A Final Report on the Initial Development of the Pacific Islands Ocean Observing System (PacIOOS) Regional Coastal Ocean Observing System

NOAA Cooperative Agreement #NA07NOS4730207

Submitted by

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BACKGROUND

The distinctive beauty of the Pacific Islands reflects the unique setting of our land, ocean, tropical climate, and biological diversity. The Pacific Islands region covers a vast area of the globe—spanning six time zones across the Pacific Ocean; the region is bisected by the International Date Line, straddles all four hemispheres, is distributed over a surface area of nearly 35 million km^2 and includes 2,500 km of coastlines and over 2,300 individual islands (Figure 1). The Exclusive Economic Zone (EEZ) of the Pacific Island jurisdictions covers an area larger than the other ten regions of U.S. IOOS combined and Hawaii alone constitutes nearly $1/5^{th}$ of the total U.S. EEZ. The Pacific Islands are uniquely an ocean region; over 99% of the surface area is ocean. The vast majority of the land lies within 10 km of the shoreline and all the land in the region is within the coastal zone.

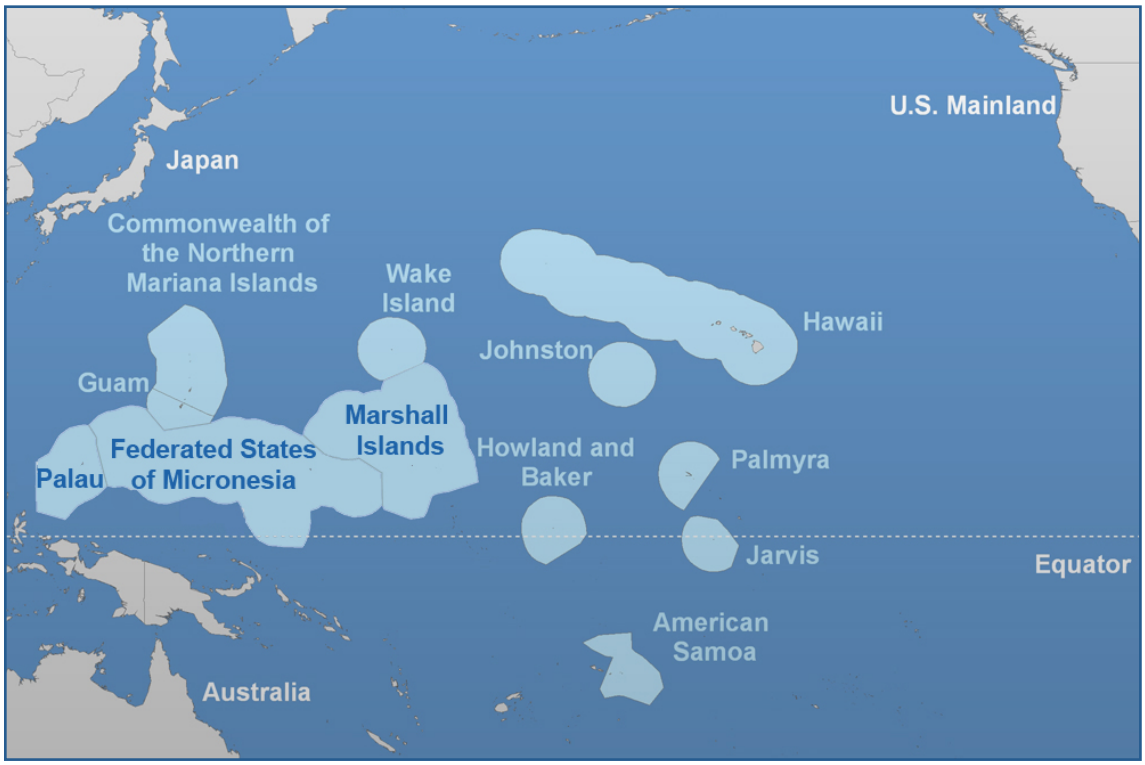

Figure 1: Constituent members and spatial distributions of the sub-regions comprising the PacIOOS regional association.

Each of the island constituents of the PacIOOS region is distinct in terms of their respective governments, languages, legal systems, geography, cultural norms, societal structure, economies, and infrastructural development needs. The extreme geographic extent and remoteness of most island locations, coupled with a variety of local and federal governance and economic realities, present both significant opportunities and challenges for the growth of regional programs. Human activity is tightly coupled to the marine ecosystem—we are the top predators, introduce nutrients and pollutants, redistribute sediments, alter environmental links between land and sea, impinge upon the natural biological order of the ecosystem and, in the process, increasingly expose ourselves, our visitors and our endemic biota to natural and anthropogenic hazards, ecological depletion, and environmental stress.

