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THE INEXPENSIVE DEVICE FOR SEA LEVEL MEASUREMENTS

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ABSTRACT

A new mareograph device has been designed at the Joint Research Centre (JRC) of the European Commission (EC) in order improve the sea level network in use for the Tsunami Hazard monitoring in the Mediterranean Sea and in the North Atlantic area (NEAMTWS area of UNESCO). The instrument has the characteristic to be cheap and very effective but its reliability, duration and quality need to be determined and qualified. For this reason a number of experimental campaigns are being conducted, whose first results are presented here. In collaboration with the UNESCO/IOC (Intergovernmental Oceanographic Commission), responsible of the definition of the Tsunami Warning System of this geographical area, a set of 20 devices has been offered by JRC for a period of 1 year of testing of the devices; the surveys for the installation of the devices is under way and the installation should be completed by the end of 2015.

Keywords: *Early Warning Systems, Tsunami, and Sea Level Measurements*

1. INTRODUCTION

The Mediterranean Sea, Black Sea and North Atlantic areas have been subject over the history to a number of devastating Tsunamis (Crete -365, Lisbon 1755 just to indicate the major events). The Inter-Governmental Oceanographic Commission (IOC) of UNESCO is therefore developing the Tsunami Warning System for this region since 2004, as a result of the international efforts after the Sumatra event.

Figure 1 – Tidal Gauges Instruments in the Mediterranean Sea, Black Sea and North Atlantic Ocean

At the same time, meteorological important events may also occur in the area, causing Storm Surge and inundation when particularly severe wind/pressure conditions are present. In both cases monitoring the sea level is extremely important in order to be able to take decisions on what is the best control strategy.

Unfortunately, the sea level instrumentation is not at the same level of quality in the whole area (Figure 1) in terms of geographical distribution and quality of the measurements. For instance, the North African coasts lacks of instrumentation that would be extremely useful to monitor Tsunamis and to be able to take quick decisions or to monitor events with automatic systems like GDACS (Annunziato 2005, 2007, De Groeve et al 2007). Turkish coasts have only a few number of instruments. Italian, French and Spanish coasts are very well instrumented; some areas in the Adriatic Sea are poorly instrumented. UNESCO/IOC established a Task Group in order to monitor the installation of instruments and to rationalize their installation. Nevertheless, one challenge in the diffusion of these instruments is their elevated initial and maintenance costs, their management and the quality of the measurements in terms of real time acquisition and data dissemination.

JRC installed 3 new mareographs in Greece in 2013. These are very advanced stations, containing 2 types of sensors (radar and pressure gauges), one high quality differential GPS antenna and an active data logger that transmits data to JRC and to NOA servers with few seconds' latency. The cost for the installation of these devices has been very high, including the installation and maintenance for 2 years.

A less complete but very effective station has then been installed in Portugal, Setubal, in order to serve the needs of the Tsunami Alerting Device, a last mile-alerting device developed by JRC that is being tested in Portugal. This device contains only a radar sensor and the data are transmitted to a local distant data collector via WI-FI transmitter and made continuously available to JRC to perform analyses and storage. The cost of this station has been 1/3 of the price of each station installed in Greece. Although this device was much less expensive than the ones installed in Greece, the large diffusion of devices is still prohibitive in terms of investment and maintenance costs. Therefore, JRC decided to create a low-cost mareograph prototype.

Based on the experience of other similar devices and the need during a Tsunami analysis, the requirements that we have fixed for the mareographs are the following:

- High quality of the data with an error of 0.5 cm maximum (sensitivity justified by the expected error in the sea level calculations)
- Short acquisition time interval, 15 s maximum (to have a well-defined sea level wave description over time)
- Small transmission latency, smaller than 30 s (this is particular important for small basins with low travel time)
- Low overall cost, less than 1.5 k€
- Autonomy, at least 3 days without solar irradiation (the autonomy can be increased to 7 days with an over cost and weight on the battery)

The prototype presented in this report costed about 1.2 k€, but the cost could be further reduced with proper selection and purchase of the material and if produced in large scale.

