# Progress Report
# NOS Tide Gauge Network

*Tide Station Operation*

Period of Activity: 01 October 2013 – 30 September 2014


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## 1. Project Summary

The National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) operates and maintains a network of 210 long-term, continuously operating coastal water level stations on all U.S. coasts and in the Great Lakes. This National Water Level Observation Network (NWLON) also includes stations on Pacific and Caribbean ocean islands, U.S. territories, and possessions. Many of these stations have now been in operation for over 100 years, with a few having been in operation for over 150 years. NOAA, through CO-OPS, has the national legal authority for coastal tides, tidal currents, and water levels, and is the U.S. leader on relative sea level information for all parts of the U.S. The operation of these stations, and their long period of record, is critical to understanding sea level rise and climate variability, both on a global and local scale. Tide gauge records provide relative sea level trends critical for coastal zone management, engineering, and long-term planning and decision-making on a local and national scale. They also provide calibration for satellite altimeters to better understand and measure global sea level changes caused by thermal expansion and changes in freshwater input. While the period of record for satellite altimeters is relatively short, tide gauge records exist for several decades, giving us a better understanding of what changes we have seen, and how that reflects future variability in sea level due to climate change. All NWLON stations are multi-purpose, providing both long-term and real-time water level information to support multiple user communities, including navigation, hazard warning and mitigation, and coastal zone management. In the climate community alone, immediate users of this data include climate researchers, NOAA and federal partners who use the information to develop climate mitigation strategies for coastal communities or for management decisions, coastal managers responsible for implementing climate change response and mitigation strategies, the general public, climate modelers requiring local information to downscale global models and develop local projections, and many others. All CO-OPS data are available real-time, and products, including long-term trends and monthly and annual means, are available

through the CO-OPS *Tides and Currents* website, and are archived at all three Global Sea Level Observing System (GLOSS) archive centers. The data are also available through the Permanent Service for Mean Sea Level. Twenty-five NWLON stations currently comprise the U.S. contribution to the GLOSS Core Network, and forty-five are part of the GLOSS-Long Term Trend (LTT) network. CO-OPS also supports the Global Earth Observation System of Systems (GEOSS) by providing on-line sea level trends and analysis for 114 international GLOSS-LTT stations, by operating and maintaining the GLOSS-ALT tide gauges at Oil Platform Harvest for satellite altimeter calibration and evaluation, and by maintaining the long-term tide station at Barbuda. These efforts directly support the NOAA Climate Program Office (CPO) deliverable with respect to sea level: to identify changes resulting from trends and variability in climate. Failure to continue operation of CO-OPS' observing systems, update long-term time series, and analyze sea level trends on a national and global scale would cause a large gap in the Global Ocean Observing System for Climate and negatively impact understanding of both local and global sea level changes as an indicator of climate change. Additionally, local sea level trend information is being used more frequently by coastal planners and decision makers as policy is beginning to reflect better climate science. Hindering access to that information through lack of support for *Sea Levels Online* and associated products would force managers to go back to making generalizations, often at the expense and risk of the general public through poor planning.

## 2. Scientific and Observing System Accomplishments

Accomplishments by CO-OPS in the area of climate variability can be divided into three primary tasks, as outlined in the 2013 work plan delivered by CO-OPS to CPO. Work conducted in FY2014 was primarily a continuation of the work begun in previous years, with some added benefit to CPO and the climate community through increased emphasis on co-location of GPS on Tide Stations, a major GLOSS recommendation in the 2012 Implementation Plan. Both tasks directly support the Climate Program Office's sea level deliverable, to identify changes resulting from trends and variability in climate. These tasks are:

- Operate and Maintain Water Level Measurement Systems on Platform Harvest (in support of calibration of the TOPEX/Poseidon and Jason-1 satellite altimeter missions) and Barbuda.

