U.S. National Sea Level Report

Contributions to the Global Sea Level Observing System

NOAA

UNIVERSITY OF SOUTH FLORIDA

University of Hawai`i Sea Level Center

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Introduction

The 2015 United States (U.S.) National Report to the Global Sea Level Observing System (GLOSS) Group of Experts (GE) XIV is a summary of various ongoing U.S. programs and activities that support GLOSS goals and objectives as outlined in the 2012 GLOSS Implementation Plan. While programs and activities addressing sea level in the U.S. extend from federal to academic, this report focuses on three primary U.S. contributions to GLOSS:

- The NOAA National Ocean Service National Water Level Observation Network (NWLON), managed by the Center for Operational Oceanographic Products and Services,
- The University of Hawaii Sea Level Center, and
- U.S. support for satellite altimeter operations and research

The first section of the report provides updates on operating status of the various components of the system. The second section provides updates on product development and delivery of data, including database support and web products, followed by the third section providing information on advancements in technology. A fourth section of the report provides an overview of sea level observations for extreme events in the U.S. Finally, the fifth section discusses regional activities in support of GLOSS.

The U.S. continues to be a leader and primary contributor to the international climate and sea level community. Vital to this continued support are international partnerships, innovative technological solutions, and sustained infrastructure for observing systems. The U.S. looks forward to continuing and enhancing collaborative sea level efforts with the international community.

Global Climate Observing System

The Global Climate Observing System (GCOS) is intended to be a long-term, user-driven operational system capable of providing the comprehensive observations required for:

- Monitoring the climate system,
- Detecting and attributing climate change,
- Assessing impacts of, and supporting adaptation to, climate variability and change,
- Application to national economic development,
- Research to improve understanding, modeling and prediction of the climate system.

GCOS addresses the total climate system including physical, chemical and biological properties, and atmospheric, oceanic, terrestrial, hydrologic, and cryospheric components. GLOSS is a primary component of GCOS.

NOAA Climate Observation Division

The NOAA Climate Observation Division (COD) supports the ocean component of GCOS and provides long-term, high quality, timely, global observational data, information and products in support of climate, Arctic, weather, and ocean research communities, forecasters, and other service providers and users, for the benefit of society (http://cpo.noaa.gov/ClimatePrograms/ClimateObservation.aspx).

In order for NOAA to fulfill its climate mission, the global ocean must be observed. A global observing system by definition crosses international boundaries, with potential for both benefits and responsibilities to be shared by many nations. All of NOAA's contributions to global ocean observations are managed in cooperation with the Joint World Meteorological Organization (WMO) - Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology (JCOMM). NOAA has historically funded nearly half of the *in situ* elements of the international ocean climate observing system. Much of this work is accomplished through the NOAA Climate Observation Division.

The COD supports the design, deployment, and maintenance of an integrated global network of oceanic and atmospheric observing instruments to produce continuous records and analyses of a range of ocean and atmosphere parameters. COD coordinates observing efforts across NOAA and other federal agencies, as well as internationally.

Sustained Ocean Observations

The networks that make up the sustained ocean observing system for climate are: tide gauge stations, dedicated ships, ships of opportunity, ocean reference stations, Arctic observing systems, tropical moored buoys, surface drifting buoys, Argo profiling floats, data and assimilation subsystems, product delivery, and continuous satellite missions for sea surface temperature, sea surface height, surface vector winds, ocean color, and sea ice. NOAA COD contributes to global implementation of nearly all networks.

The international Global Climate Observing System *Implementation Plan for the Global Observing System for Climate in support of the UNFCCC* (GCOS-138, updated 2010) (http://www.wmo.ch/pages/prog/gcos) includes a list of the GCOS Essential Climate Variables and helps guide the Climate Observation Division system design and prioritization. The NOAA *CLIMATE OBSERVATION DIVISION 2015-2020 STRATEGIC PLAN* provides the framework for NOAA contributions to the international effort. All of the work supported by COD is directed toward implementation of the GCOS Implementation Plan and the projects are being implemented in accordance with the GCOS Climate Monitoring Principles.

Tide gauge stations are necessary to the climate program for accurately measuring long-term trends in sea level change and for calibration and validation of the measurements from satellite altimeters, which are assimilated into global climate models for predicting climate variability and change. Many tide stations need to be upgraded with modern technology, particularly in less developed countries. Permanent GPS receivers are being installed, leading to a geocentrically located subset of 170 GCOS Climate Reference Stations, as identified in the original GCOS Implementation Plan, GCOS-92. The 170 Climate Reference Stations are also being upgraded for real-time reporting, not only for climate monitoring, but also to support marine hazard warning (e.g., tsunami warning). This Climate Reference Station subset of the GLOSS core network has historically been the focus of COD support.

The University of Hawaii Sea Level Center is a NOAA partner that assists in the coordination of tide gauge operations within the international community. NOAA provides long-term support for the climate work at the UHSLC. Sea level stations within the U.S. are primarily operated by NOAA's Center for Operational Oceanographic Products and Services (CO-OPS).

I. Global Sea Level Observing Network Components and Operating Status

A. Tide Station Networks

NOAA National Ocean Service

NOAA has operated and maintained a network of coastal sea level (tide gauge) stations for over 160 years, and is the legal authority for sea level in the U.S. The NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) operates 210 long-term sea level stations, called the National Water Level Observation Network (NWLON). CO-OPS sea level stations are multi-purpose, supporting diverse applications with both real-time and long-term data, from safe and efficient navigation and coastal hazard mitigation to coastal zone management and climate observation. CO-OPS provides an "end-to-end" system of data collection, quality control, data management, and product delivery. CO-OPS distributes data directly from its own web site, through the Global Telecommunication System (GTS), through OPeNDAP and SOS servers, and through some specialized methods, such as ftp server. CO-OPS maintains a rigorous set of standards and methodologies and is recognized for the high level of accuracy and reliability in data delivery. Information on CO-OPS standards and protocols can be found at: http://tidesandcurrents.noaa.gov/pub.html

In addition to maintenance of this long-term network, CO-OPS has been tasked with three primary activities in support of NOAA's COD goals, together comprising its primary contribution to GLOSS:

1) Upgrade the operation of selected National Water Level Observation Network Stations to ensure continuous operation and connection to geodetic reference frames

2) Operate and maintain water level measurement systems on Platform Harvest in

support of calibration of the TOPEX/Poseidon and Jason 1 satellite altimeter missions

3) Develop and implement a routine annual sea level and extreme event analysis reporting capability that meets the requirements of the COD.

Several NWLON stations have been identified as critical components of GLOSS (See Appendix 1 for a full listing). Appendix 2 is a listing of additional NOAA sea level stations currently contributing to the JASL database. 28 of the 210 NOAA NWLON stations are considered GLOSS stations, and contribute to the Joint Archive for Sea Level (JASL). There are 83 total NOAA operational NWLON stations that actively contribute to the JASL archive.

Upgrade of NOAA Ocean Island Station Operations

Several NWLON stations have been identified as critical components of GLOSS (See Appendix 1 for a full listing). 28 of the 210 NOAA NWLON stations are considered GLOSS stations, and contribute to the Joint Archive for Sea Level (JASL). (Johnston Atoll station was removed from the list in 2015 since it is now operated by the UHSLC). Appendix 2 is a listing of additional NOAA sea level stations currently contributing to the JASL database. There are 92 total NOAA operational NWLON stations that actively contribute to the JASL archive, of which 27 are GLOSS (GLOSS 303, Attu, Alaska has been out of service since 1966). The 18 NWLON stations identified at the 1997 International Sea Level Workshop as critical to the global system for monitoring long term sea level trends are also identified in the tables as Climate Reference Network (CRN) stations. While reference to CRN is being phased out following the revision of the GCOS Implementation Plan, stations are still identified as such for the purposes of this report during transition.

Although operation of all of the long-term NWLON and GLOSS stations is important, a subset of NOAA NWLON Ocean Island stations were targeted for priority upgrade to ensure their continuous operation, and work has been conducted over the past several years. These upgrades have included high accuracy acoustic or paroscientifc pressure sensors and redundant Data Collection Platforms (DCPs) with equal capability to the existing primary systems. Now that hardware upgrades of the highest priority stations are complete, stations will continue to be enhanced where needed with connections to geodetic reference systems (through leveling and/or GPS), followed by installation of NGS Continuously Operating Reference Systems (CORS) at selected sites. Table 1 provides a list of the ocean island NWLON stations (not including Hawaii) that were considered in this category as priority for upgrade. Stations with outstanding work in CORS installations are marked “No” in the respective category and will be addressed over the next two years

Table 1. Ocean island NOAA NWLON stations (not including Hawaii) which have been upgraded.

Station	Upgraded	Geodetic Connection	CORS (GPS)
Guam	Yes	Yes	Yes
Kwajalein	Yes	Yes	Yes
Pago Pago	Yes	Yes	Yes
Wake Island	Yes	Yes	Yes
Midway	Yes	Yes	Yes
Adak	Yes	Yes	No
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

University of Hawaii Sea Level Center

The University of Hawaii Sea Level Center (UHSLC) collects, processes, and distributes tide gauge measurements from around the world in support of various climate research activities. Primary support for the UHSLC is provided by the NOAA COD. UHSLC datasets are used for a variety of research and operational activities, including assessments of sea level rise and variability, the calibration of altimeter data, and storm surge and tsunami monitoring. In support of satellite altimeter calibration and for absolute sea level rise monitoring, the UHSLC and the Pacific GPS Facility maintain co-located GPS systems at select tide gauge stations (GPS@TG). The UHSLC currently is a designated IOC GLOSS data archive center. The UHSLC distributes data directly from its own web site and through a dedicated OPeNDAP server. The data are redistributed by the National Oceanographic Data Center (NODC), the Permanent Service for Mean Sea Level, the British Oceanographic Data Centre (BODC), and the Asia-Pacific Data-Research Center (APDRC).

The UHSLC collaborates in the operation of 53 tide gauge stations in the global sea level network. All of these sites meet GLOSS standards for tsunami monitoring and are currently providing data to appropriate warning centers. The UHSLC in collaboration with the Pacific GPS Facility operates co- located continuous GPS (GPS@TG) receivers at 10 tide gauges, which constitute to the NASA/CNES Science Working Team for altimeter calibration, and provide local estimates of absolute sea level rise.

The UHSLC distributes two sea level data sets: Joint Archive for Sea Level (JASL), and Fast Delivery Database.

Table 2. GLOSS Stations operated by or in collaboration with UHSLC.

GLOSS	STATION	COUNTRY	LAT	LONG	GPS?
182	Acajutla	El Salvador	13° 35'N	089° 50'W	
068	Ambon	Indonesia	03º 41'S	128º 11'E	
169	Baltra	Ecuador	00º 26'S	090º 17'W	GLPS
049	Benoa	Indonesia	08º 46'S	115º 13'E	BNOA
069	Bitung	Indonesia	00º 27'N	125º 12'E	BTNG
173	Callao	Peru	12° 03'S	077° 09'W	CALL
036	Chittagong	Bangladesh	22º 20'N	091º 38'E	
146	Christmas	Rep. of Kiribati	01º 59'N	157º 28'W	
291	Cilacap	Indonesia	07º 45'S	109º 00'E	CLCP
033	Colombo	Sri Lanka	06º 57'N	079º 51'E	SGOC
253	Dakar	Sénégal	14º 41'N	017º 25'W	DAKA
071	Davao	Philippines	07º 50'N	125º 38'E	
026	Diego Garcia	United Kingdom	07º 17'S	072º 24'E	DGAR
245	Fortaleza	Brazil	03º 43'S	38º 28'W	CEFT
107	French Frigate S	USA	23º 52'N	166º 17'W	
027	Gan	Rep. of Maldives	00º 41'S	073º 09'E	ADDU
109	Johnston	USA Trust	16º 44'N	169º 32'W	
145	Kanton	Rep. of Kiribati	02º 49'S	171º 43'W	
117	Kapingamarangi	Fd St Micronesia	01º 06'N	154º 47'E	
042	Ko Taphao Noi	Thailand	07º 49'N	098º 25'E	
172	La Libertad	Ecuador	02° 12'S	080° 55'W	
072	Legaspi	Philippines	13° 09'N	123° 45'E	
120	Malakal	Rep. of Belau	07º 20'N	134º 28'E	PALA
028	Male (Hulhule)	Rep. of Maldives	04º 11'N	073º 32'E	HULE
073	Manila	Philippines	14º 38'N	121º 05'E	MANL
163	Manzanillo	Mexico	19º 03'N	104º 20'W	MANZ
192	Mar Del Plata	Argentina	38º 02'S	057º 32'W	MPL2
008	Mombasa	Kenya	04º 04'S	039º 39'E	
141	Moulmein	Myanmar	16º 29'N	097º 37'E	
142	Nuku Hiva	French Polynesia	08º 55'S	140º 06'W	
045	Padang	Indonesia	00º 57'S	100º 22'E	IPA0
329	Palmeira	Cape Verde	16º 45'N	022º 59'W	TGCV
140	Papeete	French Polynesia	17º 32'S	149º 34'W	PAPE
143	Penrhyn	Cook Islands	08º 59'S	158º 03'W	
245	Ponta Delgada	Portugal	37º 44'N	025º 40'W	PDEL
018	Port Louis	Mauritius	20º 09'S	057º 30'E	
273	Pt. LaRue	Seychelles	04º 40'S	055º 32'E	SEY1
190	Puerto Deseado	Argentina	47° 45'S	065° 55'W	PDES
191	Puerto Madryn	Argentina	42° 46'S	065° 02'W	
167	Quepos	Costa Rica	09° 24'N	084° 10'W	
075	Qui Nhon	Vietnam	13º 47'N	109º 15'E	
138	Rikitea	French Polynesia	23º 08'S	134º 57'W	RKTG
019	Rodrigues	Mauritius	19º 40'S	063º 25'E	RDRG
347	Sabang	Indonesia	05º 50'N	095º 20'E	
118	Saipan	USA	15º 14'N	145º 45'E	CNMR
004	Salalah	Oman	16º 56'N	054º 00'E	
334	Salvador	Brazil	12º 58'S	038º 31'W	SALV
211	Settlement Pnt.	Bahamas	26º 41'N	078º 59'W	BHMA
037	Sittwe	Myanmar	20º 09'N	092º 54'E	

181	Ushuaia	Argentina	54° 48'S	068° 18'W	AUTF
119	Yap	Fd St Micronesia	09º 31'N	138º 08'E	
297	Zanzibar	Tanzania	06º 09'S	039º 11'E	ZNZB

The UHSLC receives support from the NOAA Tsunami Program for maintaining sea level stations in the Pacific Ocean (Quepos, Costa Rica; Acajutla, El Salvador; Callao, Matarani, and Talara, Peru; La Libertad, Ecuador; Hiva Oa, and Nuku Hiva, Fr. Polynesia; Legaspi, Philippines; and French Frigate Shoals, U.S.) and the Caribbean (Limon, Costa Rica; Punta Cana and Puerto Plata, Dominican Republic; Bullen Bay, Curacao; Roseau, Dominca; Prickly Bay, Grenada; El Porvenir, Panama; and Santa Marta and San Andres, Colombia). Maintenance in the Caribbean is provided in collaboration with the Puerto Rico Seismic Network. The data from these stations are made available to the Tsunami Warning Centers and can also be accessed through the website of the UHSLC (http://uhslc.soest.hawaii.edu/) and the IOC Sea Level Monitoring Facility (http://www.ioc-sealevelmonitoring.org/).

