Intergovernmental Oceanographic Commission

Workshop Report No. 193

WORKSHOP ON NEW TECHNICAL DEVELOPMENTS IN SEA AND LAND LEVEL OBSERVING SYSTEMS

Paris, France
14–16 October 2003

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UNESCO

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Editors: Simon Holgate and Thorkild Aarup

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Abstract

This report provides the proceedings of the Joint IOC-IHO-IALA Workshop on New Technical Developments in Sea and Land Level Observing Systems (Paris, 14-16 October 2004). The first part of the proceedings provides presentations on experiences with various tide gauge technologies (acoustic gauges, pressure gauges, radar gauges, float gauges and the Digilevel gauge) as well as intercomparison experiments and presentations from invited manufacturers. The second part provides presentations on experiences with geodetic observations (notably continuous GPS and Doris) co-located with tide gauges. The third part provides presentations on automatic sea level data quality control software and regional sea level network and data center developments.

__Note__: this report is published in electronic copy only and is available on UNESDOC, the documents database of UNESCO (http://unesdoc.unesco.org/ulis/)

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PREFACE

Thorkild Aarup and Philip Woodworth

More than ten years have passed since the Joint IAPSO-IOC Workshop on Sea Level Measurements and Quality Control (Paris, 12–13 October 1992); this was the last time GLOSS reviewed its observation technology in a major workshop (IOC Workshop Report No. 81). Since the workshop in 1992, significant advances in tide gauge, geodetic and data acquisition technologies have taken place. Additionally, data- communication technology and the Internet have developed very rapidly since then, which has enabled increased access to real-time observation data and information products.

Parallel with these technological developments, the international oceanographic community has significantly advanced the planning of the Global Ocean Observing System (GOOS) of which GLOSS is a part. GOOS is envisioned as an operational, global network that systematically acquires and disseminates data and data products on past, present and future states of the marine environment. The observing system is being developed in two related and convergent modules: (1) a global ocean module concerned primarily with detecting and predicting changes in the ocean–climate system and improving marine services (led by the Ocean Observations Panel for Climate – a transcendent from the OOSDP); and (2) a coastal module concerned with the effects of large-scale changes in the ocean–climate system and of human activities on coastal ecosystems, as well as improving marine services (led by the Coastal Ocean Observations Panel (COOP)).

The Need for Global Sea Level Observations

Sea level is such a fundamental parameter in the fields of oceanography, geophysics and climate change that, in the mid-1980s, the Intergovernmental Oceanographic Commission (IOC) established the Global Sea Level Observing System (GLOSS). GLOSS was to improve the quantity and quality of data provided to the Permanent Service for Mean Sea Level (PSMSL), and thereby for input to studies of long-term sea level change by the Intergovernmental Panel on Climate Change (IPCC). It would also provide the key data needed for international programmes, such as the World Ocean Circulation Experiment (WOCE) and later the Climate Variability and Predictability Programme (CLIVAR). GLOSS is now one of the main observational components of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of IOC and the World Meteorological Organisation (WMO).

GLOSS was conceived as a network of tide gauges (sea level stations) around the world, providing the key data needed for international sea level programmes related to oceanography, geophysics and climate change. The network was also envisaged as providing a "global baseline" around which more dense regional and national networks would be constructed for local and practical purposes. The GLOSS Core Network (GCN), as it came to be known, would be operated with high-quality gauges and to common standards, and each country would contribute to the collaborative international programme out of national funds, with co-ordination from IOC.

Requirements for global sea level measurements and of GLOSS have been stated in several documents:

(1) The 1997 GLOSS Implementation Plan, which was approved by the IOC Assembly the same year (http://www.pol.ac.uk/psmsl/training/gloss.pub.html).

Although six years have passed since that Plan was elaborated, its requirements remain valid. The Plan (and small modifications made at regular GLOSS Experts meetings) demanded:

> The establishment of a newly defined GCN of approximately 300 stations, meeting the "global baseline" objective of the original GLOSS proposal.
>
> The establishment of a smaller, specialist network (perhaps a subset of the GCN) for the purpose of ongoing calibration of satellite altimeter data. By this time, even the most enthusiastic of altimeter data users had realized that their data sets can contain long-term drifts and biases. This subset network was called GLOSS-ALT.
>
> The establishment of a modest number of gauges at locations essential for the monitoring of the ocean circulation via sea level changes, but where altimetry is not ideal. This includes straits, high latitudes and western boundary current locations. This subset was called GLOSS-OC.
>
> The recognition by agencies of the vital importance of the continuation of long-term sea level records for climate-change monitoring purposes (e.g. within the scientific reviews of the IPCC). "Long" might mean 40 years or longer in Europe, N. America etc., but less in the southern hemisphere. This set of several hundred gauges was grouped under the GLOSS-LTT heading and was not a GCN subset.
>
> The installation of GPS receivers (and possibly other forms of geodetic monitoring, such as DORIS and Absolute Gravity) at sites within most of the ALT and LTT sets, and ideally OC also, to enable vertical land movements in the gauge records to be removed.
>
> The delivery of MSL data from all GLOSS sites to the PSMSL by July in the calendar year following the data-year.
>
> The delivery of higher-frequency data (i.e. raw data, typically hourly values) in "delayed mode" form to GLOSS Centres (in practice either the PSMSL again or University of Hawaii Sea Level Center, UHSLC) with a maximum delay of 6 months. The Plan stated that this requirement could also be met by agencies by providing these data on a publicly available web site in their own organization from which the GLOSS Centres could download the data.

The major development since the 1997 Plan was elaborated has been the recognition of the need for "fast" (near-real-time) data sets, in addition to the "delayed mode" MSL and higher-frequency sets described above. In this context, "fast" means data to be provided within several days to one week, enabling assimilation of data into the new generation of ocean models (e.g. GODAE models) and for rapid use in altimeter calibration. In 1999, GLOSS established the GLOSS Fast Centre at UHSLC as a logical evolution of UH's previous WOCE fast role, and in a series of circular letters during 1999–2003 has encouraged countries to engage in this data stream. It is realized that "fast" data imply expenditure in both upgrades to gauge hardware and data transmission methods and in staff resources. However, it is considered that, as many GLOSS gauges are relatively old, such upgrades would soon be required anyway.

(2) The Second GCOS Report on the Adequacy of the Global Observing System for Climate in Support of the 9th UNFCCC Conference of the Parties (Milan, 1–12 December 2003). Available at: http://www.wmo.ch/web/gcos/gcoshome.html.

This report stated:

Sea level is among the essential climate variables that are currently feasible for global implementation and have a high impact on UNFCCC requirements.

Enhancement and extension of the global baseline and regional sea level network record is needed for climate change detection and the assessment of impacts.

Concerning the Adequacy of the Ocean Networks to Characterize Extreme Events Important in Impact Assessment and Adaptation, and to Assess Risk and Vulnerability, the report found:

Adequately characterizing extreme regional sea level events requires that high-frequency sea level observations need to be taken and exchanged and historical data from tide gauges need to be provided to the international data centres. Capacity-building efforts in developing countries for undertaking local sealevelchange measurements can benefit the global system and foster needed regional enhancement.

Concerning the ocean surface network, the report found:

Present knowledge of global sea level variability and change is not adequate. Monitoring of global sea level is technically feasible at present, but requires at minimum a global array of geocentrically located high-accuracy water level gauges, continued operation of high precision satellite altimetry and effective data exchange between nations.

(3) The Integrated, Strategic Design Plan for the Coastal Ocean Observations Module of the Global Ocean Observing System (published in 2003 as IOC GOOS Report No. 125; http://ioc.unesco.org/goos/docs/GOOS_125_COOP_Plan.pdf)

The need for sea level measurements appeared prominently in the COOP strategic design plan and sea level was ranked in the top 10 of the 17 common observation variables that are foreseen in the global Coastal Observation Network System (CONS). Specifically, the plan stated:

The GLOSS system provides the sea level data for the global coastal module of GOOS. In addition, there are other local tide gauges operated by national agencies which can provide additional data within the structure of GOOS Regional Alliances (GRAs), sometimes with real-time delivery of data and the use of models to forecast regional sea level patterns.

The GLOSS Assessment Report (IOC/INF-1190)

Progress and deficiencies in GLOSS were presented in July 2003 to the 22nd IOC Assembly at UNESCO in Paris and are contained in what is known as the GLOSS Assessment Report (GAR). The Assembly endorsed the GAR and urged Member States to give effect to each of the GAR recommendations. (The GAR also included a proposal costing $3.5M which, among other elements, would complete the GCN, ALT and OC sets and seek improvements in the number of GCN gauges reporting in near-real-time mode).

From these requirements there is an emphasis on: (1) Completion of the GCN and regional enhanced sea level networks; (2) Real-time data delivery. As a consequence, it is envisioned that many countries will follow these requirements, leading to acquisition of new tide gauges. To that end we may also see the development of “standard GLOSS quality, plug-and-play, real-time and data transmission ready”-type gauges of possibly moderate cost. An analogy of this is the “open” Argo float design. While upgrading sea level observation hardware may be one of the first steps in completing the gaps in the GCN, it should be emphasized that national support to GLOSS-committed stations, quality control, maintenance of standards, maintenance of datums, tide gauge huts, submission of GCN data to the GLOSS data centres, capacity-building etc. are also critically important to success.

The present workshop will provide a long-overdue update on tide gauge, geodetic and data-acquisition technology, especially in so far as they benefit the GLOSS programme. We hope that the experiences provided in this proceeding will serve as advice on best practice concerning present sea level technology issues, and that these experiences will be of use to responsible authorities for local and national tide gauge networks. Eventually the workshop findings will be used to update the latest of the "IOC Manuals on Sea Level Measurements and Interpretation" (Volume III, 2000) and provide "recommended GLOSS hardware" solutions to network deficiencies.

Acknowledgements

Financial support for the workshop from the National Air and Space Administration (NASA), the Office of Global Programs of National Oceanic and Atmospheric Administration (NOAA), the National Environment Research Council (NERC), the European Space Agency (ESA) and the French IOC committee.

The editors would like to thank Ray Griffiths for proofreading the document.

PART I: TIDE GAUGE TECHNOLOGY

SEAFRAME/NGWLMS Gauges

Wolfgang Scherer

(The following text is based on notes, taken by the organizers, on a presentation at the workshop by Wolfgang Scherer, later edited by him).

The type of acoustic tide gauges based on a sounding tube became known as the Next Generation Water Level Measurement System (NGWLMS) in the USA and the SEAFRAME system in Australia, and has since become widely used in many other countries.

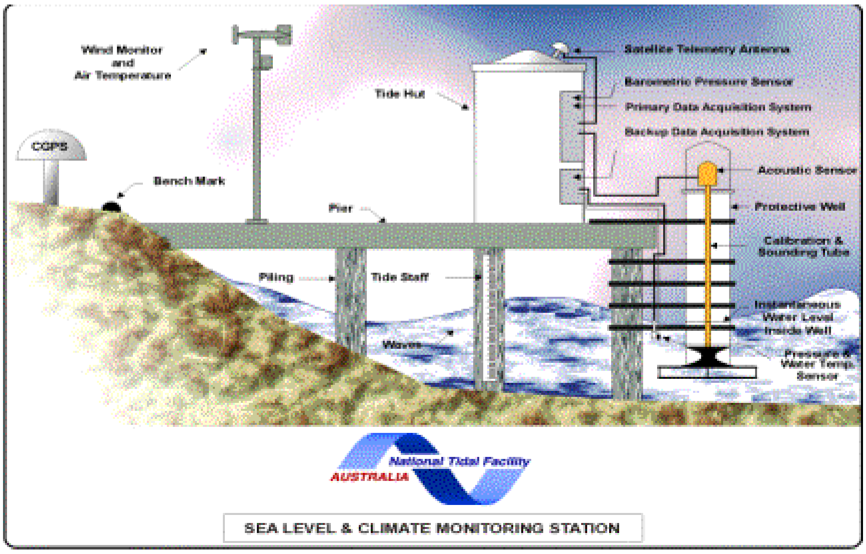

Figure 1. Schematic of the SEAFRAME acoustic tide gauge system.

The system is based on a late 1970s/early-1980s design and uses an Aquatrak water level sensor made by Bartex with a Sutron data processing and transmission system. The Aquatrak sensor sends an acoustic pulse down a 13-mm-diameter PVC sounding tube towards the water surface (maximum range 15 m). The elapsed time from transmission until the reflection of the pulse from the water surface returns to the transducer is used as a measure of the distance to the water surface. The sound tube has a discontinuity (the calibration reference point) which causes a decrease in acoustic impedance as the pulse passes it, resulting in another reflection, which propagates back to the transducer. The elapsed time for this reflection is also measured. Since the distance to the calibration reference point is very precisely known (1.2 m), this distance and the travel time can be used as a measure of sound speed in the calibration tube (i.e. the section of the tube between the transducer and the calibration reference point). This information is then used to convert the travel time of the reflection from the water surface into a distance. Air temperature and humidity affect the speed of sound, but as long as the temperature is the same throughout the whole tube, the resulting measurement will be very accurate. However, if the temperature in the tube below the calibration point is different from that above it, an error in the water level measurement will occur. Two temperature measurements, above and below the calibration reference point, are tracked and allow for subsequent corrections, if required.

The design aimed for maintenance visits every 18 months and an equipment lifetime of 15 years. Early tests showed that it was best to install the sounding tube inside an outer protective well with a 3:1 opening (10:1 being more normal in float gauge stilling wells) and with plates at the opening to reduce Bernoulli draw down. Ancillary features include a back-up pressure sensor, meteorological sensors (especially 3-hourly air pressures) and satellite transmission, including the use of the Global Telecommunications System (GTS) and a telephone and on-board recording as back-up capabilities.

Since the early installations, changes in the first specifications have occurred, including the use of alternative data-logging and transmission equipment. More information on the NGWLMS/SEAFRAME system itself and its use by different groups can be found in IOC Manuals & Guides, No 14, 2002 (Manual on Sea Level Measurement and Interpretation. Volume III: Reappraisals and recommendations as of the year 2000). This can be downloaded from http://unesdoc.unesco.org/images/0012/001251/125129e.pdf.

Fifteen years have passed since many of these gauges were installed and equipment is beginning to wear out. The requirement for modernization has resulted in an effort to devise a new system called the Sea Ranger, which would be conceptually similar to the old instrument, but would make use of new advances in electronics and acoustics during the 1990s and reduce costs from the $25,000 of a typical older complete system by a large factor.

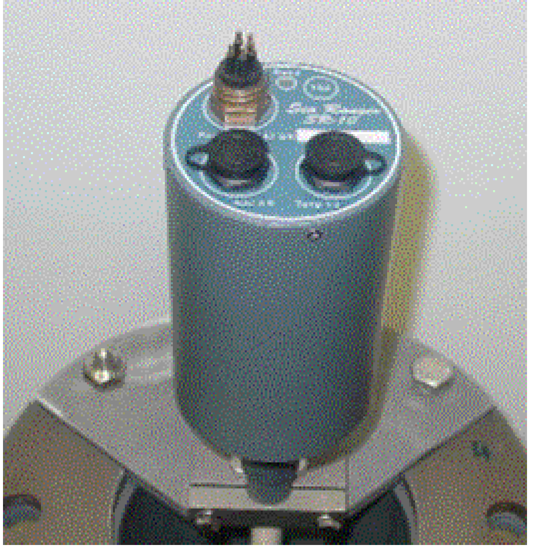

Figure 2. The Sea Ranger acoustic transducer installed over its sounding tube.

Features of the Sea Ranger include self-calibration, zero drift, data logging, multiple data ports, internal clock, additional sensor I/O and stand-alone operation. There are also improvements to the old system in installation and operation. However, as before, a temperature-controlled facility is required for the best possible calibrations and the most-precise measurements possible.

At the time of writing, equipment based on the principles of the original designs can be purchased from several suppliers, although the same Aquatrak acoustic component is common to all. It remains to be seen what technical and cost improvements the Sea Ranger acoustic component will bring to the acoustic gauge in sounding-tube technique.

Experience with Sonar Research and Development (SRD) Acoustic Gauges in Spain

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The REDMAR tide gauge network has been operating with SRD acoustic sensors for more than 10 years now. The network and experience with the advantages and problems of SRD are exposed, as well as the good quality and completeness of the data up to now.

Introduction

The REDMAR network was established by the Spanish Ports Authority (Puertos del Estado) in 1992. There were at that time two other tide gauge networks operating, one since the nineteenth century (Geographic Institute) and the other since the 1940s (Oceanographic Institute). The tide stations consisted of classical float gauges and did not transmit real-time data to the harbour.

Due to the interest shown during the 1980s by the harbour authorities in real-time sea level data, Spanish Ports Authority decided to establish a new network specially for harbour operation. After an experiment with different sensors at Cádiz harbour the SRD acoustic sensor was selected for the REDMAR.

The principal reasons for this selection, apart from the good results from the experiment, were: easy installation and maintenance; real-time radio transmission to the harbour office; and user-friendly data access and display software.

Description of the REDMAR network

At present, the REDMAR network [1] is composed of 15 SRD acoustic stations, most of them in operation since July 1992, and 6 Aanderaa pressure sensors (with compensation units for atmospheric pressure), which have been incorporated since 2001 (Figure 1). The lifetime of the acoustic sensors has been nearly reached and new technology, such as radar, is emerging and which could be interesting for the renovation of the network. It has not yet been decided whether to continue using acoustic sensors, owing to problems that will be mentioned later. In the meantime, Aanderaa pressure sensors are being used as a temporary and cheap option. In this paper we will concentrate only on the description of the SRD stations and how they have been working for the last 10 years.

In December 2002, a test station was established at Villagarcía de Arosa harbour (north-west coast of Spain), where up to eight different tide gauges are now operating, based on radar, pressure or acoustic technology. This experiment is being carried out under the ESEAS-RI project (EVR1-CT-2002-40025; European Sea Level Service–Research Infrastructure). The result will determine the selection of the new equipment to be employed in the REDMAR network in the future.

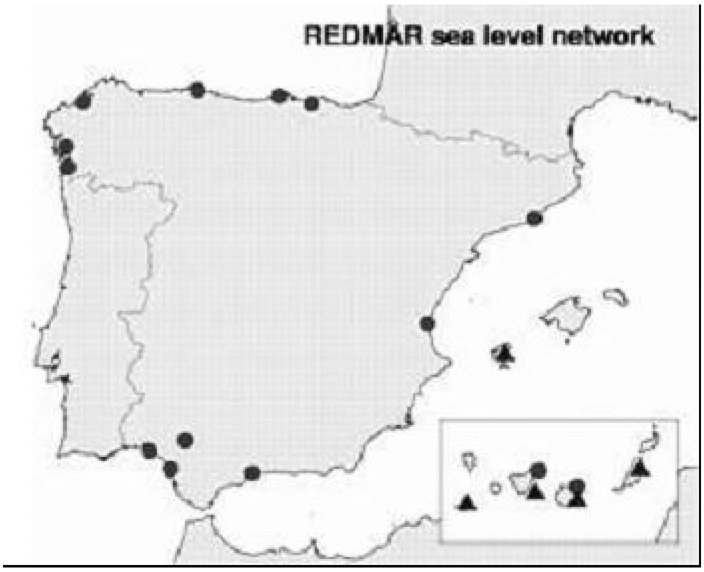


Figure 1. Left: the REDMAR stations (circles: acoustic sensors, triangles: pressure sensors); right: sonar transducer.

Measuring strategy and accuracy of the SRD gauge

The acoustic tide gauge SRD consists of an ultrasonic self-calibrated transducer that is located at a certain distance above the water surface. As can be seen in Figure 1 (right), the transducer is fixed to a metallic rectangular bar, which will be used as a target for calibration before each measurement. The distance to the target is 0.75 m.

Each measurement takes between 37 and 50 seconds and consists of the following steps:

Determination of sound velocity by sending 128 valid echoes to the target (using time between transmitted and received echo and the known distance to the bar);

Using calculated sound velocity, determination of distance to the water by sending another 128 valid echoes to the sea surface;

Determination of the sea level above the tide gauge reference, by subtracting the air distance to the previously established constant datum: distance from the transducer to the reference; in our case, the harbour datum.

The minimum time interval for SRD is 1 minute. For the REDMAR network, one value obtained in this way is stored every 5 minutes. The accuracy of each measurement is 1 cm, but, as will be shown later, for this, a very good installation is needed.

Description of a typical Spanish SRD station

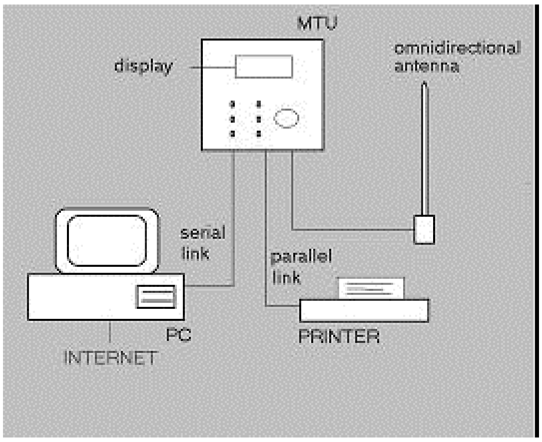
The original and most frequent configuration of an SRD station is the one with real-time data transmission by radio to the harbour office. Figure 2 shows the elements of the station at the pier (right) and at the office (left). A very important point is that the transducer must be located inside a PVC tube of 30-cm diameter (with a hole, 10% of this, at the bottom of the tube) fixed against the wall of the pier. Apart from protecting the sensor, the tube acts as a stilling well, averaging out higher-frequency oscillations. The tube must end below the lowest tide. Our experience is that the SRD gauge does not work properly if installed in the open air. The alternative is locating the sensor over an existing stilling well on the pier, inside a hut, as is the case in our Santander station.

The transducer is connected to the Low Power Telemetry Unit (LPTM2), which allows sensor configuration and at the same time displays and stores the data, sending them via radio to the harbour office. Here another intelligent unit, the Master Telemetry Unit (MTU), receives and displays the data and stores them in a PC. The role of the MTU is also to control the loss of communication with the LPTM2 asking for the data that have not been received since the last time.

Another configuration at several REDMAR stations employs modem/GSM communication instead of radio link, by means of a PC directly connected to the LPTM2 at the pier.

Software for accessing and visualizing data is installed on the PC for harbour operation. Initially provided by SRD (ITIDE programme, running under MSDOS, for radio-link stations), the Spanish Ports Authority developed new Windows software for this, called VisualMarea, which is independent of the type of tide gauge installed and the type of data transmission.

Finally, in recent years the PC in the harbour is connected to Internet and sends the data automatically each hour to the Ports Authority in Madrid.



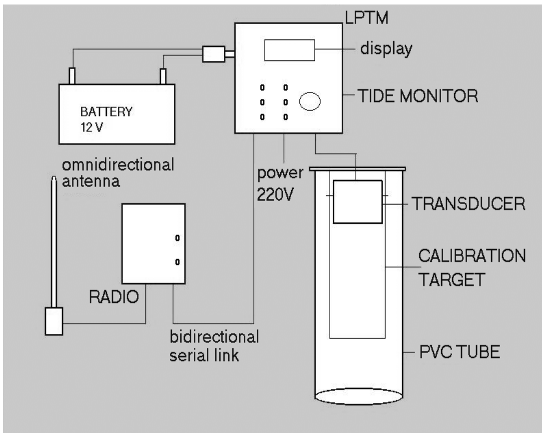


Figure 2. Elements of a typical SRD station with radio link (left: elements at the harbour office; right: elements at the pier, all of them, except the tube with the transducer, are inside a small hut).

Installation requirements and typical errors with SRD

The acoustic sensors are known to have a possible source of error that can be avoided normally with a good installation: the sound velocity employed to calculate the distance changes with temperature; the calibration for this in the SRD is made in the first 75 cm of distance to the water (the length of the metallic bar), but the existence of a gradient of temperature along the tube could affect the accuracy of the measurement during lower tides. To avoid or minimize this, different ambient temperatures along the tube should be avoided if possible (e.g. part of the tube exposed to the sunlight and part in the shade). Also, the tubes must be painted white.

From our experience we know that SRD gauges do not work properly when the distance to the sea water is more than 9 m or less than 2.5 m. This implies that they could give worse data for higher tide ranges than the ones in Spain.

Typical erroneous data are spikes (false echoes) and data with no calibration of the sound velocity (target 00). The percentage of them is dependent on the station and the sensor; they are replaced when this percentage is too high. This kind of error is detected and eliminated when applying quality control procedures to the data.

Maintenance and calibration

The proper operation of the network is guaranteed with routine maintenance and calibration every 4 months. During these visits the technicians check the following: clock, datum, communications, hole of the tube (and cleaning if necessary), batteries, presence of spikes or data with target 00, etc.

The position of the contact point of the sensor is a point on the transducer that depends on the sensor and has to be established before installation. Once defined, it is leveled to the tide gauge bench mark every 4 months to control possible movements of the installation.

The number of incidents of sensor or LPTM malfunction is approximately 1 per year for the 15 stations and 1–2 failures per year due to radio receiver–transmitter problems. There have been three accidents, which implied a complete failure of the station and need for a completely new installation, always for external reasons: a hit by a boat, lightning strike, etc. The percentage of data is normally very high, as can be seen in Table 1, although this is also dependent on the good maintenance of the different components of the station.

Table 1. Percentage of valid data during the first 10 years of the REDMAR network. The percentage is less the first year because the station was not established at the beginning of the year.

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Barc	34	96	91	98	100	85	86	99	100	100	100
Bilb	50	98	100	99	100	100	100	100	100	100	100
Bona	50	100	98	99	98	94	100	77	100	97	100
Coru	46	99	98	99	99	100	98	98	74	67	90
Gijo				50	99	96	96	95	98	87	100
Huel					30	91	99	100	100	98	100
LasP	50	98	99	98	98	96	96	88	94	100	100
Mala	50	99	98	97	91	100	99	99	100	89	100
Sant	47	100	100	100	99	100	100	100	100	100	100
Sevi	86	43	99	99	98	98	99	100	99	72	87
Tene	44	64	95	100	95	90	100	100	100	88	100
Vale	21	79	88	98	99	99	91	97	100	100	100
Vigo	17	98	100	100	100	100	100	96	100	73	100
Vill						71	100	92	100	99	95

The problem today is that equipment is old and different components begin to fail; repairs are much more expensive now. There is a new version of the SRD, but a decision has not been made about the future technology.

REDMAR: 10 years of data

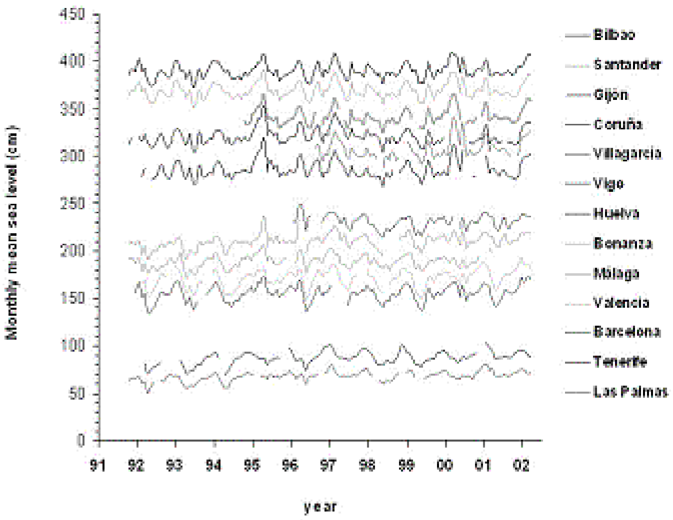


Figure 3. Monthly mean sea levels for the REDMAR SRD gauges since 1992 to 2002.

During these first 10 years, the SRD gauges have provided good quality time-series data, as can be seen in Figure 3, and have been employed for different applications: real-time data for harbour operation, validation of numerical models like the Hamsom (Spanish Ports Authority) [1] and the MOG2D (Legos), and since 2000, for verification and assimilation in the Nivmar system (Spanish storm-surge forecast) [2], developed by Spanish Ports Authority and based on the Hamsom model (http://www.puertos.es).

Conclusions and future

The Spanish experience with the SRD gauges has been very good up to now. This does not mean that, in the future, an acoustic sensor will be the best option, since it is known that the new radar technology could present several advantages, the principal one being that the microwaves are independent of the ambient temperature. Apart from this, a model with the possibility of a lower time interval and millimetric resolution could be better for harbour applications, particularly to detect higher-frequency oscillations.

After the experiment in Villagarcía de Arosa, the advantages and disadvantages will be more clear for the REDMAR and the future European Sea Level Service.

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Experience with SRD Tide Gauges and Reasoning Behind Change to Radar Tide Gauges

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Historical summary

The SAN Hydrographic Office started installing its own float-actuated "Kent" gauges in 1958. As these gauges aged, additional types, also float-actuated, were installed. These gauges proved to be reliable, but by the mid-1980s the Navy's tide gauge (TG) network was ageing. Spares for the "Kents" were becoming difficult to come by and replacement on a significant scale was urgently needed.

A project was initiated with the CSIR, Stellenbosch, to develop an accurate, modern "acoustic water level recorder." These came into service in 1990 and eight were installed throughout RSA and Namibia. These gauges were a failure. They were erratic, difficult to tune and grossly inaccurate. Virtually no usable data were obtained and the gauges were finally abandoned between 1996 and 1998.

Specifications for the replacement gauges were drawn up in conjunction with IMT (Institute of Maritime Technology) in 1995 and were tendered for in 1996, with SRD acoustic gauges meeting our requirements. These promised well and were installed, somewhat hurriedly, in 1996, mounted in tubes as recommended by the manufacturers. The supplier stated that the gauges were calibrated in the factory and were self-calibrating. It was immediately found that the gauges were very inaccurate, far beyond specification. With assistance from IMT, the gauges were calibrated and remounted without tubes. The Hydrographic Office had to devise a method for check-calibrating these gauges in situ. Their performance has subsequently been just acceptable, but not of the accuracy desired.

An OTT Kalesto radar tide gauge was tested by the Hydrographic Office in Simon's Town at the beginning of 2002. The results obtained were reaffirmed by a test at IMT in September 2002. The results from these trials indicated that the "Kalesto" performs with a higher degree of accuracy and stability than has been encountered in the past.

The present situation

Currently, the SA Navy Hydrographic Office maintains 10 tide gauges throughout the South African coastline. The network is as follows:

Port Nolloth—at present there is an SRD gauge installed. This port is next to be upgraded to a radar gauge. GPS will be installed as soon as the radar gauge is put in.
Saldanha Bay—at present there is an SRD gauge installed.
Cape Town—at present there is an SRD gauge installed.
Simon's Town—at present there is an SRD and a Kalesto gauge installed. A Hartebeesthoek Radio Astronomical Observatory (HARTRAO) GPS Rx is also fitted.
Mossel Bay—at present there is an SRD gauge installed.
Knysna—at present there is an SRD gauge installed.
Port Elizabeth—at present there is an SRD gauge installed.
East London—at present there is an SRD gauge installed and an old Kent float-actuated gauge.

Durban—at present there is an SRD gauge installed.
Richard’s Bay—a Kalesto gauge is installed, with a HARTRAO GPS Rx also fitted.

The Hydrographic Office has just recently purchased two new Kalesto radar gauges with the intention of installing one in Port Nolloth and one in Port Elizabeth. In the new financial year we hope to purchase three more Kalesto gauges. This process will continue until such time as the entire South African tide gauge network has been upgraded.

SRD gauges

The SRD gauge consists of a transducer that is connected to the data logger and control box. These are rather bulky and have a total weight of approximately 9 kg. The SRD has a measuring range of 15 m with measuring intervals selectable up to 30 min. An averaging period can be selected between 1 and 32 measurements. The claimed accuracy is 0.05% over a 2- to 10-m working range. The transducer has an acoustic frequency of 50 KHz. The battery is a lead–acid battery and, in our experience, with age, the sealed casing cracks and acid leaks into the cabinet.

An independent study was carried out by IMT on the SRD gauge,, after the SAN Tidal Superintendent had expressed concern over the accuracy and quality of the data being generated by the SRD tide gauge network. The study showed that transducers housed in tubes produced large errors due to temperature gradients that formed in the tube. The solution to this was to remove or modify the existing tubes to maintain a thermally well-mixed air column around the transducer

Regarding the accuracy of the two gauges used in the study, one was measured to have a systematic error of about 6 mm per metre over and above a fixed offset of about 24 mm. The other was measured to have a systematic error of approximately 10 mm per metre, with a fixed offset of about 36 mm. This accuracy problem was taken up with the manufacturers to establish why the claimed accuracy of 0.05% over the 2- to 10-m working range could not be achieved with the units under test. The manufacturer could not solve the problem and a method of post-data-processing was devised to improve the absolute accuracy of the data back to the claimed 0.05%. This post-data-processing could however only be possible once all gauges in the network were calibrated in situ to establish their individual calibration factors.

A refined method for in situ calibration was devised as a quality control tool. The method allows the following to be reliably established on site:

Absolute accuracy;
Measurement repeatability;
Instrument datum offset.

All gauges in the SAN tide gauge network are now calibrated every 6 months using carbon graphite poles of known length and a stainless steel target that is suspended below the gauge.

Data received from the gauge is very “spiked”. The stability of the readings is also erratic. This “spiking” in the data creates a problem when the time arrives for the annual tidal prediction run. The “spikes” have to be edited out of the data by hand; each day’s data have to be manually plotted, checked against the graphics produced by the Tech Tidal Assistant and then edited into the analysis programme, before predictions can be calculated. This is a very unscientific, time-consuming process and human error comes into play.

The quality of the lightning protection within the unit is not up to standard. A perfect example of this is the gauge in East London. It was struck by lightning and this caused a fire to start in the gauge. Due to the fact that the Hydrographic Office had placed the instrument box inside a watertight metal box, the fire burnt itself out, owing to lack of oxygen. It would appear that the data logger was not damaged in the lightning strike/fire. The power supply, junction-box telephone line and modem were damaged.

Technical support is vital, but it has been unsatisfactory. What little support we did receive was often not of any help in solving problems that arose with the gauges. Currently there has been a slight improvement in this situation, but unfortunately our new contact person does not know very much about the SRD gauge and its components. We are facing a problem of one gauge either downloading only two lines of data or downloading spaghetti/garbled data. To date, nobody has been able to assist the Hydrographic Office in solving this problem.

What the Tidal Department calls a "kick-start" is the solution to the problem of periodic inability to download data. Periodically, the power supply has to be disconnected from the gauge, followed by a pause of 30 seconds, then reconnection of the power. This problem is becoming more and more frequent and the downtime that it is creating in data analysis is becoming problematic.

In the last two years, it has become evident that the transducers are beginning to rust and this is getting worse. The HO is unsure if the rust is affecting the quality of data, but this is a possibility, since the transducers that have little or no rust are not creating as many problems.

Kalesto radar gauge

The OTT Kalesto radar gauge was tested by the Tidal Department, and was under calibration from 12 to 15 April 2002. After analysis of 1443 readings (mean of 2.496 m), it was found that, in general:

81% of the readings were within 2 mm of the above mean;
93% of the readings were within 3 mm of the above mean;
97% of the readings were within 5 mm of the above mean.

The Kalesto radar tide gauge has an integrated software filter for averaging wave motion. It is robust, compact and simple to install, and weighs only 8 kg. The Kalesto operates well clear of the sea surface, so corrosion is minimized. It has a measuring range of 1.5 to 30 m with measuring intervals of 17 seconds (mean of 40 values). The Kalesto has a claimed accuracy of 1 cm over the complete measuring range. The sensor technology works on the FMCW (frequency-modulated continuous waves) principle with microwaves 24, 125 GHz, 5 mW.

An independent study to check and calibrate the Kalesto radar tide gauge was carried out by IMT on request by the SAN Tidal Superintendent. The study showed that during the calibration period, the Kalesto performed consistently within the manufactures claimed accuracy parameters over the 2- to 7-m range. The absolute accuracy of the gauge under test was measured to have a standard deviation of better than 3 mm over the 2- to 7-m range. The independent study confirmed the results achieved by the SAN Hydrographic Office.

The refined method for in situ calibration devised for the SRD tide gauge as a quality control tool is used to calibrate the Kalesto gauge every 6 months.

The data from the gauge show very little “spiking” in the graphics; this is due to the measuring interval being 17 seconds. Therefore, in the long run, there will be very little editing of the data before the predictions can be produced, thus improving the accuracy of the Hydrographic Office's predictions. The quality of data being sent to the PSMSL has also improved, not only in quality but also in frequency of data transfer (Fast Data).

This gauge is factory-fitted with an integrated lightning protector to reduce the possibility of damage caused by over-voltage (e.g. by lightning or power surges).

The technical support obtained by OTT SA (Pty) Ltd is much improved on that of SMD. Our contact at OTT, although busy, gives us personal attention, which is much appreciated by the STI. All questions and queries are handled personally by Mr. Havenga. OTT SA will also be giving the staff of the Tidal Department a course on programming and software upgrades, so that simple hiccoughs can be handled within house.

Prospects

The SAN Hydrographic Office intends to upgrade its entire tide gauge network with the Kalesto radar tide gauges, budget permitting. It is proposed to install a GPS receiver at Port Nolloth and East London. It is also proposed to install a tide gauge and GPS receiver on Marion Island, thus restoring the South African GLOSS station status to its original 100% capability.

Currently, Fast Data are being sent to the University of Hawaii. Soon, Richards Bay and Port Nolloth will be included in the fast-data streams.

Pneumatic Sea Level Gauges

David Pugh, Southampton Oceanography Centre and Liverpool University
David Smith, Proudman Oceanographic Laboratory
Ana Paula Teles, Southampton Oceanography Centre

Summary

Pneumatic sea level gauges have several advantages over alternative systems, since they do not require vertical mounting structures. However, care is necessary to avoid systematic errors due to gas flow and waves. Examples of novel uses of pneumatic controls are given.

Principles of the bubbler gauge

Bubbler gauges can be installed where the recorder is 200 m or more from the underwater outlet, and are used as standard on the UK A-Class network of sea level stations. The pressure at some fixed point below the sea surface is related to the overlying water level:

$$P = P_A + \rho g\, h \qquad (1)$$

Where P is the measured pressure at the instrument depth, P_A is the atmospheric pressure acting on the water surface, ρ is the mean density of the overlying column of sea water, g is the gravitational acceleration, and h is the depth of the water column above the transducer.

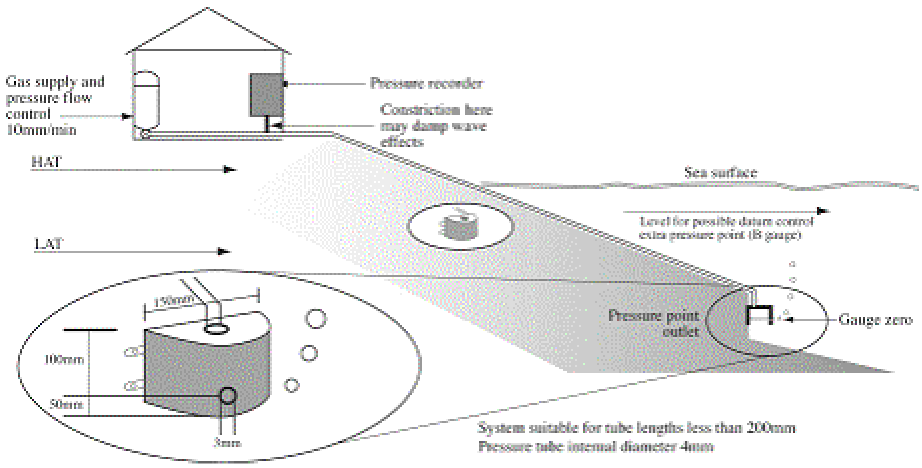


Figure 1. A typical bubbler gauge installation (From Pugh, 2004, copyright reserved).

A gas-bubbling system, such as that shown in Figure 1, is a simple tide gauge with good overall accuracy and datum stability. Compressed air or nitrogen gas from a cylinder is reduced in pressure through one or two valves, so that there is a small steady flow down a connecting tube to escape through an orifice in an underwater canister, called a pressure point. The level of the orifice is the gauge zero. At this underwater outlet, for low rates of gas escape, the gas pressure at the pressure point is equal to the water pressure P. This is also the pressure transmitted up the tube for measuring and recording.

The normal procedure is to measure the pressure using a differential transducer, which responds to the difference between the system pressure P and the atmospheric pressure P_A, so that only the difference $(P - P_A)$, the water head pressure, is recorded. If g and ρ are known, the water level relative to the pressure point orifice datum may be calculated from equation (1). For most sites, a suitable constant value of water density ρ may be fixed by observation. However, in estuaries, the density may change significantly during a tidal cycle, in which case an increase in density with water level can be included in the processing and calculations.

Theoretically, for laminar flow, the pressure drop across the connecting tube, in terms of the tube length and radius, and for the minimum air-flow consistent with preventing water from entering the system even at the maximum rate of sea level rise, is:

$$\Delta P_{max} = \left(\frac{8\eta}{10}\right)\left(\frac{\partial h}{\partial t}\right)_{max}\left(\frac{length}{radius}\right)^2 \Phi$$

where η is the gas viscosity, and Φ is a dimensionless number between 1.5 and 2.5, depending on the system design (Pugh, 1972). There is a hysteresis due to adjustments of the gas in the system through the rising and falling phases of the tide. For an 8-m tidal range.

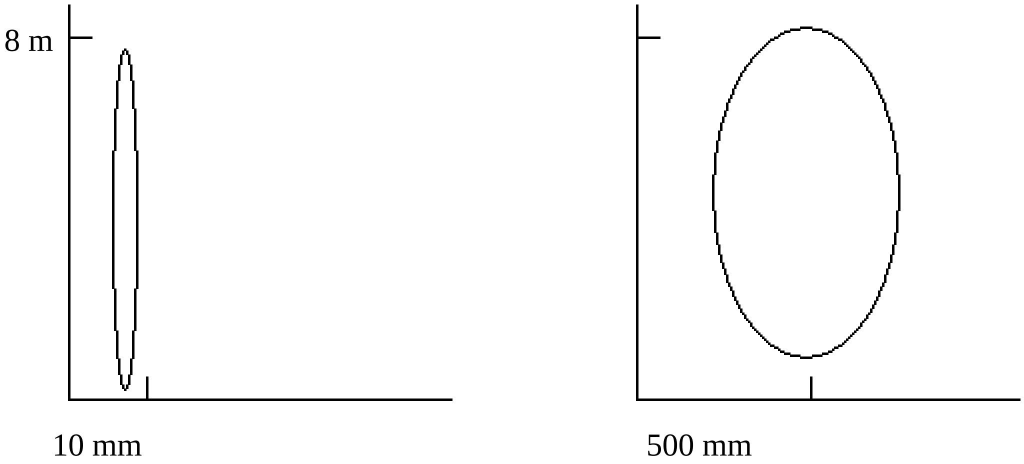


Figure 2. Hysteresis in a bubbler system with 1.9-mm tube radius. Tube lengths are 200 m (left) and 1500 m (right).

The underwater pressure point is a critical and sometimes neglected part of the system. It is designed to prevent waves from forcing water into the connecting tube. If this happened there would be large errors. To avoid errors due to waves, the critical parameter is the ratio between the total volume of air in the pressure point and connecting tube, and the area of the pressure point cross-section. In practice, the connecting tube between the underwater outlet and the recorder achieves some wave damping. For short tube lengths, if waves are a problem, a narrow wave damper can be inserted at the entrance to the pressure recording system (see Figure 1).

The theoretical wave effect on the measured level (E), where s is the wave amplitude, V is the system volume and A is the cross-sectional area of the pressure point is

$$E = \left(\frac{V}{A}\right)\left(\alpha - \frac{\alpha^2}{2} + \frac{15\alpha^3}{6} + \ldots\right) \qquad \alpha = \frac{s}{10 + h_0}$$

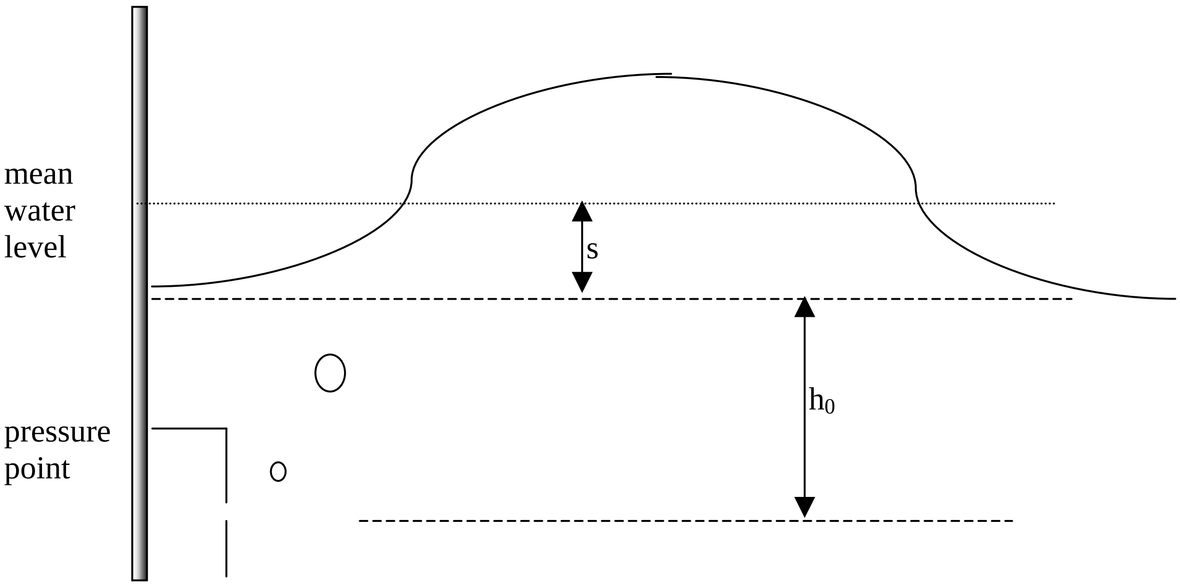


Figure 3. Wave parameters for pressure point corrections.

Which for most purposes reduces to

$$E = \left(\frac{V}{A}\right)\frac{s}{(10 + h_0)}$$

The parameter "10" in the denominator is the atmospheric pressure in water-head metres. For example, a 1-m wave amplitude on a 7-m sea level for *V/A*=0.5 m gives an error of 33 mm, but under normal conditions, errors are much less than this. For tube lengths up to 200 m, the system shown in Figure 1 will almost always be accurate to within 0.01 m.

The datum of a bubbling system is the small bleed hole on the side of the pressure point. This must be rigidly fixed to some structure or to the sea bed. Datum control accuracy can be improved by having a parallel system (called a B Gauge) with a second and more accessible pressure point fixed near mean sea level. This serves the same purpose as the datum switch for the stilling well systems, but in this case, comparing the differences between the two bubbling gauges when both are submerged checks the datum.

One great advantage of bubbling systems is that they do not need a vertical structure. Separations between the pressure point and the recorder of up to 200 m are relatively straightforward, and with careful design and corrections, connecting tube lengths of 400 m or more is possible. Other advantages of a bubbling system include the stability of a clearly defined datum, and the cheap expendable nature of the vulnerable underwater parts. Even if the connecting tube is accidentally cut, it can be repaired and the system re-established by purging water from the system with a high-pressure airflow for a short period.

UK tide gauge network

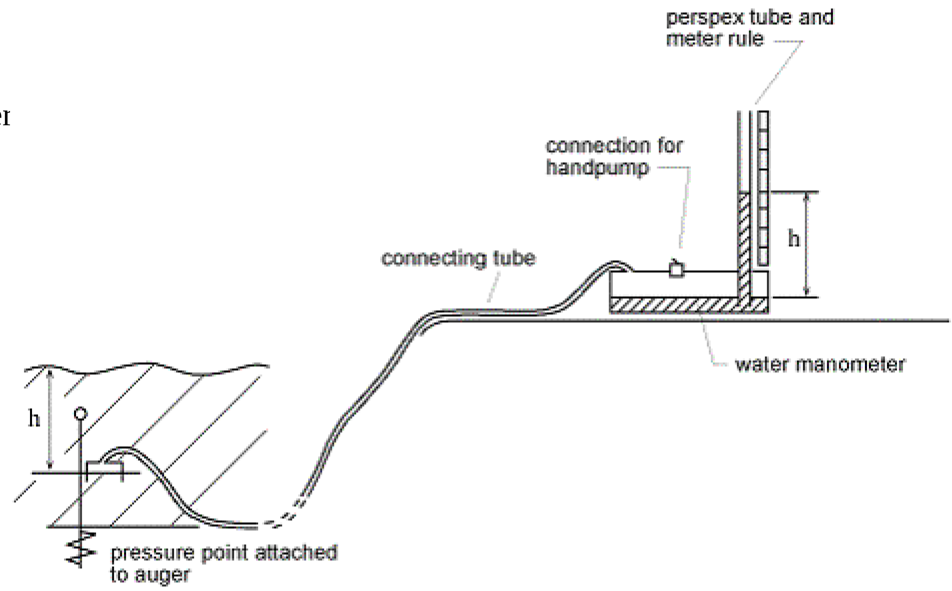
The majority of UK network sites are equipped with bubbler systems developed at the Proudman Oceanographic Laboratory (www.pol.ac.uk/ntslf/tgi). A compressor provides a supply of regulated filtered air to a pneumatic control panel. The air is then metered down to the pressure point, normally fixed about 1 m below the lowest astronomical tide, so that negative surges may be recorded. The air tube is protected in a steel channel to the pressure point. A second pressure point is fixed at mid-tide level. The elevation of this point can be accurately connected to the local geodetic network. Once the height of the mid-tide is known, the datum of the full-tide pressure point can be established. At sites on the UK network, the air-tube length ranges from 10 m to 150 m.

Figure 4. The mid-tide pressure point for the bubbler installation at Lerwick, Scotland.

Other pneumatic sea level systems

The correction for waves given above would apply equally for the slow cyclical level changes due to tides. This leads to the concept of a pneumatic gauge without the bubbling mechanism, sometimes called the "non-bubbling bubbler gauge". As sea levels rise, the water enters the pressure point just sufficiently to reduce the volume and to increase the pressure to compensate. In the above example, with V/A=0.5 m, the water would enter (and the datum level rise) by 0.1 m for a rise of 2 m from low to high tide, which can easily be corrected for by increasing the calibration factor by 5%. Figure 5 shows a very simple improvised system where the pressure is read by a manometer filled with sea water, so avoiding the need for density corrections (Pugh, 1978).

Figure 5.
Schematic diagram of a simple non-bubbler system.



Another useful pneumatic system is shown in Figure 6. Here the tidal variations in an electronic pressure sensor that measured instantaneous values were found to be seriously affected by wave noise. By housing the logger in a plastic (domestic food storage) container, with a hole in the bottom with a diameter 10% of the container, effective wave damping was achieved and the sensor was partly protected from corrosive sea water (Teles and Pugh, 2002; Teles, 2003). This is analogous to the general damping principles of traditional stilling wells. In all non-bubbling systems, there is a progressive upward datum drift as air is gradually absorbed into the sea water, but both the above systems work well for several weeks.

Pneumatic systems for measuring sea level have many advantages especially for difficult installations, and with ingenuity can make shore-based measurements possible in circumstances in which other methods are not viable.

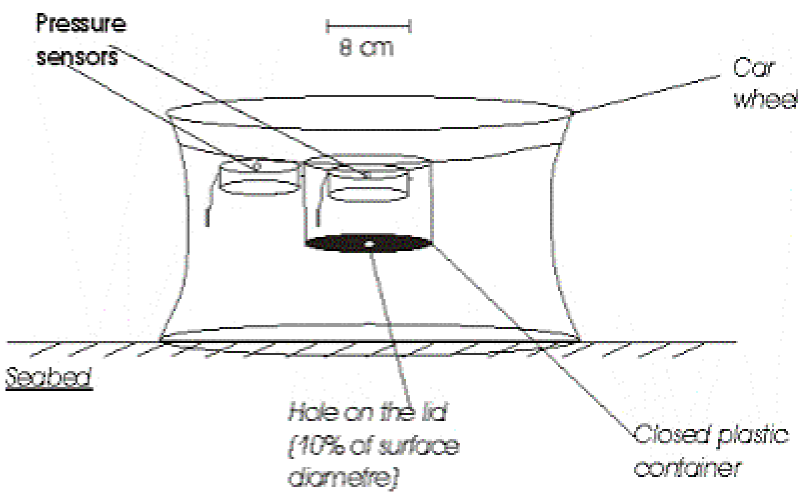


Figure 6. A simple wave damper for electronic pressure sensors.

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"B" Type Pressure Gauges in the South Atlantic

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Introduction

This paper decribes the use of precise datum control in pressure gauges run by the Proudman Oceanographic Laboratory (POL) at various locations in the South Atlantic. The method is described in detail in Woodworth et al. (1996) and is also covered more generally in IOC Manuals & Guides 1–3 (especially 3) which can be downloaded from: http://www.pol.ac.uk/psmsl/training. The use of other pressure systems by POL throughout the South Atlantic and Antarctic is also described.

Transducer pressure gauges

Transducer pressure gauges usually consist of a single transducer in the sea. The problem with these gauges is that they have poor datum control, owing to instrument drift. With calibration (best done with a tide staff), these transducers can achieve 2–3 cm accuracy and are an excellent choice for measuring sea level under hostile conditions; e.g. under polar ice. One known difficulty with pressure gauges is due to the density variations in rivers, and similarly for deep gauges, since a density profile has to be assumed for conversion of the pressure to depth.

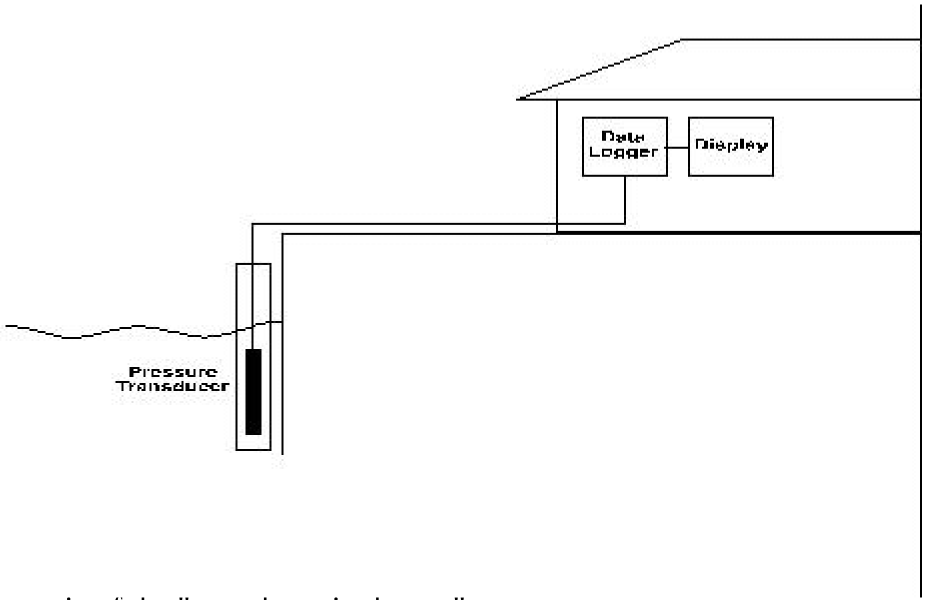

Figure 1. Schematic of the "transducer in the sea" pressure system.

"B" or "triple" pressure systems

"B" gauges are different from traditional transducer pressure gauges in that they employ an additional sensor at approximately MSL. Using this system, millimetric datum control can be achieved. However, a sizable tidal range is necessary for the system to work properly, since the half-tide sensor must spend approximately half the tidal cycle out of the water. Most coastal and island sites fulfill this requirement, though lakes may not.

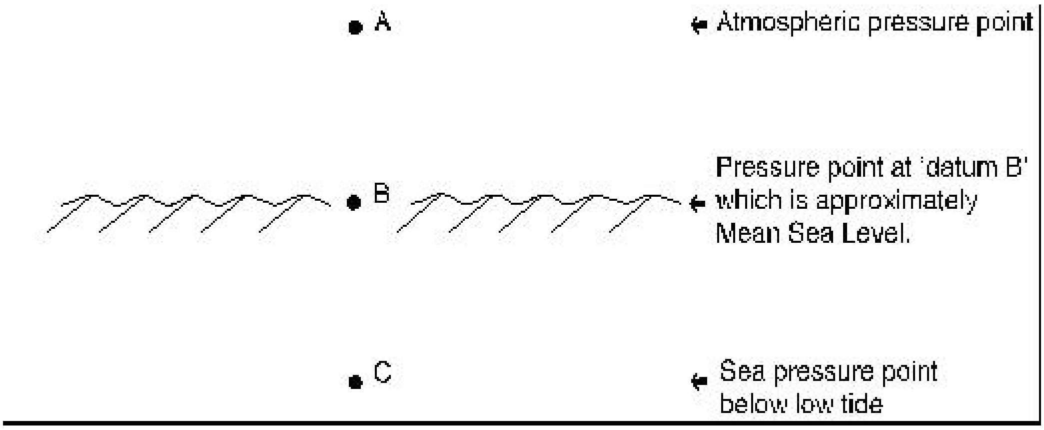

Figure 2. Schematic of a pressure gauge set-up using three pressure transducers. Note that all three transducers can drift, as can the ocean itself.

