

The continuing goals of a National Operational Wave Observing Plan is to save lives, reduce costs, ensure safe transportation and optimize marine resources. Among coastal marine users, waves continually rank very high, fifth, behind salinity, temperature, bathymetry, and sea level according to the First Annual Integrated Ocean Observing System (IOOS) Development Plan (2006). So it is not surprising that the development of this plan created considerable excitement across the nation among wave data users, IOOS Regional Associations, and wave modelers, all anxious to assist with and benefit from an improved wave observation system. In fact Regional Associations (and others) submitted nearly 200 requests for additional directional wave measurement sites to satisfy their requirements (see Appendix B).

### 2.1.a Maritime Safety

According to the Center for Disease Control and Prevention, commercial fishing is one of the nation's most dangerous occupations. In a 2008 article the center reported an average fatality of 155 per 100,000 versus an average of 4 per 100,000 for all occupations. Of the fatalities, 79-percent were the result of weather and about 40-percent resulted from large waves (http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5716a2.htm). It is difficult to quantify how many additional lives will be saved by expansion of the wave observation network due to improved wave forecast models, better education of the commercial fishing community. However, improved real-time access to information at sea, will mean additional lives will be saved. While these statistics are from one maritime industry, the benefit will be shared by all, including recreational fisherman, divers, boaters, surfers, and beach goers. In fact, there should be a reduction in nationwide drownings of approximately 100 per year, just due to rip currents.

### 2.1.b USACE Uses of Wave Data

The USACE is a process-driven organization requiring answers to questions regarding navigational concerns, dredging, beach nourishment, design, overtopping of coastal structures, flooding/storm protection, construction, operation and maintenance and climate change. All of these activities are driven by the hydrodynamics which requires knowledge of the directional wave conditions both historically for planning and in real-time for normal and emergency operations. Projects are designed and constructed to withstand extreme storm conditions. An underestimation in the design criteria can compromise the project and result in significant loss of life and property. An overestimation means the project may be overdesigned or cost-prohibitive. Sediment management, beach nourishment, and dredging all depend on accurately knowing the directional nature of the waves, since sediment transport is proportional to wave direction. As a result, directional wave accuracies of one or two degrees are required across the full range of wave periods. Corps-wide coastal activity costs are in the $100's of millions per year. Each year in the U.S., approximately 400 million cubic yards of dredged material are removed from navigation channels, berths, and terminals. This plan directly addresses Corps data requirements and will positively impact the Corps cost of operations.

### 2.1.c NOAA Uses of Wave Data

The primary mission of the NWS forecast offices is to provide accurate and timely forecast information to the public. These forecasts are derived from coarse resolution (on the order of 30-km) models run by Numerical Weather Prediction Centers. The local forecasting offices are being asked to supply the public with information, including wave forecasts, that is an order of magnitude finer in resolution, and closer to the shore. NWS forecast offices take full advantage of local wave observations, but there are a number of offices which lack real-time wave measurements to use for forecast guidance. The National Ocean Service (NOS) is responsible for providing real-time oceanographic data and other navigation products to promote safe and efficient navigation within U.S. waters. By volume, more than 95-percent of U.S. international trade moves through the nation's ports and harbors, with about 50-percent of these goods being hazardous materials. One additional foot of draft for a ship into a port may account for between $36K and $288K of increased profit per transit. US ports require wave information for secure and safe operation. Issues related to channel depth, width, alignment and obstructions all increase under storm conditions which can result in wrecks, loss of life, environmental and economic disaster. For example, operations at the port of Los Angles/Long Beach access directional wave data for safe passage through the harbor entrance. Knowing when long period swell energy approaches the entrance to the Port of Long Beach is crucial. During these events, the deep draft of the super tankers cause the ship to pitch and potentially strike the channel bottom. This information can save approximately $100 to $200K per day in operating costs. Other ports have similar issues. One benefit of this plan is that all of the locations served by the NOS PORTS program (http://tidesandcurrents.noaa.gov/ports.html) will have wave observation support.

### 2.1.d Economic Value of Observations

The development of the IOOS has always been based on the economic benefits to the nation with access to a broader, more comprehensive suite of ocean observations including waves. Economic studies have been undertaken, and although they deal with IOOS observations in general, they are still of value here. Kite-Powell, et al. (2004) presents a solid analysis of the benefits that can be derived. For instance the authors point out that the largest benefits result from data used by the largest possible groups including recreational activities because of the “very large number of people who use beaches, boat on the Great Lakes or in the coastal ocean, or engage in marine recreational fishing.” Per use benefits are small but the large number of potential users creates substantial potential benefits. The report presents order of magnitude estimates of economic benefits in the range of 10s to 100s of millions of dollars for activities such as recreational beach use, fishing, marine transportation, and other activities upon which wave conditions have an impact.

### 2.1.e Energy Source

There is an untapped renewable energy source in wind-generated waves. The energy flux per unit wave crest length (kW/m) is proportional to the square of the significant wave height multiplied by the wave period. Information about the significant wave height and period in coastal areas of the US would aid the private sector considering installing systems that convert the kinetic energy of wind-waves to other forms of useful energy. While there is great variety in the systems being implemented or proposed to capture renewable wind-wave energy, there are some common benefits and challenges. Since a large portion of the US public lives in close proximity of the coast , there is a large segment of the population that would benefit from wave-energy generation. Problems include efficiently converting wave motion which is slow and reversing direction. Most generators to date use high speed single direction motion, e.g. hydroelectric turbines. The survivability of the system in face of ocean corrosion and storms is a challenge. To date the cost of the wave power is higher than some other sources of renewable energy, but the supply is potentially large. For example, the United Kingdom is actively pursuing wind-wave energy and estimates that up to 25-percent of their electrical power could be produced this way

### 2.1.f Wave Modeling and Research

Wave observations provide real-time information while wave forecasts depend on numerical prediction models. Improved wave models are a national objective as maritime operations (hurricanes, naval activities, shipping, fishing, etc) all benefit significantly from being able to make better decisions based on better wave forecasts. Here lies the paradox, numerical wave model technologies rely on wave measurements. Ultimately, wave experts rely on directional wave measurements to gain knowledge leading toward improving wave modeling technologies. Historically these improvements have relied on large-scale, short term field experiments. These field activities have diminished over the last decade, and so have model improvements (Komen et al, 1994; The WISE Group 2007). Increasing the number of directional wave measurements with First-5 capabilities, as proposed here, will directly lead to improvements of modeling technologies and will translate into better wave forecasts for the user community.

### 2.1.g Wave Observations and Climate

Although sea level rise garners most of the coastal climate change attention, the potential for changing wave climate associated with increasing frequency and intensity of storms could have significant, and more immediate adverse economic impact. Long-term, complete wave observations are the only way to both quantify the natural variation in wave and storm climate and any climatic change. Long-term data are also required to calibrate and verify climatic models that include waves.

Although additional studies should be conducted to quantify the benefits of an expanded national wave observation network, it is clear from the discussion above that significant benefits will be realized once the plan is implemented.

# 3. Wave Observing System Design

The basic requirement of the National Operational Wave Observation Plan is to implement an in situ, high quality, 24/7, real-time operational, First-5 capable sensor network along the entire U.S. coastline and Great Lakes. The proposed network will consist of a set of four strategically-positioned arrays, or subnets, of wave observing stations that will monitor the generation and evolution of waves from the open ocean, through coastal boundary currents and islands, across the continental shelf, and finally to beaches and harbor entrances (Figures 4 and 5). The subnets are:

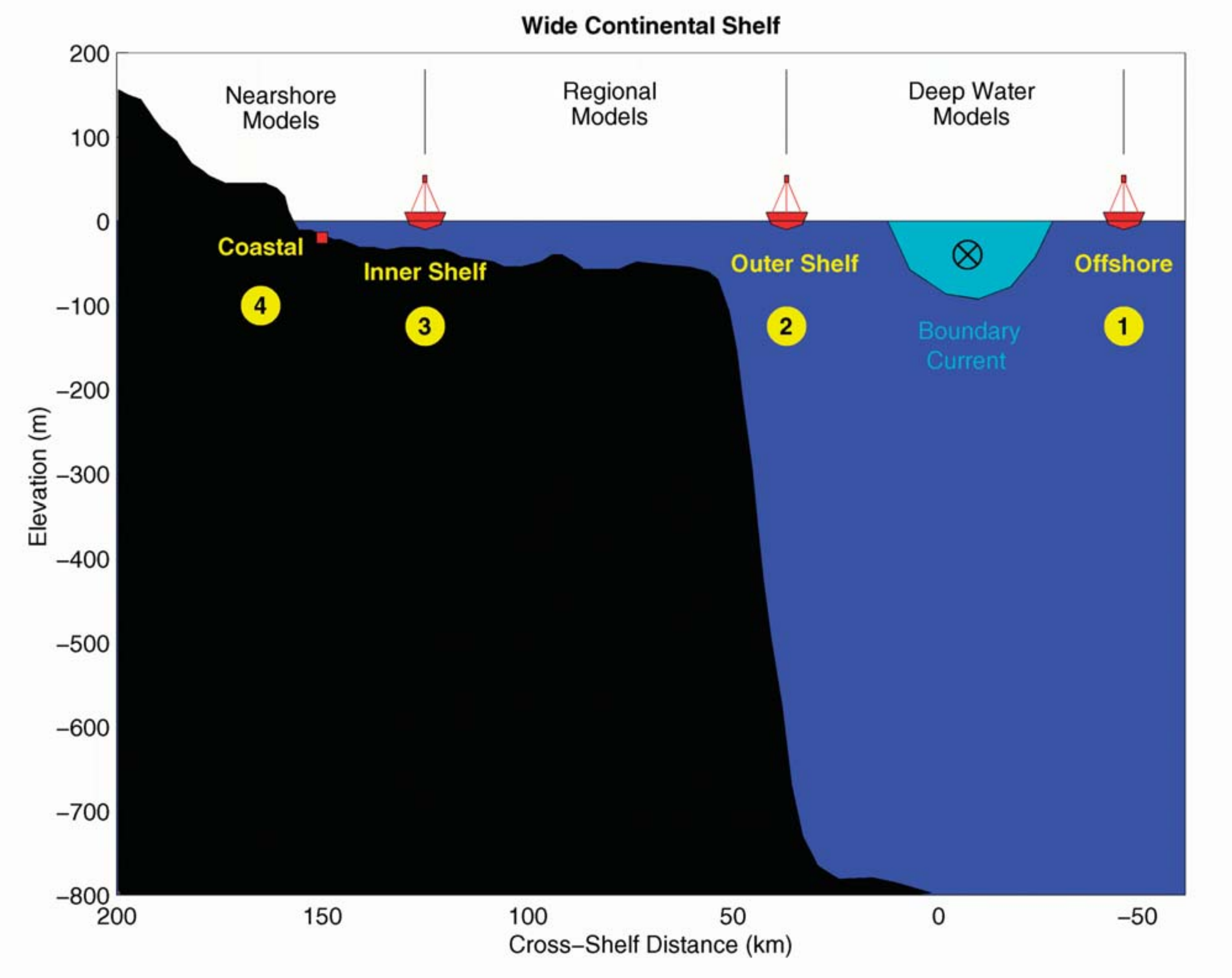

*Figure 4. The four wave observation subnets (coastal, inner shelf, outer shelf, and offshore) related to ocean bathymetry on a wide continental shelf (black area) and numerical modeling requirements. The boundary current is shown in light blue and denotes a current into the page. This representation is typical of the Atlantic and Gulf of Mexico coastlines.*

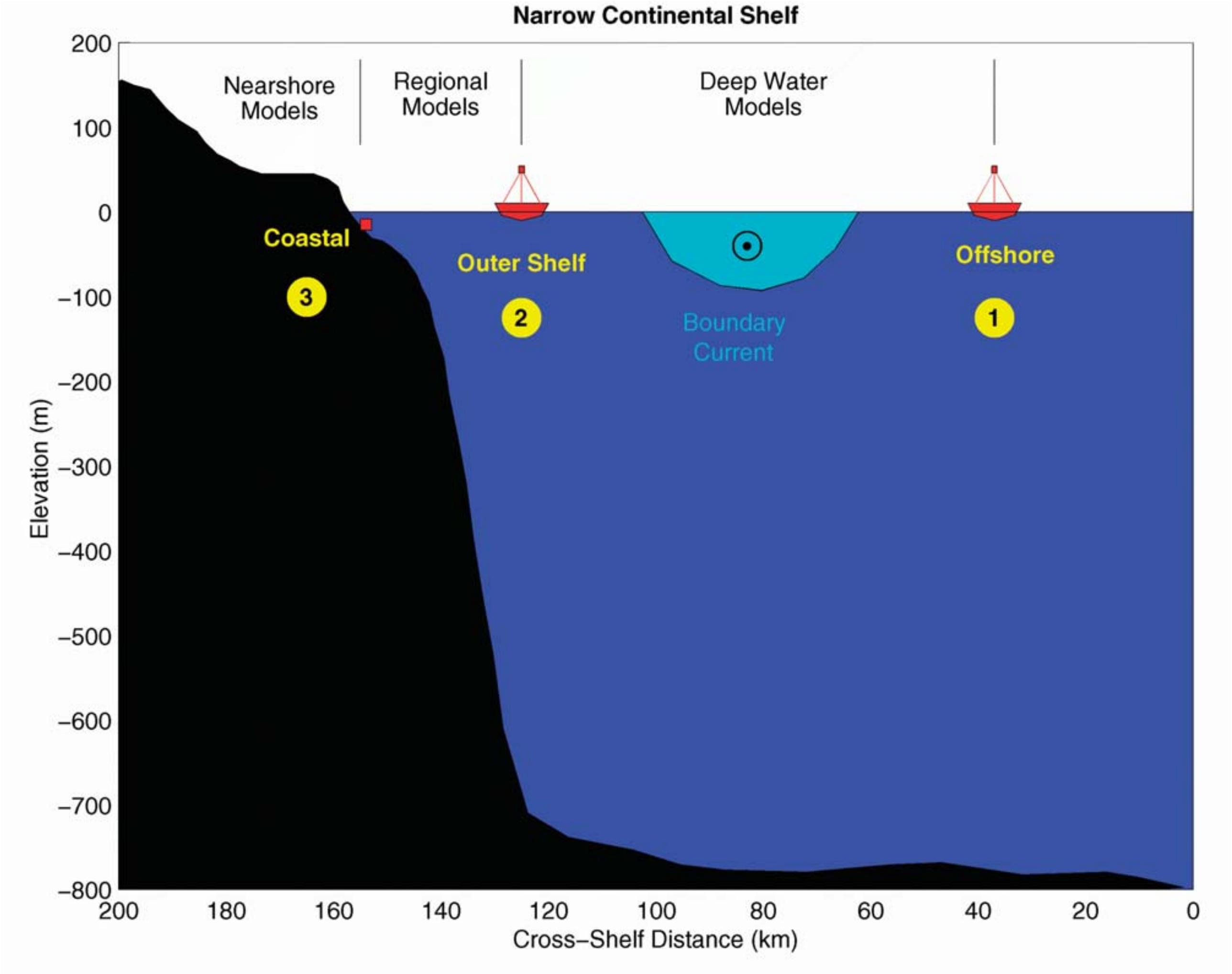

*Figure 5. The three wave observation subnets (coastal, outer shelf, and offshore) related to ocean bathymetry on a narrow shelf (e.g., Pacific Mainland, Great Lakes, Pacific Islands)*

- Offshore Subnet: deep ocean outpost stations that observe approaching waves prior to their passage into coastal boundary currents (e.g., the Gulf Stream), and which provide an early warning (approximately 1-day) of large swell or developing storm wave conditions (e.g., fetch generation areas off the Pacific Mainland);
- Outer-Shelf Subnet: an array of stations along the deepwater edge of the continental shelf-break where waves exit boundary currents and begin to transition from deep to shallow water behavior;
- Inner-Shelf Subnet: on wide continental shelves (notably the Atlantic and Gulf of Mexico coasts), an additional along-coast array of shallow water (20- to 30-m depth) stations designed to monitor cross-shelf bottom dissipation and wind generation of waves;
- Coastal Subnet: a project- or local need-driven set of shallow coastal wave observations, which provide site-specific information.

The mechanisms that cause changes in surface wave characteristics are dependent on spatial and temporal scales. These scales become important because point-source observations are technically estimates of the parameter being measured at that location. However, this statement can be relaxed for waves because of the mechanisms and scaling relationships that affect surface gravity waves. In the deep ocean basin, large synoptic-scale meteorological events are the primary forcing function of a wave climate, whether they are local or far-field storms systems. Hence, the number of measurement platforms required can be minimized as these spatial and temporal scales are quite large, a definition of the Offshore Subnet. These locations assess the time variation in the wave climate, and satellite remote sensing data complement the point source measurements with large spatial coverage over the ocean basin.

Progressing toward the coast, these scales decrease. Relaxation times (temporal changes in the wave spectrum), geographical changes (islands, shoreline configurations), and depth effects become more important. All known mechanisms in the generation, propagation, and transformation of surface gravity waves are dependent on water depth. This dependency affects the momentum transfer of the wind to the free surface, the amount of wave dissipation (e.g., whitecapping), and the transfer of energy to longer wave periods (lower frequencies). A natural break from deep to arbitrary water depth is positioned seaward of the continental shelf. Placement of the Outer Subnet at this well-defined natural break will provide data, independent of depth related mechanisms and a broad "line of sight" to the coast. In essence, the offshore measurement sites can have multiple uses (model inputs, forecasts) for long coastal reaches. They can also be used for verification of pre-operational, and future satellite based remote sensing systems. The density of measurement stations increases along the Outer-shelf Subnet, relative to the Offshore Subnet, to compensate for spatial variations. This Subnet has to be landward of any large-scale currents (e.g., the Gulf Stream, Florida Current along the Atlantic Coast) or offshore islands (e.g., the Bahamas Banks, the Channel Islands in the Southern California Bight).

The Inner-Shelf Subnet can be generalized into two subclasses. These are dictated by the width of the continental shelf, extending from hundreds of kilometers wide to almost no shelf, and thus merging with the Coastal Subnet. It is a transition zone where wind input continues to pump energy into the wave system and depth effects become important. Depth gradients cause a change in the phase and group velocities affecting the propagation and transformation of the wave energy. Growth rates, short-period (high-frequency) dissipation, and the relative rates of energy migration are functionally dependent on the water depth. Since large-scale geographical variations in the shoreline will affect the wave field, point-source measurements can no longer be relaxed spatially as in the case of the Offshore and Outer-Shelf subnets, thus increasing the number of measurement sites and increasing the spatial resolutions between them.

The Coastal Subnet is bounded by the shoreline, crossing the surf-zone and extending out to water depths on the order of 20-m, and where applicable, into harbor and estuary domains. The local spatial application of this subnet is more restrictive. Coastal gauges are particularly useful in understanding the transformation and dissipation processes of waves as they traverse complex local bathymetry, eventually breaking at the shore. Careful examination of where these gauges are deployed is required. In general, these assets are required to be seaward of the surf-zone during extreme events, yet in water depths shallow enough to minimize short-period (high-frequency) signal loss.

## 3.1 Existing Network

The existing wave measurement network consists of 181 operational wave measurement devices (Table 1). This is based on platforms actively measuring waves 24/7 and transferring the information to NDBC for quality control and dissemination to NWS field offices and over the Global Telecommunications System (GTS).

Regional maps and additional information pertaining to the existing point source measurement locations can be found in Appendix A. The existing network provides a starting point in the process of evaluating:

- What devices can be classified in a particular subnet?
- Are the existing sites strategically placed?
- Are there gaps in each subnet?
- What changes are required to achieve a First-5 standard for each site?

There are other sources of wave data providing key information in regions not specified in the Plan. For example, active self-recording (delayed-mode) sensors, large-scale field experiments, and historical wave data which will complement and enhance the planned network design will be pursued and archived with new, real-time observations. Ancillary non-directional wave data extracted from pressure records specifically designed to measure water levels from NOAA/NOS Center for Operational Oceanographic Products and Services (CO-OPS) National Water Level Observation Network will also augment the directional wave observations proposed here.

This plan divides the US coastline into seven primary regions: the Atlantic (Figure 6), Gulf of Mexico (Figure 7), Pacific (Figure 8), Alaska (Figure 9), Hawaii-South Pacific Islands (Figure 10a and 10b), Great Lakes (Figure 11), and Caribbean Sea (Figure 12). The subnets for each region will be presented including existing assets, platform upgrades to First-5 capability, and new additions. Buoy upgrades can carry two definitions, both which conform to the First-5 standards outlined above. The first is to transition a non-directional wave measurement platform to directional capabilities; the second would be to upgrade existing directional measurements to comply with First-5 requirements. As an example, a 6-m NOMAD (Navy Oceanographic Meteorological Automatic Device) buoy has a boat-shaped hull and is not symmetric. This type of buoy cannot measure wave direction and therefore requires a companion waves-only buoy (there are presently 38 deployed NOMAD buoys). Wave buoys operated by existing IOOS Regional Associations assets that do not resolve directional waves will require directional upgrades followed by field testing (Section 3.3) to confirm that they meet the First-5 standard. Table 1 summarizes the existing platforms for each region, the type of platform, including directional information.

IOOS Regional Association (RA) input, requested specifically in preparation for this plan, provided additional requirements, particularly for the coastal subnet. Each RA request is summarized in Appendix B and their original submission is provided in Appendix C.

## 3.2 Network Design

Station positioning for the existing network was essentially ad hoc, based on funding availability and local requirements. Until now, there has never been an opportunity to reassess and develop an integrated wave network based on national requirements.

The overriding philosophy of the design is to build the four subnets using existing assets whenever possible, to upgrade assets to First-5 capabilities, increase data sampling to near-continuous (e.g., onboard time series data recorder), and to rely on regional partners' support, not only in terms of collaboration and coordination, but also to take advantage of their local knowledge and understanding of their user's requirements.

The initial effort in the design was to determine the number of operational wave measurements sites in each region. This analysis included the physical position, water depth, platform, sensor type and analysis packages. A gap analysis was performed assessing where significant coverage was needed to maintain continuity of the subnets along the coast, and in an offshore direction. Long-term wave hindcasts (the USACE Wave Information Study http://www.frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html) were used to cross-reference areas of large-scale along-shore wave height gradients. These inflection points generally aligned with geographical changes (e.g. capes, embayments, shoals, and offshore islands). Locations identified from the gap analysis were modified based on suggested locations provided by the 11 IOOS Regional Associations, 47 NWS forecast offices and the requirements expressed by the seven USACE division and 22 district offices responsible for coastal projects.

**Table 1. Summary of Existing Wave Observation Platforms**

| Region | 12 m & 10 m Discus | 6-m NOMAD | 3-m Discus | | | | Other Buoy Configurations | | | | | Shallow | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Hippy | Angular Rate | Magnetometer | Strapped Down Accelerometer | 2.0 m | 1.8 m | 1.7 m | 1.1 m | Waverider | Pressure | Acoustic |
| Atlantic Coast | | | | | | | | | | | | | |
| Non-Directional | 2 | 10(1) | | | | 7 | 11 | | | | | 3 | |
| Directional | | | 2 | 6 | | | | 5 | | 2 | 4 | 1 | 7 |
| Gulf of Mexico | | | | | | | | | | | | | |
| Non-Directional | | | | | | | | | | | | | |
| Directional | 5 | | | 2 | 5 | | | 4 | | | 1 | | 5 |
| Pacific Coast | | | | | | | | | | | | | |
| Non-Directional | 2 | 4(1) | | | | 6 | | | | | | 1 | |
| Directional | | | 5 | 8 | | 3 | | | | | 21 | | |
| Alaska | | | | | | | | | | | | | |
| Non-Directional | 2 | 15(2) | | | | 2(3) | | | | | | | |
| Directional | | | | | | | | 3 | | | | | |
| Pacific Islands | | | | | | | | | | | | | |
| Non-Directional | | 3 | | | | | | | | | | | |
| Directional | | | 2 | | | | | | | | 4 | | 1 |
| Great Lakes | | | | | | | | | | | | | |
| Non-Directional | | | | | | 3(6) | | | (2) | | | | |
| Directional | | | | 1 | 5 | | | | | | | | |
| Caribbean | | | | | | | | | | | | | |
| Non-directional | | 6 | | | | | | | | | | | |
| Directional | 2 | | | | | | | | | | | | |
| Total | 13 | 38(4) | 9 | 17 | 10 | 21(9) | 11 | 12 | (2) | 2 | 30 | 5 | 13 |

Note: Number of Canadian sites is given in parentheses; these are not included in the totals

The preliminary wave design was reviewed by the Steering Committee and Expert Review Panel. Both the Steering Committee and the Review Panel were asked to think broadly beyond specific agency interests and to use the following criteria to select and prioritize the installation of new wave platforms:

- Broad User Base - Platform types and locations with broadest possible user-base and wave conditions, including extreme events (e.g., hurricanes).
- Model & Remote Sensing - Platform types and locations that can be used for model & remote sensing prediction, validation, and assimilation.
- Meteorological Complexities - Platform types and locations that account for meteorological complexities, such as the influence of winds and currents on waves.
- Emerging Technologies - Platforms types that incorporate emerging technologies, including improvements to existing technologies.
- Location Trade-offs - Platform location trade-offs and local forcing, with deep water buoys providing value to a larger area and shallow water buoys addressing more regionally specific issues.

The compilation of all requests, recommendations and reviews produced the network design proposed here. It is anticipated that the final design will evolve, within the framework of the four subnets, as sensors are deployed and results of the observations are analyzed.

### 3.2.a Atlantic Coast

The Offshore Subnet for the Atlantic Coast (Figure 6) will consist of 15 sites. One buoy operated by Environment Canada is strategically located at the northeastern end of the Atlantic Coast Offshore Subnet. Because of its location, it would be beneficial to promote a collaborative effort with the Canadian government to upgrade this, and other Canadian sites to First-5 capabilities. Of the 15 sites, five sites will be new and the remaining nine will require directional upgrades. The Outer Subnet contains 12 sites; nine will be new and three are existing platforms, with two upgrades to First-5 capabilities. The Inner Subnet contains 21 wave measurement sites; 15 exist; 14 are non-directional and require upgrades to First-5 capability. A total of six new sites would complete this subnet. The Coastal Subnet consists of 42 wave gauges; 33 exist now and 26 require directional upgrades. As a first approximation, an additional 9 new sites are recommended. Of the new sites, two are to be placed along the ocean side of Long Island (one in the eastern portion of Long Island Sound), three along the New Jersey-Delaware coast, two along the southern Outer Banks of North Carolina to near Cape Fear, and two along the northern coast of Florida.

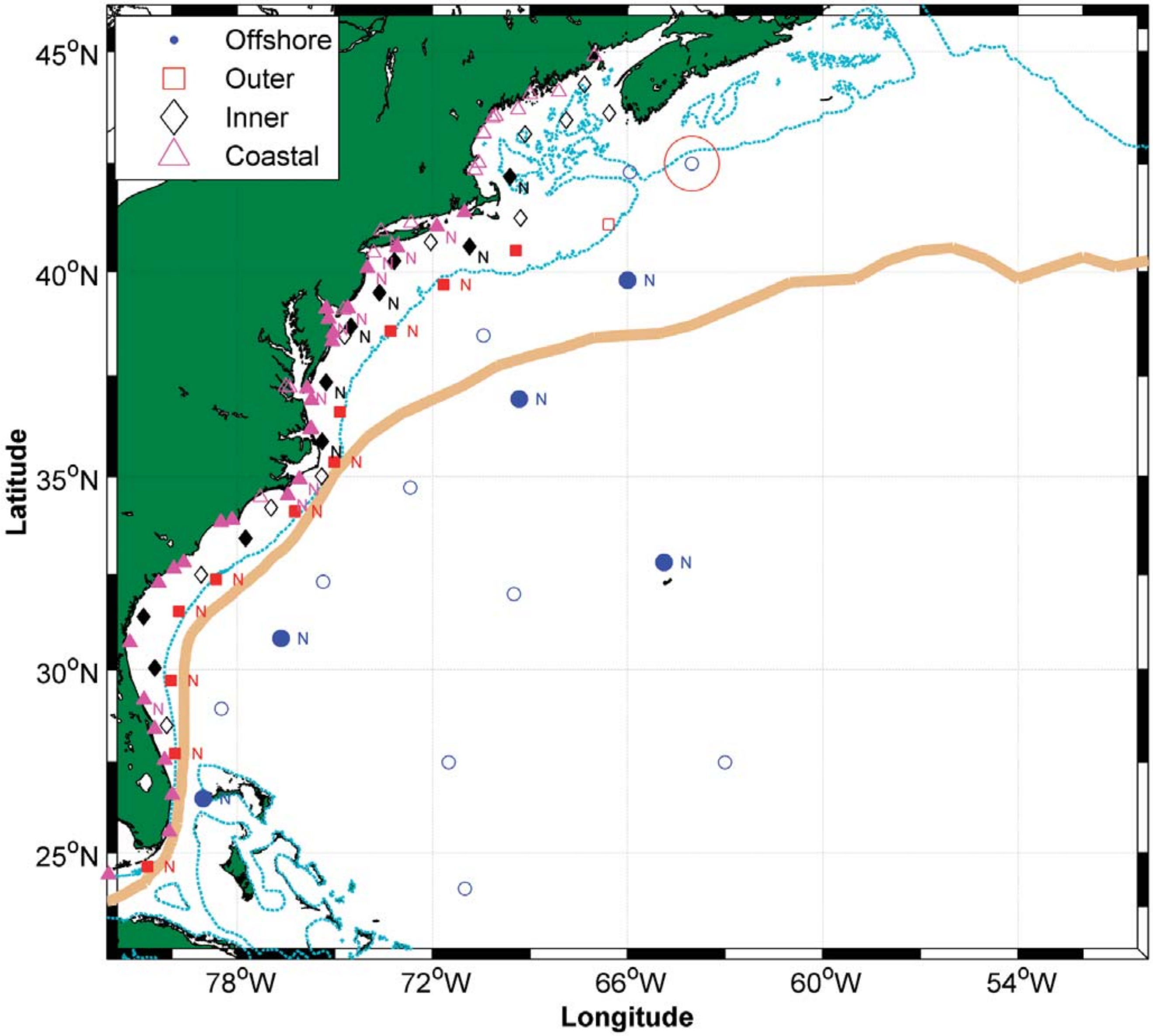

*Figure 6. Atlantic Coast Backbone design. Open symbols are non-directional sites, closed symbols are directional sites. The 200-m bottom contour is in cyan, and the north wall of the Gulf Stream is in tan. Note new locations are designated by "N." Existing Canadian Buoy is indicated by the large open red circle.*

### 3.2.b Gulf of Mexico

The Gulf of Mexico Offshore Subnet consists of six sites, including five which exist (Figure 7). All the existing sites have directional capabilities but require First-5 upgrades. The Outer Subnet will consist of nine sites; five are existing (all directional, one First-5), and four new sites. The Inner Subnet recommendation is for six sites: one existing site (upgrade to First-5) and five new locations. Twenty-four locations make up the Coastal Subnet. This will require an additional 13 new sites (11 exist, all requiring upgrades to First-5) along Texas, Alabama, the Florida Panhandle, and Florida's western coast, complementing the existing sites along the Louisiana coastline. Collaboration with the oil industry will play a critical role in the distribution of new assets in this domain.

