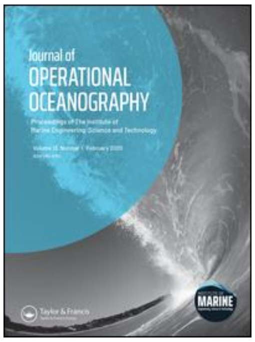

Journal of Operational Oceanography

ISSN: 1755-876X (Print) 1755-8778 (Online) Journal homepage: https://www.tandfonline.com/loi/tjoo20

NOAA's national water level observation network (NWLON)

Ashley Miller & Audra Luscher

To cite this article: Ashley Miller & Audra Luscher (2019) NOAA's national water level observation network (NWLON), Journal of Operational Oceanography, 12:sup2, S57-S66, DOI: 10.1080/1755876X.2018.1523301

To link to this article: https://doi.org/10.1080/1755876X.2018.1523301

JOURNAL OF OPERATIONAL OCEANOGRAPHY
2019, VOL. 12, NO. S2, s57–s66
https://doi.org/10.1080/1755876X.2018.1523301

NOAA's national water level observation network (NWLON)

Ashley Miller and Audra Luscher

National Oceanic and Atmospheric Administration, National Ocean Service, Center for Operational Oceanographic Products and Services, Silver Spring, MD, USA

ABSTRACT
The National Oceanographic and Atmospheric Administration National Water Level Observation Network (NWLON) is the foundation of a comprehensive system for observing, communicating, and assessing the impact of changing water levels nationwide. The network also measures other oceanographic parameters in addition to water levels, including meteorological parameters. Although initially established to support navigation, NWLON is a 'go to' source for data and products to support coastal community decision making. Real-time water level information available 24/7 is critical to emergency managers and planners monitoring changing water levels and contributes to NOAA's forecast model for tsunami and storm surge warnings. This article also discusses the role of NWLON in terms of addressing emerging observational needs around emergency management, tracking changes in sea level rise through persistent changes in high tide flooding, establishing new regional sea level scenarios and projections, and restoring tidally influenced habitats. Sea level trends have been computed at 142 water level stations using a minimum span of 30 years of observations at each location. Coupling present trends with projected future scenarios supports decisions that will remain relevant into the future.

ARTICLE HISTORY
Received 17 April 2018
Accepted 10 September 2018

KEYWORDS
Water levels; tide predictions; datums; sea level rise; inundation; national water level observation network

Introduction

The National Oceanic and Atmospheric Administration's (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) operates the National Water Level Observation Network (NWLON). This system currently consists of 210 continually operating water level stations along the U.S. coast and its territories, including the Great Lakes (Figure 1). CO-OPS and its predecessors have gathered oceanographic data along our nation's coasts for over 200 years to protect life, property, and the environment. CO-OPS has statutory responsibility for tidal measurements, analyses, predictions, and datum determination. A deterministic assessment of the size and geospatial density of water level stations for NWLON was developed to provide a rationale for the number and location of stations required to support NOAA's mission and goals (Gill and Fischer 2008).

NWLON is also the foundation for observing, communicating, and assessing the impact of changing water levels across the nation and is the 'go to' source for government and commercial navigation, recreation, and coastal ecosystem management. In addition to water levels, the stations typically also measure other oceanographic and meteorological parameters such as water temperature and wind speed. NOAA uses this information to ensure safe navigation through access to real-time data 24 h a day, seven days a week. It also helps NOAA understand air/sea interactions/responses and regional ocean dynamics during the transition from short-term to seasonal weather changes, which enables storm surge forecasts and provides the foundation for coastal sea level monitoring and planning along U.S. coasts. NOAA nowcast and forecast models use the observational data to provide a look into present and future oceanographic conditions, which can also enhance tsunami and storm surge warnings.

In recent years, CO-OPS has worked to bridge the gap between data and services to deliver usable information that supports informed decision-making for coastal communities. A number of new products and services have been developed to support communities with emergency and ecosystem management and long-range sea level planning using the observations from NWLON. This article discusses the network sustainability, storm monitoring, scenario-based planning for sea level change, and tracking of high tide flooding through new

CONTACT Audra Luscher audra.luscher@noaa.gov National Oceanic and Atmospheric Administration, National Ocean Service, Center for Operational Oceanographic Products and Services, 1305 East West Highway, Room 6650, Silver Spring 20910, MD, USA