The Federal government has played a significant role in the Pacific since the end of World War II. As the islands and their economies are each considerably more isolated than continental cities of comparable size and population, Federal resources have been needed to create and sustain infrastructure that, in other regions, might be supported by state, county, or city governments. The Federal government also plays an important role in region-wide coordination in large part associated with military facilities and activities, weather services, fisheries and coastal zone management. As we continue to integrate coastal ocean information with ocean observing capabilities into a system that serves end users, we confront resource limitations that face other regions, as well as the special dependence on Federal resources uniquely endemic to the Pacific Islands.

PROJECT SUMMARY

Coastal ocean observing system development within the PacIOOS region was initiated in 2007 through this cooperative agreement between SOEST and NOAA to establish the Hawaii Ocean Observing System (HiOOS) as a pilot observing system of PacIOOS. Given the prohibitive cost associated with developing an observing system over *an area four times larger than the continental United States*, HiOOS was instead designed as a demonstration project within the larger PacIOOS region that could be jump-started by leveraging substantial SOEST capacity and partner assets/funding. Its development as part of the national IOOS network of regional coastal ocean observing systems was undertaken with the intent, following the initial demonstration phase, of transferring technology, expertise, and best practices, with adequate Federal support, to other archipelagos in the PacIOOS region.

The initial focus of the Hawaiian effort, similar to the current focus of the national IOOS program, has been on the provision of operational products to the public, private sector, and agencies to ensure for a safe, clean, productive ocean and resilient coastal zone for all. Early scoping meetings with multiple agency personnel, followed by sustained, iterative, participatory stakeholder engagement, led PacIOOS to implement regional modeling, sensor deployment, and data integration in four key product areas: *Coastal Ocean-State and Forecasting, Coastal Hazards and Resiliency, Water Quality Sensing, and Marine Ecosystem Information and Monitoring*. New sensors were deployed primarily along the south shore of Oahu, the regional center of population, commerce and tourism, with additional water quality sensors being deployed in each of the PacIOOS insular jurisdictions outside Hawaii to begin the expansion of capacity throughout the PacIOOS region (Table 1).

Table 1: IOOS-funded observing network assets deployed and operated by PacIOOS through this Cooperative Agreement. More information about system type, variables measured, and location can be found at http://oos.soest.hawaii.edu/pacioos/focus/

Component Group	Instrument Type	Variables Measured	Location(s)
Kilo Nalu	ADCP	currents (u,v,w)Ts,Dp,Tp	Kakaʻako, Oahu
	Thermistor	T	Kakaʻako, Oahu
	Seahorse Profiler	T,S,P,turbidity,DO, chlorophyll-a	Kakaʻako, Oahu
HF Radio	WERA	Surface currents (u,v),Ts, Dp, Tp	Kakaʻako, Oahu Barber's Point, Oahu Koko Head, Oahu
Water Quality	SBE 16+V2 with ECO FLNTUS	T,S,P, turbidity, chl-a	Waikiki Coast (x3) Cetti Bay, Guam (x1) Pago Pago, AS (x1) Saipan, CNMI (x1) Majuro, RMI (x1) Koror, Palau (x1) Pohnpei, FSM (x1)
	SBE16+V2 without ECO FLNTUS	T,S,P	Waikiki Coast (x2)
	PMEL-CO2 Buoy	T,S,P, DO, CO2, turbidity, chlorophyll-a, nutrients	Kāneʻohe Bay, Oahu Ala Wai, Oahu Kakaʻako, Oahu
Gliders	iRobot SeaGlider	T,S,P,DO, chlorophyll-a	Various
Waves, Water Level, and Coastal Hazards	Waverider Buoy	Ts,Dp,Tp,Ta,SST	Waimea Bay, Oahu Mokapu Point, Oahu Kaumalapau, Lanai
	Nortek Aquadopp	currents (u,v,w), P, T	Kalaelao Harbor, Oahu
	Nortek AWAC	currents (u,v,w), P, T	Barbers Point, Oahu
Coastal Hazards	T-LiDAR	coastal imagery	Waimea Bay, Oahu Waikiki Beach, Oahu
	Camera (PL-A741)	coastal imagery	Waimea Bay, Oahu Waikiki Beach, Oahu
Remus AUV	Remus AUV	T,S,P,DO,turbidity, chlorophyll-a, currents (u,v,w), bathymetry	Various (Waikiki)
Fish Telemetry	VR3S modem	data telemetry from tags	Various (Hawaiʻi FADs)
	Fish tags	T, P	Various

The initial observing efforts of PacIOOS were possible due to significant leveraging of existing (non-IOOS) ocean observing assets within the Pacific Islands Region including: the cabled Kilo Nalu Observatory (NSF/ONR), the CRIMP-CO2 system in Kaneohe Bay (NOAA/Sea Grant and PMEL), the Hawai'i Ocean Time Series (NSF), Coral Reef Ecosystem Integrated Observing System —CREIOS (NOAA-PIFSC), NOAA CO-OPS, the UH Sea Level Center (NOAA-JIMAR), CDIP, NOAA-NWS, the Ocean Tracking Network, and various county and state agencies (especially for water quality and fish tag monitoring at aggregation devices).

