Computing Mean Sea Level Changes in Ghana

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SUMMARY

The mean sea level is commonly used to define the vertical datum since it provides the materialization of an equipotential surface. Tide-gauges are normally used to estimate the mean sea level by averaging (preferably) continuous observations of the vertical variations of sea level with respect to physical markers located at solid ground. The time-series should be long enough in order to remove variations associated with tides and other short-period effects. Furthermore, the tide-gauges also allow one to estimate variations in mean sea level by fitting simple polynomials (normally straight lines) through the mentioned (or longer) observations. However, there is an ambiguity associated with any observed variation of the mean sea level with respect to the ground reference: when it is observed a positive vertical variation the question is if it is the sea level rising or it is the ground subsiding.

Such ambiguity can be efficiently removed by installing Global Navigation Satellite Systems (GNSS) stations as close as possible to the tide-gauges. Since the vertical positions directly derived from GNSS observations are completely independent of the sea level variations (they are referred to the ellipsoid), they allow one to remove the mentioned ambiguity, and consequently, to evaluate absolute variations of sea level.

The tide-gauge located at Takoradi, Ghana is one of the oldest tide-gauges in Africa (1927). It was recently upgraded with a radar gauge (2006). In addition, the Survey Department of Ghana initiated the installation of a network of permanent GNSS sites, including one in Takoradi. However, the distance between the tide-gauge and the GNSS marker is quite large (approximately 2Km). Such distance can introduce some noise due to local variations between both points. Therefore, in order to evaluate such variations, a second GNSS station was recently installed very close to the tide-gauge and all markers accurately tied using precise levelling. Such configuration (2 permanent GNSS sites collocated with a tide-gauge) is quite unique worldwide, allowing one to conduct specific research studies.

In this work, we focus on evaluating the quality of the procedures carried out to tie all instruments and in the direct comparison between the results obtained by the geometric levelling with the ellipsoidal vertical differences between the two permanent GNSS stations. We expect that the used procedures will allow one to accurately measure absolute sea level variations in this region of Gulf of Guinea.

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1. INTRODUCTION

The earth and sea levels are not the same over a period of time. A vertical variation can occur due to natural phenomena (e.g. earthquakes) and/or human phenomena (e.g. large variation of subsurface water). Such variations need to be monitored. The use of tide-gauge allows monitoring vertical variations of sea level.

The vertical datum is normally defined by the mean sea level that provides the materialization of an equipotential surface. Tide-gauges are normally used to estimate the mean sea level by averaging continuous observations of instantaneous sea level. The time-series should be long enough in order to remove variations associated with tides and short-period effects. This allows us to quantify possible variations in the mean sea level. However, when we observe a positive vertical variation one question can be made: is the ground subsiding or is the sea level rising?

Installing GNSS stations as close as possible to the tide-gauge and connecting them can help to remove this ambiguity efficiently. GNSS observations can provide vertical variations in time with respect to a reference ellipsoid (normally, WGS84). Since such reference is fixed in space, we obtain directly the absolute movement of the GNSS site (uplift or subsidence). In order to know the absolute movement of the tide-gauge, a first-order levelling must be performed in order to connect the GNSS station(s) with the tide-gauge and additional benchmarks of the local vertical geodetic network. This levelling has to be repeated in time in order to verify if no internal movements exist between the points of the local geodetic network.

2. VERTICAL DATUM OF GHANA

The vertical datum for Ghana at the moment is defined by the reference to the mean sea level obtained from the tidal observation from a point in Accra from 9th April 1922 to 30th April 1923. This was linked to an established monument GCS 121 which was consequently linked to the trigonometric network to obtain the orthometric heights for the points in the network [Ayer & Fosu, 2006]. This reference point in Accra was used for the first primary levelling from Accra along the main road to Takoradi which started in 1933, by which time the tide gauge at Takoradi (installed in 1927) had been established, and was referenced to the primary level. Due to the significant changes in the mean sea level at Takoradi annually, another tide-gauge was established at Tema for the sake of comparison and control for the levelling in the country (cf. Figure 1).

As mentioned, vertical variations of the tide-gauges can also be expected due to solid Earth motion phenomenon like the tectonic plate movement. In the case of Southern Ghana, where these tide-gauges have been installed, the derived seismic activity can be an important cause for sudden variations. Two major earthquakes occurred on the mainland in Accra in 1862 and 1906 and one offshore in 1939, which was after the establishment of the vertical datum using the Accra tide-gauge. The use of integrated systems (GNSS plus tide-gauges) can also contribute to monitor and quantify such movements with direct consequences in the Vertical Datum of Ghana.