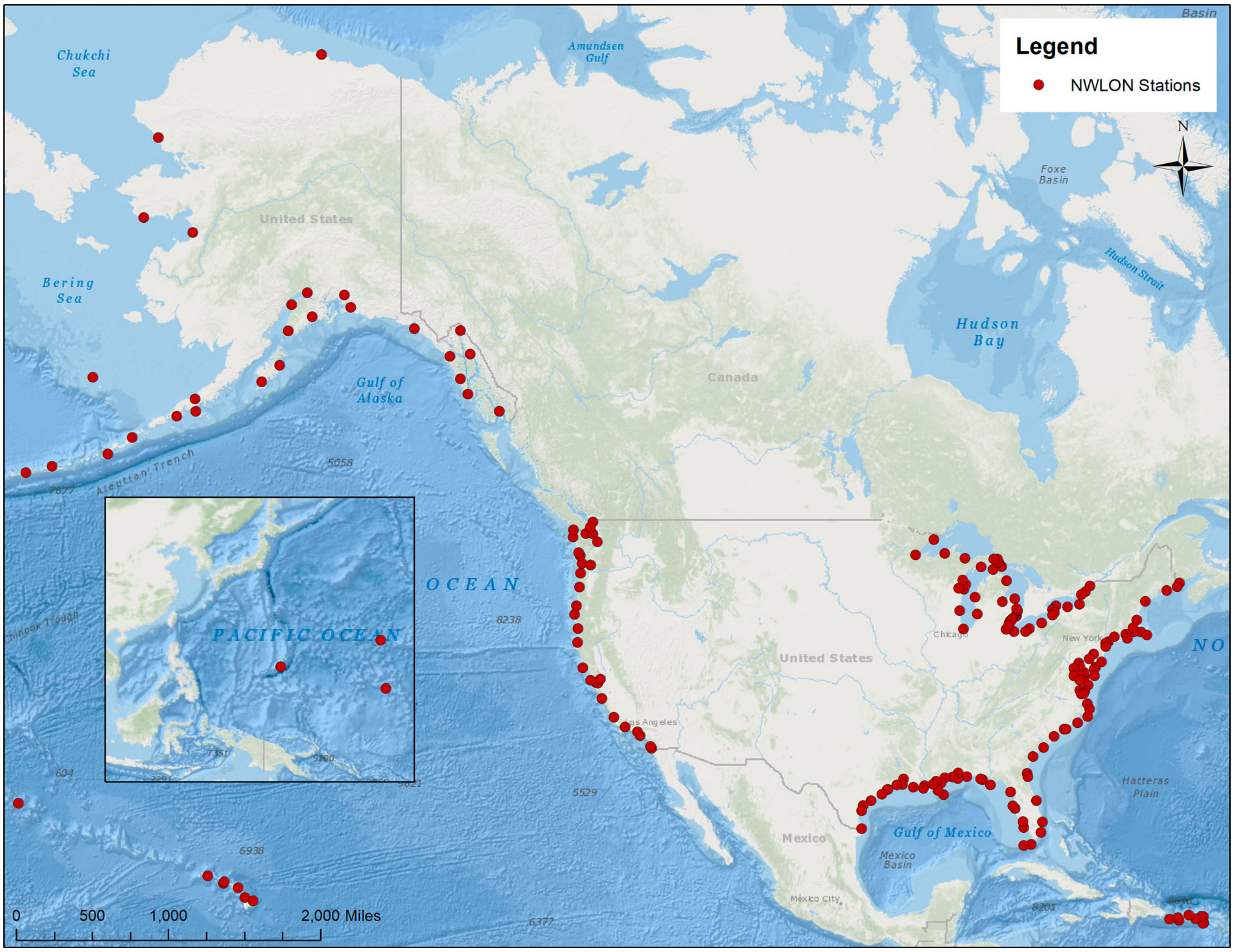

Figure 1. Locations of the National Water Level Observation Network stations.

spatial and communication products. It also discusses enabling ecosystem practitioners to use water level data associated with the spatial reference network to better understand effects of sea level rise on coastal habitats.

History of NWLON and data collection:

Since the early 1800s, NOAA and its predecessors have been measuring and predicting tides along the United States coast. The longest continual sea level record exists in San Francisco, California dating back to June 1854. CO-OPS is responsible for recording and disseminating high-accuracy operational water level data and more recently meteorological observations within NOAA. In the past, systems measured water levels with a recorder driven by a float within a stilling well, which would calm waters around the water level sensor. Prior to the 1960s, these water level data were recorded on a continuously running pen and ink strip chart; these records were collected only once a month and then sent to headquarters for processing. Later, data were recorded on mechanically punched paper tape that would be read by a computer.

Advances in technology and the need to provide near real-time data for navigation safety requirements through the Physical Oceanographic Real-Time System (PORTS®) helped evolve the NWLON to provide more customised data collection and improve measurement accuracy. In the 1980s, major technological advancements occurred through the transition from electromechanical devices to the Next Generation Water Level Measurement System (NGWLMS), which is a set of fully integrated systems encompassing new technology sensors and recording equipment, multiple state-of-the-art transmission options, and integrated data processing, analyses, and dissemination subsystem (Russin et al. 1985). To meet the mission requirement to collect continuous, high accuracy data, the NGWLMS improves operational resilience by incorporating multiple power supply sources, communications, and sensors (Aquatrak™ self-calibrating air acoustic sensor and Paroscientific pressure sensors tied into a single- or dual-orifice gas purged bubbler system), in order to mitigate data loss. Data are collected every 6 min, and transmission is controlled by a Geostationary Operational Environmental Satellite (GOES), which enables quick, up-to-date access to all of the water level and meteorological data. CO-OPS maintains a bench mark network and levels the sensor after installation and annually to determine vertical movement of the water level measurement sensor over time. Establishing 'bracketing' levels is a quality assurance check that the data collected between these dates have been collected from a vertically stable sensor and any data products derived (such as a tidal datum) are disseminated with a high level of confidence.