Annual funding at a level 40% less than the amount proposed limited the development of the PacIOOS pilot project as initially designed. However, substantial financial contributions by the University of Hawaii, the State of Hawaii, SOEST, the City and County of Honolulu, the DHS Center for Island, Maritime, and Extreme Environment Security (CIMES), the Joint Institute for Marine and Atmospheric Research (JIMAR), the UH Sea Grant College Program, and in-kind contributions by numerous PacIOOS partners have allowed for the successful demonstration of an end-to-end observing system pilot project that has achieved initial success in modeling, data management, outreach/education, project management and each of the aforementioned four key product areas and met all milestones, as detailed below, proposed in our de-scoped cooperative agreement.

ACCOMPLISHMENTS/MILESTONES

All milestones proposed through our annual descoped statements of work under this cooperative agreement have been met, as detailed in our semi-annual progress reports to the program office. A summary of key accomplishments, as it relates to observing, modeling, data management, and outreach system development, is included below.

CONDUCT REGULAR AUTONOMOUS OCEAN GLIDER MISSIONS

Beginning in September of 2007, PacIOOS has conducted ten 3-month long SeaGlider missions throughout the Hawaiian Islands using vehicles from the fleet of SOEST ocean gliders. The gliders have been critical to constraining the ROMS circulation model and provide data that is directly assimilated into ROMS forecasts. In addition to ingesting data from PacIOOS-supported missions, data from other agency/organization missions using the SOEST fleet were made available for model assimilation. While we originally proposed to have glider missions running continuously throughout each of the three-year program, decreases in annual funding forced us to scale back the frequency of our glider operations. Data from every glider mission PacIOOS has supported is available from our PacIOOS website. The direct URL to mission data is:
http://oos.soest.hawaii.edu/thredds/idd/glide.html

DEPLOY AND MAINTAIN OPERATIONAL HIGH FREQUENCY RADARS

High-Frequency radar systems were deployed at Koko Head (August 2009), Kaka'ako (December 2009), and Barber's Point (September 2010) to support surface current monitoring off the south shore of Oahu, Hawaii. All systems remain operational. The data from these three systems are uploaded to the National HFR server every hour and made available to the public via their website and our local PacIOOS website. Additionally,

data from our systems are served to the US Coast Guard search and rescue controllers in District 14 and Sector Honolulu through the USCG SAROPS system. Co-located with the HFR systems, PacIOOS has deployed AIS receivers to track AIS-transmitting vessels in the coastal ocean. This data is served in real-time via the PacIOOS data visualization system at www.pacioos.org/map.

CONDUCT REGULAR AND EVENT-DRIVEN AUV SURVEYS OF WATERS OFF WAIKIKI, HAWAII

Beginning in May 2008, PacIOOS supported 30 regular and event-driven surveys of the waters fronting Kaka'ako and Waikiki on the south shore of Oahu. Event-driven surveys were focused on examining the impact of significant rainfall and sewage spill events on the coastal waters of Waikiki. Regular and event-driven surveys gathered measurements of bathymetry, currents, optical backscatter (turbidity), temperature, and salinity. Data from each survey was processed and posted online. Data can be directly accessed at http://www.soest.hawaii.edu/OE/KiloNalu/AUV/RemusMissionList.htm

DEPLOY AND OPERATE WATER QUALITY STATIONS

PacIOOS supported the capitalization, deployment, and operation/maintenance of three water quality and CO_2 monitoring buoys (Kaneohe Bay, Ala Wai, and Kilo Nalu) and five nearshore water quality sensors (Hawaii Yacht Club, Waikiki Yacht Club, Hilton Waikiki, Waikiki Aquarium, and Hawaii Kai) in the waters surrounding Oahu. These systems each measured a subset of a range of variables, including temperature, depth, salinity, nutrients, dissolved oxygen, turbidity, chlorophyll, and carbon dioxide (air and water). Data from each system are made available through the PacIOOS website in near real-time at http://oos.soest.hawaii.edu/pacioos/focus/wq/ and can be downloaded at http://oos.soest.hawaii.edu/dchart/

