Final Report
Developing the Pacific Islands Ocean Observing System (PacIOOS)
Cooperative Agreement #NA16NOS0120024
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This report is a final comprehensive performance progress report that covers activities conducted during the final six months of the award (Dec. 1, 2023 – May 31, 2024) and a summary of activities conducted during the entire award (June 1, 2016 – May 31, 2024). The total amount awarded to PacIOOS for this award was $15,260,156.67.

1.0 Background

The Pacific Islands Ocean Observing System (PacIOOS) is a partnership of data providers and users working together to enhance ocean observations and develop, disseminate, evaluate, and apply ocean data and information products to address the environmental, economic, and public safety needs of stakeholders who call the U.S. Pacific Islands home. The PacIOOS region includes the State of Hawaii, territories of Guam and American Samoa, the Commonwealth of the Northern Mariana Islands (CNMI), the Republic of Palau, the Republic of the Marshall Islands (RMI), the Federated States of Micronesia (FSM), and the U.S. Minor Outlying Islands and Atolls.

2.0 Summary of Accomplishments

All milestones proposed through our annual revised statements of work for this cooperative agreement have been addressed, as detailed in our semi-annual program reports. A summary of key accomplishments, as they relate to each of the PacIOOS Subsystems (governance and management, observing, modeling and analysis, data management and cyberinfrastructure, and engagement) is included below.

GOVERNANCE AND MANAGEMENT SUBSYSTEM

The objective of this subsystem is to efficiently operate PacIOOS and successfully implement our projects and activities. To help ensure that direct project goals are achieved effectively, that appropriate partnerships for system growth are pursued, and that the system continues to generate public products that are valuable and relevant to the user community, PacIOOS has a governance framework in place. This framework is detailed in a Memorandum of Agreement (MOA) and executed with partner agencies and organizations.

Maintain an Active PacIOOS Governing Council

The PacIOOS Governing Council (GC) members are elected by their fellow MOA partners for 3-year terms. The GC and its Executive Committee (ExCom) provide strategic guidance to PacIOOS leadership. GC members from across the region represent various sectors and provide valuable feedback to help guide the future direction of the program. As described in the

PacIOOS MOA, staff and MOA partners held annual elections in the late summer/early fall every year for 5-6 seats (of the 18 person council). PacIOOS organized and staffed one Governing Council meeting each fall/early winter and one ExCom meeting each spring/summer. Meetings were held in person except during 2020 and 2021, when the pandemic precluded travel in the region.

Advance Strategic Planning for PacIOOS
Members of the PacIOOS GC determined that splitting the document once called the Strategic Operational Plan into a PacIOOS 5-year Strategic Framework and a PacIOOS Operational Plan would be more useful for the program. The Strategic Framework details the why and how of PacIOOS, including the vision, mission, guiding principles, thematic areas, 5-year strategic outlook, and 5-year strategic goals and objectives. This document was finalized in 2018 after a 2-year engagement effort with partners, collaborators, staff, researchers, and the broader PacIOOS community. The Operational Plan details how we will work toward a 5-year strategic framework, with an eye on safety and efficiency. The most recent versions of each document are available on the PacIOOS website.

Conduct Internal PacIOOS Evaluation
The internal PacIOOS evaluation is used to provide an objective review of what is going well and what needs more attention within the program. Annual results were presented to the PacIOOS Governing Council ExCom and were a key factor of their budget discussions.

Track Internal PacIOOS Performance Measures
Designed to provide a means for annual analysis of PacIOOS progress towards long-term system goals, the PacIOOS performance measures offer a snapshot of growth and operational reliability across core subsystems. They are not meant to be comprehensive; rather, they are designed to serve as overall progress and success indicators for advancing the program. During this award, PacIOOS staff tracked and reported on the results of the performance measures to the GC. As the measures are designed to track with the strategic direction of the program, when the new 5-year Strategic Framework was finalized, the PacIOOS ExCom re-examined the performance measures as well and made recommendations that were finalized by the full GC.

OBSERVING SUBSYSTEM

The objectives of this subsystem are to sustain current operations of in situ and remote sensing instrumentation to address partner and stakeholder needs; to foster capabilities; and to fill gaps to achieve a more balanced instrumentation network across the region. The thematic areas addressed by this subsystem include Marine Operations, Water Quality, and Ecosystem and Living Marine Resources.

Maintain and Expand the PacIOOS Array of Real-Time Waverider Buoys
PacIOOS managed the operations of Datawell Waverider buoys throughout the region. The number of sites expanded from 15 to 20. The PacIOOS Waverider network now includes locations in Hawai‘i, Guam, CNMI, American Samoa, Palau, RMI, and the FSM. Long-term partnerships between PacIOOS, the U.S. Army Corps of Engineers, and the Coastal Data and Information Program (CDIP) enable data streaming into the PacIOOS website and PacIOOS

Voyager. New interactive plots for wave buoy data were also developed and made available on the PacIOOS website. http://www.pacioos.hawaii.edu/waves-category/buoy/

Maintain and upgrade an array of real-time surface currents available online for west and south shores of Oʻahu and Hilo Bay