The heart of this device is the Raspberry Pi, which is a powerful electronic board that contains a Linux operating system with several standard components (USB, HDMI, Ethernet port, Video card, and sound card) and other busses that can easily be connected with external devices. The device therefore has a computer on which software can be installed and that can be reached remotely for debugging or software change. The other important component is the radar sensor: we have identified a relatively low cost rugged component that could be used as sea level sensor (after several tests presented in this report). Additional components are necessary in order to have an autonomous system (electrical power feed and communication). A name for the device that can capture the characteristics is IDSL, Inexpensive Device for Sea Level Measurements.

2. DESCRIPTION OF THE IDSL

2.1 The Hardware

The Inexpensive Device for Sea Level Measurement has been developed buying all standard easy to find components (see Figure 2), assembled in a compact plastic container box, with a second box containing power accumulators, needed when an autonomous installation has to be realized.

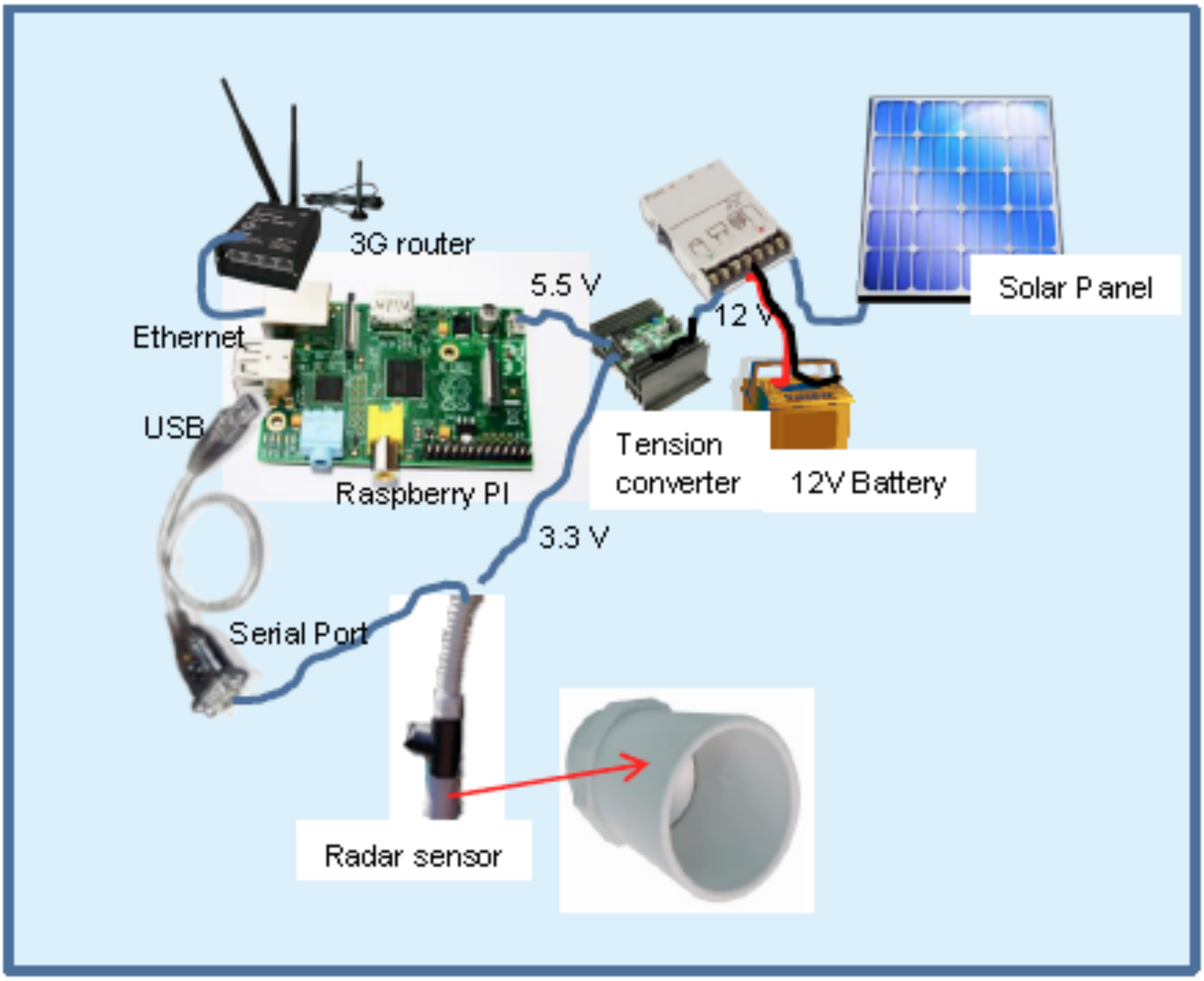

Figure 2 - Arrangement of the devices supporting the mareograph

A solar panel (100 W) is connected to a solar power regulator, needed to correctly charge the batteries; in case AC electrical power is available onsite, the regulator is fed by a voltage transformer of 13.5 V. The regulator is connected also with a small battery (7.2 AH), present in the first box. In case of AC power available this battery is used for potential temporary power failures with an autonomy of about 8 h. A second package containing additional 48 AH batteries can be connected to the first box in parallel to the 7.2AH battery.

The load section of the solar regulator feeds, through a voltage reducer, the computer/data logger, a Raspberry Pi B+ and directly the GSM modem. A Raspberry Pi is a very powerful small board (cost less than 35 euro) containing an ARM processor with Linux operating System, 4 USB ports, 1 Ethernet card and many I/O ports available to the user. The sea level sensor, a commercial radar device, is connected to the Raspberry using one of the available USB ports. The GSM modem is connected to the Raspberry using the local LAN offered by the GSM modem.