Construction of the "B" gauge

The mid-depth and full-depth transducers are both actually mounted at the same depth. In the new "all-in-one" gauges, the barometer is also at the same depth. A pipe leads from the mid-depth transducer to mid-tide point "B" (and from the barometer to "A" in the all-in-one gauge). This arrangement ensures that the correct pressures are recorded while maintaining an identical operating temperature for the three transducers. All transducers are housed in a tube which acts as a mini-stilling well.

Principle of the "triple-point" method

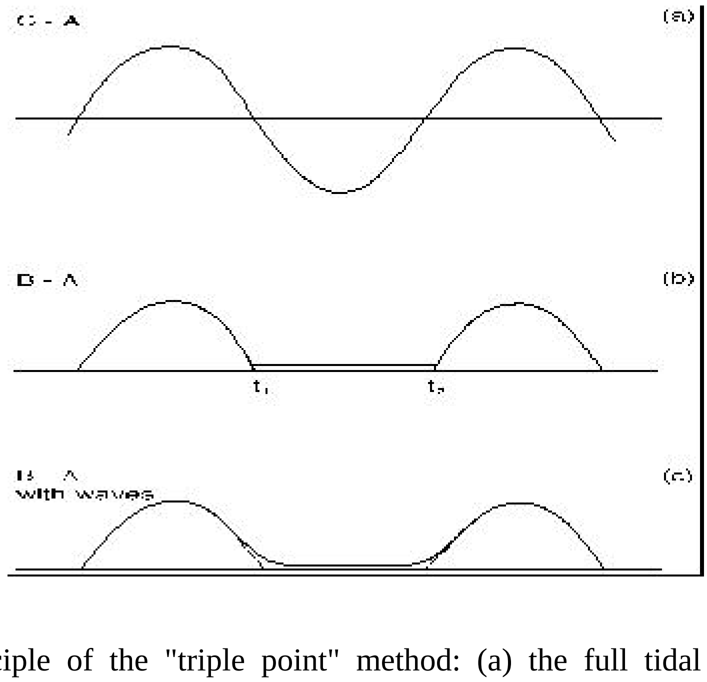

Figure 3. The principle of the "triple point" method: (a) the full tidal curve "C" with the atmospheric pressure signal "A" removed; (b) the half- tide signal "B" with the atmospheric pressure signal removed; (c) as (b) but showing the effect of waves on the half-tide curve.

The method uses the mid-tide sensor level (B) to provide a datum. Subtracting the atmospheric signal (A) from the mid-tide pressure signal (B) provides a half-tide signal with the portion of the signal where the mid-tide point is out of the water giving a fixed datum. The flat part of the B–A curve is immune from any problems with datum offsets or instrument drift. When the B–A curve is overlaid on the C–A curve, the intersection of the flat line with the full curve defines the datum of the full curve.

"B" gauges in the South Atlantic

"B" gauges using the triple-transducer system are now operated throughout the South Atlantic. Current sites are at Ascension Island, St. Helena and the Falkland Islands. In addition, POL has single pressure transducer systems at Tristan da Cunha, South Georgia and Signy in the S. Atlantic, and at Vernadsky and Rothera in the Antarctic. The principle of having a pressure measurement at approximately MSL has also been incorporated into the UK bubbler network. In this case an additional bubbler outlet is placed at MSL.

The triple system is inevitably expensive because several transducers are required. We are experimenting with cheaper transducers (Druck instead of Digiquartz) to try and reduce costs.

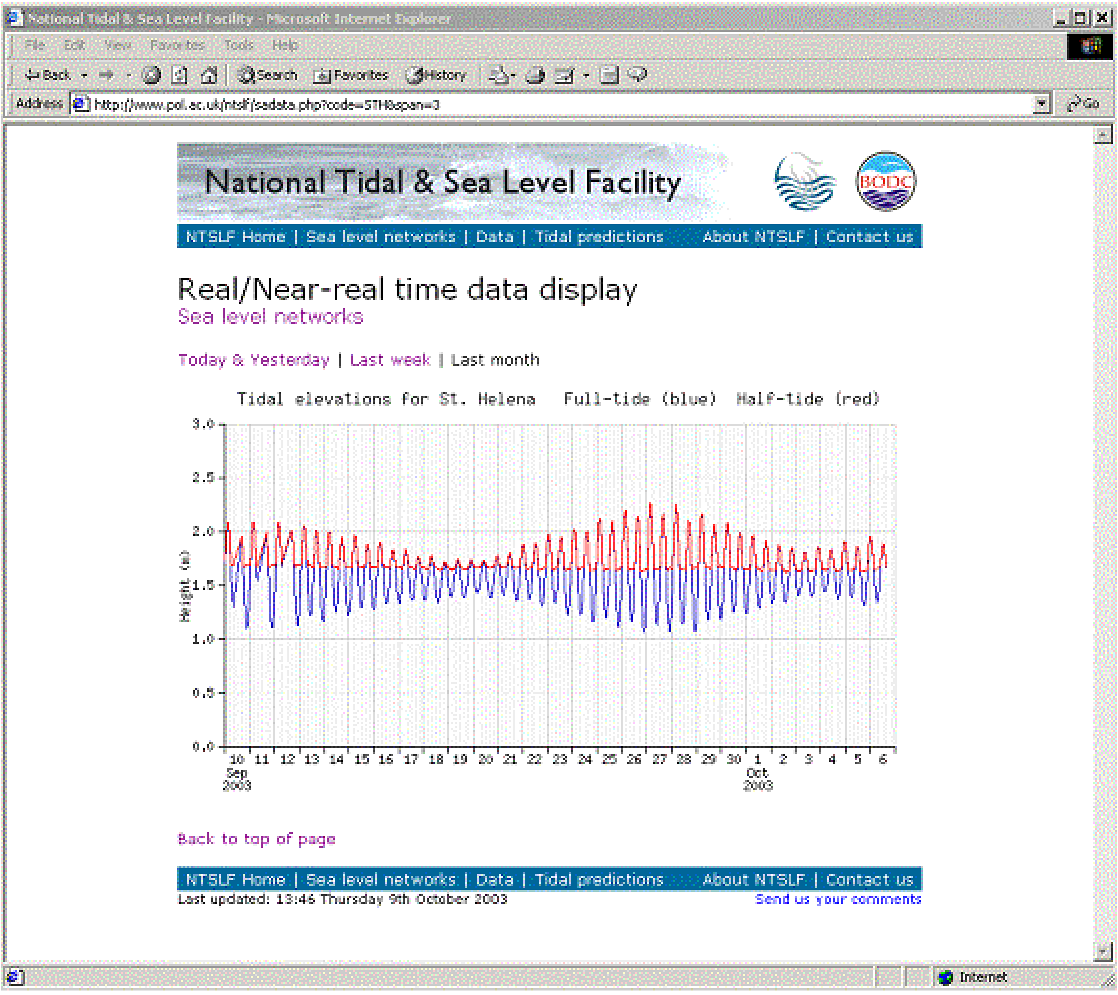

Figure 4. "Real-time" data are available from the South Atlantic "B" gauges via the web.

Data communications

Data are returned by hourly e-mails from Ascension, St. Helena and the Falklands. The facility to dial up the data loggers directly and query them at any time is also included. From Ascension the telecommunication is via the Iridium satellite, though from St. Helena and the Falklands, e-mails are sent via a local Internet Service Provider.

Once the e-mails are received at POL, they are automatically banked in the database. This allows us to provide a “real-time” data display on the web. Automatic weekly data e-mails are also provided to the University of Hawaii Sea Level Center. The data are not fully quality controlled for the “fast data" provision, but are fully checked and calibrated on a yearly basis for “delayed-mode” research-quality data.

The future

The development of better communications with POL's South Atlantic sites via the ORBComm system is currently being explored. This system, it is hoped, will allow “real-time” data to be sent from all our S. Atlantic and Antarctic sites, not just the "B" gauge sites. At present POL is undertaking field trials to explore the viability of this technology.

We are also planning to upgrade the Tristan da Cunha gauge from a single transducer system to a radar-based system in the near future. Radars have the benefit of being cheap and with low maintenance cost. Other sites will be upgraded to "all-in-one" gauges.

Pressure Gauge Experiments in India

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Pressure measurements made in differing turbid water bodies and turbulent clear-water bodies have led to the inference that the effective mean-depth in situ density value, ρ_{eff}, of these water bodies is less than the corresponding bulk density. The value of ρ_{eff} is also less than the density of the same turbid water after removal of suspended sediment. It was found that the use of bulk density to estimate tidal elevation yielded an under-estimation of tidal range. While the under-estimation was up to ≈7% of the tidal range in the Hugli estuary, it was close to zero in the clear calm waters of the Zuari estuary. The under-estimation observed at many other sites was within these two extremes. The percentage under-estimation of tidal range was in agreement with the percentage reduction in the density of water at these sites compared to the corresponding bulk density. The under-estimation could be corrected with the use of the ρ_{eff} parameter. The effective mean density directly estimated by the use of a dual pressure gauge system was in close agreement with the density of water samples measured using a precision densitometer. Good quality sea level measurements can be obtained from pressure gauges by the use of the ρ_{eff} parameter obtained from dual pressure gauge systems. When single pressure gauge systems are deployed, the mean ρ_{eff} parameter can be derived with a lesser accuracy by a procedure of periodic *in situ* calibration using a fine-resolution tide-staff. The use of ρ_{eff} will marginally improve the accuracy of water level measurements also from clear-water estuaries where mean-depth water density undergoes marginal changes with differing phases of the tide and significant changes with seasons, but will result in more significant improvements at sites where suspended sediment is high.

Introduction

A variety of devices are employed for the measurement of sea level (Joseph, 1999). Each of these devices has its peculiarities and varying suitability for various deployment environments. The accuracy that can be achieved also depends on the site conditions (Vassie et al., 1992; Joseph et al., 1997a, 1999a, 2002). Irrespective of the techniques employed, the performance in the real-deployment environments needs to be assessed to derive the optimum benefit from their use.

Pressure transducers are widely used in India for automated measurements of sea level at sites along estuaries, in gulfs and remote shallow coastal regions and on islands. The choice of pressure transducers has arisen primarily as a result of their portability and their ability to be deployed quickly on or close to the sea floor. The pressure transducers used in these gauges included metal strain gauge (Peshwe et al., 1980), quartz pressure transducer having a frequency output (Joseph and Desa, 1984), user-programmable quartz pressure transmitter directly providing temperature-compensated pressure output in computer-compatible format (Joseph et al., 1999b), and user-programmable semiconductor strain gauge providing temperature-compensated pressure output in computer-compatible format. This paper addresses the field performance of pressure gauges deployed in India.

Measurements from the turbid waters of the Hugli estuary and a partially constrained turbid water body at Appollo Bundar. Hugli estuary (Figure 1a) is exceptional in terms of its high turbidity throughout the year. At Hugli Point Station, which was fairly free from wave activity, we deployed a differential quartz (Paroscientific) pressure transducer with an FM output, whose negative port was vented to the atmosphere. Venting of the negative port was to compensate for the inverted barometer effect. The transducer housing was rigidly attached to a vertical post driven into the riverbed. The transducer's positive port was exposed to water via an oil-filled capillary tube. A flow retarding perforated cap over the positive port minimised the Bernoulli effect. This ability of a perforated cap was verified in a later experiment conducted by us in a flow flume (Joseph et al., 1995). Each value of water level recorded in the logger was an average over 30 seconds, to filter out short-period fluctuations and long-period waves (swell) in tidal records of wind waves.

The density of a water–sediment mixture (i.e. bulk density) at the measurement site (1.062 g/cm^3), together with differential pressure data, was used to estimate the water elevation above the pressure port. Readings from a tide-staff at the measurement site were used to reference the pressure-derived water level to the chart datum (CD). This referencing was done at the time of slack water during which the tidal current was negligible and, therefore, tide-staff readings could be made with minimal disturbance from current-induced piling effects. Initial offset adjustment of the pressure gauge was made at high tide so that the pressure-derived water level matched with the tide-staff measurements within observational accuracy (±1%).

A typical result of measurements at this location is shown in Figure 2a. It is seen that, as the water level decreased from the high tide stage, the difference ΔH between the pressure-derived water level and the tide-staff readings increased. In this case, the value of ΔH was positive and gradually increased with time, reaching a value of 23 cm at low tide. In a subsequent measurement, offset adjustment was carried out to obtain a match between the gauge outputs and the tide-staff measurements at low tide. In this case, a different offset was required to obtain the match. As the tide level increased, ΔH was negative and became increasingly negative (Figure 2b), reaching a value of 39 cm at high tide. The results indicated in Figure 2a,b essentially revealed an under-estimation of tidal range. Similar results were obtained when another similar pressure transducer replaced that used in the present measurements. It was possible to show that neither the temperature sensitivity of the pressure transducer nor that of the time-base in the data logger could account for the observed large under-estimation in tidal range in the Hugli measurements.

Joseph et al. (1999a) have shown that tidal range under-estimation can occur if the effective fluid density, ρ_{eff}, which actually contributed to the pressure sensed by the transducer, is less than the bulk density, ρ_b, of the water column above the transducer's pressure inlet (ρ_b being used for estimation of tidal elevation). The value of ρ_{eff} can be computed using the expression (Joseph et al., 1999a):

$$\rho_{eff} = \{(P_H - P_L)\,\rho_b\} / \{(g\,\rho_b\,R_{error}) \; (P_H - P_L)\} \qquad (1)$$

where, P_H, P_L: time-averaged pressure sensed by the gauge at high tide and low tide respectively. R_{error} is the error in tidal range (i.e. difference between true tidal range and estimated tidal range based on ρ_b)

Figures 3 (a,b) and 4 (a,b) indicate that use of ρ_{eff} in place of ρ_b significantly reduced the error in the measurement of turbid-water level. A paradoxical result, indicated by pressure measurements in the turbid waters of the Hugli estuary, is that the *in situ* effective density of natural turbid water turns out to be less than its bulk density.

Measurements made at a partially constrained turbid water body within a concrete well (Figure 5), which was hydraulically connected to the sea via two tubular ducts at its bottom portion, also revealed an under-estimation of tidal range. In this experiment, a Digiquartz temperature-compensated intelligent differential-pressure transmitter, whose accuracy under quiescent conditions is stated to be 0.01% of full-scale, was used to obtain 30-second-average water-pressure measurements. The output from a float gauge deployed within the concrete well was used for intercomparison. Measurements in this partially constricted turbid water body revealed that the pressure gauge under-estimated the tidal range by ≈2% in comparison to float-gauge measurements, when the measured water density was used for conversion of pressure to sea level (Figure 6a). An analysis (Joseph, 1996) based on equation (1) revealed that the effective water density, ρ_{eff}, which contributed to the pressure sensed by the gauge, was 1.004 g/cm^3, in contrast to the measured seawater density of 1.023 g/cm^3. Thus, the effective mean-depth *in situ* density value, ρ_{eff}, of this constricted water body was less than (≈2%) the measured density of the water sample. A comparison of tide levels recorded by the float gauge and the pressure gauge with the use of effective density is given in Figure 6b. The difference in the percentage error of water levels using measured and effective densities was within 2% (Figure 6c).

Measurements in clear water of the Zuari estuary using two pressure transducers

The main purpose of the present experiment was to directly measure the effective mean-depth water density, at least over a defined height of water column. Two Digiquartz (Paroscientific) intelligent differential-pressure transmitters were mounted with a vertical separation of 100 cm between their pressure inlets. The positive ports were attached to pairs of thin horizontal parallel plates (Figure 7), whose diameter was approximately four times that of the transducer housing, to reduce the adverse effects of flow and wind waves (Shih and Baer, 1991; Joseph et al., 2000). The two transducers were rigidly mounted on a vertical ladder. Both the transducers were positioned below the CD so that they were fully submerged during low tide. As the two pressure transducers were deployed with a vertical separation, *S*, between their pressure inlets, the value of ρ_{eff} of the water column of height *S* could be estimated in real time from the simultaneously measured time-averaged (30 seonds) pressures P_1 and P_2 using the relation:

$$\rho_{eff} = (P_1 - P_2) / (S \times g) \qquad (2)$$

where ρ_{eff}, P_1, P_2, S, and g are all expressed in the same system of units.

The density of water samples was 1.022 g/cm^3, as measured with a precision densitometer having a precision of 0.001 g/cm^3. It is seen that the effective density, ρ_{eff}, estimated by the dual pressure transducer system deployed in the clear waters of the Zuari estuary was in close agreement (Figure 8) with the density of water samples measured using a precision densitometer.

Measurement in the Mandovi–Zuari estuarine network using a metal-strain-gauge pressure gauge.

The Mandovi–Zuari estuarine network (Figure 9) joins the Arabian Sea on the west coast of India. A narrow canal, the Kumbarjua Canal, connects the two estuaries, thereby forming an estuarine network. There are some iron-ore beneficiation plants situated on the Mandovi riverbank, where the ore is washed with river water and the wash water is discharged directly into the estuary. This discharge contains high quantities of sediments rich in iron and causes high turbidity in the Mandovi estuarine water in its upstream region (de Souza, 1999).

The tide gauge used in the present work was a temperature-compensated metal-strain-gauge pressure transducer whose precision is ±0.1%. The pressure inlet remained at the center of and flush with a flat surface, thereby minimizing the undesired Bernoulli dynamic pressure effects arising from flows, waves and a combination of flows and waves (Joseph et al., 2000). The pressure transducer, electronics and a battery pack were housed in a pressure-resistant housing (Desa et al., 2003) that could be easily mated to a mounting attachment. The data sampling frequency was 2 samples/sec, and the sampled 12-bit data were averaged over 40 seconds. The data acquisition was performed at an interval of 15 minutes.

We discuss the results obtained from deployment at the Kumbarjua Canal, where turbulence in the vicinity of the pressure gauge was severe. The deployment was for a period of 2 weeks. A fine-resolution (1 cm) benchmark-leveled tide staff, which has been erected in close to the pressure gauge, was used for the purpose of inter-comparison and estimation of the ρ_{eff} parameter. For the purpose of performance evaluation of the pressure gauge, we used pressure measurements and simultaneously acquired tide-staff observations, and obtained a statistical relation between them using linear regression. When both measurements are in the same system of units, the reciprocal of the slope (m) of the linear regression equation represents the effective density, ρ_{eff}. The intercept (c) represents the vertical separation of the pressure gauge with reference to the "zero" of the tide-staff. The constants m and c obtained from the above statistical procedure were applied during post-processing to convert all the time-series pressure measurements to water level elevation. This procedure was expected to take into account many poorly understood problems of natural waters as a result of a variety of dynamically induced local effects.

The gauge was rigidly mounted on a ≈5-cm-diameter cylindrical staff, and this staff was in turn rigidly mounted on a 2-m-diameter cylindrical pillar of a bridge. The flow obstruction by the pillar introduced visibly large turbulence in the vicinity of the pressure gauge. However, the tide staff was located sufficiently far away from the pillar of the bridge and, therefore, the tide staff measurements were not influenced by the pillar. Although tide staff measurements corresponding to the entire set of pressure gauge measurements were available, in our initial analysis we used only a few representative sample sets of data, centered about the low and high tides during a spring tide, to elucidate the statistical relationship between the two measurements. This was done to examine the effectiveness of using a small data set, in view of the impracticality of making tide staff measurements over long periods. Figure 10a provides the result of regression analysis based on a small data set of pressure gauge and tide staff measurements, centered on the low and high tide during a spring tide. Figure 10b provides the daily mean of the difference, Δh, between water level elevations based on tide staff measurements and pressure-derived water levels with the application of measured density (#) and effective density (*) of water. In either case, the pressure-derived water level with reference to the "zero" of the tide-staff was derived by subtracting the offset [c] of the regression equation (Figure 10a) from the pressure-derived water level above the pressure transducer. While the difference in elevation, Δh, was in the range of approximately 8 cm to 12 cm (weekly mean in the range of 9.54 cm to 11.60 cm) with the application of measured density, the corresponding difference with the application of effective density was in the range of approximately 0.5 cm to 4 cm (weekly mean in the range of 1.33 cm to 3.34 cm). It is seen that application of effective density (i.e. reciprocal of the slope, m, of the regression equation of Figure 10a) for translation of pressure to water elevation has improved the water level measurement by 8 cm, corresponding to 4–5% of Δh (Figure 10c) in relation to the use of measured density. While the percentage Δh (i.e. % accuracy) with the use of measured density was in the range of ≈5% to ≈6% (weekly mean in the range of 5.64% to 6.50%), the percentage Δh with the use of effective density was in the range of approximately 0% to 2% (weekly mean in the range of 0.73% to 1.90%).

Regression analysis based on the entire dataset (pressure gauge and tide staff measurements) is indicated in Figure 11a. Figure 11b provides the daily mean of the difference, Δh, between water level elevations based on the tide staff measurements and pressure-derived water levels with the application of measured density (#) and effective density (*) of water when the entire data set was used for regression analysis. In either case, the pressure-derived water level with reference to the "zero" of the tide-staff was derived by subtracting the offset *c* of the regression equation (Figure 11a) from the pressure-derived water level above the pressure transducer. While the difference in elevation, Δh, was in the range of approximately 5.5 cm to 9 cm (weekly mean in the range of 6.52 cm to 8.58 cm) with the application of measured density, the corresponding difference with the application of effective density was in the range of approximately –2 cm to 2cm (weekly mean in the range of –0.96 cm to 1.05 cm). It is seen that application of effective density and offset (obtained from Figure 11a) for translation of pressure to water elevation has significantly improved the water level measurement when the entire data set was used for regression analysis. The improvement achieved from the use of effective density was 3–5% (Figure 11c) in relation to the use of measured density. While the percentage Δh (i.e. % accuracy) with the use of measured density was in the range of ≈3% to ≈5% (weekly mean in the range of 3.71% to 4.78%), the percentage Δh with the use of effective density was in the range of approximately –1.5% to 1%, which was in close agreement with the accuracy of the pressure gauge. The weekly mean was in the range of –0.76% to 0.59%.

Conclusions

Pressure gauge experiments to elucidate their performance under differing deployment environments, which are prevalent in India, led to the following inference:

Except in calm clear waters, the effective mean-depth *in situ* density ρ_{eff} of natural waters is less than their measured density;

Application of the measured density for estimation of water elevation using pressure measurements gives rise to an under-estimation of tidal range in turbulent and turbid natural-water bodies;

A dual-pressure transducer system with a suitable vertical separation is capable of correctly measuring ρ_{eff} *in situ*; in situations where appreciable density stratification exists, this vertical separation would need to be as large as is practical;

When a single pressure gauge system is deployed, the mean ρ_{eff} parameter can be derived with a lesser accuracy by a procedure of periodic *in situ* calibration using a fine-resolution tide staff. In this case, the data set must cover at least one low tide and one high tide during a spring tide in a given season. Accuracy can be enhanced by the use of a larger data set. For better reliability, tide staff readings can be made during a calm sea state. In long-term sea level measurements, it would be desirable to perform field calibrations on a seasonal basis, because the seasonal changes in the value of ρ_{eff} are related to corresponding changes in suspended sediment concentration, river-water influx, turbulence etc.;

In turbulent clear waters, presence of microbubbles (Turner, 1961; Thorpe et al., 1992) appears to play a role in influencing the effective density. In turbid water bodies, loss of weight by suspended particulates as a result of a dynamic uplift force, probably due to microturbulence in the flowing water body and/or rotation of the suspended particulates, appears to provide a logical explanation for the reduced *in situ* density observed (Joseph, 1996; Joseph et al., 1997b).

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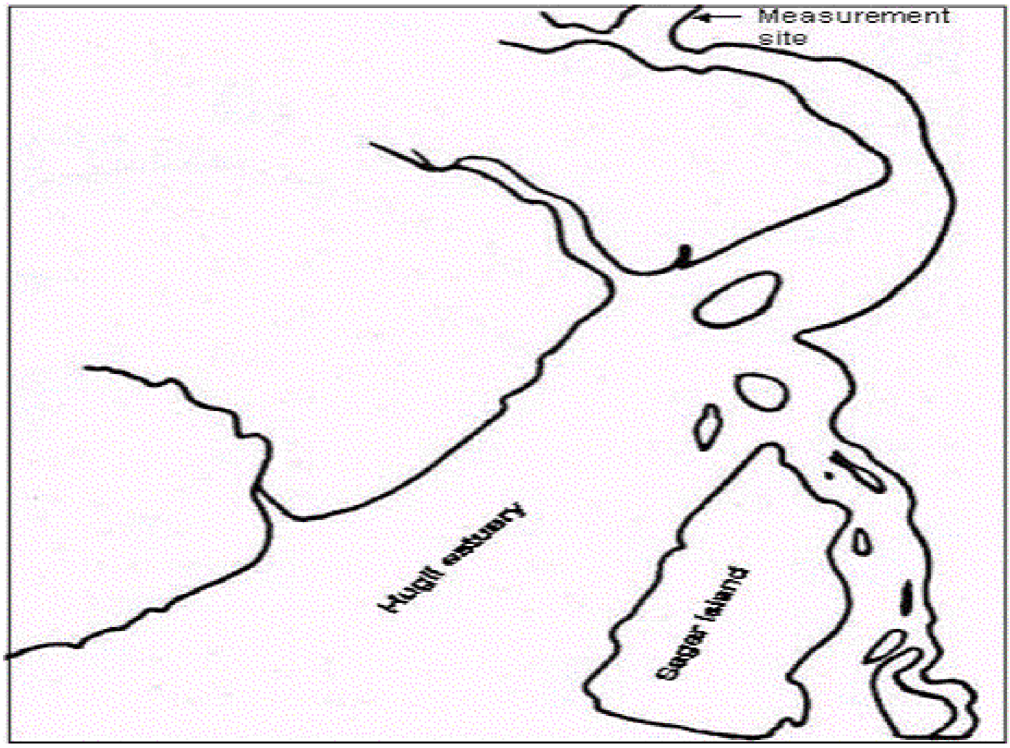


Figure 1. (a) A glimpse of the Hugli estuary, West Bengal, India.

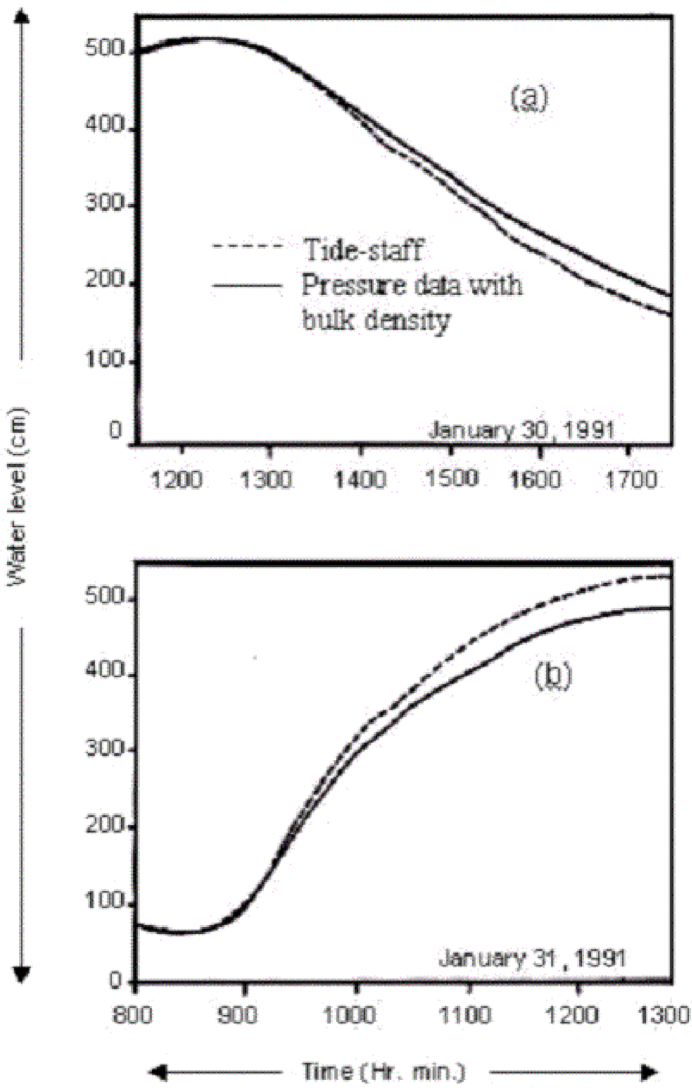


Figure 2. Tidal range under-estimation in the Hugli estuary when average bulk density was used for translation of pressure to water level; (a) offset adjusted at high water and (b) offset adjusted at low water (After Joseph et al., 1999a).

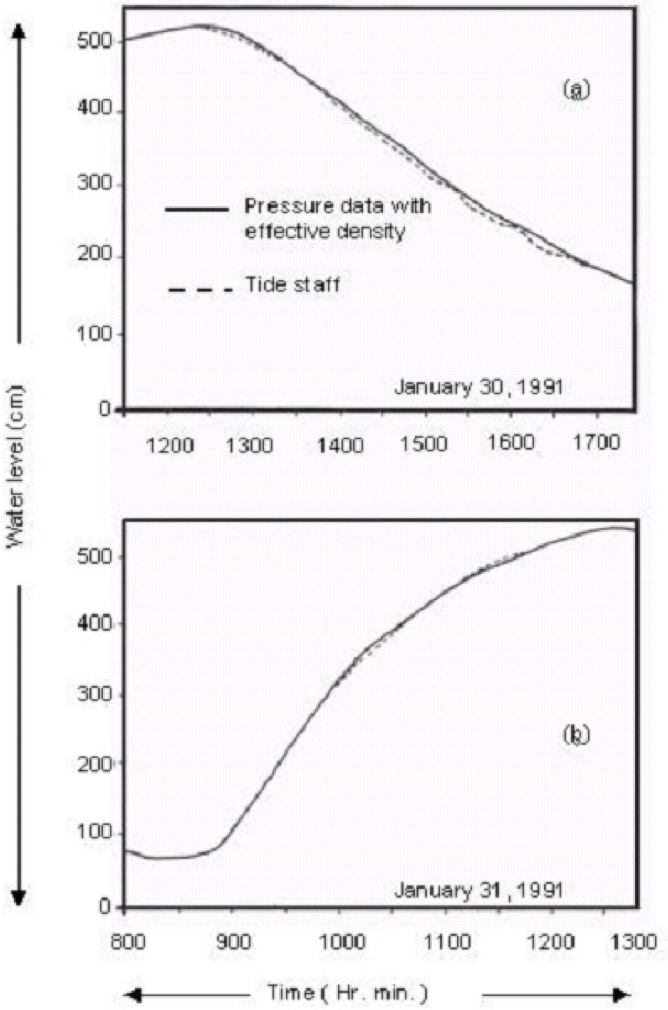


Figure 3. Correction of tidal range under-estimation of Figure 2 by the application of effective density; (a) ebb-tide phase, (b) flood-tide phase (After Joseph et al., 1999a).

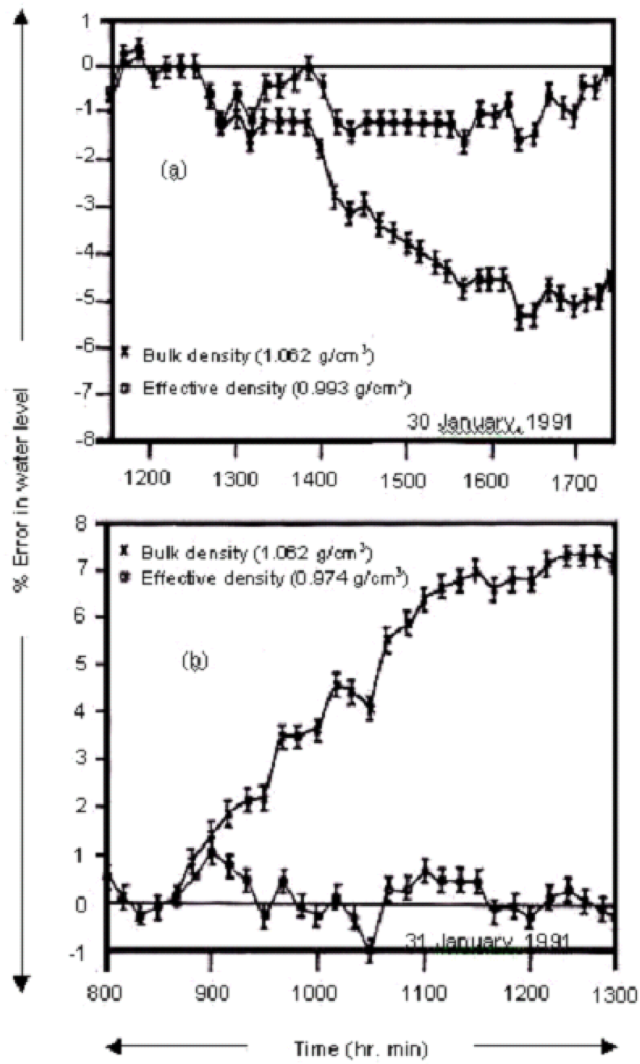


Figure 4. Percent difference in water level of Figure 2 when bulk density and effective density of turbid water were used (After Joseph et al., 1999a).

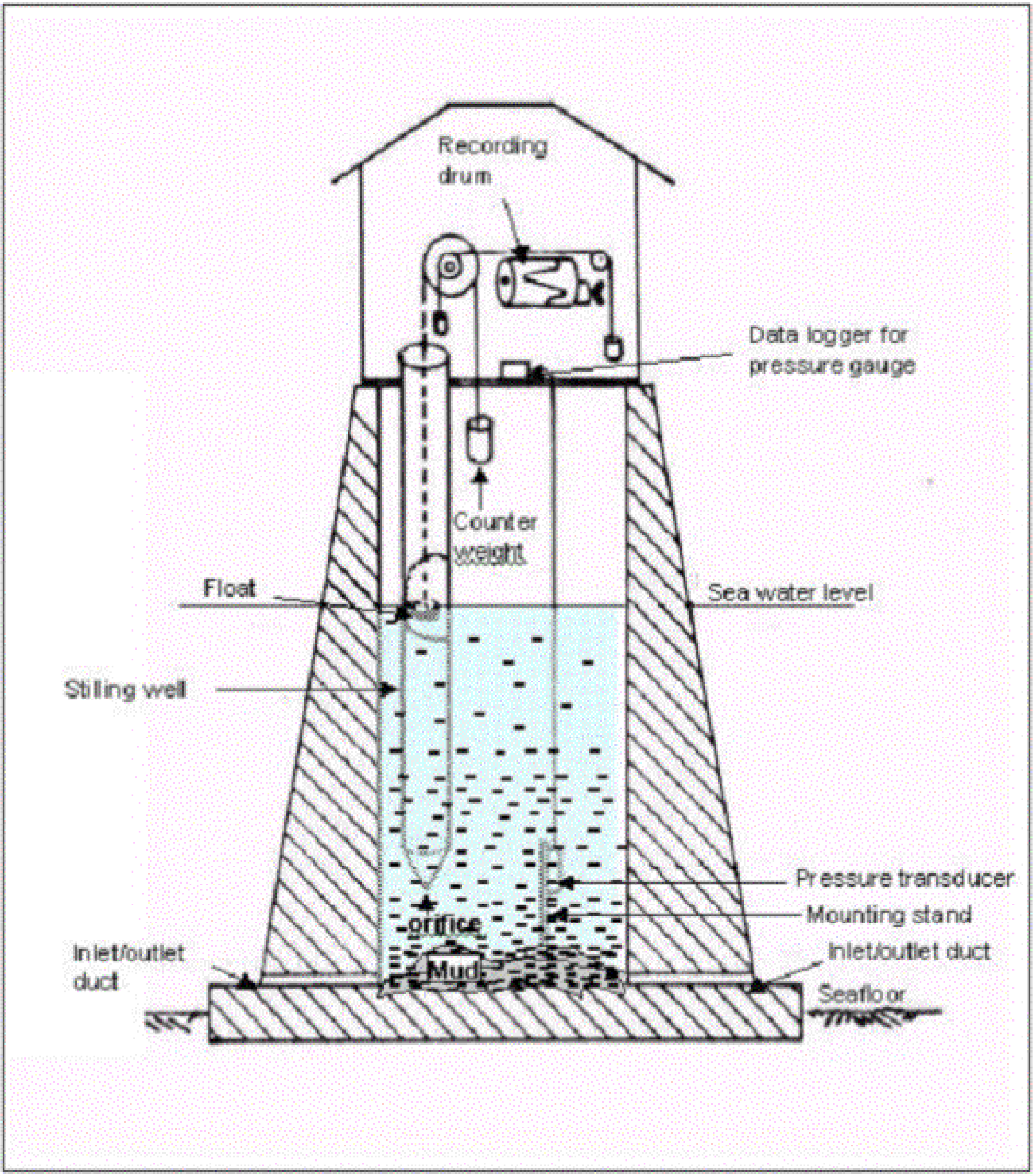
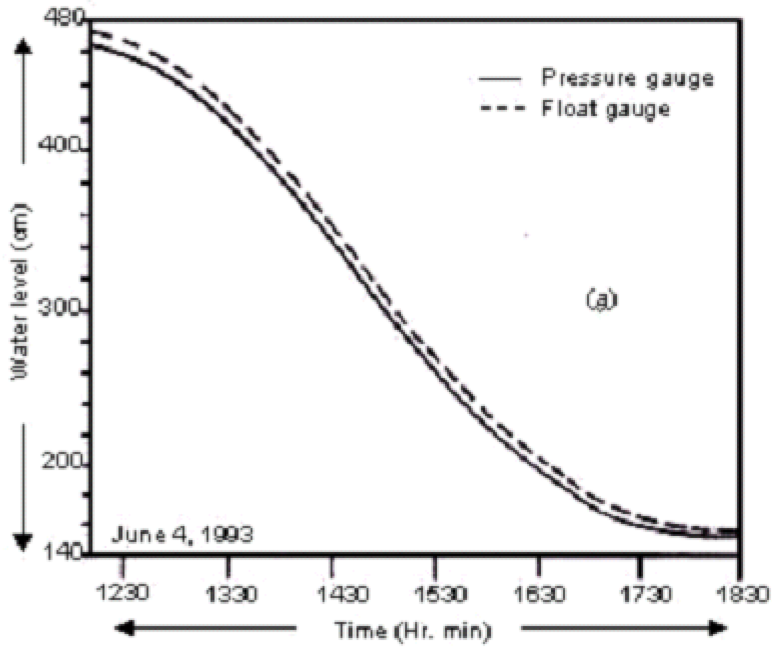


Figure 5. Concrete well, at Apollo Bundar, Bombay, which is hydraulically connected to the sea via two tubular ducts at its bottom portion and trapped sediments (After Joseph, 1996).



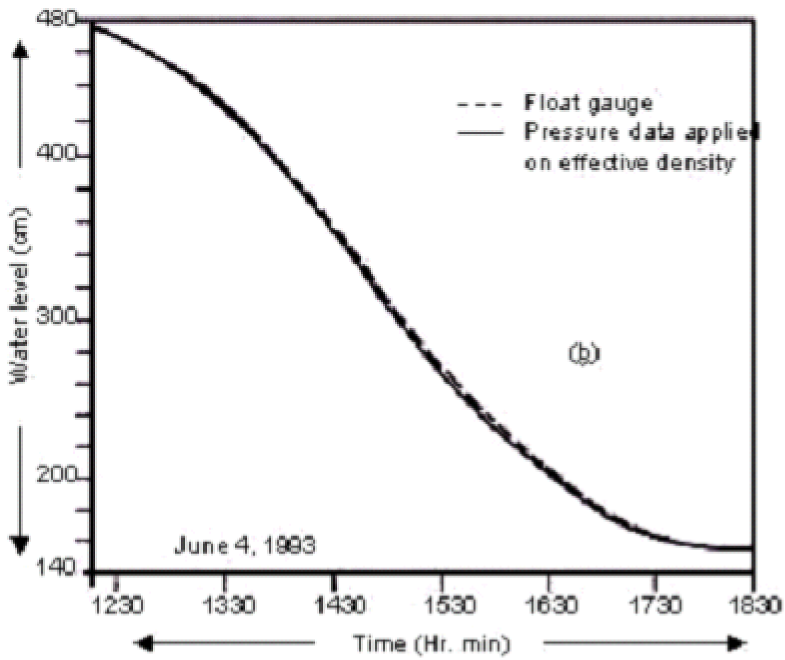
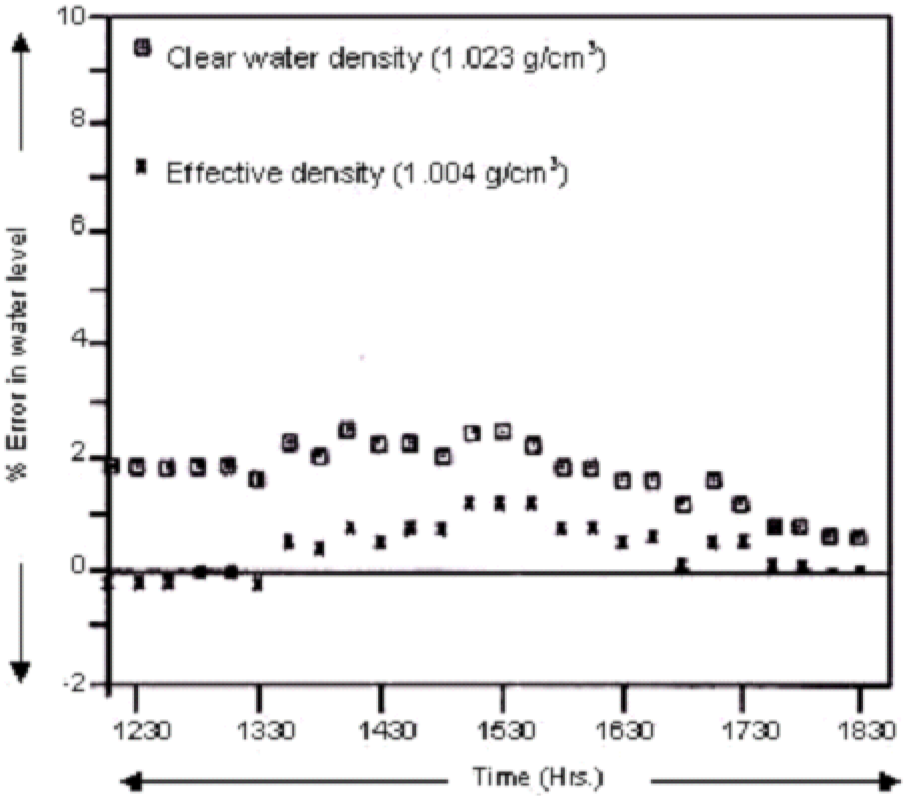


Figure 6. (a) Tidal range under-estimation by a pressure gauge deployed in a partially constrained turbid water body of Figure 5 when the measured density of clear water was used for translation of pressure to water elevation; (b) correction of tidal range under-estimation by a pressure gauge deployed in a partially constrained turbid water body of Figure 5 by the application of effective density (After Joseph, 1996).



(c)

Figure 6 continued. (c) Percent error in water level of Figure 6a when the measured density of clear water and effective density of turbid water were used (After Joseph, 1996).

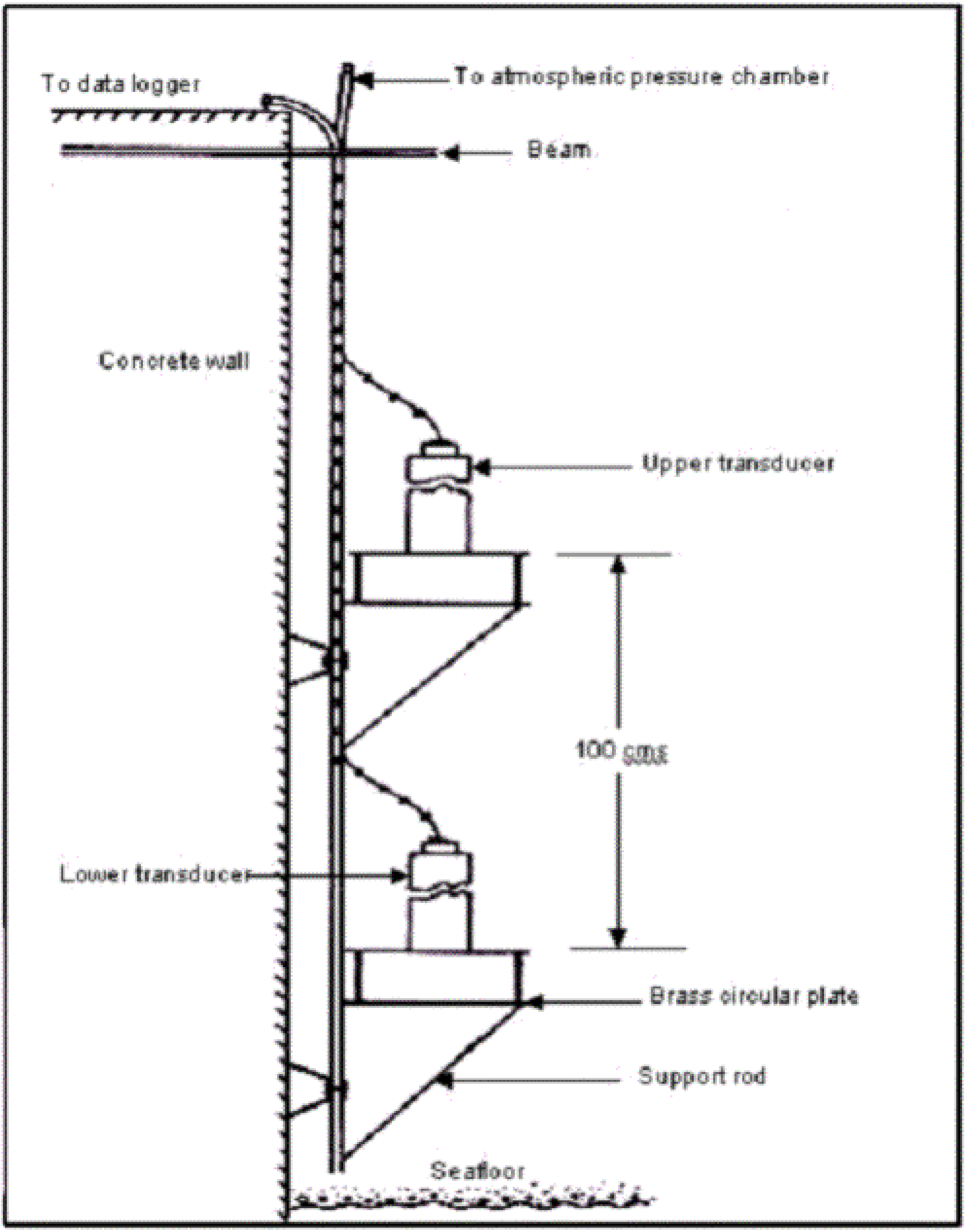


Figure 7. Schematic of dual pressure gauge system deployment in Zuari estuary, Goa, for automated *in situ* estimation of effective density of water and effective-density-compensated measurement of sea level (After Joseph, 1996).

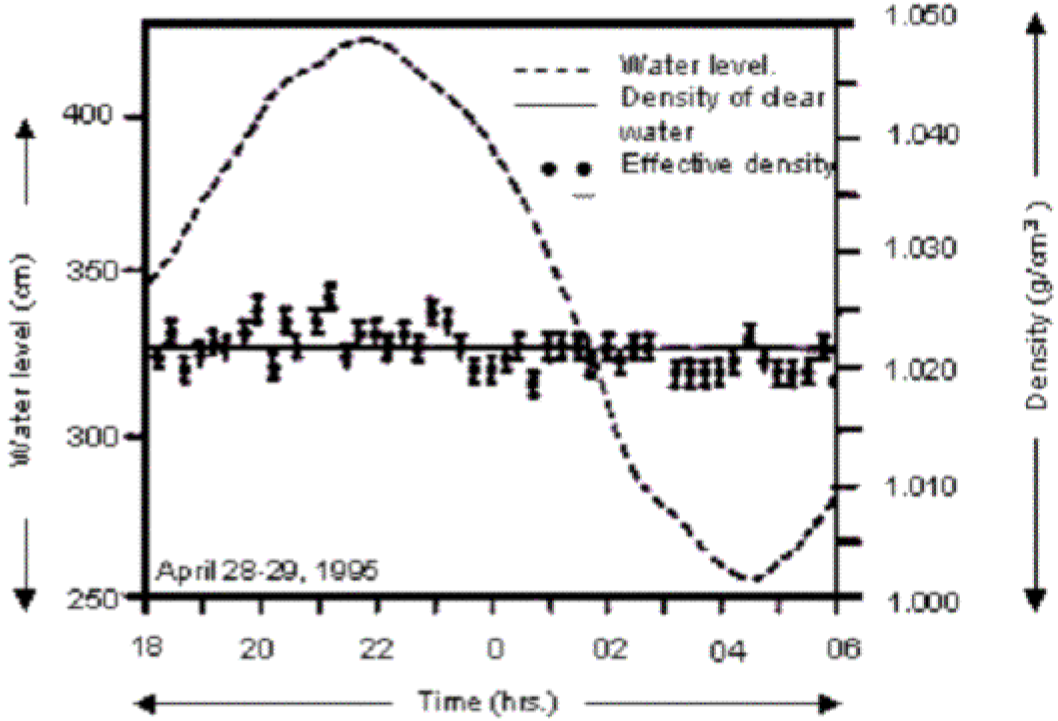


Figure 8. Comparison of measured and effective densities of the clear calm waters of the Zuari Estuary, as a function of tidal elevation above an arbitrary datum (After Joseph et al., 1999a).

Figure 9. A map of the Mandovi–Zuari estuarine network, Goa, India.

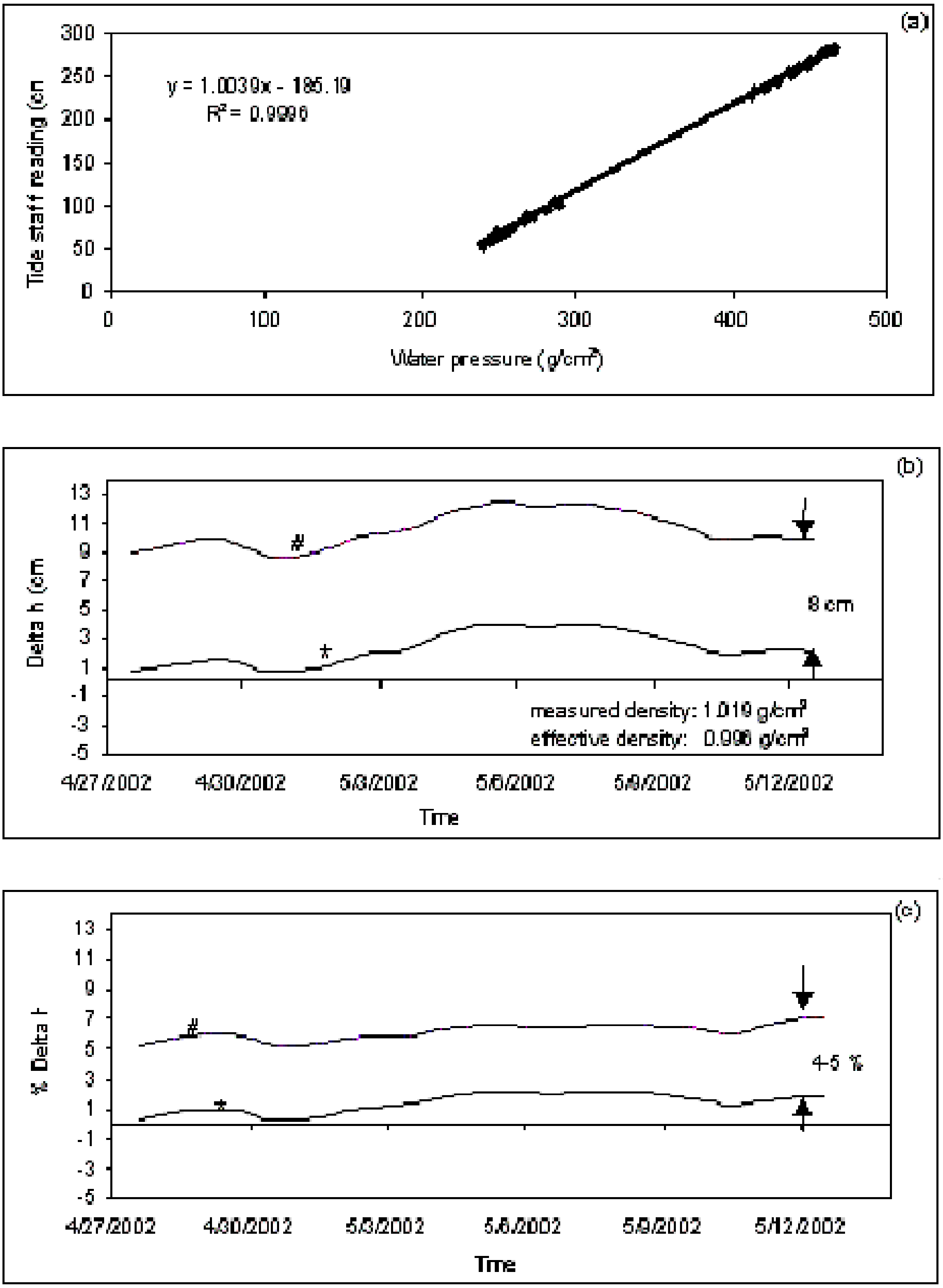


Figure 10. (a) Statistical relation based on regression analysis of a small data set of pressure gauge and tide staff measurements from Kumbarjua Canal site, centred on the low and high tide during a spring tide; (b) daily mean difference, Δh, between tide-staff measurement and pressure-derived water level based on measured density (#) and effective density (*); (c) %Δh.

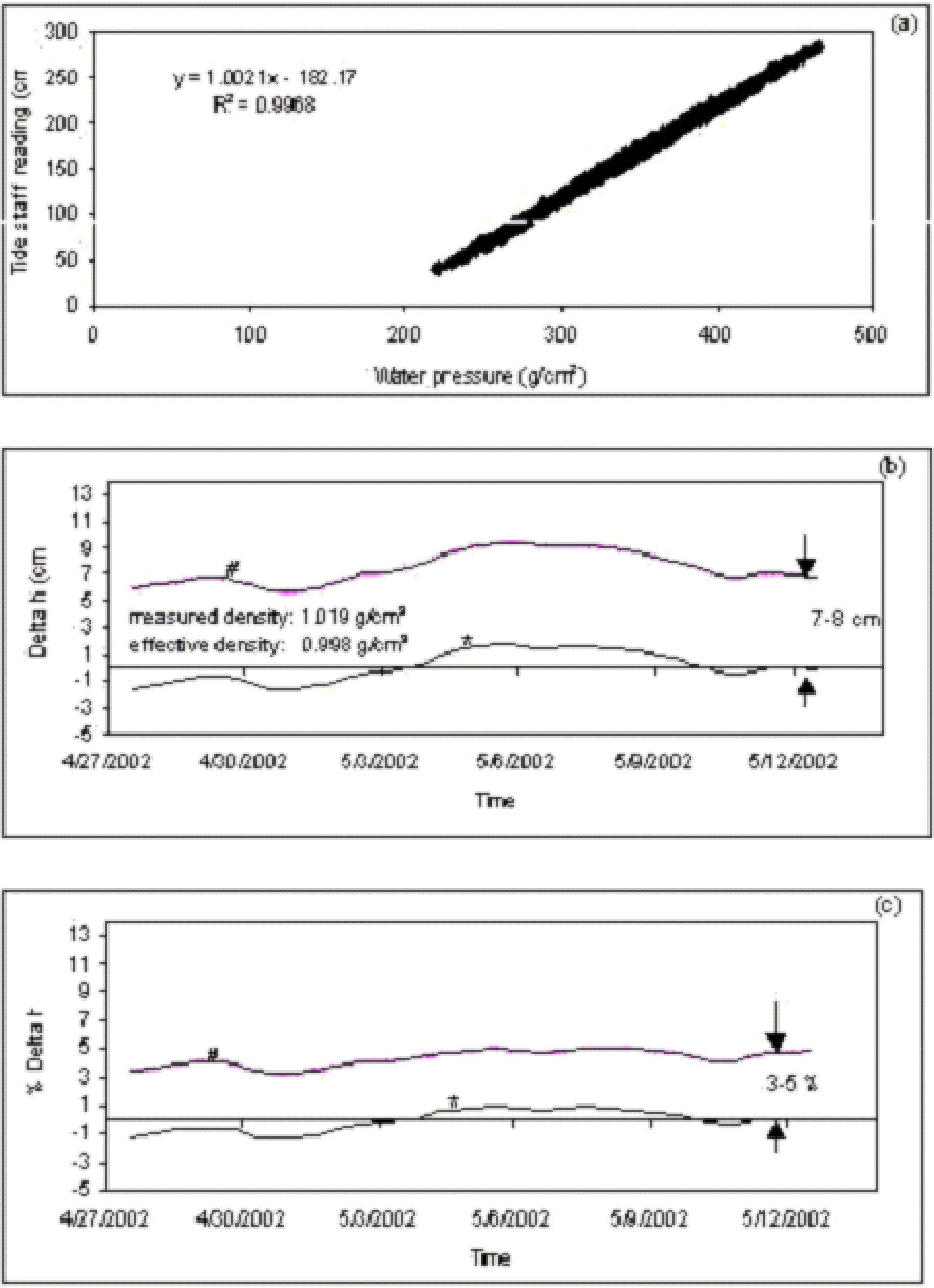


Figure 11. (a) Statistical relation based on regression analysis of the entire data set of pressure gauge and tide staff measurements from Kumbarjua Canal site; (b) daily mean difference, Δh, between tide-staff measurement and pressure-derived water level based on measured density (#) and effective density (*); (c) %Δh.

