Progress Report on the GNSS at Tide Gauge Activities: SONEL Data Holdings & Tools to access the data

(Status report – September 21, 2015)

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Background

In 2009, the GLOSS program convened a workshop on "*Precision Observations of Vertical Land Motion at Tide Gauges*" before its Xth Group of Experts meeting. The main objective was to review the geodetic methods for accurately expressing the tide gauge data in the same geocentric reference frame as the satellite altimetry data, and monitoring the vertical land movements that are recorded by the tide gauges at the sub-millimeter per year precision level, hence enabling their separation from the climatic signals. One of the main conclusions of the workshop was that the Global Positioning System (GPS) had reached the maturity to address these issues, provided continuous GPS observations were carried out at the tide gauge and were made available to the groups that have the knowledge and experience to analyze the data using the state-of-the art data analysis strategies, models and corrections. Most of these groups are committed to the International GNSS service (IGS) working group named TIGA. (Note that GPS is one of the several Global Navigation Satellite Systems (GNSS) available today).

Another important conclusion from the aforementioned workshop was that the GLOSS program should designate a dedicated "GNSS at tide gauge" data assembly center. To further examine this issue of a dedicated data center, a follow up meeting was organized at the University of Hawaii Sea Level Center (UHSLC) in 2010. The proposal of the SONEL data center, which has been acting as primary data center for TIGA since 2001 was retained, and finally adopted at the XIth GLOSS Group of Experts meeting in 2011. The GLOSS Implementation Plan released in 2012 recognizes the SONEL data center as an associated infrastructure, along with the other dedicated data centers of the program such as the UHSLC or the PSMSL.

Consistently, **the GLOSS implementation plan calls for the important upgrade of its core network sea level stations with continuous GNSS stations**, and that their observations be provided to its dedicated data assembly center (SONEL), **so that the observations and generated products be public and free to anyone in line with the IOC/UNESCO Oceanographic Data Exchange Policy**.

This report is the second status report of the SONEL GNSS at tide gauges data center since its inception in GLOSS. It has been prepared with the contributions from colleagues of the PSMSL, as an important effort has been accomplished in the interoperation of the respective databases, achieving useful merged information and combined scientific products. Most of the illustrations herein are extracted from the Internet portal of SONEL: www.sonel.org.

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Examples of GLOSS Core Network stations equiped with continuous GNSS

I- GNSS data holdings at SONEL

1. Global status overview

SONEL has currently identified 593 tide gauge sites for which a GNSS station is nearby (within 15km), or from another point of view – there are 815 GNSS stations that are nearby a tide gauge (Figure 1). Among these GNSS stations **487 are active at 513 tide gauge sites** (a measurement file was successfully retrieved within the last 30 days, in green on Figure 1: Status of the GNSS@TG data available on SONEL), 122 are dormant (no data for the last 30 days, in orange on Figure 1) at 139 tide gauge sites, and 105 are decommissioned (red cross on Figure 1) at 100 tide gauge sites. It should be noted that **101 GNSS stations have no data available** (in blue on Figure 1) at 110 tide gauge sites, mostly because of military or commercial restrictions. Note that all the statistics in this report correspond to the status on 27 August 2015. As of September 2015, SONEL data assembly center contains more than 2,400,000 daily station files of GNSS measurements in RINEX format, **contributed by over 140 different organizations**.

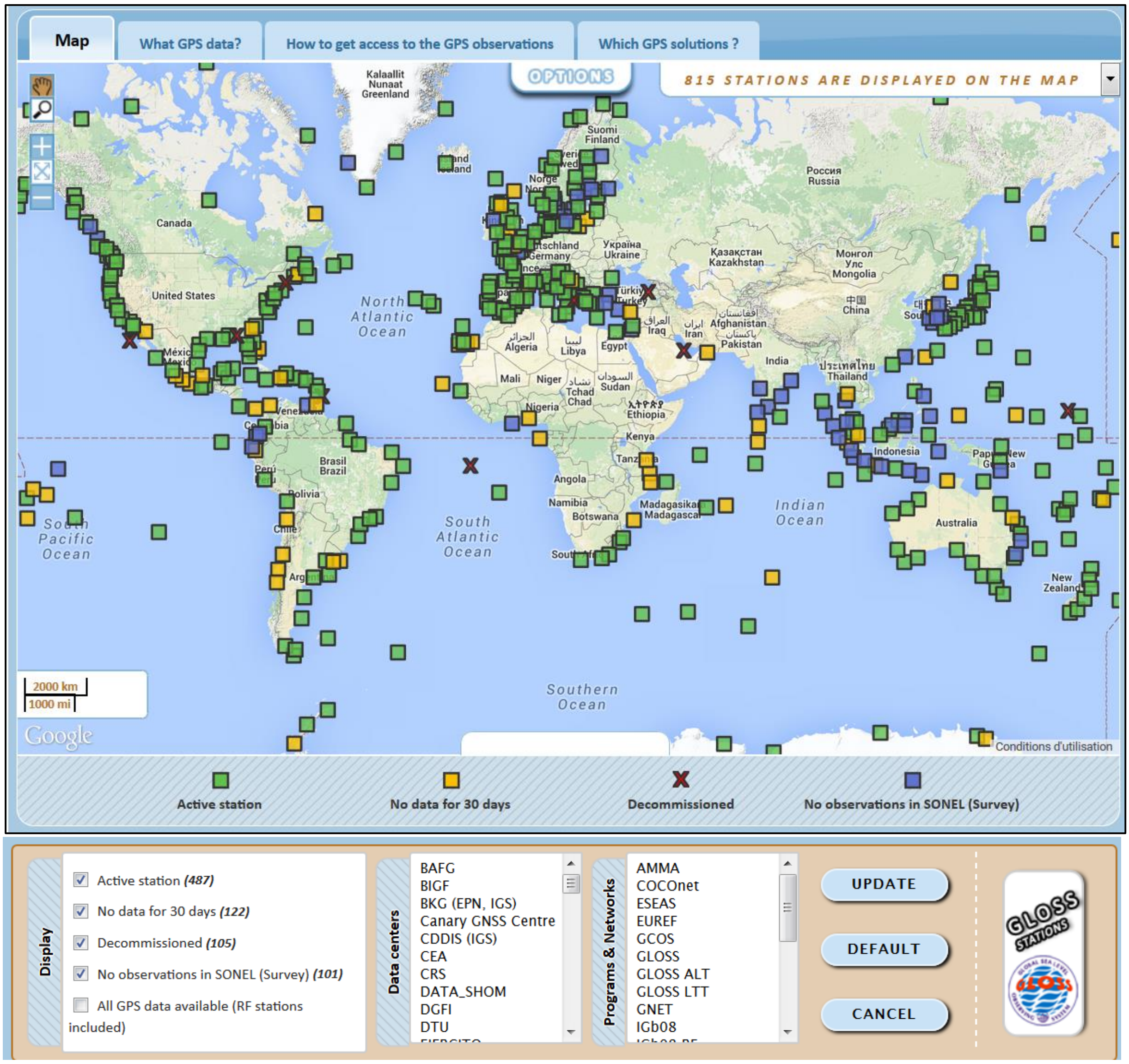

Figure 1: Status of the GNSS@TG data available on SONEL
http://www.sonel.org/-GPS-.html

Since the 13th session of the GLOSS Group of Experts meeting in October 2013, 34 new GNSS stations nearby 32 GLOSS Core Network tide gauges have been identified and their metadata collected into SONEL. Among these, some are replacing a decommissioned GNSS station or supplementing it. **18 GLOSS Core Network tide** gauges out of the above 32 **did not have any GNSS in 2013**. From the 34 new GNSS stations, there are 5 for which observations are not accessible. (Note that by GNSS it is meant a continuous GNSS station). Most of the GNSS stations are currently GPS, even though other satellite constellations may be recorded as well, such as GLONASS, Galileo or BeiDou.

Figure 2 shows the evolution of the number of daily GNSS measurement files, which informs on the number of GNSS stations actually operational. As many as 670 stations are reported (peak in the blue curve, Figure 2), which includes both the GNSS at tide gauge sites and the reference frame stations. The latter reference frame stations are important in the GNSS data analysis to ensure the realization of a stable geocentric reference frame over the entire data span. The decline at the end of the curves in Figure 2 corresponds to delays in the data flows. This situation is often noted by global data assembly centers (e.g., the PSMSL; Holgate *et al*. 2013; Woodworth and Player, 2003).