NWLON and maritime support:

NWLON provides the observational infrastructure for PORTS, an integrated real-time information system that provides comprehensive situational awareness of the operating environment, enabling the best safety and operational decisions. A cost-share partnership between federal and nonfederal organisations, PORTS delivers accurate and reliable environmental observations to users in over 30 of the nation's major ports and is a critical decision support tool for maritime commerce, economic efficiency, and coastal resource management. These PORTS sensors measure oceanographic and meteorological conditions, such as water levels, currents, salinity, wind, and bridge clearance. Each integrated system of sensors, concentrated in seaports, is tailored to the specific needs of the local community. PORTS systems come in a variety of sizes and configurations, each specifically designed to meet local user requirements. PORTS integrates data from existing NWLON stations when established. The largest existing PORTS installation has over 50 separate sensors; the smallest consists of one water-level gauge and meteorological instruments to measure winds, air temperature, barometric pressure, etc.

Beginning in the fall of 1997, the Continuous Operational Real-Time Monitoring System (CORMS) became the 'watchstander' of PORTS data, continually quality controlling and providing quality assurance. In the 2007 data collection platform upgrade, CORMS began overseeing all CO-OPS real-time data, systems, and web products when NWLON transitioned to real-time data (every 6 min instead of hourly). CORMS-experienced oceanographers provide 24/7 oversight of real-time data, ensuring the availability and integrity of more than a half-million measurement points per day, originating from around 2,000 separate oceanographic and meteorological sensors throughout the coastal U.S. Using automated software, CORMS can promptly detect system outages, data quality problems, and hazard warnings, which are either resolved or technical staff is alerted to take corrective action. In addition, CORMS also coordinates an initial response or action on customer requests.

The NWLON oceanographic data are available through CO-OPS' website in near real-time (every 6 min) in various formats, including online graphical products, text data, phone, and OPeNDAP. A metadata application programme interface (API) is also provided that can be used to retrieve a catalog of the data available about the water level stations. Metadata include information such as when the station was established, datums and harmonic constituents at the station location, bench mark locations and details, etc. The metadata help the user understand the structure, definitions, and descriptions of the data coming from the NWLON.

Recent technology improvements:

NWLON is operated in highly variable environments from the Arctic in Alaska to the Tropics in the Caribbean and Pacific Ocean. Some station locations are in remote and challenging environments with extreme conditions leading to corrosion, ice cover, biofouling, and more. While CO-OPS has sought to standardise the system, there is no single station configuration (i.e. sensor type, platform, communication or power supply) that works for all conditions. Network sustainability has been a catalyst for recent technology improvements to address operational challenges and increase efficiencies in the network. The following improvements will be discussed: connecting the network to the Global Navigation Satellite System (GNSS); upgrading primary sensors; implementing station hardening; and adapting data collection schema and infrastructure to gather 1-minute water level data for tsunami detection and warning systems.

NWLON supports the vertical reference system of tidal datums for the nation. A tidal datum is defined in terms of a certain phase of the tide (Mean Low Water [MLW], Mean Higher High Water [MHHW], etc.) and is based on a 19-year period of water level averaging called the National Tidal Datum Epoch (NTDE). The present NTDE adopted by NOAA/National Ocean Service (NOS) in the United States is 1983 through 2001. This specific 19-year period is the official time segment over which sea level observations are taken and reduced to obtain mean values for datum definition. Water level (tidal) datums are local vertical datums, which may change considerably within a geographical area due to changes in tidal hydrodynamics and range of tide. Therefore, maintaining the density of NWLON stations along the coast is critical for maintaining the national spatial reference framework. Datums are referenced to fixed points on land, known as bench marks, with data provided about these marks made available through bench mark data sheets. The NTDE must be actively considered for revision every 25 years; CO-OPS is currently planning the next NTDE update to be initiated in 2020. In nontidal areas like the Great Lakes, water level and chart datum elevations are presently referenced to International Great Lakes Datum of 1985.

CO-OPS is exploring technology improvements related to the vertical reference system by using GNSS at NWLON stations for conducting near-continuous sensor stability monitoring and establishing improved geodetic and tidal relationships in near real time. Currently, assessing sensor stability is achieved through differential levelling surveys and is the most work-intensive aspect of annual maintenance procedures for the NWLON. In addition, the potential to use GNSS to better understand and resolve the various components of relative sea level rise also exists, which improves the quality and accessibility of the suite of CO-OPS products valued by stakeholders. In 2002, CO-OPS began installing Continuous Operating Reference Stations (CORS) at NWLON water level stations and now has a total of 22 stations in operation. CORS provide GNSS data that support three-dimensional (3-D) positioning; these data are shared and analyzed by the National Geodetic Survey (https://www.ngs.noaa.gov/CORS_Map/). More recently, CO-OPS collaborated with Old Dominion University to install continuous GNSS test systems on four NWLON stations throughout Virginia and is planning to expand to additional locations where applicable.