B. Satellite Altimeter Activities

Satellite Altimeter Operations

The launch of the Jason-2/Ocean Surface Topography Mission (Figure 1), on June 20, 2008, marked an important turning point in the evolution of satellite radar altimetry from research to operations Jason-2/OSTM is a joint effort led by NASA and France's Centre National d'Etudes Spatial (CNES), with two operational agencies, NOAA and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), participating for the first time. Its primary goal is to maintain continuity of the more than two-decade record of ocean surface topography measurements established by the TOPEX/Poseidon and Jason-1 altimeter missions. The observations from Jason-2/OSTM and the earlier missions have proven invaluable in the study of sea level change, showing global mean sea level rising at approximately 2.9 mm/yr between 1993 and 2015, nearly 50% faster than over the past century, but in a strikingly non-uniform spatial pattern (Figure 1). Jason sea surface height observations are also used to study eddy variability and large-scale circulation changes in the ocean.

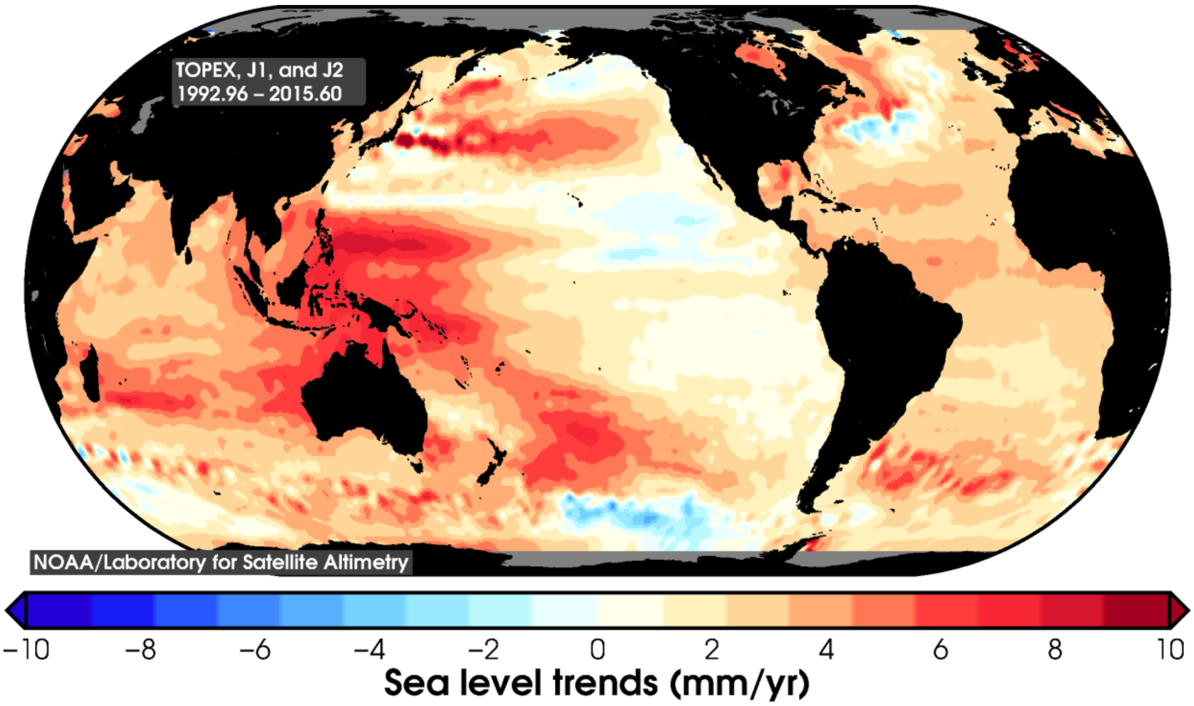

Figure 1. Sea level trends measured between 1993 and 2015 from TOPEX, Jason-1, and Jason-2/OSTM observations.

During the first six months of operation, known as the Tandem Mission, Jason-2/OSTM was flown along the same repeat orbit as Jason-1, but separated by 1 minute. In mid-February, 2009, Jason-1 was moved to an orbit that interleaves and lags Jason-2/OSTM by 5 days, effectively doubling the resolution of observations (157 km vs 315 km track spacing at equator, 5 day vs. 10 day repeat period), thereby greatly improving the ability to monitor meso-scale sea level variability. The two satellites continued this mode of operation, known as the Interleave Mission, until May 2012, when Jason-1 was put in a new orbit with a repeat cycle of 406 days to improve the resolution of the marine geoid. Jason-1 ceased transmitting in June 2012, after 11+ years of successful operation, and was officially deactivated in July 2012.

NOAA, working with CNES, is providing ground system support for Jason-2/OSTM. This includes command and control of the satellite, downloading telemetry, producing near-real time data products (OGDRs) and archiving and distributing all data products. EUMETSAT is sharing with NOAA the responsibility for downloading telemetry and producing OGDRs. CNES is producing all interim and final science data products (IGDRs and GDRs), as well as archiving and distributing them.

A series of Jason follow-on missions is being developed to maintain continuity of the sea level climate data record beyond Jason-2/OSTM. Jason-3, a NOAA and EUMETSAT mission with support by CNES and NASA, is on schedule to be launched in 2015. Jason-3 ground operations and data processing will be the same as for Jason-2/OSTM. The follow-on to Jason-3 will be Jason-CS, a joint 5-partner mission, involving the European Space Agency (ESA), as well as

NOAA, EUMETSAT, NASA, and CNES, to be launched in 2019. For Jason-CS, NOAA and EUMETSAT will exchange roles; EUMETSAT will be responsible for satellite command and control, as well as producing all science data products.

Satellite Data Analysis and Altimeter Drift Estimation

From the beginning of the TOPEX/Poseidon (T/P) mission, methods to estimate altimeter drift from comparisons with the global tide gauge network have continuously evolved, first in a research mode with NASA funding, and later becoming more general and operationally-oriented with some additional support from NOAA.

By the year 2000 the fundamental statistical footing for the method was firmly established, and it had been found that land motion at the tide gauges was the largest remaining source of error when estimating linear drift rates for the altimeters. To this point, however, the method, despite being quite general had only been applied on a regular basis to the TOPEX/Poseidon dataset. Also, a variety of versions of the basic programs existed for estimations based on data from different groups around the country.

With NOAA support, the University of South Florida (USF) was able to take assume the task of unifying the procedures for use on any altimeter dataset and put together a system that would enable taking in datasets from any source with relatively little difficulty.

USF now has in place an operational facility for ongoing comparisons between the available altimeter datasets and the global set of tide gauges using consistent, and proven, methods. These comparisons allow the estimation of any temporal drifts in the altimeter datasets, and allow the comparison of the different altimeter datasets with a single consistent sea surface height database. This means that these comparisons will be semi-absolute, in the sense that vertical offsets between different altimeters, even those which do not overlap in time, are determined as part of the procedure.

On a quasi-monthly basis USF downloads, processes and quality controls all of the tide gauge datasets that are used in USF products. These datasets are updated on a monthly basis at the UHSLC, and this timing sets a natural updating frequency for our products. In addition to updating the tide gauge datasets, code to translate any new altimeter products into the format required by our general routine must be written. This has been done for several altimeter products, including those produced at the NOAA Laboratory for Satellite Altimetry.

Satellite Altimeter Calibration

NOAA support for the TOPEX/Poseidon satellite altimeter mission through operation of a tide gauge station at Platform Harvest since 1993 provides water level measurements relative to the satellite altimeter closure analysis reference frame for calibration monitoring (B. Haines et al, 2003; Figure 2). Platform Harvest is an operational oil platform located 19.5 km west of Point Conception, CA. Maintenance of this station requires vertical surveys on the Platform to relate the water level sensor reference zeros (near the bottom catwalk) to the Global Positioning System (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. Platform Harvest tide gauge operations currently includes two digital bubbler pressure systems collecting continuous water level data streams surveyed into the Platform and Satellite Orbit Reference frames. Platform Harvest is one of several calibration sites located around the globe. Due to failure of both the primary and secondary bubbler system in 2014, data was lost between June and November 2014. Efforts in 2016 will focus on replacing one of the two bubbler pressure systems with a microwave water level sensor (MWWL), negating the need for underwater maintenance. MWWL performance will be analyzed closely to determine if both pressure systems can be replaced, ensuring the cause of the data loss will be remedied.

Figure 2. Platform Harvest Calibration Site.

C. Geodesy and Positioning

The National Geodetic Survey (NGS), an office of NOAA's National Ocean Service (NOS), is responsible for defining, maintaining and providing access to the National Spatial Reference System (NSRS). The NSRS is used by all civilian federal agencies and most of the public to establish coordinates for legal purposes. In the last 12 years the geometric component of the NSRS, latitude, longitude and ellipsoidal heights (NAD 83) has been defined via space geodetic techniques, especially GPS.

In 1986 NGS established a Continuously Operating GPS reference station network called the Cooperative International GPS Network (CIGNET) with three stations. By 1991 CIGNET had grown to 21 stations and in 1994 it was transferred to the International GPS Service now the International GNSS Service (IGS). Also in 1994 NGS established a new GPS network focused in the United States called the Continuously Operating Reference Station (CORS) network. It provides Global Navigation Satellite Systems (GNSS) data consisting of carrier phase and code range measurements in support of three dimensional positioning, meteorology, space weather, and geophysical applications throughout the United States, its territories, and a few foreign countries. Surveyors, GIS users, engineers, scientists, and the public at large that collect GPS data can use CORS data to improve the precision of their positions.

CORS-enhanced post-processed coordinates approach a few centimeters relative to the NSRS, both horizontally and vertically. The CORS network is a multi-purpose cooperative endeavor involving government, academic, and private organizations that independently own and operate each CORS. Each agency shares their data with NGS, and NGS in turn analyzes and distributes the data free of charge. As of September 2015, the CORS network contains almost 2000 stations, contributed by over 200 different organizations, and the network is growing at a rate of approximately 50 stations a year.

From the basic foundation established by the CORS network, NGS participates in a number of ways to support positioning of water level/tide gauge stations.

- NGS has completed a complete re-analysis of all CORS data and on September 7, 2011 published coordinates and velocities for all CORS in NAD 83(2011, MA11, PA11) epoch 2010.00 and IGS08 epoch 2005.00.
- NGS defines the standards and guidelines for geodetic leveling that CO-OPS and its contractors use to level between tide gauge/water level stations and reference bench marks.
- NGS is a founding member of the IGS, is one of the 10 Analysis Centers and contributes rapid and final GPS orbits to IGS. It is also an IGS Regional Data Center.
- NGS was the IGS Analysis Center Coordinator (ACC) for the period 2008-2012. Of the ten current IGS Analysis Centers, one center volunteers to perform the main product combination and quality control operations.
- NGS is the primary source of data for two GPS stations contained in the ~90+ fiducial reference frame stations used to define IGS08 reference defined and maintained by IGS.

NGS provides a collection of Web services called Online Positioning User Service (OPUS). These services allow a user to upload GPS data that they have collected to NGS and receive back a coordinate based on automated processing by NGS on its servers using its own software. OPUS also now allows solutions to be published this allows a user to upload a data set with associated metadata and store it in an NGS database and publish the coordinates for use by others. CO-OPS and NGS have begun to use this functionality to process and archive the GPS data collected by CO-OPS on benchmarks at NWLON stations.

II. Product Development and Delivery

A. Current Sea Level Research and Derived Products

The latest summaries of climate research in the U.S. are found in the annual assessments compiled as annual publications of American Meteorological Society. Annual assessments of global sea level variations based on the latest research findings are also included.

University of South Florida Altimeter Products

The University of South Florida maintains a suite of products available to users. Specifically, a set of time series describing the differences of the various altimeter datasets relative to the global tide gauge network is available.

The system USF has in place assumes that there are a finite number of altimeter databases that will be updated on a roughly monthly basis, assuming changes to that database had occurred, of course. This led to a well-defined set of codes that are quite robust. USF is doing these sorts of calculations for multiple altimeter groups. The net result has been the development of a highly responsive system, the ability to handle multiple versions of the same altimeter databases, and the ability to serve multiple altimeter users.

USF has also streamlined the annual updating and selection of the tide gauges used in the analyses. USF is now able to utilize a set of order 100 gauges (c.f., the old set of 64) that have a nearly complete global coverage, particularly in the Southern Hemisphere, and make use of improved land motion corrections.

University of Hawaii Sea Level Center Research

UHSLC research efforts have been focused on multidecadal sea level variability and extreme sea level events and climate variations. Multidecadal sea level variability in the Pacific has been related to significant changes in the Pacific trade winds (Merrifield and Maltrud, 2011; Merrifield et al., 2012). The multidecadal variations in trade wind forcing are reflected in the dominant climate indices in the region. The associated sea level changes strongly influence regional sea level trend estimates, however, the actual changes in water level and the impacts on island regions is minimal with variations on the order of centimeters over decades. The sea level records do provide an independent record of trade wind variability in the Pacific that we are comparing to storm track patterns in the western Pacific. We also are examining the basin-wide sea level response to the tropical wind adjustment, in particular in relationship to the low sea level rise rates along the eastern boundary of the basin.

The possibility of a low frequency variation in global sea level was considered based on tide gauge observations (Chambers et al., 2012). At issue is whether the globally averaged rate undergoes significant variation at multidecadal time scales during the tide gauge record, and in turn whether the recent high rates during the altimetry era represent a cyclical high trend period as part of that larger fluctuation. The possibility was not discounted, but the difficulty in estimating global averages from regionally biased tide gauge networks remains an ongoing issue for all sea level reconstructions, and ultimately it remains the limiting factor in determining the significance of globally averaged cycles at multidecadal time scales.

Changes in storm variability in the central Pacific on climate timescales have been inferred from tide gauge records at Midway Atoll (Aucan et al., 2012). Winter swell associated with North Pacific storms cause a setup of the atoll lagoon where the tide gauge is located, which can result in 1m sea level anomalies that are captured in the tide gauge record back to the mid-twentieth century. The tide gauge proxy for storm wave activity provides a rare indirect measure of wave variability in a region where other in situ measures of wave energy do not exist. The decadal variability in Midway sea level extremes provides insight into changing winds and storminess patterns in the region, and contributes to our understanding of wave climate changes due to shifting storm patterns.

NOAA Laboratory for Satellite Altimetry Research

Monthly the NOAA Laboratory for Satellite Altimetry produces global and regional time series and maps of mean sea level. The altimetry data is from the Radar Altimeter Database System, which includes data from the reference series of TOPEX/POSEIDON, Jason-1, and Jason-2 and other missions suitable for sea level change studies (ERS-1, ERS-2, Envisat, CryoSat-2, SARAL/AltiKa, and GFO). These data are used for a variety of applications, including as one of the EPA's climate indicators. At LSA the data are used with GRACE and Argo observations to monitor the sea level rise budget.

