ReefTEMPS: The Pacific Islands Coastal Temperature Network

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Abstract. While the rise in global ocean temperature continues its course, reaching 1.45+/- 0.12°C above pre-industrial level according to the World Meteorological Organization in 2023, marine heat waves frequencies and intensities increase. Consequently, coral reef ecosystems which are among the most vulnerable environments are strongly impacted with dystrophic events and corals experiencing increasing frequencies of bleaching events. That has devastating consequences for the Pacific Island Countries and Territories (PICTS) that strongly rely on these ecosystems. In-situ observation remains the best alternative for providing accurate characterization of long-term trends and extremes in these shallow environments. This paper presents the coastal temperature dataset of the ReefTEMPS monitoring network in which moored stations are implemented over a number of PICTS over a wide region in the Western and Central South Pacific from New Caledonia to French Polynesia. These in situ temperature time series are unique in several ways: in the length of some historical stations dating back to 1958 for the oldest, thus providing more than 65 years of daily data; in the number of countries sampled (16 PICTS) ; and in the variety of coral ecosystems monitored (from atolls to high islands and from barrier reef's external slopes to shallow and narrow lagoons). Measurement devices have evolved over the years to provide increasingly precise and frequent observations so that the ReefTEMPS network was endorsed as a French National Observation Service in 2020, a label ensuring quality controlled and open access data of long-term observations. All stations are publicly available in ASCII or formatted NetCDF files, either on the ReefTEMPS dedicated Information System which also allows quick visualisation of time series, or in the SEANOE marine data platform. All links and accesses to these temperature time series are provided herein. The longevity of these temperature time series allows diagnosing long-term trends, highlighting the influence of multiple processes on temperature dynamics (e.g., internal waves, cyclones, seasonal and climate modes) and documenting the time evolution of extreme events. All files are made publicly available in dedicated SEANOE repositories (DOI provided herein).

1 Introduction

Sea temperature is a key variable in oceanic, atmospheric and coupled ocean-atmosphere studies. It is an essential variable to be considered when characterising climate variability and climate change. In addition, it is also key for understanding marine ecosystems responses to thermal variability because of its wide influence on marine biogeochemistry and diversity (Kurylyk et Smith, 2023). It more particularly influences marine species spatial and temporal distributions (Pinsky et al., 2020; Righetti et al., 2019) and their life cycles (Dahlke et al., 2020). Understanding the evolution of oceanic temperatures is crucial to infer how global marine biodiversity and biomass will evolve as climate change is producing extremes that may not have been experienced by marine life before (Smale et al., 2019).

Since the 1980s, the advent of satellites has provided a better knowledge on how surface oceanic temperatures evolve at scales of ~ 25km (Minnett et al., 2019). Products such as OISST offer a retrospective view back to 1982 at 0.25° resolution (Reynolds et al., 2007). Lately, this synoptic capacity to observe surface temperature has strongly progressed into much higher spatial resolution with international efforts producing blended daily products up to ~1km resolution at global scale (e.g., MUR SST, Chin et al., 2017). This new higher resolution surface products have been complemented, since 1999, by in situ observations of the water column temperature, with the launch of the global array of autonomous free-drifting profiling floats mainly in the open ocean (ARGO, Wong et al., 2020).

Yet, coastal and shallow water areas remain largely undersampled. First, Argo floats cannot drift in shallow waters, and at the coastal scale, even the highest resolution global satellite products are plagued by many sources of artefacts that cause remotely-borne temperature observations to strongly diverge from observed in situ estimates (Goebeler et al., 2022, Smit et al., 2013). Coastal areas often display high complexity and variability in terms of bathymetry, coastlines or freshwater inputs that create thermal micro-habitats that satellite data do not resolve properly. Resolution offered by satellites can also lead to a misrepresentation of true thermal extremes experienced at the coastal zone (Schlegel et al., 2017; Van Wynsberge et al., 2017). In addition, processes affecting infra-daily sea surface temperature variability (e.g diurnal heating signal, tidal signal or internal waves, Colin and Johnston, 2020) are invisible to most remotely-sensed techniques that only provide daily estimation of surface temperature. Some satellite measurements may provide these temporal scales (e.g Himawari, Kurihara, 2016) but over short time periods. Satellite products generally provide estimates of the upper 10-m temperature based on their radiometer measurements of the skin temperature and other parameters with inherent limitations to describe the water column or benthic thermal variability experienced by sessile organisms (Minnett et al., 2019).

