University of Hawaii Sea Level Center

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Table of Contents

1. Project Summary 1
2. Scientific and Observing System Accomplishments 3
3. Outreach and Education 6
4. Publications and Reports 7
   4.1. Publications by Principal Investigators 7
   4.2. Other Relevant Publications 7

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 (global and regional sea level change), oceanographic (coastal and equatorial circulation, surface and internal tides), ocean engineering (storm surges, tsunamis), and geophysical (vertical land movement) research, as well as for operational purposes (tsunami and surge monitoring, satellite altimeter drift monitoring). While UHSLC assembles time series from a large number of tide gauge stations, its primary focus is the set of 290 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)). The GLOSS Core Network (GCN, Figure 1) is a globally distributed set of high quality tide gauge stations that meet research quality requirements as defined by the GLOSS Group of Experts. The GCN covers most major oceanic islands and island chains, with a subset of available continental coastal stations distributed evenly around the margins of ocean basins. The GCN is the primary global observing network for in situ sea level.

UHSLC serves as a global sea level data assembly center, with involvement at all stages from data collection to research based on tide gauge data. UHSLC staff interact closely with over 60 international agencies to ensure that high frequency data from over 500 tide gauge stations flows continuously into the UHSLC data center. With an international focus, the UHSLC complements the NOAA Center for Operational Oceanographic Products and Services (CO-OPS), which is responsible for U.S. National Water Level Observation Network (NWLON). The UHSLC's attention to high frequency tide gauge data makes it an important counterpart to the Permanent Service for Mean Sea Level (PSMSL), which is the primary repository for monthly averaged tide gauge data.

The UHSLC maintains a Fast Delivery database, 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 is recognized by GLOSS as the GCN Fast Delivery Data Center. Primary users of Fast Delivery data include groups involved with assessing the ongoing stability and quality of satellite altimeter data, and operational modeling centers that use tide gauge data for model validation purposes. The research community is the primary user of JASL data. Over the years UHSLC has served as a data provider for international scientific programs including NORPAX, TOGA, WOCE, GODAE and CLIVAR.

UHSLC plays an important role as a technical advisory group for GLOSS and is a key contributor to the operations and maintenance of the GCN. 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. UHSLC has been able to leverage support for tsunami monitoring stations to ensure that these datasets also meet the standards for climate research. Data from stations that UHSLC helps to main are made available in near-real time via the Global Telecommunications System (GTS) and can be accessed at http://www.ioc-sealevelmonitoring.org. The near-real time data are used by the Pacific Tsunami Warning Center, the West Coast/Alaska Tsunami Warning Center, and international centers for tsunami and hazard monitoring. Because of the importance of tide gauge stations for satellite altimeter validation and global and regional sea level reconstructions, the UHSLC maintains 11 continuous GPS receivers at tide gauge stations.