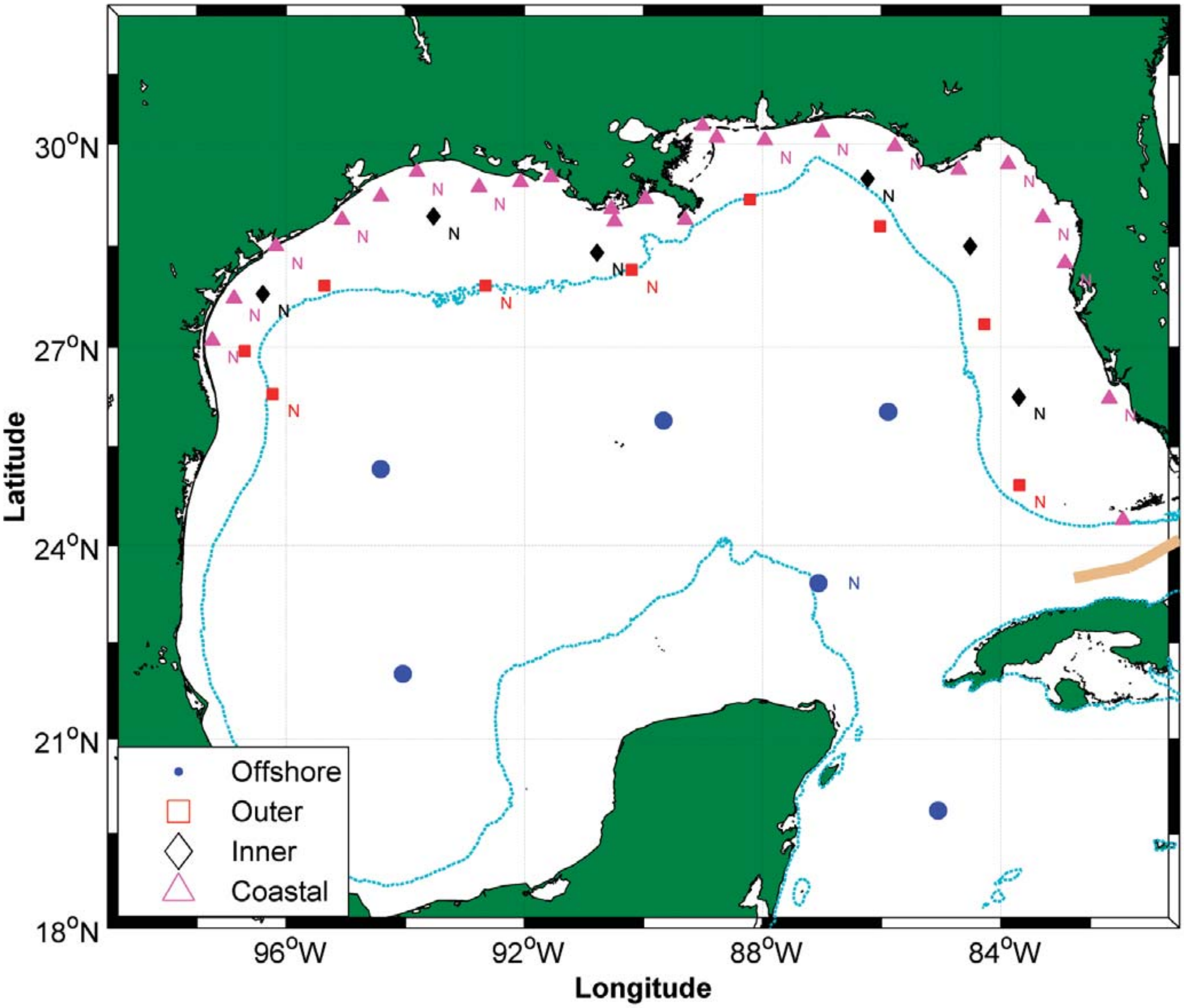

*Figure 7. Gulf of Mexico Backbone design. Open symbols are non-directional sites, closed symbols are directional sites. The 200-m bottom contour is in cyan and the beginning of the Gulf Stream is in tan. Note new locations are designated by "N."*

### 3.2.c Pacific Coast

Figure 8 displays the Pacific Coast. The Offshore Subnet will have 17 sites, of which 11 are existing platforms including 1 operated by Environment Canada. Six of the existing sites are non-directional and require upgrades and including the one operated by Environment Canada. The Canadian assets complement the US wave observations, and cost-sharing vital directional upgrades should be undertaken. There is a need for six additional sites to address the seasonal, semi-permanent meso-scale meteorological features that significantly impact the wave climate along the Pacific Coast. One will fill the gap west of Point Conception in California and five will be placed in the region between the Offshore and Outer Subnets (annotated with "MESO" in Figure 8). While the entire Pacific Coast experiences this phenomenon, priority for five new sites is given to the northern half of California and the southern half of Oregon where this issue is most pronounced, and the waves generated in this region impact a larger portion of the Pacific Coast. The design of the Outer Subnet will require 26 sites, of which 25 presently exist, six require upgrades. Because of the narrow shelf along most of this domain, only two Inner Subnet assets are required. They are located in the Straits of Juan de Fuca and require First-5 upgrades. The Coastal Subnet has 13 existing buoys; one requires a directional upgrade. Based on input from the regional partners, seven new Coastal Subnet sites are recommended to be located along Northern California, Oregon and Washington.

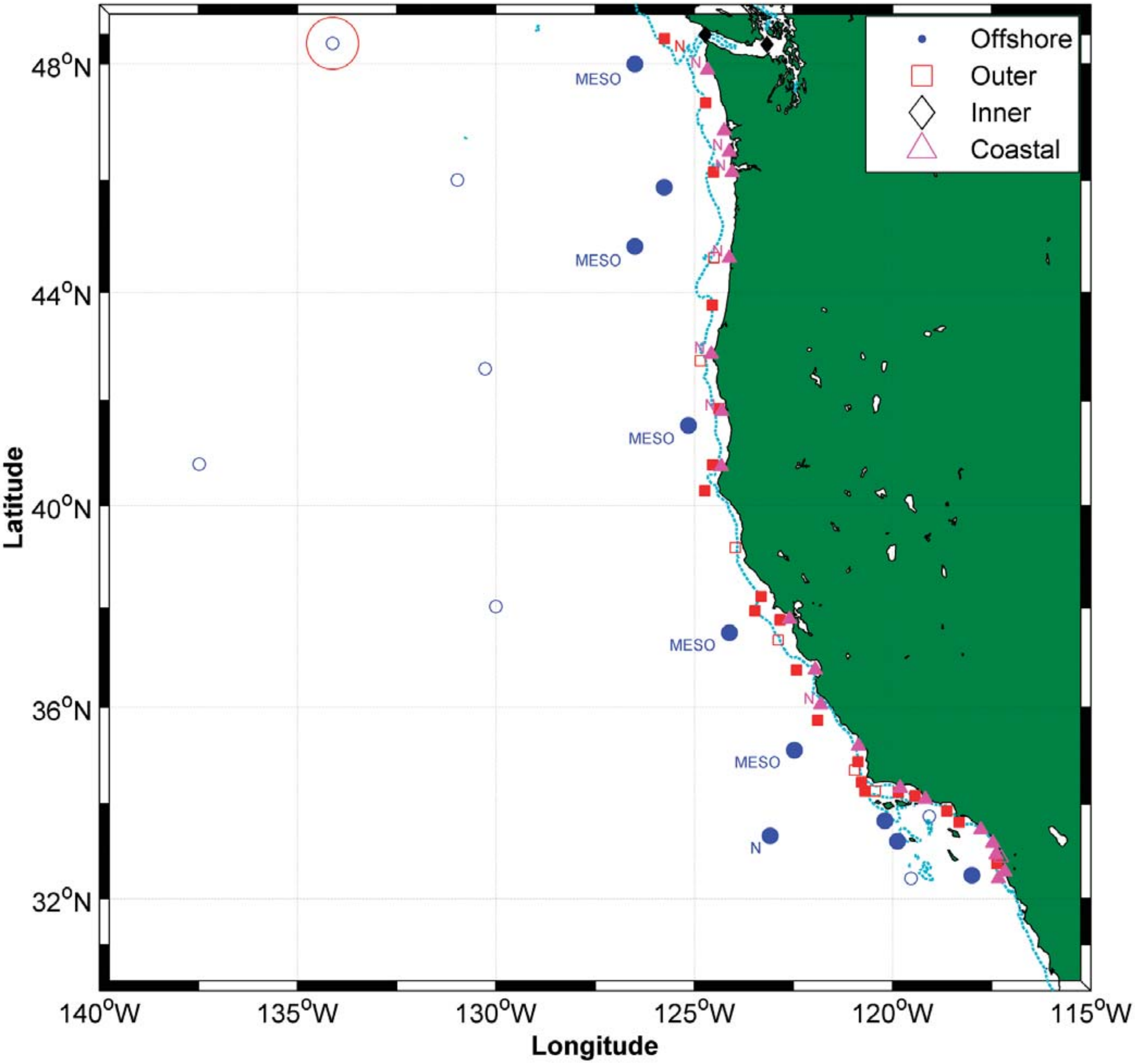

*Figure 8. Pacific Coast Backbone design. Open symbols are non-directional sites, closed symbols are directional sites. The 200-m bottom contour is in cyan. Note new locations are designated by "N." Existing Canadian Buoy is indicated by the large open red circle.*

### 3.2.d Alaska

The Alaska Network (Figure 9) includes an Offshore Subnet that is filled with eight non-directional sites requiring upgrades including two Canadian buoys which will require joint collaboration. The Outer Subnet contains 12 sites, (plus three Canadian) 9 exist, all non-directional, and three new locations. One non-directional site exists in the Inner Subnet, and five new locations are recommended. The Coastal Subnet at this time is concentrated around Cook Inlet, Prince William Sound and Anchorage proper. Nine new sites are recommended. The Alaska domain presents a number of challenges because of the harsh environment, seasonal influx of pack and floating ice, ice loads on the buoy contaminating the wave measurements, seasonal recovery and redeployment, local field support and logistics. These impediments are not insurmountable but have to be carefully examined and closely coordinated with the AOOS and regional partners to provide wave data in areas where they have not existed before, and to aid in the evaluation of modeling efforts that will be critical to this area. In fact, because of the observation challenges in Alaska, this is one domain where improved wave forecast models may ultimately allow a reduction in the number of required in-situ observations.

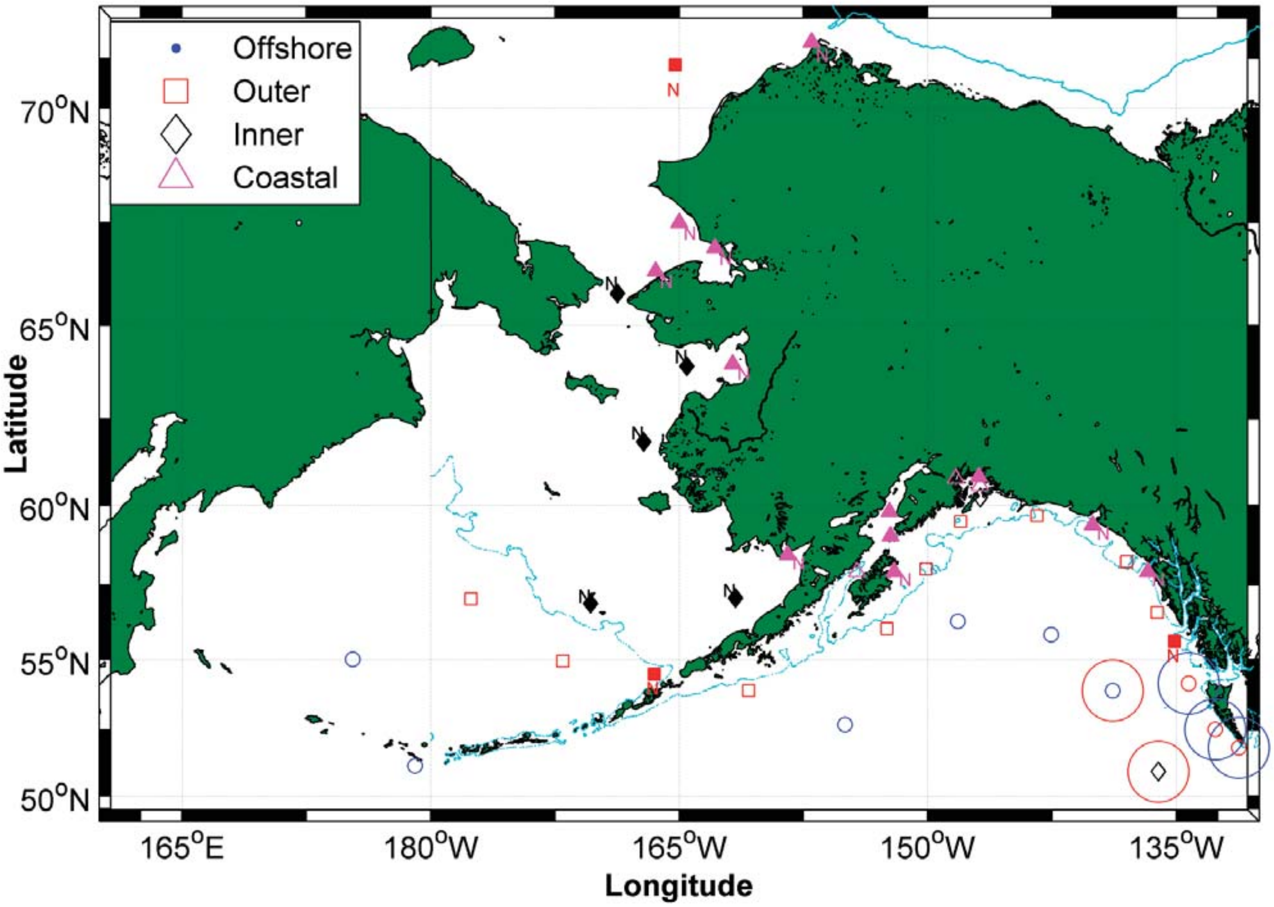

*Figure 9. Alaska Backbone design. Open symbols are non-directional sites, closed symbols are directional sites. The 200-m bottom contour is in cyan. Note new locations are designated "N," Canadian Buoys are indicated by large open red and blue symbols.*

### 3.2.e Hawaii and South Pacific Islands

The Pacific Islands contain two primary domains: the Hawaiian Islands (Figure 10a) and the South Pacific Islands (Figure 10b). The Hawaiian Island domain contains a narrow shelf and only two of the four subnets are required. The Offshore Subnet will contain six sites; five exist, including two with directional capabilities. Three require First-5 upgrades. The remaining site, which was recommended by the regional partners virtually, closes the loop around the islands. Four existing stations have been identified in the Coastal Subnet. All but one requires a First-5 directional upgrade. Five new coastal locations are included for the Coastal Subnet in the South Pacific Islands (Figure 10b).

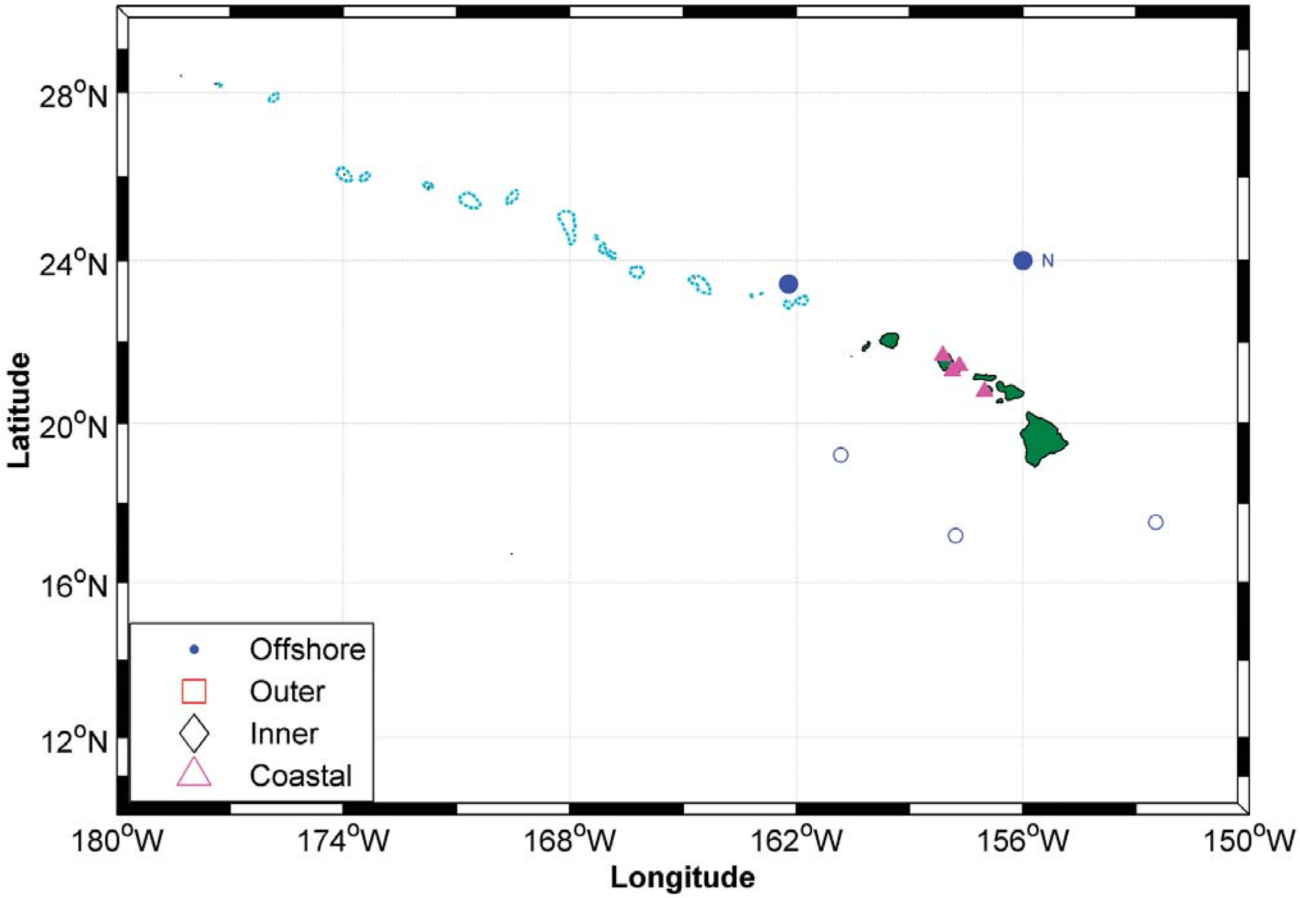

*Figure 10a. Hawaiian Islands Backbone design. Open symbols are non-directional sites, closed symbols are directional sites. The 200-m bottom contour is in cyan. Note new locations are designated by "N."*

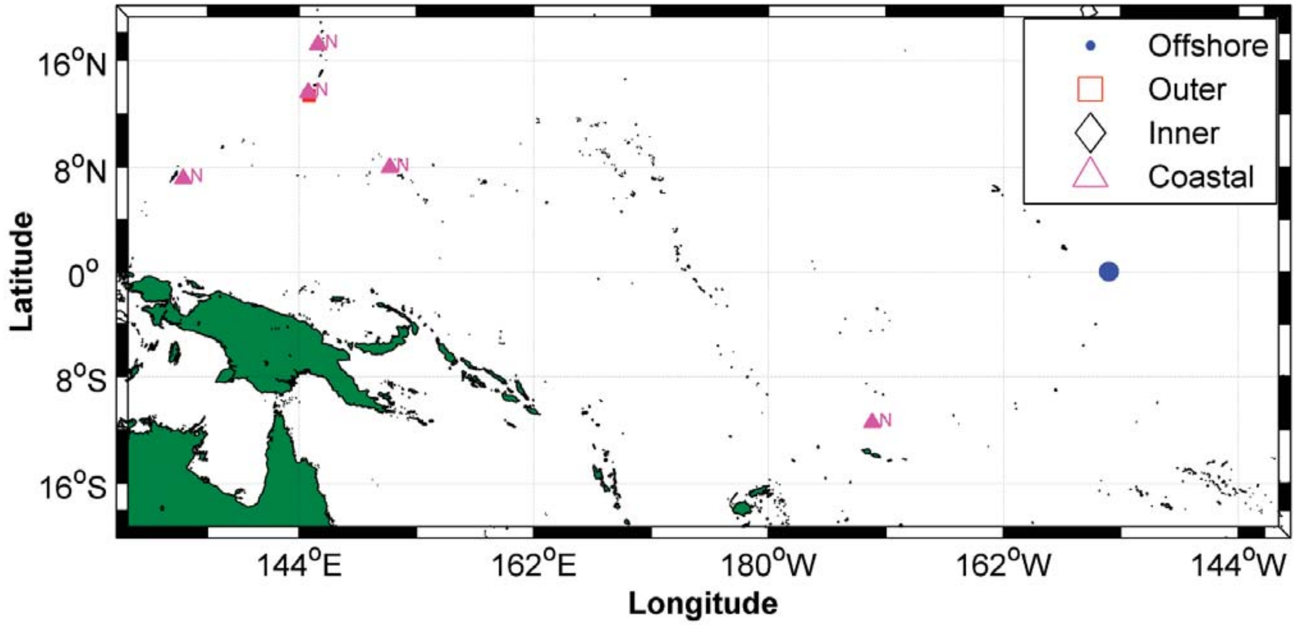

*Figure 10b. Southern Pacific Islands Backbone design. Open symbols are non-directional sites, closed symbols are directional sites. Note new locations are designated by "N."*

### 3.2.f Great Lakes

In the Great Lakes domain (Figure 11) the Offshore, Outer, and Inner Subnets fall under one definition. Hence, any buoy that is located in water depths greater than 10-m is defined as an Inner-Shelf Subnet asset. Recommendation for the design consists of 12 measurement sites in addition to the eight locations operated by Environment Canada. It is strongly recommended these sites be upgraded to directional wave capabilities in a cost-sharing basis. Of the existing nine operational sites, three require directional upgrades and the other six require First-5 upgrades. There are three new Inner Subnet sites recommended: central Lake Michigan, western Lake Erie, and eastern Lake Ontario. The recommended Coastal Subnet requires twenty new sites. Similar to Alaska, Great Lakes wave measurement buoys have to be removed during the winter due to ice cover.

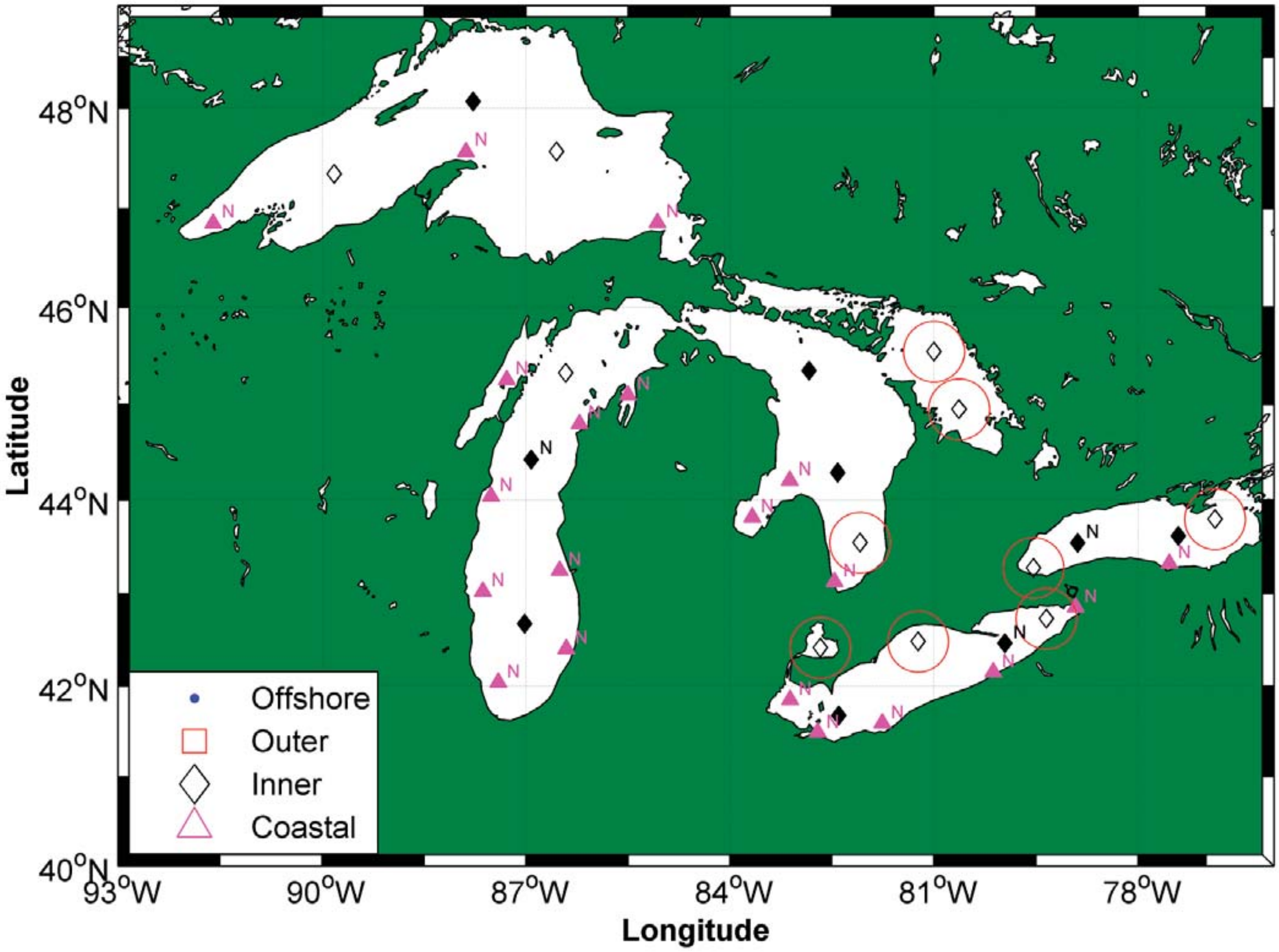

*Figure 11. Great Lakes Backbone design. Open symbols are non-directional sites, closed symbols are directional sites. Note new locations are designated by "N," Canadian Buoys are indicated by large open red symbols.*

### 3.2.g Caribbean Sea

The Caribbean Sea domain has a fully operational Offshore Subnet of eight sites (Figure 12). Of the eight, two are directional but require First-5 upgrades and the remaining six are recommended to be upgraded to First-5 capabilities. The Caribbean Regional Association identified just three Coastal sites: north and south of Puerto Rico and one in the Virgin Islands.

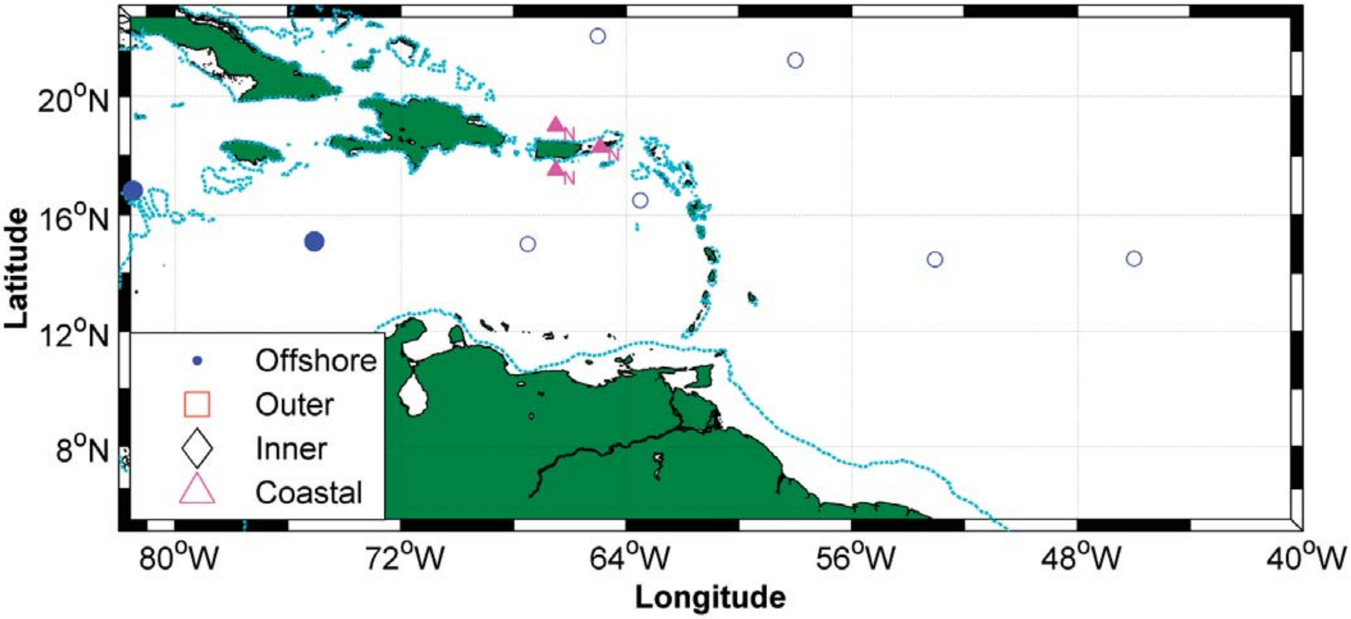

*Figure 12. Caribbean Sea Backbone design. Open symbols are non-directional sites, closed symbols are directional sites. The 200-m bottom contour is in cyan. Note new locations are designated by "N."*

### 3.2.h Network Design Summary

Table 2 summarizes the existing locations and design recommendations for each of the regions and the four Subnets. The network will include a total of 296 sensors: 56 in the Offshore, 60 Outer-Shelf, 47 Inner-Shelf, and 133 Coastal. Of these, 115 are new. First 5 directional upgrades are anticipated at 128 locations. Supporting information for each existing and new locations listed in Table 2 is provided in Appendix D.

**Table 2. Summary of Planned and Existing Wave Measurement Sites**

| Region | Offshore Subnet | | | | Outer-Shelf Subnet | | | | Inner-Shelf Subnet | | | | Coastal Subnet | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Design | Exists | New | Upgrade | Design | Exists | New | Upgrade | Design | Exists | New | Upgrade | Design | Exists | New | Upgrade |
| Atlantic Coast | 14(1) | 9(1) | 5 | 9(1) | 12 | 3 | 9 | 2 | 21 | 15 | 6 | 14 | 42 | 33 | 9 | 26 |
| Gulf of Mexico | 6 | 5 | 1 | 5 | 9 | 5 | 4 | 5 | 6 | 1 | 5 | 1 | 24 | 11 | 13 | 11 |
| Pacific Coast | 16(1) | 10(1) | 6 | 6(1) | 26 | 25 | 1 | 6 | 2 | 2 | | 2 | 20 | 13 | 7 | 1 |
| Alaska | 6(2) | 6(2) | | 6(2) | 12(3) | 9(3) | 3 | 9(3) | 6 | 1 | 5 | 1 | 15 | 6 | 9 | 3 |
| Pacific Islands | 6 | 5 | 1 | 3 | 1 | 1 | | | | | | | 9 | 4 | 5 | 1 |
| Great Lakes | | | | | | | | | 12(8) | 9(8) | 3 | 9(8) | 20 | | 20 | |
| Caribbean | 8 | 8 | | 8 | | | | | | | | | 3 | | 3 | |
| Total | 56 (4) | 43 (4) | 13 | 37 (4) | 60 (3) | 43 (3) | 17 | 22 (3) | 47 (8) | 28 (8) | 19 | 27 (8) | 133 | 67 | 66 | 42 |

Note: Number of Canadian sites is given in parentheses; these are not included in the totals

A fundamental requirement of all network locations is for platforms and sensors to possess First-5 capabilities. Since a wide range of instruments and platforms are presently in use, it is necessary to assess their accuracy. This evaluation process, described in Section 3.3, will be pursued as rapidly as possible and can run in parallel with normal data collection.

