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GPS Sea Level Measurement Device

The benefit of satellite navigation systems for Tsunami early warning systems

Bavaro M., Galliano D., Annunziato A.,Fortuny-Guasch J.

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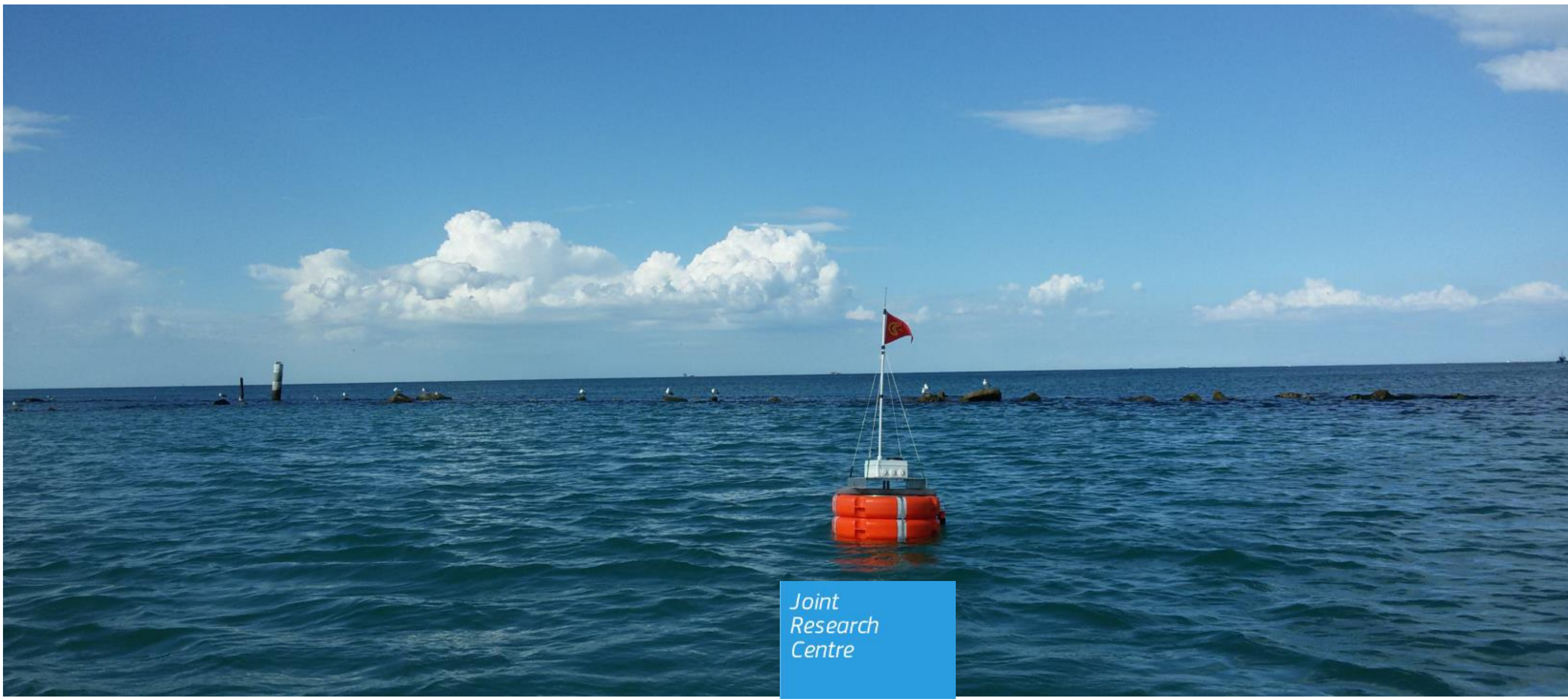

Joint Research Centre

Contact information
Name: Alessandro Annunziato
Address: IPR-68 00/021
E-mail: alessandro.annunziato@jrc.ec.europa.eu
Tel.: +(39) 0332 789519

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Abstract

This report describes the design, development and test activities of the inexpensive GNSS-based sea level monitoring device. The objective of the campaign was to demonstrate the feasibility of using a low cost Differential Global Navigation Satellite System (DGNSS) based sensor to measure and ultimately monitor in real-time the sea level. As the distance from the coast increases, the target application of predicting anomalous waves and alerting the population becomes more and more realistic. At the same time, errors between reference and deployed receiver tend to become less correlated and therefore the DGNSS process more challenging. The instrument builds on Galileo-capable single frequency GNSS receivers and ISM band radio transceivers used in combination with open source RTK software.

The description of the work can be split in two main phases: before and after the first demonstration, up to the second recently carried out experiment in the Adriatic Sea.

1 Introduction

In the frame of the Administrative Arrangement between JRC and DG-ECHO, JRC developed a relevant activity on Sea Level measurements in order to support the Member States of the North East Atlantic and Mediterranean Tsunami Warning System (NEAMTWS) of UNESCO to improve the monitoring capabilities of Tsunami events.

The objective of the work package was the installation of two floating GPS devices in the Atlantic Sea, in front of Portugal Coasts. In order to achieve this objectives 2 call for tenders have been organized by JRC and both received no offer. The reason was mainly due to the fact that this instrument is not yet mature from commercial point of view and no company considered appropriate to embark themselves in an uncertain activity never tested before. For this reason, in agreement with DG-ECHO it was decided to modify the work package and instead develop the following

- Installation of a Sea Level Network of Inexpensive Device for Sea Level Measurement (IDSL) in close collaboration with UNESCO/IOC
- In-house development and testing of a new instrument based on a floating differential GNSS-equipped device

The great importance to have an off-shore measurement for Tsunami Monitoring is justified for two main reasons. The need to measure the sea level off-shore in order to identify a potential damaging wave in time to have some minutes or tens of minutes of lead time before the wave reaches the coast ; the ability to measure the tsunami wave in open waters and not inside ports allows to have a more clear estimation of the size and the form of the wave, not modified by the internal structures of the ports.

The measurement of Sea Level using differential GPS is not a new technique and is currently extensively adopted by Japan [2]. The cost of these devices is however extremely high and their dimensions so large that the installation becomes problematic for most countries. The concept is based on the estimation of the 3D location of the GPS antenna located on the off-shore device in comparison with the similar antenna positioned at the base station. The distance between those two points cannot exceed 20 km in order to ensure that both receivers see the same set of satellites.

The availability of more affordable GPS receivers, connected with the newly created GNSS constellation allows to explore the possibility to develop a low cost floating GPS device that can be extremely useful for the monitoring of sea level around the Mediterranean Sea.

The present report, that complements the final report of the MIC7 Administrative Arrangement, reports the status of the GNSS-based IDSL measurement device.

2 *Evaluation and Proposed Solution*

Many are the possible ways to address the challenge of monitoring the sea level far away offshore, depending on the paradigm chosen. One possible choice is of course the use of a single expensive multi-frequency multi-constellation GNSS receiver, performing a combination of Real Time Kinematic (RTK) and possibly Kinematic (Precise Point Positioning) PPP. Another, perhaps equally intriguing solution is the use of many single-frequency low cost sensors connected in a mesh network which allows spanning a wider area and detecting wave fronts rather than punctual heights. In the first case the usual base-rover approach can be used, in the second case a moving-baseline would be more appropriate instead. In order to have a platform flexible enough to experiment all such solutions the widely known RTKLIB open source RTK software was chosen.

2.1 GNSS receiver

Nowadays the vast majority of single frequency GNSS receiver modules and chips are capable of code-differential positioning, usually as an alternative to SBAS, with limited support to the RTCM protocol. However, from the point of view of differential phase processing, they can be divided in three categories:

- "Type 1": those that do not explicitly provide reliable carrier phase. To this category belong the vast majority of mass-market products such as the Mediatek MT333x, the Qualcomm SiRFstar IV/V, the STMicroelectronics Teseo II/III, and so on. They can be sourced for arbitrarily low prices.
- "Type 2": those which output usable raw observables (pseudorange, carrier phase, Doppler and C/N0) but cannot perform phase ambiguity resolution. Here the uBlox 7P and M8T, the Skytraq S1315F8-RAW, and the NVS NV08C-CSM/MCM. Their price is in the few tens of Euros range.
- "Type 3": those capable of performing carrier phase ambiguity resolution inside, such as the NVS NV08C-RTK, the Skytraq S2525F8-RTK and lately the uBlox M8P. They are priced around a few hundred Euros.