- Upgrade NWLON Stations and Enhance Tidal-Geodetic Connections and Co-location of Continuous GPS at Tide Stations

### *2.1 Satellite Altimetry Support (Platform Harvest) and Barbuda GLOSS Station*

**Overview**

Support for the TOPEX/Poseidon satellite altimeter mission began with installation of an acoustic system and a digibub system on Platform Harvest in 1992 (see Figure 1a). System operations include provision of water level measurements relative to the satellite altimeter

closure analysis reference frame for calibration monitoring (see B. Hanes et al, Special Issue of Marine Geodesy, 2003 "The Harvest Experiment: Monitoring Jason-1 and TOPEX-Poseidon from a California Offshore Platform"). CO-OPS' special support for this site has included a vertical survey on the Platform necessary to relate the water level sensor reference zeros (near the bottom catwalk) to the GPS reference zero (located up top at the helipad on the Platform). Continuous data are required to monitor effects of waves on the water level measurements and to ensure provision of data during the times of altimeter over flights every ten days, so care is taken to ensure accurate and reliable data collection and dissemination. Raw and verified 6-minute interval water level data are posted on the CO-OPS web-site.

NASA/JPL is the operational partner for Platform harvest operations and maintains official liaison with the platform operators, including providing requirements for dive operations that must be performed only by platform operator contractors. CO-OPS maiantians communcations with NASA/JPL for operational status. Annual CPO funding is used to cover CO-OPS travel for routine and emergency maintenance of this site, as well as and water level and ancillary sensor calibrations. Without this funding, this site could not be maintained. This site is critical for calibration of the satellite altimeters for global sea level observation and measurement. Annual inspections and maintenance and annual levels are necessary to maintain the station, both in operation and in the verification of stability. Exploration of enhancements to communication will continue as reliable telemetry to the site is important, both for trouble-shooting of issues in station operation and maintenance of a continuous time series.Stable VSAT communications hav been extablished with one of the DCP's and attempts to establish VSAT communbication with the second DCP will continue.

One of the DCP's at Platform Harvest went down after last years annual maintenance visit, however the second redundant system was working properly and corrective maintenance was not deemed necessary. In June of 2014, the redundant system also stopped functioning properly, resulting in a complete data loss at the station. After emergency maintenance attempts and site visits, the station was brought back on-line in August 2014 however with degraded data. Final repairs awaited the schedule of the platform dive contractors to inspect and repair the underwater bubbler orifices, the underwater components were the main cause for system failure. This reair has been accomplished, and full operation was restores on November 5, 2014. Efforts this next year will focus on replacing one of the two bubbler pressure systems with a microwave water level sensor (MWWL) thus negating the need for underwater maintnenance. MWWL peformance will be analyzed closely to determine if both pressure systems can be replaced. If so, one of the major causes of lost data will have been remedied. NOAA is in the process of a multi-year transition to MWW:L sensor technology into the National Water level Observation Network (NWLON).

At the 13$^{th}$ meeting of the GLOSS experts, Barbuda was nominated as a station to be added the GLOSS core network. This recommendation was approved, but the action has not been finalized. This station is critical to the Caribbean region, filling a gap in the existing GLOSS Core Network, and as one of the only stations in the region that is able to provide the necessary data sets to the GLOSS data centers. During FY13, the site at which this station is located underwent structural improvements, for which the sensors had to be temporarily removed. There was no annual maintenance of this station in FY13 due to the rebuilding of the pier where

it was located. The station sensors were reestablished on the new pier during April 2014 using the remainder of the funding received from CPO in FY13. Care was taken to remove just the water level sensors and not interrupt the station or its benchmark network, in order to preserve the 2 year time series already collected. The station is now fully operational and was brought back on-line in time to measure the storm effects of Hurricane Gonzalo.

**In summary of FY14 accomplishments, the identified task was:**

- Operate and Maintain Water Level Measurement Systems on Platform Harvest and Barbuda

**The identified deliverables were:**

**Deliverable 1a:** Complete Annual Inspection and routine maintenance at Platform Harvest.

Support around Platform Harvest in 2014 was met with a number of obstacles. Failure of the main and backup pressure sensors resulted in a loss of observations from June 16 to August 29, 2014. Within in the month of failure, CO-OPS accessed the data collection platform to assess causes for failure. Sensor failure was found to be due to unanticipated and accelerated metal corrosion from the coupling of dissimilar metals on the nobility scale. The units were brought back to the lab and redesigned with compatible metals and a plastic liner was inserted between the metal to further prevent corrosion.

