

1 **Lagoon temperature and hydrodynamics of Reao Atoll (Tuamotu**
2 **Archipelago, French Polynesia) before and during the 2024 El-Niño**
3 **Marine Heatwave**

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14 **Abstract.** In French Polynesia, semi-closed atolls of the eastern Tuamotu Archipelago are home to fisheries and mariculture
15 activities based on giant clam resources. These activities are increasingly vulnerable to global warming, as evidenced by the
16 mass bleaching event observed in Reao atoll in March 2024, triggered by the most intense and prolonged Marine Heatwave
17 (MHW) ever recorded in this lagoon. The GAIA project (manaGement strAtegy evaluation for small-scale fisheries in Atoll
18 lagoons) was launched to address this issue and aimed to explore the sustainability of giant clam fisheries under climate change,
19 with a particular focus on processes driving thermal exposure during MHWs. To achieve this, spatial and temporal temperature
20 fluctuations, lagoon circulation, and water exchange dynamics between ocean and lagoon across the atoll rim were monitored
21 using moored autonomous oceanographic sensors. A total of 6 monitoring periods took place between December 2016 and
22 May 2025, with the most extensive instrumentation covering the entire February-March 2024 MHW event. The strength of
23 these observations lies not only in their coverage of a unique and poorly sampled ecosystem, but also in their comprehensive
24 documentation of an exceptional MHW event, from its onset and peak to its dissipation, providing an unprecedented record
25 of the full life cycle of a major thermal anomaly in a tropical semi-closed atoll lagoon. This dataset also supports future
26 modelling efforts to simulate temperature dynamics and identify thermal refugia in atoll lagoons under changing climate
27 scenarios. All data were post-processed, quality-controlled, and formatted into interoperable NetCDF files. The full dataset is
28 openly accessible through the SEANOE marine data platform: <https://doi.org/10.17882/105885> (Le Gendre et al., 2025a).

29 **1 Introduction**

30 Semi-closed lagoons are widespread in the eastern Tuamotu Archipelago, French Polynesia, yet they represent unique
31 hydrodynamic systems primarily shaped to their geomorphological configuration (Rougerie, 1995; Andréfouët and Paul,
32 2023). Unlike previously documented lagoons (Bruyère et al., 2023), semi-closed atolls are characterized by the absence of
33 reef pass, with shallow channels (approximately 1-2 meters deep) crossing the rim (“*hoa*”) found only on one side of the atoll.
34 In semi-open atolls (those including passes), water inflows through the *hoa* and the reef pass are mainly driven by tide and
35 oceanic incident waves, and outflow of excess water is drained mostly through the pass (Dumas et al., 2012; Aucan et al.,
36 2021). However, for semi-closed atolls, hydrodynamic behaviour can differ markedly and these lagoons may become
37 temporarily isolated from the ocean (Van Wynsberge, 2016). Water exchange from the ocean into these lagoons occurs only
38 when offshore wave energy reaches a threshold sufficient to drive oceanic water across the atoll rim, through *hoa*. This
39 threshold is likely modulated by tidal range and regional sea level anomalies. During periods of low swell, or when swell
40 direction is not congruent with the open rim’s orientation, exchanges become minimal or even interrupted, causing lagoon
41 water levels to drop significantly due to enhanced evaporation — a condition locally referred to as *ranoa*. Consequently, these
42 atolls can experience long periods of highly restricted water renewal, during which they are particularly sensitive to
43 atmospheric conditions and heat fluxes (Andréfouët et al., 2022). While semi-closed lagoons can become temporarily isolated
44 from the ocean, they are also highly vulnerable to the opposite extreme. Extreme surges generated by prolonged, powerful
45 incident swells, and associated land flooding (Storlazzi et al., 2018; Andréfouët et al., 2023), are exacerbated in semi-closed
46 lagoons, due to the lack of a pass to drain excess water. Monitoring lagoon water levels during such events provides key
47 insights into lagoon responses to extreme hydrodynamic forcing.

48 When these lagoons temporarily behave as closed systems, thermal stress imputed to marine organisms can be aggravated
49 (Van Wynsberge et al., 2017; in press), sometimes leading to mass mortalities (Van Wynsberge & Andréfouët, 2017;
50 Andréfouët et al., 2022). These dynamics have important consequences for giant clam populations (*Tridacna maxima*), a
51 species of ecological, economic, and cultural significance across Indo-Pacific coral reef ecosystems (Neo et al., 2015; Mies et
52 al., 2017). In the semi-closed lagoons of the Tuamotu Archipelago, giant clams can form dense aggregations that support local
53 fisheries and mariculture (Gilbert et al., 2005; Remoissenet & Wabnitz, 2012; Van Wynsberge et al., 2016; Andréfouët et al.,
54 2025). However, their symbiotic relationship with Symbiodiniaceae makes them vulnerable to thermal stress
55 (Teaniniuraitemoana et al., 2025), raising concerns under climate change scenarios. In particular, recurrent mass bleaching
56 events linked to El Niño-driven marine heatwaves (MHWs) have impacted *T. maxima* stocks, with implications for both the
57 fishery and the aquarium trade (Andréfouët et al., 2018; Van Wynsberge et al., in press). In this context, characterizing the
58 spatial and temporal variability of local temperature regimes, and understanding their drivers is essential, notably with
59 intensifying climate extremes.

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62 This study presents a rare and comprehensive dataset of multi-year monitoring of temperature and sea level inside the semi-
63 closed lagoon of Reao, [spanning December 2016 to May 2025](#). [Modelling work of Van Wynsberge et al. \(in press\)](#) evidenced
64 [that this lagoon experienced more than 20 MHW over the past decade, with strongest events that occurred in March-April](#)
65 [2016 \(duration: 40 days; maximum intensity: 1.8°C above the climatology\), in January-February 2017 \(38 days; 1.8°C\), and](#)
66 [in February-March 2024 \(41 days; 2.4°C\)](#). [Here, a more extensive instrumentation setup \(see Figure 3\)](#) enabled enhanced lagoon
67 sampling before and during the [most prolonged and intense MHW ever recorded locally \(Van Wynsberge et al., in press\)](#),
68 which was associated with the 2024 strong mixed El Niño (Pagli et al., 2025). The sampling strategy captured both horizontal
69 and vertical temperature variability via moored sensors at relevant lagoon sites and depths, as well as through vertical profiles
70 (from CTD casts). Continuous measurements of lagoon level, circulation, and ocean-lagoon exchanges have also been acquired
71 during the austral summer 2023-2024. Instrumenting the diverse geomorphological strata, including *hoa*, the inner reef slope,
72 lagoon patch reefs, and deep lagoon areas, provides a system-wide view of the hydrodynamic variability and processes within
73 the lagoon before and during such an extreme event, and sheds light on the hydrodynamic and atmospheric forcings that control
74 intensity and duration of MHW inside semi-closed atoll lagoons. After a presentation of the study site in Section 2, the
75 instruments and deployment methods are described in Section 3, followed by the sampling strategy (Section 4) and the data
76 processing and quality control procedures in Section 5. Finally, illustrative observations of this semi-closed atoll dynamics are
77 shown in Section 6.

78 2 Study site

79 Reao Atoll (18.45°S–18.6°S; 136.25°W–136.5°W) located at the eastern end of the Tuamotu archipelago (French Polynesia ;
80 Fig.1.B) is a shallow atoll known for harboring one of the world’s highest densities of the giant clam *Tridacna maxima* (Van
81 Wynsberge and Andréfouët, 2017). Its population (329 inhabitants according to the 2022 census) lives mainly in the village
82 located on the northwestern part of the atoll, and largely rely on giant clam resources (for flesh or aquarium trade). Reao is
83 classified as a semi-closed atoll, with a fully [and permanently](#) emerged rim in its north-eastern part, and a southern rim
84 segmented by an alternation of low-lying sandy islets, locally known as *motu*, and numerous shallow natural channels (*hoa*),
85 which allow limited water exchange between the lagoon and the open ocean (Fig. 1). [Large swell events \(eventually combined](#)
86 [with spring tides\) can overtop the reef and fill hoa with water. This generates variable](#) lagoon aperture (defined as the ratio of
87 the sum of the widths of all functional channels to the atoll perimeter) [in time, ranging from 1% to 13% depending on water](#)
88 level (Andréfouët et al., 2022). The numerous *hoa* vary greatly in shape (see Fig.1.C and Appendix A, Fig. A2), width and
89 depth, but the most active ones are located in the central part of the southern rim (Tarahaero; Fig. 1C). The atoll rim delimits
90 a lagoon of 38.33 km² with an average depth of 16 m (maximum depth: 32 m). Elongated along a northwest–southeast axis,
91 [the lagoon comprises three distinct basins, the northwestern \(NW\), the intermediate, and the southeastern \(SE\) basins, which](#)
92 progressively widen and deepen from north to south (Fig. 1.A; Quéré et al., 2025). Overall, the three basins exhibit a bowl-
93 shaped morphology, with shallower margins surrounding deeper central areas.

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104 Four distinct daily wind regimes (WRs) affect the area (Dutheil et al., 2020). The dominant regime (WR1) corresponds to a
105 persistent trade-wind pattern, characterized by a strong homogeneous east-southeast flow (WR1, 6.3 m s^{-1} , $\sim 100^\circ\text{N}$). Two
106 additional easterly regimes (WR2 and WR3), differ mainly in intensity (resp. 4.4 and 3.9 m s^{-1}) or orientation (resp. 107.5°N
107 and 75.3°N). A fourth regime (WR4) associated with weaker north-easterly winds (64.9°N , 3 m s^{-1}) predominates during the
108 austral summer and disappears in austral winter (in opposition to WR1). Regarding the wave climate, the region is dominated
109 in austral winter by high-amplitude, long period southwesterly incoming swells (R1, $H_s = 2.5\text{m}$, $T_p = 13.4\text{s}$ and coming from
110 190°N). During austral summer, northwesterly swells (R3) of lower amplitude (235°N , 2 m) but similar periods prevail; yet
111 Reao Atoll remains largely unaffected due to its impermeable northern rim. South-southeast wind waves (R2) generated by
112 tradewinds also occur year-round with a peak in May-July (Dutheil et al., 2021). Finally regarding offshore tide, the
113 approximate tidal range is 0.93m (FES2012 global tide solution) in the open ocean south of Reao. The oceanic tidal regime is
114 semi-diurnal in this region (Form factor = 0.058).

