GLOSS

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1. Context

1.1. French stations committed to GLOSS

There are 15 French tide gauge stations committed to the GLOSS program. Figure 1 highlights the geographical distribution of these stations around the world. We also report on an additional station which is operated in collaboration with French organisms (Sao Tomé). The stations are namely:

Gloss 242	Brest	SHOM (RONIM)
Gloss 205	Marseille	IGN / SHOM (RONIM)
Gloss 123	Nouméa	SHOM / DITTT / IRD (RONIM)
Gloss 142	Nuku Hiva (Marquises)	P.T.W.C. / C.E.A.
Gloss 138	Rikitea (Gambier)	Univ. de Hawaii / C.E.A.
Gloss 140	Papeete (Tahiti)	Univ. de Hawaii / C.E.A.
Gloss 023	Kerguelen	LEGOS / INSU (ROSAME)
Gloss 024	Amsterdam St Paul	LEGOS / INSU (ROSAME)
Gloss 021	Crozet	LEGOS / INSU (ROSAME)
Gloss 131	Dumont D'Urville	LEGOS / INSU (ROSAME)
Gloss 260	Sao Tomé	LEGOS / IRD
Gloss 204	Fort de France (Martinique)	SHOM / MétéoFrance (RONIM)
Gloss 017	Pointe des Galets (La Réunion)	SHOM / DDE
Gloss 202	Iles du Salut (Cayenne)	SHOM / DDE (RONIM)
Gloss 096	Dzaouzi (Mayotte)	---
Gloss 165	Clipperton	---

