TITLE PAGE (Proposal Cover Sheet).

Proposal submitted to Coastal Services Center, National Oceanographic and Atmospheric Administration (NOAA), Department of Commerce

Pursuant to FY 2007 Regional Integrated Ocean Observing System Development

Developing the Hawaii-Pacific Ocean Observing and Information System

Lead Principal Investigator:
Dr. Brian Taylor
University of Hawaii
Dean, School of Ocean & Earth Science & Technology (SOEST)
1680 East-West Road
Honolulu, Hawaii 96822
Email: taylorb@hawaii.edu
Phone: 808-956-6182
Fax: 808-956-9152

Names and Institutions of all Co-Principal Investigators

Dr. Bruce Appelgate, Director, SOEST Ocean Technology Group
Dr. Whitlow Au, Researcher, Hawaii Institute of Marine Biology
Dr. Benjamin Brooks, Assistant Researcher, Hawaii Institute of Geophysics and Planetology
Dr. Eric DeCarlo, Researcher, Department of Oceanography
Dr. Margo Edwards, Researcher, Hawaii Institute of Geophysics and Planetology,
Dr. Pierre Flament, Professor, Department of Oceanography
Dr. Charles Fletcher, Professor and Chair, Department of Geology and Geophysics
Dr. Kim Holland, Researcher, Hawaii Institute of Marine Biology
Dr. Roger Lukas, Professor, Department of Oceanography
Dr. Doug Luther, Professor, Department of Oceanography
Dr. Margaret McManus, Assistant Professor, Department of Oceanography
Dr. Mark Merrifield, Professor, Department of Oceanography
Dr. Geno Pawlak, Assistant Professor, Department of Ocean and Resources Engineering
Dr. Jim Potemra, Assistant Researcher, International Pacific Research Center
Dr. John Sibert, Manager, Pelagic Fisheries Research Program, Joint Institute for Marine and Atmospheric Research
Dr. Grieg Steward, Assistant Professor, Department of Oceanography

Focus Area 1: Regional Coastal Ocean Observing Systems (RCOOS) Development.

2. PROJECT SUMMARY.

a. Project Name/Title

Developing the Hawaii-Pacific Ocean Observing and Information System

b. Recipient Institution

University of Hawaii

c. Primary Contact (name, address, phone, fax, e-mail)

Dr. Brian Taylor, Dean, School of Ocean & Earth Science & Technology, 1680 East-West Road, Honolulu, Hawaii 96822 Phone: 808-956-6182; Fax: 808-956-9152; taylorb@hawaii.edu

d. Brief Project Summary including objectives and intended benefits

The School of Ocean and Earth Science and Technology at the University of Hawaii, with collaborators at local, state, and federal agencies, proposes to develop a regional ocean observing system. This regional ocean observing system will be developed initially for the state of Hawaii. This system will eventually extend to the larger Pacific Integrated Ocean Observing System Region (PacIOOS) in consultation with the PacIOOS association. The goal of this work is to provide operational products that assist agencies charged with responsibility for the safe, clean, and productive capacity of Hawaii's coastal ocean and shoreline. Scoping meetings with agency personnel identified a need for products that aid authorities, residents, and visitors in making the most informed decisions for general planning, and especially in times of crises or extreme events (e.g., hurricanes and tsunamis). To address this need, product development will focus in four thematic areas: Coastal Ocean-State and Forecast; Coastal Resiliency; Automated Water Quality Sensing; and Marine Ecosystem Stewardship. These four thematic areas constitute critical decision-making sectors, which would benefit from the delivery, in real or near-real time, of data and derived products using a suite of *in-situ* measurements and data-assimilating models. Over the three years of the project, a sequence of information product streams will be developed, enabled, and set into operational mode for the use of partners. An early example of such a product is found at hawaiibeachsafety.org

e. Partners

City & County of Honolulu: Civil Defense, Emergency Services, Environmental Services, Ocean Safety Division Planning and Permitting, Public Works

State of Hawaii: Civil Defense, Coastal Zone Management, Department of Health, Departments of Transportation and Land and Natural Resources

Federal: NOAA/ CO-OPS CRED, IDEA NOAA/ NDBC, NMFS, NWS, PDC, PMEL
Coastal Data Information Program, HYCOM consortium, Naval Research Laboratory
National Safe Boating Council, Ocean Watch, US Coast Guard, Western Pacific Regional Fishery Management Council

3. PROJECT DESCRIPTION.

a. Goal(s) and Objective(s).

Hawaii's Unique Ocean Status: The Hawaii and Pacific U.S. Flag Islands Region encompasses a large fraction of the US Exclusive Economic Zone (EEZ) (Figure 1A, APPENDIX 1). It includes a rich diversity of cultures, legal systems, economies, and agencies (public and private), highly dependent on coastal ocean information. Because this is predominantly an ocean region, wherein the large majority of inhabitants live within a few miles of the shore, an integrated observing system will have immediate and far-reaching societal benefits.

The Federal government has played a significant role in the Pacific since the end of World War II. Because 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 management, and coastal zone management. As we integrate useful Hawaii and Pacific coastal ocean information with ocean observing capabilities into a system that serves end users, we confront the resource limitations that face other regions, as well as the special dependence on Federal resources endemic to the Pacific islands.

Knowledge of the current and future state of the coastal ocean is essential for facilitating safe, healthy and productive coastal activities. This is especially the case for Hawaii, which is truly an ocean state: The Hawaiian Archipelago stretches 2451 km from Hawaii Island to Kure Atoll - the Hawaii EEZ is more than 2 million square kilometers, almost one-fifth of the United States' entire EEZ. We strive for accurate assessments of the present state of Hawaii's vast coastal ocean and for skillful forecasts of conditions throughout the Hawaii EEZ. Our vision is to enable an ocean-literate and well-informed population and policy makers. Ultimately, we envision expanding these initial efforts throughout the PacIOOS region in collaboration with the region's many stakeholders.

Catalyst Projects: Our primary objective is to integrate and expand ocean observing and forecasting among the Pacific Islands, beginning with four 'catalyst' projects focused initially on waters extending off the southern shore of Oahu, Hawaii's most populous island. Catalyst projects are integrated and support one another to enhance community capabilities in: 1) Coastal ocean-state and forecast, 2) Coastal resiliency, 3) Automated water quality sensing, and 4) Marine ecosystem stewardship. These projects will result in nearshore and offshore safety products, shipping and marine commerce products, water quality support tools, marine ecosystem indicators and products, and marine inundation forecasts and planning tools.

Coastal Ocean-State and Forecast will focus on the needs of shipping, tourism, coastal management, ocean safety, pollution control, and search and rescue operations. Utilizing a proposed array of high frequency radars along with gliders, wave buoys, coastal cameras, and numerical models this project will monitor, model, and predict channel and nearshore circulation, waves, coastal run-up, and water levels. Observations and model output will feed into a dynamic, web-based coastal ocean atlas providing interpretive products such as most-efficient inter-island shipping lanes, hazardous conditions at beaches and in harbors, pollutant dispersion, and high water levels in vulnerable communities.