DEVELOP HARBOR CONDITION FORECASTS

A water level station and current meter were installed in Barber's Point Harbor in June 2010 to assist with PacIOOS forecasting of harbor conditions. Data from these systems is used to forecast harbor surge, water level, and significant wave height within the harbor on a daily basis. Existing systems at Kaumalapau harbor are used to generate an identical prediction for that location. Data from these systems is available in real-time for harbor pilots and boat operators and can be seen at http://oos.soest.hawaii.edu/pacioos/focus/conditions/

DEVELOP WATER LEVEL, WAVE RUN-UP, AND INUNDATION FORECASTS

Using data from water level stations, regular T-LIDAR beach surveys, beach cameras, directional wave buoys, and focused empirical oceanographic surveys, PacIOOS developed high-water level and coastal inundation/flooding predictions for nine locations in the Pacific Islands region. 7-day forecasts of high water level at Hilo, Kawaihae, Honolulu, Kahului, Nawiliwili, Mokuoloe, Pago Pago, Kwajalein, and Majuro are available at http://oos.soest.hawaii.edu/pacioos/data_product/SLpred/. At two locations on Oahu (Waikiki and N. Shore) we developed 7-day forecasts of coastal inundation from wave run-up. Those forecasts can be seen at http://oos.soest.hawaii.edu/pacioos/data_product/SLpred/Wai_Exc.php.

DEPLOY AND OPERATE BEACH CAMERAS

Beginning November 2008, PacIOOS installed and has operated 2 high-resolution still cameras at Waimea Bay and Waikiki, both on Oahu. These cameras capture images from which our team can measure the maximum extent of wave inundation on the beaches. This data, when coupled with digital elevation models (DEMs) developed through regular T-LIDAR surveys, was an essential component in our development of wave inundation forecasts for Waikiki and Waimea. Image feeds from these cameras can be seen at http://oos.soest.hawaii.edu/pacioos/focus/conditions/livephotos.php.

DEVELOP AND MAINTAIN OPERATIONAL WEATHER FORECAST MODELING

With PacIOOS support, two operational weather forecast models were established for the Hawaiian Islands; the Regional Spectral Model/Mesoscale Spectral Model (RSM/MSM) and the Weather Research and Forecasting (WRF) model. Both were evaluated for accuracy and operability, and WRF was selected as the primary atmospheric forecast model for PacIOOS. During the second year of this cooperative agreement, WRF was engineered to assimilate meteorological data from the Hawaiian Islands to improve its forecast ability. WRF is still run operationally through PacIOOS for Hawaii, with expansion to the broader Pacific planned in years to come. Data from WRF is fed directly to the National Weather Service for use in their ensemble forecasting at the WFO Honolulu, and is available from the PacIOOS LAS, ERDDAP, and through the 'weather forecast' tab in our interactive data viewer at www.pacioos.org/map

DEVELOP AND MAINTAIN OPERATIONAL OCEAN CIRCULATION MODELING

The PacIOOS ocean modeling component uses the open source, community-supported Regional Ocean Modeling System (ROMS) to develop ocean circulation modeling ability in the region. ROMS is a free-surface, hydrostatic, primitive equation model discretized with a terrain-following vertical coordinate system. Forecasts include predictions of water temperature, ocean currents, salinity, and sea surface height. Daily, the near real-time observations from satellites, Argos, PacIOOS gliders, HF Radar, PacIOOS in-situ measurements, regional research cruises, and other available data sources are collected, processed, and assimilated into the model to improve forecast ability. ROMS is run for the Hawaiian Islands region, with nested grids covering Oahu and the population center of Honolulu. 7-day forecasts are generated daily with resolutions ranging from 60m to 4km. The model is in operation 24/7 and all data are served to NOAA's GNOME system, ERMA, the USCG SAROPS system, and are freely available for the public on the web through the PacIOOS LAS, ERRDAP, and at www.pacioos.org/map

DEVELOP AND MAINTAIN OPERATIONAL WAVE MODELING

PacIOOS development of wave modeling has focused on global, Hawaiian-regional, and individual island scales. Through a collaborative effort with NOAA/NCEP, and NWS Honolulu, we have implemented a global scale WW3 model. The global model is initialized 4 times daily: 0000, 0600, 1200, and 1800 Greenwich Mean Time (GMT), and is forced with NOAA/NCEP's global forecast system (GFS) winds. This model is designed to capture the large-scale ocean waves, provide spectral boundary conditions for the Hawaii regional WW3 model, and most importantly, generate a 7.5-day operational forecast. The primary purpose of the Hawaiian regional model is to capture the Island effects such as island

shadowing, refraction, and accurate modeling of local wind waves. Hawaii WW3 is forced with winds from the PacIOOS operational WRF model, which has a more suitable spatial resolution than the global scale wind field. Similar to Global WW3, Hawaii WW3 is run 4 times daily directly after Global WW3 and also provides a 7.5-day forecast. Hawaii WW3 is used to further nest into nearshore island scale models. In order to capture the shallow water effects and the nearshore coastal dynamics such as refracting, shoaling, and smaller scale shadowing, a high-resolution SWAN model is utilized to provide a 7.5-day forecast. All three wave models are operational and all data is served through the PacIOOS website via LAS, ERRDAP, and the PacIOOS data viewer (www.pacioos.org/map)