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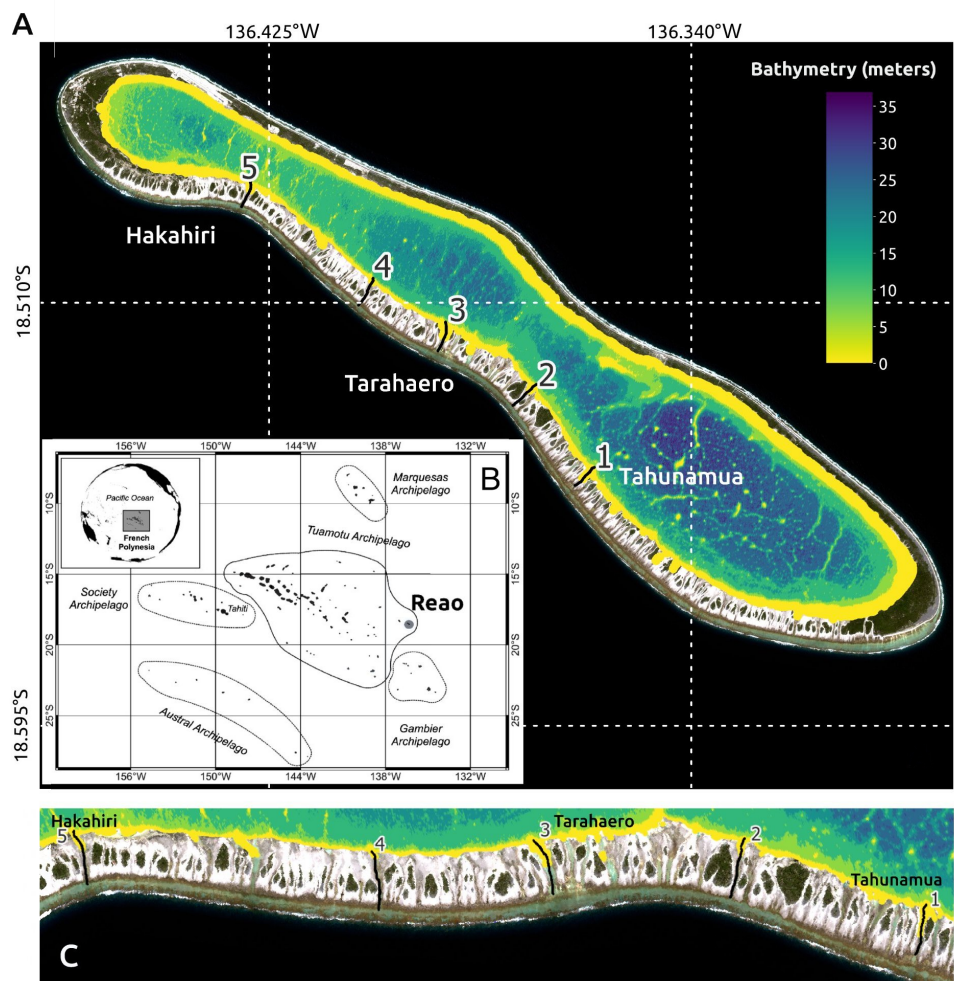
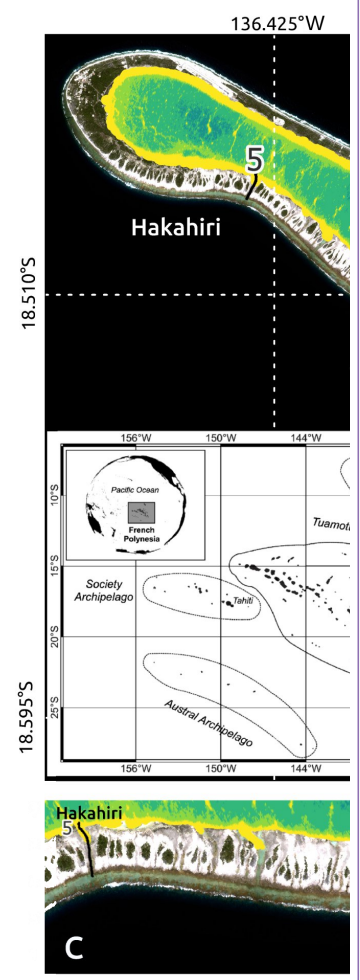
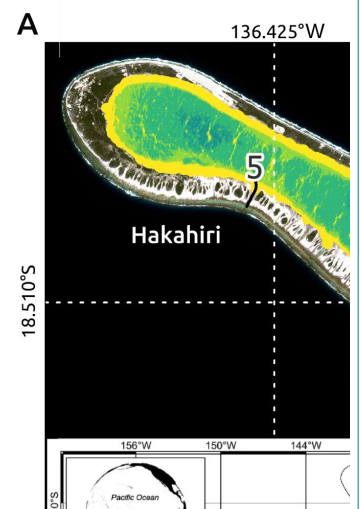


Figure 1: A) Map of Reao (A) with locality of the five main hoo (1-5). Background color refers to satellite-derived bathymetry retrieved from Sentinel-2 imagery (Copernicus Sentinel-2, 2021; Quéré et al., 2025a, 2025b) using the method of Amrari et al. (2021). B) Location of Reao within the French Polynesian archipelagos (Credit: Oriane Bruyère). C) Zoom on the southern rim and its hoo. Numbers indicate the 5 main hoo that were selected for instrumentation, Hoo n°3 (locally called Tarahaero), located



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137 along the central section of the southern rim, is associated with the highest ocean-lagoon exchange efficiency, whereas *hoa n°1* (locally
138 called Tahunamua), located along the southern section of the southern rim, is associated with the lowest.

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140 **3 Instruments, methods and deployments**

141 Various physical oceanographic instruments were deployed during the GAIA project to monitor thermal variability, ocean-
142 lagoon exchanges and lagoon dynamics (Figure 3). A total of six legs were conducted, each leg corresponding to the
143 observation period between the deployment of instruments and their subsequent withdrawal. These included moored compact
144 loggers dedicated to temperature and pressure (stations labeled with “T”), as well as different types of current meters: point-
145 measurement devices (stations labeled with “L”) and vertical profilers (stations labeled with “A” or “ADCP”). During each
146 field campaign, conductivity–temperature–depth (CTD) profiles (stations labeled with “M”) were performed throughout the
147 lagoon allowing to capture the vertical structure of the water column. All profiles were performed manually from a boat. A
148 detailed list of all instruments, including manufacturer, model, raw and processed parameters, deployment location, logging
149 frequency, and deployment period, is provided in Appendix A (Table A1).

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150 All moorings were deployed by scuba diving and adapted to the seabed habitats and deployment sites to ensure stability during
151 highly energetic events. Mooring supports were constructed from a variety of materials, including concrete blocks, steel bars,
152 and equipped with sacrificial anodes to prevent corrosion or electrolysis damage (see Fig. 2). To minimize biological fouling,
153 Acoustic Doppler Current Profilers (ADCPs) were coated with cayenne pepper and grease and then wrapped with electrical
154 tape, while smaller compact loggers were enclosed in perforated plastic cylinders (see Fig. 2a) to allow water circulation while
155 providing protection against biofouling and mechanical damage. Mooring depths were measured using a dive computer (for
156 sensors without pressure) or derived from the mean water depth over the whole deployment period (for sensors equipped with
157 pressure). All moored instruments were autonomous, containing internal batteries and memory to support long-term
158 deployment.

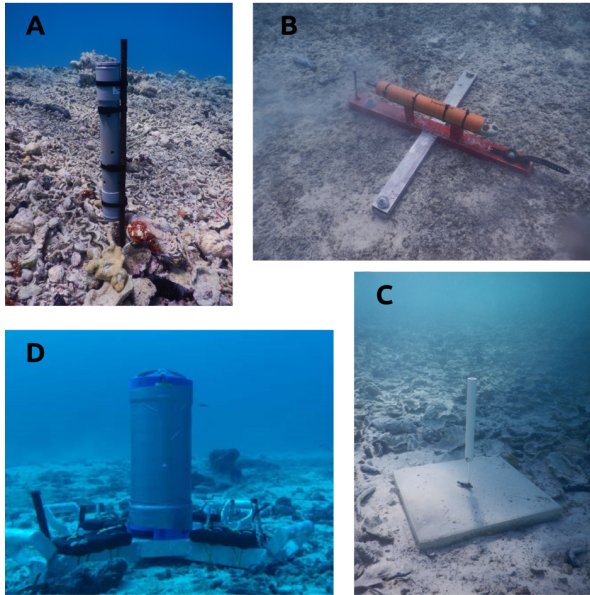


Figure 2: Photos of the moored sensors deployed in Reao Lagoon: RBRduet/SBE56 inside its protective PVC tube (A), Nortek Aquadopp (B), Lowell TCM-4 (C), Teledyne RDI ADCP Sentinel (D). Photo credit: Simon Van Wynsberge.