Existing assets that provide directional wave estimates that are not First-5 capable will also require payload upgrades. To be cost-effective, these upgrades will be staged to take advantage of maintenance/change-out schedules.

One major step in the build out of all four subnets, but particularly for the Coastal and Inner-shelf Subnets is to work closely with each of the regional partners in assessing their priorities, take advantage of their support infrastructure, and to cost-share the sensors in their region. It is envisioned that these denser, near-shore wave measurements will be operated and maintained by the regional partners where appropriate.

## 3.3. Technology Testing and Evaluation

Continuous testing and evaluation of operational and pre-operational measurement systems is an essential component of the National Operational Wave Observation Plan, equal in importance to the deployment of new assets. Testing and evaluation should commence in Year-1 of the Plan in order to insure that new and upgraded assets meet the First-5 performance requirement before they are purchased and deployed. Inter-platform tests have been pursued in the past, (O'Reilly et al, 1996; Teng and Bouchard, 2005), however with the evolution of sensors, changes in buoy designs, and new platform systems, a fresh look is required.

The Alliance for Coastal Technology (ACT) was created to support the sensor requirements of IOOS and is well-positioned to support the technology testing and evaluation component of this plan. In March 2007, ACT hosted a Wave Sensor Technologies Workshop that brought together wave sensor manufacturers and wave data users (full report at http://www.act-us.info). An overwhelming community consensus resulting from that workshop was that:

- The success of a directional (First-5) wave measurement network is dependent in large part on reliable and effective instrumentation (e.g., sensors and platforms);
- A thorough and comprehensive understanding of the performance of existing technologies under real-world conditions is currently lacking, and
- An independent performance testing of wave instruments is required.

These and other findings from the workshop will be used to guide the testing and evaluation process. One of ACT's strengths is that it has instituted a third-party mechanism for rigorous, unbiased performance verification of existing instrumentation. NDBC and USACE will work with ACT in conducting tests and evaluations of wave measurement systems. In addition to aiding in test design and data collection/analysis, ACT will serve as the independent oversight and coordination lead.

The first critical step, and the basic foundation for all technology evaluations, is to build community consensus on a performance standard and protocol framework. Prior to implementation, USACE and NDBC will develop a Wave Technical Advisory Committee and convene a Wave Technology Protocol Workshop (in accordance with ACT's established Guidelines for Evaluations). This two-day workshop will bring together the Advisory Committee, developers/manufacturers of wave measurement systems, and the NDBC, USACE and ACT testing team members. The goals of the workshop will be to:

- Identify approaches to evaluating the performance (e.g., comparisons to a presently accepted technology/approach) of current operational and pre-operational (future initiatives) in situ technologies, recognizing that different standards may need to be applied for different measurement technologies;
- Establish basic protocols for how the field tests of wave measurement systems will be conducted, and
- Develop specific protocols for how the first set of system tests will be conducted. These guidelines will include length of time for testing, analysis and quality control software and dissemination of results.

While many of the details for how tests are to be conducted can only be determined during the workshop described above, where all of the relevant players are present, it is clear from the original ACT workshop, the Wave Plan Steering Committee and Expert Panel Review that both east and west coast locations are required to appropriately evaluate the performance of wave measurement systems, given the wide spectrum of wave regimes that are of interest. The East Coast location will capture the dynamically interesting conditions associated with both extra-tropical and tropical storms, generating substantial wind seas, in deep water as well as shallow shelf conditions, some of which are also common to the Gulf of Mexico and Great Lakes. A West Coast location would capture long-period swells and deep shelf conditions typical of the Pacific Ocean. Both the USACE Field Research Facility (FRF) in Duck, NC, on the East Coast, and the Coastal Data Information Program (CDIP) at Scripps Institution of Oceanography (SIO) in La Jolla, CA, on the West Coast has appropriate local expertise and validation infra-structure. For Coastal Subnet applications, the standard is a pressure sensor based directional array. There is only one active directional array and it is located at the FRF. The FRF would serve as the primary test site, taking advantage of this array and the other wave sensors already located there. The FRF and SIO would also serve as staging locations for deep water evaluations further offshore. An alternative testing site could be considered if an ocean platform, suitable for mounting a pressure array, were to be made available through an industry partnership agreement. In this situation, the evaluation framework would remain the same irrespective of the actual site. Also, as a first step in the evaluation process, recent individual wave system testing results will be compiled and placed on a public-access web site.

As mentioned above, the testing and evaluation activities should start immediately at the beginning of plan implementation and continue annually with the intent of testing all combinations of platforms, sensor payloads, and systems. The goal will be for testing to precede significant capital investment in sensors and platforms. Facilities will need to be developed or, if the two existing sites are selected, expanded (e.g., reference instruments and spares, computing/software and eventually lab space/equipment for calibration and training) and staffed.

Procedures and resources will be established to conduct "in-place" evaluations of wave measurement systems that cannot easily be moved to the test sites. As a system performance evaluation and calibration exercise, an agreed-upon wave reference standard (e.g., instrument of known performance characteristics) would be deployed next to existing wave measurement systems for extended periods (e.g., 6-12 months, always including a storm season) for a cross-comparison. This type of testing is likely to be less cost-effective than the test and evaluation center concept, but appropriate in some circumstances.

## 3.4. Data Management

A critical component of the National Operational Wave Observation Plan is moving data and associated metadata from sensor to user. Observations supported by this plan will primarily flow through the IOOS Data Assembly Center (DAC) operated by NDBC and the USACE/CDIP. NDBC will provide the necessary assembly and timely transport of received wave data to NWS/GTS to support national and regional forecasting and warning responsibilities, and to other wave data users and the public.

The increase in the wave observation network will require additional resources to quality control (QC), disseminate and archive the information. The IOOS DAC currently processes approximately 130,000 spectral wave observations per month from the existing wave observation network. The final network design is expected to provide over 200,000 wave observations per month – an increase of 35-percent. Quality controlling wave spectral data requires instrumentation that is accurately calibrated and tested; and automated algorithms to validate and QC the spectral data. Furthermore, continuous confidence limits of the measurements should be derived for the basic wave parameters computed from the First-5 variables on a monthly basis and then annually to demonstrate performance fidelity and to isolate potential sensor or station problems. Such long-term statistics can lead to skill scores or performance metrics, which are useful to the user community and the wave modeling community, assuring maximum quality assurance.

### 3.4.a Metadata

A fundamental objective of this plan is the use of IOOS Data Integration Framework (DIF[*] ) compliant format metadata. This is a requirement for data provided by IOOS wave observers, and by the IOOS DAC, both for present, and eventually for legacy data holdings and inventories. Presently, the NOAA IOOS Program is working toward adoption of the ISO (International Organization for Standardization) metadata standards for DIF. Use of Federal Geographic Data Committee (FGDC) metadata with controlled vocabulary identification and documentation will enable wave data to be easily found through an open data discovery process.

At present, the wave observation community has limited FGDC-compliant metadata available and they are not easily discoverable. NDBC distributes the required metadata that can be accommodated in the WMO alphanumeric messages; however these formats cannot contain the full gamut of metadata that appear necessary to support IOOS. NDBC observations that are forwarded to the National Centers for archive are encoded in the WMO F291 format. Implementation of this waves plan will convert present metadata management standards into approved ISO metadata standards. Each data attribute (e.g. unit of measure, reporting convention, precision, and code definition) will be encoded and delivered in valid XML formats and made available to the public for easy access via IOOS websites. Historical metadata, including sensor maintenance schedules and software changes will be archived and made readily available via XML approved standards. The USACE/CDIP is generating compliant metadata; a complete list of the FGDC and XML metadata for all observations is available on the CDIP website (http://cdip.ucsd.edu) along with

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[*] *DIF-identified standards will be submitted to the DMAC standards process and by using vetted standard formats, wave and other IOOS data will be more easily discovered and accessed.*

maintenance schedules and historical availability of data and data products.

The netCDF files accessible via the NDBC OPeNDAP sever have the potential to convey a great deal of useful metadata about a station's configuration and how variables are measured. The files at present contain no metadata except for station name, location* , and unit of measure for each variable.

Planned NDBC improvements to metadata are to unify the procedures for generating, managing, and making wave observation metadata accessible to users – including the automatic generation and modification of metadata based on entries to user databases. Easy access and user friendly displays of metadata retrieved directly from the database or website will also be required.

Buoys may have different error characteristics due to present and local environmental conditions. This is true even if they have identical payload and mooring. Possessing different configurations obviously leads to additional non-uniformity in data quality. Metadata will be used to provide time-varying qualitative information about data reliability for each instrument so that the end user can make appropriate decisions about how to use the data. For example, poor data quality resulting from difficulty of measuring long, low swells, common in the Pacific basin, would also generate flags according to the individual buoys ability to measure such waves.

### 3.4.b Standardization of the Content and of the Data

The NOAA IOOS Program is coordinating the standardization of data content with national data providers and the eleven IOOS Regional Associations. NOAA data centers (NDBC and CO-OPS) make data available in several standard formats. Except for archival in F291 and distribution of FM65 and Wave Spectral Data, IOOS partner's data are distributed using the same methods and in the same formats as NDBC's own data.

WMO alphanumeric formats are used to distribute real-time data via the NWS Telecommunications Gateway (NWSTG). The NWSTG distributes data to NWS activities via dedicated NWS communications, to the public and commercial enterprises via the NOAA Broadcast System (NOAAPort), and internationally through the GTS. The WMO formats support real-time analysis, forecasting, warning, model initialization, and model verification, both nationally and internationally. Wave observations are encoded with meteorological observations in the US nationally-modified WMO FM12 format for Coastal Marine Automated Network (CMAN) stations and WMO FM13 format for buoy data. Wave spectral data are encoded in the WMO FM65 format. The formats are described in the WMO Manual on Codes, WMO No.-306. The units of measure and parameter names are well-defined for these codes. Information on the quality control and instruments or processes used is generally not well defined. The formats are widely used but not flexible when it comes to adding new data types.

All of the above formats are very mature and targeted at specific users that are well prepared in using the formats. The WMO alphanumeric formats are the standard for distributing real-time data among the government and commercial meteorological community, as well as the wave and ocean modeling communities. A large variety of users, including the general public, private industry, and researchers, access the real-time data in ASCII format from the NDBC and USACE/CDIP websites. The USACE/CDIP site also provides access to historical and real-time data products (time series, spectral and bulk parameters).

Improvements to the wave observation network will require data standardization improvements that (1) promote common formats for the users of the observations as well as the archive of data to replace the aged NDBC F291 formats at the Long-Term Archive Center, (2) standardize real-time data exchange formats that can transport the improved resolution required for First-5 applications, and (3) promote the adoption of an IOOS DIF standard.

### 3.4.c Data Archive and Mining Historical Wave Measurements

Many wave data users require long records (e.g. investigate variations in wave climates, to study extreme storm conditions, to evaluate improved wave models, etc.). To support this, the National Operational Wave Observation Plan includes provision for archiving the wave measurements. Archive tasks will be further detailed in the implementation plan, and coordinated with the data archiving centers: NOAA/National Oceanographic Data Center, (NODC) and the National Climatic Data Center (NCDC). Active real-time wave measurements accessible from the NDBC web site will follow the procedure outlined below.

At intervals of 45-days all real-time data products will be quality controlled by the originating data provider

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* *Geo-referenced data will be consistent with NOAA's Spatial Reference System (NSRS) which provides the foundation for all positioning and navigational activities in the US. Positioning accuracy must also be specified.*

according to the Quality Control Standards specified in NDBC Tech. Doc. 03-02. These data will then be transmitted to the Data Assembly Center at NDBC along with the calibration coefficients for their specific platform. NDBC will reformat the data consistent with existing WMO F291 standard. The final wave measurement data sets will be packaged and sent to NOAA/NODC for archiving.

Two other wave measurement data sets which are not naturally included in this process are active, self-recording (delayed-mode) instruments presently and historical wave measurements derived from short duration intensive field experiments, or deployments serving a specific local need. This plan includes funding to obtain these data and to process them similarly to real-time data. Mining for these data sets will be accomplished through the solicitation of regional partners, inter-governmental collaboration, and the private sector (e.g. oil companies). In addition to recovery of these data sets, meta-data will have to be developed. As a minimum the meta-data should include:

- Location, water depth (NSRS standards, see footnote on previous page)
- Measurement device
- Sample rate and length of record
- Analysis methods
- Calibration records
- Quality control

The centralization of wave data archives, in addition to a data provider's own archive, is necessary to insure long-term preservation of all wave data. As the implementation of the plan proceeds, there will be an increasing amount of wave data to be handled. Discussions are underway with NOAA/NODC and NOAA/NCDC to determine what the impact of this increase in data would have on the staff and computational resources. While it is difficult to estimate the amount of historical wave data which may exist until the data discovery has been completed, one can expect that older data will not be directional and will be less accurate than more modern data.

## 3.5. Operation and Maintenance

The plan requires Operation and Maintenance (O&M) tasks and funding necessary to sustain a long-term 24/7 nationwide system. Specific O&M activities are listed below.

### 3.5.a Field Service Support

After the sensors/systems are deployed, two types of field services are needed to maintain and operate: (1) scheduled and (2) unscheduled services. For a sustained, 24/7 measurement system, the sensor systems and platforms need to be maintained regularly (i.e., one should not let them keep running until they fail), so routine and scheduled field services are needed to clean, repair, or replace sensors/platforms. Maintenance will be scheduled as appropriate for each specific sensor/platform type. Although elements of the Offshore, Outer and Inner Subnets are maintained by NDBC during their normal operational routine, the service of wave systems requires extra time and resources, as will all new locations. The coastal gauges also need to be regularly maintained to ensure long-term and accurate wave observations. In addition to the scheduled field services, unscheduled field services will be required to bring failed systems back online as soon as possible. This plan provides a cost estimate for both scheduled and unscheduled field services and the costs shift from capital investment to O&M as the network matures.

### 3.5.b Ship Support

Timely instrument servicing is often dependent on weather, support team, and available ship time. The enhanced Offshore, Outer-Shelf and Inner-Shelf Subnets will require additional ship time, while coastal gauges will require ready access to small vessels when needed. Considering that ship time is expensive, this plan calls for strong coordination of ship support resources. To facilitate this aspect of the wave plan, funding and a mechanism for vessel and deployment schedules will be coordinated to take advantage of existing capabilities (NOAA, University-National Oceanographic Laboratory System, and commercial vessels), although there should be no impact to the current US Coast Guard ship support agreement with NOAA. Additional ship support may be acquired by NDBC's regional coordinators, directly by NDBC, or by the USACE sponsored CDIP operators. Shared ship support resources will be the foremost consideration for deploying and servicing wave sensor systems.

### 3.5.c Inventory of Sensor Systems

Assurance of a successful long-term operational system requires that standardized systems. An inventory of replacement and spare sensor systems will be maintained in order to insure timely repairs and replacements. These replacement wave sensor systems will be stored in multiple locations ready and calibrated for fast and easy deployment as needed. Unique or singular instruments will be avoided except for evaluation purposes. Based on NDBC and USACE operational experience, spares equal to 30-percent of the wave sensors/systems is needed for uninterrupted and sustained operations. These replacements and spares would be federally funded and made available as needed to IOOS wave observers.

### 3.5.d Sensor System Calibration and Testing

Sensor re-calibration and testing can be an expensive, time consuming process which, if not done, can adversely impact data quality. Following the NDBC and USACE present practices, this plan provides for consistent, federally supported calibration and testing of wave sensor systems (including those for both offshore buoys and coastal gauges) operated under this plan.

### 3.5.e Operator Training

Operational success is dependent on developing expertise through multiple deployments, including both successes and failures. Recognizing that some regional/coastal observers may not have extensive experience collecting First-5 quality wave measurements and that staff turnover can often be high, annual training will be provided in the operational logistics and data handling steps required for standard instrument types. This training will be done in collaboration with regional partners, will complement vendor training and will be modeled after ACT technology training exercises. The training will include lectures, field demonstrations, and hands-on practical sessions that cover all aspects of the latest theories and techniques for specific instruments. The training exercises will also be documented in the form of best practices guides for broad distribution to wave technology users. Training will begin early in the implementation of the wave plan in order to precede deployments by Regional Coastal Ocean Observing Systems (RCOOSs). As new technologies become available, additional trainings will take place as needed.

# 4. Complementary / Pre-Operational Wave Observations

This section recognizes the importance to the National Operational Wave Observation Plan of emerging and pre-operational in situ, ground-based and space-borne technologies that will improve and complement wave observations.

Continuous improvement of the wave measurement network requires incremental upgrades of existing instrumentation and the identification, nurturing and adoption of innovative technologies as they are proven. Research and development of new sensors and sensor platforms is necessary to improve the continuity of the operational data stream, and for improved accuracy and reliability, while reducing the capital and/or maintenance cost per station. Pre-operational technologies are those devices that have undergone extensive research, have been field tested beyond the "proof of concept" stage and are awaiting further evaluation prior to a full operational implementation.

Directional wave measurements can be estimated remotely from satellites and by ground-based radars. These observations have a unique advantage over in situ sensors, as they are able to image the entire wave field directly and over large areas. Satellite synthetic aperture radar (SAR) and Advanced Synthetic Aperture Radar (ASAR) can image the ocean surface day and night, and in all weather conditions. Present SAR sensors such as the Canadian RadarSat-1, European ERS-2 and Japanese ALOS/PALSAR and the European ENVISAT ASAR can provide sea surface information with 25-m resolutions over long strips about 100-km wide, or 100-m resolution over 500-km wide area strips (e.g. Pichel, 2008). Nearly the entire US East Coast (about 2100-km) can be covered by a low earth orbiting satellite pass in 5 minutes. New SAR sensors such as the Canadian RadarSat-2, Italy Cosmo-SkyMed, and German TerraSAR-X can image the ocean surface at a spatial resolution as small as 1 meter. Unlike altimeter systems (e.g. Europe's JASON-2) which provide only wave height estimates, SAR systems have the capability to provide First-5 directional spectral estimates along large swath widths, with repeat cycles from 10 hours to two days.

Remote wave observations may also be measured by ground-based high frequency (HF) and nautical radar instruments. The two primary commercially available HF radar technologies are direction finding and phased-array systems. These have significantly different wave measurement capabilities. Direction finding HF systems can only provide a single, averaged (over a radial rings of about 1-km radial spacing) wave observation. In contrast, phased-array HF systems provide two-dimensional spatial mapping of independent wave observations with maximum ranges up to about 100-km. Preliminary inter-comparisons between a phased-array radar system with a directional wave buoy measurements showed promise (Voulgaris et al, 2008, Shay et al, 2008; Haus, 2007). Nautical radars can provide continuous directional wave properties at very high spatial resolution for ranges up to 2- to 4-km.

Remote-sensed directional wave estimates complement and expand point source directional wave observations. Moreover, much of the infra-structure (data manipulation, product generation and data management) can be shared, reducing costs and increasing data integration.

Another technology that falls into the pre-operational category is acoustic current profilers. These systems are used to measure waves, as well as currents. Upward looking acoustic current profilers directly measure the pressure response of the free surface (when equipped with a pressure sensor), or follow the free surface itself (using a surface-tracking acoustic beam), and use sub-surface wave velocities computed using the Doppler shift in returns from an array of the upward-looking acoustic beams. Estimates of the directional waves are constructed from these data using linear wave theory relationships to the free surface. Another example is the Air-Sea Interaction Spar (ASIS, Graber et al. 2000) buoy which provides a stable platform to measure surface fluxes and directional wave spectra.

To encourage technological development, this plan includes funding for to help develop pre-operational wave measurement efforts. The ACT technology demonstrations model will be used to support the testing of pre-commercial or emerging wave measurement technologies. The goals of these demonstrations will be to help developers refine their instrumentation and to highlight the potential and capabilities of new technologies. The FRF and SIO test facilities will be made available (e.g., protocols, equipment/reference standards and technical staff) to technology developers through an application process, which will facilitate the continuous development, evaluation, and infusion of these new capabilities.

The National Operational Wave Observation Plan also encourages investment in research and development of critical wave observation technology through other funding sources such as the Small Business Innovation Research (SBIR) Program.

# 5. Roles and Responsibilities

This plan is an interagency effort coordinated by the NOAA IOOS® Program and the USACE. Implementation and oversight of this plan is the cooperative responsibility of the USACE and NOAA-NDBC. The Interagency Working Group on Ocean Observations (IWGOO) will work to facilitate the cooperation and involvement of other agencies.

In general the Offshore Subnet will be the responsibility of NDBC; the Outer and Inner Subnet observations will be co-shared and coordinated by NDBC and USACE. The USACE will oversee the Coastal Subnet. Establishing and maintaining an effective and efficient wave measurement system requires the partnership of federal agencies (NOAA, USACE), state and local agencies, the private sector, and Regional Associations (RA) and Regional Coastal Observing Systems (RCOOS). Because of the diversity of observers, funding sources, and deployed instruments, the USACE and NDBC will work closely with IWGOO partner agencies to encourage compliance with the plan (First-5 sensors; data handling, sensor locations). The USACE and NDBC will coordinate on the oversight of other aspects of the plan including Test and Evaluation, Training, and System Enhancements.

The USACE, NDBC and their partners will meet annually to update the inventory of established sites, to review the design and implementation progress, and to establish priorities for the next two fiscal years. It is envisioned that wave modeling activities, an increased user-base, requirements from regional partners and other US Government agencies will change in the future. Hence, a Waves Oversight Committee will meet annually to review the wave system design, assess any new input for directional measurements, evaluate success/failures, prioritize system deployments, and recommend any changes to the overall structure. During this annual review, wave data providers and users will participate and provide feedback on the success of the plan. As the operational system matures, validation of that capability will be evaluated. Metrics will be determined, some of which will include data recovery, sensor and platform survivability; specifics based on the user community; and other identifiable information that will facilitate the procurement and deployment of new or refined technologies and procedures. Interaction with partners, particularly during the initial start-up of the network, will be important to refining and improving the plan. Input will be obtained through presentations at Regional Association meetings, web surveys, workshops, and questionnaires.

# 6. Costs and Schedule

Based on the information provided in the previous sections, a simplified calculation of costs through the next five years is provided in Table 3. A refined analysis of costs based on specific upgrades to wave systems or the placement of desired instruments in specific locations will need to be performed before exact costs are known. These will be developed as part of an implementation plan. Yearly and total costs for Offshore, Outer-Shelf, Inner-Shelf, and Coastal Subnets are based on a generic unit price for locations that require "waves only" buoys, or for new buoys that are placed, regardless of the depth/distance from the shoreline. Inventory costs are computed as 30-percent of the costs for developing the four subnets. Field service support is calculated using current costs to keep a similar network of buoys operating along the coastline. Note that these costs and activities are in addition to existing funded NDBC and USACE programs. However, this plan and the associated costs take into account existing infrastructures, signed agency agreements and leveraging of available resources that will dramatically reduce overall costs and reduce risks to the success of the system. Since the cost estimate covers a series of investments, deployments, upgrades, and support activities, a decrease in available dollars would slow the deployment of the network, while an increase in available resources would reduce the time.

**Table 3. National Operational Wave Observation Plan: Cost Estimates ($k)**

| | YR 1 | YR 2 | YR 3 | YR 4 | YR 5 |
|---|---|---|---|---|---|
| **Offshore Subnet** | | | | | |
| Upgrades (37) | 600 | 960 | 960 | 960 | 960 |
| New (13) | 600 | 900 | 900 | 900 | 600 |
| **Outer-Shelf Subnet** | | | | | |
| Upgrades (22) | 500 | 500 | 500 | 400 | 300 |
| New (17) | 920 | 920 | 920 | 690 | 460 |
| **Inner-Shelf Subnet** | | | | | |
| Upgrades (27) | 195 | 325 | 455 | 455 | 325 |
| New (19) | 360 | 600 | 600 | 360 | 360 |
| **Coastal Subnet** | | | | | |
| Upgrades (42) | 520 | 520 | 650 | 520 | 520 |
| New (66) | 1,560 | 2,040 | 2,280 | 1,320 | 720 |
| **Test and Evaluation** | | | | | |
| Test and Evaluation | 1,200 | 1,300 | 1,500 | 1,600 | 1,700 |
| **Data Management** | | | | | |
| IOOS DMAC | 200 | 200 | 250 | 250 | 250 |
| Metadata | 150 | 100 | 100 | 100 | 100 |
| Standardization/QA/QC | 50 | 50 | 50 | 50 | 50 |
| Archiving / Data Discovery | 200 | 250 | 300 | 300 | 300 |
| **Operation & Maintenance** | | | | | |
| Field Service Support | 75 | 1,250 | 1,000 | 1,250 | 1,000 |
| Ship Support | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 |
| Inventory | 1,580 | 2,030 | 2,180 | 1,680 | 1,270 |
| Sensor Calibration | 100 | 150 | 300 | 500 | 500 |
| Observer Training | 75 | 75 | 50 | 50 | 50 |
| System Oversight | 200 | 200 | 200 | 200 | 200 |
| **Complementary Wave Observations** | | | | | |
| Pre-Operational | 200 | 400 | 400 | 400 | 400 |
| **Total** | 14,285 | 17,770 | 18,595 | 16,985 | 15,065 |

With the growth of deployed wave observing system assets, ship time will increase. Most of the deployed wave systems have used ship time provided by US Coast Guard partnerships, NOAA's fleet or through regular external partnerships. Over the past few years, the demands for ship time have risen, and fluctuating fuel prices have added to the uncertainty of ship contract costs. A rough order of magnitude cost for ship time to support the existing and new platforms in the Offshore Subnet and the Outer-Shelf Subnet is about $5M per year - assuming ship time from partnerships continues.

In Year-1 there are two primary objectives. The first is to begin testing and evaluating existing assets, a requirement prior to making substantial capital investments in new assets to insure that they provide First-5 capabilities. There are at least thirteen different wave buoys and gauging methods that estimate wave characteristics and most have not been rigorously evaluated. In addition, as regional partners begin to purchase and deploy wave sensors, there will be a need to provide guidance on the performance of various directional wave measurement devices. Meeting this challenge will require test sites, metrics, and operational standards to First-5 capabilities. Testing would begin at the FRF in Year-1 and at the SIO in Year-2. Also in Year-1 the Outer-Shelf Subnet directional assets will begin to be evaluated using "in-place" testing. Four sites (Atlantic, Gulf of Mexico, Pacific, and the Great Lakes) will be selected, based on operation and maintenance schedules in order to minimize costs.

The second Year-1 objective is to begin to realize the benefits of the network design by focusing on filling out the Outer and Coastal Subnets with known First-5 compliant devices. The Outer Subnet will provide the deepwater boundary conditions for improved shallow wave forecasts. The Coastal Subnet is where the most users of real-time observations reside, and provide point-source sites for model verification. Also during the initial years, work will begin on the data formats, standards, and protocols necessary to achieve wave data integration across the IOOS.

Full deployment of the National Operational Wave Observation Plan will begin starting in Year-3 and continuing until the design has been completed.

Although the costs and scheduling spans just five years, after that activities shift to sustaining the system: operation and maintenance, inventory, sensor calibration, field service support, sensor replacement and data management. This is anticipated to equal the Year-5 cost and increase annually according to the rate of inflation.

# 7. Summary

For the first time, experts in the wave community have designed a wave network that meets the nation's needs. The development and implementation of this National Operational Wave Observation Plan will provide a consistent network of accurate First-5 directional wave measurements along the US coast from deep to shallow water. The design is based on four subnets which acknowledge the natural scaling of the generation, propagation and transformation of directional waves. The underlying motivation of this schema is to align the observation system with wave modeling activities with the goal of significantly improving wave forecasts (Cardone et al., 1994; Komen et al. 1994; The WISE Group, 2007). First-5 quality directional measurements will not only provide verification of modeling efforts, they will also lead to improvements in technological advancements, useful in data fusion and assimilation techniques, improve and extend a wide range of wave observation-based products and serve as ground truth for the next generation of wave models and satellite based remote sensing systems.

The plan divides the US coastline into seven primary regions: Atlantic, Gulf of Mexico, Pacific, Alaska, Hawaii-South Pacific Islands, Great Lakes, and the Caribbean Sea. The subnets for each region were first defined by incorporating existing assets and then expanded based on physical principles of wave mechanisms, and requests from the Regional Associations. When completed, the observation network will include a total of 296 sensors: 56 in the Offshore, 60 Outer-Shelf, 47 Inner-Shelf, and 133 Coastal. Of these, 115 will be new locations. Directional upgrades are anticipated at 128 locations. This design has for years been used successfully along the California coast to incorporate wave measurements with modeling in order to fulfill the needs of a large user community for both real-time observations and forecast wave conditions.

Multiple tasks will be undertaken during the implementation process including testing existing directional platforms to determine First-5 capability; rigorous field evaluation of pre-emerging technologies that could substantially reduce procurement costs; and deployment of new assets. The plan will support IOOS® DMAC data requirements and flow wave data through the IOOS Data Assembly Centers and to permanent data archives. An integral part of this plan is to continuously review the deployment progress and to add or modify the placement of new directional wave assets.

The proposed cost estimate starts in Year-1 at about $14M, and then increases to about $17M per year, with capital investment costs being gradually replaced with operation and maintenance costs. These numbers represent the increased costs for upgrades and new sensors, and are in addition to the costs of maintaining the existing network.

The benefits to the large and diverse community of IOOS users will be significant. The plan, when implemented will equally serve requirements for general wave information in the form of height, period, and direction. It will also serve users requiring detailed, highly accurate directional wave information. The nationwide availability of real-time directional wave data will provide timely information to commercial, Naval, and recreational boating; minimize loss-of-life and property through improved forecasts, aid the US Coast Guard in their search and rescue mission, and serve the heavily populated US coastlines during storms, hurricanes, and tourist seasons.

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# Appendix A: Existing Wave Measurement Locations by Regional Association Domain

As of August, 2007, the existing national wave network consists of 181 wave measurement devices occupying the US coastal and offshore waters. The count is based on the platforms actively measuring waves 24/7 and transferring the information directly to NDBC for routine posting. This does not include historical sites no longer active, or sites that are monitoring and posting wave conditions from sponsored web sites. These locations are displayed in Figure A1, which is deceptive in its depiction of the existing network since the size of the symbols (approximately one-degree) gives the impression that the entire coastline is covered by wave observations. Closer inspection of Figures A2 – A13, which show the array regionally, better illustrates the sparseness of the existing network for the nation's coastlines.

Of the 181 sites, 111 are operated and maintained by NDBC (including sites funded by government and private sectors); plus eight new sites scheduled for future deployment. Thirty-four of the 181 are supported or co-supported by the US Army Corps of Engineers and the State of California Department of Boating and Waterways. The remaining 28 are supported by various Regional Associations. More than half of the wave instruments have the capability to estimate directional waves, though their accuracy varies.