DEPLOY AND OPERATE A NETWORK OF REAL-TIME WAVE BUOYS

PacIOOS, through this cooperative agreement, deployed, operated, and maintained four directional wave buoys in the Hawaiian Islands (Waimea, Mokapu, Barber's Point and Kaumalapau). Data from each of these systems is sent in real-time to the Coastal Data Information Program (CDIP) at Scripps Institution of Oceanography and populated on the web via the CDIP portal (http://cdip.ucsd.edu/) and via www.pacioos.org. Additionally, these data are used to inform the prediction of harbor seiche and water level at Kaumalapau and Barber's Point. Additional assets, purchased by program partners, in Guam, Majuro, Hilo, and Kahului, now complement these systems.

ACOUSTIC TRACKING OF CETACEANS AND PELAGIC PREDATORS

PacIOOS is a partner in the Ocean Tracking Network (www.oceantrackingnetwork.org) and currently, with partners in SOEST, supports an array of automated acoustic receivers that span the whole of the Hawaiian archipelago, from Midway Atoll to the Island of Hawai'i, and include systems in the Republic of Palau. These receivers monitor the presence of fish tagged with acoustic transmitters that broadcast a unique identification code and other information (depth, water properties). PacIOOS regularly tags sharks and tuna in the Hawaiian Islands, and uses this array to monitor movements of ecologically important top predators. The data collected from this system are used to estimate transfer rates between areas, describe patterns of residency and associative behavior of groups of fish, to improve estimates of the population size, and to better inform local agencies regarding public safety issues with respect to sharks and fisheries. Additionally, PacIOOS has deployed two ecological acoustic recorders (hydrophones) off Oahu to monitor the acoustic signature of the ecosystem (as a proxy for ecosystem health) and track/identify vocal cetaceans. Data from these systems is being integrated into the PacIOOS data system (http://www.hawaii.edu/HIMB/ReefPredator/Hub.html) , and complements existing information available online related to monk seal movement (www.pacioos.org/map).

DEVELOP AND OPERATE ROBUST AND COMPLIANT DATA MANAGEMENT SYSTEM

Central to the PacIOOS effort, and critical to its success, is the link between data (instrument output) and information (data-synthesis products) in the data management system. The initial focus of the PacIOOS data management system has been to provide the architecture through which data from the observing network could be archived, evaluated, integrated, and transmitted to users in the form of raw data and refined products, including the development and maintenance of the PacIOOS web pages. The data management

system, which follows the 2005 Data Management and Communication Plan for IOOS and the 2009 PacIOOS Regional Data Management Plan, provides five essential functions: 1) data archive, 2) metadata management, 3) data discovery tools, 4) data transport servers, and 5) on-line browse capabilities.

DATA ARCHIVE

The PacIOOS data archiving activities encompass initial data collection (at the individual sensor), to entry into a database or file system, to final archiving at NDBC. There are two main types of data steams within PacIOOS, data from active sensors (funded primarily through IOOS) and data from external sources. The first category includes near-shore sensors, gliders, HFR, water quality buoys, acoustic devices, and numerical models. The second category includes a huge variety of maps, single point measurements, databases, etc., both one-time and repeat observations, and are in various stages of maturity (e.g., ranging from hard-copy plots to complete databases with standard metadata). PacIOOS initially divided these into two distinct efforts. One part of the data management team is focused on maintaining the IOOS-funded data streams while another part of the team is focused on acquiring existing data in the region, including legacy data sets and continuous measurements made by PacIOOS partners. These include, for example, State Department of Health water quality measurements, NOAA and NWHI National Monument ecosystem data, USGS stream flow data, and an extensive list of data from provider's region-wide. PacIOOS has relied on NDBC for long-term archive, as well as providing data via the GTS, for all locally collected data (although at present PacIOOS has not identified any users who subscribe to GTS).

METADATA MANAGEMENT

PacIOOS is actively engaged in providing the most accurate metadata for all data and data services. This has allowed PacIOOS to become one of the first regional programs integrating assets into the National Data Catalog (http://ioos.gov/catalog/). Both FGDC and ISO metadata standards are used at present, and we will continue to rely on existing standards for metadata.