At present, the only way to obtain true continuous temperature measurements in shallow water environments comes from moored observations. While those cannot assess the spatial scales that satellites cover, they provide ground truth temperature measurements of the water column at very high frequency and over long-time periods if moored observing systems are implemented in perennial manners. It is thus of crucial importance to maintain and enhance these arrays especially in small islands surrounded by coral reef environments where ecosystems goods and services are fundamental for people's well-being (Santavy et al., 2021).

Coastal observations are hence essential prerequisites to manage and mitigate risks, generate prediction of coastal hydrodynamics including temperature dynamics and create a continuous observing network from terrestrial to oceanic ecosystems (Malone et al., 2014). Knowledge about coastal sea water temperature variability is critical as it is part of the backbone of core biogeochemical and physical observations needed to inform management bodies and scientists on coastal events and processes (Bailey et al., 2019). In a warming world that exacerbates occurrence of extreme events such as marine heatwaves (IPCC, 2023), long term coastal monitoring of high-temporal-resolution-temperature is of crucial importance for making reliable assessment of these changes at all scales, from sub-diurnal to multidecadal (Goebeler et al., 2022; Salat et al., 2019). Shorter-term observations of temperature are also proving crucial for understanding mechanisms driving short-term temperature dynamics and for validating and setting up statistical or numerical modelling tools able to simulate thermal short-term variability (McCabe et al., 2010; Van Wynsberge et al., 2017). Misrepresentation of such short-term coastal processes may hamper our ability to perform long-term future projection for coastal ecosystems (Siedlecki et al., 2021)

Those general considerations on the need for in situ monitoring of temperature in coastal environments are particularly true for coral ecosystems. In these ecosystems, concerns about temperature effects have arisen since the 1998 global bleaching event. Although “localised” bleaching and dystrophic events have been reported since 1982 in the Pacific and Indian ocean as well as in the Caribbean Sea (Goreau et al., 2000), the intensity and spatial extent of the 1998 event led to the awareness that global coral ecosystems may be durably endangered by climate variability (Hughes et al., 2017). This also stressed the necessity to better understand the complex relationships between coral bleaching and extreme ocean temperatures. In the tropical Pacific, the health of coral reef ecosystems is a fundamental issue as it has a major impact on food security as well as sources of income for Pacific islanders (Bell et al., 2017). As ocean warming and heatwaves are actually recognized as the most significant and growing threats to coral reefs (IPCC, 2023), in situ temperature monitoring appears of fundamental importance to better assess their fate in the future by being able to document lethal thresholds from in situ data and/or possibly find more heat-tolerant coral reef populations (De Carlo et al., 2019; Rivera et al., 2022) for example.

Temperature variability within coral reef ecosystems (such as lagoons, outer reef slopes, reef flats or terraces) can be controlled by a variety of physical drivers of both oceanic and atmospheric origins (Herdman et al., 2015; Grimaldi et al., 2023). Moreover, interactions of physical processes (tides, wind, waves down to turbulence within coral canopy) with complex bathymetry induced by coral reefs geomorphology can lead to thermal microclimates (Reid et al., 2020). The resulting local thermal signatures can thus be observed only by the means of in situ monitoring and strongly supports field observations for understanding coral bleaching (Safaie et al., 2018; Green et al., 2019) or coral cover spatial heterogeneity (Rogers et al., 2016). Toward that end, several in situ coastal water temperature monitoring strategies have been launched since early 2000s in the tropical Pacific, either at a regional scale (e.g Potemra et al., 2017 for the Pacific Island Ocean Observing System : PacIOOS), or at country scales (e.g Palau – Coral Reef Resarch Foundation et Colin, 2018; Australia – Lynch et al., 2014; Federated States of Micronesia, Pohnpei – Rowley et al., 2019; French Polynesia, Morea LTER Network – Leichter et al., 2013).

