



Coastal Sea Temperature Data using Low-cost Commercial Sensors around a Small Mediterranean Island

^{*1}Alberto Ribotti, ²Sergio Stagno, ²Stefano Schirru, ³Alan Deidun, ³Audrey Zammit, ³David Fernando Ramirez Montano, ⁴Alessandro Madeddu, ²Mauro Montis, ⁵Alessandro Gibertini, ¹Andrea Satta, ¹Roberto Sorgente, ^{3*}Adam Gauci, ¹Stefano Marras

1. CNR-IRBIM, Oristano, Italy

2. Netsoul srl, Cagliari, Italy

3. Department of Geosciences, University of Malta, Msida, Malta

4. Maraltro slrs, Cagliari, Italy

5. CNR-ISMAR, Roma, Italy

Abstract: The acquisition of coastal data, especially in areas of the Mediterranean, is of fundamental importance in numerical forecasting and climatological studies. Islands are particularly significant due to their central location within the sub-basins of the Mediterranean Sea. It is equally important to obtain high-quality data acquired according to common standards, which can be achieved through the exchange of information. In Sardinia, western Mediterranean, an initial experiment was conducted on the small island of San Pietro through the Citizen Science project MedSeaPOD. Twenty temperature sensors were installed at 17 sites around the island for minimum of 12 months in very shallow waters between 3 and 30 metres depth, involving local not scientist people. This made it possible to provide high-quality scientific data to the European EMODnet repository and to raise public awareness of climate change. This project has been recognized as having relevant scientific value by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and it has received the endorsement as Action of the Ocean Decade (2021-2030), within which we have established contacts with scientists from neighbouring Corsica. Terminated in September 2025, acquisitions and the activities as Action went on through the involvement of stakeholders in Sardinia measuring coastal temperature in other sites and other Mediterranean islands like Malta, through a bilateral project that has started in January 2026, where similar measurements are being collected.

Keywords: sea temperature, coastal data, shallow water, small island, western Mediterranean

INTRODUCTION

Coastal seas serve as critical transitional zones between land and open ocean, supporting rich biodiversity, essential ecosystem services, and dense human populations. These areas are increasingly subject to pressures from intensified human activity and the accelerating impacts of climate change, including more frequent extreme weather events and prolonged marine heatwaves. Marine heatwaves have increased in frequency and magnitude worldwide, with detrimental impacts on coastal ecosystems and human activities [1][2][3]. As such, scientific research in coastal zones is crucial for advancing our understanding of environmental change, assessing associated risks, as well as informing sustainable management and adaptation strategies.

Seven per cent of all global marine biodiversity is found in the Mediterranean Sea, despite the fact that it accounts for only 0.8 per cent of the world's oceans [4] and is one of the most visited and densely populated marine regions in the world. Due to its location and geographical configuration, the Mediterranean is warming at almost twice the global average rate. For this reason, the collection of high-resolution sea temperature data is essential, particularly in coastal and shallow waters where measurements are often lacking [5][6]. Over the past four decades, a consistent upward trend in sea surface temperatures around the Maltese islands has been recorded, with an average annual increase of 0.05°C . This trend is especially evident during the summer months, with mean surface temperatures aligning closely with wider Mediterranean averages, around Corsica, Sardinia, and Malta, and in the western and central Mediterranean [7][8].

All this brings forth a consensus on the need for high-resolution, long-term, depth-resolved datasets to better understand and forecast the impacts of climate change on marine systems. As highlighted in the sixth COPERNICUS ocean state report, there is a pressing requirement for improved localised monitoring capable of capturing vertical thermal structures that are often missed by current observation systems [8].

At present, most operational forecasting systems rely heavily on satellite-derived sea surface temperature data, which, while offering broad spatial and temporal coverage, only provide information about surface conditions. Subsurface temperature data are generally inferred through ocean models, which are not frequently validated due to a lack of consistent in-situ measurements, primarily in coastal areas. Subsurface data typically consist of isolated values in time rather than continuous time series from fixed locations which severely limit the understanding of key physical processes. The deployment of fixed moorings, equipped with autonomous sensors that capture temperature at multiple depths and at high temporal resolution, overcomes these limitations.