DATA DISCOVERY TOOLS

Through this PacIOOS pilot project for Hawaii, and with funds for the initial development of the PacIOOS RA, two different data discovery tools have been developed. Both are web-browser based; one (focused on the Hawaii domain) is based on Google Maps and allows users to geographically search for existing assets and data (www.pacioos.org/map) while the other is Insular Pacific focused and based on map services (GeoServer; http://128.171.104.45:8080/geoserver/www/styler/index.html). These two services were constructed as complementary, but separate services, based on input received through several meetings with stakeholders and data providers. Given the successful development of the PacIOOS RCOOS and RA, we have begun the integration of these two systems into a single system served through the PacIOOS web-portal.

DATA TRANSPORT

PacIOOS is presently running three complimentary data servers that allow for direct, binary access to the data archive. Two are based on Data Access Protocol (DAPPER and OPeNDAP), while the third is based on the Open Geospatial Consortium (OGC) Sensor Observation Service (SOS). OPeNDAP services are handled with Thematic Real-time Environmental Distributed Data Services (THREDDS). Our implementation of THREDDS (http://oos.soest.hawaii.edu/thredds/catalog.html) provides both Web Coverage Services (WCS) and a simple Web Map Service (WMS). The SOS implementation that we have employed is based on the IOOS standard developed by the OOSTETHYS group (http://oos.soest.hawaii.edu/oostethys/). Initially PacIOOS used TDS for the gridded data (e.g., model output) and SOS for point measurements. However, we now serve both point measurements and gridded data via TDS and will continue further development of a more sophisticated map server for the wider Pacific region.

DATA BROWSE

The 2005 DMAC Plan specifies this component as providing users with a way to query data via web-based browsers. We interpret this more broadly to additionally include web page development and data product development (to provide users with information based on IOOS data). Web pages for PacIOOS will continue to be developed and maintained by the data management group. PacIOOS has employed three web-browsing tools: DChart (http://oos.soest.hawaii.edu/dchart/), Live Access Server (LAS; http://oos.soest.hawaii.edu/las/getUI.do) and the Environmental Research Division's Data Access Program (ERDDAP; http://oos.soest.hawaii.edu/erddap/info/index.html). All three allow for web-based data queries, sub-setting, plotting and data download. These servers access data both directly and through the PacIOOS TDS and we are continuing to expand the data holdings in these servers in concert with our regional liaisons and PacIOOS partners.

EDUCATION AND OUTREACH

Outreach efforts through this cooperative agreement have focused on two main areas: (1) working with the data management group, regional liaisons, and existing stakeholder focus groups to maintain and update effective data products, web-based information, and web services and, (2) increasing the impact of ongoing outreach efforts through effective PacIOOS and IOOS branding, distribution of public outreach materials (flyers, PSAs, flat panel displays, commercials, press releases, articles, web features), generation of a regular newsletter detailing PacIOOS success stories, and collaboration with existing regional and national ocean outreach initiatives.

The education and outreach team, in cooperation with the web and product developers within the data management group, have worked with focus groups to refine web content and product design and continue that regular engagement. The feedback received in these regular meetings, coupled with annual feedback from the larger stakeholder community at regional meetings, is a critical component that allows PacIOOS to modify and fine-tune its products in response to user input.

Interpretation of real-time data and ocean observing products is an important part of the education and outreach mission. One area of successful development during this performance period has focused on placing real-time data in a larger temporal and spatial context through the development of a Hawaii Ocean Atlas (http://oos.soest.hawaii.edu/pacioos/outreach/oceanatlas/index.php). In the future, we plan to continue the development of this Ocean Atlas for each of the jurisdictions within the Pacific Islands region, populating the Atlas through the use of existing real-time observations and data derived from historical studies and observing programs.

Many efforts have been initiated to increase awareness for PacIOOS products and activities during the initial phase of system development. Public presentations and lectures showcasing PacIOOS developed products have been a consistent part of our outreach effort. We have generated a regular PacIOOS Newsletter. Partners have provided 10 high-definition flat panel machines on which to display ocean observing public information products and community-specific data visualizations and we are in the process of developing content for and negotiating the deployment of those systems in high traffic areas (Waikiki Aquarium, College of the Marshall Islands, Palau International Coral Reef Center, American Samoa Public Library, Outrigger Hotels, Waikiki and Hawaii Yacht Clubs, Pacific Marine Resources Institute of Saipan). We are collaborating with local agencies and the regional NOAA team to populate those machines with additional content complementary to PacIOOS efforts.

