National Oceanography Centre

PASS-SWIO

Portagauge and Satellite Sea Level Monitoring System for the Southwest Indian Ocean

Executive Summary Report

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Contents

1. Introduction

The Portagauge and Satellite Sea Level Monitoring System for the Southwest Indian Ocean (PASS-SWIO) project was funded by the European Space Agency (ESA) under the EO4Society programme. The project kicked-off on 5th May 2022, and the Final Review meeting was held on 3rd May 2024.

The PASS-SWIO project aimed to establish a sea level monitoring system for Madagascar based on the installation and deployment of a low-cost relocatable tide gauge (Portagauge, Figure 1).

The Portagauge was designed and built at the National Oceanography Centre (NOC) in the UK and shipped to Toamasina, Madagascar, where it was installed in June 2023 with the assistance of the Direction Générale de la Météorologie (DGM) who took responsibility for the local maintenance and operation of the Portagauge. The Portagauge was donated to DGM at the end of the ESA-funded project.

In addition to training in the installation and maintenance of the Portagauge, DGM staff were trained to carry out the data processing and analysis of tide gauge and satellite altimeter data, enabling them to carry out these tasks independently in the future.

Data collected by the Portagauge's Vegapuls 6X radar sensor and Trimble Alloy GNSS receiver were cross validated with satellite altimetry data and compared with historical tide gauge data, collected at another location in Toamasina Port. An analysis of characteristics of sea level variability for the Madagascar coastal region was carried out.

Discussions were held with key stakeholders to review the project and agree a Road Map for the sustainable long-term implementation of a national sea level monitoring system for Madagascar, which can serve as model for other island states and coastal countries in the Southwest Indian Ocean (SWIO) region and beyond.

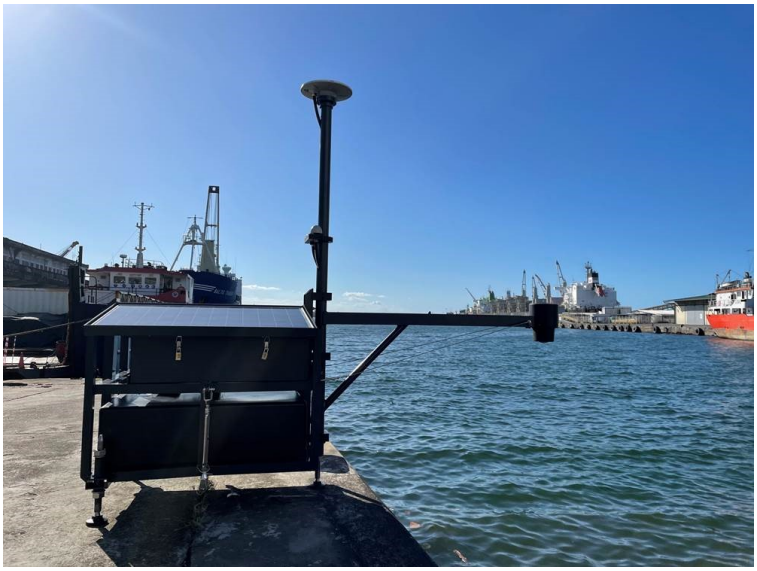

Figure 1 The Portagauge deployed at Toamasina, Madagascar

A small number of issues impacted the progress of PASS-SWIO, these included:

- Delays to the design and build due to the impact of COVID19 on the supply chain
- Longer than anticipated shipping time
- A delay in the release of the Portagauge from Customs in Madagascar
- Postponement of a planned visit to Madagascar, due to potential unrest during national elections

As a consequence of these issues the project duration was extended from 12 to 24 months.

2. Results

2.1. Portagauge Installation and Operation

The NOC Portagauge was successfully installed on 13/06/23, and to date has provided 10 months validated and processed sea level and location data. Its capability as a fully autonomous accurate and reliable tide gauge, with radar and GNSS measurement capacity, was clearly demonstrated.

The Installation Manual (D2.2) was reported by DGM staff to be clear and comprehensive.

The Portagauge radar gauge was found to provide accurate and reliable measurements of sea level and the GNSS instrument accurate and reliable measurements of position. GNSS-IR processing also provided accurate measurements of daily average sea level, which could then be used to cross-reference the radar gauge water levels to the reference ellipsoid.