3.1 Compact loggers: Temperature and Pressure

Three types of compact loggers were used across the various deployments to monitor either temperature or temperature and pressure. The first set of sensors included 15 SBE56 loggers (Sea-Bird Scientific Inc.: <https://www.seabird.com/sbe-56-temperature-sensor/product?id=54627897760> ; last access: 7 November 2025). All SBE56 deployed during the GAIA project were new and directly came from the manufacturer, thus, given the specifications of these high-accuracy sensors, the data are delivered with a maximum uncertainty of $\pm 0.01^{\circ}\text{C}$. The typical sampling period was 1 min (Appendix A - Table A1). The second set of compact loggers consisted of two RBR Ltd. models, namely TWR-2050 and RBduet T.D (https://www.bodc.ac.uk/data/documents/nodb/pdf/rbr_tide_wave_07apr2011.pdf ; <https://rbr-global.com/products/compact-loggers/rbrduet-td/> ; last access to webpage: 7 November 2025). The TWR-2050, a 10 dbar range sensor, was deployed during the first deployment period only (2016–2017) and sampled water level and temperature every 30min. Its maximum uncertainty regarding pressure was estimated around 0.5% of full scale (± 5 cm) and $\pm 0.01^{\circ}\text{C}$ for temperature. All RBRduet Temperature-Depth sensors (RBR Ltd) were returned from the manufacturer recalibration just

181 before the start of sampling. Based on their specifications, a maximum uncertainty of less than 1 cm in level and 0.004 °C in
182 temperature. can be expected. Typical sampling periods were set to 1 Hz.

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183 3.2 Current meters

184 Two types of current meters, namely drag-tilt current meters and Acoustic Doppler Current Profilers (ADCPs), were installed
185 in Reao lagoon to monitor the austral summer 2023-2024. The Lowell TCM-4 drag-tilt current meter is an autonomous, low-
186 cost instrument that estimates current velocity and direction from sensor tilt, while also recording temperature
187 (<https://lowellinstruments.com/tilt-current-meters/tcm-4-tilt-current-meter/>; last access : 7 November 2025). Five TCM4 were
188 used during the GAIA project sampling. All these sensors were new at the beginning of their deployment (Leg 4) thus
189 providing a maximum uncertainty of 5 cm s⁻¹ in current speed, 5° in direction and 0.1 °C in temperature. Their typical sampling
190 period was set to 1 min. ADCP Sentinel V series (Teledyne RD Instruments; [https://www.teledynemarine.com/en-](https://www.teledynemarine.com/en-us/products/SiteAssets/RD%20Instruments/Sentinel_V_combined.pdf)
191 [us/products/SiteAssets/RD%20Instruments/Sentinel_V_combined.pdf](https://www.teledynemarine.com/en-us/products/SiteAssets/RD%20Instruments/Sentinel_V_combined.pdf); last access : 7 November 2025) provide current
192 profiling over the water column in coastal environments. Two models were deployed: a Sentinel V20 and two Sentinel V50.
193 The Sentinel V-series provides three-dimensional velocity measurements as well as bottom temperature and pressure
194 observations. The northern basin was equipped with a V20 (1000 kHz), and two Sentinel V50 (500 kHz) were deployed in the
195 intermediate and southern basins. Globally, bursts were programmed every 20 min, with 90 pings per burst (1 s ping interval).
196 Cell sizes were set to 0.5 m for the V20 and 1 m for the V50 and the first measured cell above the blanking zone was at 1.01
197 m (resp 2.22 m) for V20 (resp. V50). Both awaited standard deviation for current speed was 0.74 cm s⁻¹. The Aquadopp
198 (Nortek) is an acoustic current meter used to measure current speed, direction, temperature, and pressure in shallow
199 environments (<https://www.nortekgroup.com/products/aquadopp-profiler2-1-mhz>; last access: 7 November 2025). During the
200 GAIA project the two models were 2MHz side-looking heads deployed in *hoa*. Burst sampling period was programmed to 20
201 min, with a cell size of 0.2 m, and a blanking distance of 0.2 m leading to precision of horizontal velocity observations of 2.3
202 cm s⁻¹.

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203 3.3 CTD Profiles

204 The CTD (Conductivity Temperature Depth) profiles were obtained using a Sea-Bird 19Plus V2 SeaCAT Profiler CTD (Sea-
205 Bird Scientific ; <https://www.seabird.com/sbe-19plus-v2-seacat-profiler-ctd/product?id=60761421596>; last access: 7
206 November 2025), which measures conductivity, temperature, and pressure at a sampling frequency up to 4Hz. The SBE19Plus
207 V2 provides high-resolution and highly reliable measurements. Its last maintenance and manufacturer recalibration date back
208 to 2022, which ensures high measurement accuracy (maximum uncertainty lower than that of moored loggers). During each
209 cast, the CTD was hand-lowered from the boat, stabilized near 2 m depth during 1 min, then returned to near the surface before
210 being lowered at a constant rate of approx 10 m min⁻¹ to the lagoon bottom and immediately brought back to the surface, at
211 20–40 m min⁻¹. Only profiles acquired during the descent were retained in the NetCDF dataset made available.

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220 4 Sampling strategy

221 The sampling design implemented under the GAIA project evolved throughout its duration to progressively address both
222 thermal and sea-level vulnerabilities of semi-closed atoll lagoons. Prior to the GAIA project, an early historical 7-month
223 deployment of a temperature and pressure sensor was performed (Leg 1, Station T1 from 17 December 2016 to 29 June 2017)
224 and helped design the project sampling.

225 At the early stage of the project, a first temperature logger was deployed in June 2021 (Figure 3, Station T2 - Leg 2 to 6)
226 during a first fieldwork dedicated to giant clam stock assessment and health monitoring. The initial objective was to begin a
227 continuous interannual record of lagoon temperature, providing a baseline reference and ensuring long-term monitoring of
228 Reao's lagoon temperature observations that are included in the SNO ([National Observation Service](#)) ReefTEMPS network
229 (Le Gendre et al., 2025). Following the acquisition of additional instruments within the GAIA project, the spatial coverage of
230 the monitoring network was substantially increased, allowing a refined characterization of thermal dynamics across key lagoon
231 sectors.

232 Subsequent field campaigns (Legs 4 to 6; from June 2023 to May 2025) implemented a more advanced experimental design
233 using up to 18 moored instruments, aimed at better understanding of the hydrodynamic functioning of the lagoon, including
234 ocean-lagoon exchanges, lagoonal circulation, and spatial and vertical temperature dynamics through multi-depth moorings.

235 4.1 Ocean-lagoon exchanges and lagoon level

236 One of the key objectives of the GAIA sampling strategy was to better understand the mechanisms governing water exchanges
237 between the ocean and the lagoon through the *hoa*. The selection of *hoa* to be instrumented (see Fig 1.B and Fig A.3) was
238 made following extensive field reconnaissance during the beginning of Leg 4, combining direct observations of their
239 functioning with geomorphological characteristics (depth, width, orientation) and local knowledge of their hydrodynamic
240 behaviour.

241 The monitoring design aimed to cover *hoa* distributed across different sectors of the reef rim and representative of the three
242 main lagoonal basins (northern, intermediate, and southern). To this end, five Lowell TCM-4 drag-tilt current meters were
243 deployed at stations L1 to L5 during Leg 4 (Fig 3.A). These autonomous instruments recorded current speed and direction,
244 together with temperature, providing insights into the temporal variability of ocean-lagoon fluxes.

245 During Leg 5, the setup was complemented by two Nortek Aquadopp current profilers deployed at stations A1 and A2,
246 corresponding respectively to the TCM-4 sites L3 and L1. These profilers allowed finer characterization of velocity structure
247 across selected *hoa*, while also documenting temperature and sea-level variability.

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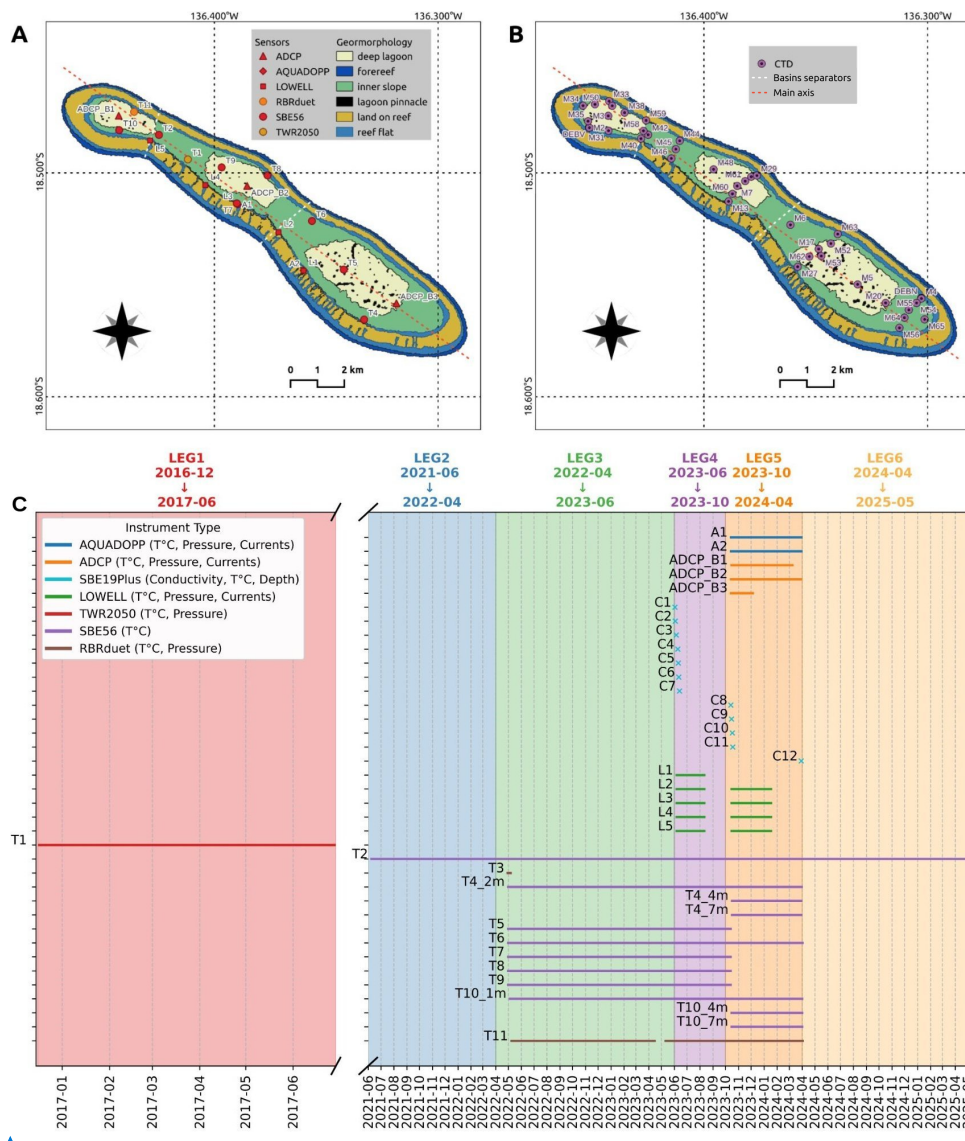
249 Lagoon water level variability was monitored during several legs of the GAIA project. The first observations were obtained
250 during Leg 1 using an RBR TWR-2050 sensor deployed at station T1, followed by an RBRduet T.D logger installed at station
251 T11 from legs 3 to 5.
252 These long-term pressure records were specifically designed to document lagoon-level variability under varying environmental
253 conditions, notably the influence of incident oceanic swells and sea-level anomalies. During Leg 5, additional sea level
254 measurements were available from pressure records provided by the Aquadopp profilers positioned in the *hoa* (stations A1
255 and A2, Fig 3.A), as well as from the three ADCP Sentinel V instruments deployed within the lagoon.