Access to high frequency radar (HFR) sites was a challenge due to changes in land ownership (Kakaʻako, Kapolei) and management (Kaʻena, Koko Head). Significant effort was required for each site mentioned. Access issues were also exacerbated during the pandemic. Ongoing maintenance and repairs to the HFR sites were completed, specifically to windmills and solar panels due to wind storms (Kaʻena), electrical systems due to lightning strikes (Pepeʻekeo), and cables due to chewing mongoose (Kalaeloa). Upgrades were successfully completed at the Kapolei (Chevron) site. Additional cables and antennae were deployed, bringing the site from 8 to 16 antennae and increasing the resolution from 7-8 degree to 3-4 degree. New FCC compliance was obtained, and new mapping interfaces containing real-time surface current information were made available on the PacIOOS website as well as PacIOOS Voyager. http://www.pacioos.hawaii.edu/currents-category/obs/

Purchase and deploy new HFR sites to provide real-time surface currents for the channel between Guam and Rota (CNMI)

Save for the antennae masts, the systems were purchased and fabricated and are ready for shipment; however, numerous challenges, including access issues during the pandemic for site visits, typhoon damage, and military expansion on Guam, have delayed our ability to obtain necessary permits and permissions for the new sites on each island. Permitting efforts remain in progress and will be continued under the Cooperative Agreement NA21NOS0120091.

Run glider missions to enhance the model skill of the PacIOOS Regional Ocean Modeling System (ROMS)

Despite multiple delays by the servicing company (which changed hands multiple times during this award), Seaglider SG523 was refurbished, repaired, and calibrated for its first glider mission in almost 10 years. From February 2 to May 10, 2023, the glider measured waters around Maui in an attempt to capture the seasonal phytoplankton blooms that occur off the Maui Nui island group, as modeled in the Hawaiʻi Regional Ocean Modeling System (ROMS) output. The seaglider completed 436 dives to approximately 900 meters depth. Each dive collected data on salinity, temperature, dissolved oxygen, and three fluorometry wavelengths throughout the water column. Each time the seaglider surfaced, data was transmitted via satellite communication, assimilated into the PacIOOS data systems, and incorporated into the ROMS.

Maintain an array of nearshore water quality sensors, and make data available online

PacIOOS maintained a network of nearshore water quality sensors across Hawaiʻi and the Insular Pacific. At the end of the award, there were 5 operational sensors in Hawaiʻi (4 on Oʻahu, 1 on Maui) and 4 in the Insular Pacific (American Samoa, FSM, RMI, and Guam). These sensors provide continuous monitoring of water quality parameters. Partners on islands other than Oʻahu played a crucial role in keeping the sensors operational and data flowing. Data from the sensors are made available through new dynamic graphs and map viewers on the PacIOOS website. http://www.pacioos.hawaii.edu/water-category/sensor

Run a successful Water Quality Sensor Partnership Program (WQSPP)
PacIOOS successfully implemented and expanded the WQSPP. This program allows partners to utilize PacIOOS sensors for short-term (6 months to 2 years) projects. The WQSPP has been popular with partners and the PacIOOS Governing Council. Projects have included monitoring water quality in locations such as Maunalua Bay (O‘ahu), Ma‘alaea Harbor (Maui), Babeldaob (Palau), and Dausokele Estuary (Pohnpei, FSM). These projects involve collaborations with local non-profit organizations and support efforts such as baseline data collection, monitoring of restoration sites, and assessment of environmental impacts. Data from completed WQSPP projects are archived and made available on the PacIOOS website.
http://www.pacioos.hawaii.edu/water/sensorarchive/

Maintain Hawai‘i Island Water Quality Buoys, and make data available online
PacIOOS maintained two water quality buoys off the coast of Hawai‘i Island - one in Hilo Bay and one in Pelekane Bay, deployed in 2018. These buoys collect data on water temperature, salinity, turbidity, chlorophyll, and dissolved oxygen. The team provides undergraduate training in marine technology and overcame challenges including storm damage, telemetry issues, and impacts from the pandemic. In 2021, the Pelekane Bay buoy was refurbished with a new data logger, a 4G modem, and an EXO sonde. Solar panels were replaced about every six months. Data from both buoys are transmitted hourly and made available on the PacIOOS website, providing valuable information on coastal water conditions in these areas.
http://www.pacioos.hawaii.edu/water-category/wqbuoy/

Deploy “bathygraph” satellite linked tags on large sharks in the Main Hawaiian Islands
Shark tracking studies were conducted by researchers from the Shark Research Group at the Hawai‘i Institute of Marine Biology (HIMB). Satellite linked “bathygraph” tags capable of providing near real-time oceanographic profiles were deployed on seventeen tiger sharks and one hammerhead shark around O‘ahu and Maui. These tags were developed under the auspices of PacIOOS and, in addition to elucidating shark habitat usage, significantly increased the amount of sub-surface oceanographic data available to end-users in the fields of ocean and atmospheric modeling. For instance, shark ID 176025 provided 513 temperature/depth profiles over a period of four months with some profiles starting at depths of over 500 meters. The horizontal tracks can be viewed on the PacIOOS website and PacIOOS Voyager. The underlying concepts and initial results of this new technology were published in *Animal Biotelemetry* (Holland et al., 2022. Ocean depth–temperature profiles for operational oceanography from a shark-borne transmitter. 10(1), pp.1-8.). http://www.pacioos.hawaii.edu/projects/sharks/

To better understand tiger shark movement and habitat use patterns around Maui, the same HIMB group deployed satellite and acoustic tags to track 41 tiger sharks off Maui. The results revealed that tiger sharks prefer insular shelf habitat, which extends from the shoreline out to a depth of approximately 200 meters. This habitat is more extensive around Maui than any other part of the archipelago. The Hawai‘i Department of Land and Natural Resources and PacIOOS provided funding for the study. The results of this work were published in *Nature Scientific Reports* (Meyer et al., 2018. Habitat geography around Hawai‘i's oceanic islands influences tiger shark (*Galeocerdo cuvier*) spatial behavior and shark bite risk at ocean recreation sites.).