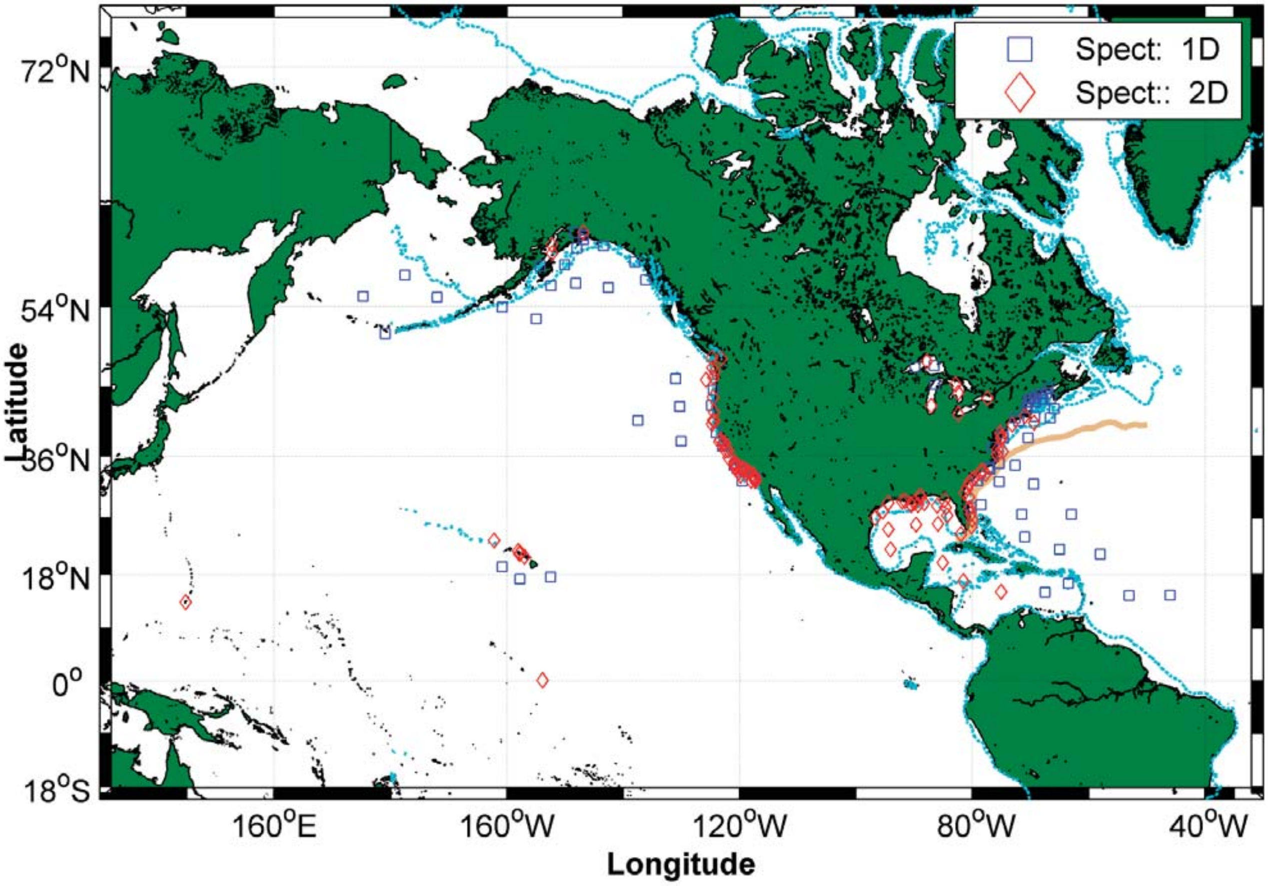

*Figure A1. Location of existing, and scheduled deployment of wave measurement devices approximate location of Gulf Stream, tan line, and 200-m depth contour, cyan line.*

It is also worthy to note there are 36 additional wave buoys maintained by Environment Canada covering the Atlantic, Pacific and Great Lakes. Some of these assets (15 identified) are crucial to the offshore subnet to establish a seamless boundary.

Figures A2-A13 sieve the wave measurement locations based on the platform and region. In most cases this is either a buoy (hull size defined) or bottom mounted sensor package. The latter case would either be a pressure sensor(s), Acoustic Doppler Current Profiler (ADCP), an Acoustic Wave and Current Profiler (AWCP).

The geographical area covered by each of the Regional Associations is approximate and are defined as closed polygons. In some cases Environment Canada buoys are plotted in a given RA domain (NERACOOS, NANOOS, AOOS, GLOS). The PacIOOS figure is divided into two parts: the Hawaiian Islands, and the South Pacific Islands.

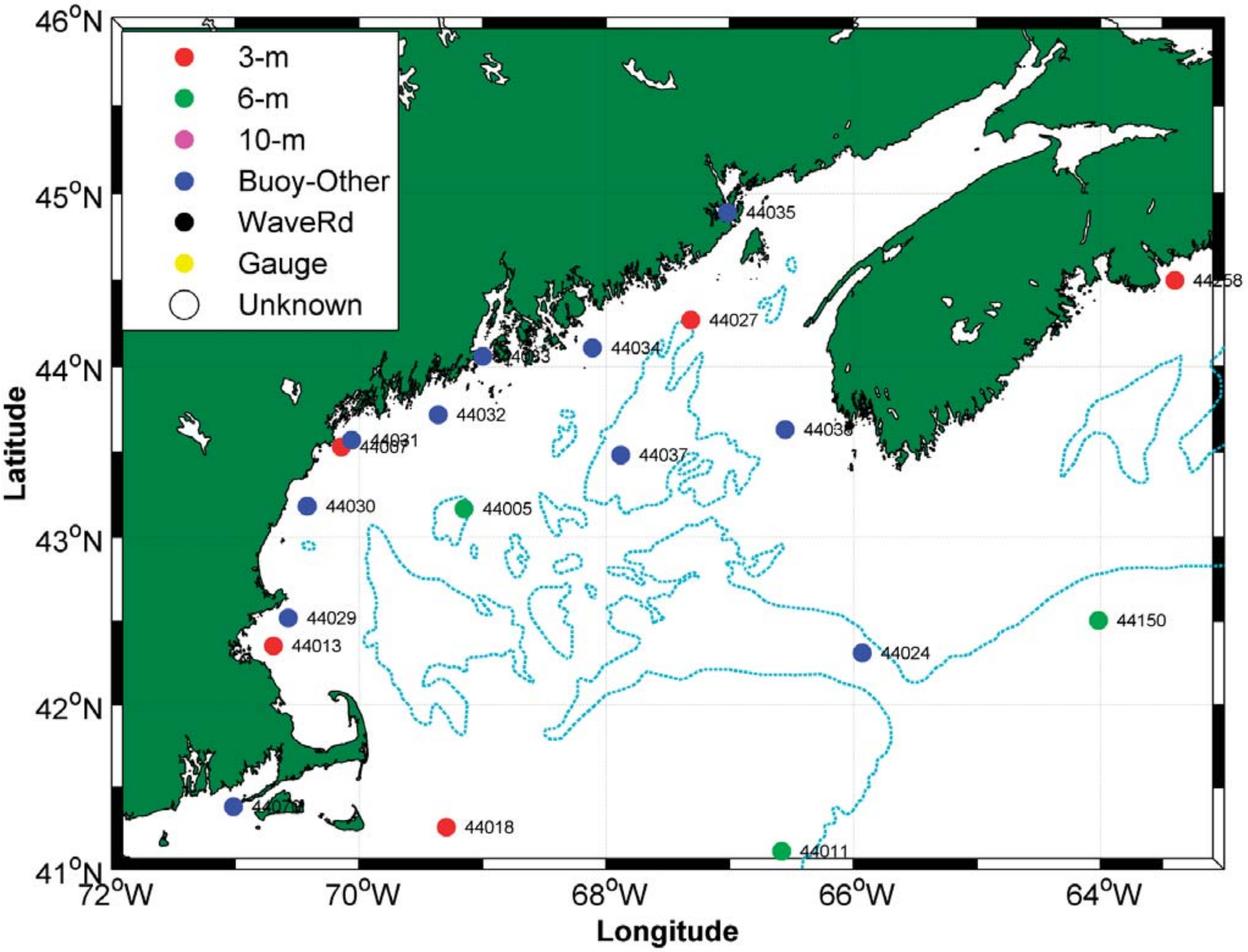

*Figure A2. Existing wave sensors for the Northeastern Regional Association of Coastal Observing Systems 200-m depth contour, cyan line.*

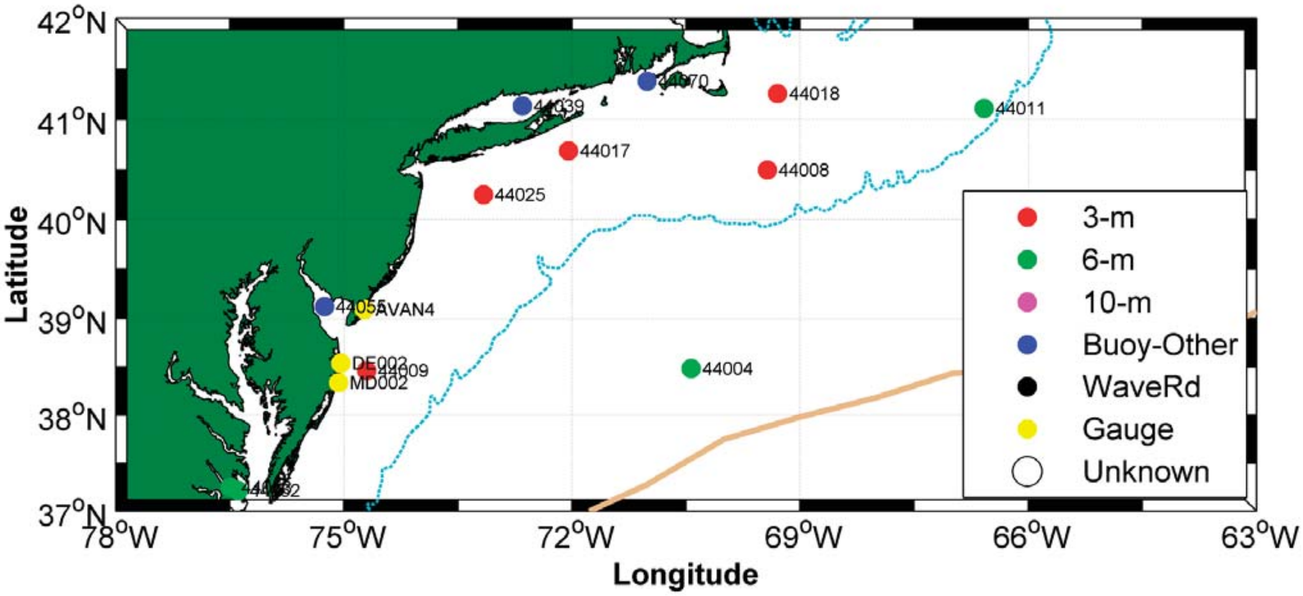

*Figure A3. Existing wave sensors for the Mid Atlantic Coastal Ocean Observing Regional Association approximate location of Gulf Stream, tan line, and 200-m depth contour, cyan line.*

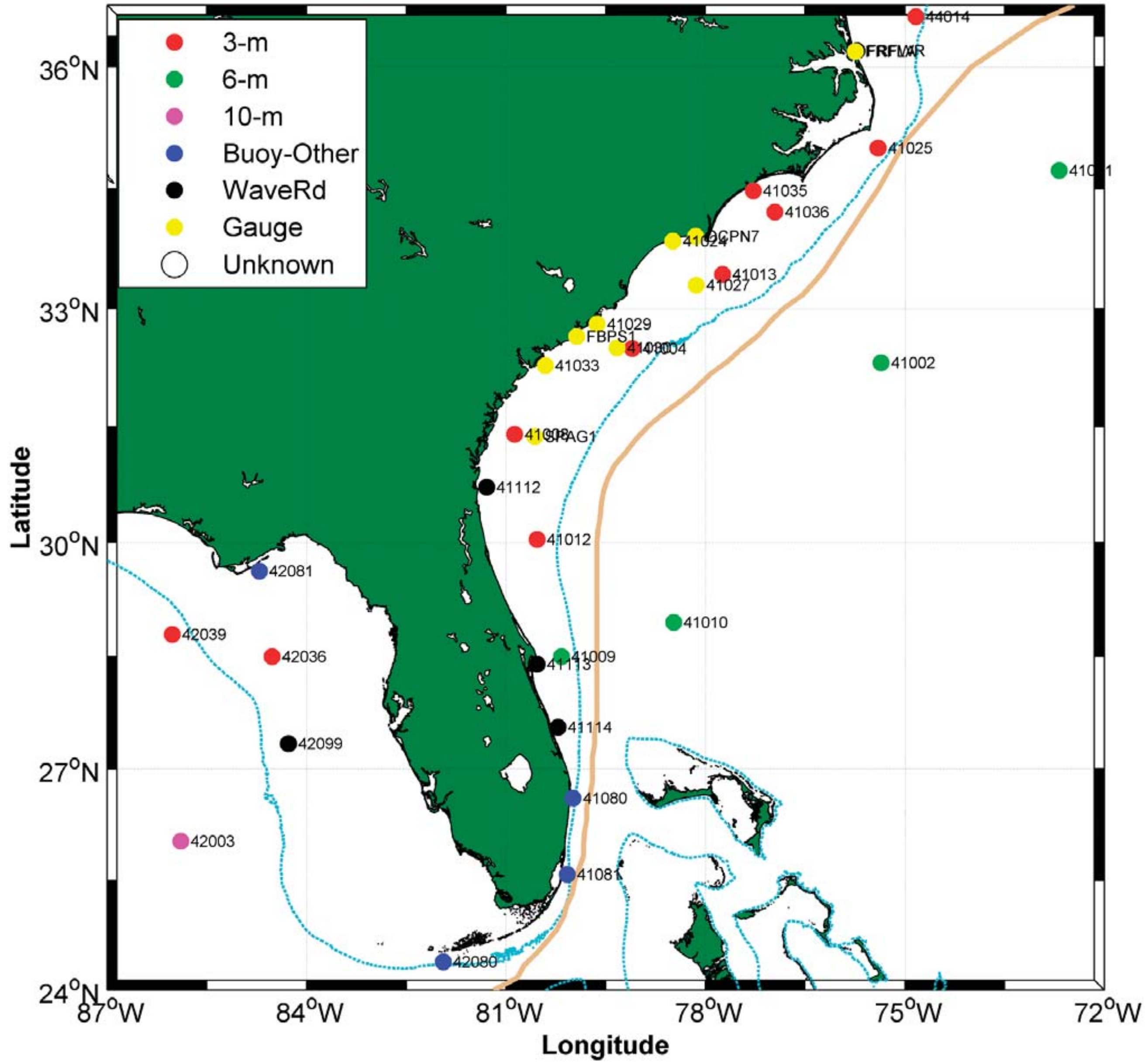

*Figure A4. Existing wave sensors for the Southeast Coastal Ocean Observing Regional Association approximate location of Gulf Stream, tan line, and 200-m depth contour, cyan line.*

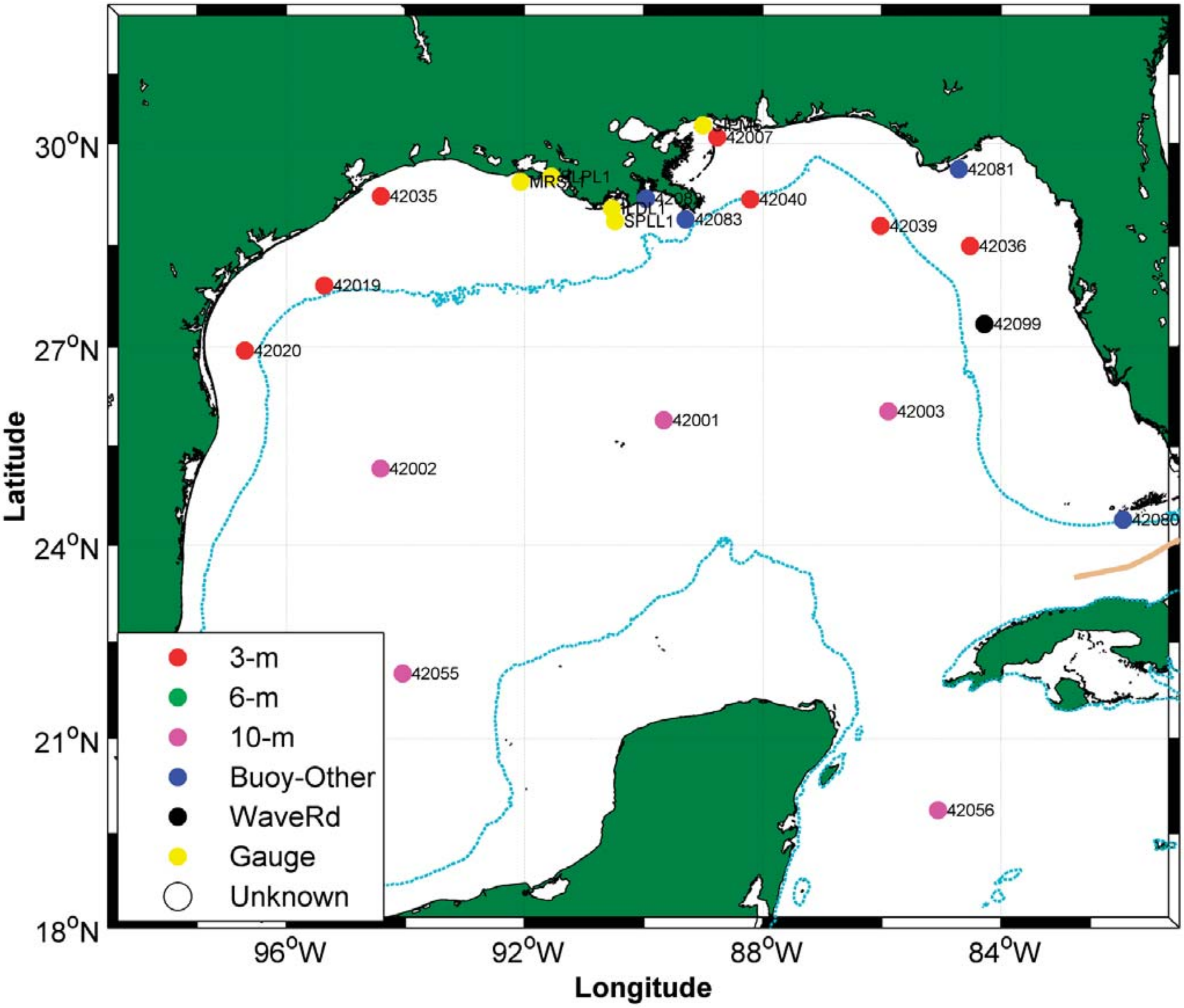

*Figure A5. Existing wave sensors for the Gulf of Mexico Coastal Ocean Observing System Regional Association 200-m depth contour, cyan line.*

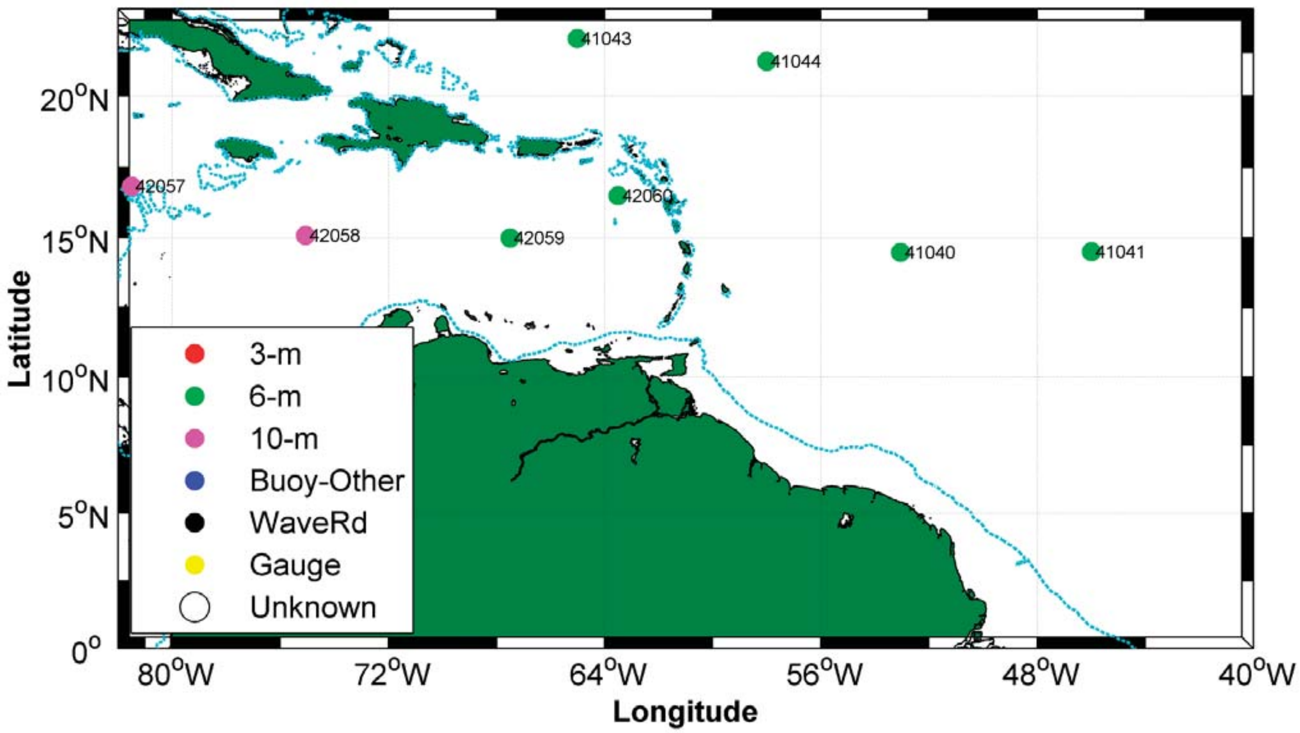

*Figure A6. Existing wave sensors for the Caribbean Regional Association 200-m depth contour, cyan line.*

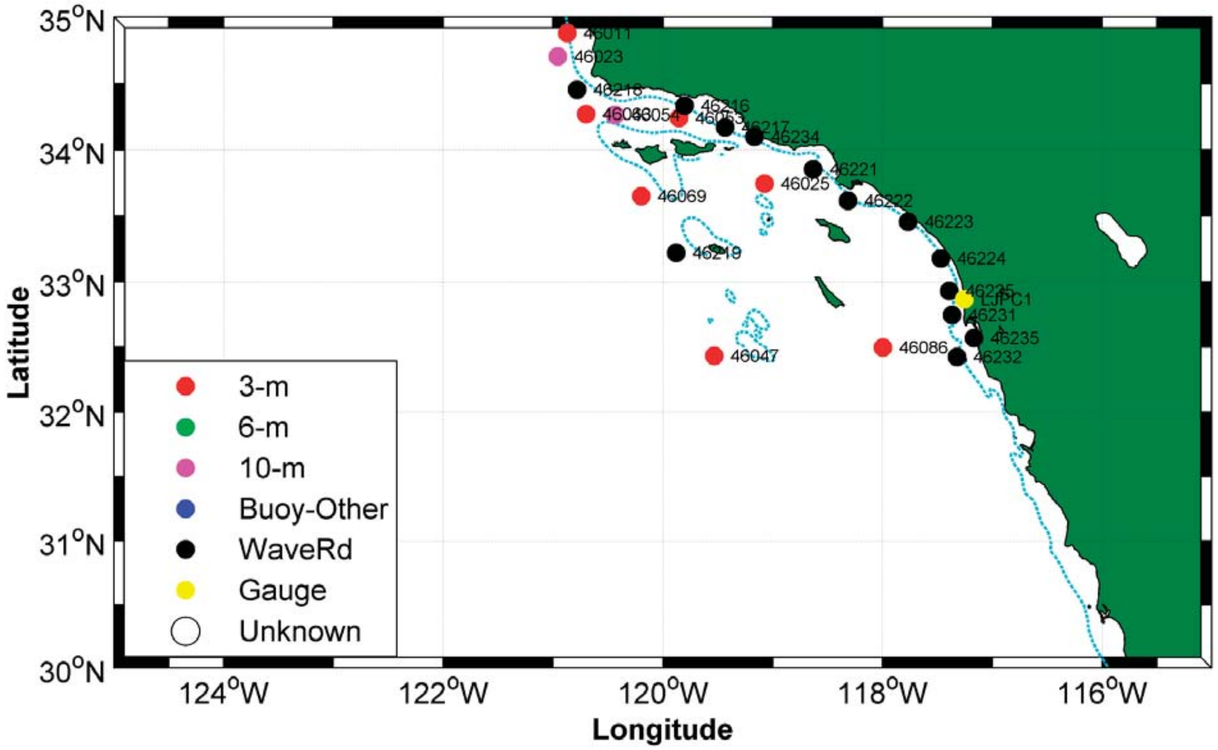

*Figure A7. Existing wave sensors for the Southern California Coastal Ocean Observing System 200-m depth contour, cyan line.*

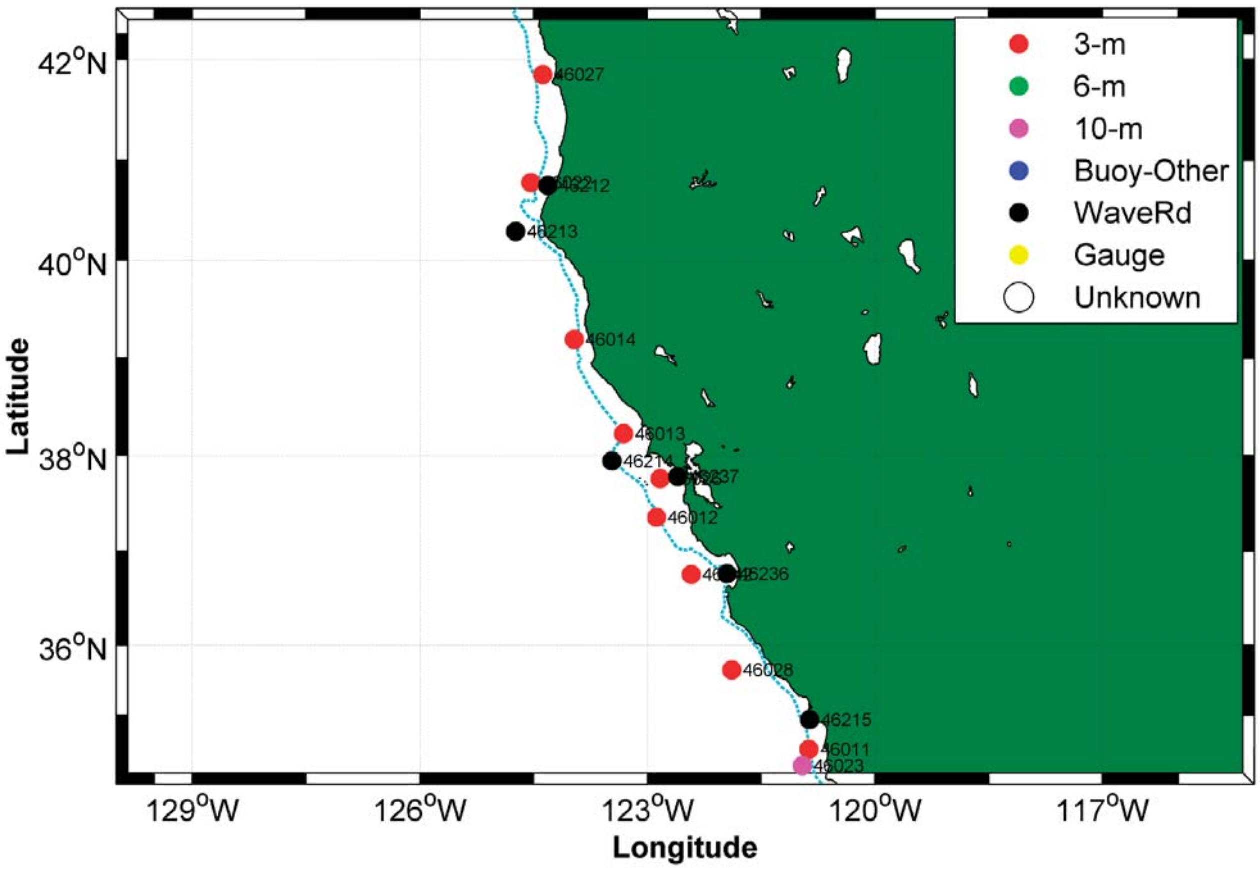

*Figure A8. Existing wave sensors for the Central and Northern California Coastal Ocean Observing System 200-m depth contour, cyan line.*

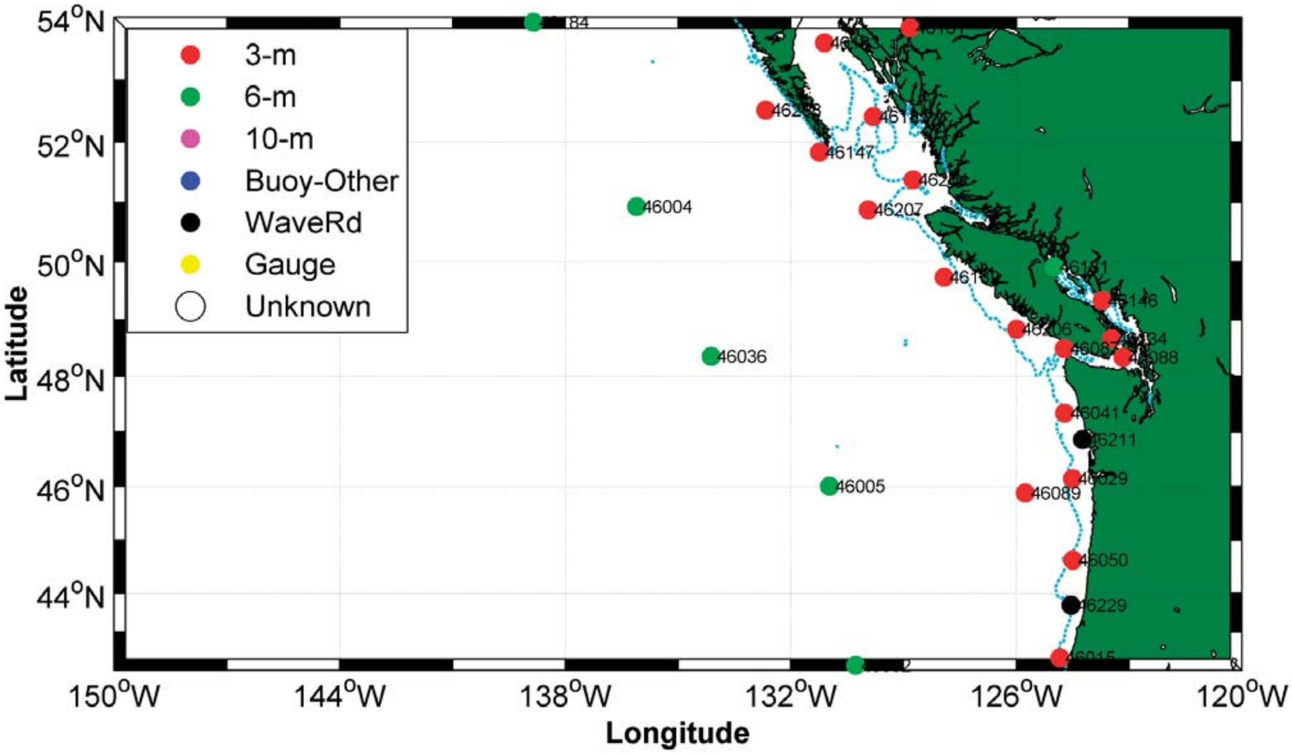

*Figure A9. Existing wave sensors for the Northwest Association of Networked Ocean Observing Systems, Environment Canada platforms are included, 200-m depth contour, cyan line.*