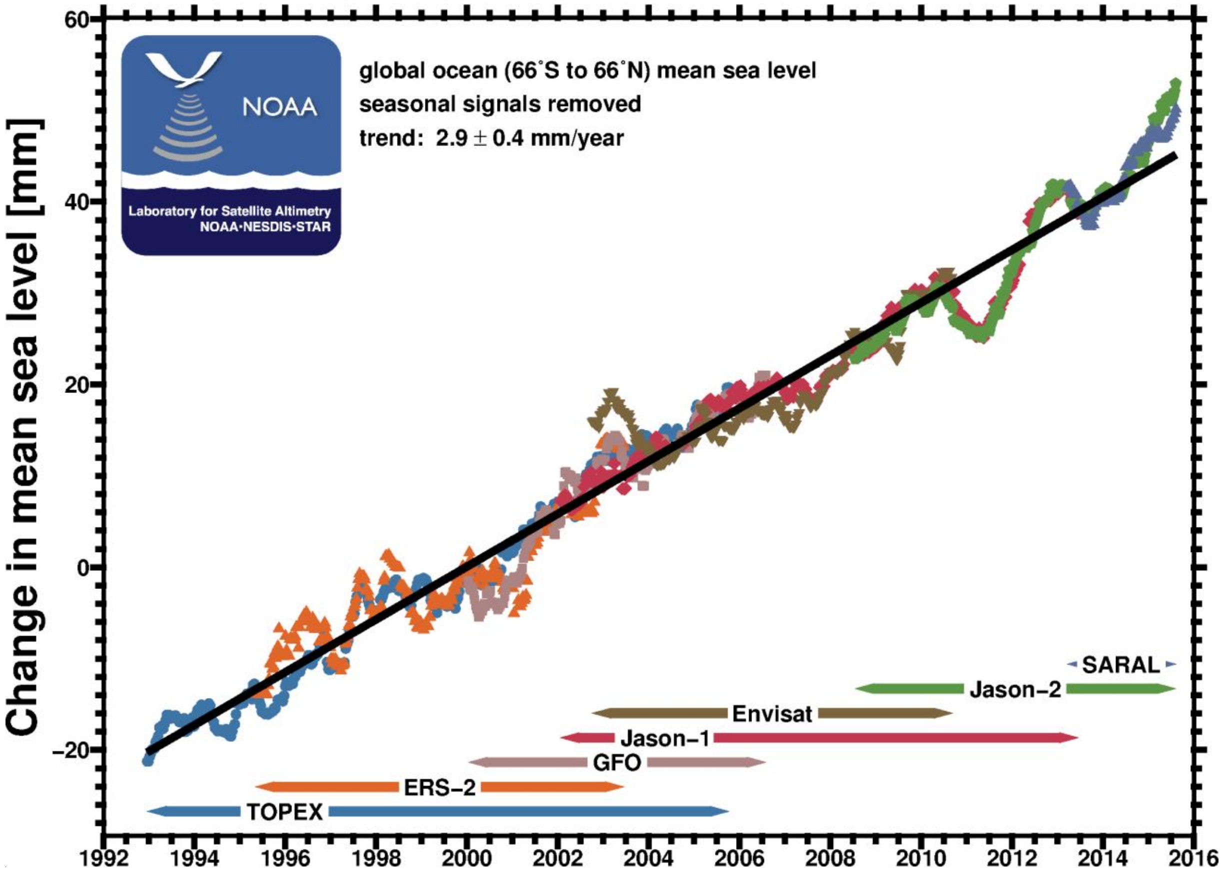

Figure 3. Variations in global mean sea level from altimetry (seasonal signals have been removed and no correction for glacial Isostatic adjustment has been applied.)

B. *Data Delivery - Database Support and Maintenance*

Permanent Service for Mean Sea Level (PSMSL)

Since 1933, the Permanent Service for Mean Sea Level (PSMSL) has been responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges. Both NOAA and the University of Hawaii Sea Level Center contribute sea level data to PSMSL for long-term archival. http://www.pol.ac.uk/psmsl/.

NOAA Database and Delivery

The NESDIS National Data Centers (NCDC, NODC, and NGDC) archive and disseminate the basic datasets used to determine both global (absolute) SLR and local (relative) SLR. These include all NOAA satellite and in-situ station data used in constructing SLR analyses (altimetry, geodetic control, atmospheric observations, SSTs and ocean thermal properties, etc.).

The NWLON is also multipurpose and supports other NOAA missions that are national in scope:

- It is a fundamental component of NOAA's capability for storm surge monitoring and warning. The NWLON data are routine data sets to the NOAA Advanced Weather Information Processing System (AWIPS) system. The NWLON stations also can be automatically put into high-rate satellite dissemination on a user-driven or event-driven trigger. These data become part of the National Weather Service (NWS) pipeline for marine forecasts. Both the real-time data and the tidal datums computed at NWLON stations provide critical input for the NOAA SLOSH model (Sea, Lake, and Overland Surges from Hurricanes), a computerized model run by the National Hurricane Center (NHC) to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes. An extensive upgrade to meteorological sensors on NWLON stations is now complete; it resulted in 181 NWLON stations (91%) including at least one meteorological sensor.

- It is a fundamental component of NOAA's capability for tsunami warning. The NOAA Tsunami Warning Centers have access to high-rate data through the GOES when events are manually or automatically triggered.

In addition to meteorological sensors, the NWLON stations are capable of adding other sensors for long-term measurements for water conductivity and temperature and for water quality parameters.

A comprehensive CO-OPS web-site is maintained and allows users full access to all data and products on a 24 X 7 basis (http://tidesandcurrents.noaa.gov). All raw observed data (6-minute data with quality control flags attached) are automatically available over the web-site after the data collection systems receive each hourly transmission and after they undergo the quality control checks. Derived data products are made available through the web-site after verification.

Access to 1-minute water level data is now available through CO-OPS' tsunami website: http://tidesandcurrents.noaa.gov/tsunami/. This site was developed in collaboration with the NOAA Tsunami Warning Centers and the Pacific Marine Environmental Laboratory (PMEL) to support tsunami warning and modeling efforts.

Harmonic analyses are routinely performed and accepted sets of harmonic constants used for tidal prediction are maintained in the database and made available over the web-site. Tide prediction products based upon the accepted sets of harmonic constituents are also made available "on-the-fly" over the web-site.

System-wide tidal datum updates to new National Tidal Datum Epochs are made using the archived data and derived products in the data base. Accepted tidal datums are maintained and can be accessed over the web-site as well. Tidal datums are computed using documented standard operating procedures. Published bench mark sheets showing bench mark locations and elevations are prepared and updated and accessible over the web-site. Water level datums (International Great Lakes Datum, IGLD) in the Great Lakes are also updated every 25-30 years to account for movement of the earth's crust due to isostatic rebound. The Great Lakes are one of the world's greatest freshwater resources, and is shared and jointly managed by the U.S. and Canada. Updates in the IGLD are critical to updating of nautical charts and navigation safety, particularly during periods of low lake levels.

During storm events and other human-induced events, real-time (6-minute) data are made immediately available to users (http://tidesonline.nos.noaa.gov/ and http://glakesonline.nos.noaa.gov/ .

Real-time water level data in context with other real-time data are accessible for some NWLON stations if they are part of a local Physical Oceanographic Real Time System (PORTS®) (http://tidesandcurrents.noaa.gov/d_ports.html).

A number of 6 and 1-minute data products are available through the Integrated Ocean Observing System (IOOS) Web Portal, available through an OPeNDAP Server in a variety of formats. http://opendap.co-ops.nos.noaa.gov/content/

Sea level data associated sea level products are all available over the web-site for use by PSMSL, UHSLC, and the WOCE communities.

University of Hawaii Sea Level Center

The UHSLC distributes three sea level data sets. For a detailed station listing, please refer to the Appendices.

Joint Archive for Sea Level (JASL)

The Joint Archive for Sea Level JASL data set is designed to be user friendly, scientifically valid, well-documented, and standardized for archiving at international data banks. JASL data are provided internally by the UH Sea Level Network and by over 60 agencies representing over 70 countries. In the past year, the UHSLC increased its JASL holdings to 14,515 station-years of hourly quality assured data. The JASL set now includes 8166 station years of data in 328 series at 248 GLOSS sites.

Fast Delivery Database

The Fast Delivery Database supports various international programs, in particular CLIVAR and GCOS. The database has been designated by the IOC as a component of the GLOSS program. The fast delivery data are used extensively by the altimeter community for ongoing assessment and calibration of satellite altimeter datasets. The fast delivery sea level dataset now includes 277 stations, 214 of which are located at GLOSS sites.

High Frequency Data

Near Real-Time Data (collection + up to a three hour delay, H-3 delay) and daily filtered values (J-2 delay) are provided, primarily for stations that UHSLC directly operates and maintains. UHSLC has committed to hosting the GLOSS High Frequency database in collaboration with the Institute of Flanders (VLIZ).

The UHSLC provides monthly maps of the Pacific sea level fields through the JCOMM. UHSLC also produces quarterly updates of an index of the tropical Pacific upper layer volume and annual updates of indices of the ridge-trough system and equatorial currents for the Pacific Ocean. The analysis includes tide gauge and altimeter sea surface elevation comparisons.

C. Web Products

NOAA Sea Levels Online

Since 2003, NOAA's primary delivery method for local relative sea level trends to the public is through its *Sea Levels Trends* website (http://tidesandcurrents.noaa.gov/sltrends). This site provides access to sea level information at both NOAA's long-term NWLON stations and international stations. Analyses of sea level trends and variability are currently available for 141 long-term NWLON stations and 239 international stations.

The site has undergone several stages of expansion and redesign since 2003. In 2008, a Google Map interface was introduced and figures were redesigned to provide easier access for users to water level stations in their region of interest. After 2010, sea level trends began to be recalculated every year for all operational stations using all newly-available data. A new graphic was introduced for each station for the comparison of the latest trend with the previously calculated trends (Figure 4). Since the error bars are shown, the user can observe the overlap in the uncertainty range of each trend, as well as the gradual narrowing of the error bars.

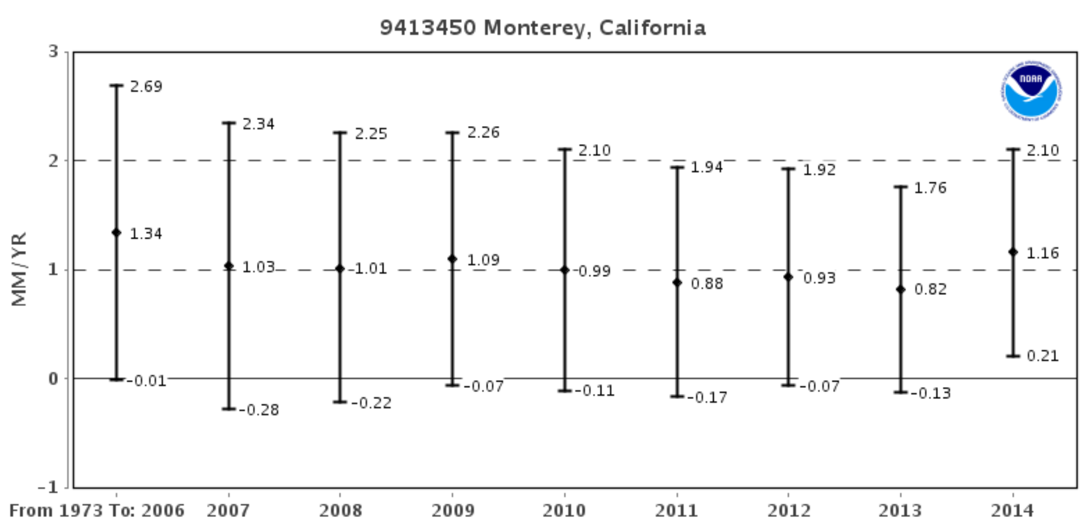

Figure 4. Comparison of previously calculated trends with the latest calculated trend.

In 2014, a subsequent redesign of the site was completed accompanied by the development of an automated product development process for the rapid dissemination of data, derived products, graphics, and metadata to the website. A consequence is that the data displayed on all graphics can be immediately downloaded by the user without having to go to other parts of the CO-OPS website to find the original source data.

In 2015, thirteen new NWLON sea level trends were added in Maine, New York, Maryland, Virginia, Florida, Alabama, Mississippi, Louisiana, Texas, California, Oregon, and Alaska. These include the first in Mississippi, and the first on the western Alaska coast and the northern Alaska coast. Statistics of the total number of hits in the sea level trends content directory of the CO-OPS website show the expansion of the continuing public interest in local sea level trend information (Figure 5). For a table of the U.S. Trends Data table to go: http://tidesandcurrents.noaa.gov/sltrends/mslUSTrendsTable.htm.

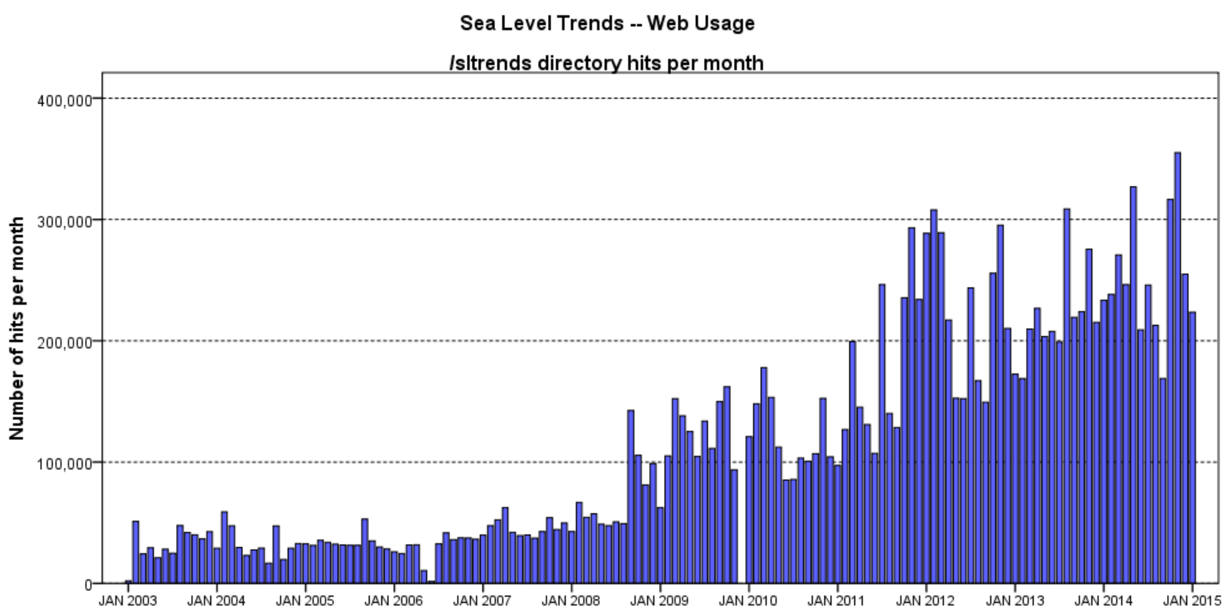

Figure 5. Monthly total of web hits in the sea level trends directory of the CO-OPS website.

Global Sea Level Trends

NOAA/CO-OPS operates and maintains 45 stations identified as long-term sea level trend stations in the GLOSS Implementation Plans of 1997/2012 and routinely analyses their long-term trends and oceanographic variability. In addition, the trend analysis has been extended to a total of 239 stations, including over 130 stations in the GLOSS Core Network (GCN) (Figure 6). The data for these stations were obtained from the PSMSL website (www.psmsl.org). Long-term sea level trends have been calculated for stations in 66 countries worldwide. The expanded number of stations captures the variability in relative sea level change internationally and contributes to local relative sea level rise estimates.

Historical stations were updated with all available data up to 2012 and a total of 135 trends were re-calculated. In some cases, the original source data may have been revised by PSMSL; therefore the calculated trends may have changed. Station-specific metadata have been incorporated, including links to the historical and real-time data, where available. The products can be found here: http://www.tidesandcurrents.noaa.gov/sltrends/sltrends_global.htm or for the Global Trends Data Table: http://tidesandcurrents.noaa.gov/sltrends/mslGlobalTrendsTable.htm.