Deploy and maintain land-based receivers to enhance data throughput from satellite-linked transmitters in the Main Hawaiian Islands

To increase data throughput from satellite tagged sharks (and other species using the same Argos satellite constellation protocols), Right of Entry permits were obtained and land-based receivers ("motes") were deployed on three islands. Three were deployed on O'ahu (Ka'ena point, Mt. Ka'ala, and Makakilo), two on Maui (Lahaina and Haleakalā) and three on Hawai'i Island (Miloli'i, Kailua-Kona, and Pu'u Anahulu). These instruments greatly increase the ability to detect transmissions from Argos satellite tags that might otherwise be missed as the satellite coverage over the Hawaiian Islands is minimal. They also significantly enhance data throughput from the tags. The concept and initial results were described in *Animal Biotelemetry* (Jeanniard-du-Dot et al., 2017. Motes enhance data recovery from satellite-relayed biologgers and can facilitate collaborative research into marine habitat utilization. *5*(1), p.17.).

Assist the IOOS Animal Telemetry Network (ATN) Data Assembly Center (DAC) with data ingest of ocean profiles from telemetered animals

PacIOOS researchers and data management team collaborated with the ATN DAC and the tag manufacturer to iron out details pertaining to quality control (QC) of oceanographic data from animal tags. The aim is to enable a machine-to-machine solution for transferring oceanographic data into publicly accessible databases. Although the ATN DAC is not yet capable of this function, PacIOOS' DMAC team moved forward with this effort. Protocols are now established for automatic transfer of our ocean profiles from the manufacturer's (Wildlife Computers) data portal to PacIOOS. This allows near real-time access to our ocean data from animal tags by our ROMS modeling team and others who are eager to take this to the next stage of testing for incorporation into their models.

Co-Investigator Kim Holland attended a workshop in Hobart in November 2019, where the group developed a proposal for GOOS to have "Animal Borne Sensors" recognized as an official "network" in the GOOS structure (along with Argo, DBCP, SHIP-OPS, etc.). This proposal has been accepted and AniBOS is now officially recognized as a GOOS Emergent Network.

Maintain a ship-based detection of tsunamis network

Network operations continued and were expanded by adding equipment to the *Ka'imikai o Kanaloa* and the *Hi'ialakai*. The team led by UH researcher James Foster improved the real-time data analysis and display package. The team successfully produced automated predictions of tsunami sea-surface displacements at ship locations for several large earthquakes. Although none of these events produced significant tsunamis that could be detected in the open ocean, they allowed the team to refine its operational approach.

MODELING AND ANALYSIS SUBSYSTEM

PacIOOS modeling efforts provided near-term forecasts for response and planning. Modeling systems for waves, wave run-up, water level, harbor surge, and ocean circulation were developed, maintained, and/or upgraded. The thematic areas covered by this subsystem include Marine Operations, Coastal Hazards, and Ecosystem and Living Marine Resources.

Maintain High Sea Level Forecasts and make available online
PacIOOS continuously maintained and refined its 6-day high sea level forecasts. The forecasts are available online and have been tailored based on ongoing user feedback. Significant efforts were made to collect and organize event documentation, such as photos and videos from community scientists, to define forecast thresholds for different magnitudes of flooding near each station. The team faced challenges with some locations, notably Pago Pago, where the forecast was temporarily down due to issues with the NOAA tide gauge data stream. Despite these setbacks, enhancements were made to several forecasts, including establishing thresholds based on ground-truthing during events. The forecasts have proven valuable during periods of extremely high-water levels experienced throughout the Pacific Islands.
https://www.pacioos.hawaii.edu/shoreline-category/highsea/

Maintain wave run-up forecasts and make available online
PacIOOS made substantial progress in developing and refining wave run-up forecasts for various locations. A significant achievement was the development of a high-resolution wave run-up forecast for West Maui, supported primarily by a NOAA Regional Coastal Resilience Grant, but also by this award. This project involved extensive data collection, with 24 instruments deployed along the West Maui shoreline to provide insights into wave dynamics and serve as validation for the forecast model. The West Maui forecast, covering 12 distinct regions from Honolua Bay to Papalaua Wayside Park, went live on June 2, 2021, after rigorous stakeholder engagement, co-design, and testing. PacIOOS continues to refine all of its wave run-up forecasts based on user feedback and on-the-ground validation during predicted events. Enhancements were also made to other forecasts, such as those for Waikīkī and the North Shore, with thresholds established based on local input and community scientist photos used for calibration.
https://www.pacioos.hawaii.edu/shoreline-category/runup/

Roeber, V., Azouri, A., Guiles, M., and D. Luther, 2018: Assessment of Numerical Models for Forecasting of Wave-driven Run-up and Currents, Abstract #IG04-A021 presented at Asia Oceania Geosciences Society (AOGS) 15th Annual Meeting, Honolulu, HI, 03-08 June.

Iwamoto, M., Luther, D. Owens, T., Langenberger, F., Guiles, M., Roeber, V., Azouri, A., and C. Tognacchini, 2018: Enhancing Coastal Community Resilience with Real-Time Notifications, and Long-Term Projections, of Hazardous Wave-driven Flooding and Erosion Events in West Maui, Abstract #24 presented at the Pacific Risk Management ‘Ohana (PRiMO) 16th Conference in Honolulu, HI, 07-09 August.

