Project information	
Project full title	EuroSea: Improving and Integrating European Ocean Observing and Forecasting Systems for Sustainable use of the Oceans
Project acronym	EuroSea
Grant agreement number	862626
Project start date and duration	1 November 2019, 50 months
Project website	https://www.eurosea.eu

Deliverable information	
Deliverable number	D5.9
Deliverable title	**Operational monitoring systems available at the three sites**
Description	The installation of the multi-functional equipment at three locations
Work Package number	5
Work Package title	Coastal Resilience and Operational Services Demonstrator
Lead beneficiary	National Oceanography Centre
Lead authors	Angela Hibbert, Begoña Pérez Gómez
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Due date	31/08/23
Submission date	31/08/23
Comments	The final tide gauge installation is pending, so this deliverable report will be updated once all relevant work is complete

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 862626.

https://doi.org/10.3289/eurosea_d5.9

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Executive summary

Tide gauges can capture sea level variability on multiple timescales, from high frequency events like waves, tides and tsunamis, to seasonal and interannual changes and the longer-term trends associated with Climate Change. However, financial constraints dictate that they are often maintained to lower standards than the stringent accuracy requirements demanded by the IOC-UNESCO's Global Sea Level Observing System (GLOSS) for monitoring sea level rise. In addition, a sparsity of Global Navigation Satellite System (GNSS) receivers at the coast means that there are large uncertainties in rates of land motion at tide gauges, which also hampers the estimation of long-term sea level trends.

Task 5.1.1 has devised prototype low maintenance tide gauge systems, powered by renewable energy and which monitor both land motion and sea level using novel techniques such as ground-based GNSS Interferometric Reflectometry (GNSS-IR). These systems eliminate the need for costly ongoing levelling exercises and also incorporate customisations to local monitoring needs, such as sensors for lightning detection and wave height. Despite a number of unforeseen setbacks, these prototype systems are now operating at 2 locations in the Mediterranean Sea and a third system is in transit to Colombia for installation by local stakeholders who have been trained in the installation methodology by the WP5 team. It is hoped that there is potential to advance these technological solutions as a global standard, via the GLOSS community.

1. Introduction

Coastal inundation poses a significant threat globally, particularly to major population centres, infrastructure and economic activity that are concentrated within the coastal zone. The Mediterranean Sea is particularly vulnerable to storm surges driven by atmospheric pressure and surface winds from extratropical cyclones, generating large swell waves that can adversely impact shipping. Strong seiche activity (such as the Balearic 'Rissaga' events) and meteotsunamis can also be triggered by these weather events, which further hazards are posed by earthquake-induced tsunamis and the longer-term impacts of sea level rise.

Tide gauges can capture this whole spectrum of sea level variability and therefore fulfil an essential role in hazard warning systems regionally, such as the Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-eastern Atlantic, the Mediterranean and connected seas (ICG/NEAMTWS). Nevertheless, there are notable gaps in sea level monitoring networks in the Mediterranean Sea, particularly along the North African coast. This is partially due to the considerable financial cost of implementing and maintaining tide gauges, which means that they often fall into a state of disrepair. Alternatively, they may be installed and maintained to lower (and less costly) standards than the stringent accuracy requirements demanded by the IOC-UNESCO's GLOSS for monitoring sea level rise. In this latter case, they are useful only as an operational early warning tool and cannot be considered to be multi-hazard warning systems.

In addition, as a 2018 survey by the EuroGOOS Tide Gauge Task Team revealed[1], there were only 17 GNSS receivers co-located with tide gauges in the Mediterranean Sea. As a result, there are large uncertainties in rates of vertical land motion at tide gauges, which hampers the estimation of long-term sea level trends.

Task 5.1.1 (Low cost and maintenance free tide gauges) aims to address these issues by developing a new standard of low-maintenance tide gauge system, with minimal ongoing operating costs, geared to ensuring system longevity through the use of renewable power, dual telemetry systems for added resilience and the use of above-water sensors to minimise system degradation. In addition, the tide gauge system offers high-frequency sampling for tsunami monitoring purposes, as well as measuring sea level, vertical land motion, atmospheric pressure and a variety of wave parameters both at the coast and in the nearshore area, thus meeting the monitoring needs of multiple stakeholders including port authorities, hazard warning networks and the scientific community. The tide gauge prototype also exploits a new technique known as GNSS Interferometric Reflectometry (GNSS-IR), which allows the measurement of mean sea level whilst simultaneously measuring vertical land movement and can be used at tide gauges to produce continuous levelling information without the extra cost of conventional levelling. This task aims to trial this tide gauge system in 2 locations in the Mediterranean Sea (Barcelona and Taranto), adding bespoke monitoring functionality to suit local requirements. Data are distributed to stakeholders in near-real time via the IOC's Sea Level Station Monitoring Facility and to the internet browser-based Oceanographic Services for Ports and Cities (OSPAC) monitoring and forecasting tool that has been developed by in Task 5.2.

Task 5.1.1 has also used the Barcelona tide gauge installation as an opportunity to train local stakeholders from a 3rd location in tide gauge installation and maintenance, thus enabling them to deploy a 3rd prototype tide gauge independently. This 3rd location was initially planned to be in Alexandria, Egypt, but due to difficulties in obtaining local permissions to proceed, this was subsequently changed by grant amendment to Buenaventura, Colombia. At the time of writing (August 2023) the 3rd tide gauge is currently en-route to Buenaventura via air freight in preparation for an imminent deployment.

It is hoped that the prototype tide gauge system can become a blueprint for subsequent tide gauge installations along the sparsely monitored Southern Mediterranean coastline.

This deliverable report describes the process of establishing the prototype in the 3 locations. It presents an update to milestone MS14, which described the deployment of the prototypes in the first 2 locations. This deliverable report will be updated in due course once the 3rd tide gauge installation is complete.

[1] https://eurogoos.eu/download/list-of-tide-gauge-stations-co-located-with-a-permanent-gnss-station-in-europe-may-2018/?wpdmdl=10730&refresh=64dc89213558f1692174625

2. Scope and Implementation Methodology

2.1. Planned implementation methodology

For each planned installation site, a team of local stakeholders (Table 1) was assembled, co-ordinated by a key local WPS contributor. For Barcelona and Buenaventura, the co-ordinating stakeholder was Puertos del Estado (PdE), whilst for Taranto, the co-ordination of stakeholders was led by Euro-Mediterranean Center on Climate Change (CMCC).

Table 1. List of key stakeholders assembled for each tide gauge installation

Barcelona Stakeholders	**Taranto Stakeholders**	**Colombian Stakeholders**
Enrique Alvarez Fanjul (PdE)	Viviana Piermattei (CMCC)	Enrique Alvarez Fanjul (PdE)
Begoña Pérez Gómez (PdE)	Giovanni Coppini (CMCC)	Begoña Pérez Gómez (PdE)
Javier Romo Garcia (Port of Barcelona)	Daniele Piazzolla (CMCC)	Capitán de Corbeta Jonathan Gómez
Joaquim Cortes (Port of Barcelona)	Juan Francisco Martinez Osuna (CMCC)	Juan Leonardo Moreno (DIMAR)
David Pino (Port of Barcelona)	Maria Santoro (Port of Taranto)	Yosamy Garcia Sanmiguel (DIMAR)
	Gennaro Ruggieri (Port of Taranto)	Laura Vasquez (DIMAR)
	Gianluca Semitaio (Port of Taranto)	Ana Lucia Caicedo Laurido (DIMAR)
	Serena Tinelli (Port of Taranto)	

It was intended that the tide gauge implementation team at the National Oceanography Centre (NOC) would engage remotely via videoconferencing with each set of stakeholders to gather their monitoring requirements in terms of both the geographical area of interest and the key environmental parameters to be observed. This would be followed by an in-state visit by a NOC tide gauge engineer to assess the suitability of potential monitoring locations and to understand what design customisations might be needed to suit the characteristics of each site. For instance, tide gauges must generally be sited:

- Where they are exposed to the open ocean (i.e. not up-river, in an estuary or behind sand banks or lagoons)
- On stable, solid ground
- Where there is no risk of drying out at Low Water.

Some site problems, such as high vessel traffic (which can damage a tide gauge), may be overcome by using underwater sensors or specially designed protective steelwork, so the site survey presents an opportunity to explore these issues and possibilities.