The solar panel takes energy and connects to a charge regulator. The regulator recharges the battery, when the panel voltage is within a certain range. In addition, it controls the output tension to the loads. When the battery discharges below a certain voltage (11 V) the loads are disconnected, until the battery goes back to more than 12 V (hysteresis). The output voltage from the regulator (12V) is sent to a voltage converter that reduces the voltage to 5.5 V (to feed the Raspberry) or 3.3 V (to feed the radar sensor).

The Raspberry receives input from the Radar sensor through an RS232 connection to one of its USB ports and transmits the data via a 3G router, connected with its Ethernet port.

In order to measure the battery and the panel tensions we use a voltage divider (to have a signal smaller than 5 V) and an Analog Digital Converter, applied on the Raspberry device (Figure 3). An external "watchdog" circuit is also included to make sure that, in case of irresponsive device for any reason a reset of the Raspberry is actuated. Additional devices present on the board are a temperature and a pressure sensor (pressure sensor only in the latest models).

The overall cost, also considering the metallic supports and the cost to assemble all the parts has been about 1.3 k€; no attempt to optimize the costs has been done and only off-the-shelf products have been adopted at retail prices. This means that a margin for cost reduction in case a large-scale production is performed, could be achieved.

Optimization of the power consumption is necessary due to the need to transmit continuously the data (every 5 s) and considering the power consumption of the various devices (2.5-3 W Raspberry, 3.5W GSM modem are the main sources). Therefore a combination of 100 W solar panel and 42.2 AH has been considered sufficient to keep on for at least 3 days a device installed at latitude 43.8 north.

2.2 The software

The control software of the device (the executable is named tad) is a single program started during the initialization phase of the operating system. In order to manage all the asynchronous operations, the program is multithreaded: this reduces the impact of lengthy operations on the overall responsiveness of the software.

At starting time, the control software reads its configuration, a set of named parameters in config.txt file, such as the USB port to access, the URL template to post the data to, or the parameters for the alert level calculation.

The sensor module is then started: it will start feeding the analysis module with the values provided by the sensors. Every sensor will write independently in a structure that contains all sensor data: water level, pressure, temperature, and battery charge, solar panel input.