Maintain existing Haleʻiwa Harbor (Oʻahu) Surge Forecast, make available online, and advance the development of a new harbor surge forecast for Kahului (Maui)
PacIOOS maintained and upgraded the Haleʻiwa Harbor Surge Forecast. Significant progress has been made towards developing a harbor surge forecast for Kahului Harbor in Maui. This effort included a comprehensive literature search, historical data analysis, and consultations with partners at the State of Hawaiʻi Harbors Division and USACE. The team developed a plan for deploying pressure sensors and current meters to quantify wave-generated threats and their spatial variations within the harbor. http://pacioos.org/shoreline-category/harborsurge/

Azouri, A., 2016: Observations, Forecast, and Modeling of 0.5-200 Min Infragravity Oscillations in Haleiwa Harbor Region, Hawai'i. Ph.D. Dissertation, U. of Hawaiʻi at Manoa, December, 2016.

Azouri, A., Roeber, V., and D. S. Luther, 2018: The Response of Harbor Environments Protected by

Irregular Fringing Reef Systems to Strong Gravity Wave Forcing -- A Case Study, Abstract #1181 presented at 36th International Conference on Coastal Engineering 2018, Baltimore, MD, 30 July - 3 August.
Azouri, A. and D.S. Luther, 2018: Existence and forcing of resonant infragravity oscillations on harbor to island scales, Abstract #CD23A-02 presented at 2018 Ocean Sciences Meeting, AGU, Portland, OR, 12-16 Feb.

Enhance user experience with coastal hazard forecasts on the PacIOOS website

PacIOOS emphasized ongoing stakeholder engagement to ensure the coastal hazard forecast tools meet community needs. This includes collaborations with various partners and community scientists for validation and feedback on forecasts. For example, an archive plotting function was implemented, allowing users to view historical forecast plots. This feature provides access to all available historical forecast plots, reaching back to the initial implementation of each forecast.

Maintain and upgrade Regional Ocean Modeling System (ROMS) forecasts in operation for Hawai‘i, Mariana Islands, and Samoan Islands

ROMS provides forecasted conditions of salinity, ocean currents, and water temperature, all at depth up to seven days into the future. PacIOOS ROMS forecasts were maintained for various areas and grid sizes in Hawai‘i, the Mariana Islands, and Samoa. Other notable accomplishments include:

- *Model Upgrades and Improvements*: The team tested and implemented a new version of the ROMS code, which improved the model's performance and reduced errors. They also developed an ensemble prediction system. Extensive updates were made to the operational software to enhance reliability and accommodate various data sources, including satellites, Argo floats, and HFR.
- *New Model Developments:* A high-resolution ROMS grid (approximately 100-m resolution) was developed for Kāne‘ohe and the surrounding area along O‘ahu's windward shore. This model generates 3-day forecasts for ocean currents, water temperature, and salinity with hourly output. Additionally, a pathogenic microbe model for the Ala Wai canal was developed and tested, involving sensor deployments and collaboration with Dr. Grieg Steward, UH researcher, for data processing and validation.
- *Reanalysis and Data Integration:* The team performed a 10+ year reanalysis using over 100 million observations, which was incorporated into the PacIOOS data stores and operational system. This reanalysis provided a consistent dataset for further studies of ocean dynamics around Hawai‘i and demonstrated the value of integrating observational and forecasting data.
- *Coupled Physical-Biogeochemical Model*: Significant progress was made in developing an operational coupled physical and biogeochemical forecast for the Hawaiian Islands. The team integrated the PacIOOS ROMS configuration with the GFDL-developed COBALT model, aiming to create a full forecasting system that included geochemistry and base food web for the PacIOOS regions.
- *Observation Impact Assessment:* The team developed methods to assess the impact of observations on daily analyses and forecasts. They examined metrics such as transport, Eddy Kinetic Energy (EKE), and isopycnal depth in Hawai‘i, and transport and EKE in Guam. An experimental setup was created to quantify how each observation improved or degraded the forecast for specific metrics.

- *Regional Expansions and Collaborations:* The team also collaborated with NOAA CRED to develop a model for a portion of the Northwestern Hawaiian Islands to examine physical flow across coral reefs. Additionally, they worked with GFDL to develop regional MOM6 capability for Hawai‘i.

ROMS forecast data and products (including Ala Wai Plume Forecast) available online
All forecasts and data output are available via the PacIOOS website. The Ala Wai Turbidity Plume Model simulates the possibility of a plume developing at the Ala Wai Canal for the upcoming two days, and also includes a hindcast for the previous three days. Turbidity (water clarity) is impacted by various factors, including rainfall, waves, wind, and tidal movement. Very high turbidity levels are normally caused by large amounts of storm water runoff that can severely impact the nearshore water quality. The plume model relies on real-time water quality data, the PacIOOS Waikīkī ROMS ocean model, and the PacIOOS O‘ahu SWAN wave model. Visual impact is significant after severe rain events. Hawai‘i Surf News Network and the Waikīkī Rough Water Swim have both posted the plume forecast on their websites.
http://www.pacioos.hawaii.edu/currents-category/model/
http://www.pacioos.hawaii.edu/water/model-plume-alawai/

Maintain wave models for Hawai‘i, Mariana Islands, and Samoan Islands
PacIOOS consistently maintained operational wave forecast models for Hawai‘i, Mariana Islands, and Samoan Islands. http://www.pacioos.hawaii.edu/waves-category/model/

DATA MANAGEMENT AND CYBERINFRASTRUCTURE (DMAC) SUBSYSTEM

The DMAC subsystem is the core foundation and steward of the data lifecycle, from initial collection to ingestion into the cyberinfrastructure, quality control, public dissemination, product generation, and long-term storage and archive. PacIOOS operates a fully functional Regional Data Assembly Center (RDAC) that achieves these objectives.

