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The Global Sea Level Observing System

IMPLEMENTATION PLAN

2012

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GLOBAL SEA-LEVEL OBSERVING SYSTEM (GLOSS)

IMPLEMENTATION PLAN – 2012

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This 2012 GLOSS Implementation Plan has been developed from discussions at the 11th and 12th session of the GLOSS Group of Experts (13-15 May 2009, and 9-11 November 2011). The plan is an update and builds on the first and second GLOSS Implementation Plan (IOC Technical Series No 35 and No 50).

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EXECUTIVE SUMMARY

The Global Sea-level Observing System (GLOSS) was established by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1985 to provide oversight and coordination for global and regional sea-level networks in support of scientific research. The first GLOSS Implementation Plan (GIP) in 1990 established the GLOSS Core Network (GCN) of ~300 tide gauges distributed around the world, technical standards for GLOSS tide gauge stations, as well as the basic terms and obligations for Member States participating in GLOSS. The second GIP in 1997 expanded the GLOSS programme to include sub-networks focused on long historical records suitable for the detection of long-term sea-level trends and accelerations (GLOSS-LTT), a calibration network for satellite altimetry (GLOSS-ALT), and a network suitable for monitoring aspects of the global ocean circulation (GLOSS-OC). In addition, a strategy for integrating Global Positioning System (GPS) into monitoring of land levels at GLOSS tide gauges was developed.

The focus of the GIP 2012 remains the GCN and the datasets that result from this network. The new plan calls for two significant upgrades to the GCN motivated by scientific and operational requirements:

1) all GCN stations are required to report data in near-real time, which will be tracked at a Sea-level Station Monitoring Facility. This will involve upgrades in power, data acquisition platforms, and communication packages; however, these upgrades are cost-effective in terms of the benefits that a real-time system will provide for ocean monitoring and improved station performance due to early detection of station malfunctions;
2) continuous measurements of the Global Navigation Satellite System (GNSS), in particular the U.S. Global Positioning System (GPS), the Russian GLONASS, or the newly established European GALILEO, or equivalent systems, in the vicinity of the tide gauge benchmark (TGBM) are required for all GCN stations. This upgrade will support satellite altimetry calibration and research efforts aimed at determining geocentric global sea-level rise rates as well as regional changes in sea level. Most relevant, vertical land movements can significantly alter the rates of sea-level rise expected from the sole climatic contributions of ocean thermal expansion and land-based ice melting, possibly magnifying the impacts of sea-level rise on the coast. In many cases, this requirement can be met by taking advantage of existing GNSS receivers maintained by other groups, as long as a precise geodetic tie to the GCN tide gauge can be made using, e.g. conventional levelling.

The organization of the plan is as follows. An overview of the GLOSS programme (chapter 1) and a brief summary of the uses of tide gauge data (chapter 2) are presented. The current status of the GLOSS programme is considered (chapter 3), followed by a discussion of the sea-level monitoring requirements raised by advisory groups and panels (chapter 4), as well as a self-assessment based on specific research and operational applications (chapter 5). These requirements are used to develop implementation goals for the GLOSS networks and data centres (chapter 6). Minor modifications are proposed for the administrative structure of GLOSS aimed at providing improved oversight of the implementation plan (chapter 7). The success of the plan depends critically on the participation of Member States, whose obligations are summarized (chapter 8). The successful Training, Education and Mutual Assistance programmes that have been a corner stone of GLOSS will be continued to help meet implementation requirements (chapter 9). Additional technical and programmatic details are included in a set of appendices.

RÉSUMÉ EXÉCUTIF

Le Système mondial d'observation du niveau de la mer (GLOSS) a été créé par la Commission océanographique intergouvernementale (COI) de l'Organisation des Nations Unies pour l'éducation, la science et la culture (UNESCO) en 1985. Sa mission consiste à superviser et coordonner les réseaux régionaux et mondiaux d'observation du niveau de la mer afin de soutenir la recherche scientifique. En 1990, le premier Plan de mise en œuvre du GLOSS a donné lieu à la création du réseau de base du GLOSS (GCN), constitué d'environ 300 marégraphes répartis partout dans le monde, et a fixé les normes techniques des stations marégraphiques du Système ainsi que les conditions et obligations fondamentales à respecter par les États y participant. En 1997, le deuxième Plan de mise en œuvre du GLOSS a élargi le programme pour y intégrer des réseaux secondaires axés sur l'étude d'enregistrements historiques de longue durée permettant la détection des tendances à long terme de l'évolution du niveau de la mer et de ses accélérations (GLOSS-LTT), la calibration des altimètres satellitaires (GLOSS-ALT) et la surveillance de la circulation générale des océans (GLOSS-OC). En outre, une stratégie d'intégration du Système de positionnement global (GPS) dans le dispositif de surveillance du niveau du sol à l'emplacement des marégraphes du GLOSS a été élaborée.

Le Plan de mise en œuvre de 2012 reste centré sur le GCN et les ensembles de données issus de ce réseau. Ce nouveau plan nécessite d'apporter au GNC deux grandes améliorations motivées par des exigences d'ordres scientifique et fonctionnel :

1. Toutes les stations du GCN doivent communiquer en temps quasi réel des données qui seront suivies par un dispositif de surveillance du niveau de la mer. Pour ce faire, une augmentation de puissance et une modernisation des plates-formes d'acquisition de données et des progiciels de communication seront nécessaires ; toutefois, ces mises à jour seront rentables compte tenu des avantages que présente un système en temps réel pour la surveillance des océans et pour le renforcement de l'efficacité des stations, étant donné que leurs dysfonctionnements seront rapidement détectés.
2. Des mesures effectuées en continu à proximité du niveau de référence des marégraphes (TGBM) par le Système global de navigation par satellite (GNSS), en particulier par le Système de positionnement global (GPS) américain, le GLONASS russe, le GALILEO européen, récemment créé, ou par d'autres systèmes équivalents, sont indispensables pour toutes les stations du GCN. Cette amélioration facilitera la calibration des altimètres satellitaires ainsi que les travaux de recherche visant à déterminer les taux globaux d'élévation du niveau de la mer par rapport au centre de la Terre et les évolutions du niveau de la mer à l'échelle régionale. Surtout, les variations du niveau du sol peuvent modifier de manière significative les taux d'élévation du niveau de la mer prévus en tenant uniquement compte des conséquences climatiques de la dilatation thermique des océans et de la fonte des glaces terrestres amplifiant peut-être l'impact de l'élévation du niveau de la mer sur les côtes. Dans bien des cas, utiliser les récepteurs GNSS déjà existants entretenus par d'autres organisations peut permettre de satisfaire cette exigence, pourvu qu'un lien géodésique précis puisse être établi avec les marégraphes à l'aide d'une technique classique de nivellement par exemple.

Le plan s'organise comme suit. Le chapitre premier donne d'abord une vue d'ensemble du programme GLOSS, puis le chapitre 2 présente un résumé succinct des différentes utilisations des données marégraphiques. L'état actuel d'avancement du programme GLOSS est ensuite abordé au chapitre 3, puis le chapitre 4 évoque le débat sur les exigences en matière de surveillance du niveau de la mer, posées par des groupes et comités consultatifs, tandis que le chapitre 5 constitue une auto-évaluation se posant sur des recherches spécifiques et des applications opérationnelles. Ces exigences servent à élaborer des objectifs de mise en œuvre pour les réseaux et centres de données du GLOSS, comme le montre le chapitre 6. De légères modifications de la structure administrative du GLOSS sont ensuite proposées au chapitre 7 afin d'améliorer la supervision du plan de mise en œuvre. Le succès du plan est largement tributaire de la participation des États membres, dont les obligations sont résumées au chapitre 8. Le chapitre 9 porte sur les programmes réussis de formation, d'enseignement et d'assistance mutuelle, qui constituent une pierre angulaire du GLOSS et vont être reconduits afin d'aider à répondre aux impératifs de mise en œuvre. Enfin, un ensemble d'appendices contient des détails supplémentaires relatifs aux techniques et aux programmes.

SINOPSIS

El Sistema Mundial de Observación del Nivel del Mar (GLOSS) fue establecido en 1985 por la Comisión Oceanográfica Intergubernamental (COI) de la Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura (UNESCO) a fin de que supervisara y coordinara las redes mundiales y regionales de medición del nivel del mar para respaldar a las investigaciones científicas. De conformidad con el primer Plan de Ejecución del GLOSS elaborado en 1990 se estableció la Red Básica del GLOSS, compuesta por unos 300 mareómetros distribuidos en todo el mundo, y se definieron normas técnicas para las estaciones mareográficas del GLOSS así como las condiciones y obligaciones básicas para los Estados Miembros participantes en el GLOSS. El segundo Plan de Ejecución, en 1997, amplió el programa del GLOSS para incluir redes secundarias centradas en registros históricos de larga duración adecuados para la detección de las tendencias a largo plazo de la evolución del nivel del mar y sus aceleraciones (GLOSS-LTT), una red de calibración de altímetros de satélites (GLOSS-ALT), y una red de observación de la circulación oceánica mundial (GLOSS-OC). Además, se formuló una estrategia para integrar el Sistema Mundial de Localización (GPS) en la vigilancia del nivel del suelo en los sitios en que se encuentran los mareómetros del GLOSS.

Las prioridades del Plan de Ejecución de 2012 siguen siendo la Red Básica del GLOSS y los conjuntos de datos producidos por esa red. En el nuevo Plan se aboga por dos importantes mejoras de la Red Básica, que obedecen a necesidades científicas y operacionales:

1) todas las estaciones de la Red Básica deben comunicar datos en tiempo casi real, de cuyo seguimiento se encargará un Servicio de vigilancia del nivel del mar. Esto supone mejoras en términos de potencia, plataformas de adquisición de datos y programas informáticos de comunicación; ahora bien, estas mejoras serán rentables habida cuenta de las ventajas que ofrecerá un sistema en tiempo real para la vigilancia de los océanos y un mejor desempeño de las estaciones gracias a la detección temprana de sus disfunciones;
2) para todas las estaciones de la Red Básica se necesitan mediciones continuas efectuadas en las cercanías de la marca de referencia para los mareómetros (TGBM) por el Sistema Mundial de Navegación por Satélite (GSNS), en particular el Sistema Mundial de Localización de los Estados Unidos de América, el GLONASS ruso o el sistema europeo recientemente establecido, GALILEO, o sistemas equivalentes. Esta mejora facilitará la calibración de los altímetros de satélites y las actividades de investigación destinadas a determinar las tasas mundiales de elevación geocéntrica del nivel del mar así como la evolución del nivel del mar a escala regional. Además, los movimientos verticales del suelo pueden alterar considerablemente las tasas de aumento del nivel del mar previstas solamente a partir de las consecuencias climáticas de la dilatación térmica de los océanos y el deshielo en tierra, con la posibilidad de que se amplifiquen los efectos de la elevación del nivel del mar sobre las costas. En muchos casos, esta cuestión puede resolverse aprovechando los receptores existentes del GSNS mantenidos por otros organismos, siempre que pueda efectuarse una conexión geodésica precisa con los mareómetros de la Red Básica, utilizando, por ejemplo, la técnica tradicional de la nivelación.

La organización del Plan es la siguiente: se presenta un panorama del Programa del GLOSS (capítulo 1) y un breve resumen de las utilizaciones de los datos mareográficos (capítulo 2). Se analiza la situación actual del Programa del GLOSS (capítulo 3), y se examinan las necesidades en materia de vigilancia del nivel del mar planteadas por grupos asesores y grupos de expertos (capítulo 4), así como una autoevaluación basada en aplicaciones científicas y operacionales concretas (capítulo 5). Estas necesidades se utilizan para definir los objetivos de las actividades de las redes y centros de datos del GLOSS (capítulo 6). Se proponen modificaciones menores de la estructura administrativa del GLOSS, con objeto de mejorar la supervisión del plan de ejecución (capítulo 7). Para que el plan se lleve a cabo satisfactoriamente es indispensable la participación de los Estados Miembros, cuyas obligaciones se sintetizan (capítulo 8). Proseguirán los fructuosos programas de Capacitación, Educación y Asistencia Mutua que han sido una piedra angular del GLOSS y ayudarán a atender las necesidades vinculadas a la ejecución de las actividades (capítulo 9). En una serie de apéndices figuran detalles técnicos y programáticos adicionales.

РАБОЧЕЕ РЕЗЮМЕ

Глобальная система наблюдений за уровнем моря (ГЛОСС) была создана Межправительственной океанографической комиссией (МОК) Организации Объединенных Наций по вопросам образования, науки и культуры (ЮНЕСКО) в 1985 г. для осуществления общего контроля и координации глобальных и региональных систем наблюдений за уровнем моря в поддержку научных исследований. В соответствии с первым Планом осуществления ГЛОСС (ПОГ) 1990 г. были определены: Основная сеть ГЛОСС (ОСГ), состоящая примерно из 300 мареографов, развернутых по всему миру; технические стандарты для станций с мареографами ГЛОСС; базовые условия и обязательства государств-членов, участвующих в ГЛОСС. В соответствии со вторым ПОГ (1997 г.) программой ГЛОСС также были охвачены: подсети, занимающиеся длинными сериями исторических данных наблюдений, предназначенными для определения долгосрочных тенденций, связанных с уровнем моря, и их ускорения (ГЛОСС-ДСТ), калибровочная сеть для спутниковой альтиметрии (ГЛОСС-АЛЬТ) и сеть для мониторинга ряда аспектов циркуляции Мирового океана (ГЛОСС-ЦО). Кроме того, была разработана стратегия использования Глобальной системы позиционирования (GPS) для мониторинга высот земной поверхности у мареографов ГЛОСС.

В центре внимания ПОГ 2012 г. остаются ОСГ и наборы данных, которые обеспечивает эта сеть. Этот новый план предусматривает существенное усовершенствование ОСГ по двум направлениям в свете научных и оперативных потребностей:

1) От всех станций ОСГ требуется представление данных в режиме времени, близком к реальному; эти данные будут отслеживаться в рамках механизма мониторинга станций определения уровня моря. Это потребует мер усовершенствований в плане энергообеспечения, платформ получения данных и коммуникационных пакетов, однако эти меры будут экономичными тому, что система данных в реальном режиме времени принесет пользу мониторингу океана, а также благодаря повышению эффективности станций в результате быстрого обнаружения неполадок в их работе;

2) Для всех станций ОСГ необходимы постоянные измерения, проводимые глобальной навигационной спутниковой системой (ГНСС), в частности, американской Глобальной системой позиционирования (GPS), российской системой ГЛОНАСС, новой европейской системой GALILEO или аналогичной системой в непосредственной близости от реперов мареографов (ТБГМ). Такое усовершенствование будет содействовать настройке спутниковой альтиметрии и исследованиям, направленным на определение темпов геоцентрического глобального повышения уровня моря, а также региональных изменений уровня моря. Необходимо иметь в виду, что вертикальные движения земной массы способны существенно изменять темпы повышения уровня моря, прогнозируемые исключительно на основе теплового расширения океана под воздействием климата и таяния ледников на суше, и могут заметно увеличить последствия повышения уровня моря для прибрежных районов. Во многих случаях удовлетворение этих потребностей можно обеспечить путем использования существующих устройств, которые принимают данные ГНСС и эксплуатацией которых занимаются другие группы, при условии возможности точной геодезической привязки к мареографу ОСГ, например, путем обычной нивелировки.