256 **4.2 Lagoonal circulation**

257 The three ADCPs (stations B1 to B3, Fig. 3.A) were strategically located to capture current profiles from the surface to the
258 bottom in each of the three main lagoonal basins and broadly positioned along the atoll’s main axis. This configuration enabled
259 the characterization of internal lagoon circulation patterns and their response to hydrodynamic forcing, including wind stress
260 and ocean–lagoon exchange processes. Combined, these complementary observations provide a comprehensive view of
261 lagoon-level variability and circulation dynamics under contrasting meteorological and oceanic conditions.

262 Building on this carefully designed sampling strategy, the following section describes the procedures applied to process,
263 validate, and standardize the collected data to produce a high-quality, interoperable dataset.

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Figure 3: Spatial and temporal coverage of the observation network at Reao Atoll. (A) Deployment location of moored loggers and (B) Reference stations during Conductivity, Temperature, Depth (CTD) vertical casts. Background colors on the map refer to reef geomorphology, from Andrefouet et al. (2012). The timeline (bottom panel, C) details the temporal coverage of all deployed instruments, including the initial campaign (December 2016 to June 2017) and the subsequent legs conducted under the GAIA project (June 2021 to May 2025). For the SBE19Plus CTD profiles, each marker C1 - C12 indicates a distinct date where several stations shown in (B) were sampled (Le Gendre et al., 2025a).

4.3 Spatial and vertical temperature variability

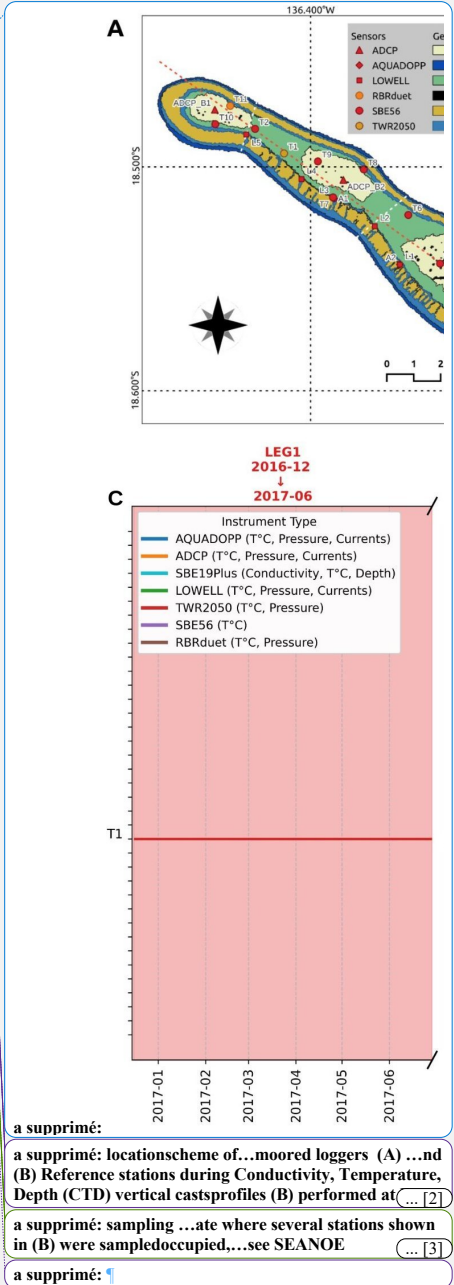
To characterize spatial temperature variability, a network of moored SBE56 loggers was deployed across different lagoonal and rim environments (stations T1 to T11; Fig. 3A), covering the northern, intermediate, and southern basins for periods ranging from 6 to 34 months, depending on the sensor (Table A1). Temperature loggers were placed in the 1-3 m depth range where giant clams are preferentially found. However, two lagoon patch reefs (stations T4 and T10) were instrumented with additional loggers placed deeper (4.5 and 7 m depth) to set up vertical temperature sensor arrays during Leg 5 (6 months), which includes the February-March 2024 MHW event. Vertical stratification of temperature was further characterized with CTD vertical profiles performed in June 2023 (2–13 June), October 2023 (13–18 October), and during the 2024 MHW, on 29 March. CTD profiles were spatially distributed to cover the Northern basin, where mariculture activities take place, and along five radials crossing the lagoon widthwise according to a distance gradient to the open rim (Fig. 3B). Because CTD profiles measured both temperature and salinity, they also provided insights on water renewal, basin characteristics and vertical stability of water masses.

5 Data processing and quality controls

The processing and quality control procedures applied to this dataset build upon extensive prior experience in lagoon monitoring. To ensure both data quality and interoperability—using consistent file formats and instrument types—the same methods for processing, formatting, and quality control as described in previous studies were applied (Bruyère et al., 2022; Bruyère et al., 2023a; Bruyère et al., 2023b).

Raw data were retrieved from each instrument using the manufacturer’s software and saved on a secure network drive. Each file was renamed following a standardized nomenclature containing key deployment information: Atollname_Station_Instrument-Model_SerialNumber_Depth_LegNumber.filetype. Data were then visually inspected to identify and remove bad records (e.g., out-of-water readings, spikes, or outliers) and to determine the exact start and end times of valid observations (based on our field notes and confirmed using pressure and temperature plots).

Data was subsequently converted into formats suitable for processing with Python 3 routines, typically ASCII or MATLAB files, processed as needed and finally exported as NetCDF files. Each NetCDF file includes temperature, pressure, current, or other relevant variables, together with comprehensive metadata such as deployment dates, time reference (expressed in UTC



for all instruments), geospatial coordinates, depth, instrument model and serial number, project and investigator information, processing history, and comments to ensure reusability.

Specific processing steps were applied depending on instrument type:

- RBRduet T.D sensors: pressure data were corrected for a constant atmospheric pressure (101 325 Pa) to minimize weather-related variability. No precise vertical referencing by DGPS was possible due to deployment conditions. Water level was calculated relative to the long-term mean depth. For wave analysis, pressure records were filtered using a Fourier transform to obtain a pressure spectrum (3–25 s period), and linear wave theory with a homogenous cut-off frequency (0.33) was applied to compute wave parameters. Two output files were generated: one with 1-minute resolution for temperature and water level, and another with 1-hour resolution containing derived wave parameters.
- Current meters (ADCPs, Aquadopps, and Lowell TCM-4): vertical profiles near the surface were removed to avoid contamination from acoustic reflections or noise. Data were converted to consistent coordinate systems (East - North - Up), and orientation conventions were harmonized with oceanographic standards. Temporal and vertical resolutions were retained according to deployment settings.
- Compact loggers (SBE56): temperature data were generally retained at the original sampling frequency without additional processing.
- CTD casts: standard processing using SeatermV2 software was applied, including conversion to .cnv, low-pass filtering, alignment of sensors, derivation of secondary parameters, and vertical bin averaging (0.5 m). No specific treatments for handling salinity spikes were required as no such spikes were recorded in the data.

After processing, all datasets were visually inspected using Ferret and NetCDF tools to certify the quality of the time series and detect eventual anomalies. Any remaining outliers or unusual observations were flagged in the NetCDF global attributes. Metadata were systematically checked to verify the completeness and correctness of global and variables' attributes. These procedures ensure a high-quality, standardized, and interoperable dataset suitable for scientific analysis and long-term monitoring of lagoon dynamics.

6 Overview of observations

In this datapaper, an overview of observations is provided in order to highlight the quality and scientific interest of the dataset. This section is, however, not intended to provide an extensive analysis and interpretation of data. To enhance trust-building, external sources of wind, wave, sea surface temperature (SST) and tide data have hereafter been used and aligned with our temperature, water level and current data. Winds, waves and SST were extracted from ERA5 reanalysis (<https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=overview>, ; Hersbach et al., 2020). Tidal

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342 harmonics were extracted from the Finite Element Solution oceanographic model, version 2012 (Stammer et al., 2014), and
 343 tidal recomposition was performed using the first 8 harmonics. Winds and SST data were extracted at the grid point closest to
 344 the center of the atoll (18.5°S, 136.5°W), while incident waves and tidal harmonics were extracted at an oceanic grid point at
 345 the vicinity of the southern rim of Reao (18.75°S, 136.6°W). Finally, marine heat waves categories were determined using the
 346 long term series of lagoon temperatures modeled by Van Wynsberge et al. (in press) as climatology. Briefly, they used the in-
 347 situ temperature time series to train and validate Generalized Additive Models (gam) that infer the daily minimum temperature
 348 and the diurnal temperature range, from oceanic and atmospheric regional data.