Figure 1 – Location of the existing tide-gauges in Ghana**.**

The tide-gauge in Takoradi was upgraded in 2006 with a radar gauge with the support of Proudman Oceanographic Laboratory (POL). This tide-gauge is part of the Global Sea Level Observing System (GLOSS), an international programme conducted under the auspices of the World Meteorological Organisation (WMO) and the Intergovernmental Oceanographic Commission (IOC). GLOSS aims at the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research [IOC, 1997].

3. GNSS AND BENCHMARK INSTALLATION

In 2007, Instituto Geofísico D. Luíz (CGUL/IDL) from Portugal in collaboration with Survey Department of Ghana (SDG) and Building and Roads Research Institute (BRRI) of Ghana, submitted a project to ODINAfrica (http://www.odinafrica.org/) and UNESCO called GNSS Upgrades In Tide-gauges of Africa (GUITA) with the major goal of installing three GNSS permanent stations collocated with tide-gauges in Ghana (Takoradi) and Mozambique (Pemba and Inhambane). Such project was carried out during the second semester of 2007 and beginning of 2008.

Figure 2 – Details of the installed GNSS stations in Takoradi: TADI station installed by SDG (above); TKTG station installed by CGUL/IDL-SDG-BRRI (below left) and position of TKTG with respect to the tide-gauge (below right)**.**

In Takoradi, there was already a GNSS permanent station (cf. Figure 2). In fact, SDG initiated the installation of a network of permanent GNSS sites in 2007, one of which is installed in Takoradi (TADI). However, the distance between the tide-gauge and the GNSS site is quite large (approximately 2km). In such distances, vertical variations due to local heterogeneities may be present causing that the absolute vertical motions on the GNSS site and on the tide-gauge can differ. One way to verify possible relative variations is to perform repeated levelling surveys through the years. However, this has some disadvantages, namely the extensive resources required to accomplish this survey of several kilometres. Furthermore, in case of TADI, the marker is located in the roof of a building (cf. Figure 2), which force to combine geometric with trigonometric levelling (less precise). This can cause degradation in the quality of the solution for the vertical difference between the GNSS site and the tide-gauge, as we will discuss

.

Therefore, it was decided to install a second GNSS station, coded TKTG, in the proximity of the tide gauge (about 40m) in 2008. This station will permit to know the absolute variations of the local area where the tide-gauge is located. Notice that since the tide-gauge is located in an old pier, it does not ensure stability, and consequently, the existence of local variations is probable. TKTG is located on a slightly stable area formed by compacted sediments. However, the relative motion between TKTG and the tide-gauge can be easily observed periodically due to the short distance between both markers. And, consequently, the absolute vertical variation of the tide-gauge itself estimated.

Since TKTG is also not installed in a very stable area, the observed vertical variations might be not representative of the true vertical variations for the region of Takoradi. However, the direct measurement of the baseline between TKTG and TADI will permit to evaluate the true vertical motion of the tide-gauge

.

In addition, some benchmarks were installed near the above system, allowing a more efficient and precise tie between these systems. The installation of benchmarks permits more efficient levelling surveys between the GNSS systems and the tide-gauge. Furthermore, in case of unavailability of one of the systems or some the benchmarks, the network can still be reconstructed.

Figure 3 details the location of all benchmarks that were observed and the location of the two different systems (GNSS and tide-gauge).