A One-Year Comparison of Radar and Bubbler Tide Gauges at Liverpool

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Data from a new radar tide gauge and from a conventional bubbler pressure gauge were obtained over a period of a year at a test site at Liverpool in north-west England. A comparison of the data sets demonstrated that the two systems have similar individual accuracies of about 1 cm, consistent with the accuracies required for gauges in the UK and global networks. Radar technology has advantages over some other types of gauge in ease of installation and maintenance. Therefore, our findings suggest that radar has to be given strong consideration in future applications, especially at locations where variations in water density preclude the effective use of pressure systems.

Findings

Low-cost radar tide gauges have become available during the last few years from several manufacturers. Although this technology is relatively new to most of the tide gauge community, as demonstrated by the mere brief mention of radar sensors in a recent review of tide gauge systems (IOC, 2002), their low cost means that they are now being purchased by a number of agencies as replacements for older instruments or for completely new networks. Therefore, it is essential that as much experience of them is shared as soon as possible.

There were several presentations on radar gauges at the present Workshop. Our own experience is limited to one, the OTT Kalesto system. This was installed at Liverpool in northwest England in March 2002 and operated until the end of April 2003 without any important gaps. Liverpool, with a tidal range of almost 10 m at some spring tides, is a demanding location for testing a radar gauge. Therefore, for a successful test, the radar range measurement has to be shown to be equally precise over distances of several metres to over 10 m. Liverpool also experiences frequent storm surges in winter, which places demands on the accuracy of gauges in different sea states and weather conditions.

The Kalesto uses a frequency-modulated continuous wave (FMCW) system in which transmitted radar waves are mixed with signals reflected from the surface to determine the phase shift between the two waves and thereby the range. They offer several advantages over float, pressure and acoustic gauges. The main advantage is the ease of installation and maintenance.

The Kalesto transmits FMCW radar pulses within a ±5º cone, with a range accuracy claimed by the manufacturers to be 1 cm over a measuring range of 1.5 to 30 m. If this accuracy were verified, then the gauge would be a suitable candidate for use in many applications, including within the Global Sea Level Observing System (IOC, 2002). The reference tide gauge chosen was a bubbler pressure system, being one of 44 such gauges in the UK National Network (Woodworth et al., 1999). The advantages and disadvantages of bubblers are well known (Pugh, 1972, 1987; IOC, 2002). Their main disadvantages, as for all pressure gauges, are the need to know well the density of the sea water above the pressure point (Figure 1), and to identify any long-term drift in the pressure measurements, which in this case are performed by a differential (compared to atmospheric pressure), temperature-corrected Paroscientific Digiquartz transducer. Any drifts in the differential pressure (i.e. sea level) measurement are monitored by a variant of the "mid-tide pressure sensor" method involving the use of a second bubbler pressure point at approximately mean sea level (Woodworth et al., 1996).

A detailed report on our findings from the comparison exercise can be found in Woodworth and Smith (2003). The comparison period of just over a year was the minimum required for a useful test, and resulted in as much being learned of the bubbler (reference) system, particularly with regard to its sensitivity to density changes, as the radar (test) system itself. In brief, we concluded from the available data that the radar appears to function as well as the bubbler most of the time, with accuracies for both systems of $\leq$ 1 cm. The radar produces a slightly noisier data set, with a possible bias of several centimetres compared to the bubbler during storms. However, that should be an acceptable level of accuracy for monitoring storm surges around UK coasts (Flather, 2000). If radar gauges are to be used elsewhere in the UK Network or in GLOSS, we recommend that further work be undertaken:

- To understand better the different systematic biases in both radar and bubbler systems, especially those due to waves, and to water density when the gauges are to be located near rivers.

- To develop an *in situ* calibration system for the radar gauge, removing the need for periodic laboratory calibration checks on range stability. (An in situ calibration system has already been considered for the Kalesto by colleagues in South Africa, as shown by Ruth Farre at the present Workshop.)

- To design systems which are as far as possible weather- and tamper-proof. Although radar gauges offer advantages over some other types of gauge with regard to ease of installation and maintenance, the same features could present drawbacks in certain locations, if sites are exposed to harsh environmental conditions or if there are site security problems.

Further insights into these technical challenges might stem from collaborative work presently being undertaken within the GLOSS community, as demonstrated by the various presentations at the Workshop. It is impossible for any one organization to test all possible types of gauge, so it is imperative that experience be shared as widely as possible.

Acknowledgements

We should like to thank David Jones and Peter Foden of POL and Nigel Grimsley of OTT Hydrometry Ltd. for their help with this project.

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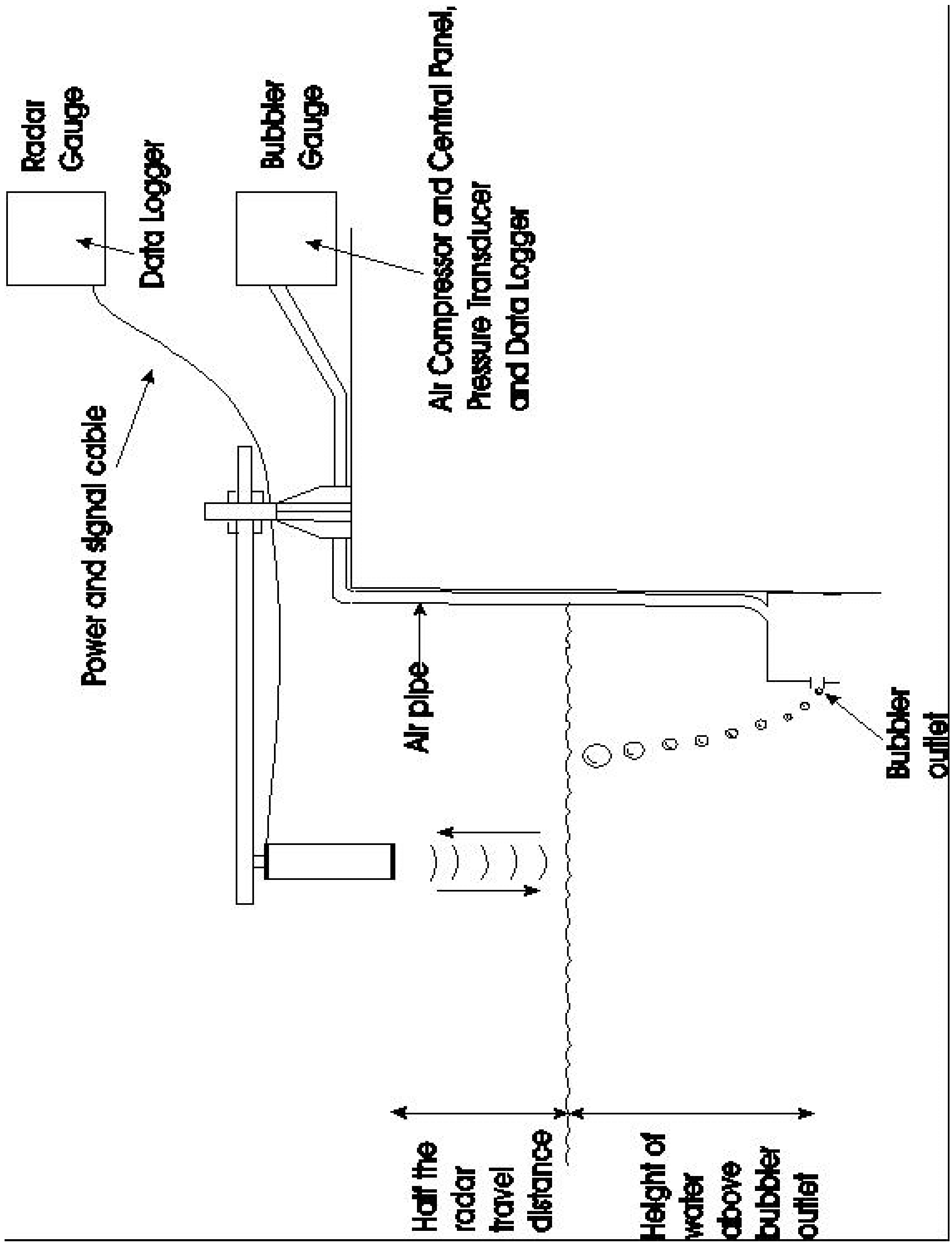

Figure 1. Schematic of the radar and bubbler gauge systems at Liverpool.

Comments on Van de Casteele Tests in the Brest and Le Conquet Tide Gauge Stations

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Service Hydrographique et Océanographique de la Marine
France

RONIM is the name of the national tide gauge network in France. It is managed by the SHOM (Service Hydrographique et Océanographique de la Marine). By the end of 2003, 20 tide gauges were operational. The most ancient tide gauge stations were equipped with acoustic sensors (MORS Co.). The more recent ones were equipped with BM70 radar sensors (Krohne Co.).

The standardization of the network with the same sensors and the same data-acquisition unit is in progress, but for the moment, for historical, technical and economic reasons, three kinds of station characterize the RONIM network:

- Those equipped with acoustic sensors in a PVC stilling well or in a stilling tube (e.g. Brest);
- Those equipped with BM70 radar sensors in a PVC stilling tube (e.g. La Rochelle);
- Those equipped with BM70 radar sensors in a stainless-steel stilling tube (e.g. Le Conquet).

To evaluate the quality of these three types of station, intercomparisons using the Van de Casteele (VDC) method were performed at the Brest and Le Conquet stations on 17 and 18 April 2003.

The VDC method, developed by an engineer of the Institut National de Géographie (IGN), is used to characterize the errors of a tide gauge. It involves carrying out simultaneous measurements between the tide gauge and a reference sensor. The latter is usually a direct-measurement instrument, such as a tide staff or a probe, provided that these instruments are themselves calibrated.

The maximum possible number of measurements is required. The water height is plotted on the *y*-axis and the difference between the reference instrument and the tide gauge is plotted on the *x*-axis. Figure 1 shows the different kinds of typical error highlighted by the VDC test.

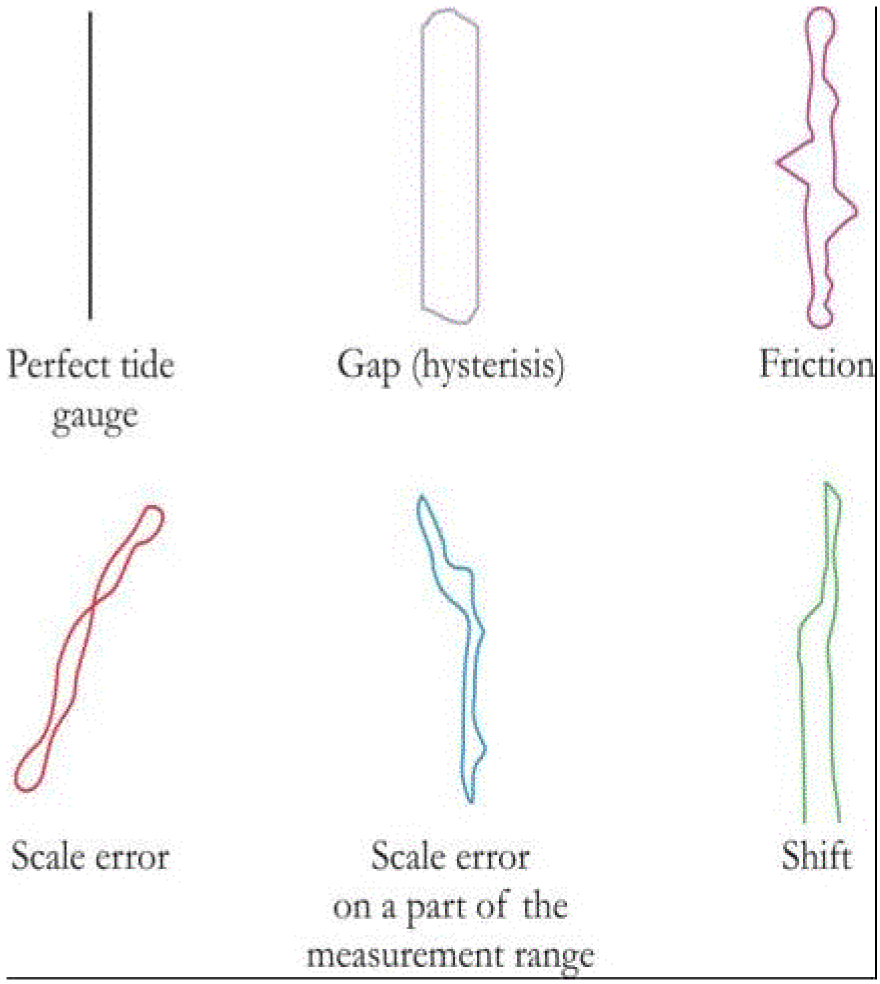


Figure 1. Diagram showing the different kinds of typical error highlighted by the VDC test.

In Brest and Le Conquet, the experiment was conducted during one spring-tide cycle, between low tide and high tide, every 5 minutes. One measurement is the mean value over 10 seconds (readings on the tide-staff and from the probe were interpolated by eye during 10 seconds). The sounding probe was calibrated in the lab and was taken as the reference.

Simultaneous measurements were made with the following instruments:

The SHOM probe in a stilling well or a stilling tube;
The tide-staff;
The acoustic sensor in a stilling well (Brest);
The BM70 sensor in a PVC stilling tube (Brest);
The BM70 sensor in a stainless steel stilling well (Le Conquet).

We comment on the result for each one. Figure 2 shows the comparison between the probe and the tide-staff. Although the tide-staff was outside any well and so subjected to wave action, we see that interpolation by eye between two 10-cm graduations is quite efficient. The average error was 1 cm and the RMS Error was 1.2 cm.

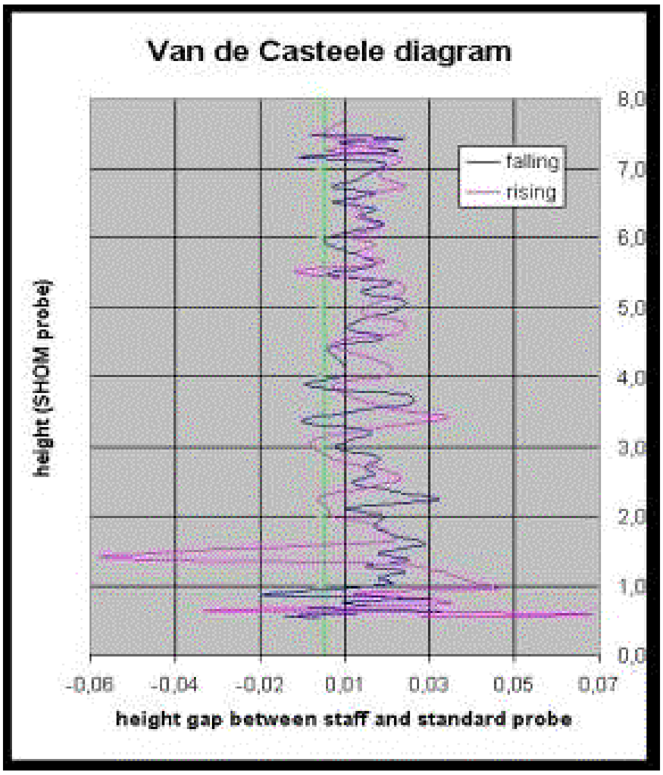


Figure 2. Comparison of the SHOM probe (in a stilling well) and the tide staff plots.

The VDC graph of the acoustic sensor (Figure 3) revealed systematic errors near low water as well as hysteresis. The RMS error was 2 cm. Temperature gradients observed in the stilling well by several temperature sensors explain such errors.

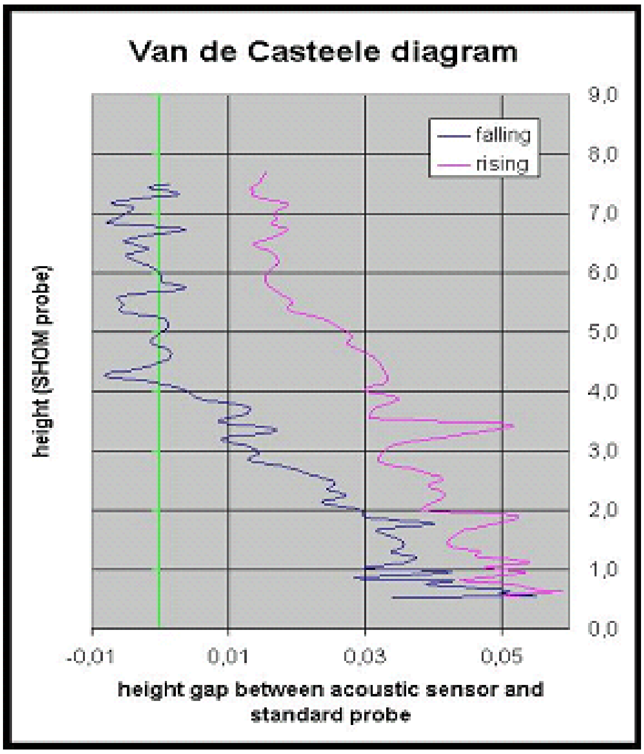


Figure 3. Comparison of the SHOM probe and acoustic-sensor (in a stilling well) plots.

The VDC graph for the BM70 radar (Figure 4) installed in a PVC tube clearly shows the typical propagation of a radar wave in a PVC tube. This defect is manifested in the form of sinusoids.

Fortunately, it is possible to enter a table of corrections in the radar sensor to minimize such defects. This graph shows the characteristics of a radar sensor without corrections.

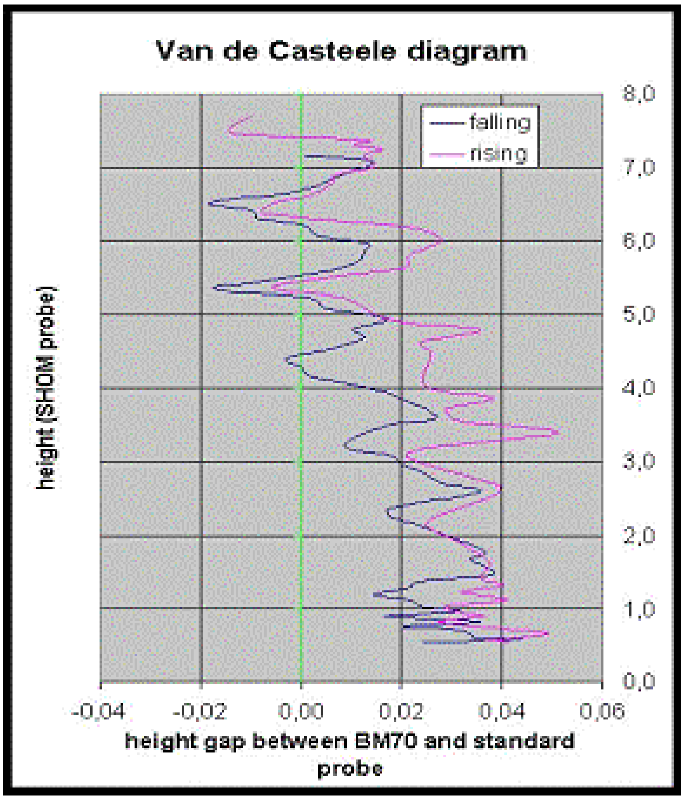


Figure 4. Comparison of the SHOM probe and BM70 radar (in a PVC tube) plots.

The VDC graph of the BM70 installed in a stainless steel stiling well (in Le Conquet) gave quite the best results (Figure 5). The average error was 1 mm and the RMS of the errors was 1 cm.

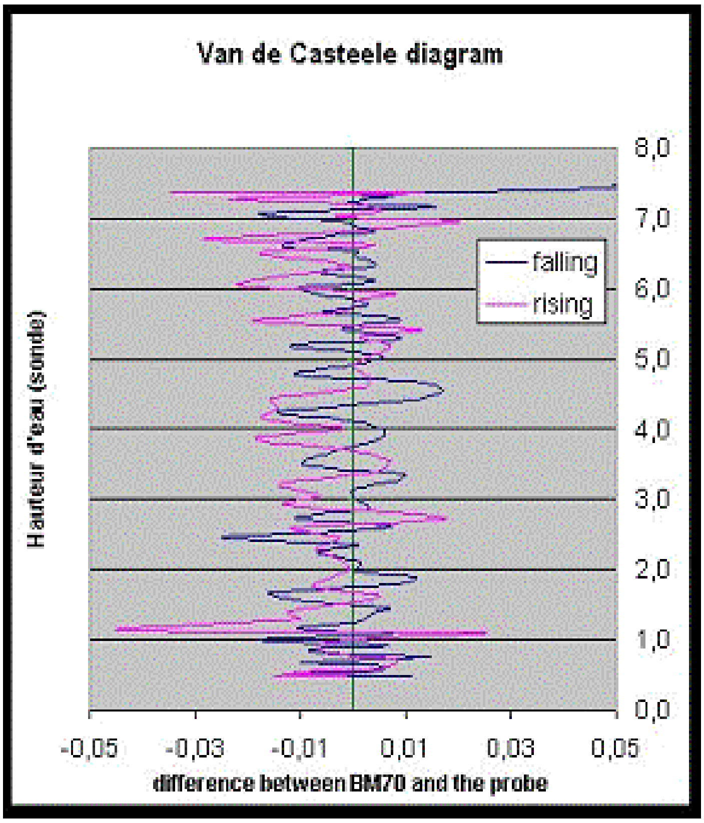


Figure 5. Comparison of the SHOM probe and BM70 radar (in a stainless-steel stilling well) plots.

The past 10 years of tide measurements in Brest come from the acoustic sensor. Attempts to find a model to correct systematic errors of this sensor were studied (rapport d’étude n°005/02, Olivier Devauchelle et al.). Devauchelle proposed correction functions based on models of a linear or exponential gradient of temperature.

The celerity of an acoustic wave is : $c = c_0(1 + aT(z))$

Temperature measurements confirm that an exponential law is a proper law to model the temperature gradient in the well. $T(z) = T_0 - \Delta T(1 - e^{-z/h_0})$

We have: $\Delta t = 2\int_0^h \frac{dz}{c(z)}$,

If we assume that the gradient is weak, we obtain : $h = \frac{c_0 \Delta t}{2}(1 + aT_0) + a\Delta T(h_0(1 - e^{\frac{A\Delta t}{Bh_0}}) - \frac{c_0 \Delta t}{2})$

This form of the expression above is : $h = h_{mes} + \delta h$

h_{mes} is the acoustic measured automatically corrected of the temperature measured near the sensor.

The correction is $\delta h = a\Delta T h_0(1 - e^{-\frac{h_{mes}}{h_0}(1 + aT_0 - a\Delta T)} - \frac{h_{mes}}{h_0})$. It is a function of the gradient, the characteristic height, the temperature at the top of the well (close to the ambient temperature), and the height measured by the sensor.

Figure 6 shows the VDC curve obtained after applying the correction. The average error was 0.6 mm and the RMS error was 0.8 mm.

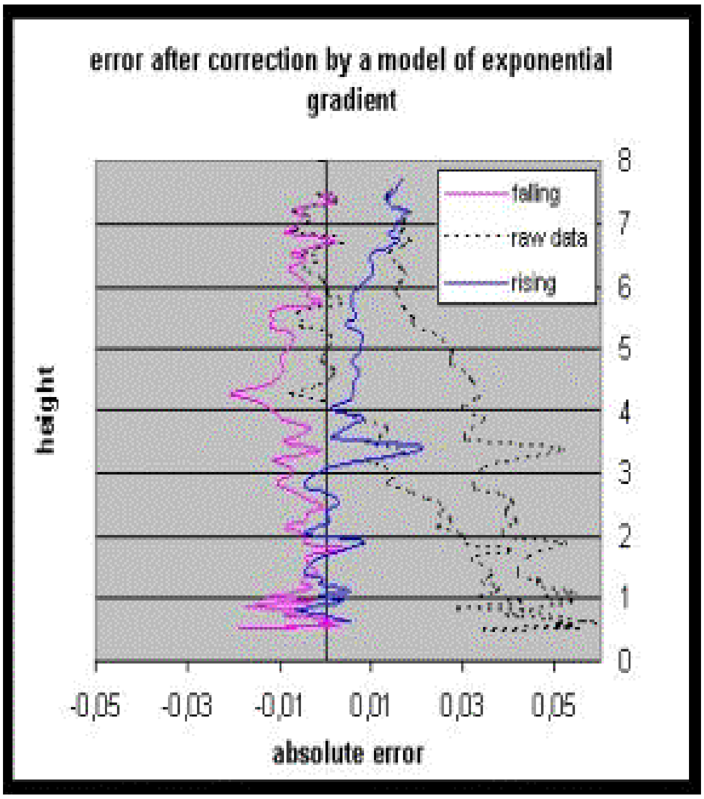


Figure 6. Error correction of height measurements using an exponential gradient model.

Conclusions

The VDC test of the acoustic sensor revealed an RMS error of 2 cm and a maximum error of 6 cm at low tide. We must take into account the fact that this bad result was obtained under limited but unfavourable conditions: it was warm (near 20°C outside); and it was very high spring tide. With comparisons over one year (to have average conditions of tide and meteorology), the RMS would probably fall below 1 cm, which would satisfy GLOSS requirements.

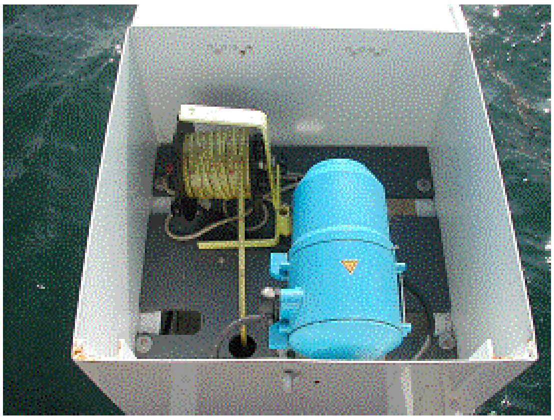
To improve the quality of the sea level data in Brest for the last ten years, we plan to:

- Get statistics of ambient temperature by season; we have already noticed that there is a strong correlation between ambient temperature and the error of the acoustic sensor (the latter is checked every week);

- Compare the acoustic data with radar data over one year.

The aim is to minimize the systematic errors so as to obtain a centered distribution of the errors.

By the year 2010, every acoustic sensor will have been replaced by radar gauge. A new Krohne radar, the BM100, is under test. It seems to give even better results than the BM70.



Le Conquet sea level observatory

Test and Evaluation of the MIROS SM-094 Microwave Altimeter

Mark Bushnell
NOAA/NOS/CO-OPS

The Center for Operational Oceanographic Products and Services (CO-OPS) is the office within the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) that is responsible for Water Level (WL) and water-current observations in United States coastal waters. CO-OPS manages the National Water Level Observation Programme (NWLOP, consisting of 175 stations) which delivers hourly updates of six-minute WL and meteorological observations. CO-OPS also operates the Physical Oceanographic Real-Time System (PORTS™, located in 10 harbours) which provides real-time 6-minute observations of WL, currents, meteorological data, salinity/water density, and other parameters. Data are made available within 1-2 minutes of the observation, distributed online and through toll-free phone calls. CO-OPS maintains a Continuously Operational Real-time Monitoring System (CORMS) to provide staffed 24x7 quality control of the data.

CO-OPS also operates the Ocean System Test and Evaluation Programme (OSTEP) to facilitate the transition of new sensors and systems to an operational status. OSTEP tests instruments to ensure that CO-OPS requirements are met, develops operational deployment and implementation procedures, and establishes quality control criteria.

Through PORTS, OSTEP funding has been received for development of an operational bridge clearance (air gap) system. The Miros SM094 microwave sensor has been identified as a device with manufacturer specifications that meet CO-OPS requirements (±3 inches at ranges up to 175 feet in all weather). CO-OPS presently owns six units which have been extensively bench-tested, and field-tested on five bridges, two piers, and in a wave-generating tank. Two are now permanently installed on bridges over the Chesapeake and Delaware Canal in support of the Chesapeake Bay PORTS. Operational implementation is scheduled for January 2004.

A less precise laser range-finder has been employed for coarse validation of the Miros SM094 sensor when deployed on a bridge. A Laser Technology Impulse 200LR provides reliable ranges to the water surface. When fitted with an inclinometer to ensure truly vertical ranging, the 200LR has the following specifications: maximum range of 575 metres, accuracy of 3 cm at 50 metres range, resolution of 1 cm, inclinometer accuracy of 0.1 degree.

In addition, precision trigonometric leveling using a Leica total station is employed to provide a very accurate measure of height. In conjunction with nearby NWLOP stations, this permits excellent measurement of the SM094 height above a water level datum.

Early in the testing it became clear that the SM094 greatly exceeded the performance characteristics required for air-gap use, and had good potential for use as a precise water level sensor. Initial tests were conducted at the Chesapeake Bay Bridge Tunnel pier directly adjacent to a NWLOP water level gauge. Two-Hz data from a free cycling SM094-50 were logged to a laptop, plotted, and compared with the standard 6-minute NWLOP station values. The two series were simply demeaned for comparison, since no absolute leveling was conducted. The observed centimetre-level differences (Figure 1) encouraged additional testing.

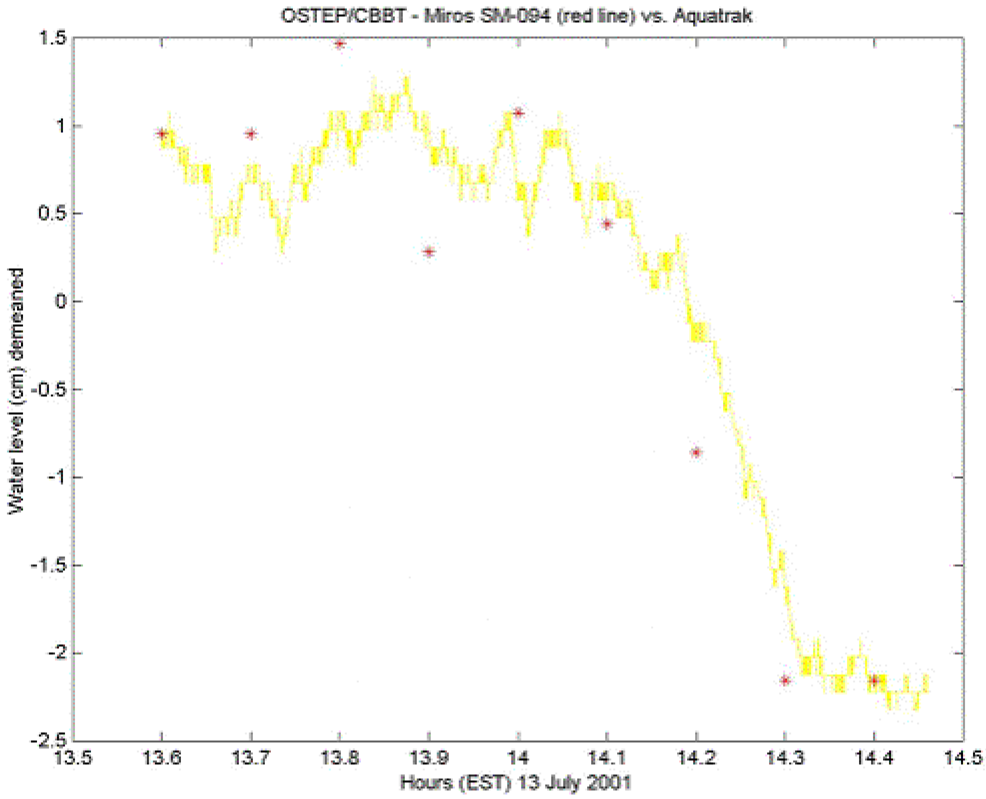


Figure 1. Demeaned comparison of Miros SM094 (line) with 6-minute NWLOP water level data (dots).

Subsequent tests were conducted at the US Army Corp of Engineers Field Research Facility in Duck, North Carolina. The heavily instrumented FRF pier extends seaward 600 metres and supports a NWLOP WL station at the very end. The SM094-50 was installed adjacent to the WL station, and again data were gathered in free-cycle mode (i.e. not in synchronization with the WL station) on a laptop computer.

For water level data intercomparisons, similar data-processing techniques for the two sensors are critical. CO-OPS NWLOP uses an iterative process known as the Data Quality Assurance Process (DQAP) to smooth observations and provide a first order of quality control. One hundred and eighty-one samples are gathered at a 1 Hz rate over a 3-minute period and the mean and standard deviation computed. Outliers beyond three standard deviations are discarded and a new mean and standard deviation are computed. The final output consists of the recomputed mean and standard deviation, and the number of discarded outliers. Although this filter is fairly rudimentary, it was easily integrated years ago into data-collection platforms with limited processing capability and, perhaps more importantly, it is easily described, understood, and replicated.

The Miros SM094-50 provides a more sophisticated first-order recursive smoothing algorithm with a user-selectable time constant. The SM094 provides two output channels which may be separately filtered. CO-OPS leaves channel 1 unfiltered and sets the second channel time constant to 30 seconds.

Figure 2 shows the difference between the CO-OPS and Miros smoothing processes. The DQAP smoother was applied to the 2-Hz raw Miros data (decimated to 1 Hz), and this series was subtracted from the Miros data smoothed by the recursive filter and decimated to an equivalent 6-minute sample time. Differences of up to 6 cm are seen, attributable only to the two different smoothing algorithms performed on data from the same sensor. Without knowledge of the absolute true water level, it is prudent to demonstrate that the newer technology is favorably comparable to the older, and this is best achieved through similar data-processing techniques.

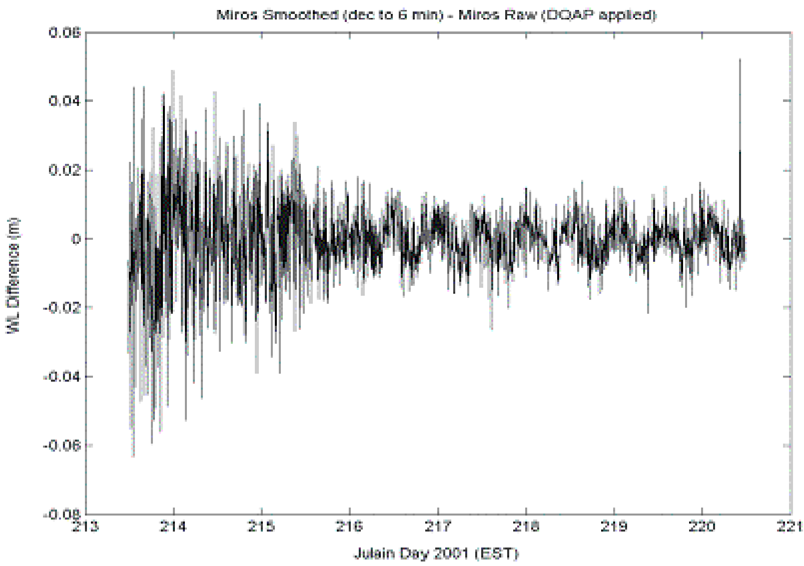


Figure 2. Difference time series of two different smoothing processes (Miros recursive minus NWLOP DQAP) operating on a single data set from a Miros SM094.

The Miros SM094 tests conducted at the USACE/FRF have shown agreement with CO-OPS standard water level observations obtained from acoustic-based sensors to be better than 1 cm (both one standard deviation and average absolute error). It appears that the most significant differences are attributable to temperature gradients in the acoustic sounding tube of the acoustic-based sensor.

At the same time, CO-OPS is also implementing the use of a new Data Collection Platform (DCP) which permits greatly expanded data-processing capabilities. These new DCPs permit the use of advanced smoothing algorithms (yet to be determined) and more efficient use of the GOES satellite. Our third test of the SM094 used this new DCP with new code to acquire, log, and transmit the data. The test was cut short by Hurricane Isabel, which badly damaged the 0.1-inch-thick stainless-steel mounting frame. Although water intruded into the electronics, the sensor appears to have recovered without damage after drying out. Miros is investigating new electronic housings and/or seals.

Miros is implementing an advanced Digital Signal Processing (DSP) chip in the SM094 which will permit a greatly increased rate of data output (up to 100 Hz), wave information output, a higher utilization of electromagnetic return from the sea surface, and large-capacity internal data storage. These advances will enable further corrections to the observations to be developed and applied, if future tests determine they are required.

CO-OPS will continue with comprehensive tests of this and other microwave-based sensors. Long-term stability and failure mode studies are planned. Assuming satisfactory results are obtained, we plan to replace the majority of the acoustic sensors with microwave devices. Substantial decreases in installation and maintenance costs coupled with increased performance and reliability are possible.

Experience with the Vega Radar Gauge on a Buoy

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In November 2002 the Institut für Planetare Geodäsie of the Dresden University of Technology installed a sea level monitoring system on an oceanographic buoy in the southern Baltic Sea. The buoy is part of the Marine Monitoring Network (MARNET) of the Bundesamt für Seeschifffahrt und Hydrographie (BSH) and is operated by the Institut für Ostseeforschung Warnemünde (IOW).

For the determination of the sea level with respect to the buoy, the radar gauge VEGAPULS 41, manufactured by the company VEGA Grieshaber, and a pressure gauge were used. The radar gauge is primarily designed for continuous measurements of the liquid level in storage tanks. Nevertheless, even under the special conditions of the open sea, it provides useful and reliable information.

The paper describes the technical specifications of the VEGA radar gauge, as well as our practical experience from about one year of operation. The advantages, disadvantages, accuracy and reliability of the radar gauge will be discussed. Most of the results can be applied to coastal operations, although the results were obtained under different environmental conditions.

Introduction

One goal of the project Baltic Sea Water and Energy Cycle Study (BASEWECS) is the validation of an oceanographic model of the Baltic Sea, which was developed at the Institut für Meereskunde at the University of Kiel (Lehmann, 1995). Part of this project is the validation of sea-surface heights obtained by the oceanographic model. Sea level measurements, like tide gauge observations and altimetric sea-surface heights, have been used for this purpose (Novotny et al., 2002). In addition, a multi-sensor system for the monitoring of sea level changes on a floating platform was developed at the Institut für Planetare Geodäsie of the Dresden University of Technology. It has been deployed on a buoy about 40 km offshore in the southern Baltic Sea (northeast of the island of Rügen in the Arkona Sea; Figure 1) in November 2002.

The buoy is part of the Marine Monitoring Network (MARNET) of the Bundesamt für Seeschifffahrt und Hydrographie and is operated by the Institut für Ostseeforschung Warnemünde (IOW, 2003). It has a height of about 18 m, of which, 12 m are under the sea surface. The accessible platform is 3 m by 6 m. The power supply of the buoy is based on solar and wind energy. Therefore, all components of the buoy were carefully selected with respect to their power consumption. The power consumption for the sea level measuring unit was limited to 10 W, 24 V.

Our low-power multi-sensor sea level measuring system has to operate almost autonomously. Maintenance cruises are usually possible at intervals of about 3 months. All data have to be stored on a data logger and are downloaded manually during the maintenance cruises. Remote communication via mobile phone or satellite links is limited and not sufficient for data transfer (especially of the GPS measurements). The system consists of:

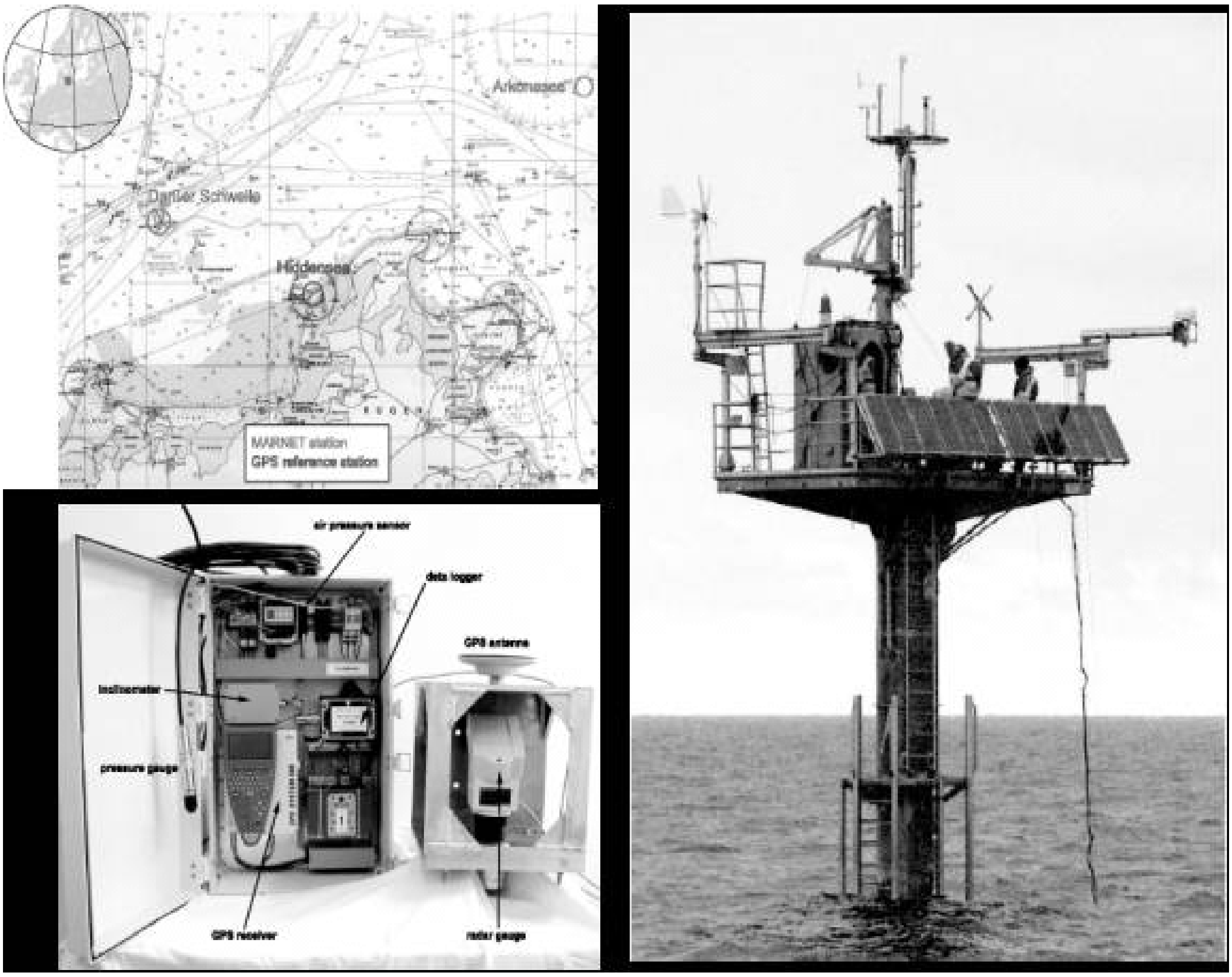
- The data logger — for the management of the measurement regime, the data storage and the pre-analysis of the measurements;
- The GPS receiver with antenna — for the height determination in a geocentric reference frame;
- The pressure gauge - mounted approximately 2 m under the water surface to measure the sea level height relative to the buoy;
- The air pressure sensor - to reduce the absolute pressure gauge measurements;
- The VEGAPULS radar gauge — as an experimental sensor to measure the sea level height;
- The inclinometer — to account for the changing height eccentricity between the pressure gauge, the radar gauge and the GPS antenna, due to the tilt of the buoy.

The system was designed to enable the measurement of sea level heights in a geocentric reference system with an accuracy of a few centimetres. One major problem of the concept is the determination and monitoring of the eccentricities between the GPS antenna and the pressure gauge under the special environmental conditions. In this sense, the VEGAPULS radar gauge is an excellent complement of the system, because it can be fixed to the GPS antenna mechanically (Figure 1). A main drawback is the fact that the VEGAPULS radar gauge is not designed for offshore sea level measurements and has, to our knowledge, never been used before for such an application. It is designed to control the level of chemical fluids in storage tanks, and its response to very fast changes is delayed. For this reason we have initially considered the radar gauge as an experimental sensor.

Due to the low power concept of the entire buoy and the limited data-storage capacity, the multi-sensor system is operated with a measurement regime of 15 minutes' operation mode and 45 minutes' sleeping mode every hour. The sampling rate in the operation mode is 1 Hz. The measurements of the pressure gauge are stored with a sampling frequency of 5 Hz.

Based on these measurements, the preliminary experience of the reliability and the accuracy of the VEGA radar gauge under the special operating conditions on a buoy will be presented. Advantages and disadvantages in the short-term and the long-term behaviour will be discussed with respect to possible systematic errors in the radar gauge measurements.

Figure 1. *(next page)* Top: location of the MARNET stations; bottom: multi-sensor system; right: MARNET Station Arkonasee.►



The VEGAPULS radar gauge

Some features of the VEGAPULS 41/61 radar gauge manufactured by VEGA Grieshaber are shown in Table 1. The main requirements for our application (low power consumption, low weight, analog interface, low cost) are met by the instrument.

The VEGAPULS radar gauge is operated with a power supply in an output range of 12 to 24 V DC. A two-wire cable serves for the power supply and the analog data transmission (Figure 2). To connect the additional display unit VEGADIS, a 6-wire cable is necessary. The VEGADIS also allows a set-up of the most important parameters of the VEGAPULS radar sensor.

The radar sensor can be connected to a computer via the serial interface using the VEGACONNECT unit. A more convenient set-up, a check of the radar echoes and the measuring quality, as well as the storage of measurements on a PC, is possible with the corresponding software from VEGA.

Table 1. Specifications of the VEGA radar gauge.

Output Signals	
Analog	4 ... 20 mA
Digital	Profibus PA
Power supply and output signal on one two-wire cable (loop powered 12-24 V)	
Measurement range:	0 ... 10 m (tuneable up to 30 m)
Measurement interval	1 second
Accuracy	5 mm
Resolution	1 mm
Apex angle:	22 degrees
Radar frequency:	26 GHz
Operating principle	Pulse radar with time-transformation function

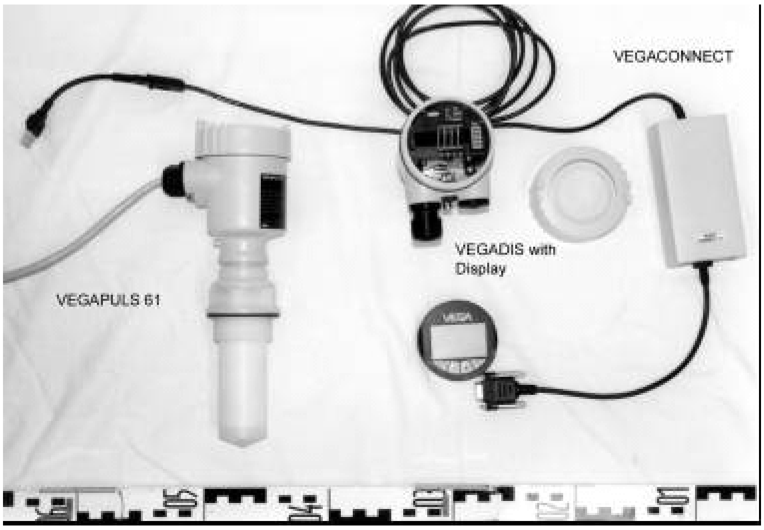


Figure 2. Components of the VEGA radar system.

More information about the instrument features and details of the operating principle can be found at VEGA's homepage: http://www.vega.com

First check of the sensor

A first test of the radar gauge performance was done by measuring a constant distance. As a reference, the distance was measured with a measuring tape. Both measurements agreed to within 1 mm. Figure 3 shows the variation in the mean distance over 2,200 seconds. The noise level is below 5 mm, which corresponds to the specifications of the manufacturer.

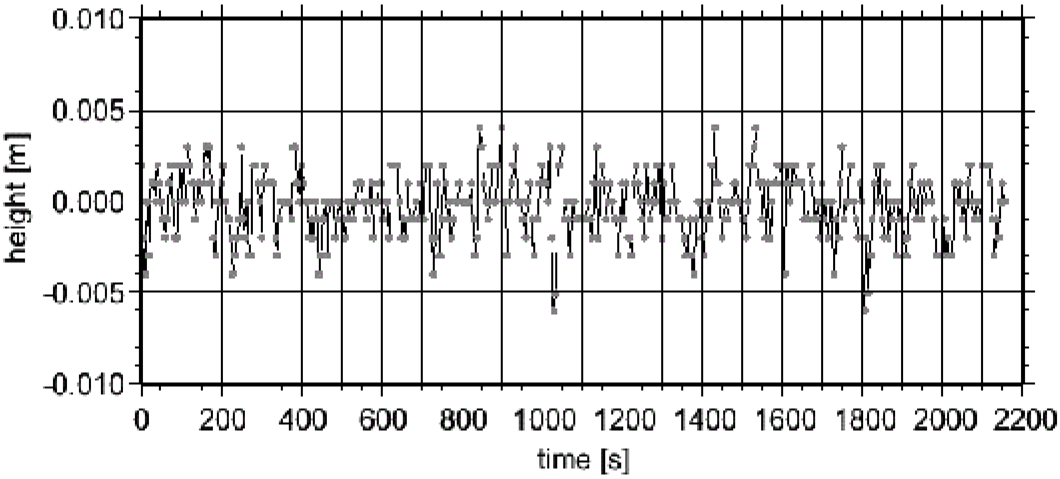


Figure 3. Measurements of a constant distance.

Reliability of the radar gauge

One important question is the reliability of the data acquisition. Within the time span of 168 days with 4,021 sampling periods each of 15 minutes duration, we have observed altogether 23 failure periods of the radar gauge, which means a failure rate of 0.6%. The time span covers the winter season with rather harsh conditions (storm surges, ice at the buoy etc.). A comparison of radar gauge failure events and extreme inclinations of the buoy during a 15-minute period indicates that most of the failures are related to an extreme inclination of the buoy of more than 15 degrees (compare Figure 6). In this case, the radar gauge direction is out of vertical by more than half the apex angle. So it was not possible to measure the radar echoes reliably.

Evaluation of the original measurements

A typical example of the original high-frequency (1 Hz) sea level observations obtained on the buoy is shown in Figure 4. The measurements of the radar gauge and the pressure gauge are reduced by the average of the observation interval in the figure. Note, that the pressure gauge is mounted about 2 m below the sea surface. Therefore, the pressure gauge observations show smoothed waves. Nevertheless, the observation of the radar gauge shows a much smoother behaviour. In particular, the waves with a period of about 5 seconds during that time are not well registered. This is also obvious comparing the standard deviations and extreme values of both records (Table 2).

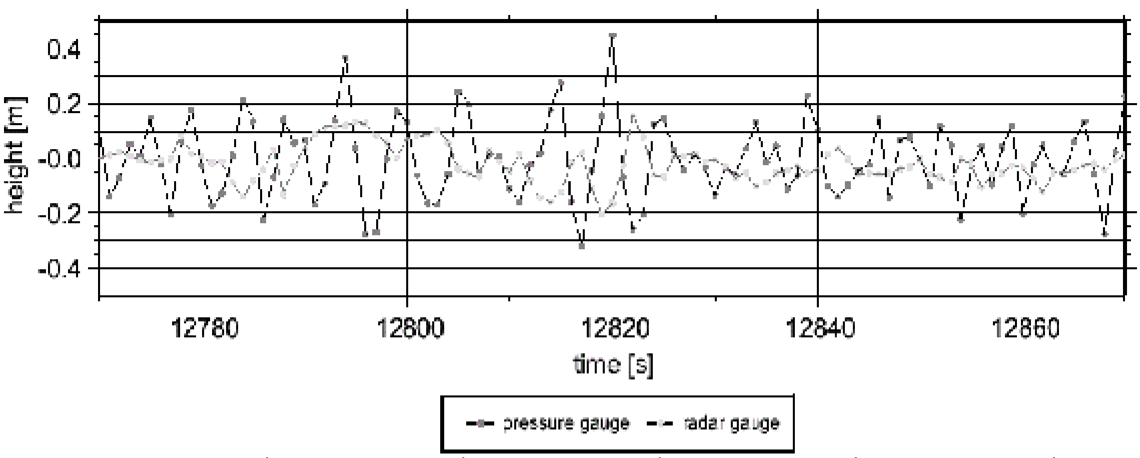


Figure 4. Comparison of 1-Hz measurements of pressure and radar gauge.

Table 2. Comparison of 1-Hz measurements of pressure and radar gauge.

	Standard deviation [m]	**Extreme values [m]**
Pressure gauge	0.154	–0.460/+0.466
Radar gauge	0.087	–0.309/+0.332

Evaluation of the 15-minute averages

Here we consider how the lack of high frequency variations in the radar gauge record affects the 15-minute mean sea level heights. Before computing the 15-minute averages, all individual 1-Hz observations of the radar and the pressure gauge were reduced for the effect of the changing height eccentricity between both sensors using the inclinometer observation. The resulting averages are shown in Figure 5 for a period of 44 days. Again, both records were reduced by their mean value. Figure 5 shows clearly that the two tide gauges measure an equal sea level variation of about 0.8 m. In this case, the standard deviations and extreme values are in a good agreement (Table 3).

Table 3. Comparison of pressure and radar gauge measurements (15-minute averages).

	Standard deviation [m]	Extreme values [m]
Pressure gauge	0.176	–0.289/+0.967
Radar gauge	0.176	–0.289/+0.991

The differences between the 15-minute averages of the two gauges are shown in Figure 6. They are less than ±0.05 m. The standard deviation of the difference record is 0.017 m. There is a small systematic behavior in the record, which seems to be related to the extreme inclination of the buoy. Possible reasons are a decreased accuracy of the radar gauge at higher inclinations of the buoy (which could be fixed by a cardanic fastening) and a limited accuracy of the reduction of the height eccentricities between the gauges (caused by a limited a priori knowledge of the eccentricity and/or the accuracy of inclinometer measurements).

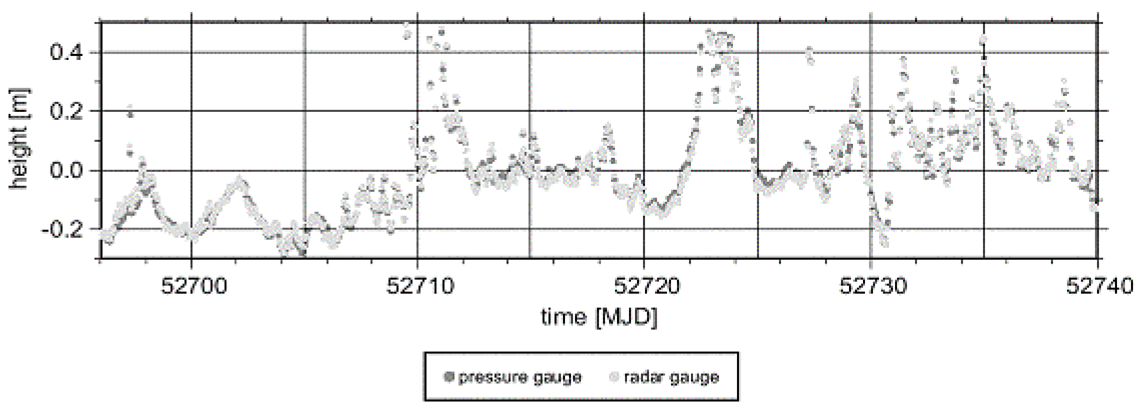


Figure 5. Comparison of pressure and radar gauge measurements (15-minute averages).