План имеет следующее содержание. Сначала представлены обзор ГЛОСС (глава 1) и краткое изложение форм использования данных мареографов (глава 2). В главе 3 рассматривается сегодняшний статус программы ГЛОСС, глава 4 посвящена потребностям в мониторинге уровня моря, выявленным различными консультативными группами, в главе 5 содержится самооценка работы, основывающаяся на конкретных оперативных и научных программах. На базе потребностей ГЛОСС разработаны ее цели, которые должны реализовываться ее сетями и центрами данных (глава 6). В главе 7 предлагаются незначительные модификации административной структуры ГЛОСС, направленные на улучшение общего надзора за планом ее осуществления. Его успех в решающей степени зависит от участия государств-членов, чьи обязательства излагаются в главе 8. В главе 9 рассматриваются успешные программы подготовки кадров, образования и взаимопомощи, которые стали краеугольным камнем ГЛОСС и продолжают содействовать удовлетворению потребностей, связанных с ее осуществлением. В приложениях приводятся дополнительные технические детали и подробности, касающиеся программы.

ملخص تنفيذي

أنشأت اللجنة الدولية الحكومية لعلوم المحيطات (IOC) التابعة لمنظمة الأمم المتحدة للتربية والعلم والثقافة (اليونسكو) النظام العالمي لرصد مستوى سطح البحر (GLOSS) في عام 1985 لتوفير خدمات الإشراف والتنسيق فيما يخص الشبكات العالمية والإقليمية المعنية برصد مستوى سطح البحر بغية دعم البحوث العلمية. ونصت خطة التنفيذ الأولى للنظام العالمي لرصد مستوى سطح البحر (GLOSS) التي اعتمدت في عام 1990 على إنشاء الشبكة الأساسية (GCN) للنظام العالمي المذكور، وهي شبكة تضم حوالي 300 محطة لقياس مستوى المد، موزعة على مناطق العالم كافة. كما حددت خطة عام 1990 المعايير التقنية لمحطات قياس مستوى المد التابعة للنظام العالمي لرصد مستوى سطح البحر (GLOSS)، وكذلك الشروط والواجبات الأساسية الخاصة بالدول الأعضاء المشاركة في هذا النظام. أما خطة التنفيذ الثانية للنظام العالمي لرصد مستوى سطح البحر (GLOSS) التي اعتمدت في عام 1997، فوسعت نطاق برنامج النظام العالمي بحيث يشمل الشبكات الفرعية التي تركز على البيانات التاريخية الطويلة التي تتيح الكشف عن الاتجاهات المتعلقة بتغير مستوى سطح البحر ومدى تسارع هذا التغير في الأجل الطويل (GLOSS-LTT)، فضلاً عن شبكة لمعايرة أجهزة القياس الساتلي للارتفاعات (GLOSS-ALT)، وشبكة تتيح رصد جوانب دوران المحيطات على الصعيد العالمي (GLOSS-OC). وتم أيضاً إعداد استراتيجية لاستخدام النظام العالمي لتحديد المواقع (GPS) لرصد مستوى سطح الأراض في محطات رصد مستوى المد التابعة للنظام العالمي لرصد مستوى سطح البحر (GLOSS).

وتركز خطة تنفيذ النظام العالمي لرصد مستوى سطح البحر (GLOSS) لعام 2012 على الشبكة الأساسية (GCN) التابعة للنظام العالمي ومجموعات البيانات التي تنتجها هذه الشبكة. وتدعو الخطة الجديدة إلى إدخال تحسينات مهمة على الشبكة الأساسية (GCN) استجابة لعدد من المتطلبات العلمية والتشغيلية. وتتمحور هذه التحسينات حول المسألتين التاليتين:

(١) يتعين على جميع المحطات التابعة للشبكة الأساسية (GCN) أن توفر البيانات بصورة شبه آنية، مع الإشارة إلى أن مرفقا معنياً بأنشطة الرصد في محطات رصد مستوى سطح البحر سيتولى تتبع هذه البيانات. ويفترض ذلك تعزيز الطاقة وتحسين المنصات المخصصة للحصول على البيانات وعمليات الاتصالات. ولكن تجدر الإشارة إلى أن هذه التحسينات تعتبر فعالة من حيث التكاليف بالنظر إلى ما ستقدمه النظم التي تعمل بصورة آنية من فوائد فيما يخص عمليات رصد المحيطات، وإلى التحسن الذي سيشهده أداء المحطات نتيجة للكشف المبكر عن أوجه الخلل المرتبطة بعمل المحطات؛

(٢) ن عمليات القياس المتواصلة الخاصة بالنظام العالمي لاستغلال السواتل لأغراض الملاحة (GNSS)، ولا سيما النظام العالمي لتحديد المواقع (GPS) في الولايات المتحدة الأمريكية، والنظام العالمي لاستغلال السوات لأغراض الملاحة في الاتحاد الروسي (GLONASS)، ونظام غاليليو لاستغلال السواتل لإغراض الملاحة الذي أنشئ حديثاً في الاتحاد الأوروبي (GALILEO)، أو النظم المماثلة، بالقرب من العلامة المعيارية لقياس مستوى المد (TGBM)، مطلوبة لجميع المحطات التابعة للشبكة الأساسية (GCN) للنظام العالمي لرصد مستوى سطح البحر (GLOSS). وسيتيح هذا التحديث دعم عملية معايرة أجهزة القياس الساتلي للارتفاعات والجهود البحثية الرامية الى تحديد معدلات ارتفاع مستوى سطح البحر بالنسبة إلى مركز الأرض على المستوى العالمي، وكذلك التغيرات الإقليمية في مستوى سطح البحر. والأهم من ذلك هو أن التحركات العمودية للأراضي يمكن أن تحدث تغييراً كبيراً في معدلات ارتفاع مستوى سطح البحر الناجم عن الظاهرتين المناخيتين المتمثلتين في التمدد الحراري للمحيطات وذوبان الجليد القائم على سطح الأرض، مما قد يؤدي إلى تعظيم آثار ارتفاع مستوى سطح البحر على السواحل. ويمكن في الكثير من الحالات معالجة هذا الموضوع عن طريق الاستفادة من أجهزة الاستقبال القائمة، التابعة للنظام العالمي لاستغلال السواتل لأغراض الملاحة (GNSS) والتي تديرها جهات أخري، ما دام من الممكن إقامة روابط جيوديسية دقيقة مع أجهزة قياس مستوى المد في الشبكة الأساسية (GCN) النظام العالمي لرصد مستوى سطح البحر (GLOSS)، وذلك عن طريق استخدام الطريقة التقليدية في قياس المناسيب على سبيل المثال.

وتنظَّم بنية خطة التنفيذ على النحو التالي: يجري تقديم لمحة عامة عن برنامج النظام العالمي لرصد مستوى سطح البحر (GLOSS) (الفصل ١) وملخص مقتضب لأوجه استخدام بيانات قياس مستوى المد (الفصل ٢). ثم يُنظر في الوضع الراهن لبرنامج النظام العالمي لرصد مستوى سطح البحر (GLOSS) (الفصل ٣)، وتلي ذلك مناقشة تتناول متطلبات رصد مستوى سطح البحر التي حددتها الأفرقة والهيئات الاستشارية (الفصل ٤)، ثم يُقدم تقييم ذاتي يستند إلى بحوث وتطبيقات تشغيلية محددة (الفصل ٥). ويجري استخدام هذه المتطلبات لتحديد أهداف تنفيذية خاصة بالشبكات ومراكز البيانات التابعة للنظام العالمي لرصد مستوى سطح البحر (GLOSS) (الفصل ٦). ثم يُقترح إدراج تعديلات طفيفة في البنية الإدارية للنظام العالمي لرصد مستوى سطح البحر (GLOSS) بغية تحسين علمية الإشراف على تطبيق خطة التنفيذ (الفصل ٧). ويعتمد نجاح الخطة اعتماداً حاسماً على مشاركة الدول الأعضاء التي يُعرض ملخص لالتزاماتها (الفصل ٨). أما البرامج الناجحة الخاصة بالتدريب والتعليم والمساعدة المتبادلة، التي كانت حجر الزاوية في النظام العالمي لرصد مستوى سطح البحر (GLOSS)، فسوف تتواصل بغية ضمان الوفاء بمتطلبات التنفيذ (الفصل ٩). وتتضمن الخطة أيضاً ذيولاً تقدِّم المزيد من التفاصيل التقنية والبرنامجية.

概要

全球海平面观测系统（GLOSS）由联合国教育、科学及文化组织（UNESCO）政府间海洋学委员会（IOC）于1985年创立，目的是配合科研需要，管理和协调全球及区域海平面网络。1990年，第一个GLOSS全球实施方案（GIP）建立了由分布在世界各地约300个验潮仪组成的GLOSS核心网络（GCN），确定了GLOSS验潮站的技术标准以及参与全球海平面观测系统的会员国的基本条款和义务。1997年第二个全球实施方案扩大了GLOSS计划的范围，纳入了侧重适合于监测海平面长期趋势和加速度（GLOSS-LTT）的长期历史记录子网络、卫星测高（GLOSS-ALT）校准网络以及适合监测全球大洋环流（GLOSS-OC）情况的网络。此外，还制定了有关战略，将全球定位系统（GPS）纳入GLOSS验潮仪陆地高度的监测。

2012年全球实施方案的重点仍然是GLOSS核心网络和来自该网络的数据集。从科学和业务化的要求出发，新方案要求对GLOSS核心网络进行两大升级：

1) 所有GCN站均需以近实时的方式报告数据，由海平面监测设施跟踪。这就需要对供电、数据采集平台和通信程序包进行升级。但这种升级是具有成本效益的，因为实时系统对于海洋观测大有好处而且通过及早发现站点运转故障还可提高站点的运行性能；
2) 所有GCN站均需要有全球卫星导航系统（GNSS），特别是美国的全球定位系统（GPS）、俄罗斯的GLONASS系统或新创建的欧洲伽利略系统或其他类似系统在验潮基准点（TGBM）附近的连续测量。这一升级将配合卫星测高校准以及旨在确定相对于地心的全球海平面上升速度以及地区层面海平面变化的研究工作。最相关的、纵向陆地运动可在很大程度上改变所预计的仅仅由海洋热膨胀和陆地冰雪融化的气候因素而造成的海平面上升，并可能加大海平面上升对海岸的影响。在许多情况下，只要能为GCN验潮仪确定准确的大地连测（比如采用常规水准测量），便可利用由其他小组维护的现有全球导航卫星系统接收器来满足这一要求。

方案的结构如下：全球海平面观测系统方案概览（第1章）和验潮数据用途的简要介绍（第2章）；探讨GLOSS方案的现状（第3章），然后讨论咨询小组和专家组提出的海平面监测要求（第4章）并根据特定的研究和业务化应用做出自我评估（第5章）；参照这些要求来制定GLOSS网络和数据中心的实施目标（第6章）；对GLOSS的行政管理结构提出微调建议，以便改进对方案实施的监督（第7章）；方案成功与否完全决于会员国的参与，对会员国义务的概述（第8章）；成功的培训、教育和互助计划一直是GLOSS项目的基石，将继续开展这些计划，帮助满足实施要求（第9章）。另外，一系列的附录中还列出了详细的技术性资料和有关计划的资料。

CHAPTER 1

OVERVIEW OF GLOSS

Tide gauge observations provide information on a wide spectrum of oceanographic processes, ranging from surface and internal tides to surface currents and ocean eddies. In situ observations of sea level also are needed to monitor and understand global sea-level rise, as well as interannual to decadal sea-level variations, which provide insight into ocean circulation changes on climate time scales. In addition, sea-level observations are used to examine extreme events associated with tsunamis, storm surges, and other factors leading to short-term coastal inundation. Given the multi-dimensional, multi-purpose nature of tide gauge observations, there is considerable benefit to be gained from well-designed sea-level observing networks that support a broad research and operational user base.

The Global Sea-Level Observing System (GLOSS) was established by the Intergovernmental Oceanographic Commission (IOC) in 1985 to provide such a service. GLOSS provides oversight and coordination for global and regional sea-level networks in support of, and with direction from, the oceanographic and climate research communities. GLOSS remains under the auspices of the IOC and is one of the observing components under the World Meteorological Organization (WMO)/IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM). GLOSS relies on the participation of tide gauge operators to maintain tide gauge stations to a research quality standard. At present nearly 70 nations participate in the GLOSS programme.

GLOSS contributes to the Global Ocean Observing System (GOOS), particularly its climate, coastal and operational service modules, through the progressive development of the sea-level measurement network, data exchange and collection systems, and preparation of sea-level products for various user groups. More generally, GLOSS is fully supported by the United Nations Framework Convention on Climate Change, of which Article 5 (b) calls upon the Parties to the Convention to 'support international and intergovernmental efforts to strengthen systematic observation and national scientific and technical research capacities and capabilities, particularly in developing countries, and to promote access to, and the exchange of, data and analyses thereof obtained from areas beyond national jurisdiction'.

Various tide gauges networks have contributed to GLOSS, each with a different focus and each changing over time as research priorities evolve. The main component is the GLOSS Core Network (GCN[1]), a global set of ~300 tide gauge stations that serves as the backbone of the global in situ sea-level network (Appendix A). GCN gauges were allocated to each island or group of islands at intervals not closer than 500 km, and along continental coasts at intervals generally not less than 1000 km, preference being given to islands to maximise the exposure to the open ocean. The establishment of the GCN was also meant to enhance the data holdings of the Permanent Service for Mean Sea Level (PSMSL[2]), which is the preeminent global data bank for long-term sea-level change information from tide gauges [Woodworth and Player, 2003]. Other GLOSS designated networks have focused on Long Term Trends (LTT), the stability of satellite altimeter time series (ALT) [Mitchum et al.,

1 www.gloss-sealevel.org
2 www.psmsl.org

2010], as well as various aspects of ocean circulation (OC) [Woodworth et al., 2002]. In support of the World Climate Research Programme (WCRP), GLOSS designated 170 stations to serve as the sea-level network for the Global Climate Observing System (GCOS).

Tide gauge data from the GLOSS networks are assembled and archived at two data centres. The British Oceanographic Data Centre (BODC[3]), in collaboration with the PSMSL, is responsible for delayed mode datasets and for ensuring that GLOSS station data ultimately are incorporated into the PSMSL. The University of Hawaii Sea Level Center (UHSLC[4]) collects, assesses, and distributes fast delivery data, which are used extensively for satellite altimeter monitoring. The UHSLC also collaborates with the National Oceanic and Atmospheric Administration (NOAA) National Oceanographic Data Center (NODC) to maintain the Joint Archive for Sea Level (JASL). The database consists of research quality hourly and daily values for GLOSS and non-GLOSS stations. The GLOSS data centres have contributed data assembly support for international scientific programmes such as TOGA (Tropical Ocean Global Atmospheres), WOCE (World Ocean Circulation Experiment), CLIVAR (Climate Variability and Predictability), and GODAE (Global Ocean Data Assimilation Experiment).