Extreme warming events, previously cited as heatwaves or marine heatwaves, have increased in frequency and magnitude worldwide, with detrimental impacts on coastal ecosystems and human activities. Sea Surface Temperature (SST) satellite data from the Copernicus Marine Service show an average summer surface temperature in the Mediterranean over 2.5°C in 2018 and of 5°C to 6°C in 2022. The seas around Sardinia reached temperatures over 30°C in summer 2022. However, these satellites do not have such a high resolution to cover coastal areas with a seabed below 50 m, nor to measure the main oceanographic parameters (temperature, salinity, and pressure) between the surface and the bottom. A recent study on Mediterranean heatwaves during the period 1989-2018, only uses NOAA's SST-AVHRR satellite data, thus not covering coastal areas [9]. Similarly, Garrabou [10] uses SST data from the Copernicus Marine Service and the Optimum Interpolation Sea Surface Temperature of NOAA for the studied period 2015-2019 but complementing them with hourly high-frequency time series of temperature only, acquired by underwater operators using HOBO data loggers and uploaded to the EMODnet repository. This base of information, created within the homonymous project, consists of data generally acquired every 5 m between the surface and 40 m depth in Mediterranean coastal areas.

However, not all Mediterranean coasts are covered by the same number and frequency of samplings. In Sardinia there are only five samplings dating back to 2017, three located in the north-east and two in the south-east. Considering the high number of tourists on the island in summer, the amount of data that could be acquired in coastal areas would

be considerable, with an important direct impact on the knowledge of the state of Sardinian coastal marine ecosystems and, indirectly, on the economy of the island (mainly fishing and tourism).

Every day, local fishers, sailors, spear fishers, swimmers, freedivers, and divers, dive in the waters of the Mediterranean Sea and are potential acquirers of scientifically useful data. Why not provide these people with a tool to actively contribute to monitoring the health of our sea? Citizen science and data crowd sourcing are the tool to facilitate the monitoring and protection of the marine environment and raise general awareness of the impact of climate change on the sea and marine life.

Based on these considerations, between mid-September 2023 and 2025, two small Italian-Sardinian SMEs (Netsoul srl and Maraltro slrs), the Council of Carloforte (the village on the small island of San Pietro in Sardinia), and an institute in Oristano (Sardinia, Italy) of the National Research Council (CNR), started a Citizen science pilot project that was codenamed MedSeaPOD (Mediterranean Sea People's Observatory Data; <https://www.medseapod.org/>). This was supported by the EC European Marine Observation and Data Network (EMODnet) of DG MARE. It has received the endorsement from the IOC UNESCO as Ocean Decade Action Call 8/24, supported by the Parc Naturel Marin du Cap Corse et de l'Agriate (<https://parc-marin-cap-corse-agriate.fr>) in Corse using HOBOS in the northern part of the island. Challenges 2, 5, 6, and 7 of the Ocean Decade (support the protection of ecosystems and biodiversity; develop climate-change solutions; increase coastal-community resilience; expand ocean observations) underline the importance of small islands in the study of climate change.

MedSeaPOD was a research and development pilot project based on scientifically rigorous processes for collecting large-scale localised data, through an integrated Global Positioning System, sea temperature and pressure, in Sardinian coastal marine areas. This was being achieved through extensive citizen science activities centred around the small island of San Pietro on the South-West coastline of Sardinia. The project aimed to process, display, and share the collected data with the scientific community, policy makers, and civil society, through an innovative and interactive data visualisation system. The data acquired had the potential to be used to develop new conservation programs for coastal ecosystems and raise awareness among the population about the ongoing effects of climate change through creative and effective communication approaches.