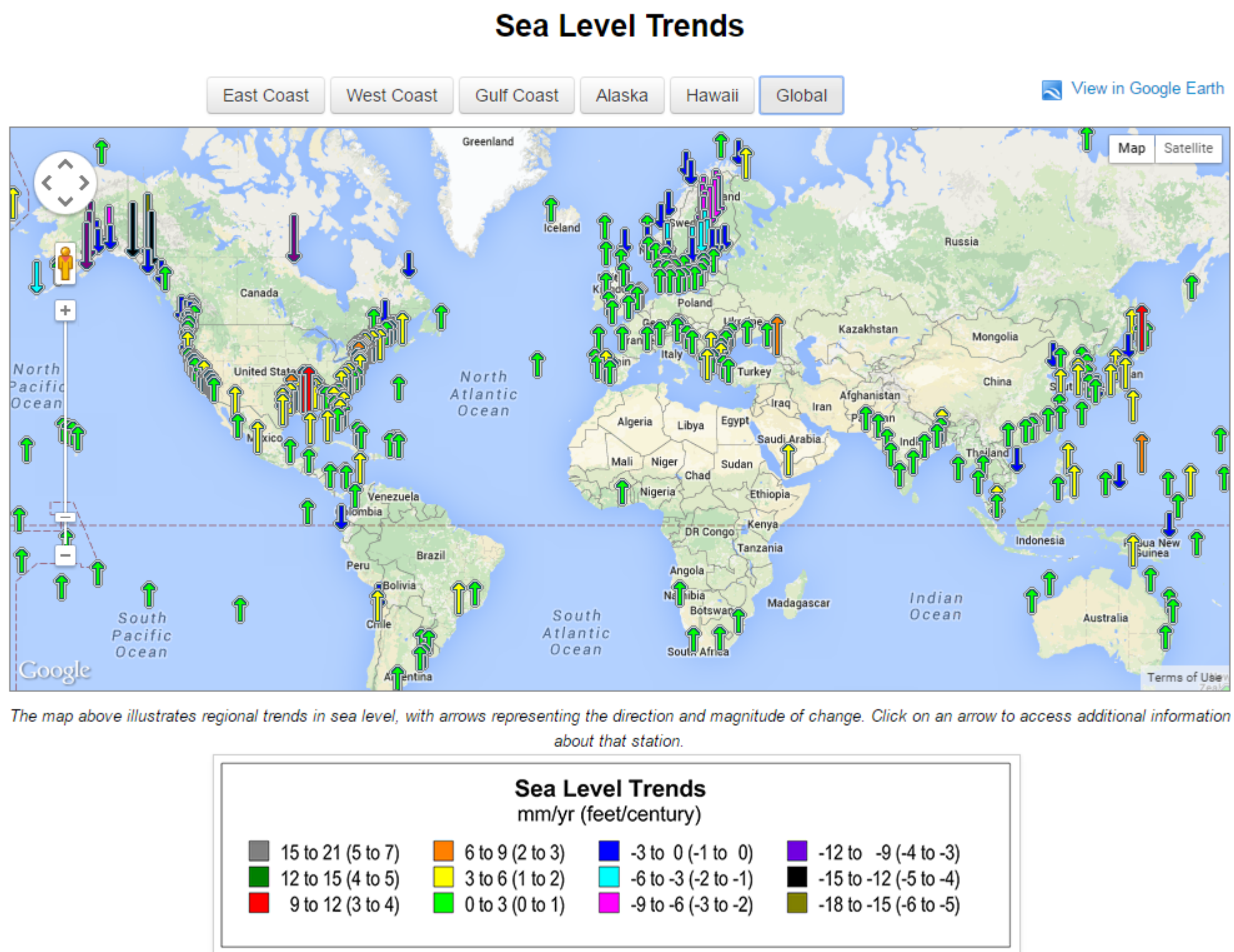

Figure 6. Global Sea Level Stations on *Sea Levels Trends.*

Monitoring "Nuisance" Tidal Flooding

There has been considerable focus on relatively rare (i.e., high magnitude/low probability) inundation events (e.g., tropical cyclones), and for that matter sudden versus gradual changes in sea level. The destructive impacts from land-falling tropical storms, such as Hurricane Katrina and Sandy (Atlantic) and Typhoon Haiyan (Pacific) for example, received considerable attention. Due to climate change-related sea level rise, today's infrastructure has become increasingly prone to flooding from these rare, catastrophic events (Sweet et al., 2013).

However, recently decision-makers have begun to take notice of the potential impacts of more common (i.e., low magnitude/high probability) inundation events growing in frequency due to sea level rise (Sweet et al., 2014). Impact elevation thresholds for "nuisance flooding" levels are defined locally by the National Weather Service for emergency planning purposes and include overwhelmed storm water drainage capacity at high tide, frequent road closures, and general deterioration and corrosion of infrastructure not designed to withstand frequent inundation or saltwater exposure. In general, infrastructure that is 0.3-0.6 above average high tide is susceptible to recurrent tidal flooding around the U.S. (Figure 7a). There is growing recognition that the frequency of such recurrent nuisance tidal flooding events will increase dramatically with rising sea levels and surpass tipping points (Figure 7b) in the coming decades when impacts will have the greatest cumulative impacts on built, social-human, and natural systems over the coming decades (Sweet and Park, 2014).

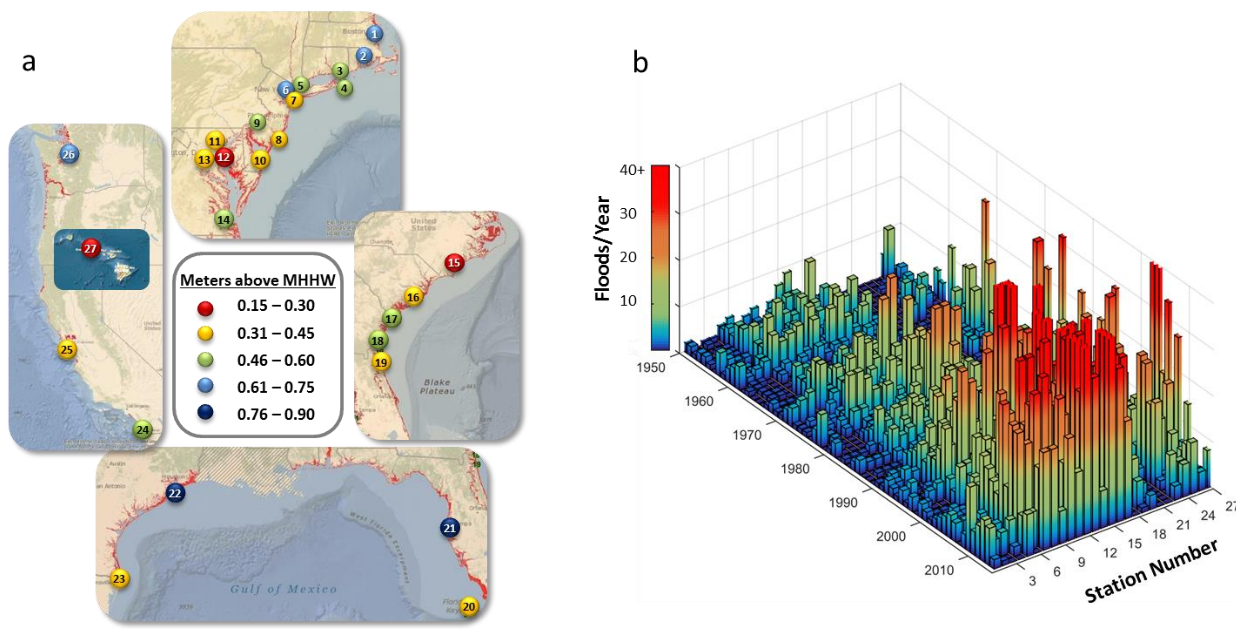

Figure 7: (a) NOAA defined local elevation thresholds for minor "nuisance" flooding impacts and in (b) the annual frequency of days impacted by a nuisance level flood around the U.S. over 1950-2014. From Sweet and Park (2014).

Coastal Inundation Dashboard

CO-OPS is presently beginning development of an experimental product to provide inundation alerts and historical information in order to help warn communities when potential inundations events may occur. Alerts will be triggered based on observed or forecasted water level exceeding defined flood thresholds. The product also intends to better help coastal communities plan for the future by providing past information such as the historical frequency of inundation events to highlight the increase of flood events even in the absence of significant weather, referred to as nuisance floods. This product will also integrate established inundation landmarks to provide local communities with flood information in relation to well-known local landmarks such as a statue, park or building. The product will initially be developed for three coastal areas: Hampton Roads, VA; New York City; and coastal North Carolina.

University of Hawaii Sea Level Center

The University of Hawaii Sea Level Center website hosts a variety of products, in addition to providing access to raw sea level data. Products include: global sea level deviations, tide gauge-altimeter analysis (deviations and anomalies), upper ocean volume, current indices, and topography. http://uhslc.soest.hawaii.edu/

NOAA Laboratory for Satellite Altimetry

NOAA's Laboratory for Satellite Altimetry website includes resources and links to a variety of satellite altimeter products. Projects included on the site include: satellite altimeter sea level rise data, near real-time processed analysis, historical sea level, ERS altimetry data, information on Geosat, geophysics research, and sea floor topography. It also provides updates on new research, and provides access to partner agency websites. http://ibis.grdl.noaa.gov/SAT/SAT.html

Pacific Storms Climatology Project

The Pacific Storms Climatology Products project website (Figure 8) **http://www.pacificstormsclimatology.org/** provides access to an integrated suite of products that delineate patterns and trends of storm frequency and intensity - "storminess"- within the Pacific region. These products are derived from analyses of historical records collected from in-situ stations located throughout the Pacific. The primary audience for these products is scientists, engineers, and others with a technical background. This site also provides access to information that will help non-technical users to learn about the climate-related processes that govern extreme storm events.

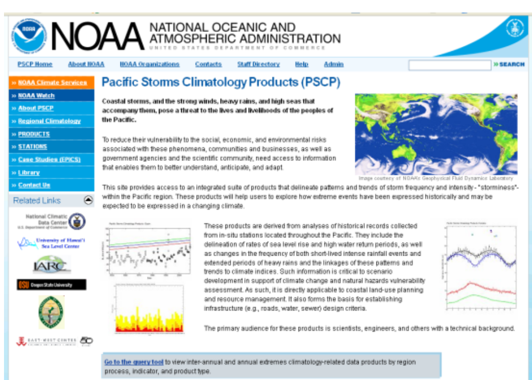

Figure 8. Pacific Storms Climatology Products Website.

D. Using Sea Level Data and Research to Inform Policy

The U.S. Army Corps of Engineers (USACE), the primary agency responsible for coastal engineering projects in the US has recognized the potential for changing sea levels to impact the planning and design of coastal projects. The USACE goal is to develop practical, nationally consistent, legally justifiable, and cost effective measures, both structural and nonstructural, to reduce vulnerabilities and improve the resilience of our water resources infrastructure to changes associated with rising global sea level.

The first guidance was issued in 1986 followed by the publication of the 1987 National Research Council study "Responding to Changes in Sea Level: Engineering Implications" (NRC, 1987). The sea-level change (SLC) guidance was brought up-to-date in 2009 in the form of an Engineer Circular (EC) 1165-2-211, “Incorporating Sea-Level Change Considerations in Civil Works Programs” (USACE, 2009a, further updated to EC 1165-2-212 in 2011). The 2009 guidance was developed with sea-level science experts at NOAA’s National Ocean Service and the U.S. Geological Survey. The 2009 EC directs the formulation and evaluation of project alternatives using low, intermediate, and high rates of future SLC for both the “with” and “without” project conditions. The existing trends computed by NOAA at long-term tide stations are used as the baseline “low” rate for projects in the vicinity of the station. Various climate models are used for the out-year projections. Engineer Circulars have a two-year lifespan, so the EC has been superseded by Engineer Regulation 1100-2-8162, "Incorporating Sea Level Change in Civil Works Programs," released in December 2013.

In July 2014, USACE published further guidance on how to adapt to changing sea levels, Engineer Technical Letter 1100-2-1, "Procedures to Evaluate Sea Level Change: Impacts, Responses and Adaptation", which explains how USACE staff will account for the direct and indirect physical and ecological effects of projected future sea level change on USACE projects and systems of projects, including considerations for adapting to those effects. The ETL presents a broadly applicable method with special attention to four USACE mission areas (Flood Damage Risk Reduction, Coastal Storm Damage Reduction, Navigation, Ecosystems) as well as insight into application to multipurpose projects. The information presented in the technical letter is applicable to the full range of USACE projects and systems, from simple to complex, from small to very large, and over the full life cycle. The procedure recommends three sea level change curves for use ranging from the extrapolated historical sea level trend to a higher curve that incorporates additional ocean warming and ice melt. The tiered approach acknowledges the potential significant impacts of extremes, and cumulative and system effects.

The USACE is currently developing additional implementation guidance in the form of another Engineering Technical Letter (ETL) that will outline the recommended planning and engineering approach at the regional and project level for addressing impacts of extreme water levels. The guidance development is utilizing an interdisciplinary team that includes representatives from all the different regions of the USACE as well as from other key federal agencies dealing with infrastructure and systems. Representatives include numerous agencies, including the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), Federal Emergency Management Agency (FEMA), U.S. Coast Guard, U.S. Naval Academy, Federal Highway Administration, Bureau of Reclamation, National Park Service (NPS), and the U.S. Navy. Personnel from the University of Southampton (UK), HR Wallingford (UK), and Moffatt & Nichol are also participating. Among the topics to be covered are:

- Characterizing past and current extreme water levels prior to adding expected future conditions. Using extreme water level characterization to help explain the expected loading condition prior to looking into adaptation.
- Determining how to make a historical analysis of extremes and surges transferable to the future including effects of expected climate change and the appropriate description of uncertainty.
- Defining categories of extreme events with appropriate descriptive parameters. Breaking down loading into components of water level and components of storms. Include alongshore spatial distribution of extreme loading.

III. New Measurement Technology

A. GPS on Tide Gauges

Continuous GPS

Precise determination of vertical land motion at tide stations continues to be a priority area of investigation for NOAA. Previously, NOAA has investigated use of GPS data from CORS located nearby tide stations to estimate absolute sea level change (Snay *et al*. 2007). Using funding provide by NOAA Office of Climate Observations, new CORS will continue to be established at NWLON stations that are part of the Global Sea Level Observing System (GLOSS) network as budgets allow. Table 3 (below) provides the current listing of co-located CORS and NWLON stations that are within 1.0 km of each other and for which leveling connections can be made in the future.

Table 3. Table of NOAA NWLON and CORS stations located within 1.0 km of each other.