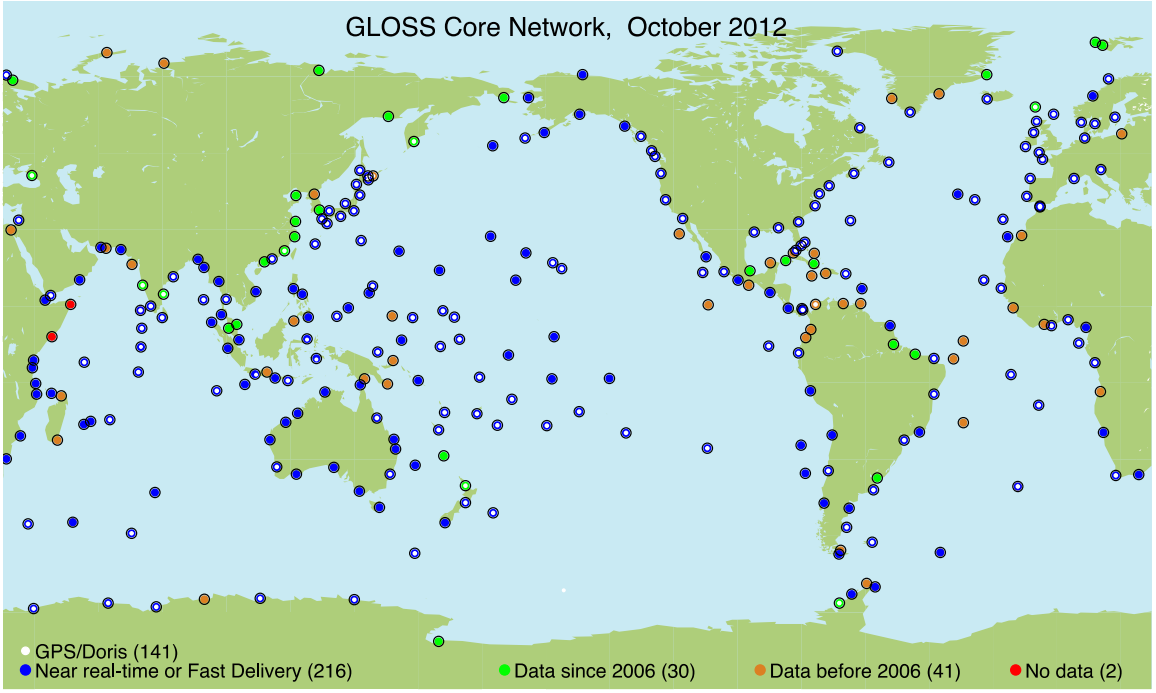


Figure 1. Status of the GLOSS Core Network of tide gauge stations.

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 climate and oceanographic research. Ongoing

scientific assessment helps to ensure the quality of the various UHSLC databases. UHSLC researchers are involved in studies of global and regional sea level trends and change, assessments of extreme sea level events, the evaluation and advancement of global and regional ocean circulation models, and intercomparisons with satellite altimeter data.

2. Scientific and Observing System Accomplishments

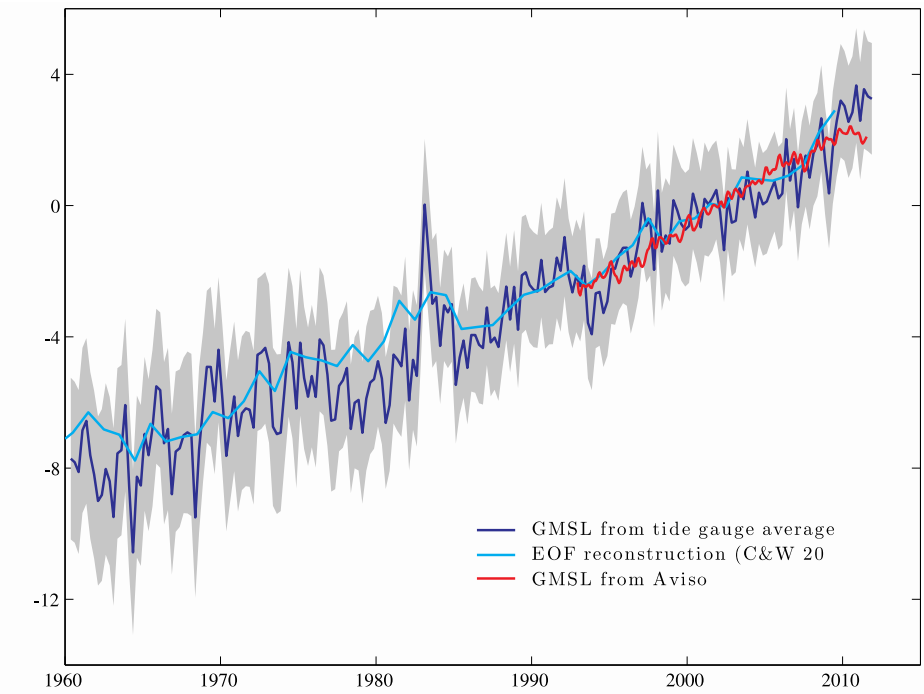
UHSLC data analysts review real-time tide gauge data each day to ensure station function, each month to flag and when appropriate correct for outliers and timing problems, and each year to assess the overall data quality, particularly associated with the stability of the reference datum. Maintaining these functions and populating the Fast Delivery and Research Quality/JASL databases were our main observing system deliverables during FY13. 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.