Geocentric coordinates of TGBMs are required if the tide gauge measurements are to be located within the same global geodetic reference frame. To derive such coordinates and to define land motion at tide gauges, GLOSS has since the 1990s collaborated with the International GPS Service for Geodynamics (IGS, today International GNSS Service) through its GPS Tide Gauge Benchmark Monitoring Project (TIGA) [Schöne et al., 2009]. To derive geocentric sea-level estimates, provide robust projections of sea-level change and subsequent assessment of its actual impact along the coasts, the vertical position of the tide gauges (or their benchmarks) must be known to high precision in a long-term stable geocentric reference frame like the International Terrestrial Reference Frame (ITRF) [Altamimi et al., 2011]. The main advantage is to convert the relative sea-level readings to a time series of land level referred to the centre of the Earth. This allows for altimeter calibration, the establishment of a World Height Datum for surveying and geodetic purposes (sea level in many countries having been used as the effective vertical datum), the estimation of absolute ocean currents between different tide gauge locations, or climate related studies of sea-level change [Plag and Pearlman, 2009]. The combination of the vertical displacement and sea-level time series also supports studies of global isostatic adjustment (GIA) and tectonics. Geodetic technologies, especially GNSS in continuous mode, have improved the accuracy of vertical land motion measurements at tide gauges, whether due to GIA or to other land motion processes. Wöppelmann et al. [2009] showed that using a global-scale, fully consistent processing strategy throughout the entire GNSS data span considerably reduced technique errors and analysis artifacts, providing useful vertical velocities to account for land motions in tide gauge records.

Tide gauges have been used to monitor the stability of satellite altimeter sea surface height observations. These methods were first proposed based on GEOSAT data and were fully developed and proven during the TOPEX/Poseidon mission. (See Mitchum [2000] for a description of the modern formalism). In recent years the methods have been generalized and applied to all present altimeter missions, and the drift estimation calculations have become quasioperational. At present it is possible to detect globally uniform drift in the altimetric time series at the order of a few tenths of a millimeter per year.

GLOSS historically has been a supporter of tsunami monitoring as many GLOSS stations have provided high frequency data in near real-time to regional warning centres. GLOSS stations provided some of the only near real-time observations available during the devastating 2004 Indian Ocean tsunami [Merrifield et al., 2005], and the IOC through GLOSS has overseen the development of the water level component of the Indian Ocean Tsunami Warning System (IOTWS) since 2005. GLOSS stations are essential components of the Pacific Tsunami Warning System (PTWS) as well as other regional tsunami networks in the Caribbean and the NE Atlantic, and Mediterranean.

The primary motivation for the GLOSS programme stems from the desire to monitor, and thereby eventually to contribute to an understanding of, sea-level change and variability over a broad range of time and space scales. The scientific requirements that inform and shape the practices promoted by the GLOSS programme are derived from the recommendations of international scientific studies, such as the Intergovernmental Panel on Climate Change (IPCC), from the observational requirements of various parts of the WCRP, and from the frequently stated concerns of many States that parts of their coastlines are potentially threatened by significant sea-level change.

3 www.bodc.ac.uk
4 uhslc.soest.hawaii.edu

Given the significant advances in ocean observing systems and observing technologies, and the growing importance of the sea-level observing system for an evolving user base, it is timely to reassess the specific goals of the GLOSS programme, and to redefine the implementation strategy needed to reach these goals. Here an updated implementation plan is provided that builds on previous plans put forward in 1990 and 1997. Many of the elements of the previous plans, as well as the technical requirements and strategies for sea-level observing outlined in the IOC Manual on Sea-Level Measurement and Interpretation, Vol. IV [IOC, 2006] and earlier volumes, remain relevant and references will be made to these documents rather than repeat that information here. This document focuses primarily on the current scientific and operational motivations that define the requirements for sea-level monitoring, and the specific implementation strategies needed to meet these requirements. The biggest changes since the 1997 plan involve new requirements for land motion monitoring in support of climate change studies, and enhanced data transmission rates in support of tsunami and storm surge applications.

SCIENTIFIC AND PRACTICAL APPLICATIONS OF SEA-LEVEL INFORMATION

Sea level is one of the most useful oceanographic parameters. Sea-level data are vital to scientists for studies of fluctuations in major ocean currents and global climate change, to engineers for the design of coastal installations, to a large community engaged in what is now called 'operational oceanography' (e.g. the provision of flood warnings from storm surges or tsunamis), and in local applications such as provision of tide tables for port operations. Some of these different applications are described briefly below; for more details of these examples one might read Pugh [1987, 2004].

The applications can differ in their requirements for accuracy, frequency and latency of sea-level data. However, the IOC Manuals [IOC, 2006] have made it clear that a suitable selection of gauge and telemetry hardware can be made for any particular location, such that the requirements of all applications can be accommodated. As a consequence, the number of users of the sea-level data will be as large as possible, and the stakeholder support for the long-term maintenance of the installation will be maximised. Moreover, there could even be cost savings arising from the use of a smaller number of high-quality sensors suitable for all applications, instead of deployment of multiple instruments for separate purposes.

2.1 SEA-LEVEL RISE, OCEAN CIRCULATION AND SATELLITE ALTIMETER CALIBRATION

Global sea level is believed to be rising at a rate of approximately 3 mm/year since 1993, although there are large regional departures from this global-average value [Bindoff et al., 2007]. A sea-level record from a single gauge can barely be expected to show such an increase in a single year (the accuracy of an annual mean of sea level from a scientific-quality gauge being centimetric or, in some cases, subcentimetric). However, over an extended period the gauge should be capable of demonstrating whether the global-average rise applies to any particular location. Therefore, requirements for data from such a gauge are concerned with accuracy (i.e. datum control), rather than frequency and latency.

The PSMSL and BODC hold what is called 'delayed mode' data, which in principle has been quality controlled, and is the most suitable to a wide range of scientific research, of which sea-level rise is one example. Once again, in these applications accuracy is the major consideration.

Sea-level data are also used by oceanographers to monitor fluctuations in ocean currents, as changes in currents modify the topography of the sea surface. Particularly important gauges are those which come in pairs on two sides of straits, such that flows through these restricted passages can be monitored, the spatial and temporal sampling of the alternative sea-level measurement technique of satellite altimetry not being optimal for such monitoring. Another example includes the measurement of sea level for coastal upwelling monitoring [Aman and Testut, 2003]. Requirements for high accuracy are as important in these oceanographic applications as for sea-level rise, but with additional requirements for near-real time data reporting (data to a centre within e.g., one hour).

Near-real time (or 'fast') reporting from gauges of comparable high accuracy is also necessary if data are to be used in applications such as the calibration of space-based altimeters [Mitchum, 2000]. Such calibrations must be performed within a timescale comparable to the provision of altimeter data (e.g. days to weeks), if the calibrated altimetric product is to be useful to operational monitoring of the large-scale ocean circulation.

2.2 COASTAL ENGINEERING STUDIES

Estimates of the frequency of extreme coastal sea levels are required by engineers so as to design sea defences and other coastal infrastructure, and by insurance agencies to assess flood risk. Such studies require at least several years of delayed-mode sea-level data (depending on the technique used, see Pugh [1987], chapter 8) with hourly, or ideally more frequent, sampling. The data used in these applications should, as always, be as accurate as possible, although slightly lower accuracy standards could be tolerated.

2.3 NATIONAL AND LOCAL DATUMS

Historically, many national datum levels for land surveys have been based on measurements of mean sea level over some defined period. These levels are often used to define state and national boundaries, for example as specified in the United Nations Convention on the Law of the Sea. Low water levels are used as the datum for tidal predictions and for the datum level in hydrographic charts. To determine these datums one requires several years of data as for determination of extreme levels.

2.4 OPERATIONAL OCEANOGRAPHY

The floods in the UK and Netherlands of 1953 might be said to have marked the start of 'operational oceanography' in Europe. In the following years, expanded tide gauge networks were established and real-time telemetry was developed, such that information on surge levels across the continental shelf could be used in combination with tide-surge numerical models to provide flood warnings several days ahead. Nowadays, many countries have similar flood forecast schemes [Flather, 2000; Alvarez Fanjul et al., 2000; Woodworth and Horsburgh, 2011]. Near-real time sea-level data can also be assimilated into other types of ocean models, providing information on ecosystems and water quality. The requirements in these applications are lower for accuracy (perhaps several cm is adequate, i.e. comparable to or better than surge model precision), frequency of 1 hour or more frequent, and latency of typically within 1 hour (i.e. a shorter time than surge development). It is a regrettable fact that many major population centres in developing countries still do not possess effective warning; a list of the main schemes in each region is included in Table 7.1 of Woodworth and Horsburgh [2011].

A more extreme example of operational oceanography concerns tsunami monitoring. Following an alert of a possible tsunami based on seismic information, tide gauge data can be used to verify the existence of a real tsunami, or to cancel the alert in the event of no tsunami. The tide gauge data are necessarily of lower relevance to warnings in their own vicinity, rather than to locations further along the tsunami's path. Requirements in this example are less for accuracy and datum control rather than frequency (e.g. 20 second sampling) and especially latency. The latter has stimulated research into new methods for transmitting tide gauge information to centres as fast as possible (e.g. Holgate et al., [2008]) and the implementation of automatic tsunami detection algorithms [Pérez et al., 2009].

Another important requirement of the use of tide gauge data for assimilation into models or for warnings is the need to implement automatic quality control procedures in near-real time, in order to avoid erroneous values entering the operational systems. The GLOSS Quality Control document, based on previous European Sea-Level Service (ESEAS) work reflects this need. In Europe, a sea-level near-real time quality control product has been approved and implemented within the MyOcean project [Pérez et al., 2010; Pouliquen et al. 2011].

2.5 TIDE TABLES AND PORT OPERATIONS

Tide tables have been the major product of sea-level measurements since the first recordings in the 17th and 18th centuries [Cartwright, 1999]. They are used extensively by port operators, fishermen and indeed anyone who uses or enjoys the coast. Although in principle 18.6 years of data are needed to produce the best 'tidal constants' employed to make tidal predictions, adequate constants can be derived from one year of data or sometimes less. For example, tide tables have been amongst the first demonstrable products of the recent ODINAFRICA III project, which has included several new installations [Woodworth et al., 2007]. Long tide gauge records are also useful for monitoring changes in tidal constituents over time, due to both natural and human causes (e.g., dredging, harbour and coastal construction).

Nevertheless, port operations will always benefit from real-time display of sea level instead of, or alongside, tidal predictions. Consequently, port operations might also be considered part of operational oceanography. Similar observations may pertain to operation of sluices and barrages.

2.6 INTERACTIONS BETWEEN APPLICATIONS OF SEA-LEVEL DATA

It is important to emphasize that the uses of sea-level data for science and for practical purposes are interdependent. For example, knowledge of long-term relative sea-level rise needs to be input into the engineering design of coastal structures, many of which will have a lifetime of many decades or a century. Another example is that access to the real-time data needed for operational oceanography will tend to result eventually in higher quality delayed mode information, as faults can be identified and remedied immediately. Consequently, the point above can be repeated that a tide gauge installation is most efficiently installed and maintained if all applications are considered together.

In many of these applications the rapid exchange of reliable data, nationally, regionally and even globally, can increase the value of the work. This exchange of data and expertise is something which GLOSS can actively encourage.

STATUS OF GLOSS IN 2011

The status of the GCN has improved substantially in the last decade, primarily in terms of the increase in near real-time and fast delivery stations (Figure 1). Of the 290 stations in the GCN (as defined in 2010), 246 (85%) have provided data within the past five years to one of the GLOSS Data Centres.

Approximately 57% of the GCN stations have data provided in near real-time via the Global Telecommunication System (GTS) or the Internet. Transfer of quality-assured data in Fast Delivery mode (within ~1 month) occurs for 216 stations (67%). 122 stations have continuous GNSS and 26 stations have Doppler Orbitography Integrated by Satellite (DORIS) equipment at or near the tide gauge (see http://www.sonel.org/spip.php?page=cgps for a full list of GNSS and http://www.sonel.org/-Doris,26-.html?lang=en for DORIS stations at tide gauges).

Important contributions to GLOSS in the last decade have come from the development of regional densified sub-systems such as in the Mediterranean. This has benefitted from a contribution to the Mediterranean and Black Sea networks from the MedGLOSS project[5] of UNESCO/IOC and the Mediterranean Science Commission (CIESM). These activities overlap with and contribute to the NE Atlantic & Mediterranean Tsunami Warning System (NEAMTWS), developed by UNESCO/IOC, that has encouraged Member States to upgrade equipment for real time data provision.

Two regional components of the GCN that have undergone considerable improvement in recent years are the Indian Ocean/Southeast Asia region, and greater Africa. Tide gauge upgrades and new installations in the Indian Ocean have been carried out under the auspices of the IOTWS, with ongoing technical support and network coordination provided by GLOSS. More than 50 tide gauge stations are now reporting sea-level data in real time (Figure 2). Several countries have plans for further expansion of their national networks.

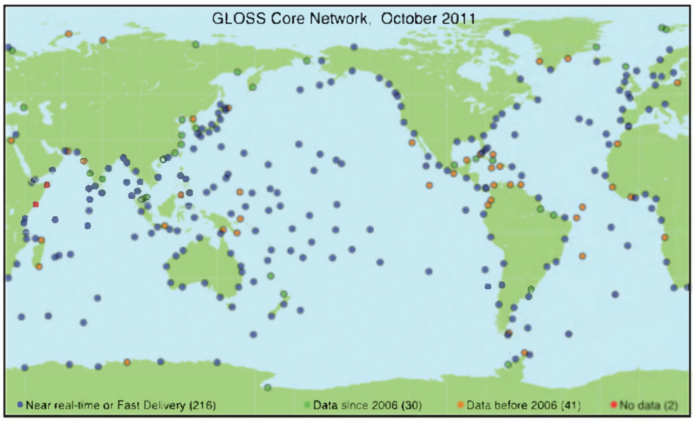

Figure 1*. Status of data reporting for sea-level stations in the GLOSS Core Network in 2011. 216 stations report in "Near real-time" or "Fast Delivery" modes (blue), with high frequency data (hourly or better reports) within ~1 hour to ~1 month of collection, respectively. Delayed mode data within 5 years (green, 30 stations) or greater (orange, 41 stations) include monthly averages provided to the Permanent Service for Mean Sea Level (PSMSL). Nearly all of the 216 near real-time or fast delivery stations also provide delayed mode data. Only 2 stations have not provided some form of data to a GLOSS Data Centre.*

Since 2003 through the combined efforts of the Ocean Data and Information Network for Africa (ODINAFRICA), the Government of Flanders (Belgium), the IOC, GLOSS, PSMSL, and national and international partners, significant progress has been made in improving the tide gauge network along the African continent and on nearby islands. Eleven new stations have been constructed and nearly 20 existing stations have undergone substantial upgrades to full operational status. Information on the network (equipment types and location, reports, training, etc.) is available on the African

[5] medgloss.ocean.org.il

Figure 2. *Sea-level network of the Indian Ocean Tsunami Warning System (IOTWS).*

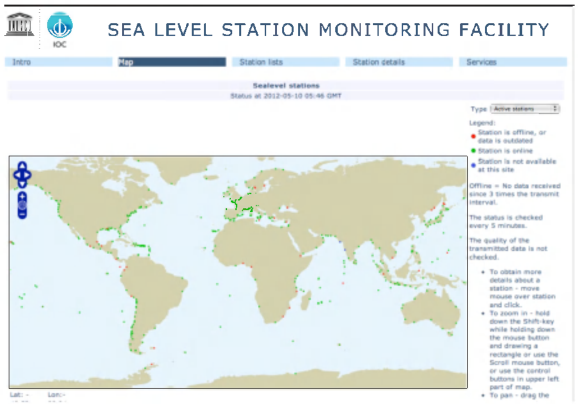

Figure 3. *Website of the IOC Sea-level Monitoring Facility maintained by the Flanders Marine Institute (http://www.ioc-sealevelmonitoring.org).*

Sea-Level Network website[6] and the Africa page of the GLOSS website[7], which also provide access to the raw 1 minute and quality controlled 15 minute data from the new sites.