349 6.1 Ocean-lagoon exchanges and lagoon level

350 Lagoon water level was strongly influenced by ocean-lagoon exchanges. Figure 4 shows the temporal variability of ocean-
 351 lagoon exchanges over a 5-day subset for the five instrumented *hoa*, highlighting differences in exchange intensity and
 352 dynamics among sites, together with lagoon-level variations at station T11. This period was selected as it encompasses a short
 353 but energetic incident swell event (from 22 to 24 October 2023, Fig. 4).

354 Briefly, inflow and outflow were calculated using scatter plots of current speed (y-axis) as function of current
 355 directions (x-axis), with dots representing observations in their initial sampling frequency (every 1 min for Lowell
 356 inclinometers and every 20 min for Aquadopp currentmeters). These scatter plots of data were similar to two
 357 gaussians, centered on the direction of inflow and outflow, respectively. The direction for which the
 358 current speed reached its maximum was considered as the main direction of the *hoa*. We then defined
 359 inflow currents as currents entering the *hoa* with the main direction $\pm 90^\circ$. Other currents were
 360 characterised as outflows.

361 Globally, a good synchronicity in the patterns of inflow/outflow between the five instrumented *hoa* was observed (based on
 362 velocity projections along each *hoa*'s main axis). For all of them, inflows and outflows followed the offshore tidal trend, with
 363 inflows dominating between mid-flood and mid-ebb, and vice versa (Fig. 4). During this period, current speed in the *hoa*
 364 reached values exceeding 1 m s^{-1} (station L2 at the peak of the event). Within the lagoon, tidal variability ranges from a
 365 complete absence of tidal signal during Ranoa phases (when no exchanges between ocean and lagoon) to only a few centimeters
 366 of tidal amplitude (maximum observed 25 cm) when lagoon water levels are particularly high (Fig. 6). It is noteworthy that
 367 during the swell episode shown in Fig. 4, the most active *hoa*—i.e., those exhibiting the strongest inflowing currents—were
 368 the central ones along the southern rim (L3, A1, and L2). At the peak of the event, all *hoa* were almost exclusively inflowing
 369 for about two consecutive tidal cycles. Similarly, lagoon drainage appears to occur mainly through the central *hoa* (L4, L3, A1
 370 and L2), which exhibit longer durations and higher intensities of outgoing currents compared to those located at the northern
 371 and southern extremities. Figure 4 also demonstrates good congruence between Aquadopp and Lowell-TMC4 records, since

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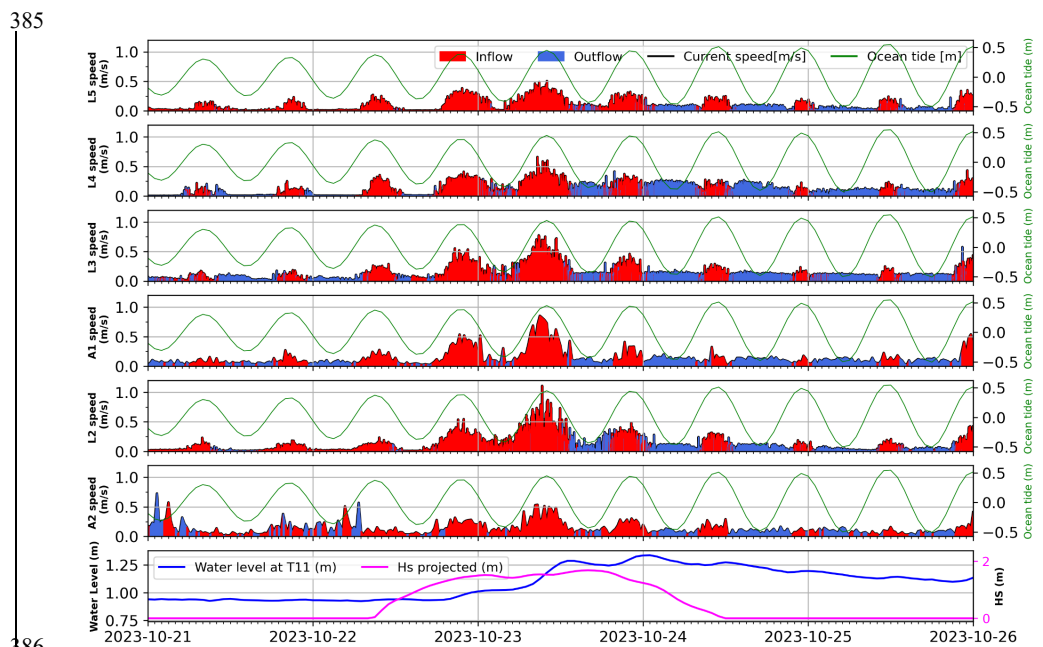
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376 similar currents speed and direction were found for instruments A1 and L3, which were positioned a few meters apart, in the
 377 same *hoa*. Finally, the lagoon water level rises more rapidly during the filling phase than it falls during the drainage phase,
 378 with an increase in lagoon level exceeding 30 cm in less than 24 hours.

379 At the beginning of the time series, A2 currents exhibit intra-phase flow reversal alternating between inflow and outflow within
 380 a single drainage or filling phase. This inconsistent behaviour of A2 currents with other currents might be explained by the
 381 location of the sensor in a *hoa* with a coarser complex bathymetry (see locations of sensors in the different *hoa* in Appendix
 382 A2) and the slightly different orientation of this section of rim. Such location appears to have an impact on A2 currents when
 383 current speed is rather low in other *hoa*. When currents' speed increase due to swell events, a better coherence is observed
 384 with A2.



386 Figure 4: Current speed and direction (inflow in red, outflow in blue) recorded by Lowell-TCM4 L2, L3,
 387 L4, L5) and Aquadopp (A1, A2) in *hoa*. Instruments A1 and L3 were positioned a few meters apart within
 388 the same *hoa*. The ocean tide (recomposed from FES2012 global tidal harmonics at 18.75°S, 136.6°W) is shown as solid
 389 green lines in each panel. The bottom panel displays the lagoon water level at T11 (blue) and ERA5 projected significant wave height
 390 (pink, H_s at 18.75°S, 136.6°W) projected onto the direction normal to the southern rim (210°).
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a supprimé: Finally, the lagoon water level shows a faster filling than drainage phase, with an increase of more than 30 cm in less than 24 hours. [4]

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L5

L4

L3

A1

L2

A2

Water level at T11 (m) Hs projected (m)

2023-10-21 2023-10-22 2023-10-23 2023-10-24 2023-10-25 2023-10-26

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407 6.2 Lagoonal circulation

408 Globally, current velocities display very low magnitudes (average velocities around 2.5 cm s^{-1} for the three instruments, and
409 for all cells across the profiles). Depth-averaged current velocities generally exhibit relatively stronger currents in the northern
410 basin than in the intermediate and southern basins (up to 0.1, 0.07, 0.06 m s^{-1} maximum current velocities respectively for B1,
411 B2 and B3). Fig. 5 presents a 7-day example (25 November–1 December 2023) of circulation observed by the three current
412 profilers (stations B1, B2 and B3) in relation to wind-induced slope. Winds and currents are both projected along Reao’s main
413 axis and slope is computed as the difference in depth anomalies between B1 and B3. During most of the period, positive
414 projected wind values indicate weak trade winds (blowing from east-southeast), which induce a slight sea surface slope (up to
415 2 cm approximately). Over the displayed period, currents exhibit vertically sheared structures at all stations and the subsurface
416 currents mainly tend to flow slowly southeastward (note that the first few meters from the surface were discarded to avoid
417 “contaminated” values). Around 28 November, a wind reversal event (northwest slight wind burst) is observed. The effects
418 of this reversal are most clearly visible at station B3. During this event, surface currents in B3 are predominantly directed
419 southeastward, in agreement with the wind forcing, while subsurface currents show a marked intensification northwestward.
420 This results in a temporary reorganization of the vertical current structure compared to the preceding period. At stations B1
421 and B2, this signal is present but less clearly defined although currents in the intermediate part of the water column also show
422 a reversal and intensification toward the northwest. These patterns suggest the existence of overturning circulations as
423 described in Dumas et al. (2012) for the case of Ahe atoll. At this stage, we cannot determine whether these circulation cells
424 are specific to each basin, but further hydrodynamics modeling will provide insights about these patterns.

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- a supprimé: Finally, the effect of a wind reversal (with a northwest wind burst around 28 November) appears on Fig. 5 with the establishment of the inverse patterns of circulation

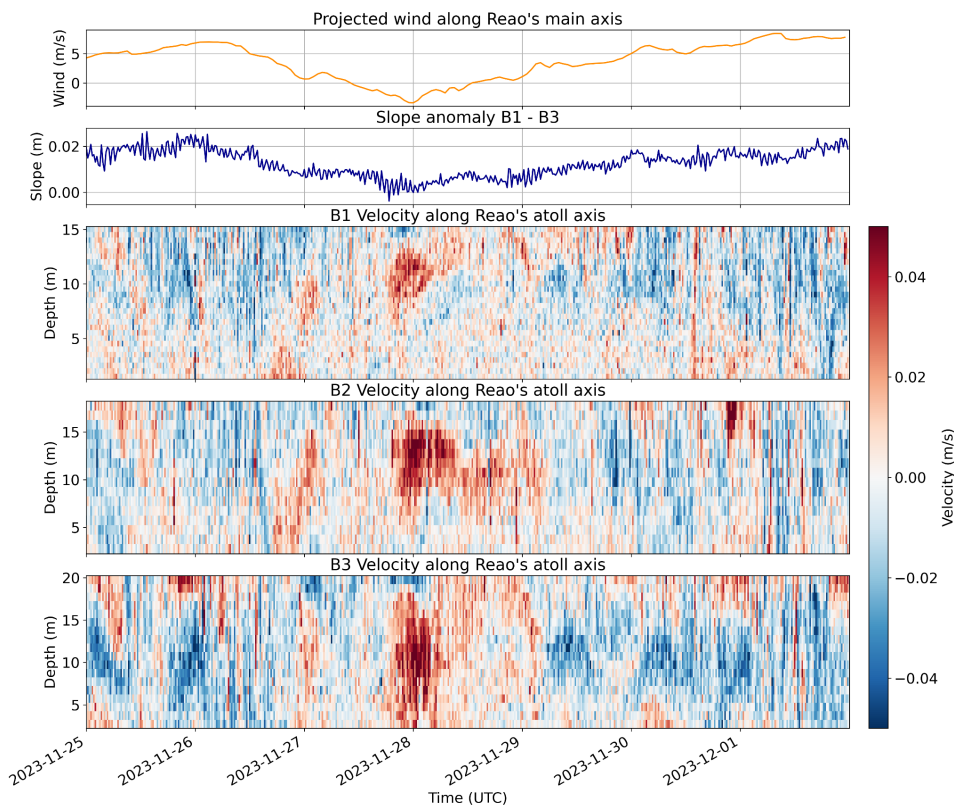


Figure 5: From top to bottom: ERA5 winds (18.5°S, 136.5°W) projected onto Reao's major axis (positive values indicate winds blowing from southeast toward northwest); Time-varying sea surface slope, computed from sea level anomalies between ADCP B1 and ADCP B3; positive values indicate higher water levels at B1 relative to B3; Profiles of projected current velocities along Reao's main axis (positive values indicate currents flowing toward the northwest along the same axis). Note that all variables are expressed as projections onto the atoll's main axis (Figure 3), which is oblique relative to geographic directions; therefore, the color scale represents along-axis flow components rather than strictly zonal or meridional directions