The PacIOOS data management team significantly expanded its capabilities and reach. After completing a thorough server evaluation to improve recovery efficiency from potential server failures, the team upgraded server hardware for DMAC central infrastructure, and successfully migrated from a single server to a Virtual Machine (VM) stack, enhancing system reliability and eliminating single points of failure. This migration included the transition of key services such as the PacIOOS website, THREDDS, ERDDAP, and Data Turbine.

DMAC efforts resulted in substantial growth in data accessibility and usage. Unique visitor counts increased from 3,000 to over 229,665 per semi-annual reporting period, with data transfers growing from 245 GB to over 23.31 TB. The PacIOOS website and wave buoy pages consistently received over 1 million page views per reporting period.

PacIOOS has been at the forefront of biological data integration within IOOS. The team successfully worked with NOAA's Pacific Islands Fisheries Science Center (PIFSC) to publish reef fish population data via standard data services, developing a new biological schema in the process. This initiative expanded to include data from the National Coral Reef Monitoring Program and coral reef monitoring data from Micronesia, all made available through OBIS.

PacIOOS also became the first IOOS Regional Association to be recertified by NOAA for another five years, highlighting its continued excellence in ocean observing and data management. The PacIOOS DMAC team developed many **new data tools and functionalities** for existing tools. Some of these accomplishments are highlighted below:

- Developed the Hawai‘i Sea Level Rise Viewer to support the State of Hawai‘i Sea Level Rise Vulnerability and Adaptation Report. The viewer provides easy access to coastal hazard exposure areas and vulnerability layers. Homeowners, planners, and other users can explore flooding and coastal erosion for a variety of sea level rise scenarios. Potential economic loss and flooded highways are also displayed in the viewer. Initial funding was provided by NOAA's 2016 Regional Coastal Resilience Grants Program, while ongoing maintenance and updates are supported by IOOS.
- Created a photo data collection platform for the Hawai‘i Sea Grant King Tides effort, including a mobile app interface and map viewer.
- Customized a photo data collection web app for the West Maui Wave Run-up project.
- Added new functionalities to dynamic website maps, enhancing user interaction and data visualization.
- Collaborated with the Ocean Tipping Points (OTP) team to enable users to explore data layers from the Hawai‘i Case Study in an interactive map viewer and to download them from the PacIOOS website. OTP aims to support effective ecosystem-based management by providing resource managers and practitioners with tools to anticipate, avoid, and respond to coral reef change in Hawai‘i and beyond.
- In collaboration with UH Hawai‘i Institute of Marine Biology (HIMB), PacIOOS developed an interactive map viewer allowing users to explore the estimated coral cover around the Main Hawaiian Islands. Based on diver surveys and environmental datasets collected between 2000 and 2009, the study uses statistical distribution models to estimate coral distribution.

PacIOOS also expanded its data offerings by integrating **new partner data layers** covering a wide range of oceanographic, meteorological, and ecological data across the Pacific region. New data layers available via PacIOOS data services and/or PacIOOS Voyager include the following:

a. Weather station data
   - Real-time observations from Moku o Loʻe (Coconut Island) in Kāneʻohe Bay, Oʻahu
   - Nine-year observation record from Rock Islands Southern Lagoon in Koror State, Palau

b. Updated NOAA Coral Reef Watch products
   - Higher resolution data for coral bleaching monitoring
   - Daily average night-time sea surface temperature (SST)
   - SST anomaly
   - Coral bleaching hotspots
   - Degree heating weeks
   - 7-day maximum coral bleaching alert area
   - Marine heatwaves

c. Multi-scale Ultra-high Resolution (MUR) sea surface temperature data

d. Ocean Tipping Points (OTP) Hawai‘i Case Study data

- Over 40 data layers showing the influence of environmental factors and human-based activities on coral reef ecosystems across Hawai‘i

e. Biological data
- Reef fish population data from NOAA Pacific Islands Fisheries Science Center
- National Coral Reef Monitoring Program data (2007-2019)
- Rapid Ecological Assessments of Fish Large-Area Stationary Point Count Surveys (2000-2007)
- Coral reef monitoring data from Micronesia (fish, invertebrate, and benthic substrate)

f. Coastal water quality measurements
- Data from 25 locations on Maui, collected by Hui O Ka Wai Ola

g. High-resolution tsunami hazard maps
- Regional tsunami model for the Mariana Islands
- Detailed data for Apra Harbor, Agana Bay, and Tumon Bay in Guam
- Nearshore hazard maps for the Agat Coast and Agat Marina on Guam

h. Real-time data from the Kilo Nalu Nearshore Observatory
- Wave parameters
- Water properties
- Ocean currents

i. Water characteristic data from three short-term water quality sensors in Maunalua Bay, O‘ahu

ENGAGEMENT SUBSYSTEM

The objective of this subsystem is to strategically identify and address the needs of PacIOOS partners and stakeholders in order to facilitate informed decision-making.