Coastal Resiliency is focused on improving community preparedness for marine hazards and the impacts of climate change. A major problem facing island communities is inundation by high water levels associated with extreme tides, high waves, storm surge and tsunami, and rising sea level. Resiliency products include: frequently updated maps of specific beach safety conditions (see hawaiibeachsafety.org for an early example); coastal inundation and erosion alerts; and vulnerability projections related to sea-level rise, chronic erosion, and high wave and water level events. Resiliency products are designed to improve community development, disaster mitigation planning, and transportation logistics.

Automated Water Quality Sensing will expand and implement modifications of existing coastal water quality monitoring. Data, delivered in near-real time web products, will mitigate the problem caused by delays between the initial identification of potential water quality altering events, sampling and implementation of water quality alerts. In the case of sewage or oil-spills, these delays can lead to unnecessary closure of uncontaminated beaches or failure to promptly close those that are contaminated. The proposed system, when combined with circulation models, will provide early warning of impending water quality problems, improve prediction of affected areas, and decrease response time for mitigation efforts.

Marine Ecosystem Stewardship will expand existing fish tracking and cetacean monitoring arrays. Stewardship products will include fishing and marine mammal forecasts. The intent is to provide data to support forecas ts of environmental fluctuation and long-term climate change on living marine resources.

Products: The following generalized products will be tailored to user specifications and made available through the on-line Hawaii Ocean Observing System Atlas:

a. State-wide ocean and coastal state forecasts using nested model output;
b. Barbers Point and Honolulu Harbor wave & water level conditions;
c. Mamala Bay circulation, wave state, wind, and precipitation including the following user interfaces:
    i. Search and rescue vectors,
    ii. Pollution dispersion,
    iii. Most efficient route vectors;
d. Waikiki Beach circulation and wave state updated several times hourly, including:
    i. Difference maps showing developing conditions;
e. State-wide beach and nearshore safety conditions;
f. Near real-time water quality and plume dispersion data/maps for Waikiki and Honolulu coastal waters;
g. Marine inundation forecasts;
h. Coastal vulnerability maps based on sea-level rise scenarios;
i. Highly resolved Hawaii sea-level rise time series;
j. Acoustic monitoring and near-real time forecasts of the movement and congregation of marine mammals near Oahu;
k. Times, locations and quantities of congregating predatory fish (tunas, marlins, sharks) near Oahu.

b. Background.

Hawaii's immense beauty reflects the unique setting of our land, ocean, climate, and biological diversity. Coastal waters, low shore lands, and steep watersheds strongly influence each other and are modulated by the character of our land use. Hawaii is not vast. Almost half the land lies within 5 miles of the shoreline and no point is further than 29 miles from the sea. This is significant as it means that terrestrial and marine environments are closely linked and human actions may have unintended rapid and far-reaching impacts. We introduce pollutants, block the natural migration of some materials and accelerate others, alter environmental links between land and sea, and in the process expose ourselves and our visitors to hazards, ecological depletion and environmental pollution.

Assisting Stakeholders: The goal of a regional ocean observing system is to assist federal, state, and local authorities in understanding and managing these major challenges. This requires efficient integration of observations, data management and communication, modeling and analysis to provide operational products of high quality and reliability. Hawaii's most significant management challenges are focused in the coastal zone and channel waters that link the islands. Hence, it is critically important to enhance and promote an ability to accurately observe and forecast coastal and regional ocean conditions. Our ultimate goal is to provide comprehensive, quantitative descriptions of inter-island currents, waves, nearshore circulation, run-up, and water levels in near-real time, and in high resolution. From this basis can emerge products to facilitate coastal ocean-state forecasts, improve coastal resiliency, track coastal water quality, and enhance marine ecosystem stewardship.

In the development of this proposal, a year of scientific retreats, interagency meetings, and one on one communications between investigators and partners led to identification of the four catalyst projects focusing on observing and modeling the ocean, reducing hazard vulnerability, monitoring water quality, and managing marine ecosystems. To enhance the scope and immediate utility of the project a decision was made to put initial emphasis on Mamala Bay, the southern shore of Hawaii's most populous island, Oahu, with elements extending to other appropriate coastal regions in Hawaii as possible and appropriate within the context of an archipelagic-scale sea-state forecasting ability. Meetings with stakeholders led to an observing system with three interrelated components: 1) <u>Regional and Coastal Observations</u>, 2) <u>Modeling</u>, and 3) <u>Data Management and Product Development</u>.

Regional and coastal observations will be captured by a network of nearshore sensors including autonomous vehicles, acoustic-tracking networks, water-quality monitors, a high frequency coastal radar system, digital cameras and T-LIDAR surveys, an infrared camera, water-level stations, and wave and current gauges. Instruments will measure a range of physical, biological and chemical parameters, delivered in near-real time to a data management system. This information will be used for model assimilation, model validation and product development and delivery.

Modeling will consist of three coupled sub-models: a) an ocean circulation model of progressively finer resolution, b) a regional high-resolution atmospheric model, and c) a regional-to-shoreline series of wave models and empirical run-up forecasts.

Data management and product development will include an alliance with the Pacific Services Center and the NOAA IDEA Center. The collaboration will lead to development of an integrated data archiving and serving system to disseminate data and products to stakeholders. Data servers will handle internal data sharing between the observational and modeling components, and will include web-based and binary transfer servers in compliance with DMAC standards.

Present Situation: The proposed Hawaii Ocean Observing System will leverage a significant array of existing ocean observing instruments (Figure 1, APPENDIX 1). Nevertheless, there are large data voids in Hawaii's coastal ocean. With the exception of satellite observations of sea surface temperature and sea surface height, there are no continuous observations from which maps of ocean state variables can be made at any useful resolution. For other conditions such as ocean currents, and for all subsurface variables, the approach to providing spatial maps requires statistical or dynamic models and/or new observations. Similar voids exist in water quality observations around Oahu, with only two systems at the Kilo Nalu Observatory (http://www.soest.hawaii.edu/OE/KiloNalu/research.htm) and CRIMP-CO_2 in Kaneohe Bay (http://www.pmel.noaa.gov/co2/coastal/kbay/) currently producing time series data. These data streams must be complemented by synoptic data gathering to provide useful spatially resolved products to end users.

Circulation, sea level, temperature and salinity fields from the operational models developed by the Naval Research Laboratory (NLOM, NCOM) and run operationally by NavOceano are available through arrangements with the International Pacific Research Center (IPRC) within SOEST. However, these data assimilation and model products do not provide spatial resolution necessary for the ocean information products that are of most interest to Hawaii's coastal ocean users.

