University of Hawaii Sea Level Center

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1. Project Summary

The purpose of the University of Hawaii Sea Level Center (UHSLC) project is to ensure that tide gauge data from around the world are collected, quality assessed, distributed, and archived for use in climate, oceanographic, ocean engineering, and geophysical research. While UHSLC assembles time series from a large number of tide gauge stations, our primary focus is the set of stations that constitute the Global Sea Level Observing System (GLOSS, under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) and the World Meteorological Organization (WMO)) and the Global Climate Observing System (GCOS, a joint undertaking of the WMO, UNESCO, the United Nations Environment Programme, and the International Council for Science). The GLOSS (Figure 1) and GCOS networks cover most major oceanic islands and island chains, with a subset of available continental coastal stations distributed evenly around the margins of ocean basins. Because of their importance for global and regional sea level reconstructions, vertical land motion monitoring is recommended at all GLOSS and GCOS stations, and the UHSLC maintains 11 continuous GPS receivers at these stations. The UHSLC participates actively in the operational and scientific oversight of GLOSS and GCOS through the GLOSS Group of Experts.

As a sea level data assembly center, the UHSLC is responsible for the Fast Delivery dataset, which provides preliminary, quality-assured, hourly tide gauge data within 4-6 weeks of collection, and the Research Quality dataset, which is an archive of hourly tide gauge data that have undergone a complete quality assessment generally within 1 year of collection. The Research Quality database is maintained in collaboration with the National Oceanographic Data Center (NODC) as part of the Joint Archive for Sea Level (JASL). The UHSLC acquires tide gauge data from nearly 500 tide gauge stations maintained by 65 international agencies. UHSLC technicians and data analysts collaborate directly with international partners to maintain 80 high profile stations that are important for the global sea level observing effort. UHSLC involvement ensures that research quality datasets are available from otherwise sparsely sampled areas of the global ocean, and that developing nations have access to training, technical support, and data processing services as needed.