In 2008, CO-OPS initiated efforts to identify a new primary sensor for the NWLON and began suitability testing of microwave radar sensor technologies. The sensor is positioned above the water and receives reflected radar impulses. Algorithms using 'time of flight' technology provide the range to the water level and derive a height. The transition was desirable because of the benefits of locating the sensor outside the water, which reduced diving requirements, biofouling, and susceptibility to damage from waves and storm surge. Unlike acoustic sensors, the microwave radar sensor does not have temperature dependence or hydraulic pressure effects (Park et al. 2014), resulting in fewer data quality reviews and sensor calibration checks.

To prevent introduction of undetected systemic errors from a sensor transition, comparisons were completed between operational sensors already installed and microwave radar test locations across the United States coasts. In most cases, water level measurements from test and operational sensors were in good agreement, with measurements varying less than .02 metre of each other (Heitsenrether and Davis 2011). This validation allowed CO-OPS to proceed with sensor transition within the NWLON, and acoustic sensors began to be replaced with microwave radar water level technology (MWWL) starting in 2012. Due to efficiencies gained associated with installation and maintenance of these sensors, transition became a top priority and by 2018, 22 NWLON stations have been fully transitioned to MWWL with the remaining transitions anticipated to be completed by 2025. A minimum of one year of simultaneous data comparison between the acoustic and the MWWL sensor is required to ensure that the tidal datum record can be maintained and transitioned through the new sensor. Data from both sensors are processed every month, compared, and issues are flagged and investigated by scientists to validate the new sensor. Once consistency is confirmed, dissemination of the data is switched from the acoustic to the MWWL sensor and is supported by an operational backup pressure sensor for data redundancy.

As local decision makers and emergency managers have come to rely on real-time dissemination of NWLON data (especially during storm and tsunami threats), demand for hardened stations has grown. Station hardening adds stability to the infrastructure so that it can withstand wind and waves up to a Category 4 hurricane. The hardened station can remain functioning during extreme events, providing the infrastructure to remain functional during extreme events, providing continuity of information during safety of life and property missions. Impacts from storms in the early 2000s resulted in investments by CO-OPS and its Gulf of Mexico partners to make significant upgrades throughout Mobile Bay and Texas. Threats from water and coastal hazards are a growing problem as witnessed by the 2017 tropical storm season, which included six major hurricanes with two Category 5 storms and was the most expensive year on record for billion-dollar weather and climate disasters[1]. The importance of station hardening was demonstrated in 2017 when only a few station outages were experienced in the Gulf of Mexico and only one complete loss occurred at Port Aransas, Texas.

Station hardening entails improving structures on which sensors are attached, with the most robust enhancement occurring through the NWLON 'Sentinel' design (Figure 2). Currently, NWLON includes 10 sentinels, operated by NOAA or our partners. Sentinels are 25-foot tall structures with 4-foot diameter steel posts driven 60–80 feet into the sea floor for stability. They are strategically placed in commercial ports and coastal storm prone areas, ensuring that data are available to help emergency managers prepare for, mitigate, and respond to

Figure 2. 'NOAA Sentinels' are water level stations designed to withstand wind and wave action from category four hurricanes (winds from 131 to 155 miles per hour).

severe coastal storms and facilitate reopening of ports after storms pass. Other station-hardening methods employed throughout the network include: developing clear engineering criteria that allow building elevated structures to ensure stations are above probable flooding levels; choosing solid structures and piers when installing on partner infrastructure; using waterproof enclosures and armoring cabling; strengthening connections and supports; and improving back-up power capacity.

A final recent improvement relates to adapting the NWLON to collect 1-minute water level data for enhanced tsunami detection and warning systems. CO-OPS has been involved with tsunami detection and warning for coastal hazard mitigation since the Coast and Geodetic Survey started the Tsunami Warning System in 1948 to provide warnings to the Hawaiian Islands. However, after the 2004 Indian Ocean earthquake and tsunami, CO-OPS upgraded its instrumentation with new hardware (specifically data collection platforms) and software to increase the rate of data collection and transmission at all coastal NWLON stations. A number of new NWLON stations were also established in tsunami prone areas including the Caribbean, U.S. West Coast, and throughout the Pacific. These stations now have the capability to collect high resolution, 1-minute water level data, available to the Tsunami Warning Centers via satellite transmission and CO-OPS 1-minute water level data application. It allows external customers to view the 6-minute and 1-minute data numerically or graphically for all tsunami-capable tide stations in increments of up to four days.

NWLON products:

Tide predictions and published tide tables are traditional, long-standing products developed from data collected through the NWLON. Tides are primarily driven by astronomic forces but water levels deviate from predictions when weather and other factors occur along the coast. The Operational Forecast System (OFS) was developed to enhance the tide prediction products by taking weather and other non-astronomic influences into account and providing tidal forecasts at any location and are based on 3-D hydrodynamic modelling driven by oceanographic and meteorological data. Using real-time data as well as predictions based on historical data from the NWLON, model forecasts can be created, which support a number of the products that will be discussed in the following sections.