At this point, the program is in an infinite loop, waiting for data to be processed. It will be stopped by a break signal or when the system shuts down. There is no way to alter the running configuration: in case of need, after changing the configuration file, the program must be restarted. It is possible to access remotely the Raspberry and act on the operating system.

The software pushes data into the JRC server every 5 seconds with a method developed by JRC and already applied to other sensors installed. A web service, present on the JRC Internet network allows to store the data; another software continuously monitor the presence of new data and stores them in the local SQL server database. All the data are therefore available at this web site: http://webcritech.jrc.ec.europa.eu/tad_server/?ID=64

The result of the Imperia experimental campaign (see later) allowed to debug, improve, optimize the software in order to keep alive as much as possible to application. For instance the automatic reboot of the Raspberry every 1h, then relaxed to 6h, has been found beneficial in terms of reliability and accumulation of error conditions from various sources.

3. RESULTS OF IMPERIA SEA LEVEL CAMPAIGN

As a result of a Collaboration Agreement between the Joint Research Centre and the Italian Istituto Superiore per la Ricerca Ambientale (ISPRA), it was possible to install the first IDSL device in the same location where another sea level measurement, installed by ISPRA, is located. The installation location is inside a restricted military area, belonging to the local Coast Guard, thus very well secured (Fig. 3, 4).

The installation has been performed in November 2014; for the first two months very unstable behavior was present due to a bad choice of the solar panel voltage regulator. When the voltage (due to bad insulation and lack of battery power) was decreasing, the regulator did not switch off the load at 11V as expected but down to 4-5 V. This caused a block of the Raspberry that could not switch on again when the power was restored. As a consequence several missions to the site were necessary to recharge the battery and switch on back the device. After having changed the regulator in January 2015, the device worked fine without any major problem charging over the day and discharging over-night. Only in two occasions, in case of prolonged bad weather conditions, after 3.5 days of no sun, the device was off for few hours but when light returned, it switched back on as expected.

Figure 3 - The installation location in Imperia, inside the Porto Maurizio harbor

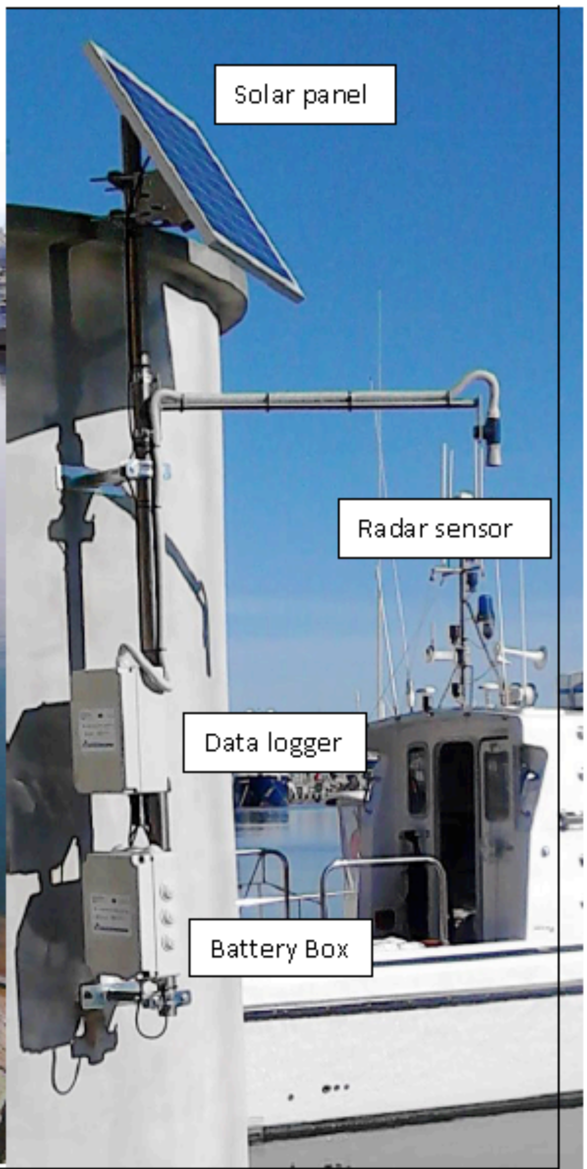

Figure 4 - Detail of the IDSL installation

Two major findings from the Imperia campaign are emerging:
- the large oscillations of the harbor sea level
- the important effect of the temperature on the sensor