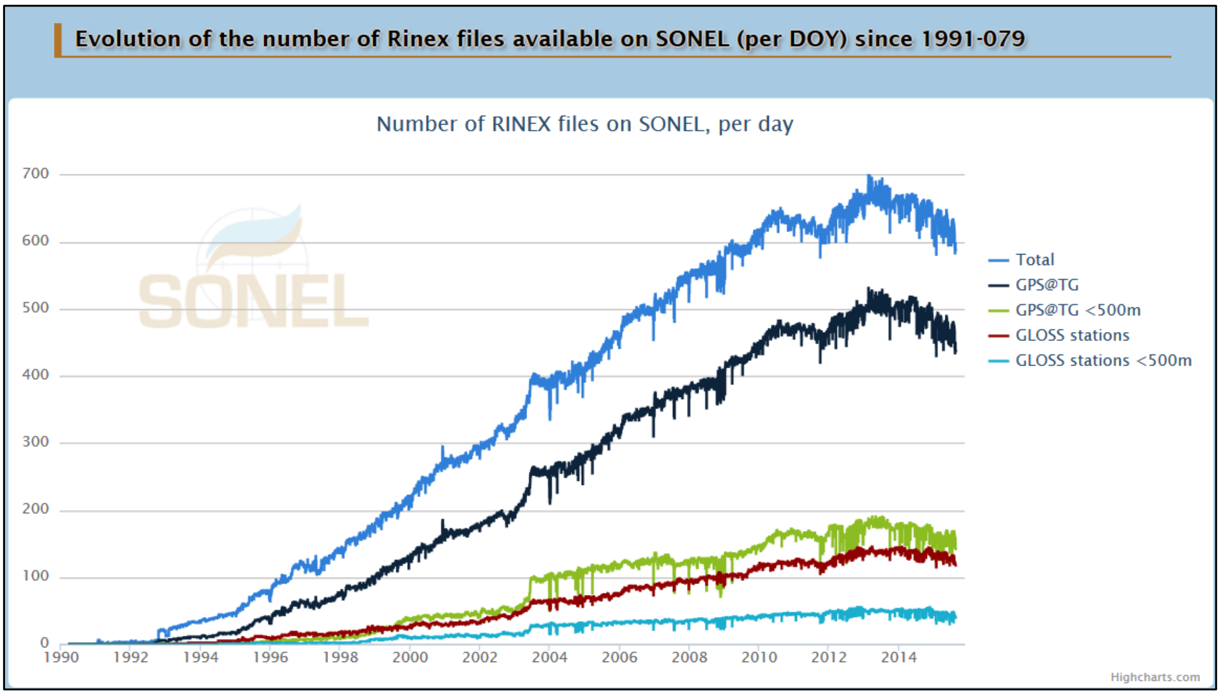

Figure 2: Evolution of the GNSS stations operational (providing measurements to SONEL)
http://www.sonel.org/What-GPS-data.html

2. GLOSS Core Network status overview

According to the latest version of the GLOSS station handbook as of 2012 (http://www.gloss-sealevel.org/station_handbook/stations/#.VflnKpePv0F), the GLOSS core network comprises 290 tide gauge sites. Figure 3 shows that **208 of these stations are near one or more GNSS stations** (this corresponds to 303 GNSS stations nearby a GLOSS tide gauge site). The 82 tide gauges for which no GNSS station has been found in the vicinity are in white on Figure 3. Appendix 1 provides a list of the GLOSS Core Network sites with some relevant information on the data availability related to the GNSS stations nearby, and the leveling connections of the GNSS antenna and tide gauge benchmarks.

Figure 3: Status of the GLOSS tide gauge network with a GNSS station nearby
http://www.sonel.org/-GLOSS,81-.html?lang=en

For 21 stations, a GNSS station has been identified but the data are currently not available (in blue on Figure 2, see also Table 1). It is worth reminding here that, beyond the formal commitment to the GLOSS program, there is a clear interest to distribute the GNSS measurements freely. Deriving accurate vertical velocities from GNSS measurements is still a challenge in Geodesy. Thus, the GLOSS implementation plan calls for the important upgrade of its core network sea level stations with continuous GNSS stations, and that their observations be provided to its dedicated data assembly center (SONEL), so that the observations and generated products be public and free to anyone in line with the IOC/UNESCO Oceanographic Data Exchange Policy. This will enable confrontation of the products from current state-of-the-art GNSS data analysis strategies, and hopefully advances to ultimately obtain vertical velocities at tide gauges that are robust and reliable.

GLOSS tide gauge	Country	GPS acronym
Prince Rupert	Canada	BCPR
Xiamen	China	Unknown
Tumaco	Colombia	TUMA
La Libertad	Ecuador	SALN, SEEC
Nuku-Hiva	French Polynesia	Unknown
Takoradi	Ghana	TKTG, TADI
Cochin	India	Unknown
Chennai / Madras	India	Unknown
Marmagao	India	Unknown
Minicoy	India	Unknown
Vishakhapatnam	India	VISA
Ambon	Indonesia	CAMB
Waikelo	Indonesia	WAIK
Malin head	Ireland	Unknown
Stockholm Stupi	Sweden	STH0
Goteborg – Torshamnen	Sweden	Unknown
Ko Lak	Thailand	Unknown
Legaspi	Philippines	PLEG
Davao Gulf	Philippines	PDAV
Pusan	South Korea	PUSW
Godthab	Denmark/Greenland	NUUK

Table 1: GLOSS stations (21) for which a continuous GNSS station has been identified nearby but its measurements are currently not available

Figure 4 is similar to Figure 2 but focusing on GLOSS tide gauge sites. (Note that several GNSS stations may be near a GLOSS station).

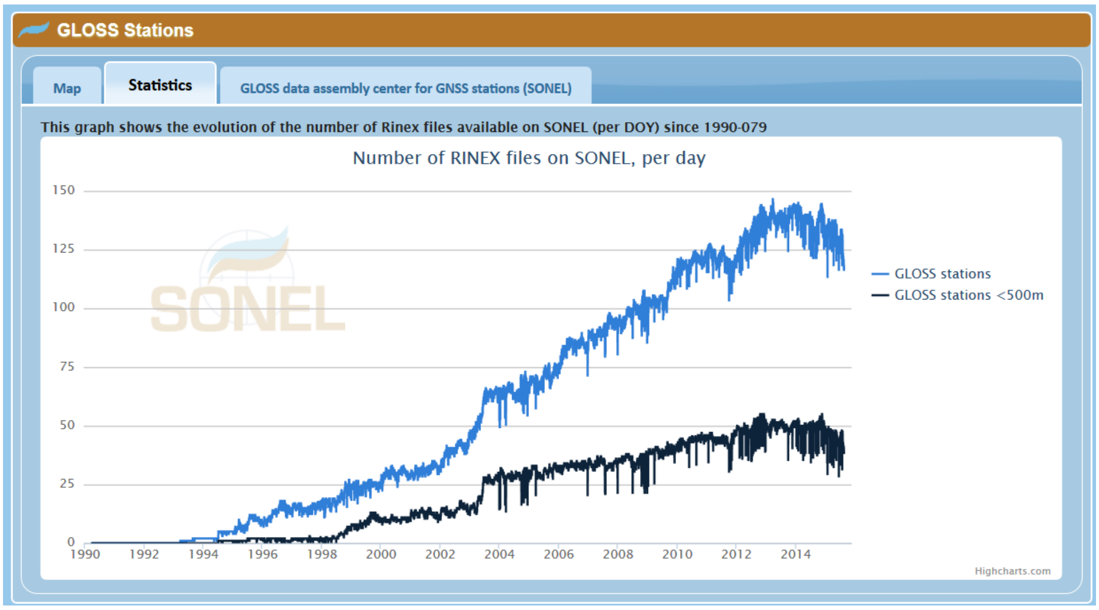

Figure 4: Evolution of the GNSS stations operational (providing data to SONEL) near a GLOSS site
http://www.sonel.org/GNSS-data-at-or-nearby-GLOSS-Core.html

Figure 5 highlights the information on distance between the GNSS antenna and the tide gauge. This information is important as the likelihood of leveling links between the instruments decreases with distance (resources, expertise…), and thus raises the question of usefulness of the distant GNSS antennas to monitor the vertical land movements at the tide gauge. This issue was first discussed by Bevis *et al*. (2002), and most recently by Gill *et al*. (2015). As highlighted by Gill *et al*. (2015), the leveling error can potentially become a significant part of the total error budget at distances longer than 1.0 km, thus **stations more than 1.0 km away should not be considered as "co-located" in the practical sense**. For the 120 GLOSS tide gauges with a GNSS antenna less than 1000 m distant, 59 are within 100 m and 61 are between 100 m and 1000 m.