During the pilot project most "type 2" receivers were tested but eventually the uBlox NEO-6T and M8T were chosen mainly because they were easier to source in a European framework. "Type 3" receivers were also tested, but using a bespoke open source RTK engine was seen as a good opportunity to first learn and then eventually optimise and improve the algorithms.

The most straightforward way to assess the usability of a module for RTK is verifying the carrier phase double differences in zero-baseline. When two receivers are connected to the same antenna and tracking steadily, both their Phase Lock Loops (PLLs) align the carrier phase to the signal incident at the antenna maintaining an integer number of cycles against the satellites antenna phase centre. The only exception could be a half-cycle ambiguity if an *atan()* discriminator is used and the navigation data are decoded by the receiver in counter-phase, which is perfectly viable due to the polarity-insensitive nature of data decoding of GPS. The two phase observations are indeed different numbers, but their difference shall be integer and fixed until slips in either receiver occur. It is important to perform the differences at the same precise epoch time, or the relative movement of the satellites respect to the receiver will cause the phases to build up to a different amount amongst the visible satellites and thus non-integer inter-satellites differences may show up.

In the following a sample zero-baseline dataset collected with a pair of uBlox NEO-M8T with a rooftop antenna on June 13th in Ispra at 20:00 UTC is shortly described. The GPS double differences between two M8T receivers are shown in Figure 1.

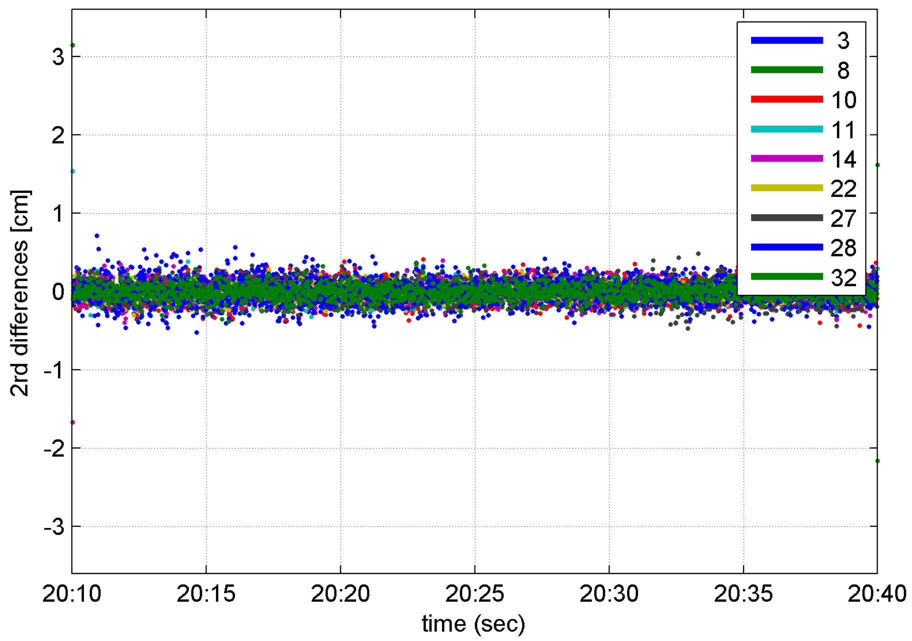

Figure 1: Double differences on GPS satellites between two uBlox NEO-M8T receivers in zero-baseline configuration. Their standard deviation is significantly smaller than 1 cm

Incidentally, uBlox released this year a Galileo capable firmware for their latest timing and high-precision products, so the Galileo carrier phases could also be analysed, see Figure 2. GSAT0203 (E26) was used as reference satellite, but the phase residuals for GSAT0102 (E12) do not always converge towards zero as the C/N0 of the satellite was floating around 30 dBHz.

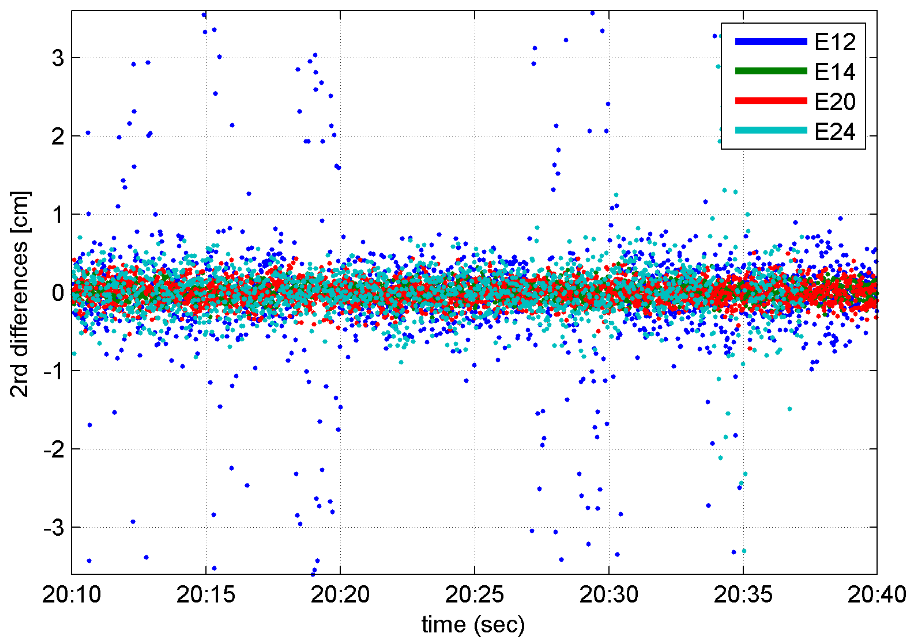

Figure 2: Double differences on Galileo satellites between two M8T with firmware version 3.01 TIM 1.10. The standard deviation is slightly higher than for GPS, suggesting that different tracking loop parameters are used for the European constellation.

Unlike Code Division Multiple Access (CDMA) systems, Glonass uses Frequency Division (FDMA) and therefore satellites broadcast on slightly different carriers, spaced by integers of 562.5 kHz. This causes the carriers to experience slightly different group delays when passing through the analogue front-end (filters and amplifiers). Such delays are fixed and can be calibrated but result in non-integer double differences otherwise, as shown in Figure 3.

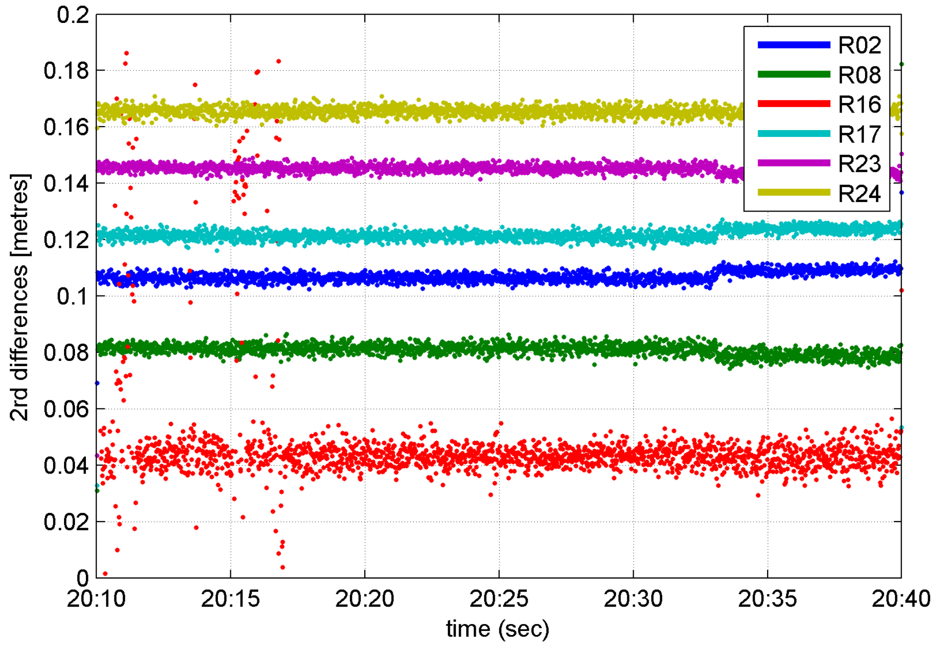

Figure 3: Double differences on Glonass satellites between two M8T modules. It can be seen that double differences do not sit on multiple of integer wavelengths but rather have arbitrary fractional residuals.