As concerned residents of the Pacific Islands region, we are dedicated to the "K through Gray" education of our public so that present and successive generations may make informed choices to enhance the use and preservation of the life-sustaining resource that is our ocean. As educators at various universities throughout the region, we are also dedicated to the preparation of our primary and secondary students and education of undergraduate and graduate students. PacIOOS has been involved in the collaborative generation of primary school curriculum through the NOAA-funded Navigating Change Program. PacIOOS provides a foundation for research experiences for both undergraduate students at the University of Guam, the 10-campus University of Hawaii system, the College of Micronesia, the College of the Marshall Islands, and the American Samoa Community College.

KEY OUTCOMES

Hundreds of partners and agencies throughout the region use PacIOOS data and information for real-time and process-oriented decision making on a regular basis. In the past five years, PacIOOS websites have been accessed hundreds of thousands of times by over 20,000 unique individuals. It would not be possible to capture the scope of the impact of this initial PacIOOS development effort in the pages of this report and mere numbers fail to quantify the value of PacIOOS services. In an effort to illustrate some of our impact we have included three success stories on the use of our data and information by stakeholders. These stories are just three of many, covering the full range of PacIOOS thematic activities, our team has assembled in the past few years.

Protecting Palau's Ecosystems through Shark Tracking

Backed by the people of Palau, in mid 2000's, Palau passed laws and established regulations to ban shark fining and prohibit the use of steel leaders on long line fishing vessels. More recently, Palau received international attention and recognition as the world's first shark sanctuary after President Johnson Toribiong declared Palau to be a Shark Sanctuary during his address to the United Nations 64th General Assembly on September 25, 2009. As a shark sanctuary, all sharks within the territorial waters of Palau are protected from any fishing activity. However, the local government is limited in its efforts to monitor and to effectively manage the shark populations. In response, a devoted group of organizations are working to understand more about the ecology of these sharks and the effectiveness of the Sanctuary through acoustic tagging.

An international team of researchers, conservationists, commercial dive operators, and government agencies has joined together to deploy and operate an array of acoustic devices to monitor the movement of sharks in the waters of Palau. The Micronesian Shark Foundation, the Save Our Seas Foundation, and the Australian Institute of Marine Sciences established the 14-station acoustic array in the waters of Palau. In an effort to support Palau's world-leading effort to conserve and protect sharks within their EEZ, PacIOOS contributed 4 receivers and 4 tags to augment the existing array and increase spatial coverage of the observing efforts.

The PacIOOS contribution expands the range of acoustic arrays, providing a more precise and complete picture of shark movement in the Palauan archipelago. The results aid in improving shark populations, overall ecosystem health, and in evaluating the effectiveness of the Sanctuary. It also allows for the monitoring of other megafuana in the region, including manta rays and dugongs. Public awareness and participation are also on the rise with our partner's citizen science and outreach efforts.

Wave Observations to Support Economic Efficiency, Public Safety, and Environmental Protection

The Kaumalapau Harbor on Lanai is the most exposed harbor in the State of Hawaii. The Lanai Oil Company authorizes fuel barges to enter the harbor 24 hours prior to arrival. Knowing the expected surge conditions in the harbor for the barge's arrival is a critical component. In years past, the Lanai Oil Company would return 2-3 barges a year to Honolulu still full of fuel because ocean conditions were too rough to safely enter the harbor. This cost ~$22,000 each time, a very large expense to the small fuel operations and the people of Lanai.

In response, PacIOOS and the University of Hawaii (UH) deployed a wave buoy just outside the Kaumalapau Harbor in 2007. This is one of six wave buoys operated by PacIOOS and UH around the Hawaiian Islands. The wave buoy provides real-time information on the wave heights, direction and period. Terry McBarnet, President of the Lanai Oil Company, discussed the value of the buoy to his operations: "This information is extremely helpful in predicting the surge conditions within the harbor. By taking the swell forecast 24 hours before the barge will arrive and comparing that information to what we

see on the wave buoy, it helps us predict the surge conditions during that critical period when the barge will be pumping fuel into our storage tanks."

Since the deployment of the buoy in 2007, barge companies know ahead of time when they can safely make the drop off and have not had to return a single barge. In addition to cost savings, the information improves crew safety and reduces threats of barge damage or oil spills.

This effort greatly complements the PacIOOS goal to improve the safety and efficiency of marine operations through applied observations. PacIOOS will continue to collaborate with partners to fund and deploy similar technology as well as assure the delivery of accurate data through sophisticated, but user-friendly portals.

Providing Ocean Current Data to Assist Search and Rescue Operations

The U.S. Coast Guard (USCG) provides emergency planning and response for search and rescue missions in the Pacific Islands using SAROPS, the Search and Rescue Optimal Planning System. In order to reach their goal of saving at least 93% of all people whose lives are in distress, the USCG strives to incorporate the most accurate oceanographic data into SAROPS.