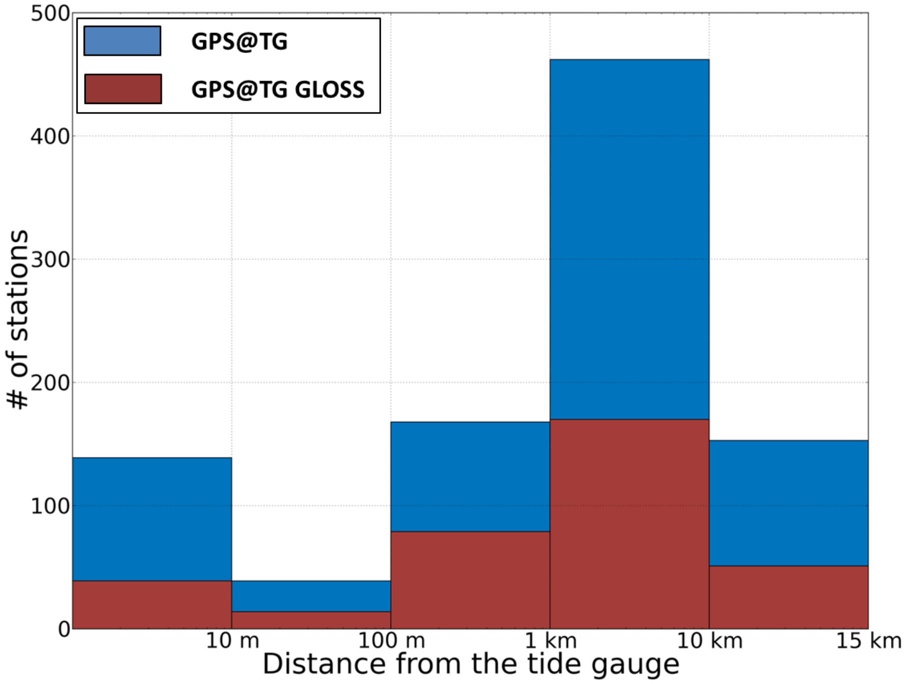

Figure 5: GNSS antenna distance to the tide gauge

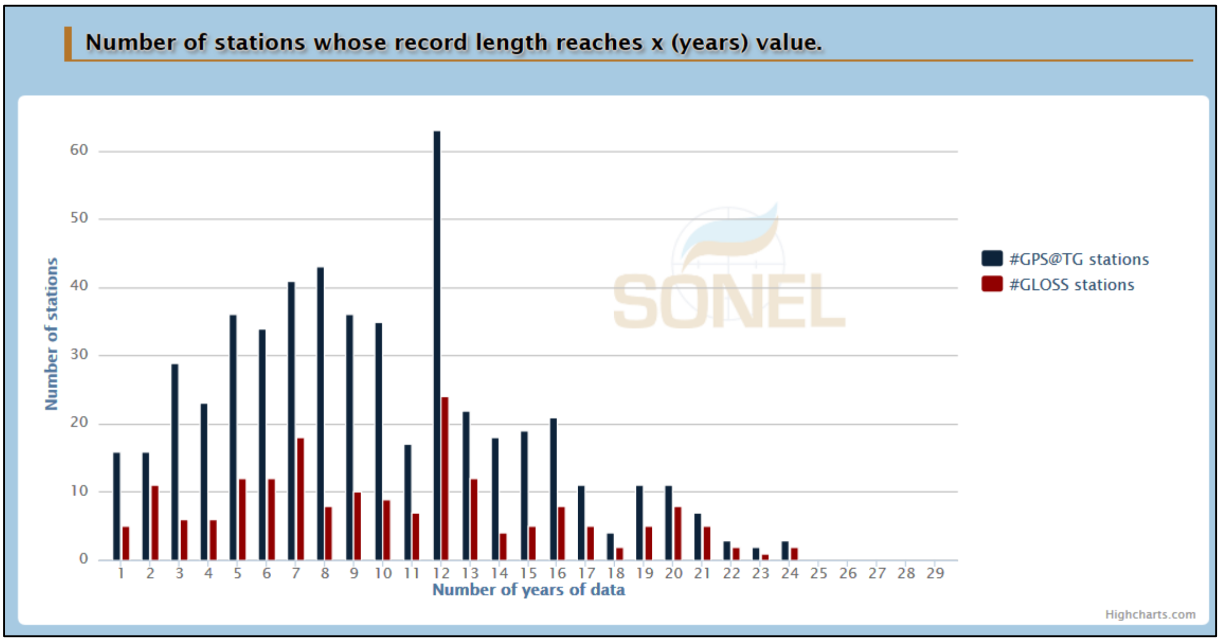

Figure 6a: Number of stations whose record length reaches a given number of years of data
http://www.sonel.org/What-GPS-data.html

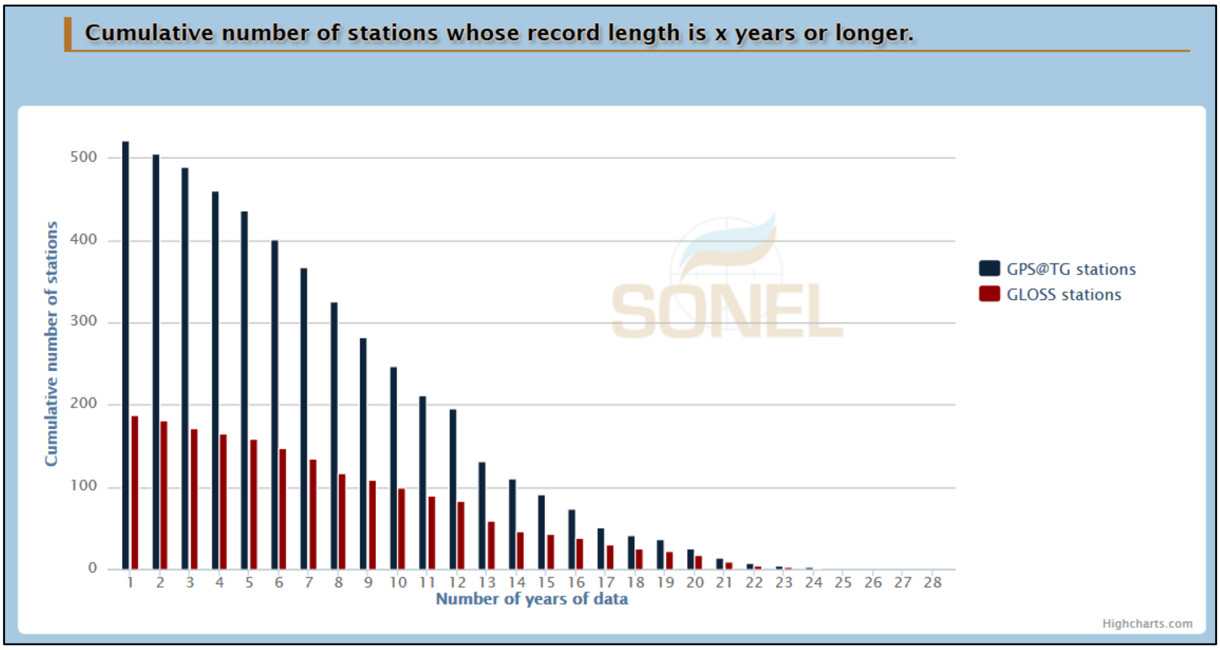

Figure 6b: Cumulative number of stations whose record length reaches a threshold number of years of data
http://www.sonel.org/What-GPS-data.html

The distribution of the number of GPS stations against their record length or against a minimum record length are shown in Figure 6a and 6b, respectively. The record length is calculated as the difference between the last and the first data file available, without considering gaps. The information on large data gaps is stored and available on the SONEL website. The GPS record length is a critical factor in order to derive an accurate vertical velocity. According to Santamaría-Gómez and Mémin (2015) **a minimum record length of a decade** is required in certain tropical areas to reduce the surface pressure loading effects in the vertical velocity estimates below 0.4 mm/year.

3. TIGA and COCONet status overview

There are 122 GNSS stations at tide gauges that are committed to the TIGA working group of the International GNSS service (IGS). As of August 2015, 98 GNSS stations are operational, 12 are decommissioned and the rest are likely operational or dormant (no data for the last 30 days). Some of the latter stations (dormant) have not provided data for more than one year are: Freeport (FREE) in *Bahamas*, Puerto de la Luz (PLUZ) in *Spain*, Klaipeda (KLPD) in *Lithuania*, Manzanillo (MANZ and MNZO) in *Mexico*, Sheerness (SHEE) in *UK*. It should be noted that 56 of the 122 TIGA stations are nearby a GLOSS tide gauge.

Regarding the Continuously Operating Caribbean GPS Observational Network (COCONet; http://coconet.unavco.org), 22 GNSS stations have been identified near a tide gauge, that is, 3 more than in the last GLOSS group of experts meeting in 2013. All of them are providing daily files of measurements, except Mona Island (MOPR) in *Puerto Rico*, which stopped reporting data on 24 August 2011, Cancun (CNC0) in *Mexico*, which stopped reporting data on 14 December 2012, and Barbados (BDOS), which was decommissioned on 13 December 2013.