NOAA's Wave Watch III provides basin-scale wave spectral state and forecast information, but at a resolution that is too coarse for detailed use within island groups. Surfline, an online surf-forecast service, provides a similar product (with vastly superior graphical interface) by subscription, and they also provide a high-resolution product that considers the refraction and diffraction of waves in the coastal regime. Unfortunately, these products do not extend into the nearshore (shoreward of the locations where waves begin to break), so their use by Ocean Safety, Civil Defense, Planning, and Water Quality agencies is limited and based largely on the judgment of a few experienced individuals.

As for product delivery, some existing web portals currently serve ocean data products, but relatively few ocean state information products are available to Hawaii end users. NOAA information products such as advisories provided by the Pacific Tsunami Warning Center and marine weather information and forecasts provided by the National Weather Service are available. There are, however, needs for critical ocean information products that are not being met.

Implementing a New Modeling Environment: Hawaii's coastal ocean has distinct physical regimes and features that are unique to tropical islands. For example, local atmospheric processes cause small-scale modulations in the fluxes of heat, momentum, rain, and evaporation. Remotely-forced swells are transformed by complex island topography, ultimately dissipating their energy on Hawaii's reefs and shorelines. These processes in turn induce small-scale phenomena that modify transport, mixing, and residence time in coastal waters and affect the distribution of heat, momentum, freshwater, nutrients, sediment, pollutants, and ultimately, marine ecologies.

Modeling of oceanic processes for island coasts is particularly challenging because shelves are narrow and the bathymetry irregular. For example, deep ocean currents, local wind forcing and wind gradient effects, and wave-driven flows can all affect circulation across the entire shelf of an island. Tidal flows are sometimes strongly modified in the vicinity of islands, and unique mechanisms for generating energetic internal tides have been identified. Island-trapped waves have now been observed at a number of sites. Only through the development of appropriate physical models and data assimilation techniques can the complex circulation near islands be quantitatively assessed and forecast.

The impact of hurricanes, large swell, and tsunamis on coastal communities and marine environments is also a major concern. More change to a coastal environment can occur during a single high-energy event than over an entire season. These impacts will likely increase in regions where sea level is rising. The relationship between climate variation and changes in extreme inundation events is an important factor.

Similarly, the shorter and longer term impacts of sudden changes in water quality associated with extreme runoff or sewage spills represent an important concern of local and state decision makers. For example, large scale pollutant discharges such as the 48 million gallons of raw sewage pumped into the Ala Wai Canal in March 2006 led to terrible water quality conditions that have been aggravated by excessive runoff associated with unusually heavy rains. This particular episode led to water contamination postings and closure of numerous Waikiki beaches for several months, adversely affecting the use of aquatic resources by tourists and local residents alike. The complex relationship between the stratification ensuing from spills and freshwater runoff, climatic variations at various spatial and temporal scales as well as physical forcing processes that affect the fate and distribution of such inputs to the marine environment remains poorly understood and yet is of vital importance to the health, safety and economic welfare of our island communities.

To capture these complexities and quantify their effects, it is necessary to build an integrated suite of models. The need for high model resolution in the nearshore region as well as the need to account for large-scale circulation changes requires a nested approach, both for the ocean and for atmospheric forcing. High quality and high-resolution physical state assessments and forecasts are a required core element of any regional coastal ocean observing system and will form the basis for a broad array of products to enhance shipping, harbor management, search and rescue, nearshore ocean safety, forecasts of coastal inundation and erosion, water quality tracking and forecasting, mitigating vulnerability to climate change, and ecosystem stewardship.

c. Audience.

Emergency responders identify drownings as the #1 preventable cause of death among visitors and residents. County planning departments cite coastal erosion, sea-level rise, and the lack of appropriate setbacks as major management challenges. State and county water quality personnel and environmental groups recall the 2006 spill of 48 million gallons of raw sewage into Waikiki waters and ask for real-time monitoring of water quality and knowledge of the fate of such spills and their effects. Island communities and transportation officials point to the marine commerce industry as providing a lifeline of food and necessities between the mainland and Hawaii and along the island chain. Harbor masters and boat owners desire accurate predictions of the seiche amplitudes in their harbors forced by winds, high swell and tsunamis.

The users for ocean observing products are spread across all levels of government, the ocean recreation and commerce communities, the hotel and tourism industry, the media, residents and visitors, and nongovernmental organizations. Despite their diversity and range of interests, this audience is asking for increasingly focused, innovative, and highly accurate products upon which to base decision-making, planning, user safety, and future cultural and community emphasis. In all cases, partners and investigators recognize that web-based, dynamic and frequently updated map-oriented products can provide ocean end users with an improved basis for decision-making and planning.

d. Approach.

Regional and Coastal Observations:

Coastal Ocean-State and Forecast*:* Utilizing a proposed array of high frequency radars along with gliders, wave buoys, coastal cameras, and numerical models this project will monitor, model, and predict channel and nearshore circulation, waves, coastal run-up, and water levels. A critical aspect of this proposal is the use of high frequency (HF) Doppler radars for observing surface currents along the south shore of Oahu. These will measure surface currents to at least 100 km from the island, with an averaging time of 1/4 hour. They consist of a low power transmitter (< 30 W) sending radio waves in the 10 to 150 MHz frequency band, and receivers listening to the signal backscattered from ocean waves. The return signal is Doppler-shifted by wave propagation and by surface currents, and also contains information on wind direction and wave spectrum. Two or more radars are used to construct maps of vector currents, and two-dimensional wave spectra. The data will be processed in real time, yielding derived products (currents, wind direction, wave spectra) that will be made available in the Hawaii Ocean Observing System Atlas, and, more importantly, will be used in the generation of data products (a) through (g) listed on page 3. The domain will be covered by implementing two radars configured at low frequency (8-16 MHz), operated in long-range (>100 km) medium resolution (1 km) mode, strategically placed at the principal headlands Barbers Point and Koko Head. A third very high frequency (50- 150 MHz) radar will be operated at reduced range (<20 km) but very high resolution (< 100 m) from a site in Waikiki, to increase surface map detail and resolve cross-shore flows in this important area. Building up on the experience gained during a pilot deployment in 2003 along the west shore of Oahu, the radars will be of the WERA type (Gurgel et al., 1999). One radar will be provided cost-free for this project, from the existing equipment pool of the University of Hawaii.

Two autonomous ocean gliders owned by SOEST will be employed for additional data collection to provide regional spatial information, as well as time series information at fixed locations ("virtual moorings"; Figure 1C, APPENDIX 1). The Seagliders use Sea Bird CTDs to measure conductivity, temperature, and pressure and thus derive salinity, density and sound speed. Each glider also carries a dissolved oxygen sensor (SBE-43) and a fluorometer/backscatter sensor (WET Labs BB2F). GPS measurements taken between dives allow surface currents to be estimated. After each dive, the gliders communicate via Iridium satellite to a ground station, where data are quality-controlled, archived, and made available in near-real time via the Internet to the public and to other members of our team for additional product development. Seagliders can collect data to 1000 m depth. By diving deeply, the gliders escape strong surface currents and make headway along desired transects. Seagliders have been operated continuously at sea for up to 6 months, and have successfully operated through typhoons. After each dive, the gliders communicate via Iridium satellite to a ground station, where data are uploaded, archived, and made available in near-real time via the Internet.