The main goals of this pilot project were threefold. Firstly, to generate a dataset of temperature along the coastal areas of Sardinia and constitute a benchmark for future measurements and analysed by the global scientific community. Secondly, to generate an "active awareness" of the impact of climate change on marine ecosystems. This was to the public domain, citizens, politicians, and decision-makers. Finally, the ultimate goal was to popularise scientific research. This implied making the research easily understandable and shareable to make it perceived as essential to the environmental, social, and economic well-being of all operators of the sea and citizens.

In this work, the activities within MedSeaPOD, results, and some data analysis are discussed and further steps presented as the activities are going on despite of the end of the project last mid-September 2025.

MATERIALS AND METHODS

Temperature Sensors

Sea temperature, water pressure, and GPS data are acquired using small commercial sensors. At mid-October 2023, after having evaluated different sensors, the choice fell on the robust data loggers from Onset Corp. and TechnoSmart. Before deployments, tests occurred in the CNR laboratory in Oristano on Onset HOBO 1-800-loggers with temperature sensor and a multiparametric probe Idronaut OS310 (CTD) through a Lab Companion RW3 3025 heating bath circulator at defined temperatures to evaluate criticalities in data acquisition (not shown) with all instruments involved in the project.

The first installations took place in May 2024 at 17 sites (Fig. 1 and Table 1) spread across the island of San Pietro. From the outset, the project's activities were carried out in collaboration with various community groups, such as freedivers, diving centres and local fishermen, who were active participants in our Citizen Science activities. Their logistical support was crucial to the project's success, providing assistance with site selection, monitoring, and the retrieval and installation of sensors.

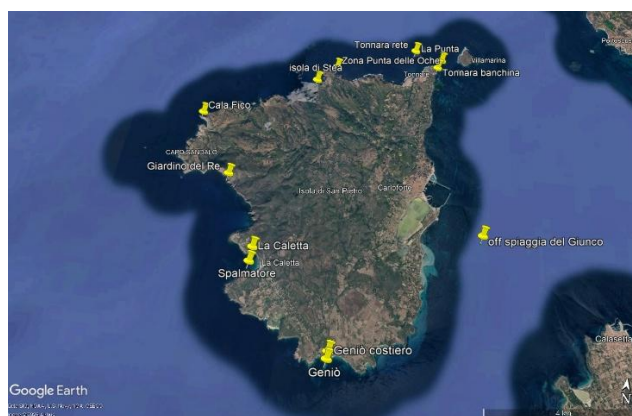


Fig. 1: Map of the sites of the sensors positioned between 4 and 31 m depth

Table 1: The costal sites of the HOBO around the island of San Pietro with their depth and the Citizen involved.

Citizen	Location	Depth [m]
Freediver	Geniò	3.9
Freediver	Spalmatore	0.7
Tuna local fishers	Tonnara banchina (quay)	4.2
Diving	Punta delle oche	20.0
Freediver	Isola di Stea	10.0
Diving	Caletta /right buoy	5.0
Tuna local fishers	Tonnara 30	30.0
Tuna local fishers	Tonnara rete (net)	31.0
Diving	La punta	2.9
Diving	Relitto (Wreck)	12.0
Diving	Tempio	27.0
Freedivers Group	Cala Fico	13.1
Freedivers Group	Giardino del Re	5.5
Freedivers Group	Punta nera	5.7

Diving	Tacche bianche	17.5
Diving	Mezza luna	12.0
Diving	Corno	18.5

Once recovered, data have been downloaded from each Pod then re-deployed on the same site to continue acquisition and then sent to a server. During some maintenance, HOBO T-sensors have been compared with those from the CTD, deployed over the site, to have a further verification of their quality (see paragraph 3). Valid data have been included in an online dataset accessible freely to users directly from the website of the project. Data and metadata have been sent to EMODnet Physics (see paragraph 2.3).

The Web Interface

Within the MedSeaPOD project, two web-based visualisation systems were developed to address distinct objectives: (i) the rapid publication and dissemination of data, and (ii) the exploration of more immersive and unconventional approaches to data analysis. By offering user-friendly visualisation formats, MedSeaPOD democratised access to scientific information, making it usable for researchers, policymakers, and the general public.