The comparison of the sea level measured by the ISPRA mareograph and the IDSL showed that the IDSL was presenting quite extensive oscillations of several tents of cm that are not present in the ISPRA device (Figures 5 & 6). The ISPRA device is a wire ultrasonic sensor located inside a dumping pipe. In order to understand if this oscillation was real or not we have performed two pictures close to the measurement point, showing the position of the water surface. The pictures, in Figure 6, taken in a moment of high peak and low peak, show that indeed the oscillation is present and that the measurement was correctly reporting the 15 min period oscillation.

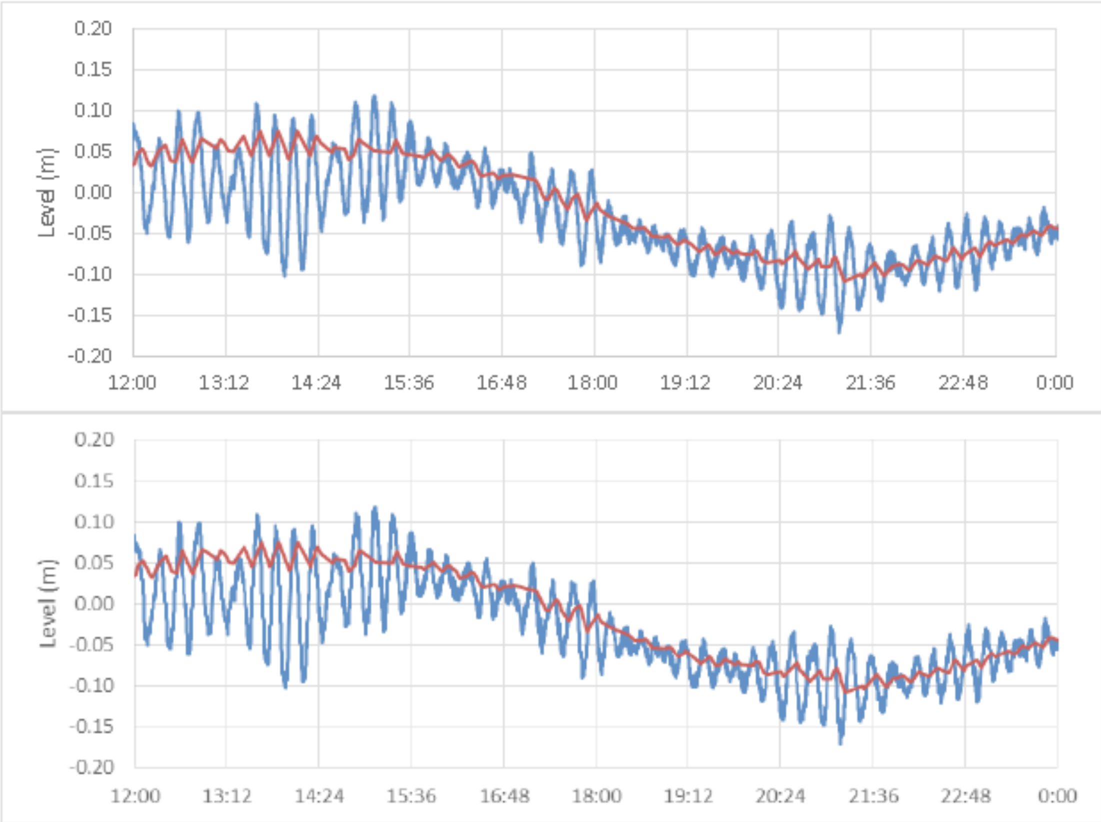

Figure 5, Measure sea level by the ISPRA tide gauge (red curve) and by the IDSL (blue curve)