In the analysis above, R01 was used as reference satellite, and it is quite clear that R16 is experiencing cycle slips having a C/N0 around 30 dBHz.

For the reasons above it was decided not to use Glonass but just a combination of GPS and Galileo. The antenna of choice was a Tallysman of the Accutenna™ family.

2.2 Radio link

In order to establish a serial communication connection between base and rover modules, a simple radio modem can be used. Common serial cable replacement radios exist in unlicensed and ISM band, respectively at 2.4 GHz and 868, 434 or 169 MHz. The characteristics vary very much, but typically 2.4GHz radios are short range, whilst ISM band modules allow reaching as far as several kilometres. Many factors play in being able to achieve long range communication, but the most crucial one for a temporary deployment is probably being able to have a clear line of sight signal path. The maximum radius of the first Fresnel zone is

F_1=1/2 √(cD/f)

And a rule of thumb, 80% of the ellipse should be free from obstacles in order to have line-of-sight radio link performance. Assuming that the buoy antenna can only be at about 1 or 2 metres above the sea level, at 868 MHz the base antenna height for a 10km link should be more than 100 metres, which is not easy to achieve. Considering that Free Space Path Loss

FSPL=(4πdf/c)^2

where d is the distance, f the frequency in Hertz and c the speed of light, depends on the square of the frequency it may seem beneficial to use sub-GHz frequencies. However in some cases one may decide to trade FPSL to improve on the Fresnel zone clearance.

All tests were conducted using a pair of Xbee-Pro 868 configured with 100 mW output power. The communication rate is fixed at 24kbps, but the firmware imposes a time duty cycle limitation of 10% in order to comply with regulatory requirements thus allowing only about 2400 bps for continuous operation. If such figure is exceeded during the communication, the module goes in an idle state which requires either waiting an arbitrarily long time or a reset. Duty cycling makes sense in a crowded environment, but is clearly sub-optimal in a point-to-point link over the sea as the receiver sensitivity does not benefit from the 10dB that the Shannon–Hartley theorem should guarantee given the reduced amount of information in the channel. The declared sensitivity of XBee Pro 868 is around -112 dBm.

2.2.1 LP-WAN technology

Interestingly, technology has recently made a leap forward in Low Power Wide Area Networks (LP-WAN). Two radically different approaches are used to achieve long range communication for IoT applications: on one side modulations like LoRa, on the other those used by Sigfox. LoRa is a Chirp Spread Spectrum (CSS) modulation which leverages spreading code gain whilst SigFox uses a more conservative narrowband FSK. By having a narrowband signal a tight receive filter can guarantee very little amount of noise to pass through with a consequent increase of SNR. Both allow trading channel capacity for sensitivity, which should guarantee much longer distances to be achieved between base and buoy. However the LoRa modulation would be preferred in our case as a wideband signal allows ranging on its own. In the next phase of the project, a new module from HopeRF will be evaluated: the HM-TRLR-S which is capable of both LoRa and narrowband FSK modulations. In comparison with the above Xbee, LoRa declares a sensitivity of -126 dBm for a 3125 kbps link, which is 60 times better.

2.3 Hosting platform

RTKLIB is open source and can be compiled for both Windows and Linux. Several small embedded PCs with relatively low power consumption exist in the market so the choice is not trivial. The main trade-offs between power consumption, interfaces, computing power, software support and price brought to the evaluation of .the RaspberryPi family, the various Beaglebones, the Odroid family, the Intel Edison and others. Finally the RaspberryPi model A+ was chosen, mainly because of the following characteristics:

- Power consumption lower than 1W
- USB, I2C, or SPI port for the GPS
- Serial or SPI port for the radio link with the base
- Computing capacity for about 10 standard instances of RTKLIB per second
- Low cost (about 20 EUR) and small size (65x56 mm2)
- Largest community support

In view of a remote deployment, a daughterboard for the Single Board Computer (SBC) was designed (see Figure 4) with the following features in mind:

- Boost switching converter to power the SBC and its peripherals using a single cell LiPo battery
- Battery charger compatible with most solar panels
- uBlox NEO and Skytraq S2525 nested design footprint
- 3G modem for remote login and control
- Low power microcontroller with RTC, battery capacity monitoring, power switch gate for the SBC and the 3G modem, connected to the I2C, serial and SPI busses

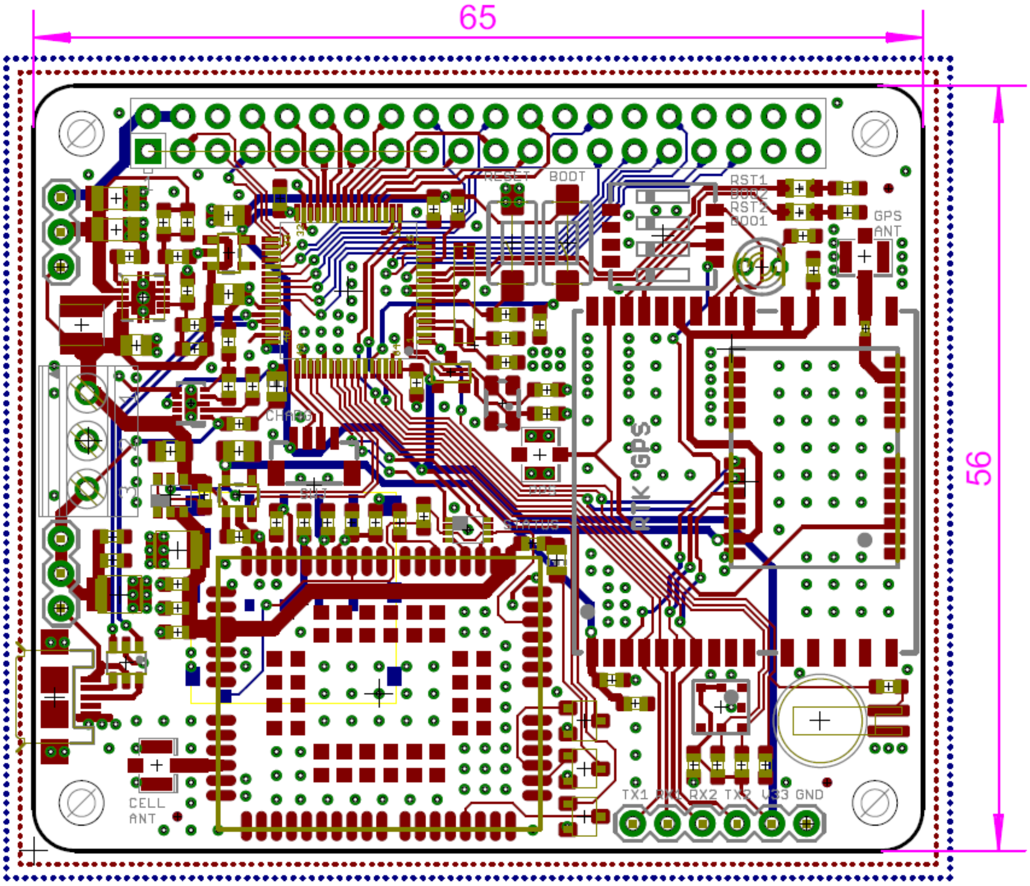

Figure 4: PCB design of the daughterboard to the RaspberryPi type A+.

2.4 Position computation approach

Monitoring sea level does not require the precise differential position to be used directly on the buoy (rover), therefore this is one case where in principle the position computation can be carried out on the rover itself (using corrections coming from the base) or alternatively on the base (using observations coming from the rover). Also, one reading of the sea level every 5th second is satisfactory to anticipate an anomaly.

Computing the rover position on the base does not impose any requirement on the rover which only has to transmit its observations to the base. The base does not have to comply with tight power constraints. Another advantage is that the base can monitor accurately the readings from the rover, which is useful at the early stages of deployment of a new system. Although very simple, this approach was not preferred to the classical one for reasons explained later.