A bespoke tide gauge is then designed by NOC tide gauge engineers to meet both the observational monitoring requirements of the stakeholders as well as the site characteristics. The NOC engineers then design manufacture and test the equipment before shipping and installing the tide gauge system in its final location. The end-to-end timescale for such a process typically takes 3-6 months per site, so at the project outset, it was envisaged that tide gauges would be operational at all 3 sites by 31/10/22.

2.2. Deviations from the planned approach

The Task 5.1.3 implementation team encountered a number of setbacks that impeded timely delivery of the tide gauges for Barcelona, Taranto and Alexandria/Buenaventura and this demanded deviations from the planned approach. These are described in Table 2 along with the solution that was implemented.

Table 2. Issues leading to deviations from the planned tide gauge implementation methodology

Issue	Deviation/Solution
The key local stakeholder in Alexandria (Prof Mohamed Said) was unable to obtain the local approvals needed to proceed with the prototype so that no progress had been made by November 2021	A grant amendment was submitted and agreed to change the 3rd location to Buenaventura, Colombia. This delayed the delivery date for the 3rd installation beyond the initial deliverable date of 31/10/22
COVID-19 lockdown restrictions in Europe during 2020/21 prevented NOC engineers from undertaking site surveys, whilst enforced homeworking and supply-chain issues increased delivery timescales.	Potential locations were down-selected to the final site using photographs and videos of the locations supplied by Port of Barcelona staff, but delays were inevitable, delaying the planned installation to April 2022.
Although installation site permissions were agreed by the Port of Barcelona, in February 2022 the co-ordinators of a nearby nautical college objected to the installation.	A NOC engineer attended site in April 2022, to agree a solution with the Port of Barcelona and the nautical college. The planned installation was postponed to June 2022 accordingly.
COVID-19 restrictions in Italy between March 2020 and mid-2021 hindered the logistics for arranging videoconferences to collate stakeholders' monitoring requirements for Taranto.	Monitoring requirements were agreed by videoconference in February 2021. This delayed matters, but delivery by October 2021 remained feasible.
Restrictions on foreign travel to Italy (including requirements for quarantine and vaccination status) were not lifted until in May 2022, by which stage military operations in Taranto related to the Ukrainian conflict had led to further local security restrictions. Both of these factors meant that the port authority did not identify a suitable installation site for more than 12 months.	The installation was postponed until contact could be re-established with the port authority (September 2022) and the installation site was agreed promptly thereafter, but the planned installation was unavoidably delayed to February 2023.
An indefinite strike by staff at the Spanish Consulate in the UK meant that NOC engineers could not obtain appropriate work permits to install the Barcelona tide gauge as planned in April 2022. This also delayed the Buenaventura installation as in-person training of the Colombian technician was planned for delivery during the Barcelona installation.	A Spanish company (SIDMAR Estudios y Servicios Oceanográficos S.L.) was procured to install the tide gauge under NOC supervision. This demanded a grant amendment which was agreed in early February 2023, delaying the planned Barcelona installation to March 2023 and the Buenaventura installation to a later date.
A ~6-week delay occurred while the NOC obtained fiscal representation in the European Union (necessitated by the departure of the UK from the European Union), to allow the shipping of the tide gauges to Spain and Italy.	The NOC appointed a logistics company (Europa) to ship the tide gauges and clear customs. This delayed all planned installations to April 2023.

Issue	Deviation/Solution
There was a delay in Italy in obtaining the final ordinance allowing the installation in Taranto and port entry permits.	This delayed the Taranto installation to June 2023
There was a long delay (March to August 2023) while Colombian stakeholders (DIMAR) arranged the importation documentation.	The tide gauge was finally shipped to Colombia (by air freight to expedite matters) in August 2023. Installation is anticipated during Autumn 2023.

As a result of these mitigating factors, the deliverable date was ultimately rescheduled to 31/08/23 and the implementation methodology was adjusted accordingly. Since no further adjustments to deliverable dates are possible at present, this deliverable report has been submitted with the Buenaventura tide gauge installation pending. This report will therefore be updated once the installation is complete.

2.3. Implemented methodology

Agreement of monitoring requirements

The monitoring requirements of Barcelona, Taranto and Buenaventura stakeholders were identified and agreed through video conference-based discussions during April 2020, February 2021 and March 2022 respectively. These stakeholder requirements are shown in Table 3

Table 3. Stakeholder monitoring requirements established for each port

Barcelona	Taranto	Buenaventura
High frequency sampling (1min) and low latency of data transmission for sea level data to facilitate tsunami warning	High frequency sampling (1min) and low latency of data transmission for sea level data to facilitate tsunami warning	High frequency sampling (1min) and low latency of data transmission for sea level data to facilitate tsunami warning
Observations of wave activity outside the harbour wall to support navigation	Observations of wave activity at the coast and in the nearshore area	Observations of wave activity in the nearshore area
Atmospheric pressure observations to reduce the effects of atmospheric noise in tidal predictions	Atmospheric pressure observations to reduce the effects of atmospheric noise in tidal predictions	Atmospheric pressure observations to reduce the effects of atmospheric noise in tidal predictions
Highly accurate observations of mean sea level and vertical land motion to understand the impacts of climate change	Highly accurate observations of mean sea level and vertical land motion to understand the impacts of climate change	Highly accurate observations of mean sea level and vertical land motion to understand the impacts of climate change
Minimal maintenance requirements	Minimal maintenance requirements	Minimal maintenance requirements
Warnings of potential lightning strikes in order to improve safe operations (and timely shutdowns) of a nearby energy centre		

Agreement of monitoring locations

During the stakeholder engagement videoconferences, potential tide gauge sites were identified using Google Earth imagery. As part of this, a visualisation tool was used that identifies the footprint (or Fresnel zone) for GNSS-IR monitoring at a given location, so that local stakeholders could ensure that this technique was applied in the region of greatest interest. This allowed potentially suitable locations to be narrowed to 3 sites in Barcelona (Figure 1).

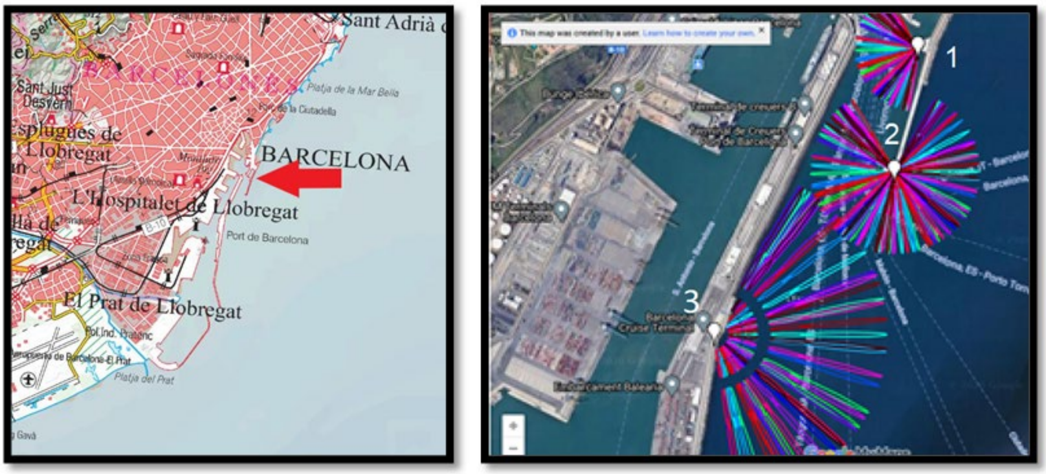

Figure 1. Area of interest for Barcelona tide gauge shown by red arrow (left) and specific sites shown by white markers (right). Radial lines denote the area of the sea surface that can be 'seen' by GNSS-IR technology at each location. These are also known as Fresnel zones.

These sites were further down-selected based upon (1) photographs and videos obtained by port officials and (2) local knowledge of the spatial impact of extreme wave conditions (with potential for causing damage to the monitoring equipment). As a result, it was settled that the principal monitoring system would be located at site 1 (adjacent to a nautical college), where there is less exposure to environmental extremes. It was agreed that a secondary monitoring scheme would be located at site 2 and would comprise a low-cost GNSS-IR system to observe SWH outside the harbour wall from the upper level of a lighthouse. These locations are shown in Figures 1 & 2.