Emergency management products

Real-time water level information is critical to helping emergency managers monitor changing conditions along our coasts. To better understand the present and forecasted impacts of water level from hurricanes, a web-based publicly available product, Storm QuickLook was developed to support the operational needs of NOAA and emergency managers. The Storm Quicklook offers an integrated product to view hurricane and storm surge forecasts with real-time observations, eliminating the need to compile this information on the fly from multiple websites. This product provides an overview of near real-time oceanographic and meteorological observations at NWLON stations affected by a tropical cyclone. A Storm QuickLook is initiated when the National Hurricane Center (NHC) issues a tropical storm or hurricane warning for the U.S. or its territories (Puerto Rico, Guam), and updates are posted every 6 h, roughly 1 h after the NHC releases an updated forecast alert. Due to the nature of the events, posting can continue for many days, and occasionally a QuickLooks are initiated for extratropical storms or spill events when significant response efforts and impacts are expected.

The Storm QuickLook product contains three main sections (Figure 3). The first is the map showing the location of CO-OPS stations within proximity to the storm track, which is overlaid with the current satellite

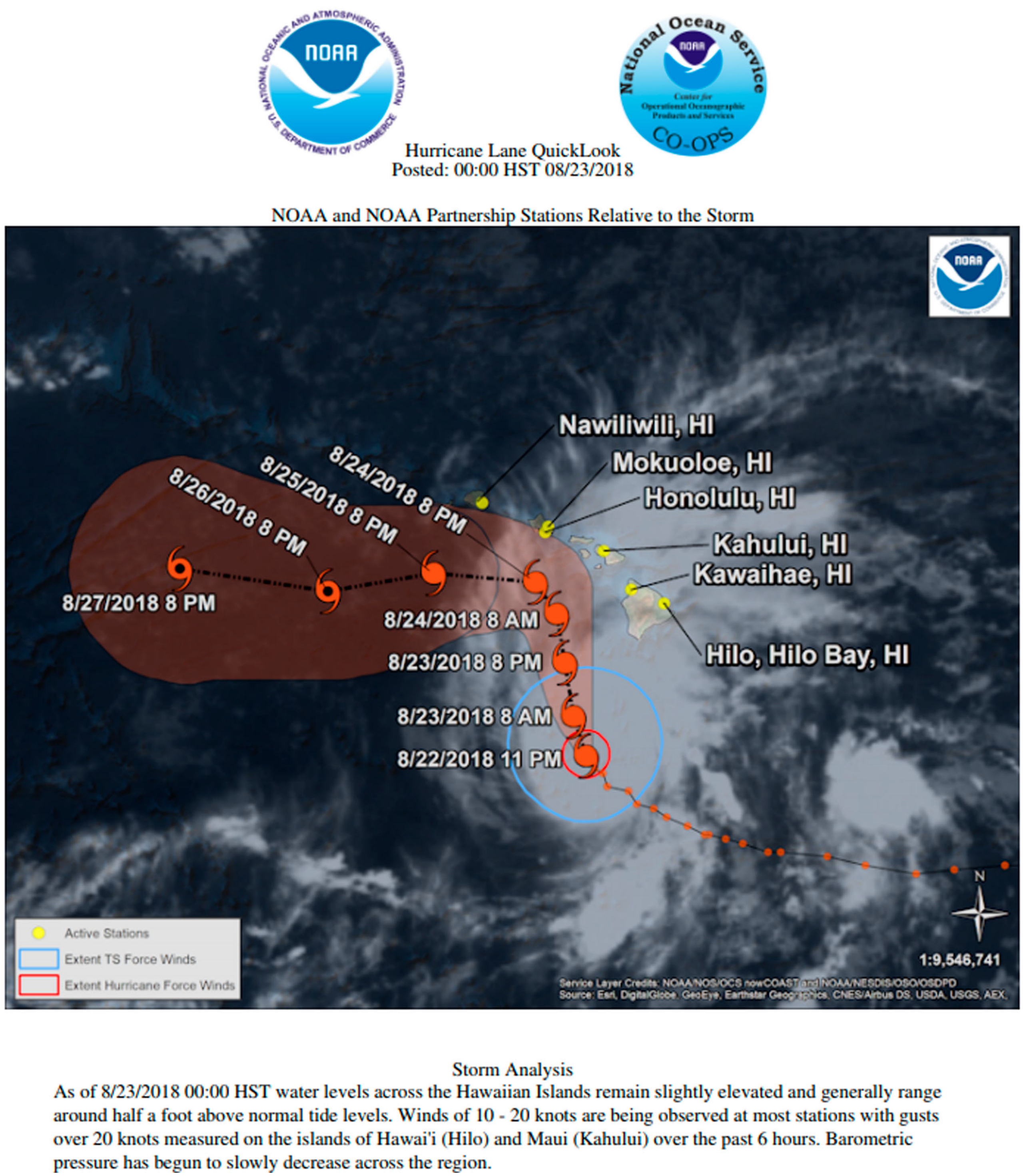

Figure 3. Storm Quicklook Product for Hurricane Lane in August 2018.

imagery. The storm analysis section provides an overview of present oceanographic and meteorological conditions, links to additional CO-OPS products, and the latest NHC public alert. Lastly, below the map and storm analysis are plots of water level and meteorological data at the selected locations from the map, which are updated in near real-time every 6 min. Water level plots contain a line denoting the MHHW datum to provide an approximate level at which flooding inundation may occur. Once tropical cyclone warnings have been terminated, a document highlighting the highest values based on the preliminary observed water levels, highest storm surge, and extremes of meteorological variables is generated and provided to