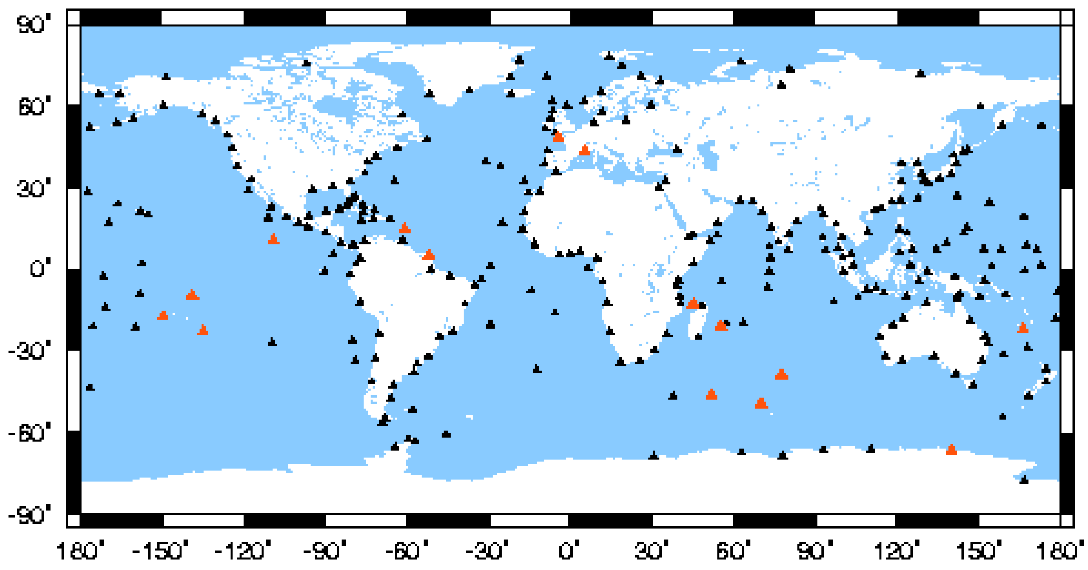

Fig. 1: Geographical distribution of the French stations committed to GLOSS

1.2. Two operational networks: RONIM and ROSAME

There are actually two co-ordinated tide gauge networks in France, that is, networks that are acknowledged and funded to install and maintain tide gauges, to collect their data, as well as to archive, to analyse and to distribute it under certain conditions. These networks are: RONIM, which stands for Réseau d'Observation du NIveau de la Mer, and ROSAME, which stands for Réseau d'Observation Subantarctique et Antarctique du niveau de la MEr. The first is operated by the French hydrographic and oceanographic service (SHOM) and aims primarily at hydrographic applications. The second network is operated by a research laboratory (LEGOS, Toulouse). Further information can be found at the web pages http://www.shom.fr/fr_page/fr_act_oceano/maree/ronim_f.htm for RONIM and at http://www.legos.obs-mip.fr/fr/observations/rosame/ for ROSAME.

In addition to these institutional networks, a multitude of individual agencies perform sea level measurements at a local scale, for instance Direction Départementale de l'Equipement (DDE), Electricité de France (EDF), Institut Géographique National (IGN), Commissariat à l'Energie Atomique (CEA), Ports Autonomes, with no actual means for a tide gauge 'network' infrastructure. This situation is an important rationale for establishing a service like SONEL (see section 3): to federate the various networks and individual observing stations by assembling their data in agreed standards into a unique service (Wöppelmann 2004).

The situation may, however, evolve rapidly by the emergence of local tide gauge networks under the responsibility of local authorities. Plans are discussed within these agencies that become more concerned about sea-level rise and higher frequency of extreme events like storm surges. It is important to anticipate such evolution to ensure the maximum efficiency in existing and future services related to coastal sea level measurements, to get a greater benefit from those through synergy and co-operation (Allain 2005).

An important news to be mentioned here is the expansion of the RONIM network to the overseas in the last few years, hopefully filling the gaps in the initial proposed French stations to GLOSS which were not operational, namely Nouméa (New Caledonia), Fort-de-France (Martinique), and Iles du Salut (Cayenne, French Guyana). Two additional stations are already planned in the Indian Ocean, at La Réunion and at Mayotte. Section 4 provides details station by station for each of the French stations committed to GLOSS.

2. Technical evolutions

2.1. Tide gauge technologies

In the last two decades considerable progress has been made in the modernization of tide gauge networks. This progress originally arose out of research purposes, in particular storm surges and climatic related sea-level changes. Furthermore, more modern observation technologies have become available: traditional mechanical float devices have progressively been replaced by electronic and digital ones which are mainly based either on the measurement of the subsurface pressure, or on the measurement of the time of flight of a pulse, acoustic or radar. In the last few years, radar technology has been given strong consideration for sea level monitoring.

At present, the RONIM tide gauges use two types of sensors: acoustic and radar. The oldest stations use MORS acoustic sensors. They have been used since the early 1990s. Their main problem is their high sensitivity to the temperature gradient between the transducer and the sea surface, which is difficult to correct, specially in large tidal range conditions. This problem is less relevant, yet by no means negligible in the Mediterranean stations, where the tidal range is much smaller than on the Atlantic coast. Keeping up with technological innovations has led SHOM to gradually replace these acoustic tide gauges by radar tide gauges, beginning with the Atlantic harbours. The first radar sensor was installed in Le Havre in October 1998, and currently the majority of the tide gauge stations are radar (20 out of the 26).

The first results of 8-year-long experience at SHOM are detailed in Martin Miguez et al. (in press). The performance of the radar sensors has been assessed using the Van de Casteele test (see section 2.2), which has been revealed to be an efficient method to detect the main deficiencies of the installations and evaluate the data quality. The experience so far shows that radar tide gauges present interesting advantages with regard to ease of operation and that their accuracy is consistent with GLOSS target of 1-cm accuracy in the individual sea level height measurement over long periods (IOC 1997, 2006), provided the installation is correctly performed. Indeed, the operation of radar sensors has also shown that, in addition to the classical stilling well problems, there is a risk of interaction of the protective structure with the radar signal. As the use of a stilling well was required by SHOM, these inconveniences were first successfully avoided by employing stainless steel tubes. Their high price of the steel tubes was, however, a drawback. Currently the SHOM has opted to purchase the Khrone OPTIFLEX

1300C radar model, which sends the signal along a wave guide cable, thus reducing the probabilities of the signal being affected by the tube and improving the accuracy with a very good directivity, but adding an interface in contact with the water.