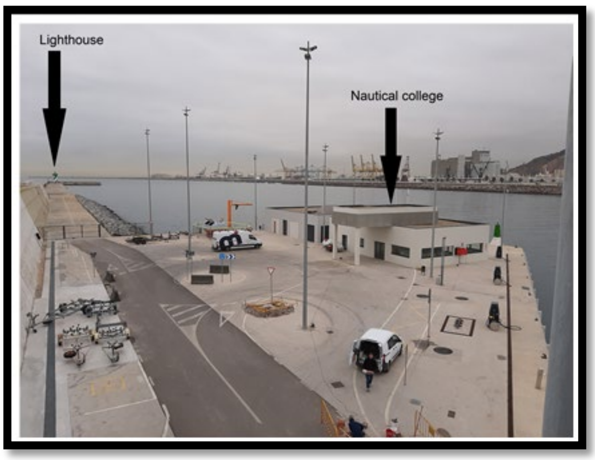

Figure 2. Principal tide gauge site (Site 1) adjacent to the Nautical College and the secondary site at the lighthouse (Site 2) for the low-cost GNSS system

For Taranto, although potential monitoring locations were identified with local stakeholders in February 2021, due to COVID-19 restrictions within Italy and subsequent site security issues linked to the conflict in Ukraine, contact with local stakeholders was temporarily lost and could not be re-established until 27/09/22. Once contact was re-established, local stakeholders confirmed that a suitable location had been identified on a newly-constructed quay (Figure 3).

Figure 3. Agreed site for Taranto tide gauge installation, indicated by red arrows

In August 2022, a suitable monitoring site in Buenaventura (Figure 4) was identified by the local stakeholders, DIMAR. In contrast to the up-estuary location of an existing tide gauge, this site would be exposed to the open ocean, facilitating improved understanding of the relationship between oceanographic processes in the inner and outer bay area.

Figure 4. Agreed site for Buenaventura tide gauge installation at Hotel Maguipi. The right panel shows the planned location of sensors (red circle) and the supplementary electronics (yellow circle)

Tide gauge design

Once the locations were finalised, the tide gauge designs were produced and the final specification was agreed with key stakeholders as follows:

Barcelona

For the primary tide gauge site in Barcelona (beside the nautical college), the monitoring system would comprise:

1. A steel monument to support a geodetic quality GNSS antenna and a Yagi satellite communications antenna
2. A pivoting steel arm attached to (1) with mounting points for dual radar water level sensors and bespoke protective steel caps for each sensor
3. A steel frame to support 4 X 80W solar panels to power the system
4. A Trimble Alloy GNSS receiver to monitor vertical land motion and sea level, collecting carrier phase and range of visible satellites, plus signal to noise ratio at 5 sec intervals.
5. 2 x YSI WaterLog Nile 502 radar water level sensors with manufacturer's reported accuracy of +/- 2mm, recording 1 sec samples averaged across 1 min.
6. A Meteosat YAGI antenna to transmit data free of charge at 6 min intervals to the Global Telecommunications System (GTS) and the IOC-UNESCO Sea Level Station Monitoring Facility
7. A Vaisala PTB110 Barometer sampling at 6 min intervals
8. A freestanding fibreglass electronics cabinet to be located directly behind the solar panel array and containing: (a) a SUTRON Satlink3 datalogger with GSM capability to transmit sea level data at 1 min intervals for tsunami warning purposes via a roaming SIM card, (b) supporting electronics and telemetry equipment and (c) 6 x 35Ah lead crystal batteries
9. A small fibreglass cabinet containing GNSS datalogging and telemetry equipment to be mounted inside the lighthouse at the harbour entrance.

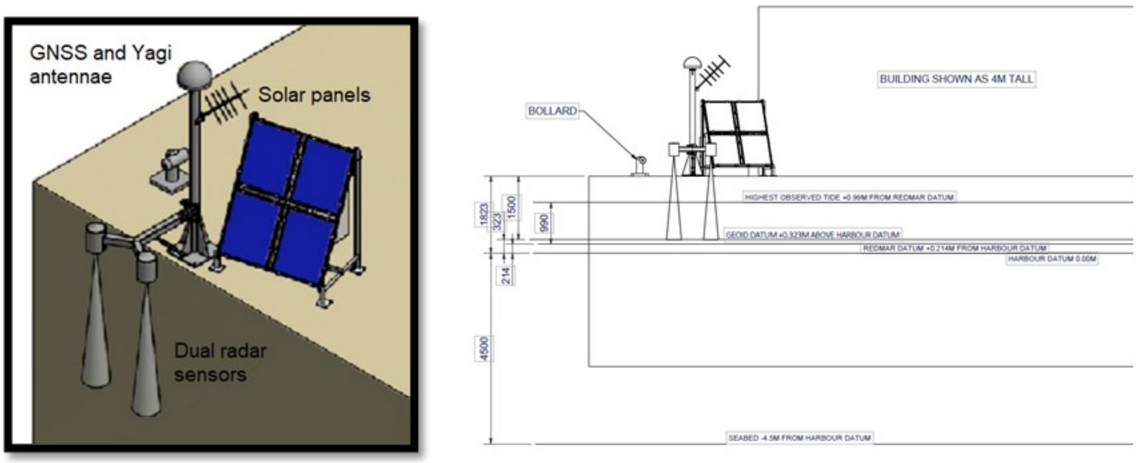

Figure 5. 3-D (left) and 2-D (right) representation of the agreed tide gauge design for Barcelona

The design of these primary tide gauge components is shown in Figure 5. At the secondary tide gauge site (the lighthouse), a low-cost Emlid REACH M2 GNSS antenna was to be mounted on the lighthouse, powered by an existing array of batteries. This would measure SWH outside the harbour wall, where large swell waves can adversely impact navigation.

Meanwhile, close to the airport at El Prat de Llobregat, an INGESCO Previstorm Thunderstorm Warning System would be installed to detect potential lightning strikes (by monitoring the electrical field) and to provide advance notification of these to the port energy centre.

Taranto

For the tide gauge site in Taranto the monitoring system would comprise:

1. An aluminium 'A' frame with mounting points for a geodetic quality GNSS antenna, a Trimble GPS and a Yagi satellite communications antenna
2. An aluminium right-angle swinging frame attached to (1) with mounting points for the 2 radar sensors and a bespoke protective cap for the conventional Nile radar sensor
3. A steel frame to support 1 X 400W solar panel to power the system
4. A Trimble Alloy GNSS receiver to monitor vertical land motion and sea level at the coast, as well as SWH across the nearshore area. To this end the instrument would collect carrier phase and range of visible satellites, plus signal to noise ratio at 5 sec intervals.
5. 1 x YSI WaterLog Nile 502 radar water level sensor with manufacturer's reported accuracy of +/- 2mm, recording 1 sec samples averaged across 1 min.
6. 1 x MIROS RangeFinder narrow beam (5°) radar sensor monitoring sea level and wave parameters, with a manufacturer's reported accuracy of +/- 1mm (for sea level). This would record 1 sec sea level samples averaged across 1 min and transmit wave parameters at the coast every 1 min using a 20 min window.
7. A Meteosat YAGI antenna to transmit data free of charge at 6 min intervals to the Global Telecommunications System (GTS) and the IOC-UNESCO Sea Level Station Monitoring Facility
8. A Vaisala PTB110 Barometer sampling at 6 min intervals
9. A freestanding fibreglass electronics cabinet to be located directly behind the solar panel array and containing: (a) a SUTRON Satlink3 datalogger with GSM capability to transmit sea level data at 1 min intervals for tsunami warning purposes via a roaming SIM card, (b) supporting electronics and telemetry equipment and (c) 8 x 35Ah lead crystal batteries

The design of this tide gauge is shown in Figure 6.