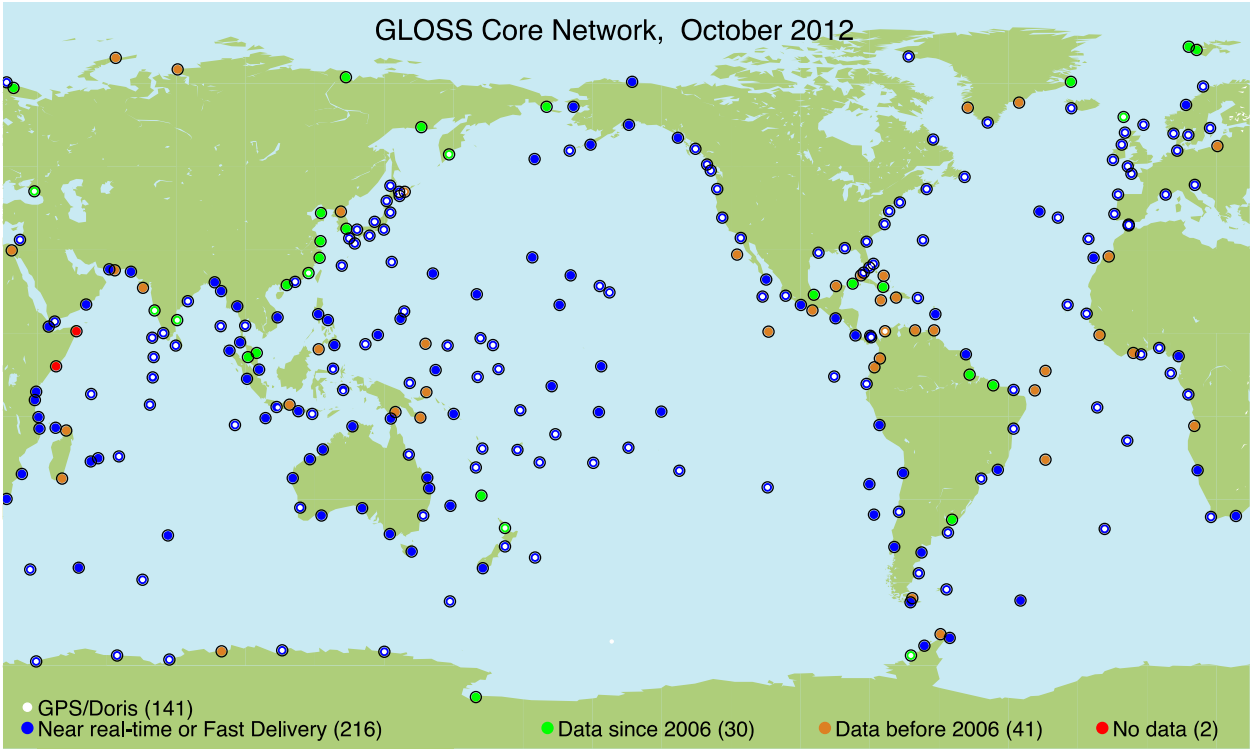

Figure 1. Status of the GLOSS Core Network of tide gauge stations.

A key benefit of having a sea level data assembly center in a university setting is that UHSLC scientists actively utilize tide gauge data for oceanographic and sea level change research. Ongoing scientific assessment helps to ensure the quality of the various UHSLC databases. UHSLC datasets are used by the research community notably for global and regional sea level reconstructions and assessments of extreme sea level changes, for the evaluation and advancement of global and regional ocean circulation models, for the calibration of satellite altimeter data which is critical for global sea level trend assessments, and for the production of oceanographic products. UHSLC station data also are made available in near-real time via the Global Telecommunications System (GTS) to the Pacific Tsunami Warning Center, the West Coast/Alaska Tsunami Warning Center, and international centers for tsunami and hazard monitoring. Over the years the UHSLC has provided tide gauge data for international scientific programs including NORPAX, TOGA, WOCE, GODAE and CLIVAR.

2. Scientific and Observing System Accomplishments

Our primary observing system accomplishments during FY12 revolved around our sea level data assembly activities. UHSLC data analysts reviewed real-time tide gauge data each day to ensure station function, each month to flag and when appropriate correct for outliers and timing problems, and each year to assess the overall data quality, particularly associated with the stability of the reference datum. Maintaining these functions and populating the Fast Delivery and Research Quality/JASL databases were our main deliverables. Our accomplishments for

data management met objectives in that the core function of each database was maintained, and both databases were expanded to take on new station installations as they became available.

Tide gauge operation and maintenance continues to be one of our primary contributions to the global observing system. Most small island states and a large number of developing countries do not have the infrastructure or resources for maintaining tide gauges at the level needed for scientific applications. A tide gauge installed for the primary purpose of providing tide information for port operations does not necessarily provide climate relevant information without proper level control and data quality assessments over time. The UHSLC provides a traveling technician team that assists international collaborators in maintaining GLOSS and GCOS tide gauge stations to GLOSS standards. Our field objectives during FY12 were to service 15 tide gauge stations and to install 5 GPS stations. We were able to service 20 stations, 14 stations directly and 6 stations indirectly through remote guidance of local technical staff. We installed 2 continuous GPS stations (Gan and Male, Maldives) during the reporting period, and installed the remaining 3 GPS stations (Cilacap, Benoa, Manado, Indonesia) one month after the reporting period.

Various metrics describing the status of the global sea level monitoring effort based on tide gauges were considered. Our first metric is an estimate of globally averaged sea level based on tide gauge data, with the metric being the uncertainty of that estimate. The metric provides an assessment of the overall health of the network, as the uncertainty will decrease as the number of independent tide gauge stations increases, and as land motion corrections are taken into account with GPS monitoring. The second metric takes into account the reliability of the network. It simply is a measure of data return across the global array. The third metric is a measure of coverage. It is a measure of the percentage of ocean surface area that the tide gauge network has some predictive skill in hindcasting, as determined by correlations studies versus overlapping altimeter time series. We are working through a processing code to automatically update these indices on our website based on the most recent Fast Delivery datasets. We hope to have these in operation by January 2013.