In this regard it must be said that, unlike other types of tide gauges, radar sensors do not need to be installed within sheltering structures. Radar sensors have proven robust enough to endure harsh weather, showing little sensitivity to the external conditions. Moreover, the stilling well is no longer indispensable to reduce the spurious effect of waves in the tidal signal: due to the radar high sampling frequency, this effect can be eliminated by filtering the data. Finally, the open-air stations are less expensive, both to install and to maintain (less cleaning operations). But, open-air stations have drawbacks too: lack of security in harbours, calibration problems due to rough surface of sea, … SHOM is willing to further investigate these technical issues in the coming years.

2.2. 'In situ' calibration and Tide Gauge performances

To examine and further assess the performance of modern tide gauge measurements, the Van de Casteele test is revisited in Martin Miguez et al. (submitted). The application of the test to different sets of data at different locations in the world under different environmental conditions shows the test as a simple procedure which immediately gives a qualitative and quantitative illustration of the errors involved in the sea level measurement, capable of sensing the presence of a fault whatever tide gauge technology is involved. Developed under the era of mechanical tide gauges, the Van de Casteele test has been erroneously restricted in the collective mind to this type of tide gauge (IOC, 1985). Martin Miguez et al. (submitted) outlines the interest to bring this test back into fashion to examine and further assess the accuracy of modern tide gauge measurements, whether they are acoustic, pressure or radar. The experience with the Van de Casteele test has shown that this test is a very cost-effective option to evaluate the performance of the tide gauges and in particular of the new radar equipment in the French RONIM network (Martin Miguez et al., in press). The findings suggest that even the most recent radar gauges are subject to systematic errors that cannot be neglected depending upon the application. Moreover, the 1-cm accuracy level required by GLOSS for the individual sea-level measurement cannot be evaluated on the sole RMS estimate of the differences between the tide gauge measurement and the standard or reference gauge. In this context, the Van de Casteele test is a simple but helpful tool which immediately gives a qualitative illustration of the errors involved in the sea level measurement. It therefore provides a mean to investigate the accuracy - or the lack of accuracy - of the instrument by detecting systematic errors, which may then be studied and hopefully corrected. However, whereas this procedure has proven capable of sensing the presence of faults whatever tide gauge technology is involved, further work should be undertaken to diagnose their cause. This will obviously require a better understanding of the physics of the measurement techniques, in particular for the radar tide gauges. It should be mentioned that the Van de Casteele test provides with an estimation of the quality of the sea level data as long as the correct performance of the probe used as a reference can be ensured, that is to say, provided the sea conditions are calm so that the manual readings can be made correctly. In conclusion, it is recommended that such quality control experiences are brought back into fashion and are conducted on a regular basis, in particular following the upgrading of the tide gauge stations.

2.3. Continuous geodetic monitoring of vertical land motions at tide gauges

The problem of correcting the tide gauge records for the vertical land motion upon which the gauges are settled has only been partially solved. At best, the analyses so far have included model corrections for one of the many processes that can affect the land stability, namely the Glacial-Isostatic Adjustment (GIA). An alternative approach is to measure (rather than to model) the rates of vertical land motion at the tide gauges by means of space geodesy. Wöppelmann et al. (2007) implemented a dedicated GPS processing strategy to correct the tide gauges records, and thus to obtain a GPS-corrected set of 'absolute' or geocentric sea level trends. For comparison purposes, Wöppelmann et al. (2007) further computed the global average of sea level change according to Douglas (2001) rules, whose estimate is 1.84 ± 0.35 mm/yr after correction for the GIA effect (Peltier 2001). They obtain a value of 1.31 ± 0.30 mm/yr, a value which appears to resolve the 'sea level enigma': Munk (2002) stressed that the sum of climate-related contributions to sea level change was low (0.7 mm/yr) compared to the observations over the last 50-100 years (1.8 mm/yr) by referring to this factor 2 difference as the 'enigma' of sea level change. Since then, the more recent results now indicate a 1 mm/yr contribution from the melting of global land ice reservoirs (Mitrovica et al. 2006), as well as a 0.4 mm/yr contribution from the thermal expansion of the world ocean (Antonov et al. 2005).