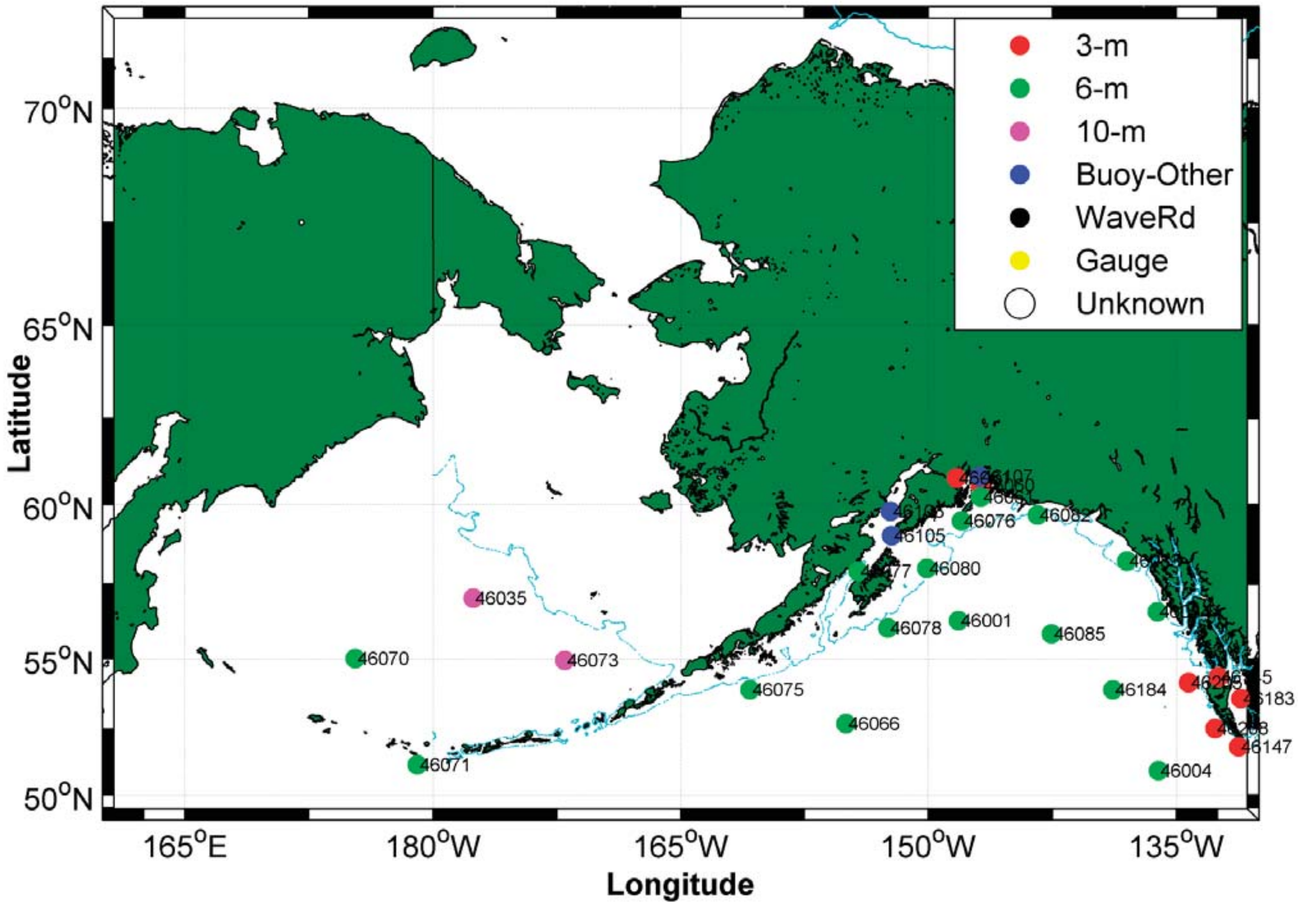

*Figure A10. Existing wave sensors for the Alaska Ocean Observing System, Environment Canada platforms are included 200-m depth contour, cyan line.*

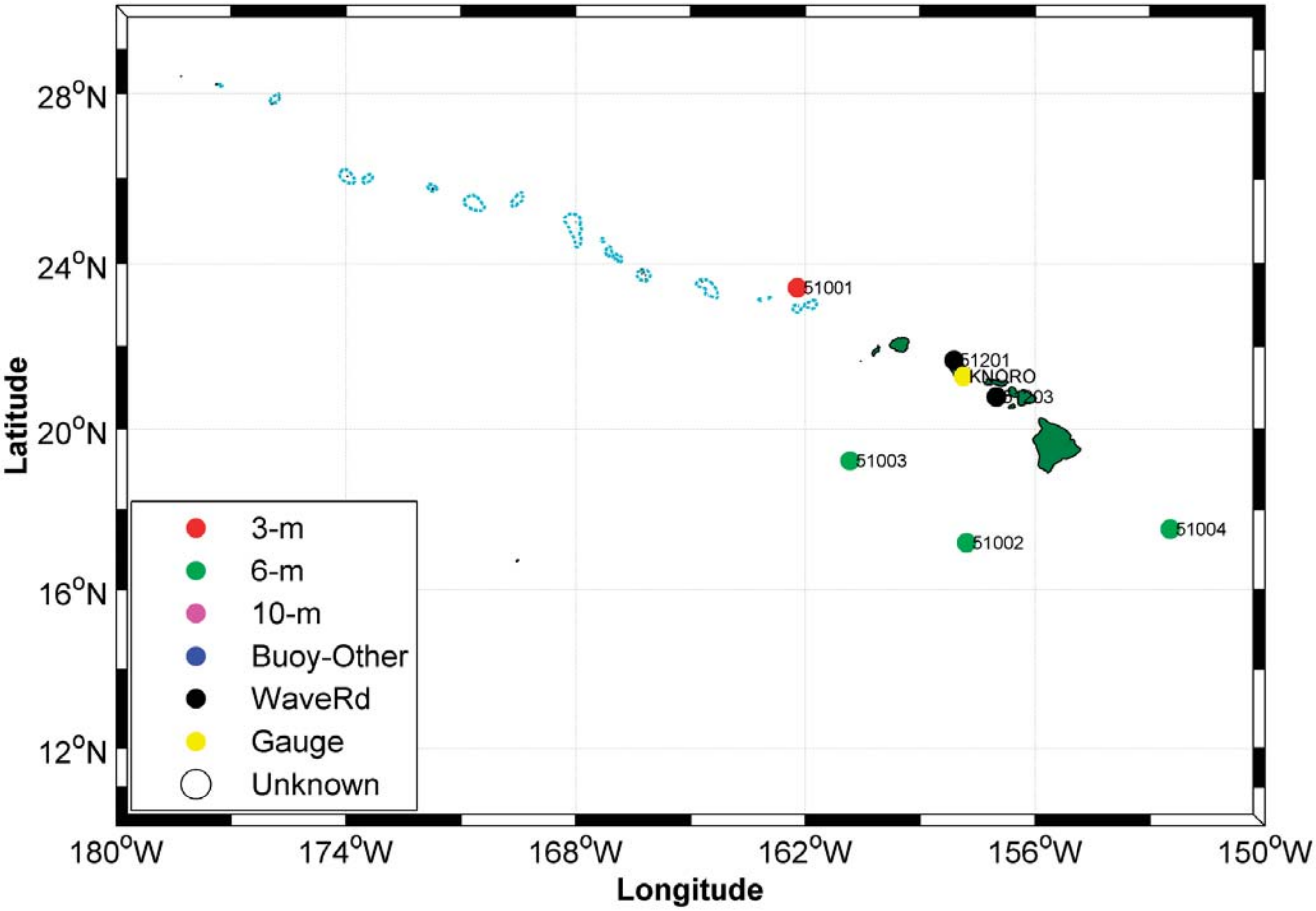

*Figure A11. Existing wave sensors for the Pacific Islands Integrated Ocean Observing System, Hawaiian Islands (200-m depth contour, cyan line).*

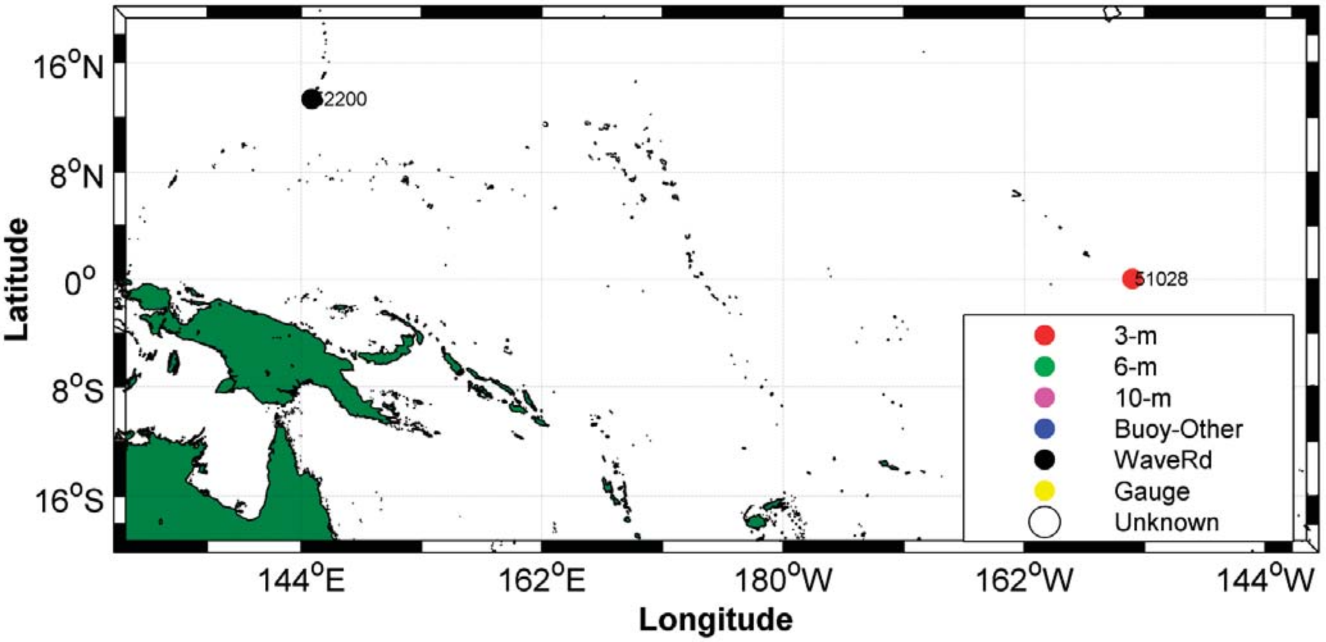

*Figure A12. Existing wave sensors for the Pacific Islands Integrated Ocean Observing System, South Pacific Islands.*

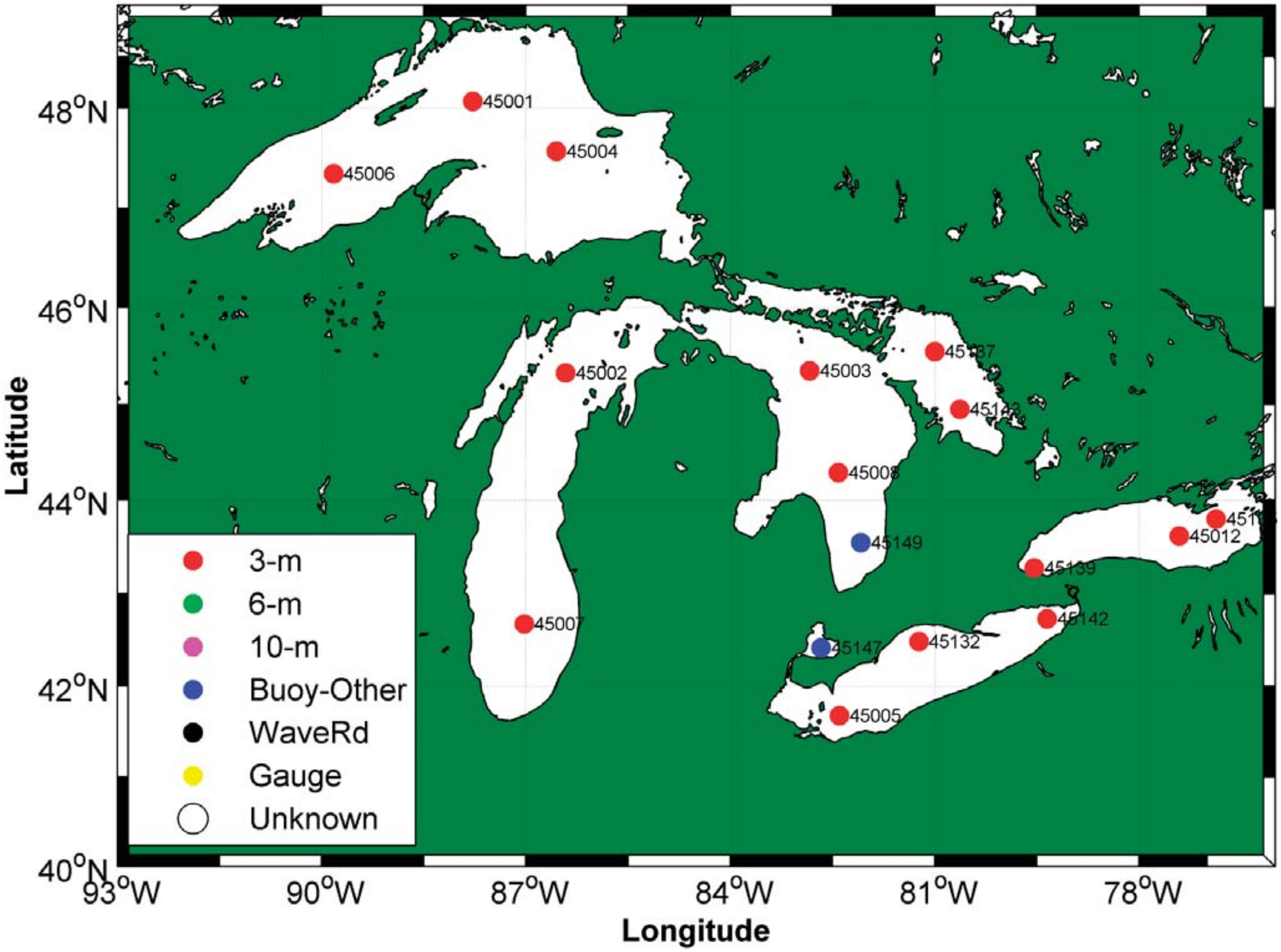

*Figure A13. Existing wave sensors for the Great Lakes Observing System, Environment Canada platforms are included, 45100 series.*

# Appendix B: Regional Association Requests

In 2005, NDBC received IOOS® funds to add oceanographic sensors to the weather buoy fleet. NDBC reached out to the IOOS Regional Associations (RA) to understand their oceanographic requirements as they related to the NDBC platforms (both buoy and Coastal Marine Automated Network or CMAN stations). Each RA responded with recommendations for ocean currents, temperature, salinity and wave observations for the NDBC platforms. Almost unanimously, the RAs asked for directional waves for the buoys and CMAN stations.

To better understand the RA requirements for waves relative to this plan, the NDBC Regional Association Coordinators for Coastal Ocean Observation Networks (RACCOONS) again solicited the RAs in May 2007 for specific wave requirements including directional upgrades to existing NDBC assets, new wave observation sites.

Since the time frame to obtain the RA requirements was short, less than three months, the information included in the report varies by RA and by system requested. Most RAs provided detailed responses to wave observations using existing NDBC buoy or CMAN platforms. New measurement sites were identified with fixed longitude/latitude locations. In some cases, only general locations were mentioned. For these specific sites, there was no mention of what specific device needed. The locations were not reviewed or eliminated based on physical restrictions (e.g., the Gulf Stream, very shallow water, harbor entrances). Other groups were also contacted. The USACE field offices: New York, Detroit, Mobile and Alaska Districts provided input. In general, their selected locations are very near the coast. NOAA's National Ocean Service, Physical Oceanographic Real-Time System (PORTS) also requested wave measurements near PORTS sites.

The panel anticipates that the number of requested wave measurement sites will increase. The information received to date is summarized in Table B1 and Figure B1. Graphics for individual Regional Association requests are shown in Figures B2-B13. The RA original responses are included in Appendix C.

**Table B1. Regional Association Wave Measurement Site Request**

| Regional Association | Directional Upgrades | | New Wave Sites |
|---|---|---|---|
| | CMAN | Buoy | |
| GOMOOS | | 3 | 7 |
| MACOORA | | 2 | 19* |
| SECOORA | 1 | 2 | 26* |
| GCOOS | | | 9* |
| SCCOOS | | 1 | 1 |
| CenCOOS | | 2 | 6 |
| NANOOS | 1 | 0 | 11 |
| ACOOS | 2 | 5 | 10 |
| PacIOOS | | 2 | 16** |
| GLOS | 1 | 2 | 22* |
| CaRA | | 1 | 5*** |
| NOAA-PORTS | | | 13 |
| **TOTAL** | **5** | **20** | **145** |

*Includes USACE Input from New York, Detroit, and Mobile Districts
**Counted but not plotted (only general information)
***Two identified, remainder not plotted

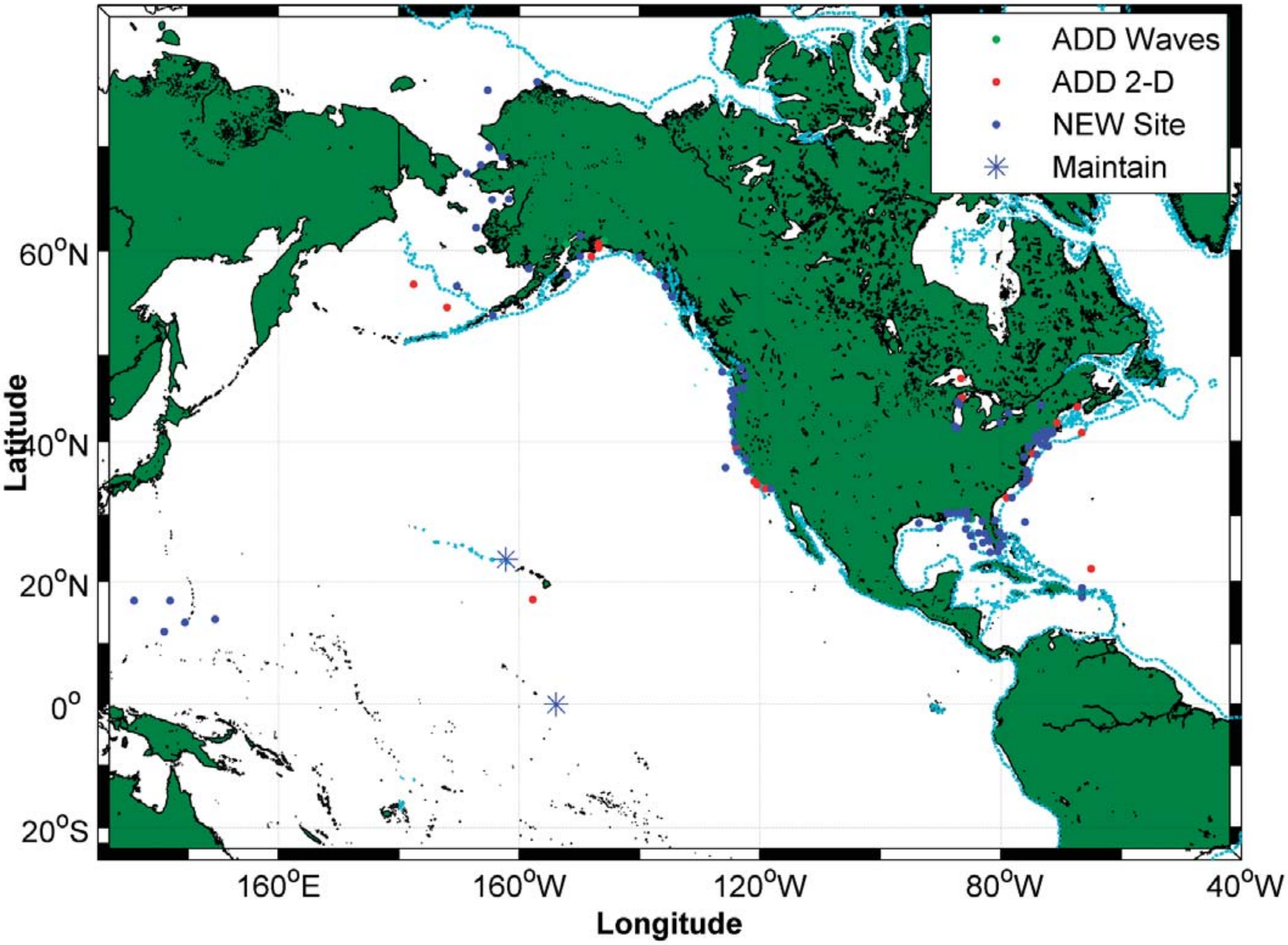

*Figure B1. Location of Regional Association requests (70000 series station numbers) for wave measurement devices, approximate location of Gulf Stream, tan line and 200-m depth contour plotted in cyan.*

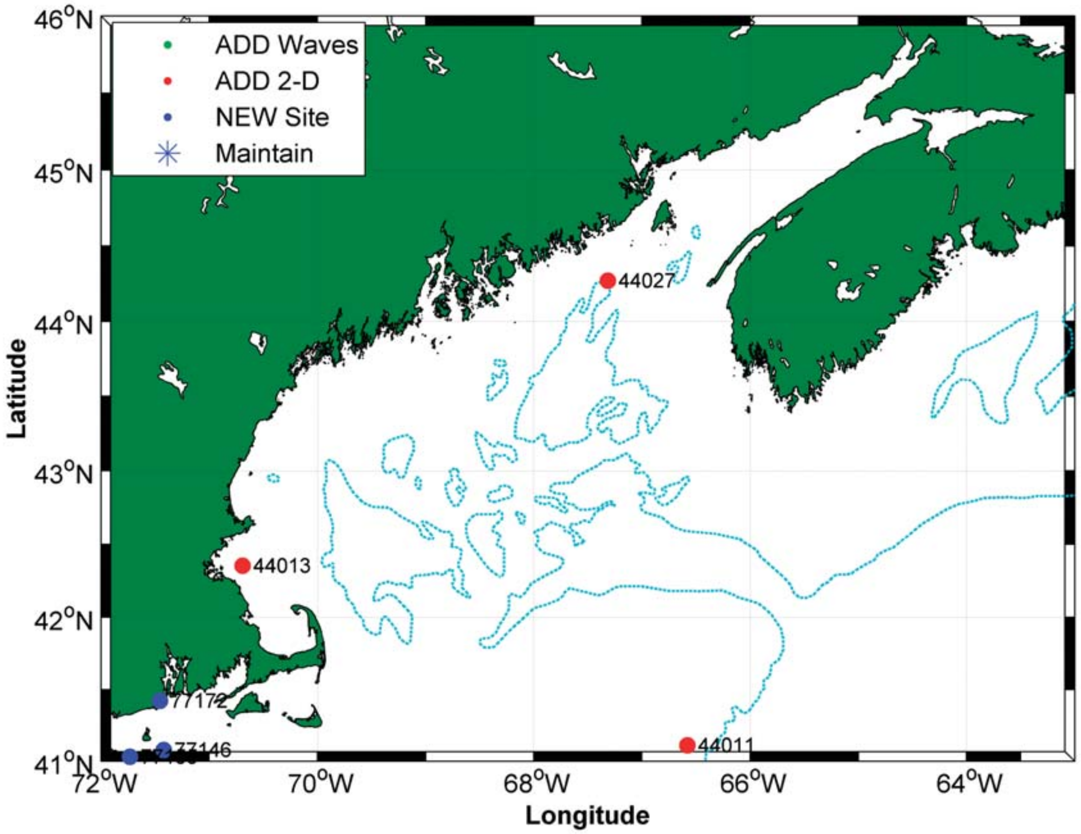

*Figure B2. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Northeastern Regional Association of Coastal Ocean Observing Systems, and 200-m bottom contour plotted in cyan.*

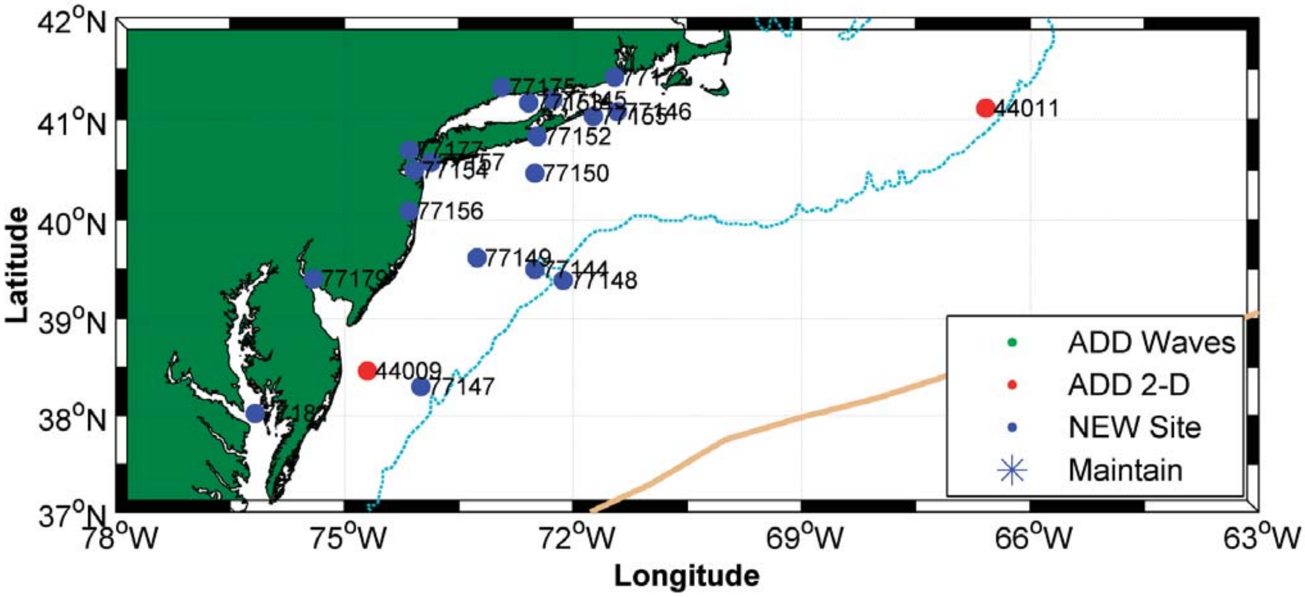

*Figure B3. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Mid-Atlantic Coastal Ocean Observing System Regional Association, approximate location of the Gulf Stream, tan line, and 200-m bottom contour plotted in cyan.*

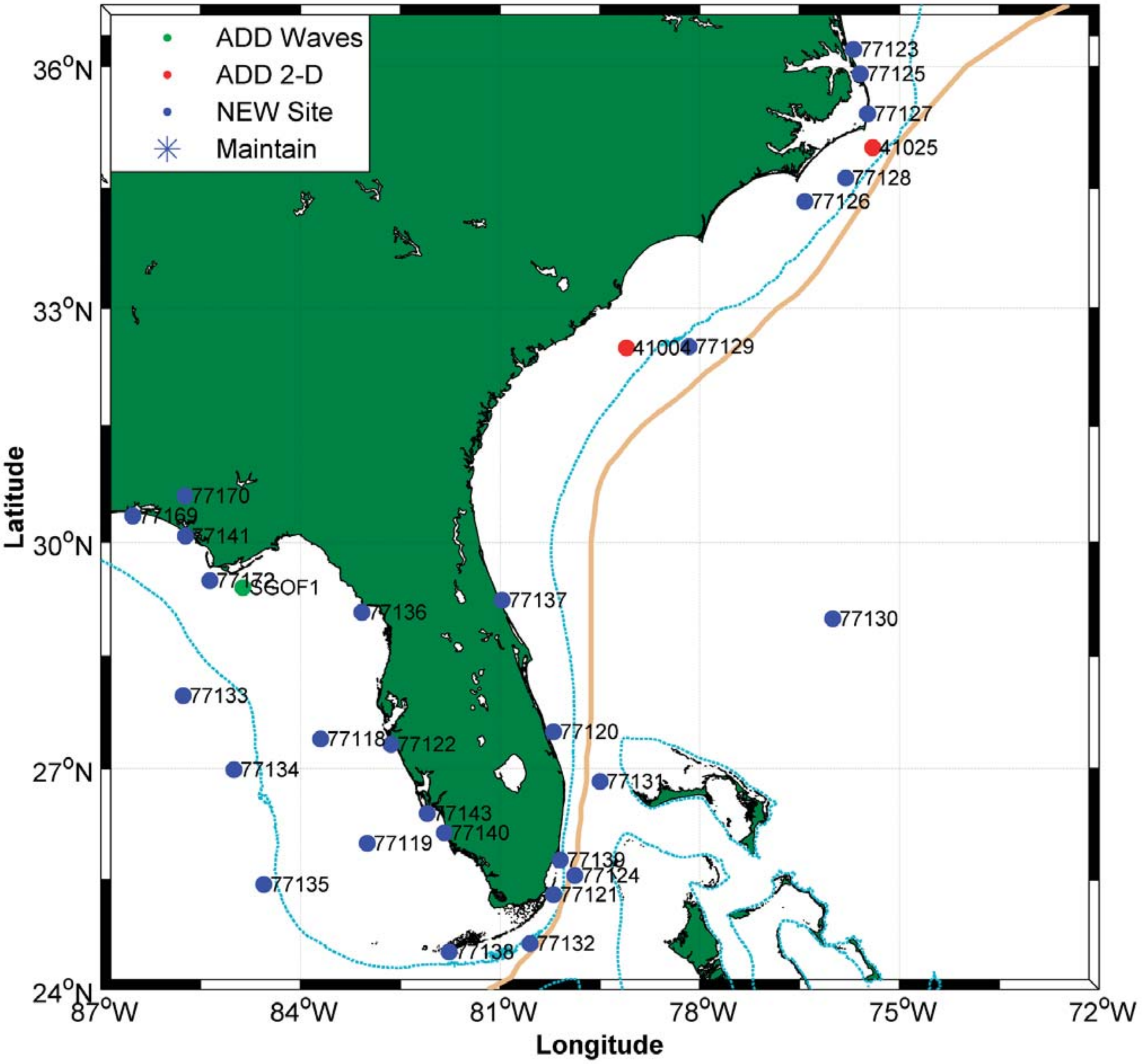

*Figure B4. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Southeast Coastal Ocean Observing Regional Association, approximate location of the Gulf Stream, tan line, and 200-m bottom contour plotted in cyan.*