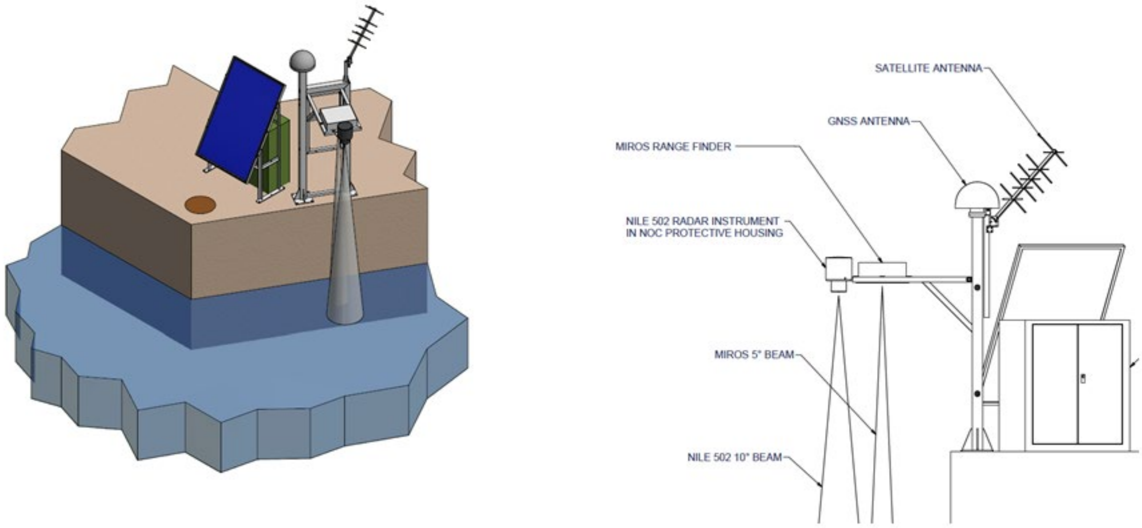

Figure 6. 3-D (left) and 2-D (right) representation of the agreed tide gauge design for Taranto

Buenaventura

For the tide gauge site in Buenaventura the monitoring system would comprise:

1. A steel monument to support a geodetic quality GNSS antenna and a Yagi satellite communications antenna
2. A pivoting steel arm attached to (1) with mounting points for dual radar water level sensors and bespoke protective steep caps for each sensor
3. A Trimble Alloy GNSS receiver to monitor vertical land motion and sea level at the coast, as well as SWH across the nearshore area. To this end the instrument would collect carrier phase and range of visible satellites, plus signal to noise ratio at 5 sec intervals.
4. 2 x YSI WaterLog Nile 502 radar water level sensors with manufacturer's reported accuracy of +/- 2mm, recording 1 sec samples averaged across 1 min.
5. A GOES YAGI antenna to transmit data free of charge at 6 min intervals to the Global Telecommunications System (GTS) and the IOC-UNESCO Sea Level Station Monitoring Facility
6. A Vaisala PTB110 Barometer sampling at 6 min intervals
7. A freestanding fibreglass electronics cabinet to be located directly behind the hotel, with a mounting frame on the upper elevation to support 3 x 80W solar panels. This would allow low elevation of the solar panels to maximise solar efficiency in this low-latitude location.
8. The electronics cabinet would host: (a) a SUTRON Satlink3 datalogger with GSM capability to transmit sea level data at 1 min intervals for tsunami warning purposes via a roaming SIM card, (b) supporting electronics and telemetry equipment and (c) 4 x 38Ah lead crystal batteries

The design of this tide gauge is shown in Figure 7.

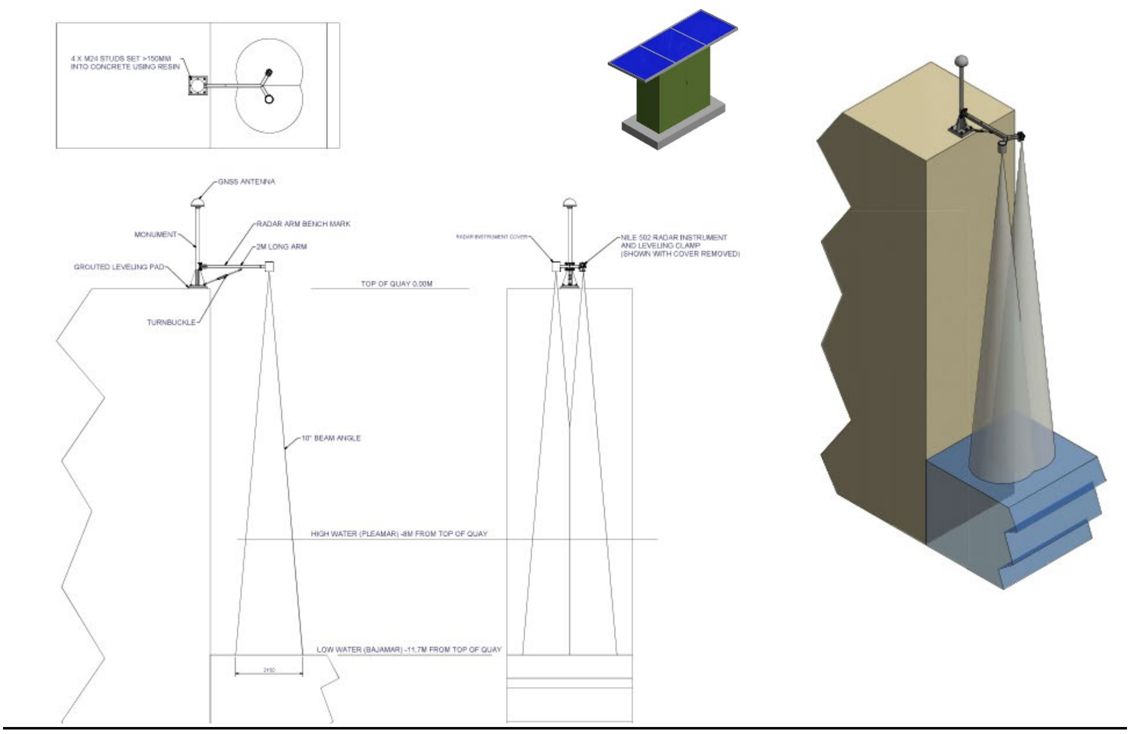

Figure 7. 2-D (left) and 3-D (right) representation of the agreed tide gauge design for Buenaventura. The solar panels are shown mounted on the upper surface of the electronics cabinet (in green)

System manufacture and testing

For each location, the instrumentation was procured and supporting frames were manufactured, assembled and tested the in a laboratory environment for a period of 4 weeks. These tests included the calibration of the radar sensors, to ensure that they complied with manufacturers' reported accuracy. This involved moving radar sensors through a known range of heights relative to a fixed target and comparing known distances with those recorded by the instrument. All were found to operate within acceptable tolerances and the resulting calibration tables were retained for inclusion within installation reports for each location. Testing of the barometer, solar power functionality, battery charge and data transmission via satellite were all successfully concluded.

Since the tide gauge installation in Barcelona was to be undertaken by SIDMAR, under NOC supervision, an installation guidance manual was prepared[2] and shared with SIDMAR staff so that they could familiarise themselves with the equipment and the installation methodology in advance. Similarly, since a tide gauge technician from CMCC was to assist with the Taranto tide gauge installation, an installation manual was also prepared for the Taranto system[3]. Particular care was taken to prepare installation guidance for the Buenaventura tide gauge in both English and Spanish language versions, since this instrumentation was to be installed by DIMAR independently and would be led by a Spanish-speaking technician[4]. The equipment was then packaged in preparation for shipping.

System installation

Barcelona

In July 2021, INGESO engineers fitted the Previstorm lightning detection sensor close to the airport at El Prat de Llobregat, providing a real-time data feed to port operators. The remainder of the tide gauge was installed between the 4th and 7th of April 2023, during which NOC engineers Steve Mack and Barry Martin supervised the installation of the primary tide gauge and the secondary monitoring system by engineers from SIDMAR (José María Cortés Crespo and Roberto Sevilla), whilst also training Yosamy García Sanmiguel (DIMAR, Colombia) in installation methods (to support deliverable D5.6). Begoña Pérez Gómez (PdE) attended to facilitate the process. The installation was completed in accordance with the installation manual provided, the installation process itself was documented in a detailed installation report[5] and the data streams were made live. The completed tide gauge is shown in Figure 8.

Following installation, a bespoke tide gauge maintenance manual has been produced to assist local stakeholders to keep the tide gauge in a good state of repair and has been submitted as part of deliverable D5.6.

[2] Barcelona installation manual is supplied as part of deliverable D5.6 Documentation associated to the capacity building
[3] Taranto installation manual is supplied as part of deliverable D5.6 Documentation associated to the capacity building
[4] Buenaventura installation manual is supplied as part of deliverable D5.6 Documentation associated to the capacity building
[5] Barcelona tide gauge installation report is submitted as part of MS24 Installation of documentation including calibration sheets.