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6.3 Observed thermal patterns with a focus on the 2024 MHW event

The temperature time series allowed us to characterize the seasonal trend of temperature in Reao's lagoon. As already described in other atoll lagoons (Van Wynsberge et al., 2017), lagoon temperature showed a greater annual amplitude than ocean SST

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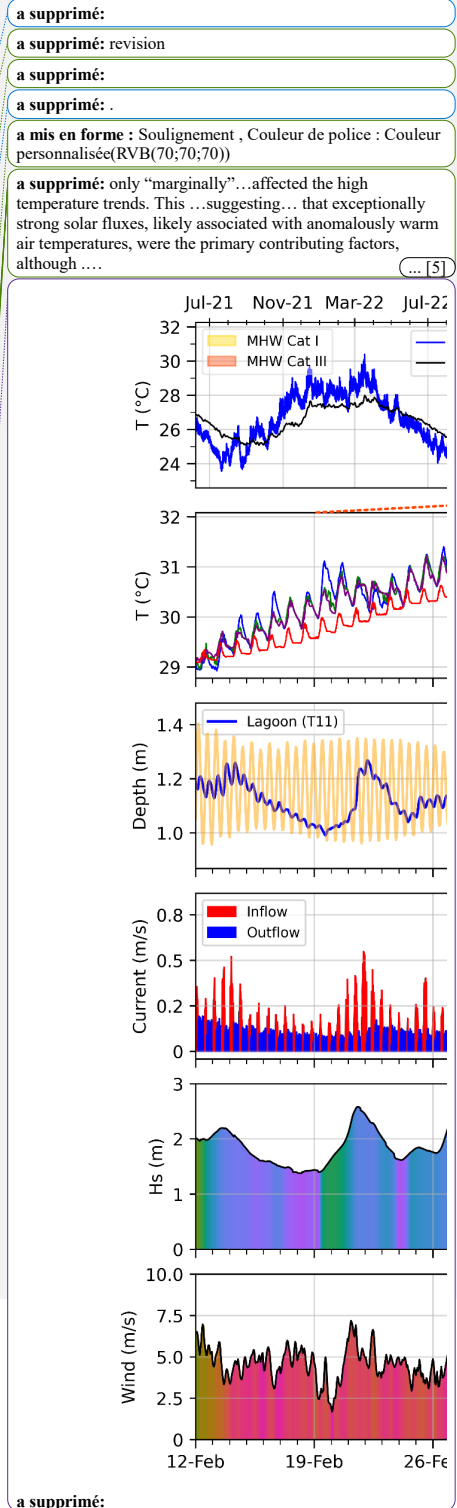
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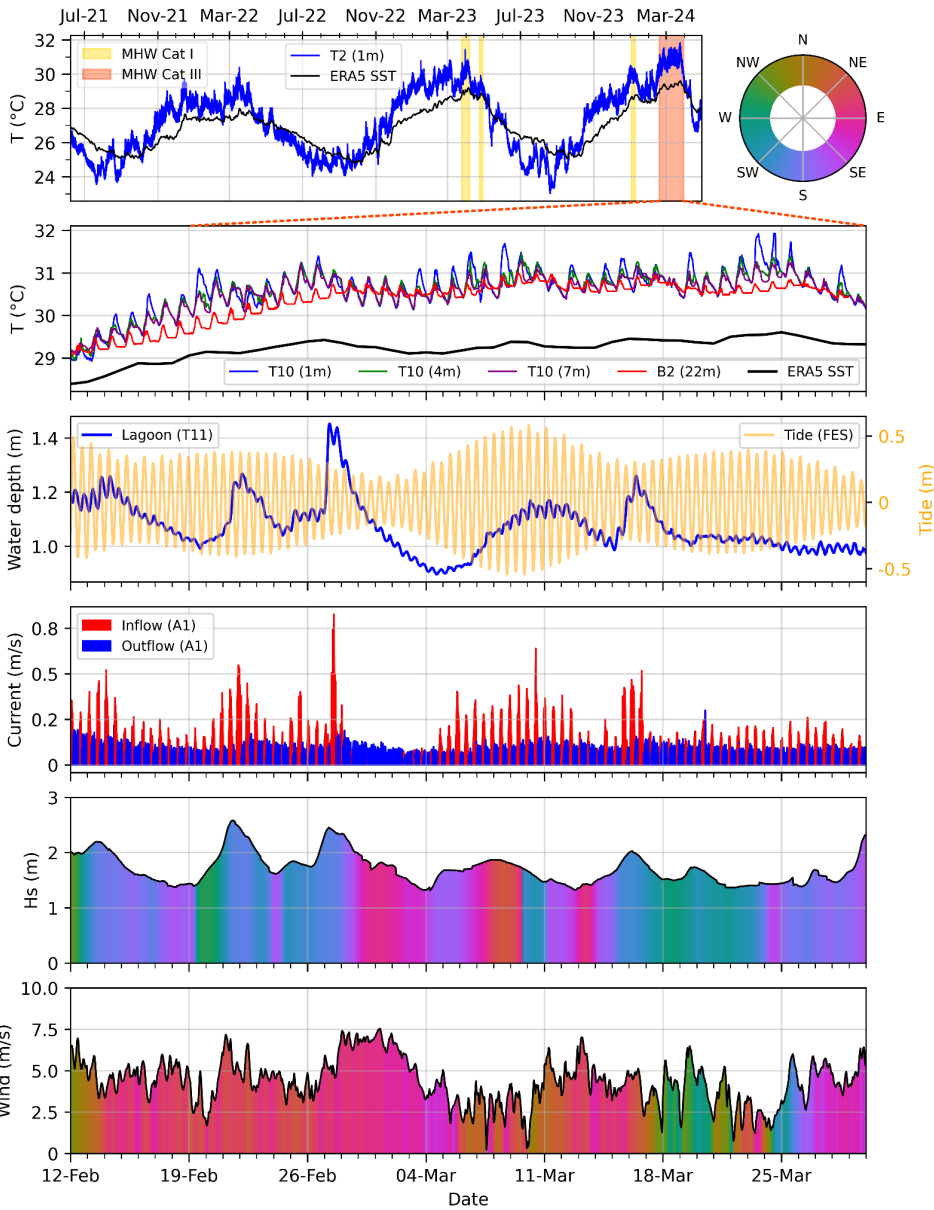
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(here ERA5 SST at 18.75°S, 136.6°W), with higher lagoon temperature than ocean SST in austral summer, and vice versa in austral winter (Fig. 6.A). Although not shown in the figures presented here, the Reao dataset also highlighted differences in temperature within the lagoon depending on reef geomorphology, bathymetry, and proximity to ocean-water exchanges, which is a common feature of atoll systems (Rogers et al., 2016; Green et al., 2019; Grimaldi et al., 2023; Reid et al., 2020).

During the GAIA sampling, the Reao lagoon experienced four distinct MHWs: three short category I events, and one category III event (Van Wynsberge et al., in press). The category I events spanned 13 days (25 March–7 April 2023), 5 days (24–29 April 2023), and 6 days (3–9 January 2024). MHW categories are defined, following Hobday et al. (2016), based on the difference between the daily SST 90th percentile and the SST climatology for the corresponding day of the year. Briefly, if the SST on a given day reaches the climatology plus this difference, the event is classified as a Category I MHW; if it reaches twice the difference, it is a Category II MHW, and higher multiples correspond to higher categories.