Happy 10 Years!

In 2017, PacIOOS celebrated its 10-Year Anniversary. The entire PacIOOS team, including staff, researchers, and Governing Council members celebrated with visits to ocean observing assets. PacIOOS also produced a 10-Year Anniversary brochure summarizing PacIOOS' development over the past decade.

Release new PacIOOS website

PacIOOS launched its new website in 2016. The organization of content was completely restructured and a modern design was implemented to allow for easy data and information access, and to enhance the overall user-experience. Through a responsive design, the website adjusts to desktop, tablet and mobile sizes. The new website is built within a content management system and highly customized to feature PacIOOS data tools. Data visualizations were newly developed to integrate dynamic data plots and multi-functional map viewers.
As part of the website launch, PacIOOS fully launched its new branding and logo. New outreach materials, data visualizations, and other products incorporate the new look and feel.

The website has consistently attracted between 40,000 to 74,000 unique users per semi-annual reporting period, with session numbers ranging from 105,000 to over 218,000. This growth in web traffic underscores the increasing relevance and utility of PacIOOS' online resources. The team also focused on creating more web stories that are easily shareable on social media, effectively amplifying PacIOOS' message across various platforms.

Co-host Animal Telemetry Network (ATN) workshop with IOOS
PacIOOS collaborated with the IOOS ATN coordinator to host the PacIOOS Animal Telemetry Network Workshop in Honolulu (2018). The workshop brought together over 55 researchers, resource managers, and ocean enthusiasts to explore regional needs and priorities for animal telemetry observations, data sharing, and data management.

Support capacity building for ocean observing in the Pacific Islands
PacIOOS expanded its regional presence to build capacity across the Pacific Islands. A major achievement was the expansion of the PacIOOS Regional Liaison Network, with new liaison positions established in the FSM, CNMI, Guam, and Palau to complement the liaison positions already established in American Samoa and the RMI. To ensure strong local connections, PacIOOS partnered with respected organizations in each region: Conservation Society of Pohnpei in FSM; Pacific Coastal Research and Planning in CNMI; Micronesian Conservation Coalition on Guam; and the Coral Reef Research Foundation in Palau. These partnerships have greatly enhanced PacIOOS' ability to understand and address local needs.

PacIOOS partnered with Micronesia Conservation Trust to develop a new Capacity Building Liaison Officer position based in Pohnpei, FSM. This liaison trained communities and agencies in Pohnpei in the collection and analysis of oceanographic data. PacIOOS also implemented regional engagement workshops with our local partners in Pohnpei (FSM), Majuro (RMI), and CNMI to facilitate learning about PacIOOS assets and local concerns around knowledge gaps. PacIOOS was a regular contributor in the Data Buoy Cooperation Panel (DBCP) capacity building workshops and initiatives in the Pacific Islands.

Support activities related to OceanObs'19
PacIOOS significantly contributed to the international, decadal event held in Honolulu in September 2019, including leading or collaborating on multiple community white papers that were subsequently published in Frontiers of Marine Science (listed below with PacIOOS co-investigators, researchers, students, and staff in **bold**). Director Iwamoto gave an invited plenary presentation at the conference and participated in the planning committee for the "Breaking Waves Breaking Barriers" women in ocean science official side event.

Iwamoto MM, Dorton J, Newton J, Yerta M, Gibeaut J, Shyka T, Kirkpatrick B and Currier R (2019) Meeting Regional, Coastal and Ocean User Needs with Tailored Data Products: A Stakeholder-Driven Process. Front. Mar. Sci. 6:290. doi: 10.3389/fmars.2019.00290

Ostrander CE, **Iwamoto MM** and **Langenberger F** (2019) An Innovative Approach to Design and Evaluate a Regional Coastal Ocean Observing System. Front. Mar. Sci. 6:111. doi: 10.3389/fmars.2019.00111

Guiles M, Azouri A, Roeber V, **Iwamoto MM**, **Langenberger F** and **Luther DS** (2019) Forecasts of Wave-Induced Coastal Hazards in the United States Pacific Islands: Past, Present, and the Future. Front. Mar. Sci. 6:170. doi: 10.3389/fmars.2019.00170

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During OceanObs'19, IOOS celebrated its 20th Anniversary. PacIOOS collaborated with the IOOS Office and the IOOS Association to host a reception for 450 invited guests. PacIOOS also hosted the IOOS Fall meeting during the same week.

In the days leading up to OceanObs'19, PacIOOS hosted the 4th Pacific Islands Training Workshop on Ocean Observations and Data Applications for the Data Buoy Cooperation Panel (DBCP) in Honolulu, which included over 35 participants from over 14 Pacific Island countries. In addition to hosting the workshop, PacIOOS staff provided 1.5 days of hands-on training on four spheres of capacity: needs assessment; pre-deployment; field work/operations; data telemetry, access, and utility. Other workshop topics included discussions on global ocean observing systems, data utilization, quality control, and best practices. The workshop was deemed a huge success, setting the standard for hands-on activities and interactive learning.

Collaborate with organizations across the region and beyond

Collaboration is essential for the success of PacIOOS efforts. PacIOOS continued to foster and maintain crucial partnerships with a multitude of organizations representing various levels of government, academia, non-governmental organizations, and industry. These collaborations expanded PacIOOS capabilities and impact. It is also our partners and users that continue to inform program priorities and activities. For example, PacIOOS targeted outreach to over 500 partners across the region to solicit feedback for the next 5-year proposal development, resulting in 370 responses on coastal and ocean observing needs, priorities, and potential collaborations.