To validate regional forecasts of wave conditions and improve boundary conditions, three Datawell directional wave buoys will be utilized. Two buoys are in place off east and north shores of Oahu, covering northwest swell and higher frequency trade wind waves. A third buoy will be installed off the east coast of Lanai in May 2007 (in a U.S. Army Corps of Engineers project) to provide information on swell arrivals from the southern hemisphere. Buoys report directional wave spectra at 30-minute intervals via radio link to shore stations. Equipment and installation costs are provided through other projects (ONR, Army Corps), and funding is sought in this proposal to maintain these buoys in an operational mode. Acquisition and data quality control will be handled through a subcontract with the Coastal Data Information Program, a collaborator with UH in establishing the buoys. Wave conditions shoreward of the breaker zone will be monitored at high priority locations using video cameras similar to those used in the well-tested Argus system developed at Oregon State University (Dail et *al*., 2000, Becker et *al*., 2007). Time series of wave run-up (1 Hz sampling, 20 minute bursts) will be collected every 30 minutes during daylight hours. Seabird SBE 26 wave sensors will be deployed at each shore station for calibration/validation purposes. Nearshore wave observations at the Kilo Nalu observatory will also provide a basis for model validation.

Coastal water levels will be provided by nested coastal models. Combined with wave estimates, water level information is necessary for a number of our coastal state and inundation products (b, d, e, and g on page 3). Of particular interest are mesoscale eddies that are known to impinge on Hawaiian Island coastlines causing prolonged periods of anomalously high water levels (Firing and Merrifield, 2004). Our regional model assimilates altimeter track data, which is essential for specifying the local eddy field. However, altimeter data are less accurate near land, which contributes to poor model skill near the islands where water level predictions are most needed. To improve eddy forecasting we will augment existing water level stations to include a stable sensor for measuring sea level that will report at 5-minute intervals via GOES satellite. Existing gauges include National Ocean Service (NOS) stations, and real-time Pacific Tsunami Warning Center (PTWC) stations (Figure 1; APPENDIX 1) that measure high frequency fluctuations associated with tsunamis. Because of instrument drift, these sensors do not provide reliable estimates of low frequency water level. The proposed upgrades will be made at Haleiwa and Waianae on the north and west shores of Oahu. A third installation will be at Barbers Point on southwest Oahu.

Additionally, the complete NOS and PTWC water level array will be used to monitor sea-level rise and low frequency variability throughout the islands, which are known to exhibit strong spatial gradients (Firing et al., 2004; Caccamise et al., 2005). These water level data will be useful for specifying energetic island-trapped wave events that cause strong coastal flows that oscillate for days after local storms (Luther, 1985; Merrifield et al., 2002).

Seiche motions are an operational problem for many local harbors because the natural frequencies of small basins lie within an energetic portion of the offshore surface wave spectrum (Okihiro et al., 1993). The phenomenon is of particular concern for Barbers Point Harbor, which handles important aspects of Oahu bulk shipping traffic and is home to a large floating dry dock. A current and water level recorder will be installed to provide real-time observations of conditions within the harbor to alert users and operators as seiching modes develop (product b). Observations will be used in combination with time series of offshore wave spectra to develop predictions of seiche events based on wave model forecasts.

Coastal Resiliency: Pacific island communities are at risk due to a range of natural hazards (e.g., hurricane and tsunami inundation, coastal erosion, etc.) (Firing and Merrifield, 2004; Fletcher et al., 2003). Damage from these events is often predictable; that is, digital elevation models combined with water level forecasts allow predictions of vulnerability to be developed, and on-line products emerging from this knowledge can fill an important gap in community planning (e.g. Genz et al., 2007).

Wave and water level events are largely predictable hours to days in advance. Low-lying communities can be mapped using LIDAR available from NOAA and Army Corps surveys. Heavy rainfall associated with Kona storms and winter gales is tracked by radar. GIS layers of infrastructure and development patterns are widely available. A major goal of the Hawaii Ocean Observing System is to bring together the predictability of these processes in an integrated product (g on p. 3) designed to deliver warnings and forecasts to the user community.

An important factor in community vulnerability is the ability to model wave run-up. Present models are largely empirical and developed on continental shorelines lacking reefs. To develop a run-up forecasting ability, we will deploy an observational network of digital cameras and tripod LIDAR (already owned by SOEST) surveys at 3 focus sites (Waikiki, North Shore, Windward shore) equipped with wave and water level sensors mentioned above. By integrating digital photography, high frequency beach surveys using T-LIDAR, water level, and wave state, we will develop an empirical basis for modeling run-up. The cameras will provide high frequency imagery (~ every 30 minutes with 1Hz 20 minute burst capability) and the T-LIDAR surveys will occur at least once every 2 weeks. The T-LiDAR surveys are necessary to provide rapid cm-scale elelvation control that will be used to convert the photos into accurate run-up maps at the sub-10cm level. Temporal changes in the elevation data themselves will also provide a temporal map of beach erosion and/or aggradation for each site.

Additionally, using high resolution coastal DEM's, GIS layers, predictions of wave and water level events, and coastal erosion history, coastal resiliency products will include maps of marine inundation (product g), forecasts of community vulnerability under sea-level rise scenarios (product h), and dynamic beach safety forecasts of wave, wind, and circulation conditions at guarded beaches around the state (product e).

Water Quality: Coastal water quality will be monitored using an array of sensors, imagers, and *in situ* samplers along with event-focused autonomous underwater vehicle (AUV) surveys. Poor water quality around Oahu is commonly associated with polluted runoff at times of high rainfall (e.g., De Carlo et al., 2007). These events result in shifts of optical, thermal, saline and other chemical properties that will be observable at nearshore sensor sites. Similarly, sewage spills like the March 2006 Ala Wai Canal event are also characterized by a distinct fresh water signature. A further source of concern for the south shore region arises from potential surfacing of the sewage plume from the Sand Island outfall, located several kilometers to the west of Waikiki and other important recreation sites. These surfacing events, combined with unfavorable westerly winds, can drive contaminated waters toward recreational areas. Our nearshore sensor network will enable detection of changes in water properties associated with these diverse events, providing the basis for water quality and plume dispersion alerts (product f).

An important component for event identification and for effective event-driven surveys will be establishing a baseline of temporal and spatial variability in water properties. Continuous water chemistry and physics observations, begun in 2006 at the south shore Kilo Nalu Observatory (Figure 1D; APPENDIX 1) sponsored by NOAA Sea Grant, NSF and ONR, will provide a foundation for this baseline. The NSF and ONR-sponsored work, extending through late 2008, also includes periodic (monthly) and event-driven AUV surveys targeted at establishing levels of variability in alongshore water properties and baroclinic flow structure.