If RTK computation is performed by the rover, the base station sends corrections and the rover sends back the computed position. Each epoch data from the base are necessarily heavier than an altitude reading message which can be just a few bytes. In fact a set of corrections normally carries the precise time plus pseudoranges, carrier phase, and preferably Doppler, C/N0, cycle slip count for several satellites in view. As the base is stationary and virtually exempt from multipath, the age of the correction can be safely be as large as 10-20 seconds. The rover can instead run the RTK engine at several Hz without overloading the radio link. One drawback is of course that the rover has to have enough intelligence to compute RTK. This intelligence comes at the cost of power consumption and imposes a certain stress on the reliability of the Ambiguity Resolution (AR) engine. Albeit more demanding, this approach was chosen as in the future it could allow a certain degree of GNSS coupling with pressure, temperature and inertial sensors. In particular, the peculiar movement of the buoy in stormy weather could represent a challenge for a Phase Lock Loop (PLL) that most likely has been optimised for automotive use so the availability of accelerometers/gyros could help detect and correct cycle slips. The presence of a magnetometer could compensate for the antenna phase windup.

2.4.1 Use of external commercial correction services

Finally the presence of a base providing corrections and collecting the rover telemetry might be not strictly necessary. The smart rover could be able to retrieve reference data from commercial PPP or RTK correction services, such as those in L-band. The upload to a server of the altitude readings could be done directly connecting to a cellular network or a LPWAN gateway, assuming there is coverage. The use of a Virtual Reference Station (VRS) could be challenging or even inappropriate far offshore: the interpolation of the corrections would be suboptimal given the heavily biased geometry of the reference stations. PPP services would be more effective, but the availability of a second frequency at the rover would be desirable in order to continuously estimate the ionospheric delays.

2.5 Software architecture

A few different pieces of code run on the RaspberryPi controlled by the *crond* daemon. The stock version of *rtkrcv*, the console version of the real-time RTK engine from RTKLIB was modified to allow the headless execution as background process. A few patches were applied to the uBlox parser to introduce Galileo message and observations decoding. The interface with the hardware peripherals (the GNSS receiver and the radio modem) is handled by a separate gateway application that exposes serial ports (UART, SPI, I2C) on multiple TCP/IP sockets. In this way, multiple different instances of rtkrcv using different settings can run on the same stream and their result can be combined prior to delivery to the base (see Figure 5).

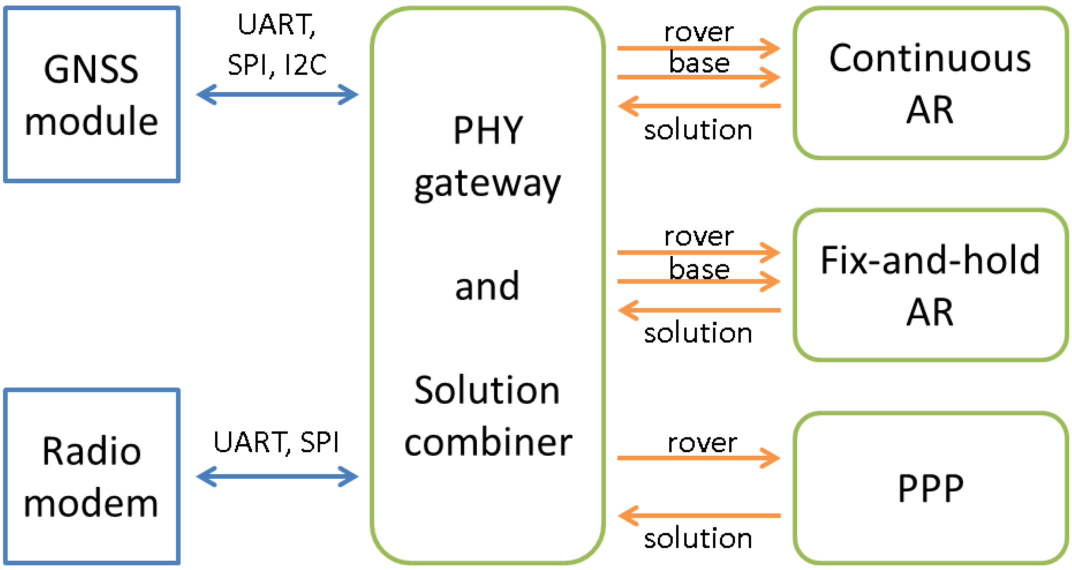

Figure 5: Software architecture

The first advantage of having an intermediate layer between the devices and the RTK engine is the possibility of filtering or adding messages to either the rover or the base streams. Secondly, each engine will produce a different solution and they must be combined prior to be communicated to the monitoring server. Combining implies individual consistency checks against solution history as well as instantaneous weighting amongst the engines. The solution combiner has the capability of coherently logging all data streams for post-mission analysis. Finally, the gateway can stop the differential navigation engines if data from the base are not received for a certain period of time. They are then automatically restarted by *crond*.

3 System demonstration

Two tests of the designed system were carried out on the Italian coast. The first in Spotorno (44.232094°/8.427952°), Liguria (on the Tirreno sea) at the end of February 2016 and the second in Punta Marina (44.434824°,12.301035°), Emilia Romagna (on the Adriatico sea) at the end of May 2016. In both cases an IDSL tide gauge was also mounted on the edge of the water, in order to have a reference measurement to test against. For the base, a Novatel 702GG antenna and a log-periodic UHF antenna with +7dBi gain were used.

3.1 First demonstration in Spotorno

The first test gave confidence to the team about the feasibility of using GNSS for sea level measurement but also highlighted the many limitations of the prototype available at the time, especially in terms of reliability and handling.

The rover required manual login over SSH to start the RTK engine and did not have satisfactory logging capability. The radio antenna was mounted on the side of the box resulting very close to the water and practically invisible to the base antenna in presence of medium waves. The battery was very heavy and placed on the far side of the box, unbalancing the buoy. The GNSS receivers pair only supported GPS (uBlox NEO-6T) and the base GNSS antenna was placed in a place suffering from far and slow multipath as well as significant sky obstruction thus leaving very few good satellites to compute AR with (see Figure 6 and Figure 7).

Figure 6: Mounting the base antennas on a lamp post at about 5 metres height, with sky obstruction from the steep coast in the North-West direction.

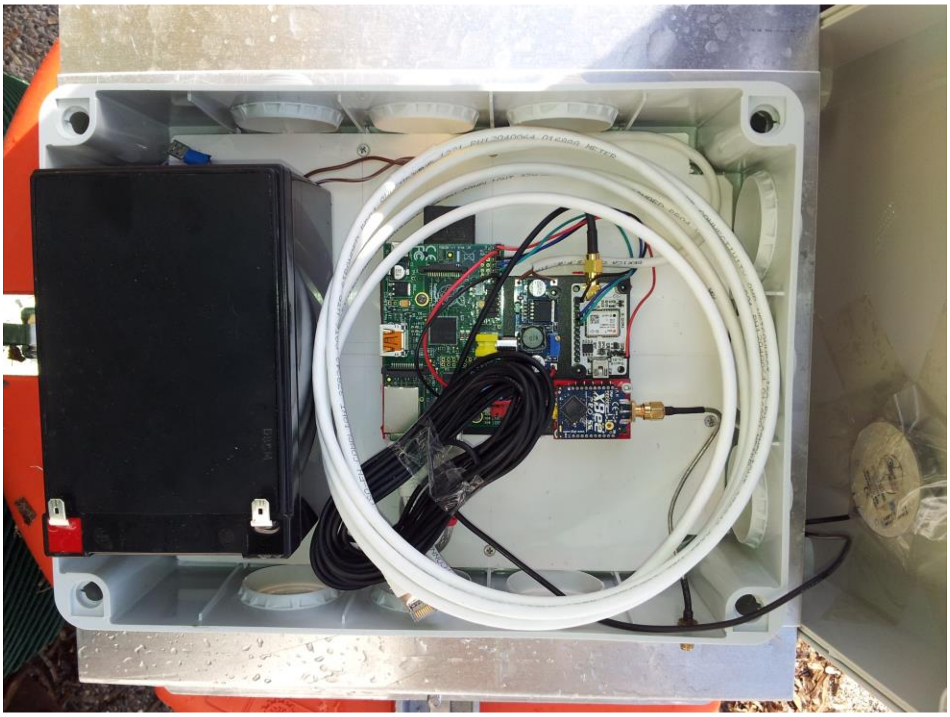

Figure 7: Waterproof box used for the first demonstration, with large, heavy and unbalanced 12V battery (bottom right), GNSS antenna hidden under the lid (left) and radio antenna on the side panel (top).

