University of Hawaii Sea Level Center

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1. Project Summary

The University of Hawaii Sea Level Center (UHSLC) is a research group aimed at improving our understanding of global sea-level rise and regional sea level variability. Toward this goal, the UHSLC participates in the operation and maintenance of the global sea level observing system based on island and coastal tide gauge stations. UHSLC technicians work with international agencies, particularly in developing countries, to ensure that tide gauge stations are maintained in accordance with procedures specified by scientific oversight groups. The UHSLC also assembles and quality controls tide gauge data from the global network of stations. UHSLC researchers use tide gauge observations in studies of sea-level rise, regional sea-level variability, tides, extreme sea-level events, tsunamis, wave-driven setup, and vertical land movement contributions to relative sea level. Having sea level researchers, technicians, and data analysts working side by side ensures that the tide gauge climate record is maintained at the highest level.

The UHSLC focuses on the collection of high frequency measurements that are available in near-real time usually via the Global Telecommunications System (GTS). The center complements the Permanent Service for Mean Sea Level (PSMSL), which is the primary archive for historic monthly-averaged time series of sea level. Data are provided to the UHSLC from ~ 450 stations maintained by 65 international agencies. The UHSLC is a major contributor to the Intergovernmental Oceanographic Commission Global Sea Level Observing System (GLOSS), and participates in operational and scientific oversight through the GLOSS Group of Experts. The UHSLC is primarily concerned with the implementation of the GLOSS Core Network of stations, and the Global Climate Observing System (GCOS) sea level network, a subset of GLOSS designated as being of high importance for climate research. Without UHSLC participation, both the GLOSS and GCOS datasets would be severely compromised.

The UHSLC distributes near-real time and delayed mode data directly from its host web site, http://uhslc.soest.hawaii.edu. The center collaborates with NOAA's National Oceanographic Data Center (NODC) to maintain the Joint Archive for Sea Level (JASL), which is a research quality database of hourly sea level from an expanded set of global stations.

UHSLC datasets are used in conjunction with operational numerical models, for the calibration of satellite altimeter data (Figure 1), the production of oceanographic products, and research on interannual to decadal climate fluctuations and short-term extreme events (Mitchum et al., 2010). UHSLC station data are made available directly to the Pacific Tsunami Warning Center, the West Coast and Alaska Tsunami Warning Center, the Japanese Meteorological Agency for tsunami monitoring, and other national and international tsunami warning agencies. Over the years the UHSLC has provided tide gauge observations for various national and international research programs, including the North Pacific Experiment (NORPAX), the Tropical Ocean Global Atmospheres Experiment (TOGA), the World Ocean Circulation Experiment (WOCE), the Global Ocean Data Assimilation Experiment (GODAE), and the Climate Variability and Predictability (CLIVAR) program.

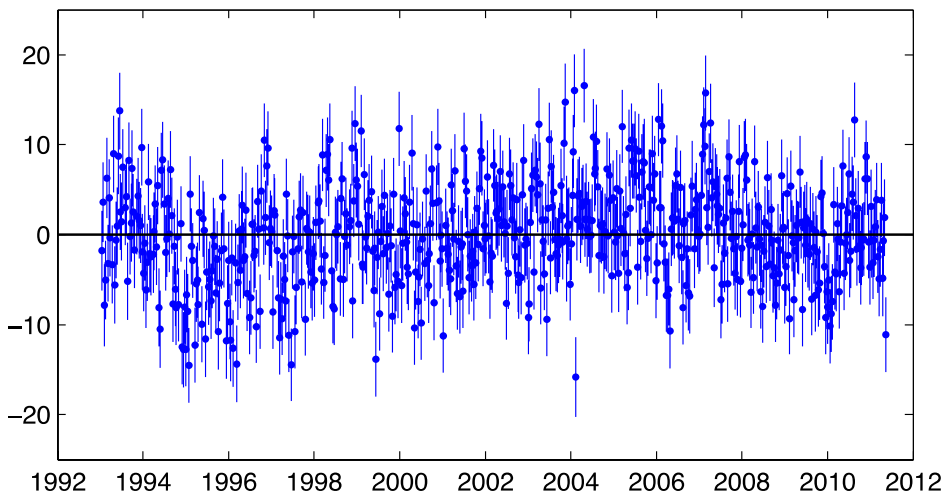

Figure 1. *An example of how the UHSLC Fast Delivery Dataset is used to check altimeter datasets for possible drift. This example uses the TOPEX/Poseidon, Jason-1 and Jason-2 merged altimeter dataset produced at the Goddard Space Flight Center (provided by Brian Beckley, NASA). Point-wise (10-day sampling) the standard deviation in the altimeter, tide gauge differences is typically 5-6 millimeters. Fitting a trend to this difference time series (not shown) yields a drift estimate that is not significantly different from zero, meaning that there is no evidence for any altimeter drift in this case. This type of analysis is routinely performed for multiple altimeter datasets produced by multiple groups (Figure provided by Gary Mitchum, University of South Florida).*