UHSLC research efforts were 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 (Figure 2). 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 underlying causes of the wind shifts remains an open question; however, we are working with global models to test various forcing scenarios.

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

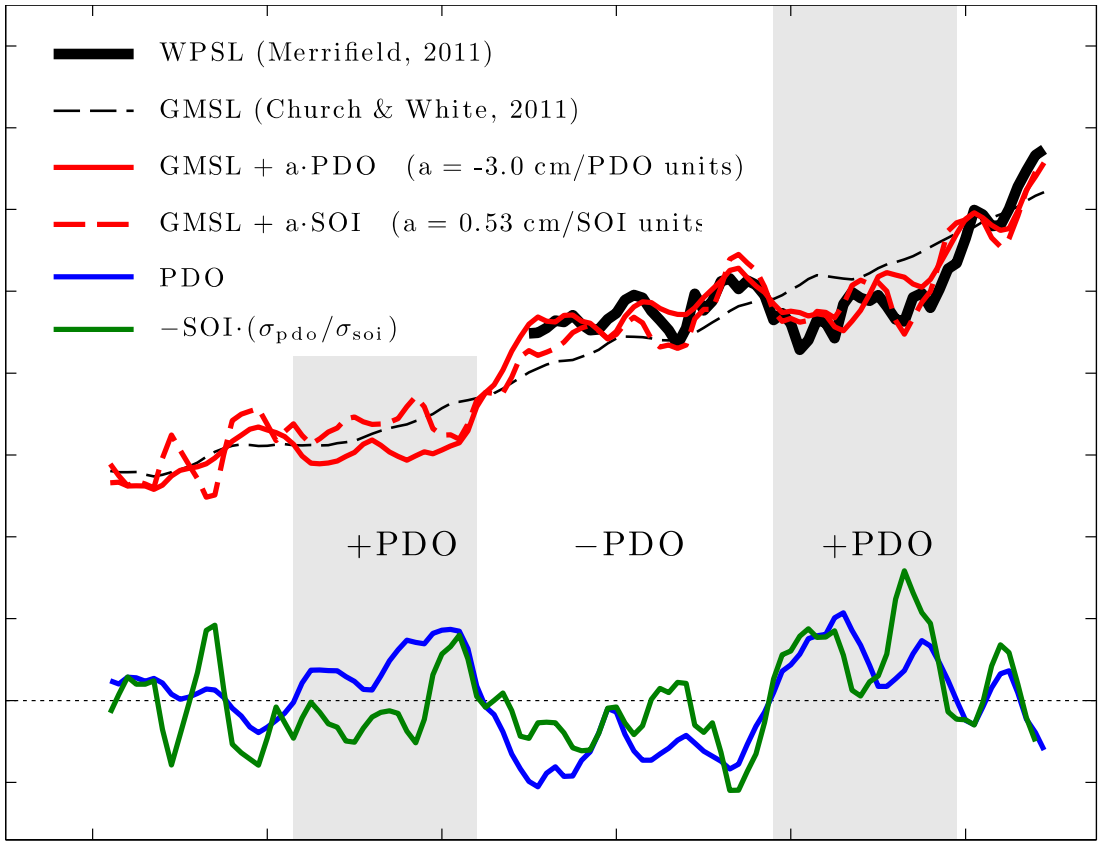

Figure 2. Western Pacific Sea Level (WPSL) (black) compared to WPSL reconstructions based on the PDO (red) and the SOI (red dash) with the Church and White (2011) GMSL included (black dash). The PDO index (blue) and scaled SOI (green) are shown for comparison.

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.