Water quality observations will include a nearshore sensor network deployed on the south shore of Oahu (six sites from Kilo Nalu past Honolulu Harbor and Waikiki to the Waikiki Aquarium (Figure 1D; APPENDIX 1)). Standardized instruments at 2 of the 6 sites will provide temperature, salinity, current magnitude and direction, pressure, nitrate, chlorophyll a, and total suspended sediments (TSS), with CO_2 measurements in water and air implemented in the second year of the project to help monitor regional responses to ocean acidification associated with increased atmospheric CO_2. Standardized instruments at the other 4 sites will provide temperature, salinity, pressure and optical properties (proxy for TSS). Water samples will be taken routinely in the vicinity of all six sites to ground truth autonomous measurements. Autonomous event-based water sampling will also be implemented in the second year at 2 sites. A rigorous data quality assurance program will be implemented. In addition to providing input for development of product f, the extensive data from this nearshore network will be accessible over the Internet for natural resource managers, regulators, researchers, educators, and the public.

Because of their low density, freshwater inputs of surface runoff, submarine groundwater and treated sewage outflow typically float on top of and then mix laterally with marine waters in Hawaii's coastal zone. In addition to the obvious differences in salinity, these fresh waters are uniquely characterized by cooler temperatures (ca. 18-22^{0}C/y) than surface seawater (ca. 24-28^{0}C/y) and are thus readily identifiable via thermal infrared (TIR) spectrographic imaging. Existing AHI and/or Merlin TIR systems **(**http://www.higp.hawaii.edu/ahi/) will be used to provide detailed surface images of freshwater inputs and their mixing at these resolutions throughout the proposed study area prior to and, on a seasonal basis, subsequent to deployment of our nearshore sensing network. Resultant TIR surface water maps will accurately determine extant freshwater portals and coastal mixing pathways throughout the survey area on a seasonal basis, as well as allow for optimum placement of the nearshore sensors described above.

The water quality observational network will make use of event identification algorithms to trigger adaptive sampling methodologies including REMUS AUV surveys for spatial context, and discrete water sampling that will enable more comprehensive lab-based water quality measurements. As part of the proposed work, the REMUS AUV's sensor suite (upward- and downward-looking ADCPs and a Seabird SBE-49 FastCAT C-T sensor) will be augmented with optical backscatter and fluorescence measurements, and will be equipped with GPS navigation to enable surveys over an extended area and into confined waterways, such as the Ala Wai Canal. An example AUV track is shown in Appendix 1, frame D.

Principal data products from AUV event-driven surveys will be horizontal and vertical distributions of temperature, salinity, fluorescence and particle abundances in near-surface waters over the survey domain. This information may be supplemented by Seagliders operating in the event vicinity. These products will be delivered within 4-6 hours of survey completion to the ocean atlas and, from there, via secure web interface to Hawaii State DOH and Honolulu City and County Environmental Services partners. In addition to establishing the spatial extent for potential pollutant coverage, these distributions can identify discrete 'hot-spots' that may indicate isolated sources. Where possible, surveys into 'source' waterways will enable pollutant flux estimates. Spatial estimates will be made of pollutant dilution and residence times within the survey region, an important aspect of the intent of product f.

Marine Ecosystem Stewardship: Fish tracking and acoustic monitoring arrays will automatically and in real-time detect the presence of large fish and cetaceans at selected sites along the south shore of Oahu. Data will be incorporated into population models to forecast the likelihood of fishing and whale watching success and to assist vessel operators avoid interaction with protected marine mammals (product j).

An array of automated acoustic receivers is now operational in the Hawaiian archipelago, stretching from the island of Hawaii Island to Midway Atoll. These receivers monitor the presence of fish tagged with acoustic transmitters that broadcast a unique identification code and other information (e.g., depth). Receivers are installed on all thirteen offshore FADs surrounding Oahu (Figure 1B; APPENDIX 1) to monitor movements of tunas. An additional array of 30 acoustic receivers is operational around Oahu in depths of 30 meters or less to monitor the movements of large coastal sharks. This array monitors movements of ecologically important top predators, and the data collected from this system are used to estimate transfer rates between areas, describe patterns of residency at FADs and associative behavior of groups of fish (Dagorn, et al 2007), to improve estimates of the population size, and to better inform local agencies regarding public safety issues with respect to sharks (product k). Under the proposed integrated observing system, the existing network of coastal and FAD-mounted VR2s will be maintained and selected stations will be upgraded to VR3S sonic modem-linked units for real-time monitoring.

The Oahu fish-tracking array is a local component in a larger network that monitors animal movements at different scales. SOEST is a major partner in the newly created Ocean Tracking Network (http://www.oceantrackingnetwork.org) that will enable the local array to increase its extent beyond the south shore of Oahu to the entire Hawaiian archipelago, to the Pacific Basin, and ultimately to a global scale. The acoustic monitoring array will target the detection of dolphins and whales. There are approximately sixteen species of cetaceans that inhabit the waters of Hawaii. Humpback whales and spinner dolphins are the two most prevalent marine mammals in inshore waters. Acoustic monitors record data on the occurrence of marine mammals in the vicinity of the sensor, including the time of occurrence, the duration of occurrence and the species involved. Passive acoustic sensors in an array provide additional information, such as location fixes, and the speed and direction of traveling animals.

The acoustic monitoring array will be a part of a larger program in which Ecological Acoustic Recorders (EAR's) (Lammers, et al., 2007), which have been developed jointly by HIMB and NOAA's Coral Reef Ecosystem Division (CRED; Figure 1D, APPENDIX 1), are being used to monitor environmental sounds at several locations in the Pacific. There are currently four EAR's deployed within the main Hawaiian Islands: off Kaneohe Bay and Kaena Point, Oahu; at La Perouse Bay, Maui; and near Lehua Rock off Niihau. Four EAR's are deployed in the Northwest Hawaiian Is., four off Tutuila Is., American Samoa, and by June 2007 there will be four units at Wake atoll, Guam and the Commonwealth of the Northern Mariannas. All of these deployments have been in conjunction with NOAA. We will use EAR technology to monitor two areas along the south shore of Oahu: 1) the Kilo Nalu study area in the near-shore waters off Kewalo Basin, and; 2) the Makapuu restricted fishing area (RFA) with joint focus on marine mammal and vessel detection.

Modeling: One key to product development for three of the Hawaii Ocean Observing System themes (coastal ocean-state and forecast, coastal resiliency and water quality sensing) will be data-assimilating numerical models. The core of this system will be a set of nested of ocean circulation models. Regional atmospheric models will provide surface boundary conditions, and surface wave models that take output from the ocean and atmosphere models will provide high-resolution near-shore wave and water levels. Initially, these models will be run separately, but the eventual goal is to have a single, locally run coupled model providing nowcast and forecast products of ocean circulation, wave state, and water levels that will assist the generation of products (a) through (g) listed on page 3.

