Permanent Service for Mean Sea Level (PSMSL) activities November 2011 – October 2013

Overview

The Permanent Service for Mean Sea Level (PSMSL) is based at the National Oceanography Centre (NOC, formerly Proudman Oceanographic Laboratory (POL)) on the campus of the University of Liverpool in the UK. It acts as the global data bank for long term sea level information from tide gauges, and provides a wider service to the sea level community. For many years it has been a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) and operates under the auspices of the International Council for Science (ICSU). PSMSL is in the process of applying for membership of the new ICSU World Data System (WDS).

PSMSL was established in 1933 by Joseph Proudman who became its first Secretary. Thus 2013 marks the 80th anniversary of the founding of PSMSL. To celebrate this milestone, PSMSL has organised or co-organised three meetings:

- A session at EGU 2013**:** Global and regional sea level rise and variability: from past to future (April 2013).
- A symposium entitled "Implications of sea level change for the coastal zone - A symposium to mark the 80th anniversary of the Permanent Service for Mean Sea Level (PSMSL)" at the IAHS/IAPSO/IASPEI Joint Assembly in Gothenburg, Sweden (July 2013).
- A workshop in Liverpool, UK, on major research topics in sea level science. The workshop, held in October, included talks reviewing aspects of the IPCC Fifth Assessment Report (Working Group I). There were also presentations covering many aspects of regional variability in sea level.

The primary aim of the PSMSL is to provide the global data bank for long term sea level information from tide gauges. PSMSL has continued to increase its efforts in this regard and over the last 2 years over 41000 station-months of data were entered into the PSMSL database, increasing the total PSMSL data holdings to over 717000 station-months. The entire PSMSL data set is available from the website: www.psmsl.org, along with new products to aid access and exploration of the data set (e.g. station, trend and anomaly maps). In addition, the PSMSL, together with the British Oceanographic Data Centre (BODC), are responsible for the archive of delayed-mode higher-frequency sea level data (e.g. hourly values and higher frequency) from the Global Sea Level Observing System (GLOSS) core network.

The PSMSL has continued its close involvement in the development of a sea level network in Africa (through the Ocean Data and Information Network for Africa – ODINAfrica – project) through colleagues in the Ocean Engineering and Technology Group (OETG) of NOC. The OETG have worked with local tide gauge operators as necessary on the installation, maintenance and resolution of problems at the African and Indian Ocean tide gauges. In particular, they have continued to provide advice to GLOSS on OTT gauges, data transmission and Broadband Global Area Network (BGAN) systems. Specifically, over the last 2 years ongoing training and support has been provided to the tide gauge operators for the tide gauges in Cameroon, Ghana and Nigeria.

Technology development to support the GLOSS programme has included design and assembly of a second generation sea level measuring station system that requires limited operator intervention, and the development of a facility and methodology for calibration of offsets in the measured range of the radar and for estimation of radar range accuracy; obviating the need for local operators to make dipping measurements.

PSMSL staff have continued to be active in a variety of international meetings, working groups, conferences and workshops including IOC GE-GLOSS and IOC Coordination Groups for tsunami warning systems, IPCC, GGOS, and EGU. In addition, they have answered many enquires relating to sea level and have appeared on radio and television discussing aspects of sea level change.

Activities

1. Introduction

Since 1933, the Permanent Service for Mean Sea Level (PSMSL) has operated at the National Oceanography Centre (NOC), Liverpool (and its predecessors), with the aims of providing the global data bank for long term sea level information from tide gauges, and of providing a wider Service to the sea level community. It was a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) until its dissolution and works under the auspices of the International Council for Science (ICSU) and is applying for membership of the new ICSU World Data System (WDS).

The data set and ancillary information are provided free of charge and are made available to the international scientific community through the PSMSL website. The metadata includes descriptions of benchmarks and their locations, types of instrumentation and frequency of data collection (where available) as well as notes on other issues that we feel the users should be aware of (e.g. earthquakes that are known to have occurred in the vicinity or subsidence due to local groundwater extraction). The free access to data by users is central to the PSMSL's mission, and conversely no supplier is ever paid for their data, nor are licensing terms ever entered into.

2. Staffing and funding

Dr. Lesley Rickards continues as the Director of the PSMSL. The main PSMSL scientific staff concerned with the collection and analysis of monthly mean sea level data have been Prof. Philip Woodworth, Dr. Simon Holgate, Dr. Svetlana Jevrejeva and Dr. Mark Tamisiea. Ms. Kathy Gordon continues to be responsible for management of the mean sea level data set and Dr. Andrew Matthews has worked on re-structuring the database, improving data delivery and providing new tools to aid data input, quality control and reporting. Last year saw the departure of Dr. Simon Holgate, who we thank for all of his contributions over the last 10 years. And we welcome Dr. Simon Williams, already a well-established scientist within NOC, to the PSMSL scientific staff.