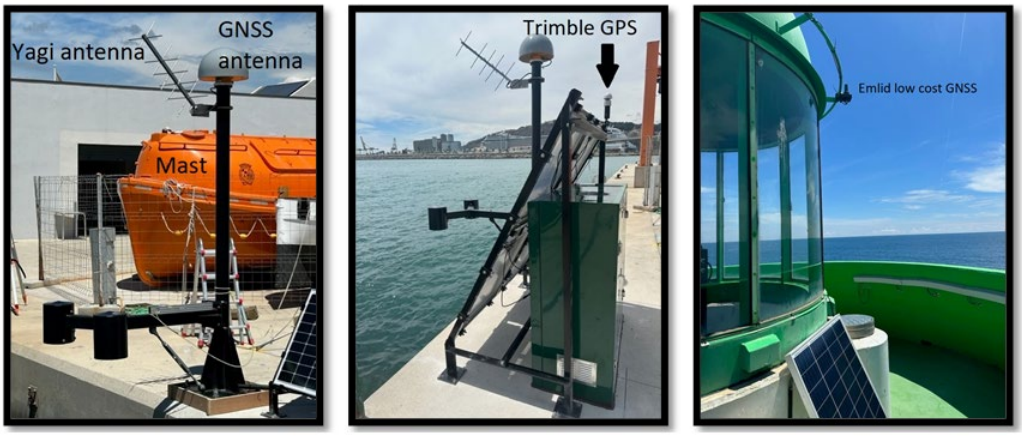

Figure 8. Completed tide gauge installation at Barcelona primary site (left) and (middle) and secondary site (right)

Taranto

Between the 26th and 29th of June 2023, NOC engineers Geoff Hargreaves and Barry Martin completed the installation of the tide gauge alongside Juan Francisco Martinez Osuna and Daniele Piazzolla of CMCC. The installation was completed in accordance with the installation manual provided, with the exception of a customisation to the Yagi Meteosat antenna. It was felt that instead of attaching this antenna to the main 'A' frame of the tide gauge (where it might interfere with the Trimble Alloy GNSS receiver) it would be better positioned on the solar panel frame. The installation process itself was documented in a detailed installation report[6] and the data streams were made live. The completed tide gauge is shown in Figure 9.

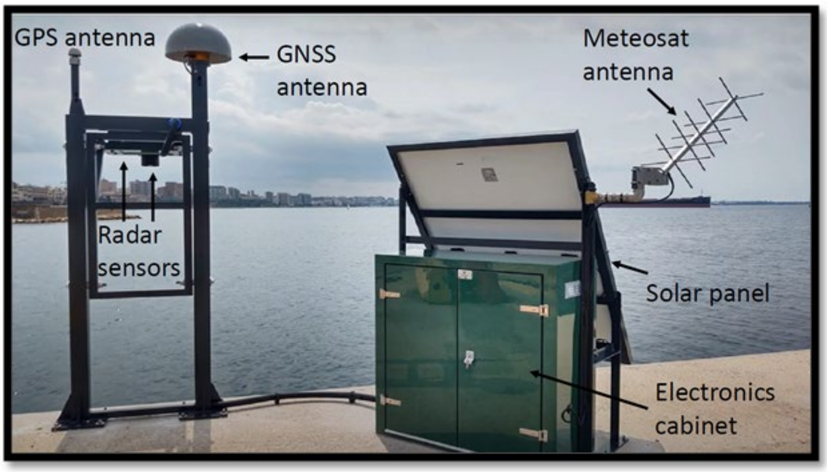

Figure 9. Completed tide gauge installation at Taranto

Following installation, a bespoke tide gauge maintenance manual has been produced to assist local stakeholders to keep the tide gauge in a good state of repair and has been submitted as part of deliverable D5.6.

[6] Taranto tide gauge installation report is submitted as part of MS24 Installation of documentation including calibration sheets.

Buenaventura

At the time of writing, the Buenaventura tide gauge is in transit to Colombia and the installation is to be undertaken in due course by local stakeholders at DIMAR, led by Yosamy Garcia Sanmiguel. This report will be updated in this respect upon completion of the installation and a tide gauge installation report will also be prepared.

In preparation for the installation, a bespoke tide gauge maintenance manual has been produced to assist local stakeholders to keep the tide gauge in a good state of repair. Both English language and Spanish language versions of this have been prepared and submitted as part of deliverable D5.6.

3. Multiparametric data streams

Multiparametric monitoring is now in place at both sites and providing data to international portals as well as to PdE, where work is ongoing to assimilate the data feeds into the OSPAC software.

3.1. Barcelona

The following data streams were implemented for this site:

Sea Level

1 min averages of sea level from dual radar sensors are transmitted via a roaming SIM card at 1 min intervals to the PdE ftp site (enoc.puertos.es) with a 10 sec latency for incorporation into the OSPAC software. Data are time stamped at 10 sec past the minute to which they relate. 40 sec should be subtracted from time stamps to accurately represent the midpoint of the averaging period.

In addition, 1 min averages of sea level from the same dual radar sensors are transmitted via a free Meteosat satellite communications system to the Global Telecommunications System (GTS) from where they are accessed by the IOC sea Level Station Monitoring Facility (IOC SLSMF) and are made publicly available (Figure 10, SEA LEVEL STATION MONITORING FACILITY[7]) This telemetry method has a maximum latency of 6 min. Data are time stamped one minute later than the minute to which they relate. Therefore, 90 sec should be subtracted from time stamps to accurately represent the midpoint of the averaging period to which they relate.

[7] http://www.ioc-sealevelmonitoring.org/station.php?code=barc2

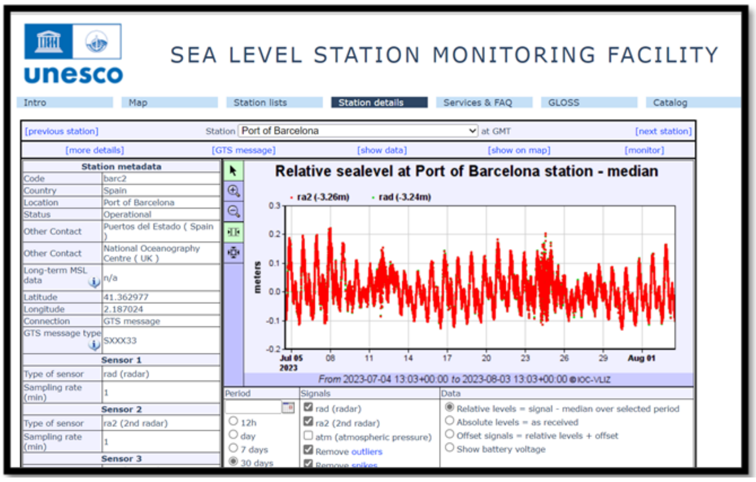

Figure 10. Sea level data received at IOC SLSMF for Port of Barcelona

Atmospheric pressure

6 min samples of atmospheric pressure are transmitted via a roaming SIM card at 1 min intervals (i.e. the barometer reading will be constant for 6 transmissions) to the PdE ftp site (enoc.puertos.es) with a 10 sec latency for incorporation into the OSPAC software. Data are timestamped at 10 sec past the sampling time.

In addition, 6 min samples of atmospheric pressure from the same barometer are transmitted via a free Meteosat satellite communications system to the Global Telecommunications System (GTS) from where they are accessed by the IOCSLSMF and are made publicly available (Figure 11, SEA LEVEL STATION MONITORING FACILITY[8]. This telemetry method has a latency of ~10 sec. Data are timestamped at 1 minute after the sample was taken. Consequently 60 seconds must be subtracted from the time stamps.

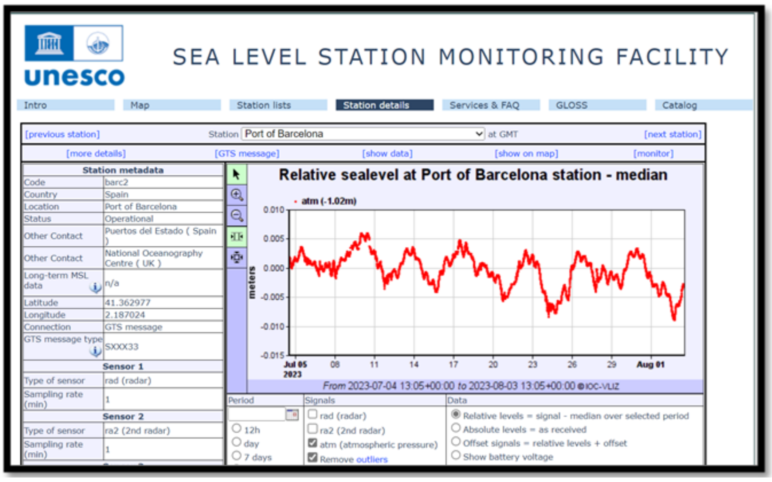

Figure 11. Atmospheric pressure data received at IOC SLSMF for Port of Barcelona

[8] http://www.ioc-sealevelmonitoring.org/station.php?code=barc2

Electrical field monitoring (lightning detection)

Previstorm data (consisting of 1 sec samples of electrical field activity, V/m) are transmitted via a roaming SIM card at 1 min intervals to the PdE ftp site (enoc.puertos.es) with a negligible (<1sec) latency for incorporation into the OSPAC software.