2. Scientific and Observing System Accomplishments

Scientific Accomplishments

Sea level trends during the period of high-accuracy satellite altimetry (1993-present) have been examined in the context of longer tide gauge records by UHSLC. Altimeter trend patterns have been dominated by high rates in the western tropical Pacific, suggestive of an intensifying La Niña-like pattern (Merrifield, 2011) (Figure 2). While the altimeter sea level time series was short in duration (i.e., < 10 years), a plausible explanation for the trend pattern was that it was associated with internannual ENSO events, which are well known to dominate sea level variability in the tropical Pacific. As the altimeter record has grown and the trend pattern

persists, it appears less likely that the trend is a reflection of ENSO events. Tide gauge records in the western tropical Pacific dating back to the WWII era indicate that the recent high rates in the western tropical Pacific represent a significant increase in trend relative to the period 1950-1990. The trend change is corroborated by shorter records from stations installed during the TOGA era. The change in sea level trend in the western tropical Pacific coincides with an increase in the strength of the trade winds averaged across the Pacific, as determined using ECMWF wind products. To investigate whether the observed wind trend is dynamically consistent with the sea level pattern, model simulations driven by the trending wind stress pattern were examined (Merrifield and Maltrud, 2011). The resulting sea level response closely matches the observed change in the western tropical Pacific, supporting the notion that the sea level trends are indicative of a multidecadal intensification of the Pacific trades, particularly zonal winds off the equator.

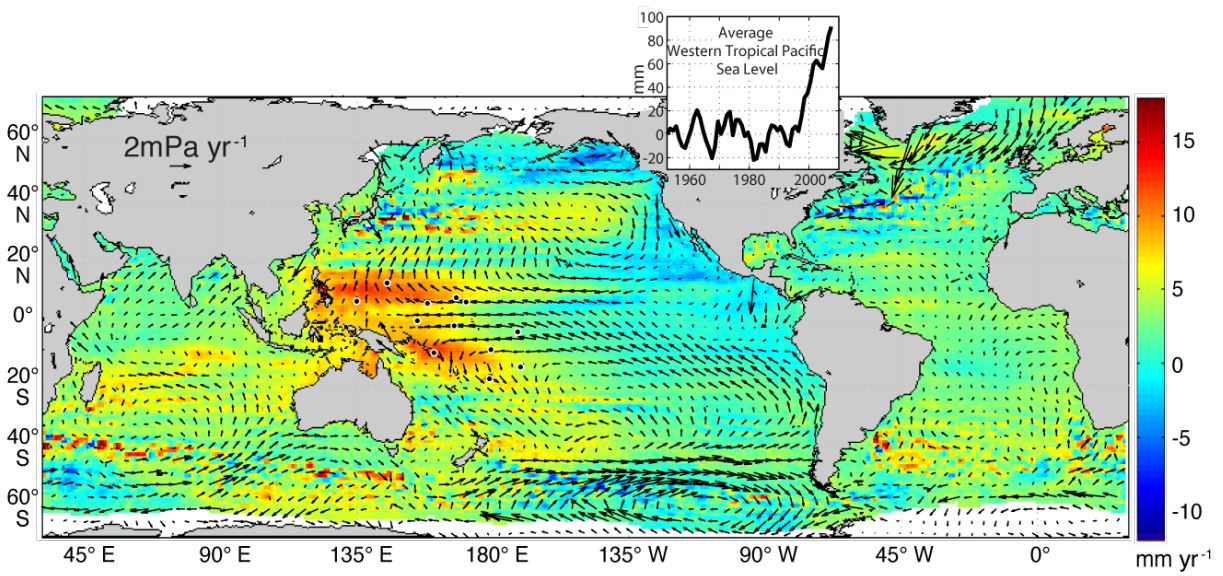

Figure 2. Linear trend (1993-2010) of satellite altimeter SSH showing the region of high rates in the western Tropical Pacific. Vectors denote ECMWF wind stress trends for the same period. The inset is the time series of average sea level obtained from 11 tide gauges (tide gauge locations denoted by solid dot) (from Merrifield and Maltrud, 2011).