To better assess the ongoing status of GLOSS real-time stations, a centralized network reporting system has been implemented. The IOC and the Flanders Marine Institute (VLIZ, Belgium) have developed a web-based global sea-level station monitoring service for viewing sea-level data received in real time from different network operators through a number of different communications channels (Figure 3). The particular aims of this service are to provide information about the operational status of global and regional networks of real-time sea-level stations, and to provide a display service for quick inspection of the raw data stream from individual stations. The service provides a global station monitoring service for real-time sea-level measuring stations in the GCN, and the networks under the regional tsunami warning systems in the Indian Ocean, North Eastern Atlantic and Mediterranean, Pacific and the Caribbean. The number of stations being tracked by the web-service has grown from about 25 stations at the end of 2007 to presently nearly 460 stations. The tracking tool is particularly useful for quickly identifying malfunctioning stations, which should improve the overall data return of the GCN.

The accuracy and versatility of the radar altimetry satellite drift estimation depends primarily on having the greatest possible global coverage of tide gauges that span the altimetric time period and report on a reasonably near to real-time basis, and on having independent estimates of vertical land motion at the tide gauges. The first requirement controls random errors, while the land motion estimates control possible bias errors. The GLOSS near real-time and fast delivery stations (Figure 1) are the majority of the tide gauge stations used in the drift estimation network. At present, however, land motion errors dominate the drift estimation error budget, and these errors in turn dominate the error budget for estimates for global mean sea-level change from satellite altimetry. The solution to this problem is to obtain, generally from continuous GNSS observations, independent estimates of land motion at as many of the GLOSS stations as possible.

The number of GNSS receivers at or close to tide gauges (Figure 4) has increased remarkably to now more than 300 stations worldwide [Wöppelmann et al., 2007b]. More than 100 stations now provide data to TIGA on a regular basis. The discrepancy between the available and participating stations is due in part to the missing co-location information, e.g. leveling between the GNSS sites and tide gauge benchmarks. Other reasons are the unavailability of either GNSS or tide gauge data at international data centres or the smaller distance criteria between the GNSS and tide gauge site applied by TIGA.

Figure 4. *GLOSS Core Network tide gauge station No. 28 at Male, Maldives equipped with a continuous GPS receiver (highest dome) collocated with water level sensors (photo courtesy of D. Caccamise).*

6 www.iode.org/glossafrica
7 www.gloss-sealevel.org/data/africa_and_west_indian_ocean/

SEA-LEVEL MONITORING REQUIREMENTS FROM OCEAN, CLIMATE, AND GEODETIC STUDY GROUPS AND RESEARCH PROGRAMMES

A number of research programmes and scientific study groups have made cases for various types of sea-level measurements within a global sea-level observing system. Several of these are summarised below, together with a general case for sea-level studies within national and regional activities. GLOSS will work as closely as possible with all bodies in order to provide suitable sea-level information.

In 2006, the WCRP convened a workshop "Understanding Sea-Level Rise and Variability" (6-9 June 2006, Paris) to identify the uncertainties associated with past and future sea-level rise and variability, and to determine the research and observational activities needed for narrowing these uncertainties. The summary statement from the workshop[8], reiterated in a volume of reviews of each area of sea-level science following the workshop [Church et al. 2010], provided the following recommendations for GLOSS:

(i) Complete the GLOSS network of approximately 300 gauges, each with high-frequency sampling and real-time data availability. Gauges should be linked to absolute positioning where possible (either directly at the gauge or leveling to nearby absolute networks) to enable an assessment of the coastal signatures of the open ocean patterns of sea-level variability and the incidence of extreme events, as well as the calibration of satellite altimeters.

(ii) Install GPS[/GNSS] positioning at all appropriate GLOSS tide gauge stations to determine changes in global and regional sea level.

(iii) Pursue data archaeology and complete the GLOSS network of tide gauges, each with high-frequency sampling and real-time data availability, to enable an assessment of the incidence of extreme flooding events.

(iv) The need for an open data policy was also emphasized with timely, unrestricted access for all. For GLOSS this pertains to the access of real-time, high-frequency sea-level data from the GLOSS Core Network and co-located GPS/GNSS stations.

The GOOS/GCOS Ocean Observations Panel for Climate (OOPC) is eager to advance sustained climate observations however possible. It is doing so within the framework of the consensus recommendations of the international climate community. Furthermore it is noted that the Second Report on the Adequacy of the Global Observing Systems for Climate[9] highlights the need for sea-level measurements for several purposes and calls for an enhancement and extension of the global baseline and regional sea-level networks for climate change detection and assessment of impacts.

In the Integrated, Strategic Design Plan for the Coastal Ocean Observations Module of the Global Ocean Observing System[10] it is clearly stated that the GLOSS system provides the sea-level data for the global coastal module of GOOS. The Strategic Plan also recognizes that there are other local tide gauges operated by national agencies that can provide additional data within the structure of GOOS Regional Alliances. The GLOSS sites may in some cases also provide a platform to measure additional 'common variables' foreseen in the global coastal network of the coastal module of GOOS.

The coastal panel of the Global Terrestrial Observing System (GTOS) has identified sea-level rise as a key coastal issue requiring terrestrial observation. The topic of sea-level changes and their impacts on coastal development have been discussed at recent meetings. Such interests from an 'impacts' perspective are consistent with GLOSS LTT scientific objectives.

8 www.wmo.int/pages/prog/wcrp/pdf/summary%20statement%202006-1004_low-res.pdf

9 http://193.135.216.2/web/gcos/gcoshome.html

10 http://ioc.unesco.org/goos/docs/GOOS_125_COOP_Plan.pdf

Geocentric coordinates of the benchmarks are required if the tide gauge measurements are to be located within the same global geodetic reference frame as e.g., altimeter data or to establish a global vertical reference frame. As the tide gauges and their benchmarks will move over time for natural or artificial reasons, continuous and long-term space geodetic measurements are required to establish a consistent reference frame. On one hand, absolute gravity measurements are accurate enough to detect, but not continuously, these vertical movements. On the other hand, over the past fifteen years, considerable developments have taken place with the Global Navigation Satellite Systems (GNSS) (e.g., the Global Positioning System (GPS) or GLONASS) and other space geodetic techniques (e.g., DORIS) in order to provide precise geocentric positioning of tide gauge benchmarks, and, over periods of typically a decade of continuous monitoring, of rates of vertical movement of the marks.

Starting at the beginning of the 1990s, the GPS technology developed into an inexpensive and operational tool for geodynamic monitoring, and a dedicated operational service, the (at that time) International GPS Service for Geodynamics (IGS, today International GNSS Service), started as a Pilot Service in 1992 and was formally established in 1994 [Dow et al., 2005]. Since the beginning of its service the IGS operates a large network of continuously operated GPS stations and provides e.g., station coordinates and station velocities in a global reference frame.

In 1993, the International Association for the Physical Sciences of the Oceans (IAPSO) Commission on Mean Sea Level and Tides (CMSLT) organized the 'Surrey Workshop' on the topic of height monitoring of tide gauges [Carter et al., 1994], which was a follow-up of a previous meeting held in 1989 [Carter et al., 1989]. Recommendations have been made from this workshop to formally request the IGS to provide the expertise and extend its service to organize and manage the operation of the GPS-augmented global sea-level monitoring network as a fully integrated component of the IGS/IERS-ITRF. The products should be coordinates and velocities of the tide gauge stations' benchmarks in the ITRF system. It was also recommended that the PSMSL archiving system should be designed to provide the vertical benchmark velocities derived from selected IGS solutions, along with explanatory information including experts that can be contacted by users of the system.

In March 1997, the IGS and PSMSL organized a GPS workshop in Pasadena [Neilan et al., 1997] focused on the implementation of the 'Surrey recommendations', particularly with regard to the science requirements for long-term sea-level monitoring at tide gauges, and for altimeter calibration (e.g. GLOSS-ALT). The workshop started with the implementation of a long-term plan for the establishment of a global network of GPS-equipped tide gauges. A technical committee (CGPS@TG Joint Working Group[11] was jointly setup by the IGS, the PSMSL, GLOSS and IAPSO/CMSLT to define the technical standards for stations [Bevis et al., 2002]. A GLOSS workshop (Group of Experts Meeting) in Hawaii [IOC, 2001] concluded the findings and recommended the establishment of an IGS Pilot Project. A charter and Terms of References were drafted, and in 2001 the IGS formally established the Tide Gauge Benchmark Monitoring Pilot Project (TIGA)[12] [Schöne et al., 2009]. In 2010, the Pilot Project became a permanent service of the IGS.

The main goal of the IGS TIGA Working Group is to utilize the expertise of the GNSS community to solve issues related to the accuracy and reliability of the GNSS height component at tide gauge sites. TIGA aims on the establishment of a global network of high-quality continuously operating GNSS stations at or near tide gauges beyond the IGS core network, to process their GNSS station data and to provide time series of vertical motion in a well defined global reference frame. TIGA does not operate tide gauges or GNSS stations but relies on voluntary contributions by agencies, universities or other organizations. However, based on the recommendations in [Plag et al., 2000] and [Bevis et al., 2002], the GNSS stations have to meet specific standards before accepting them for TIGA. The basic requirement is the co-location of the GNSS antenna (or benchmark) and the tide gauge zero to an accuracy better 1mm/year. A second pre-requisite is free data exchange and the availability of metadata information. All accepted stations are operated according to GLOSS standards [e.g., IOC, 2006].

Sea level (and therefore GLOSS) is recognized as an essential geodetic parameter by the Global Geodetic Observing System (GGOS[13]), sea level having been used historically as a vertical datum in many countries. GGOS is engaged in the identification of practical projects wherein the value of geodetic measurements to sea-level science can be made, thereby providing for the long-term maintenance of geodetic networks and the provision of practical information on sea and land levels to a range of stakeholders. The complementarity between sea level and geodetic studies is demonstrated well by Plag and Pearlman [2009] and Blewitt et al. [2010].

11 imina.soest.hawaii.edu/cgps_tg/
12 adsc.gfz-potsdam.de/tiga
13 www.ggos.org

SEA-LEVEL MONITORING REQUIREMENTS FOR RESEARCH AND PRACTICAL APPLICATIONS

To evaluate current and future implementation priorities for GLOSS, some of the primary ways will be considered in which sea-level data are being used for oceanographic and climate research as well as for practical applications associated with storm surges and tsunami monitoring. This in turn will help to identify specific requirements for a sea-level observing system as a whole in terms of measurements, transmission rates, data assembly and archiving, etc. The list of applications is not exhaustive, but those selected span a broad enough user base that the resulting sea-level observing requirements should be encompassing and comprehensive. The research and operational topics that will be considered are: 1) sea-level rise and decadal ocean variability, 2) surface currents and upper ocean heat content, 3) tidal processes, 4) storm surges, 5) tsunamis, and 6) satellite altimeter monitoring.

5.1 SEA-LEVEL RISE AND DECADAL VARIABILITY

Tide gauge measurements provide the primary resource for estimating global and regional sea-level rise over the past several centuries [e.g. Bindoff et al., 2007; Mitchum et al., 2010], as well as decadal time scale sea-level fluctuations that provide insight into climate variability, such as the Pacific Decadal Oscillation (PDO) and North Atlantic Oscillation (NAO), and long-term modulations of the upper ocean circulation and heat content. The observing network and data handling requirements for sea-level rise and long-term variability research are listed in Table 1.

Because sea-level rise and decadal variations are relatively weak amplitude signals, mm to cm changes over decades, tide gauge datum stability is one of the key observing considerations. Stability requires repeat leveling surveys, preferably at annual intervals but up to 3 years may be suitable depending on the overall stability of the site. Continuous GNSS receivers at the tide gauge or at the primary benchmark also provide suitable level ties over time.

Sensor stability is also a consideration in terms of the introduction of bias errors into the dataset due to level shifts of the sensor reference datum, typically during servicing, sensor drift, which tends to be a problem particularly for pressure transducers, and changes in sensor technology over time, which may lead to non-stationary errors unless careful intercomparisons are performed [Martin Miguez et al., 2012]. In addition, the combination of tide gauge and GNSS information (and knowledge of the leveling connections between them) at all stations in the GCN will provide an important validation of a Worldwide Vertical Datum [Ihde and Sánchez, 2005; Plag and Pearlman, 2009].

For establishing estimates of global sea-level rise and for monitoring the stability of satellite altimeter datasets, an estimate of absolute sea-level rates is required at each tide gauge. For this application, any vertical drift of the tide gauge primary benchmark must be tracked over time, as well as relative movements between the benchmark and the tide gauge itself. Continuous GNSS measurements at the primary benchmark, or within a reasonable distance, which itself is a function of the local site stability, are needed to get the required 1mm/year accuracy (see e.g., Bevis et al. [2002] for a detailed discussion on this issue to satisfy this requirement). DORIS sensors and other technologies may also provide suitable estimates of vertical motion [Ray et al., 2010; Willis et al., 2010].

Various statistical analyses have been used to reconstruct the temporal behaviour of global and regional sea level, which can then be used to estimate rise rates. Reconstructions require first and foremost a suitable spatial distribution of tide gauge stations. Dense networks in Europe and North America provide excellent coverage for regional reconstructions; however, for global coverage there is a high premium on tide gauge records in the tropics and southern hemisphere where relatively few stations historically exist. Reconstructions also require long, continuous time series and so maintenance of the longest tide gauge records, no matter the spatial distribution, is a high priority. Land motion corrections are important for reconstruction estimates for the same reasons described above.

Since datum stability is crucial for sea-level rise estimation, sea-level rise research efforts require access to quality-assessed datasets that include tests for level shifts and sensor drift. Detailed metadata information describing benchmark surveys, ancillary GNSS time series (vertical rates), details of the primary water level sensor used to construct the sea-level time series, and the schedule of maintenance visits to the tide gauge station are required.