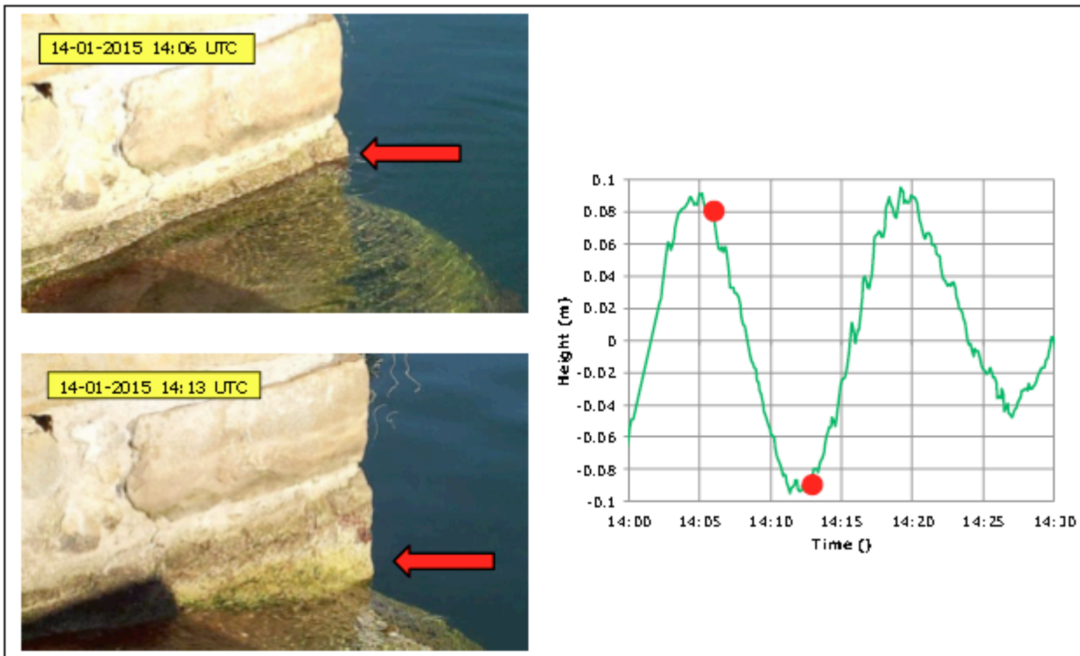

Figure 6 – Detail of the harbor oscillations on January 14th 2015

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It would be interesting to perform an analysis of the harbor response to external sea level variations because if this is the case it could be that, in case of important events (i.e. Tsunami) this natural harbor oscillation could eventually lead to a large amplification factor, like in some locations in the Pacific (i.e. Crescent City or Hilo).

The temperature effect is still under checking (Fig. 7). The radar sensor is equipped with internal temperature compensation. This is necessary in order to have a signal that is as much as possible temperature independent and compensate the variation of the air sound speed as a function of temperature. The speed of sound in air increases by about 0.6 meters per second, per degree centigrade; this means that an increase of the air temperature of 1 degree centigrade, if not compensated, would result in a faster travel time and thus in a shorter time of fly below the sensor; the sensor would "believe" that the sea level is higher than in reality. Similarly an increase of the sensor temperature, not reflected in a similar increase of the air temperature could result in an over compensation and thus the sea level indicated would be lower. The actual air temperature of the path between the sensor and the target may not match the temperature measured at the sensor itself.

This is in fact what happens to the sensor installed in Imperia when there is hot sun shining: a progressive decrease of the indicated sea level in comparison with the reference sea level. As the sun decreases, or during cloud-cover days (we know it from the battery voltage behavior), the measured signal by both instruments is very similar.

In order to have the possibility to correct the discrepancy present in the sea level, we have found that the error shift in the sea level correlates well with the Raspberry CPU temperature (curve red in the upper plot of Figure 7). When the temperature increases above 40-41 degrees Celsius the shift appears. Although the use of the CPU temperature is an indirect estimation of the air temperature, this was the only available that we could use in the prototype device installed in Imperia. In the final device, we have included two air temperature sensors, one connected with the sea level device for a temperature compensation and another one to have the measurement transmitted to the server and eventually allow more direct correction, if necessary.