Alongside the monthly mean sea level data collection, the PSMSL, together with BODC, is responsible for an archive of delayed-mode higher-frequency sea level data from the GLOSS network. This activity has so far included Miss Elizabeth Bradshaw and other colleagues in the British Oceanographic Data Centre (BODC).

Funding continues to be provided by the UK Natural Environment Research Council (NERC, the parent body of NOC). The document prepared in 2010 by PSMSL for NERC as part of its review of National Capability to aid future funding decisions resulted in PSMSL being one of the two areas in NOC given a high rating enabling us to continue to operate at the same level of funding. The document highlighted PSMSL's unique role and the synergy generated by its co-location with NOC.

3. PSMSL-related scientific meetings, activities and events

PSMSL staff have continued to be active participants in the IOC Group of Experts on the Global Sea Level Observing System (GLOSS) and Global Geodetic Observing System (GGOS) meetings, and co-convened sea level sessions at the EGU. PSMSL has contributed to the IPCC Fifth Assessment Report with Dr Svetlana Jevrejeva a lead author for Working Group I, Prof. Philip Woodworth a review editor and other PSMSL staff also contributing.

2013 marks the 80th anniversary of the foundation of the PSMSL. To commemorate this PSMSL has hosted or co-convened the following events:

- A workshop in Liverpool, UK, on major research topics in sea level science. The workshop, held in October, included talks reviewing aspects of the IPCC Fifth Assessment Report (Working Group I). There were also presentations covering many aspects of regional variability in sea level.
- A symposium entitled "Implications of sea level change for the coastal zone - A symposium to mark the 80th anniversary of the Permanent Service for Mean Sea Level (PSMSL)" at the IAHS/IAPSO/IASPEI Joint Assembly in Gothenburg, Sweden (July 2013).
- A session at EGU 2013**:** Global and regional sea level rise and variability: from past to future (April 2013).

4. Collection, analysis, publication and interpretation of monthly and annual means of sea level from the global network of tide gauges

Over the last two years, approximately 41181 station-months of MSL data from about 866 stations were added to the PSMSL databank (and a further 2978 months were updated), bringing the total PSMSL data holdings to over 717504 station-months from 2170 stations. Most of the data originated from Europe and North America together with significant data sets from Japan and Australia. There are gaps in data receipts from parts of SE Asia, central and South America; these are presently being targeted to try to improve data flow. Africa continues to receive special attention through ODINAfrica and the Indian Ocean Tsunami Warning System (IOTWS), although data flow has improved considerably over the last decade. Close links have been maintained with the University of Hawaii Sea Level Center and other international sea level data centres.