5.2 SURFACE CURRENTS AND UPPER OCEAN HEAT CONTENT

An understanding of how sea level varies in space and time provides insight on changes in the wind-driven ocean circulation and distribution of upper-ocean heat. Ocean variability associated with interannual climate variations, such as the El Niño Southern Oscillation (ENSO), have distinctive sea-level expressions. Sea-level gradients measured between station pairs also provide a measure of the surface geostrophic transport, which has been used to monitor ocean circulation at key choke points (e.g. Meredith et al., 2011). Sea level has also been used to detect ocean eddies as they impinge on deep ocean island locations [Mitchum, 1995]. Support of ongoing research in ocean circulation and upper ocean processes presents a range of requirements for the global tide gauge network (Table 1).

Interannual variations tend to have higher amplitudes (10s of cms) than decadal variations and long-term trend; however, datum control remains an issue. Moreover, to examine ocean processes across all available time scales, long continuous records are essential. Lengthy data gaps are difficult to circumvent in time series analyses. To avoid data gaps and to improve tide gauge datum control, back up water level sensors are recommended at each station. Multiple sensors provide a simple means for detecting level shifts in the primary data channel, and should that channel fail between maintenance visits, secondary sensors can bridge the data gap.

Studies of interannual ocean variability require a complete global network of the highest quality data. For most applications daily averages are sufficient for the sample period; however, hourly or even higher frequency data may be useful for improved data quality assessments.

Global coverage should be complemented by denser networks in regions of high scientific interest. Circulation chokepoints, such as the Drake Passage and Indonesian Throughflow, require more stations than provided by the GLOSS Core Network for transport estimates. Continuation of the TOGA array of island tide gauge stations in the Pacific remains a priority for ENSO monitoring and prediction. Lastly, tide gauge stations in Polar regions are especially important for ongoing research on climate change.

5.3 TIDAL PROCESSES

Tide gauges were developed to measure the surface tide and to perform tidal predictions. This application typically requires a few years of continuous hourly data for most practical applications. Research of tidal processes; however, raises the requirements for the observing network. Internal waves at tidal frequencies, or internal tides, have a surface elevation expression that can be detected by tide gauges. Changes in internal tide amplitude and phases over time may provide an indication of changes in local stratification and currents. Tide gauges have been used to monitor the variability of internal tides over long records [Mitchum and Chiswell, 2000; Colosi and Munk, 2006]. Tidal flows over topography can also generate internal waves, that have been found to cause seiche motions detected in harbour tide gauge datasets [Giese et al., 1990]. In addition, the surface tide itself appears to be exhibiting long-term changes in amplitude for natural reasons that are not completely understood [Jay, 2009], and in some locations this is added to changes caused by harbour and coastal development (dredging activities, e.g. Hamburg or Sevilla).

Tidal studies require at least hourly data, with higher frequency data needed to examine harbour seiches. Datum stability typically is less of an issue in examining tidal phenomena, although tidal prediction over time is more accurate if datum shifts are minimized.

Detection of changes in tidal amplitudes and phases over time (e.g. Woodworth, 2010) requires detailed metadata describing the primary sensor, raw sampling strategy, and any mechanical or digital filtering that has been applied to the data. Metadata records should contain this level of detail.

5.4 STORM SURGES AND TSUNAMIS

Tide gauges provide the longest records available for studies of historic storm surges. Tide gauge data also are being used operationally for storm surge monitoring and modeling [Flather, 2000; Alvarez Fanjul et al., 2000; Pérez et al., 2012]. The examination of storm surge signals requires high-frequency data, with a real-time reporting capability if operational activities are being supported. Dense regional networks are required in regions of intense tropical (e.g., Bay of Bengal) and extratropical (e.g., Western Europe) storm activity.

The devastating tsunamis originating in Sumatra (2004) and Japan (2011) have highlighted the value of tide gauge data for regional tsunami warning. Most tide gauges remained operational during both tsunamis despite turbulent water conditions and strong wave-driven forces (Figure 5). The use of solar and battery powered water level stations that transmit data without reliance on the local power grid has proven to be an effective approach for a low-cost, distributed tsunami warning system. For this purpose, high-frequency tide gauge data must be available in near-real time (e.g., 5-15 minutes) as the data are collected. A basin-wide distribution of stations is needed, with additional stations positioned in earthquake zones where tsunamis are generated. Near tsunamigenic zones such as Japan or Indonesia, or in smaller basins such as the Mediterranean, shorter data latencies (1-2 minutes) are preferable.

GLOSS cannot maintain complete (or high density) storm surge and tsunami water level systems, these are best handled at the national and regional levels, but GLOSS Core stations can be configured to support storm surge and tsunami warning, thereby contributing to regional infrastructure and serving as best practice stations. For storm surge and tsunami research, a valuable contribution from the GLOSS programme would be the assembly and serving in delayed mode of as many high frequency time series that are affected by surge and tsunami events.

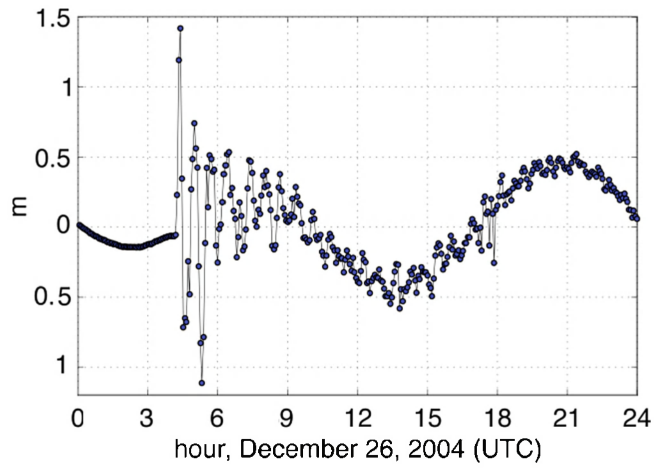

Figure 5. *Tide gauge water level time series at Male, Maldives during the 2004 Sumatra tsunami.*

5.5 SATELITE ALTIMETRY

Tide gauges provide an effective means of monitoring the vertical stability of sea surface height (SSH) data sets from satellite altimeters [Mitchum, 2000]. An example is shown in Figure 6. This has proven to be particularly useful in detecting problems with individual altimeters, and also when inter-comparing SSH obtained from different satellites. As altimeter SSH is the most important dataset for ongoing global and regional sea-level rise monitoring, tide gauges thus support sea-level rise studies directly through their individual data records, and indirectly as an important datum control on SSH.

Two key requirements for support of satellite altimetry are global coverage of the tide gauge network, and the need to monitor any vertical movement in the tide gauge benchmarks over time. Global coverage ensures a robust assessment of globally averaged SSH and potential regional biases in SSH trends, for example due to regional variations in surface waves and/or atmospheric water vapor content. The comparison method depends on altimeter SSH and tide gauge sea-level differences. Vertical movements of the tide gauge benchmarks are therefore indistinguishable from altimeter SSH drift, and independent measurements of the land motion at each tide gauge are thus essential.

SSH drift monitoring is most useful if performed on a time-scale similar to the sample period of the altimeters; however, preliminary quality control of the tide gauge data is required to flag spurious shifts and obvious drift problems. The provision of hourly data at monthly intervals meets these requirements.

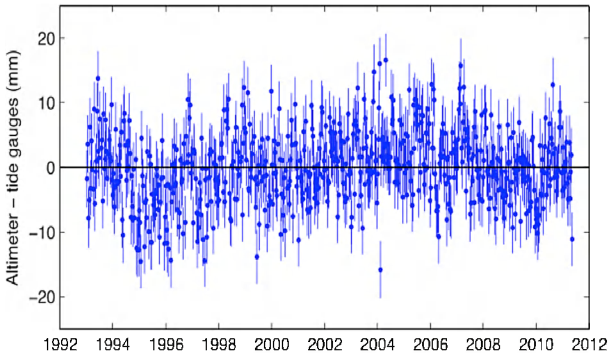

Figure 6. *An example of how the GLOSS Fast Delivery Dataset is used to check altimeter datasets for possible drift. This example uses the TOPEX/Poseidon, Jason-1 and Jason-2 merged altimeter dataset produced at the Goddard Space Flight Center (provided by Brian Beckley, NASA). The standard deviation of the altimeter and tide gauge differences (10 day sampling) 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).*

The expansion of the GLOSS Fast Delivery activity, which is the basis of the altimeter SSH comparisons, has led to an increase in the number of tide gauges that meet these requirements and can therefore contribute to satellite SSH stability estimates. But more progress is possible in some regions (e.g., the Intra-American Sea, Central and South America and Africa) and continued expansion is necessary. It should be noted, though, that the progress already made has allowed a significant decrease in the error bar on global sea-level rise estimates.

The largest improvements in the satellite SSH stability estimates have come via the rapid expansion in the number of continuous GNSS receivers located near to tide gauges and from improved processing of the available GNSS data. These advances are largely due to the TIGA project that GLOSS initiated. A point has now been reached where the stability of the International Terrestrial Reference Frame (ITRF), which is at the level of a few tenths of a millimeter per year, is a critical issue. To say this another way, the method of combining of tide gauges and altimetry is sufficiently advanced that error bars of a few tenths of a millimeter per year for global sea-level rise estimates are achievable and can likely be further reduced. This will happen with the continued expansion of the GLOSS Fast Delivery dataset and further improvements in TIGA.

	A. sample interval	B. reporting interval	C. spatial coverage	D. datum stability
1. Sea-level rise, decadal	1 month	1 year	global, polar	high
2. Surface currents, heat	1 day	1 month	global, choke points, tropics	high
3. Tidal processes	15 minute	1 year	global	medium
4. Storm surge	15 minute	1 hour	storm regions	low
5. Tsunamis	1 minute	1-15 minutes	global, fault zones	low
6. Altimeter	1 day	1 month	global	high

Table 1. *Tide gauge requirements for different scientific applications.*

CHAPTER 6

IMPLEMENTATION PLAN

6.1 THE GLOSS CORE NETWORK AND ADDITIONAL GLOSS DATABASES

The GCN remains the main focus of the GLOSS programme. Stations at roughly 1000 km intervals along the continental margins and at all the major island groups provide sufficient global coverage for a range of oceanographic applications ("global" in Table 1, column C). The GCN has never been 100% operational - even with recent advances only 75% of GCN stations report data regularly (within one year) to the GLOSS Data Centres. Nevertheless, operation and maintenance of the GCN satisfies nearly the full range of research and operational requirements for the global sea-level network (Table 1), and commitment to the GCN is a main requirement for Member States participating in the GLOSS programme. Therefore, the goal for the GCN is to be 100% operational.

Real-time data communication options are increasing and becoming more economical with time. The benefits of converting all GCN stations to real-time or near real-time reporting capability include improved data return as station problems are identified and addressed in a timely fashion, the ability to assimilate tide gauge data into operational models for storm surge and coastal inundation and the support of tsunami warning and hazard monitoring (Table 1, B4-5). The implementation goal is for all GCN stations to report data in near real-time via the GTS or Internet file transfer. Exceptions may include remote GCN stations that do not support operational activities, and for which limited power budgets prevent frequent data transfer. Many high latitude stations fall into this category.

Sensors for estimating ground motion at tide gauges (continuous GNSS, absolute gravity measurements [Teferle et al., 2009; Williams et al., 2001], DORIS) are also becoming more economical and practical to install and maintain. In addition, space-based geodetic techniques provide a means to assess ground motion on a regional scale and to extrapolate relative sea-level trends from tide gauges to adjacent coastlines (e.g., Brooks et al., 2007). Estimates of absolute heights and vertical land motion trends at TGBMs, using continuous GNSS or comparable technologies, will be standard for all tide gauge stations in the GCN in support of oceanographic, climate, and geodetic research and altimeter operations (Table 1, D). In this regard, the GCN will serve as the primary GLOSS network for altimeter drift monitoring, and the GLOSS-ALT network will be discontinued.

Research efforts on decadal and longer time scale sea-level variations and global sea-level reconstructions are well supported by the GCOS network of tide gauge stations, which was designed to emphasize a globally distributed set of stations (at a larger spacing than the GCN) with long record lengths. The current GCOS set is made up primarily of GCN stations with a small number of non-GCN stations. Given the proposed upgrades to the GCN, particularly the emphasis on ground motion monitoring, GLOSS will propose to the WCRP that the GCOS network be reconstituted as a subset of the GCN. If non-GCN stations are deemed essential for GCOS, those stations should be incorporated into the GCN. The GLOSS Chair will initiate a review of the GCOS network with the goal of establishing a new GCOS station list by the GLOSS Group of Experts meeting in 2013.

Long tide gauge records are of high importance for a range of applications, and it is essential to archive data from long-record stations even if they are located close to one another (e.g., the dense network of long tide gauge records in Europe). An implementation goal for GLOSS is to ensure that ongoing hourly data collected at stations with long historic records are archived in the GLOSS-LTT database. The GLOSS-LTT will complement the data banking activities of the PSMSL, the main repository of monthly datasets.

In certain regions of interest, examination of oceanographic processes requires denser station coverage than afforded by the GCN. These include circulation choke points such as the Drake Passage and the Indonesian Throughflow, the tropical Indo-Pacific where tide gauges have been useful for ENSO studies, and Polar regions that otherwise are poorly sampled by satellite altimetry (Table 1, C1,2,4). The GLOSS-OC database of stations will continue into the next implementation phase of GLOSS, with an emphasis on stations that provide enhanced spatial coverage in regions of high importance to oceanographic research. Stations in the GCN that are within these regions of interest will also be listed in the GLOSS-OC database.

GLOSS is committed to increased support for the tsunami warning and storm surge communities through near-real time transmissions at GCN stations (Table 1, B4, 5). There are mutual benefits in this activity as it is envisioned that broadening the user base for individual stations will increase national awareness to maintain the stations to GLOSS standards, and near-real time monitoring of data streams will improve data return. As a service to operational tsunami warning, GLOSS experts are available to define standards for tsunami warning monitoring and to devise optimal network configurations (i.e., multi-purpose networks). GLOSS will seek to maximize the overlap between sea-level monitoring and real-time tsunami warning by developing best practice recommendations and station designs that serve both purposes. As a specific implementation goal, GLOSS will take responsibility to serve quality assessed, high frequency datasets (~1 minute sample period) for all GLOSS tide gauge stations that report in near-real time, particularly those for stations in storm and tsunamigenic regions. Stations supported in this manner will be part of the GLOSS-HF database; all stations in the GCN will be included in the GLOSS-HF database.

In summary, GLOSS will actively seek to implement one network of stations, the GCN, which will have more ambitious reporting (near-real time) and datum control (continuous GPS) requirements than in the past. The GLOSS Fast Delivery Center will support satellite altimetry and hence the old GLOSS-ALT network will be discontinued. GLOSS will continue to support data acquisition and assembly for the 170 GCOS stations as an important sub-network of the GCN for climate observing. The GLOSS-OC and GLOSS-LTT stations will be supported as GLOSS databases, not networks that GLOSS directly implements. A new GLOSS database, GLOSS-HF, will be maintained in support of tsunami and storm surge research.