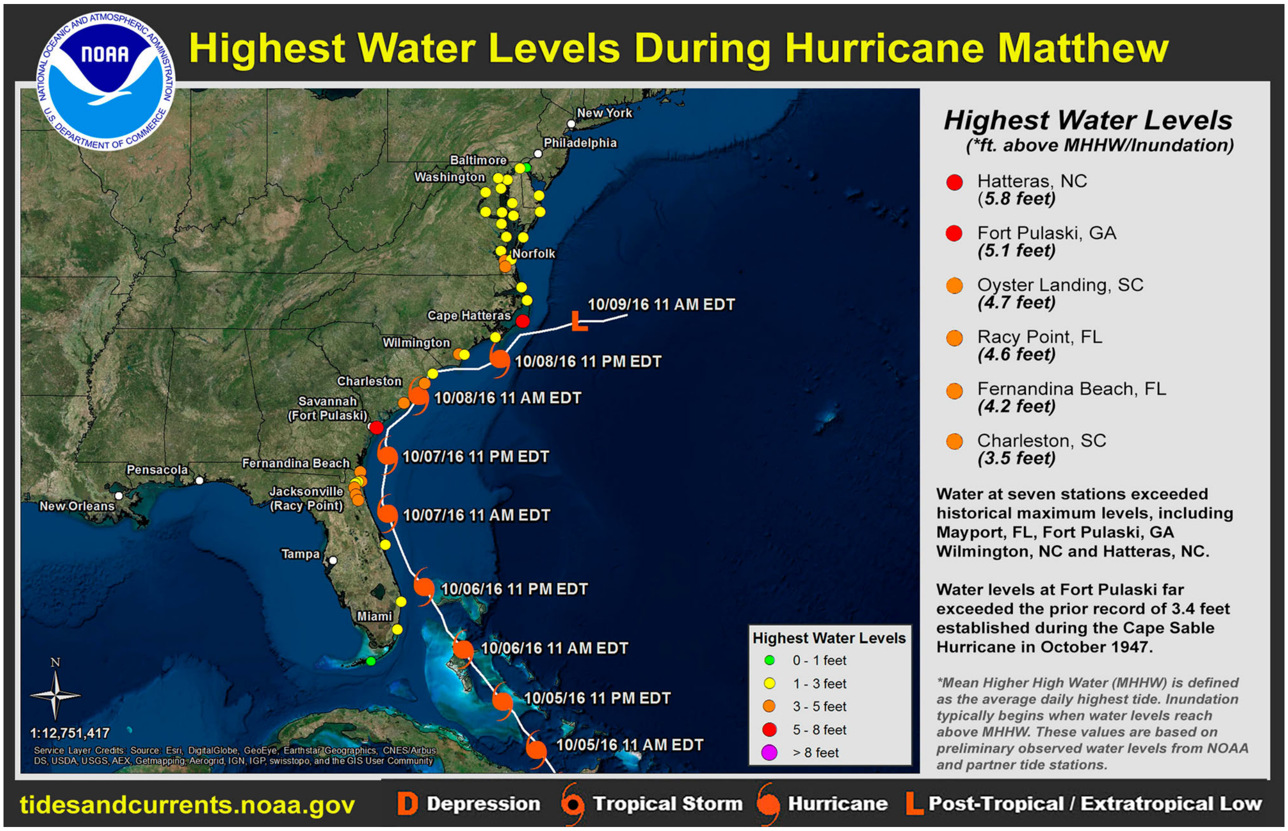

Figure 4. Highest Water Levels during Hurricane Matthew in October 2016.

the NHC and corresponding National Weather Service (NWS) offices to be used for post-storm evaluation. A summary graphic is also created to communicate the highest water levels measured at each water level station within the storm's path for the media and other external audiences (Figure 4).

Sea level planning and management products

CO-OPS and its predecessors have measured mean sea level dating back over 150 years. Mean sea level trends, either a sea level rise or sea level fall, have been computed at 142 long-term NWLON stations using a minimum span of 30 years of observations at each location. These measurements have been averaged by month to remove the effect of higher frequency repeatable phenomena (such as tidal, seasonal, and interannual variations) in order to compute an accurate linear sea level trend. Long-term variations in sea level occur over various time scales and demonstrate repeatable cycles, gradual trends, or intermittent anomalies. Monitoring sea level is also a key component of maintaining the tidal datum reference framework, since changes in sea level must be considered when CO-OPS updates tidal datums.

Understanding trends in sea level, as well as the relationship between global and local sea level, provides critical information about the impacts of the Earth's climate on our oceans and atmosphere. Changes in sea level are directly linked to a number of atmospheric and oceanic processes. Changes in global temperatures, hydrologic cycles, coverage of glaciers and ice sheets, and storm frequency and intensity are examples of known effects of a changing climate, all of which are directly related to, and captured in, long-term sea level records. Resolution of local impacts are important to long-term planning in coastal communities. Due to multiple variables affecting future conditions along the coast, communities cannot take a 'one-size-fits-all' approach when planning for future sea level rise. To address the uncertainty, local decision makers have developed site-appropriate sea level scenarios based on NWLON both in terms of projections and responses to meet the specific circumstances in a community.