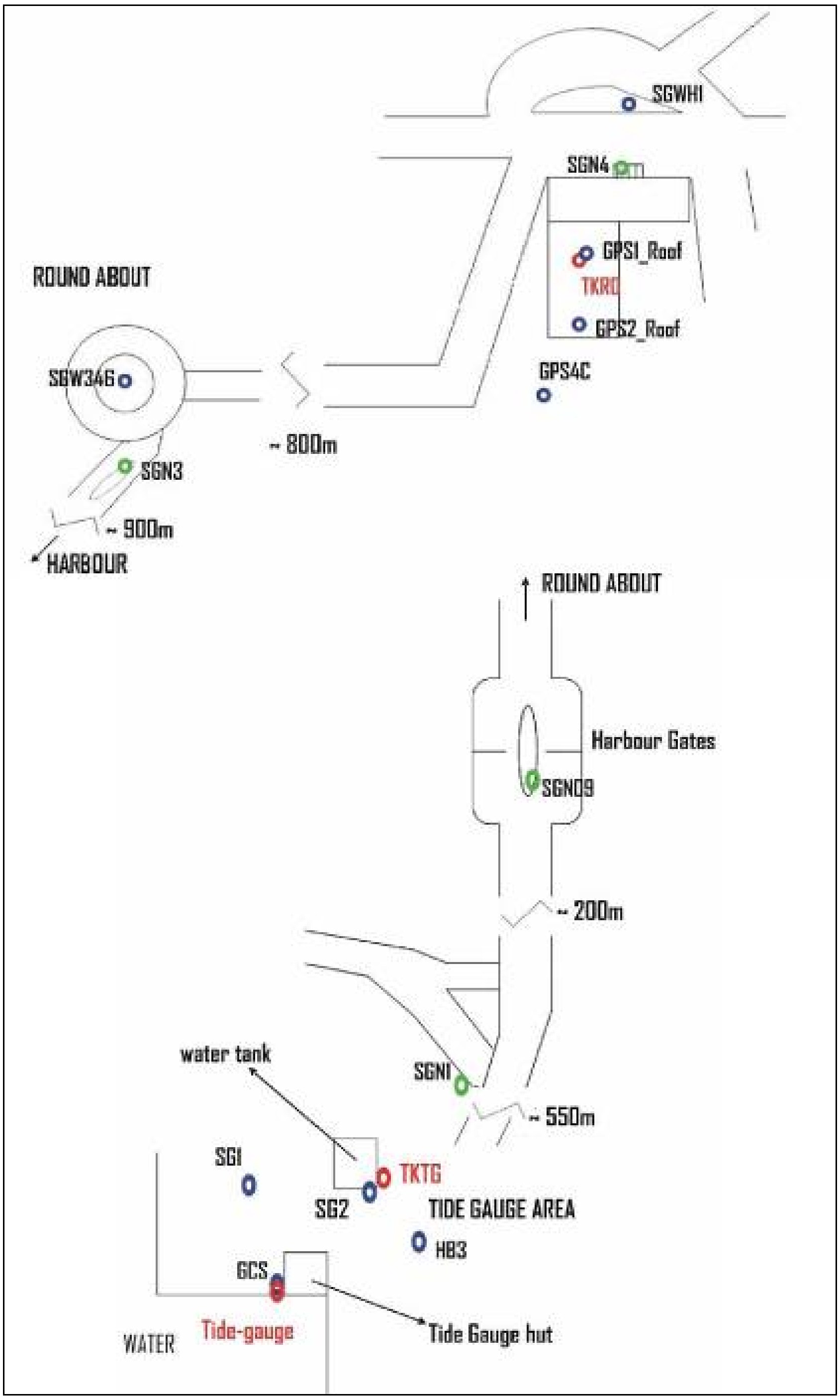

Figure 3 – Sketch of Takoradi SDG office (where TADI is installed) and harbour (where TKTG is installed) areas. The components of the geodetic network are shown: TADI and TKTG GNSS Stations and tide-gauge (red) together with existing (blue) and installed (green) vertical benchmarks**.**

4. DATA ACQUISITION AND PROCESSING

4.1 Leveling

A high-precision levelling was conducted between the two GNSS stations, the benchmarks and the tide-gauge using an automatic level.

In the high-precision levelling, seven closed circuits between the GNSS stations and the tide-gauge were surveyed. All of these circuits were observed two times and the closing error varied between 1mm and 2mm, which is under the tolerance for high-precision levelling.

However, the location of the TADI marker on the top of the roof, forced us, as already mentioned, to carry out a trigonometric levelling to connect it with the surrounding benchmarks. This task had some problems due to the absence of proper equipment. Logistics issues forbid us to make use of the equipment initially planned. They had to be replaced at last minute by local theodolites with much less precision. Furthermore, due to lack of time, no local check of the acquired observations was done. The consequence was that gross errors were committed that are reflected in the results. This levelling is planned to be repeated by May 2008.

4.2 GNSS Data Processing

The coordinate solutions were obtained using GIPSY [Zumberge et al., 1997], a well-recognized academic processing software package. Figure 4 summarizes the procedures used is order to compute a unique solution for the positions of the two stations with respect to ITRF2005.