Along these lines, the ReefTEMPS initiative has been federating past and on-going coastal scale projects or temperature datasets in the South-Central and South-West Pacific islands. One of the strengths of this network is to maintain long-time observational efforts for quality measurements so that it gathers a number of in situ coastal temperature data dating back from 1958. The ReefTEMPS monitoring initiative is thus dedicated to documenting a range of temporal scales from long-term trends of coastal ocean temperature associated with climate change and their impacts on coral reef systems to shorter time scale processes shaping coastal thermal regimes within these ecosystems. In addition to honouring the observational effort, the origins and scientific values of the past gathered datasets from different institutions, this paper aims to present the philosophy and quality of this coastal reef monitoring current network and its future directions, in order to ensure the continuity of such crucial observations. This paper is also a means by which to advocate future and more global collaborations on these observations that will ensure the sustainability of the network regardless of the turmoils linked to funding uncertainties.

The paper is organised as follows. After a description of the history and current status of ReefTEMPS in section 2, section 3 provides details on sampling devices used since the beginning of observations. Section 4 sets out the overall strategy and methods that ensure data quality while part 5 presents the philosophy of data management and dissemination. Finally, after a brief presentation of some key applications of such temperature data in section 6, section 7 is dedicated to the perspectives and future evolutions of ReefTEMPS.

2 ReefTEMPS: Coastal temperature monitoring in Pacific Islands

2.1 History

The ReefTEMPS (Pacific Islands Coastal Temperature Network) initiative, was officially launched in 2010 by the GOPS (Grand Observatoire de l'environnement et de la biodiversité terrestre et marine du Pacifique Sud), by federating existing coastal monitoring strategies and datasets and adding numerous sites of measurements in the South Pacific. In practice, the adventure actually began much earlier. As early as 1958, in Nouméa (New Caledonia, NC), ORSTOM (Office de la Recherche Scientifique et Technique Outre Mer, now IRD, Institute of Research for Sustainable Development)'s oceanographers were convinced of the crucial value of repeated and prolonged measurements of sea parameters (temperature and salinity). Using the material resources available at that time (oceanographic bucket), they worked hard to maintain daily observations of temperature and salinity at the first long-term lagoon monitoring station of Anse Vata– Nouméa (Dandonneau, 1986, Fig. 1 - Appendix B1). Ten years later, in 1967, a second historical station was set up, closer to the open ocean, on the islet of the Amédée lighthouse (Fig. 1 - Appendix B1). The foundation of the ReefTEMPS network was born.

From 1992 to 2009, management and continuity of the existing monitoring network in New Caledonia lagoons has been steered by IRD with the support of the Zoneco program (https://www.zoneco.nc/) with the start of new observation stations around the mainland of NC, on both the west and east coasts and both northern and southern lagoons. This geographical extension began mainly in 1997 when electronic sensors replaced manual sampling. 2010 was the official birth year of the ReefTEMPS framework driven by the GOPS. In addition to major improvements on data archiving and dissemination infrastructures (Hocdé & Fiat, 2013), ReefTEMPS expanded to other PICTS during 2011-2015. In 2011, with financial support from the Australian Agency for International Development (AusAID), the Pacific Community (SPC) launched a project to help Pacific Island countries in setting up pilot projects to monitor coastal fisheries and associated habitats. In this context, a dozen sensors were deployed in Marshall Islands, Cook Islands, Papua New Guinea, Micronesia, Tuvalu and Kiribati and were integrated in ReefTEMPS. In 2012, through a collaborative initiative, management of the historic stations on Wallis and Futuna was entrusted to the University of New Caledonia. The same year, the Pacific Centre for Environment and Sustainable Development (PaCE-SD) at the University of South Pacific in Fiji joined the ReefTEMPS initiative and began observations in Fijian coastal waters, thus developing a long-lasting collaboration with ReefTEMPS which endures to this day. Finally, in 2021, the Direction des Ressources Marines de Polynésie Française (DRM) also integrated ReefTEMPS by including their historical data from the French Polynesian lagoon network RESOLAG (Liao et al., 2023) to the ReefTEMPS dataset and has since become another major partner of the network.

As an international observation network based in both the French Pacific territories and the Pacific Island states (Hocdé et al., 2021), ReefTEMPS has been a key asset in the creation and design of France's multi-agency Research Infrastructure for coastal ocean observation ILICO (Cocquempot et al., 2019). Since 2019, ReefTEMPS has been one of the nine National Observation Services (SNO) integrated in ILICO. These networks are accredited through a peer-reviewed evaluation process overseen by French national research agencies every 5 years. ReefTEMPS was labelled as SNO by the french governmental "Ocean-

Atmosphere" commission for the 2020-2024 period and for the three parameters: temperature, conductivity and pressure. As a labelled network, ReefTEMPS is required to acquire and disseminate openly data of international quality standards.