3.2 Endurance test in Ispra

As the first demonstration had suffered tremendous problems of reliability, the whole system was upgraded and reinstalled, static, in Ispra between two buildings of the JRC site. The base was connected to a solar panel to provide a constant power supply and the rover was connected to AC power to exclude power failures and left logging for many days continuously. Every day at midnight UTC the base would restart and being offline for a few minutes would cause the rover AR engine to exceed the maximum age of data and go into standalone mode. However the system quickly recovered, reporting less than 0.5% standalone fixes, delivering a standard deviation of only 14 cm differential positioning (see Figure 8).

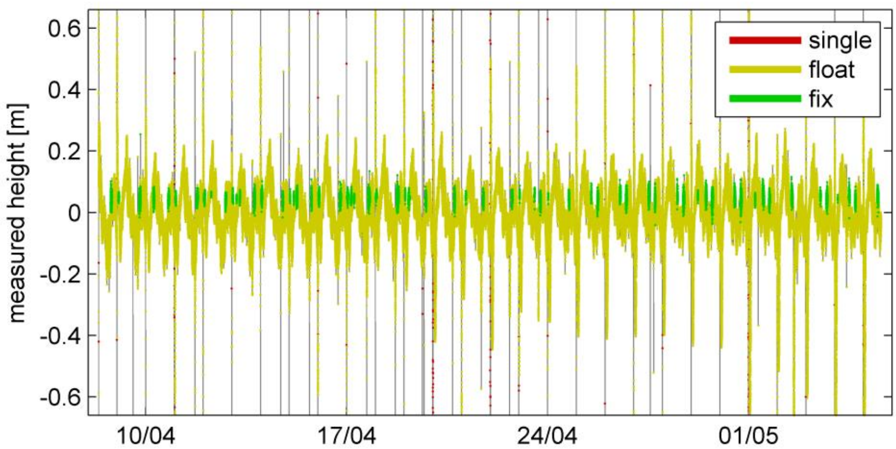

Figure 8: One month of continuous operation of the system. The threshold for ambiguity validation was set at 30.

Interestingly, at the end of the month the plot suggested a remarkably repeatable trend. The zoom of the results over a 4 days period span (see Figure 9) shows how either base or rover would be affected by the same multipath periodic of 1 day. The period is naturally linked to the ground track of GPS satellites causing the satellite positions in the sky to repeat each sidereal day.

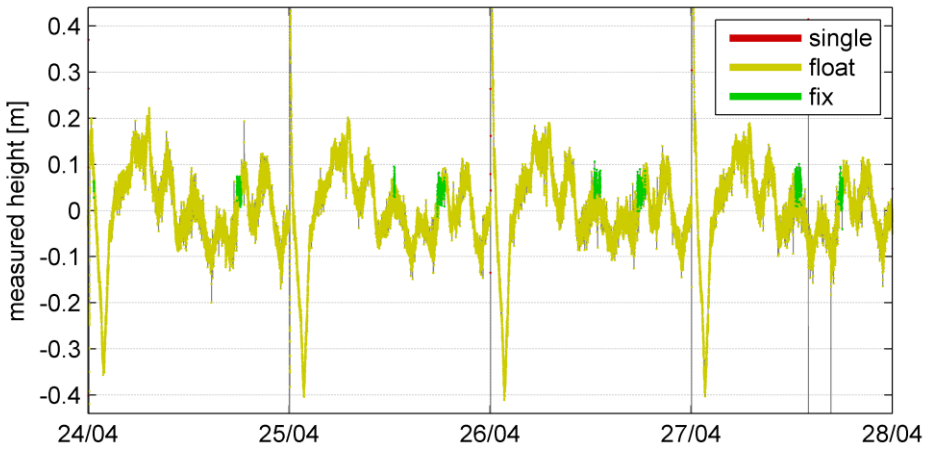

Figure 9: Zoom over 4 days of the plot obtained with 30 days continuous operation of the differential system in static mode and external power supply.

The observables analysis showed heavy multipath on the rover observations, despite being the antenna mounted on the rooftop of the building (see Figure 10). In particular, E18 and G12 were at 60° and 70° elevation respectively.

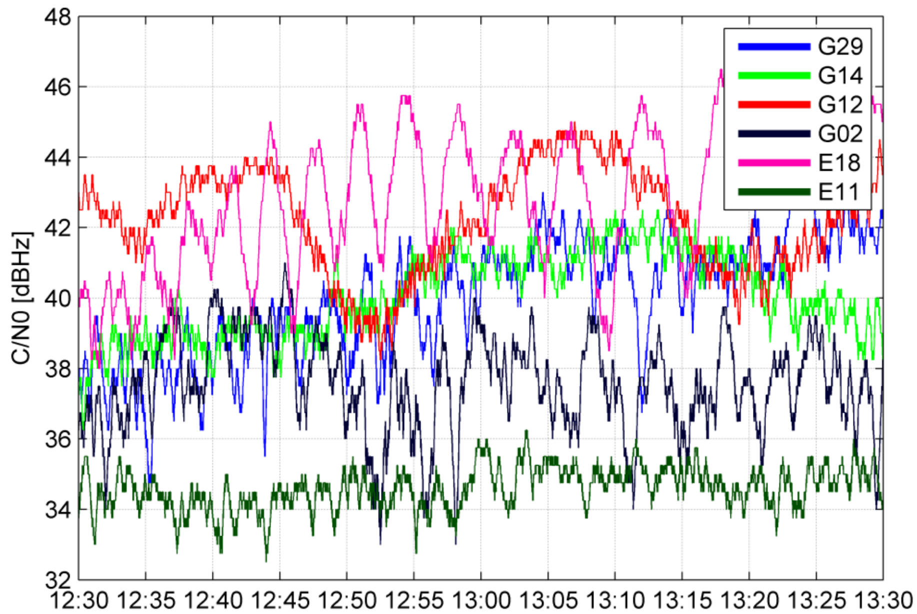

Figure 10: Static dataset collected on the rooftop of building 72C at JRC on May 18th 2016, showing clear multipath signatures, respectively faster and slower, for E18 and G12 transiting at high elevations.

Having identified the problem, the high power consumption of the first prototype was addressed. The main contributors to the power budget were the RaspberryPi model B and the Xbee Pro radio module. As mentioned above, the first was replaced with the model A+ and the second was powered using a switching regulator instead of a linear one with a power reduction of about 30%. Also, the number of height readings was reduced from 1 per second to 1 every 5th second, reducing the time that the Power

Amplifier (PA) in the radio needed to be turned on. In total power consumption went from about 700 mA to less than 300 mA, effectively more than doubling battery life.

Galileo was added just by switching from a NEO-6T to a NEO-M8T. The receiver was also configured to output observations at 4 Hz and a pre-filter was applied prior to communicating to the base the elevation information.

3.3 Second demonstration in Punta Marina (Ravenna)

For the demonstration in Punta Marina a second smaller box was built to be installed over the floating package. A 20 Ah USB power bank was used and steadily fixed inside the box. The radio antenna was placed at the top of a 1 metre high lightweight plastic post to improve the radio link range. A red flag also allowed the device to be easier to be identified (and retrieved) from a distance (see Figure 11).

Figure 11: Sea level measurement device placed at about 2 km from the coast on the first day.

A temporary subscription to a commercial RTK service (www.gpsemiliaromagna.it, provided by Topcon) allowed geo-referencing the base antenna in less than one hour. Ideally a VRS could also have been used with the rover device too, but the RTCM3 messages offered on the NTRIP channel were not completely supported by RTKLIB. Both base antennas were placed at about 6 metres from the ground. In this way the range capability of the 868 MHz radio was clearly impaired but at least the GNSS antenna had clear view of the sky.