II- Data access tools

1. General

SONEL strives to provide user-friendly access to its data holdings by developing web-based interfaces such as clickable maps. For the last couple of years, the maps have given information on which GNSS stations are near a tide gauge, its activity status, and data availability. Some display options on the subset of stations can be chosen on the panel just below the map (checkboxes). For instance, what data is retrieved from a specific data center, or whether the station belongs to a particular network or program? The selection options could be further developed upon request, if the users express a particular interest.

The station symbols on the maps are usually clickable to show basic details such as name, latitude, longitude, and a link that leads the user to a full page of details. For each station, one may learn whether SONEL has collected data files of observations, what is the first and latest observation available at SONEL, but also one can display a detailed calendar to see and retrieve the daily file of observations in RINEX format by clicking on a specific day on the calendar table. The user may also find what tide gauge is nearby and if there are other tide gauges or GNSS stations, in which case a link can lead to the co-located station information web-page. If leveling data is available between the GNSS antenna and the tide gauge, a link to that information is also available as well.

Furthermore, if the observations of that station have been processed by at least one analysis center contributing a *'GNSS solution'* to SONEL, the GNSS position time series may be viewed and downloaded in ASCII file format. In this respect, the SONEL team has been working since the GLOSS Group of Experts meeting in 2011 to provide new web-based features to manipulate and display those time series (de-trended, annual cycle removed, etc.). The SONEL team has also been working on extending the web-based clickable maps to enable a comprehensive view and a simple access to some relevant products like: (i) the GNSS vertical velocities (section II.2), and perhaps more interestingly, (ii) the combined linear trends from the GNSS and the tide gauge records (section II.3). The latter objective has been achieved through a stimulating and productive cooperation between the SONEL and the PSMSL teams.

2. GNSS solutions

First, it may be helpful to clarify what is meant by a *'GNSS solution'*. Here, for a given station, it consists of the average station position and velocity, which are valid over the input observation time span or record length, as well as its 'residual' position time series. The term 'residual' refers to the difference between the observational positions and the linear model predictions at given epochs, typically weekly though the IGS is moving to daily with its latest reprocessing campaign. The linear model may include offsets, in which case their values are estimated as well in the same adjustment run. Each solution is expressed in a specific geocentric reference frame (the most accurate and stable at the moment of the solution release).

SONEL is able to handle several types of GNSS solutions. First, it can display solutions from different analysis centers. Hence, the level of agreement in the vertical velocity at a given station can be appraised, and provide some additional reliability beyond the formal uncertainties from an individual analysis center solution. Second, SONEL can also handle multiple solutions from a single analysis center. For instance, it may be interesting to update a solution by incorporating new models or corrections (reprocessing), as long as these comply with the up-to-date IGS-agreed international recommendations (see http://acc.igs.org/reprocess.html).

a) Global comprehensive view

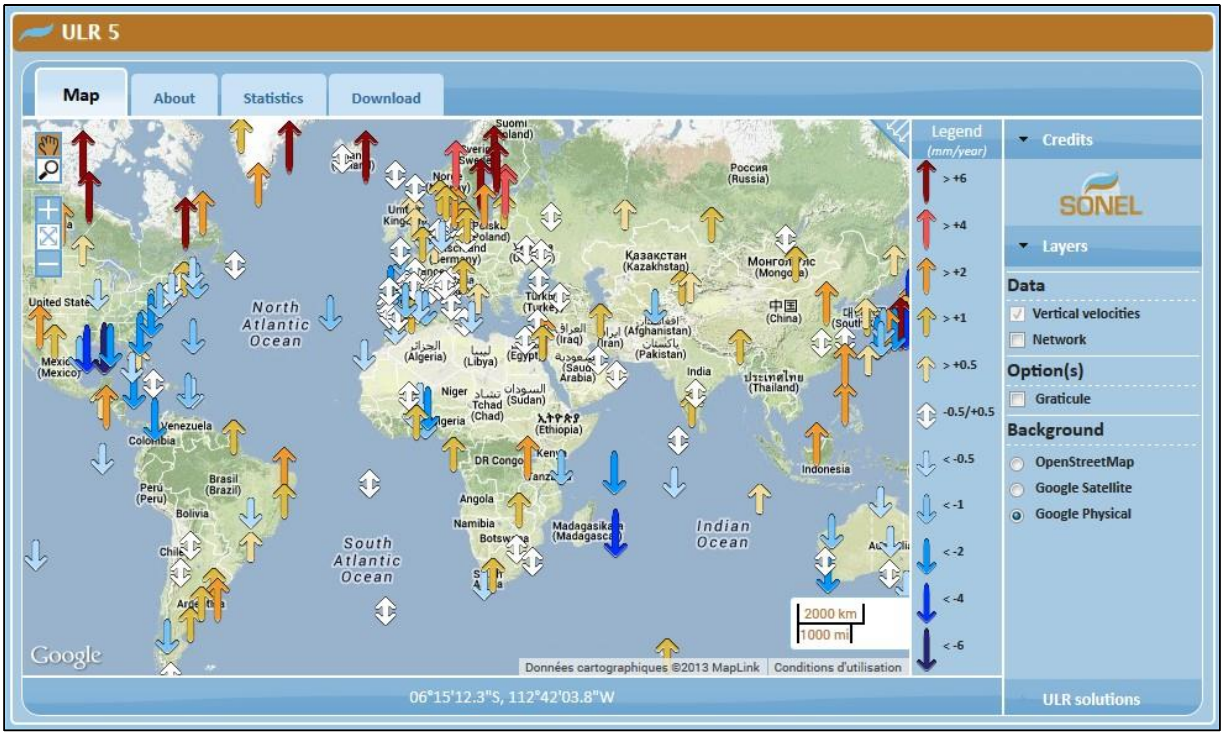

Figure 7: Display on a web-based clickable map of the GNSS vertical velocities from ULR5 solution http://www.sonel.org/-Vertical-land-movement-estimate-.html?lang=en

Figure 7 shows the GNSS solution webpage: http://www.sonel.org/-Vertical-land-movement-estimate-.html?lang=en, which displays a clickable map with the GNSS vertical velocities of a given *'GNSS solution'*. The upward arrows indicate land uplift, whereas the downward arrows indicate subsidence. Double-end arrows indicate velocities within -0.5 to +0.5 mm/year.

The arrows are clickable to obtain a small popup window with the station name, its vertical velocity, the associated time span, data completeness, and a link to the station web-page with full information on the station and its 'GNSS solutions' (see next section).

The detailed description of a given 'GNSS solution' is split into "tabs" to reduce the amount of information displayed in a single web-page. The default-selected tab corresponds to the vertical velocity map of the network of processed stations for which a robust vertical velocity has been estimated. The tab called "About" gives technical details on how the solution was processed (main features of the analysis strategy) and in which geocentric reference frame it is expressed. Another tab called "Statistics" provides common statistics and graphs for the solution. Finally, the tab called "Download" gives comprehensive access to download the GNSS solution files (table of all the vertical velocities that were estimated, individual station position time series files assembled in a .zip file, global solution file in SINEX format, table of estimated discontinuities, etc.).

This facility of making available a 'GNSS solution' is currently available for the ULR analysis center solutions (ULR4 and ULR5 solutions). As mentioned previously, SONEL can handle other GNSS analysis center solutions, including DORIS solutions (Section IV).

b) Local specific view (to a particular station)

The 'GNSS solution' data for a specific station can be accessed either through the aforementioned 'GNSS solution' map, or through the former GNSS general information map presented in Section I.2, which describes what observations are available (Figure 1). Note that a GNSS station webpage can also be accessed directly by using the GNSS acronym in the "Search" facility on the left-hand panel that is available from any page on the SONEL website (exact spelling but case insensitive).

Whenever a 'GNSS solution' is available for a given station, the individual station webpage will show a "GPS position time series" block of information that otherwise will not appear. This block displays the (residual) position time series, but it has been improved to provide visual tools that support the analysis of the results (Figure 8). Firstly, general information is displayed (reference frame, ellipsoid, average position and velocity). Secondly, the graphs are now dynamic, which means that the vertical scale can be adjusted (+/- buttons) and the information on a point of the curve under the cursor (residual, epoch) can be displayed.

In addition, the trend has been added back to the residual position time series (default display). However, the user may choose to remove this trend through a checkbox. The annual signal and the estimated position offsets can be added back, for instance, to assess the linearity or to check the quality of the results. The horizontal components of the positioning are also accessible. They may provide information on problems that have occurred with the station. The vertical bars on the graphs highlight the dates when a position or velocity discontinuity was estimated. These discontinuities are detailed on the left of the graph frame. Finally, the "Download" button below the graph allows for retrieval of the (residual) position time series corresponding to the user's view of the graph.