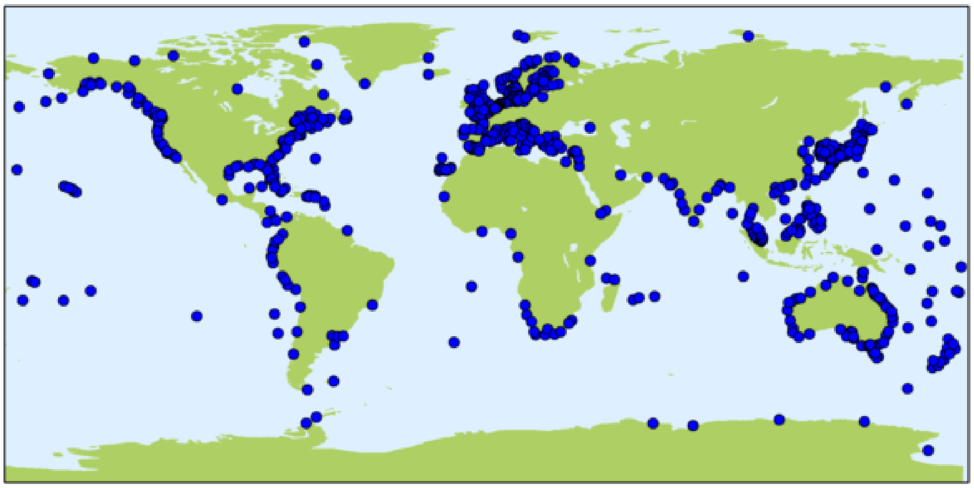


Figure 1: Stations providing new data received between August 2011 and July 2013

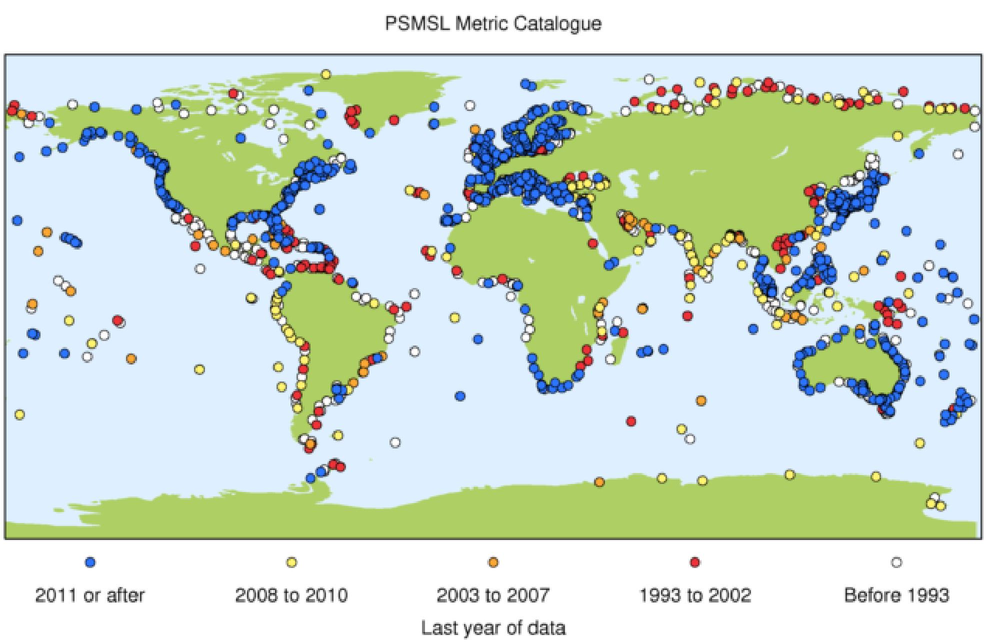


Figure 2: Year of most recent data received by PSMSL

5. PSMSL web-site and products

The PSMSL website (www.psmsl.org) continues to be developed. The dedicated station web pages have been enhanced and now include links to other GLOSS related data streams (e.g. high frequency and real-time tide gauge data and GPS at tide gauges). In order to improve ease of access and exploration of the PSMSL data set, there are now several ways of obtaining the data: files and plots of individual stations can be accessed *via* a map-based explorer or a table, or the entire dataset can be downloaded.

5.1 Interactive map showing long-term trends

The relative sea level trends map allows interactive investigation of global mean sea level trends since 1900. A period of at least thirty years must be selected. The map will display the annual sea level trend at each station that has suitable data available over the selected period. The methods page (www.psmsl.org/products/trends/methods.php) has further details.

Note that these measured trends are not corrected for local land movement. Furthermore, no attempt has been made to assess the validity of any individual fit, so results should not be treated as a publication quality values suitable for use in planning or policy making.

The map should be used with some care as anomalous trends have many causes:

- land movements (e.g. earthquakes, glacial isostatic adjustment)
- unexplained instrumental datum shifts
- changes in atmospheric pressure
- short records

A more complete account can be found in the geophysical signals section of the PSMSL web-site (see: www.psmsl.org/train_and_info/geo_signals/). A table of long term trends derived from annual mean values of sea level in the PSMSL RLR data set demonstrates the rate of change of sea level at each station.

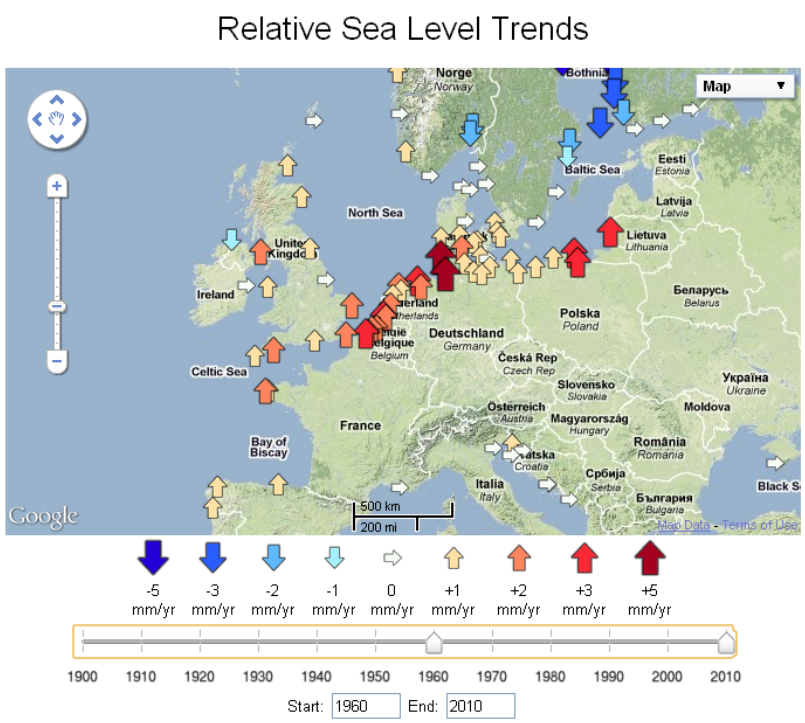
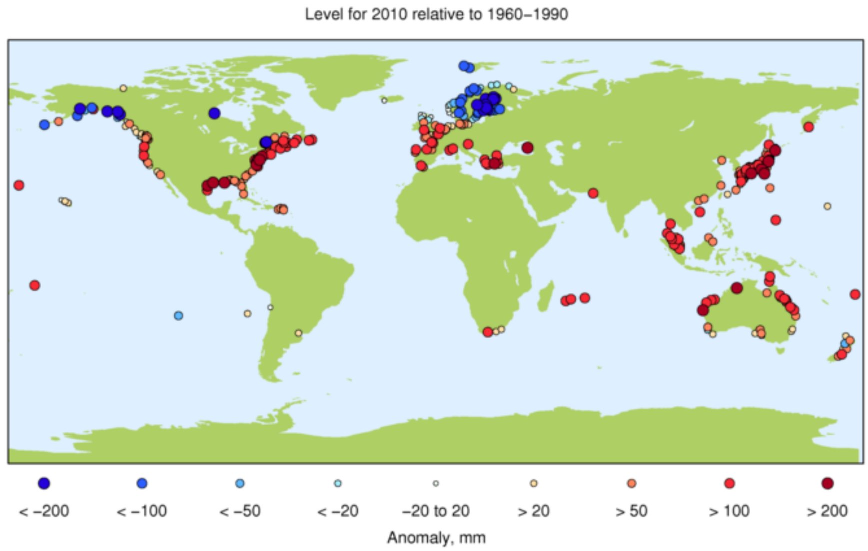