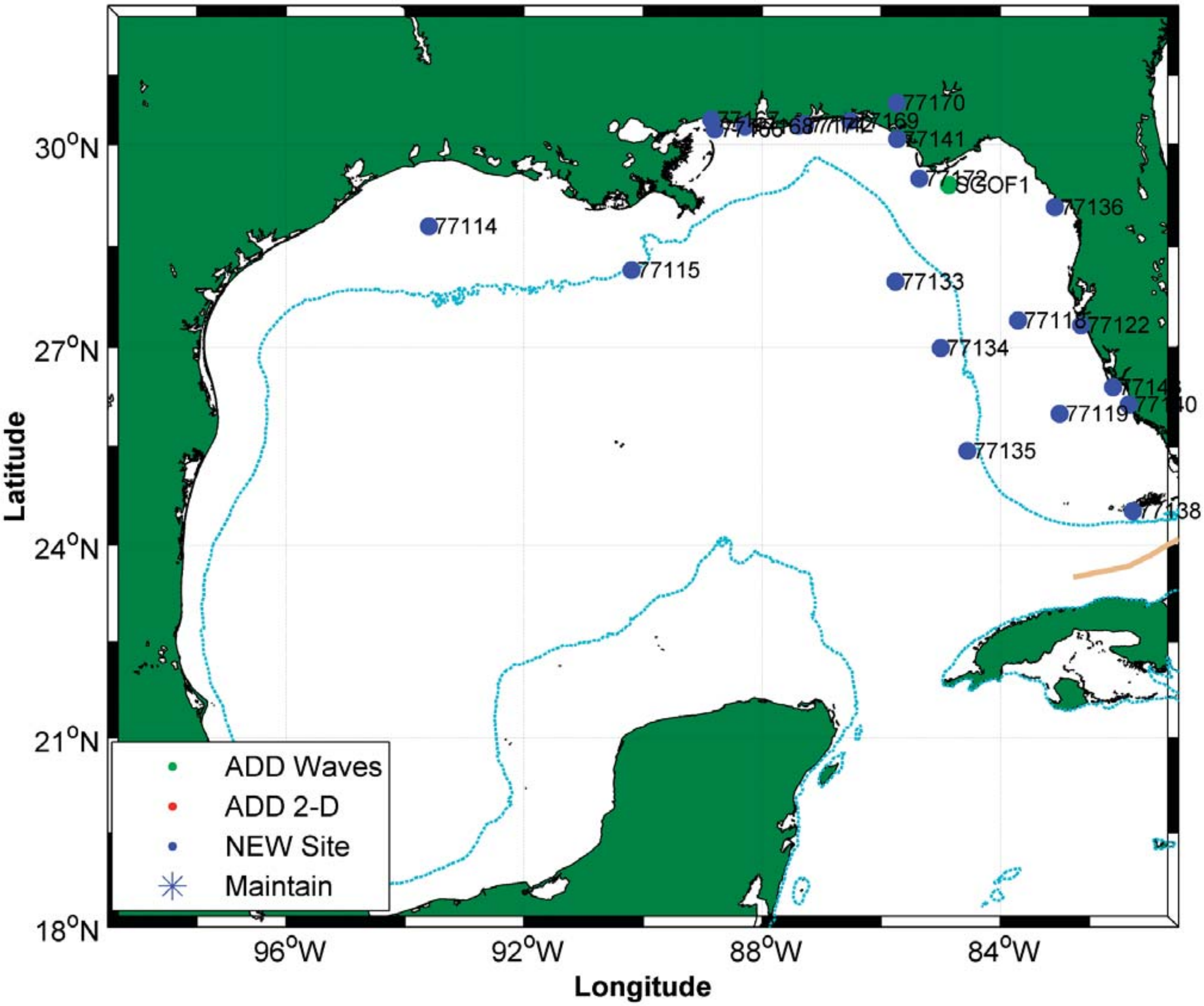

*Figure B5. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Gulf of Mexico Coastal Ocean Observing System-Regional Association, approximate location of the Gulf Stream, tan line, and 200-m bottom contour plotted in cyan.*

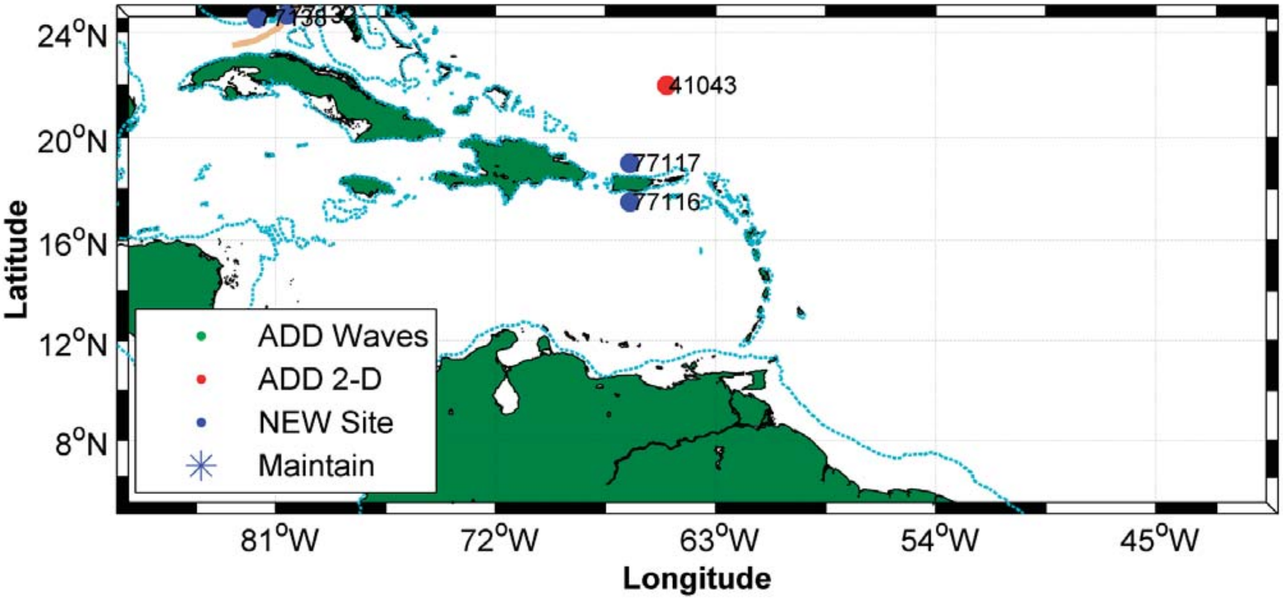

*Figure B6. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Caribbean Regional Association, approximate location of the Gulf Stream, tan line, and 200-m bottom contour plotted in cyan.*

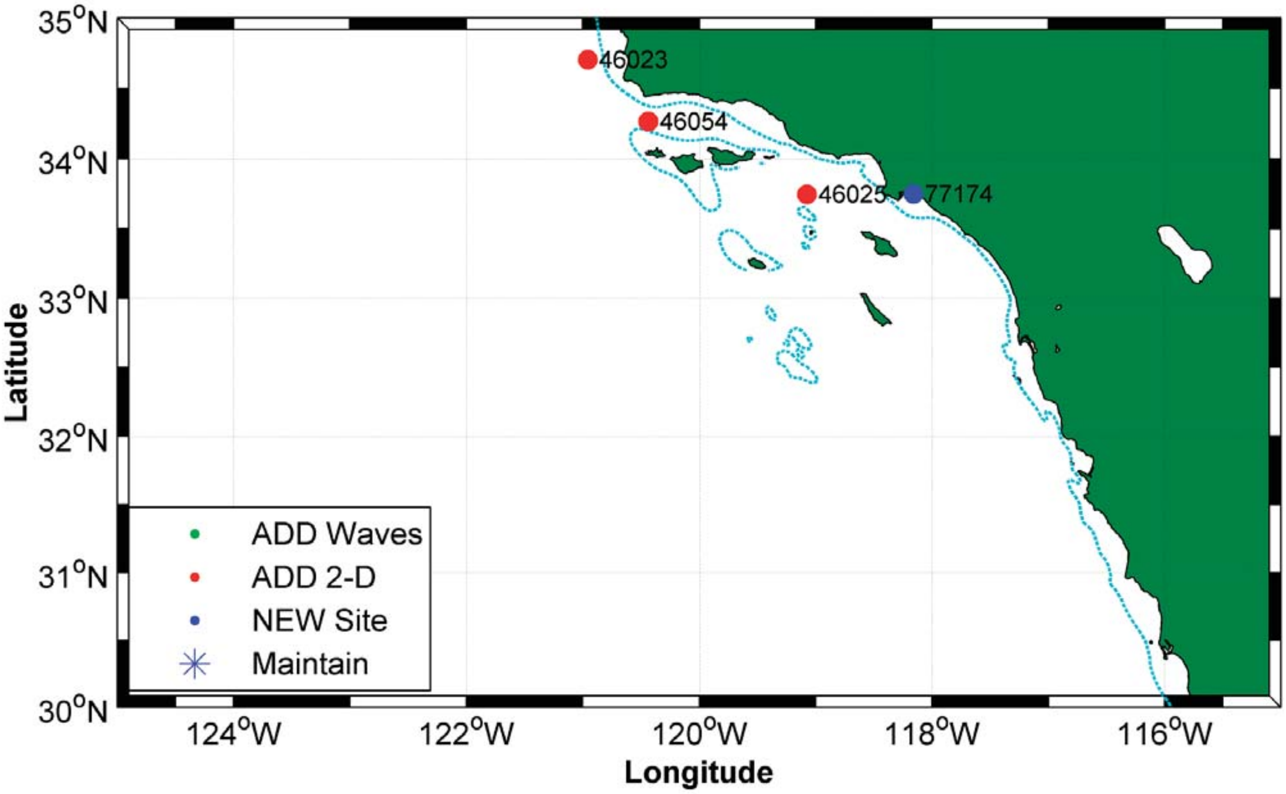

*Figure B7. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Southern California Coastal Ocean Observing System, 200-m bottom contour plotted in cyan.*

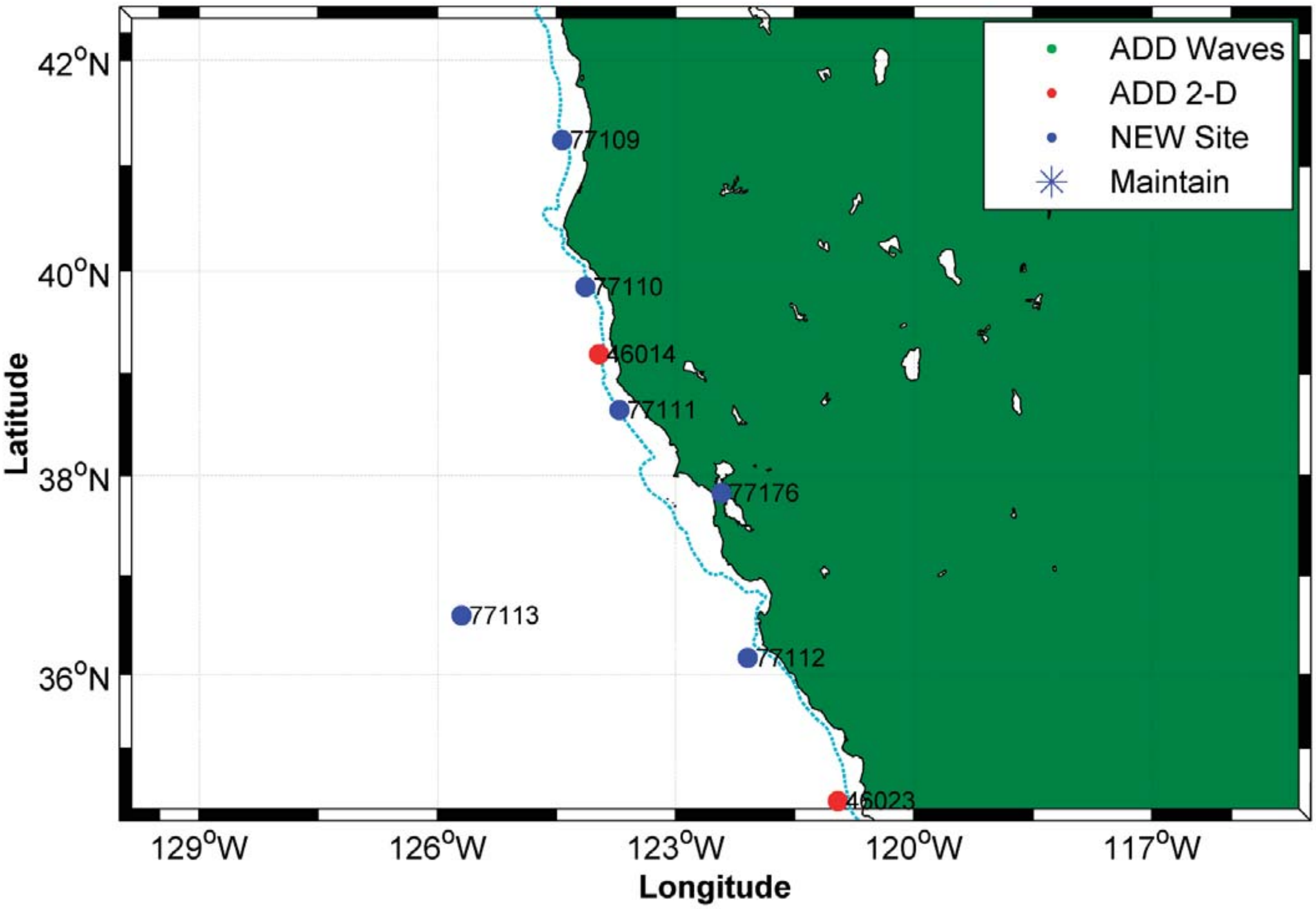

*Figure B8. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Central and Northern California Ocean Observing System, 200-m bottom contour plotted in cyan.*

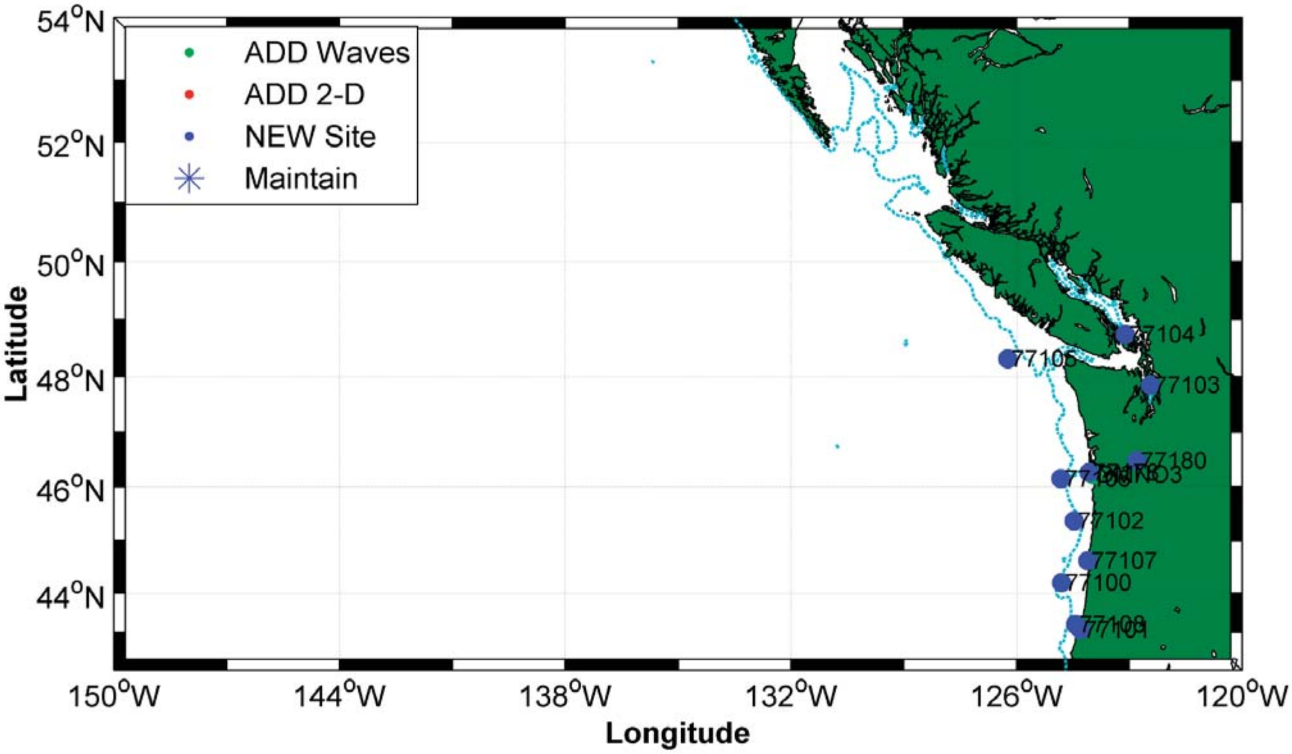

*Figure B9. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Northwest Association of Networked Ocean Observing Systems, 200-m bottom contour plotted in cyan.*

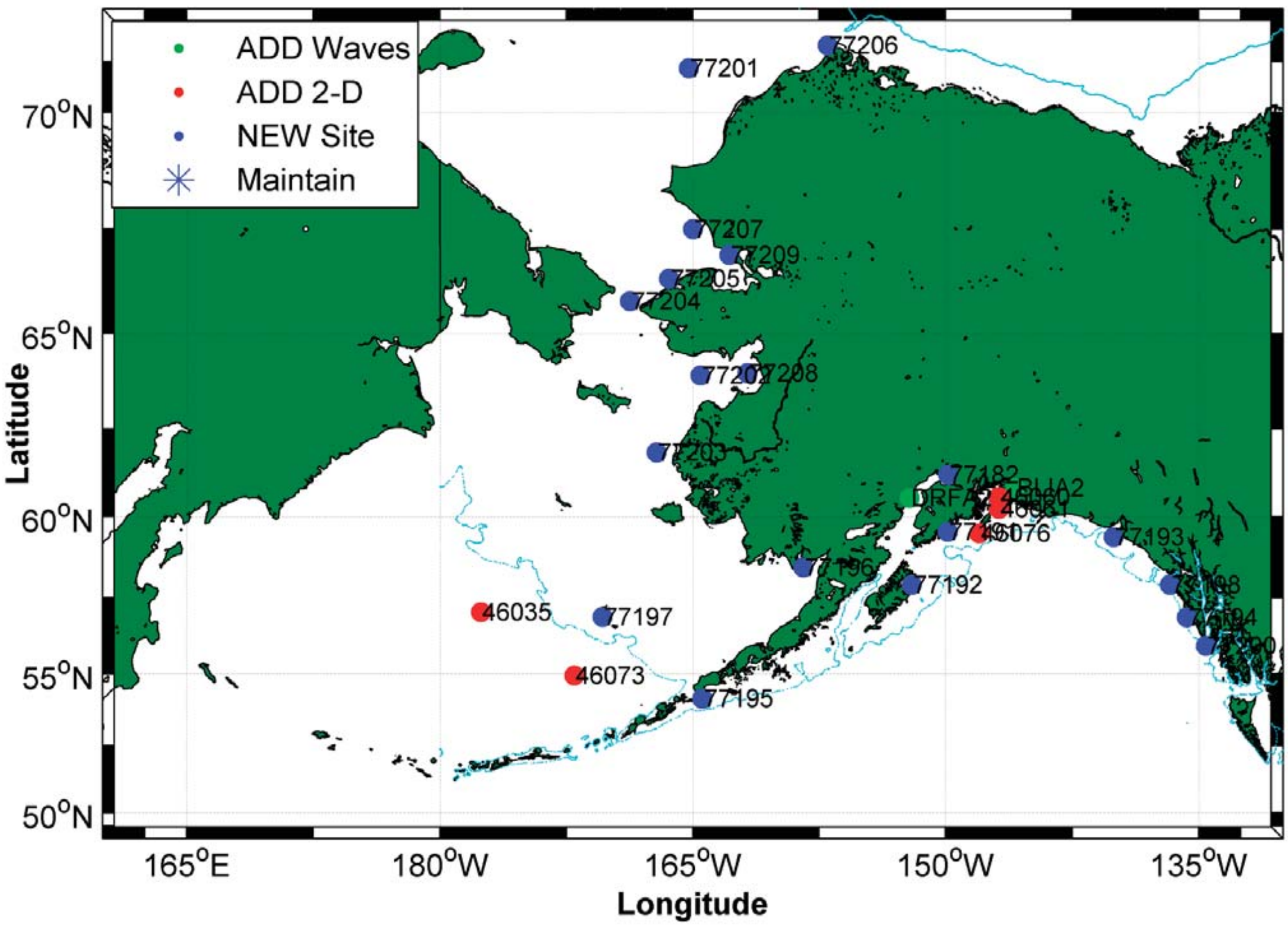

*Figure B10. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Alaska Ocean Observing System, 200-m bottom contour plotted in cyan.*

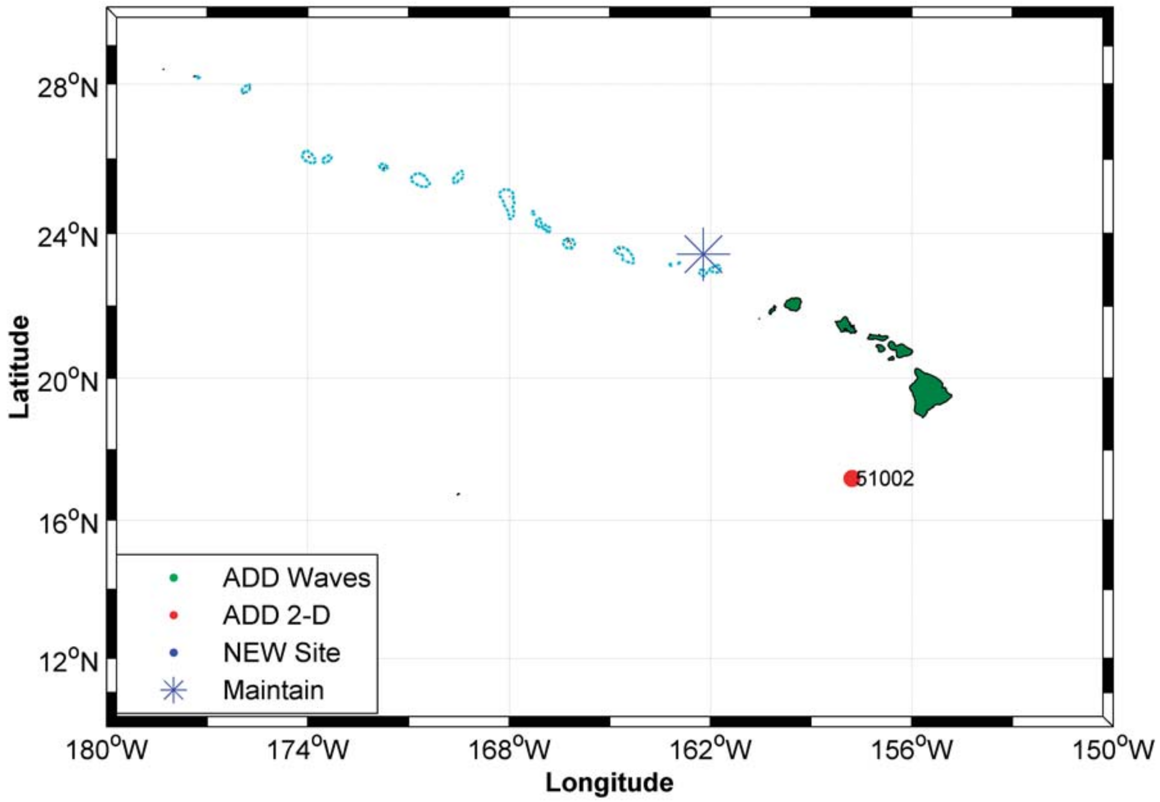

*Figure B11. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Pacific Islands Integrated Ocean Observing System, Hawaiian Islands, 200-m bottom contour plotted in cyan.*

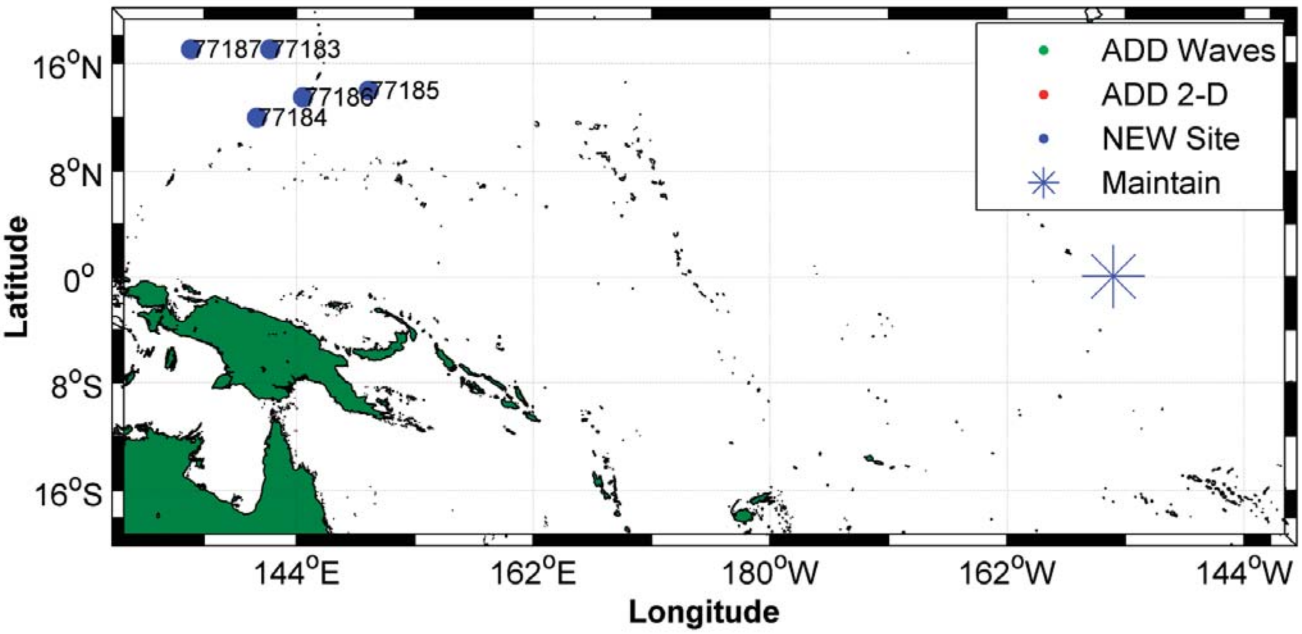

*Figure B12. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Pacific Islands Integrated Ocean Observing System, for the South Pacific Islands.*

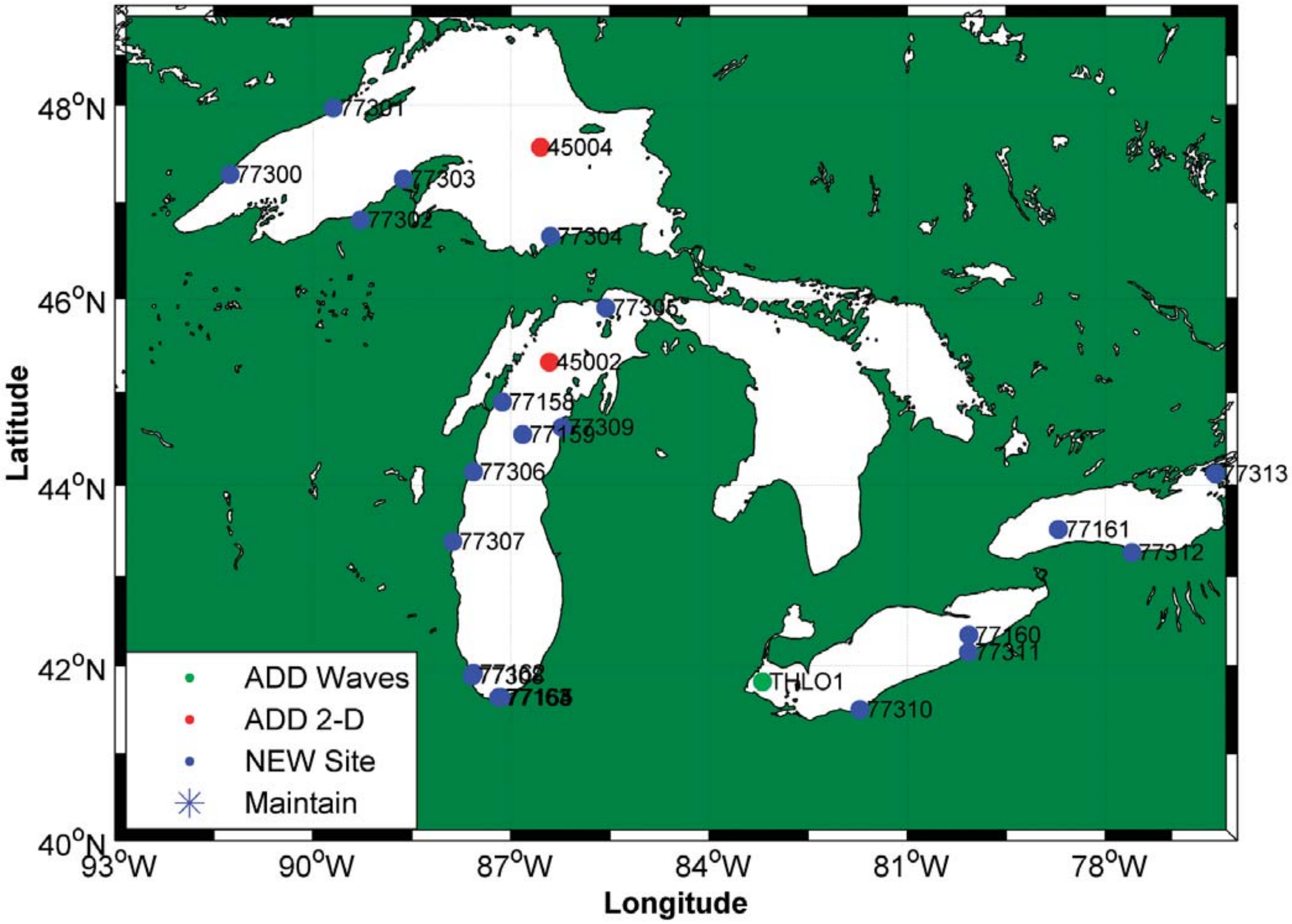

*Figure B13. Upgrades to existing and new (70000 series station numbers) wave measurement sites for the Great Lakes Observing System.*

The Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) have only requested three existing NDBC buoys to be upgraded to directional capabilities, and seven new sites along the south shore of Massachusetts. This area has been heavily gauged through the existing Gulf of Maine Ocean Observing System, (GoMOOS) and the need for wave measurements are balanced by the existing array.

Alternately, the Mid-Atlantic (MACOORA) is much smaller in size compared to NERACOOS, there are few existing sites, so the request for new assets is substantially larger. However, again the majority of the sites are designated as coastal, and exemplifies a critical need for more wave information in Long Island Sound.

The Southeast Coastal Ocean Observing Regional Association (SECOORA), made a very concerted effort in the evaluation of their existing wave sites and the processes of this region. Tropical systems tend to track in this region. The interaction of the Gulf Stream is also a major influence affecting the wave environment. Also, the continental shelf increases in width making the spatial variation in the wave environment highly variable, requiring more sites to capture these processes.

The Gulf of Mexico Coastal Ocean Observing System Regional Association (GCOOS-RA) has focused on building the observing system by integrating observations from many sources. These include contributions from state resource agencies and the activities of the Gulf of Mexico Alliance. The role of NDBC and their operational buoy network in the Gulf of Mexico is also a critical element. These assets have directional wave capabilities. In addition there has been an influx of meteorological and current measurements derived from the oil industry. The Texas coast alone contains three NWS forecast offices, in Corpus Christi, Galveston and Brownsville; the USACE district offices have multiple projects along the Texas coastline. It is a shoreline reach susceptible to tropical systems, justifying additional wave measurements.

The Caribbean Regional Association (CaRA) focused more on the Coastal Subnet. The two sites north and south of Puerto Rico replace existing NOAA's National Center for Environmental Prediction virtual buoys, a wave model output. Four other locations are defined at harbor entrances, (San Juan, Ponce, Charlotte, Amalie) and in the shallow-water reefs along the south shore of Puerto Rico.

The Southern California Coastal Ocean Observing System (SCCOOS) and CeNCOOS (Central and Northern California Ocean Observing System) already have considerable coverage through existing Coastal Data Information Program (CDIP) and NDBC stations. They requested only one upgrade and one new site. The CeNCOOS has requested four new locations to complete the existing array, while the NOAA/NOS PORTS program requires waves for both Los Angles/Long Beach Harbor and San Francisco (two sites that have existing CDIP buoys that could be used). No Coastal Subnet sites were added because of the modeling efforts embedded in CDIP that provide near full coverage of this domain. The one Offshore Subnet location completes the existing NDBC array along the US Pacific Mainland coast.