Altogether, the resulting agreement between the records of 17 mm is within the expected range if one considers the error budget of the system:

Error of the radar gauge (random error)	0.5 cm;
Error of the analog digital converter	1 cm;
Error of the pressure gauge	1–2 cm;
Error of eccentricity / inclination change	1–2 cm.

Taking these values into account, one can conclude that, even under the special circumstances of open-sea conditions, the 15-minute averages of the radar gauge fulfill the expected performance. The limitation of the 1-Hz observations of the radar gauge does not lead to aliasing effects in the low-frequency band of more than 2 cm, which corresponds to the accuracy of the whole-system performance.

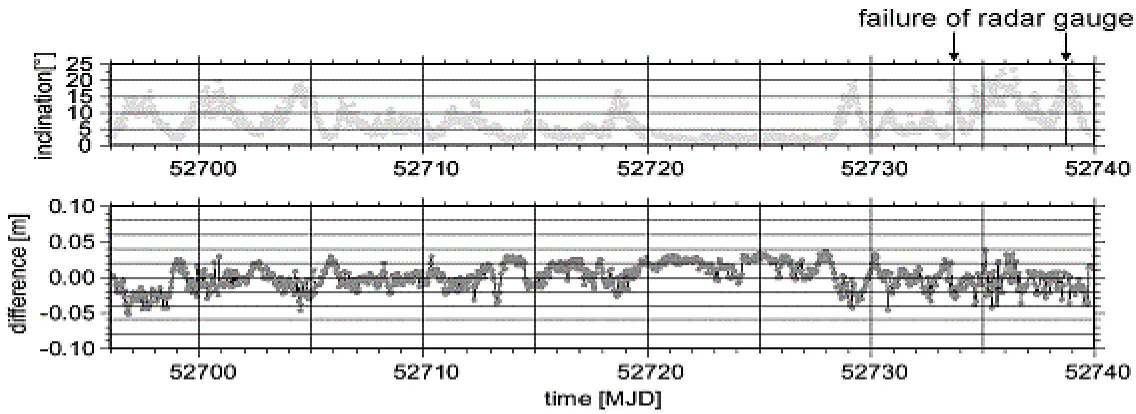


Figure 6. Difference of pressure and radar gauge and extreme inclination of the buoy.

Absolute evaluation of the radar gauge

Another independent method to validate the radar gauge measurement is shown in Figure 7.

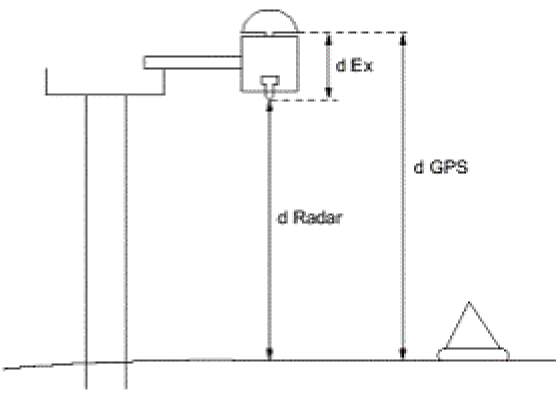


Figure 7. Left: principle of the absolute comparison with the GPS buoy; right: GPS buoy.

During a maintenance cruise, additional GPS measurements were performed with a small GPS buoy consisting of a floating belt and a GPS antenna. Using these observations, the height difference d_{GPS} between the GPS antenna on the platform and the GPS buoy can be computed for each 1-Hz period. This height difference can be compared to the measurements of the radar gauge d_{RADAR} and the well known eccentricity d_{EX} between the platform GPS antenna and the reference point of the radar gauge. These measurements should fulfill the following equation:

$$d_{Radar} + d_{EX} - d_{GPS} = 0.$$

Using the measurements of a 3-hour experiment we determined the following mean values:

d_{RADAR} = 8.660 m
d_{GPS} = 8.938 m ± 1 cm
d_{EX} = 0.289 m ± 1 mm

and obtain a misfit of 11 mm (8.660 m + 0.289 m – 8.938 m = 0.011 m). That means that possible systematic errors of the radar gauge measurements on the oceanographic platform do not exceed the accuracy of the experiment of about 1 cm.

Summary

It has been shown that the application of a radar gauge is an appropriate tool to measure sea level changes. In our project the radar gauge VEGAPULS 41 was operated on an oceanographic buoy 40 km offshore in the southern Baltic Sea. The radar gauge shows a high reliability of 99.4 %. Missing measurements can be mainly explained by the special environmental conditions. Although the apex angle of 22° of the radar gauge is rather wide, the buoy occasionally shows an inclination of more than ± 10 degrees. Therefore, one should expect even better results for onshore applications.

The major drawback of the radar gauge is the limited ability to track short-term sea level variations like waves. This is caused by the rather low sampling interval, the kind of signal-processing inside the instrument and the wide apex angle. It seems that the mean values, as computed over intervals of several minutes, are not influenced by this specific behavior. In this application we used 15-minute averages. Comparing theses values with the corresponding averages of a pressure gauge in an observation period of 44 days we have obtained differences similar to those of the system performance of about 2 cm. A direct comparison using a small floating-belt GPS buoy confirms that the mean value does not contain major systematic errors.

One general advantage of the radar gauge is the reduced maintenance of the system, since all parts are above the water surface. This also enables an easy combination with a GPS antenna.

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Acknowledgement

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Cost-Effective Ways of Providing Digital Data from Float Gauges

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The modernization of the Norwegian tide gauge network was finalized by end 2002 using well proven technology, i.e. the traditional, but modern, digital float gauge. To meet the increased requests for near-real-time data the modernization focused on the whole system from tide gauge, data transmission, quality control, data base to data export. The aim was to establish a faster, better and cheaper 24-hour service for our customers. This is obtained using automatic routines for quality control, storage of data in a database and presenting of data on Internet and Intranet.

Introduction

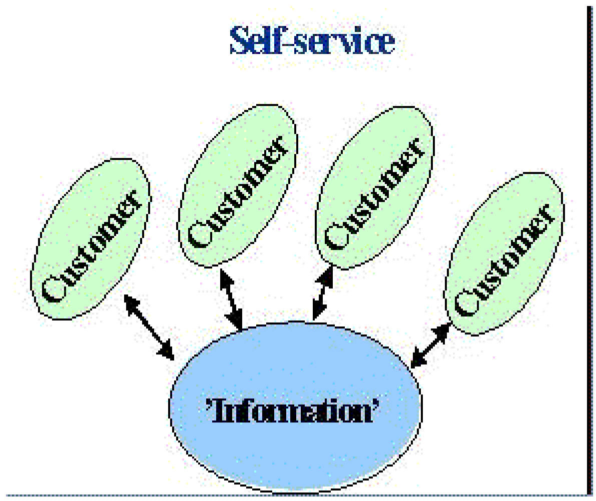
During 1980–81, the first discussions on how to modernize the Norwegian tide gauge network were initiated. The background for the modernization was the difficulties caused by old and improperly designed stilling wells and the higher drive for information. The customers experienced slow response to inquiries for access to observations, statistics, end results etc. Between 1986 and 1991 the tide gauge network (23 gauges) was converted from analog to digital instruments. In retrospect, this first modernization was quite successful, i.e. the general objectives outlined from the beginning were reached within agreed time and budgets.

In 1998–1999, the first steps in a new modernization of the network were taken. The digital instruments at some of the tidal stations had been running for more than 10 years and it was time to look for new technology. One of the requirements in the specification was that the data loggers should be able to deliver near-real-time data. New sensors for measuring water level should also be considered. A test of a radar gauge, provided by the Miros company (www.miros.no), back in 1997, showed promising results, but our opinion in 1998–1999 was that more thorough tests were required before we could recommend this gauge to be used at the Norwegian Hydrographic Service (NHS) permanent tidal stations. During 1998–1999, the surveys of market and available technologies were completed and several companies were invited to tender for the delivery of new data loggers and sensors for water level and barometric pressure. The Norwegian company Instrunor AS, now a part of the Telenor Connect company (www.telenorconnect.com), won the competition. It was decided that we should still use well proven technology, i.e. the traditional, but modern, digital float gauge.

During the 1990s, with a higher drive for information, the customers expected to get faster access to:

- Water level observations;
- Tide tables;
- Statistics;
- Calibration information;
- Leveling information.

There was also the requirement of the Norwegian Government that more effective routines had to be implemented by governmental departments. This implied an improvement of quality, price and production time and ideally that public services should be faster, better and cheaper.



Based on the technological development and the requirement of the Norwegian Government, the Oceanographic Group at NHS during the 1990s introduced the slogan *From country store to self-service*. The customers used to apply directly to the staff of the Oceanographic Group and ask for data or other information, and the products were delivered in return to the customers; typically a "*country store"*. By using new technology it is now possible to carry out most of these deliveries faster, better and cheaper. NHS has during the last few years developed Intranet and Internet services where the customers can search for and download wanted products (*self-service*).

Tide gauge network, overview

A modern tide gauge network consists of several tide gauges that are connected to a central computer by some kind of communication system (telephone, satellite, radio etc.). After quality control, the data are stored in a database where they can be analyzed and distributed to internal or external users Figure 1).

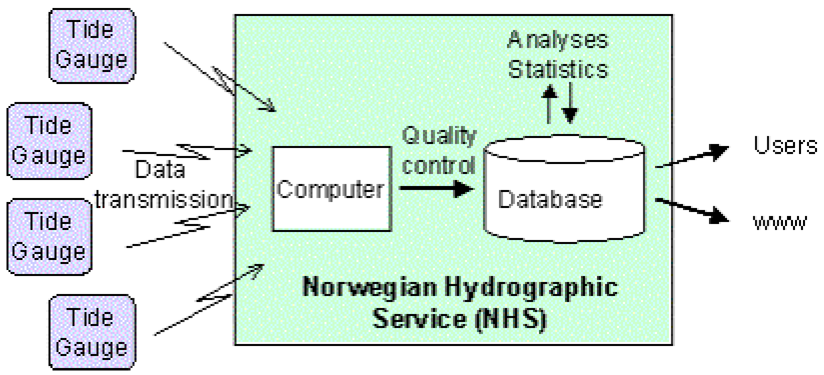


Figure 1. Schematic representation of the Norwegian tide gauge network.

Tide gauge

The tide gauge itself (Figure 2) is composed of a data logger that reads and stores data from different sensors and a modem that communicates with a computer at NHS. It has 220 V AC power supply and is equipped with battery back up in case of power failure. The water level sensor needs to be leveled from a stable benchmark and calibrated at regular intervals.

Furthermore, a solid and stable construction for the sensors is required, and the site has to satisfy certain conditions concerning water depth, environmental conditions, ship traffic, currents, access etc. (see Manual on Sea Level Measurement and Interpretation, Volume I: Basic Procedures. IOC, 1985; (www.pol.ac.uk/psmsl/manuals/).

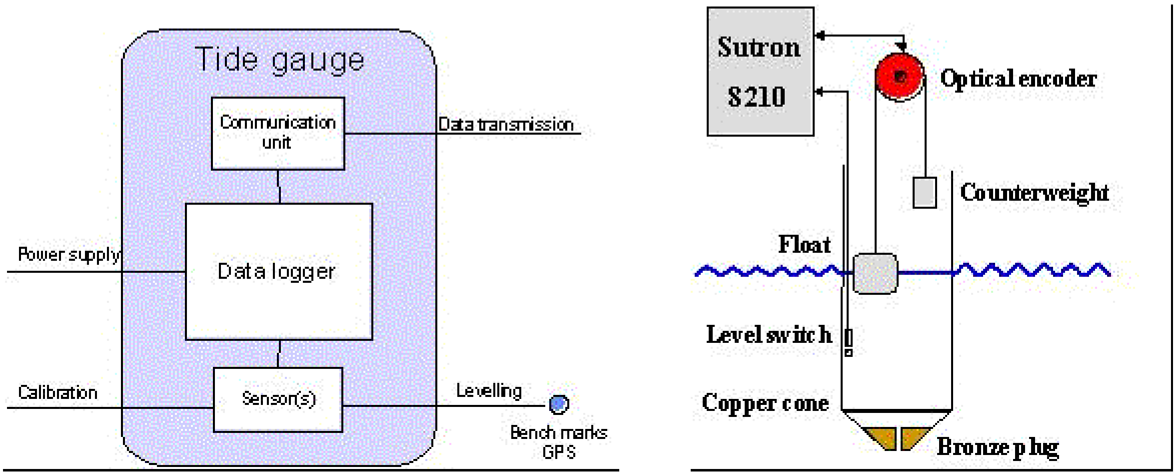


Figure 2. Schematic representation of the tide gauge used in the Norwegian tide gauge network.

The water level is measured using a digital float gauge. It consists of a data logger (Sutron 8210), a traditional float, chain and counterweight system and an optical encoder. The data logger "administers" the data sampling, stores the data and transfers the data to a central computer at NHS.

Calibration and maintenance

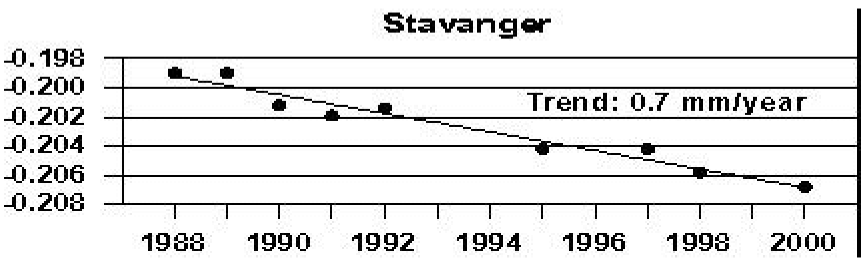
Calibration and maintenance of the tide gauges is carried out by staff from NHS.

Datums and datum connections at the tide gauges

A tide gauge must be coupled to benchmarks in the vicinity of the gauge. Most of the tide gauges in the Norwegian network are connected to three benchmarks.

Leveling

Most of the gauges are installed on modern quays built on solid rock, but some are located in slightly unstable areas. Leveling was done once a year until 1994. The leveling showed no significant vertical motion in the majority of the tide gauges and these are today leveled every third year. The others are leveled every year. Leveling records for two stations, Stavanger and Heimsjø, are shown in Figure 3 *(below and next page).*



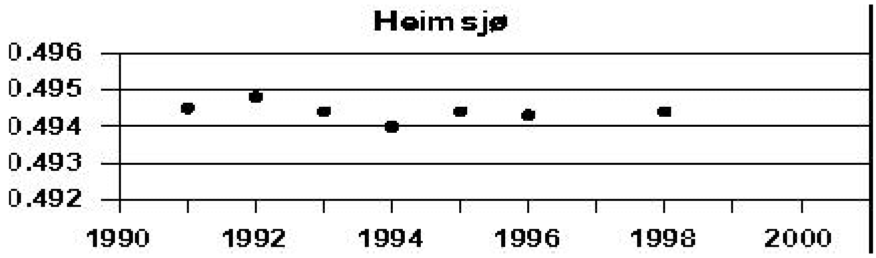


Figure 3. Leveling record for the Stavanger (decreasing trend) and Heimsjø (no trend) tide gauges.

The Stavanger site is unstable and sinking at a rate of approximately 0.7 mm/year. Heimsjø is installed on solid rock and the Contact Point shows no sign of sinking. The vertical scale is the height (in metres) of the Contact Point relative to the Tide Gauge Bench Mark (TGBM). The Norwegian Mapping Authority Geodetic Institute does the precise leveling.

Data communication

The communication with the remote stations may be done either interactively or automatically using a dialed connection on the ordinary telephone network. The PCBASE2 application developed by the Sutron Corporation is used for the data communication (www.sutron.com).

Data management

The tide gauges and data communication are only part of the network. Quite as important is to have a good system of quality control, documentation, data processing and archiving.

Quality control

Quality control must be done regularly and before the data are made available to users. At NHS we have developed an automatic quality control where a flag is set if:

There is a gap in the time-series;
A 10-minute interval datum is identical to the four preceding values;
There is a "jump/spike" in the data.

Tolerances are determined from looking at the distribution and standard deviation of the "jump/spike" test over time for each station. Open-coast stations with high-energy-wave environments generally have higher tolerances than inside "quiet" stations. The automatic control is performed before the data are stored in the database. In addition, the data are manually controlled every workday. Graphical presentation is the key to the thorough inspection and control of the water level observations. An important part of the inspection is to compare residuals from neighboring ports.

Data from a level switch is used for supervising the stability of tide gauge zero (TGZ). The level switch is a tiny float, which switches a current loop when the water level passes the water where the level is mounted. The computer registers the time when the level switch turns on or off. This level is well known (approximately at mean sea level), and can be compared with the tide gauge observations at the same time. The level switch has been very important in detecting several problems, such as drift (trend) in the observations. The plot in Figure 4 shows data for the level switch for Ny-Ålesund for the period 2000–2002.

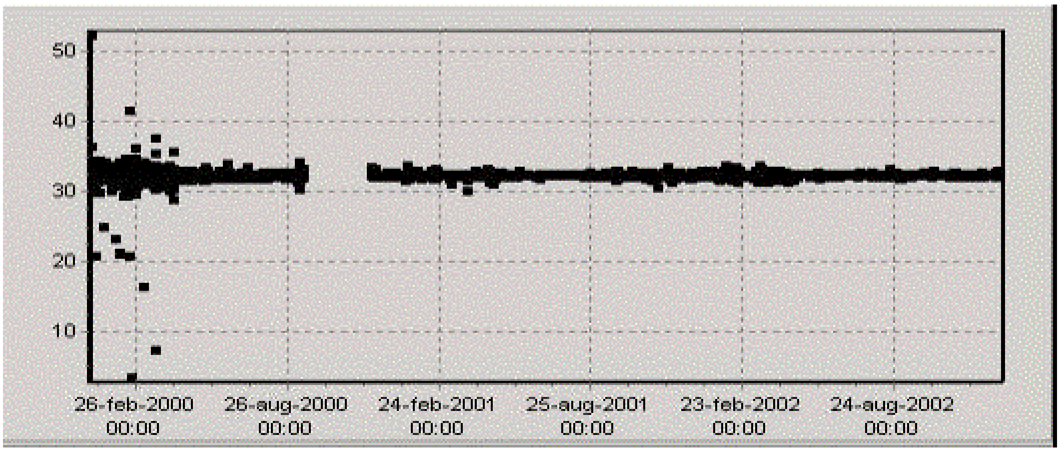


Figure 4. Level switch record for the Ny-Ålesund station for 2000–2002.

Database

By the end of 2002 the Norwegian water level database (Oracle) contained about 1325 years with accepted water level observations. All data have been through a quality control, and all corrections are flagged and documented. Figure 5 gives an overview of the series from the permanent tide gauges that are operated today.

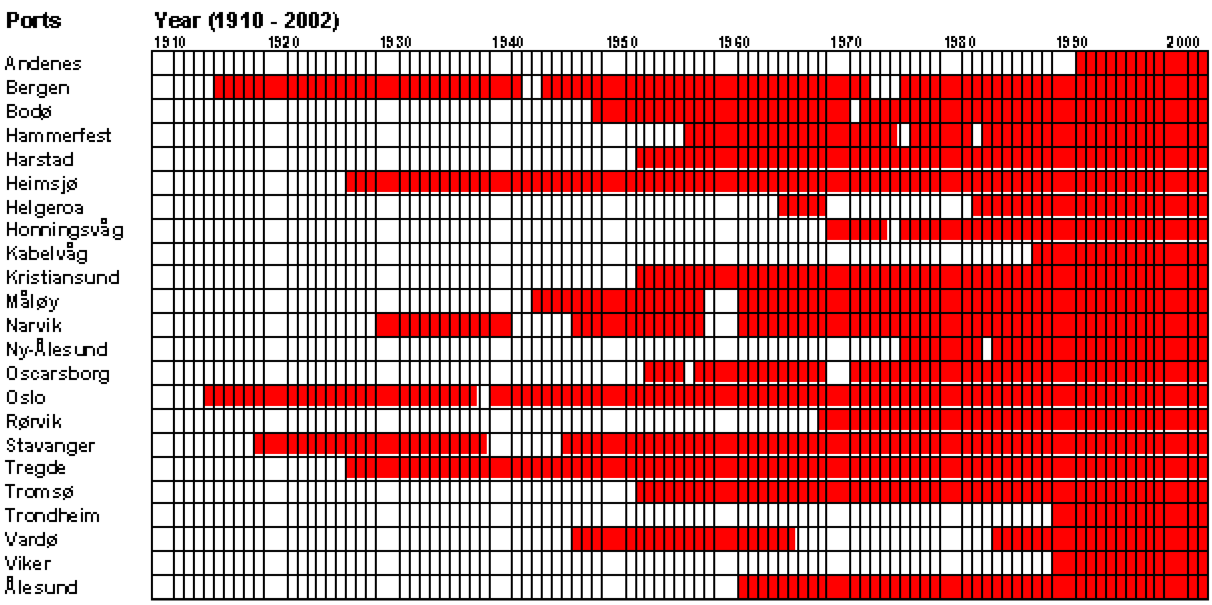


Figure 5. An overview of the time-series from the permanent tide gauges in operation today.

In addition, 420 series from secondary ports are available.

Data capture

It is clearly seen that stable operation of the network relies heavily on good organizational and administrative routines, together with tight routines for continuous quality control. Table 1 shows the data capture for the Norwegian tide gauge network for the last eight years.

Table 1. Data capture for the Norwegian tide gauge network, 1995–2002.

Year	**Data capture for the entire network**
2002	99.4 %
2001	99.6 %
2000	98.8 %
1999	99.4 %
1998	98.1 %
1997	97.7 %
1996	98.0 %
1995	97.1 %

Data analyses and statistics

Software for:

Tidal analyses (based on the Foreman tidal analysis software (IOS));
Tidal predictions (based on the Foreman tidal analysis software (IOS));
Secondary port analyses (developed by NHS);
Statistics (NHS is using Matlab and software developed by NHS).
is available at NHS.

Data export and data exchange

A database is a very good basis for displaying and exporting data. At NHS, an Intranet is used by internal users to collect data from the database by themselves. In co-operation with the Norwegian Meteorological Institute, water level observations, predictions, residuals and water level forecasts are presented on Internet (http://met.no/cgi-bin/vannstand-tabell.cgi).

Sea level data and information will soon be available on the NHS web pages (the web address is not yet available).

The Digilevel

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Introduction

The objective of this work is to introduce a new technology for sea level measurements. To meet the GLOSS standards for data acquisition and processing, a digital system, called Digilevel, was developed in the 1990s, in Brazil, by the Oceanic Instrumentation Laboratory, of COPPE–UFRJ. It resembles an electronic tide staff with sensors spaced 1 cm apart along a staff that is housed in the stilling well.

A general description of this system is provided in section 2; section 3 describes the methodology used to evaluate the Digilevel performance in recording sea level data according to the GLOSS standards. Section 4 gives a summary and some recommendations for future work.

Sensor characteristics

(Contact person: Mr. Luiz Falcão, e-mail: luizfalcao@terra.com.br)

The main utility of the Digilevel is the measurement of the water level in the ocean, lakes, rivers, dams and other water bodies. It is compatible with different types of equipment, such as graduated rulers, buoy limnigraphs and pressure tide gauges, among others.

The major advantages of this system consist in:

No linearity or calibration errors;
No temperature and time drifts;
No data conversion needed;
Easy data transfer;
Long periods of data acquisition and retention.

Nowadays, electronic readings are made at 15-minute intervals. The data are buffered into a data collection platform (DCP) in the tide station's protective housing. The DCP can be interrogated by telephone to directly download the data at the user’s processing station. This operation is typically performed daily with the DCP buffer size well over a month. Data collected can be downloaded to a PC by using a Windows-interface programme.

Table 1 next page gives the basic technical specifications of the Digilevel.

Table 1. Basic technical specifications of the Digilevel.

SENSOR RULER Resolution: 1 cm Length: N × 1.28 m *Electrodes: stainless steel* Structure: stainless steel and epoxy-resin	CONTROL UNIT *Sample rate: 1 minute to 6 hours* Storage capacity: 32,000 samples Display: LCD (2 lines × 16 characters) Interfaces: Serial RS-232 Modem 2400 bps (optional) Battery life: 2 months electrical power (optional) *Set-up: date, hour and sample rate*
DATA COLLECTOR Storage capacity: 32,000 samples Indications: power on communication error Interface: Serial RS-232 Battery life: 5 days	

System evaluation
(Contact person: Lt. Cdr. Marcelo Fricks Cavalcante, e-mail: 112@chm.mar.mil.br)

To evaluate Digilevel data quality, in conformity with GLOSS standards, a study has been carried out by CHM. The methodology basically consists of time-series comparisons between Digilevel and an analog equipment (a float gauge). During the last four months some changes have been made in the Digilevel system and considerable improvement has been noticed.

At the beginning of July, the clock sensor of this system was replaced by a different one, in an attempt to solve the above-mentioned phase discrepancies. The improvement in the agreement between both series was clearly noticeable, but there are still some large differences at the lower levels, as also occurred in May. It was found that these differences were due to some incrustations on the Digilevel staff, which had all its underwater components completely cleaned on July 28.

Time-series comparisons for August indicated a more stable situation, in which the differences were, in general, below 10 cm in amplitude and the monthly means of the two sensors were found to differ by only 1 cm, the Digilevel being greater than the conventional analog equipment. Since the two time-series have very similar behavior, in phase and in amplitude, it is difficult to assume that all the discrepancies between both series were exclusively attributable to the Digilevel.

Statistical analysis of both time-series gave a correlation coefficient of 0.99, with a standard deviation of 4.27 for 744 data points.

Summary and future work

The Digilevel system was introduced and its performance has been evaluated. The system, considering its simplicity and the quality of the data, can be assumed to be a promising option to be used in sea level measurement.

Recent tests have indicated some upgrade of the system performance. For example, the change of the clock sensor as well as the implementation of routine maintenance led to some improvement in the Digilevel data quality compared to that of the analog equipment. The differences between the two time-series were found, in general, to be below 10 cm, with monthly means of raw data differing by only 1 cm. At this point, another tide gauge should be installed, in order to provide a third source of information to complement the evaluation, since now the differences are low, and the Digilevel cannot be blamed for all the measurement error. The evaluation will continue in order to verify the reliability and confidence level of the system.

Acknowledgments

To Rafael Guarino Soutelino for the help during the Digilevel evaluations.

Comparison of Several Technologies at the Spanish Test Site

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Puertos del Estado,
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Introduction

To compare the accuracy and the operational characteristics of different technologies for measuring the sea level, and under the ESEAS-RI project (EVR1-CT-2002-40025), a test station was established in Villagarcía (NW Spain). Since December 2002, different types of tide gauge have been installed; some were lent by other institutions or companies, others were bought by Puertos del Estado (Spanish Ports Authority, PE).

The number of people interested in the experiment has been increasing and new equipment has been incorporated into the test station, so that there is no unique starting date for all the gauges. PE intends to establish a contract to maintain the test site operational for up to one more year.

Figure 1. Location of the Port of Villagarcía, emplacement of the test site.

The Port of Villagarcía (Figure 1) is situated on the north-west coast of Spain, in the sheltered waters of the Ría of Arousa (42º36'N, 8º46'W).

The emplacement has several advantages: it has an adequate tidal range (mesotidal, up to 4.2 m), it is subject to varying meteorological conditions, and has 24-h surveillance.

At this port, PE has operated an acoustic SRD tide gauge station since 1997, which forms part of the REDMAR (PE tide gauge network). The sea level data obtained from this station undergo near-real-time quality control (automatic detection of spikes, interpolation of short gaps and adjustment of the time of measurement) and are processed and analyzed in more detail annually. The tide gauges, which form part of the test station, were placed on a different dock, approximately half a kilometre from the REDMAR permanent station (Figure 2).

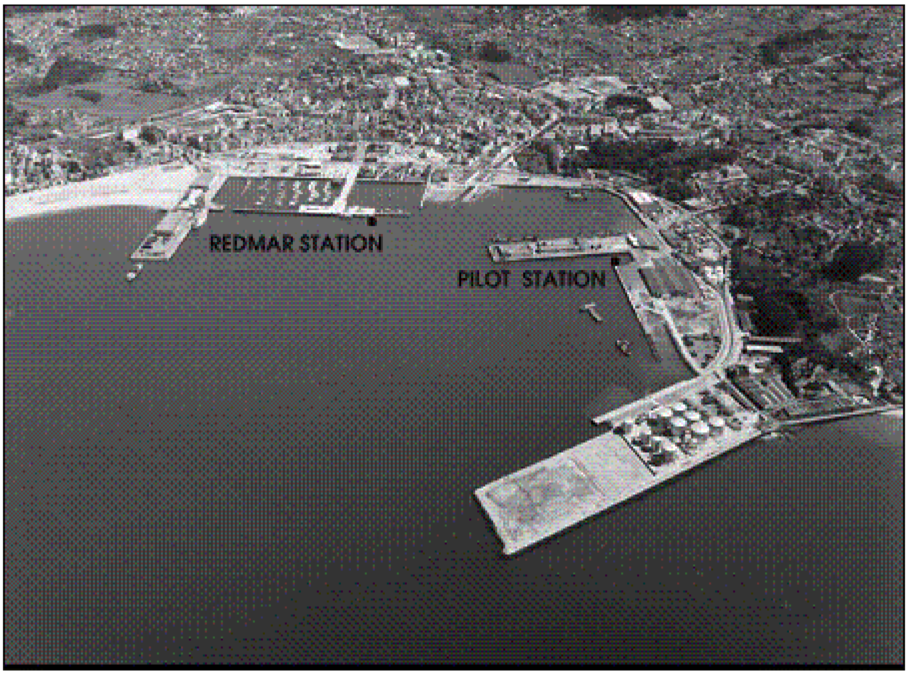

Figure 2. Location of the REDMAR station and the test site at the port of Villagarcía.

Apart from the permanent gauge (SRD), eight other gauges using four different technologies (acoustic, radar, pressure, float) have been installed at the test site during the experiment, although only six of them have so far produced data suitable for the intercomparison:

- Acoustic: Aquatrak (AQU), provided by NOAA, and SRD (permanent REDMAR station);
- Radar: Vegapuls (VEG) and Seba (SEB), both with pulse methodology, (owned by PE), Miros (MIR) and Radac (RAD) with CWFM (continuous-wave frequency-modulation technology), provided by the respective companies for the experiment (Figure 3);
- Pressure: Aanderaa, differential-pressure transducer (discarded, owing to installation difficulty), and Seabird (SBE) which is an absolute pressure transducer, provided by SIDMAR (the company that installed and maintains the gauge);
- Float: Thalimedes (discarded after confirmation that this sensor was not suitable for large tidal ranges).

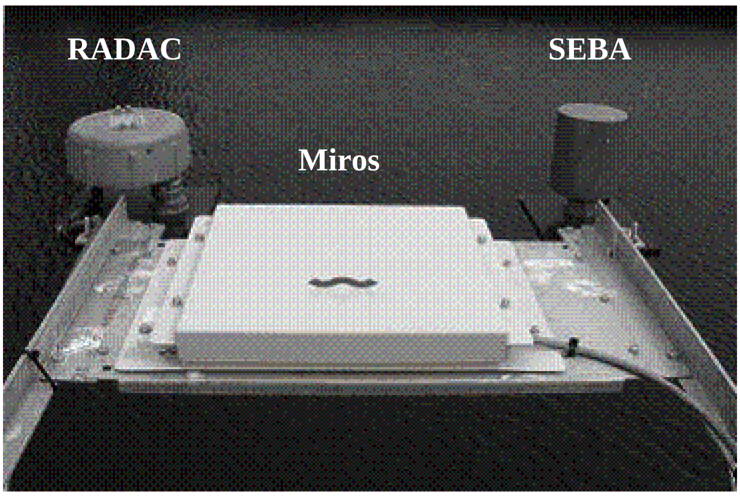

Figure 3. Picture of three of the radar sensors installed at the test site.

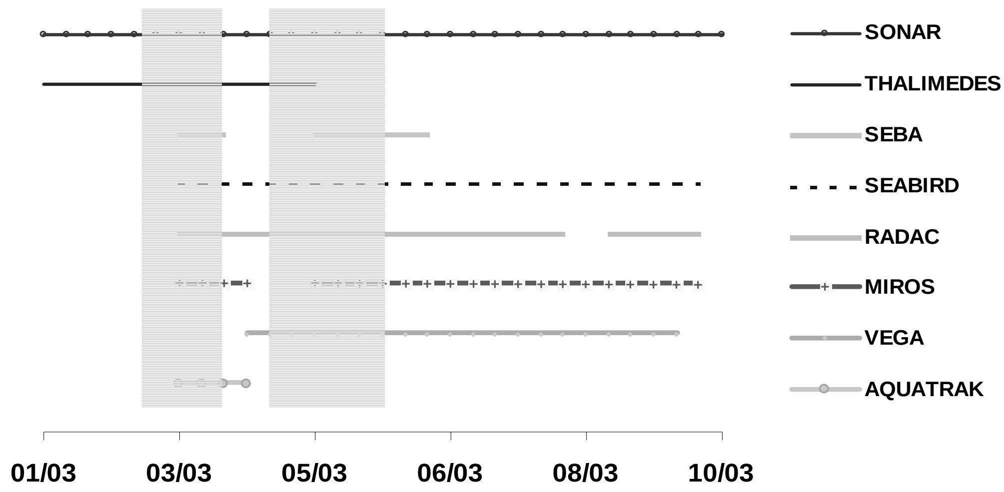

Figure 4. Periods of functioning of the gauges and periods of intercomparison (inside the grey boxes).

Preparation of data

The sampling strategy for the first comparisons was designed to fit the SRD data from the reference REDMAR station. SRD data are stored every 5 minutes, and each measurement is an average of 30–50 seconds. The data from the rest of the sensors were processed to be coherent with this, although this was not possible for all the gauges. In particular, Aquatrak, Miros and Seba were averaged over a 1-minute period and recorded every 5 minutes, whereas Vegapuls and Seabird provided data averaged over a 5-minute period.

Our first purpose was to evaluate the quality of the sea level series provided by the different tide gauges, without studying other incidences and maintenance aspects in detail, so far.

Problems encountered

These are some of the difficulties encountered that may affect this first study of the data:

- As explained above, it was not possible to average over exactly the same period, owing to differences in the methods of sampling;
- Data from all the sensors were recorded by independent data-loggers or computers, which have their own clock. Time differences may arise that must be compensated for. In certain cases data were lagged (by not more than 10 minutes) to obtain the maximum correlation between them. A more detailed study of the functioning of the clock and the precision of the time assignment remains to be done, although in the future external control of the clock by GPS should not be a problem;
- Some sensors give distance to water level and some others give sea level, and in different units. Mean values were substracted from the raw data so that all series are centered on 0 and comparison is easier;
- The Seabird measures the total hydrostatic pressure and the temperature. Data were corrected taking into account the water temperature and the atmospheric pressure, but not salinity;

- The distance between the Radac sensor and the sea surface was insufficient and this led to the loss of information on high tide levels for this sensor;
- The Aquatrak sensor did not have thermistors along the tube, so this correction was not possible in Villagarcía. However, data do not seem to be affected by temperature changes.

Variables evaluated and statistical comparison

After achieving homogeneous, 0-centred, simultaneous time-series, we made the comparisons between each pair of sensors. With this aim, we studied the scatter-diagrams of the sea level data provided by the gauges and obtained the coefficient of determination, which indicates the amount of variability shared by the series. We also performed a linear-regression analysis between them and calculated the slope, which indicates the differences between the tidal range registered by each gauge and their distinct "sensitivity" to changes in sea level (change in measured distance over true distance). Finally, we obtained the root mean-square error (RMS), that is to say, the mean absolute deviation between the sea level series.

Results for the first period: March

The coefficient of determination R^2 was always very high and ranged from 0.9997 (between Seba and SRD) to 0.9987 (between Miros and Radac). The slope (Figure 5a) indicates that Aquatrak seems unable to record the same tidal range as the other gauges (the tidal range recorded by Aquatrak is 1% smaller). There might be some problem with the tube calibration, which is currently under study. Miros is the tidal gauge that registers the largest tidal range (but with differences of only 0.1%).

According to the RMS, the most similar are the SRD and the Seba gauges (Figure 5b). However, if we bear in mind that many sensors only have an accuracy of 1 cm, an important part of the RMS that we have obtained is not significantly different.

a)

		X_1	X_2	X_3	X_4	X_5	X_6
	b	AQU	MIR	SBE	SEB	SRD	RAD
Y_1	AQU	1	0.971	0.978	0.972	0.972	0.972
Y_2	MIR	1.030	1	1.007	1.001	1.001	1.005
Y_3	SBE	1.022	0.993	1	0.994	0.994	0.991
Y_4	SEB	1.028	0.998	1.005	1	1.000	1.003
Y_5	SRD	1.028	0.998	1.005	1.000	1	1.000
Y_6	RAD	1.028	0.994	1.008	0.996	0.999	1

b)

RMS	AQU	MIR	SBE	SEB	SRD	RAD
AQU	0.0	3.6	3.1	2.9	2.9	3.0
MIR	3.6	0.0	2.2	2.5	1.9	2.8
SBE	3.1	2.2	0.0	3.0	2.3	2.6
SEB	2.9	2.5	3.0	0.0	1.6	2.1
SRD	2.9	1.9	2.3	1.6	0.0	2.3
RAD	3.0	2.8	2.6	2.1	2.3	0.0

Figure 5. Results of the intercomparison of the different gauges in March. Slope of the linear regression (a) (dimensionless) and RMS (b) (results in centimetres).

Results for the second period: May–June

During this period, the Aquatrak was not working, owing to a malfunction, and was substituted by a new pulse radar (Vegapuls) which began working at the end of March.

The coefficient of determination R^2 is 1.00 between Seabird and Vegapuls. According to the slope (Figure 6a), SRD and Miros are the gauges that measured the greatest tidal ranges, and Seabird, the smallest. Nevertheless, differences are very small (0.1%).

The RMS shows a remarkable reduction in relation to the results obtained for the previous period (Figure 6b). Mean absolute deviations between sensors ranged from 0.7 to 2.6 cm and, if we discard the RMS value between Radac and the other sensors, we obtain an overall RMS of 1.6 cm. The longer period of data, the improvements in the external equipment and the more stable meteorological conditions might explain this.

a)

		X_1	X_2	X_3	X_4	X_5	X_6
	b	GEO	MIR	SBE	SEB	SRD	RAD
Y_1	GEO	1	0.999	1.004	1.000	0.997	1.004
Y_2	MIR	1.000	1	1.004	1.001	0.997	1.005
Y_3	SBE	0.996	0.996	1	0.996	0.993	0.999
Y_4	SEB	0.999	0.999	1.003	1	0.996	1.005
Y_5	SRD	1.003	1.002	1.007	1.003	1	1.007
Y_6	RAD	0.995	0.995	0.999	0.995	0.992	1

b)

RMS	GEO	MIR	SBE	SEB	SRD	RAD
GEO	0.0	1.7	0.7	2.2	1.3	2.5
MIR	1.7	0.0	1.8	1.3	1.6	1.8
SBE	0.7	1.8	0.0	2.4	1.5	2.6
SEB	2.2	1.3	2.4	0.0	1.8	1.8
SRD	1.3	1.6	1.5	1.8	0.0	2.5
RAD	2.5	1.8	2.6	1.8	2.5	0.0

Figure 6. Results of the intercomparison between the different gauges in May–June. Slope of the linear regression (a) and RMS (b) (results in centimetres).

Summary

If we take into account that many of the difficulties encountered were not related to the performance of the sensor, but to the installation problems, all gauges performed well and provided data of sufficient quality during this first stage of the experiment. However, longer and more simultaneous time-series are needed to perform a better evaluation. This first study focused on level accuracy, but other aspects, such as datum stability and maintenance requirements, will be considered in the coming months.

Future work

A bubbler gauge from POL (Proudman Oceanographic Laboratory) will be incorporated into the experiment. With that new equipment, we shall be able to make a comparison that covers nearly all the available technologies for measuring sea level.

In a few months we hope to have a time-series long enough to perform harmonic analysis on a reliable basis. We shall also study the evolution of the mean sea level (monthly) provided by the different gauges, so as to detect possible instrumental drift. We shall carry out cross-spectrum analysis of the data in order to study the different responses depending on the frequency range. This is interesting particularly for those sensors that measure over a very small time interval (1 second or less), since this could make them useful for other applications.

Additional remarks

We still do not know the influence that extreme meteorological conditions can have in the performance of radar systems. In addition to this, more precise studies should be made to find out their capability for measuring high-frequency events, such as waves. Another aspect yet to be considered is the possibility of installing the sensors within a protective tube.

Developments in Satellite Communication: Applications to Sea Level Data Delivery

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Peter Foden[2], John Marshall[2] and David Smith[2]
[1]Scottish Association for Marine Science
[2]Proudman Oceanographic Laboratory

Recent developments in low-power two-way satellite communication systems, such as Orbcomm and Iridium, have transformed data collection from small self-contained remote platforms. For the first time it has been possible not only to collect data in near real time, but also to perform remote diagnostics and software upgrades. In the case of sea level data, simultaneous improvements in embedded processor technology and availability have enabled a new, focused approach to the way sea level data are acquired and retrieved remotely. For example, it has been possible to converge the data logging and telemetry systems used both in the UK tide gauge network and at the Proudman Oceanographic Laboratory's sea level stations on remote islands in the Antarctic and the Southern Ocean. The new instrumentation can be modular and offer data-on-demand, as well as the option to deliver data via e-mail and web pages.

Introduction

Mobile satellite systems (MSS) may be classified according to orbit altitude, as follows:

GEO - geostationary earth orbit, approximate altitude: 35,000 km;
MEO - mid-altitude earth orbit, approximate altitude: 10,000 km;
LEO - low earth orbit, approximate altitude: <1000 km.

LEOs can be further sub-divided into Big LEO and Little LEO categories. Big LEOs will offer voice, fax, telex, paging and data capability, whereas little LEOs will offer data capability only, either on a real-time direct-readout ('bent pipe') basis, or as a store-and-forward service.

Since the satellite footprint decreases in size as the orbit gets lower, LEO and MEO systems require larger constellations than GEO satellites to achieve global coverage and avoid data delays. Less energy is, however, generally required for LEO and MEO satellite communication, because of the shorter average distance between transmitter and satellite. Some systems operate several high-gain antennas to generate "spot beams" and so reduce the requirement of the mobile to have a complex antenna and/or high-output power. A key feature of several MSS currently under development will be their inter-operability with existing public switched-telephone and cellular networks, using a dual-mode handset, for example.

Because of the commercial forces which are driving the implementation of the new systems, many will primarily focus on landmasses and centres of population, and will not offer truly global or polar coverage. These systems will not in general be acceptable for global ocean monitoring. Furthermore, while the technical capabilities for the new MSS do currently exist, delays are inevitable, owing to problems with spectrum allocation, licensing (in each country where the service will be offered), company financing, and availability of launch vehicles and ground stations.

It is unlikely that all of the planned systems will overcome all of these hurdles. Indeed, major financial difficulties have hit a number of systems, with Starsys having been cancelled, Iridium having collapsed (and relaunched), and both Orbcomm and New ICO having been in and out of Chapter-11 bankruptcy protection in the USA. Mergers are becoming increasingly common, as market reality forces system planners to cut their losses and pool resources: CCI, Teledesic, Ellipso and New ICO have all recently signed buy-out or collaboration agreements with cellphone entrepreneur Craig McCaw.

From a technical point of view, some systems do offer significantly enhanced capabilities compared to existing methods. Potential advantages include two-way communication, more timely observations, and greater data rates and volumes. Some systems may also prove to be considerably less expensive than existing channels, although this is still unclear. However, dangers will exist for marine scientific users of most MSS, in that they will generally be small-minority users of the system, with consequent lack of influence on pricing. The arrangements for data distribution are also unlikely to be tailored to oceanographic applications, in particular those that require data insertion on the GTS.

Description of candidate satellite systems

The following paragraphs describe the salient features of those systems that might have a marine scientific application. In many cases systems are at an early planning stage, and reliable technical information on which to base an evaluation is unavailable. This section is summarized in tabular form in the Annex to the present paper.

Little LEOs

Argos

Argos has been used by the oceanographic community for more than two decades, and is a dependable, true polar, operational data collection and platform location system. Traditionally, communication is one-way only, at 400 baud, with practicable data rates of about 1 kbyte per day. Transmissions by the mobile in this mode are unacknowledged by the system and therefore have to incorporate some form of redundancy if data transfer is to be assured. The system enjoys a particularly clean part of the spectrum (401.65 MHz), with minimal interference from other users. Until now, Argos has flown as an attached payload on the NOAA TIROS weather satellites, but the recent launch on board the Japanese ADEOS-II vehicle and projected launches on board the European METOPS platforms marks an important diversification of service provision.

Enhancements to the Argos on-board equipment (Argos-2) include increased receiver bandwidth and sensitivity, with a highly significant move to two-way communication ("downlink messaging") now being piloted aboard ADEOS-II, launched in December 2002, but now dead. Next-generation Argos equipment (Argos 3) will fly from 2004 onwards, and will offer order-of-magnitude increases in data rates, as well as two-way communications. The system is one of the few that offers true global coverage, and currently has no commercial requirement to recover the cost of the launch or space segment equipment.

The first of the Argos-2 satellites, NOAA-K (NOAA-15) was launched in May 1998, and was followed in September 2000 by NOAA-L (NOAA-16), and by NOAA-M (NOAA17) in June 2002. New direct readout stations continue to be commissioned, bringing the current total to more than 30. Additions during the year have included Hatoyama (Japan, NASDA), Oslo (Norway, NMI), Las Palmas (Canary Islands, CLS), Singapore (Singapore, SMM) and Santiago (Chile, Meteo Chile). This continues the programme of improving data timeliness by exploiting the use of Argos in "bent-pipe" mode. Further enhancements to the on-board equipment

(Argos-3), to the ground processing centres and software, including new on-line facilities for users, are at the planning stage.

Orbcomm

This company was awarded the first FCC Little-LEO licence in late 1994. Satellites consist of discs about one metre in diameter prior to deployment of solar panels and antenna. Two satellites were launched into polar orbit during 1995, using a Pegasus rocket piggy-backed on to a Lockheed L-1011 aircraft. After a prolonged period of launcher problems, 35 satellites are now in orbit, making up the complete constellation, although Orbcomm have been awarded a licence for an expansion to a 48-satellite constellation. Of these satellites, 30 are currently operational. The A, B, C and D planes are at 45° inclination and therefore have poor coverage at high latitudes: only two satellites, in the F and G planes (70°), offer a near-polar service, and these have proved to be unreliable. No further launches have been announced.

The system offers both bent-pipe and store-and-forward two-way messaging capabilities, operating in the VHF (138–148 MHz) band. User terminals are known as Subscriber Communicators (SCs). Although there have been significant problems with interference close to urban areas, this is not expected to impact offshore operations, and trials of the system have been encouraging. Operational experience of the system is growing rapidly, although it remains difficult to obtain detailed technical information from Orbcomm.

The message structure currently consists of packets transmitted at 2,400 bps (scheduled to rise to 4,800 bps), and coverage is now global and near continuous between the polar circles. Messages are acknowledged by the system when correctly received and delivered to a user-nominated mailbox. The platform position is determined, if required, using propagation delay data and doppler shift, or by an on-board GPS receiver. Position accuracy without GPS is similar to that offered by Argos, i.e. kilometre-scale.

The limitations of the store-and-forward mode messages (known as globalgrams) have become apparent, with SC-originated messages limited to 229 bytes and SC-terminated messages limited to 182 bytes. Each SC can theoretically have a maximum of 16 globalgrams stored on each satellite. Currently, satellites will not accept or process globalgrams when in view of a ground ("gateway") station. As messages have to be designated as globalgrams or bent-pipe by the SC at the moment of origination, this presently limits the flexibility of the system to adapt to different coverage situations. Work-arounds do, however, exist, and it is expected that the next generation of SCs will be able to adapt more readily to changes in satellite communications mode.

Authorized transceiver manufacturers include Panasonic, Elisra (Stellar) and Quake. Elisra were the first to offer a transceiver with a fully integrated GPS engine, although Panasonic now also have one available. Quake sell a fully integrated unit which features a built-in antenna, as well as GPS. Prices of most units are falling, with models now available for around $500.

The ground segment has continued to expand, and there are now active stations in Italy, Morocco, Argentina, Brazil, Curação, Japan, Malaysia and Korea, in addition to the four in the USA. However the Japanese station is not available for international registrations. Further potential sites have been identified in Russia, Ukraine, Philippines, Botswana, Australia and Oman. Sixteen international service distribution partners have been licensed. Non-US customers have faced considerable difficulties because of the absence of ground stations, lack of spectrum licensing and the presence of other in-band users. However the situation is improving. Currently, subscription costs within Europe are on a fixed cost per unit with two bands of usage (above and below 4 kbytes per month with a typical monthly rate for the higher band being $70). A fully metered billing system based on users' actual data throughput was to be implemented in July 2000 but was postponed, officially owing to technical problems. If this billing system is implemented with the planned charges ($6/kbyte) then it will result in a massive increase in airtime costs for any user with data rates over 0.5 kbytes/day. Metered billing is apparently implemented outside Europe.

Orbcomm has suffered financial difficulties, and filed for "Chapter-11" bankruptcy protection in September 2000. The parent company, Orbital Sciences Corporation, has now put together a new consortium to run Orbcomm. The outstanding debts are believed to stem largely from the system rollout phase, with net running costs being of much smaller concern. Industry opinion in Orbcomm continues to grow, largely because of the commitment of many third-party equipment and system manufacturers to the success of the system, and evidence of increasing service take-up by a diverse range of customers.

Starsys

This system was to have been broadly similar to Orbcomm, except that it offered bent pipe mode only, thus limiting its usefulness to coastal areas. Further work on the system, in which the operators of the Argos system were closely involved, was suspended some years ago. The FCC licence was returned in late-1997 and the system is now no more than one of the first memorials to the many failures in the business.

Iris/LLMS

This European-led system appears to be similar to Argos, using two polar-orbiting satellites with store-and-forward capability. However, terminals are alerted by the satellite downlink signal, and two-way communications and message acknowledgement are supported. Location is by doppler and ranging, and message lengths of up to a few kilobytes are permitted. Some provision is planned for terminal–terminal communication within the satellite footprint. A single satellite was in orbit for system tests, but nothing further has been heard, and the parent company's website (www.saitrh.com) no longer makes any mention of the system.

Vitasat/Gemnet

This was a 36 + 2 satellite constellation proposed by CTA Commercial Systems. Their experimental satellite was the failed Vitasat launch in 1995. CTA is reported to have been taken over by Orbital Science Corporation, the parent organization of Orbcomm, and the 36-satellite Gemnet component has been cancelled. However, the volunteer VITA organization still exists and currently has one satellite in orbit, with plans to rent bandwidth on two other existing satellites, HealthSat-2 and UoSat-12. This proposal received FCC clearance in December 2000, and the company have now brought HealthSat-2 on line. The mission is to offer low-cost messaging services to developing countries.

Faisat

The Final Analysis Company have planned this 32 (+ 6 spare) satellite constellation to provide data-messaging services, principally aimed at small messages (~100 bytes), but with support for larger messages as well. It will operate in both bent-pipe and store-and-forward modes. The first satellite launch, on the Russian Cosmos vehicle, was scheduled for early 2000, but nothing has been reported. Further launches were to have occurred roughly twice a year. The system received FCC authorization in April 1998. A test satellite (also part of the Vitasat system) was launched in 1997.

Leo One

This US-designed system consists of a planned 48-satellite constellation offering store-and-forward two-way messaging at up to 9600 bps. An FCC licence was granted in February 1998, and a spectrum-sharing agreement signed with the operators of the Russian maritime satellite system, TSYKADA. Commercial operation was expected to start in 2003, although no details are known regarding the launch schedule. Orbit inclination was to have been 50°, giving useful coverage up to latitudes of about 65°. No further details have been reported and the website no longer exists.

Gonets

Two GONETS LEO messaging systems were proposed by the former Soviet Union, using both UHF and L/S-band communication channels. Both will offer true global coverage from high inclination 1,400-km orbits. One system, GONETS-D already has 8 satellites in orbit with a further 36 planned. No operational experience has been reported to date.

Other Systems

Six E-Sat satellites are planned. Launches were to have started in 2001, but nothing has so far been announced. The system is aimed principally at the US utility industry for remote metering. The Italian based Temisat is another planned system, which is intended to offer global coverage. Little further has been heard of the European SAFIR store-and-forward messaging system, which has two satellites in orbit, but has yet to relaunch a service following major technical problems.

Big and broadband LEOs

Iridium

Iridium filed for "Chapter-11" bankruptcy protection in August 1999, and underwent financial restructuring. Financial difficulties continued and the system ceased operation in April 2000. At that time, Iridium had its complete constellation of 66 satellites plus spares in orbit, and offered a true global service through a network of ground stations backed up by inter-satellite links. The system has since been rescued from planned de-orbiting and resurrected by the US Department of Defense. A commercial service has also been relaunched. Most Iridium phones are data-capable and will interface with a standard modem. Throughput is about 2400 bps. The component parts of some phones are now being repackaged as stand-alone modems. A short-message service (1,900 bytes max per message) was introduced in late-2002, as well as a dropout-tolerant direct Internet connection at up to 10 kbps. This service (Short Burst Data) is still being evaluated by the community. Of particular interest to tide gauge operators in the early days of Iridium was the Motorola L-band transceiver module, which was designed to be easily integrated with sensor electronics via a standard serial interface. This product has now reappeared as the Motorola 9522 modem. Discussions are underway regarding the implementation of a "soft-SIM" user-identification facility as a way of minimizing the costs of system membership for occasional users such as Argo floats, which might only place a call once every 10 days.

Iridium continues to add to its constellation, with five new satellites launched in February 2002, and operational experience with the data service is starting to grow. However it is likely that its survival will depend heavily on continuing support from defence interests.

Teledesic

This "Internet in the Sky" system planned a 288 (originally 840) LEO constellation to carry global broadband services, such as video conferencing, the Internet, etc. It recently merged with Celestri, another proposed broadband LEO system. Since then there has been some doubt over the actual make-up of the combined constellation. Teledesic has suffered because of the financial difficulties of Iridium, as Motorola, one of Teledesic's primary investors and head of the industrial partnership developing the system, transferred engineering effort and funding to prop up Iridium. Teledesic has received FCC licensing for operations in the USA, and recently joined forces with Craig McCaw's New ICO. The constellation plan has been further trimmed to 30 MEOs, and the company announced in October 2002 that it was suspending its satellite construction work.

Globalstar

Globalstar was Iridium's main competitor in the mobile satellite-telephony market. After a bad start in September 1998, when 12 satellites were lost in a single launch failure, Globalstar now has its complete 48-satellite constellation in space, and commenced a limited commercial service in the USA in October 1999. Service has since been expanding to other regions and was available in the UK in mid-2000. Globalstar differs significantly from Iridium in that, for a call to be made, the user must be in the same satellite footprint as a gateway station. There is no inter-satellite relay capability as in Iridium. This means that coverage will not be truly global, especially in the short term, as far fewer gateways have been built than originally planned. Although Globalstar was currently in a much stronger financial position than any of its competitors, only 55,000 subscribers had been signed by late 2001 and the company laid off half of its work force in August 2001. Globalstar subsequently filed for "Chapter-11" bankruptcy protection in February 2002.

Data services at 9600 bps are planned to be commercially available at some time in the future. As with Iridium, this is likely to be very dependent on the initial success of the basic voice service. Globalstar also has a second-generation system planned, said to involve 64 LEO satellites and 4 GEO satellites. Little else is known about the planned enhancements of this system.

Other Systems

Other planned big LEOs include Ecco (by the owners of Orbcomm), Ellipso (a hybrid elliptical LEO/MEO system, now merged with Teledesic and New ICO), LEO SAT Courier (a German-led system which was originally a much smaller little LEO system), Signal and SkyBridge. Most of these systems seem to be on indefinite hold.