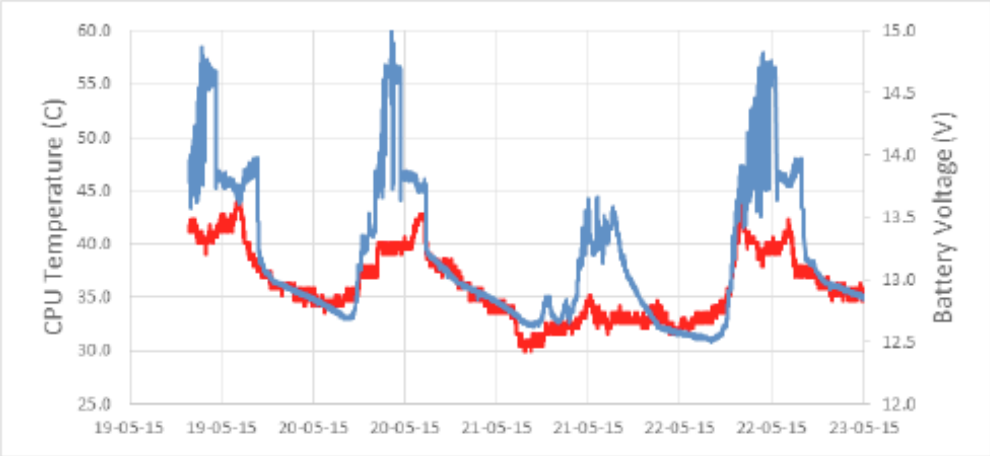
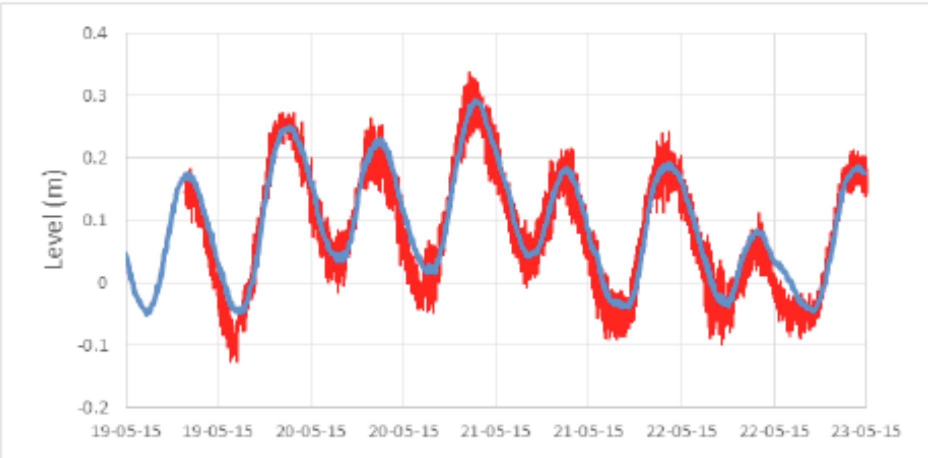
	*The left figure shows the classical battery charge/discharge cycle (blue curve): two days with very good solar insulation, the third day bad insulation and the fourth one with again good insulation. The red curve represents the CPU temperature of the Raspberry Pi+*
	*The comparison of the IDSL measured sea level (red) with the ISPRA sensor shows that in some periods, when the solar panel is charging, the IDSL deviates from the trend of the ISPRA signal, with a reduced value up to 6-7 cm in defect*

Figure 7 – Sea Level Measurement and temperature effects

4. OFFER OF 20 IDSL TO UNESCO NEAMTWS

The Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-eastern Atlantic, the Mediterranean and connected seas (ICG/NEAMTWS) was formed in response to the tragic tsunami on 26 December 2004, in which over 250,000 lives were lost around the Indian Ocean region. The Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) received a mandate from the international community to coordinate the establishment of the Tsunami Warning System.