Furthermore, the application of the GPS corrections clearly reduces the standard deviation of the individual tide gauge sea level trends from their mean value, a reduction close to the value anticipated by Mitchum (2000) of about 0.4 mm/yr for the land motion error source in tide gauge calibrations of satellite altimeters. The GPS corrections assume, however, that the land motions at the tide gauges are linear and uniform over the last 100 years. Nevertheless, this assumption is a step forward than ignoring the land motion source of error or expecting this error to cancel out in the global average. The geodetic monitoring of land motions remains a major scientific issue and an important reason for the development of the TIGA pilot project in relationship with the GLOSS programme. TIGA stands for "GPS Tide Gauge Benchmark Monitoring". It is a pilot project of the International GNSS Service (IGS) established in 2001 to analyse GPS data from stations at or near tide gauges on a continuous basis (see details at http://adsc.gfz-potsdam.de/tiga/index_TIGA.html). A second assumption was necessary in Wöppelmann et al. exercise to apply the vertical velocity observed at the GPS antenna to the tide gauge because of the lack of local high-precision levelling data. This is another key issue that GLOSS should address.

Regardless of the application, whether local or global, we have shown that GPS data analysis have reached the maturity to provide useful information to separate land motion from oceanic processes recorded by the tide gauges or to correct these latter. Moreover, whereas the observational information provided by a tide gauge may appear as the most adequate and useful quantity for the coastal management (i.e. a relative sea level height with respect to the underlying land upon which the gauge is settled), to devise any appropriate plan to manage the coastline it is preferable to understand which is the relative magnitude of the mechanisms that potentially underlay the relative sea-level rise (Stewart 1989). Is the relative sea-level rise due to eustatic changes or due to the local land subsidence? To identify the causes of the changes acting at a particular place on the long term time period, monitoring the vertical land motion at the tide gauge becomes mandatory.

The situation of the continuous GPS stations operating at GLOSS tide gauges is detailed in a dedicated report of the group of experts meeting. In section 4, we summarise the status at the French tide gauge stations.

2.4 Real-time data

The data of the four ROSAME stations are transmitted in real-time via Argos, as well as Sao Tomé station. Moreover, the Kerguelen tide gauge will be put on GTS by Météo-France for the IOTWS. The Dumont d'Urville station is in the process to be included in the IOTWS.

As a pilot project, real-time data (raw data at 1s.) were first collected in 2006 at Brest through ADSL. These Internet solution will now be extended to more RONIM tide gauges, in particular at La Réunion and Mayotte for which data will be put on GTS too by Météo-France for the IOTWS.

A real-time data quality control software, based on ESEAS-RI ideas, is now being developed and will be operational in October 2007 for RONIM real-time data.

3. Data distribution

Raw data (10 min. sampling) from RONIM stations are retrieved weekly by SHOM and made available directly at the French sea level data centre SONEL through Internet (see www.sonel.org for more details). In addition to the raw data, hourly data are provided after a rather complete and classical IHO compliant quality control procedure. The latency of the latter data is about 2-3 months. It should be pointed out that a free data policy is applied for years at SHOM for scientific applications in line with the WMO Resolution 40, under certain conditions of course. These conditions prevail today. Only the data communication media changed in January 2003, based on modern technologies. Conditions and duties that the user accept by using the data provided in SONEL are:

- to register as user of SONEL ;
- to briefly describe the objectives of the study;
- to provide a copy of any result, either partial or final;
- to acknowledge SONEL and its relevant contributors as source of data;
- to inform SONEL contacts about any data problem;
- to agree not to transfer SONEL data to third parties (Instead of, provide the address of SONEL !).