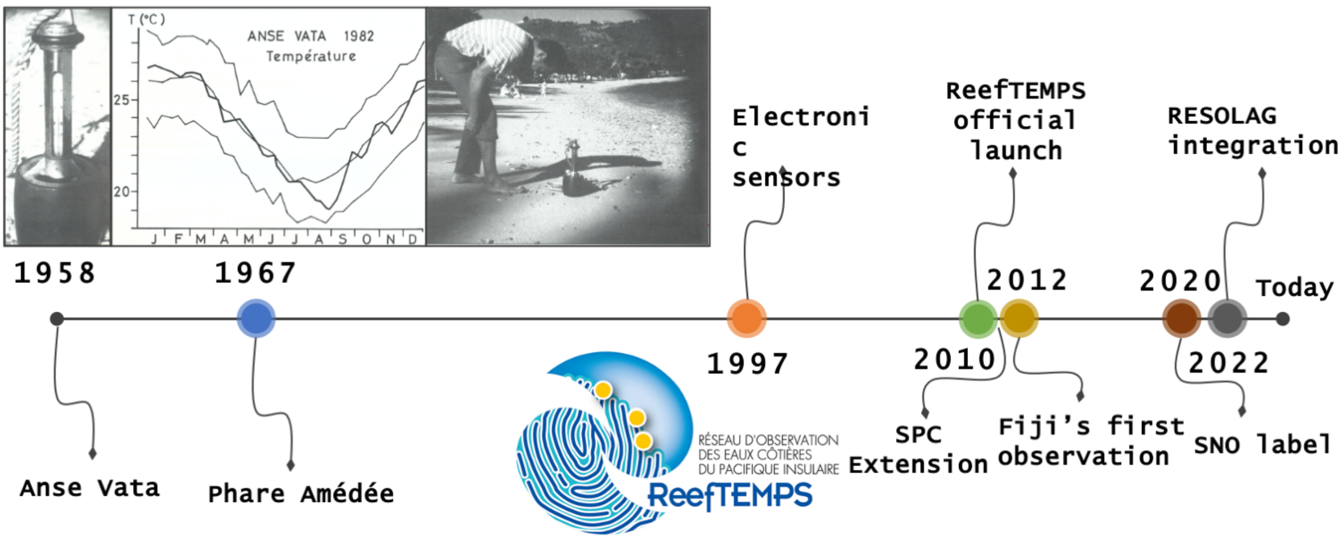


Figure 1: Timeline of the main events of the ReefTEMPS Network. During the first period until 1997, bucket measurements were done as depicted in the inserted photos from Dandonneau (1986). Left panel of the insert: zoom on an oceanographic bucket. Centre: seawater temperature at Anse Vata station using bucket (bold line: 1982 time series, lights lines represent average, minimum and maximum through the year from 1958 to 1982 observations). Right: scientist reading temperature value on an oceanographic bucket.

2.2 The current ReefTEMPS Network

The tropical and subtropical Pacific is the area of the world oceans that supports the largest habitat for coral reefs and is home to the greatest coral species richness (Maragos and Williams, 2011; Fig. 2 upper right panel). The ReefTEMPS temperature monitoring network encompasses the three regions of Oceania (Micronesia, Melanesia and Polynesia), covering 16 PICTS (see Fig. 2, Tables A1 & A4, Appendix B2) and extending roughly from 10 to 30°S and from 134°E (Palau) to 134°W (Gambier islands). Such huge spatial coverage is a challenge to maintain over time and some stations have been discontinued due to fluctuating collaborations and fundings (57 stations interrupted). The duration of time series ranges from 6-8 months for the shortest series to more than 65 years for the longest (Anse Vata station, New Caledonia). 26 stations have more than 10 years of observations (approx. 20% of the monitored sites). The total observation time, covering periods between the start and end dates of all stations sums actually to 320744 days, equivalent to approximately 878 years of data. The study sites that have the higher numbers of monitoring stations and currently contribute the most to the observations of coastal temperature are New Caledonia, Fiji and French Polynesia, which constitute the secure and core observations of ReefTEMPS. New Caledonia (Fig. 2 - Bottom left), due to its history of coastal observations, represents the "backbone" of this network with both the largest number of monitored sites (53) and the longest time series. Most stations are located in its southwest lagoon but some long-term sites are also spread out further north and on the east coast of the mainland ("Grande Terre"), as well as on remote reefs (e.g Entrecasteaux reefs, Chesterfield islands). Fiji currently has 15 monitored sites around Viti Levu Island, Beqa Island, the Vatu-i-Ra Passage, the Lau Group and the northernmost island of Rotuma. In French Polynesia ReefTEMPS covers the 5 main archipelagos, sampling both atolls and high islands lagoons with a total of 20 stations.