An ultrasonic tide gauge was also installed in the neighbour harbour of Marina di Ravenna to be used as a reference for the experiment. In the morning the first static test onshore, the first range tests and the first endurance test were performed (see Figure 12).

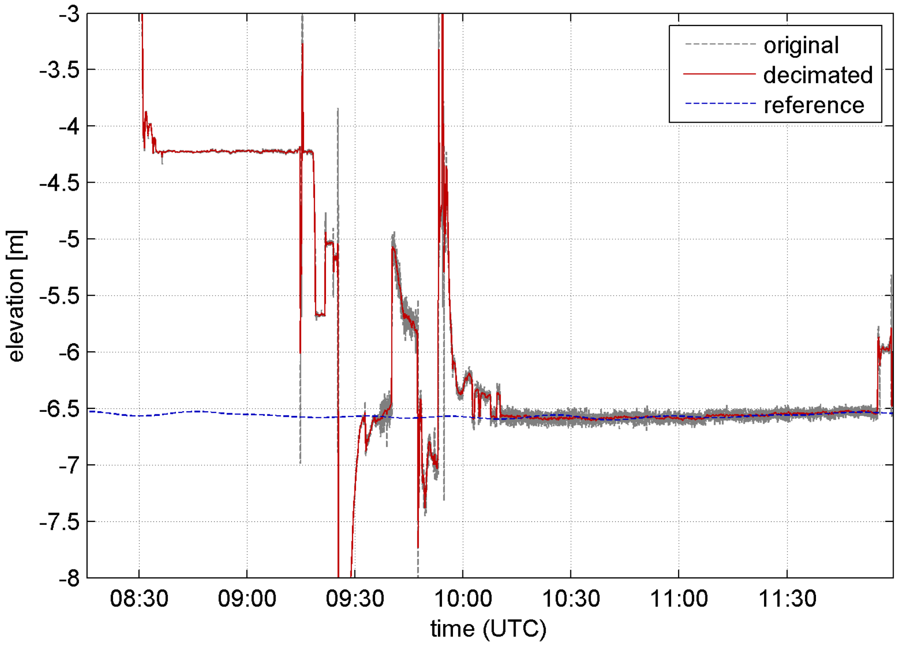

Figure 12: Results of the first half of the first day. First (08:30) buoy onshore, then going down to the water edge, then being lifted on the boat, then being carried off the coast, then (from 10:15) left for about 1 hour measuring sea level, then finally being lifted again on the boat (11:50) to be brought back to the office for preliminary data analysis.

The first range test showed an achievable radio range of about 2 km, which was in line with the expectations (see Figure 13 and Figure 14).

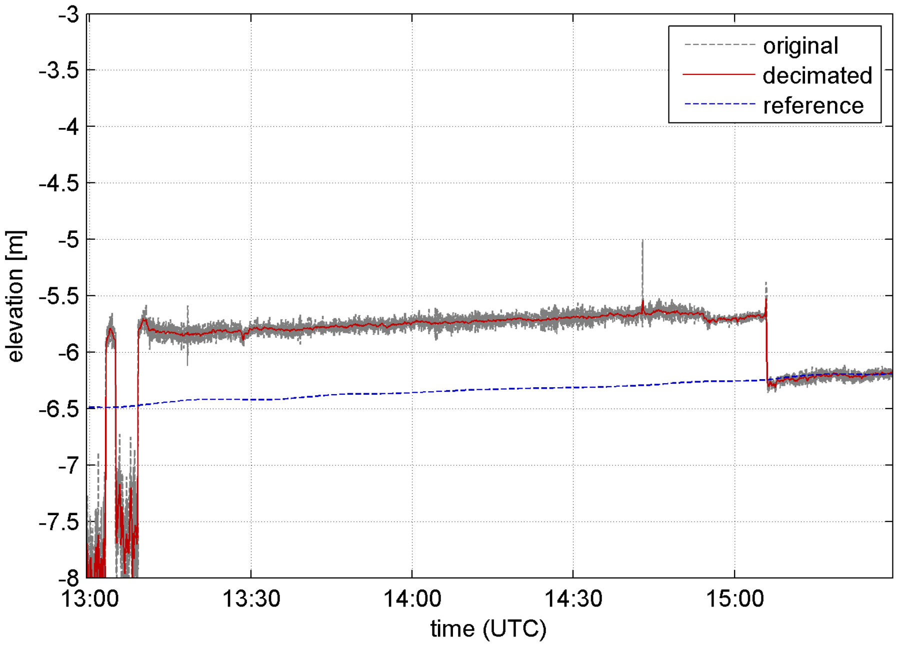

Figure 13: The device was brought offshore and kept on the boat for a couple of hours (from 13:15 to 15:00), then dropped into the sea at which point perfectly matches the reference again.

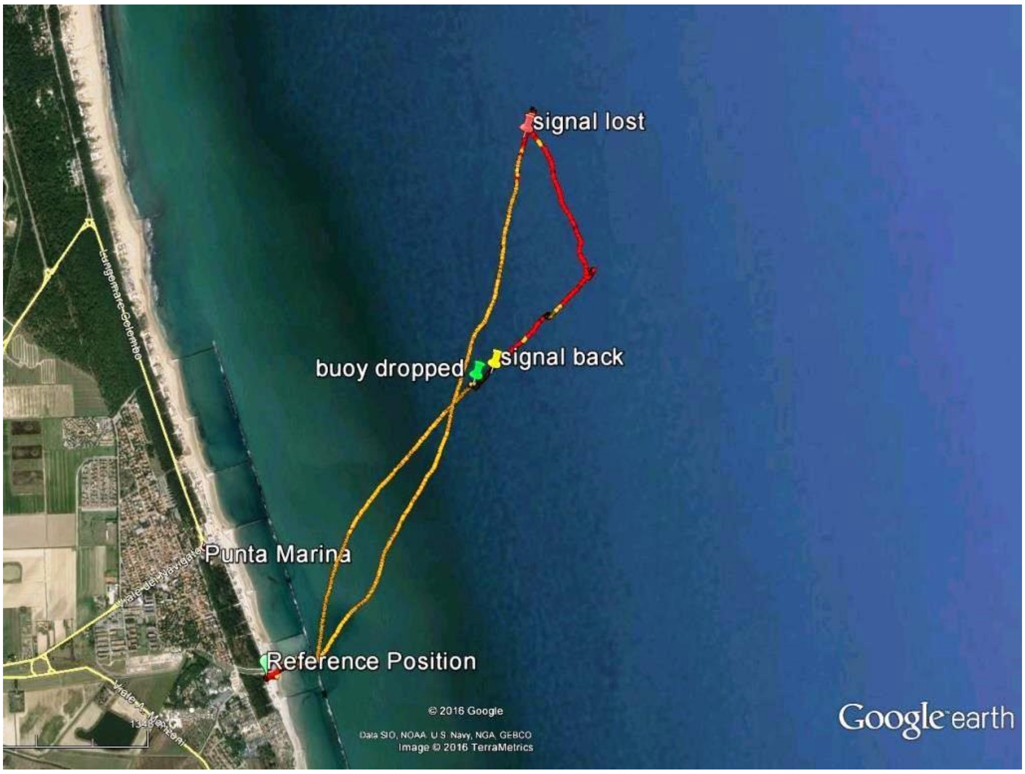

Figure 14: Boat reaching up to 3.3 km with a good RF link, lost when dropping the device in water and only regained steadily at 2.2 km distance.

The buoy was then left overnight measuring sea level at 300 metres from the coast. In the following 15 hours it did show a remarkable match with the mareograph, being able to follow the tide precisely. Unfortunately due to a bug in the RTK engine at midnight the rover stopped receiving the corrections from the base for 90 seconds and when transmission recovered, it was unable to quickly converge to the previous state. However all the data had been stored correctly on the rover and in post processing it was possible to fix the bug and obtain a seamless result (see Figure 15). The software was then modified to avoid this inconvenience in the future.