Installation of the new equipment was met with delays. CO-OPS coordinated work with NASA's Jet Propulsion Lab (JPL) to support the qualified dive contractor with completing a successful dive operations to clean and inspect the underwater equipment. The installation of this equipment was dependent on scheduling by JPL. The contracted dive support comes at a considerable cost to JPL, therefore, they scheduled installation with a number of other maintenance tasks. The dive was scheduled months after sensor failure and resulted in the observations being offline for an extend period of time. The station is once again fully operational as of November 5, 2014.

**Deliverable 1b:** Install IP modems to establish redundant communications.

It has been determined that an IP modem is not feasible at Platform Harvest to establish redundant communications. Instead a VSAT satellite transmission solution has been established.
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**Deliverable 1c**: Complete Annual Inspection and routine maintenance at Barbuda.

Station sensor equipment was removed from the pier this past March and the station secured in order to preserve the time series. The pier has been now been rebuilt and dredging completed.

**Deliverable 1d:** Repair damaged Barbuda sensors as identified on last annual inspection.

The sensors temporarily removed for pier construction have been re-established and the station is now fully operational as of April 14, 2014.

## *2.2 Tide Station Upgrades and Geodetic Connections*

There are several coastal and island NWLON stations critical to the Global Ocean Observing System for Climate. The operation and maintenance of the ocean island stations of the National Water Level Observation Network (NWLON) has been increasingly more difficult over time due to the slow abandonment of the island facilities by the U.S. Department of Defense, at which some of the stations reside. Finding routine and/or cost-effective flights can be difficult, yet these stations require high standards of annual maintenance to ensure the integrity of their long term data sets. Annual maintenance is extremely important, especially in light of the fact that corrective maintenance is logistically very difficult and expensive. Therefore, over the past few years, a portion of the CO-OPS contribution to the NOAA Climate Program Office has been to upgrade hardware and software at 11 identified critical ocean island sites, creating redundancy in data collection to ensure continuous time series, improving communications where necessary, and establishing geodetic connections and continuous GPS monitoring sites (CORS) where they did not previously exist. Establishing a geodetic connection, and monitoring rates of land motion at sea level observation points is critical in understanding the mechanisms contributing to local rates sea level rise and better quantifying rates of global change. All of this work supports the CPO deliverable to identify changes resulting from trends and variability in climate. Observations are critical to this sea level work.

**Table 1. Status of Ocean Island NWLON Station Upgrades and Improvements**

| Station | Upgraded | Geodetic Connection | CORS Operating |
|---|---|---|---|
| Guam | Yes | Yes | Yes |
| Kwajalein | Yes | Yes | Yes |
| Pago Pago | Yes | Yes | Yes |
| Wake Island | Yes | Yes | No* |
| Midway | Yes | Yes | No* |
| Adak | Yes | Yes | Yes |
| Bermuda | Yes | Yes | Yes |
| San Juan, PR | Yes | Yes | Yes |
| Magueyes Island, PR | Yes | Yes | Yes |
| Charlotte Amalie, VI | Yes | Yes | Yes |
| St. Croix, VI | Yes | Yes | Yes |

* Will be included in the FY14 work plan and will require no additional funding (being taken on by University of Hawaii)

In 2014, CO-OPS continued working with the National Geodetic Survey, on the co-location of Continuously Operating Reference Stations (CORS) on NWLON tide stations, which continues to be the most substantial remaining task. Four CORS installations were continued and two more planned for FY13: Midway, Wake Island, San Francisco, California, Bermuda, South Beach, Oregon and Virginia Key, Florida are all underway. CO-OPS works closely with NGS to continue forward progress on all sites, and seek efficiencies wherever possible.

In light of the increased global focus on co-location of continuous GPS measurements at long-term tide stations for climate observation and the GLOSS requirement to include a continuous GPS sensor at all GLOSS stations, CO-OPS continues focusing on additional gaps in co-located CORS/NWLON coverage beyond the initial 11 sites. Lead time for additional CORS at NWLON stations remains at least 24 months and must allow for flexibility as opportunities for cost savings and leveraging. These outcomes reflect this lead time. All funding received to date by CPO has gone and will continue to go to the installations as outlined in previous work plans. A summary of each location and the status of deliverables is as follows:

**The identified task was:**

- Upgrade NWLON Stations and Enhance Tidal-Geodetic Connections and Co-location of Continuous GPS at Tide Stations

**The identified deliverables were:**

**Deliverable 2a:** Installation of a CORS station at Midway Island, within 1 km of the tide station.

In progress, continued from FY10: Progress was slow but continuous. However, to expedite the process an agreement was established with University of Hawaii to lead CORS installation at Midway Island. Completion is anticipated in FY15.