One of the most important activities of the Warning Centers is · Collection, record, processing and analysis of sea level data for confirming and monitoring the tsunami or for cancelling elements of the alert system

Given the lack of instrumentation is some parts of the Mediterranean Sea this activity in some cases is not easy. For this reason the European Commission decided to support the development of the system by offering the installation of 20 devices to the countries that are part of the NEAMTWS. After an international call of interest the following devices allocation has been attributed.

	Priority	Country	Organization	Status	Location	Zone	Survey
IDSL-01	0	Italy	JRC/IPSRA	Installed	Imperia	Tirrenian Sea	n.a.
1	1	Greece	NOA		Western Corinth Gulf	Aegean Sea	
2	1	Italy	INGV		Crotone	Ionian Sea	
3	1	Lebanon	CNRS	Surveyed	Batroun	Mediterranean East	3 Jun 2015
4	1	Maroc	CNRST		Casablanca	North Atlantic	
5	1	Portugal	IPMA	Surveyed	Sagres	North Atlantic	24 Apr 2015
6	1	Romania	NIEP	Surveyed	Mangalia	Black Sea	27-28 May 2015
7	1	Spain	IGN	Surveyed	Cadiz	North Atlantic	3-4 Jun 2015
8	1	Tunisia	INM		Tabarka	Mediterranean Central	
9	1	Turkey	KOERI	Surveyed	Fethiye	Mediterranean East	12 Jun 2015
10	2	Italy	INGV	Surveyed	Pantelleria	Mediterranean Central	15 Jun 2015
11	2	Maroc	CNRST		Marina Sidi Abbed (Rabat)	North Atlantic	
12	2	Portugal	IPMA	Surveyed	Albufeira	North Atlantic	24 Apr 2015
13	2	Romania	NIEP	Surveyed	Costanta	Black Sea	27-28 May 2015
14	2	Spain	IGN	Surveyed	Cartagena	Mediterranean West	3-4 Jun 2015
15	2	Tunisia	INM		Zarzis	Mediterranean Central	
16	2	Turkey	KOERI		Cesme	Mediterranean East	
17	3	Italy	INGV		Otranto	Ionian Sea	
18	3	Romania	NIEP	Surveyed	Sulina	Black Sea	27-28 May 2015
19	3	Turkey	KOERI		Kemer	Mediterranean East	
20	4	Turkey	KOERI		Foca	Mediterranean East	

As of June 2015, a number of surveys at the proposed installation sites has been performed and the precise locations and installation modes have been defined. Other surveys will be performed soon and the installation should be concluded before the end of 2015.

After the installation all the data will be available at the following JRC web site with the possibility to visualize or download the data for analysis purpose: http://webcritech.jrc.ec.europa.eu/tad_server

Figure 8 – Geographical distribution of the IDSL devices installation sites; the sites for Tunisia are not indicated as not yet available

5. CONCLUSIONS

The Joint Research Centre of the European Commission has developed a new mareograph for Tsunami and Storm Surge monitoring. The device is characterized by very high temporal (5 s) and space resolution (error<0.5 cm) connected with a low construction cost which makes possible a wide distribution of these devices to cover many areas in the Mediterranean Sea that lack of reliable and effective real time sea level measurements.

The initial experimental campaign organized by JRC in collaboration with ISPRA, showed very positive outcome for the first 6 months of continuous operation. This convinced the UNESCO/IOC to accept the proposal of JRC to test 20 new devices for an extended experimental campaign of at least 1 year. The new devices will be installed during 2015 and will be an important contribution to the development of the UNESCO Tsunami Early Warning System that is being built in the Mediterranean Sea and connected seas (Marmara and Black Sea) and North Atlantic areas.

AWCKNOWLEGMENTS

The JRC would like to acknowledge the Istituto Superiore per la Ricerca Ambientale (ISPRA) that allowed to conduct the Imperia experimental campaign; at the same time the Italian Coast Guard whose locations has been used for the physical installation.

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