MEOs

New ICO

New ICO (formerly ICO Global Communications) is the third of the three main players in the global satellite-telephony market. However it also has suffered severe financial difficulties and filed for "Chapter-11" bankruptcy protection in August 1999, just two weeks after Iridium. The system, formerly known as Inmarsat-P, but now fully autonomous, will use a constellation of 12 MEO satellites backed by a 12-station ground segment to provide a truly global voice, fax, data and messaging service. The aim is to complement and be inter-operable with existing digital cellular-telephone networks. Prior to filing for bankruptcy protection, the first launch was planned for late 1999 with commercial service rollout scheduled for the third quarter of 2000. The company emerged from "Chapter-11" protection in May 2000, and the first satellite was launched in June 2001, with service scheduled to start in 2003. However, ICO appear not to have launched any more satellites since 2001 and there is still no definite date for service rollout.

When the complete constellation is in service, two satellites will always be visible from any point on the earth's surface. The space segment is being built by Boeing Satellite Systems. Data rate will be 9600 bps. Many large manufacturers are engaged in developing dual-mode ICO/cell phone handsets. An ICO "engine", is to be defined for the benefit of third-party equipment manufacturers (OEMs).

New ICO have joined forces with Teledesic (both owned by ICO–Teledesic Global), with major revisions to the scope of both systems. In particular, New ICO is now putting a far greater emphasis on data services, rather than voice services which are now widely recognized as having a smaller potential.

West and East

Little is known about these systems, designed by Matra Marconi Space, except that a combination of MEO and GEO satellites was planned, with multimedia-like services scheduled to begin in Europe via West in 2003. A follow-on vehicle supporting a fully-fledged ATM switch is planned for 2004. The Matra Marconi website makes no mention of these systems and they are probably on indefinite hold.

GEOS

Inmarsat D+

This is an extension of the Inmarsat D service using the new (spot-beam) Inmarsat Phase 3 satellites and small, low-power user terminals. The system was initially designed as a global pager or data-broadcast service, with the return path from the mobile used only as an acknowledgement. D+ permits greater flexibility, but the uplink packets are still limited to 128 bits. The first ground station has been implemented in the Netherlands by the existing Inmarsat service provider (Station 12), but useful technical information has been difficult to obtain. The only remaining manufacturer of D+ transceivers seems to be Skywave. The Skywave unit includes an integral antenna and is specifically designed for low-power applications.

The service may prove particularly attractive to national meteorological services, since protocols already exist with Inmarsat service providers for the free transmission of observational data to meteorological centres for quality- control and insertion on to the GTS. Inmarsat, given its assured multinational backing and established infrastructure, is also extremely unlikely to disappear.

ODL

Oceanographic DataLink (ODL) was a demonstrator system sponsored by the US Office of Naval Research; it uses Intelsat C-band transponders to communicate with small oceanographic packages at rates of up to 10 kbps. New signal-processing techniques allow such transponders to be used in low-energy applications. Both antenna and transceiver size are small (the complete package is expected to be video-cassette size), and data costs are expected to be low. Successful bench trials were completed, and the results of field evaluations are awaited with interest, but no information has been forthcoming. The parent company (Viasat) website no longer mentions the project.

Inmarsat Mini-M, Thuraya, ACes, AMSC, etc

These advanced GEOs offer voice-band communications using compact handsets or laptops by implementing high-gain steerable spot beams to achieve sufficient link margin. Data services may be available using a modem connection on the handset. Coverage is generally regional and not advertised for oceanic areas.

Acknowledgements

The assistance of Richard Winterburn of MES Communications Ltd in the preparation of this report is gratefully acknowledged.

Further reading

Hanlon, J. (1996) Emerging LEOs telemetry options for use in scientific data buoys: a marine instrument manufacturer's perspective. In: Proceedings of the DBCP Technical Workshop, Henley on Thames, October 1996. DBCP Technical Document No 10, WMO, Geneva.

Hoang, N. (1999) Data relay systems for drifting buoys utilizing low-earth orbit satellites. In: Proceedings of the DBCP Technical Workshop, Hawk’s Cay, October 1998. DBCP Technical Document No 14, WMO, Geneva.

Useful web sites

General information

Little LEO status, launch dates	*http://www.ee.surrey.ac.uk/SSC/SSHP/const_list.html*
Constellation overview	*http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations/*
The Satellite Encyclopaedia	*http://www.tbs-satellite.com/tse/online/*
General satellite news/gossip	*http://www.hearsat.org/*
Satellite news	*http://www.spacedaily.com/*
General space news	*http://www.space.com/spacenews/*

Specific operators

Argos	*http://www.cls.fr/*
	http://www.argosinc.com/
Ellipso	*http://www.ellipso.com/*
E-SAT	*http://www.dbsindustries.com/*
Final Analysis	*http://www.finalanalysis.com/*
Globalstar	*http://www.globalstar.com/*

GOES	*http://www.goes.noaa.gov/*
Inmarsat	*http://www.inmarsat.org/*
Iridium	*http://www.iridium.com/*
LEO One	*http://www.leoone.com/*
LEO SAT Courier	*http://www.satcon-de.com/*
METEOSAT	*http://www.esoc.esa.de/external/mso/meteosat.html*
New ICO	*http://www.ico.com/*
Orbcomm	*http://www.orbcomm.com/*
Ocean DataLink (ODL)	*http://www.viasat.com/*
SAFIR	*http://www.fuchs-gruppe.com/ohb-system/*
Skybridge	*http://www.skybridgesatellite.com*
Teledesic	*http://www.teledesic.com/*
Thuraya	*http://www.thuraya.com/*
VITA	*http://www.vita.org/*
West	*http://www.matra-marconi-space.com/*

Table 1. Overview of mobile satellite systems with possible oceanographic applications - update 2003

System	**Status***	**Date (if known)**	**Orbit type**	**Buoy position**	**Message type**	**Terminal size**	**Power (W)**	**Comments**
ARGOS	Operational		Little LEO	Doppler Shift	data: 32 bytes	Handheld	1	Various enhancements, incl. 2-way messaging, are scheduled
ECCO (CCI Global)	On hold		LEO	GPS Required	voice/data	Handheld	TBD	12 equatorial satellites planned by 2003. Status questionable – merged with ICO-Teledesic Global
ELLIPSO	Licensed On hold		Big LEO	GPS required	voice/data	Handheld	TBD	17 satellites in highly elliptical orbits, serving major land masses. Status questionable – merged with ICO-Teledesic Global
EYESAT	Experimental		Little LEO	GPS Required	data: 60 bytes	Handheld	5	1 satellite 1995, principally for radio amateurs

System	Status*	Date (if known)	Orbit type	Buoy position	Message type	Terminal size	Power (W)	Comments
E-SAT	Licensed On hold		Little LEO	GPS Required	data: TBD	TBD		6 satellites for utility metering (aimed at Continental US only initially)
FAISAT	Licensed On hold	Service 2002+	Little LEO	GPS Required	data: 128 bytes	Handheld	10	38 satellites 2000+ Test satellite launched 1997
GEMNET	Cancelled (pre-op)		Little LEO	GPS Required	data: no maximum	Laptop	10	1st satellite 1995 - launch failure 36 satellites by ???
Globalstar	Operational	1999	Big LEO	GPS Required	voice/data: no maximum	Handheld	1	48 satellites + spares (constellation complete) Limited coverage due to lack of ground stations. Financial difficulties.
GOES, Meteosat, GMS	Operational		GEO	GPS required	data: various options	Laptop	10	4 satellites; directional antenna desirable NOAA / ESA / Japanese met satellites.
GONETS-D	Pre-operational		Little LEO	GPS/ Glonass	Data	Handheld	TBD	8 satellites in orbit, 36 more planned
GONETS-R	Planned On hold?		Little LEO	GPS/ Glonass	Data	Handheld	TBD	48 satellites planned
INMARSAT-C	Operational		GEO	GPS required	data: no maximum	5.5 kg	15	Steered antenna not required
INMARSAT-D+	Operational		GEO	GPS required	data: 128 bytes uplink, 8 8 bytes downlink	Handheld	1	Global pager using existing Inmarsat-3 satellites Note very oriented to downlink

System	Status*	Date (if known)	Orbit type	Buoy position	Message type	Terminal size	Power (W)	Comments
INMARSAT-Mini-M	Operational		GEO	GPS required	voice/data: no maximum	Laptop	1	Mobile phone using regional spot-beams
ICO (New ICO)	Licensed On hold?	Service 2003	MEO	GPS required	voice/data: no maximum	Handheld	1	Global voice and packet data services. Recently merged with Teledesic to form ICO Teledesic Global. 12 satellites planned, only one launched so far.
Iridium	Revived	Service resumed 2001	Big LEO	GPS preferred	voice/data: no maximum	Handheld	1	72 satellites in orbit
IRIS/LLMS	Experimental On hold		Little LEO	Doppler + Ranging	data: up to few kbytes	Handheld	1	1 satellite in orbit. Belgian messaging system part of an ESA research prog.
LEO One	Licensed On hold	Service mid 2003	Little LEO	GPS Required	data:uplink 9600bps, downlink 2400bps	Handheld	Max 7	48 satellite constellation, store and forward + 8 spares. No polar sats
LEO SAT Courier	Planned On hold?	Service 2003+	Big LEO	GPS required	Data /voice	Handheld	1-5	72 satellites
OCEAN-NET	Experimental		GEO	Moored	no maximum	Large		uses moored buoys + Intelsat
Ocean DataLink (ODL)	Experimental On hold?		GEO	GPS	no maximum	Handheld	TBD	uses Intelsat
Odyssey	Cancelled (pre-op)		MEO	GPS required	voice/data: no maximum	Handheld	1	12 satellites were planned

System	**Status***	**Date (if known)**	**Orbit type**	**Buoy position**	**Message type**	**Terminal size**	**Power (W)**	**Comments**
Orbcomm	Operational	1998	Little LEO	Doppler or GPS	data: no maximum	Handheld	5	35 satellites in orbit, 30 operational, expansion to 48 sats licensed
SAFIR	Pre-operational On hold		Little LEO	Doppler or GPS	data: no maximum	Laptop	5	2 satellites in orbit
Signal	Planned On hold?		Big LEO		voice/data			48 satellites planned
SkyBridge	Licensed On hold	Service 2002+	Big LEO	GPS Required	Broadband	Larger than handheld		80 satellites planned, recycling GEO spectrum allocations
Starsys	Cancelled (pre-op)		Little LEO	Doppler + Ranging	data: 27 bytes multiple msgs	Handheld	2	12 satellites 1998+ 24 satellites 2000+
Teledesic	Licensed On hold	Service Late 2004	Big LEO	GPS required	Broadband			288 LEOs planned, now reduced to 30 MEOs FCC licence granted, merged with new ICO
Temisat	Experimental		Little LEO		Data			7 satellites planned for environmental data relay. 1 satellite launched 1993.
Thuraya	Operational		GEO	Integral GPS	Voice/data	Handheld		1 multiple spot beam satellite in orbit (over Middle East), 1 planned
Vitasat	Pre-operational		Little LEO	GPS Required	Data			2 satellites in orbit, 2 more planned
WEST	Planned On hold	Service 2003+	MEO	GPS Required	Broadband			9 satellites planned

* Status of systems is categorized according to seven groups:

Planned: Little is known about the system except a name, notional type, and services to be offered. Mostly not licensed, although some may be.

Licensed: System has been licensed by a national or international regulatory agency (in most cases the FCC), but no satellites have been launched.

Experimental: System has one or more satellites in orbit for experimental purposes (not usually part of the final constellation). Includes new systems planning to use existing satellites.

Pre-operational: System is in process of launching, or has launched, its constellation but is not yet offering full services. Some limited evaluation service may be available.

Operational: System has full or nearly full constellation in place and is offering readily available service to external users (not necessarily commercial).

Cancelled: System has been cancelled, either before satellites launched (pre-op) or after (post-op).

On hold: No progress reported or scheduled.

The ROSAME Tide Gauge Network: Technical Aspects and Specific Constraints

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Introduction

The ROSAME tide gauge network (Réseau d'Observation Sub-antarctique et Antarctique du Niveau de la Mer) is a French contribution to the Global Sea Level Observing System (GLOSS). It is composed of four permanent stations in the southern part of the Indian Ocean, on the islands of Crozet, Kerguelen, and Saint-Paul and at the French base of Dumont d'Urville in Antarctica. This network was initiated at the beginning of the 1990s during the World Ocean Circulation Experiment (WOCE). These stations satisfy the WOCE requirements for in situ sea level data (i.e. high precision sea level measurements, hourly data acquisition, real-time transmission, etc). The principal objectives of this network are the monitoring of the Antarctic Circumpolar Current, the study of the ocean dynamics in the Kerguelen region and the validation of altimetric data (TOPEX/Poseidon, ERS−1 and 2, Jason 1 and ENVISAT).

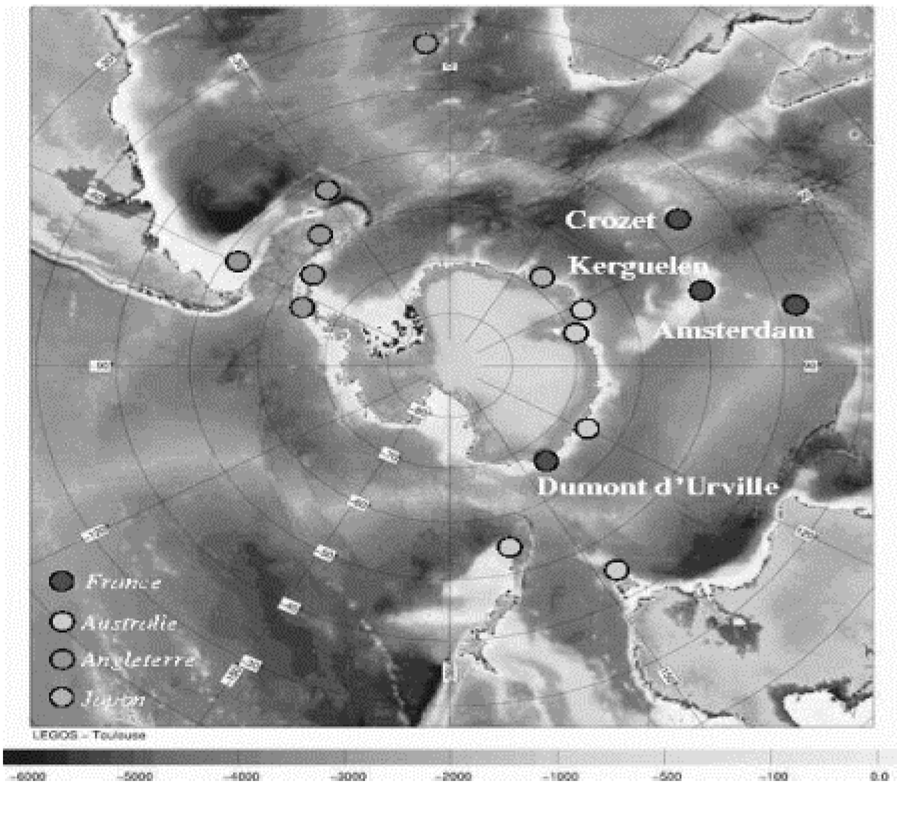


Figure 1. Location of the ROSAME stations in the context of the in situ sea level measurements in the Southern Ocean.

Figure 2. Bottom pressure sensor and stilling well of the Kerguelen tide gauge. Sensors have to be changed every two years in order to be recalibrated by the constructor.

Sensors and stations

All sites are equipped with a pressure sensor, a seawater temperature sensor and an atmospheric barometer. Kerguelen and the new Crozet station also have a conductivity sensor. These sensors are connected to a central station which pilots the acquisition of the data and builds a message which is transmitted by satellite via the Argos system. All the ROSAME stations are powered by batteries. A yearly maintenance is carried out at each site during the logistic rotation of the oceanographic research vessel "Marion Dufresne". During these operations, battery and sensor are changed, infrastructure and equipment are controlled and fixed.

The frequency of data acquisition is one hour, except for the Dumont d'Urville station where it is half an hour. All these stations have a back-up memory.

Data processing and banking

The measured parameters are transmitted in quasi-real time via the Argos system to CLS (Collecte-Localisation-Satéllites) centre in Toulouse. The data are then received and processed in LEGOS by an automatic-acquisition/quality control/fast-delivery software for real time follow-up of data coming from a tide gauge network (see P. Téchiné et al. in the present report for a detailed presentation of the software). Controlled data are made available via Internet at the Hawaii Sea Level Data Center (Fast Delivery).

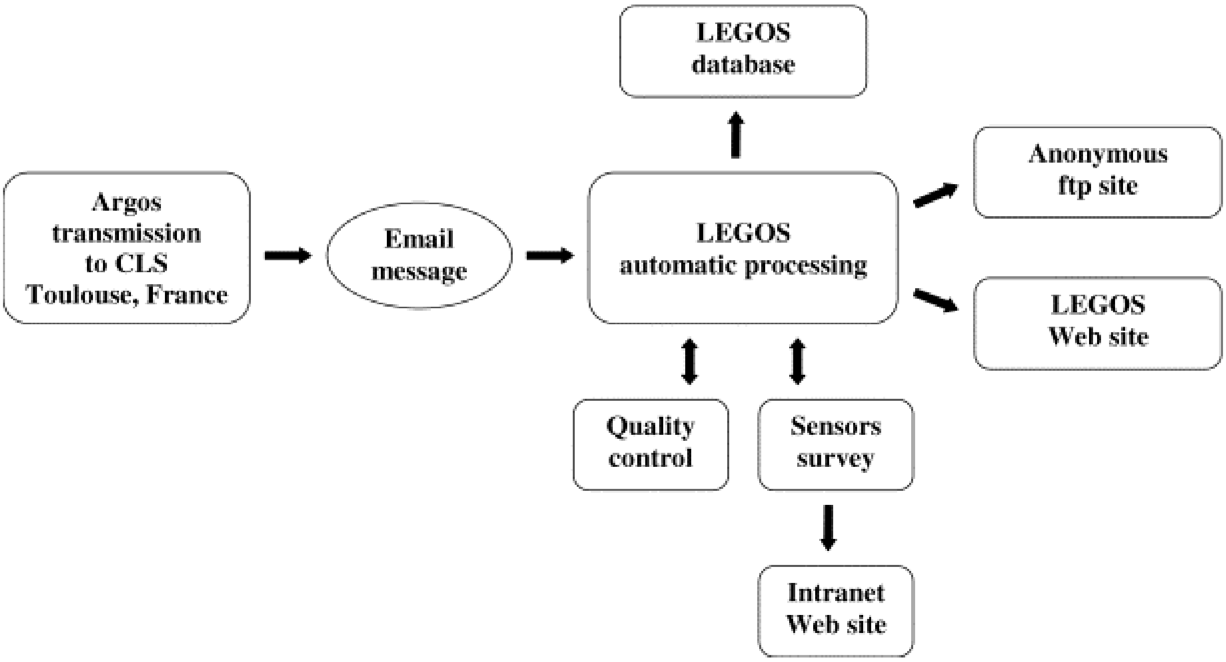


Figure 3. Schema of the automatic software presently developed at LEGOS for the ROSAME network.

Constraints associated with the network

The choices made to build and maintain the ROSAME network were partly due to the constraints of the different sites. Indeed, the French islands in the southern part of the Indian Ocean and Antarctica are subject to rough climatic conditions and are often difficult of access. Maintenance of the network is scheduled only once a year and its success depends on the weather conditions at that time. Indeed, when the conditions are too rough, it is quite impossible to undertake the planned work. Moreover, these conditions lead to a rapid aging of the equipment and impose strong mechanical constraints on the infrastructure (see the example of Crozet in the next section). At Saint-Paul Island there is no scientific base and no problem can be solved before the next call of the vessel, so that even a very simple problem left unresolved may lead to an important loss of data (see next section for example).

Our conclusion is that logistics are probably the key factor in good maintenance of a remote tide gauge network. Technical problems are, in most cases, not critical and can be overcome.

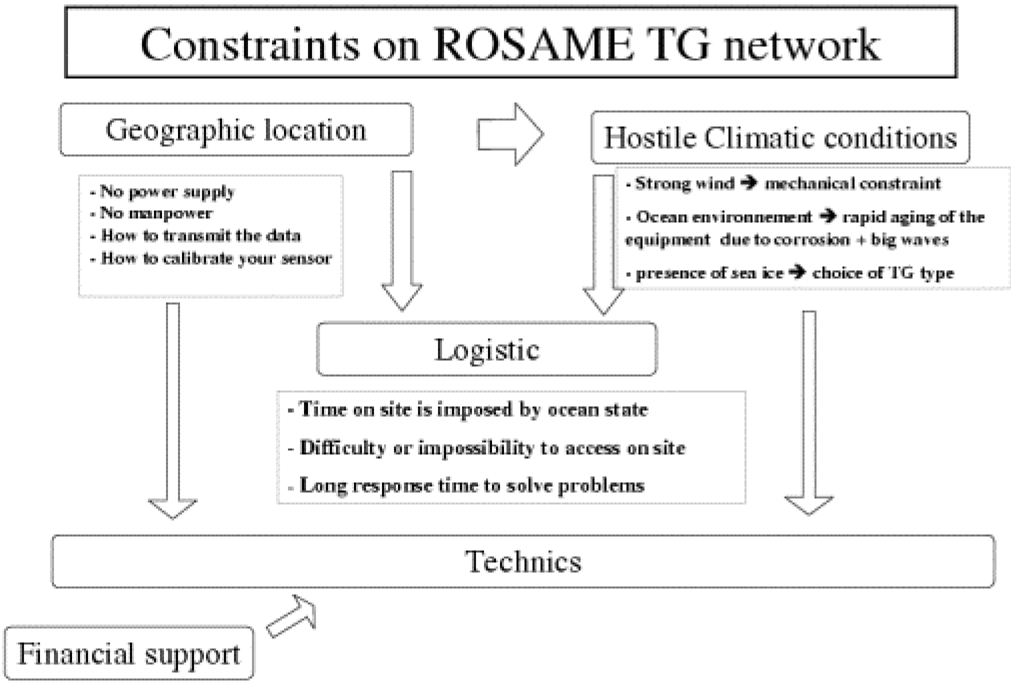
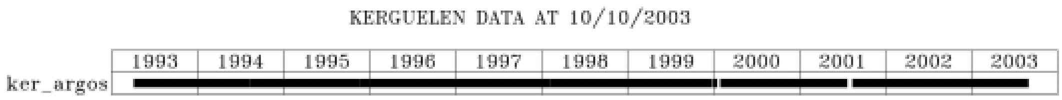
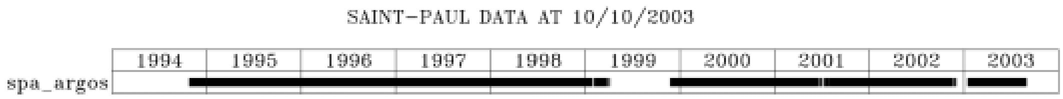


Figure 3. Schematic presentation of constraints associated with the ROSAME tide gauge network.

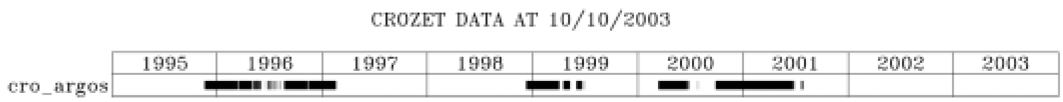
History of the network and illustration of the constraints



The Kerguelen station was installed in 1992; it has operated since 1993 without any problem. It has at present yielded one of the longest time-series in this part of the world.



Saint-Paul was installed in 1994; it has operated since then with only a few problems of batteries that are, in this case, very constraining, owing to the fact that this island does not have the benefit of a scientific base and is completely desert.



Crozet was installed in 1995; this station has been a real headache since its installation. Its beginning was marked by electronic problems. Then at the beginning of 1997, the station was rendered inoperative by a landslide. Reinstalled in 1998, other electronic problems lead to the station being sent back to the constructor; likewise in 1999. On 30 July 2001, the station was broken down by a storm. A new installation was scheduled in 2003. Crozet is probably the most hostile island in this region, owing to a very rough climatic environment, and furthermore the tide gauge site is very exposed to swell and waves.

Dumont d'Urville was installed in 1997; there were many problems in the connection of the sensor, probably owing to iceberg calving which damaged the cable connect the station to the sensor. This station now operates quite well.

To complete this network, two moorings are maintained in the vicinity of Crozet and Saint-Paul Islands, in order to have dynamical information on the link between the coastal sea level measurements and the sea level offshore.

IHO Requirements for Tidal Information

Steve Shipman
Professional Assistant Hydrographer at the IHB

Introduction

The primary concerns of The International Hydrographic Organisation (IHO) are the safety of navigation, the protection of the marine environment and the safety of life at sea. In this respect the Member States of the IHO require tidal information in order to be able to:

Conduct hydrographic surveys;
Publish nautical charts;
Publish tide tables;
Issue maritime safety information.

Datum values

Mean sea level (MSL) is a commonly used reference level, particularly for measuring heights on land. However because of the need to ensure safety of navigation, nautical charts adopt a reference level such that the depth of water depicted on a chart should be the least that a mariner will find in that position, other than in extreme meteorological conditions. Chart datum is therefore a low water datum. IHO Technical Resolution TR A2.5 states that Lowest Astronomical Tide (LAT) should normally be used for chart datum and gives the following definition:

"LAT is defined as the lowest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. It is recommended that LAT be calculated either over a minimum period of 19 years using harmonic constants derived from a minimum of one year's observations or by other proven methods known to give reliable results. Tide levels should, if feasible, reflect the estimated error values obtained during the determination of these levels."

Note that TR A2.5 also resolves that heights on shore should be referred to MSL and that MSL should be retained as the datum above which the heights of lights are given.

Charts of estuaries and inland waters may also need to show clearance heights for overhead structures, such as bridges and power lines. In this situation, safety of navigation requires that a minimum clearance be shown and hence it is necessary to use a high water datum. TR A2.5 resolves that in this situation Highest Astronomical Tide (HAT) should be used, the definition of which is similar to that for LAT, namely:

HAT is defined as the highest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. It is recommended that HAT be calculated either over a minimum period of 19 years using harmonic constants derived from a minimum of one year's observations or by other proven methods known to give reliable results. Tide levels should, if feasible, reflect the estimated error values obtained during the determination of these levels.

Consequently height and depth information depicted on nautical charts can be referenced to three different datums, LAT, MSL and HAT. Moreover LAT, as a low water datum, can show significant spatial and temporal variation across the area covered by medium- to small-scale charts. The depths shown on a particular chart, relative to LAT, will be referenced to a datum that varies with respect to the fixed land datum or MSL. Whilst the same variation occurs with HAT, its use for clearance heights means that it will normally only be used on large-scale charts where the variation will be much less.

The variation in the range of the tide, and hence in the level of LAT, is mainly due to the geography of the landmasses, seabed topography, water body resonance and the Coriolis force. Hydrographic surveyors and marine cartographers need to account for this variation where it is significant. In a local area the tide can be observed at a particular point and analyzed as stated above to give the value of LAT. Across larger areas it will be necessary to assess the relationship between various measurements of LAT to produce a co-tidal chart or model. This will include both variation in the range and the time of the tide and in some circumstances may have to accommodate variations in these factors between High and Low water and between the Spring and Neap tidal cycles.

Where co-tidal models are available, their major weakness lies in the limited availability of the data from which they are constructed. Offshore areas have been a particular problem, although the availability of hydrocarbon exploration and production platforms and the development of seabed tide gauges have improved matters. The required density of data, whilst clearly depending on the variation in the tidal regime, will be much greater than that required by GLOSS to model MSL.

It should be noted that the reduction of soundings to chart datum is normally only applied on the continental shelf. Tidal variation off the shelf is small relative to the depth, is not an issue in safety of navigation and is therefore not normally applied.

Quality of data

Tidal measurements taken during hydrographic surveys, in addition to being used for sounding reduction, can be analyzed to provide the tidal constituents, which in turn can be used to predict future tidal heights. Publication S-44, IHO Standards for Hydrographic Surveys sets down standards for the quality of tidal observations, namely:

Tidal heights should be observed so that the total measurement error at the tide gauge, including timing error, does not exceed +/- 5 cm at 95% for Special Order surveys[*]*. For other surveys +/- 10 cm should not be exceeded.*

[*]*Special Order surveys: - Harbours, berthing areas, and associated critical channels with minimum under-keel clearances*

It also states that:

Tidal height observations should be made throughout the course of a survey for the purpose of providing data for tidal analysis and subsequent prediction, for which purposes the observations should extend over the longest possible period and not less than 29 days.

The shorter the period of observation, the fewer the number of constituents that can be revealed by analysis and hence the poorer will be future predictions.

Predicted/real tides

Mariners have traditionally relied on predicted tides and, provided sufficient constituents are available, these predictions are satisfactory for navigation other than in critical areas. The major weakness in predicted tides is the variation from the real tide due to the actual meteorological conditions differing from the "mean" effect during the tidal data capture. In critical areas this has led to the establishment of "warning services" that monitor the situation so as to provide advice of anomalously low values, to prevent ships grounding, and of anomalously high values where there is a risk of coastal flooding.

Increasing use, particularly in critical areas, is being made of transmitting tide gauges which allow mariners to receive real-time actual tides. Alternatively, warnings can be transmitted indicating the variation from predicted. These can be issued as local or regional warnings and can also be included as part of Automatic Identification Systems (AIS) now being introduced in some areas. Electronic Chart Display Systems (ECDIS) allow tidal information, real or predicted, to be shown on the Electronic Navigation Chart (ENC) but in a separate window. Technology would allow soundings to be altered for the height of tide but safety-of-navigation considerations do not allow depth data to be changed from that issued by the National Hydrographic Offices. IHO Publication S-52 Specifications for Chart Content and Display Aspects of ECDIS states that:

Tidal adjustment - Depth information should only be displayed as it has been provided in the ENC and not adjusted by tidal height.

A global vertical reference

As digital data sets increase in availability so the demand to merge them into a combined picture increases. The use of different datum values for heights and depths leads to discontinuities in the data when so merged. This could be overcome by the use of a common, global vertical reference datum. There is a great deal of interest in this within the scientific community. It would seem that an MSL/geoidal surface is the preferred option, but it could be a long time before a sufficiently high-resolution model is available. Whilst the scientific community is interested in sub-centimetre values, the decimetre level is more appropriate to nautical cartography and it may be that a spheroidal datum will meet nautical cartographic requirements.

Real Time Kinematic GPS (RTK-GPS) allows soundings to be reduced in real time without the need for tidal measurements (See Figure 1). Soundings thus referenced to the ellipsoid could be better integrated with other data sets that are similarly referenced. However the mariner will still require data referenced to chart datum and this now requires knowledge of the relationship between the ellipsoid and chart datum. Therefore, whilst the use of RTK-GPS has removed the need for tide readings and a co-tidal model, it has introduced the need for an ellipsoidal – chart datum model! It should also be noted that currently the maximum useable range from an RTK-GPS reference station is limited to about 40 km; however there is much work underway to extend this to 700 to 800 km.

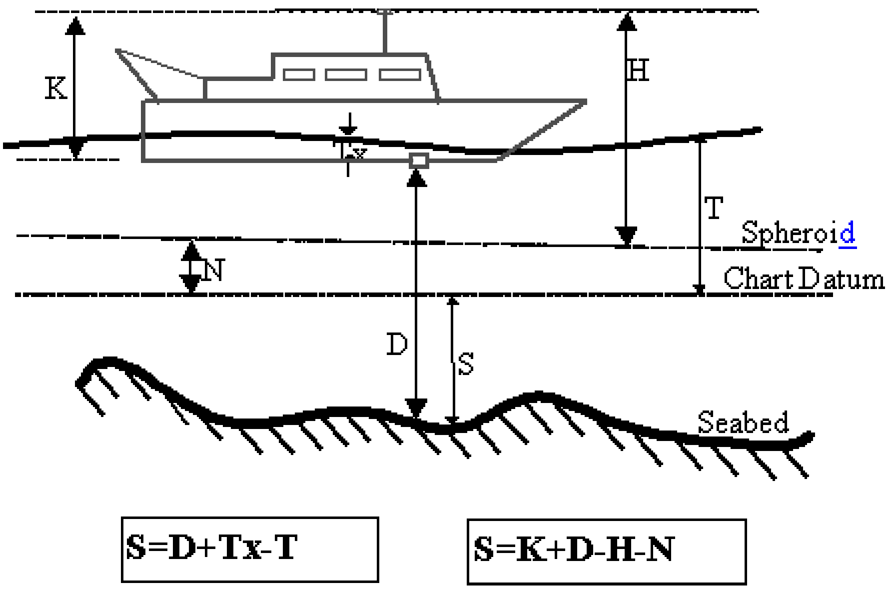


Figure 1. Diagram of the Real Time Kinematic GPS (RTK-GPS) system which allows soundings to be reduced in real time without the need for tidal measurements; *spheroid* is the conventional radar altimetric reference surface for measuring sea height.

Conclusions

The safety of navigation, protection of the marine environment and safety of life at sea will benefit from:

More data collection for longer periods to generate better models and improve the accuracy of tidal prediction;

Increased transmission of real-time tidal data (or variation from predicted) via a greater variety of delivery mechanisms with integrity checking;

A common global vertical datum to facilitate the integration of data sets.

COOP and GLOSS

Keith R. Thompson
Dalhousie University
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The Coastal Ocean Observations Panel (COOP) is charged with providing advice for the design and implementation of the coastal module of the Global Ocean Observing System (GOOS). It is one of the principal components of GOOS which itself is "… a global network that systematically acquires, integrates and distributes ocean observations, and generates analyses, forecasts and other useful products". The purpose of the coastal module of GOOS is to establish a sustained and integrated ocean-observing system that makes more effective use of existing resources, new knowledge, and advances in technology, to provide the data and information required to: (i) improve the safety and efficiency of marine operations; (ii) more effectively control and mitigate the effects of natural hazards; (iii) improve the capacity to detect and predict the effects of global climate change on coastal ecosystems; (iv) reduce public health risks; (v) more effectively protect and restore healthy ecosystems; and (vi) more effectively restore and sustain living marine resources.

The scope of COOP includes the making of marine observations, development and operation of models, generation and distribution of data/information products, data management and communication, enabling research and the implementation of pilot projects, capacity-building and the transfer of technology.

COOP is based on a global observing system with regional enhancements. The global system is based, initially, on existing observing elements (e.g. satellites, GLOSS). It will primarily monitor large-scale changes, provide a background for regional changes, set standards and controls, and help validate satellite observations.

Observations will be used to detect and to predict change in the coastal ocean, in response to user needs. In the initial stages of the design of the coastal observing system, COOP considered almost 100 variables and ranked them using an objective procedure based on user needs. (For details see the COOP Strategic Plan.) The highest-ranked variables for prediction are all physical, mainly because physical models are fundamental to many sea level-rise forecasting systems, and all operational systems presently in use forecast physical variables. Sea level ranked fourth for predictability, reflecting its importance in driving and validating coastal circulation models. Sea level ranked first for detectability, reflecting the importance of sea level for quantifying sea level rise regionally and globally. In summary, COOP considers coastal sea level to be a variable of critical importance to its mission, and GLOSS to be an essential observing element in the initial observing system.

For many of the applications of interest to COOP (e.g. storm surge and surface current forecasting, projecting flooding risk into the next century, monitoring flows through straits), the station density provided by the GLOSS Core Network is insufficient. COOP therefore strongly supports a significant expansion of the Core Network. The needs of COOP are for near-real-time, hourly sea level with an accuracy of at least 1 cm and good datum control (allowing millimetre-per-year changes to be detected with decadal length records). In all stages of data collection, transmission, QA/QC, generation of products and data management, COOP sees an extremely important role for regional sea level observing networks and, where appropriate, GOOS Regional Alliances.

Development, Production and Application of a Radar Sensor for Measuring Water Level

Simon Wills
Managing Director
Ott Hydrometry Ltd

Introduction

Ott Messtechnik GmbH is a company dedicated to the design, manufacture and application of hydrometric instruments.

The company was founded 132 years ago and is based in the town of Kempten in southern Bavaria, Germany. The company was sold to an American Corporate company, Danaher, in 2002 and as such is now located in the Water Quality Division of the company, specifically in the Hydromet area as a lead company in this division.

As a leading manufacturer of hydrometric instruments the company is represented in 82 countries around the world with seven dedicated subsidiary companies in key markets including the UK.

One area that company has been active in for many years is the area of tide level measurement, using a variety of instrument types. One of the more recent developments has been the introduction of the Kalesto radar system; this sensor can be integrated into a total station and this is explained more fully below.

Product development, production and support

Product development

When a company like Ott develops a new application, it is essential that the application be suitable to the job it is required to do.

Market research and investigation as to the exact requirements for the development of a specific instrument are undertaken in an extremely methodical process to ensure the development will meet both the clients' requirements and make commercial sense.

Included in this process are specific tollgates, which must be passed as the product is developed, and at any stage in the process the development can be reassessed and particular aspects of design or specification can be revisited; and, if required, repeated or re-designed.

Production method

Once a product has passed the development stage, one of the most important areas is then the production of that instrument.

Production within OTT is carried out in a process known in manufacturing as One-Piece-Flow; in this method, instruments are literally produced in a system that starts with assembly and finishes with the complete instrument.

Instruments are produced in Production Cells that are dedicated to that particular instrument; this ensures:

Efficient production time;
Minimal waste;
A visual method of production;
Easy quality-checking that is in-built into the production.

Product support

Once produced and sold to a customer, product or system support then becomes a primary objective for the company. In countries that have dedicated subsidiary companies established, part of their role is to support the products in their market.

In the UK and Ireland this role is carried out by OTT Hydrometry Ltd, a subsidiary company that has offices in Nottingham (UK) and Naas (Dublin, Ireland).

OTT Hydrometry Ltd has four main operating divisions, which are dedicated to:

Technical sales/support;
Turnkey solutions (OTT Hydro-Service);
System management (OTT Data-Solutions);
Instrument rental (OTT Hire-Line).

Through these divisions the subsidiary companies are able to offer a full support to the local customer base.

OTT technology – tide measurement

Ott has a long history of producing instruments that are dedicated to tide measurement. One of the original tide gauge instruments produced by Ott was a development carried out in conjunction with the German North Sea Gauging Office in the early part of the twentieth century, based on a float system with integrated timing enabled by an accurate mechanical watch mechanism.

This development had continued through a number of developments that have included:

Chart recorders based on float and counterweight mechanisms;
Pneumatic recorders with large gas supply systems integrated into the mechanism;
Through to today’s latest contributions from:

Integrated shaft encoder and data loggers – Thalimedes;
Small pneumatic systems – Nimbus;
Kalesto, a radar-based measurement technology, described in more detail below.

Kalesto

The Kalesto downward-facing radar sensing system was introduced in 1998, primarily for water level recording in inland water applications, such as flood level recording.

Following on from the original applications, the use of Kalesto was extended to include tidal measurement.

The unit is well suited to this role because of its robust construction combined with its specifications:

Size	Length 500 mm × 160 mm diameter
Weight	8 kg
Sensor	FMCW radar, 24.125 GHz, 5 mW, RS 485 communication
Resolution	Millimetric
Accuracy	1 cm over entire range
Range	30 m
Power supply	12 V DC (9 – >15 V)
Consumption	500 mA active (<1μA passive)

Using the flexibility of the RS 485 signal generated from the system, the sensor can be integrated into a logging system at a distance of up to 1 km from the ultimate-sensor location.

Once installed the Kalesto only requires a low power source, of 12 V (15 V if Kalesto is over 300 m from power source), and because of the lower power consumption of the sensor, the system can easily be powered by an alternative power supply such as solar power. Figure 1 illustrates the system's flexibility.

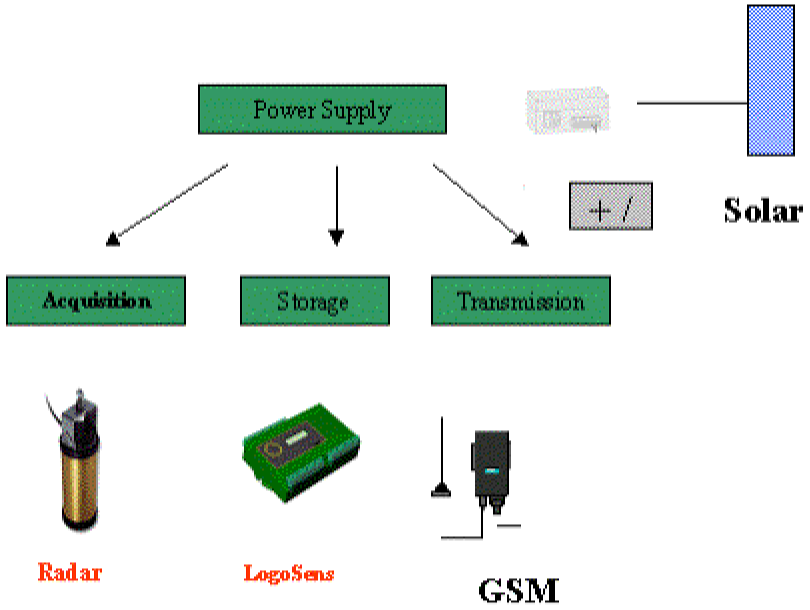


Figure 1. Representation of the Kalesto system powered by solar panel and local battery.

All of these system elements can be combined to form a complete station that is compact and easy to install at site, as shown in Figure 2.

Here the Kalesto unit is located beneath a reflecting signal-converter device that allows the "dead zone" portion of the signal send-and-receive process to be taken up in a horizontal plane, thus allowing far greater depth of water to be measured close to the sensor.

The system is controlled in this instance by a LogoSens Station Manager, an Ott device that allows the site to be managed and controlled remotely via GSM telemetry signals.

Figure 2. A Kalesto system installed on the tidal reach of the River Mersey (UK) in a compact housing.

The systems are easily assembled and can be erected by an experienced installation team within a single day (Figure 3).

Figure 3. Sequence of actions involved in the installation a Kalesto radar gauge.

Miros Range-Finder – Presentation of Sensor, Principles of Design and Associated Software

Rune Gangeskar and Elisabeth Nøst
Miros A/S.

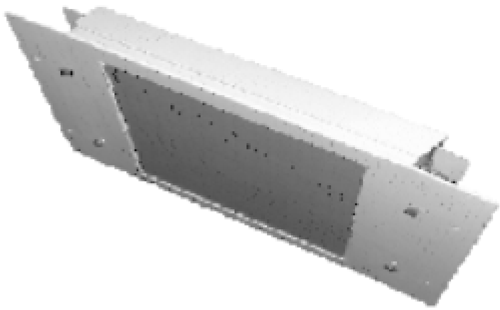
Introduction

Miros A/S is a Norwegian high-technology company, founded in 1984 and located in Asker, near Oslo. Miros offers complete electronic Met–Ocean monitoring stations for use offshore, onshore, and from vessels anywhere in the world. Miros has developed three radar-based sensor systems for measuring and monitoring ocean waves, ocean currents, and water level:

Microwave doppler radar (directional ocean waves and current);
Wavex System (directional ocean waves and current);
Range-finder (water level, air gap, non-directional ocean waves).

The Miros Range-Finder (Figure 1) measures the range between the sensor and the water surface with high accuracy, and it is designed to resist various sorts of strain in connection with its operation in marine environments, such as exposure to sea spray and weather. The raw data output of the range-finder is a time series that can be used as is or as an input to associated software for calculation of various statistics describing the range and water level, or for calculation of the wave spectrum and integrated wave parameters.

Figure 1. Miros range-finder.



A software package that can be installed on a standard Windows PC is available on CD. This software package consists of five modules, including system control, sensor interfacing, data processing, and a flexible graphical user interface (GUI).

Sensor

The sensor and the processing performed inside the sensor to provide the raw-data output are considered in this section.

The Miros Range-Finder (Figure 1) is a continuous wave swept-frequency microwave altimeter (Figure 2). Electromagnetic waves with a wave length of 3 cm are emitted from the antenna (transmitted signal in Figure 2). The electromagnetic waves are scattered back to the range-finder from the sea surface (reflected signal in Figure 2).

The reflected signal will be delayed relative to the transmitted signal, depending on the distance that the electromagnetic waves have traveled. This leads to a difference frequency, called the beat frequency (Figure 2), between the transmitted and reflected signal when looking at a snapshot of the two signals.

If there is a Doppler contribution present, from an approaching sea swell, for instance, there will be a bias in the reflected signal frequency. The influence of this bias on the measurements can, however, be eliminated by integration of one up-down-sweep.

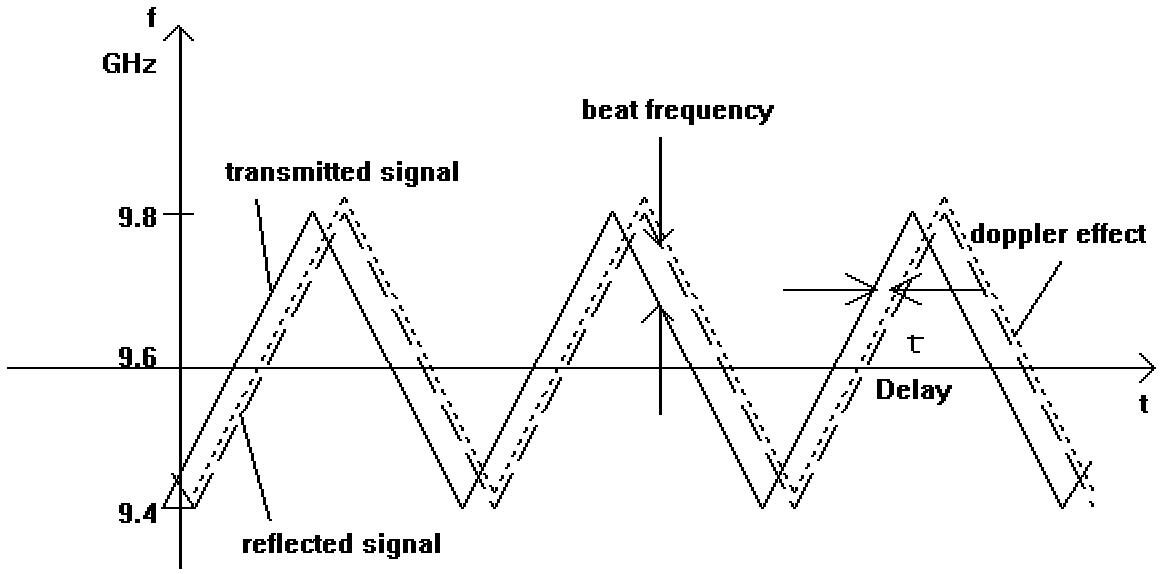


Figure 2. Principle of the Miros continuous wave swept frequency.

The beat frequency signal is further processed to obtain range values. Hamming, windowing, fast Fourier transform (FFT), removal of fixed echoes, top detection, threshold detection, interpolation, and tracking are the main elements of this processing. The tracking eliminates the effects of multi-path and multiple time-around echoes, as well as lost signal for a short period.

The following types of the Miros range-finder are available:

Type	**Range**
SM-094/10	1 – 10 m
SM-094/20W	1 – 20 m
SM-094/20N	3 – 20 m
SM-094/50	3 – 50 m
SM-094/85	3 – 85 m

Some essential specifications are:

Accuracy of one single measurement ≈1 cm;
Accuracy of averaged measurements ≈1 mm;
Physical dimensions: 70 × 510 × 420 mm;
Weight: 7 kg;
Power: 0.2 A at 22 – 32 V;
Emitted frequency: 9.4 – 9.8 GHz;
Emitted power: 0.25 mW;
Digital interface: RS-422/RS-232;
Analog output: 0 – 10 V.

The digital interface is ASCII-based at 9600 baud, 8 data bits, no parity, and 1 stop bit. The data format of the sensor output is:

hh.hhh<HT>aa.aaa<CR><LF>

where the ”hh.hhh” and ”aa.aaa” are two floating point numbers giving the measured ranges after low-pass filtering with filters having their time constants separately defined by the user. This means that, for instance, the ”hh.hhh” can provide 2-Hz raw data by setting the corresponding time constant to 0.5 s, whilst the ”aa.aaa” can provide 5-minute-averaged data by setting the corresponding time constant to 300 s.

A mounting bracket, for simple installation on a pier or a similar construction, can be delivered together with the range-finder.

The range-finder can be configured by the user by changing various internal software parameters. Detection thresholds, time-out, and time constants for averaging and tracking are some of the parameters that can be configured this way.

Miros is at present about finishing the work with a new-generation range-finder including a new digital signal processor (DSP). The new range-finder will have an internal data storage with a capacity for years of data. Time-series data will be processed internally in order to provide wave-spectrum data directly from the sensor. The data output rate will be significantly increased, with a maximum of approximately 100 Hz. In addition, a higher utilization of the electromagnetic return from the sea surface will be obtained, thanks to a higher computational capacity.

Water level software

The water level software can be installed on a standard Windows PC from a CD, and it consists of the following five modules:

System manager;
Water level sensor interface;
Time-series to spectrum;
Wave processing;
Display system.

The system manager module controls the other modules, and gives various sorts of system information, in addition to information about alerts and events. The system manager can be set up to automatically start, stop, or restart the other modules, and to send an e-mail to a specific address if something changes the status of the system.

The water level sensor interface module handles the communication with the sensor, and stores time-series data to files. These files have a well-arranged structure in a tabular format, with time stamps and various statistical information. In addition, the water level sensor interface shows real-time data on the display. The interface module can communicate with many different sorts of sensors.

The time-series to spectrum module reads time-series from files, calculates the wave spectra, and stores the wave spectra to files. In addition, the time-series and wave spectra are displayed in real time.

The wave-processing module reads wave spectra from files, calculates integrated wave parameters (e.g. the significant wave height and average wave period), and stores the parameter values to files. The integrated wave parameters are displayed in real time.

The display system module shows various sorts of data (Figure 3). A number of single values, time-series, tabulars, historical graphs, and wave spectra can be displayed at the same time. Each user can build up her/his own display in a very flexible and user-friendly way. A typical example is shown in Figure 3, with four singles showing the water level average, the averaging time, and the minimum and maximum value during the last 5 minutes. Two singles at the bottom of the display show the significant wave height and the mean zero-upcrossing period. One historical graph shows the history of the average sea level, and another graph shows the wave-frequency spectrum. The visibility of certain parts of the display is not as good in this paper as in the real system because only a gray-scale bitmap is shown here.

Figure 3. Typical display (gray-scale bitmap) of the display system module.

The user can choose whether to have a lot of information in the display or just have a little information in a simple and clear display (Figure 4).

The display system module can be used for viewing historical data as well as real-time data.

References on uses

Up to now Miros has delivered 35 range-finders with good operational results. The range-finder has been used in tide level projects in Trondhjem in Norway, in Villagarcía in Spain (in the European Sea Level Service project), in USA by NOAA, at the Incheon Test Site in Korea, and offshore at Draugen and Heidrun in the North Sea. The range-finder has also been used on platforms for measurement of air gap, subsidence, and non-directional wave monitoring. NOAA has used several sensors for bridge clearance measurements. Finally, the range-finder has been used on military and commercial high-speed vessels for air gap monitoring and structural testing.

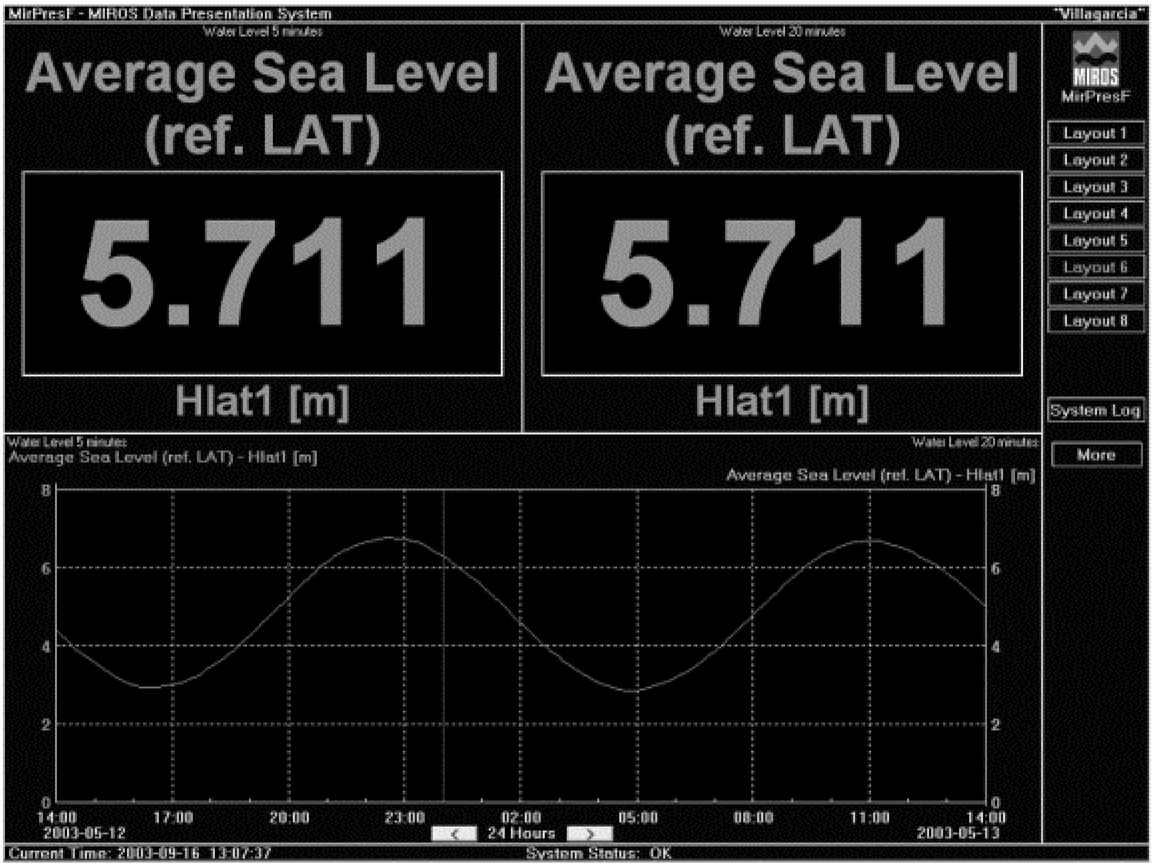


Figure 4. Simple and clear layout (gray-scale bitmap) showing two singles and one history graph.

Other information sources

Belén Martín and Pérez Gómez, B. (2004) Comparison of several technologies at the Spanish test site. In: IOC Workshop on New Technical Developments in Sea and Land Level Observing Systems, Paris, 14–16 October 2003. IOC Workshop Report 193. UNESCO, Paris.

Bushnell, M. (2004) Test and Evaluation of the MIROS SM094 Microwave Altimeter.. In: IOC Workshop on New Technical Developments in Sea and Land Level Observing Systems, Paris, 14–16 October 2003. IOC Workshop Report 193. UNESCO, Paris.

Grønlie, Ø. (2002) Electromagnetic sensor measures water level. Sea Technology, September 2002, pp. 10-13.

PART II: GEODETIC DEVELOPMENTS

The ESEAS Data Portal: Principal Considerations

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The European Sea Level Service (ESEAS) is developing a data portal giving access to tide gauge data as well as other observations and meta-data from ESEAS Observing Sites (OS). A key conceptual criterion is the requirement that the link between data producer and data remain unbroken along the chain from the producer to the user as long as possible. Moreover, design and implementation of the data portal are based on several other basic criteria, resulting in a portal with minimum requirements of the user and easy contribution of the producer.

Introduction

In the context of global or regional Earth observation systems, observational data are rapidly increasing, while access to data and derived information is often hampered either by unavailability of the data or by complex access systems requiring considerable effort by the user to identify relevant data bases and to extract desired data and information. Most solutions are based on a hierarchical structure of global, regional and local data centres, each of them having copies of certain data sets archived. In these systems, the link between data producers and the data sets is often broken at a very early stage and multiple copies of data sets exist in various archives. Meta-information available with the different data sets is often not sufficient to clearly identify the processing the data have undergone. Consequently, it is often not clear which of the copies has been quality controlled and to what extent; when errors are detected, it cannot be ensured that all copies are updated.

Neither the Global Observing System (G3OS; GCOS–GOOS–GTOS) nor the Global Sea Level Observing System (GLOSS) has fully solved the problems inherent in the present approach to data archiving. What seems to be necessary is an approach that maintains the link between data and the original producer as long as possible, reduces the number of copies of a given data sets ideally to one, and provides easy access to a multitude of data sets and information. We expect that this will eventually be achieved through a global data network (which we here denote as datanet) allowing direct access to all local data centres. At the same time, such a datanet would need to have built in a sufficient level of redundancy to avoid data being lost because certain providers are no longer available or because of errors.