Figure 3: Sample map showing relative sea level trends

5.2 Interactive map showing sea level anomalies

Annual mean sea level can vary considerably from year to year in response to various meteorological and oceanographic forcings, typically by hundreds of millimetres. The product allows one to examine the global variations in a year of your choice. The map presents the difference between the annual RLR data for each station (which is quality and datum controlled) compared to that station's long term mean over the baseline period of 1960-1990.

The long term trend at each station (estimated using the baseline period) can be removed if required. This will prevent results being dominated by long term changes, but will result in the loss of stations for which there is not enough data to calculate a trend. Further information is provided on the methods and derived trends pages of the PSMSL web-site.



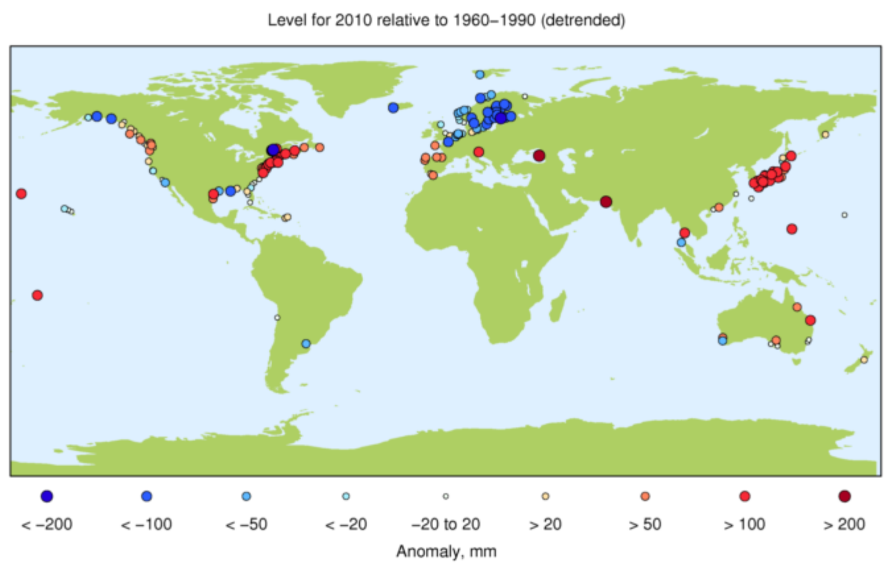


Figure 4: Sea level anomalies for 2010 relative to 1960-1990.
(Top image: not detrended. Bottom image: detrended)

6. Collection of delayed-mode higher-frequency data from GLOSS Core Network sea level measuring stations

The PSMSL together with BODC is responsible for an archive of delayed-mode higher-frequency sea level data (e.g. hourly or more frequent values) from the GLOSS network of 290 stations. This activity builds on the earlier work carried out as the Delayed-mode Sea Level Data Assembly Centre (DAC) for the World Ocean Circulation Experiment (WOCE). Between August 2011 and July 2013, new data have been received from Australia, Brazil, Canada, Germany, Iceland, Japan, Korea, UK and USA (NOAA). Further data from UK

GLOSS sites have been digitized from the original charts to fill in some gaps in the historical record. These are being added to the high-frequency delayed-mode databank.