The nature of this wind intensification and sea level response is under investigation. The wind shift may be associated with natural climate variations at decadal time scales. If so, it is different in character from the well-studied Pacific Decadal Oscillation (PDO) in that the sea level time series is not significantly correlated with the PDO index (Merrifield, 2011). Instead, the wind shift appears to correlate with various measures of global warming, including sea-surface temperatures and outgoing long-wave radiation. The wind intensification also runs counter to model predictions of a weakening atmospheric circulation in the Pacific in response to anthropogenic forcing (e.g., Vecchi and Soden, 2007; Yu and Zwiers, 2010). Further model simulations are underway to gain a better understanding of low frequency, wind-forced sea level fluctuations in the Pacific and elsewhere.

The UHSLC maintenance of the hourly sea level database under JASL has led to a number of analyses of extreme sea level events and their relationship to storm patterns and sea level change.

We are near completion of a manuscript that describes the "geography" of annual extreme sea level events. Our approach is to deconstruct tide gauge annual extremes into tidal, seasonal, high frequency storm, and low frequency sea level components. We then construct proxies for each of the components of extreme sea levels based on oceanographic (altimeter, tide model) and atmospheric (atmospheric pressure, winds) forcing fields. The proxies allow a continuous mapping of extreme fields over the entire ocean, with the tide gauges serving primarily as calibration points. From these maps, regions of tidally-driven versus non-tidally driven extremes emerge, which allows for an assessment of extreme climatology's in places where tide gauges do not exist (Figure 3). The results of this analysis were presented at a workshop on extremes at the GLOSS meeting in 2011 and a manuscript is in final preparation.

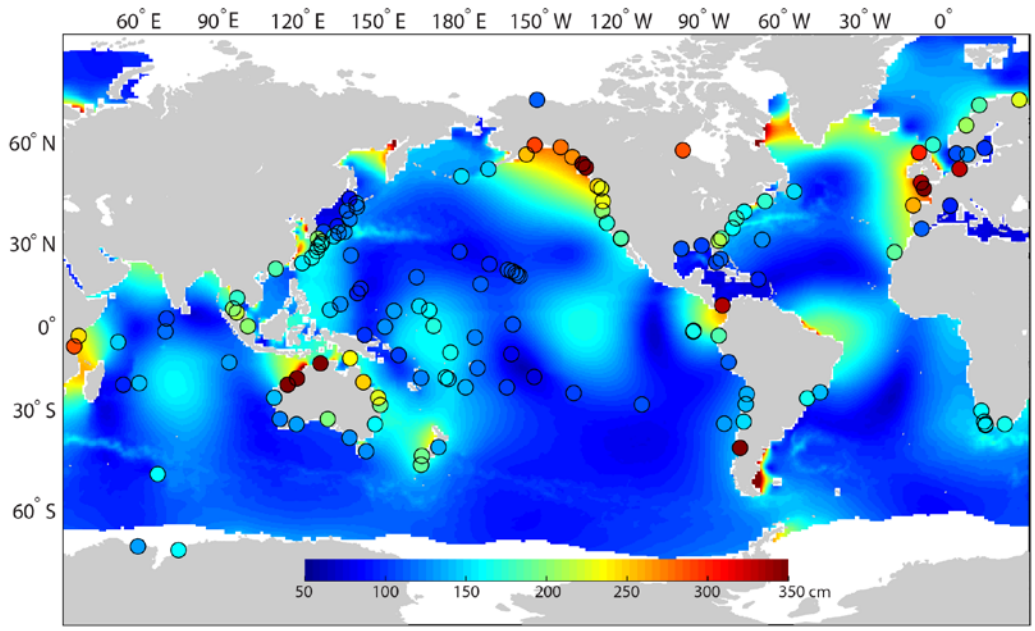

Figure 3. Time average of annual maxima sea level observed at tide gauges (dots) versus the predicted value based on extreme component proxies.

Based on previous studies of global sea level trends (Merrifield et al., 2009), UHSLC researchers are computing a new sea level metric. The metric will measure the uncertainty in estimating global sea level from tide gauges, thus providing an ongoing estimate of global sea level to complement altimeter based products. The tide gauge global sea level will be extended back in time, similar to the reconstruction of Church and White (2006). We expect to have the index ready by summer 2012.

UHSLC researchers took the lead on the sixth OCO contribution to the BAMS State of the Climate report section on sea level patterns during 2010.