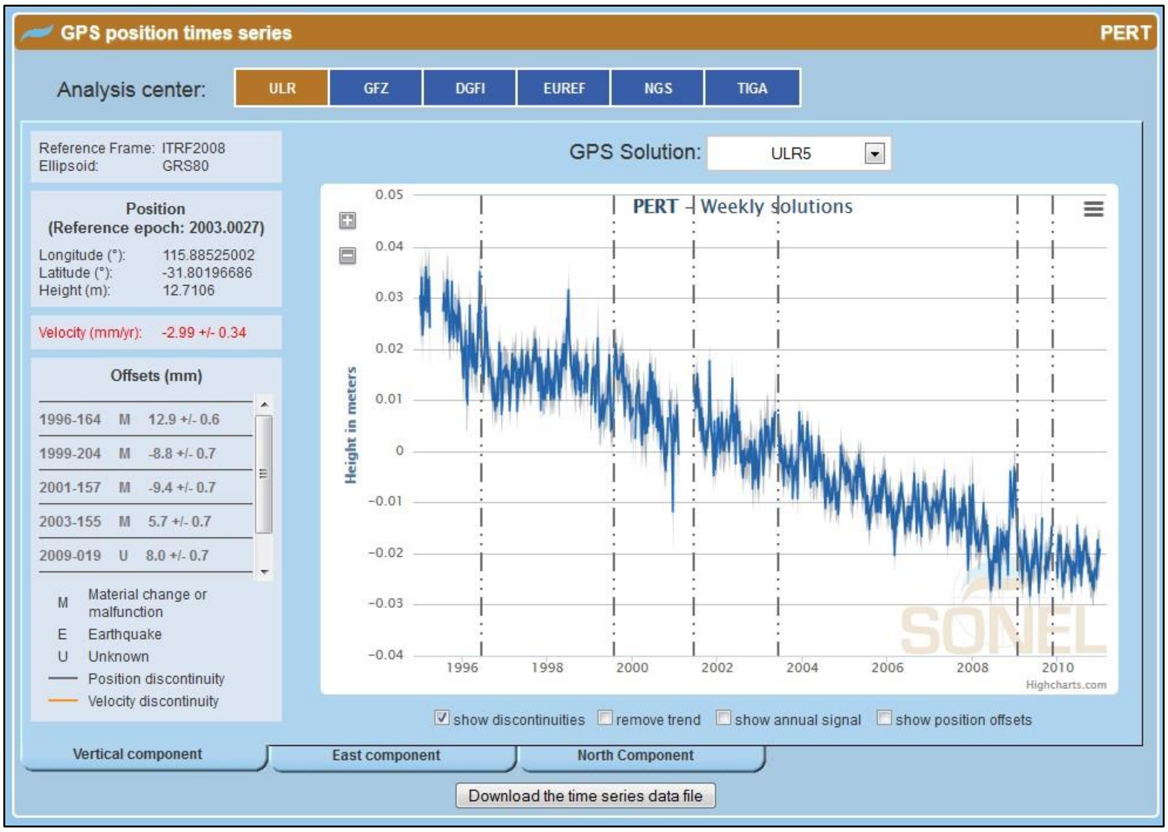

Figure 8: An example of 'GNSS solution' for the PERT station (Perth, Australia).

c) Latest GNSS solution (GPS) and GNSS solutions for GLOSS stations

The latest GNSS solution at tide gauges available on SONEL was released by the University of La Rochelle (ULR) in 2012, and is called ULR5 (see progress report in 2013). However, a new GNSS solution, called ULR6, is now imminent from this group. It was submitted to the second reprocessing campaign of the IGS. ULR6 comprises 749 GNSS stations for which the entire dataset of measurements available between 1995.0 and 2014.0 was reprocessed using the most up-to-date models and corrections available. As many as 610 GNSS stations have been identified as potentially useful for a sea-level application. Note that not all the stations cover that period of 1995 to 2014, and thus the number of stations at any given time in Figure 9 is less than this total.

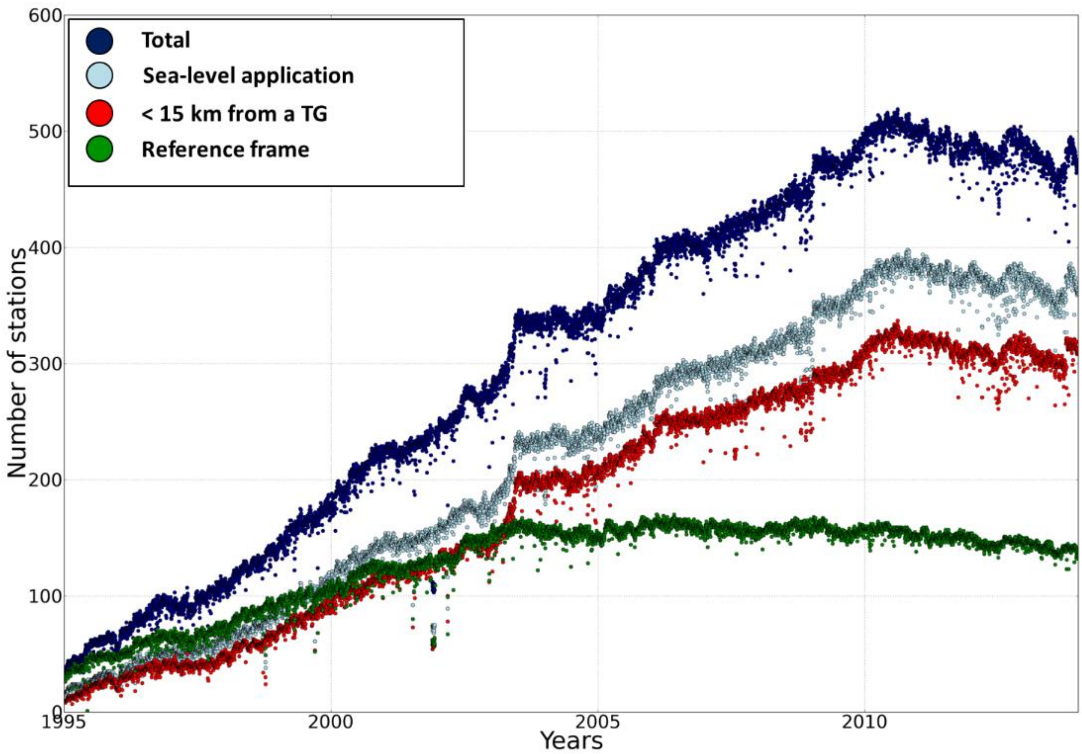

Figure 9: Number of processed stations per day in the forthcoming ULR6 solution.

A minimum of three continuous years without an offset (e.g., due to an equipment change or an earthquake) in the time series were required to estimate a “robust” vertical velocity. This duration is the minimum to limit introducing biases from the seasonal cycles. Ultimately, there were 391 GNSS stations potentially useful for a sea-level application for which a GNSS velocity was estimated. The median uncertainty on the estimated vertical velocities is about 0.36 mm/year (Figure 10).

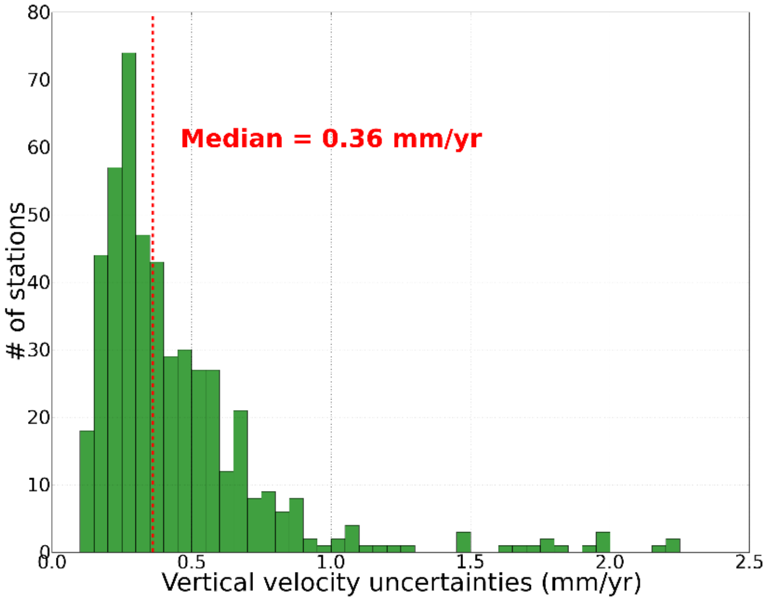

Figure 10: Formal errors on the estimated GNSS vertical velocities

Figure 11 shows the 170 GLOSS Core Network sites for which a robust GNSS vertical velocity is expected to be soon available from the ULR6 solution. It should be noted, however, that only 9 sites have the GNSS antenna within 100 m, 23 sites (9+14) within 500 m, and the others (147) are located at larger distances (Figure 12). In the latter case, the assumption that the GNSS antenna is sensing the same vertical land motion as the tide gauge requires extreme caution, hence exacerbating the need for repeated leveling campaigns to validate the assumption (Bevis *et al*., 2002; Gill *et al*., 2015). In many instances, leveling information is unavailable, thus reducing the number of effective tide-gauge-GPS pairs for GLOSS applications. In this respect, the map in Figure 11 shows an optimistic view of the real status. Appendix 1 provides additional details on each GLOSS Core Network station co-location with GNSS.