Ocean modeling will be based on the Regional Ocean Modeling System (ROMS) in use by IPRC investigators. The outer domain will cover the main Hawaiian Islands with nesting to the scale of individual embayments. Experience has shown the need for good lateral boundary conditions and realistic atmospheric forcing to simulate local circulation. Lateral boundary conditions will be obtained from the Navy's operational model (HYCOM), and the SOEST atmospheric model will provide surface forcing. The system will assimilate local data, including those from the regional observing system, although not all data will be assimilated in order to have independent information for validating and quantifying model performance. The benefits of using ROMS are its functionality and the large user community for this type of application.

Surface fluxes will be provided by a locally-run regional atmospheric model. The Department of Meteorology in SOEST is presently running such models operationally. The present system of regional/multi spectral models will be expanded to include a nested weather research and forecast (WRF) model.

The Department of Ocean and Resources Engineering (ORE) in SOEST runs a hierarchy of wave models providing estimates of wave and water level states in specific coastal locations. The overarching model is based on Wave Watch III, and is run for the entire Pacific Basin at 100 km, for the islands at 10 km, and the Simulating Waves Nearshore (SWAN) model is run at 100 m resolution. Through the proposed effort we will continue to run this WWIII/SWAN system but incorporate the output from atmospheric and ocean circulation models as well as specifically focus on observing system pilot sites on Oahu.

Data Management: Data management and communications will play a critical role in the success of the Hawaii Ocean Observing System. This includes archiving of various observations and model outputs as well as delivery of end-user products, specifically the development and maintenance of the web-based Hawaii Ocean Observing System atlas mentioned previously. Management protocol will adhere to the IOOS Data Management and Communications (DMAC) guidelines and provide: 1) archival of all data, 2) a consistent metadata format for all data, 3) web-based browsing capabilities through a Live Access Server (LAS) and a Web Map Server (WMS), 4) data transport via OPeNDAP and ftp/http, and 5) a web-based search tool for data and data product searching.

Data users range from modelers, who require direct, fast access to raw binary data, to end users who desire web-based, and possibly hard-copy, products. The system will be flexible enough to provide all services to all users. Data storage will be achieved through a direct access RAID storage arrays with long-term archival of unique datasets being accommodated at the Hawaii Ocean Observing System while common data streams (e.g., geospatial atmospheric or oceanographic physical parameters) will be transferred to the appropriate national data centers in a timely fashion. It is anticipated that the observations and models proposed for the Hawaii Ocean Observing System will generate several terabytes per year. Backups will involve direct copy to other servers in SOEST.

Collected data and model output will be the responsibility of the lead PI for each system component (e.g., HF radar, Seaglider, etc.); however, members of the DMAC team will ensure that data formats are consistent with national standards as well as Hawaii Ocean Observing System web-browsing and data transport mechanisms. Associated metadata and quality-control/assurance (QC/QA) will also be provided by the PI's, while the DMAC team will provide consistent metadata for end users. LAS and WMS servers will provide searchable web-based products from plots for QC/QA to final derived data deliverables. These complimentary servers provide options for time/space domains as well as geospatial data display. Building on existing capabilities already in place at SOEST, the Hawaii Ocean Observing System atlas will provide binary data transport via OPeNDAP and ftp/http. We will also provide direct access to binary data via NFS mounting for model access to forcing and assimilated fields. SOEST has significant, demonstrated experience delivering a broad spectrum of data and data products using standard web-based tools,

Finally, DMAC personnel will collaborate with PI’s and outreach/education specialists to integrate data streams and develop useful derived data products and data delivery systems. The former represents effort above and beyond what support personnel for a particular sensor can provide. The latter requires technical skills to deliver derived data products effectively as well as the ability to collaborate with end users to determine what are useful products, how to facilitate product delivery and how to provide on-going user input into refining data products and delivery systems.

Outreach and Education: In year two of this project, we will hire an outreach and educational specialist. This individual will work closely with staff in the NOAA IDEA center (see attached letter of support), principal investigators and technical staff to effectively interpret and communicate complex scientific information to natural resource managers, regulators, researchers, educators, and the public in a clear, understandable manner.

The outreach and educational specialist will focus on two major project areas: (1) the web-based Hawaii Ocean Observing System atlas, which will automatically (and frequently) update map-oriented products to provide ocean end users with an improved basis for decision-making and planning. Our outreach and educational specialist will train users and receive input (through demonstration workshops) on how well beta versions of the web site meets the needs of multiple user groups. In addition, the outreach and education specialist will convene regular meetings with PIs and technical staff to present the needs of stakeholders and to work with technical staff to develop the most effective web design and user interface for this product. This feedback loop is a critical component that will allow researchers to modify their products in response to the needs of the user community; (2) A Hawaii Ocean Observing ‘brochure’ will be produced twice a year to emphasize recent findings from our ongoing research projects in the Hawaiian Islands, as well as our outreach, and education endeavors. We will use the highly successful “Gulf of Maine Monitor” as our guide for this endeavor.

As concerned residents of the State of Hawaii, we are dedicated to the education of our public. Both the Hawaii Ocean Observing System atlas and the Hawaii Ocean Observing brochure will be readily accessible to this general audience. As educators in the University of Hawaii system we are also dedicated to the education of our undergraduate and graduate students. The proposed Hawaii Ocean Observing System will provide the foundation for research experiences for both undergraduate students through the degree program in Global Environmental Science (GES), and graduate students through the MS and PhD degree programs.

Project Management Structure: In order to ensure that the direct project goals are effectively achieved and that the system continues to generate products that are valuable and relevant to the user community, a management structure, to be led by lead-PI Brian Taylor will be implemented immediately. As System Director, Taylor will oversee high-level system management, coordinate with partner organizations and with the broader PacIOOS regional association and represent the Hawaii Ocean Observing System on a national level. Additionally, an Operations Manager will be charged with assuring that continuous delivery of high quality products is maintained. This will include practical coordination of system components with a focus on ensuring that observational components are effectively integrated with data management, modeling and outreach efforts. The System Director and Operations Manager will receive input from and work closely with an executive steering committee that will nominally comprise a subset of project PIs along with representatives from partner organizations including the IDEA center, the Pacific Services Center and other key stakeholders.

e. Benefits

The users of ocean observing products are spread across all levels of government, the ocean recreation and commerce communities, the hotel and tourism industry, the media, residents and visitors, and nongovernmental organizations.

Offshore Safety: Hawaii ocean hazards are highly variable in space and time and the requirements for real-time offshore hazard warnings and other information products are substantial. Moreover, when search and rescue missions are mounted these variable conditions must be taken into account to be most effective. We will work with the NWS Pacific Region and the USCG to develop warning and search & rescue products that meet federal requirements while better serving the cruise ship industry, commercial shipping (including the upcoming Super Ferry service), and recreational users.