Nationally, PacIOOS consistently engaged with agency partners such as the U.S. Army Corps of Engineers, U.S. Coast Guard, the U.S. Pacific Fleet, and the Western Pacific Regional Fisheries Management Council. PacIOOS continued strong collaborations with various NOAA offices such as PIFSC and the National Weather Service (NWS), and active participation in NOAA-led groups, including the Pacific Island Regional Team (PIRT), Sentinel Site Program, Pacific Regional Outreach Group (PROG), and the Pacific Risk Management ʻOhana (PRiMO). These collaborations continue to be instrumental in aligning PacIOOS' communication efforts with the needs and interests of key governmental stakeholders. A standout project in this partnership has been the deployment and maintenance of a MAPCO2 buoy in Fagatele Bay, American Samoa, in collaboration with NOAA Sanctuaries and local partners.

State and local government partnerships expanded. They have worked closely with the Hawaiʻi State Office of Planning and the Office for Coastal and Conservation Lands (as well as the UH Coastal Geology Group) on climate adaptation initiatives, contributing to the state's resilience planning. A notable partnership was established with the State of Hawaiʻi Department of Health, Clean Water Branch, leading to the deployment of water quality sensors in locations such as Maunalua Bay and Keʻehi Lagoon, Oʻahu.

Collaboration with academic institutions continued to be another focus area. The team worked closely with the National Estuarine Research Reserve, Kauaʻi Community College, University of

Guam (UOG), and the Hawai‘i Institute of Marine Biology. Collaboration with UH Maui College to integrate PacIOOS Voyager into oceanography lab activities continued. The water quality team continually mentored undergraduate and high school students through their sensor and buoy programs, providing valuable hands-on experience in ocean observing techniques. These partnerships helped to disseminate PacIOOS' work within academic circles and facilitated the integration of PacIOOS data and tools into educational programs.

PacIOOS also cultivated strong relationships with non-profit organizations, including The Nature Conservancy, Hawai‘i Waterkeepers, the Marshall Islands Conservation Society, Micronesia Conservation Trust, and the Conservation of Pohnpei. These partnerships have helped to extend PacIOOS' reach into community-based and environmental sectors, enhancing the organization's impact at the grassroots level.

Industry partnerships were not overlooked, as demonstrated by the collaboration with the Hawai‘i Pilots Association. This partnership led to the deployment of a weather station at the entrance of Honolulu Harbor, providing crucial wind data for the safe piloting of large cruise ships. This project exemplifies how PacIOOS engages with industry stakeholders to address specific needs when expanding its observing network.

Collaborate with NOAA OCM, other partners, and coastal management stakeholders to implement the Regional Ocean Data Ocean Sharing Initiative (RODSI)
PacIOOS initiated this project by coordinating a steering committee with local OCM leadership, staff, and other NOAA and EPA partners, who collectively decided to focus initially on Hawai‘i and the territories (Guam, CNMI, and American Samoa). They compiled a list of target stakeholders, including coastal resource managers, EPA directors, and water resources staff, to understand specific management and policy decisions that could benefit from improved data sharing or new datasets. With the help of a consultant, the team collaborated with coastal managers to assess and characterize data needs in the region and identify projects to address those needs, building on a 2019 national data review and a 2020 regional survey.

Characterize the ocean data needs for the Pacific Islands Region
The consultant completed an analysis of management and policy decisions related to datasets and tools needed by coastal zone managers in Hawai‘i, American Samoa, the CNMI, and Guam. PacIOOS, OCM, and the consultant met with coastal managers as a group to draft goals and action steps addressing data challenges for priority management issues. A report based on this workshop was completed and approved by the steering committee. The workshop resulted in two top-line project concepts: a data visualization tool (data portal) and new data requests (specific datasets and data collection technology).

Implement one or more projects in the Pacific Islands ocean data needs report
PacIOOS partnered with PI-CASC and the USGS Western Geographic Science Center to identify locations of current and future areas of coral reef resilience in Guam and American Samoa. This project mapped environmental conditions associated with reef resistance to change or recovery from disturbance. The results, including GIS layers and virtual manager workshops, are available on ScienceBase.gov and via an interactive web map PacIOOS developed to view individual layers and zoom to the target geography for the coral reef resilience project.

To support the RODSI, PacIOOS hired two new staff members: a RODSI Data Management Specialist, and a RODSI Data and Products Developer. These new team members quickly began facilitating and implementing new data tools as requested by island partners. New data tools include the Maui Fire Hub and a collaborative website for the Hawai‘i Coral Bleaching Collaborative, making previously unavailable data accessible to communities in Hawai‘i.

Throughout the project, PacIOOS demonstrated flexibility and adaptability, adjusting timelines and approaches as needed to ensure the initiative's success. The team consistently engaged with stakeholders, partners, and coastal managers to ensure that the RODSI addressed real needs and provided tangible benefits to the Pacific Islands region.

Ongoing outreach with stakeholders and partners to ensure ocean data needs are met
Communication with partners continued via Email, phone calls, and meetings. During the pandemic, PacIOOS communications pivoted to virtual engagement, including online presentations, workshops, and participation in various committees and working groups. This shift helped to maintain strong connections despite challenges posed by travel restrictions.