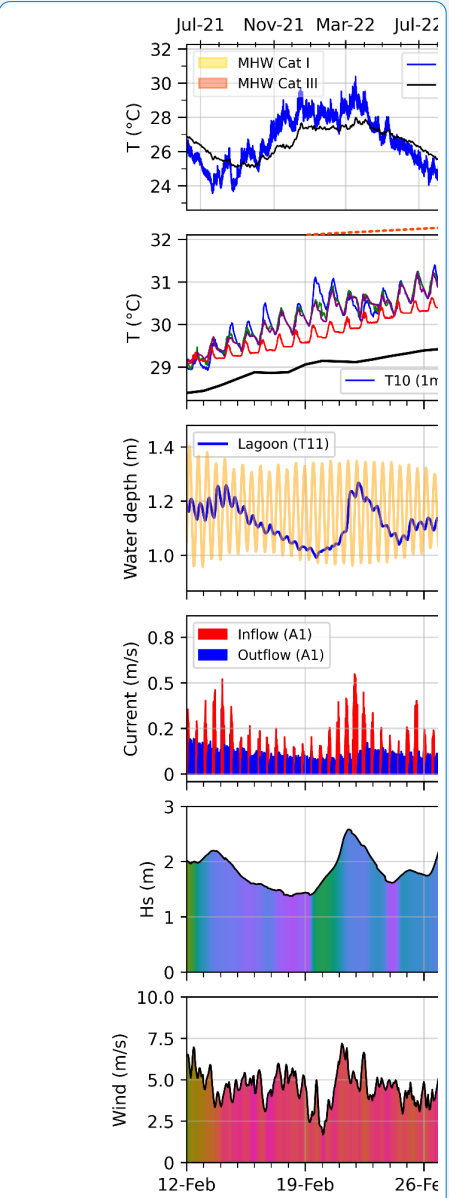
The category III event, which occurred from 19 February to the end of March 2024, persisted for 41 days and resulted in mass bleaching of giant clams (Van Wynsberge et al. in press). During this period, both oceanic SST and lagoon temperature increased, but the lagoon warmed more rapidly, remaining at 1 m depth on average 1.42 °C (at maximum 1.7°C) above SST at T2, 1.45°C (max 1.77°C) above SST at T10, 1.45°C (max 1.76°C) above SST at T11, and 1.27°C (max 1.55°C) above SST at T4. Although not shown in the figure presented here, it is worth noting that during the 2024 MWH, slightly higher temperature was found at T10 in the shallow northern basin than at T4 located in the deep wide southern basin (0.15°C difference in mean at 4.5 m depth). This is in congruence with previous temperature gradients reported across Reao's lagoon during austral summer (Van Wynsberge et al., 2024). Only weak vertical temperature gradients were observed between 1 m, 4 m, and 7 m depths at station T10, although the diurnal amplitude was more pronounced at 1 m (Fig. 6.B). Temperature recorded in the middle of the lagoon at 22 m depth at the B2 station followed the same general trend, with a delayed response and smoother daily variability, indicating greater thermal inertia of deep lagoon waters. The apparent flattening of the diurnal signal at B2 during the night can be explained by higher wind speeds during the day than at night. Stronger daytime winds enhance vertical mixing, allowing the daily temperature cycle to reach deeper layers, whereas weaker nighttime winds limit this mixing. Overall, during this unprecedented event, the lagoon alternated between high-level of water and ranoa phases, and winds were blowing mostly from E/SE. Unexpectedly, oceanic (exacerbated ocean-lagoon exchanges during certain periods such as the end of February 2024) and wind forcings seemed to have little affected the high temperature trends. This suggests that exceptionally strong solar fluxes, likely associated with anomalously warm air temperatures, were the primary contributing factors, although assessing the validity of this hypothesis requires further analyses (i.e., heat budget calculations) which are beyond the scope of this datapaper.





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519 **Figure 6:** From top to bottom: (A) Temperature interannual time series at T2 station (blue) and ERA5 SST at 18.5°S, 136.5°W
 520 (black). Marine heatwave categories were computed from a statistical hindcast model of temperature (Van Wylsberg et al., in
 521 revision), following Hobday et al. 2016 method, without any detrending of time series and using the period 1993-2022 as climatology
 522 (30 years). (B) Zoom on the 2024 MHW category III event at T10 (1 m, 4 m, 7 m), ADCP B2 station and outside the lagoon (ERA5
 523 SST). (C) Lagoon water level at T11 and oceanic tide (recomposed from FES2012 global tide solution at 18.75°S, 136.6°W) and . (D)
 524 Current speed and direction (as inflow/outflow between ocean and lagoon) in hoa at A1. (E) Significant wave height and wave
 525 direction extracted from ERA5 at 18.75°S, 136.6°W. (F) Wind speed and direction computed from wind components extracted from
 526 ERA5 at 18.5°S, 136.5°W.
 527
 528 Figure 7 displays CTD profiles at two different sampling dates (17 October 2023 and 29 March 2024). Globally, CTD network
 529 evidenced a southeast-northwest gradient across the three basins, the northwest basins showing warmer and more saline waters.
 530 Toward the southeastern part of the lagoon, temperature and salinity decreased at both dates. CTD profiles network (that did
 531 not cover the southeast part of the lagoon) captured on 17 October 2023 shows quite marked vertical stratification, due to low
 532 wind before and during the period of measurement. In the shallow Northwest basin, a thermocline and a halocline were well
 533 formed, with surface water (~0-5 m depth) warmer and less saline than deeper water. Although similar patterns were observed
 534 at some stations in the intermediate basin, stations located closer to the hoa exhibited an inverted temperature profile, with
 535 lower temperatures in the surface layer, associated with a pronounced salinity stratification (nearly 0.6 PSU less in surface
 536 water than bottom values). These differences are explained by the inflow of fresher and less saline water than the lagoon
 537 through the hoa, which primarily affects the surface layer at these stations. During the 2024 MHW event (29 March 2024),
 538 water columns displayed limited vertical stratification in terms of both temperature and salinity, probably because of higher
 539 wind speed at the time of measurements. Spatial differences nevertheless persisted between basins (highest temperature and
 540 salinity in the northwestern basin), and lowest temperatures were found at immediate proximity of hoa (e.g M40, M15, 341
 541 Fig. 3.B) in the intermediate basin.
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 lagoon (ERA5 SST). (C) Oceanic tide (recomposed from
 FES2012 global tide solution at 18.75°S, 136.6°W) at ... [6]
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 marked stratification in the Northwest basin, but also reflects
 the influence of hoa in the central part of the lagoon, mainly
 visible through salinity, with variations of nearly 0.6 PSU
 between the surface and bottom layers. During the 2024 MHW event,

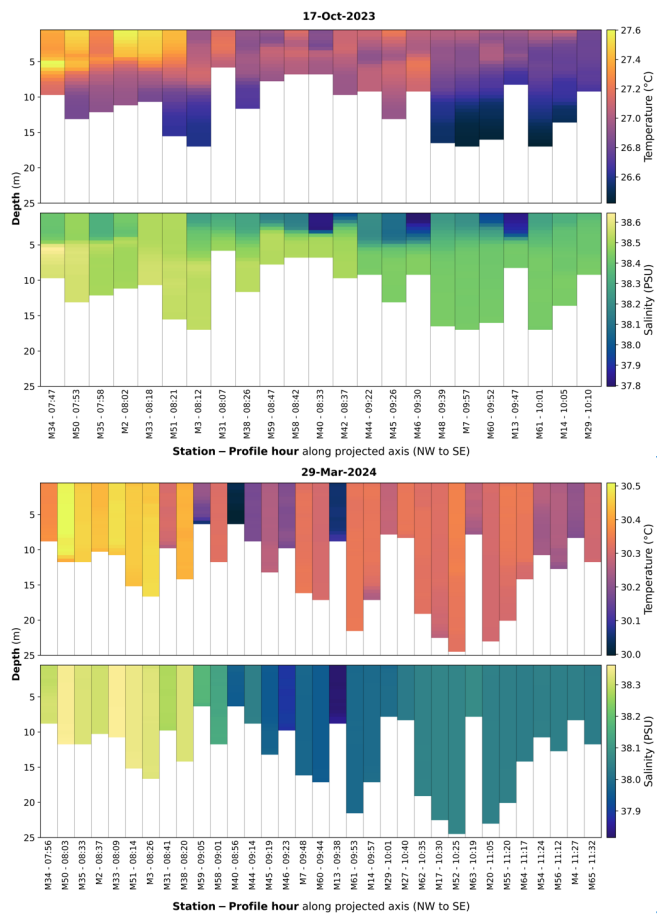
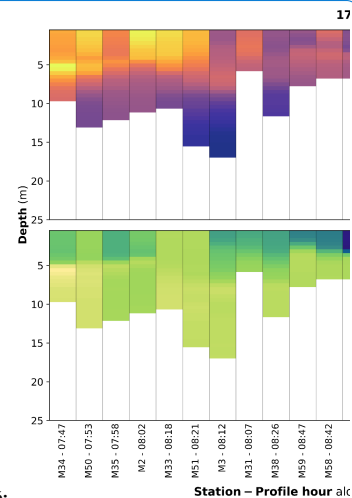


Figure 7: Temperature and salinity profiles for stations projected along Reao's main axis. Profiles are arranged from northwest (left) to southeast (right) across the atoll lagoon. Top : CTD profiles on 17 October 2023. Bottom: CTD Profiles during the 2024 MHW event on 29 March 2024. CTD cast times are given in local time.



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594 **7. Data Availability**

595 The whole dataset presented herein is publicly available in NetCDF format through the SEANOE open data platform
596 (<https://www.seanoe.org/>, Seanoe, 2023) in a dedicated repository.
597 DOI: <https://doi.org/10.17882/105885> (Le Gendre et al., 2025a).

598 **8. Conclusions**

599 Our dataset presented for the lagoon of Reao Atoll provides a unique and comprehensive record of thermal fluctuations and
600 hydrodynamics in a semi-closed tropical ecosystem, including an exceptional MHW event in summer 2024. Multi-year and
601 multi-depth observations will allow for a detailed characterization of the spatial and vertical variability of temperature, ocean-
602 lagoon exchanges through the *hoa*, internal circulation, and lagoon water level dynamics. Beyond improving our understanding
603 of the functioning of semi-closed atolls and their vulnerability to thermal stress, these data will provide valuable support for
604 future modeling (e.g statistical or hydrodynamics) and remote sensing analyses. The availability of the data in a standardized
605 NetCDF format, along with comprehensive metadata, facilitates reuse for future works.

606

607 **Author contributions.** SVW set up the ANR GAIA project and raised funds. RLG and SVW designed and conducted the
608 experiments as principal investigators. EL and CC organized, processed, checked, and archived the data sets. EL prepared the
609 initial version of the paper and designed the figures, with contributions from all co-authors.

610 **Competing interests.** The contact author has declared that none of the authors has any competing interests.

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Appendix A

Table A1. Detailed list of instruments moored at the Reao lagoon.