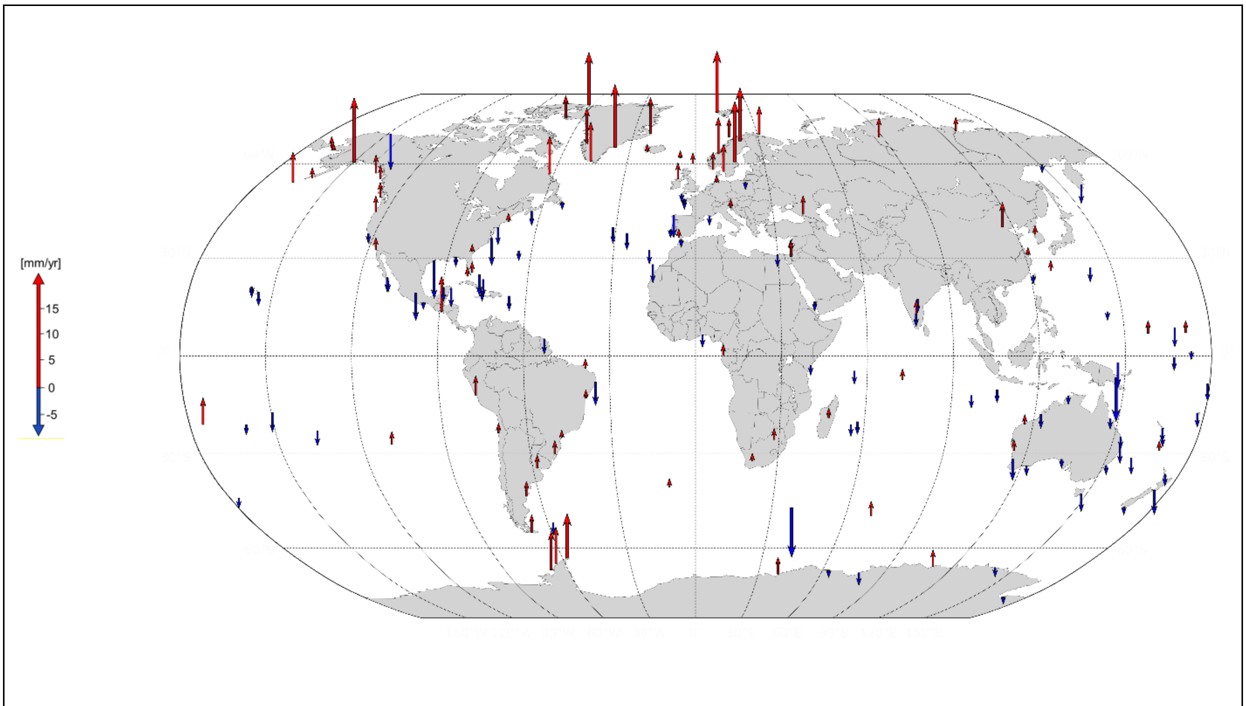

Figure 11: GNSS vertical velocity field of ULR6 solution at GLOSS tide gauges (170 sites out of 290)

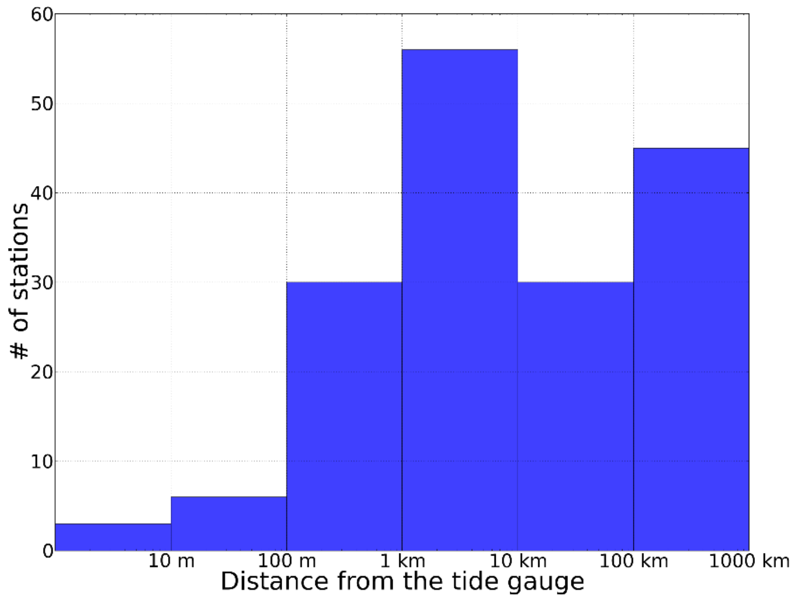

Figure 12: Distance between a GLOSS Core Network tide gauge and the closest GNSS vertical velocity (170 sites) from ULR6

3. Combined products (from the PSMSL & SONEL)

In collaboration with the PSMSL, the rates of relative sea level change (RSL) from tide gauges and the vertical land movements (VLM) estimated from the GNSS velocities have been combined to produce rates of absolute (geocentric) sea level change (ASL) following the simple relationship:

$$ASL = RSL + VLM$$

The rates of relative sea level change are provided by the PSMSL (Figure 13). These rates are calculated over a given period using the annual time series from the RLR dataset. The period can be chosen by the user between 1900 and 2013, with a minimum time span of 30 years. The computation requires 70% of data completeness over the chosen period.

The vertical land movements are estimated using the ULR5 GNSS solution available from SONEL as a demonstrative product. Note that two working hypotheses are necessary when using GPS data to correct vertical land movements in tide gauge records. The first requires that the linear vertical land movement estimated from the GPS data is consistent over the multi-decadal to century timescale of the tide gauge record. The second hypothesis requires that the land motion detected by the GPS antenna is consistent with that affecting the tide gauge at the level of a few tenths of a millimeter per year. Both are necessary working hypotheses, which have been discussed extensively in the literature. See for instance Bevis *et al*. (2002) or Santamaría-Gómez *et al*. (2012).

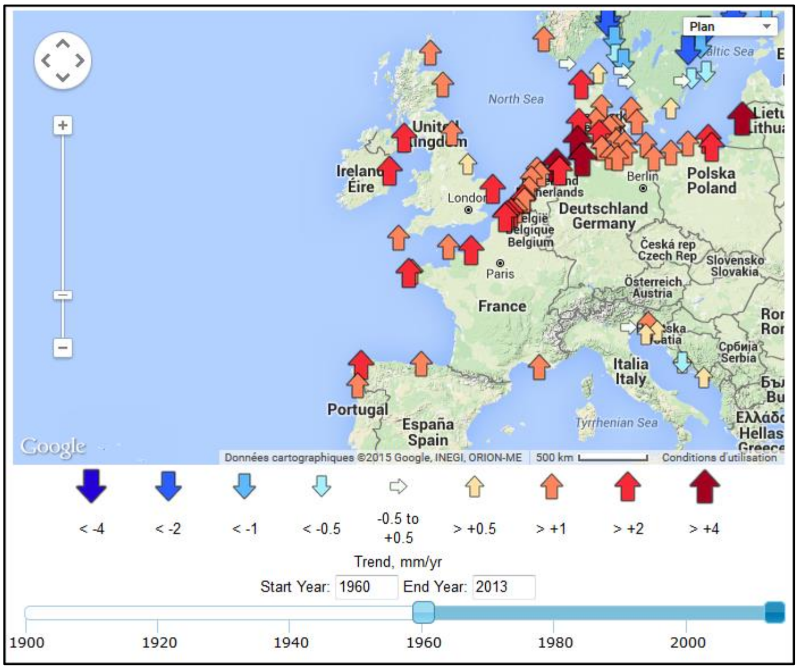

Figure 13: Rates of relative sea level change computed by the PSMSL over a given period
http://www.psmsl.org/products/trends/

Figure 14 displays the results of absolute (geocentric) sea level trends on a clickable map. By default, these are over the 1900-2011 period. The user can then select another period, either by entering the start and end of the period, or by using the scroll time span arrows below. In general, the longer the station record, the lower the error in the derived sea level trend. Based on the knowledge of many previous studies, PSMSL does not provide sea level trends for tide gauge stations with less than 30 years of data. Accordingly, the associated products in SONEL are limited in this respect to a minimum time span of 30 years.