Data are also accessible via a dedicated laptop in the Port of Barcelona, which uses a software platform plugin known as Previstorm® Viewer for Windows™. An example of this is shown in Figure 12

Figure 12. Example screenshot from Previstorm® Viewer for Windows™.

Vertical land motion

RINEX 3 data files from the Trimble Alloy GNSS receiver are transmitted every 15 mins to the NOC via FTP. They contain observations of carrier phase and range, plus signal-to-noise ratio at 5 sec intervals from each satellite that is in view of the receiver. On a daily basis, the 15 min files are combined to produce a daily file of 30 second data which is sent via ftp to the SONEL data portal (Figure 13, GPS Barcelona Tide Gauge 2[9], SONEL station code 4586, IGS site reference BCTG).

[9] https://www.sonel.org/spip.php?page=gps&idStation=4586

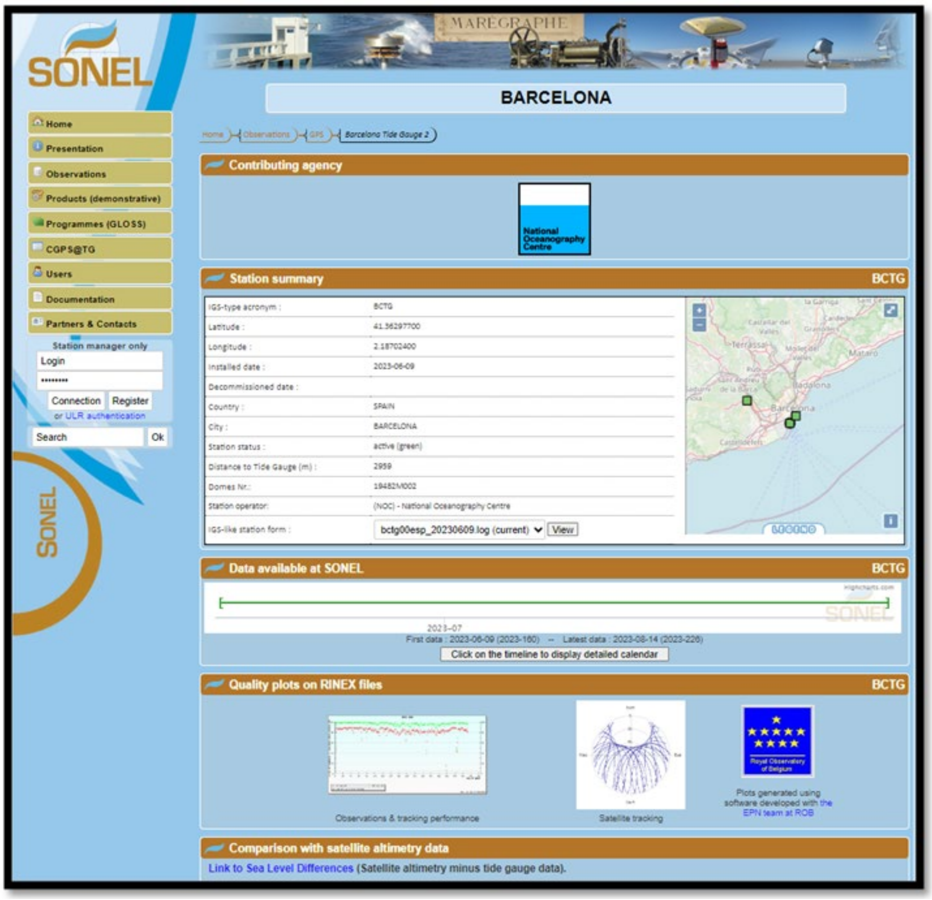

Figure 13. Vertical land motion at SONEL for the Port of Barcelona tide gauge

Geocentric sea level

The 15-minute data files from the Trimble Alloy GNSS receiver are processed in near real-time using the interferometric reflectometry (IR) technique, to produce sea level heights at 15 minute intervals in an ellipsoidal reference frame (like that used for satellite altimetry). The latency is around 1 hour. These data are transmitted to the PdE ftp site (enoc.puertos.es) for incorporation into the OSPAC software. These data have been shown to display good agreement with sea level data from the conventional Nile radar sensors (Figure 14).

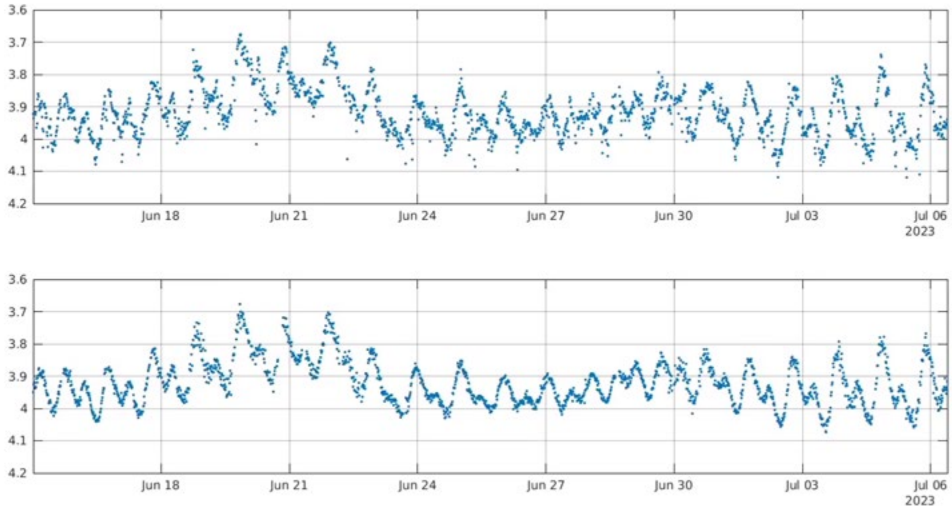

Figure 14. Sea level from GNSS-IR (top) and conventional radar sensor (bottom) at Barcelona Site 1

Significant Wave Height

1 sec samples of carrier phase and range, plus signal-to-noise ratio are transmitted via a roaming SIM card at hourly intervals to the NOC in the form of RINEX 3 data. These are currently processed manually every few days, using the IR technique, to produce hourly estimates of SWH. The results are currently in a calibration phase. Agreement between these observations and those of an offshore wave buoy has been shown to be very good (Figure 15). The NOC plans to refine this to produce a near real-time SWH product to support OSPAC in Autumn 2023.

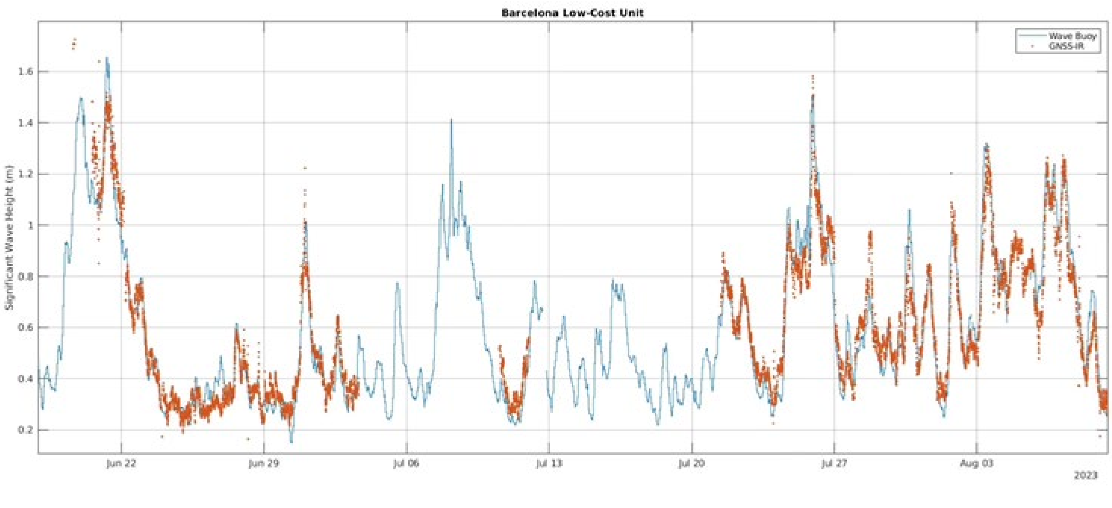

Figure 15. Comparison of SWH from GNSS-IR at the Barcelona lighthouse and an offshore wave buoy maintained by PdE

3.2. Taranto

The following data streams were implemented for this site:

Sea Level

1 min averages of sea level from a Nile radar sensor are transmitted via a roaming SIM card at 1 min to the PdE ftp site (enoc.puertos.es) with a 10 sec latency for incorporation into the OSPAC software. Data are time stamped at 10 sec past the minute to which they relate. 40 sec should be subtracted from time stamps to accurately represent the midpoint of the averaging period.