It was agreed shortly after the 8th GLOSS GE meeting, held in Hawaii, in 2001, to make the tide gauge data from the RONIM stations that are committed to GLOSS also accessible through the GLOSS Fast delivery data centre at University of Hawaii. This seems currently the case for Brest and Marseille stations, but we remind that the agreement applies to the other GLOSS stations too. It should be highlighted that, as a full acknowledged scientific service, the data from the ROSAME network is throughout available to the scientific community at the GLOSS Fast delivery data centre for years, and can also be retrieved at the anonymous FTP server ftp.legos.obs-mip.fr/pub/soa/niveau_mer/rosame

The daily, monthly and annually averages of sea level are now directly retrieved at SONEL data centre server by the PSMSL. This should hopefully shorten the latency of mean sea level data availability at the PSMSL.

Regarding SONEL, a workshop was held at La Rochelle, in April 2006. The objectives of the workshop were twofold: i) to assess its interest, and ii) to discuss its future. Indeed, SONEL is currently a pilot project set up without any dedicated means or legitimate national framework, based on a voluntary basis and 'best effort' philosophy. SONEL aims at:

- setting up a comprehensive and co-ordinated sea-level infrastructure at the national level;
- improving the knowledge on sea level and its variations;
- rationalising the efforts and the resources on sea-level observation in France;
- enhancing and to harmonising the observing networks;
    - federation of existing networks and integration of new emerging tide gauge networks:
    - co-localisation with other techniques (Meteo, GPS / DORIS…)
    - data standards (quality, latency…)
- ensuring the distribution and the quality of the data;
- rescuing archaeological data and to promote its use;
- sharing experiences & results (technical, scientific);
- ensuring a co-ordinated participation to programs;

The participation was successful, even gathering participants from abroad that are concerned and interested by the subject. The workshop concluded that SONEL as a pilot project has already demonstrated its utility; the limits of the voluntary participation has shown its limits. Acknowledgement and a legitimate framework at the national institutional level are now mandatory to maintain and to develop the service, in order that it becomes an operational one upon which international structures and sea-level programmes can rely.

4. Overview station by station

GLOSS 242: BREST

Since January 2004, a radar gauge Krohne BM100 records the "official" data for Brest station. The previous MORS IEE acoustic tide gauge is still working alongside the radar in the same stilling well for comparison purposes. Calibration of the acoustic and radar tide gauges were performed. These experiments assessed the performances of the radar device (Martin Miguez et al., in press).

The tide gauge benchmarks were first linked to the permanent GPS station by precise levelling in 1999. Six leveling operations were carried out between 1999 and 2004. The distance between the GPS and the tide gauge is about 350 metres. The levelling results show that the whole site is stable at the millimetre level. This ensures that the GPS is actually monitoring the vertical motion that affects the tide gauge. The GPS station is operating continuously since October 1998 and is committed to IGS TIGA pilot project (see section 2.3).

Last but not least, a data archaeology exercise is conducted for a couple of years following the rediscovery of ancient data, in particular the earliest tide gauge measurements recorded between 1846 and 1860. The rediscovered tide gauge data were submitted to a thorough process of quality control (Pouvreau et al. 2006, Wöppelmann et al. 2006). All the hourly Brest tide gauge data discovered so far are now available on the SONEL data server (see section 3). In addition, several decades of sea-level data of the 18th century were also discovered. They are currently under investigation.