The sea level change arrows on the map are clickable to obtain a small popup window with the station name and a summary of the data including the combined velocity or absolute sea level change, the GNSS and tide gauge linear trends (velocities), the selected time period, and the links to the station web-pages, either at the PSMSL (tide gauge) or at the SONEL (GNSS).

For a selected time period, the user can further select the region of interest (zoom options), and download the selected data as a table (.CSV format) or as a PDF file, for the stations in that region for which the computation was performed. Similarly the user can first select the region, and then the time period.

Another option is the possibility to switch from absolute to relative sea level trends, in which case the user is displaying the data computed by the PSMSL, but restricted to the stations for which a nearby robust GNSS velocity is available.

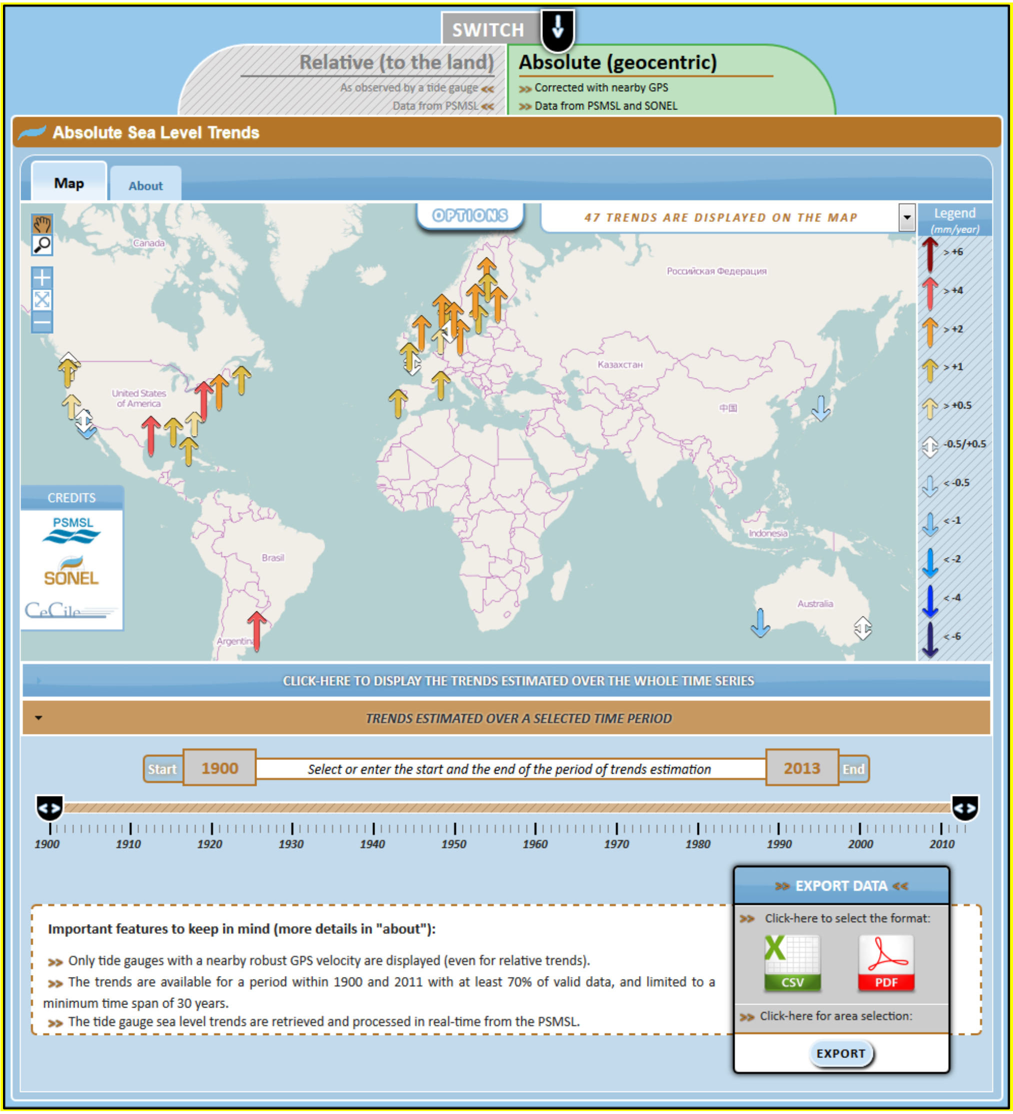

Figure 14: GNSS Absolute (geocentric) sea level trends over the 1900-2013 period
http://www.sonel.org/-Sea-level-trends-.html?lang=en

III-Future work

1. Finalization and distribution of the ULR6 solution

The ULR6 GNSS solution presented earlier in the report is not yet available on the SONEL website. The major reason is that the ULR group is now finalizing the solution by incorporating the lessons learned from the participation into the IGS reprocessing campaign. It is expected that the final solution be available in the 1st half of 2016.

2. Other vertical velocity solutions (TIGA, DORIS…)

SONEL has been developing its infrastructure to cope with different GNSS solutions, that is, updated solutions from a given analysis center, but also solutions from other groups within the GNSS area or from other geodetic methods. That said, only state-of-the art solutions at the time of submission will be considered; the standard criteria being at least the adoption of the latest IGS-agreed models and corrections. Figure 8 indicates how the user may choose a particular solution (the analysis centers displayed in Figure 8 are tentative and only serve as an example at this stage). Interestingly for the users, either for comparison or for supplemental data in areas without GNSS, DORIS solutions are envisaged with the CLS group via the International DORIS Service. The question whether absolute gravity may be provided has been considered as well, even though too few groups have invested in this costly but accurate geodetic method.

3. New products for satellite altimetry and height system applications

The focus of SONEL developments has initially been to implement user-friendly tools (i) to access the GNSS data, and (ii) to determine the combined rates of sea level change (section II) with the PSMSL colleagues. Other combined products can be envisaged, in particular for satellite altimetry applications or geodetic and hydrographic datum connections. For these applications, however, the geodetic connection between the GNSS antenna and the tide gauge is critical. This is also important data for studies of long term trends in sea levels, even though one can make the somewhat reasonable (or not) assumption of local stability when this data is missing.

SONEL attempts to gather all the available geodetic connections (mostly leveling results) for the tide gauges and integrate those into its database. It includes the connections with nearby DORIS stations (about 30 DORIS stations are nearby a tide gauge). Figure 15 shows that 135 tide gauges have a geodetic link to a GNSS station on SONEL, and 5 tide gauges with a DORIS station. Among the 135 tide gauges, 68 belong to the GLOSS network (Figure 16).

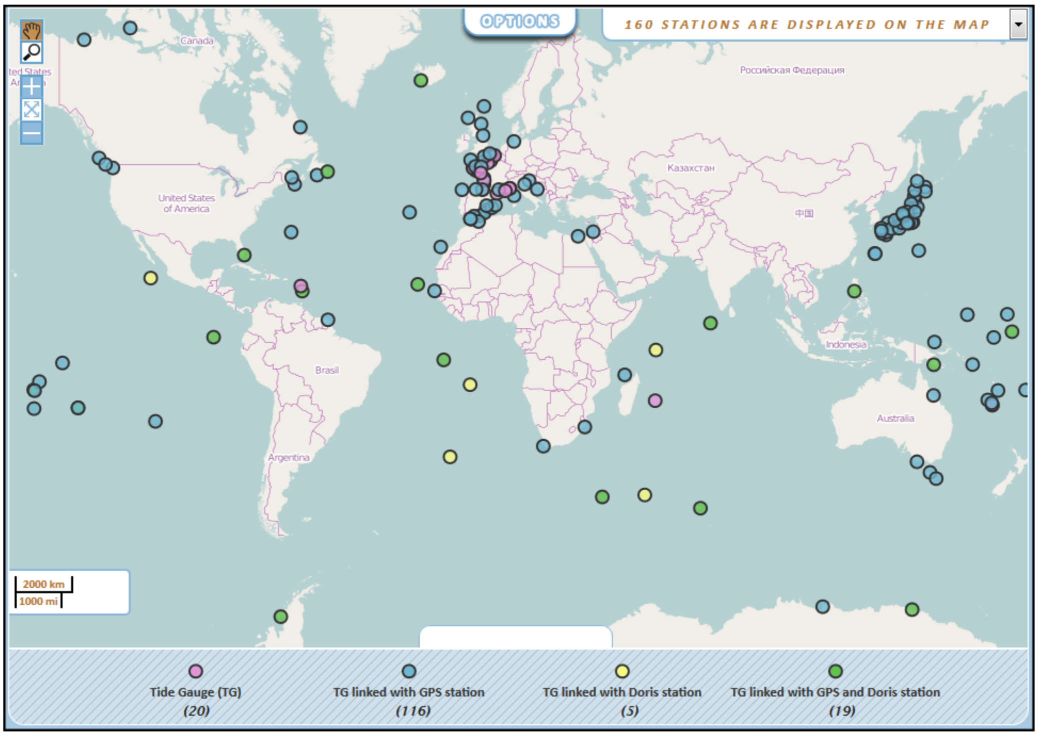

Figure 15: Status of the leveling campaign data at tide gauges stored in SONEL
http://www.sonel.org/-Stability-of-the-datums-.html?lang=en

A major challenge is the analysis of reports from leveling campaigns, aimed at linking the tide gauge data reference level (for instance the RLR when the data are retrieved from the PSMSL) and the GNSS antenna reference point. For instance, many of the leveling reports are observing tide gauge benchmarks that are not reported in the PSMSL data base or in the PSMSL diagrams. These diagrams are useful to showing where the tide gauge reference level or RLR is. Another difficulty is the identification (name) of the benchmarks which are not the same in leveling report or in the PSMSL data base, making it difficult or impossible to guess if they are actually the same.