Tide gauges provide a measure not only of surface tides but also internal tides. Understanding the variability of the tide gauge internal tide signal provides insights into long-term changes in the internal tide climatology, which ultimately is a source of energy for the internal wave continuum in the ocean and to ocean mixing. We continue to examine the characteristics of internal tides in the Hawaii region (Powell et al., 2012) in the hopes of gaining better insights into how to interpret internal tide variability in long tide gauge records, particularly the Honolulu Harbor record which dates back to the 1800s.

We led an international team of authors that contributed to the BAMS State of the Climate report, describing global and regional sea level change during 2012. In addition the UHSLC PI was the lead author on the GLOSS Implementation Plan 2012, which set priorities and goals for the global sea level observing effort. In addition, the UHSLC PI is a lead author on the IPCC AR5 Working Group I report, with contributions to the chapter on sea level projections, a co-author on the sea level section of the Pacific Island Regional Climate Assessment, and a contributing author to "Global sea level rise scenarios for the United States National Climate Assessment" (Parris et al., 2012), and to the National Climate Assessment Development and Advisory Committee report on the Hawaii and Pacific Island region.

Because our project is involved with data collection, we address the following:

a. Yes, our data are distributed in real time on the Global Telecommunications System.

b. Where do your real time data reside? Are the data available online?
   Data are available via the IOC Sea Level Monitoring Facility website (http://www.ioc-sealevelmonitoring.org).
c. Where do your delayed mode data reside? Are the data available online? What is the date of the most recent data available publicly?
   Delayed mode data are available at the UHSLC Fast Delivery and Research Quality databases (also known as the Joint Archive for Sea Level), the Permanent Service for Mean Sea Level (monthly data), and at the GLOSS Delayed Mode data center at the British Oceanographic Data Centre. Most recent delayed mode data were collected within 4-6 months (Fast Delivery data).
d. Where are your data archived and with what frequency?
   Data are archived at the UHSLC website (Fast Delivery - monthly, Research Quality/JASL - annually), and at the World Ocean Data Center (annually).
e. What is the web site where the data for your program can be accessed? If you haven't updated your web site recently, please do so now.
   http://uhslc.soest.hawaii.edu
f. Have you successfully retrieved your program's data from the website or Data Assembly Center where your data reside, just to ensure the accessibility of the data? If not, please do this now and address any problems with data access.
   Yes, data are accessible.
g. Do you have a data management plan for the data collected as part of your project? If so, list the url where the data management plan can be found.
   Yes, as part of the GLOSS Implementation Plan (http://www.gloss-sealevel.org/publications/).

h. Is your observing project compliant with the National Environmental Policy Act (NEPA) and other NOAA Environmental Statutes (e.g. Marine Mammal Protection Act (MMPA), Endangered Species Act (ESA), Essential Fish Habitat (EFH), and the National Marine Sanctuaries Act (NMSA)?

Yes.

2.1. Outreach and Education

UHSLC staff members respond regularly to questions from the public regarding global and regional sea-level rise concerns. Sea level time series and tidal prediction charts are provided to numerous international agencies on an annual basis and upon request. We are involved in the training of undergraduate summer interns on various projects related to sea level variability. The UHSLC provides support to the Pacific Island Ocean Observing System (PacIOOS) in the production of real-time high sea level and coastal inundation products based on tide gauge data (http://oos.soest.hawaii.edu/pacioos/data_product/SLpred/Wai_Exc.php). A graduate research assistant at the University of Hawaii was supported in part during FY 2012 who is embarking on a PhD project on global sea level trend patterns. UHSLC scientists took part in the Third Caribbean Training Course for Operators of Sea Level Stations, June 4-9 2012, Merida, Mexico as well as the GLOSS Group of Experts Meeting, November 2011, Paris, France.

3. Publications and Reports

3.1. Publications by Principal Investigators

Published

Aucan, J., R. Hoeke, and M. A. Merrifield, 2012. Wave-driven sea level anomalies at the Midway tide gauge as an index of North Pacific storminess over the past 60 years, *Geophys. Res. Lett.*, **39**, 17, doi:10.1029/2012GL052993.