Tide Station	Lat., deg., N	Lon., deg., E	Relative Sea Level Rate (2σ error), mm/yr	Time Span for Tide Gauge Data (years)	CGPS Station (distance to tide gauge), km	NGS-adopted IGS08 Vertical Velocity at CGPS Station, mm/yr	Multi-solution ITRF2008 Vertical Velocity at CGPS Station (2σ), mm/yr	Time span of CGPS Data used in multi-solution (years)
Eastport, ME	44.903	293.015	2.13 (0.20)	1929 – 2012 (84)	EPRT (0.85)	-0.2	-0.23 (0.40)	1998.7 – 2011.3 (12.6)
Newport, RI	41.505	288.673	2.73 (0.18)	1930 – 2012 (83)	NPRI (0.54)	-1.3	-0.33 (0.40)	1999.6 – 2007.7 (8.1)
Sandy Hook, NJ	40.467	285.990	4.06 (0.23)	1932 – 2012 (81)	SHK1 (0.52) SHK2 (0.53)		-2.75 (0.94) -0.50 (6.10)	1998.0 – 2006.3 (8.3)

					SHK5 (0.52) SHK6 (0.53)	-0.6	-2.23 (2.64) -0.50 (6.10)	1995.8 – 2006.3 (10.5) 2006.3 – 2011.3 (7.0) 2006.3 – 2011.2 (6.9)
Reedy Point, DE	39.558	284.427	3.67 (0.55)	1956 – 2012 (57)	RED1 (0.46) RED2 (0.49) RED5 (0.46)	-3.1	-3.05 (3.12) +1.88 (6.92) N/A	1999.1 – 2007.3 (8.2) 2000.1 – 2007.3 (7.2)
Gloucester Point, VA	37.247	283.500	3.81 (0.47)	1950 – 2003 (54)	GLPT (0.18) VAGP (0.19)	-2.5 -2.7	-2.24 (0.40) N/A	1997.5 – 2006.6 (9.1)
Duck, NC	36.183	284.253	4.59 (0.94)	1978 – 2011 (34)	DUCK (0.39)	-1.7	-2.09 (0.40)	1997.6 – 2003.3 (5.7)
Beaufort, NC	34.720	283.330	2.70 (0.39)	1953 – 2012 (0.39)	NCBE (0.21)	Predicted	N/A	
Charleston, SC	32.782	280.075	3.10 (0.23)	1921 – 2012 (92)	SCHA (0.28)	Predicted	N/A	
Key West, FL	24.553	278.192	2.29 (0.15)	1913 – 2012 (100)	CHIN (0.68)	Predicted	N/A	
Grand Isle, LA	29.263	270.043	9.07 (0.49)	1947 – 2012 (66)	GRIS (0.28)	-7.3	-7.15 (6.94)	2007.2 – 2011.3 (4.1)
Galveston PP, TX	29.285	265.212	6.61 (0.70)	1957 – 2012 (56)	TXGV (0.13)	0.0	+0.12 (7.40)	2007.1 – 2011.3 (4.2)
La Jolla, CA	32.867	242.742	2.02 (0.26)	1924 – 2012 (89)	SIO3 (0.75)	-0.6	+0.17 (0.40)	1994.0 – 2012.2 (18.2)
Crescent City, CA	41.745	235.817	-0.81 (0.34)	1933 – 2012 (80)	CACC (0.13)	Predicted	N/A	
South Beach), OR	44.625	235.957	2.34 (0.82)	1967 – 2012 (46)	ORSB (0.46)	Predicted	N/A	
Cordova, AK	60.558	214.247	1.28 (1.02)	1979 2012 (34)	EYAC (1.05)	Predicted	N/A	
Kodiak, AK	57.732	207.488	-10.78 (0.98)	1975 – 2012 (38)	KODK (0.72)	+12.5	+12.32 (0.42)	2003.0 – 2006.6 (3.6)
Unalaska, AK	53.880	193.463	-5.48 (0.56)	1957 – 2012 (56)	AV09 (0.58)	+1.7	+2.52 (0.80)	2004.3 - 2013.5 (9.2)
Honolulu, HI	21.307	202.133	1.42 (0.45)	1905-2012 (107)	HNLC (0.0)	-0.1		1997 – 2011(14)
Bermuda	32.373	295.297	2.09 (0.82)	1932-2012 (80)	BRMU (0.7)	-1.1		1994 – 2011(17)

The following NWLON Stations are in planning for co-location in FY 16-18:

Station ID#	**Location**
9414290	San Francisco, CA
9455090	Seward, AK
9461380	Adak Island, AK
9462620	Unalaska, AK
9468756	Nome, AK
9497645	Prudhoe Bay, AK
9755371	San Juan, PR

General GPS Technology Implementation at NOAA

GPS technology and procedures will be implemented in operational plans:

- to support the development of a seamless, geocentric reference system for the acquisition, management, and archiving of NOAA water level data. This will provide a national and global digital database, which will comply with the minimum geo-spatial metadata standards of the National Spatial Data Infrastructure (NSDI) and connect the NOAA water level database to the NGS National Spatial Reference System (NSRS);
- to establish transformation functions between NOAA chart datum (MLLW) and the geocentric reference system to support NOAA 3-dimensional hydrographic surveys, the implementation of Electronic Chart Display and Information Systems (ECDIS), and the NOAA Vertical Datum transformation (V-Datum tool) and tidal datum models. Integration of GPS procedures into NOAAPORTS® operations will support the development of tidally-controlled Digital Elevation Maps and Models for use in programs such as marsh restoration.
- to support water level datum transfers by using GPS derived orthometric heights.
- to monitor crustal motions (horizontal and vertical) to support global climate change investigations.

GPS-derived orthometric heights can be accurately determined and used for water level datum transfers according to (a) the established guidelines for 3-D precise relative positioning to measure ellipsoid heights, (b) properly connecting to several NAVD88 bench marks, and ©) using the latest high-resolution modeled geoid heights for the area of interest. In many remote locations, the use of GPS-derived orthometric heights for datum transfer will be more efficient (timely) and more cost-effective than the use of conventional differential surveying techniques and may, under certain circumstances, preclude the installation of additional water level stations to establish a datum. In September 2015, NOAA published a NOAA technical report that provides general guidance for the determination of vertical land motion at long-ter
m continuously operating water level stations, for the purpose of separating this signal from relative water level change as measured at the water level station and the subsequent determination of absolute water level change. The report can be found at: http://www.tidesandcurrents.noaa.gov/publications/NOS_Tech_report_139.pdf.

B. Continued Testing of MWWL Sensors and Transition to Operations

Based on the many advantages offered by microwave radar wave level sensors (MWWL), successful MWWL installations reported throughout the international community, and previously reported results from NOAA's first phase of laboratory and long term field testing, the effort to introduce MWWL measurement technology across NOAA's NWLON continues. Also, a second phase of field testing has recently commenced, with the primary objective of better understanding MWWL sensor performance in intermediate to high energy wave regimes.
As previously reported, CO-OPS recommended limited operational use of radar water level sensors across the NWLON in low wave energy sites based of results reported in the following 2011 reference: (http://tidesandcurrents.noaa.gov/publications/Technical_Report_NOS_CO-OPS_061.pdf). A conservative approach has been pursued for the initial transition to operations effort, with MWWL installations being limited to low wave energy NWLON station sites. This is not to

suggest that MWWL sensors cannot meet operational performance requirements in higher energy wave environments but rather an indication of NOAA's very limited amount of supporting field test data along with lack of thorough understanding of a MWWL sensor's performance over a broad range of ocean wave conditions to date.

Transition to Operations in Low Wave Environments

Since many NWLON stations are located in low wave environments, similar to test locations that yielded excellent test long-term results, NOAA has been able to make significant progress with the initial transition efforts, even with a conservative approach to site selection to date. Since CO-OPS first installation of operational MWWL sensors in Mobile Bay, Alabama in July 2011, several additional operational installations have followed. A transition committee has been formed to oversee all decisions on related efforts, which fall under three different categories of applications:

1. Introducing MWWL sensors to a subset of existing NWLON stations located in environments that can be easily classified as favorable.
2. Use of MWWL sensors at new or rebuilt NWLON long-term stations.
3. Use of MWWL sensors in new, temporary water level stations that are established to support hydrographic surveys.

To assist in evaluating suitability of proposed MWWL installation locations, an environmental assessment of each prospective site is compiled and reviewed by the overseeing committee. This is based on all available oceanographic and meteorological archive data as well as bathymetry and coastal boundary conditions. As the number of MWWL station sensor continued to increase, NOAA has continued to develop new laboratory facilities to support routine calibration and verification testing. All of the test results that NOAA has obtained over the past several yeast, including problems encountered and lessons learned, have been used to develop and document a standard, five-step MWWL sensor pre-deployment laboratory test procedure. This test procedure is specifically designed to decrease the likelihood of problems during field deployment. CO-OPS has implemented the requirements to conduct the following tests to verify sensors' basic functionality and accuracy prior to field deployment:

1) Fixed Target Test for Resolution Verification
2) Time Response Verification
3) Sensor Offset Derivation
4) Dynamic Liquid Target Test
5) Range Accuracy Verification

Continued Radar Water Level Sensor Field Testing – Intermediate to High Wave Environments

Test results reported from CO-OPS first phase of laboratory and field testing of radar water level sensors, during 2008-2011, supported CO-OPS operational use in low wave energy environments only, as reported in 2013. Understanding measurement capabilities in high wave energy environments has remained in work in progress. A new series of supporting field test data was recently collected, analyzed, and reported.

CO-OPS experience with the Xylem\Waterlog radar sensor from 2007- 2011 prompted additional questions to be raised concerning the operational characteristics of this sensor. A series of technical reviews and discussions led to consensus that an additional series of field testing was warranted. During 2013, test radar water level platforms were co-located with NWLON Aquatrak sensors and independent wave gauges to provide data in the intermediate- and high-surface energy regimes.

NWLON station sites were selected for additional field testing based on comparison of empirical cumulative distribution functions (ECDF) of water level standard deviation over a period of 1 year. Four station sites selected were: Duck, N.C. (re-installation); Lake Worth, Fla.; La Jolla, Calif.; and Monterey, Calif.

Data collected at each site included: 1 Hz range measurements from both the operational NWLON acoustic sensor and the test radar sensor; half hourly wave bulk parameters and spectra from a Nortek Acoustic Waves and Currents (AWAC) sensor; 6-minute average wind speed and direction; 6-minute average air temperatures near the top and bottom of the Aquatrak well's sounding tube.

Analysis results from data covering a total period of 19 months at Phase II test locations were reported in 2014. Data collection at the four sites was still ongoing, along with continued analysis efforts at the time this summary article was written. The primary results reported to date are as follows (Park et al. 2014):

- The majority of Aquatrak versus radar water level differences are due to systemic errors in the Aquatrak system including:
    - Temperature-induced speed-of-sound errors
    - Wave- and current-induced hydraulic pressure errors
    - Buoyancy-driven water level resonance
- Radar sensor captures water level variability with higher fidelity than the Aquatrak when waves are present.

Plans for Long-Term Radar Water Level Transition to Operations across NWLON

With two extensive data sets (from 2008-2011 and then 2013-2014) providing quantitative evidence of radar water level sensors performance capability, along with many benefits over the acoustic system, CO OPS has developed a plan to transition to radar sensors at most of its NWLON stations.

Since 2011, CO-OPS has transitioned radar water level sensors to operations in three different applications: existing long-term NWLON stations, temporary stations supporting hydrographic surveys, and newly constructed or rebuilt stations. Since 2011, radar water level sensors have been installed at more than twenty short-term stations (hydrographic and vertical datum transformation software [VDatum] support), six existing long-term NWLON stations for one-year overlap, and six new long-term stations.
CO-OPS plans ten to twenty radar water level upgrades to NWLON stations per year with a three-year cycle per station.

- Year 1 - Purchase equipment, perform reconnaissance, and design.
- Year 2 - Install radar water level sensor and collect one year of overlapping data record.
- Year 3 - Remove legacy primary sensor and components (well).

During the transition, CO-OPS will operate both radar water level sensors and existing acoustic and pressure sensors concurrently for one year, if possible, to ensure the stability, continuity, and consistency of data. To make sure the systems perform satisfactorily in varying operational conditions for more than one year, CO-OPS also will conduct long-term comparisons for at least five years at ten NWLON stations. This requirement is driven internally and by the international Global Sea Level Observing System/climate community to ensure the continuity of the data record throughout the transition to a new sensor technology.

To support the transition to operations and the planned increase in radar water level sensor usage throughout NWLON and PORTS, CO-OPS developed a standard radar water level sensor pre-deployment laboratory test procedure designed to significantly decrease the likelihood of problems during field deployment. The procedure is based on extensive test results, including problems encountered and lessons learned. Efforts to create an associated permanent laboratory facility are underway.

Transitioning the radar sensors has also involved the development of a series of new sensor mounting hardware for use on operational installations. Several new types of horizontal extension arms to accommodate the sensors' 10° dispersive beam have been designed and implemented, as well as a geodetic leveling collar to enable survey rods and/or tapes to be consistently located to a leveling point that can easily be referenced to the sensor's zero range point. The WaterLog sensor's zero range point is referenced to the bottom of the circular flange that is used for mounting the sensor. However, because the width of the sensor's electronics housing is larger than the diameter of its flange, a survey leveling rod cannot be set atop the flange such that the rod is straight/vertically level. If the sensor's zero point is referenced to the bottom of the circular flange, the sensor can be mounted so that this flange bottom sits flush against another flat, metal surface, providing additional area for rod placement at the same vertical location as the sensor's flange bottom.

IV. Measurement of Extreme Water Levels

A. Station Configurations and Upgrades

Data and datum continuity are extremely important to any long-term monitoring observing system. Observing systems required for long-term sustained monitoring purposes must aspire to un-interrupted measurement of water level, even during the harshest environments that cause the extreme highest and lowest water levels. Collection of long-time histories of the frequency and duration of extreme events enables exceedance probability analyses for high and low waters, for instance (see Section V.C. Exceedance Probability).

By virtue of their location at the ocean's edge, water level observing stations are exposed to severe damage from wind, storm surge and waves during the very storms which make their operation so important. Stations not designed to withstand severe conditions are often severely damaged or destroyed resulting in significant data gaps until the systems can be replaced and brought back on-line. It is important for all applications of the data from sea level stations to collect the extreme low water values as well and stations are established to measure the full anticipated excursion of water levels, from extreme lowest to extreme highest. Strengthening key water level station infrastructure and sensor configurations ensures that observations of water level, wind speed and direction, barometric pressure, and air and water temperature will be available when the information is needed most and without interruption over the long-term. NOAA National Water Level Observing Network (NWLON) water level stations have several attributes to ensure data and datum continuity listed below. Other agencies and organizations employ these or other similar attributes.

- Primary and backup sensors and data collection platforms (DCPs). A less expensive and less accurate pressure system is used to fill gaps using comparative gains and offsets if the primary sensor (acoustic sensor) malfunctions or exceeds measurement capability (either maximum of minimum measurement limited exceeded due to storm surge or storm withdrawal).
- Complete redundancy. At some locations, two separate independent systems are installed within a short distance. If one primary/backup system goes down or is destroyed, a completely separate system (both primary and backup DCP's and sensors) provides continuous data. This is more expensive but is an option that has proven itself at remote locations where it is often extremely hard and expensive to perform corrective maintenance and repair.
- Multiple modes of data collection. NOAA uses 6-minute interval satellite radio communication as a primary mode backed up by telephone. If a storm destroys both of these connections, data are continued to be collected for up to a month with internal memory for subsequent download by field personnel.

- Hardened water level station structures. NOAA uses existing piers and wharf structures wherever possible, however if these do not provide the appropriate level of hardening to withstand flooding form storm surge and waves, raised instrumentation platforms are installed atop existing infrastructure. I some instances, separate high four-pile structures are designed and built next to existing infrastructure to ensure data continuity during extreme surges. Integrating new technology. NOAA is investing in new Microwave Water Level systems (MWWL) to eventually replace existing primary system acoustic and pressure sensors where feasible. These systems should provide even better performance in terms of lost data because they have no components in the water subject to damage and costly repair and maintenance.
- Independent hardened structures. Even with all of the steps taken in the previous bullets in place, water level stations can still often be destroyed and damaged if the storm makes landfall near the station and it is subjected to extreme waves, flooding, extreme winds, and debris fields and damage of the nearby supporting piers and docks. NOAA has recently implemented a NOAA Sentinel system (described below) to ensure data continuity even during some of the most severe events and direct "hits".

NOAA Sentinels are deployed in open coastal areas most vulnerable to severe storms such as land-fall hurricanes in the US Gulf of Mexico. Sentinels have been established at four locations which were selected based on two objectives; re-establish NWLON stations either destroyed or heavily damaged by recent hurricanes; and establish new stations in areas identified as gaps in the NWLON. Additional Sentinels are being established with partnership federal and state agencies as funding becomes available. Two Sentinels off the coast of Texas have just been completed, and four more have been funded and are underway through Texas A&M University.

NOAA Sentinels are large single-pile structures (see Figure 9). A single-pile structure presents a minimal profile to a storm coming from any direction. Engineering specifications based on Category 4 generated wind and wave action analysis determined that the platforms stand at least 25 feet above the sea surface on a 4-foot diameter single pile. The piles are driven 60-80 feet into the seafloor to ensure stability. The Sentinels are expected to enhance GLOSS objectives by ensuring continuous records during storm events and reducing the number of long data gaps due to storm damage. These stations will also improve the ability to record maximum water levels.