Station	Instrument	Raw parameters	Date Start (UTC)	Date End (UTC)	Longitude (deg W)	Latitude (deg S)	Freq	Depth (m)	Processed parameters	Legs
A1	AQUA DOPP	Current, pressure, temperature	2023-10-13 22:00:00	2024-03-30 00:40:00	- 136.389478	- 18.51418	20 minutes	1.45	Current speed and direction, temperature, water level	5
A2	AQUA DOPP	Current, pressure, temperature	2023-10-13 22:00:00	2024-03-30 00:00:00	- 136.360166	- 18.543549	20 minutes	1.77	Current speed and direction, temperature, water level	5
AD CP_B1	ADCP	Current, pressure, temperature	2023-10-14 19:40:00	2024-03-08 11:00:00	- 136.442767	- 18.474505	20 minutes	17.54	Current speed and direction, temperature, water level	5
AD CP_B2	ADCP	Current, pressure, temperature	2023-10-14 01:00:00	2024-03-29 08:40:00	- 136.385366	- 18.505844	20 minutes	21.71	Current speed and direction, temperature, water level	5
AD CP_B3	ADCP	Current, pressure, temperature	2023-10-14 01:00:00	2023-12-05 00:00:00	- 136.318634	- 18.558222	20 minutes	22.92	Current speed and direction, temperature, water level	5
CTD	SBE19 Plus	Conductivity, temperature, depth	2023-06-02 19:01:00	2024-03-29 21:32:00	X	X	4 Hz	X	Conductivity, Temperature, Depth	4, 5

L1	LOWE LL	Inclination, temperature	2023-06- 06 10:00:00	2023-08- 11 09:59:00	- 136.38949 5	- 18.51414 4	1 minu te	1.6	Current speed and direction, temperature, water level	4
L2	LOWE LL	Inclination, temperature	2023-06- 06 10:00:00	2024-01- 17 09:59:00	-136.42875	- 18.48556 3	1 minu te	2.0	Current speed and direction, temperature, water level	4, 5
L3	LOWE LL	Inclination, temperature	2023-06- 06 10:00:00	2024-01- 17 09:59:00	- 136.38949 5	- 18.51414 4	1 minu te	1.6	Current speed and direction, temperature, water level	4, 5
L4	LOWE LL	Inclination, temperature	2023-06- 06 10:00:00	2024-01- 17 09:59:00	-136.42875	- 18.48556 3	1 minu te	2.0	Current speed and direction, temperature, water level	4, 5
L5	LOWE LL	Inclination, temperature	2023-06- 06 10:00:00	2024-01- 17 09:59:00	-136.42875	- 18.48556 3	1 minu te	2.0	Current speed and direction, temperature, water level	4, 5
T1	TWR2 050	Pressure, temperature	2016-12- 17 00:00:00	2017-06- 29 03:30:00	- 136.41185 5	- 18.49401 4	30 minu tes	3.6	Temperature, water level	1
T2	SBE56	Temperature	2021-06- 08 10:01:25	2025-04- 28 09:49:03	- 136.42477 9	- 18.48304 7	20 minu tes	1.25	Temperature	2, 3, 4, 5, 6
T3	RBRd uet	Pressure, temperature	2022-04- 29 10:13:29	2022-05- 06 09:58:29	- 136.43594 4	- 18.47280 7	15 minu tes	1.7	Temperature, water level	3
T4_ 2m	SBE56	Temperature	2022-04- 30 10:00:00	2024-03- 30 09:56:02	- 136.33306 52994	- 18.56552 56421	30 minu tes	1.72	Temperature	3, 4, 5

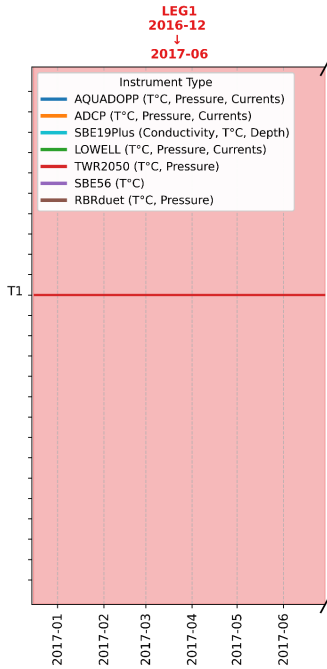
T4_4m	SBE56	Temperature	2023-10-16 10:21:50	2024-03-29 09:51:50	- 136.33297 96838	- 18.56549 73138	30 minutes	4.5	Temperature	5
T4_7m	SBE56	Temperature	2023-10-16 10:27:23	2024-03-29 09:57:23	- 136.33287 95619	- 18.56548 19472	30 minutes	7.0	Temperature	5
T5	SBE56	Temperature	2022-04-30 10:00:00	2023-10-13 09:56:07	- 136.34220 1	- 18.54318	30 minutes	1.8	Temperature	3, 4
T6	SBE56	Temperature	2022-04-30 10:00:00	2024-04-01 09:50:25	- 136.35637 7	- 18.52148 2	30 minutes	1.25	Temperature	3, 4, 5
T7	SBE56	Temperature	2022-04-30 10:00:00	2023-10-13 09:42:32	- 136.39000 2	- 18.51360 7	30 minutes	1.15	Temperature	3, 4
T8	SBE56	Temperature	2022-04-30 10:00:00	2023-10-13 09:53:42	- 136.37624 1	- 18.50116	30 minutes	1.4	Temperature	3, 4
T9	SBE56	Temperature	2022-04-30 10:00:00	2023-10-13 09:41:03	- 136.39676 5	- 18.49756 8	30 minutes	1.4	Temperature	3, 4
T10_1m	SBE56	Temperature	2022-05-04 10:29:59	2024-03-31 09:55:22	- 136.44257 0405	- 18.48093 29083	30 minutes	1.15	Temperature	3, 4, 5
T10_4m	SBE56	Temperature	2023-10-15 10:23:08	2024-03-31 09:53:08	- 136.44250 84927	- 18.48089 35738	30 minutes	4.5	Temperature	5

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T10 _7m	SBE56	Temperature	2023-10-15 10:25:07	2024-03-31 09:55:07	- 136.44242 86355	- 18.48076 71817	30 minu tes	7.0	Temperature	5
T11	RBRduet	Pressure, temperature	2022-05-08 10:05:56	2024-04-01 17:29:00	- 136.43590 3	- 18.47279 4	15 minu tes	1.023 8	Temperature, water level	3, 4, 5



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Figure A1: Instrument deployments at Reao Atoll, including the first deployment (December 2016 to June 2017) and subsequent deployments conducted under the GAIA project (June 2021 to May 2025).

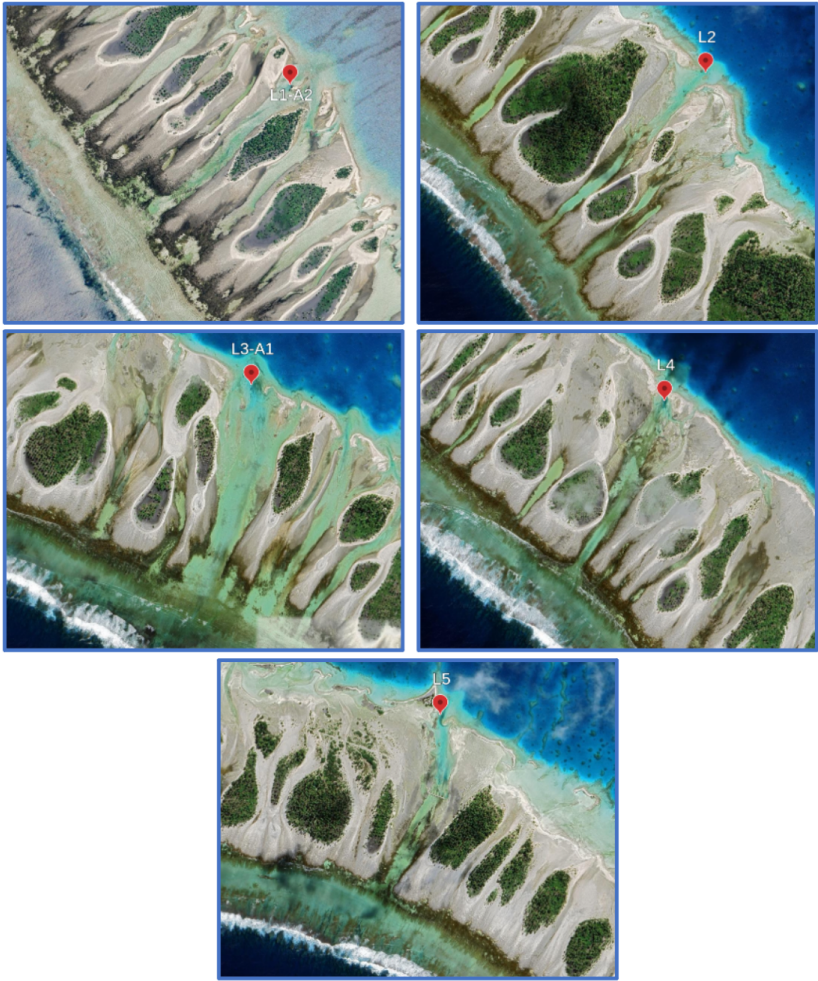


Figure A1: Zooms on the locations of the five instrumented *hoa* (© Google Maps)

Page 5 : [1] a supprimé Simon Van Wynsberge 03/03/2026 01:53:00

Page 5 : [1] a supprimé Simon Van Wynsberge 03/03/2026 01:53:00

Page 12 : [2] a supprimé Esther Ladet 18/02/2026 09:06:00

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Page 12 : [3] a supprimé Simon Van Wynsberge 03/03/2026 01:49:00

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Page 15 : [4] a supprimé Romain Le Gendre 18/02/2026 04:50:00

Page 18 : [5] a supprimé Simon Van Wynsberge 16/03/2026 20:57:00

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Page 20 : [6] a supprimé Esther Ladet 17/02/2026 16:02:00

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Page 20 : [7] a supprimé Simon Van Wynsberge 03/03/2026 01:22:00

Page 21 : [8] a supprimé Romain Le Gendre 20/04/2026 21:39:00