PacIOOS significantly expanded its reach and impact across the Pacific region. A cornerstone of the communications effort was the consistent publication and distribution of a monthly e-newsletter, with a subscriber base that grew from 1,530 to over 2,470 recipients; a steady increase of 100-200 new contacts annually.

PacIOOS remained active in community outreach and educational events, participating in a wide range of activities, including Marine Educators' Night, Friends of Kewalos annual Park Clean up, SOEST Open House, and GIS Day at the University of Hawai‘i. The team provided specialized lectures, such as a tiger shark lecture at the Hawaiian Islands Humpback Whale National Marine Sanctuary and modeling lectures to American Samoa Community College and Guam college students. These efforts demonstrate the team's commitment to engaging with diverse audiences and sharing PacIOOS' data, tools, and services across various platforms and communities.

PacIOOS kiosks were installed throughout the region. These kiosks, located at locations such as the UOG, College of Marshall Islands, Kailua Sailboards & Kayaks, Dolphin Quest on Hawai‘i Island, Mokupāpapa Discovery Center in Hilo, Maui Ocean Center, and Kaua‘i Community College, served as important points of information dissemination and public engagement.

PacIOOS used social media, primarily Facebook and Twitter, to share information about new tools and resources. The PacIOOS Facebook page increased from 1,250 likes to more than 1,545 likes, while our Twitter following grew from 250 to over 540 followers. Our consistent expansion on social media demonstrates PacIOOS' commitment to public engagement and information dissemination. Popular content across these platforms varied, covering a wide range of PacIOOS activities and marine-related topics.

PacIOOS also increased public awareness and interest in PacIOOS through targeted and engaging press releases and new outreach materials, including new video content (e.g., documentation of wave buoy deployments), participation in local media (e.g., appearances on

Hawai‘i Public Radio's Bytemarks Café Show and the "Island Focus" television show), and the publication of articles in various outlets (e.g., Master Mariners Magazine and the Waikīkī Aquarium quarterly magazine "Kilo I‘a").

Update the IOOS Education and Outreach Inventory
PacIOOS updated the Education and Outreach Inventory annually with PacIOOS activities. https://docs.google.com/a/noaa.gov/spreadsheets/d/1gjQiCa_cf1IGUNZPSoS4OG5CAKSXW_ejCFEVjLEOZHE/edit?usp=sharing

3.0 Ongoing PacIOOS Observations and Activities
Activities under this award are complete. Ongoing PacIOOS core activities will continue under NA21NOS0120091 award.

4.0 Personnel and Organizational Structure
Ms. Melissa Iwamoto became Principal Investigator for PacIOOS on July 1, 2017. The former PI, Mr. Chris Ostrander, moved to a position outside the PacIOOS region in August 2017. In addition, Dr. Margaret McManus began overseeing the PacIOOS wave buoy operations, and Dr. Steven Colbert took over management of the PacIOOS water quality buoys on Hawai‘i Island.

PacIOOS created and filled a new position: PacIOOS Operations Coordinator. Mr. Chip Young started this position on March 1, 2019. The PacIOOS Operations Coordinator is responsible for the coordination and management of the day-to-day operations of PacIOOS; provides field and technical support for PacIOOS components as needed; and helps identify and facilitate the realization of opportunities to increase the ability of PacIOOS to address stakeholder needs.

PacIOOS partner, UH Sea Grant College Program, also hired a new Marshall Islands Coastal Management Extension Faculty. This position is partially supported by PacIOOS to liaise with partners and stakeholders on the ground, maintain the PacIOOS near shore sensor in Majuro, help with the maintenance and recovery of the PacIOOS wave buoy, and validate the PacIOOS wave run-up forecast.

Several organizations became MOA partners with PacIOOS, increasing the number of MOA partners to 64. New MOA partners during the award period include the following:

- The Nature Conservancy’s Hawai‘i Program
- State of Hawai‘i Department of Land and Natural Resources, Division of Aquatic Resources
- Trilogy Excursions
- Surfline/Wavetrak, Inc.
- The Hawai‘i Pilots Association (HPA)
- Ebiil Society (Palau)
- Palau Conservation Society
- Marshall Islands Conservation Society
- Guam Coastal Management Program
- Association of Pacific Island Legislatures (APIL)

5.0 Budget Summary

Final financial reports have been submitted via eRA Commons, and a final funding draw down has been made through the Automated Standard Application for Payments (ASAP). Expenditures under this award totaled $15,260,153.36, ending with a balance of $3.31.

All equipment charged directly to the award by the University of Hawai‘i is included in the final property report SF-428-B, remains on the inventory of the University, and will continue to be used by PacIOOS to achieve the milestones of Cooperative Agreement NA21NOS0120091.

Summary Budget Table

Cost Categories	Amount provided	Amount spent	Balance
Personnel	$5,642,964.67	$6,155,974.16	-$513,009.49
Fringe Benefits	$1,716,406.00	$1,843,131.99	-$126,725.99
Travel	$598,897.00	$375,605.81	$223,291.19
Equipment	$1,385,286.00	$1,276,158.22	$109,127.78
Supplies	$1,009,485.00	$1,006,889.65	$2,595.35
Contractual	$436,428.00	$335,195.30	$101,232.70
Other	$1,154,239.00	$914,948.42	$239,290.58
Total Direct Charges	$11,943,705.67	$11,907,903.55	$35,802.12
Indirect Charges	$3,316,451.00	$3,352,249.81	-$35,798.81
Total Amounts	**$15,260,156.67**	**$15,260,153.36**	**$3.31**