At the request of the USCG, PacIOOS integrated state-of-the-art technology, the High-Frequency Radar (HFR) systems into SAROPS. HFR technology measures surface current speed and direction in near real-time. PacIOOS provides the data in a compatible format for use in SAROPS. Recognizing the value of this partnership, Captain David Swatland acknowledged, "Easy access to near real-time, comprehensive data on the marine environment is critical to our missions."

Tests in the mid-Atlantic region showed that the inclusion of HFR data into the SAROPS system decreased search areas by 66% over 96 hours. HFR enables ocean current tracking in near real-time, thus aiding search and rescue crews in mapping the probability path of people lost at sea. Knowing how currents will move people or life rafts in the water reduces the area that rescue crews must search for survivors. Combing less area takes less time and increases the chance of saving lives.

PARTNERSHIPS

Dedicated partners of PacIOOS listed below have been instrumental in the initial development of ocean observing capacity in the Pacific Islands region and have provided resources and funds for component systems, contributed data and/or products, maintained and managed observing instrumentation, assisted in planning or served on the PacIOOS Governing Council (whose Members are shown in **bold**).

Federal: NOAA (**Pacific Islands Fisheries Science Center—Coral Reef Ecosystem Division**, IDEA Center, National Data Buoy Center, National Weather Service, Pacific Marine Environmental Lab, CO-OPS, Pacific Services Center, National Marine Sanctuary Program, Pacific Islands Benthic Habitat Mapping Center, Coastal Storms Program), **US Army Corps of Engineers**, US Coast Guard, US Navy (Oceanographic Office, Joint Typhoon Warning Center, Naval Maritime Forecast Center, Office of Naval Research, Pacific Command), US Geological Survey, Environmental Protection Agency 9th District, Department of Homeland Security (National Center for Island, Maritime, and Extreme Environment Security (CIMES), Federal Emergency Management Agency), **Western Pacific Regional Fishery Management Council,** National Park Service, National Science Foundation, US Department of Agriculture

State: Department of Land and Natural Resources, Department of Health, Ocean Resources Management Plan (Office of Planning), **Department of Transportation – Harbors**, Hawaii Community Development Authority, Hawai'i State Civil Defense, Pacific Disaster Center, **Marine and Coastal Zone Advocacy Council, State Office of Planning—Coastal Zone Management Program**, University of Hawai'i (**SOEST**, Hawai'i Institute of Marine Biology, Joint Institute for Marine and Atmospheric Research, Infrasound Laboratory, UH Sea Level Center, International Pacific Research Center, EPSCoR, Hawaii Mapping Research Group, UH Sea Grant College Program, Pacific Aquaculture and Coastal Resources Center, Waikiki Aquarium)

Territorial: **American Samoa Environmental Protection Agency**, American Samoa Community College, American Samoa Department of Marine and Wildlife Resources, American Samoa Department of Commerce, American Samoa Coral Reef Task Force, University of Guam, **Office of the Governor of Guam**, Guam Bureau of Planning and Statistics**, Office of the Governor of the Commonwealth of the Northern Mariana Islands**, CNMI Coastal Resources Management Office, CNMI Department of Environmental Quality

International: **College of the Marshall Islands**, Marshall Islands Department of Justice, Marshall Islands Sea Patrol, Marshall Islands Coastal Management Advisory Council, **College of Micronesia**, **Palau International Coral Reef Center,** Palau Automated Land and Resource Information System

Local: County of Hawai'i (Office of Planning), County of Maui (Office of Planning, Office of the Mayor), City and County of Honolulu (Board of Water Supply, Department of Environmental Services, Ocean Safety Division), County of Kauai (Office of Planning, Ocean Safety Division)

NGO: Alliance for Coastal Technologies, Conservation Society of Pohnpei, **Hawaii Harbor's User's Group**, Marine and Environmental Research Institute of Pohnpei, Mariana Islands Nature Alliance (MINA), Pacific Marine Resources Institute (PMRI), Yap Community Development Program

Private: Atlantis Adventures, Guam Fisherman's Cooperative, Hilton Hawaiian Village, Honolulu Yacht Club, **Liquid Robotics Inc., Outrigger Hotels and Resorts,** Sea Engineering, Sheraton Waikiki Hotel, Waikiki Yacht Club

EQUIPMENT

All equipment proposed to be purchased under the annual revised budgets and work statements has been purchased, deployed and/or put in to service, consistently maintained in good working order, and is presently being used by PacIOOS under award NA11NOS0120039. All equipment was purchased by the University of Hawaii and remains in the inventory of the University, for exclusive use by PacIOOS.

FINANCIAL STATEMENT

Final financial reports have been submitted to NOAA's Grants Management Division via Grants Online, and a final funding draw down has been made through the Automated Standard Application for Payments (ASAP). Expenditures under this award totaled $5,268,224.90.