In the ESEAS RI projects (see http://eseas.org and Plag, 2002, for more information on the ESEAS and the ESEAS-RI project) the general principles for such a global datanet are used as a basis for an initial implementation of a simplified version. The ESEAS Data Portal (ESEAS DP) will give access to data from ESEAS Observing Sites (EOS). The parameters made available include sub-hourly and hourly sea level observations, monthly mean sea level, near-real-time access to sub-hourly or hourly tide gauge data, daily files of CGPS data, derived quantities, such as sea level extremes, sea level trends, time series of daily GPS solutions, vertical land movement rates, and time series of absolute gravity. For some EOS, meterorological parameters are made available, too.

The concept and implementation of the DP is based on several principal considerations and design criteria, which are described in the next section. In Section 3 we describe the data model and the components of the DP; that is, the ESEAS Data Server (DS), which contains secondary copies of data owned by the different ESEAS Operational Centres (OC), the ESEAS Data Access Manager (DAM), which is the link between the DS and the third component, the user interface provided by the ESEAS Product Delivery Page (EPDP).

General considerations and design criteria

The concept and the technical implementation of the ESEAS DP are governed by six principles:

(1) The underlying principle for the technical implementation is that the requirements in terms of operational system and software availability at the ESEAS OCs, on the one side, and the users, on the other side, should be as low as possible;

(2) To ensure maximum contributions, the work required by the ESEAS OCs in contributing data should be kept to a minimum;

(3) The link between data and data originator should be kept unbroken as long as possible;

(4) The quality and format of the data and products provided by the EPDP in particular for the ESEAS Observing Sites should be homogeneous, independent of the data's origin

(5) As far as possible, the underlying software has to be transportable in order to allow ESEAS components, including the ESEAS DP, to be relocated to other institutes;

(6) The DP should give comprehensive access to the complete data.

In the following, we discuss the main consequences of these principles. The overall logic and structure of the data flow and access is given in Figure 1.

Taking into account the current technology available to diverse and geographically distributed systems, the general concept of the user interface representing the ESEAS DP is based solely on websites that pose minimal constraints on the user systems and software. Basically, any reasonably advanced browser should be sufficient to give full access to the EPDP. Likewise, the links between the ESEAS OCs and the ESEAS DS are kept at a low technological level.

The requirements concerning the formats of data to be made available to the ESEAS DS by the ESEAS OCs are kept as low as possible. In principle, data can be delivered to the ESEAS DS as they are.

The guiding principle is that the link between data originator and the data themselves should remain unbroken for as long as possible. In other words, the ESEAS OCs should own the data as long as possible along the chain to the users.

The ESEAS DP has the task of homogenising and standardizing data before they are delivered to the user. No such data are stored at the DP; rather, this task is carried out based on data owned by the ESEAS OCs whenever a user request is made.

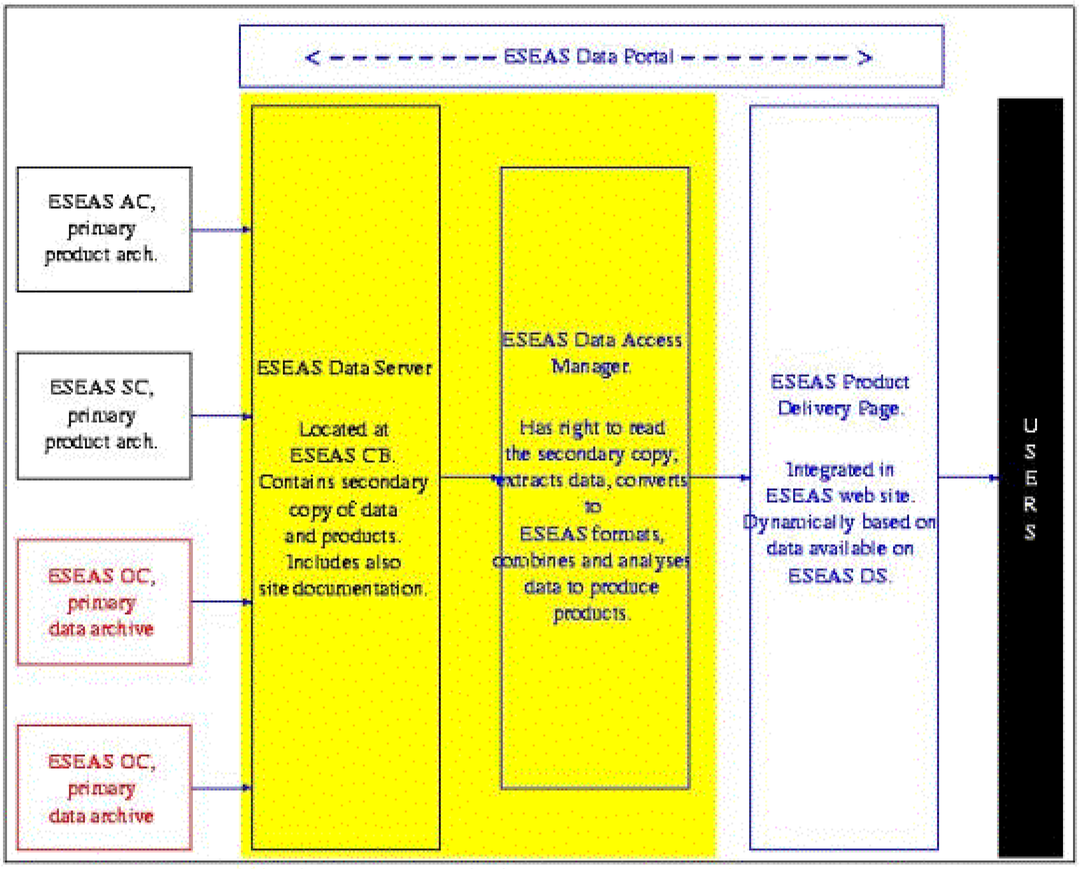

Figure 1. Data flow between ESEAS Data Centres and the ESEAS Data Portal.

The ESEAS OCs provide access to meta-information and observations either on their servers or as secondary copies on the ESEAS DS. If the latter is used, the secondary copies are owned by the respective OCs and are updated by them. The ESEAS DAM continuously updates the database tables and provides selected data sets on request from the PDP.

All software tools used to develop and maintain the ESEAS DP are publicly available for different hardware platforms. It can be expected that the ESEAS Central Bureau (CB) and other ESEAS components in the course of time may be re-located to other institutes. This implies that certain server functions and software may have to be moved to new operating systems. Therefore, no commercial development tools are used, so as to keep the complete ESEAS DP software package independent and relocateable.

In the following section we first define the structure and elements of the ESEAS DS. Then the functionality of the ESEAS DAM is described. Finally, we give a definition of the ESEAS PDP.

The components of the ESEAS Data Portal

The principal data model for the ESEAS DS is based on a station concept, i.e. all data are organized according to stations, which are the EOS. However, any EOS must be associated with an ESEAS OC and this OC owns all information for that particular site. Thus, under the main directory ESEAS-DAS, there is a directory for each ESEAS OC. These directories have the same name as the user name used by the OC to access the ESEAS DS. As far as possible, the data are owned by those who produced or supplied data to the DS. Thus, normally an OC will own all data located in the directory of that particular OC. With respect to products provided by ESEAS Analysis Centres (AC) or ESEAS Supporting Centres (SC), the data organization has not yet been worked out. However, station-dependent products will be linked to respective EOS and the owning OCs.

Meta-data (i.e. data necessary for documentation of the actual observations) are currently provided in relational tables, which can easily be integrated into a database. In a future version, much of the data and documentation will be based on XML and implemented in a relational database. Currently, we have not implemented the XML version. Documentation of the DS itself, the OCs and the OS is based on flat ASCII files, which are denoted as master files.

This approach was selected mainly for practical reasons. In this way, each OC can edit the information easily using any of the editors for ASCII files they are used to. No requirements concerning software, such as those of a database client, have to be met in order to enter the necessary information. Entries in the different relational tables are made independently by the OCs in their master files.

The structure of the master files is relational and thus will be easy to implement in a relational database. Moreover, there is a hierarchy creating all links between the different tables. On the top level is the file "eseasds master.txt", which defines all OCs. On the next level, there is for each OC the file "oc master.txt", which defines all EOS associated with this OC. Level three contains for each EOS the file "eos master.txt". Here all observing locations at that site are defined separately for each physical parameter. Finally, level four contains master files for each instrument. File names contain the name of the EOS for redundancy reasons.

Thus, in addition to the subdirectories for all OCs, ACs and SCs, the main directory of the Data Server contains several files, namely:

"eseasds master.txt": an ASCII file containing the definition of all Ocs;

"oc master.txt": a template for an ASCII file containing the information on an OC including the definition of all EOSs associated with this OC;

"eoc master.txt": a template for an ASCII file containing the information on an EOC, including the definition of all instruments operated at the site, all markers at the site, and all data records available.

The contents of the different files are described in ESEAS (2004). The structure of files containing time-series is also documented there. For time-series, a general structure is used allowing the same type of files for all parameters and to combine different parameters in one file.

The general structure of entries in these master files is a key separator parameter-string. Each key is a predefined word denoting a column in a table. A separator consists of one or more blanks. A parameter-string is a text of variable length. The parameter-string may run over several lines in the ASCII file. Depending on the type of data (e.g. numbers, dates, character strings) to be provided for a certain key word, the parameter-string may have some requirements in respect of content and format.

In the definition of the columns of the different tables, an attempt has been made to be comprehensive. Consequently, for many columns, information is optional.

The ESEAS Data Access Manager has two main tasks, namely:

- To maintain an updated data base of the EOS and the available data;
- To handle all requests for data from the EPDP and, if necessary, to reformat data and produce the requested products.

The content of the database is dynamically created and based on the information provided by the ESEAS OCs on their respective home directories. Currently, the data base has several flat files created on the basis of the master files provided by the individual OCs.

Requests from users for selected data sets are also handled by the DAM, which has to prepare the data sets and provide these to the PDP. The DAM takes into account the data policy specified by the individual OC.

In its fully developed version, the ESEAS Product Delivery Page will give access to site documentation and all data from all ESEAS OSs. For a given site, the observations may include parameters such as hourly, daily and monthly sea level values, meteorological and oceanographic parameters (air pressure, air temperature, wind, sea temperature, salinity), GPS RINEX data, daily GPS-derived co-ordinates, and absolute gravity values. Access of a single OS to the documentation will be hierarchical with general information on the top level and more detailed and parameter-specific information on lower levels. Access to sites will be through interactive maps where sites according to different selection criteria can be displayed or through tables of sites filtered according to selection criteria. Access is also possible for different observables, which results in a list of the EOSs providing data for these variables.

Current status of implementation

At the time of writing, the definition of the tables for the data bases has been completed in first version, and this version is implemented in the respective master files used by the OCs to provide the entries for the tables. The software for the automatic updating of the data base itself on the basis of the master files is under development. Development of the software to create the web pages of the PDP dynamically from the data base has started.

Conclusions

The ESEAS aims to provide access to information including observations related to as many European tide gauges as possible. The information and data to be provided for an EOS concerns not only the tide gauge itself but also relevant other parameters, such as air pressure, sea temperature, and vertical land movement.

The ESEAS DP will give users access to information and data based as far as possible on the most recent version of data available at the OCs. For that, the link between data originator and the data made available is kept unbroken within the ESEAS.

The data model, which is based on a concept for an EOS, and the way of collecting and combining the information developed so far, allows the different OCs to work independently and with very low requirements concerning tools to be used. This, we hope will lead to a high level in the amount of information and observations that will be available through the ESEAS DP.

Acknowledgement

The ideas presented here are the result of many discussions with the participants in the European Sea Level Service and the ESEAS Research Infrastructure project. The document is produced under the European Sea Level Service Research Infrastructure (ESEAS-RI) project. This project is funded by the European Commission under contract EVR1-CT-2002-40025.

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ESEAS (2004) Definition of the ESEAS Data Portal. ESEAS-RI Project Report eseas-ri-wp1-dps), ESEAS CB, Norwegian Mapping Authority, Honefoss, Norway.

Plag, H.-P. (2002) European Sea Level Service (ESEAS): status and plans. In: M. Poutanen and H. Suurmüki (eds.) Proceedings of the 14-th General Meeting of the Nordic Geodetic Commission, Espoo, Finland, 1–5 October 2002. Nordiska Kommissionen för Geodesi, pp. 80-88.

An Inventory of Co-Located and Nearly Co-Located CGPS Stations and Tide Gauges: Status Report, October 2003

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Introduction

Considering the interest in getting a better idea of the status and the opportunities offered by the continuous GPS positioning of tide gauges, an action item was agreed at the Seventh Session of the GLOSS Group of Experts, in Hawaii [26-27 April 2001] *to update the list of GPS receivers at tide gauge sites at regular intervals*. The latest status report was presented at the Workshop on Vertical Crustal Motion and Sea level Change in Toulouse [17-19 September 2002].

Actually, the CGPS@TG list is continuously updated. Information provided by e-mail or by HTML forms is stored in a database as soon as it arrives. The contents of this database can be browsed and searched through a user-friendly web interface. So, as the survey results will become dated as soon as the printed report is released, we just outline some interesting features here, and encourage anyone interested in the details to have a look at the internet version of the report which is accessible at:
http://www.sonel.org/stations/cgps/surv_update.html

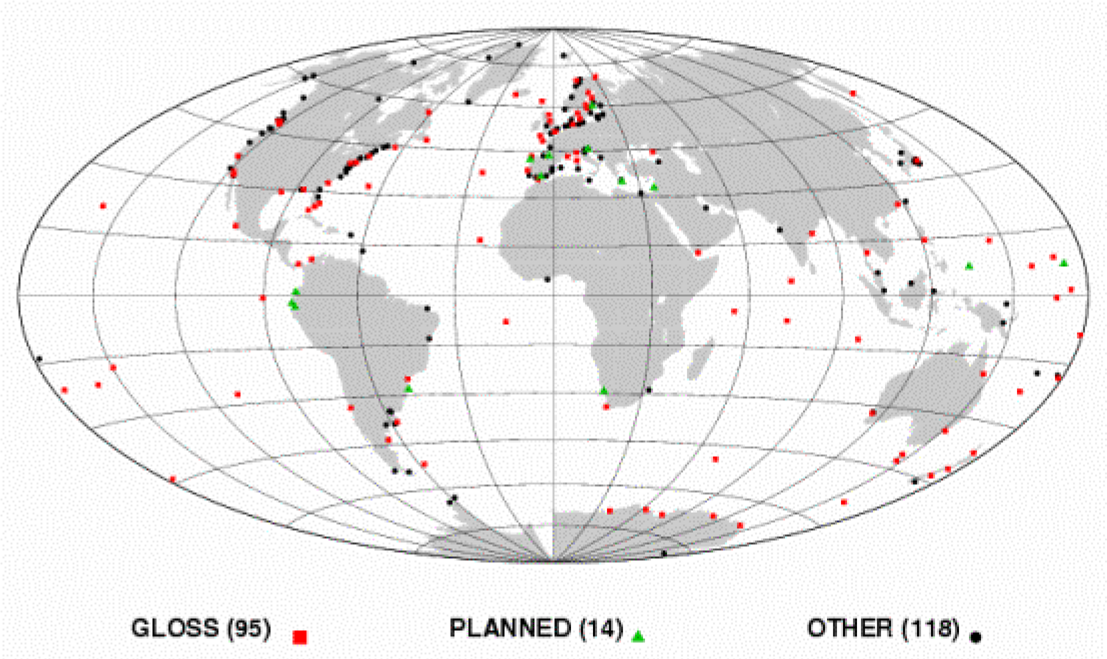
In particular, detailed specific maps and useful tables can be retrieved there.

Main results of the survey

The number of operational permanent GPS stations less than about 10 km away from a tide gauge has increased from 153 to 213 since the last progress report. There are still 14 planned stations meeting the vicinity criterion. Overall, there is a world-wide but uneven distribution of these stations (Figure 1).

As many as 95 stations are tide gauges committed to GLOSS. It is also quite interesting to notice the distance between the GPS antenna and the tide gauge. An extended survey shows that 65 GPS stations are less than 1,000 m away from the tide gauge (29 out of 65 are GLOSS), 8 stations are between 1 and 3 km and 29 are between 3 and 10 km. However, distance information is still missing for 99 stations.

This feature is critical for some applications, such as long-term-trend sea level studies. In no circumstances can it be assumed that even relatively close sites are not moving differentially at the millimetre/year level. Therefore, frequent leveling (at least annual) are required over a long period of time (10-20 years). Experience shows that these regular leveling surveys are often neglected over time, particularly if the distance involved is more than a few hundred metres. Where the distance is more than 1 km, it is unlikely anyone will perform a leveling tie on a regular basis. Moreover, the leveling error can become a significant part of the total error budget. So, stations more than 1 km away cannot be considered "nearly co-located" in the practical sense, though they may still be of interest for other applications. Nevertheless, some GPS stations are considered here even if they are more than 10 km away from the tide gauge. This is acceptable if there is evidence of local stability and if a rigorous and frequent surveying programme is undertaken within CGPS@TG project.



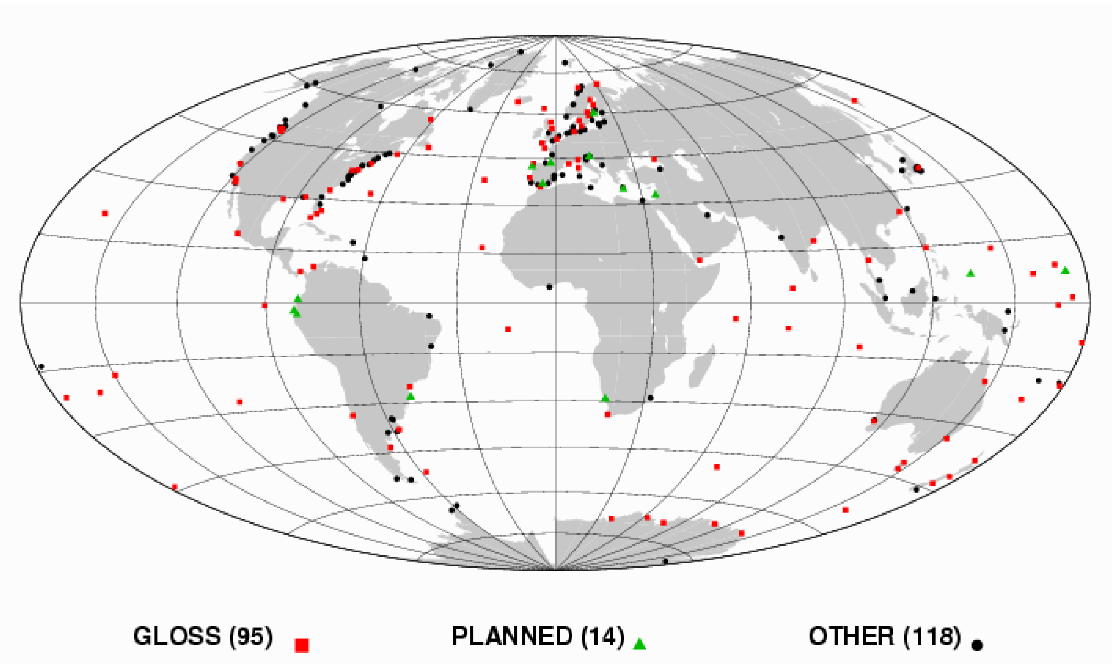


Figure 1. Distribution of CGPS sites.

Outlook

The survey indicates that the data of almost 40% (79 out of 213) of the stations do not seem to be available to the GLOSS or IGS scientific community yet. The remaining 134 stations provide GPS observations freely on Internet. Of these 134 stations, 42 contribute to the IGS TIGA Pilot Project. Of course, all these stations may not be useful for scientific applications. A close inspection should therefore be made. More information is also needed to actually benefit from CGPS@TG site co-locations; for instance:

Distance between GPS antenna and tide gauge;

Height difference (leveling or geodetic tie) between GPS and tide gauge benchmarks (accompanied by its accuracy and date of measurements);

Tide gauge zero definition with respect to the TGBM;

GPS data collection (accessibility, delivery, commitment to IGS TIGA pilot project);

Operational contacts for both GPS and tide gauge.

Some references and useful documents on the web

IGS-PSMSL [1997]: Proceedings of the Workshop on Methods for Monitoring Sea Level, 17–18 March 1997, Pasadena (California), 202 pp.

Bevis, M. (1998) Continuous GPS positioning of tide gauges: some preliminary considerations.

Report to the IGS. GLOSS Bulletin No. 6.

Bevis, M., Scherer, W., Merrifield, M. (2000) Technical issues and recommendations related to the installation of continuous GPS stations at tide gauges.

CGPS@TG Working Group: CGPS@TG Website - A technical forum on continuous GPS monitoring of tide gauges.

TIGA Website: GPS Tide Gauge Benchmark Monitoring - Pilot Project of the International GPS Service, http://op.gfz-potsdam.de/tiga/index_TIGA.html

ESEAS Website: European Sea Level Service, http://www.eseas.org

Annex: Station status

GPS Name	Country	GLOSS	LTT	ALT	Distance
MCMURDO	ANTARCTICA	---	N	N	-1
O HIGGINS	ANTARCTICA	---	N	N	50
PALMER	ANTARCTICA	---	N	N	200
BAHIA BLANCA	ARGENTINA	---	N	N	26112
BUENOS AIRES	ARGENTINA	---	N	N	-1
LA PLATA	ARGENTINA	---	N	N	-1
MAR DEL PLATA	ARGENTINA	192	N	N	5
QUEQUEN	ARGENTINA	---	N	N	-1
RAWSON	ARGENTINA	191	N	N	32767
RIO GRANDE	ARGENTINA	---	N	N	-1
BURNIE	AUSTRALIA	ALT	N	Y	-1
CASEY	AUSTRALIA	278	N	N	794
COCOS ISLAND	AUSTRALIA	046	N	N	-1
DAVIS	AUSTRALIA	277	N	N	705
FREMANTLE	AUSTRALIA	053	Y	N	-1
HOBART	AUSTRALIA	ALT	N	Y	11500
MACQUARIE	AUSTRALIA	130	N	N	472
MAWSON	AUSTRALIA	022	N	N	488
PERTH	AUSTRALIA	---	N	N	-1
SYDNEY	AUSTRALIA	057	Y	N	-1
TOWNSVILLE	AUSTRALIA	060	Y	N	1000
FREEPORT	BAHAMAS	211	N	N	5
BAHRAIN	BAHRAIN	---	N	N	-1
BARBADOS	BARBADOS	---	N	N	-1
CANANEIA	BRAZIL	194	N	N	10
FORTALEZA	BRAZIL	---	N	N	-1
SALVADOR	BRAZIL	---	N	N	7000
ALBERT HEAD	CANADA	LTT	Y	N	12000
ALERT	CANADA	---	N	N	450
CHURCHILL	CANADA	---	N	N	6000
HALIFAX	CANADA	222	N	N	-1
HOLBERG	CANADA	---	N	N	15000
HOLMAN	CANADA	---	N	N	250
NAIN	CANADA	224	N	N	730
NANOOSE	CANADA	---	N	N	2000
PATRICIA BAY	CANADA	---	N	N	500
ST. JOHN'S	CANADA	223	N	N	-1

GPS Name	Country	GLOSS	LTT	ALT	Distance
UCLUELET	CANADA	---	N	N	32767
PALMEIRA	CAPE VERDE	329	N	N	5
EASTERN ISLAND	CHILE	137	N	Y	-1
PUNTA ARENAS	CHILE	---	N	N	-1
VALPARAISO	CHILE	175	N	N	25
XIAMEN	CHINA	090	N	N	-1
CARTAGENA	COLOMBIA	207	N	N	4000
COOK	COOK ISLANDS	139	N	N	-1
DUBROVNIK	CROATIA	---	N	N	-1
ESBJERG	DENMARK	---	N	N	-1
FAROE ISLANDS	DENMARK	237	N	N	4000
KOBENHAVN	DENMARK	LTT	Y	N	7300
QAQORTOQ	DENMARK	---	N	N	-1
THULE	DENMARK	---	N	N	300
GALAPAGOS	ECUADOR	169	N	Y	2000
ALEXANDRIA	EGYPT	---	N	N	3200
LAUTOKA	FIJI	---	N	N	-1
SUVA	FIJI	122	N	N	-1
METSAHOVI	FINLAND	NULL	N	N	30000
OLKILUOTO	FINLAND	---	N	N	12000
VAASA	FINLAND	LTT	Y	N	20000
AJACCIO	FRANCE	ALT	N	Y	500
BREST	FRANCE	242	Y	N	350
DUMONT D'URVILLE	FRANCE	131	N	N	500
KERGUELEN	FRANCE	023	N	Y	3500
LA ROCHELLE	FRANCE	---	N	N	100
MARSEILLE	FRANCE	205	Y	N	5
NOUMEA	FRANCE	123	N	N	3625
TAHITI	FRANCE	140	N	Y	-1
BORKUM	GERMANY	---	N	N	750
CUXHAVEN	GERMANY	284	Y	N	-1
HELGOLAND	GERMANY	---	N	N	150
SASSNITZ	GERMANY	---	N	N	-1
WARNEMUENDE	GERMANY	---	N	N	-1
WISMAR	GERMANY	---	N	N	-1
TAKORADI	GHANA	---	N	N	-1
SOUDHAS	GREECE	---	N	N	5000
GUAM	GUAM	149	Y	Y	-1
REYKJAVIK	ICELAND	229	Y	N	-1
BOMBAY	INDIA	---	N	N	-1
VISHKHAPATNAM	INDIA	035	N	N	-1
TOLITOLI	INDONESIA	---	N	N	7800
CAGLIARI	ITALY	---	N	N	-1
GENOVA	ITALY	LTT	Y	N	-1
LAMPEDUSA	ITALY	---	N	N	-1
PORTO CORSINI	ITALY	---	N	N	-1
TRIESTE	ITALY	---	N	N	-1
VENEZIA	ITALY	---	N	N	-1
ABURATSUBO	JAPAN	---	N	N	-1
KOZU SHIMA	JAPAN	---	N	N	5
MERA	JAPAN	086	N	N	5
MINAMIIZU	JAPAN	---	N	N	5
MIYAKE SHIMA	JAPAN	---	N	N	5
OKADA	JAPAN	---	N	N	5
OMAEZAKI	JAPAN	---	N	N	5
SHIMIZU-MINATO	JAPAN	---	N	N	5
TONOURA	JAPAN	---	N	N	-1
UCHIURA	JAPAN	---	N	N	5
YOKOSUKA	JAPAN	---	N	N	5
WAJIMA	JAPAN	---	N	N	-1
SYOWA	JAPAN (ANTARCTICA)	095	Y	N	-1
KIRIBATI	KIRIBATI	113	N	N	-1
DAUGRAVGRIVA	LATVIA	---	N	N	-1
LIEPAJA	LATVIA	---	N	N	-1
RIGA	LATVIA	---	N	N	-1
KLAIPEDA	LITHUANIA	---	N	N	250
BINTULU	MALAYSIA	---	N	N	100
GETING	MALAYSIA	---	N	N	5

GPS Name	Country	GLOSS	LTT	ALT	Distance
MALDIVES	MALDIVES	028	N	N	5
MANZANILLO	MEXICO	163	N	N	5
POHNPEI	MICRONESIA	115	N	N	-1
NAURU	NAURU	114	N	N	-1
TERSCHELLING	NETHERLANDS	---	N	N	10
AUCKLAND	NEW ZEALAND	127	Y	N	5
CHATHAM ISLAND	NEW ZEALAND	128	N	Y	4000
DUNEDIN	NEW ZEALAND	---	N	N	400
LYTTELTON	NEW ZEALAND	LTT	Y	N	2
WELLINGTON	NEW ZEALAND	101	Y	N	800
ANDENES	NORWAY	322	N	N	-1
BODO	NORWAY	---	N	N	-1
NARVIK	NORWAY	---	N	N	-1
NY ALESUND	NORWAY	---	N	N	-1
STAVANGER	NORWAY	---	N	N	10000
TROMSOE	NORWAY	---	N	N	-1
TRONDHEIM	NORWAY	---	N	N	9000
VARDOE	NORWAY	323	N	N	-1
BALBOA	PANAMA	168	Y	N	-1
LAE	PAPUA NEW GUINEA	---	N	N	-1
MANUS	PAPUA NEW GUINEA	---	N	N	-1
MANILA	PHILIPPINES	073	Y	N	-1
CASCAIS	PORTUGAL	246	Y	N	-1
LAGOS	PORTUGAL	---	N	N	-1
PONTA DELGADA	PORTUGAL	245	N	N	1550
PETROPAVLOVSK	RUSSIA	093	N	N	-1
TUAPSE	RUSSIA	098	Y	N	-1
SAMOA	SAMOA	---	N	N	-1
SEYCHELLES	SEYCHELLES	273	N	Y	5500
NANYANG	SINGAPORE	---	N	N	-1
RICHARDSBAY	SOUTH AFRICA	---	N	N	10
SIMONSTOWN	SOUTH AFRICA	268	Y	N	10
ALICANTE	SPAIN	---	N	N	5
ALMERIA	SPAIN	---	N	N	10
CEUTA	SPAIN	249	N	N	-1
LA CORUNA	SPAIN	243	Y	N	10
PALMA DE MALLORCA	SPAIN	---	N	N	-1
SAN FERNANDO	SPAIN	---	N	N	10959
SANTANDER	SPAIN	---	N	N	5000
VALENCIA	SPAIN	---	N	N	-1
GOTEBORG	SWEDEN	233	N	N	-1
LOVO	SWEDEN	LTT	Y	N	15000
MAARTSBO	SWEDEN	LTT	Y	N	11000
SKELLEFTEA	SWEDEN	LTT	Y	N	10000
STOCKHOLM	SWEDEN	---	Y	N	-1
VISBY	SWEDEN	---	N	N	4000
TAIPEI	TAIWAN	---	N	N	-1
KO LAK	THAILAND	039	N	N	-1
TONGA	TONGA	125	N	N	-1
TRABZON	TURKEY	---	N	N	-1
TUVALU	TUVALU	121	N	N	-1
ABERDEEN	UK	LTT	Y	N	10
ASCENSION	UK	263	N	Y	-1
BERMUDA	UK	221	Y	Y	-1
DIEGO GARCIA	UK	026	N	Y	-1
LIVERPOOL	UK	---	N	N	10
LOWESTOFT	UK	---	N	N	10
NEWLYN	UK	241	Y	N	10
NORTH SHIELDS	UK	LTT	Y	N	5
PORTSMOUTH	UK	---	N	N	50
SHEERNESS	UK	LTT	Y	N	10
STANLEY	UK	305	N	N	-1
ANNAPOLIS	USA	LTT	Y	N	-1
ATLANTIC CITY	USA	220	Y	N	-1
BAR HARBOR	USA	---	N	N	100
BOSTON	USA	---	N	N	-1
CAPE CANAVERAL	USA	---	N	N	7000
CAPE HENLOPEN	USA	---	N	N	2900

GPS Name	Country	GLOSS	LTT	ALT	Distance
CHARLESTON	USA	ALT	Y	N	7400
CRESCENT CITY	USA	---	N	N	-1
EASTPORT	USA	---	N	N	100
FERNANDINA	USA	---	N	N	-1
FORT MACON	USA	---	N	N	2800
FORT STEVENS	USA	---	N	N	9400
GALVESTON	USA	217	Y	N	4200
GLOUCESTER	USA	---	N	N	100
HAMPTON ROADS	USA	---	N	N	-1
HARVEST	USA	---	N	N	-1
HONOLULU	USA	108	Y	N	5
HORN POINT	USA	---	N	N	100
KELSO	USA	---	N	N	4600
KENAI	USA	---	N	N	2700
KETCHIKAN	USA	---	N	N	-1
KEY WEST	USA	216	Y	N	-1
KITTY HAWK	USA	---	N	N	400
KWAJALEIN	USA	111	Y	Y	-1
LA JOLLA	USA	159	Y	N	-1
MIAMI	USA	218	N	N	300
MOBILE	USA	---	N	N	5500
MONTAUK	USA	---	N	N	8600
NEAH BAY	USA	LTT	Y	Y	7900
NEWPORT	USA	290	Y	N	100
NEWPORT	USA	---	N	N	4700
NEW YORK	USA	---	N	N	-1
PENSACOLA	USA	288	Y	N	-1
POINT BLUNT	USA	---	N	N	6500
POINT LOMA	USA	---	N	N	8400
PORTLAND	USA	---	N	N	-1
SAN FRANCISCO	USA	158	Y	N	-1
SAN PEDRO	USA	LTT	Y	N	-1
SANDY HOOK	USA	---	N	N	-1
SEATTLE	USA	LTT	Y	N	5900
SELDOVIA	USA	---	N	N	1500
SOLOMONS	USA	---	N	N	100
ST. CROIX	USA	---	N	N	-1
WACHAPREAGUE	USA	---	N	N	100
VANUATU	VANUATU	---	N	N	-1
ADEN	YEMEN	003	Y	N	-1

Geodetic Developments within the European Sea Level Service (ESEAS)

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Abstract

In 1996, European Commission Cost Action 40 (EOSS - European Sea Level Observing System) was started. One result of this Cost Action was the proposal to establish a European Sea Level Service (ESEAS).. Work on the establishment of ESEAS was started in July 2001 to bring together a major fraction of the previously scattered sea level observing and research resources in Europe into a co-ordinated research organization, in order to study sea level variations at inter-annual and century time scales and assess potential future changes in sea level and extreme sea levels. This paper focuses on geodetic developments within ESEAS and the European Commission-funded ESEAS-Research Infrastructure (ESEAS-RI) project, which started in November 2002.

Introduction

This paper is not intended as an overview of EOSS or ESEAS. For information on ESEAS and the ESEAS-RI project, the reader is referred to http://www.eseas.org/. For information on EOSS, the reader is referred to http://www.eseas.org/eoss/eoss.html.

This paper focuses on geodetic developments within ESEAS. The ESEAS Technical Committee (TEC) was established in September 2001.. In November 2002, following the kick-off meeting for the ESEAS-RI project, it was decided that the ESEAS TEC should establish four working groups in parallel with the four main work packages (WP's) of the ESEAS-RI project, namely:

WP1: Quality control of the hourly tide gauge data accessible through the ESEAS;

WP2: Determination of vertical land movements at tide gauges in order to decontaminate the relative sea level records for this bias;

WP3: Determination of sea level variations on inter-decadal time scales in the North Atlantic and the semi-enclosed European seas, as well as assessment of secular relative sea level trends for the European coasts;

WP4: Improvement of the network of ESEAS Observing Sites through upgrading of selected tide gauges and co-location of gauges with continuous GPS.

The geodetic developments within ESEAS are being carried out through the ESEAS TEC, ESEAS Working Group 2 and ESEAS-RI Work Package 2. The research objectives are to develop the appropriate processing and analysis strategy for the use of continuous GPS (CGPS) at sites close to tide gauges in order to obtain reliable estimates of vertical land movements, and to assess their contribution to changes in relative sea level. This involves not only involves the use of CGPS at tide gauges, but also absolute gravity and leveling.

ESEAS Observing Sites with CGPS

The current ESEAS network of Observing Sites is given as Figure 1, where the triangles indicate designated MedGLOSS sites which are available to ESEAS through co-ordination with MedGLOSS.

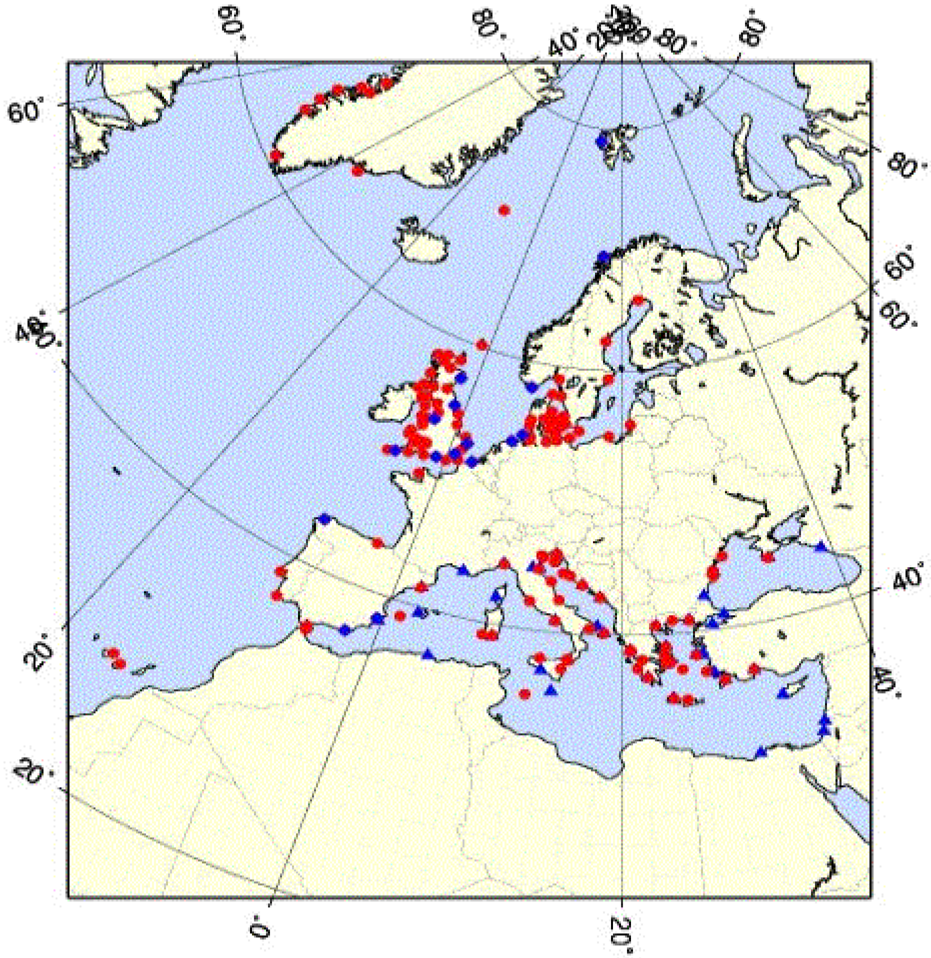

Figure 1. The ESEAS Network of Observing Sites. (http://www.eseas.org/abouttheeseas/)

From Figure 1, it can be inferred that the ESEAS Observing Sites cover several areas of Europe with types of coasts being affected by different physical processes (e.g. tectonic activity, post-glacial rebound, sedimentary compaction, impact of human activities).

In terms of geodetic information, almost all of the ESEAS Observing Sites have precise leveling connections between a Primary Tide Gauge Benchmark (PTGBM) and a network of local benchmarks. However, only about 35 have a CGPS station at or close to the tide gauge, and only a few have absolute-gravity measurements. A summary of the ESEAS Observing Sites which have CGPS stations (and absolute gravity) is given in Table 1, which is ordered in terms of the PSMSL Code of the tide gauges.

Of particular note in Table 1 is that 5 of the 35 ESEAS Observing Sites have dual-CGPS stations. That is to say that there is one CGPS station at or close to the tide gauge and a second dual-CGPS station within 20 km of the tide gauge, which is located on solid rock. This dual-CGPS station technique was first proposed by Working Group 1 of EOSS (Plag et al, 2000).

Table 1. ESEAS Observing Sites with CGPS Stations.

Site				CGPS Station Information			**Absg?**
PSMSL CODE	**PSMSL STATION NAME**	**LAT**	**LON**	**ID**	**PERIOD**	**NETWORKS**	
025021	NY-ALESUND	78 56 N	11 56 E	NYAL NYAL	1993 1997	EPN EPN	
040041	ANDENES	69 19 N	16 09 E	ANDE	2000	NMA	
040301	TREGDE	58 00 N	07 34 E	TGDE	2003	NMA	
080161	KLAIPEDA	55 42 N	21 08 E	KLPD	2003	ESEAS-RI	YES
110047	WLADYSLAWOWO	54 48 N	18 25 E	WLAD	2003	ESEAS-RI	In prep
120004	SASSNITZ	54 31 N	13 39 E	In prep			
120012	WARNEMUNDE 2	54 11 N	12 05 E	In prep			
125001	TRAVEMUNDE	53 58 N	10 53 E	In prep			
140001	LIST	55 01 N	08 26 E	In prep			
140004	BUESUM	54 08 N	08 51 E	In prep			
140012	CUXHAVEN 2	53 52 N	08 43 E	In prep			
140016	BORKUM (FISCHERBALJE)	53 35 N	06 40 E	BORK	2000	EPN	
140032	HELGOLAND 2	54 09 N	07 52 E	HELG	1999	EPN	
170011	ABERDEEN I	57 09 N	02 05 W	ABER	1998	UoN	YES
170053	NORTH SHIELDS	55 00 N	01 26 W	NSTG	1998	UoN	
				MORP	2000	EPN	
170068	LOWESTOFT	52 28 N	01 45 E	LOWE	1999	UoN	
170101	SHEERNESS	51 27 N	00 45 E	SHEE	1997	UoN	
170131	PORTSMOUTH	50 48 N	01 07 W	PMTG	2001	UoN	
170161	NEWLYN	50 06 N	05 33 W	NEWL	1998	UoN EPN	YES
				CAMB	1998	UoN	
200031	LA CORUNA II	43 22 N	08 24 W	ACOR	1998	EPN	
210021	CASCAIS	38 41 N	09 25 W	CASC	1997	EPN	
210031	LAGOS	37 06 N	08 40 W	LAGO	2000	EPN	
220051	ALICANTE I IBIZA	38 20 N 38 54 N	00 29 W 01 26 E	ALAC ???	1998 In prep	EPN ESEAS-RI	
240011	CAGLIARI	39 12 N	09 10 E	CAGL	1995	EPN	
250011	GENOVA	44 24 N	08 54 E	GENO	1998	EPN	
270035	PORTO CORSINI	44 30 N	12 17 E	???	1996	UoB	
270061	TRIESTE LAMPEDUSA	45 39 N 35 29 N	13 46 E 12 37 E	??? LAMP	2000 1999	UoB EPN	
279002	KOPER	45 34 N	13 45 E	???	In prep	ESEAS-RI	In prep
280031	SPLIT HARBOUR	43 30 N	16 26 E	???	In prep	ESEAS-RI	
290004	LEVKAS	38 50 N	20 42 E	???	In prep	ESEAS-RI	
310052	ANTALYA II	36 50 N	30 37 E	???	In prep	ESEAS-RI	YES
340001	CEUTA	353 54 N	05 19 W	CEUT CEUD	2001 2003	EPN ESEAS-RI	
370045	LAS PALMAS C	28 08 N	15 25 W	PLUZ	2003	ESEAS-RI	

Notes

Station	ID	???	Information not supplied in the response to the 1st call for participation
Station	Period	In prep	Station in preparation, as indicated in the response to the 1st call for participation
Station	Networks	EPN	Part of EUREF Permanent Network (http://www.epncb.oma.be/) and International GPS Service (http://igscb.jpl.nasa.gov/)
Station	Networks	ESEAS-RI	New CGPS station installed through the ESEAS-RI project

Notes

Station	Networks	NMA	CGPS station operated by the Norwegian Mapping Authority
Station	Networks	UoB	CGPS station operated by the University of Bologna, Italy
Station	Networks	UoN	CGPS station operated by the University of Nottingham, UK in association with the Proudman Oceanographic Laboratory, UK or the UK Met Office

One of the benefits of the dual-CGPS station technique is that it can be used to assess both localized land movements occurring at the tide gauge and the underlying geophysical crustal motion experienced by both stations (Teferle et al., 2001, 2002). Along with precise leveling, such information will very important when combining estimates of vertical land movements for the last few years with estimates of changes in relative sea level for the past few decades.

ESEAS-RI Work Package 2

The research and development that is being carried out as part of ESEAS-RI Work Package 2 has been separated into eight tasks:

T2.1: Define, implement and validate a CGPS processing strategy, with special emphasis on the vertical component, which will enable the determination of vertical station velocities in a consistent reference frame with an accuracy of 1 mm/yr;

T2.2: Define, implement and validate a strategy for the analysis of CGPS time-series, which will enable the determination of vertical station velocities in a consistent reference frame with an uncertainty of less than 0.5 mm/yr;

T2.3: Carry out a coherent processing of all observations from CGPS stations co-located with ESEAS Observing Sites, based on the strategy developed in T2.1;

T2.4: Assemble information on physical parameters that may affect CGPS time series, e.g. ocean-tide loading, atmospheric-pressure loading and hydrological loading;

T2.5: Carry out a coherent analysis of the time-series from CGPS stations co-located with ESEAS Observing Sites, based on the strategy developed in T2.2 (with input from T2.4);
T2.6: Carry out absolute-gravity measurements at selected ESEAS Observing Sites;

T2.7: Assemble information on (historical and current) precise leveling at all ESEAS Observing Sites that are co-located with CGPS stations;

T2.8: Assess the contribution of vertical land movements and absolute sea level variations to changes in relative sea level, using the results from T2.5 in conjunction with T2.6 and T2.7.

To date, the focus has been on the definition, implementation and validation of the strategies for the processing of the CGPS data and the subsequent analysis of the time-series of co-ordinate variations (tasks T2.1 and T2.2).

The processing of the CGPS data from each ESEAS Observing Site will be based on the use of the same global parameters but with the following three different softwares/strategies:

GIPSY/OASIS II with Precise Point Positioning;
Bernese 4.2 with Double Differencing;
GAMIT with Double Differencing.

The solution time-series files from each ESEAS GPS data-analysis centre will then be analyzed using the following three different softwares/strategies:

A deterministic approach based on variance analysis and EOFs to model linear and non-linear components;

A stochastic approach to noise analysis based on an MLE, with the combined modeling of co-ordinate offsets and periodic signals, and uncertainties computed based on power-law noise;

A stochastic approach to noise analysis, with the separate modeling of co-ordinate offsets and periodic signals, and the computation of uncertainties based on empirical estimates of white noise and coloured noise.

Over the next twelve months, task T2.3 will enter into an operational phase in order to produce time-series that can be used as input to task T2.5, along with information from task T2.4. For the ESEAS-RI project, it has been decided that station-motion models for solid Earth tides and ocean tide loading will be applied during the CGPS processing, whereas station-motion models for non-tidal ocean loading, terrestrial hydrological loading and atmospheric pressure loading will be considered during the time-series analysis. Through co-operation with the IERS Special Bureau for Loading, as a first output from task T2.4, atmospheric-pressure loading time-series going back to the year 2000 for all CGPS@TG stations at ESEAS Observing Sites are currently being computed.

Separate from the CGPS processing and analysis, work has also been carried out on absolute gravity and leveling (tasks T2.6 and T2.7). In terms of absolute gravity, multiple AG measurements have been made at Newlyn, Aberdeen and Lerwick in the UK and preparations are in hand for measurements to be carried out at the Wladyslawowo tide gauge. In terms of leveling, a draft form requesting leveling information has been prepared and circulated and a software package that will be used to analyze the precise leveling information and assess whether any deformations may have occurred within a few kilometres of the tide gauge has been developed and tested.

Conclusions

Geodetic developments within the European Sea Level Service (ESEAS) have been initiated and are detailed in this paper.. For updated information on the work of ESEAS and the ESEAS-RI project the reader is referred to http://www.eseas.org/.

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Vertical Movement and Absolute Gravity: Brest Experiment (1998–2002)

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This paper presents the absolute-gravimetry experiment conducted in Brest (France) since 1998. The Brest tide gauge, which has been recording sea level for nearly 200 years, is included in the GLOSS. This long time-series shows an estimated mean-sea level variation of about 1.3 mm per year, reaching 1.4 mm per year after correction for the Post Glacial Rebound (PGR). To estimate precisely the sea level contribution in the tide gauge records of the Brest Observatory, the control of vertical movements is needed. For that purpose, a permanent GPS was installed in 1999 which is part of the RGP (French GPS permanent network) and the IGS (International GPS service). This type of co-localization is recommended by the ESEAS European Sea Level Project. In addition, some absolute-gravity experiments have been carried out to study different subjects, such as ocean loading or sea level trend. In spite of the under-sampling of these measurements, some comments can be formulated. A global increase can be deduced from the first three experiments (the fourth one of December 2002 met technical and environmental recording problems). The large variation (about 1.9 μgal per year) has to be interpreted as the sum of different effects. The seasonal signal will be studied in future work and some additional absolute-gravity measurements are planned for the coming years.

Introduction

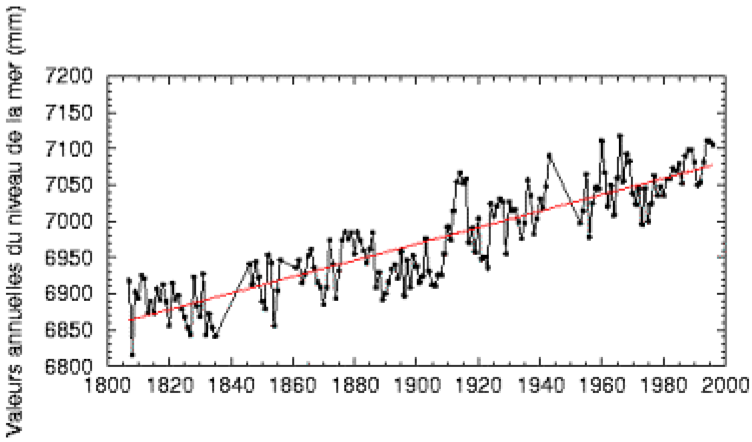
The tide gauge records give an interesting estimation of the mean sea level increase. To assess these values we need to know the vertical movement of the tide gauges. For that purpose, national and international programmes give attention to the co-localization of permanent GPS data (SONEL, RGP, ESEAS..) and tide gauges. The analysis of the GPS data can lead to estimation of the movement with various degrees of precision. If GPS data are very precise in the horizontal plane (X,Y), the precision is rather less in the vertical, due in part to uncorrected tropospheric effects. An example is the comparison of four different computations with the permanent GPS Brest data (RGP, EUREF, REGAL, TIGA solution) available to users. These solutions can lead to erroneous interpretation: for two of them (RGP, REGAL), the Brest station is in subsidence, and for the two others (EUREF and TIGA) the station is being uplifted.

Absolute gravity measurements can then be regarded as some complementary information on vertical movement (Lequentrec-Lalancette et al., 2002). The observed variations in the gravity values after suitable corrections can actually be linked to vertical movements with a precision of 1 mm/year (Williams et al., 2001).

Results

The Brest station provides some permanent measuring devices, such as the tide gauge, the GPS, a meteorological station and some sparse absolute-gravity stations. The Brest tide gauge is very famous, as it is the only tide gauge to show measurements since 1806 (Figure 1).

Figure 1. *(next page)* Annual sea level values in Brest since 1806. ►



The mean sea level trend is about 1.4 mm/year since the end of the nineteenth century. The absolute-gravity measurements in Brest have been made since 1998 with the French absolute gravity FG5#206 from the EOST (Amalvict et al., 2000).

Four measurements show a gravity variation with a mean square fit of about –0.21 µgal/year. The scattering of this fit (σ=1.9 µgal/year) excludes evident interpretation of the results as vertical movement recordings (Figure 2).

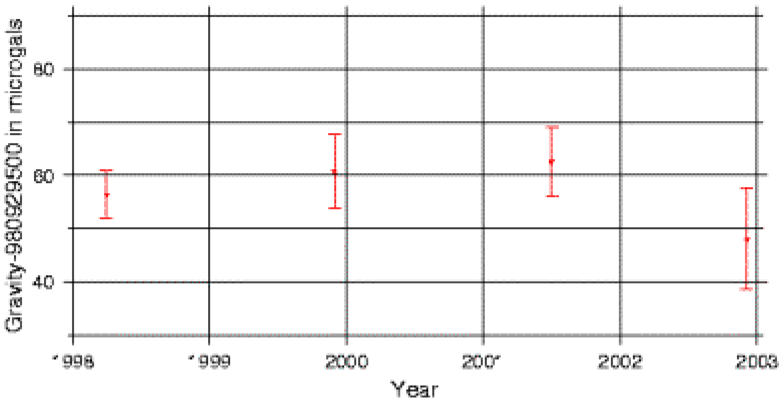


Figure 2. Absolute-gravity recordings in Brest since 1998.

In order to improve these results we have first to continue periodic absolute-gravity measurements and secondly to study the causes of gravity variation in this oceanic area. The oceanic or hydrological noise in particular can create some gravity variations of a few microgals which can disturb the gravity signal. Some new hydrological studies show that the aquifer characteristics vary a lot between the gravity recordings. We shall have in the future to estimate the gravity variations induced by the underground water circulation.

In conclusion, further measurements are needed to control and improve these preliminary results and whether for geodetic or gravity considerations, the improvement of the different corrections must be pursued along with the increase in the measurements (GPS and absolute gravity).

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Developments with DORIS

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Introduction

DORIS was initially developed for the determination of terrestrial satellite orbits, but after a few months it became interesting to use this system other purposes relating to geodesy, such as positioning, global tectonic motion, vertical deformation of the Earth's crust, or geocentre-motion determination. Year by year the performance of the system has been improved. This led the IERS directing board to include DORIS as a new technique for the realization of the terrestrial reference frame in 1994, and the CNES and IGN to propose this technique for a wide range of new satellites, such as Jason, Envisat or Spot-5 which was launched a few months ago, or upcoming missions, such as Cryosat or others. The aim of this paper is to present a short review of the main characteristics of DORIS and to emphasize the evolution of the system to be expected in terms of network densification.

How does it work?

DORIS is a one-way Doppler uplink system that uses a set of ground beacons that broadcast continuously on two frequencies, 2 GHz and 400 MHz, in order to correct Doppler measurements for ionospheric delay. Each beacon also includes an ultra-stable oscillator and meteorological sensors to correct the data for tropospheric delay. The space segment is made up of the whole set of satellites carrying the DORIS onboard receiver. It also includes an ultra-stable oscillator and provides the unique time reference. Since the launch of Spot-4 in 1998, a navigator computes the real-time orbit directly onboard, and since the launch of Jason in 2001, the onboard instrument can also receive measurements from two beacons simultaneously on two different channels. The master beacons in Toulouse and Kourou are used to upload information provided by the control centre to the satellite receivers.

The network

The coverage of the system relies on a ground network of fully automated tracking stations distributed around the Earth. Figure 1 shows the current network. It was designed in order to optimize the system for quite continuous tracks of the satellite's orbit. It offers a very homogeneous distribution over all continents and oceans. There are now around 60 beacons deployed in around 30 countries. The objective is to increase this number, thanks to the capabilities of the new onboard receivers to make simultaneous measurements from two beacons. A lot of propositions have been made in the frame of the International DORIS Service, in order to densify this network, and decisions on new beacons are close to being taken, as the new satellites are now in orbit, and last-generation beacons are now available us. With this network, a coverage of around 90% is theoretically possible with Jason-1.

Figure 1. The DORIS permanent network.

The space segment

Six DORIS receivers are currently working onboard TOPEX–Poseidon, Jason, Envisat and the Earth observation satellites Spot-2, Spot-4 and Spot-5. Spot-3 was unfortunately lost 3 years after its launch in 1993. The Spot satellites are on a near-polar 800-km orbit, as the European Envisat remote-sensing satellite launched in 2002. The two altimetric systems TOPEX/Poseidon and Jason are on a 1300-km orbit with an inclination of 66°. In 2004 and 2005, two other satellites are supposed to have a DORIS receiver onboard: Cryosat and Jason-2. More than 12 years of continuous tracking data have been already collected, and we expect a lot of the current configuration with six satellites in orbit at the same time.

The applications

DORIS was developed for precise orbit determination and precise positioning on Earth. The goal the TOPEX/Poseidon mission set itself was to measure the satellite's altitude to within 13 centimetres. DORIS soon began calculating orbits to within 10 centimetres, then 2.5 centimetres. Over the years, performance demands on the DORIS system have continued to increase. Now, the overall accuracy specifications for the Jason-1 satellite altimetry system require DORIS to calculate orbits to within just 1 centimetre, and the onboard orbit computation is also working with great precision on Jason.

In terms of positioning, the high precision obtained during the first years has led the International Earth Rotation Service (IERS) to include DORIS in 1994 as a new technique for the ITRF determination.

Our group has provided four complete solutions for ITRF determination (in 1995, 1996, 1997 and 2000). Even if the DORIS solutions are still less precise than the other geodetic techniques, performances have been regularly improved. Then DORIS data have also been used for the monitoring of the horizontal and vertical crustal motions, as well as geocentre or polar motion. Few articles have been published in the last five years on these topics.