In addition, data up to the end of 2012 from the gauges that are part of the ODINAfrica and Indian Ocean network have been downloaded, processed and quality controlled, although not all of the gauges have been operational for the entire period. The data (both 1 minute and 15 minute) are available on the GLOSS web-site. Work has also been underway to set up a European Delayed-Mode Sea Level Data Portal building on the work of the EU funded European Sea Level Service – Research Infrastructure (ESEAS-RI) project. This is undergoing testing and when operational will provide the GLOSS Data Archive with a regular supply of European GLOSS data.

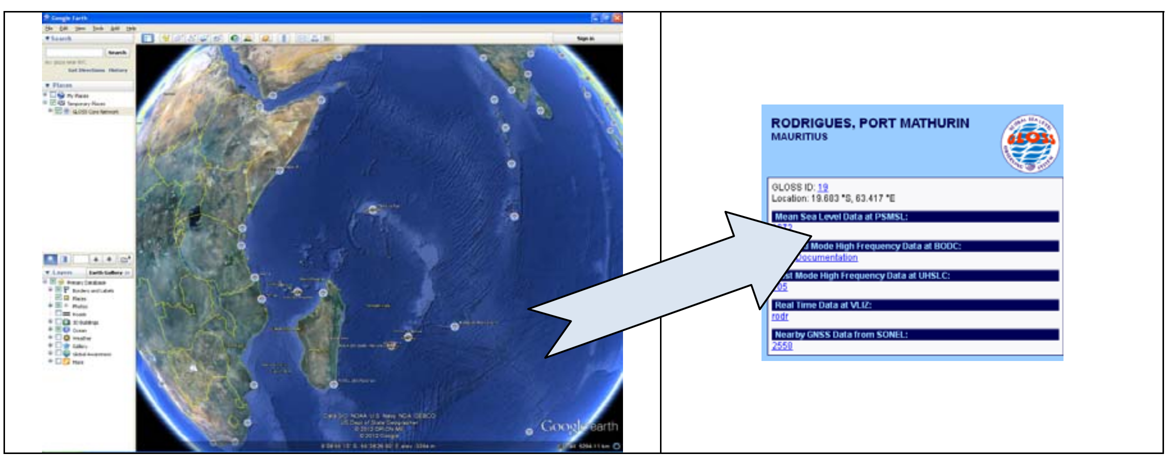
7. GLOSS Activities

7.1 GLOSS web-site

The GLOSS web site (www.gloss-sealevel.org) is maintained and updated by the PSMSL and BODC on behalf of GLOSS. New material has been added, the GLOSS Station Handbook and the GLOSS network status has been updated. Following the GE-GLOSS-XII meeting in November 2011, the web-library of GLOSS country reports has been updated, and information extracted from the reports has been used to update the GLOSS Station Handbook. The Handbook has also been updated to reflect the new GLOSS10 definition.

A kml file has been produced to allow exploration of the GLOSS network with links to the appropriate GLOSS Station Handbook page and also to the GLOSS Data Streams (mean sea level data from PSMSL, real-time monitoring from VLIZ, fast-mode from UHSLC, delayed-mode from BODC, nearby GNSS data from SONEL). Examples are shown in the illustrations below.

During the current year, the web-site has been reviewed and a new version designed which will become live towards the end of 2013.