In addition, 1 min averages of sea level from the same Nile radar sensor are transmitted via a free Meteosat satellite communications system to the Global Telecommunications System (GTS) from where they are accessed by the IOC sea Level Station Monitoring Facility (IOC SLSMF) and are made publicly available (Figure 16, SEA LEVEL STATION MONITORING FACILITY[10]). This telemetry method has a maximum latency of 6 min. Data are time stamped at 1 minute past the minute to which they relate. 90 sec should be subtracted from time stamps to accurately represent the midpoint of the averaging period.

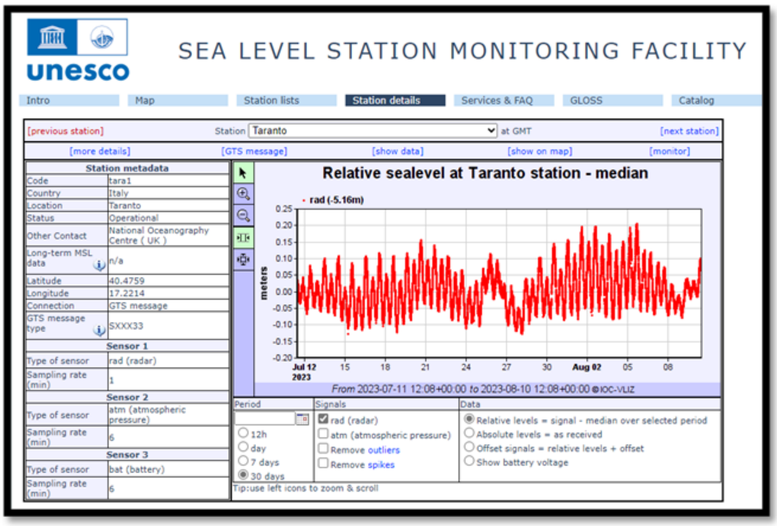

Figure 16. Sea level data received at IOC SLSMF for Port of Taranto

Atmospheric pressure

1 min samples of atmospheric pressure are transmitted via a roaming SIM card at 1 min intervals (i.e. the barometer reading will be constant for 6 transmissions) to the PdE ftp site (enoc.puertos.es) with a 10 sec latency for incorporation into the OSPAC software. Data are timestamped at 10 sec past the sampling time.

1 min samples of atmospheric pressure are transmitted every 6 mins via a free Meteosat satellite communications system to the Global Telecommunications System (GTS) from where they are accessed by the IOCSLSMF and made publicly available (Figure 17, SEA LEVEL STATION MONITORING FACILITY[11]). This

[10] http://www.ioc-sealevelmonitoring.org/station.php?code=tara1
[11] http://www.ioc-sealevelmonitoring.org/station.php?code=tara1

telemetry method has a maximum latency of 6 min. Data are timestamped at 60 secs after the sample was taken, so this must be deducted from each time stamp.

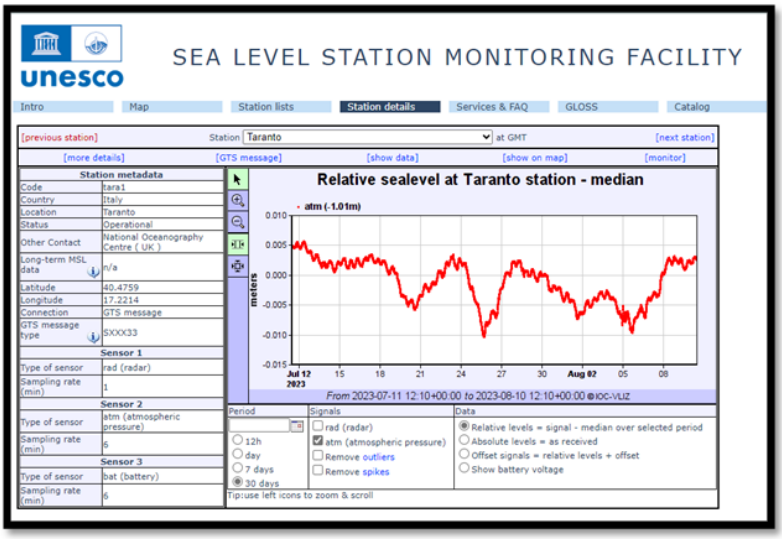

Figure 17. Atmospheric pressure data received at IOC SLSMF for Port of Taranto

Vertical land motion

RINEX 3 data files from the Trimble Alloy GNSS receiver are transmitted every 15 mins to the NOC via FTP. They contain observations of carrier phase and range, plus signal-to-noise ratio at 5 sec intervals from each satellite that is in view of the receiver. On a daily basis, the 15 min files are combined to produce a daily file of 30 second data which is sent via ftp to the SONEL data portal (Figure 18, GPS Taranto tide gauge[12], SONEL station code 4586, IGS site reference BCTG).

[12] https://www.sonel.org/spip.php?page=gps&idStation=4587

Figure 18. Vertical land motion at SONEL for the Taranto tide gauge

Wave monitoring

Using the MIROS RangeFinder, every 1 minute the following wave spectral parameters are computed for 2Hz raw data across a 20 min-time window:

- Water level (m)
- Hm0 (significant wave height (m))
- Hmax (maximum wave height (m))
- Tm02 (mean zero up-crossing period (s))
- Tp (primary wave peak period (s))

These data are transmitted via a roaming SIM card to the PdE ftp site (enoc.puertos.es), with negligible latency, for incorporation into the OSPAC software. Data are time stamped at 10 sec past the minute to which they relate. 610 sec should be subtracted from time stamps to accurately represent the midpoint of the averaging period. An example of the MIROS data is shown in Figure 19.

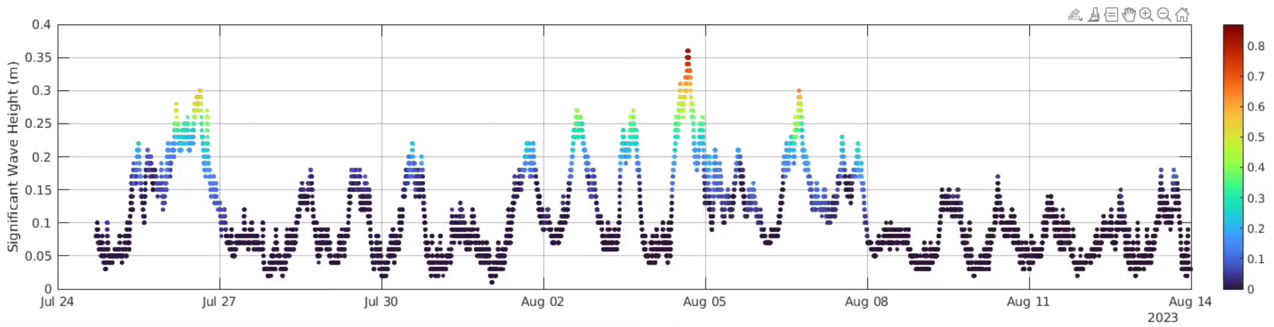

Figure 19. Significant wave height from the MIROS radar sensor at Taranto

In addition, the 15 min data files from the Trimble Alloy GNSS receiver are currently processed manually every few days using the interferometric reflectometry (IR) technique, to produce hourly estimates of SWH across the nearshore area. The results are currently in a calibration phase. The NOC plans to refine this to produce a near real-time SWH product to support OSPAC in Autumn 2023.

Geocentric sea level

The 15 min data files from the Trimble Alloy GNSS receiver are processed in near real-time using the interferometric reflectometry (IR) technique, to produce sea level heights at 15 minute intervals. The latency is around 1 hour. These data are transmitted to the PdE ftp site (enoc.puertos.es) for incorporation into the OSPAC software. These data have been shown to display good agreement with sea level data from the conventional Nile radar sensors (Figure 20).