**Deliverable 2b:** Installation of a CORS station at Wake Island, within 1 km of the tide station.

In progress, continued from FY10: Progress is slow but continuous, as a partnership with National Weather Service is being explored and will allow installation on their buildings and utilization of their communications systems.Completion is anticipated in FY15.

**Deliverable 2c**: Installation of a CORS station at San Francisco Bay, within 1 km of the tide station.

In progress, continued from FY10: Following a number of issues with potential sites for the CORS, NGS is now partnering with the National Park Service and NOAA Sanctuaries and is waiting on an update to get this included with a major facilities reconstruction planned this year. We will need to get National Park Service Approval as NOAA-NMS-Farallones is leasing the land from NPS. This is underway. San Fransisco is now on hold.

**Deliverable 2d**: Installation of a CORS station at Bermuda, within 1 km of the tide station.

In progress, continued from FY12: Bermuda is a critical climate observations site and is a GLOSS core network station, although not a CO-OPS National Water Level Observation Network. In order to maintain a continuous record at this location, in FY12 equipment was purchased to install redundant water level data collection platforms as well as CORS, to upgrade

this station. We are working with Bermuda National Surveyors office to built a new CORS site at the airport. Bermuda. NGS has approved installation of the CORS and planned for FY15.

NOTE: The tide station was damaged during the direct hit from Hurricane Gonzalo. Funds may be required to bring that station back to operational status in FY15.

**Deliverable 2e**: Installation of a CORS station at Virginia Key, Florida within 1 km of the tide station.

In progress, continued from FY12: A possible location has been identified at the University of Miami-RSMAS, and we are investigating what permits may be needed. This location is favorable because NOAA already has an agreement with RSMAS. CORS is awaiting a test date before full approval by NGS. The University is about to have a major cell tower installed and planning is contigent on this activity.

**Deliverable 2f:** Installation of a CORS station at Kwajalein, within 1 km of the tide station.

In progress: NWS found a possible location which looks very promising. This location would also serve as a reference frame site. This location is a roof top mount about 1.5-2.0 km from tide gauge. Temporary tide gauge was removed due to pier construction this year. If completed the station will be reinstalled during FY15. Kwajalein has been approved for CORS installation as well for FY15.

**Deliverable 2g:** Installation of a CORS station at Pensacola, FL, within 1 km of the tide station.
In planning in FY14

**Deliverable 2h:** Begin the installation of CORS station at Pago Pago, within 1 km of the tide station
Install completed in FY14.

**Deliverable 2i:** Begin the installation of CORS station at Cedar Key, FL within 1 km of the tide station.
In planning in FY14

All deliverables directly support CPO's sea level deliverable. Additionally, co-location of continuous GPS on tide stations was identified as a priority at OceanObs '09 as a global climate priority, and is highlighted in the GLOSS 2012 Implementation Plan as a requirement for all GLOSS stations. The funding already received will provide significant progress on the GLOSS requirement for GNSS colocation with a tide station. The only stations remaining on the GLOSS Core Network without an existing CORS are:

San Juan, Puerto Rico
Nome, Alaska
Pago Pago, American Samoa
Prudhoe Bay, Alaska
Seward, Alaska

Sitka, Alaska
Unalaska, Alaska

Of these stations, 3 are Global Climate Reference Stations, and will be the priority for FY15 planning: Seward, Sitka, and Nome. It should be noted, however, that several stations still need to have differential level ties made between the CORS and tide station. Work in subsequent years will focus on completing the priority stations and making level connections.

Summary: The Kwajelein and Bermuda sites have been approved and installation of the CORS is planned for FY15. The University of Hawaii is leading the CORS installation for Sand Island, Midway Islands and Pago Pago, American Samoa. San Francisco is on hold and Virginia Key is still in the testing and planning stages. Seward and Sitka (and possibly Nome) are also in the planning stages in FY 15.