Solar panels were found to provide charging capability to ensure the battery provided sufficient power for continuous operation throughout the deployment.

A problem with data transmission over the mobile data network using a global mobile SIM card was resolved through the use of a local mobile network (Telma) SIM card.

2.2. Capacity Building for Tide Gauge operation and sea level data processing

An important part of the project was to help develop a national capacity within Madagascar to install, operate and maintain the Portagauge, and also to be responsible for data management, validation and processing. In person and online training was delivered to DGM staff and we are confident that DGM now has the capacity to carry out these tasks.

2.3. Sea Level Data Sets for Madagascar Coastal Regions

A number of data sets have been produced for the PASS-SWIO project and are available through the project web site for analysis and applications. These data sets are:

- Toamasina Portagauge Radar Gauge data (13/06/23 - 25/04/24)
- Toamasina Portagauge GNSS data (13/06/23 - 29/04/24)

- Satellite altimeter data
  Along-track time series of sea surface height anomaly, available as a zip file containing:
  - Jason-1, Jason-2 and Jason-3: 2002-2022
  - Sentinel 3A 2016-2022
  - Sentinel 3B 2018-2022

2.4. Validation of Satellite Altimeter and Tide Gauge data

Eight months of Portagauge data have been quality controlled and validated using tidal analysis software. These data were found to be of excellent quality, yielding no suspect data during the validation period. Comparison of key tidal constituents between the historical SHOM and Portagauge time series displayed good agreement, even though they were derived from different locations within the port and despite the brevity of the Portagauge record compared with the SHOM record. This provides confidence in quality of the Portagauge data, and confirms that a relatively short time series can be used to generate accurate tidal constituents

Satellite altimeter and tide gauge data for Toamasina have been carefully cross-validated against each other, for historical tide gauge data (2010-2022) and Portagauge data (June 2023 to February 2024). A high level of agreement has been found between both sets of in situ data and the satellite data. This provides confidence that satellite altimeter data can be used to support analyses of sea level variability in the northeast coastal regions of Madagascar close to Toamasina.

The results are available in the PASS-SWIO report (D3.2), *Cross-validation of in situ and satellite altimeter sea level data*.

2.5. Assessment of Satellite Altimeter Data from Specialised Coastal Processing

Thanks to support from the ESA Network of Resources, PASS-SWIO was able to carry out an assessment of satellite altimeter data from specialised coastal processing, to discover if these data could be useful for coastal applications. It was concluded that data from the specialist coastal processor were not found to provide more accurate sea surface height data than those from the standard product in the range 5-10km from the coast, but that the specialised processing does provide data in near coastal locations (within 5km of the coast) where the standard product does not.

The PASS-SWIO *Technical Note on the Analysis of Sentinel-3 Altimeter data at the coast of Madagascar* provides full details.

2.6. Sea Level Variability Analysis

A *Sea Level Variability Report* (D3.3) has been produced which provides an analysis of characteristics of sea level variability for the Madagascar coastal region. Analysis of tidal characteristics was based on tide gauge and tide model data. Satellite altimeter data were processed and analysed to provide information on seasonal and inter-annual variability (including long-term trends). This analysis enabled the identification of regions where the patterns of variability are coherent, and where they are different, and also to identify regions potentially more at risk from sea level surges due to extreme events. This

has been used to support the identification of future tide gauge locations in the development of a sea level monitoring system for the Southwest Indian Ocean.

2.7. Implementation Road Map

The *Implementation Road Map* (D4.1) provides recommendations to establish a long-term, sustainable, national sea level monitoring system for Madagascar. It also provides a model for a sea level monitoring system for developing island states and coastal nations, based on low-cost tide gauges and satellite data. It was developed with input from Madagascar organisations with an interest in using sea level data for a range of applications. The PASS-SWIO team will continue to work with Madagascar partners to find a way to implement these recommendations.