First system: Data Visualiser (Fig. 2), designed for rapid data dissemination and use in citizen science contexts, where ease of access and clarity of representation are key elements. By simply uploading a CSV file, raw data is automatically transformed into an interactive two-dimensional graph, created using the ECharts library.

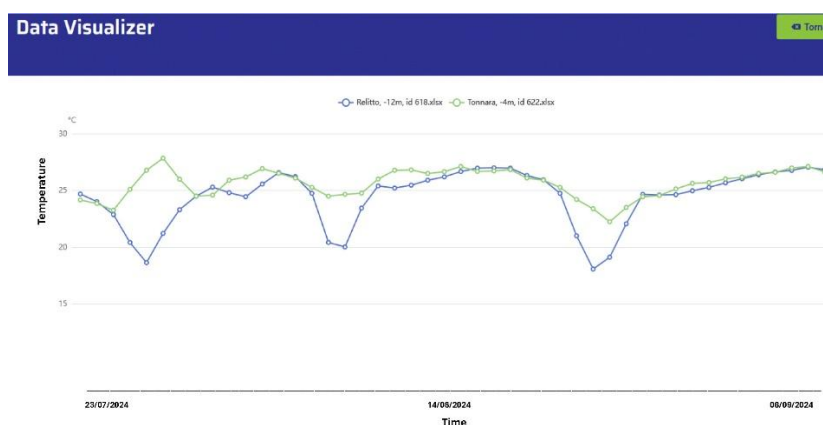


Fig. 2: The Data Visualizer

Users can navigate between different time series by selecting them by location, immediately view data such as depth and sensor ID, and apply a filter to narrow down the time interval of interest. The timeline on the x-axis dynamically adapts to the series displayed, allowing users to both see a cumulative overview and focus on specific details. The system also offers the ability to compare multiple datasets simultaneously, hide or isolate individual series, and generate exportable graphs for later use.

Second system: 3D Explorer (Fig. 3) adopts a more experimental approach, based on Three.js, which transforms measurements into a three-dimensional experience that can be navigated directly from the browser, both on desktop and mobile devices. In this environment, each individual sample is represented by a point in space: the X-axis

corresponds to the time of detection, the Z-axis to the date and the Y-axis to the temperature. In this way, the distribution of points draws a space-time grid that can be freely explored by the user. By changing perspective, it is possible to emphasise the daily temperature range or observe temperature trends over longer periods.

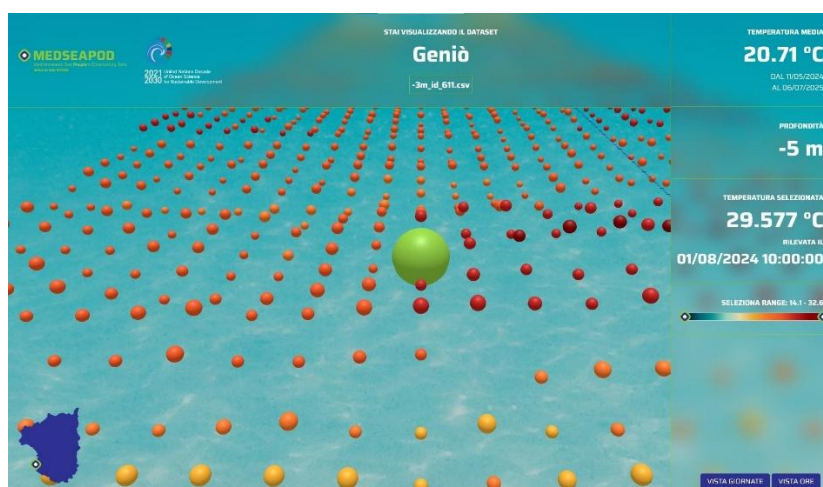


Fig. 3: The 3D Explorer. On the left down corner the site of the sensor on the island

To make exploration intuitive, the points change colour according to temperature, following a colour map that ranges from blue for the lowest values to red for the highest. The user can interact with the display by clicking on a single point to read the exact value and date of detection or filter the entire dataset by selecting a temperature range. The explorer also includes support elements such as three-dimensional axes with reference marks, a two-dimensional mini map showing the geographical location of the sensor, and a side panel with summary statistics (average, range of temperatures detected, depth).