Overall, to date, the ReefTEMPS network currently comprises 118 monitoring temperature stations (61 currently active) with mean duration of observations above 2430 days. Since time series are generated by instrument type, this corresponds to a total of 132 files. In terms of depth, sensors are distributed between 0.5m and 60m (61 % in the 0-10m, 33% in the 10-20m, and 6% > 20m) (see Appendix A - Table A4). The vast majority of observation stations consist of measurements at a single depth, while two stations in New Caledonia (Uitoe and Hienghène) are equipped with multiple vertical levels of instrumentation.

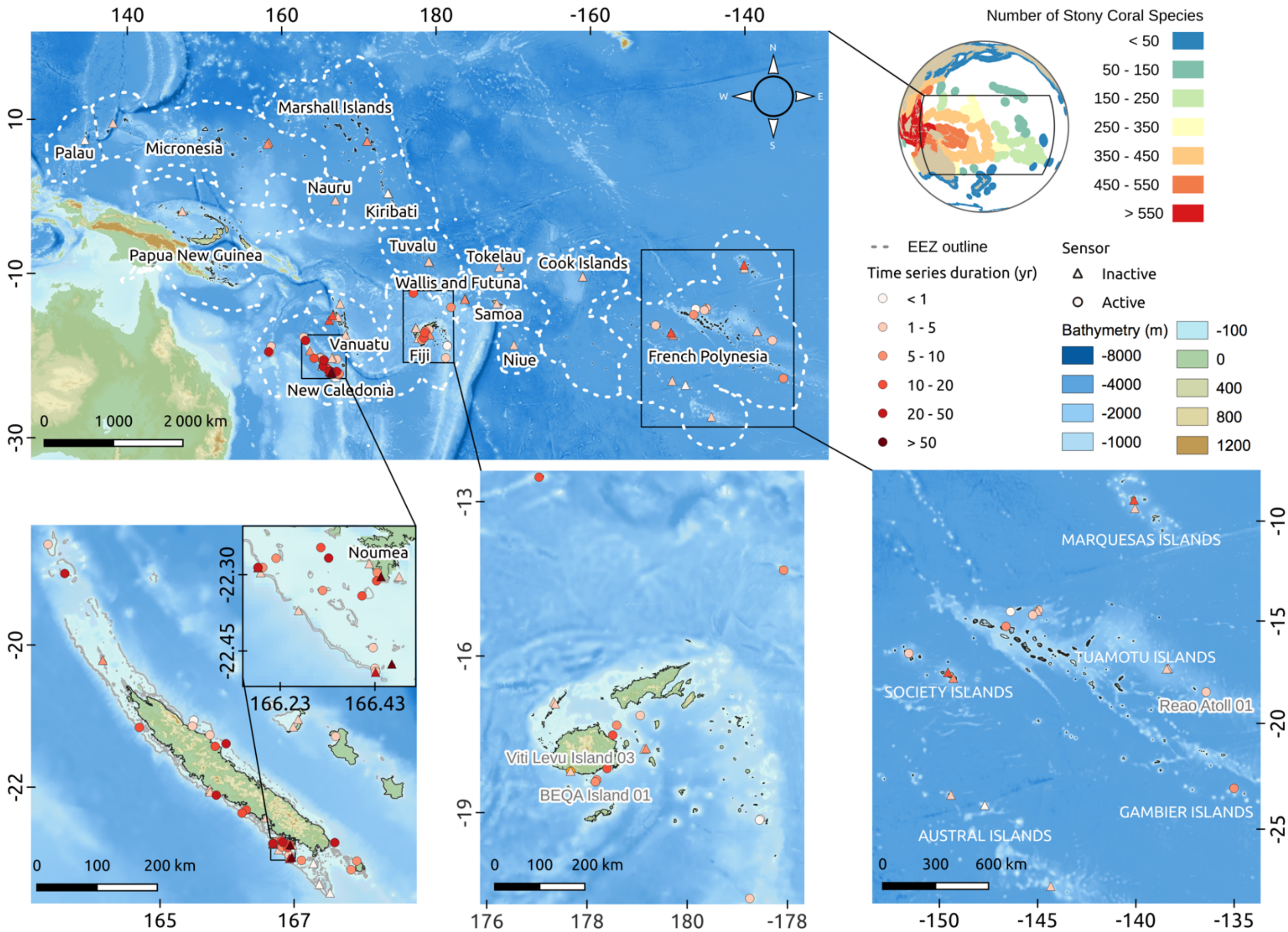


Figure 2: Overview of geographical distribution and length of time series (in years) of ReefTEMPS monitoring stations. Detailed zooms are provided for New Caledonia, Fiji and French Polynesia. Circles/triangles indicate respectively active/inactive stations. The upper right panels depict the number of stony coral species across the world (from The Atlas of Global Conservation, Hoekstra et al., 2010) illustrating the coral reef context in which ReefTEMPS is set. Bathymetric data used come from GEBCO grid (GEBCO Compilation Group, 2022).

3 Sampling devices

Due to the wide temporal range of the ReefTEMPS dataset, measurement methods have evolved over the years in line with technological advances. Starting from simple observations with an oceanographic bucket deployed from the shore by a human operator (see Fig. 1), the network has grown to include a variety of automatic sensors with increasing accuracy, frequency of acquisition and capacity of storage. Most of the instruments used now are autonomous compact loggers containing internal batteries and memories, deployed by scuba diving and fixed on the seabed (see Fig. 3). Moorings have been designed to be adapted to the habitats and to withstand heavy agitation such as the ones induced by cyclones or storms. To prevent sensors from biofouling, mechanical damage or wildlife, they are all deployed inside plastic cylinders with holes that allow water circulation. A few sites (especially in French Polynesia, see buoys section) were also initially instrumented using buoys but this sampling strategy is now replaced by moored sensors to be congruent with the whole network.