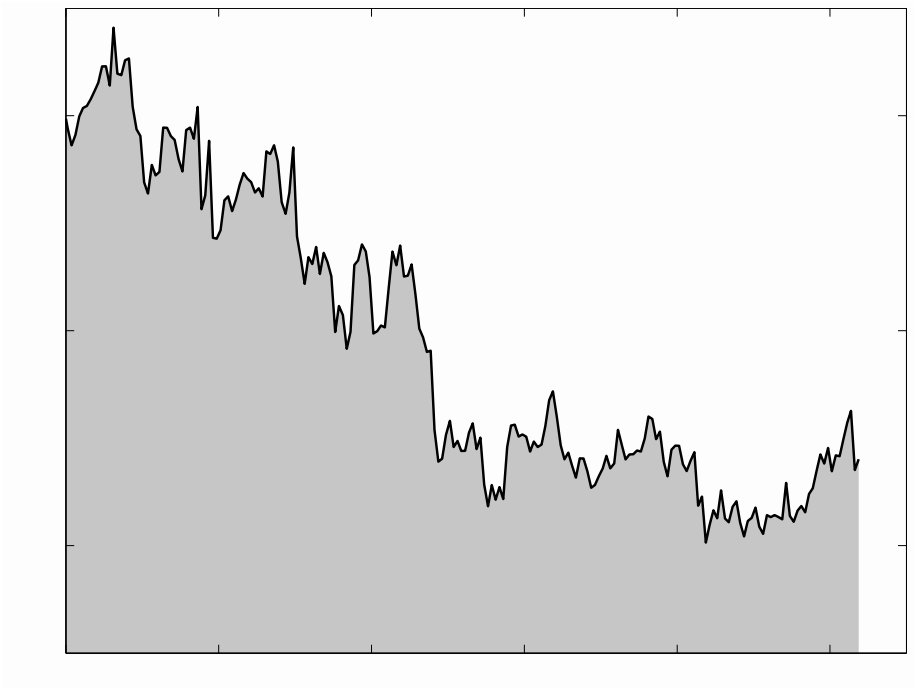
Tide gauge operation and maintenance continues to be one of our primary contributions to the global observing system. Most small island states and a large number of developing countries do not have the infrastructure or resources for maintaining tide gauges at the level needed for scientific applications. 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 Core Network stations to GLOSS standards. Our field objectives during FY13 were to service 15 tide gauge stations and to install 1 GPS station. We were able to visit and service 18 stations, with additional support provided by remotely supervised repairs by our technicians in consultation with onsite technical counterparts. We installed 3 continuous GPS stations (Cilacap, Benoa, Manado, Indonesia) during the reporting period as a carry over from FY12. We have not yet installed the 1 GPS station slated for FY13, but we intend to prior to the June 2014 termination of the UHSLC contract cycle. Our goal was to conduct maintenance trips at 5 tsunami stations in the Caribbean and 5 in the Pacific Ocean. We've have completed the 5 station visits in the Pacific, and we've finished 3 out of the 5 in the Caribbean. A technician is in the field during October 2013 to complete 3 station visits in the Caribbean.

We made progress during FY13 on a sea level performance metric, which is based on the performance of the tide gauge network in estimating global mean sea level (GMSL), independent of the satellite altimeter measurements. The tide gauge based estimate of GMSL (Figure 2) is calculated by averaging the first differences of monthly tide gauge sea levels from the combined UHSLC Fast Delivery and Research Quality datasets onto a 2° grid and correcting the gridded differences for glacial isostatic adjustment (GIA). We then perform a simple average over the gridded first difference series and integrate forward in time to obtain an estimate of GMSL variability. The monthly time series is then smoothed with a convolution low-pass filter giving an approximate temporal resolution of 3 months. Some quality control of the historical records was necessary to correct for obvious drifts and drastic level changes. The simple estimate of GMSL is entirely independent of satellite measurements, but it agrees well with GMSL calculated from the multimission Aviso gridded sea surface height product and the most widely

cited tide gauge reconstruction of annual GMSL using EOFs from altimetry (Church and White, 2011). Periods longer than interannual are similar between the simple average and the annual reconstruction from EOFs, and the larger differences at interannual and shorter periods decrease in time as the network improves.

The improvement of the network in time is quantified by a 1-σ error about the calculation of GMSL from tide gauges, which may be treated as a metric of the network performance. The error is shown as a symmetric gray error bar about the GMSL curve in Figure 2 and as an individual time series in Figure 3. The 1-σ error is estimated by calculating the standard deviation of the differences between GMSL from Aviso and GMSL from tide gauges during the altimeter period for each monthly configuration of the tide gauge network since 1960. For example, to calculate the error for a month during the 1960s, we use only locations with data during that month to calculate GMSL during the altimeter period from tide gauges and compare to Aviso. This estimate of the uncertainty includes instrumental error, error in the GIA model, error due to unaccounted for land motion, and spatial sampling error. The error calculation based on the availability of gauges from 1960-present shows a clear downward trend with a sharp decrease in the 1980s and slight increase in recent years. This reduction in error over the last 50 years is the result of decreasing spatial sampling error as the tide gauge density increased in previously undersampled regions. There are only minor recent changes in the network, thus the reason for the recent increase in error is unclear. A more detailed analysis of the network and the sea level time series will be necessary to assess the cause of the recent increase in error.