A distinctive feature is the presence of a narrative layer, designed to enrich the simple reading of data with contextual information. Through the “curiosities” section, the application provides brief explanatory notes related to the temperature ranges observed. For example, this indicates optimal conditions for certain marine species, periods characterised by strong winds when values are particularly low, or situations of thermal stress for marine fauna in the event of high temperatures.

EMODnet

Temperature data were acquired from 17 sites with periods ranging from 6 to 12 months, and sensors being repositioned immediately after data download. Given the limited number of files obtained and in agreement with EMODnet Physics representatives, it was decided to activate an account in the Zenodo dataset for uploading to the international EMODnet repository at the end of the project via a dedicated web interface (files and associated metadata). This was done following the instructions provided in the “Submission Service Help Guide for Data Submitters”, available on the European repository website. The data will then be merged into EMODnet to be made available to various users, both public and private, at the end of the project and after verification of the data provided by EMODnet Physics managers.

RESULTS: DATA ANALYSES

Despite the small size of the island of San Pietro, an initial analysis of data from some sensors recovered at the end of September 2024, after four months of sampling, showed similar trends but significant differences in temperature values. An illustrative example (Fig. 4) shows data from two sensors deployed at comparable depths.

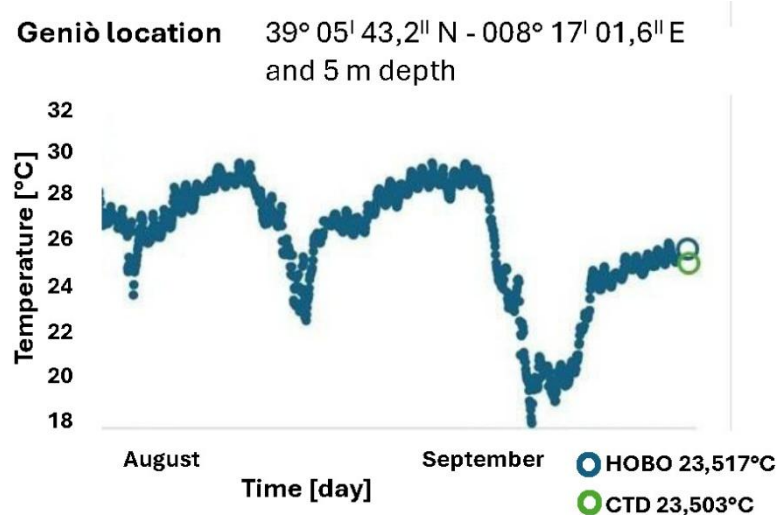


Fig. 4: The two circles at the end of the raw timeseries at Geniò site highlight the comparison of the HOBO (blue circle) and the CTD (green circle)

The first sensor, located at the southernmost site (Geniò; blue line), recorded data from May to September 2024, while the second sensor, positioned at the northernmost site (Tonnara Banchina; green line), collected data from May 2024 to September 2025 (see their locations and deployment depths in Fig. 1 and listed in Table 1).



Fig. 5: Daily mean temperature recorded at two coastal stations around the island of San Pietro: Geniò (south, 3.9 m depth; blue) and Tonnara banchina (north, 4.2 m depth; green). (A) Full record from May 2024 to September 2025. (B) Zoom on the common observation period (May-September 2024).