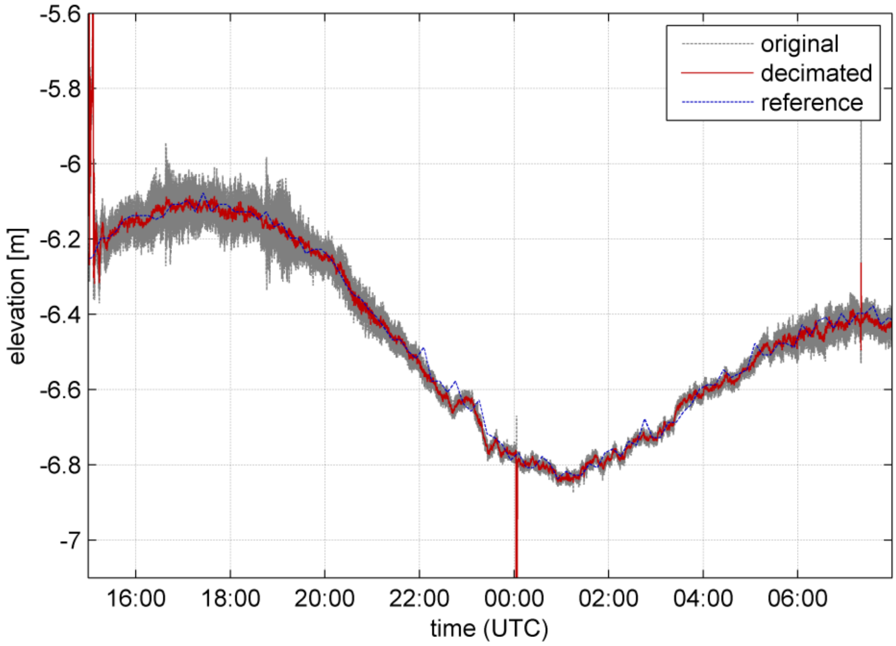

Figure 15: Overnight measurement of sea level. The reference is almost indistinguishable in the plot as perfectly overlaps with the filtered and decimated version of the rover's internal RTK solution. It is interesting to note that also the small peaks, like the ones at 22:45 are very well estimated by the device.

On the second day, an endurance test was carried out offshore (at about 2.2 km) distance from the base. The curve again matched the reference (see Figure 16) even if in this period the larger wavy sea level conditions cause some large fluctuations. These are not visible by the reference ultrasonic system as it was positioned inside the port.

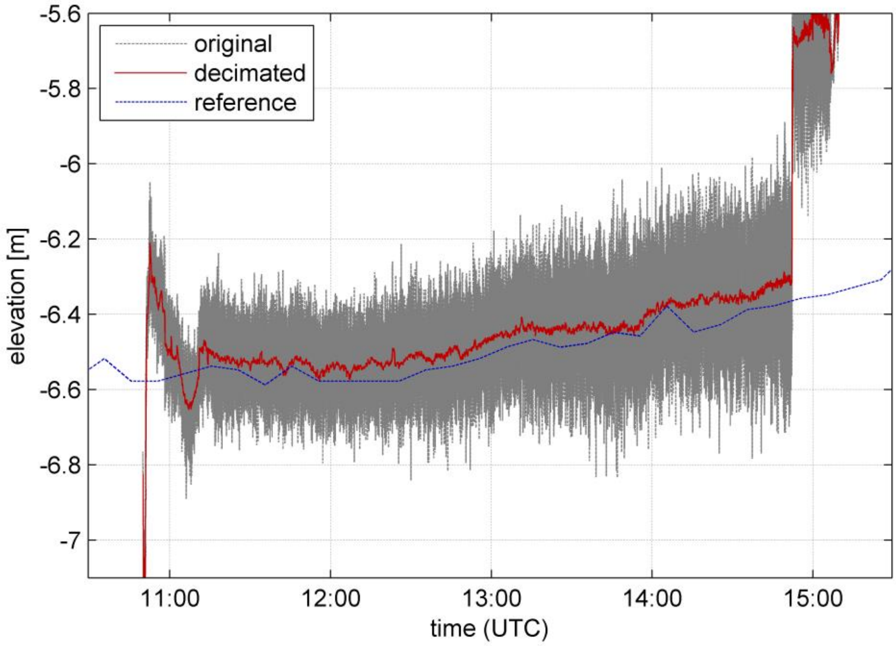

Figure 16: Measured sea level in open sea (2.5 km from the coast) on June 1st 2016. The device was retrieved and lifted on the boat at around 14:50.

By post-processing the on-board logs of the rover GNSS it was possible to zoom in time and see how waves had grown stronger far from the coast. Peaks of about 70 cm can be seen in Figure 17 and the Discrete Fourier Transform (DFT) measures a frequency of about 0.3 Hz.

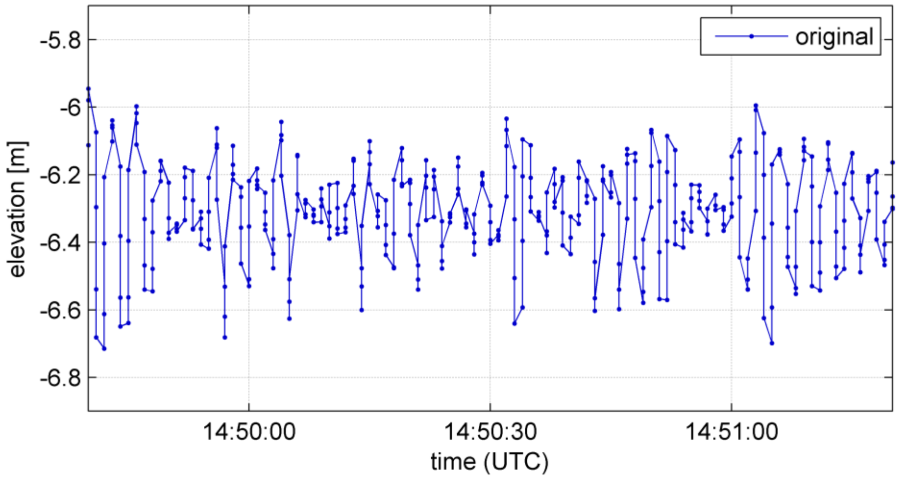

Figure 17: Zoom of figure Figure 16, where waves can clearly be seen at the 4 Hz rover observation rate, topping 70 cm in height.

4 The benefit of Galileo

RTKLIB performs double differences on a constellation by constellation basis. Therefore, Galileo satellites are added to the AR engine only when more than two are tracked as one is to be used as reference. Despite this unnecessary limitation, the number of satellites used by the AR engine in the two days of tests was in average 9.9 with Galileo and 7.7 without, a margin of about 25% which helped especially in the poorest GPS visibility moments (see Figure 18).

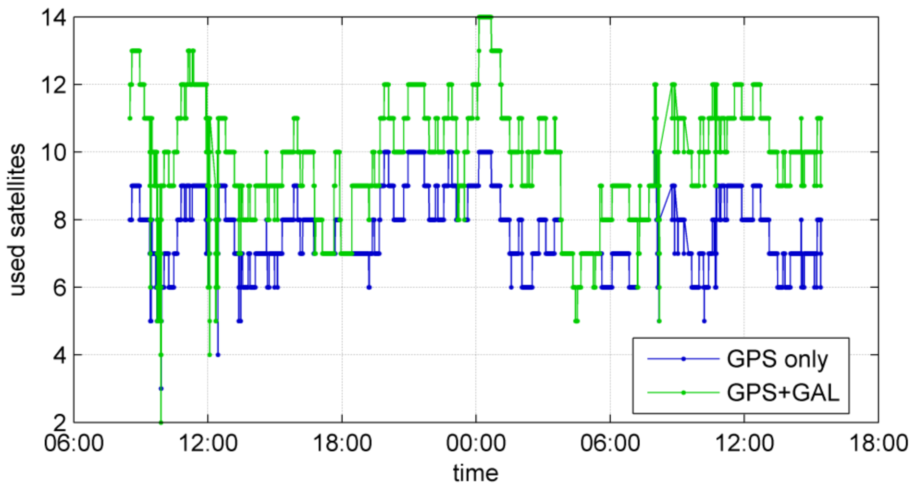

Figure 18: Effect of enabling Galileo in the AR engine on May 2016. Number of satellites in a GPS only solution (blue) versus GPS+GAL (green).