UHSLC research during FY13 has focused on understanding the dynamics that govern long-term regional sea change and the effect of regional variability on calculations of global mean sea level. Two separate studies were completed and submitted to high-impact journals.

The first study builds upon previous UHSLC research in the Western Tropical Pacific (WTP) in which elevated long-term sea level change rates in the WTP during recent decades were linked to increasing trade wind strength. Our new results link recent near-zero coastal sea level change rates in the Northeast Pacific (NEP) to the same trade wind forcing. The relative contributions to decreased NEP rates from remote equatorial wind-stress, local longshore wind-stress, and local wind-stress-curl are examined. Regressions of sea level onto wind-stress time series and comparisons between NEP and Fremantle sea levels suggest the decreased rate in the NEP is primarily due to oceanic adjustment to strengthened trade winds along the equatorial and coastal waveguides. The predictability of decadal sea level change rates along the NEP coastline is therefore largely determined by tropical variability. In addition, we demonstrate the importance of accounting for regional, wind-driven sea level variations when attempting to calculate accelerations in the long-term rate of sea level rise.

The second study focused on the approximately 2 mm/yr difference between average sea level change rates over the Northern and Southern Hemispheres as observed by satellite altimeters. Our findings show that this hemispheric difference is unprecedented during the 20th Century. The result is obtained by averaging sea level change rates over objectively identified areas of the global ocean and assessing recent rates in the historical context of longer time series. The character of recent Northern Hemisphere trends is such that areas of large positive rate are at least partially compensated by regions of negative or near-zero rate. This is not the case in the Southern Hemisphere, where rates in the South Atlantic, South Pacific, and Indian basins are more uniform in magnitude and sign. Comparisons between sea level and atmospheric

variability suggest that recent regional rates in the Northern Hemisphere are consistent with historical modes of sea level change. In contrast, the uniform variability across the Southern Hemisphere appears to be unique.

As in previous years, 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. UHSLC datatsets are featured prominently in those assessments. In addition, the UHSLC PI was a lead author on the IPCC AR5 Working Group I report, with contributions to Chapter 13: Sea Level Change.

Because the UHSLC is involved with data collection, we address the following point by point:

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/).

3. 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. During FY13 undergraduate interns from Brown University and the University of Hawaii participated in studies of coastal flooding due to total water level fluctuations (i.e., including

wave-driven setup and runup). 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 2013. Her PhD thesis research focuses on global sea level reconstructions from tide gauges and their relationship to atmospheric forcing fields.

4. Publications and Reports

4.1. Publications by Principal Investigators

Published

Merrifield, M. A., A. S. Genz, C. P. Kontoes, and J. J. Marra, 2013: Annual maximum water levels from tide gauges: Contributing factors and geographic patterns. *J. Geophys. Res.*,**118**, 2013.

Merrifield, M. A., and Coauthors, 2013: Global sea level [in "State of the Climate in 2012"]. *Bull. Amer. Meteor. Soc.*, **94** (8), S121-S123.

Submitted

Thompson, P. R., M. A. Merrifield, J. R. Wells, and C. Chang, 2013: Wind-driven regional sea level variability in the Northeast Pacific. Submitted to *J. Climate*.

Ford, M., J. M. Becker, M. A. Merrifield, and Y. T. Song, 2013: Marshall Islands fringing reef and atoll lagoon observations of the Tohoku tsunami. Submitted to *Pure and Applied Geophys*..

Thompson, P. R., and M. A. Merrifield, 2013: An anomalous recent difference in hemispheric sea level change rates. Submitted to *Nature Climate Change*.

4.2. Other Relevant Publications

Gehrels, W. R., and P. L. Woodworth: 2013 When did modern rates of sea-level rise start? *Global and Planetary Change* **100**, 263-277.

Houston, J. R., 2013: Global sea level projections to 2100 using methodology of the Intergovernmental Panel on Climate Change. *J. Waterway, Port, Coastal, and Ocean Eng.*, **139**:2, 82-87.

Hamlington, B. D., R. R. Leben, M. W. Strassburg, R. S. Nerem, K.-Y. Kim, Contribution of the Pacific Decadal Oscillation to global mean sea level trends. *Geophys. Res. Lett.*, 2013, **40**, 18.

Church, J. A., D. Monselesan, J. M. Gregory, and B. Marzeion, 2013: Evaluating the ability of process based models to project sea-level change. *Environmental Res. Lett.*, **8**, 1, 014051.