CO-OPS, in collaboration with scientists on the U.S. Global Change Research Program Sea Level Rise Task Force at the request of the White House Council on Climate Preparedness and Resilience, further advanced scenario-based community planning by developing gridded relative sea level (RSL, which includes both ocean-level change and vertical land motion) projections for the United States using the NWLON associated with an updated set of global mean sea level (GMSL) scenarios

(Sweet et al. 2017). The probabilistic projection approach was taken, as it recognises the inherent dependency of future GMSL rise on future greenhouse-gas emissions and associated ocean-atmosphere warming. The 1-degree gridded set of scenario-based RSL projections for the U.S. filled a gap in climate information needed to support a wide range of coastal assessment, planning, and decision-making processes and provides scenario estimates of future RSL rise (and potential impacts) for locations within an individual grid.

In addition to community planning support, sea level data are also used and referenced in guidance documents for coastal defense and civil works projects by U.S. Army Corps of Engineers (USACE) through Circulars[2] and the Sea Level Change Curve Calculator[3], a web-based tool that calculates projected rates of sea level change for any location along the U.S. coast. The tool can be used to assess vulnerability to future sea level change and to compare several published sea level rise scenarios. CO-OPS sea level data also supported the Department of Defense by enhancing understanding of the risk to coastal military installations by vulnerability assessments of rising global sea level and local extreme water levels from storm events, tidal variations, and dynamic conditions including waves on military sites (Hall et al. 2016). The report also poses future scenarios that can be used as a foundation for site-specific studies.

Another consequence of RSL rise is the increase in lesser extremes resulting in occasional minor coastal flooding experienced during high tides. These events are becoming more noticeable and widespread, as it no longer takes a strong storm to cause coastal flooding. High tide flooding has increased on all three U.S. coasts between 300 percent and 925 percent since the 1960s (Sweet et al. 2014). Public inconveniences such as frequent road closures, overwhelmed storm drains, and compromised infrastructure are causing significant economic impacts to coastal communities. Miami Beach will soon embark on a $100 million project to raise roads, install pumps and water mains, and revamp sewer connections[4]. To support communities with better managing these events, CO-OPS began issuing a High Tide Bulletin to provide an outlook capability for local decision makers to understand when their community may experience higher than normal high tides. The bulletin is issued quarterly and identifies specific dates and areas where tides could be elevated from perigean tides over three months. This product also supports the King Tides Project International (http://kingtides.net/), a citizen-science initiative capturing data and images related to the risk and impacts of sea levels in coastal communities.

The High Tide Bulletin has been integrated into a new web-based tool—Coastal Inundation Dashboard (https://tidesandcurrents.noaa.gov/inundationdb/), a geospatial product that integrates a number of CO-OPS inundation products (e.g. Inundation History, Top Ten Water Level, Extreme Water Level, and Sea Level Trends)—and will soon provide the geospatial framework for launching a next generation Storm Quicklooks. Inundation alerts are triggered using the OFS when observed or forecast water levels at NWLON stations exceed a minor flood threshold. Stations experiencing possible inundation are listed at the top and display blinking station markers. These events are tracked annually to demonstrate the number of historic flood days per year based on exceedance of minor flood thresholds and helps communities to track how high tide flooding is changing in their area. Impact graphics also depict actual flooding along with corresponding water level observations from the nearest NOS tide station, relating measured water level with on-the-ground effects.

A set of nationally consistent impact thresholds for minor, moderate, and major coastal flooding were recently released in a report on the patterns and projections of high tide flooding along the U.S. coast (Sweet et al. 2018). Using the new threshold methodology, CO-OPS can monitor more than 100 NWLON locations for high tide flooding, including those where no official NWS thresholds exist. By using a spatially consistent coastal flood threshold, a national definition of coastal flooding and impacts can be established, and communities can use this information to assess their flood risk compared to other regions. This framework will be critical as CO-OPS works with other organisations to develop interseasonal to interannual flood outlooks for the nation.

Ecosystem management products

Sound coastal ecosystem management practices, including the planning and monitoring of restoration sites, coastal engineering, and land-use planning, must be framed by a thorough understanding of the relationship between water levels, tidal datums, and geodetic (land-based) elevations. Coastal ecosystems are highly affected by the tidal hydrologic cycle, which can influence the assemblage of organisms along the coast. In tidal areas, a small change in elevation can strongly affect salinity and saturation levels and thus determine whether ecosystems that can live in an area. For examples, grasses are often very sensitive to long periods of inundation and can live only in the upper third of the tidal range. Therefore, high-accuracy land elevations, water levels, long-term data monitoring, and predictive ecosystem modelling provide the scientific framework to support coastal restoration science and management.