Chambers, D. P., M. A. Merrifield, R. S. Nerem, 2012. Is there a 60-year oscillation in global mean sea level? *Geophys. Res. Lett.*, **39**(18), L18607.

Kruk, M. C., J. J. Marra, P. Ruggiero, D. Atkinson, M. Merrifield, D. Levinson, M. Lander, 2012. Pacific Storms Climatology Products (PSCP): Understanding extreme events, *Bull. Amer. Met. Soc*., doi:10.1175/BAMS-D-11-00075.1.

Merrifield, M. A., and M. E. Maltrud, 2011. Regional sea-level trends due to a Pacific trade wind intensification, *Geophys. Res. Lett*., **38**, L21605, doi:10.1029/2011GL049576.

Merrifield, M. A., P. R. Thompson, and M. Lander, 2012. Multidecadal sea level anomalies and trends in the western tropical Pacific, *Geophys. Res. Lett.*, **39**, 13, doi:10.1029/2012GL052032.

Merrifield, M. A., P. Thompson, D. P. Chambers, G. T. Mitchum, M. Menéndez, R. S. Nerem, E. Leuliette, L. Miller, S. Holgate, J. J. Marra, and W. Sweet, 2012. [Global oceans] Sea level

variability and change [in "State of the Climate in 2011"], *Bull. Amer. Meteor. Soc.*, **93** (7), S68–S69.

Powell, B. S., I. Janekovic, G. S. Carter, and M. A. Merrifield, 2012. Sensitivity of internal tide generation in Hawaii, *Geophys. Res. Lett*., 39,10, doi:10.1029/2012GL051724.

Submitted

Merrifield, M. A., A. S. Genz, C. P. Kontoes, and J. J. Marra, 2012. Annual extreme water levels from tide gauges: Contributing factors and geographic patterns, submitted to *J. Geophys. Res*.

Abstracts

R. S. Nerem, D. P. Chambers, M. Merrifield, and G. T. Mitchum, A 20 year climate data record of sea level change: What have we learned? 20 Years of Progress in Radar Altimetry, 24-29 Sept 12, Venice.

Other Reports

IOC, 2012 Global Sea Level Observing System (GLOSS) Implementation Plan – 2012. UNESCO/IOC, 41pp. 2012. (IOC Technical Series No.100)

Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss, 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

Merrifield, M. A., A. Allen, C. Clark, J. J. Marra, G. T. Mitchum, C. Ostrander, W. V. Sweet, 2012. Global and regional sea level change and the IOOS program, https://docs.google.com/file/d/0BwW7dLnWT2C0WFpROENONDFlU1U/edit?pli=1.

Data Reports

Caldwell, P. and M. Merrifield. Joint Archive for Sea /Level Data Report: November 2011, 2011. JIMAR Contribution No. 11-377, Data Report No. 22, SOEST, University of Hawaii at Manoa, Honolulu, Hawaii, 66 pp.

3.2. Other Relevant Publications

Cazenave, A., and F. Remy, 2011. Sea level and climate: measurements and causes of changes, *Climate Change*, DOI:10.1002/wcc.139.

Ray, R. D., and B. C. Douglas, 2011. Experiments in reconstructing twentieth-century sea levels, *Progress in Oceanography*, **91**, 496-515.

Sallenger, A. H., Jr., K. S. Doran, P. A. Howd, Hotspot of accerated sea-level rise on the Atlantic coast of North America, 2012. *Nature Climate Change*, doi:10.1038/nclimate1597.

Sutton, P., and D. Roemmich, 2011. Decadal steric and sea surface height changes in the Southern Hemisphere, *Geophys. Res. Lett.*, **38**, L08604.

Woodworth, P. L., M. Menendez, and W. R. Gehrels, 2011. Evidence for century-timescale accelerations in mean sea levels and for recent changes in extreme sea levels, *Surveys in Geophys*., **32**, 603-618.