Observations from the Geniò site (Fig. 5A, blue line), located south of San Pietro at a depth of 3.9 m, provide detailed evidence of the seasonal thermal evolution of the surface layer during May-September 2024. The hourly series, after removal of spurious instrumental spikes, reveals a coherent daily signal consistent with atmospheric forcing and surface heat fluxes typical of the central-western Mediterranean [11]. In May 2024, daily mean temperatures ranged between 21 and 23 °C, with relatively low variability and standard deviation ~0.8-1.1 °C, indicative of a partially mixed water column undergoing spring transition. In the following month, daily averages progressively increased to 24-26 °C, reflecting enhanced radiative heating and the establishment of surface stratification, as commonly observed in the Mediterranean basin [12] [13]. The summer months of July and August exhibited a pronounced warm plateau: daily means reached 27-28 °C in July and peaked around 30 °C in August. The summer warm plateau is defined as the seasonal phase, typically in July-August, when the sea surface layer remains persistently warm (~27-30 °C in the Mediterranean) for several weeks, with limited daily variability. This condition arises from strong solar heating, enhanced vertical stratification, and reduced wind-driven mixing, which together maintain a quasi-stable thermal equilibrium in the upper ocean.

The amplitude of daily fluctuations increased under stable atmospheric conditions and strong radiative forcing, suggesting a tight air-sea coupling and reduced vertical mixing [14][15]. In September, a progressive decline in daily means towards 25-26 °C marked the onset of seasonal cooling, associated with the weakening of summer stratification and the transition to autumnal conditions [16]. Overall, the Geniò station documents the seasonal thermal cycle of the near-surface water column in the southwestern Sardinian coastal sector, confirming the strong sensitivity of the 3-5 m layer to local atmospheric forcing, air-sea heat exchanges, and synoptic variability [17].

Observations from the Tonnara banchina site (Fig. 5A, green line), located along the northern coast of San Pietro at a depth of 4.2 m, documented the daily evolution of near-surface temperature during the period 10 May 2024 to mid-September 2025. The hourly time series, resampled onto a regular grid and averaged as daily means, highlights a marked cooling phase during the first weeks: from initial conditions of about 21 °C on 10 May 2024, daily means rapidly decreased to ~17.5-18 °C in the following days. During the second half of May 2024, a moderate warming phase was observed, with temperatures fluctuating around 18-19 °C, followed by more moderate variations reflecting persistent atmospheric variability and a significant influence of coastal circulation. This pattern is consistent with the occurrence of surface mixing processes and the possible influence of upwelling events, already described along the western Sardinian coast by [18], [11], and [19].

Overall, the Tonnara banchina site reveals a surface thermal dynamic distinct from that observed at the southern Geniò site (Fig. 5B), with a signal characterised by greater sub-seasonal variability and the absence of a summer warm plateau. The lack of such a plateau, i.e. the absence of a prolonged period of persistently high surface temperatures, suggests that in the northern sector the surface layer is more strongly influenced by local mixing processes, coastal upwelling, and mesoscale circulation patterns. These findings confirm the role of atmospheric forcing and mesoscale structures in modulating coastal thermal variability in the south-western Sardinian sector.

CONCLUSIONS: FROM MEDSEAPOD TO MISTRAL

MedSeaPOD was a two-year citizen science pilot project funded between September 2023 and 2025 with the aim of measuring sea temperature around the island of San Pietro, located southwest of Sardinia. The project has been successful, with several local Citizen Science collecting data at depths ranging from 4 to 30 m since May 2024. Thanks to the low maintenance costs of the monitoring sites, measurements are going on also after project's life, with the ambition of linking to networks and agencies across the Mediterranean that provide comparable observations.

MedSeaPOD, its recognition as an Ocean Decade Action Call 8/24, and the 2026 funded bilateral project Mediterranean Initiative for Sea Temperature Research and Logging (MISTRAL), represent steps toward a longer-term goal of connecting groups that acquire long time series of coastal data and fostering information exchange to improve data quality. In June 2025, MedSeaPOD received endorsement from IOC-UNESCO as an Ocean Decade Action. Nonetheless, these initiatives have already enabled collaboration among the three islands where coastal temperature measurements at multiple depths are ongoing. In our Ocean Decade Action Call 8/24, we have engaged with the endorsed Decade Programmes CoastPredict and Science We Need for the Mediterranean Sea We Want (SciNMeet), fostering synergy through shared goals in coastal monitoring and predictive modeling; the discussions highlighted opportunities for collaboration, including data-sharing, joint use of advanced technologies, and aligning methodologies, which will enhance the accuracy and impact of both initiatives in addressing climate change challenges in marine ecosystems.