Figure 9. One of the US NOAA Sentinel Tide Stations in the Gulf of Mexico.

B. The Role of Coastal Tide Stations in U.S. Storm Surge Warning

For tropical cyclones impacting the U.S. coast, tide gauges play a crucial role in monitoring real-time conditions and recording events of record. Many stations in hurricane-vulnerable areas such as the Gulf of Mexico have been hardened to withstand hurricane conditions, continuing to transmit critical storm tide measurements during the worst of storm conditions. Forecasters, emergency managers, first responders, and other decision makers depend upon real-time water level records during severe storm surge events in order to monitor and respond to evolving severe conditions.

The NOAA storm surge monitoring network in Mobile Bay has employed the use of a new water level sensor system based upon microwave radar technology. These sensors are located high enough to observe severe surge events, and are located on robust platforms that are likely to withstand extreme floods and winds. CO-OPS has approved the MWWL sensor technology for collecting water level data in all conditions except the ice environment. So far about 149 stations that are part of the National Water Level Observation Network (NWLON) and 31 stations that are part of the Physical Oceanographic Real-Time System (PORTS) have been approved for transition to microwave radar technology, with station upgrades tentatively planned to begin in 2015 and planned to be completed over the next 12 years.

Additionally, it is critical that the peak water level event of record is recorded for coastal regions because this information is needed to define engineering design conditions, set insurance rates, develop evacuation plans, and validate storm surge models. First, long term water level records are analyzed in order to understand the frequency and level of significant storm surges. Engineers use this data to set design conditions for coastal regions (e.g., for 100 year or 500 year events). CO-OPS also analyzes the records at long-term stations to provide this analysis to decisions makers (see Section V.C. for discussion; http://tidesandcurrents.noaa.gov/est/). However, if water level observations are lost during the highest water level events, the accuracy of these analyses are compromised. Second, storm surge models are used to augment sparse observation records (due to the rare occurrence of events, the relatively low density of observation stations, and the historical loss of those stations due to storm surges). This is often done by simulating conditions from thousands of hypothetical storms. However, the accuracy of these models cannot be validated with a small historical observation record that does not contain the maximum water level events (due to station failure or loss during storms), and the analyses and products based on them (engineering design conditions, building codes, insurance rates, evacuation plans) have lower confidence and accuracy.

CO-OPS produces several products supporting users of storm surge records, both during and following tropical cyclones that impact the coast of the U.S. and its territories. When the National Weather Service issues a tropical storm or hurricane warning for the U.S. coast, CO-OPS issues the Storm QuickLook product (http://tidesandcurrents.noaa.gov/quicklook.shtml). This product provides a synopsis of near real-time water level and meteorological observations at locations affected by the tropical cyclone. It is updated four times per day (typically one hour after the National Hurricane Center issues a forecast showing the path of the hurricane). The Storm QuickLook product contains three main sections: 1) a map highlighting NOS tide gauge locations and tropical cyclone data (including track, intensity and satellite imagery), 2) an analysis section with a summary of present water level conditions along with the latest NWS public advisory information about the storm, and 3) time series plots of water level, wind and barometric pressure observations from CO-OPS, which are updated in real-time. Additional useful information is displayed including the time and height of the next high tide and the 24 hour maximum observed water level. The QuickLook product highlights the subset of the stations that most significantly affected by a storm, and provides links to real-time data at additional locations. Real-time water level observations within the QuickLook product are displayed on Mean Higher High Water (MHHW). MHHW provides an estimate of when flooding inundation may occur at coastal locations and allows for an easier comparison between observed storm tide and storm surge guidance, which is referenced to ground level (AGL). Water level observations can be adjusted to display on Mean Lower Low Water (MLLW), Mean Sea Level (MSL) or the North American Vertical Datum of 1988 (NAVD88).

Following a significant storm surge event, it is important to validate the maximum water elevation due to the storm. One such method that is robust and highly accurate is to review water level data measured at NOS tide gauges during the storm. CO-OPS provides a report to the National Weather Service highlighting preliminary maximum storm tide and storm surge measurements, as well as maximum wind and minimum barometric pressure measured during the period where the storm's impacts were felt along the coast. These reports are typically disseminated within 5 days following a storm to provide local Weather Forecast Offices and their customers with a rapid assessment of water level measurements. For significant storms, CO-OPS will issue a Water Level and Meteorological Data Report, which includes a brief synopsis of the storm, along with data tables highlighting extreme storm tide, storm surge and meteorological observations at all locations affected by a storm and time series plots highlighting water level data before, during and after the storm. In 2012, reports were completed for Hurricane Isaac and Hurricane Sandy. These and other reports can be found on http://www.tidesandcurrents.noaa.gov under Publications.

C. Web Products

Exceedance Probability

Since 2011, NOAA/CO-OPS has provided exceedance probability statistics for select water level stations through its *Extreme Water Levels* website (http://tidesandcurrents.noaa.gov/est/). Extremely high or low water levels at coastal locations are a public concern and an important factor in coastal hazard assessment, navigational safety, and ecosystem management. Exceedance probability, the likelihood that water levels will exceed a given elevation, has been calculated based on historic extreme water level values. The product provides exceedance probability statistics for stations with at least 30 years of data. When used in conjunction with real time data, exceedance probability levels can be used to evaluate current conditions and determine whether a rare event has occurred. This information can also be instrumental in planning for the possibility of dangerously high or low water events on a local level. Because these statistics are station specific, use for evaluating surrounding areas may be limited.

Access to statistics for individual stations is via a Google Map Interface where users can select a station in a region of interest (Figure 10). The web site provides access to the monthly highest and lowest water levels overlain by the exceedance probability levels which rise or fall with the sea level trend rate, exceedance probability curves relative to return periods, and exceedance probability levels relative to tidal datums.

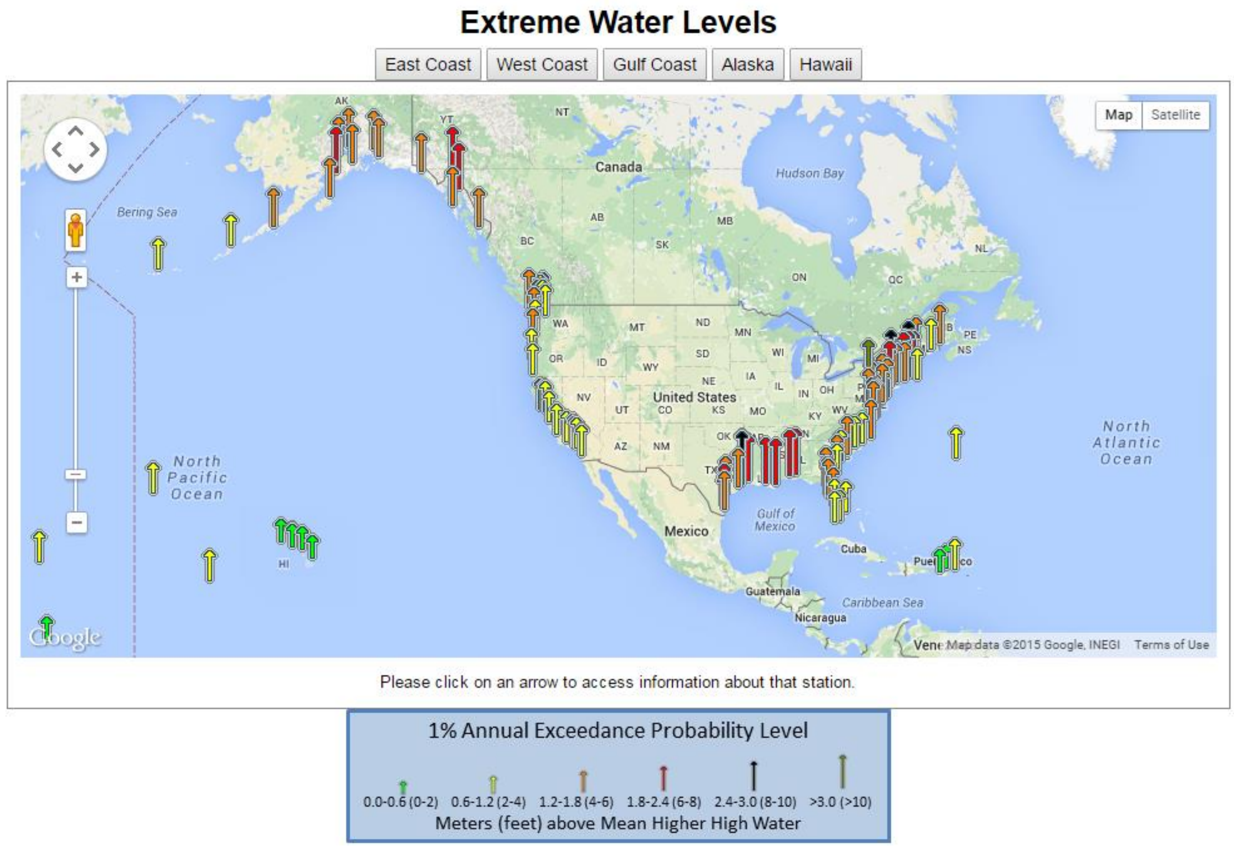

Figure 10: Google Map Interface for Exceedance Probability Statistics on Extreme Water Levels.

The methodology used in the calculation of exceedance probability levels was documented in "Extreme Water Levels of the United States 1893-2010" a NOAA Technical Report published in 2013. An appendix was added to the report in which the statistics were recalculated for Bridgeport, CT, The Battery, NY and Sandy Hook, NJ, taking into account the peak storm tides from Hurricane Irene in 2011 and Hurricane Sandy in 2012. The effect was to raise exceedance probability curves at the 100-year return period by 0.22 - 0.33 meters. The recalculated statistics for these three stations were incorporated into the website.

The exceedance probability statistics along with the sea level trends on the NOAA/CO-OPS website have been incorporated into the U.S. Army Corps of Engineers Sea Level Change Curve Calculator (http://corpsclimate.us/ccaceslcurves.cfm). The calculator is a tool used for the comprehensive evaluation of Corps projects with respect to various scenarios for future sea level change. The purpose is to conduct screening-level assessments of the vulnerability of projects and identify those requiring more detailed analysis and possible near-term adaptation.

A popular addition to the Extreme Water Levels website is the Top Ten List (Table 4). The list was compiled and has been periodically updated to respond to general interest in where recent storm surge events have ranked in the historical water level records of a station. These rankings are not adjusted for sea level trends. Statistics of the total number of hits in the extreme water levels content directory of the CO-OPS website show the growing interest in the exceedance probability information (Figure 11).

Top Ten Highest Water Levels for long-term stations in meters above MHHW (as of 1/2015)

* --- Inferred Level ! --- Last Recorded Level # --- High Water Mark

Station Number	Station Name	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
1611400	Nawiliwili, HI	9/11/1992	7/31/2004	9/10/1981	11/6/2006	1/10/2005	2/4/1985	12/13/2008	11/25/2003	9/24/2003	12/20/1968
	(since 1954)	0.961	0.374	0.370	0.360	0.349	0.348	0.337	0.333	0.331	0.330
1612340	Honolulu, HI	9/11/1992	12/20/1968	1/17/1969	1/8/1974	7/11/1995	6/14/2003	9/24/2003	6/3/2004	12/22/1995	7/31/2008
	(since 1905)	0.447	0.423	0.362	0.362	0.359	0.359	0.350	0.348	0.347	0.338
1612480	Mokuoloe, HI	1/8/1974	12/20/1968	12/13/2008	11/13/2004	11/25/2007	11/23/1984	8/9/2006	11/12/1996	9/6/2003	12/21/1987
	(since 1957)	0.445	0.415	0.409	0.389	0.373	0.372	0.371	0.363	0.359	0.357
1615680	Kahului, HI	1/8/1974	12/20/1968	1/7/1978	8/9/2006	11/24/1995	12/11/1977	11/25/2007	12/31/2001	6/14/1981	6/3/2004
	(since 1951)	0.376	0.376	0.367	0.352	0.352	0.346	0.336	0.336	0.334	0.326
1617760	Hilo, HI	1/20/1981	6/4/2004	1/12/2005	12/31/1982	2/6/1993	12/24/1996	7/31/2004	8/26/1984	8/8/1991	7/22/2005
	(since 1946)	0.417	0.402	0.386	0.374	0.371	0.371	0.368	0.365	0.362	0.361
1619000	Johnston Atoll	1/13/1958	1/7/1962	1/8/1974	1/18/1959	8/19/1972	2/23/1986	1/19/2003	10/5/1994	1/11/1954	1/1/1999
	(1947-2003)	0.846	0.663	0.541	0.541	0.541	0.516	0.508	0.495	0.480	0.470
1619910	Midway Atoll	1/11/1958	2/21/1986	12/20/1964	1/14/2011	2/12/1998	1/16/2005	1/20/2015	1/11/2004	12/18/2013	12/20/2004
	(since 1947)	* 0.867	0.793	0.775	0.722	0.716	0.671	0.609	0.598	0.584	0.573
1630000	Apra Harbor, Guam	8/28/1992	6/4/2008	7/22/2005	7/23/2013	7/4/2002	5/5/2008	12/11/2008	7/30/2008	8/28/1984	8/19/2013
	(since 1948)	0.594	0.408	0.388	0.384	0.372	0.367	0.365	0.365	0.353	0.349
1770000	Pago Pago, Samoa	9/8/2014	1/22/2011	1/31/2014	4/18/2011	10/8/2014	7/13/2014	3/20/2011	12/13/2012	8/11/2014	2/19/2011
	(since 1948)	0.517	0.515	0.495	0.492	0.488	0.474	0.473	0.472	0.469	0.469
1820000	Kwajalein	9/8/2010	2/28/2006	1/31/2014	4/7/2012	2/19/2011	1/21/2011	10/26/2007	3/8/2012	7/23/2013	10/27/2011
	(since 1946)	0.621	0.620	0.607	0.604	0.598	0.582	0.579	0.578	0.574	0.573
1890000	Wake Island	8/31/2006	10/28/1992	9/15/1994	1/17/1953	8/29/2004	8/19/1997	10/6/1968	9/28/1996	9/1/2004	8/21/1986
	(since 1950)	1.214	0.981	0.718	0.612	0.561	0.523	0.490	0.471	0.470	0.453
2695540	Bermuda	9/25/1987	12/1/1967	10/26/1995	10/28/2011	12/27/1976	9/8/1998	11/11/2011	10/27/2003	10/17/2012	11/22/1961
	(since 1932)	0.660	0.639	0.612	0.570	0.563	0.555	0.537	0.531	0.528	0.517
8410140	Eastport, ME	1/10/1997	4/6/1977	1/29/1979	1/9/1978	9/6/1979	12/5/1976	1/21/2011	12/20/1968	1/10/1982	1/3/2014
	(since 1929)	1.509	1.476	1.378	1.354	1.329	1.323	1.279	1.259	1.253	1.245
8413320	Bar Harbor, ME	12/29/1959	2/7/1978	1/27/1963	1/9/1978	1/29/1979	1/21/2011	1/2/2010	12/22/1995	1/10/1982	12/4/1990
	(since 1947)	1.084	1.075	1.054	1.039	1.020	0.970	0.952	0.947	0.932	0.911
8418150	Portland, ME	2/7/1978	1/9/1978	3/16/1976	12/4/1990	11/20/1945	11/30/1944	4/16/2007	1/2/1987	12/29/1959	4/7/1958
	(since 1912)	1.286	1.229	1.025	1.022	1.019	1.019	0.993	0.985	0.958	0.958

NOAA/Center for Operational Oceanographic Products and Services

Table 4. Top Ten List of the ten highest water levels recorded at the extreme water level stations.