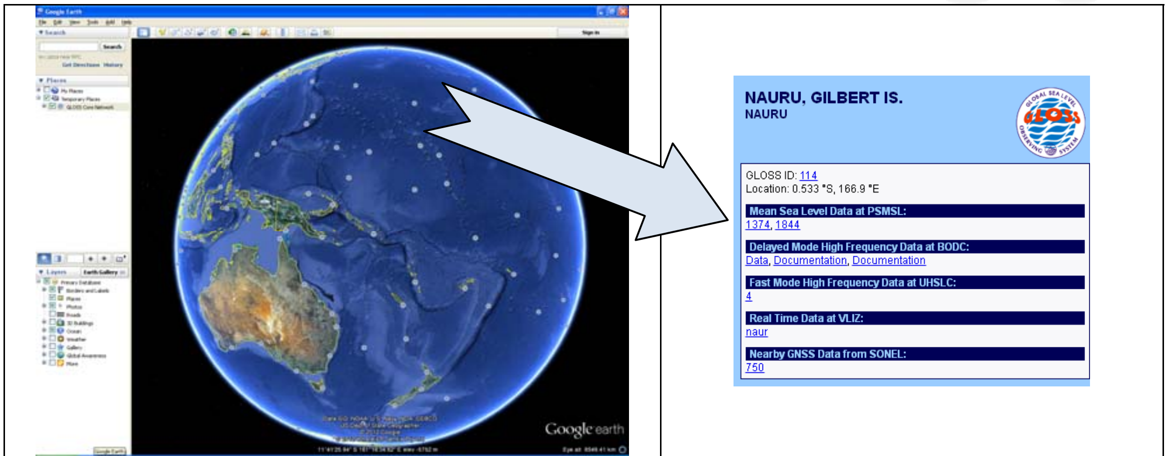


Figure 5: GLOSS Stations kml file for Google Earth

7.2 GLOSS Status from a PSMSL Viewpoint

The PSMSL provides an annual summary of the status of the GLOSS Core Network (GCN) from its viewpoint. An 'operational' station from a PSMSL viewpoint means that recent MSL monthly and annual values have been received and checked as far as possible, and have been includdd in the databank. For each of the GCN stations the year of the last data entered into the databank, if any, is used to place the station into one of four categories:

- Category 1: 'Operational' stations for which the latest data is within the 5 years before the current year;
- Category 2: 'Probably operational' stations for which the latest data is within the period 6 to 15 years before the current year;
- Category 3: 'Historical' stations for which the latest data is earlier than 15 years before the current year;
- Category 4: For which no PSMSL data exist.

During 2010 the latest revision of the GLOSS Core Network was agreed with 290 stations included. Twenty-two new stations have been added and 23 removed. As the new stations are operational and providing data, this has improved the status of the network (64% of the stations are Category 1, having reported their data from 2007 or more recently to PSMSL, Figure 6a). However, although improvements to the network will feed through to status improvement in the coming years, further work is still required to develop the network further in order that all stations can be Category 1.

PSMSL has also started to produce status maps for all of the GLOSS data streams. Currently these can be found on the PSMSL web-site at www.psmsl.org/products/gloss, although they may be moved to the GLOSS web-site in the future. There are 3 categories: “operational” (for PSMSL this means data in the last 5 years), “has some data” and “no data”. In addition to the standard style maps (the example for PSMSL is shown in Figure 6b), there are two interactive maps that allow one to explore the data held by the different GLOSS data streams. One map covers the GLOSS sites; the other all tide gauge sites where at least one of the data streams holds data. These web pages are currently undergoing testing and will be finalised soon.

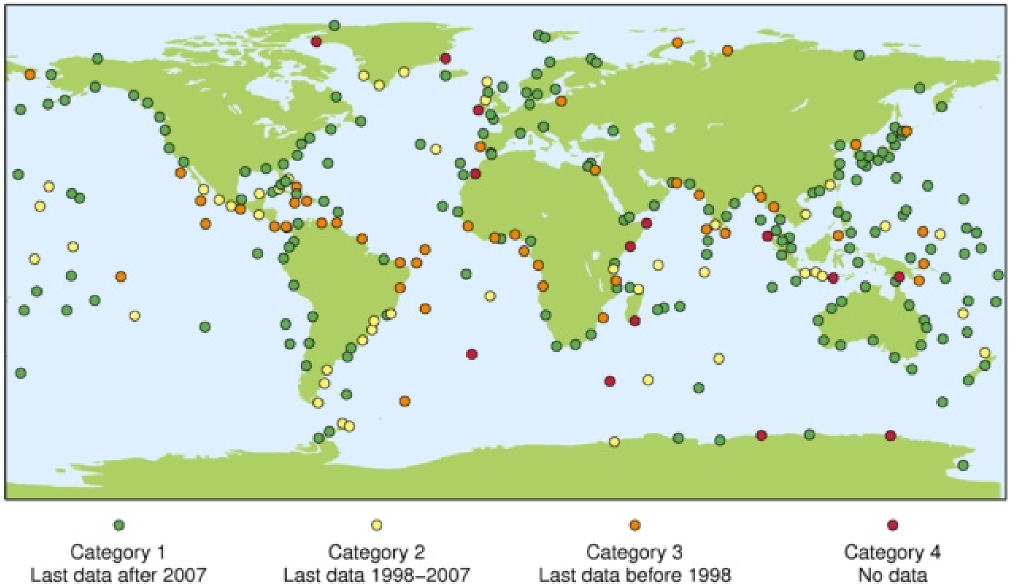


Figure 6a: Status of the GLOSS Core Network from a PSMSL perspective (December 2012)