6.2 GLOSS DATA CENTRES

GLOSS data centres (Table 2) are associated with scientists involved with sea-level research. This involvement helps to maximize the quality of GLOSS datasets. In this implementation plan, the distributed system of data banking will be maintained. A new implementation requirement is that the various centres will optimize relational database tools and cross-referencing techniques, giving the feel of a centralized GLOSS

	Location	Responsibilities	Data holdings	Data updates
Monthly averages	PSMSL	Final monthly averages from originators	GCN, GLOSS-OC, GLOSS-LTT	Annual
Delayed mode	BODC	Final high frequency data from originators	GCN, GLOSS-OC, GLOSS-LTT	Annual
Fast mode	UHSLC	Preliminary QC data from originators	GCN, GLOSS-OC	4-6 weeks
Hourly data products	JASL/UHSLC	Final high frequency data with corrections	GCN, GLOSS-OC	Annual
Sea-level monitoring facility	VLIZ	Plots and downloads of raw data	GCN, GLOSS-OC	Near real-time
GNSS data	SONEL	Archive for GNSS data near GLOSS stations	GCN, GLOSS-OC, GLOSS-LTT	Annual

Table 2. *GLOSS Data Centres.*

web server for all related data and metadata sets. This coordination will also serve to improve reporting on the status of the GLOSS programme.

6.2.1 PSMSL

Since 1933, the PSMSL has been responsible for the collection, publication, analysis and interpretation of sea-level data from the global network of tide gauges. It is operated under the auspices of International Council for Science (ICSU) and is a member of the World Data System (WDS) of ICSU. It is based at the National Oceanography Centre (NOC, Liverpool) by means of support from the UK Natural Environment Research Council (NERC).

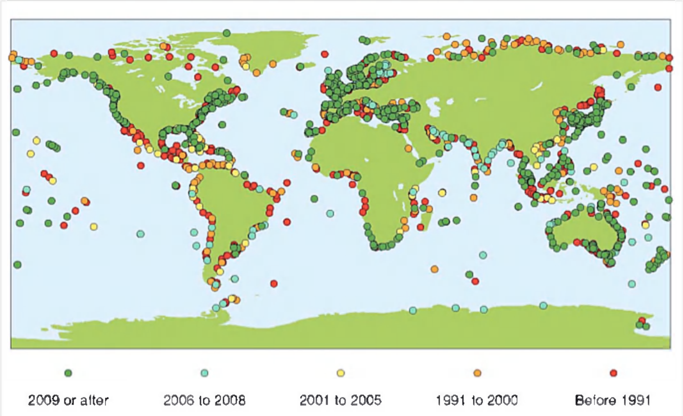

Figure 7. *Status of PSMSL data holdings (October 2011).*

As of October 2011, the database of the PSMSL contains 60,206 station years of monthly and annual mean values of sea level from approximately 2070 tide gauge stations around the world received from over 195 national authorities (Figure 7). On average, approximately 1500 station years of data are entered into the database each year although the annual figure varies between 500 and 4000 station years.

As it has since its inception, GLOSS will strive to increase the data flow of monthly averages to the PSMSL. Completion of the GCN will be an important step in this direction. As the main repository of tide gauge data for climate research, GLOSS will coordinate the GLOSS-LTT database with PSMSL to ensure consistency between the databanks. GLOSS will serve hourly data from GLOSS-LTT stations, and point to the PSMSL for monthly averages.

6.2.2 GLOSS Delayed Mode Data Centre

The GLOSS Delayed Mode Data Centre is operated by the BODC in collaboration with PSMSL. It has the responsibility for assembling, quality controlling and distributing the “final” version of GLOSS sea-level data sets, as well as all supporting metadata information. In the next implementation phase, the Delayed Mode Centre will handle hourly (or sub-hourly) values, together with ancillary variables (e.g. atmospheric pressure) where these are available, from the GCN, GLOSS-LTT, and GLOSS-OC databases. These should be supplied by September of the year following the data-year together with comprehensive metadata (including benchmark information). The Delayed Mode Centre will, on request from member nations, form and provide the PSMSL with monthly averages based on the final data sets received. PSMSL relies on Member Nations to provide the final version of the hourly (or sub-hourly) time series with all quality control assessments applied and documented.

In collaboration with IOC, the BODC, with assistance from PSMSL, provides an essential coordination role for GLOSS, including the production of the GLOSS Station Handbook. In the past this has been distributed as a PC and CD ROM product, but now is available online from the GLOSS web-site[14].

6.2.3 GLOSS Fast Delivery Center

The GLOSS Fast Delivery Center is operated by the UHSLC, which has the responsibility for assembling and distributing a version of GLOSS sea-level data sets that has undergone preliminary quality control by Member Nations, as well as all supporting metadata information. “Fast delivery” implies posting of the data within 4-6 weeks. The UHSLC provides Fast Delivery quality control services for Member States that do not have that capability.

6.2.4 The Joint Archive for Sea Level

The Joint Archive for Sea Level (JASL) acquires hourly datasets from GLOSS and non-GLOSS tide gauges from around the world that have received a final quality assessment from the data originators. JASL provides an independent check of the data, primarily to identify any remaining outliers, timing issues, or datum shifts. Any quality issues with the data are brought to the attention of the data originators for reconciliation. JASL then assembles a single hourly time series for each station, or a series of sub-records if datum changes occur over time. The JASL dataset therefore represents a “data product”, as problematic data points are not simply flagged and left in the records as they are by BODC for the GLOSS Delayed Mode Dataset, but changes to the data actually are implemented by JASL analysts (e.g., level adjustments, timing shifts, outlier removal). These changes are documented in the metadata information.

14 www.gloss-sealevel.org/station_handbook/

In the next implementation phase, GLOSS welcomes continued support by JASL in the formation of hourly data products for all stations in the various GLOSS datasets. To avoid confusion for data originators, it is recommended that BODC and JASL coordinate annual data requests for quality assessed data so that there is a single GLOSS point of contact.

6.2.5 GLOSS Sea-Level Station Monitoring Facility

The Flanders Marine Institute (VLIZ, Belgium) hosts a Sea-Level Station Monitoring Facility that includes GLOSS Core stations. VLIZ provides a web-based global sea-level station monitoring service for viewing sea-level data received in real-time from different network operators primarily via the GTS, but also through other communications channels. The service provides information about the operational status of GLOSS stations through quick inspection of the raw data stream. The sea-level station monitoring system also runs a web-service for direct data access. The sea-level station catalogue system developed and maintained at VLIZ, links sea-level station metadata repositories. The PTWC, UHSLC, PSMSL/GLOSS handbook, and soon TIGA metadata systems are linked. The system is used to quality control the metadata, and to disambiguate station codes. It also offers a unique reference code for each station. The operational status of all stations is checked weekly, and station operators are contacted regarding failing stations.

In the next implementation phase, GLOSS will continue to rely on VLIZ as its real-time monitoring centre. GLOSS will work with VLIZ to include all GCN stations in the monitoring facility, as well as those GLOSS-OC stations that report in real-time. All tide gauge operators that take part in tsunami and storm surge activities, whether associated with GLOSS or not, are encouraged to have their data included in the monitoring facility station list. While recent raw data records are available through the monitoring website, VLIZ will work with the GLOSS High Frequency Data Centre to ensure that downloaded high frequency records are included in an accessible database.

6.2.6 GLOSS High Frequency Data Centre

A GLOSS High Frequency Data Centre will be established with close ties to the other GLOSS data centres. The GLOSS-HF centre will import all high frequency datasets that have been quality assessed by the originator. While the primary focus will be on GLOSS stations, the centre will be encouraged to include all high quality datasets that are of research quality, particularly in support of tsunami and storm surge analyses.

6.2.7 GLOSS GNSS at Tide Gauge Data Centre (TIGA)

The TIGA Working Group from the IGS comprises analyses centres as well as a dedicated GNSS at tide gauge data centre [Schöne et al. 2009]. The latter data centre serves as the GLOSS data assembly centre for GNSS stations at or nearby tide gauges, focusing on GLOSS needs in addition to TIGA requirements. This role has been played by the SONEL[15] observing service, which is supported by the University of La Rochelle and the French CNRS/INSU institute (the founding members are SHOM, IGN, LIENSs and LEGOS). SONEL provides information about the status of GNSS stations at or nearby tide gauges through a web-based monitoring facility. It assembles, archives, and distributes GNSS observation and metadata that can be accessed through the web-based facility, as well as anonymous FTP server.

In the next implementation phase described in this plan, GLOSS will continue to rely on TIGA for the assembling, processing and distribution of GNSS data at tide gauges. GLOSS will work with TIGA to define the useful sea-level oriented products of GNSS analyses and its most appropriate standards and formats for distribution to the sea-level community, concise while informative and complete. Key to this endeavour will be the maintenance of survey records linking the GNSS antenna to the tide gauge benchmark.

Towards this aim, SONEL has started coordinating with BODC and PSMSL to make this important metadata available for all GCN stations. All tide gauge operators, whether associated with GLOSS or not, are encouraged to have their data and metadata included in the SONEL data centre facility for further TIGA processing.

6.3 REGIONAL NETWORKS

The GLOSS Core Network has been complemented by the definition of regional sets of gauges in several parts of the world, providing an extension and local densification of the GCN. Although arrangements may differ in each case, one would envisage in future each regional activity having its own methods of coordination, local workshops and products, and international data centre, in addition to representation within the GLOSS Group of Experts. Regional GLOSS networks are encouraged to expand, particularly in partnership with the regional tsunami warning systems or the GOOS Regional Alliances.

15 www.sonel.org/

The European Sea Level Community is an example of a regional effort with ties to GLOSS. There continues to be a clear societal demand for monitoring, understanding and predicting sea-level changes for the European region as a whole and therefore a need for the best possible European sea-level data. The European Sea Level Community has made a number of efforts in the past to establish and maintain a regional presence. A plan is being developed to ensure that the basic elements required for a European sea level infrastructure are in place; some of these already exist and others are under development. They are:

1. A mechanism for the exchange of real-time sea level information from national agencies.
2. A mechanism for the exchange of delayed mode information for science and other off-line analyses.
3. A mechanism for the exchange of GNSS data at tide gauges.
4. A community mechanism by which interested people can meet to exchange ideas on new science and technology, decide on standards and data provision and, most importantly, represent the region in GLOSS. This community can be considered both institutional (e.g. a 'club' of tide gauge agencies) and scientific, with a mixture of both at different times.

6.4 STRATEGIES FOR SUSTAINABILITY

An ongoing challenge for GLOSS has been network sustainability. It is common for a short-term aid programme or tsunami initiative to lead to a welcome expansion of the GCN. This was demonstrated in the Indian Ocean following the 2004 tsunami, and also around the African continent through the efforts of the ODINAFRICA III project. However, few of these programmes have a long-term operation and maintenance strategy or capability. It is hard to attract aid funds simply to maintain existing infrastructure. Although water level sensors and data acquisition equipment are available now from private vendors, the operation of the station as a whole requires an attention to detail, particularly in maintaining datum control, which is hard to sustain unless regular and routine maintenance tasks are provided by well-trained technicians. For small Member States, it is often financially impractical and inefficient to maintain a specialized staff to look after in some cases only one or two national tide gauge stations. Moreover, groups that currently do maintain a far-reaching network of stations will find it more and more difficult to provide routine service as travel costs continue to rise.

The solution would seem to lie in improved regional collaboration and coordination targeted at operations. The notion of regional networks that cross national boundaries has long been promoted by GLOSS, but there are few successful models. Regional initiatives are expensive and they require a long time commitment. Where a regional approach would be most effective is in a shared technical resource, whereby trained technicians would provide ongoing support for a manageable set of stations (visits every 1-2 years) within each region. This would include servicing tsunami warning as well as sea-level components of the network, although ideally a given station would serve both whenever possible. In this next implementation phase, GLOSS will promote the concept of traveling technical experts within regions, and will seek to identify funding sources. Member States are strongly encouraged to support this effort through direct financial or in-kind support.

ADMINISTRATION OF THE GLOSS PROGRAMME

The administration of GLOSS requires local coordination, provided by national contact points, and global organisation overseen by the GLOSS Technical Secretary and the GLOSS Group of Experts. GLOSS data policies and procedures are reviewed by the GLOSS Data Coordination Panel.

7.1 NATIONAL CONTACT POINTS FOR GLOSS

Each GLOSS Member State should designate a National Contact Point, or GLOSS Contact, to the IOC Secretariat. National Contact Points receive no funding from IOC for their GLOSS activities; the support of National Contacts' activities is one of the commitments required of an IOC Member State participating in GLOSS. The specific responsibilities of the National GLOSS Contacts are to:

(i) promote the GLOSS Implementation Plan at the national level, and provide national coordination, particularly if more than one agency or group is involved in the operation and maintenance of equipment at GLOSS stations in the national network. The Contacts should distribute GLOSS documentation and publications to the national institutions and persons concerned;
(ii) ensure that national needs for GLOSS data, products, and scientific and technical advice are brought to the full attention of the GLOSS programme; supply information to IOC on training needs;
(iii) organise regular reviews of the national GLOSS stations through appropriate national channels to ensure that their operation is in accordance with GLOSS requirements;
(iv) ensure data flow from national tide gauges and GNSS receivers to GLOSS data centres in accordance with the IOC Oceanographic Data Exchange Policy[16] (in particular Clause 1: Member States shall provide timely, free and unrestricted access to all data, associated metadata and products generated under the auspices of IOC programmes);
(v) report to IOC on the status of national stations that contribute to GLOSS, help to identify potential solutions for stations with poor or no data return;
(vi) publicise GLOSS and sea-level studies in general.

7.2 GLOSS TECHNICAL SECRETARY

Centralized oversight for the GLOSS programme is provided by the GLOSS Technical Secretary, who is an IOC staff member. The specific responsibilities of this post are to:

(i) facilitate communication between GLOSS Member States and the GLOSS Group of Experts, between GLOSS and other components of JCOMM (e.g. JCOMMOPS), and between GLOSS and international scientific bodies and operational agencies that make use of GLOSS data such as tsunami warning centres;
(ii) monitor the operational status of nationally committed GLOSS gauges and identify problem stations;
(iii) provide administrative support to the IOC Group of Experts on GLOSS;
(iv) manage the IOC budget for GLOSS;
(v) act as a broker for donor/recipient equipment arrangements and other forms of aid;
(vi) organise training activities and consultant visits;
(vii) oversee publication and distribution of GLOSS publications.

16 www.ioc-sealevelmonitoring.org/IOC_Oceanographic_Data_Exchange_Policy.pdf

7.3 GLOSS GROUP OF EXPERTS

The GLOSS Group of Experts (GE) is required to:
(i) advise the IOC on the implementation of the GLOSS programme;
(ii) evaluate and update the GLOSS Implementation Plan regularly;
(iii) ensure proper liaison with international research programmes and relevant international organizations;
(iv) provide advice on the development of Training, Education and Mutual Assistance (TEMA) components of GLOSS, regarding training of specialists, provision of instruments, their installation and maintenance, and data evaluation and interpretation;
(v) report periodically to the IOC governing bodies.