Vertical datums are important pieces of information needed when working with tidally influenced ecosystems. A datum is a base elevation used as a reference from which to reckon heights or depths. A tidal datum is a standard elevation defined by a certain phase of the tide and is used as a reference to measure local water levels. Tidal datum information supports inundation analysis (frequency and duration) for tidally influenced habitats, as accurate estimates of local inundation regimes contribute to the successful restoration of degraded wetlands. Inundation analyses above a specified elevation threshold are also available using observed and historical data from NWLON stations, which is important for analyzing return frequencies for coastal flooding. In addition, CO-OPS also provides annual and monthly exceedance probability levels for select CO-OPS water level stations with at least 30 years of data. When used in conjunction with real-time station data, exceedance probability levels can be used to evaluate current conditions and determine whether a rare inundation event is occurring.

CO-OPS recently developed a Tidal Analysis Datum Calculator, a publicly-accessible tool to support datum computation from water level data with a variety of tidal signals. The Tidal Analysis and Datums Calculator (https://access.co-ops.nos.noaa.gov/datumcalc/index.jsp) uses a Butterworth digital filter to remove high frequency (>4 cycles per day) water level variability information in order to identify tidal high and low waters from observed water level data (Licate et al. 2017). The tool allows users to load water level data and quickly generate a simple suite of tidal datums. Statistical analysis indicates that the tool generates tidal datum elevations comparable to those generated by CO-OPS internal water level processing tools with manual verification.

To further support coastal restoration planning, CO-OPS also provides an ArcGIS add-in tool called MAPTITE, which aids in the selection of vegetation types for different restoration elevations based on a combination of a digital elevation model derived from GPS observations, local tidal datums, and grass species tolerances. By delineating planting areas and providing point data that can be uploaded to GPS receivers for those areas, MAPTITE allows users to accurately plant appropriate species during restoration, promoting growth of native species in order to successfully create or restore ecosystem functions of the marsh.

Conclusion

NOAA and its predecessors have been delivering oceanographic data along our nation's coasts for over 200 years to protect life, property, and the environment. The network and products associated with it have evolved to meet the emerging needs of its users to make critical emergency and coastal management decisions. NOAA provides the federal backbone observing systems of NWLON, accompanying national standards, data management, and expertise that provide the operational infrastructure at the national level needed to monitor sea level along all U.S. coasts.

Notes

1. Smith, Adam, economist for NOAA, quoted in a CNN report "US shatters record for disaster costs in 2017" by Brandon Miller, CNN Meteorologist Updated 12:06 PM ET, Mon January 8, 2018 https://www.cnn.com/2018/01/08/us/2017-costliest-disasters/index.html).
2. USACE Circular No. 1165-2-212 Sea-level change considerations for civil works programmes. http://www.corpsclimate.us/docs/EC_1165-2-212%20-Final_10_Nov_2011.pd
3. USACE Sea Level Curve Calculator http://www.corpsclimate.us/ccaceslcurves.cfm
4. Flechas, Joey January 28, 2017. "Miami Beach to begin new $100 million flood prevention project in face of sea level rise." Miami Herald. https://www.miamiherald.com/news/local/community/miami-dade/miami-beach/article129284119.html.

Acknowledgements

Thank you to Helen Worthington and Richard Edwing for editorial support. Figure development of Storm Quicklook Product for Hurricane Lane and Highest Water Level for Hurricane Matthew created by the NOAA CO-OPS Storm Quicklook Team.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Gill S, Fischer K. 2008. A network gaps analysis for the national water level observation network. Silver Spring (MD): National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services. NOAA Technical Report NOS CO-OPS 048.

Hall JA, Gill S, Obeysekera J, Sweet W, Knuuti K, Marburger J. 2016. Regional sea level scenarios for coastal risk management: managing the uncertainty of future sea level change and extreme water levels for department of defense coastal sites worldwide. U.S. Department of Defense, Strategic Environmental Research and Development Program.

Heitsenrether R, Davis E. 2011. test and evaluation report limited acceptance of the design analysis waterlog® h-3611i microwave radar water level sensor. Silver Spring (MD): National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services. NOAA Technical Report NOS CO-OPS 061.

Licate L, Huang L, Dusek G. 2017. A comparison of datums derived from co-ops verified data products and tidal analysis datum calculator. Silver Spring (MD): National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services. NOAA Technical Report NOS CO-OPS 085.

Park J, Heitsenrether R, Sweet W. 2014. Water level and wave height estimates at NOAA tide stations from acoustic and microwave sensors. J Atmos Ocean Technol. 31(10):2294–2308.

Russin E, Beaumariage D, Deibel L, Zumwalt B. 1985. A technical development plan for a next generation water level measurement system. OCEANS 85 Ocean Engineering and the Environment. IEEE Conferences.

Sweet W, Dusek G, Obeysekera J, Marra J. 2018. Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold. Silver Spring (MD): National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services. NOAA Technical Report NOS CO-OPS 086.

Sweet W, Kopp R, Weaver C, Obeysekera J, Thieler R, Zervas C. 2017. Global and regional sea level rise scenarios for the United States. Silver Spring (MD): National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services. NOAA Technical Report NOS CO-OPS 083.

Sweet W, Park J, Marra J, Zervas C, Gill S. 2014. Sea level rise and nuisance flood frequency changes around the United States. Silver Spring (MD): National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services. NOAA Technical Report NOS CO-OPS 073.