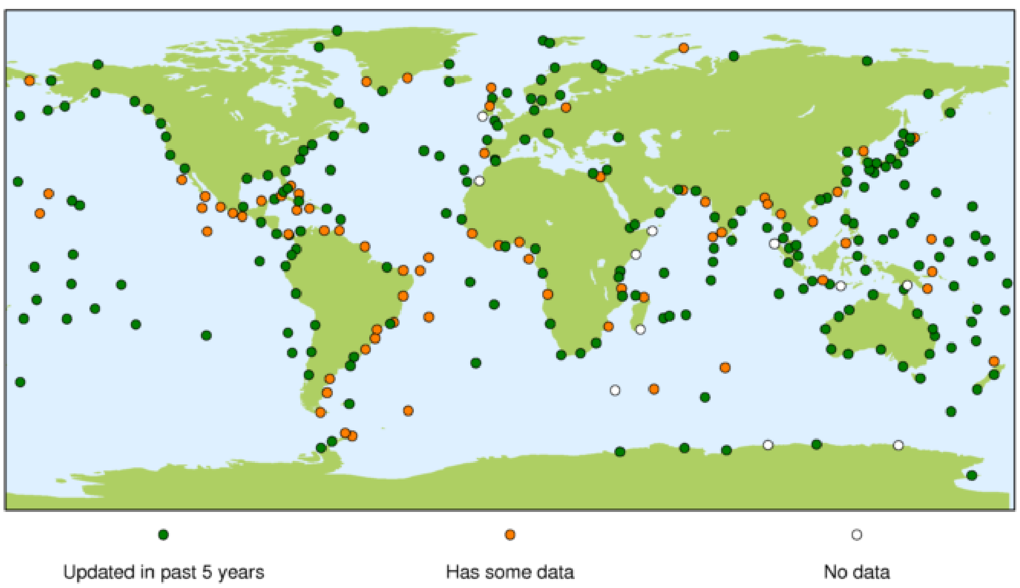


Figure 6b: Status of the GLOSS Core Network from a PSMSL perspective (October 2013)

7.3 GLOSS Training Courses and IOC Indian Ocean Tsunami Warning System fellowships

GLOSS training courses have been held in many countries since the mid-1980s. In the early years these were organised and hosted by PSMSL. More recently (since the 2004 tsunami) individual training courses for technicians have been held at NOC/PSMSL. Two members of staff (Peter Foden and Jeff Pugh) from the Ocean Engineering and Technology Group (OETG) of NOC have worked with local tide gauge operators as necessary on the installation, maintenance and resolution of problems at the African and Indian Ocean tide gauges. In particular, they have continued to provide advice to GLOSS on OTT gauges, data transmission and Broadband Global Area Network (BGAN) systems. Operation of the ODINAfrica gauges is periodically checked the on the VLIZ real-time sea level data monitoring web-site and any problems highlighted when found to the appropriate authority, such as VLIZ, EUMETSAT or local tide gauge personnel.

During the last 2 years specific ongoing support has been provided to the tide gauge operators for the tide gauges in Cameroon, Ghana and Nigeria. In addition training for a technician from Nigeria was undertaken – although unfortunately the Nigerian tide gauge was lost to a storm whilst the technician was being trained. Various training materials (e.g. PowerPoint presentations) are available for trainees who visit NOC Liverpool and PSMSL; these cover installation of tide gauges, calibration, levelling, etc. In addition, material and equipment is available for practical hands-on sessions, which can be tailored to individual trainees needs. Post-training support is available via e-mail and telephone.

7.4 Technology development

7.4.1 Development and design of a second generation sea level measuring station system that requires limited operator intervention.

Following discussion between the GLOSS Technical Secretary, PSMSL and the NOC/OETG staff, it was agreed that it would be beneficial to construct a second generation ODINAfrica gauge which would be more reliable, less power hungry and require less maintenance. It was noted that a system that does not use pressure sensors (i.e. a radar gauge) would last longer without maintenance visits and a more robust (corrosion-proof) satellite antenna would greatly help reliability. Various different loggers and tide gauges were considered to meet the requirements outlined above (e.g. Waterlog DCP, OTT RLS, Vega, DAA, etc.). Battery replacement would still be an issue, but this is considered the sort of minimal maintenance that can be carried out locally. Following on from this work has been carried out in collaboration with the GLOSS Technical Secretary by the NOC/OETG in constructing two second generation sea level stations from components provided with funding from IOC.

Two Waterlog DCP loggers were supplied to NOCL by IOC, together with two OTT RLS radar sensors and component parts, which were assembled to provide two complete tide gauge systems. The new systems are contained within two separate cabinets instead of the one cabinet used in the existing ODINAfrica installations. This allows a much larger rechargeable battery to fitted, thus extending the operational life between servicing. This is something that had been a serious issue with the previous ODINAfrica equipment. In addition, alternative battery chargers have been fitted that extend the charging life-time of the battery. These two complete tide gauge systems have been tested and are ready to be deployed in Africa or the Indian Ocean once a suitable location has been agreed.

7.4.2 Development of a facility and methodology for calibration of offsets in the measured range of the radar and for estimation of radar range accuracy, obviating the need for local operators to make dipping measurements.

Radar gauges generally perform well and are stable, but the determination of their datum has been addressed in the field with the use of complementary measurements with a tide pole, or by dipping measurements in an adjacent stilling well where one exists. However, this has never been a satisfactory situation, and enthusiasm by local operators to make regular tide pole or dipping measurements has never been high. This, together with the availability of a new generation of sensors (in particular the DAA 3611i), has provided motivation for developing a calibration facility.