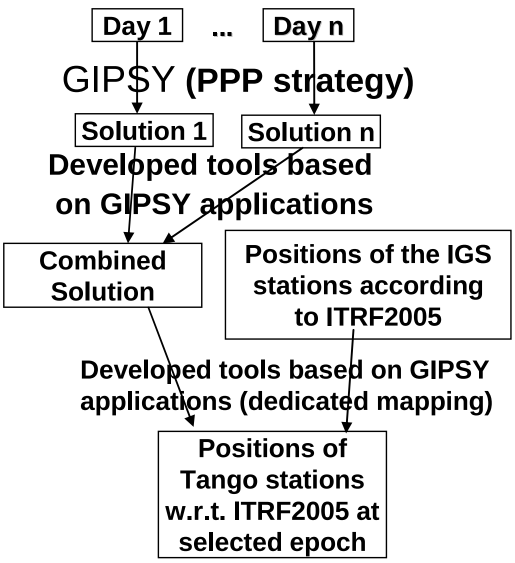

Figure 4 – Methologhy used to compute the coordinate of the GNSS stations with respect to ITRF2005.

Daily files between 23rd and 31st January 2008 were used to compute the solutions for both stations. First, each day was processed by computing station-by-station position using the Precise Point Positioning (PPP) strategy. Next, the daily solutions were combined into a single-campaign solution by computing optimized 7-parameter Helmert transformations. The reference daily network solution is arbitrarily selected. The campaign solutions are still in an unknown reference frame: the frame of the orbits of the chosen daily reference. A global reference network is used to project over the selected epoch (31st January 2008) using the position and velocity solutions retrieved from the ITRF2005 data set. These stations are then projected into the reference network by estimating another 7-parameter Helmert transformation.

In order to evaluate the variation in the vertical component of TADI, another set of data from 30th May to 5th June 2007 was also processed. In this way, two different ellipsoidal heights were computed for TADI, spanning a period of about 8 months.

5. RESULTS

5.1 Comparison between Ellipsoidal Heights for TADI

Table 1 shows the values obtained for the ellipsoidal height of TADI computed by combining the solutions for several days at two different epochs (June 2007 and January 2008).

Table 1 – Comparison between Ellipsoidal Heights (TADI).

Epoch	**Ellipsoidal Height (m)**	**Standard deviation (m)**	**Daily files**
June 2007	59.3544	0.0012	7
January 2008	59.3549	0.0013	5

These results show that there is no significant variation between the vertical position of the TADI station for the period considered. Although this time-span is too short to derive any definitive conclusions about the stability of the TADI station on the vertical component, these results point into that direction.

5.2 Comparison between Ellipsoidal and Pseudo-Orthometric Height

Table 2 compares the values computed for the ellipsoidal and pseudo-orthometric heights for TADI and TKTG for January 2008. We use here the expression “Pseudo-Orthometric” because our zero was assumed to be on the tide-gauge marker. Although close to the orthometric national system of Ghana, it is not identical, therefore the prefix “pseudo” was introduced to make such distinction.

Table 2 – Comparison between Ellipsoidal and Pseudo-Orthometric Heights.

Site	Ellipsoidal Height (m)	Pseudo-Orthometric Height (m)	Pseudo-Geoid Undulation (m)
TKTG	28.366	2.981	25.385
TADI	59.355	33.669	25.686

The first conclusion is that a gross error should be present on the levelling survey. It is not possible a variation of 30cm in such a short distance. Since all geometric levelling surveys had redundant observations, the error is probably on the trigonometric survey. As already mentioned, the reobservation of the points surveyed with trigonometric processes will be done.

As mentioned, it is not possible to compare these results in absolute terms, although they are not distant of the values predicted by global models (e.g., NGA [2007] predicts a geoid undulation of 23.07m for this area) because no real orthometric reference were used. We intend to connect the local network to the Ghanaian national vertical datum in the near future in order to be able to use this network as vertical fiducial points in Ghana.

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BIOGRAPHICAL NOTES

Rui M. S. Fernandes is Assistant Professor of University of Beira Interior and Associated Researcher of Center of Geophysics of University of Lisbon / Institute Geophysical D. Luíz. He obtained the MPhil in Geomatics Engineering by University of Coimbra, Portugal (1990) and he has the Ph.D. in Earth and Space Sciences by Technical University of Delft, The Netherlands (2004). His current research topics are focused on the application of Geodetic Space techniques to Geodynamics and Reference Systems, in particular in Africa. He belongs to some organizations like American Geophysical Union and is member of IAG (International Association of Geodesy) working groups.

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