In order to assess the quality of the Galileo pseudoranges in an easy way, a zero baseline test between a pair of uBlox receivers connected to a GNSS RF Constellation Simulator (RFCS) was performed. The test revealed that the noise on the Galileo pseudoranges was slightly higher than the GPS, against the author’s expectations.

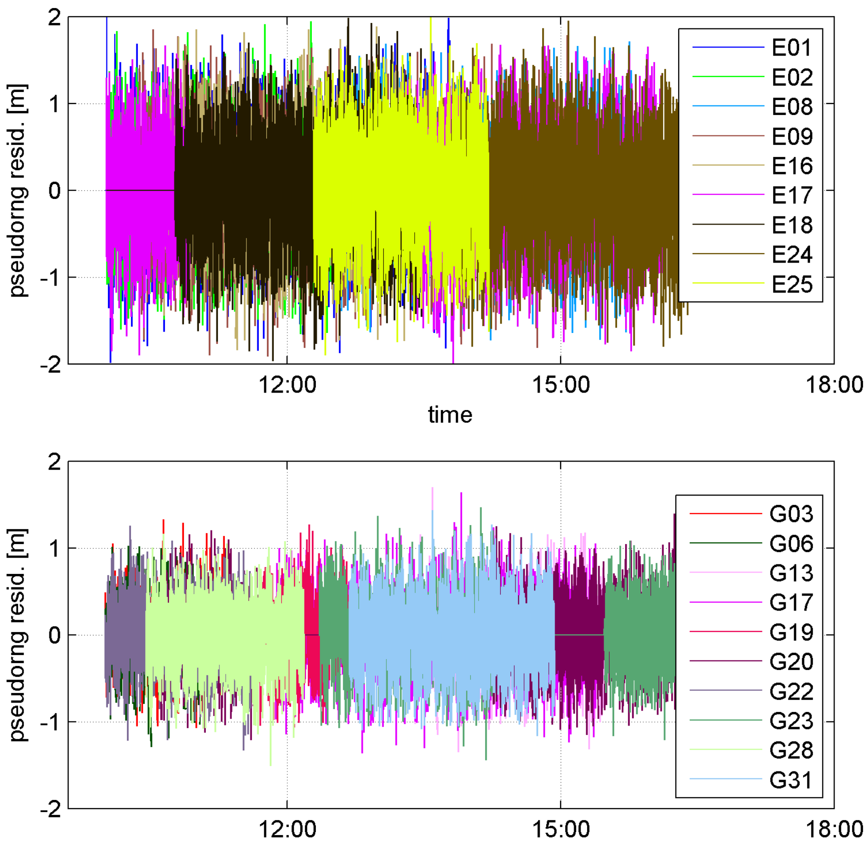

Figure 19: Zero baseline test between a pair of uBlox NEO-M8T receivers. Pseudorange measurement noise is higher on Galileo than it is on GPS.

In order to validate the above result the multipath envelope for both GPS and Galileo was measured using again the constellation simulator. The multipath ray was configured at -6dB power for both GPS and Galileo and the range rate at 1 cm/sec and 0.5 cm/sec for GPS and Galileo. The envelope was calculated by double differencing the receiver pseudoranges against those generated by the RFCS. As the latter are inherently noise free, only the second (inter-satellite) difference increases the noise floor. The GPS envelope shows that some other correlator than the standard EML for BPSK is being used, providing exceptional multipath rejection and errors up to 10 metres worst case (see Figure 20).

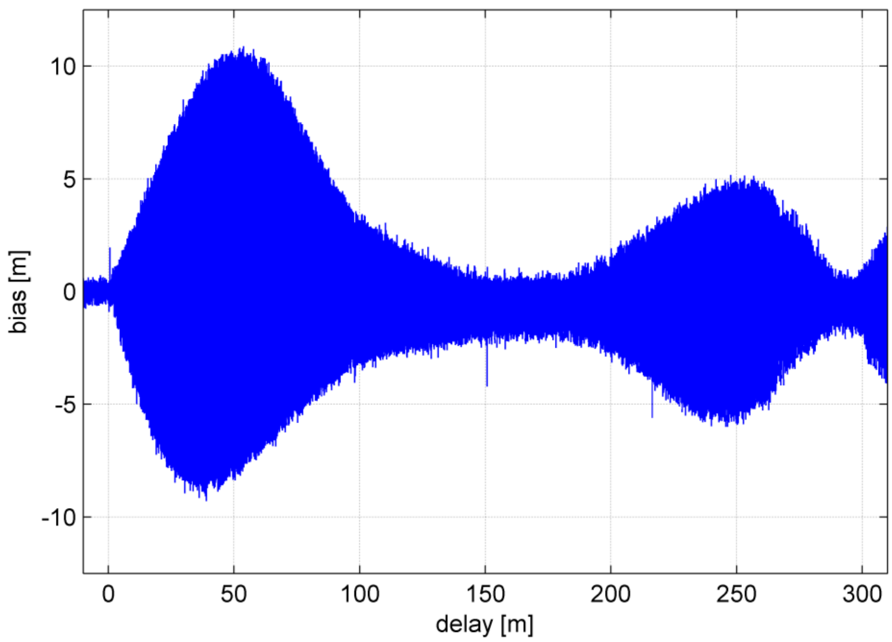

Figure 20: GPS multipath envelope, built with a constellation simulator injecting slow-varying controlled multipath.

5 Conclusion

In conclusion, the development of a low cost sea level measurement monitoring device based on differential GNSS is feasible. Most of the complications have already been overcome, but improvements in range, battery consumption and software stability should be pursued in future activities. Also the engineering of a floating buoy needs to be performed because the experimental apparatus that was used is suitable for a small time campaign but for sure it could not withstand a long term period of measurements with severe waves and storms. There are several commercial solutions for a floating buoy, some of them also with solar panel integrated that can be used. Alternatively, the instrument itself could be positioned on an existing floating device, instrumented for other objectives, that could host this additional instrument.

The following steps include the engineering of the device and the search for a long term solution. The feasibility and the high quality of the data has been achieved successfully with this experimental campaign.

References

[R01] Annunziato, "T*he Inexpensive Device for Sea Level Measurements*", Science of Tsunami Hazards, ISSN 8755-6839, Vol 34, Num 4, 2015

[R02] T. Nagai, H. Ogawa, Y. Terada, T. Kato, M. Kukada, "*GPS buoy application to offshore wave, tsunami and tide observations*", ASCE Proc. Of the 29th International Conference on Coastal Engineering (ICCE'04), 1, 1093-1105 -2004

[R03] Bisnath, S., Wells, D., Howden, S., Dodd, D., Wiesenburg, D., Stone, G., "*Development of an Operational RTK GPS-Equipped Buoy for Water Level Recovery*," Proceedings of the 16th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GPS/GNSS 2003), Portland, OR, September 2003, pp. 59-66

[R04] Mader, G., Martin, D., Schöne, T. (2003): "*Final report SSG 2.194 GPS water level measurements*," (Mid-Term Reports of IAG Section II), http://gfzpublic.gfz-potsdam.de/pubman/item/escidoc:237574

[R05] RTKLIB: An Open Source Program Package for GNSS Positioning, http://www.rtklib.com/

[R06] Ublox timing products, https://www.u-blox.com/en/product/neolea-m8t

[R07] "*LoRa™ Modulation Basics*", Semtech application note AN1200.22

[R08] Digi Xbee Pro 868, http://www.digi.com/products/xbee-rf-solutions/modules/xbee-pro-868

[R09] "*Long RF range in real life (114 km) South Africa*" http://www.ti.com/general/docs/video/watch.tsp?entryid=4645945175001

List of abbreviations and definitions

Acronym	Long version	Notes
AR	Ambiguity Resolution	Process determining the number of cycles between the transmitter (satellite) and receiver (user) antennas, leading to very high accuracy.
GNSS	Global Navigation Satellite System	GNSS replaces GPS including by definition other global positioning systems such as Galileo (EU), Glonass (Russia) and Beidou (China).
GPS	Global Positioning System	Often used to identify the American Navstar satellite system.
RTK	Real Time Kinematic	High accuracy navigation technique by mean of carrier phase AR

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