MISTRAL has a goal of comparing data acquisition and quality assurance methods, required to establish standard procedures for high-quality datasets. To this end, a comparative analysis of the methodologies adopted by participating groups is undertaken, focusing on differences in logger positioning, deployment depths, sampling frequency, and data processing. Standard operating procedure (SOP) are drafted to produce a harmonised methodology suitable for adoption by other Mediterranean partner sites. Existing collaborations with research groups will be used to gather additional subsurface temperature data. MISTRAL is continuing the work begun by MedSeaPOD, involving regional research groups such as the Marine Protected Areas of Tavolara to the east and Capo Carbonara to the south-east of Sardinia. This approach will consolidate and extend ongoing initiatives and provide the foundation for scalable, interoperable coastal monitoring practices across the Mediterranean region.

MedSeaPOD has accelerated ocean knowledge by leveraging citizen science to crowdsource large-scale environmental data in coastal areas. The integration of localised data collection with global scientific models enhances the accuracy of climate impact predictions on coastal ecosystems. This directly contributes to the Sustainable Development Goals (SDGs), especially Goal 14 (Life Below Water), by providing actionable insights for marine conservation and climate change adaptation strategies.

Then, by integrating the participation of citizens into data collection and dissemination processes, MedSeaPOD and MISTRAL foster a collaborative and inclusive approach to marine monitoring and awareness-raising, emphasising the critical role of community-driven efforts in addressing the impact of climate challenges. MISTRAL is a two-years bilateral project between the National Research Council of Italy (CNR) and the

Oceanography Malta Research Group (OMRG) within the Department of Geosciences at the University of Malta.

Malta has a central geographic position and a strong oceanographic tradition. Between 2019 and 2022, OMRG deployed HOBO Water Temperature loggers at 5 m intervals from 5 m down to 60 m around the Maltese Islands. These loggers are recording temperature every hour, generating a unique and continuous time series that enables detailed analysis of stratification patterns and interannual variability [20]. Owing to its central location between the eastern and western Mediterranean basins, Malta is strategically positioned to address critical gaps in regional observational coverage.

MISTRAL employs existing coastal marine infrastructure, such as systems moored on the seabed with temperature sensors at depths ranging from 5 to 60 metres, recording data at hourly intervals. The project aims to standardise best practices for the installation of moored systems, sensor calibration, quality control of acquired data and metadata generation, with the aim of producing standardised time series for the EMODnet and SEANOE repositories, in accordance with FAIR principles. By comparing Italian and Maltese data, the project will enable an analysis of seasonal stratification and thermal anomalies (i.e. marine heatwaves) in coastal areas of the central and western Mediterranean.

The project will establish a standard operating procedure for monitoring sea temperature, strengthening cooperation between the two countries and paving the way for the integration of marine data. MISTRAL will add value to MedSeaPOD, demonstrating how shared infrastructure and protocols, together with open science, can transform local monitoring into a coordinated transnational contribution to climate research, the study of marine resilience, and provide highly useful material for the European University of the Sea. Furthermore, the project, as MedSeaPOD has already done, will contribute to Challenges 2, 5, 6 and 7 of the Decade of the Oceans.

Then the success of MedSeaPOD demonstrates the value of Citizen Science in generating high-resolution coastal datasets, while fostering ocean literacy among local communities. By scaling up this model across the Mediterranean, we can create a resilient, decentralised network of observations critical for climate adaptation and marine spatial planning.

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Data Availability Statement

The data that support the findings of this study are openly available in Zenodo at <https://zenodo.org/records/22942730>

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