The International DORIS Service

Finally, 3 years ago, an International DORIS Service was created. Its objective is to enhance the international co-ordination, to sollicit groups to participate as analysis centres, and to have a stronger participation in IERS. Based on the fact that now the system provides more accurate measurements, with a new generation of instrumentation, on board and on the ground, based on terrestrial and space co-locations, and linked to an International DORIS Service, DORIS can now enter a new phase in which it will contribute substantially to monitoring Earth. It is an exciting challenge to open this geodetic system to better international co-ordination; this is the purpose of the International DORIS Service, with a view to improving performance and the range of applications.

DORIS performance

In the early 1990s, when only one satellite was in orbit, the precision of absolute positioning was about 4 cm. This precision was regularly improved as new satellites were launched, and reached around 1.5 cm accuracy. Six satellites are now in orbit. Although we still have only preliminary results, sub-centimetre precision in absolute positioning is possible, as well as velocities with a mm/year precision, particularly in the vertical direction. Such improvements are also due to better-quality instruments on the new missions. Other improvements have been obtained year-by-year, thanks to new models, as for example new gravitational-potential models. The latest model, which will be developed under the GOCE mission, will probably allow another jump in performance, especially for the lower satellites, such as Spot or Envisat, or the future Cryosat. Improvement in non-gravitational models has also allowed us to achieve greater precision.

Co-location with geodetic techniques

DORIS is connected to the other geodetic techniques. In term of orbital instrumentation (DORIS and SLR on TOPEX/Poseidon and Evisat; DORIS, SLR and GPS on Jason), it allows a better estimation of the orbits of satellites carrying DORIS receivers, as was successfully done for the Jason orbit. In terms of ground-network co-location (Table 1), it allows a better estimation of the DORIS reference system when there are local links between different geodetic systems. Finally, it is particularly interesting for monitoring the vertical crustal motion of tide gauges.

Table 1. The DORIS network’s co-locations.

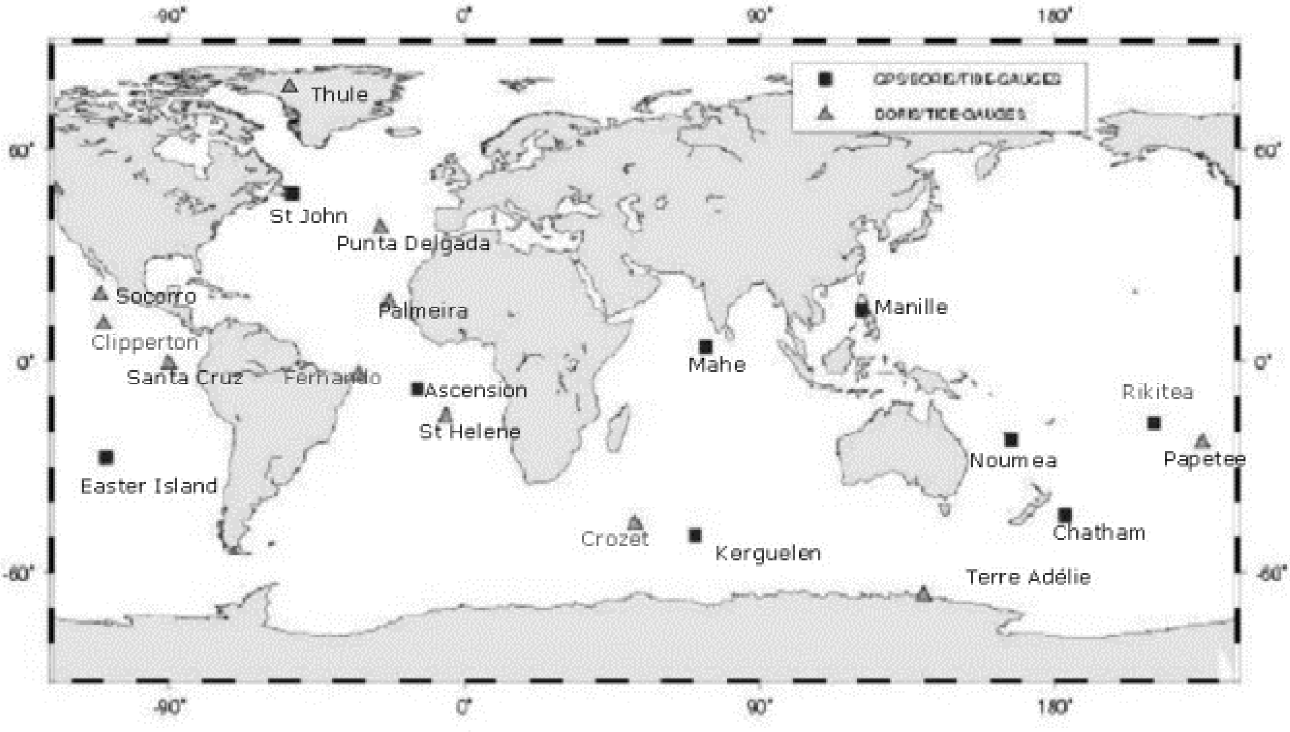
DORIS-SLR	7 sites
DORIS-GPS	28 sites
DORIS-VLBI	9 sites
DORIS-Tide gauges	14 sites

Sea level change monitoring

Geodetic techniques should be useful in the future in the analysis of tide gauge data, which provide invaluable historical records. However, these data are also limited for the study of sea level change because tide gauges can only measure relative sea level, owing to vertical crustal deformation of coasts; and obviously they do not cover the oceans uniformly. High-precision satellite altimetry, operational since the beginning of the 1990s, is a useful new tool for monitoring “absolute” sea level, with a global coverage of the ocean. But, at the mm/yr level, several factors (instrumental drift, for example) may still affect the determination of sea level change by satellite altimetry. Therefore, the detection of residual systematic errors may rely on comparing sea level measurements by altimetry and tide gauges. The comparisons performed in the last decade proved to be very useful for detecting errors in data-processing or instrumental drift, such as that of the radiometer on board the satellite. On the other hand, this type of comparison was limited by the fact that the vertical crustal motion of tide gauges was not corrected, because no monitoring data were available. For a few years now, this has become a new objective of geodetic techniques, such as GPS and DORIS, to correct tide gauge measurements for vertical crustal deformation; this has promoted the development of co-located sensor networks.

DORIS, tide gauges and permanent GPS co-locations

Figure 2 shows the DORIS sub-network of beacons co-located with tide gauges. As the DORIS system has already demonstrated its potential to determine precise vertical land movement, our group proposed recently to the French Centre national d'études spatiales (CNES) to densify the DORIS network, with beacons close to tide gauges in the GLOSS network. Four new beacons have been proposed, two already accepted and close to being installed, at Crozet and Rikitea, and two still under discussion, for Clipperton and Fernando de Nohrona. This proposal for densification was made after consideration of the availability of tide gauge data, and had to take account of constraints in the DORIS system (which we not develop here). If this



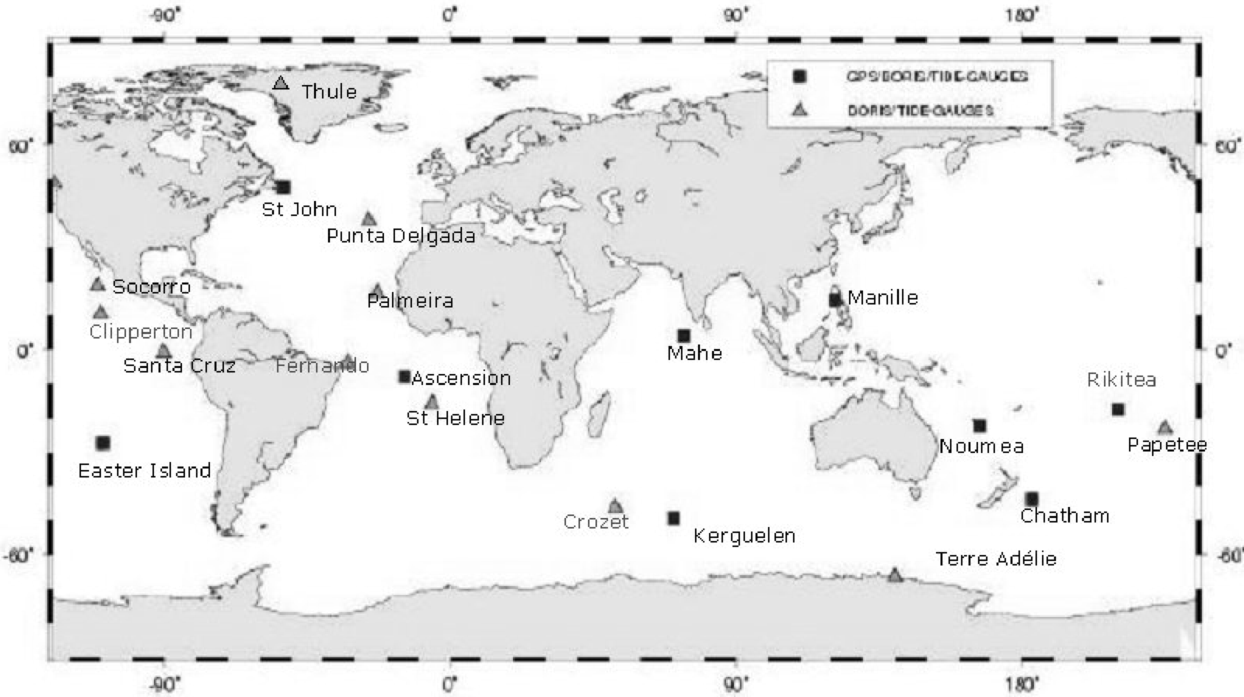


Figure 2. Permanent DORIS sites, tide gauges and GPS co-locations (<10 km).

Conclusion

After more than 12 years of orbitographic and geodetic performance, DORIS became one of the main tracking systems for the altimetric missions of the Jason series. An International DORIS Service has been created (http://ids.cls.fr), and it is used for different applications in current geodesy. The network has been extended and will continue. Recently, IDS has been chosen as a geodetic service of IAG, together with the existing IGS, IVS and ILRS services. The system is strongly supported by CNES and IGN for the coming year, which supposes new satellites in orbit with DORIS on board, and improved performance of the beacons. DORIS could also be a good geodetic system for other disciplines, such as oceanography, first of all because it is the primary orbital system of TOPEX/Poseidon, Jason 1 and Envisat, and secondly because it can be used to monitor vertical crustal deformation, thanks to GPS co-location with tide gauges in the GLOSS network.

References

See the bibliography on DORIS at http://ids.cls.fr/html/report/publications.html

The New Italian Tide Gauges

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Introduction

The Italian tide gauge network RMN is formed by 26 new stations uniformly distributed along the Italian coasts and located mainly inside ports.

In the older stations, paper-recording buoyant-mechanic tide gauges worked for many years, until 1986, when local-recording electronic-float tide gauges and EPROM data storage were installed in all the existing stations. The stations forming the RMN are now all equipped with two different tide gauges: a main electronic acoustic instrument, with wave guide and temperature compensation, and a secondary mechanical float gauge with paper recording, which is used as a measurement check, for the analysis of particular events or phenomena and for data recovery in case of occasional main-instrument failure. Tide gauges are referred to geo-referenced points (benchmarks) fixed by high-accuracy leveling, and verified with reference to the nearest official topographic benchmark. Stations are also provided with an anemometric sensor (wind speed and wind direction at 10 metres height), a barometric sensor, an air-temperature sensor and a water-temperature sensor. All the stations are equipped with a local system of data management/storage and with a real-time transmission device connected to the APAT Centre in Rome. Since the new tide gauge network has been fully operational, the APAT provides updated information on historical series, real-time observations, astronomical-tide forecasts, and data analyses for planning and scientific purposes.

Tide gauge data and updated local tide constants are published in the RMN Annual Bulletin. Moreover, APAT has carried out a recovery of the historical data collected by the pre-existing set of stations, both in paper and digital form, in order to add historical observations to the new National Network archive.

National tide gauge network components

The new local stations collect observations from the sensors, process the data and store the results on local and portable devices. To carry out all the necessary activities, the sites are equipped with an automatic station and a standard set of sensors.

The Automatic Weather Station collects the data from sensors at fixed intervals of time, which can be configured via the station keyboard or directly at the "front end". In addition to meteorological parameters, the battery voltage is also recorded.

The data produced by an analog sensor are converted to digital format by a 14-bit A/D converter. The use of this kind of converter instead of the common 12-bit ones, allows a greater measurement precision, as well as a better resolution.

Data validation is carried out at the station by algorithms depending on calculated and measured values. Rejected data are marked and, when necessary, an alarm is sent.

Valid data are processed by the station using the most common statistical techniques (daily averages, maximum and minimum values, etc.). The statistical parameter-processing interval can be predefined in the station configuration; it might be different from sensor to sensor and, for the same sensor, from function to function.

Measured and processed data are stored both in the onboard station RAM and in the portable memory card. Both forms of storage are managed as cyclic archives: in the event of memory exhaustion, the most recent data replaces the oldest. The Memory Card allows the preservation of the data collected by the station if there are prolonged communication problems with the front end due, for instance, to a lack of power.

The communication with the front end is bi-directional and can be managed not only from the APAT Centre by means of a station (periodic or ad-hoc) call procedure, but also directly from the stations whenever a technical (malfunction) or operational (over threshold etc.) alert warning is activated.

In case of communication problems with the Centre, data are stored locally by the station. Once communication is restored, all the data stored since the last successful call are automatically transmitted.

Technical features of the equipment

All the equipment makes use of standard input/output:

- All the sensors are equipped with universally recognized standard outputs (4–20 mA, 0–5Vcc, Pt100, RS232 etc.);
- The automatic station is configured interfacing with many sensors by means of standard output;
- The interface with an analogue output sensor requires the simple resetting of extreme values (through the local keyboard), while the protocols for sensors with RS 232 or RS 485 output can be easily set up by an update of the station firmware. Thus, all the mentioned features make it possible to interchange every sensor with others available on the market, or even to replace totally the automatic station with another one, provided it has the same standard inputs. All the sensors adopted are fully compliant with World Meteorological Organisation (WMO) recommendations.

The station is equipped with a serial port, which interfaces with external devices (maintenance terminals or laptops).

The station is supplied with a perpetual calendar date clock equipped with an automatic correction for a leap year. Every year there is a 10-minute correction in precision. The clock of all the stations of the network can be directly synchronized from the front end.

The SM3840 station is able to interface with most of the available meteorological sensors, regardless of the kind of electrical output.

The station power-supply unit includes three components:

A 50-W solar panel;
A regulator/battery charger, regulating the voltage produced by the solar panel and managing the battery charge;
A 63-amp-hour battery.

The installed tide gauge sensor is an electronic acoustic device. To exclude any possible interference due to the presence of the other electronic devices within the stilling well, the sensor is supplied with a wave guide that conducts the ultrasonic waves to a cylindrical bundle. The operation of the sensor is controlled by a microprocessor which manages all the main functions of the instrument. Before installation in stations of the National Tide Gauge Network (RMN), the functionality of each sensor is verified during a long test period at the Marina di Ravenna station.

The traditional instruments are supported by an electro-optical transducer, which replaces the commonly found brushings from the contacts of the dynamo and the potentiometer. Moving parts are therefore limited to the sensor element only. The result is a remarkable increase in sensor reliability.

Sensors

The tide staff is made of a material that guarantees long-term resistance to extreme climatic conditions and ensures the necessary rigidity and sturdiness even after long exposure to the water. The graduation of the staff is made by cut marks directly on the Plexiglas slab.[The numbers and graduation marks are in black and yellow, with positive and negative graduation marks in accordance with the recommendations of the Intergovernmental Oceanographic Commission (IOC).

The mechanical hydrometer ID5793 is an instrument able to measure sea level by exploiting the vertical movement of a float attached to a steel cable supported by a pulley. The rotation of the pulley as the float rises or falls with the water level is translated to a pen that registers the measurement on paper wrapped on a steel drum; the paper records for a period of one week. The tool, which is a natural evolution of the tide gauge, is currently used by the Italian hydrographic and tide gauge offices; its reliability was considerably improved, thanks to a few precautions, particularly the adoption of a cable well in anti-torsion steel for the suspension of the float and the counterweight, instead of the drilled ribbon used previously. This meets the specification of an operational life of at least 15,000 full cycles.

A numerical indicator accurate to four digits allows the direct reading of the level. The instrument's components are contained in a metal box, painted and completely airtight and perfectly resistant to fire and corrosion. The box is fitted with a glass window for reading the trace without the need to open the instrument. The disassembly of the drum for the replacement of the paper is particularly easy and rapid. The float and the counterweight are shaped so as not interfere with one another as their levels change with the water level.

The acoustic hydrometer sensor exploits a ceramic transducer. It emits ultrasonic pulses towards a surface and senses returning echoes; the on-board electronics performs distance calculation, computing the time interval between emission and reception of each pulse. To avoid spikes, the recorded value is the arithmetic mean of a programmable number of consecutive samples. This heavy-duty sensor, featuring IP65 protection, is ideally suited to the marine environment. It is easily programmable and many functions may be fine-tuned in order to compensate and correct environmental disturbance by means of 27 independently parameter settings using four buttons and four digital displays. The main parameters are:

- Distance calibration; it is possible to set the measurement to match a reference value (for instance, comparison with a tide staff value);
- Range: setting within 0.5–15 metres;

- Number of pulses per acquisition, to adjust power emission to environmental conditions and measured distance;
- Range: maximum variation of measured value between two consecutive acquisitions (1–20);
- Range sampling: number of measurements falling outside the above-defined range beyond which the measurement is accepted (0–200);
- Number of samples over which the arithmetic mean is calculated to give the recorded measurement (0–200);
- Offset: value (positive or negative) to be added to measurements;
- Zero zone: the range (0.5–full scale) ignored by the sensor; very useful when obstacles stand between the sensor and the surface to be measured;
- Fine tuning of the relation between measurement range (metres) and electrical output (mA).

The air-temperature sensor is a Pt100 resistance element. To avoid problems with the loss of tension caused by conductors, the connection is made through four wires. A plastic screen protects the element from solar radiation.

The water-temperature sensor is a Pt100; the material is inox steel AISI 316 with an IP68 protection level. The sensor is installed inside the cabin, placed in the stilling well by means of a weighted steel cable.

The atmospheric-pressure sensor is equipped with a compensation circuit that highly reduces errors due to temperature (less than 0.4 hPa between 0 and 40°C).

All the components of the station can work in the temperature range –30 to +50°C and in the humidity range 0 to 100%.

The station electronics is installed, together with the atmospheric-pressure sensor and the telephone terminal, in a fibreglass cabin with an IP65 protection level.

Wind sensors are installed on a 10-m anemometric pole. The pole is self-supporting, which means that it does not require wind counterbalancing; so there are normally no big problems in installing the equipment in the limited space available near the cabins. Due to the hinge placed near the middle of the pole, the tipping trajectory is a 5-m circle whose centre is at a height of 5 m; therefore the required free space at the ground level is very limited. The mechanical simplicity makes the pole compatible with the aggressiveness of the marine environment; dismounting requires the movement of only one hinge, which can be easily unlocked even if corroded, thanks simply to the mass and to the remarkable lever arm of the moving part.

Equipment installation and engineering

The installation of the local stations is done according to a general scheme, with possible changes depending on the site's characteristics. In fact, in a few cases, moving the stations or a few parts of it (in particular the anemometer pole) with respect to the originally planned position has considerably improved the quality of data.

Each tide gauge station is provided with a topographic reference, easily accessible but hardly removable, in order to determinate geometrically the position of the hydrometric “0” (zero).

Each referenced position is derived relative to a quoted reference point whose characteristics are fully compliant with the Italian Military Geographic Institute (IGM - Istituto Geografico Militare Italiano) requirements. For each benchmark, the plan metric position in Gauss – Boaga and the geographic co-ordinates (with reference to the IGM Italian trigonometric network, and the altimetric position of absolute height with respect to the new IGM altimetric network, subsequent to 1942) have both been determined.

Each benchmark has been referred to the national IGM trigonometric network through operational leveling based on geodetic precision (tolerance) triangulations, trilaterations or traversals, always using the forced-vertexes centralization method; or following the specific authorization of the works director and the approval of the IGM. The leveling specification has been carried out using GPS direct plotting by a static differential method (tolerance 5 mm + 2 ppm D). Each tide gauge has been related to the new national altimetry network (subsequent to 1942), on the basis of the nearest valid IGM benchmark, through high-accuracy geometric leveling. The leveling, which referred to safe lines (i.e. easy to follow, little sloping linear elements, such as roads, quays, banks etc.), has been of the “from the middle” kind in order to guarantee the highest possible precision. For each level-difference measurement, the automatic level has always been placed between the two target lines (while never being farther than 40 m from them) with the uncertainty tending to zero; the distance between target lines and level has been accurately calculated with a tape measure kept in a perfect horizontal position. At every step, the automatic level and the two targets were simultaneously found in the station, since specific rules do not allow moving the target back until the direct (frontal) target reading has been completely carried out.

The measurements have always begun and ended on the reference points and were made using the fractionated-leveling method; that is, dividing every leveling line into several parts each of which was delimited by secondary intermediate benchmarks.

In every step, from one reference point to another, the measurements of the level differences have been repeated separately, twice forward and twice back, on different days and at different times, avoiding conditions of poor visibility (e.g. high ambient temperature, presence of haze or fog), strong wind and poor grating visibility, and whenever the horizontal line of vision between instrument and target reading was tangent to obstacles. The difference between the measured difference of level going forward and the one measured going back, on every single part, has never been greater than the tolerance $T = \pm\ 3L/2$ mm, where L is the step length in kilometres.

PART III: QUALITY CONTROL AND DATA CENTRE DEVELOPMENTS

An Automatic Acquisition/Quality Control/Fast-Delivery Software For Real-Time Follow-up of Data Coming from a Tide Gauge Network

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The ROSAME network and São Tomé

ROSAME is the Réseau d'Observation Subantarctique et Antarctique du Niveau de la Mer (Subantarctic and Antarctica Sea Level Observation Network). It is implanted in the Terres Australes et Antarctiques Françaises (French Southern and Antarctic Territories, Figure 1).

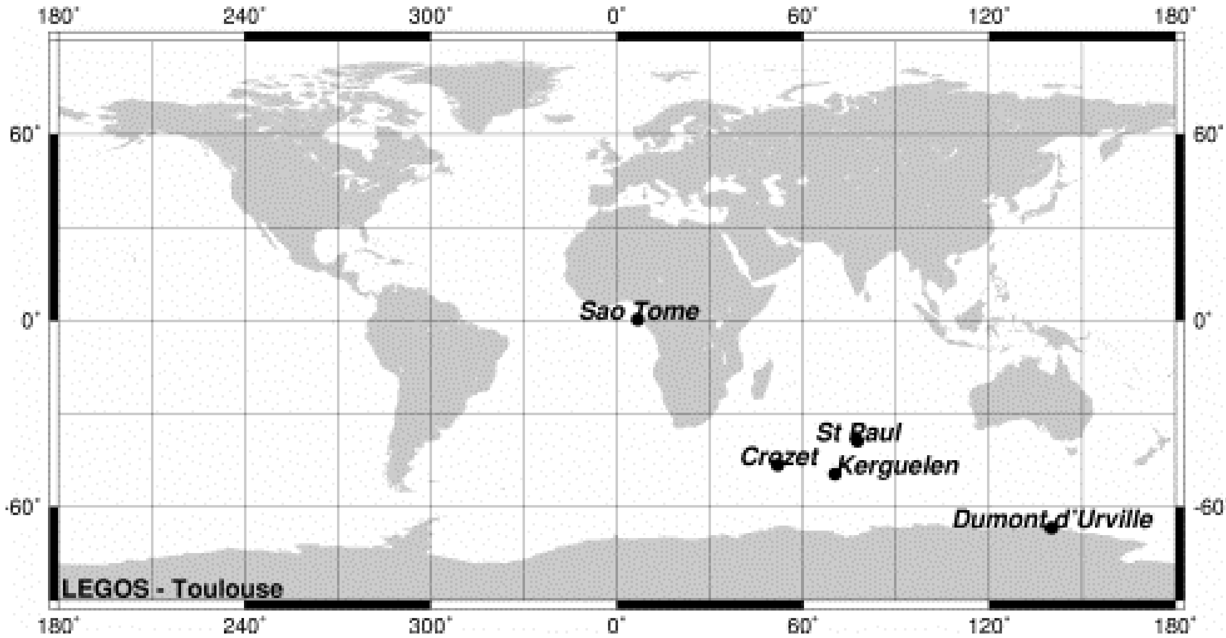

Figure 1. ROSAME network and São Tomé.

ROSAME network consists of four coastal tide gauge stations in the Indian Ocean and Antarctica:

Kerguelen is on the wharf of Port aux Français, the French scientific base in Kerguelen;
St Paul is in the crater of a partly immersed volcano which communicates with the ocean;
Crozet is on Possession Island in the Crozet archipelago. The Crozet bottom-pressure sensor does not exist any more; it was destroyed by a storm in July 2001. A new tide gauge station was installed at the end of 2003;
Dumont d'Urville is near the French scientific base at Dumont d'Urville in Antarctica.

Since June 1999, LEGOS processes data from the São Tomé station on São Tomé Island in the Gulf of Guinea.

Automatic real-time acquisition and transmission of data

Hourly measurements of atmospheric pressure, seabed water pressure, temperature and conductivity are automatically made at the same time by the tide gauge station (Figure 2).

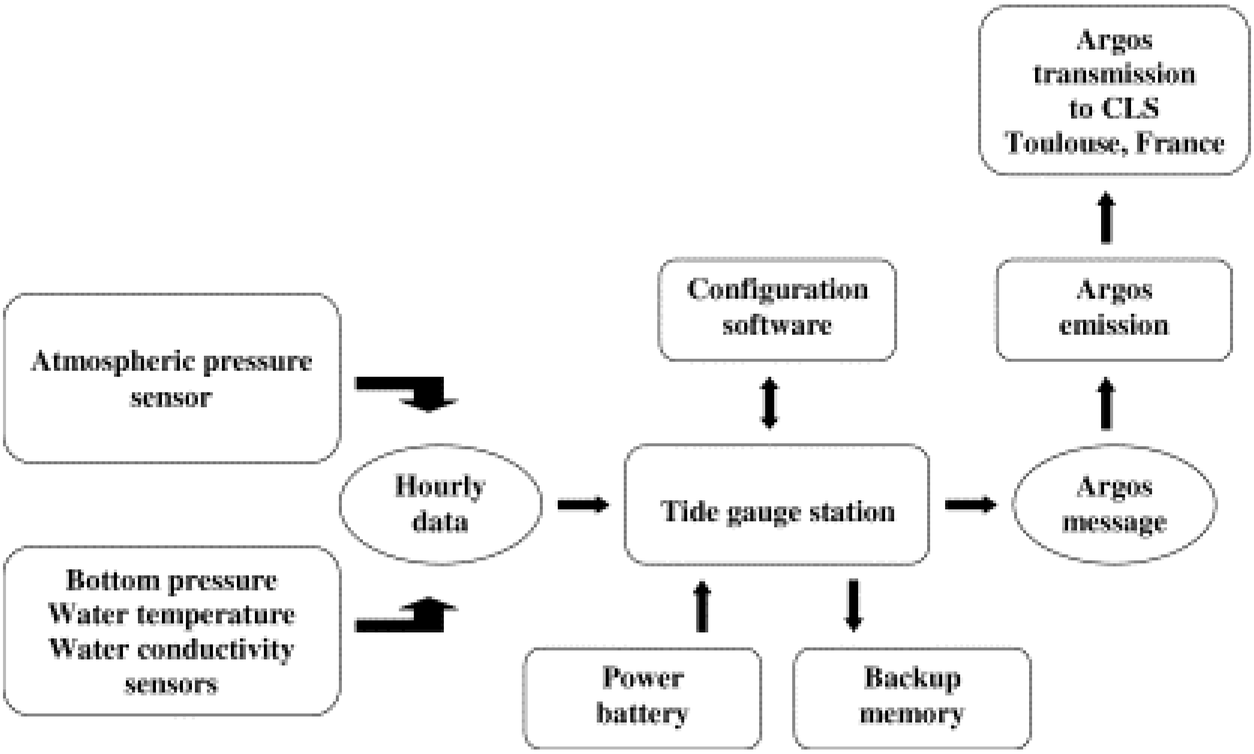

Figure 2. Automatic real-time acquisition and transmission of data.

The tide gauge station automatically builds an Argos message containing real-time data for the preceding 7 hours and transmits the message every 200 seconds, via the Argos system (by satellite) to the CLS Processing Centre in Toulouse.

Automatic acquisition/quality control/fast-delivery software

The CLS Processing Centre automatically sends Argos messages by e-mail to LEGOS (Figure 3). The e-mail message is automatically processed.

The sensor survey is already operational on the LEGOS intranet website. Quality control will soon be applied to the data. At the end of the data-processing, an anonymous ftp site will be updated, as well as the LEGOS website, where everyone will be able to follow the evolution of the data.

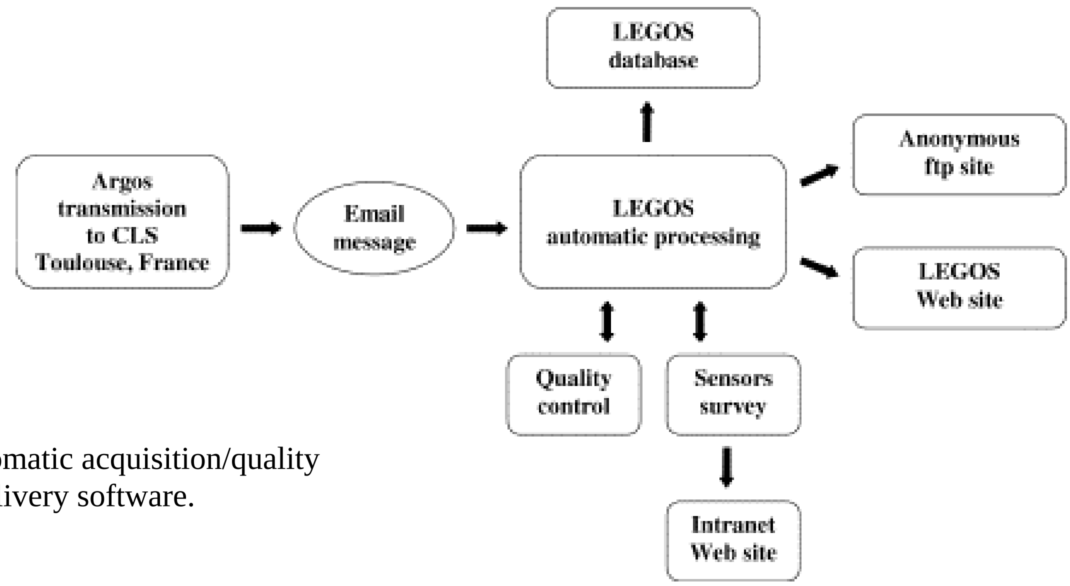

Figure 3. Automatic acquisition/quality control/fast-delivery software.

Software characteristics

The processing programme is based on modules written in Perl language. It allows the possibility of adding new tide gauges or new sensors or of integrating a new transmission system without having to modify the core programme. Graphics are done with GD:Graph Perl module. Visualization of the data is generated by a Perl CGI module and done on dynamic Web pages. Perl language is used in all processing steps to give homogeneity to the programme code.

Automatic acquisition

Argos messages are collected by the CLS Processing Centre in Toulouse, then sent to a dedicated e-mail address at the Service d'Observation of LEGOS. Processing is automatically activated by e-mails containing Argos messages.

About 60 e-mails are received a day from four tide gauge stations: Kerguelen, St Paul, Dumont d'Urville and São Tomé. As one e-mail can contain several Argos messages from different tide gauges, at least 60 processings are carried out daily.

Automatic-processing steps

Processing decodes Argos telemetry and computes raw data. Multiple transmission of values by the Argos system is used to control quality: In Figure 4, two Argos messages were sent at different times from same tide gauge by two different satellites (K and L). Some data appear in the first message and are repeated in the second message.

01009 14719 9 32 K	01009 14719 9 32 L
2003-10-02 22:10:17 1	2003-10-02 23:08:21 1
B0 BA **81 80**	B8 BA 80 **81**
83 80 7C 7F	**80 83 80 7C**
8B 66 C7 B5	8B 72 F7 CF
9E 70 78 8D	5E D6 79 C1
EE 07 F4 A0	E2 37 B8 1F
F7 4F 60 7D	D2 4F 60 7D
B2 **49 49 48**	AB 47 **49 49**
CA C7 40 80	**48 CA C7** 10

Figure 4. Example of Argos telemetry.

For each sensor, the number of times these data appear in various Argos messages is computed. For repeated values, the highest number of the repeats is retained. This computation will be soon operational and automatically included in the processing.

Physical values are computed from raw data using sensor-calibration values. As we have simultaneous measurements triggered by a tide gauge station, seawater salinity and density are computed using UNESCO algorithms. If there is no conductivity sensor, we assume a constant salinity.

Finally sea level is computed before the database is updated:

$$h = (P_{bottom} - P_{atmos})/(\rho * g)$$

Use of chronograms

Chronograms allows us to describe the state of parameters and follow their evolution. Chronograms describe the type of tide gauge stations and sensors in which model and serial number are represented as well as the parameters measured. They also describe the state of tide gauge stations and sensors (inactive, operational or under test), the sensor-calibration sheet and calibration date, and the time step of data acquisition.

When we decide to change the tide gauge sensor, we write new calibration values in the chronogram (Figure 5) whenever necessary. That allows us to follow the evolution of the hardware in real time.

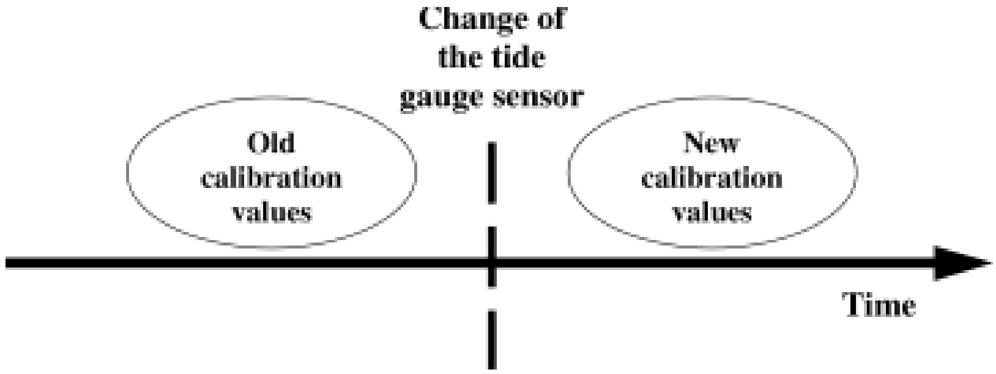

Figure 5. Practical use of a chronogram.

As we have all hardware modifications or changes in calibration values written in chronograms, it is very easy to (re)compute historical data, to evaluate data quality and, for example, determine sensor drifts.

Quality control

Quality control is the step we are working on presently. Electronic mail is used as an alarm system to detect problems: When a tide gauge station is switched on, we receive first an initialization message. By comparing Argos messages received, an alarm e-mail is sent if a new initialization message is received from the tide gauge station, even if no maintenance operation is in progress.

In the same way, processing sends an alarm e-mail if the same Argos message is received repeatedly, if there is no Argos message received at all or if an error arises during automatic processing.

For each sensor, values exceeding sensor thresholds are removed. Gaps between successive acquisitions are computed and compared to detection thresholds of measure error: An alarm e-mail is sent when such a problem occurs.

Finally, a visual inspection of the data is carried out every day on the LEGOS “Service d’Observation” intranet website to see the evolution of the data and make a sensor survey.

Intranet website

On the intranet website, we have gathered important information for an operational follow-up of tide gauge stations and in situ interventions. In Figure 6, real-time follow-up of Kerguelen data is presented for 10 days on atmospheric pressure, seawater temperature and bottom pressure.

The date of the latest processing allows us to know when the last Argos message was received. Dates of first and last measurements are printed above graphics for each sensor. We have compared the date of the last updated processing with the date of the last received value; there is only a difference of 1 hour and 10 minutes.

Minimum, maximum and latest values are printed below each graphic.

When multiple transmission of values by the Argos system and quality control are taken into account, wrong data at the end of atmospheric pressure and bottom pressure columns will disappear. For each sensor, a second curve will be printed to show how many times values are repeated in Argos messages, as a quality indicator.

TECHNO parameters have links to similar web pages with graphics for percentage of memory occupied, battery voltage, etc.

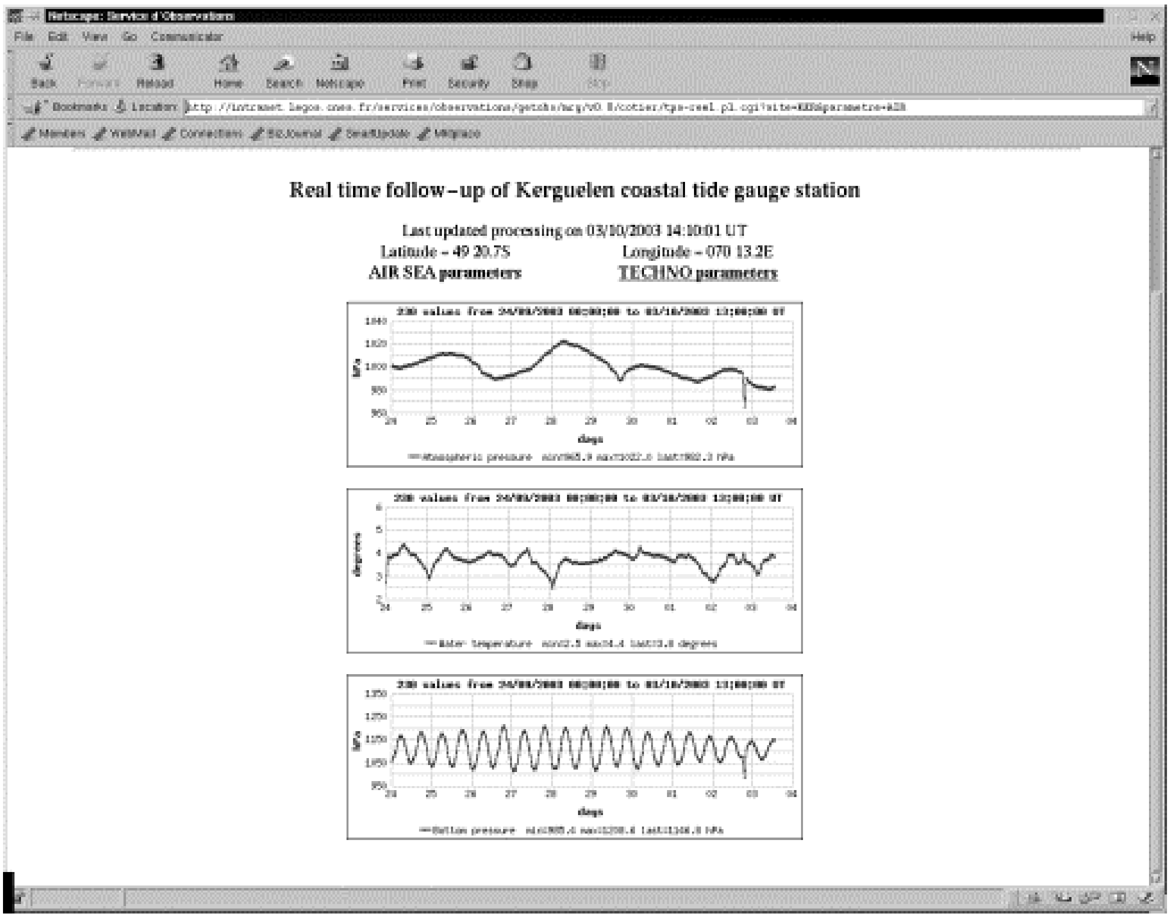

Figure 6. Intranet website

Fast delivery

Presently, the data-processing sequence takes time and the sea level data are sent to the Hawaii Sea Level Center monthly. In 2004, with the new automatic processing, the ROSAME and São Tomé database will be updated weekly on an anonymous ftp site. We expect to deliver our data on a daily basis when all the steps in the software have been optimized.

The future

The same real-time processing algorithm will allow us, if necessary, to recompute historical data using chronograms.

Sea level data from the ROSAME network and São Tomé will be accessible in real time on the LEGOS website.

This automatic acquisition/quality control/fast-delivery software for real-time follow-up can be extended to new tide gauges or new transmission systems.

JCOMMOPS *In Situ* Observing Platform Support Centre

http://www.jcommops.org/)

E. Charpentier

The JCOMM *In Situ* Observing Platform Support Centre (JCOMMOPS) was established by JCOMM-I in June 2001. JCOMMOPS is operated by the Technical Co-ordinators of (i) the Data Buoy Co-operation Panel (DBCP), (ii) the Ship-of-Opportunity Programme (SOOP), and (iii) the Argo sub-surface profiling-float programme. DBCP, SOOP and Argo provide the resources needed to run JCOMMOPS. The Centre basically provides support in an integrated way for the implementation and the operations of these programmes. A complete description of JCOMMOPS, including its terms of references, can be found at http://www.jcommops.org/doc/jcommops/jcommops.htm.

JCOMMOPS development started in early 2001 in conjunction with recruitment of the Argo Technical Co-ordinator and therefore became a two-person centre, i.e. the latter and the Technical Co-ordinator of the DBCP and SOOP. Focus was initially placed on the development of the Argo Information Centre (AIC). Then development of a common database and web products by the AIC, the DBCP and SOOP could start. The work, which is shared between the Argo and the DBCP-SOOP Technical Co-ordinators can be split into the following tasks:

The normal tasks of the Technical Co-ordinators of the DBCP, SOOP and Argo (co-ordination and day-to-day operation of JCOMMOPS):

Facilitating programme implementation through provision of:

Information on programme status;

Information on deployment opportunities;

Practical information on how to initiate new programmes;

Technical assistance, e.g. satellite data communication, Global Telecommunication System (GTS);

Facilitating programme operations through:

User assistance, including technical aspects, e.g. Argos, GTS;

Relay of quality information from data users back to data producers (e.g. DBCP QC guidelines);

Encouraging free and unrestricted distribution of the data, including real-time data;

Acting as focal point for marine *in situ* observing systems.

Specific JCOMMOPS developments and provision of on-line tools:

- JCOMMOPS website design (static pages, site structure and informational content); this is now basically done, although the JCOMMOPS website is regularly being updated.
- Database design and conceptual relational model (based upon expected needs for the DBCP, SOOP, and Argo). The database model is now completed, but is routinely updated to support newly developed tools. The data base contains comprehensive information on *in situ* marine observing platforms, related programmes, agencies and

contact points, sensors, sensor types, platform types, WMO allocation, Argos IDs, ship call signs, ocean basins, GTS originating centres, acronyms, documents, images, meetings, FAQS, GTS codes, marine GTS observations, buoy monitoring statistics, locations, statistics, issues, SOOP lines, SOOP line types, etc.

- Database implementation (dedicated server: Oracle). This is being carried out, although, owing to its large size, the database will soon be moved to a new server.
- Database initialization and data loading from various sources, including the Argos database for Argo float location and WMO numbers, TC DBCP and SOOP original data bases, and files regularly submitted by the SOOP, DBCP, and Argo operators to JCOMMOPS. This includes development of specific tools to automatically load submitted files into the database. A substantial amount of work was done in this regard. Work is nearly completed as far as buoy, float, and SOOP data are concerned. Information on deployment opportunities still needs to be uploaded into the database.
- Design of geographical information system (GIS) map products (using ESRI ArcMap and ArcIMS). Specific products are already online (see below).
- Development of specific tools to permit database access from the GIS (done).
- Development of dynamic web products (i.e. queries and web pages directly accessing the data base, e.g. automatically updated lists of floats, clickable maps, etc.). Specific products are already online (see below).

Regarding GLOSS, some support was also provided by means of (i) a dynamic map showing the GLOSS stations by category, and (ii) a higher-resolution status map of the GLOSS network, also providing colour codes for the different GLOSS station categories. Status of the GLOSS fast-delivery network might also be provided in the future through co-operation with the GLOSS fast-delivery centre at the University of Hawaii.

In October 2003, the following JCOMMOPS services were available:

Integrated products

Platform status by country (monthly histogram for drifting buoys, moored buoys, floats; XBT part still to be developed) http://w3.jcommops.org/cgi-bin/WebObjects/PTFcountry;

Monthly GTS report (input from five countries, originally the SOOP monthly BATHY report, see annex) http://w3.jcommops.org/cgi-bin/WebObjects/GTSReport;

JCOMMOPS status maps (summary of all types of maps produced, plus links)
http://www.jcommops.org/status_maps.html;

Monthly JCOMMOPS GTS status maps (high-resolution map)
ftp://ftp.jcommops.org/GTS/Maps/;

Deployment opportunities (static pages so far, information will be added in the data base and a dedicated application [query] to search for specific opportunities will be developed):
http://www.jcommops.org/depl_opport/depl_opport.html (see annex);

Allocation of WMO numbers and ship call signs to specific transmitting platforms (buoys, floats, XBTs): http://w3.jcommops.org/cgi-bin/WebObjects/WMO_Telecom (see annex).

List of contact points:
http://w3.jcommops.org/cgi-bin/WebObjects/Search.woa/wa/contact;

List of electronic mailing lists:
http://www.jcommops.org/mailing_lists.html;

List of meetings (dynamic application, query, document lists, etc):
http://w3.jcommops.org/cgi-bin/WebObjects/Search.woa/wa/meeting;

JCOMMOP generic database search engine:
http://w3.jcommops.org/cgi-bin/WebObjects/Search;

Glossary and list of acronyms:
http://w3.jcommops.org/cgi-bin/WebObjects/Search.woa/wa/glossary;

Drifting Buoy Co-operation Panel

DBCP monthly dynamic status map (zoom, click on buoy)
http://w3.jcommops.org/WebSite/DBCP (see annex);

DBCP real-time dynamic map (updated daily, zoom, click on buoy)
http://w3.jcommops.org/WebSite/DBCP_RT;

Application to relay quality information from PMOCs to PGCs via a dedicated web page (potentially usable for VOS provided that WMO Pub. 47 is routinely imported into JCOMMOPS database) http://w3.jcommops.org/cgi-bin/WebObjects/QCRelay;

Monthly DBCP GTS status by country (high-resolution map)
ftp://ftp.jcommops.org/DBCP/Maps/;

Histograms showing difference between buoy data distributed on GTS and first-guess field
http://w3.jcommops.org/cgi-bin/WebObjects/Histogram;

Time-series regarding the quality of buoy data (from buoy monitoring statistics)
http://w3.jcommops.org/cgi-bin/WebObjects/StatsSeries.woa/wa/progDirect?prog=DBCP);

Links to products developed and made available elsewhere, such as the Information Service Bulletin on non-drifting Ocean Data Acquisition Systems (ODAS) which is operated by MEDS:
http://www.meds-sdmm.dfo-mpo.gc.ca/odas/main.htm;

Argo

Argo Information Centre website and products developed by Mathieu Belbéoch:

Argo list of operational floats:
http://w3.jcommops.org/cgi-bin/WebObjects/List (see annex);
Argo dynamic map (refreshed daily):
http://w3.jcommops.org/website/ArgoMap;

Argo monthly maps (high resolution)
ftp://ftp.jcommops.org/Argo/Maps/;

Argo float deployment notification:
http://w3.jcommops.org/cgi-bin/WebObjects/Notification;

AIC Newsletter:
http://w3.jcommops.org/cgi-bin/WebObjects/Newsletter.woa/wa/news;

Ship Observations Team (SOT)

SOT Mailing list:
sot@jcommops.org;

SOT web page:
http://www.jcommops.org/sot/;

SOOP line sampling indicators:
http://w3.jcommops.org/cgi-bin/WebObjects/SOOP_Indicators;

SOOP semestrial survey (see annex for semestrial survey map):
http://www.jcommops.org/soop/semestrial_survey.html;

SOOP semestrial dynamic map (colours by country, zoom, click on drop):
http://w3.jcommops.org/WebSite/SOOP;

SOOP monthly GTS dynamic map (colours by GTS origin, zoom, click on drop, see annex):
http://w3.jcommops.org/WebSite/SOOPM;

Monthly SOOP GTS status by originating centre (high-resolution map, see annex):
ftp://ftp.jcommops.org/SOOP/Maps/;

Definition of SOOP lines (query):
http://w3.jcommops.org/cgi-bin/WebObjects/Search.woa/wa/soopLines;

GTSPP monthly QC report (query, see annex):
http://w3.jcommops.org/cgi-bin/WebObjects/GTSPPQCReport
GLOSS

GLOSS yearly dynamic status map (zoom, click on buoy):
http://w3.jcommops.org/WebSite/GLOSS;

GLOSS status map (high-resolution map, see a black-and-white version below)
ftp://ftp.jcommops.org/GLOSS/Maps/;


GLOSS Status, October 2003
JCOMMOPS
Category 1 : 'Operational' stations for wich the latest data is 1998 or later.
Category 2 : " Probably operational" stations for wich the latest data is within the period 1988-1997.
Category 3 : 'Historical' stations for wich the latest data is earlier than 1988.
Category 4 : Stations for wich no PSMSL data exist.
GLOSS

GLOSS Archive Centre and CLIVAR "Delayed-Mode" Sea Level Data Centre at BODC

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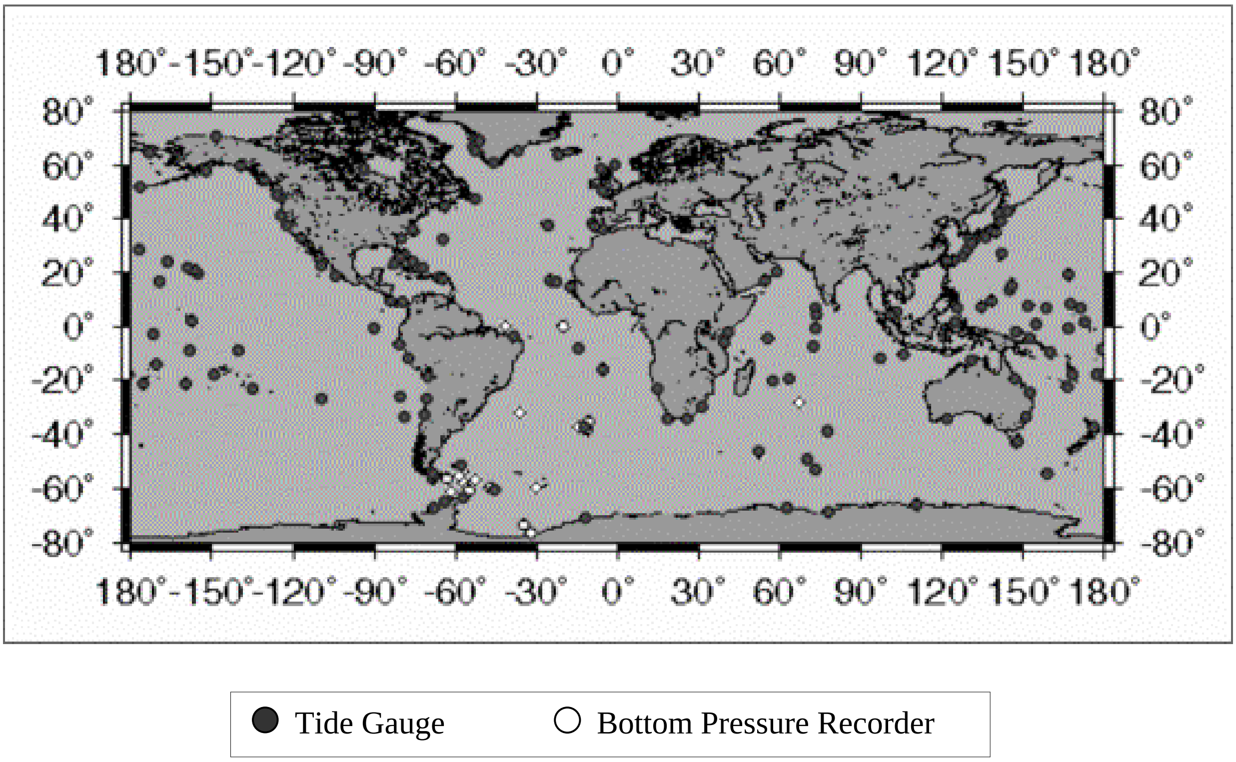
Introduction

The British Oceanographic Data Centre (BODC) is the UK's National Oceanographic Data Centre and has over 25 years' experience in data processing, quality control, banking and general management of oceanographic data. BODC operates both on a national and international level, from being the data centre for the UK Tide Gauge Network to acting as the "delayed-mode" sea level Data Assembly Centre for the World Ocean Circulation Experiment (WOCE). For WOCE, BODC was responsible for assembling, quality controlling and disseminating the data collected. Over 3,550 site-years from 160 stations in over 20 countries were quality controlled and stored at BODC. This included data from many types of instruments, such as float and stilling wells, pressure sensors, bubbler gauges, acoustic gauges and bottom-pressure recorders. In addition, there were a few sites that had other parameters recorded, such as atmospheric pressure, air temperature, sea temperature, wind speed, gust wind speed and wind direction. Following on from this, BODC will be acting as the "delayed-mode" sea level centre for the CLIVAR (Climate Variability and Predictability) project, performing a similar role as in WOCE.



When sea level data arrive at BODC, they are converted into the BODC internal format (currently a subset of netCDF). This allows visual inspection of the files using internally developed software, EDTEVA, and any problems flagged. Documentation is then compiled, containing information about the tide gauge, the site, the quality control and any unresolved problems. The metadata are then stored in the BODC data base and the data and site history can be made available via the web.

Quality control procedure

The standard procedure at BODC for the quality control of sea level data includes:

Producing a tidal analysis and comparing constituents with previous data series and adjacent sites;

Screening the series, looking for spikes, gaps, timing errors and datum shifts;

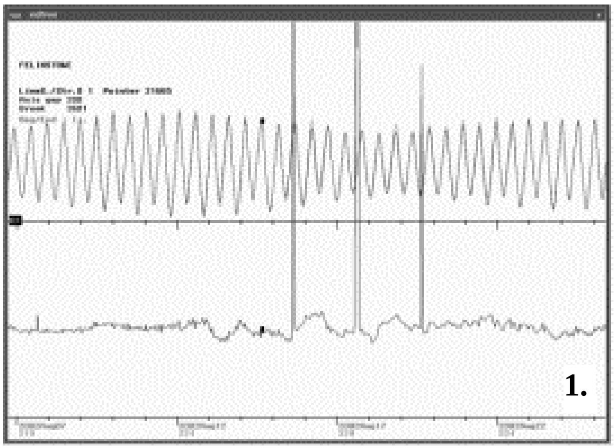
Screening the series with previously banked series from the same site;

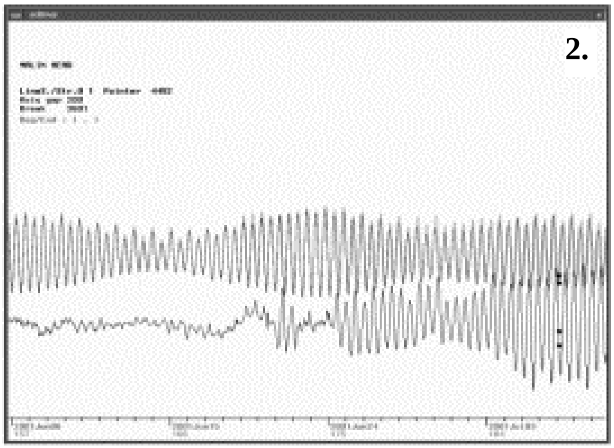
Screening the series with neighbouring stations covering the same period;

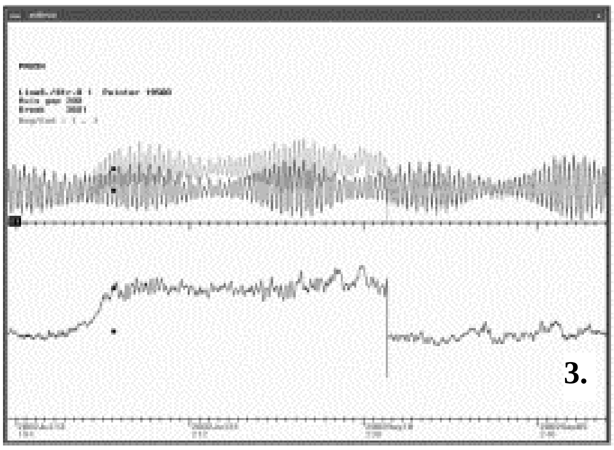
Other parameters, such as sea temperature and atmospheric pressure, can be displayed at the same time to aid in quality control;

Checking the statistics produced, i.e. mean sea level, with those produced in previous years.