The composition of the GE is not fixed. GE meeting attendees are invited from a global pool of expert scientists, engineers, agency representatives, and tide gauge operators based on perceived needs and priorities of the GLOSS programme. Oversight of the GE, leadership of the GE meetings, and selection of GE ad hoc committees is the duty of the chair of the GE, in close consultation with the Technical Secretary. During GE intercessional periods, the GE Chair will consult with subsets of the GE as necessary depending on the issues to be addressed.

7.4 GLOSS DATA COORDINATION PANEL

The GLOSS Data Coordination Panel is an ad hoc committee of the GE that includes as members the directors of the GLOSS data centres. The Coordination Panel serves to:
(i) coordinate data exchange between GLOSS data centres;
(ii) advise on technical aspects of software exchange, data standards, quality control procedures, product generation etc.;
(iii) report on the status of GLOSS datasets as required by the GE and GLOSS Technical Secretary;
(iv) manage GLOSS data coordination with JCOMMOPS.

7.5 SCIENTIFIC WORKING GROUP

The GLOSS Scientific Working Group (SWG) was created for the sole purpose of providing the Chair of the Group of Experts with advice on scientific questions and issues that were presented. This group was not intended to serve an oversight group, but was strictly intended to be in support of the Chair of the Group of Experts. This group was initially comprised of a Chair and a large group of members whose expertise was hoped to span the range of scientific queries that might be presented to the Chair of the Group of Experts.

It quickly became apparent that this model was not a good one, as it was too difficult to anticipate the questions. The questions that were presented to the group rarely involved more than one or two of the SWG members, and questions inevitably arose that no one in the group, despite its breadth, was really capable to deal with. Rather than expand the group a new model was followed.

The group was transitioned to a floating membership whose members came and went depending on the questions that were posed. Basically, the Chair of the SWG is the only permanent member of the group, and the Chair of the SWG called on members of the larger community as necessary to address the questions posed by the Chair of the Group of Experts.

This new organizational model has worked well. It also has the advantage of paralleling the structure of the Group of Experts itself, which has traditionally not had permanent members, but has drawn on necessary expertise as the demands on the GLOSS network have evolved. This type of structure is able to react quickly to changing demands and questions much more effectively than a large, static group might hope to do.

7.6 GLOSS FUNDING

Different contributors (e.g., CNES, France; NASA, USA) have provided funds for GLOSS on an occasional basis and two steady donors, NOAA, USA and NERC, UK, have contributed on an annual basis over the past ten years. GLOSS has also partnered with ODINAFRICA and various tsunami and sea-level hazard monitoring projects concerning observation equipment and training. The IOC has provided secretariat support and a small regular programme contribution.

Extra budgetary resources will be increasingly important to fund GLOSS activities, as UNESCO/IOC's contribution has remained largely flat over the years. IOC Member States are strongly encouraged to provide direct financial and in kind support for GLOSS activities. This might take the form of additional resources for the agencies maintaining GLOSS tide gauges for periodic sensor upgrades, travel for GLOSS representatives to GE meetings, support for regional workshops, technical support on a regional scale, or grant support for scientists working on sea-level research. More than most observing systems, the success of GLOSS depends on broad support from all Member States.

OBLIGATIONS OF GLOSS MEMBER STATES

Member States of the IOC that participate in GLOSS will agree to:

(i) designate GLOSS National Contacts with the duties as described in Section 7.1. Enable GLOSS Contacts to fulfil their obligations by providing adequate funding and resources to them;
(ii) require their national authorities that operate tide gauge stations within the GCN to provide high frequency data in near-real time and metadata to the GLOSS Sea-level station Monitoring Facility;
(iii) require their national authorities that operate tide gauge stations within the GCN and the GLOSS-OC to provide preliminary quality assessed hourly data and metadata to the GLOSS Fast Delivery Data Center at monthly intervals, in accordance with the GLOSS Quality Control Manual[17];
(iv) require their national authorities that operate tide gauge stations within the GCN, the GLOSS-OC, and the GLOSS-LTT to provide final quality assessed high frequency and monthly data and metadata to the GLOSS Delayed Mode Data Centre/PSMSL, or JASL by September of the year following the datayear, in accordance with the GLOSS Quality Control Manual;
(v) require their national authorities that operate tide gauge stations at non-GLOSS stations to provide monthly data to the PSMSL by September of the year following the data-year, including metadata;
(vi) encourage their national authorities that operate tide gauge stations at non-GCN stations with the capability of near-real time data access to provide high frequency data and metadata to the GLOSS Sea-level station Monitoring Facility (this as a complementary set of information to that from GCN sites);
(vii) require GNSS data from receivers at GLOSS sites be transmitted to the GLOSS GNSS Centre at preferably monthly intervals or on daily basis;
(viii) maintain all GLOSS tide gauge stations (tide gauges and GNSS receivers) to GLOSS standards. Propose replacement sites for GCN stations that have a low probability of being maintained to GLOSS standards. Repair malfunctioning GCN stations as soon as possible to avoid data gaps;
(ix) inform the IOC Secretariat of all changes with regard to the state of GLOSS stations, data submission and National GLOSS Contacts. Consult regularly the 'GLOSS Station Handbook'[18] and provide new details as necessary to ensure that station information is uptodate;
(x) identify sea-level products based on GLOSS tide gauge data that would benefit national agencies, and assist with the development, production, and/or distribution of these sea-level products;
(xi) participate in and contribute to GLOSS in its widest sense through regional training workshops and programmes, shared technical support, and other activities that serve to fulfil the goals of the GLOSS Implementation Plan.

17 www.gloss-sealevel.org/data/
18 www.gloss-sealevel.org/station_handbook/

CAPACITY DEVELOPMENT AND IMPLEMENTATION ASSISTANCE

Since its start the GLOSS programme has contained a strong capacity development component. As GLOSS has primarily been driven by global research needs, capacity development activities have tended to focus on solving observation and reporting gaps in the GCN through communication of best practices with respect to tide gauge operation and maintenance, and direct implementation assistance. In recent years GLOSS has expanded its focus (where appropriate) to also include advice and observations in support of sea-level hazard monitoring.

Examples of GLOSS capacity development and implementation assistance activities include:

(i) organization of training courses for gauge operators and specialists in sea-level observation, tide gauge operation, precise leveling to geodetic benchmarks, tidal prediction, data analysis and quality control, and of specialists to make maximum local use of the gauge data; and data analysis (more than 20 courses have been convened with more than 300 trainees, see http://www.gloss-sealevel.org/training/)
(ii) provision of a range of manuals and training materials on the hardware and data analysis tools freely available on the web (see http://www.psmsl.org/train_and_info/).
(iii) organization of technical expert visits concerning site selection for stations and national network developments;
(iv) provision of tide gauge sensor, GNSS, and satellite transmission equipment and spare parts;
(v) financial support for attendance at relevant international workshops, training courses, fellowship visits etc.
(vi) facilitation of mutual partnering assistance between institutions in the GLOSS network concerning capacity development projects

Capacity development activities will continue to be an essential component of the GLOSS programme. Funding for capacity development activities are fully dependent on contributions of extra-budgetary resources from Member States either directly or in kind. Partnership with other programmes and projects can also play an important role, as for instance seen in the recent collaboration between GLOSS and ODINAFRICA/IODE, the IOC's Indian Ocean Tsunami Warning System project, the German Indonesian Tsunami Early Warning System (GITEWS), the development of Haiti Warning Services for Coastal Hazards, and the Oman National Multi-Hazard Early Warning System.

Many Member States make in kind contributions to capacity development activities by for instance covering local organizing costs for training courses, supporting tide gauge installations by construction/refurbishment of a tide gauge huts, installation of electricity, diver assistance, designation of a local tide gauge operator to carry out tide staff readings, leveling, and miscellaneous maintenance tasks.

Proposals for capacity development projects or implementation assistance should be submitted to the GLOSS GE Chair or the Technical Secretary. Member States addressing requests for assistance in setting up stations should give as many details as possible regarding existing facilities, equipment required, infrastructure needed (e.g. construction of a suitably secure building for gauge equipment, telephone connections etc.), and implications for training. Any recipient country will subsequently be responsible for committing its appropriate tide gauge authority to provide ongoing gauge maintenance and submission of sea-level data for international exchange. In addition, it will be responsible for the support of any visiting foreign consultant dealing with gauge installation, local transport, customs clearances etc.

GCN2010 STATION LIST

GLOSS No.	Station Name	Country	Latitude	Longitude
262	Lobito	Angola	-12.33333	13.56666
185	Bahia Esperanza	Argentina	-63.3	-56.91666
192	Mar Del Plata	Argentina	-38.05	-57.55
190	Puerto Deseado	Argentina	-47.75	-65.91666
191	Puerto Madryn	Argentina	-42.76666	-65.03333
181	Ushuaia	Argentina	-54.81666	-68.3
61	Booby Island	Australia	-10.6	141.91666
58	Brisbane (West Inner Bar)	Australia	-27.36666	153.16666
40	Broome	Australia	-18	122.21666
59	Bundaberg, Burnett Heads	Australia	-24.76666	152.38
52	Carnarvon	Australia	-24.9	113.65
278	Casey	Australia	-66.28333	110.53333
47	Christmas Island	Australia	-10.41666	105.66666
46	Cocos Island (Keeling)	Australia	-12.7	96.9
62	Darwin	Australia	-12.46666	130.85
277	Davis	Australia	-68.45	77.96666
54	Esperance	Australia	-33.86666	121.9
53	Fremantle	Australia	-32.05	115.73333
148	Lord Howe Island	Australia	-31.51666	159.06666
130	Macquarie Island	Australia	-54.5	158.93333
22	Mawson	Australia	-67.6	62.86666
124	Norfolk Island	Australia	-29.06666	167.95
51	Port Hedland	Australia	-20.31666	118.56666
55	Portland	Australia	-38.34333	141.61333
56	Spring Bay	Australia	-42.55	147.93333
57	Sydney, Fort Denison	Australia	-33.85	151.23333
308	Thevenard	Australia	-32.15	133.64
60	Townsville	Australia	-19.25	146.83333
12	Exuma	Bahamas	23.78333	-76.1
211	Settlement Point	Bahamas	26.71666	-78.98333
36	Chittagong	Bangladesh	22.33333	91.83333
120	Malakal	Belau	7.33333	134.46666
194	Cananeia	Brazil	-25.01666	-47.93333
198	Fernando De Noronha	Brazil	-3.83333	-32.4
336	Fortaleza	Brazil	-3.71666	-38.46666
265	Ilha Da Trindade	Brazil	-20.5	-29.3
200	Ponta Da Madeira	Brazil	-2.56666	-44.36666
351	Porto De Imbituba	Brazil	-28.23	- 48.65
352	Porto De Macaé	Brazil	- 22.385	- 41.77
193	Porto Do Rio Grande	Brazil	-32.1	-52.103
195	Rio De Janeiro - Ilha Fiscal	Brazil	-22.9	-43.16666

334	Salvador	Brazil	-12.96666	-38.51666
199	St Peter & St Paul Rocks	Brazil	0.91666	-29.35
350	Port Sonara	Cameroon	4.005	9.125
333	Alert	Canada	82.5	-62.31666
222	Halifax	Canada	44.66666	-63.58333
224	Nain	Canada	56.55	-61.7
155	Prince Rupert	Canada	54.31666	-130.33333
223	St. John's, Newfoundland	Canada	47.56666	-52.71666
156	Tofino	Canada	49.15	-125.91666
329	Palmeira	Cape Verde Islands	16.755	-22.98333
174	Antofagasta	Chile	-23.39	-70.24
189	Capitan Prat Base (Antarctica)	Chile	-62.29	-59.38
176	Juan Fernandez Island	Chile	-33.37	-78.5
137	Pascua (Easter) Island	Chile	-27.15	-109.45
178	Puerto Montt	Chile	-41.29	-72.58
177	San Felix	Chile	-26.17	-80.07
175	Valparaiso	Chile	-33.03333	-71.61666
94	Kanmen	China, People's Rep.	28.08333	121.28333
79	Laohutan (Dalian)	China, People's Rep.	38.86666	121.68333
283	Lusi	China, People's Rep.	32.13333	121.61666
247	Xiamen	China, People's Rep.	24.45	118.06666
78	Zhapo	China, People's Rep.	21.58333	111.83333
170	Buenaventura	Colombia	3.9	-77.1
207	Cartagena	Colombia	10.4	-75.55
171	Tumaco	Colombia	1.83333	-78.73333
261	Pointe-Noire	Congo	-4.78333	11.83333
143	Penrhyn	Cook Islands	-8.59	-158.06666
139	Rarotonga	Cook Islands	-21.2	-159.76666
167	Quepos	Costa Rica	9.4	-84.16666
257	Abidjan	Cote D'ivoire	5.25	-4
214	Cabo San Antonio	Cuba	21.9	-84.9
276	Gibara	Cuba	21.11666	-76.13333
215	Siboney	Cuba	23.1	-82.46666
228	Ammassalik, Greenland	Denmark	65.5	-37
225	Godthaab/Nuuk, Greenland	Denmark	64.16666	-51.73333
315	Ittoqqortoormiit/Scoresbysund, Greenland	Denmark	70.48333	-21.96666
343	Pituffik/Thule, Greenland	Denmark	76.55	-68.86666
344	Qaqortoq, Greenland	Denmark	60.71666	-46.03333
237	Torshavn, Faroe Islands	Denmark	62.01666	-6.76666
2	Djibouti	Djibouti	11.6	43.15
169	Baltra, Galapagos Islands	Ecuador	-0.43333	-90.28333
172	La Libertad	Ecuador	-2.2	-80.91666

349	Alexandria	Egypt	31.21666	29.91666
1	Suez (Port Taufig)	Egypt	29.93333	32.56666
182	Acajutla	El Salvador	13.5833	-89.83333
116	Chuuk, Caroline Is.	Fed. Micronesia	7.45	151.85
117	Kapingamarangi, Caroline Is.	Fed. Micronesia	1.1	154.78333
115	Pohnpei, Caroline Is.	Fed. Micronesia	6.59	158.15
119	Yap, Caroline Is.	Fed. Micronesia	9.51666	138.13333
122	Suva	Fiji	-18.13333	178.43333
242	Brest	France	48.38333	-4.5
165	Clipperton Is.	France	10.28333	-109.21666
21	Crozet Is.	France	-46.425	51.87
131	Dumont D'urville	France	-66.66166	140.01
96	Dzaoudzi (Mayotte)	France	-12.78333	45.25
338	Fort-de-France	France	14.58333	-61.05
23	Kerguelen Is.	France	-49.345	70.22
205	Marseille	France	43.3	5.35
123	Noumea, New Caledonia	France	-22.3	166.43333
142	Nuku Hiva, Marquesas Is.	France	-8.93333	-140.08333
17	Pointe Des Galets, Reunion Is.	France	-20.93333	55.3
24	Saint Paul Is.	France	-38.71166	77.53833
202	Cayenne	French Guiana	4.85	-52.28333
140	Papeete, Tahiti	French Polynesia	-17.53333	-149.56666
138	Rikitea, Gambier	French Polynesia	-23.13333	-134.95
284	Cuxhaven, Steubenhöft	Germany	53.86666	8.71666
335	Takoradi	Ghana	4.88333	-1.75
255	Conakry	Guinea	9.51666	-13.71666
209	Port-Au-Prince/Les Cayes	Haiti	18.56666	-72.35
77	Quarry Bay	Hong Kong	22.28333	114.21666
229	Reykjavik	Iceland	64.15	-21.93333
34	Chennai/Madras	India	13.1	80.3
32	Cochin	India	9.96666	76.26666
281	Marmagao	India	15.41666	73.8
29	Minicoy, Laccadive Is.	India	8.28333	73.05
38	Port Blair, Andaman Is.	India	11.68333	92.76666
31	Veraval	India	20.9	70.36666
35	Vishakhapatnam	India	17.68333	83.28333
68	Ambon	Indonesia	-3.7	128.2
49	Benoa	Indonesia	-8.73333	115.2
291	Cilacap	Indonesia	-7.56666	108.98333
69	Manado (Bitung)	Indonesia	1.43333	125.2
45	Padang (Teluk Bayur)	Indonesia	-1	100.36666
347	Sabang	Indonesia	5.83333	95.33333
292	Surabaya	Indonesia	-7.21666	112.73333
346	Waikelo	Indonesia	-9.38333	119.21666
337	Chabahar	Iran	25.3	60.6