GLOSS 205: MARSEILLE

Although the original floating gauge is still operating in Marseille since February 1885, a modern acoustic tide gauge was installed in June 1998 (MORS Radarson). The calibration carried out in June 2004 shows that the old tide gauge is more precise and stable than the modern one. Further 'in situ' experiences indicate that the acoustic gauge presents an apparently unpredictable behaviour for heights above a certain level, about 65cm above the chart datum (Martin Miguez 2006). The replacement of the acoustic gauge is scheduled in 2008 by IGN with the collaboration of SHOM. The mechanical tide gauge may hopefully continue its records beyond 2008, and thus ensure an useful overlapping period. TGBMs are levelled yearly. The results show a locally stable site at the millimetre level. The permanent GPS station is operational since July 1998 and is committed to TIGA.

GLOSS 123: NOUMEA-NUMBO

A modern radar tide gauge was installed at Nouméa by SHOM in January 2005 to replace the floating and the acoustic gauges that were getting older. The new tide gauge is located at a site called Numbo, which is about 6 km distance from the older one (Chaleix). Unfortunately, the plan mentioned in the previous report to operate both French old and new tide gauges simultaneously for at least a year was not carried out. Furthermore, the IGS station is now about 10 km distance, and it is set up on a different basement. A permanent GPS station was envisaged by IRD at the top of the new tide gauge, but the idea is apparently abandoned.

GLOSS 138, 140, 142

The University of Hawaii maintains these three stations (Rikitea, Papeete, Nuku Hiva).

- Station 138 (Rikitea, Gambier) operates a floating gauge in a stilling well. It transmits data hourly via the GOES satellite system. The Université de Polynésie Française (UPF) plans to install permanent GPS within the next two years.
- Station 140 (Papeete, Tahiti). A permanent GPS station was installed by CNES on the top of the tide gauge. It is operating since August 2003 and is intended to be submitted to TIGA. A DORIS station is also operating about 7 km from the tide gauge since July 1995, alongside with an IGS station.
- Station 142 (Nuku Hiva, Marquises) operates pressure sensors for measuring water level. It transmits data hourly via the GOES satellite system. The UPF plans to install permanent GPS within the next two years.

GLOSS 021, 023, 024, 131, 260

The four stations of the South Indian Ocean are part of the ROSAME network. They are equipped with pressure sensor (water level pressure, seawater temperature, and atmospheric pressure). Kerguelen, Saint-Paul, and Crozet have recently been equipped with conductivity gauges. These stations are automatic and transmit the data through ARGOS. The hourly data, after validation, are transmitted to the Hawaii Centre. Real-time data for these four tide gauges can be seen on the LEGOS web page http://www.legos.obs-mip.fr/en/soa/

- Station 23 (Kerguelen) is operational since April 1993, with only a short gap of a few days in January 2000. Monthly tide gauge calibrations were performed until 2003. The TGBMs were connected in December 2003 by precise levelling and differential GPS to the IGS permanent station. This IGS station is located at a distance of about 3 km. It is operational since November 1994, close to a DORIS station, which is operational since January 1998.
- Station 21 (Crozet) is installed since December 1994. It has been operational from November 1995 to February 1997, from December 1998 to June 1999, from March 2000 to June 2000, and from September 2000 to July 2001. It was destroyed end of July 2001. A new infrastructure was built in December 2003. It was destroyed again in February 2007.
- Station 24 (Amsterdam-St Paul) is operational since October 1994, with a gap from April to June 1999. It operates at the moment in an autonomous mode due a data transmission problem.
- Station 131 (Dumont d'Urville) was installed in February 1997. It has been operational from February 1997 to August 1997, from February 1998 to May 1998, and from February 1999, with a short gap in January and February 2000. It was reinstalled in January 2006 with high data acquisition frequency (2 minutes) but the data link was broken beginning of 2007 by an iceberg. It operates at the moment in an autonomous mode.
- Station 260 (Sao tomé) was installed in 1989 by IRD. It is part of the French PIRATA network. Data are transmitted in real-time via the Argos system and profcessed by the LEGOS. The station is operational and data are available on the Hawaii Sea Level center and on the ROSAME ftp site (see section 3).