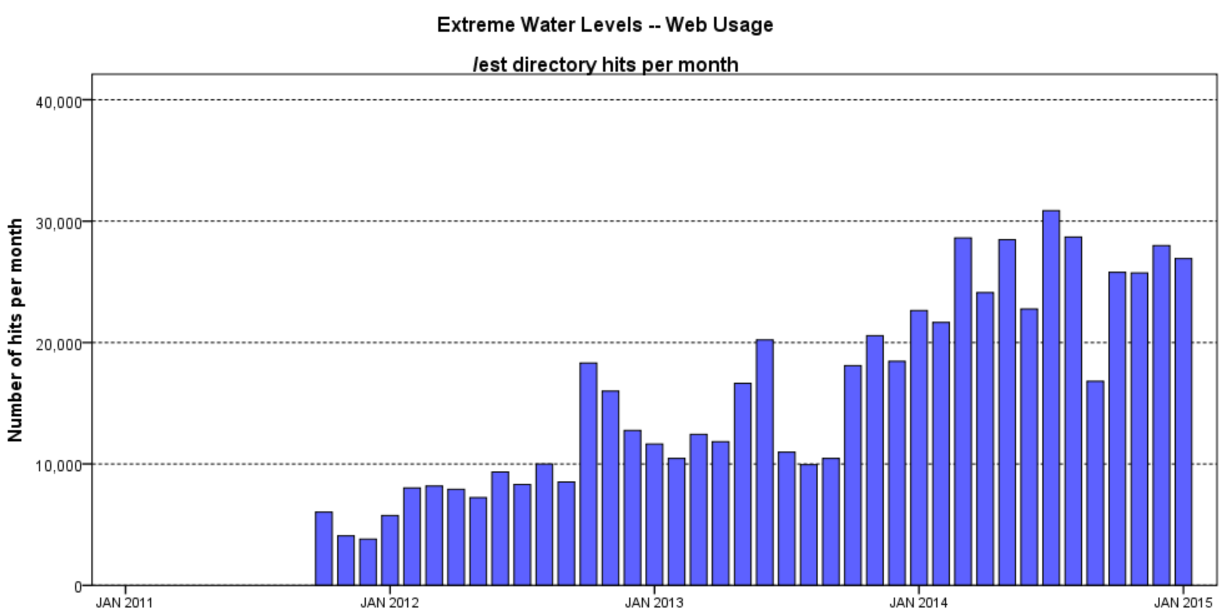

Figure 11. Monthly total of web hits in the extreme water levels directory of the CO-OPS website.

Probabilistic estimates of extreme water level under a changing climate

Work on probabilistic estimates of extreme still water level events under a changing climate is on-going. Recent efforts are summarized at http://www.noaaclimatepacis.org/slr/workshop2/ This site outlines activities carried out in association with the 2nd Technical Workshop, the "Best Practices for the Formulation of Localized Sea Level Rise/Coastal Inundation 'Extremes' Scenarios in the Pacific Islands" held November 6-7, 2013 in Honolulu. This workshop brought together government, academic, and other experts to share knowledge and explore our current understanding of information and methods that can be used to project long-term changes in sea level and coastal inundation in the Pacific Islands. The guidance and products (Figure 12) that can be accessed here represent the most recent results of efforts to develop and apply innovative methodologies and best practices for the formulation of probabilistic estimates of extreme still water level events under a changing climate for specific locations in the Pacific Islands (http://www.noaaclimatepacis.org/slr/phase2.php).

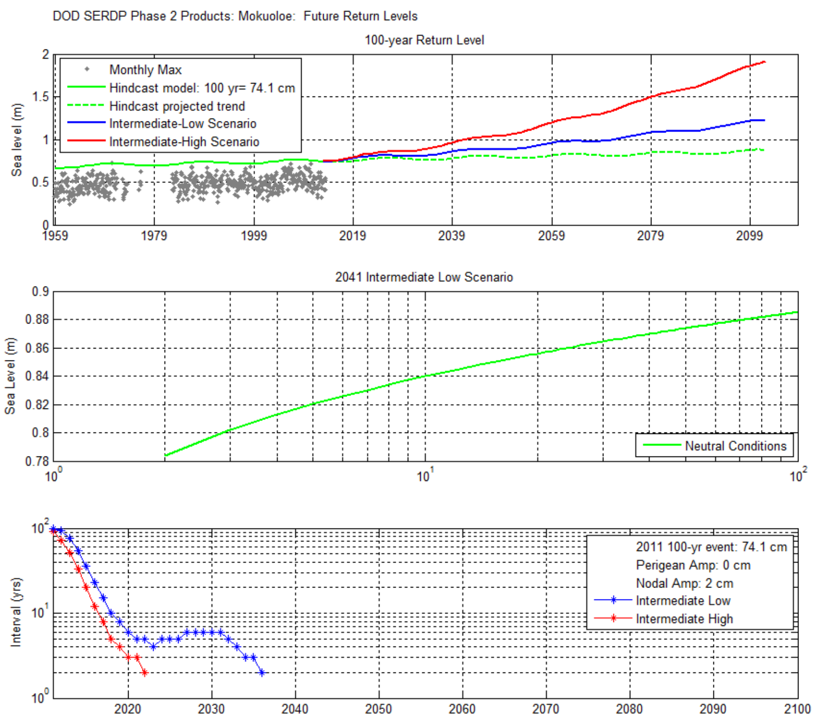

Figure 12. From top to bottom: a) Time-varying 100-year Return Level for the Hindcast Observed model (green line), NCA SLR Intermediate-Low (blue) and Intermediate-High (red) Scenario. All models consider seasonal, perigean, and nodal contributions to the location parameter and seasonal contribution to the scale parameter; b) 2041 NCA SLR Intermediate-Low Scenario exceedance probability curves (return level estimations) for: neutral covariate conditions (green), Positive covariate conditions (blue), and negative covariate conditions (red); c) Recurrence interval decay curves, showing change in return level interval associated with 2011 Hindcast observed 100 yr return level elevation under NCA SLR Intermediate Low (blue) and High (red) scenarios.

Mean Sea Level Anomaly (MSLA) Outlooks

Regular communications among representatives of the US NOAA, University of Hawaii, New Zealand NIWA, Australian CSIRO and BOM, among others over the past year or so have lead towards the development of an experimental ensemble (statistical and dynamical) mean sea level anomaly (MSLA) outlook. This activity represents a center of action within a broader effort to support regional collaboration in the areas of data and observations, applied research and analysis, product development, and outreach and training. The outlooks (Figure 13) respond to a need from community planners, resource managers, and other decision-makers for information about the potential for coastal flooding and erosion to threaten coastal structures and property, groundwater reservoirs, harbor operations, waste water systems, sandy beaches, coral reef ecosystems, and other social and economic concerns. Currently, information of this type is limited in scope and not well integrated.

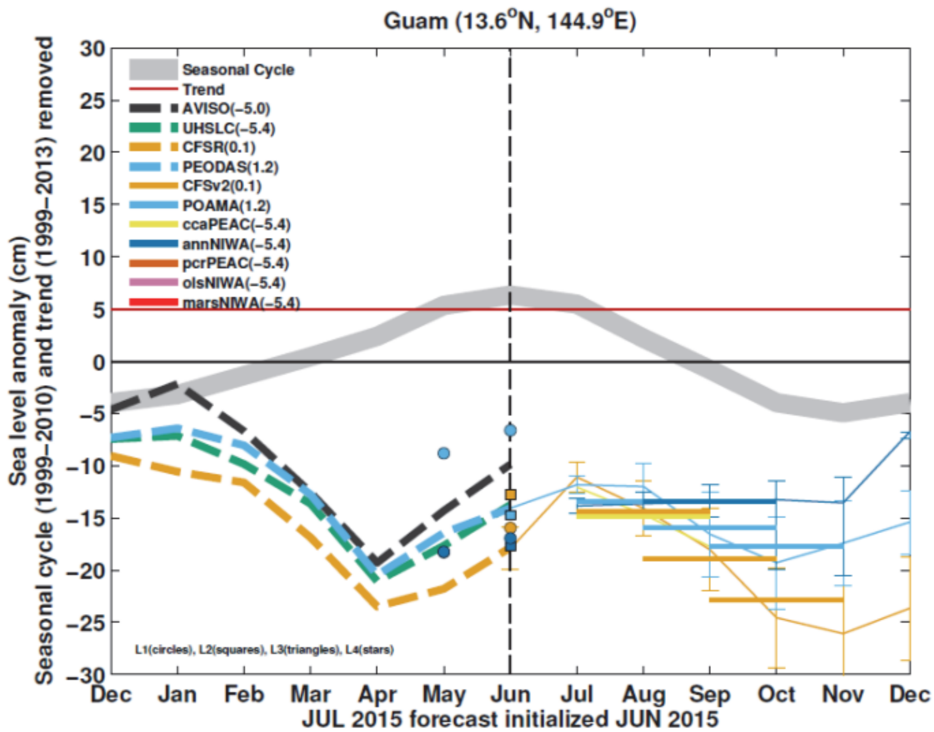

Figure 13. Example of experimental MSLA Ensemble Outlook for for July–December, 2015 and observations for the previous seven months.

V. Regional Activities

A. Pacific Islands Integrated Water Level Service

Regional partners including the US NOAA, NZ NIWA and Met Service, and Australian CSIRO and BOM among others are coordinating on the creation and distribution of climate-related sea level products. This group has identified the development and distribution of actionable information related to high waves and water levels at a seasonal scale as an area of mutual interest (see above). Joint efforts in this area constitute path-finding activities directed towards aligning complementary interests and activities, sponsoring joint projects, and leveraging funding as a way to minimize duplication of effort and maximize the use of agency resources in the Pacific. It represents a center of action within a broader effort to support regional collaboration in the areas of data and observations, applied research and analysis, product development, and outreach and training and demonstrate the value of regionally integrated water level-related products and services.

B. Support of Regional Tsunami Warning Systems

U.S. Tsunami Program

Although the frequency of damaging tsunamis in the U.S. is low compared with many other natural hazards, the impacts can be extremely high. In 2011, The National Research Council of the National Academies of Science released a report titled *Tsunami Warning and Preparedness* that offered many suggestions for improvement of the national tsunami mitigation, preparedness, response, and warning capability. In order to implement these recommendations, NOAA relies on a network of global data, acquired and processed in real-time, in addition to high-quality global databases supporting advanced scientific modeling. NOAA has upgraded its sea level stations for near-shore monitoring, upgraded and expanded the network of seismic stations in partnership with the USGS, and expanded the Deep-ocean Assessment and Reporting of Tsunami (DART®)stations in the Atlantic, Caribbean, Gulf of Mexico and Pacific regions as part of the GEOSS. NOAA, in collaboration with the National Tsunami Hazard Mitigation Program (NTHMP), is advancing modeling and mapping activities, hazard assessment and data stewardship, quantitative assessment of socio-economic impacts and increased tsunami mitigation and preparedness.

New and Upgraded Tsunami Capable Tide Stations

Following the 2004 Indian Ocean tsunami disaster, the U.S. evaluated and strengthened its national tsunami warning system. NOAA has upgraded its existing National Water Level Observation Network (NWLON) tide stations with new Data Collection Platforms (DCPs) and communication technology, and filled gaps in the existing water level network with new tsunami-capable NWLON tide stations. NOAA's Tsunami Warning Centers also receive sea level data (1-minute averages transmitted every 5 minutes) from GLOSS stations operated by the University of Hawaii Sea Level Center (UHSLC). These tide stations, in addition to international tide stations in multiple countries, comprise an integrated coastal water level observation network, critical for tsunami detection and warning.

From 2005-2007, NOAA installed 17 new stations and 33 NWLON station upgrades, in support of the U.S. Tsunami Program. In addition to these priority locations, NOAA has been systematically upgrading NWLON stations along all U.S. Coasts, including its possessions and territories. There are currently 208 of 210 NWLON stations operating with full tsunami capabilities.

NWLON stations configured to support tsunami collect 1-minute averaged water level values in addition to the standard 6-minute averaged values. Unlike the previous generation of DCPs which transmitted 6-minute average water level values hourly via Geostationary Operational Environmental Satellites (GOES), the new DCPs transmit water level data every 6 minutes. 6-minute GOES transmissions include primary and backup 6-minute averaged water level data, as well as 1-minute water level data. The messages also include data quality parameters (mean, standard deviation and outliers) and data from any meteorological sensors operating at the station, as well as the preceding water level values from the primary and redundant sensors which can be used to fill data gaps should a transmission be missed. Upgraded NWLON stations also collect 15-second data from the backup water level sensor, which are stored at the backup DCP on a flash memory card. 15-second data are not transmitted via GOES, or routinely archived, but are available for post-event analysis and modeling through the DCP's 56K modem or direct serial connection at the DCP. Enhancements are also under development, in order to increase two-way communication capabilities at tsunami stations for diagnostics, firmware upgrades, reconfiguration, trouble shooting, and data retrieval, thereby eliminating the need to travel to the site, and promoting quicker response to problems and outages.

IOC Tsunami Warning Systems

The IOC of UNESCO has successfully coordinated the Pacific Tsunami Warning System since 1965. After the 2004 Sumatra tsunami, IOC was mandated to assist Indian Ocean Member States in development of an Indian Ocean Tsunami Warning System (IOTWS). The IOC also assisted at the same time with the development Early Warning Systems for tsunami and other coastal hazards in both the Caribbean (CARIBE EWS) and the Mediterranean and Northeast Atlantic Ocean (NEAMTWS). These TWSs, all continue to be coordinated by the IOC, are supported by the Member States which collect, analyze, and disseminate seismic and sea level data in support of warning and preparedness. The U.S. has played an active role in the PTWS, IOTWS, and the CARIBE EWS, both through collection of observations and providing tsunami warnings, and through provision of technical expertise and also has participated in the sessions of the NEAMTWS.

Sustainable Sea Level Observations

In support of the CARIBE-EWS, the U.S. through NOAA's National Ocean Service installed in 2011 a new, sustainable sea level station in Barbuda. Site selection was focused on providing maximum benefit to the region through enhanced warning products, and was founded on scientifically-assessed vulnerability in the country of Antigua and Barbuda. This station contributes data to the Tsunami Warning Centers. It was temporarily removed in 2013 due to pier reconstruction and dredging, but was re-established in 2014. The sustainable nature of the construction of this station as a long-term station makes it an ideal site for a Caribbean GLOSS station.

Puerto Rico Seismic Network of the University of Puerto Rico at Mayagüez

The Puerto Rico Seismic Network (PRSN) of the University of Puerto Rico at Mayagüez (UPRM) operates 6 sea level stations in Puerto Rico. The 6 tide gauge stations are NOS compliant and were funded by FEMA and the UPRM and installed and with the support and guidance of NOS/NOAA between 2006 and 2008. All of these stations also meet GLOSS standards for sea level observations and are currently providing data to appropriate warning centers and weather service offices. At the moment of this report one of the stations (Penuelas) is in the process of being relocated to another site off southern Puerto Rico. The data are transmitted every 6 minutes on GOES. In addition some of these stations have been updated to transmit data every minute over the internet. The data can be accessed on the home page of the PRSN, http://redsismica.uprm.edu, Tides and Currents site of NOAA, http://tidesandcurrents.noaa.gov and Tides on Line site of NOAA http://tidesonline.nos.noaa.gov/monitor.html.

Each station is equipped with an acoustic and pressure sensor, 2 DCPs, air and water temperature sensors. All stations also have a meteorology package consisting of a wind, air temperature/relative humidity, barometric and rain gauges. The wind sensors were upgraded to meet the specification of the WMO. The power of the station is autonomous and runs off solar panels. Timing is provided with a GPS. For leveling purposes, each sea level station has 6 benchmarks which have all been observed with GPS. Second-order, class I levels were used in connections at all the stations.