The Northwest Association of Networked Ocean Observing Systems' (NANOOS) priority is to expand the Outer-Shelf Subnet. In Alaska, AOOS, requires directional wave data in the Coastal Subnet, specifically in the Seward, Valdez and Cook Inlet/Anchorage areas to aid in commercial ship traffic and recreational fishing. The two NDBC sites in the Bering Sea remain a critical area for directional wave upgrades not only to commercial fishing industries, but also for requirements of the USACE Alaska district.

The Pacific Islands, PacIOOS, has its own unique set of challenges, small islands with fringing reefs isolated by large expanses of open-ocean. Twenty new sites were requested for these areas including American Samoa, the Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia, Guam, the Republic of the Marshall Islands, the Republic of Palau. Two existing NDBC sites (51001 and 51028), were identified as critical, to be maintained at all costs. One site, northwest of the Hawaiian Island chain, was requested for directional upgrades.

The Great Lakes Observing System (GLOS) Regional Association requested two directional upgrades to existing NDBC platforms, three Inner-Shelf Subnet additions, and ten new Coastal sites, where there are three along the Chicago shoreline (USACE-Chicago District). One additional assessment of the GLOS is to integrate and upgrade to directional, the Environment Canada assets.

# Appendix C: Requirements Matrix

This appendix includes the input from the Regional Associations in response to the May 2007 request from NDBC Regional Association Coordinators for Coastal Ocean Observation Networks for specific wave requirements including directional upgrades to existing NDBC assets, new wave observation sites. This appendix provides supporting information to Appendix B.

## Table of Wave Requirements by Regional Association

<table>
<tr><th>Regional Association</th><th>Category 1: Moored Buoys</th><th>Category 2: Wave Profilers</th></tr>
<tr><td><b>Northeastern Regional Association of Coastal Ocean Observing System (NERACOOS)</b></td><td><b>Installed NDBC Buoys – Needs Directional Waves</b>
<table>
<tr><th>WMO #</th><th>Location</th></tr>
<tr><td>44027</td><td>Jonesport, Maine</td></tr>
<tr><td>44011</td><td>Georges Bank</td></tr>
<tr><td>44013</td><td>Boston</td></tr>
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<tr><td><b>Mid-Atlantic Coastal Ocean Observing System (MACOORA)</b></td><td><b>Installed NDBC Buoys – Needs Directional Waves</b>
<table>
<tr><th>WMO #</th><th>Location</th></tr>
<tr><td>44009</td><td>Delaware Bay</td></tr>
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<b>New Buoy Locations</b>
<table>
<tr><th>Latitude</th><th>Longitude</th><th>Location</th></tr>
<tr><td>39.50</td><td>-72.50</td><td>Shelf Break</td></tr>
<tr><td>41.20</td><td>-72.27</td><td>Eastern Long Island Sound</td></tr>
<tr><td>41.08</td><td>-71.42</td><td>SSE of Block Island</td></tr>
<tr><td>38.3</td><td>-74.00</td><td>Btwn Balt. And El. Trunk Canyons</td></tr>
<tr><td>39.39</td><td>-72.13</td><td>Hudson Canyon @Shelf Break</td></tr>
<tr><td>39.62</td><td>-73.26</td><td>Off Barnegat Inlet NJ</td></tr>
<tr><td>40.47</td><td>-72.50</td><td>Off Middle Long Island</td></tr>
<tr><td>38 .77</td><td>-74.97</td><td>Delaware Bay Entrance</td></tr>
<tr><td></td><td></td><td>Ches Bay Entrance</td></tr>
<tr><td></td><td></td><td>Lynnhaven Anchorage</td></tr>
<tr><td></td><td></td><td>York River between the Elbow the river entrance</td></tr>
<tr><td></td><td></td><td>Between 12 and 24 fathom Curve near Duck, NC</td></tr>
<tr><td></td><td></td><td>Between 12 and 24 fathom Curve at Cape Henlopen</td></tr>
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<tr><td></td><td></td><td>Staten Island, NY<br>Raritan Bay</td></tr>
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<tr><td><b>Southeast Atlantic Coastal Ocean Observing System Regional Association (SECOORA)</b></td><td><b>Installed NDBC Buoys – Needs Directional Waves</b>
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<tr><th>WMO #</th><th>Location</th></tr>
<tr><td>41025</td><td>Diamond Shoals</td></tr>
<tr><td>41004</td><td>Edisto</td></tr>
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<b>New Buoy Locations</b>
<table>
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<tr><td>27.33</td><td>-82.64</td><td>C15</td></tr>
<tr><td>36.21</td><td>-75.69</td><td>Duck 20m</td></tr>
<tr><td>25.56</td><td>-79.88</td><td>E of Miami</td></tr>
<tr><td>35.91</td><td>-75.59</td><td>Jennette's Pier</td></tr>
<tr><td>34.34</td><td>-76.42</td><td>Lookout Shoals</td></tr>
<tr><td>35.59</td><td>-75.46</td><td>Pea Island</td></tr>
<tr><td>34.62</td><td>-75.80</td><td>E of Cape Lookout</td></tr>
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</table>

<table>
<tr><th colspan="3">Table of Wave Requirements by Regional Association</th></tr>
<tr><th>Regional Association</th><th>Category 1: Moored Buoys</th><th>Category 2: Wave Profilers</th></tr>
<tr><td><b>SECOORA (continued)</b></td><td><b>New Buoy Locations (continued)</b>
<table>
<tr><td>32.51</td><td>-78.16</td><td>E of Charleston, SC</td></tr>
<tr><td>29.00</td><td>-76.00</td><td>E of New Smyrna Beach</td></tr>
<tr><td>26.83</td><td>-79.50</td><td>E of West Palm Beach</td></tr>
<tr><td>24.63</td><td>-80.55</td><td>Florida Straits</td></tr>
<tr><td>27.98</td><td>-85.76</td><td>West Florida Shelf 1</td></tr>
<tr><td>26.99</td><td>-85.00</td><td>West Florida Shelf 2</td></tr>
<tr><td>25.44</td><td>-84.55</td><td>West Florida Shelf 3</td></tr>
<tr><td>29.08</td><td>-83.08</td><td>Cedar Key</td></tr>
<tr><td>29.24</td><td>-80.97</td><td>Daytona</td></tr>
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<tr><td>25.77</td><td>-80.10</td><td>Miami</td></tr>
<tr><td>26.14</td><td>-81.84</td><td>Naples</td></tr>
<tr><td>30.08</td><td>-85.73</td><td>Panama City</td></tr>
<tr><td>30.29</td><td>-87.28</td><td>Pensacola</td></tr>
<tr><td>27.40</td><td>-83.70</td><td>No S. Florida Buoys</td></tr>
<tr><td>26.00</td><td>-83.00</td><td>No S. Florida Buoys</td></tr>
<tr><td>27.50</td><td>-80.20</td><td>No S. Florida Buoys</td></tr>
<tr><td>25.30</td><td>-80.20</td><td>No S. Florida Buoys</td></tr>
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<tr><td><b>Gulf of Mexico Coastal Ocean Observing System (GCOOS)</b></td><td><b>New Buoy Locations</b>
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<tr><th>Latitude</th><th>Longitude</th><th>Location</th></tr>
<tr><td>28.80</td><td>-93.60</td><td>Gulf Gap Region</td></tr>
<tr><td>28.15</td><td>-90.20</td><td>Gulf Gap Region</td></tr>
</table></td><td><b>Installed C-MAN Stations – Needs Directional Waves</b>
<table>
<tr><th>WMO #</th><th>Location</th></tr>
<tr><td>SGOF1</td><td>Tyndall AFB</td></tr>
</table></td></tr>
<tr><td><b>Caribbean Regional Association (CaRA)</b></td><td><b>Installed NDBC Buoys – Needs Directional Waves</b>
<table>
<tr><th>WMO #</th><th>Location</th></tr>
<tr><td>41043</td><td>Hurricane Buoy</td></tr>
</table>
<b>New Buoy Locations</b>
<table>
<tr><th>Latitude</th><th>Longitude</th><th>Location</th></tr>
<tr><td>17.50</td><td>-66.50</td><td>PR Virtual Buoy #1</td></tr>
<tr><td>19.00</td><td>-66.50</td><td>PR Virtual Buoy #2</td></tr>
<tr><td></td><td></td><td>Harbor Entrance San Juan</td></tr>
<tr><td></td><td></td><td>Harbor Entrance Ponce</td></tr>
<tr><td></td><td></td><td>Charlotte Amalie</td></tr>
</table></td><td><b>New Stations</b>
<table>
<tr><th>Latitude</th><th>Longitude</th><th>Location</th></tr>
<tr><td></td><td></td><td>Around Reef Shallows</td></tr>
</table></td></tr>
<tr><td><b>Southern California Coastal Ocean Observing System (SCCOOS)</b></td><td><b>Installed NDBC Buoys – Needs Directional Waves</b>
<table>
<tr><th>WMO #</th><th>Location</th></tr>
<tr><td>46054</td><td>Santa Barbara</td></tr>
<tr><td>46025</td><td>Santa Monica Basin</td></tr>
</table></td><td></td></tr>
</table>

## Table of Wave Requirements by Regional Association

| Regional Association | Category 1: Moored Buoys | Category 2: Wave Profilers |
|---|---|---|

**Central California Ocean Observing System (CeNCOOS)**

**Category 1: Moored Buoys**

**Installed NDBC Buoys – Needs Directional Waves**

| WMO # | Location |
|---|---|
| 46014 | Pt. Arena |
| 46023 | Pt. Arquello |

**New Buoy Locations**

| Latitude | Longitude | Location |
|---|---|---|
| 41.25 | -124.43 | |
| 39.85 | -124.14 | |
| 38.65 | -123.71 | |
| 36.17 | -122.09 | |
| 36.60 | -125.70 | |

**Northwest Association of Networked Ocean Observing Systems (NANOOS)**

**Category 1: Moored Buoys**

**Installed NDBC Buoys – Needs Directional Waves**

| WMO # | Location |
|---|---|
| 46050 | Stonewall Banks |

**New Buoy Locations**

| Latitude | Longitude | Location |
|---|---|---|
| 44.20 | -124.80 | Heceta Bank (Mid-Shelf) |
| 48.30 | -124.03 | Interior St. San Juan de Fuca |
| 45.37 | -124.47 | Washington Shelf |
| 47.85 | -122.44 | Puget Sound |
| 48.74 | -123.11 | Boundary Pass |
| 48.31 | -126.24 | Juan de Fuca Eddy |
| 46.15 | -124.82 | Astoria Canyon |
| 44.62 | -124.11 | Yaquina Bay |
| 43.40 | -124.43 | Coos Bay |

**Category 2: Wave Profilers**

**Installed C-MAN Stations – Needs Directional Waves**

| WMO # | Location |
|---|---|
| DMNO3 | Desdemona Sands |

**Alaska Ocean Observing System (AOOS)**

**Category 1: Moored Buoys**

**Installed NDBC Buoys – Needs Directional Waves**

| WMO # | Location |
|---|---|
| 46060 | West Orca Bay |
| 46061 | Seal Rocks |
| 46076 | Cape Cleare |

**New Buoy Locations**

| Latitude | Longitude | Location |
|---|---|---|
| 59.55 | -149.87 | Resurrection Bay |
| 57.92 | -152.00 | Kodiak |
| 59.39 | -140.06 | Yakutat |
| 56.88 | -135.70 | Sitka |
| 54.16 | -164.43 | Unimak Pass |
| 58.46 | -158.43 | Bristol Bay |
| 56.89 | -170.36 | St. Paul |
| 57.93 | -136.71 | Near Juneau |
| 55.95 | -134.58 | Near Wrangell |

**Category 2: Wave Profilers**

**Installed C-MAN Stations – Needs Directional Waves**

| WMO # | Location |
|---|---|
| DRFA2 | Drift River Terminal, AK |
| BLIA2 | Bligh Reef Light, AK |

## Table of Wave Requirements by Regional Association

<table>
<tr><th>Regional Association</th><th>Category 1: Moored Buoys</th><th>Category 2: Wave Profilers</th></tr>
<tr><td><b>Pacific Islands Integrated Ocean Observing System (PacIOOS)</b></td><td>
<b>Installed NDBC Buoys – Needs Directional Waves</b>
<table>
<tr><th>WMO #</th><th>Location</th></tr>
<tr><td>51002</td><td>Detect winter swells from the west.</td></tr>
<tr><td>51001</td><td>Maintain Directional Waves</td></tr>
<tr><td>51028</td><td>Maintain Christmas Island (should Boeing Sea Launch terminate sponsorship) to meet requirements to detect southerly swell 24 hours before arrival</td></tr>
</table>
<b>New Buoy Locations</b>
<table>
<tr><th>Latitude</th><th>Longitude</th><th>Location</th></tr>
<tr><td></td><td></td><td>America Samoa Buoys (4)</td></tr>
<tr><td></td><td></td><td>Guam, T.T, Pac NW Buoys (16)</td></tr>
</table>
</td><td></td></tr>
<tr><td><b>Great Lakes Observing System (GLOS)</b></td><td>
<b>Installed NDBC Buoys – Needs Directional Waves</b>
<table>
<tr><th>WMO #</th><th>Location</th></tr>
<tr><td>45004</td><td>Marquette</td></tr>
<tr><td>45002</td><td>N. Michigan</td></tr>
</table>
<b>New Buoy Locations</b>
<table>
<tr><th>Latitude</th><th>Longitude</th><th>Location</th></tr>
<tr><td>44.90</td><td>-87.13</td><td>NE of Whitefish Point, WI</td></tr>
<tr><td>44.55</td><td>-86.82</td><td>Between Frankfort, MI and Kewaunee, WI</td></tr>
<tr><td>42.36</td><td>-80.07</td><td>Btwn Long Point, ON and Presque Isle, PA</td></tr>
<tr><td>43.52</td><td>-78.71</td><td>North of Olcott, NY</td></tr>
<tr><td>47.29</td><td>-91.26</td><td>Silver Bay MN</td></tr>
<tr><td>47.97</td><td>-89.69</td><td>Grand Portage MN</td></tr>
<tr><td>46.82</td><td>-89.28</td><td>Ontonagon MI</td></tr>
<tr><td>47.25</td><td>-88.63</td><td>Keweenaw Upper Light MI</td></tr>
<tr><td>46.65</td><td>-86.40</td><td>Grand Marais MN</td></tr>
<tr><td>45.90</td><td>-85.56</td><td>Lansing Shoal Light MI</td></tr>
<tr><td>44.15</td><td>-87.57</td><td>Manitowauk WI</td></tr>
<tr><td>43.39</td><td>-87.88</td><td>Port Washington WI</td></tr>
<tr><td>40.42</td><td>-80.22</td><td>Chicago Upper Intake IL</td></tr>
<tr><td>44.63</td><td>-86.23</td><td>Port Betise</td></tr>
<tr><td>41.51</td><td>-81.72</td><td>Cleveland West Phead OH</td></tr>
<tr><td>42.16</td><td>-80.07</td><td>Erie Pierhead PA</td></tr>
<tr><td>43.26</td><td>-77.60</td><td>Rochester Harbor NY</td></tr>
<tr><td>44.13</td><td>-76.33</td><td>Cape Vincent NY</td></tr>
<tr><td>44.48</td><td>-73.30</td><td>Lake Champlain, NY</td></tr>
</table>
</td><td></td></tr>
</table>

# Appendix D: Table of Existing and New Wave Observation Locations

This appendix includes detailed information for each existing and proposed wave measurement site, organized into the seven regions and four subnets. These tables provide the supporting details for Tables 1 and 2 including: an NDBC identification number, location, depth (if known), gauge/buoy type, hull diameter and whether the sensor measures directional waves (2D) or not (1D). Wave instruments which are not included in the plan, either because they are too shallow and would be in the surf zone during storms, owned by Environment Canada, a near duplicate of an adjacent instrument, or not in a useful location are indicated by "omitted" being entered in the Subnet column.

## Table of Existing and New Wave Observation Locations

| NDBC No. | Local Station Number | Owner | Latitude (degrees) | Longitude (degrees) | Depth (m) | Subnet | Gauge Type | Hull (m) | Measurement Device | Wave Spectra | Directional Upgrade |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Atlantic Coast** | | | | | | | | | | |
| 41024 | SUN2 Sunset Nearshore | Caro-COOPS | 33.848 | -78.489 | 10 | Coastal | ADCP | Bottom Mount | RDI ADCP | 2D | yes |
| 41029 | CAP 2 Capers Nearshore | Caro-COOPS | 32.810 | -79.630 | 11 | Coastal | ADCP | Bottom Mount | RDI ADCP | 2D | yes |
| 41033 | FRP 2 Fripp Nearshore | Caro-COOPS | 32.280 | -80.410 | 10 | Coastal | ADCP | Bottom Mount | RDI ADCP | 2D | yes |
| 41035 | Onslow Bay, NC | NDBC | 34.476 | -77.279 | 10 | Coastal | Discus | 3 | Angular Rate Sensor | 1D | yes |
| 41080 | Atlantic, Near LKWF1 (TO BE DEPLOYED) | NDBC | 26.609 | -79.992 | | Coastal | Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 41081 | Florida Strait, Near FWYF1 (TO BE DEPLOYED) | NDBC | 25.581 | -80.081 | | Coastal | Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 41112 | 132 Fernandina Beach, FL | CDIP | 30.719 | -81.293 | 16 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 41113 | 143 Cape Canaveral nearshore, FL | CDIP | 28.400 | -80.533 | 10 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 41114 | 134 Fort Pierce, FL | CDIP | 27.562 | -80.220 | 16 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 44007 | Portland 12 NM SE Portland, ME | NDBC | 43.531 | -70.144 | 22 | Coastal | Discus-F | 2.4 | MicroStrain 3DM-G | 2D | yes |
| 44013 | Boston 16NM E Boston, MA | NDBC | 42.354 | -70.691 | 55 | Coastal | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 44029 | A0102 | GoMOOS | 42.520 | -70.570 | 65 | Coastal | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 44030 | B0102 | GoMOOS | 43.183 | -70.418 | 62 | Coastal | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 44031 | CO201 | GoMOOS | 43.570 | -70.060 | 46 | Coastal | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 44032 | E0104 | GoMOOS | 43.720 | -69.360 | 100 | Coastal | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 44033 | F0103 | GoMOOS | 44.060 | -69.000 | 110 | Coastal | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 44034 | I0103 | GoMOOS | 44.110 | -68.110 | 100 | Coastal | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 44035 | J0201 | GoMOOS | 44.891 | -67.017 | 35 | Coastal | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 44039 | Central Long Island Sound | UConnDMS | 41.138 | -72.655 | 27 | Coastal | Discus-F | 2.4 | TRIAXYS | 2D | yes |
| 44040 | Western Long Island | UConnDMS | 40.956 | -73.580 | 18 | Coastal | Discus-F | 2 | TRIAXYS | 1D | yes |
| 44052 | Goodwin Islands | VECOS | 37.217 | -76.389 | | Coastal | AWAC | Bottom Mount | Nortek AWAC to NOMAD surface buoy | 2D | |
| 44053 | Gloucester Pt, VA | VIMS | 37.248 | -76.497 | 2 | Coastal | ADCP | Bottom Mount | RDI ADCP to surface buoy | 2D | yes |
| 44054 | Lower Delaware Bay | DCMP | 38.883 | -75.183 | 8 | Coastal | TRIAXYS | 1.1 | TRIAXYS | 2D | yes |
| 44055 | Central Delaware Bay | DCMP | 39.122 | -75.256 | | Coastal | TRIAXYS | 1.1 | TRIAXYS | 2D | yes |
| 44070 | Buzzards Bay MA. Offshore | NDBC | 41.393 | -71.004 | 33 | Coastal | Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 44071 | CHLV2 - Chesaopeake Light,VA (TO BE DEPLOYED) | NDBC | 36.910 | -75.710 | 12 | Coastal | CMAN/Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 69123 | New | | 29.198 | -80.851 | | Coastal | | | | 2D | |
| 69124 | New | | 34.528 | -76.433 | | Coastal | | | | 2D | |
| 69125 | New | | 34.932 | -76.077 | | Coastal | | | | 2D | |
| 69126 | New | | 37.197 | -75.846 | | Coastal | | | | 2D | |
| 69127 | New | | 39.129 | -74.598 | | Coastal | | | | 2D | |
| 69128 | New | | 40.084 | -73.993 | | Coastal | | | | 2D | |
| 69129 | New | | 40.573 | -73.083 | | Coastal | | | | 2D | |
| 69130 | New | | 41.060 | -71.856 | | Coastal | | | | 2D | |
| 69162 | New | | 29.198 | -80.851 | | Coastal | | | | 2D | |
| AVAN4 | Avalon, NJ | Stevens Inst | 39.090 | -74.731 | 5 | Coastal | Pressure | Bottom Mount | | 1D | yes |
| DE002 | Coast Del DE002 | USACE | 38.540 | -75.040 | 10 | Coastal | Pressure | Bottom Mount | | 2D | |
| FBPS1 | Folly Beach Pier, SC | U of SC | 32.652 | -79.938 | 4 | Coastal | ADCP | Bottom Mount | | 2D | yes |
| FRFLA | 111 FRF - Linear Array, Duck, NC | USACE | 36.187 | -75.743 | 9 | Coastal | Pressure | Bottom Mount | | 2D | |
| 44056 | 630 FRF Waverider, Duck, NC | USACE | 36.199 | -75.721 | 17 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| MD002 | Ocean City, MD MD002 | USACE | 38.340 | -75.070 | 9 | Coastal | Pressure | Bottom Mount | | 2D | |
| OCPN7 | OCP1 | CORMP | 33.908 | -78.148 | 6 | Coastal | ADCP | Bottom Mount | | 2D | yes |
| 41004 | EDISTO-41 NM SE Charleston, SC | NDBC | 32.501 | -79.099 | 34 | Inner-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41008 | Grays Reef 40NM SE Savannah, GA | NDBC | 31.402 | -80.871 | 18 | Inner-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 41009 | Canaveral 20NM E Cape Canaveral, FL | NDBC | 28.501 | -80.165 | 42 | Inner-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41012 | ST Augustine, FL 40NM ENE St Augustine, FL | NDBC | 30.041 | -80.533 | 37 | Inner-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 41013 | Frying Pan Shoals, NC | NDBC | 33.436 | -77.743 | 24 | Inner-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 41025 | Diamond Shoals | NDBC | 35.006 | -75.402 | 68 | Inner-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41036 | Onslow Bay, NC | NDBC | 34.211 | -76.953 | 31 | Inner-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 44005 | Gulf of Main 28NM Portsmouth, NH | NDBC | 43.169 | -69.149 | 201 | Inner-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 44009 | Delaware Bay 26NM SE Cape May, NJ | NDBC | 38.464 | -74.702 | 24 | Inner-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 44017 | 23NM SW Montauk Point, NY | NDBC | 40.692 | -72.048 | 45 | Inner-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 44018 | SE Cape Cod 30NM E Nantucket, MA | NDBC | 41.259 | -69.294 | 74 | Inner-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 44025 | Long Island 33NM S Islip, NY | NDBC | 40.250 | -73.166 | 36 | Inner-Shelf | Discus | 3 | Datawell Hippy | 2D | |

## Table of Existing and New Wave Observation Locations

| NDBC No. | Local Station Number | Owner | Latitude (degrees) | Longitude (degrees) | Depth (m) | Subnet | Gauge Type | Hull (m) | Measurement Device | Wave Spectra | Directional Upgrade |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | **Atlantic Coast (continued)** |  |  |  |  |  |  |  |  |  |  |
| 44027 | Jonesport, ME | NDBC | 44.273 | -67.314 | 189 | Inner-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 44037 | M0102 | GoMOOS | 43.484 | -67.883 | 285 | Inner-Shelf | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 44038 | L0102 | GoMOOS | 43.633 | -66.550 | 98 | Inner-Shelf | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 68100 | New |  | 42.203 | -69.622 |  | Inner-Shelf |  |  |  | 2D |  |
| 68101 | New |  | 40.594 | -70.862 |  | Inner-Shelf |  |  |  | 2D |  |
| 68102 | New |  | 39.503 | -73.626 |  | Inner-Shelf |  |  |  | 2D |  |
| 68103 | New |  | 37.340 | -75.263 |  | Inner-Shelf |  |  |  | 2D |  |
| 68104 | New |  | 35.877 | -75.385 |  | Inner-Shelf |  |  |  | 2D |  |
| 68114 | New |  | 38.700 | -74.500 |  | Inner-Shelf |  |  |  | 2D |  |
| 41001 | 150 NM East of Cape Hatteras, NC | NDBC | 34.729 | -72.678 | 4,426 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41002 | S Hatteras 250 NM E Charleston, SC | NDBC | 32.319 | -75.360 | 3,316 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41010 | Canaveral E 120NM E Cape Canaveral, FL | NDBC | 28.953 | -78.479 | 873 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41046 | E Bahamas | NDBC | 23.999 | 70.994 | 5,500 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41047 | NE Bahamas | NDBC | 27.469 | -71.491 | 5,231 | Offshore | Discus | 12 | Angular Rate Sensor | 2D | yes |
| 41048 | W Bermuda | NDBC | 31.978 | -69.649 | 5,261 | Offshore | Discus | 12 | Angular Rate Sensor | 2D | yes |
| 41049 | NEW Hurricane Buoy (TO BE DEPLOYED) | NDBC | 27.500 | -63.000 |  | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 44004 | HOTEL 200 NM E Cape May, NJ | NDBC | 38.484 | -70.433 | 3,182 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 44024 | Buoy N-Northeast Channel | GoMOOS | 42.312 | -65.927 | 225 | Offshore | Discus-F | 2 | Strapped-down Summit Accelerometer | 1D | yes |
| 44150 | LaHave Bank | Env. Canada | 42.505 | -64.018 | 1,300 | Offshore | NOMAD | 6 |  | 1D | yes |
| 66100 | New |  | 26.508 | -79.043 |  | Offshore |  |  |  | 2D |  |
| 66101 | New |  | 36.940 | -69.330 |  | Offshore |  |  |  | 2D |  |
| 66102 | New |  | 39.800 | -66.000 |  | Offshore |  |  |  | 2D |  |
| 66103 | New |  | 30.830 | -76.650 |  | Offshore |  |  |  | 2D |  |
| 66104 | New |  | 32.820 | -64.880 |  | Offshore |  |  |  | 2D |  |
| 44008 | Nantucket 54NM SE Nantucket, MA | NDBC | 40.500 | -69.431 | 59 | Outer-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 44011 | Georges Bank 170NM E Hyannis MA | NDBC | 41.111 | -66.580 | 87 | Outer-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 44014 | Virginia Beach 64NM E Virginia Beach, VA | NDBC | 36.611 | -74.836 | 54 | Outer-Shelf | Discus | 3 | Datawell Hippy | 2D |  |
| 67101 | New |  | 27.740 | -79.904 |  | Outer-Shelf |  |  |  | 2D |  |
| 67102 | New |  | 29.711 | -80.027 |  | Outer-Shelf |  |  |  | 2D |  |
| 67103 | New |  | 31.536 | -79.783 |  | Outer-Shelf |  |  |  | 2D |  |
| 67104 | New |  | 32.378 | -78.646 |  | Outer-Shelf |  |  |  | 2D |  |
| 67105 | New |  | 34.118 | -76.221 |  | Outer-Shelf |  |  |  | 2D |  |
| 67106 | New |  | 35.367 | -75.017 |  | Outer-Shelf |  |  |  | 2D |  |
| 67109 | New |  | 24.614 | -80.757 |  | Outer-Shelf |  |  |  | 2D |  |
| 67114 | New |  | 39.688 | -71.655 |  | Outer-Shelf |  |  |  | 2D |  |
| 67115 | New |  | 38.588 | -73.284 |  | Outer-Shelf |  |  |  | 2D |  |
| 41027 | SUN3 Sunset Mid-Shelf | Caro-COOPS | 33.302 | -78.137 | 30 | Omitted | ADCP | Bottom Mount | RDI ADCP | 2D |  |
| 41030 | CAP 3 Capers Mid Shelf | Caro-COOPS | 32.506 | -79.328 | 30 | Omitted | ADCP | Bottom Mount | RDI ADCP | 2D |  |
| 44137 | East Scotia Slope | Env. Canada | 42.268 | -62.000 | 180 | Omitted | NOMAD | 6 |  | 1D |  |
| 44138 | SW Grand Banks | Env. Canada | 44.267 | -58.633 | 1,470 | Omitted | NOMAD | 6 |  | 1D |  |
| 44139 | Banqureau Bank | Env. Canada | 44.267 | -57.084 | 1,500 | Omitted | NOMAD | 6 |  | 1D |  |
| 44140 | Tail of the Bank | Env. Canada | 42.868 | -51.467 | 1,300 | Omitted | NOMAD | 6 |  | 1D |  |
| 44141 | Laurentian Fan | Env. Canada | 43.000 | -58.000 | 4,527 | Omitted | NOMAD | 6 |  | 1D |  |
| 44251 | Nickerson Bank | Env. Canada | 46.450 | -53.384 | 69 | Omitted | NOMAD | 6 |  | 1D |  |
| 44255 | NEBurgeoBank | Env. Canada | 47.269 | -57.353 | 185 | Omitted | NOMAD | 6 |  | 1D |  |
| 44258 | Halifax Harbour | Env. Canada | 44.500 | -63.400 | 180 | Omitted | Discus | 3 |  | 1D |  |
| ALSN6 | Ambrose Light Tower | NDBC | 40.450 | -73.800 | 29 | Omitted | CMAN | 0 | AWAC | 2D |  |
| FRFB1 | 625-FRF Baylor 1860, Duck, NC | USACE | 36.184 | -75.745 | 8 | Omitted | Staff Gauge | Pier Mount |  | 1D |  |
| FRFB2 | 641-FRF Pressure Gauge, Duck, NC | USACE | 36.183 | -75.749 | 2 | Omitted | Pressure | Bottom Mount |  | 1D |  |
| SPAG1 | US Navy Tower | SABSOON | 31.375 | -80.567 | 25-45 | Omitted | ADCP | Bottom Mount | RDI ADCP | 2D |  |