Conferences, Meetings, Expert Panels, and Working Groups

- February 2011 - WCRP/IOC Workshop on Regional Sea Level Change, Paris, France, presentation on Pacific sea level trends
- January 2011 - Hawaii Climate Change Meeting, Honolulu, Hawaii, presentation on Hawaii Region Sea Level Change
- March 2011 - PACOM conference, presentation on Pacific Sea Level Variability

- A metric that reflects the state of the global sea level network based on global sea level reconstructions.

Observing System Accomplishments

Tide Gauge Operations

The UHSLC assists with the operation and maintenance of 78 tide gauge stations in collaboration with local operators. All of these stations transmit data in real-time via the GOES, Inmarsat, Meteosat, or GMT satellites. The majority of stations transmit 5 to 15 minute transmissions of 1 to 3 minute averages, with even higher rates at major tsunami generation zones. Of the 77 UHSLC stations, 54 contribute to the GLOSS Core network, and 39 to the GCOS network. 21 stations have collocated or nearby GPS or DORIS reference stations. The UHSLC shares responsibility for the sites with local operators, which lowers our costs by reducing travel for our technicians while raising the reliability of the stations and the data quality. At most locations, on-site personnel perform regular maintenance, tide staff measurements, and provide security. UHSLC's role has been to provide spare parts as needed, to visit the sites on 1-3 year intervals to repair and upgrade components and to ensure the proper operation of the station, to trouble-shoot problems as they arise in coordination with local operators, and to quality assess the datasets. In the long-term, we provide training on station operation and maintenance with the aim of eventually transferring full responsibility of the station to local agencies.

Station	**Date of Visit**
Muscat	2010/11
Sibolga	2010/12
Curacao	2011/01
Dominica	2011/05
Grenada	2011/05
Ponta Delgada	2011/06
Malakal	2011/07
Saipan	2011/08
Yap	2011/08
Baltra	2011/08
Santa Cruz	2011/08
La Libertad	2011/08

Table 1. Station maintenance visits by UH technicians.

New station installations and upgrades of existing OCO stations during 2010-2011 are listed in Table 1. All are equipped with open-air radar sensors, and most feature a backup float gauge or acoustic sensor, for stable and accurate long-term measurements. Most of these sites are either in the GLOSS Core Network or they will be proposed as new additions to the network once it is established that the station is a well-established station with a proven track record. In addition, we intend to recommend many of these sites as replacements for nearby GCOS stations that have a low probability of becoming operational, particularly in the Caribbean region. In addition to the stations visited during 2010-2011, UHSLC technicians worked remotely with on-site personnel to fix problems at 50 stations in the UHSLC network. In terms of tsunami stations, we installed Curacao, Dominica, Grenada, and La Libertad during the reporting period.

Dataset Holdings

During 2010-2011, we completed a complete redesign of the UHSLC database and website (http://uhslc.soest.hawaii.edu/). The database is now a relational database with netCDF-CF compliant metadata and formats. We've reinstated our THREDDS server. The website has a number of new features that improve data searching and downloading for users.

The Joint Archive for Sea Level (data latency: 1-2 years) is a collaborative effort between the National Oceanographic Data Center (NODC), the World Data Center-A for Oceanography, and the UHSLC. A NOAA Liaison officer supported by National Coastal Data Development Center (NCDDC) helps maintain the JASL. The JASL consists of a quality assured database of hourly sea level time series from stations around the world. We consider this to be our research quality database, complementary to the monthly averaged data maintained as PSMSL.

The UHSLC maintains a fast delivery database (data latency: 1 month) in support of various national and international programs (e.g., GODAE, CLIVAR, GLOSS, GCOS). To ensure active participation and coordination with the international community, 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. In particular, fast delivery data are used for monitoring the latest JASON altimeter and for the tie between JASON, TOPEX/Poseidon, ERS, and GEOSAT satellites (Figure 1).

Real-time data are received via a number of transmission channels. For example, data from UHSLC operated stations are received at the data center within minutes of transmission using the geostationary meteorological satellite system and the GTS. Data from the U.K. stations are received via email and updated within hours of transmission. NOAA CO-OPS data are obtained via the GTS and a backup download from their web site. Data from Chile and other countries that use the GOES are acquired via the GTS and also downloaded from the GOES web site.