Nearshore Safety: Improved warnings of Hawaii's nearshore hazards are needed for myriad recreational user groups. Dangerous wave conditions and associated currents are a perpetual reality along Hawaii's beaches, reefs and rocky coasts, at harbor entrances and within harbors. Numerous successful lawsuits have claimed inadequate warnings of hazards, and improvements in this regard will find immediate application among emergency responders and ocean safety personnel. SOEST already provides near-real time updating of beach hazard ratings for the Honolulu City & County Ocean Safety Division (hawaiibeachsafety.org). This product was successfully developed by focusing on direct product engineering on the basis of user-defined needs from state and county offices, the hotel and security industry, state health officers, lifeguards and emergency responders, tourism officials, and others. Ocean safety officials on the neighbor islands anticipate using a similar product tailored to their shores.

Improving Community Resiliency: Improving community resiliency will be achieved by developing marine inundation products related to high waves, high tides, heavy rainfall, and rising sea level. Our goal is to integrate model and sea-state observations, coastal run-up, coastal GIS layers and coastal digital elevation models to produce a line of web forecasts of marine inundation, erosive wave events, beach safety conditions, and interpretive products that quantify community vulnerability under higher sea levels. This will serve agencies and stakeholders concerned with highway overtopping, wave impacts on coastal structures, wave run-up and high water level related erosion events, dangerous beach conditions, and probability forecasts of future hazard zones under higher sea levels. Product design will be guided by the user community. Identified users include county ocean safety personnel and emergency responders, state and county public works offices, civil defense, land use managers, NOAA offices and agencies, and public media outlets.

Water Quality: The overarching goal of the water quality component is to enhance public safety in the coastal zone. Products will allow agency personnel to respond quickly to developing hazards, and to accurately predict beach water quality conditions, and monitor potential for beach closures. This will be achieved with development and rapid delivery of on-line products describing changes in the quality of coastal waters will help quantify the vulnerability of aquatic resources and the potential for exposure of users to pathogenic organisms and other pollutants during existing and developing event conditions. The on-line products will be integrated with daily operations of agency users enhancing their capabilities, and extending their mission capacity. Specialized media products will also be designed for ready integration into the daily decision-making of visitors and island residents alike.

Key users identified from discussions with Federal and state agency personnel include immediate responders from the Hawaii State Department of Health (Clean Water Branch), and City and County of Honolulu (Department of Environmental Services), land use managers, as well as NOAA and EPA. Other stakeholders who would benefit include the Hawaii Visitors Bureau public media outlets and the travel and tourism industry (e.g., Waikiki Hotel Association).

Marine Ecosystem Stewardship: Responsibilities for monitoring and protecting marine resources falls on the Hawaii Department of Land and Natural Resources, Division of Aquatic Resources (DAR) for state waters and on NOAA Fisheries and the Western Pacific Regional Fishery Management Council (WPRFMC) for Federal waters. Per-capita fishing participation in Hawaii is highest of any state by an order of magnitude. Recreational and commercial fishers using small boats in Hawaii make approximately $5x10^5$ fishing trips per year landing $5x10^6$ pounds of ahi (yellowfin tuna, *Thunnus albacares*). Charter fishing and whale watching are major tourist attractions and commercial pressure to expand these sectors is increasing.

Summary of Benefits: We have proposed to develop a regional ocean observing system, initially for the state of Hawaii, and specifically focused on the south shore of Oahu, but with the expectation of eventual expansion to all the major islands of Hawaii and the larger PacIOOS region, given appropriate resources. It is critical that our first ocean observing efforts be focused on a limited region of the state of Hawaii in order to gain experience in the establishment of a full, end-to-end system linking *in situ* observations, data assimilative models and product development and dissemination. After the successful development of this proof-of-concept project, we envision extending this effort to the larger PacIOOS region. Our data management protocols will adhere to the IOOS Data Management and Communications (DMAC) guidelines as described in the *data management* section. This will contribute to the establishment of IOOS at both the regional and national levels.

f. Milestone Schedule

A timeline for major tasks, target milestones for important intermediate and final products, and key project outcomes are graphed in Appendix 2. Lines in blue represent observations, lines in red represent products, and lines in black represent modeling efforts.

g. Project Budget

See APPENDIX 3

REFERENCES

Becker, J. M., Y. L. Firing, J. Aucan, R. Holman, M. Merrifield, and G. Pawlak, Video-based observations of nearshore sand ripples and ripple migration, J. Geophys. Res., 112, C01007, doi:10.1029/2005JC003451, 2007.

Caccamise, D. J., M. A. Merrifield, M. Bevis, J. Foster, Y. L. Firing, M. S. Schenewerk, F. W. Taylor, D. A. Thomas, Sea level rise at Hawaii: GPS Estimates of Differential Land Motion, Geophys. Res. Lett, 32., L03607, doi:10.1029/2004FL021380, 2005.

Dagorn, L., K. Holland, D. Itano. 2007. Behavior of yellowfin (Thunnus albacares) and bigeye (T. obesus) tuna in a network of fish aggregating devices (FADs). Mar. Biol. 151:595-606

Dail, H. J., M. A. Merrifield, and M. Bevis, Steep beach morphology changes due to energetic wave forcing, Mar. Geology, 162, 443-458, 2000.

De Carlo, E.H., Hoover, D.J., Young, C.W., Hoover, R.S. and Mackenzie, F.T. (2007) Impact of storm runoff from subtropical watersheds on coastal water quality and productivity. Applied Geochemistry. In Press http://dx.doi.org/10.1016/j.apgeochem.2007.03.034

Firing, Y. L., and M. A. Merrifield, Extreme sea level events at Hawaii: The influence of mesoscale eddies, Geophys. Res. Lett., 31 (24), L2430610.1029/2004GL021539, 2004.

Firing, Y. L., M. A. Merrifield, T. A. Schroeder, and B. Qiu, Interdecadal Sea Level Fluctuations at Hawaii, J. Phys. Oceanogr., 34, 2514-2524, 2004.

Fletcher, C., Rooney, J., Barbee, M., Lim, S.-C., and Richmond, B., 2003. Mapping shoreline change using digital orthophotogrammetry on Maui, Hawaii. Journal of Coastal Research, SI 38, p. 106-124.

Genz, A.S., Fletcher, C.H., Dunn, R.A., Frazer, L.N., and Rooney, J.J., 2007. Predictive accuracy of shoreline change rate methods and alongshore beach variation on Maui, Hawaii. Journal of Coastal Research, 23(1), p. 87-105.

Gurgel, K.W., G. Antonischki, H.H. Essen, and T. Schlick (1999), Wellen Radar (WERA): A new ground-wave HF radar for ocean remote sensing, Coastal Eng., 37, 219– 234.

Lammers, M.O., Brainard, R.E. and Au, W.W.L., Mooney, T.A. and Wong K. In review. “An Ecological Acoustic Recorder (EAR) for long-term monitoring of biological and anthropogenic sounds on coral reefs and in nearby waters.” Submitted to the J. Acoust. Soc. Am.

Lehodey, P. 2001. The pelagic ecosystem of the tropical Pacific Ocean: dynamic spatial modelling and biological consequences of ENSO. Prog. Ocean. 49:439–468.