## Table of Existing and New Wave Observation Locations

| NDBC No. | Local Station Number | Owner | Latitude (degrees) | Longitude (degrees) | Depth (m) | Subnet | Gauge Type | Hull (m) | Measurement Device | Wave Spectra | Directional Upgrade |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Gulf of Mexico** | | | | | | | | | | |
| 42007 | Biloxi 22NM SSE Biloxi MX | NDBC | 30.090 | -88.769 | 15 | Coastal | Discus | 3 | Magenotometer Only | 2D | yes |
| 42035 | Balveston 22NM E Galveston TX | NDBC | 29.232 | -94.413 | 14 | Coastal | Discus | 3 | Magenotometer Only | 2D | yes |
| 42080 | Florida Strait, Near SANF1 | NDBC | 24.388 | -81.947 | | Coastal | Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 42082 | NEW Near GDIL1 (TO BE DEPLOYED) | NDBC | 29.197 | -89.964 | | Coastal | Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 42083 | NEW BURL1 (TO BE DEPLOYED) | NDBC | 28.892 | -89.297 | | Coastal | Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 69148 | New | | 26.228 | -82.176 | | Coastal | | | | 2D | |
| 69149 | New | | 28.253 | -82.920 | | Coastal | | | | 2D | |
| 69150 | New | | 28.924 | -83.295 | | Coastal | | | | 2D | |
| 69151 | New | | 29.704 | -83.876 | | Coastal | | | | 2D | |
| 69152 | New | | 29.962 | -85.780 | | Coastal | | | | 2D | |
| 69153 | New | | 30.055 | -87.958 | | Coastal | | | | 2D | |
| 69154 | New | | 29.370 | -92.764 | | Coastal | | | | 2D | |
| 69155 | New | | 28.893 | -95.065 | | Coastal | | | | 2D | |
| 69157 | New | | 27.730 | -96.875 | | Coastal | | | | 2D | |
| 69158 | New | | 27.100 | -97.238 | | Coastal | | | | 2D | |
| 69159 | New | | 29.592 | -93.807 | | Coastal | | | | 2D | |
| 69166 | New | | 28.500 | -96.167 | | Coastal | | | | 2D | |
| 69167 | New | | 30.167 | -87.000 | | Coastal | | | | 2D | |
| ILDL1 | CSI-05 | CSI-LSU | 29.053 | -90.533 | 7 | Coastal | ADCP | Bottom Mount | | 2D | yes |
| MRSL1 | CSI-03 | CSI-LSU | 29.440 | -92.061 | 6 | Coastal | ADCP | Bottom Mount | | 2D | yes |
| SIPM6 | CSI-13 | CSI-LSU | 30.266 | -89.008 | 7 | Coastal | ADCP | Bottom Mount | | 2D | yes |
| SLPL1 | CSI-14 | CSI-LSU | 29.517 | -91.550 | 3 | Coastal | ADCP | Bottom Mount | | 2D | yes |
| SPLL1 | CSI-06 | CSI-LSU | 28.867 | -90.483 | 21 | Coastal | ADCP | Bottom Mount | | 2D | yes |
| 42036 | West Tampa 106NM WNW Tampa FL | NDBC | 28.500 | -84.517 | 55 | Inner-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 68107 | New | | 27.793 | -96.392 | | Inner-Shelf | | | | 2D | |
| 68108 | New | | 28.943 | -93.531 | | Inner-Shelf | | | | 2D | |
| 68109 | New | | 28.572 | -91.615 | | Inner-Shelf | | | | 2D | |
| 68110 | New | | 29.490 | -86.236 | | Inner-Shelf | | | | 2D | |
| 68164 | New | | 26.250 | -83.700 | | Inner-Shelf | | | | 2D | |
| 42001 | Middle GoM 180NM S Southwest Pass LA | NDBC | 25.900 | -89.667 | 3,274 | Offshore | Discus | 12 | HIPPY / Angular Rate Sensor | 2D | |
| 42002 | West GoM 240NM SSE Sabine TX | NDBC | 25.167 | -94.417 | 3,200 | Offshore | Discus | 10 | Datawell Hippy / MO | 2D | |
| 42003 | E GoM 262NM S Panama City FL | NDBC | 26.033 | -85.892 | 3,233 | Offshore | Discus | 10 | Angular Rate Sensor | 2D | yes |
| 42055 | Bay of Campeche | NDBC | 22.017 | -94.046 | 3,381 | Offshore | Discus | 12 | Angular Rate Sensor | 2D | yes |
| 42056 | Yucatan Basin | NDBC | 19.874 | -85.059 | 4,446 | Offshore | Discus | 12 | Angular Rate Sensor | 2D | yes |
| 66123 | New | | 23.419 | -87.062 | | Offshore | | | | 2D | |
| 42019 | Freeport TX 60NM S Freeport TX | NDBC | 27.913 | -95.360 | 84 | Outer-Shelf | Discus | 3 | Magenotometer Only | 2D | yes |
| 42020 | Corpus Chirsti TX 50NM SE Corpus Christi TX | NDBC | 26.944 | -96.696 | 88 | Outer-Shelf | Discus | 3 | Magenotometer Only | 2D | yes |
| 42039 | Pensacola 115 ESE Pensacola FL | NDBC | 28.794 | -86.021 | 291 | Outer-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 42040 | Mobile South 64NM S Dauphine Island AL | NDBC | 29.185 | -88.214 | 274 | Outer-Shelf | Discus | 3 | Magenotometer Only | 2D | yes |
| 42099 | 144 ST. Petersburg, offshore, FL | CDIP | 27.340 | -84.275 | 94 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | yes |
| 67107 | New | | 24.914 | -83.690 | | Outer-Shelf | | | | 2D | |
| 67110 | New | | 27.913 | -92.655 | | Outer-Shelf | | | | 2D | |
| 67111 | New | | 28.150 | -90.200 | | Outer-Shelf | | | | 2D | |
| 67121 | New | | 26.295 | -96.225 | | Outer-Shelf | | | | 2D | |

## Table of Existing and New Wave Observation Locations

| NDBC No. | Local Station Number | Owner | Latitude (degrees) | Longitude (degrees) | Depth (m) | Subnet | Gauge Type | Hull (m) | Measurement Device | Wave Spectra | Directional Upgrade |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Pacific Coast** | | | | | | | | | | |
| 46211 | 36  Grays Harbor, WA | CDIP | 46.860 | -124.245 | 40 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46212 | 128  Humbolt Bay, South Spit, CA | CDIP | 40.753 | -124.313 | 40 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46215 | 76  Diablo Canyon, CA | CDIP | 35.204 | -120.859 | 23 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46216 | 107  Goleta Point, CA | CDIP | 34.333 | -119.803 | 183 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46223 | 96  Dana Point, CA | CDIP | 33.459 | -117.768 | 370 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46224 | 45  Oceanside offshore, CA | CDIP | 33.179 | -117.471 | 223 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46225 | 100  Torrey Pines, outer, CA | CDIP | 32.930 | -117.392 | 549 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46232 | 133  Coronado Islands, Mexico | CDIP | 32.426 | -117.323 | 180 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46234 | 141  Port Hueneme nearshore, CA | CDIP | 34.100 | -119.167 | 21 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46235 | 155  Imperial Beach, nearshore, CA | CDIP | 32.570 | -117.167 | 18 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46236 | 156  Monterey Canyon, outer, CA | CDIP | 36.761 | -121.947 | 168 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46237 | 142  San Francisco bar, CA | CDIP | 37.781 | -122.599 | 15 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 69116 | New | | 47.901 | -124.667 | | Coastal | | | | 2D | |
| 69117 | New | | 46.495 | -124.115 | | Coastal | | | | 2D | |
| 69118 | New | | 46.139 | -124.041 | | Coastal | | | | 2D | |
| 69119 | New | | 44.623 | -124.114 | | Coastal | | | | 2D | |
| 69120 | New | | 42.867 | -124.569 | | Coastal | | | | 2D | |
| 69121 | New | | 36.052 | -121.807 | | Coastal | | | | 2D | |
| 69122 | New | | 41.797 | -124.307 | | Coastal | | | | 2D | |
| LJPC1 | 73  Scripps Pier, La Jolla, CA | CDIP | 32.867 | -117.257 | 6 | Coastal | Pressure | Pier mount | Pressure | 1D | |
| 46087 | Neah Bay WA | NDBC | 48.494 | -124.727 | 261 | Inner-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 46088 | New Dungeness- Hein Bank WA | NDBC | 48.333 | -123.166 | 106 | Inner-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 46002 | Oregon 275NM W Coos Bay OR | NDBC | 42.599 | -130.272 | 3,374 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46005 | Washington 315NM W Aberdeen WA | NDBC | 46.008 | -130.968 | 2,780 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46006 | SE PAPA 600NM W Eureka CA | NDBC | 40.800 | -137.479 | 4,023 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46025 | Santa Monica Basin 33NM WSW, CA | NDBC | 33.746 | -119.076 | 860 | Offshore | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46036 | SouthNomad | Env. Canada | 48.353 | -134.117 | 3,500 | Offshore | NOMAD | 6 | | 1D | yes |
| 46047 | Tanner Banks 121NM W San Diego CA | NDBC | 32.433 | -119.533 | 1,394 | Offshore | Discus | 3 | Schaevitz LSOC_30 inclinometer | 2D | yes |
| 46059 | California 357NM W San Francisco CA | NDBC | 38.033 | -130.000 | 4,717 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46069 | South Santa Rosa Island CA | NDBC | 33.650 | -120.200 | 1,005 | Offshore | Discus | 3 | Datawell Hippy | 2D | |
| 46086 | San Clemete Basin | NDBC | 32.498 | -117.999 | 1,856 | Offshore | Discus | 3 | Datawell Hippy | 2D | |
| 46089 | Tillamook OR | NDBC | 45.881 | -125.766 | 2,230 | Offshore | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 46219 | 67  San Nicolas Island, CA | CDIP | 33.221 | -119.882 | 335 | Offshore | Waverider | 0.9 | Datawell Hippy | 2D | |
| 66122 | New | | 33.330 | -123.090 | | Offshore | | | | 2D | |
| 66501 | New Meso-Scale Offshore | | 48.000 | -126.500 | | Offshore | | | | 2D | |
| 66502 | New Meso-Scale Offshore | | 44.830 | -126.500 | | Offshore | | | | 2D | |
| 66503 | New Meso-Scale Offshore | | 41.540 | -125.150 | | Offshore | | | | 2D | |
| 66504 | New Meso-Scale Offshore | | 37.510 | -124.120 | | Offshore | | | | 2D | |
| 66505 | New Meso-Scale Offshore | | 35.120 | -122.480 | | Offshore | | | | 2D | |
| 46011 | Santa Maria 21 NM NW Point Arguello CA | NDBC | 34.880 | -120.869 | 188 | Outer-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 46012 | Half Moon Bay 24NM SSW San Francisco CA | NDBC | 37.357 | -122.881 | 213 | Outer-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46013 | Bodega Bay 48NM NNW San Francisco CA | NDBC | 38.225 | -123.317 | 127 | Outer-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46014 | Pt Arena 19NM N Point Arena CA | NDBC | 39.196 | -123.969 | 284 | Outer-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46015 | Port Orford 16NM W Point Orford OR | NDBC | 42.747 | -124.847 | 424 | Outer-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46022 | Eel river 17NM WSW Eureka CA | NDBC | 40.781 | -124.542 | 509 | Outer-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46023 | Pt Arguello 17NM WNW Point Arguello CA | NDBC | 34.703 | -120.957 | 393 | Outer-Shelf | Discus | 10 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46026 | San Francisco 18NM W San Francisco CA | NDBC | 37.759 | -122.833 | 55 | Outer-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 46027 | St Georges 8NM WNW Cresent City CA | NDBC | 41.850 | -124.381 | 48 | Outer-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 46028 | Cape San Martin 55NM WNW Morro Bay CA | NDBC | 35.737 | -121.889 | 1,112 | Outer-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 46029 | Columbia River Bar 78NM SSW Aberdeen WA | NDBC | 46.144 | -124.512 | 135 | Outer-Shelf | Discus | 3 | Datawell Hippy | 2D | |
| 46041 | Cape Elizabeth 450NM NW Aberdeen WA | NDBC | 47.341 | -124.714 | 115 | Outer-Shelf | Discus | 3 | Datawell Hippy | 2D | |
| 46042 | Monterey 27NM W Monterey Bay CA | NDBC | 36.753 | -122.423 | 2,115 | Outer-Shelf | Discus | 3 | Datawell Hippy | 2D | |
| 46050 | Stonewall Banks 20NM W Newport OR | NDBC | 44.627 | -124.503 | 118 | Outer-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |

## Table of Existing and New Wave Observation Locations

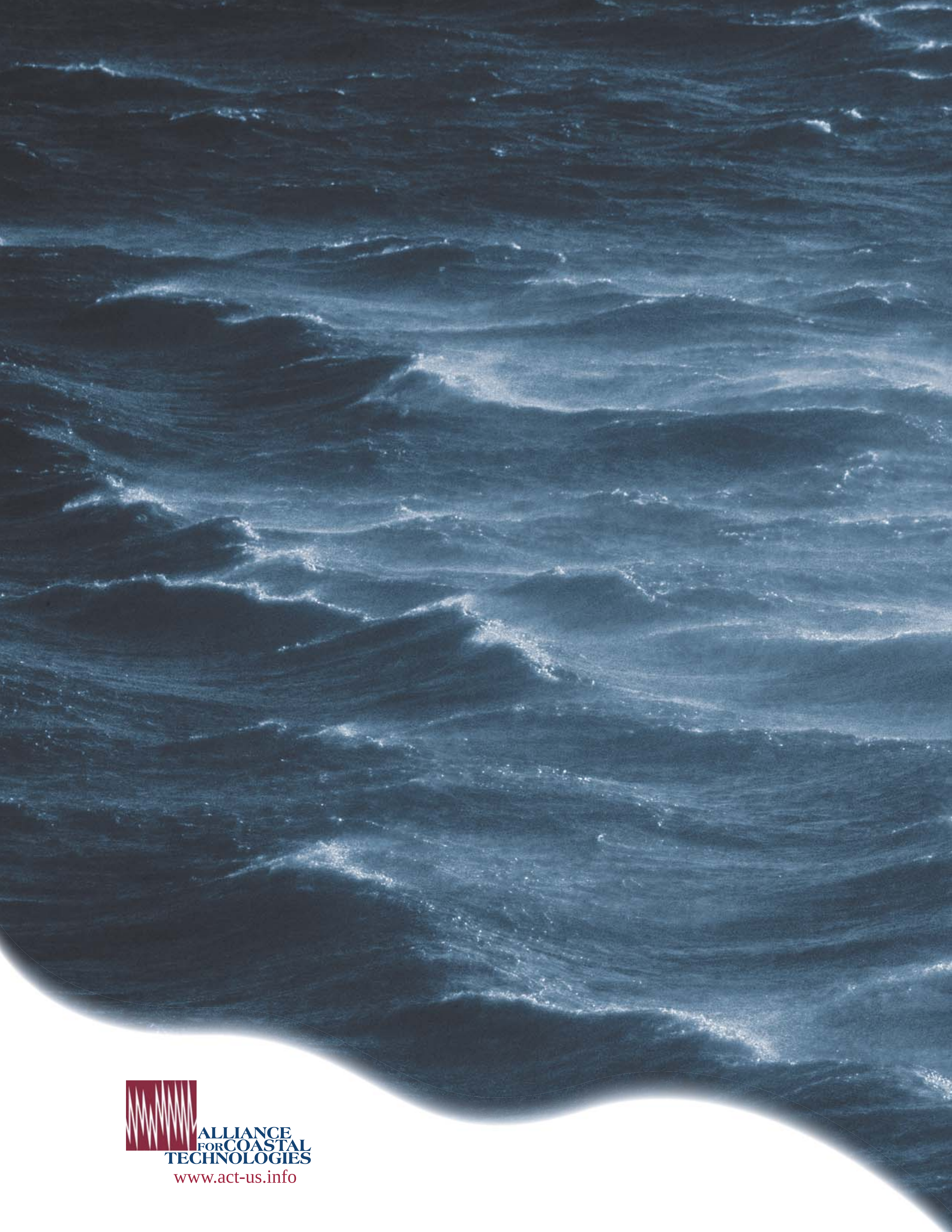
| NDBC No. | Local Station Number | Owner | Latitude (degrees) | Longitude (degrees) | Depth (m) | Subnet | Gauge Type | Hull (m) | Measurement Device | Wave Spectra | Directional Upgrade |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Pacific Coast (continued)** | | | | | | | | | | |
| 46054 | Santa Barbara West 38NM W, CA | NDBC | 34.267 | -120.438 | 447 | Outer-Shelf | Discus | 10 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46063 | Pt Conception CA 50NM W Santa Barbara CA | NDBC | 34.273 | -120.699 | 632 | Outer-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 46213 | 94 Cape Mendocino, CA | CDIP | 40.293 | -124.739 | 319 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46214 | 29 Point Reyes, CA | CDIP | 37.946 | -123.470 | 550 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46217 | 111 Anacapa Passage, CA | CDIP | 34.170 | -119.436 | 105 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46218 | 71 Harvest, CA | CDIP | 34.454 | -120.782 | 549 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46221 | 28 Santa Monica Bay, CA | CDIP | 33.855 | -118.633 | 363 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46222 | 92 San Pedro, CA | CDIP | 33.618 | -118.317 | 457 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46229 | 139 Umpqua offshore, OR | CDIP | 43.770 | -124.549 | 187 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | |
| 46231 | 93 Mission Bay offshore, CA | CDIP | 32.747 | -117.369 | 200 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | |
| 67120 | New | | 48.427 | -125.755 | | Outer-Shelf | | | | 2D | |
| 46134 | PatBay | Env. Canada | 48.667 | -123.467 | 68 | Omitted | Discus | 3 | | 1D | |
| 46206 | LaPerouseBank | Env. Canada | 48.834 | -126.000 | 73 | Omitted | Discus | 3 | | 1D | |
| | **Alaskan Coast** | | | | | | | | | | |
| 46060 | West Orca Bay 36NM SSW Valdez AK | NDBC | 60.588 | -146.833 | 457 | Coastal | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46077 | Shelikof Strait, AK | NDBC | 57.920 | -154.254 | 213 | Coastal | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46081 | Western Prince William Sound, AK | NDBC | 60.796 | -148.281 | 396 | Coastal | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46105 | Cook Inlet AK | NDBC | 59.050 | -152.230 | | Coastal | Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 46106 | Cook Inlet AK | NDBC | 59.800 | -152.300 | | Coastal | Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 46107 | Montague Strait | NDBC | 60.840 | -146.919 | | Coastal | Discus-F | 1.8 | MicroStrain 3DM-G | 2D | yes |
| 46061 | Seal Rocks 55NM S Valdez AK | NDBC | 60.233 | -146.834 | 219 | Inner-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46001 | Gulf of Alaska 88NM S Kodiak, AK | NDBC | 56.296 | -148.172 | 4,206 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46004 | Middle Nomad | Env. Canada | 50.933 | -136.100 | 3,600 | Offshore | NOMAD | 6 | | 1D | yes |
| 46066 | S Aleutians 380NM SW Kodiak, AK | NDBC | 52.696 | -154.984 | 5,000 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46070 | SW Bering Sea, AK | NDBC | 55.003 | 175.284 | 3,804 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46071 | Western Aleutians, AK | NDBC | 51.157 | 179.050 | 1,269 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46072 | Central Aleutians 230NM Southwest of Dutch Harbor | NDBC | 51.625 | 172.167 | 3,641 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46085 | Central Gulf of Alaska Buoy, AK | NDBC | 55.855 | -142.559 | 3,722 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46035 | Bering Sea 310NM N Adak, AK | NDBC | 57.051 | -177.576 | 3,717 | Outer-Shelf | Discus | 12 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46073 | Southeast Bering Sea | NDBC | 54.942 | -172.029 | 4,184 | Outer-Shelf | Discus | 12 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46075 | Shumagin Islands, AK | NDBC | 53.926 | -160.806 | 2,345 | Outer-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46076 | Cape Cleare AK | NDBC | 59.499 | -148.000 | 201 | Outer-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46078 | Albatross Banks, AK | NDBC | 56.054 | -152.451 | 4,206 | Outer-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46080 | Northwest Gulf 57NM E Kodiak AK | NDBC | 58.013 | -150.092 | 274 | Outer-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46082 | Sape Suckling 84NM SE Cordova, AK | NDBC | 59.685 | -143.421 | 317 | Outer-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46083 | Fairweather Grounds 92NM SE Yakutat, AK | NDBC | 58.249 | -137.993 | 137 | Outer-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46084 | Cape Edgecumbe, AK | NDBC | 56.593 | -136.162 | 1,280 | Outer-Shelf | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 46147 | South Moresby | Env. Canada | 51.833 | -131.233 | 2,000 | Outer-Shelf | Discus | 3 | | 1D | yes |
| 46205 | West Dixon Entrance | Env. Canada | 54.167 | -134.269 | 2,675 | Outer-Shelf | Discus | 3 | | 1D | yes |
| 46208 | West Moresby | Env. Canada | 52.517 | -132.668 | 2,950 | Outer-Shelf | Discus | 3 | | 1D | yes |
| 67122 | New | | 55.633 | -135.099 | | Outer-Shelf | | | | 2D | |
| 67123 | New | | 54.500 | -166.500 | | Outer-Shelf | | | | 2D | |
| 67124 | New | | 70.878 | -165.244 | | Outer-Shelf | | | | 2D | |
| 68111 | New | | 57.072 | -161.609 | | Inner-Shelf | | | | 2D | |
| 68112 | New | | 63.937 | -164.534 | | Inner-Shelf | | | | 2D | |
| 68113 | New | | 61.857 | -167.158 | | Inner-Shelf | | | | 2D | |
| 68118 | New | | 56.886 | -170.356 | | Inner-Shelf | | | | 2D | |
| 68119 | New | | 65.806 | -168.726 | | Inner-Shelf | | | | 2D | |
| 69172 | New | | 57.917 | -152.001 | | Coastal | | | | 2D | |
| 69173 | New | | 59.389 | -140.062 | | Coastal | | | | 2D | |
| 69174 | New | | 58.463 | -158.433 | | Coastal | | | | 2D | |
| 69175 | New | | 57.926 | -136.707 | | Coastal | | | | 2D | |
| 69176 | New | | 66.346 | -166.410 | | Coastal | | | | 2D | |

## Table of Existing and New Wave Observation Locations

| NDBC No. | Local Station Number | Owner | Latitude (degrees) | Longitude (degrees) | Depth (m) | Subnet | Gauge Type | Hull (m) | Measurement Device | Wave Spectra | Directional Upgrade |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Alaskan Coast (continued)** | | | | | | | | | | |
| 69177 | New | | 71.321 | -157.002 | | Coastal | | | | 2D | |
| 69178 | New | | 67.500 | -165.000 | | Coastal | | | | 2D | |
| 69179 | New | | 64.000 | -161.750 | | Coastal | | | | 2D | |
| 69180 | New | | 66.907 | -162.837 | | Coastal | | | | 2D | |
| 46184 | North Nomad | Env. Canada | 53.917 | -138.850 | 3,600 | Offshore | NOMAD | 6 | | 1D | yes |
| 46131 | Sentry Shoal | Env. Canada | 49.917 | -125.000 | 18 | Omitted | NOMAD | 6 | | 1D | yes |
| 46132 | SouthBrooks | Env. Canada | 49.734 | -127.918 | 2,040 | Omitted | Discus | 3 | | 1D | yes |
| 46145 | CentDixonEnt | Env. Canada | 54.367 | -132.450 | 257 | Omitted | Discus | 3 | | 1D | yes |
| 46146 | Halibut Bank | Env. Canada | 49.334 | -123.717 | 40 | Omitted | Discus | 3 | | 1D | yes |
| 46181 | NanakwaShoal | Env. Canada | 53.833 | -128.819 | 21 | Omitted | Discus | 3 | | 1D | yes |
| 46183 | North Hecta Strait | Env. Canada | 53.600 | -131.100 | 62 | Omitted | Discus | 3 | | 1D | yes |
| 46185 | SouthHecateSt | Env. Canada | 52.417 | -129.800 | 230 | Omitted | Discus | 3 | | 1D | yes |
| 46204 | West Sea Otter | Env. Canada | 51.383 | -128.750 | 224 | Omitted | Discus | 3 | | 1D | yes |
| 46207 | East Dellwood | Env. Canada | 50.883 | -129.933 | 2,125 | Omitted | Discus | 3 | | 1D | yes |
| | **Hawaii & Pacific Islands** | | | | | | | | | | |
| 51201 | 106 Waimea Bay, HI | CDIP | 21.673 | -158.116 | 200 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 51202 | 98 Mokapu Point, HI | CDIP | 21.415 | -157.678 | 100 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 51203 | 146 Kaumalapau, Lanai, HI | CDIP | 20.788 | -157.010 | 201 | Coastal | Waverider | 0.9 | Datawell Hippy | 2D | |
| 69172 | New - American Samoa | | -12.500 | -172.036 | | Coastal | | | | 2D | |
| 69173 | New - Guam | | 13.617 | 144.737 | | Coastal | | | | 2D | |
| 69174 | New - Palau | | 7.117 | 135.150 | | Coastal | | | | 2D | |
| 69175 | New - Federated States of Micronesia | | 7.950 | 150.967 | | Coastal | | | | 2D | |
| 69176 | New - Northern Mariana Islands | | 17.133 | 145.483 | | Coastal | | | | 2D | |
| KNORO | Kilo Nalu Observatory, Oahu, HI | PacIOOS | 21.289 | -157.865 | 10 | Coastal | ADCP | Bottom Mount | RDI ADCP | 2D | yes |
| 51001 | NW Hawaii 170NM WNW Kauai, HI | NDBC | 23.432 | -162.208 | 3,252 | Offshore | Discus | 3 | Datawell Hippy | 2D | |
| 51002 | SW Hawaii 215NM SSE Hilo, HI | NDBC | 17.191 | -157.781 | 5,002 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 51003 | W Hawaii 205NM SW Honolulu, HI | NDBC | 19.221 | -160.821 | 4,920 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 51004 | SE Hawaii 185NM SE Hilo, HI | NDBC | 17.523 | -152.481 | 4,901 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 51028 | Christmas Island DWA | NDBC | 0.020 | 206.087 | 4,572 | Offshore | Discus | 3 | Datawell Hippy | 2D | |
| 66121 | New | | 24.000 | -156.000 | (1) | Offshore | | | | 2D | |
| 52200 | 121 Ipan, Guam | CDIP | 13.354 | 144.788 | 200 | Outer-Shelf | Waverider | 0.9 | Datawell Hippy | 2D | yes |
| | **Great Lakes** | | | | | | | | | | |
| 69131 | New | | 46.852 | -91.598 | | Coastal | | | | 2D | |
| 69132 | New | | 46.856 | -85.066 | | Coastal | | | | 2D | |
| 69133 | New | | 45.256 | -87.283 | | Coastal | | | | 2D | |
| 69134 | New | | 44.040 | -87.514 | | Coastal | | | | 2D | |
| 69135 | New | | 43.026 | -87.633 | | Coastal | | | | 2D | |
| 69136 | New | | 42.042 | -87.409 | | Coastal | | | | 2D | |
| 69137 | New | | 43.250 | -86.505 | | Coastal | | | | 2D | |
| 69138 | New | | 45.096 | -85.495 | | Coastal | | | | 2D | |
| 69139 | New | | 44.207 | -83.117 | | Coastal | | | | 2D | |
| 69140 | New | | 43.819 | -83.669 | | Coastal | | | | 2D | |
| 69141 | New | | 41.852 | -83.113 | | Coastal | | | | 2D | |
| 69142 | New | | 41.594 | -81.754 | | Coastal | | | | 2D | |
| 69143 | New | | 41.491 | -82.706 | | Coastal | | | | 2D | |
| 69144 | New | | 42.153 | -80.127 | | Coastal | | | | 2D | |
| 69145 | New | | 42.854 | -78.916 | | Coastal | | | | 2D | |
| 69146 | New | | 43.325 | -77.537 | | Coastal | | | | 2D | |
| 69168 | New | | 43.128 | -82.459 | | Coastal | | | | 2D | |
| 69169 | New | | 42.406 | -86.406 | | Coastal | | | | 2D | |
| 69170 | New | | 44.798 | -86.210 | | Coastal | | | | 2D | |
| 69171 | New | | 47.568 | -87.885 | | Coastal | | | | 2D | |

## Table of Existing and New Wave Observation Locations

| NDBC No. | Local Station Number | Owner | Latitude (degrees) | Longitude (degrees) | Depth (m) | Subnet | Gauge Type | Hull (m) | Measurement Device | Wave Spectra | Directional Upgrade |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Great Lakes (continued)** | | | | | | | | | | |
| 45001 | Mid Superior 60NM NNE Hancock MI | NDBC | 48.064 | -87.777 | 262 | Inner-Shelf | Discus | 3 | Magenotometer Only | 2D | yes |
| 45002 | N Michigan N Manitou Washington Islands | NDBC | 45.329 | -86.417 | 181 | Inner-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 45003 | N Hurion 37NM NE Alpena MI | NDBC | 45.350 | -82.838 | 146 | Inner-Shelf | Discus | 3 | Magenotometer Only | 2D | yes |
| 45004 | 78NM EW Marquette MI | NDBC | 47.572 | -86.550 | 212 | Inner-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 45005 | W Erie 28NM NW Cleveland, OH | NDBC | 41.677 | -82.398 | 13 | Inner-Shelf | Discus | 3 | Magenotometer Only | 2D | yes |
| 45006 | W Superior 48NM N Ironwood MI | NDBC | 47.348 | -89.825 | 178 | Inner-Shelf | Discus | 3 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 45007 | S Michigan 43NM SE Milwaukee, WI | NDBC | 42.676 | -87.025 | 165 | Inner-Shelf | Discus | 3 | Magenotometer Only | 2D | yes |
| 45008 | S Huron 43NM E Oscoda MI | NDBC | 44.289 | -82.415 | 58 | Inner-Shelf | Discus | 3 | Angular Rate Sensor | 2D | yes |
| 45012 | L Ontario 20NM NNE Rochester NY | NDBC | 43.621 | -77.406 | 145 | Inner-Shelf | Discus | 3 | Magenotometer Only | 2D | yes |
| 45132 | Port Stanley | Env. Canada | 42.483 | -81.233 | 21 | Inner-Shelf | Discus | 3 | | 1D | yes |
| 45135 | Prince Edward Pt | Env. Canada | 43.800 | -76.868 | 68 | Inner-Shelf | Discus | 3 | | 1D | yes |
| 45137 | Georgian Bay | Env. Canada | 45.550 | -81.001 | 55 | Inner-Shelf | Discus | 3 | | 1D | yes |
| 45139 | West Lake Ontario | Env. Canada | 43.277 | -79.540 | 35 | Inner-Shelf | Discus | 3 | | 1D | yes |
| 45142 | Port Colborne | Env. Canada | 42.734 | -79.350 | 27 | Inner-Shelf | Discus | 3 | | 1D | yes |
| 45143 | South Georgian Bay | Env. Canada | 44.950 | -80.633 | 37 | Inner-Shelf | Discus | 3 | | 1D | yes |
| 45147 | Lake St. Clair | Env. Canada | 42.417 | -82.668 | 6 | Inner-Shelf | WaveKeeper | 1.7 | TRIAXYS | 1D | yes |
| 45149 | Southern Lake Huron | Env. Canada | 43.550 | -82.083 | 58 | Inner-Shelf | WaveKeeper | 1.7 | TRIAXYS | 1D | yes |
| 68115 | New | | 42.465 | -79.961 | | Inner-Shelf | | | | 2D | |
| 68116 | New | | 43.543 | -78.891 | | Inner-Shelf | | | | 2D | |
| 68117 | New | | 44.425 | -86.928 | | Inner-Shelf | | | | 2D | |
| | **Carribean Sea** | | | | | | | | | | |
| 69114 | New - Ponce, Puerto Rico | | 17.500 | -66.500 | | Coastal | | | | 2D | |
| 69115 | New - San Juan, Puerto Rico | | 19.000 | -66.500 | | Coastal | | | | 2D | |
| 69165 | New - St Thomas, Virgin Islands | | 18.300 | -64.927 | | Coastal | | | | 2D | |
| 41040 | Western Atlantic | NDBC | 14.480 | -53.039 | 4,801 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41041 | Middle Atlantic | NDBC | 14.507 | -45.997 | 3,353 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41043 | Southwest Atlantic | NDBC | 21.989 | -65.014 | 5,259 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 41044 | NEW Hurricane Buoy (TO BE DEPLOYED) | NDBC | 21.200 | -58.000 | | Offshore | NOMAD | 6 | | 1D | yes |
| 42057 | Western Caribbean | NDBC | 16.834 | -81.501 | 293 | Offshore | Discus | 10 | Angular Rate Sensor | 2D | yes |
| 42058 | Central Caribbean | NDBC | 15.093 | -75.064 | 4,042 | Offshore | Discus | 10 | Angular Rate Sensor | 2D | yes |
| 42059 | Eastern Caribbean | NDBC | 15.006 | -67.496 | 4,900 | Offshore | NOMAD | 6 | Schaevitz LSOC_30 inclinometer | 1D | yes |
| 42060 | NEW Hurricane Buoy (TO BE DEPLOYED) | NDBC | 16.500 | -63.500 | | Offshore | NOMAD | 6 | | 1D | yes |



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