GLOSS 165: CLIPPERTON

Two pressure gauges WLR7 were moored at Clipperton in early 2005 for a couple of months. As far as we know there are no definitive plans at the moment to install another temporary or permanent tide gauge by any French agency. But the status of the Clipperton Island has changed recently and the question of creating a permanent observatory is raised.

GLOSS 204: FORT-DE-FRANCE, MARTINIQUE

The GLOSS station list still reports station Nr. 204 to be "Le Robert" (see GLOSS web pages), although there were no plans to install a tide gauge there for years and a proposal to change to Fort-de-France was submitted during the last group of experts meeting. We report on Fort-de-France here. A Krohne BM70A radar tide gauge was installed by SHOM in October 2005. The station is part of the RONIM network. The tide gauge is operated in collaboration with the local authorities of Meteo-France and the French Navy.

GLOSS 202: CAYENNE-ILES DU SALUT, FRENCH GUYANA

A Krohne Optiflex radar tide gauge was installed in November 2006 by SHOM. The station is included as part of the RONIM network. The tide gauge is operated with the collaboration of the local authority DDE Guyanne.

GLOSS 017: POINTE DES GALETS, LA REUNION

The float tide gauge is operated by DDE La Reunion. Tidal charts corresponding to the period 1997-2002 were digitised into hourly data by SHOM. The observations from the period 2003 to 2005 are now available at SHOM, but pending for digitisation. A radar tide gauge is planned to be installed in October 2007 by SHOM with the collaboration of DDE and Meteo-France. The station will contribute to IOTWS, and will be included in the RONIM network too.

GLOSS 096: DZAOUDZI, MAYOTTE
The station is not operational. The floating gauge was uninstalled by DDE Mayotte. A new radar tide gauge is, however, planned in 2007 or 2008 as a joint collaboration between SHOM, DDE and Meteo-France. The station will contribute to IOTWS and will be included in the RONIM network as well.

5. Concluding remarks

The table below provides a synthetic view of the station status regarding the GLOSS criteria (IOC 2006, pp. 52).

Station	Type	Digital	Precision	Control	Meteo	Leveling	CGPS,...	Real-time
Brest	Radar	Yes	1 cm	Weekly	Pressure	Pluri-annual	GPS	2007
Cayenne	Radar	Yes	1 cm	Semestrial	Pressure	Initial	No	No
Clipperton								
Crozet	Pressure	Yes	1 cm	Never	Pressure	2006	No	Yes
Dumont	Pressure	Yes	1 cm	2001	Pressure	2001	GPS + DORIS	Yes
Dzaoudzi	2008							
Kerguelen	Pressure	Yes	1 cm	Monthly	Pressure	2003	GPS + DORIS	Yes
La Réunion	Floating	No	Doubtful	Semestrial	No	Initial	No	No
Fort-de-France	Radar	Yes	1 cm	Semestrial	Pressure	Initial	No	No
Marseille	Floating Acoustic	No Yes	3 mm 1-2 cm	Yearly	No	Yearly	GPS	No
Nouméa-Numbo	Radar	Yes	1 cm	Initial	No	Initial	GPS + DORIS	No
Nuku-Hiva	2008							
Papeete	Acoustic	Yes	1 cm	Initial	No	Initial	GPS + DORIS	Yes
Rikitea	2008							
Saint-Paul	Pressure	Yes	1 cm	Never	Pressure	2006	No	Yes
Sao Tomé	Pressure	Yes	1 cm		No	No	No	No

To conclude the authors would like to acknowledge here the numerous and most valuable contributions made by Bernard Simon (SHOM) during the last decades in the domains of the sea-level observation, the understanding of the sea-level variability, and their application to tidal analyses and predictions, navigation, hydrography and coastal management, in France, of course, but also abroad within international bodies like IHO. Bernard Simon retired in April 2007, but not before putting into paper his expertise and knowledge in a comprehensive manual, which is edited by the Institut Océanographique, and will be translated to English very soon (Simon 2007).

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