Lehodey, P., F. Chai, and J. Hampton. 2003. Modelling climate-related variability of tuna populations from a coupled ocean–biogeochemical-populations dynamics model. Fish. Oceanogr. 12:4/5, 483–494.

Luther, D.S., Trapped waves around Hawaiian Islands, Proc. 'Aha Huliko'a Hawaiian Winter Workshop, University of Hawaii, 261-301, 1985.

Merrifield, M. A., L. Yang, and D. S. Luther, Numerical simulations of a storm generated island-trapped wave event at the Hawaiian Islands, J. Geophys. Res., 107, 3169, doi:10.1029/2001JC001134, 2002.

Okihiro, M., R. T. Guza, and R. J. Seymour, Excitation and seiche observed in a small harbor, J. Geophys. Res., 98, 18201-18211, 1993.

Senina, I, J. Sibert, P. Lehodey. 2007. Adjoint parameter estimation for ecosystem models of large pelagic fish spatial population dynamics: application to skipjack tuna. Unpublished MS.

4. APPENDICES

APPENDIX 1

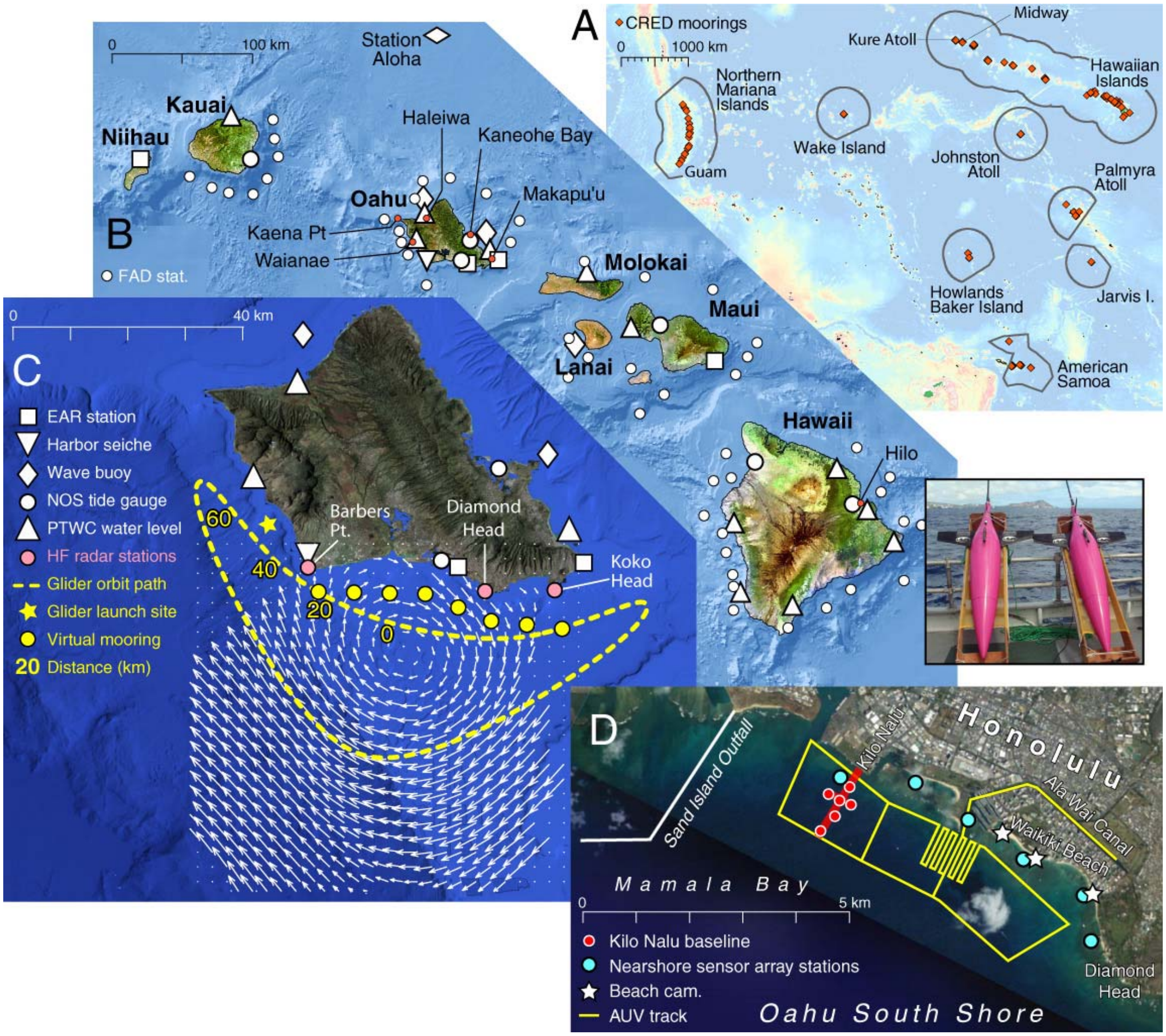

Figure 1: (A) The Pac-IOOS region including the locations of existing CRED monitoring stations. (B) The main Hawaiian Islands showing existing observing system components. (C) The island of Oahu with existing (white) and proposed (color) observing system components. (D) The Waikiki section of Mamala Bay showing proposed observing system components including additions to the existing Kilo Nalu cabled observatory.

APPENDIX 2

Year 1	Year 2	Year 3
1-2 Gliders deployed continuously		
Glider subsurface temp/salinity on-line		
Koko Head and Barbers Point Coastal Radars deployed		
	Radar surface current maps on-line	
	Waikiki Coastal Radar deployed	
		Nearshore currents on-line
AUV monthly surveys, event surveys beginning year 1, Qtr4		
AUV monthly survey products on-line, event survey products on-line year 1, Qtr4		
Nearshore Water Quality Stations deployed		
	TIR over flights at 4 month intervals	
	Water quality products on-line	
Haleiwa, Waianae Water level station upgrades		
	Barbers Point Water Level/Seiche station deployed	
	Harbor seiche products on-line	
Sea level heights/trend products on-line		
Beach cameras, Seabird's deployed		
	Run-up product on-line	
T-T-LIDAR surveys ongoing		
	Coastal inundation products on-line	
RSM/MSM atmospheric model in operation		
	WRF atmospheric model in operation	
		WFR data assimilation
Surface wind map products on-line		
NLOM/NCOM ocean state products on-line		
ROMS model in operation		
	ROMS ocean state products on-line	
	HYCOM/POM in operation	
	HYCOM/POM products on-line	
		ROMS data assimilation
Regional wave model in operation		
Directional wave buoys deployed		
	Oahu south shore wave model in operation	
Wave state products on-line		
150 transmitters deployed each year on yellowfin tuna		
EAR at Kilo Nalu deployed		
	Deep EAR deployed & Fish track receivers upgraded	
	Yellowfin tuna forecasts on-line (fully operation in year 3)	
Software for real-time detection of cetacean sounds developed		
	Ecosystem model coupled to model outputs	
		Marine mammal occurrence
		Biological activity on-line
		Vessel traffic on-line