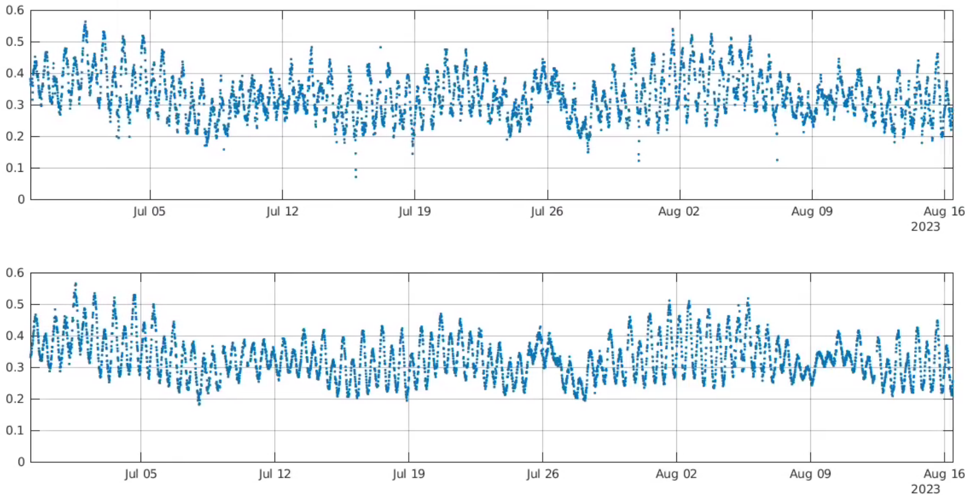

Figure 20. Sea level from GNSS-IR (top) and conventional radar sensor (bottom) at Taranto

3.3. Buenaventura

The following data streams are planned to be implemented for this site[13]:

Sea Level

1 min averages of sea level from dual radar sensors are to be transmitted via a roaming SIM card at 1 min intervals to the PdE ftp site (enoc.puertos.es) with a 10 sec latency for incorporation into the OSPAC software. Data are time stamped at 10 sec past the minute to which they relate. 40 sec should be subtracted from time stamps to accurately represent the midpoint of the averaging period.

In addition, 1 min averages of sea level from the same dual radar sensors will be transmitted via a free GOES satellite communications system to the Global Telecommunications System (GTS) from where they are accessed by the IOC sea Level Station Monitoring Facility (IOC SLSMF) and are made publicly available (Figure 21, <insert weblink when available>) This telemetry method has a maximum latency of 6 min. Data will be

[13] This information will be updated once the Buenaventura tide gauge installation is complete.

time stamped one minute later than the minute to which they relate. Therefore, 90 sec should be subtracted from time stamps to accurately represent the midpoint of the averaging period to which they relate.

<insert figure when available>

Figure 21. Sea level data received at IOC SLSMF for Port of Buenaventura

Atmospheric pressure

6 min samples of atmospheric pressure will be transmitted via a roaming SIM card at 1 min intervals (i.e. the barometer reading will be constant for 6 transmissions) to the PdE ftp site (enoc.puertos.es) with a 10 sec latency for incorporation into the OSPAC software. Data will be timestamped at 10 sec past the sampling time.

In addition, 6 min samples of atmospheric pressure from the same barometer will be transmitted via a free Meteosat satellite communications system to the Global Telecommunications System (GTS) from where they are accessed by the IOCSLSMF and will be made publicly available (Figure 22, <insert weblink when available>). This telemetry method has a latency of ~10 sec. Data will be timestamped at 1 minute after the sample was taken. Consequently 60 seconds must be subtracted from the time stamps.

<insert figure when available>

Figure 22. Atmospheric pressure data received at IOC SLSMF for Buenaventura

Vertical land motion

RINEX 3 data files from the Trimble Alloy GNSS receiver will be transmitted every 15 mins to the NOC via FTP. They will contain observations of carrier phase and range, plus signal-to-noise ratio at 5 sec intervals from each satellite that is in view of the receiver. On a daily basis, the 15 min files will be combined to produce a daily file of 30 second data which will be sent via ftp to the SONEL data portal (Figure 23, <insert weblink when available>) SONEL station code <TBA>, IGS site reference< TBA>).

<insert figure when available>

Figure 23. Vertical land motion at SONEL for the Buenaventura tide gauge

Geocentric sea level

The 15-minute data files from the Trimble Alloy GNSS receiver will processed in near real-time using the interferometric reflectometry (IR) technique, to produce sea level heights at 15 minute intervals in an ellipsoidal reference frame (like that used for satellite altimetry). The latency is around 1 hour. These data will be transmitted to the PdE ftp site (enoc.puertos.es) for incorporation into the OSPAC software. These data will be checked for good agreement with sea level data from the conventional Nile radar sensors (Figure 24).

<insert figure when available>

Figure 24. Sea level from GNSS-IR (top) and conventional radar sensor (bottom) at Buenaventura

Significant Wave Height

1 sec samples of carrier phase and range, plus signal-to-noise ratio will be transmitted via a roaming SIM card at hourly intervals to the NOC in the form of RINEX 3 data. Initially, these will be processed manually every

few days, using the IR technique, to produce hourly estimates of SWH. Once this calibration phase is complete and the data have been checked for good agreement with other data sources (Figure 25), the data will be refined to a near real-time SWH product to support OSPAC.

<insert figure when available>

Figure 25. SWH from GNSS-IR at Buenaventura

4. Conclusion

Whilst the prototype multiparametric operational monitoring systems have been successfully deployed at Barcelona and Taranto in fulfilment of this deliverable, the 3rd prototype system is still in transit to Buenaventura. The Task 5.1.1 implementation team expects this installation to be complete imminently. However, it must be acknowledged that this task and associated deliverables have been delayed significantly by a variety of unforeseen events. It would be fair to say that certain of these events would not have been perceived as major risks at the proposal stage of the EuroSea project, namely the possibility of the global COVID-19 pandemic and the resulting lockdown measures that were taken by governments in response. These imposed unavoidable delays due to periods of enforced homeworking, pandemic-related supply-chain problems and restrictions on international travel. This demanded a heavy reliance upon newer ways of working such as videoconferencing, which were used to good effect in agreeing tide gauge locations and functionality with local stakeholders. Even so, delays were inevitable, simply because for a long period between 2020 and 2021, NOC engineers could not travel overseas to complete the tide gauge installations. In contrast, it was foreseeable that the departure of the UK from the EU might cause risks to timely delivery, but the nature of these risks could not be defined at that stage, since trade agreements and working arrangements for non-EU citizens had yet to be agreed. Consequently, the difficulties that arose in relation to arranging work permits were unexpected and took some time to address. The difficulties experienced in obtaining permissions to install a tide gauge in Alexandria were foreseen and as a result, the WP5 team identified alternative locations and engaged with new stakeholders at an early opportunity, so that the location could be switched at short notice. Nevertheless, delays could not be avoided as this complication simply compounded earlier delays.

Lessons have been learned from these events and the Task 5.1.1 team is developing tide gauge implementation protocols to identify risks associated with supply chains and logistics and address these at an early stage. Potential future pandemics are now a known risk and can be accounted for in project planning and mitigated through vaccination measures.

Notwithstanding these delays, the Task 5.1.1 team is pleased to have successfully delivered the prototype multiparametric monitoring systems in Barcelona and Taranto, with a 3rd to follow in Buenaventura imminently. The first 2 installations have been comprehensively documented in installation reports and dedicated maintenance guidance has been prepared for all 3 sites to help local tide gauge operators to ensure that these systems remain operational.

Of particular note is the successful implementation of the innovative GNSS-IR technique, which has allowed equipment that is conventionally used to monitor vertical land motion, to be used to monitor other key parameters such as sea level and significant wave height. The excellent agreement that has been found between observations of SWH and sea level from this method and those obtained by conventional monitoring systems is a key achievement that has the potential to revolutionise coastal monitoring systems. It demonstrates how existing networks of geodetic quality GNSS receivers that are situated close to the coast can be used for monitoring multiple coastal parameters and how future tide gauge installations might potentially be limited to the installation of one multi-purpose instrument. Additionally, the efficacy of the low-cost (circa EUR1000) GNSS instrumentation for monitoring SWH in Barcelona indicates that there is scope for densifying sea level and wave monitoring networks globally at a fraction of the usual costs.