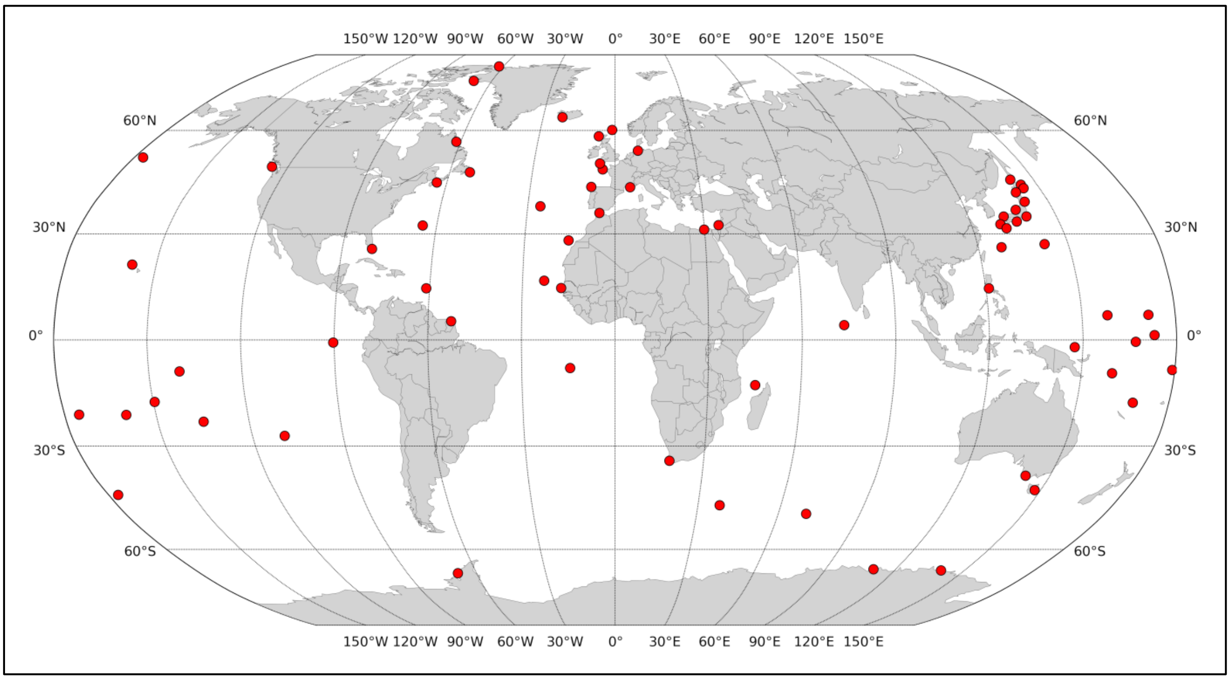

Figure 16: GLOSS tide gauges for which the geodetic connection with the nearby GNSS station is known in SONEL.

Figure 17 further highlights the missing geodetic connections. These are currently known for only 14% of the GNSS co-located tide gauges in SONEL. About 114 tide gauges (Figure 17, orange circles) are within 1 km from a GNSS station, but for which the geodetic connection at present is unknown in SONEL.

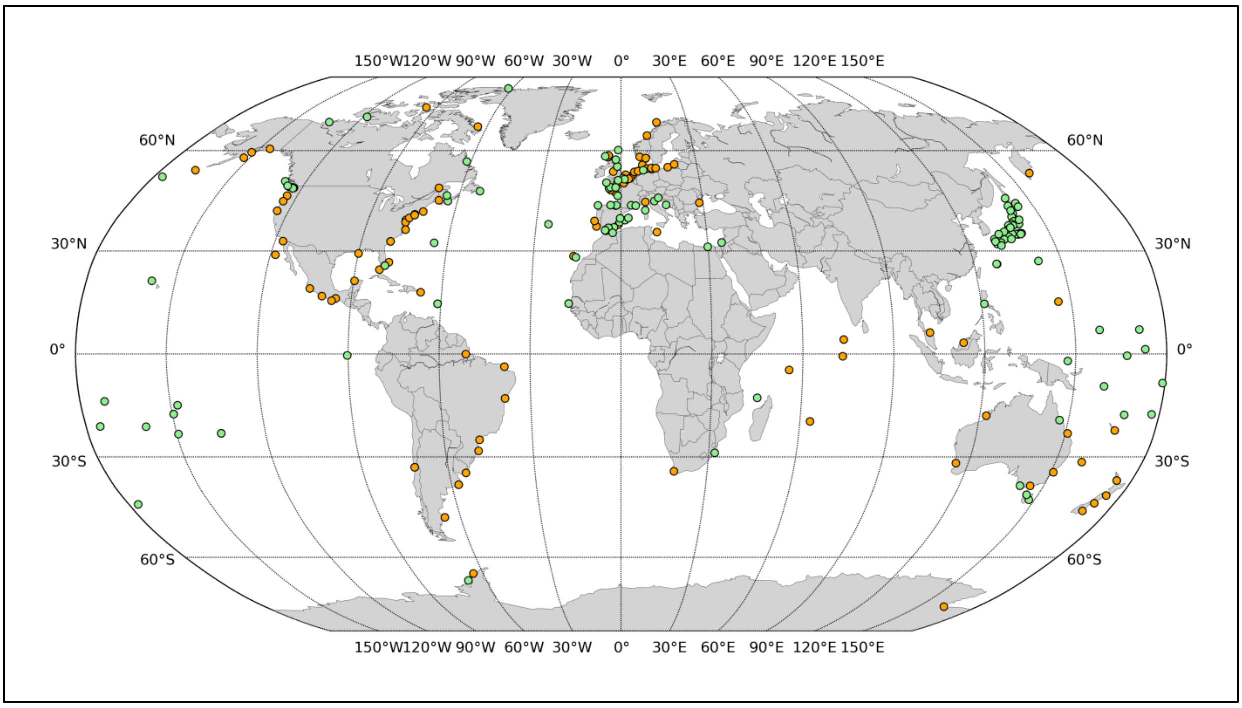

Figure 17: Tide gauges with a known geodetic connection to a GNSS antenna in SONEL (green circles) and tide gauges without that information but within 1000 m from a GNSS antenna (orange circles).

4. Summary of major limitations today

The major limitation for the GLOSS applications is the availability of continuous GNSS station at the very tide gauge locations (long term trends, satellite altimetry, datum unification). Only 18% (52 out of 290) are co-located at a GLOSS station (at or within 100 m). Progress is still needed in this respect to fulfill the GLOSS Implementation Plan requirements (IOC, 2012) for a core network station.

Another important issue is the free and open access to the relevant GNSS observation following the international guidelines of the IGS/TIGA, that is, daily files in RINEX format with a 30s sampling.

Equally important is the need for information on the equipment changes or any change of its immediate environment (metadata) as soon as possible by updating the GNSS station log-sheet, which should follow the IGS standards, and to inform the SONEL network station manager, Ing. Elizabeth Prouteau (elizabeth.prouteau@univ-lr.fr).

Last but not least, whenever the GNSS station is not directly installed on the same tide gauge roof or ground, it is necessary to undertake repeated leveling connections for at least five years to assess that the GNSS antenna and tide gauge are not experiencing differential land motions at 0.1-0.2 millimeter per year level (Bevis et al., 2002; Gill et al., 2015). In any case, the availability of the initial connection is critical for satellite altimetry comparisons or calibrations, and vertical reference unifications on land (height systems) and sea (chart datums).

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