Suspicious data points are flagged and any timing errors or datum shifts are noted. No data values are changed without the permission of the data collector.







1. Spikes in residual from bubbler gauge at Felixstowe.

2. Timing error possibly due to chart digitisation, from Malin Head, Ireland.

3. Datum shift seen in residual, possibly due to a blockage in the bubbler gauge at Portrush, Northern Ireland.

Documents are also assembled for each site. They should include the following information:

- Country and organization responsible for data collection and processing;
- Position information and location of gauge and site description;
- Instrument information, e.g.
  Make, model, dimensions etc.
  Calibration information;

- Benchmark and datum information, e.g.
  Description of benchmarks
  Datum relationships and datum history;
- Data sampling/processing, e.g.
  Sample interval
  Averaged or instantaneous measurement;
- Quality control information;
- Gaps in data, location of spikes, timing errors and datum shifts.

BODC’s role as a GLOSS Archiving Centre

BODC is acting as an International Archiving Centre (IAC) for GLOSS. The GLOSS implementation plan states that:

At regular intervals, for example every year, and at the termination of a Centre’s operations, each Centre sends complete copies of its data holdings to an International Archiving Centre (IAC) where data will be archived.

In addition to archiving data, and as a further part of its role as an IAC, BODC also maintains and updates the GLOSS Station Handbook. This is a web-accessed resource, listing information about the GLOSS core network of tide gauges, and providing links to the (high-frequency, e.g. hourly) data. Continuing this work, we aim to develop the GLOSS Station Handbook into a more user-friendly resource. One way in which this will be done is to put all the information in the Handbook into a database, with the user accessing the information via a series of forms, rather than from the list of stations available at present. It is intended that the GLOSS Station Handbook will then become a focal point or gateway for users to access GLOSS data, metadata and other background information. Linking to the IGS TIGA (GPS Tide Gauge Benchmark Monitoring) database is a further example of the other types of relevant information that could be included.

The upgrade of the Handbook will also provide improved access to the data stored at UHSLC, BODC and PSMSL (fast, delayed-mode and mean sea level) and, where available, there will be direct links to the data sets from national and regional networks. Already many GLOSS sites have location maps included, these will be improved and photographs of the tide gauges and their benchmarks will be included. Maintenance of the Handbook will become more efficient than it is at present.

The future for sea level data at BODC

In the short term BODC will continue to act as a GLOSS International Archiving Centre for delayed-mode high-frequency (hourly, 15-minute, and 6-minute) data. As part of this role, BODC will work more closely with the University of Hawaii "fast-delivery" centre, to provide a seamless interface for users to the data, via a single gateway to the data sets. To continue the good co-operation between UHSLC and PSMSL/BODC there should be an annual exchange of the delayed-mode data, so that the data archive at each site will be the same, and the data can be "mirrored" at each site, to improve access for users.

BODC will actively seek out data from national on-line data collections (if these are available) and pull data annually from these sites. Where on-line data collections do not exist, data will continue to be requested from the data collectors.

The GLOSS implementation plan says that:

Sea level measurements should be accompanied by observations of atmospheric pressure, and also winds and other environmental parameters, which are of direct relevance to the sea level data analysis.

BODC will request, quality control and archive these ancillary data (e.g. atmospheric pressure, water temperature, salinity, etc.) where they are available.

BODC is a partner of the European Sea Level Service – Research Infrastructure project and as part of this project we are working towards standardized quality control and agreed common format(s) for data delivery through the ESEAS Data Portal.

In the medium term, BODC, together with UHSLC, will work through the requirements of CLIVAR Global Synthesis and Observations Panel (GSOP) and Data Planning Group, and the GLOSS Group of Experts. In the long term, BODC can see the need to provide a single point of access to all oceanographic data (whether real-time or delayed-mode) for a wide variety of users and perhaps this could be achieved by becoming an element of a virtual data centre. There are various groups and organizations already considering this in the context of the future of global oceanographic data management. Here at BODC we plan to take into account the requirements of the strategic design plan produced by the GOOS Coastal Ocean Observations Panel (COOP), the plan for the Data Management and Communications (DMAC) sub-system of the US Integrated Ocean Observing System (IOOS) – UHSLC participates in the DMAC initiative – and recommendations from the JCOMM/IODE Expert Team on Data Management Practices, amongst others.

Background Information

Hankin, S., DMAC-SC (2003) The U.S Integrated Ocean Observing System (IOS) Plan for Data Management and Communications (DMAC), Part I, Ocean. Arlington, Va. 40pp. (see: www.dmac.ocean.us/dacsc/imp_plan.jsp).

IOC/UNESCO (1997) Global Sea Level Observing System (GLOSS) Implementation Plan - 1997. Intergovernmental Oceanographic Commission, Technical Series No. 50, 91pp.

IOC/UNESCO (2003) The Integrated, Strategic Design Plan for the Coastal Ocean Observations Module of the Global Ocean Observing System. GOOS Report No. 125; IOC Information Documents Series N°1183. UNESCO, Paris.

Report on GLOSS Activities in the Western Indian Ocean Region

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Introduction

Measurements of sea level is a vital component of oceanographic observation programmes, ranging from immediate operational requirements of ship navigation and storm-surge prediction to long-term monitoring and prediction of global sea level changes due to climate variations. The Intergovernmental Oceanographic Commission (IOC) of UNESCO established the Global Sea Level Observing System (GLOSS) to address the growing concern over a global increase in mean sea level. The objective of GLOSS was to provide high-quality standardized data from which various products could be obtained for local, regional as well as international uses. Through GLOSS, a network of tide gauges has been installed around the globe for sea level monitoring. The western Indian Ocean (WIO) region is actively participating in GLOSS.

The WIO component of GLOSS consists of a network of about 15 designated tide gauge stations managed by national institutions with technical assistance from IOC, PSMSL and the University of Hawaii. This network provides a set of valuable sea level data in the region. However, some of the stations are non-operational, owing to faulty gauges, lack of maintenance and lack of human resources for maintenance.

These stations need to be upgraded or replaced, as spare parts are no longer available.

Data analysis and archiving

Sea level data from stations that are operational are downloaded from the tide gauges on a monthly basis and archived at the respective national institutions before being forwarded to PSMSL and to the University of Hawaii Sea Level Center for inclusion in the global sea level database.

Some of the institutions in the region are now able to perform quality control and analysis of the data to produce tide predictions. The predictions are distributed to interested organizations dealing with the marine environment to facilitate their navigational activities. Several scientists in the region use sea level data as inputs in oceanographic research, coral reef studies and pollution monitoring.

Maintenance and leveling of tide gauges

The capacity for repair and maintenance of the gauges in the region has been limited. Most of the stations rely on the services of technicians from the University of Hawaii Sea Level Center. Where the know-how exists, lack of spare parts and equipment (tools) has been a major hindrance to carrying out minor repair jobs and leveling.

Training course

One GLOSS training course on sea level data analysis has been held in the WIO region. The course took place at the University of Cape Town in 1998.

A number of sea level specialists from the Western Indian Ocean region attended the course. This contributed to some extent to capacity-building for scientists in the region. However, follow-up courses are needed. The hosting of such courses requires lecture and computer facilities, with the possibility for "hands-on" training with tide gauge and geodetic equipment. It is also advantageous if the host establishment or country contains a sufficient number of suitable lecturers, to keep the need for external experts to a minimum.

GOOS–AFRICA and GAINS initiatives

The GOOS–Africa Workshop was held in Nairobi, 19–23 November 2001.

Sea level specialists from the region have participated in the drafting of the GOOS–AFRICA project proposal on sea level monitoring. The objective of the project is to establish a comprehensive network of tide stations in Africa. The project aims at ensuring that all coastal and island states in Africa undertake modernization of the existing tide gauges and establish new gauges if necessary and improve their capabilities in sea level data analysis and interpretation.

The GAINS initiative also aims at installing new gauges at some locations in Africa where no measurements are available. The GAINS proposal has recently been submitted to the EU for funding consideration.

The western Indian Ocean region will benefit from the project through installation of additional stations at suitable sites in the region and training courses for scientists and technicians.

National contacts and Regional Co-ordinators

The GLOSS Implementation Plan describes the responsibilities of national "GLOSS Contacts" and "Regional Co-ordinators" who are fundamental to the development of the programme in each country in the IOCINCWIO region. They have the responsibility to ensure smooth data flow and to promote GLOSS in a number of important ways.

The current Regional Co-ordinators are Charles Magori (Kenya), for East Africa, and Prof. Geoff Brundrit (South Africa), for southern Africa. A list of national contacts is available on the GLOSS–Africa website.

GLOSS–Africa website

A new website has been established by Charles Magori and Clive Angwenyi for sea level activities in Africa. The web page is hosted at the IOC/UNESCO server www.ioc.unesco/glossafrica.

On the website, the status of tide stations in the region is clearly presented.

Recommendations

More needs to be done to fully develop GLOSS in the WIO region. During the Cape Town course in 1998, recommendations were made by the many young scientists present for the formation of an African GLOSS Network to co-ordinate future sea level activities in Africa (including elements involving GPS, altimetry, data analysis, training etc.) The UCT meeting also pointed to the fact that GLOSS in the region requires a major programme of tide gauge upgrades and, in addition, suggested that maximum use should be made of Regional Oceanographic Data Centre developments (e.g. ODINAFRICA). All of these recommendations were consistent with those of the Pan-African Conference on Sustainable Integrated Coastal Management (PACSICOM) held in Maputo in 1998.

To achieve a regional network that is fully operational, there is an urgent need to develop adequate capacity. This can be achieved by training local technicians in tide gauge installation, maintenance and benchmark leveling. Scientists should be trained in quality control of sea level data and analysis. This will ensure that the region produces continuous high quality data for use at local and regional levels and for contribution to international oceanographic programmes and data centres (e.g. TOGA, WOCE, UHSLC, PSMSL, etc).

Follow up seminars for those already involved in sea level measurement in the region should be organized so that they can exchange ideas with their colleagues in the region (and elsewhere) and share their experience and increase their capabilities.

New initiatives like GAINS should include budget proposals for Regional Co-ordinators to facilitate visits within the region (to inspect tide stations), hold regional workshops and training courses, prepare reports and stimulate the many scientific and other uses of sea level data.

A brief overview of the status of GLOSS in the western Indian Ocean region

Kenya: Recent data exist from Lamu and Mombassa. A number of scientists from Kenya have attended GLOSS Experts meetings and training courses (most recently GE-VI in 1999 and Cape Town in 1998, respectively).

Tanzania: Recent data exist from Zanzibar. One scientist attended the 1998 Cape Town training course.

Mozambique: Two stations (Pemba and Inhambane) were installed in 1992 and 1993, respectively. We expect to start receiving quality data from these stations. Two other stations for which data are available are Beira (1984), Chinde (1983), Macuse (1982) Momat (1982) and Mocimba de Praira (1984). Mozambique scientists attended the Cape Town training course.

Madagascar: Recent data exist from Nosy Be. One scientist attended the 1995 Dehra Dun training course.

South Africa: Has a number of gauges with records starting in the mid-1950s. However, only a partially successful upgrade programme from float to acoustic gauges in the 1990s led to an interruption in the supply of good quality data. Several scientists attended the 1998 training course at the University of Cape Town, of which Prof. Geoff Brundrit is the South African GLOSS National Contact and Regional Contact for southern Africa.

Prior to 1999, the South African Hydrographic Office operated the Namibian- gauges at Walvis Bay and Luderitz. However, they have since been transferred to the Namibian Ministry of Agriculture with plans for modernization in place. One scientist attended the Cape Town 1998 training course.

Djibouti: At the Jeddah GLOSS course in 2000, the gauge at Djibouti was claimed to be operational but no recent data are flowing to data banks, since there are problems with hardware.

An effective gauge there would be an ideal complement to Aden (Yemen), which is installing new gauges. One specialist attended the Jeddah GLOSS training course in 2000.

Indian Ocean Islands: Mauritius has recent data from Port Louis and Rodrigues. Seychelles has recent data from Pt. La Rue. Mauritius scientists have attended several GLOSS training courses.

Sudan: Latest data are from 1994 when the Port Sudan gauge expired. Plans are in place for new systems. One specialist attended the Jeddah GLOSS training course in 2000.

Somalia: A Fisher and Porter (float-type) tide gauge was installed in Mogadishu in 1988. There has been no consistency in submission of information to data centres. A Leopold Steven float gauge was installed at Kismayu in 1988 but is unlikely to be operational. As soon as the situation in Somalia clears, attempts should be made to re-establish contact and find out the state of the Mogadishu station. Hafun station has not yet been installed.

Caribbean Planning for Adaptation to Global Climate Change (CPACC) Sea level/Climate change Monitoring Network

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Introduction

The Caribbean Planning for Adaptation to Global Climate Change (CPACC) project is a four-year project, which originated from a request made to the Organisation of American States (OAS) by the CARICOM countries at the Global Conference on Sustainable Development of Small Island Developing States (SIDS, 1994) for assistance with research on the potential impacts of climate change for the CARICOM region. The project became effective in April 1997 with the approval of the World Bank through a 6.7-million-dollar grant from the Global Environment Facility (GEF). The OAS was the executing agency, with regional and local management through a Regional Project Implementing Unit (RPIU) in association with the UWI Center for Environment and Development (UWICED), and the CARICOM Secretariat as chair for the activities of the participating countries (PAC).

The overall objective of the project is to support Caribbean countries in preparing to cope with the adverse effects of global climate change, particularly sea level rise, in coastal areas through vulnerability assessment, adaptation planning, and capacity-building. To achieve this aim the project took a regional approach involving the co-operative efforts of twelve CARICOM countries, through the support and participation of a number of regional institutions. The various components of the project were executed through national pilot demonstrations and regional training and technology transfer. This approach aimed to strengthen regional capability, both institutional and human resources, for monitoring and analyzing climate change and sea level dynamics and trends, through the identification of socio-economic, environmental and geographic areas that are particularly vulnerable. The ultimate objective is to facilitate the development of an integrated management and planning framework for cost-effective policy options for response and long-term adaptation programmes for coastal and marine areas.

Project scope and components

The overall project involved nine components executed as pilot projects in a number of countries or comprehensively through all the countries.

- Design and establishment of a sea level/climate monitoring system (all countries);
- Establishment of data bases and information systems (all countries);
- Inventory of coastal resources and uses (all countries);
- Formulation of policy framework for integrated coastal and marine management (all countries);
- Coral-reef monitoring for impacts of climate change (Bahamas, Belize, and Jamaica);
- Coastal vulnerability and risk assessment (Barbados, Grenada, and Guyana);
- Economic valuation of coastal and marine resources (Dominica, St. Lucia, and Trinidad and Tobago);

- Formulation of economic/regulatory proposals (Antigua and Barbuda, St. Kitts and Nevis);
- Greenhouse gas inventory/vulnerability of agriculture and water resource sectors (St. Vincent and the Grenadines).

Research executed in the areas outlined by these components aimed to provide valuable information with respect to marine and land-based biodiversity, the physical and coastal characteristics of each island and to provide inputs for future coastal zone management. In addition information on the present and historical geomorphology can be gleaned and changes in sea level and potential sea level rise can be assessed. The focus of this report is to assess the current status, limitations, and key issues in the operational performance of component 1 of the project, i.e. The CPACC Sea Level/Climate-Monitoring Station Network. In addition, an evaluation of the problems associated with the operational performance of the network is undertaken and a number of recommendations identified based on operational experience of the network.

Operational aspects of component 1

Eighteen sea level/climate-monitoring stations were installed in the twelve participating CARICOM countries in late 1998 and early 1999 (see Table 1. for details of the station installation and data availability). These stations were designed to collect data for seven parameters: sea level, sea surface temperature, air temperature, barometric pressure, relative humidity, wind and rainfall. Data collection is executed at 6-minute intervals for all sea level data and at 15-minute intervals for the remaining parameters (see Table 2). Data obtained from the stations are transmitted automatically via the GOES satellite system through a 1-minute satellite window every 3 hours to the CPACC Regional Archiving Centre (RAC) at the Department of Surveying and Land Information, Faculty of Engineering, University of the West Indies, St Augustine, Trinidad.

Table 1. CPACC Sea Level/Climate-Monitoring Station Network: distribution of stations.

Antigua (1)	Dominica (1)	St Kitts and Nevis (1)
Bahamas (3)	Grenada (1)	St Lucia (1)
Barbados (1)	Guyana (3)	St Vincent (1)
Belize (1)	Jamaica (2)	Trinidad and Tobago (3)

Table 2. CPACC Sea Level/Climate-Monitoring Station Network: data-collection interval.

Parameters Observed	**Measuring Interval (Min)**
Sea Level	1.6
Air Temperature	15
Barometric Pressure	15
Relative Humidity	15
Rainfall	15
Sea Surface Temperature	15
Wind	15

The RAC was established in 2000 to house the satellite downlink, and initially to perform data archiving for the sea level and sea surface temperature data. Due to institutional difficulties, the role of the RAC was expanded to include data collection for all sensors at the respective stations, daily QA/QC on the incoming data and monitoring of the station transmissions/operations, and the identification for the Caribbean Institute of Meteorology and Hydrology (CIMH)/Regional Network Co-ordinator (RNC) for their action, those stations showing operational or communication problems (missing transmissions, out-of-range values, data discontinuity) and thus threatening the network. The CIMH was given the role of Regional Network Co-ordinator (RNC), with the responsibility for repairs, maintenance and the issuing of spares to the individual countries through a local meteorological officer, and the execution of QA/QC of the meteorological data. This portfolio involves initiating problem-resolution procedures, determining whether problems are due to the communication process or sensor malfunction. Steps for corrective action are then to be communicated to the relevant local National Agency/Meteorological Office for problem resolution and issuing of spares as required. To facilitate this operation, a trust fund of US$50,000 was vested with the CIMH. This arrangement has however not functioned very effectively. While monthly reports are prepared by the RAC and distributed to the relevant organizations and the local meteorological offices outlining problems associated with the data collection, little action is taken.

Training

Training was provided with the support of the OAS in a number of areas. The CIMH/RNC representative received one week's training on the operational maintenance of the stations and the RAC Co-ordinator received one week's training on the operations of the satellite downlink stations and transmission extraction at the instrumentation vendors in Chantilly, Virginia. In addition the RAC Co-ordinator received one week's training on the analysis and archiving of the sea level data at the University of Hawaii Sea Level Center, Hawaii. In an effort to improve the maintenance capabilities of the countries involved, the RAC suggested that the meteorological officers involved receive additional training. Twelve local meteorological officers received one week's training from a representative of the instrumentation vendor in problem identification and corrective maintenance. Five local technicians received one week's training in the installation of the GPS time modules and more detailed problem identification and maintenance.

Current status

Initially, 18 stations were installed in the CPACC network; as of November 2003, only four stations are functional. In addition, since the commission of the network, stations have experienced various levels of success with respect to sea level observations. Table 3 shows the productivity of each station for each operational year as it relates to the sea level data obtained (under each percentage are the number of months the station was operational). In 2000 the archive held at the instrument vendors in Chantilly, Virginia, experienced a crash and all the data for the latter part of 1999 were lost. In addition, data were similarly lost for December 2000 to June 2001 and the RAC.

Key issues

A number of factors have contributed to the current state of the network. These factors range from environmental to technical, incorporating a number of human-resource issues.

Environmental impact

The Caribbean region is prone to seasonal storms and hurricanes. These adverse weather conditions have resulted in damage to the climate-observation equipment in a number of countries. In February 2002, the Belize City station was destroyed when it was struck by lightening during the passage of hurricane Lenny. The station at Great Inagua was swept out to sea as a result of storm surges in November 1999. The stations at Roseau and Basseterre were dismantled as a precautionary measure prior to hurricane Lenny. These stations have however not been recommissioned successfully since being taken down, owing to limited expertise in the reinstallation process. While transmissions were received from Roseau after the reinstallation, all the sensor values were out of range. In the case of Basseterre since its reinstallation, no transmissions have been received at the base station. In addition to damage inflicted by adverse weather conditions, damage inflicted by human beings is also a major concern. In 2000, the station in Bridgetown, Barbados, was struck by a cruise ship. The process to seek reparations for the reconstruction of the station required more than two years and while some settlement has been made, the station has yet to be reinstalled. In September 2003 the station at Charlotteville, Tobago, was vandalized and is currently awaiting replacement parts. The station at Port of Spain, Trinidad, is vandalized regularly and has only functioned intermittently throughout its entire life cycle. These problems are due in part to the fact that these stations are located in ports where there can be considerable volumes of unregulated traffic of people. The station at Guayaguayare, Trinidad, was dismantled in March 2002, owing to construction work to be executed at the port. The station has still to be reinstalled. º

Table 3. CPACC Sea Level/Climate-Monitoring Network: operational status and productivity (1997–2003) as of November 2003.

Location Lat./Long.	**1998 %**	**1999 %**	**2000 %**	**2001 %**	**2002 %**	**2003 %**	**Series Length**	**Current Status and Remarks**
Parham, Antigua N 17º 09'30"; W 61º 47' 20"	Not installed	9 (4 mts)	No data	0.8 (3 mts)	0.02 (1 mts)	Computation incomplete	Intermittent	Not transmitting
Great Inagua, Bahamas N 21º 03' 07"; W 73º 38' 47"	0.6 (2 mts)	0	No data	0	0	Computation incomplete	2 mts	Not transmitting data
Nassau, Bahamas N 25º 05' 10"; W 77º 22' 06"	Not installed	26 (6 mts)	No data	23 (5 mts)	19 (6 mts)	Computation incomplete	3 years	Operational
Lee Stocking Island, Bahamas N 23º 46' 24"; W 76º 06' 20"	16 (4 mts)	30 (6 mts)	No data	16 (6 mts)	50 (12 mts)	Computation incomplete	4 years	Operational
Bridgetown, Barbados N 13º 06' 06"; W 59º 37' 42"	Not installed	5 (3 mts)	No data	NT	0	Computation incomplete	1 year	Out of service
Belize City, Belize N 17º 28' 51"; W 88º 12' 08"	17 (4 mts)	23 (6 mts)	No data	NT	0	Computation incomplete	1 year	Out of Service
Roseau, Dominica N 15º 18' 20"; W 61º 23' 42"	9 (2 mts)	28 (6 mts)	No data	1.5 (5 mts)	Bad	Computation incomplete	3 years	Out of service
Parika, Guyana N 06º 50' 48"; W 58º 23' 06"	Not installed	9 (4 mts)	No data	5 (1 mts)	0	Computation incomplete	2 years	Out of service

Location Lat./Long.	**1998 %**	**1999 %**	**2000 %**	**2001 %**	**2002 %**	**2003 %**	**Series Length**	**Current Status and Remarks**
Rosignol, Guyana N 06º 18' 15"; W 57º 30' 45"	7 (2 mts)	18 (6 mts)	No data	28 (6 mts)	22 (7 mts)	Computation incomplete	4 years	Operational
Prickley Bay, Grenada N 12º 00' 20"; W 61º 45' 56"	16/bad (4 mts)	28/bad (6 mts)	No data	NT	0	Computation incomplete	2 years	Not transmitting
Discovery Bay, Jamaica N 18º 28' 06"; W 77º 25' 00"	7 (4 mts)	29 (6 mts)	No data	23 (6 mts)	4 (6 mts)	Computation incomplete	31/2 years	Intermittent transmissions
Kingston, Jamaica N 17º 56' 54"; W 76º 50' 42"	8 (2 mts)	28 (6 mts)	No data	10 (3 mts)	35 (10 mts)	Computation incomplete	4 years	Operational
Basseterre, St. Kitts N 17º 17' 24"; W 62º 42' 36"	Not installed	0	No data	3 (4 mts)	0	Computation incomplete	Intermittent	Not transmitting
Castries, St. Lucia N 14º 01' 20"; W 61º 00' 06"	7 (2 mts)	26 (6 mts)	No data	25 (5 mts)	0	Computation incomplete	2 years	Out of service
Port of Spain, Trinidad N 10º 38' 56"/W 61º 30' 51"	12 (4mts)	8 (2mts)	No data	11 (6mts)	2 (12mts)	Computation Incomplete	Intermittent	Intermittent Transmissions
Guayaguayare, Trinidad N 10º 08' 20"/W 61º 00' 06"	8 (2mts)	0.5 (1mt)	No data	30 (6mts)	8 (3mts)	Computation Incomplete	3yrs	Out of Service
Charlotteville, Tobago N 11º 19' 25"/W 60º 32' 55"	16 (4mts)	17 (4mts)	No data	42 (6mts)	81 (12mts)	Computation Incomplete	4yrs	Not Transmitting
Kingstown, St. Vincent N 13º 07' 50" – W 61º 11' 55"	Not Installed	10 (5mts)	No data	36 (6mts)	88 (12mts)	Computation Incomplete	4yrs	Out of Service

Technical Impact

Each station has a designated 1-minute satellite window to transmit the data collected over a 3-hour period. The transmission time at each station is determined by the station clock time. Often this clock loses time due to instrument wear and limited maintenance. Inaccurate clock settings result in data being transmitted outside of the station's designated satellite window. If the data are transmitted during the designated period of another station, one station cancels out the other station's data, thus resulting in transmissions not reaching the downlink base station and in data loss. Also, malfunctioning sensors can produce no data or erroneous data. Occasionally the length of such erroneous streams can exceed the satellite window capacity. Due to limited expertise the local technicians have not displayed their confidence in changing the sensors that need changing. In addition, since the transition of the satellite downlink station from the vendor site in Chantilly, Virginia, to the RAC in St Augustine, Trinidad, no transmissions were received for Prickley Bay, Grenada, or Basseterre, St Kitts, both at the local RAC site and at the mirror site at the University of Hawaii Sea Level Center (UHSLC). Each station has a prescribed station ID by which it is recognized at the GOES reception sites. It has not been determined whether these stations have been prescribed with the correct ID.

Achievement of aims

One of the original aims of Component 1 was to facilitate the collection of sea level/climate-monitoring data to make research on and modeling of sea level processes possible. Modeling the different factors involved in sea level and tides in each country or the Caribbean at large requires sea level observations of various lengths. For example, determination of tidal species and constituents, which facilitate tidal predictions, requires fewer data than estimates of relative or absolute sea level.

Constituents/species and tidal predictions

While the tidal species for each of these CPACC countries have been identified over the years by such studies as those of Kjerfve (1981), for a number of these countries tidal constituents and useful tidal predictions are not available, owing to lack of data. Table 4 shows the data requirements to facilitate the assessment of various aspects of the tidal regimes at a given station.

Table 4. Analytical capabilities with various lengths of tidal data.

Length of Data Observations	Analytical Capabilities
1 day	Tidal Species
15 days	M2 and S2 construction and destruction
30 days	Group level, 14 constituents
1 year	Identification of harmonic constants/tidal predictions
4.6 years	Impact of M2, S2 and N2 all in phase
10 years	Stability of harmonic constants and error bounds
18.6 years	Estimates of RSL and ASL change

Relative sea level (RSL) and mean sea level (MSL)

To assess relative sea level (RSL) change, hourly tidal data for a duration of ≥18.6 years is needed to model the full tidal cycle inclusive of the nodal regression as the node moves backwards and forwards from east to west. Such an analysis does not consider the land movement at the location of the tide gauge referencing the observations to the local country datum. It should be noted that sea level is point-specific, rising in some areas and falling in others. Mean sea level (MSL) is also another useful value to be determined for a station. MSL values may vary however. The value obtained for a specific period of observations will be different from that obtained for another period of observations.

Absolute sea level (ASL) rise

An analysis of absolute sea level (ASL) change requires hourly tidal data in conjunction with continuous GPS observations in close proximity to the tidal station. Tidal observations need to be for ≥18.6 years in order to model the cycle. The heights determined to the zero of the tide gauge are referenced to the geoid by GPS observations, so heights can now be compared globally based on approximately the same reference system. Problems in this area are due in part to the fact that heights are referenced to a global datum which experiences seasonal changes (geoid goes through seasonal changes due to hydrological, oceanic and atmospheric loading affecting precise estimates at the millimetric level), and the reference-frame construction is still in a developmental stage fine tuning various equations and has not been resolved.

Episodic events

Episodic events, such as tsunamis, resulting from earthquakes and underwater volcanic eruptions require a time interval of ≤6 minutes for the duration of the event. A more accurate time scale is required to model the changes in a real-time mode.

Current capabilities

Based on the data obtained for each of the stations, only preliminary tidal analysis and estimates of land movement could be completed (See Table 5).

Table 5. CPACC Sea Level/Climate-Monitoring Station Network: tidal regime estimates.

Country	Station	**Tidal Species**	**Estimated Tidal Range (m)**	**Country**	Station	**Tidal Species**	**Estimated Tidal Range (m)**
Antigua	Parham	D	0.38*	Grenada	Prickley Bay	No good data obtained	
Bahamas	Great Inagua	SD	0.83*	Jamaica	Discovery Bay	MSD	0.62
	Lee Stocking Is.	SD	1.13		Kingston	MSD	0.40
	Nassau	SD	1.3	St Kitts	Basseterre	Insufficient data obtained	
Barbados	Bridgetown	SD	0.87*	St Lucia	Castries	MSD	0.64
Belize	Belize City	SD	0.50	St Vincent	Kingstown	MSD	0.67
Dominica	Roseau	MD	0.47	Trinidad & Tobago	Charlotteville	SD	1.03
Guyana	Rosignol	SD	2.98		Guayaguayare	SD	1.56
	Parika	SD	2.09		Port of Spain	SD	1.28

The CPACC project executed a number of campaign-type GPS observations consisting optimally of five days of continuous observations at each of the 18 sites in 1998 and 2000. Unfortunately results from these campaigns have only been released for eight stations for the sessions outlined in Table 6. A number of requests were made to the personnel who executed the surveys to provide the information from the campaigns to the project, but the data have not been forthcoming.

A preliminary analysis was executed on the observations executed at the Port of Spain, Trinidad station to determine if there is any evidence of change. Initially the data shows a change in height at Port of Spain of 2cm over the 2 years and 4 month observations (approx. 8mm/yr). But these height differences obtained are still within the noise level of the observations due to the limited nature of the observations. The analysis also took into account movement (velocities) of the base station.

Table 6. CPACC Sea Level/Climate-Monitoring Station Network: GPS campaign observations.

Country	Station	**Year of Observations**	**Heights Determined (m)**
Bahamas	Great Inagua	1998; 2000	-36.678
	Lee Stocking Island	1998; 2000	-29.724
	Nassau	1998	-31.036
Belize	Belize City	1998	-3.664
Grenada	Prickley Bay	1998; 2000	-34.234
Trinidad and Tobago	Charlotteville	1998; ?	-41.327
	Guayaguayare	1998; ?	-40.843
	Port of Spain	1998; 2001	-39.971

Conclusion

There are two key considerations:

1) Essentially lost data transmissions result in data gaps. These data gaps influence the value of the data collected, since the gaps impact on the various levels of analysis that can be applied (see Table 4). Current data-collection achievements only facilitate the modeling of tides to the group level for most of the stations. Only at two or three of the stations can the data currently collected facilitate the determination of harmonic constants and the development of tidal predictions;

2) Due to the nature of the Caribbean, with its numerous islands and remote locations, access to some stations presents a challenge in terms of financial and human resources. The economic situation in a number of these countries and the resulting limited financial resources pose a major impediment to regular maintenance at remote sites, thus hindering continuous operation of the stations. A number of the countries have limited technical expertise; as a result only limited corrective maintenance is executed. The absence of GPS cards at the stations to facilitate synchronization of the stations contributes to the need for regular station visits to adjust the station clocks. Also, from an administrative standpoint, placing the responsibility for repairs of the stations outside the portfolio of the agency responsible for archiving and disseminating the data collected puts the collection agency in a precarious position. Basically the agency is not in control of its work environment and cannot be held responsible for the shortcomings of the data set and there is not a clear line of accountability.

Recommendations

Problems with data continuity still plague the network and further complications in getting the network fully operational have been compounded by the delay in getting the Mainstream Adaptation to Climate Change (MACC) phase of the project on-stream. Several corrective measures have been identified, and are to be undertaken in the MACC phase of the project. One involves the installation of GPS time modules in each station to eliminate clock drift, since data transmission outside of designated satellite windows has been a major problem for data continuity. Financial support and technical expertise are needed to get all the stations back on-line and supply local training. Experience from similar networks has shown that technical expertise is needed to ensure that effective corrective measures are taken for optimum networks. Also, commitment from each country to provide the dedicated support of their local officers is also needed. These measures require financial input form the MACC phase of the project. In addition, where funds are available, consideration should be given to the installation of continuous GPS receivers at key locations in the Caribbean. The administration of the data collection and maintenance of the station needs to be regulated, preferably to have one agency responsible for both operations. Also, additional programming code needs to be developed to aid data retrieval and the separation of the sea level data archiving and analysis form the resources required to handle the archiving of the meteorological data. Based on the users' needs, these data sets are stored in different formats. Sea level data are stored by element and meteorological data are stored by observation. This presents a number of difficulties, since the sensors at each station collect the data by element. The meteorological data collected then have to be reformatted by the application of code to provide the data in the format suitable for most of the meteorological analysis software. It is hoped that an injection of financial and human resources from the MACC phase of the project will help alleviate the problems that are currently plaguing the network.

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Kjerfve, B. (1981) Tides of the Caribbean. Journal of Geophysical Research 86(C5):4243-4247.

Spanish Ports Authority Sea Level Software

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During the last few years, automatic processes have been developed at the Spanish Ports Authority (Puertos del Estado) for the quality control and processing of near-real time and historical data. In this paper, the specific software is described for analyzing sea level data provided by the REDMAR tide gauge network; the software allows loading in the Authority's data base, distribution via Internet and assimilation in a numerical model to be effected in near-real time (http://www.puertos.es).

Introduction

The increasing quantity of data generated by the marine measurement networks of Puertos del Estado requires computer applications that allow an efficient exploitation and the availability of data in near-real time. On the other hand, automation is needed for the periodic generation of reports (normally annually) which can also be made available in the web page.

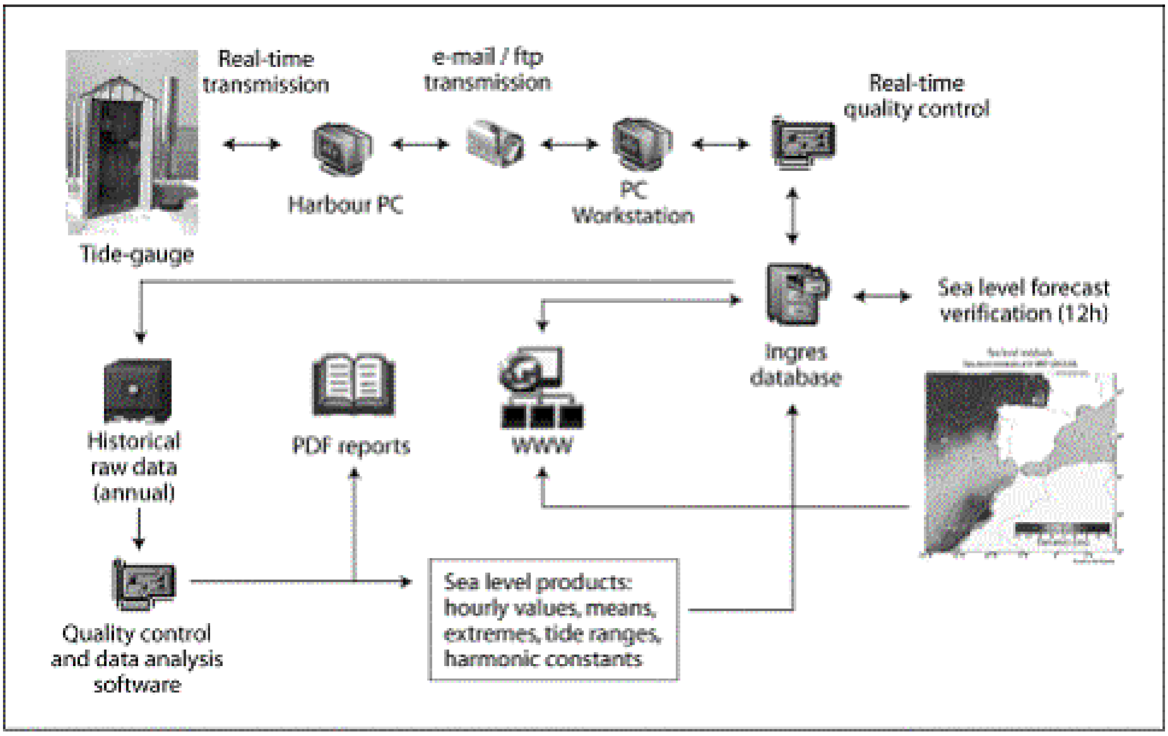


Figure 1. Scheme of the flow of sea level data and data processing from a tide gauge station to the web page of Puertos del Estado.

The REDMAR network (Pérez and Rodríguez, 2004) has been in operation since 1992 and consists of 21 tide gauges around the Spanish coast, including the Balearic and Canary Islands. Figure 1 shows a scheme of the flow of data from a particular tide gauge station and the different steps in the processing: every hour, every 12 hours and historical series (annual). Raw sea level 5-min data are received automatically at a Unix workstation in the Puertos del Estado, via e-mail, ftp or modem, from which different automatic procedures process and distribute the data.

Near-real time data processing

Each hour raw 5-min data are received automatically from each tide gauge and after a preliminary quality control are stored in the Ingres Data Base and shown on the web page. This preliminary check controls the following: detection of spikes by the method of eliminating the value that differs from the previous one by more than a predefined amount, detection of constant sea level heights during more than 15 minutes and detection of values clearly outside the normal range. After this process, data are stored with different quality control flags, depending on the problem encountered, and represented on the web page with different colours, depending on the value of the corresponding flag.

Sea level forecast validation and assimilation (every 12 hours)

Nivmar is a storm surge forecasting system based on the application of the HAMSOM circulation model to the tide gauge data. It is run every 12 hours and provides a forecast of the meteorological residual (Alvarez Fanjul et al., 2001) for the next 48 hours.

Apart from the preliminary near-real time quality check, every 12 hours another automatic process retrieves the last month of sea level data from the Ingres Data Base in order to prepare them for the Nivmar system. Data are processed in the following steps:

- 5-min data quality control: this is a more elaborate quality control for detection of spikes, which will be explained later;
- Computation of hourly sea level values by applying the Cartwright filter (54 points from 5-min to 1 hour) (Pugh, 1987);
- Computation of hourly meteorological residuals for the last month of data, by subtracting the astronomical tide.

These residuals are used to validate, every 12 hours, the forecast provided by the storm-surge model (which, since it is forced only by pressure and wind, provides only the meteorological component of sea level). At the same time, the difference between the mean of the observed residuals and the predicted ones is obtained to improve the quality of future predictions, as a very simple and effective assimilation scheme.

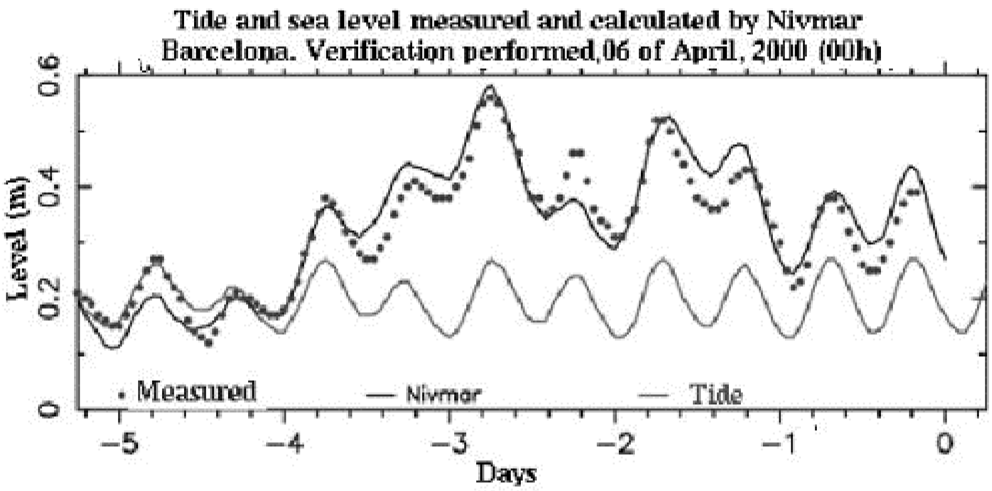


Figure 2. Example of validation of the storm surge forecasting system Nivmar with the tide gauge data for the Barcelona tide gauge. The value of 0 on the *x*-axis corresponds to the initial time of prediction, and comparison is made with the predictions of previous days.

At this stage a more detailed algorithm is applied for the detection of spikes, the most frequent type of error in acoustic sensors. It consists of: (a) fitting a spline to a moving window on the 5-min data; the size of the window and the degree of the spline depend on the station; (b) computation of 5-min meteorological residuals; (c) step (a) applied again to the meteorological residuals for the detection of less obvious spikes.

With this algorithm it is guaranteed that no wrong value is employed in the storm surge forecast validation.

Historical data processing

A set of Unix procedures has also been developed for the historical (normally annually) sea level data processing, with the principal characteristic of providing all interesting sea level products and final pdf reports by just running one instruction. This is the scheme of the package:

Input: 5-min data from N stations and from a particular year, and configuration files;

Process: A Unix procedure with the year as an argument: proc.sealevel year;

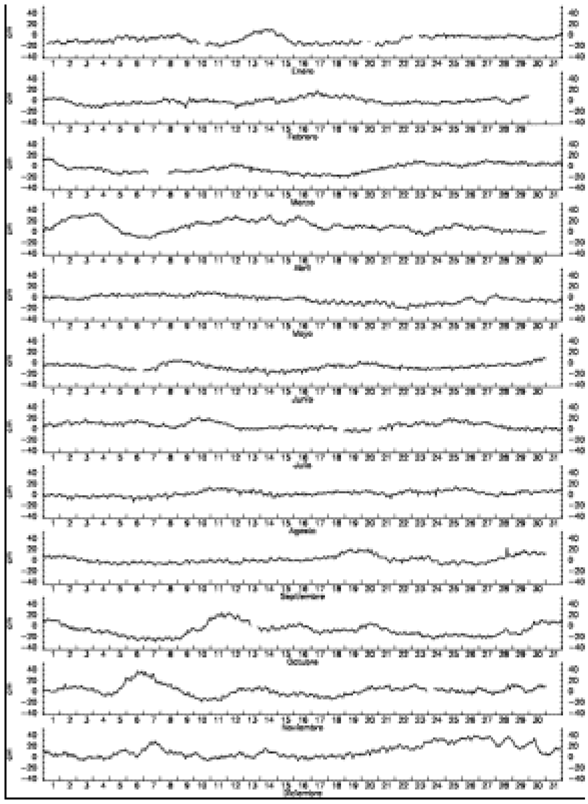
Output: Derived data: harmonic constants, meteorological residuals, extremes (daily, monthly and annual), means (daily, monthly and annual), histograms of hourly sea levels and residuals, etc, pdf report with plots and tables and files prepared for loading into the historical Ingres Data Base.

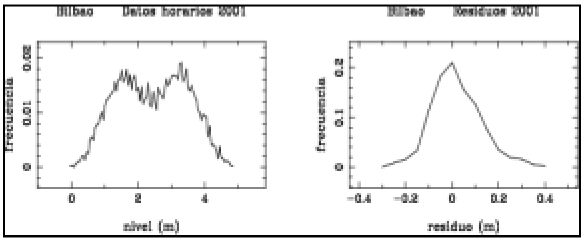
The configuration files include all the station dependent information, such as: latitude, longitude, parameters for the spike-detection algorithm, database codes, names for plots and tables, etc. The software employed for the harmonic analysis and prediction is the one developed by Foreman (1977). The formats used up to now are the ones employed by the Hawaii Sea Level Center software (Caldwell and Kilonsky, 1992), as well as the programme for computation of daily and monthly means. This could be changed in order to adopt ESEAS standards.

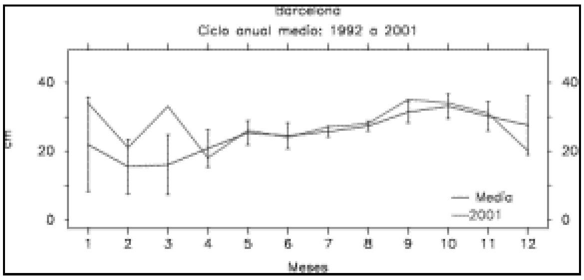
The principal procedure, “proc.sealevel”, consists of calling on other basic procedures that can be run independently if necessary; these basic procedures are: proc.qc1 (quality control), proc.plotqc (plots of flagged data), proc.analysis (harmonic analysis, prediction and residual computation), proc.means (computation of mean sea levels), proc.extremes, proc.tideinfo (preparation of table of harmonics and histograms), proc.tabextremes (update of historical extremes table for each station), proc.loadbase (preparation of data to be included in the Data Base) and proc.report (production of the final LaTeX and pdf annual report).

As stated earlier, all the derived information is finally stored in the Ingres Data Base and the reports included on the web page. Figure 3 gives an example of different plots available in this report.

Figure 3. *(next page)* Examples of different plots included in the annual report: meteorological residuals (left), histograms of hourly and residuals, and mean sea level cycle (right). ►







Future work

At this moment work is being done to include other tools that will improve the data processing, such as the employment of Empirical Orthogonal Functions and comparisons between adjacent stations. On the other hand, an adaptation will be made to standards decided within the project ESEAS-RI (European Sea Level Service, Research Infrastructure), both concerning data formats and dataprocessing algorithms.

References

Caldwell, P.C., and Kilonsky, B.J. (1992) Data processing and quality control at the TOGA Sea Level Center. Joint IAPSO-IOC Workshop on Sea Level Measurements and Quality Control, Paris, 12-13 October, 1992. IOC Workshop Report No. 81, UNESCO. pp. 122-135.

Alvarez Fanjul, E., Pérez, B., Rodríguez, I. (2001) Nivmar: a storm-surge forecasting system for Spanish waters. Scientia Marina 65:145-154.

Foreman, F.G.G. (1977) Manual for tidal heights analysis and predictions. Institute of Ocean Sciences, Patricia Bay. Pacific Marine Report 77(10):101.

Pérez, B. and Rodríguez, I. (1994) Redmar. Spanish Harbours tidal gauges network. Processing of tidal data. Clima Marítimo Report 57.

Pugh, D.T. (1987) Tides, surges and mean sea level. Wiley, 472 pp.

Standard Routines for Quality Control of Tide Gauge Observations in the European Sea Level Service (ESEAS)

María Jesús García (IEO) and Lesley Rickards (BODC)

Introduction

The European sea level data set comprises more than 1,000 years of observation held in more than 50 data archives. Although hampered by national diversity in operation, uneven technological developments, non-standardized products, different levels of quality assurance, ESEAS aims to enhance the value of sea level data sets by setting up standard routines for operational quality control, co-ordinated with MedGLOSS network for standardization of data access and data quality. The ESEAS standards are described based on the experience of:

National tide gauge networks;

WOCE sea level data assembly centres;

IOC GLOSS programme;

IOC Manuals and Guides No. 14, Vol. I, II & III;

IOC Workshop Report No. 81 (1992);

EOSS position paper;

Work of ESEAS TEC.

Data and information

Apart from the sea level data, essential additional information is needed not only for archiving and quality control, but is essential when the data are exchanged and/or integrated into a regional or global data set. The following information should accompany the data in order to have a fully effective sea level data bank:

Agency: country and organization, originator identifiers, start and end dates

Station: geographical position and measurement interval, instrumentation (manufacture, calibration methods, history, etc), site (location, benchmarks, datum relationship and history)

Data: processing procedures

QC flags

To keep all the values and the not deleted erroneous or suspicious values, criteria for flagging data are described. There are many schemes used to flag data quality. The criteria for ESEAS are being described according to the GETADE (Group of Experts on Technical Aspects of Data Exchange):

0 = no QC performed;
1 = QC performed; element correct;
2 = QC performed, element inconsistent with statistics;
3 = QC performed, element doubtful (= questionable);
4 = QC performed, element bad (= erroneous = wrong);
5= value was changed (interpolated or moved) after QC;
6-8 reserved;
9 missing values.

QC levels

The sea level data can be used for different purposes. The QC requirement of the data depends on the purposes. For fast-delivery mode, basic QC for spikes, gaps and timing errors is required. For the delayed mode, a complete QC is required: TA (Tidal Analysis. inspection of residual), CN (Comparisons with neighbouring tide gauges), CM (Comparisons with models or predictions).

Control checks

QC0: metadata: apply to the header;
QC data-checks: apply to the height values;
Date and time in consecutive order;
Measurement system stability and calibration practices;
Broad range;
Spikes;
Shift and drift time;
QC time-series: apply to the means values;
Land stability: shift and drift datum. Needs to be implemented;
Inhomogeneities, EOF, trend test, correlation, etc.;
QC visualization: data with the corresponding flag in colour.

Most of the above quality checks are well known. Some methods are described below:

Spikes:
New Method*:* Fitting of a spline to a moving window of data;
Action: (a) flag = 5 on values that differ by more than N sigmas;
(b) Computation of the meteorological residual and application of fitting method to the residual data.

Inhomogeneities:
Objective*:* Find the inhomogeneity in the climate series to detect a probable datum shift.
Gives the break values. Can be applied to the station or to the difference between two stations.
Method:

$$T_v = v \cdot (\overline{z_1})^2 + (n - v) \cdot (\overline{z_2})^2$$

The jump is obtained by:

$$\Delta = \sigma(\overline{z_{2m}} - \overline{z_{1m}})$$

EOF: Empirical orthogonal function.
Objective: estimate the variances and trends.
Can be used to detect possible errors
Method: calculate the common mode; commonly, it represents the maximal variance.
Reconstruction of the common mode at each station.
Calculate the linear regression for each ζi

Mann-Kendall test for trends
Objective: Study the trend friability. Apply to the original and retrograde series.

Case 1: $\alpha 0=0.2781$, $\alpha 1=0.7219 > \alpha 0$ *(no reliable trend)*
Case 2: $\alpha 0=1.0000$, $\alpha 1=1.0062\ e\text{-}9 < \alpha 0$ *(reliable trend)*

Cross-correlation:
Objectives: Find the lag of maximum correlation between two series and the coefficient Correlation between series. Can be used to detect error and in filling gaps.

Exchange format

The exchange format is built on WOCE, UHSLC, GETADE guidelines. A flexible format is described by the tables or file structures:

(1) Header line with codes
(2) Data

Heights at any sampling and daily mean: date, hour, height, qcflag;
Monthly and annual mean: date, hour, mean, nd, qcflag;
Tide ranges: date, time, high value, date, time, low value, tide range, qcflag;
Extremes: date, time, extreme value, codes, date, time, extreme value, code, qcflag;
Where: date: yyyymmdd, hour: hhmmss, height (metres), codes: (1= max, 0= min).

Standard codes

Station reference (PSMSL): http://www.pol.ac.uk/psmsl/http://www.pol.ac.uk/psmsl
Data dictionary (GF3): http://www.ices.dk
Sea level glossary: http://www.pol.ac.uk/psmsl/
Marine xml dictionary (in near future): http://ioc.unesco.org/marinexml

Available software

Nowadays, there exist software packages developed by different institutions, such as UHSLC, TASK2000, ETDEVA, PE (Spain) and others, to perform the sea level QC, but it will be very useful to develop a complete software application with all these specifications.

ANNEX I

PROGRAMME OF THE WORKSHOP

14 OCTOBER 2003

0900-0915 Opening of the Workshop and Welcome to IOC (Colin Summerhayes)
Local Arrangements (Thorkild Aarup)
Introduction to the Workshop Agenda (Philip Woodworth)

PART I: TIDE GAUGE TECHNOLOGIES

Acoustic gauges:
09115-1015 SEAFRAME/NGWLMS gauges (Wolfgang Scherer)
Experience with SRD gauges (Begoña Perez)
Experience with SRD gauges and why we swapped to radar gauges (Ruth Farre)

Pressure gauges:
Pressure transducer gauges (Dov Rosen)

1035-1055 Break

1055-1300 Pneumatic sea level gauges (David Pugh)
South Atlantic "B" type gauges (Simon Holgate)
Pressure gauge experiments in India (Antony Joseph)
Experience in Chile with Handar pressure gauges (Juan Fierro)

Radar gauges:
Comparative test of a bubbler and Ott Kalesto radar gauge at Liverpool (Philip Woodworth)

1300-1400 Lunch

1400-1540 Comments on Van de Casteele tests in the Brest and Le Conquet tide gauge stations (Ronan Le Roy)
Test and evaluation of the Miros SM-094 sensor (Mark Bushnell)
Experience with the Vega radar gauge on a buoy (Lutz Eberlein and Gunter Liebsch)

Float gauges:
Cost effective ways of providing digital data from float gauges (Daniel Hareide)

Digilevel gauge:
A Digilevel gauge in Brazil (Marcelo Fricks Cavalcante)

1540-1600 Break

Comparison experiments:
1600-1700 Comparisons of several technologies at the Spanish test site (Belén Martín and Begoña Pérez)
Comparisons of gauges in Germany (Christoph Blasi)

Developments in satellite communication: applications to sea level data delivery (David Meldrum)

On-line quality control software:
Display software for habour unit (Dov Rosen)

15 OCTOBER 2003

"Special Needs" statements:

0830-1025 Needs of GLOSS - GLOSS Adequacy Report and need for "plug and play", "turn-key GLOSS packages" comprising gauge, DCP, met station etc. (Thorkild Aarup)
Special needs of "hostile regions" (i.e. polar regions):
The Rosame tide gauge network: Technical aspects and specific constraints (Laurent Testut)
Needs of IALA (Torsten Kruuse/Jillian Carson-Jackson)
IHO requirements for tidal information (Steve Shipman)
Needs of Tsunami Warning System - Gaps and improvement of the Tsunami sea level network in the Pacific Region (F. Schindele)
COOP and GLOSS (Keith Thompson)
JCOMMOPS (in situ Observing Platform Support) Centre in Toulouse (Etienne Charpentier)

1025-1045 Break

Short presentations by invited manufacturers:

1045-1315 OTT Hydrometry (Simon Wills)
Miros SM-094 Range Finder gauge - presentation of sensor, principles of design and associated software. (Rune Gangeskar and Elisabeth Nøst)
RD Instruments Europe (H-L. Kyriakidis)
Aanderaa (Anders Tengberg and Rune Fjellheim)
Discussion on what has been learned: What is best for GLOSS?

1315-1400 Lunch

PART II: GEODETIC DEVELOPMENTS

14.00-1600 Brief Introduction (Richard Bingley)
The ESEAS Data Portal: Principal Considerations (Hans-Peter Plag)
GPS time series and reference frame issues (Zuheir Altamimi)
An inventory of co-located and nearly co-located CGPS stations and status report, October 2003 (Guy Woppelmann)
Developments within IGS TIGA (Tilo Schoene)
Geodetic Developments within ESEAS (Richard Bingley)

1600-1610 Break

1610-1750 Developments with absolute gravity (Trevor Baker and Simon Williams)
Vertical movement and absolute gravity: Brest experiment (Marie-Francoise Lalancette)
Developments with DORIS (Jean-Francois Cretaux and Laurent Soudarin)
Developments in satellite altimetry calibration (ALT) (Gary Mitchum)

Multiple RA calibration over Lake Erie and South Pacific (C.K Shum)

16 OCTOBER 2003

0900-1200 The new Italian tide gauges (Gabriele Nardone)

PART III: QUALITY CONTROL AND DATA CENTRE DEVELOPMENTS

An automatic acquisition/quality control/fast delivery software for real-time follow-up of data coming from a tide gauge network. (Philippe Techine)
JCOMMOPS in situ Observing Platform Support Centre (Etienne Charpentier)
GLOSS fast delivery centre (Mark Merrifield)
GLOSS archive centre and clivar "delayed-mode" sea level data centre at BODC (Elizabeth Bradshaw and Lesley Rickards)
Permanent Service for Mean Sea Level (PSMSL) (Svetlana Jevrejeva/Philip Woodworth)
Report on GLOSS activities in the Western Indian Ocean region (Charles Magori)
Caribbean planning for adaptation to global climate change (CPACC) (Shelley-Ann Jules-Moore)
Southern Ocean Centre and NTF, Australia (Bill Mitchell)
Spanish Ports Authority sea level software (Begoña Perez)
ESEAS project (European Sea Level Service) (Maria-Jesus Garcia)

PART IV: WORKSHOP REPORT DISCUSSION

OFF-LINE EXHIBITS OFFERED

David Pugh: Wave damping for digital systems (poster)
RD Instruments Europe (small booth 3*2 m)
EEC/Aquatrak (small booth 4m square)
Aanderaa (small space)

ANNEX II

LIST OF PARTICIPANTS

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