Measurements were first made in the field, rather than in the laboratory. Three radar gauges (DAA 3611i, OTT RLS and the Vega VegaPuls61) were installed at the Holyhead tide gauge station in Wales, UK. The resulting data was then used to evaluate their performance against the existing onsite reference gauge, the Tide Gauge Inspectorate Bubbler system. The results of the tests with the real sea surface and with the stirrup were consistent. They showed that the DAA 3611i unit performed exceptionally well showing a mean difference (i.e. difference from its nominal reference mark) of approximately 2 mm.

Subsequently, an additional testing phase was carried out at the NOCL Kempston Street facility to see if the above 'real world' figures could be repeated in a laboratory environment. The tests consisted of two sections, one utilising the previously used metal plate as the target and the other, a small water pool. Multiple measurements were made for each sensor, varying the range distance between the sensor and the targets. Overall the RLS and DAA radar gauges agree with the results from the 'real world' experiments. The DAA seemed to mirror the findings in all tests to a very high degree (to within 2 mm).

Of the three radars under study, the DAA performed best and provided sea level data that was compatible with the vertical reference mark on the equipment. However, this good situation cannot be taken for granted with any other DAA sensors, so checks will need to be made with every new unit. A simple test facility will be maintained at NOCL (either/or the metal and water targets) to check any new purchase, which thereafter can be deployed without the need for tide pole or dipping checks. A short report has been produced and supplied to the GLOSS Technical Secretary describing the tests carried out and the results.

8. **Publications**

Four scientific papers directly using the PSMSL data set were published during the last year by NOC scientists partially supported by the PSMSL (listed below). These address global sea-level rise and regional changes, as well as dynamic ocean topography. Perhaps the most notable, in terms of high-level quality control, is the paper by Woodworth et al., "Towards worldwide height system unification using ocean information". The work on this paper and the continuing research has led to a systematic review of the datum information at the studied tide-gauge sites.

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

Henry, O.; Prandi, P.; Llovel, W.; Cazenave, A.; Jevrejeva, S.; Stammer, D.; Meyssignac, B. & Koldunov, N., "Tide gauge-based sea level variations since 1950 along the Norwegian and Russian coasts of the Arctic Ocean: Contribution of the steric and mass components", *Journal of Geophysical Research-Oceans*, 2012, **117**, C06023.

Woodworth, P.; Hughes, C.; Bingham, R. & Gruber, T., "Towards worldwide height system unification using ocean information", *Journal of Geodetic Science*, 2012, **2**, 302-318.

Woodworth, P. L.; Foden, P. R.; Jones, D. S.; Pugh, J.; Holgate, S. J.; Hibbert, A.; Blackman, D. L.; Bellingham, C. R.; Roussenov, V. M. & Williams, R. G., "Sea level changes at Ascension Island in the last half century" *African Journal of Marine Science*, 2012, **34**, 443-452.

One further paper that merits inclusion is an updated overview of PSMSL and its data sets. This paper is now the definitive article for citation of the PSMSL data set:

Holgate, S.J; Matthews, A.; Woodworth, P.L.; Rickards, L.J.; Tamisiea, M.E.; Bradshaw, E.; Foden, P.R.; Gordon, K.M.; Jevrejeva, S. & Pugh, J., "New Data Systems and Products at the Permanent Service for Mean Sea Level" *Journal of Coastal Research*, 2013, Volume 29, Issue 3: pp. 493 – 504.
doi: http://dx.doi.org/10.2112/JCOASTRES-D-12-00175.1

In order to assess the wider usage of the PSMSL data set, a search of the scientific literature for the year 2012 was carried out. The result is that 61 papers have been published which have used the PSMSL data set.

PSMSL has also contributed to the IPCC Fifth Assessment Report with Dr Svetlana Jevrejeva a lead author for Working Group I, Prof. Philip Woodworth a review editor and other PSMSL staff also contributing.

9. Summary and forward look

It can be seen that PSMSL continues to be active with regard to workshops/conferences and with data acquisition and analysis. The functions provided by the PSMSL are in as much demand as ever and new products continue to be developed. Future plans include:

- Improved integration of the mean sea level data set with higher frequency data and improving the quality of accompanying metadata;
- Keeping contact with data suppliers (the trend being to acquire data from websites rather than direct supply) and ensuring that data made available in real-time are also contributed to PSMSL;
- Inclusion of information on uncertainties/errors in the tide gauge data;
- Addition of bottom pressure record section and data to the PSMSL web-site;
- Redevelopment of capacity building/training material.

Particular thanks as usual go to PSMSL staff and to colleagues at the National Oceanography Centre and British Oceanographic Data Centre who contribute part of their time to PSMSL activities.