3. Project Deliverables

The formal project deliverables are listed below. All are available through the project website: https://www.satoc.eu/projects/pass-swio/

3.1. Reports, Documents

- D1.1 PASS-SWIO Training Material
- D2.2 Portagauge installation and operation instructions (in English and French)
- D3.1 Data Set and Report for Tide Gauge and Satellite Data
- D3.2 Validation Report
- D3.3 Sea Level Variability Report
- D4.1 Implementation Road Map
- D5.3 Executive Summary Report
- D5.4 Final Report (this report)
- D5.5 Communications Package
- D5.7 Final Presentation

3.2. Data Sets

The PASS-SWIO data sets are listed below and available on the project data set webpage at https://www.satoc.eu/projects/pass-swio/data.html

Toamasina Portagauge Radar Gauge data (13/06/23 - 25/04/24)

- Primary Results File - *HA_053_000001_007603_GS_02_PR.txt*
- Time Series Results File - *HA_053_000001_007603_GS_02_TS.t2k*
- Daily mean sea level File - *HA_053_000001_007603_GS_02_DM.txt*
- Monthly mean sea level File - *HA_053_000001_007603_GS_02_MM.txt*

Toamasina Portagauge GNSS data (13/06/23 - 29/04/24)

- Quality controlled daily mean sea level: *PG1_GNSS_swio_daily.txt*
- Quality controlled daily mean GNSS position: *SWIO00MDG_IGS20.neu*

Historic Toamasina SHOM Tide Gauge data (01/01/2010 – 29/03/2022)

- Time Series File - *HA_112_000001_058741_GS_02_TS_Toamasina.t2k*

Satellite altimeter data
Along-track time series of sea surface height anomaly, available as a zip file containing:

- Jason-1, Jason-2 and Jason-3: 2002-2022
- Sentinel 3A 2016-2022
- Sentinel 3B 2018-2022

There is one file per satellite track. The naming convention is *sss*_cmems_p*oooo*.nc, where *sss* is satellite series (s3a, s3b or j1j2j3) and oooo is relative orbit number, e.g. s3a_cmems_p0012.nc, j1j2j3_p0222.nc.

3.3. Training material

The PASS-SWIO training material for tide gauge and satellite altimeter data processing and validation is listed below and is available from the Training section of the project website at https://www.satoc.eu/projects/pass-swio/training.html

- Checking and Validation of Tide Gauge sea level data
- Processing and Submission of Portagauge GNSS position data
- Satellite altimeter data: Accessing and pre-processing
- Satellite altimeter data: Validation and analysis of sea level variability

4. Project Recommendations

Detailed recommendations are provided in the PASS-SWIO Implementation Road Map. Main points are:

Full Implementation of Portagauge based sea level monitoring system

We recommend the implementation of a rolling programme of installation of the Portagauge at the five remaining Madagascar Ports of National Interest, for a minimum of 6 months at each, with the next two installations on the northwest coast at Mahajanga and Nosy Be.

Madagascar Sea Level Data Management infrastructure

We recommend the establishment of a co-ordinated national data management infrastructure for sea level data, linked to international sea level data measurement systems, to ensure the sea level data are available nationally and internationally. This should include the provision of tidal predictions for the sites where tidal harmonics are available.

Other Recommendations

1. The PASS-SWIO Implementation Road Map should be provided to the relevant Madagascar stakeholder agencies, to the IHO, the Indian Ocean Commission and WIOMSA.
2. The GNSS data should be made available to the FTM for analysis and processed to provide information on Vertical Land Movement at coastal locations. The issue of the low precision of the local geoid model for Madagascar should be addressed.
3. BNGRC and NOC should hold discussions regarding Tsunami warning systems for the Southwest Indian Ocean.
4. Noting that the Esteves and Ballesteros (2021) study[1], which developed an index of exposure to coastal change, could not include sea level change or geomorphology in their analysis for Madagascar due to lack of comparable data, and the fact that the east coast of Madagascar was assessed to have a very high exposure to coastal change, we recommend a scientific programme to provide improved data on these key parameters.
5. The Pangalanes Canal on the northeast coast of Madagascar (south of Toamasina) is a series of link inland lakes and waterways and provides an important safe transport link instead of the open Indian Ocean which is vulnerable to large swells. However, it is subject to changes in water level following prolonged rain, which can flood coastal villages. There is a Sentinel 3B track that runs along this canal for much of its length, and the use of Fully Focussed SAR altimeter processing to provide accurate water levels could be of interest.

[1] Ballesteros, C. and Esteves, L.S. (2021) Integrated Assessment of Coastal Exposure and Social Vulnerability to Coastal Hazards in East Africa, Estuaries and Coasts, https://doi.org/10.1007/s12237-021-00930-5

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