## *2.3 National Water Level Observation Network Data Availability*

All CO-OPS real-time and long-term water level data and sea level trends are available through several channels. Real-time water level data are available for all CO-OPS tide gauges via the internet, web services, and the Global Telecommunications System. All raw and verified data and products, standards and procedures, and data analysis reports can be accessed through http://tidesandcurrents.noaa.gov. Data can also be accessed through the IOOS web portal at http://opendap.co-ops.nos.noaa.gov/content/. Sea level products are also available online, through the CO-OPS *Sea Levels Online* web site for U.S. (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml) and global (http://tidesandcurrents.noaa.gov/sltrends/sltrends_global.shtml) stations, as well as through the NOAA National Oceanic Data Center and others, which provide links to the CO-OPS website. Real time data are also available through the IOC Sea Level Station Monitoring Facility (http://www.ioc-sealevelmonitoring.org/) and CO-OPS works routinely with Vlaams Instituut voor de Zee to ensure data continuity and availability. Data are archived regularly in-house, and sea level data sets are provided to all GLOSS archive centers for U.S. GLOSS stations. One-minute water level data are archived weekly at the NOAA National Geophysical Data Center in Boulder, CO. CO-OPS personnel routinely verify access to the data through these channels to ensure availability. In 2013, data availability from the National Water Level Observation Network was over 96%.

## *2.4 Summary of Accomplishments*

FY14 was a busy year for CO-OPS met with many challenges with respect to advancing CPO's program deliverable of identifying changes resulting from trends and variability in climate. Tide gauges play a critical role in ocean observing for climate, from a broad global research perspective down to a granular local need for actionable information. The observations from the NWLON provide necessary local sea level trends for local planning and policy, enhance the understanding of global climate change, provide calibration for satellite altimeter measurement of sea level, and are an important component in the ability to downscale climate models for local projections. In FY14, CO-OPS maintained and enhanced operation of critical stations, increased the coverage of paired GPS-on-tide gauge sites, and worked closely with a number of

stakeholders. We were fortunate to receive near-level funding in FY14. Without the information and tools that CO-OPS provides, climate researchers would not have the raw data they need to understand changes in sea level, and coastal decision makers would not have that translated information available for management decisions that protect life and property.

## 3. Outreach and Education

NOS/CO-OPS routinely engages in education and outreach to multiple stakeholders. In particular, there is a growing need to translate technical climate data and products (especially sea level trends) into understandable and actionable information. CO-OPS personnel works closely with coastal managers, through training and one-on-one technical guidance, to explain and provide recommendations on incorporating sea level information into policy and planning. CO-OPS personnel also play a lead role in key climate questions within the research community.

Since 2012, CO-OPS scientists have established a close working relationship with Pacific Regional Climate Director, The relationships in the Pacific has helped establish a collaborative solution around the expedited CORS installation in the Pacific Islands.

CO-OPS personnel are also very active in national and international conferences on sea level and climate change, providing papers, presentations, and posters, and engaging the climate community in discussion. CO-OPS has been working with other NOS offices to document protocols necessary for establishing NOAA Trust Resources as "sentinel sites for climate change impacts," one component of NOAA's emerging Sentinel Sites Program. This includes determining which areas require additional sea level monitoring, and how to tie sea level stations to geodetic infrastructure, to establish a complete picture of local land/sea interactions and local coastal processes in the face of climate change. Through this cross-NOAA effort, we have also been working with the National Estuarine Research Reserve's Coastal Training Program.

CO-OPS, NGS, and OCS conducted geodetic and tidal datums training through a widely attended two hour webinar, completing a NOS milestone. Seventy attendees from as far away as Florida and Alaska representing Sentinel Site Cooperatives, USCOE, Alaska Division of Geological & Geophysical Surveys and many others posed questions to experts from the three offices. These experts demonstrated their great depth of knowledge with a highly intelligent conversation about tidal and geodetic datums fielding questions on topics such as VDatum, OPUS, and datums in remote areas. The success of this training lays the groundwork for developing stronger data partnerships and for future training that could expand the attendees' capacity to compute local water level datums.

## 4. Publications and Reports

### *4.1. Publications by Principal Investigators*

No publications to report at this time, but will be releasing a technical report on CO-OPS will have a MWWL in the next yearly report.