330	Castletownbere	Ireland	51.65	-9.90333
239	Malin Head	Ireland	55.36666	-7.33333
80	Hadera	Israel	32.46666	30.88333
340	Trieste	Italy	45.65	13.75
210	Port Royal, Kingston	Jamaica	17.93333	-76.85
327	Abashiri	Japan	44.01666	144.28333
82	Aburatsu	Japan	31.35	131.25
103	Chichijima	Japan	27.08333	142.18333
88	Hakodate	Japan	41.47	140.43
326	Hamada	Japan	34.9	132.06666
85	Kushimoto	Japan	33.49	135.46
89	Kushiro	Japan	42.58	144.22
86	Mera	Japan	34.55	139.49
104	Minami-Tori-Shima	Japan	24.18	153.58
83	Nagasaki	Japan	32.44	129.52
81	Naha	Japan	26.21666	127.66666
87	Ofunato	Japan	39.01666	141.75
95	Syowa	Japan	-69	39.6
325	Toyama	Japan	36.46	137.14
324	Wakkanai	Japan	45.41666	141.68333
8	Mombasa	Kenya	-4.05	39.66666
146	Christmas Island, Line Is.	Kiribati	1.98333	-157.48333
145	Kanton Island, Phoenix Is.	Kiribati	-2.49	-171.43
113	Tarawa, Gilbert Is. (Betio)	Kiribati	1.36333	172.93
307	Won San	Korea, PDR	39.16666	127.45
84	Pusan	Korea, Republic of	35.1	129.03333
271	Fort Dauphin (Taolanaro)	Madagascar	-25.01666	47
15	Nosy-Be	Madagascar	-13.4	48.28333
293	Chendering/Kuala Terengganu	Malaysia	5.26666	103.18333
43	Pengkalan TLDM Lumut	Malaysia	4.23333	100.61666
27	Gan	Maldives	-0.7	73.16666
28	Male, Hulule	Maldives	4.16666	73.5
111	Kwajalein	Marshall Is.	8.73333	167.73333
112	Majuro	Marshall Is.	7.1	171.36666
18	Port Louis Harbour	Mauritius	-20.15	57.5
19	Rodrigues, Port Mathurin	Mauritius	-19.68333	63.41666
267	Acapulco, Gro.	Mexico	16.83333	-99.91666
161	Cabo San Lucas	Mexico	22.88333	-109.9
160	Isla Guadalupe	Mexico	28.88333	-118.3
163	Manzanillo, Col.	Mexico	19.05	-104.33333
213	Progreso, Yuc.	Mexico	21.3	-89.65
164	Puerto Angel	Mexico	15.65	-96.5
162	Socorro Is.	Mexico	18.73333	-111.01666
212	Veracruz, Ver.	Mexico	19.2	-96.13333

282	Tan Tan	Morocco	28.5	-11.05
10	Inhambane	Mozambique	-23.91666	35.5
11	Pemba	Mozambique	-12.96666	40.48333
37	Akyab (Sittwe)	Myanmar	20.15	92.9
141	Moulmein (Mawlamyine)	Myanmar	16.48333	97.61666
314	Walvis Bay	Namibia	-22.9493	14.49856
114	Nauru, Gilbert Is.	Nauru	-0.53333	166.9
127	Auckland-Waitemata Hbr.	New Zealand	-36.51	174.46
129	Bluff	New Zealand	-46.6	168.35
128	Chatham Island	New Zealand	-43.95	-176.55
134	Scott Base	New Zealand	-77.51	166.46
101	Wellington	New Zealand	-41.17	174.47
259	Lagos	Nigeria	6.42052	3.40725
118	Saipan	North Mariana Is.	15.23333	145.73333
322	Andenes	Norway	69.19	16.09
345	Ny Alesund	Norway	78.93333	11.95
234	Rorvik	Norway	64.86666	11.25
321	Tregde	Norway	58	7.56666
323	Vardo	Norway	70.33333	31.1
4	Salalah	Oman	17	54
295	Gwadar	Pakistan	25.11666	62.33333
30	Karachi, Manoro Island	Pakistan	24.8	66.96666
168	Balboa	Panama	8.96666	-79.6
208	Coco Solo	Panama	9.36666	-79.88333
63	Alotau	Papua New Guinea	-10.31666	150.45
272	Daru	Papua New Guinea	-9.05	143.2
331	Lombrum (Manus)	Papua New Guinea	-2.03333	147.36666
65	Rabaul	Papua New Guinea	-4.2	152.18333
173	Callao (La Punta)	Peru	-12.05	-77.15
71	Davao, Davao Gulf	Philippines	7.08333	125.63333
70	Jolo, Sulu	Philippines	6.06666	121
72	Legaspi, Albay	Philippines	13.15	123.75
73	Manila, South Harbour	Philippines	14.58333	120.96666
246	Cascais	Portugal	38.4167	-9.2499
250	Funchal (Madeira)	Portugal	32.3862	-16.5465
245	Ponta Delgada (Azores)	Portugal	37.4416	-25.4027
244	Santa Cruz Del Flores (Azores)	Portugal	39.2728	-31.0745
231	Barentsburg (Sptizbergen)	Russia	78.06666	14.25
312	Dikson	Russia	73.36666	80.65
97	Kaliningrad	Russia	54.95	20.21666
25	Mirny (Antarctica)	Russia	-66.55	93.01666
274	Murmansk	Russia	68.96666	33.05
92	Nagaevo By	Russia	59.73333	150.7
93	Petropavlovsk-Kamchatsky	Russia	52.98333	158.65
98	Port Tuapse, Black Sea	Russia	44.1	39.06666

309	Provideniya	Russia	64.5	-173.18333
99	Russkaia Gavan	Russia	76.23333	62.58333
313	Tiksi (Tiksi Bukhta)	Russia	71.66666	128.75
90	Yuzhno Kurilsk	Russia	44.01666	145.86666
260	Sao Tome	Sao Tome/Principe	0.34833	6.73666
253	Dakar	Senegal	14.66	-17.44
339	Pointe La Rue	Seychelles	-4.67166	55.52666
44	Keppel Harbour	Singapore	1.46666	103.83333
66	Honiara	Solomon Is.	-9.43333	159.95
6	Hafun (Dante)	Somalia	10.45	51.25
7	Mogadishu	Somalia	2.01666	45.33333
13	Durban	South Africa	-29.88333	31.03333
20	Marion Is.	South Africa	-46.86666	37.86666
76	Port Elizabeth	South Africa	-33.57	25.37
268	Simonstown	South Africa	-34.18333	18.43333
249	Ceuta (Spanish N. Africa)	Spain	35.54	-5.19
243	La Coruna	Spain	43.2131	-8.2317
251	Las Palmas, Canary Is.	Spain	28.13333	-15.41666
33	Colombo	Sri Lanka	6.93333	79.85
233	Goteborg – Torshamnen	Sweden	57.41	11.48
341	Stockholm	Sweden	59.31666	18.08333
9	Mtwara	Tanzania	-10.28333	40.18333
297	Zanzibar	Tanzania	-6.15	39.18333
39	Ko Lak	Thailand	11.78333	99.81666
42	Ko Taphao Noi	Thailand	7.83333	98.43333
125	Nuku'alofa	Tonga	-21.16666	-175.25
203	Port of Spain	Trinidad and Tobago	10.65	-61.51666
121	Funafuti, Ellice Is.	Tuvalu	-8.38333	179.21666
221	Bermuda, St. Georges Is.	U.K.	32.36666	-64.7
26	Diego Garcia Is.	U.K.	-7.28333	72.4
266	Edinburgh, Tristan Da Cunha	U.K.	-37.05	-12.3
263	English Bay, Ascension Is.	U.K.	-7.91666	-14.41666
248	Gibraltar	U.K.	36.14823	-5.36492
264	Jamestown, St Helena	U.K.	-15.96666	-5.7
187	King Edward Point, South Georgia	U.K.	-54.25	-36.75
236	Lerwick	U.K.	60.15	-1.13333
241	Newlyn	U.K.	50.1	-5.55
342	Rothera	U.K.	-67.57166	-68.12833
305	Stanley, Falklands/Malvinas	U.K.	-51.75	-57.93333
238	Stornoway	U.K.	58.2	-6.38333
302	Adak, Aleutian Is.	U.S.A.	51.86666	-176.63333
149	Apra Hbr, Guam, Marianas	U.S.A.	13.43333	144.65
220	Atlantic City, NJ	U.S.A.	39.35	-74.41666
219	Duck, NC	U.S.A.	35.18333	-75.75
289	Fort Pulaski, GA	U.S.A.	32.03333	-80.9

107	French Frigate Shoals,	U.S.A.	23.86666	-166.28333
217	Galveston (Pier 21), TX	U.S.A.	29.31666	-94.8
287	Hilo, Hawaiian Is.	U.S.A.	19.73333	-155.06666
108	Honolulu, Hawaiian Is.	U.S.A.	21.3	-157.86666
109	Johnston Is., Hawaiian Is.	U.S.A.	16.73333	-169.53333
216	Key West, FL	U.S.A.	24.55	-81.8
159	La Jolla (Scripps Pier), CA	U.S.A.	32.86666	-117.26666
106	Midway Island, Hawaiian Is.	U.S.A.	28.21666	-177.36666
290	Newport, RI	U.S.A.	41.5	-71.33333
74	Nome	U.S.A.	64.5	-165.41666
144	Pago Pago, American Samoa	U.S.A.	-14.28333	-170.68333
288	Pensacola, FL	U.S.A.	30.4	-87.21666
151	Prudhoe Bay, AK	U.S.A.	70.4	-148.52666
158	San Francisco, CA	U.S.A.	37.8	-122.46666
206	San Juan	U.S.A.	18.46666	-66.11666
100	Sand Point, AK	U.S.A.	55.33333	-160.5
150	Seward, AK	U.S.A.	60.11666	-149.43333
154	Sitka, AK	U.S.A.	57.05	-135.33333
157	South Beach, OR	U.S.A.	44.38	-124.03
102	Unalaska, Aleutian Is.	U.S.A.	53.88333	-166.53333
332	Virginia Keys	U.S.A.	25.73166	-80.16166
105	Wake Island, Marshall Is.	U.S.A.	19.28333	166.61666
188	Vernadsky (Faraday), Argentine Is.	Ukraine	-65.25	-64.26666
300	Montevideo	Uruguay	-34.9	-56.25
348	Vanuatu	Vanuatu	-17.76666	168.3
328	La Guaira	Venezuela	10.61666	-66.93333
75	Quinhon	Viet Nam	13.76666	109.21666
3	Aden	Yemen, PDR	12.78333	44.98333

SELECTED **ACRONYMS**

BKG	Bundesamt für Kartographie und Geodäsie
BODC	British Oceanographic Data Centre
CIESM	The Mediterranean Science Commission
CLIVAR	Climate Variability and Predictability
CMSLT	Commission on MSL and Tides of IAPSO
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
ENSO	El Niño Southern Oscillation
ESEAS	European Sea-Level Service
GALILEO	European GNSS
GCN	GLOSS Core Network
GCOS	Global Climate Observing System
GE	Group of Experts
GEOSAT	GEOdetic SATellite
GGOS	Global Geodetic Observing System
GIA	Global Isostatic Adjustment
GIP	GLOSS Implementation Plan
GITEWS	German Indonesian Tsunami Early Warning System
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema (Global Navigation Satellite System) (Russia)
GLOSS	Global Sea-Level Observing System
GLOSS-ALT	GLOSS subset used for ALTimetry calibrations
GLOSS-OC	GLOSS database used for ongoing ocean circulation monitoring
GLOSS HF	GLOSS database used for high frequency datasets
GLOSS-LTT	GLOSS Long Term Time-series
GNSS	Global Navigation Satellite System
GODAE	Global Ocean Data Assimilation Experiment
GOOS	Global Ocean Observing System
GTOS	Global Terrestrial Observing System
GPS	Global Positioning System (U.S.)
GTS	Global Telecommunication System
IAPSO	International Association for the Physical Sciences of the Oceans
ICSU	International Council for Science
IERS	International Earth Rotation and References Systems Service
IGS	International GNSS Service
IOC	Intergovernmental Oceanographic Commission of UNESCO
IODE	International Oceanographic Data and Information Exchange
IOTWS	Indian Ocean Tsunami Warning and Mitigation System

IPCC	Intergovernmental Panel on Climate Change
ITRF	International Terrestrial Reference Frame
JASL	Joint Archive for Sea Level
JASON	Follow-on mission to TOPEX/POSEIDON
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology (WMO & IOC)
JCOMMOPS	JCOMM in situ Observing Platform Support Centre
MedGLOSS	Mediterranean Programme for the Global Sea-Level Observing System (IOC and CIESM)
NAO	North Atlantic Oscillation
NEAMTWS	Tsunami Early Warning and Mitigation System in the North-Eastern Atlantic, the Mediterranean and Connected Seas
NERC	Natural Environment Research Council (UK)
NOAA	National Oceanic and Atmospheric Administration (USA)
NOC	National Oceanography Centre (Liverpool, UK)
NODC	National Oceanographic Data Center (USA)
ODINAFRICA	Ocean Data and Information Network for Africa
OOPC	Ocean Observation Panel for Climate (WCRP GOOS GCOS)
PDO	Pacific Decadal Oscillation
PSMSL	Permanent Service for Mean Sea Level
PTWS	Pacific Tsunami Warning System
RLR	Revised Local Reference (of the PSMSL)
SSH	Sea Surface Height
TEMA	Training, Education and Mutual Assistance (UNESCO IOC)
TIGA	IGS Working Group Tide Gauge Benchmark Monitoring Project
TGBM	Tide Gauge Bench Mark
TOGA	Tropical Ocean Global Atmosphere
UHSLC	University of Hawaii Sea-Level Center
UNESCO	United Nations Educational, Scientific and Cultural Organization
VLIZ	Flanders Marine Institute (Belgium)
WCRP	World Climate Research Programme
WDS	World Data System (of ICSU)
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

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