As part of the JCOMM SLP-Pac, the UHSLC operates a Specialized Oceanographic Center that produces sea surface topography maps (monthly) and diagnostic time series (quarterly) for the Pacific Ocean. This activity is a continuation of one of the earliest examples of operational oceanography. The analysis includes comparisons of tide gauge and altimeter sea surface elevations that are available at our web site *(http://uhslc.soest.hawaii.edu/products).*

Review of Deliverables

Our deliverables for 2010-2011 included:

- Continued operation and maintenance of the Fast Delivery and Research Quality data products.
- Continued operation and maintenance of UHSLC tide gauge stations.
- 7 new GPS stations at GLOSS tide gauges.

All goals were met with regard to base operations (database maintenance, station operation), but we are behind schedule with regard to the add-on task - the installation of 7 new GPS stations. This portion of the project will be conducted during the second half of our funding cycle, which runs from July 2011-June 2012. Permitting delays are creating issues for us. We are relying on host countries to set up the permits for us and to help us with shipments and custom charges. These tasks are taking longer than anticipated due to more stringent regulatory procedures. We are targeting 5 stations and may have to delay 2 to the next funding cycle. We will use any extra funds remaining in our current budget for equipment for future installations.

The UHSLC project does involve data collection, and so here are our answers to the following five questions:

a. Are your data distributed in real time on the Global Telecommunications System?
   Yes.

b. Where do your real time data reside? Are the data available online?
   Real time data accessible at http://www.ioc-sealevelmonitoring.org/. We are in the process of reinstalling our real-time server at the UHSLC website.

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 available at UHSLC/JASL website (http://uhslc.soest.hawaii.edu/data/rqd). Data are updated annually, although because of changes in quality assessments associated with radar sensors, we are behind on a group of stations. We intend to be caught up through 2011 by mid-2012.

d. Where are your data archived and with what frequency?
   Data are archived at UHSLC.

e. What is the web site where the data for your program can be accessed?
   http://uhslc.soest.hawaii.edu/data/

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?
   Yes.

2.1. Outreach and Education

A hands-on demonstration of sea-level rise impacts for Pacific Islands was given at the SOEST Open House in 2011. UH researchers responded to a number of phone call and email questions from the public regarding sea-level rise concerns. Sea level time series and tidal predictions charts are provided to numerous international agencies. A graduate research assistant at the University of Hawaii was supported in part during FY 2011. We hired two undergraduate students during 2010-2011 and gave them research experience working with sea level datasets. The UHSLC PI contributed to climate assessment reports for the IPCC AR5 and the Pacific Island Region Climate Assessment (PIRCA).

3. Publications and Reports

3.1. Publications by Principal Investigators

Merrifield, M. A., 2011: A shift in western tropical Pacific sea level trends during the 1990s. *J. Climate*, **24**, 4126-4138, doi:10.1175/2011JCLI3932.1.

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., G. Mitchum, E. Leuliette, D. Chambers, S. Nerem, P. Woodworth, S. Holgate, L. Miller, and S. Gill, 2011: Sea level variations, 2010 annual assessment [in "State of the Climate in 2010]. *Bull. Amer. Meteor. Soc*., **92 (6)**, S98-S100.

3.2. Other Relevant Publications

Cazenave, A., and F. Remy, 2011: Sea level and climate: measurements and causes of changes. *Climate Change*, **2**, 647-662.

Woodworth, P. L., M. Menéndez, and W. R. Gehrels, 2011: Evidence for Century-Timescale Acceleration in Mean Sea Levels and for Recent Changes in Extreme Sea Levels. *Surveys in Geophysics*, **32**, 603-618.

3.3. Other References Cited in the Report

Church, J.A., and N. J. White, 2006: A 20th century acceleration in global sea-level rise. *Geophys. Res. Lett*., L01602, doi:10.1029/2005GL024826.

Merrifield, M. A., S. T. Merrifield, and G. T. Mitchum, 2009: An anomalous recent acceleration of global sea level rise. *J. Climate*, **22**, 5772–5781.

Mitchum, G. T., R. S. Nerem, M. A. Merrifield, and W. R. Gehrels, 2010: Modern sea level change estimates. In: J.A. Church, P.L. Woodworth, T. Aarup and W.S. Wilson (Editors), *Understanding sea-level rise and variability*. Wiley-Blackwell.

Vecchi, G. A., and B. J. Soden, 2007: Global warming and the weakening of the tropical circulation. *J. Climate*, **20**, 4316–4340.

Yu, B., and F. W. Zwiers, 2010: Changes in equatorial atmospheric zonal circulations in recent decades. *Geophys. Res. Lett*., **37**, L05701, doi:10.1029/2009GL042071.