A GOES receiver and central recording system is operational at the Puerto Rico Seismic Network to receive the data from these and other sea level stations operated by NOAA and other sea level operators in the Caribbean and Adjacent regions. These stations are monitored 24/7 as part of the PRSN Earthquake and Tsunami Information and Warning System. XCONNECT software of Sutron is used for display and quality control of the data. The West Coast and Alaska Tsunami Warning Center software, Tide View, is used to mesh observed tsunami information with the forecast model and compare observed waves with predicted tide and estimated tsunami arrival times, as well as digitally filter the tsunami signal. PRSN is also developing a suite of codes in house to add quality control to sea level data, and to feed 1-minute live stream to remote clients, including the Tsunami Warning Centers.

The PRSN also supports efforts to improve sea level observations in the Caribbean for tsunami and other coastal hazards. In 2008 it hosted the IOC-GLOSS-PRSN Caribbean Training Course for Operators of Sea Level Stations, and had a workshop this year to discuss post-tsunami survey measurements. In 2008 it also installed a NOAA/NOS and GLOSS compliant station in the Dominican Republic for which it continues to provide support. In 2012-2013 it assisted with the upgrading of the Road Town, Tortola, British Virgin Islands station and also installed a tsunami ready tide gauge in the Dominican Republic, in the south province of Barahona. The data from these stations are available thru the PRSN website, as well as the IOC Sea Level Monitoring Facility.

It has been collaborating with the University of Hawaii in the installation and upgrade of an additional 10 stations in the Caribbean in support of tsunami monitoring. As part of these efforts, as of 2011, El Limon in Costa Rica, Curacao, Grenada, Dominica and Puerto Plata and Punta Cana have been installed. By 2014, when this project ends, additional stations are to be installed in Turks and Caicos, Panama and Colombia (2 stations). By 2011 the PRSN in coordination with the Tsunami Unit of UNESCO has plans to install a new coastal sea level station in Port au Prince, Haiti. In 2011, also with UNESCO, the PRSN has begun evaluating additional sites for the installation of sea level stations in the Central America and several islands in the Caribbean. The website of the PRSN has links to data of many of the stations operational in the Caribbean and Adjacent regions.

Caribbean Tsunami Warning Program

The Caribbean Tsunami Warning Program (CTWP) was established by the US NWS in 2010 in Mayagüez, Puerto Rico.). This office currently provides support and guidance for tsunami observations, including seismic and sea level systems, tsunami forecasting, communications and education and preparedness. It works closely with the Pacific Tsunami Warning Center and the National Tsunami Warning Center, the UNESCO Intergovernmental Oceanographic Commission's Intergovernmental Coordination Group for Tsunamis and Other Coastal Hazards Warning System for the Caribbean Sea and Adjacent Regions, GLOSS as well as other local, national and regional stakeholders.

At the request of the CARIBE EWS it maintains a database on sea level stations in the Caribbean and hosts on its website (http://www.srh.noaa.gov/srh/ctwp/) an interactive Google Map of sea level stations. It prepares monthly reports of sea level data availability at different centers, including the IOC Sea Level Monitoring Facility, NOAA, the PRSN and the University of Hawaii Sea Level Center. As of September 2015 the CARIBE EWS station inventory (Figure 19) includes 136 coastal stations (including existing, planned, gap and nonoperational stations) and 7 DART stations in the Caribbean and Western Atlantic (non US mainland). Of these stations, all the DART stations have been installed and 70 coastal sea level stations are contributing data over GOES or FTP, most at least every 5 or 6 minutes (26% increase over 2013 when there were just 55 coastal sea level station). Currently there are plans to install new sea level stations in Haiti, Turks and Caicos, Venezuela, Belize and Anguilla. Thru UNAVCO (US GPS Consortium), sea level stations were installed in Mexico and Jamaica along with high rate GNSS equipment and augmented the Barahona station in DR with GNSS equipment. UNAVCO has plans to install at leas one addition high rate GNSS stations at another existing tide gauge sites in the region. There are still real time sea level observational gaps in northeastern South America, offshore Central America and some locations in the Lesser and Greater Antilles. For these locations efforts are underway to install or identify funding for upgrades/new stations. In addition to maintaining an inventory of sea level stations in the Caribbean and Western Atlantic basin, the CTWP helped organize the 4th regional GLOSS-CARIBE EWS sea level network operator's workshop **"Strengthening Sea Level Observation Network and Coordination Activities in the Caribbean"** in November 2014 in Mayaguez, Puerto Rico. The course was organized within the framework of the Intergovernmental Oceanographic Commission IOC of UNESCO (GLOSS, IOCARIBE and Tsunami), the US National Oceanic and Atmospheric Administration (NOAA) and the Puerto Rico Seismic Network of the University of Puerto Rico at Mayagüez. The purpose of the course was to provide the sea level station operators and data analysts in the region lectures and hands on training on the science and operations of sea level stations for tsunami and other coastal hazards warning purposes. The workshop included 4 days of lectures, presentations and exercises and a field trip to a station operated by the PRSN. 44 sea level station professionals representing 18 Member States and Territories from the Caribbean, Central America, northern South America, Mexico, US Mainland, Puerto Rico and Hawaii participated in the training activity. **The UNESCO IOC CARIBE EWS is trying to identify a source of funding to host a 5th course in 2016.**

In the intersessional 2013-2015 period the CTWP worked with GLOSS Chair and other stakeholders in updating the core list of GLOSS stations for the Caribbean. Also, the CTWP prepared a special contribution on Radar (Microwave) sensors in the Caribbean for an upcoming GLOSS manual on these types of sensors.

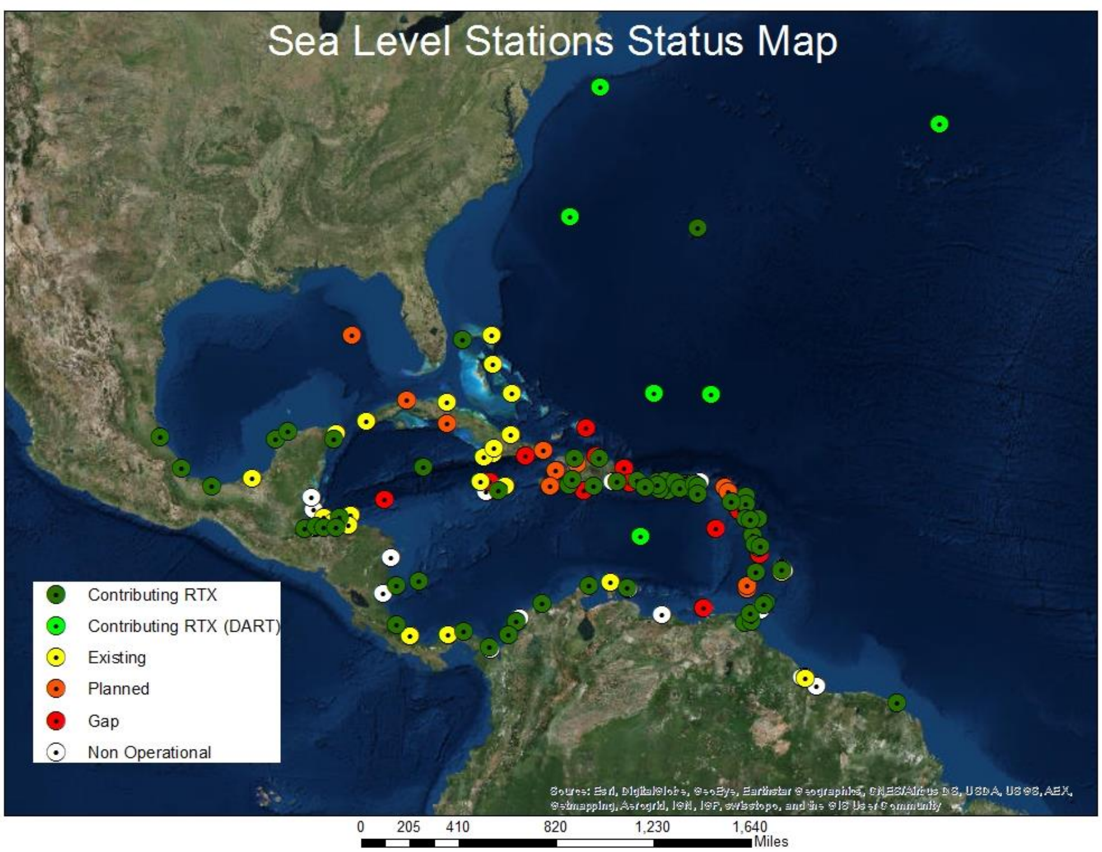

Figure 14. Current status of sea level stations in the Caribbean (September 2015).

APPENDIX 1: NOAA CO-OPS GLOSS Stations in the United States

GLOSS ID	Location	Status
74	Nome, AK	• Ongoing, currently using a dual orifice digital/bubbler system and a separate pressure gauge backup • PSMSL data through 2014 • JASL (0595A) data to 2015
100	Sand Point, AK	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (574A) data to 2015
102	Unalaska (Dutch Harbor), AK	• Ongoing, currently using redundant digital bubbler gauges and DCPs • PSMSL data through 2014 • JASL (041B) data to 2015
105	Wake Island	• Ongoing, currently using an acoustic gauge with pressure gauge backup – with fully redundant digital bubbler gauge and DCP • PSMSL data through 2014 • JASL (051A) data to 2015
106	Midway Island	• Ongoing, currently using an acoustic gauge with pressure gauge backup – with completely redundant acoustic sensor and DCP • PSMSL data through 2014 • JASL (050A) data to 2015
108	Honolulu. HI	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (057B) data to 2015
109	Johnston Island	No longer operated by NOAA as of 2003 – operated by UHSLC since 2004 • PSMSL data through 2003 • JASL (052A) data to 2015
111	Kwajelein	• Ongoing, currently using a digital bubbler gauge with pressure gauge backup • PSMSL data through 2014 • JASL (055A) data to 2015
144	Pago Pago, AS	• Ongoing, currently using redundant digital bubbler gauges and DCPs with pressure gauge backup • PSMSL data through 2014 • JASL (056A) data to 2015
149	Apra Harbor, Guam	• Ongoing, currently using completely redundant digital bubbler gauges and DCPs with backup pressure gauges • PSMSL data through 2014 • JASL (053A) data to 2015
150	Seward, AK	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (560C) data to 2015

GLOSS ID	Location	Status
151	Prudhoe Bay, AK	• Ongoing, currently using a digital/bubbler system with a redundant acoustic gauge and DCP during the ice – free season • PSMSL data through 2014 • JASL (579A) data to 2015
154	Sitka, AK	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (559A) data to 2015
157	South Beach, OR	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (592A) data to 2015
158	San Francisco, CA	• Ongoing, currently using a dual orifice digital/bubbler system with a backup pressure gauge • PSMSL data through 2014 • JASL (551A) data to 2015
159	La Jolla, CA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (554A) data to 2015
206	San Juan, PR	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (245A) data to 2015
216	Key West, FL	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (242A) data to 2015
217	Galveston Pier 21, TX	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (775A) data to 2015
219	Duck Pier, NC	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (260A) data to 2015
220	Atlantic City, NJ	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (264A) data to 2015
221	Bermuda	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (259A) data to 2015
287	Hilo, HI	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (060A) data to 2015

GLOSS ID	Location	Status
288	Pensacola, FL	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (762A) data to 2015
289	Fort Pulaski, GA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (752A) data through 2015
290	Newport, RI	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL (253A) data to 2015
302	Adak, AK	• Ongoing, currently using completely redundant digital bubbler gauges with a pressure gauge backup • PSMSL data through 2014 • JASL (040A) data to 2015
332	Virginia Key, FL	• Ongoing, currently using an acoustic gauge with pressure gauge • PSMSL data through 2014 • JASL (755A) data to 2015

APPENDIX 2: Status of additional operational non-GLOSS NWLON Stations in the United States

JASL ID	Location	Status
039A	Kodiak, AK	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data to 2015
058A	Nawiliwili, HI	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data to 2015
059A	Kahului, HI	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data to 2015
061A	Mokuoloe, HI	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2013
240A	Fernandina Beach, FL	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012

JASL ID	Location	Status
246A	Magueyes Island, PR	• Ongoing, currently using an acoustic gauge with pressure gauge backup – with redundant DCP • PSMSL data through 2014 • JASL data through 2012
252A	Portland, ME	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
254A	Lime Tree bay, VI	• Ongoing, currently using an acoustic gauge with pressure gauge backup – with redundant DCP • PSMSL data through 2014 • JASL data through 2012
255A	Charlotte Amalie, VI	• Ongoing, currently using an acoustic gauge with pressure gauge backup – with redundant DCP • PSMSL data through 2014 • JASL data through 2012
261A	Charleston, SC	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data to 2015
279A	Montauk, NY	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
552A	Kawaihae, HI	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2013
555A	Monterey, CA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
556A	Crescent City, CA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data to 2015
557A	Port Orford, OR	• Ongoing, currently using a digital bubbler gauge and DCP with a pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
558A	Neah Bay, WA	• Ongoing, currently using a digital bubbler gauge and DCP • PSMSL data through 2014 • JASL data to 2015
561A	Seldovia, AK	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2012 • JASL data through 2012
562A	Valdez. AK	• Ongoing, currently using an acoustic gauge with pressure gauge backup

JASL ID	Location	Status
		• PSMSL data through 2014 • JASL data through 2012
564A	Willapa Bay (Toke Point), WA	• Ongoing, currently using completely redundant digital bubbler gauges and DCPs • PSMSL data through 2014 • JASL data through 2012
565A	Port San Luis, CA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
567A	Los Angeles, CA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
569A	San Diego, CA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2015
570A	Yakutat, AK	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data to 2015
571A	Ketchikan, AK	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data to 2015
572A	Astoria, OR	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
573A	Arena Cove, CA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
575A	Charleston, OR	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
576A	Humboldt Bay (North Spit), CA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
578A	Santa Monica, CA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
583B	Cordova, AK	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014

JASL ID	Location	Status
		• JASL data through 2012
594A	Platform Harvest, CA	• Ongoing, currently two DCP's with paroscientific pressure digital bubbler sensors • JASL data 1995 through 1999
740A	Eastport, ME	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
741A	Boston, MA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
742A	Woods Hole. MA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
743A	Nantucket, MA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
744A	New London, CT	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
745A	New York (The Battery), NY	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
746A	Cape May, NJ	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
747A	Lewes, DE	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
749A	Chesapeake BBT, VA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
750A	Wilmington, NC	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
753A	Mayport, FL	• Removed in 2000, used an acoustic gauge with pressure gauge backup. Replaced with Mayport, Bar Pilots Dock. • PSMSL data through 2000 • JASL data through 2000

JASL ID	Location	Status
757A	Naples,FL	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
759A	St. Petersburg, FL	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
760A	Apalachicola, FL	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
761A	Panama City Beach, FL	• Ongoing, currently using an acoustic gauge with pressure gauge backup • JASL data through 2012
763A	Dauphin Island, AL	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
765A	Grand Isle, LA	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
766A	Sabine Pass, TX	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL through 2014 • JASL data through 2012
767A	Galveston Pleasure Pier, TX	• Removed in 2011, used an acoustic gauge with pressure gauge backup. Replaced with Galveston, North Jetty. • PSMSL data through 2011 • JASL data through 2011
769A	Rockport, TX	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
770A	Corpus Christi, TX	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data 1992 through 2012
772A	Port Isabel, TX	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
773A	Clearwater Beach, FL	• Ongoing, currently using an acoustic gauge with pressure gauge backup • PSMSL data through 2014 • JASL data through 2012
774A	Port Canaveral (Trident	• Ongoing, currently using an acoustic gauge with pressure gauge backup

JASL ID	Location	Status
	Pier), FL	• PSMSL data through 2014 • JASL data through 2012

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