3.1 Oceanographic bucket

For the two long-term sites of New Caledonia, Anse Vata and the Amédée islet, data were first collected using the oceanographic bucket (see Fig. 1). This device was as simple and robust as a water-taking bucket equipped with a thermometer and deployed using a rope to collect water. It allowed temperature measurements to be taken with an accuracy close to 0.1°C and had been used daily for nearly 47 years. The nominal acquisition time for both stations was 7am local time and the targeted depth using the bucket was ~0.5m.That method was abandoned in 2005 to move to more automatic measurements. At the Amédée station, the construction in 1977 and extension in 1993 of a pontoon slightly shifted the sampling point from the initial position from the beach, moving it away from the shoreline by 44m, then 64m. That changed to 4.5m with the arrival of autonomous electronic loggers. In French Polynesia, two stations had also been sampled daily using buckets in Tahiti (Society Islands, from 1979 to 1989) and in Ua Pou (Marquesas Islands, from 1986 to 1989).

3.2 Compact autonomous loggers

From 1997 to 2009, a few main initial sensor brands were used for monitoring coastal temperatures in New Caledonia, French Polynesia and Wallis Island. The first set of electronic and autonomous sensors deployed were HOBO®, for which various models were successively used (Stowaway : https://www.onsetcomp.com/resources/documentation/1513-stowaway-xti ; Optic Stowaway : https://www.onsetcomp.com/resources/documentation/1086-k-man-optt ; UTBI-001 TidBit : https://www.onsetcomp.com/products/data-loggers/utbi-001; last access: 5 September 2024). Depending on the brand, the accuracy ranged from 0.2 to 0.4°C, but these sensors provided a higher temporal resolution compared to the punctual observation using a bucket. They provided infra-daily resolution, acquiring data continuously at frequencies between 10 and 30 min. Autonomous loggers from RBR Ltd, the RBR TD1060 were also initially deployed in New Caledonia. In addition to temperature (accuracy 0.002°C, drift ~0.002°C/year; manufacturer's manual), they also provided observations of pressure. Due to several logger failures or drifts, these RBR sensors were gradually abandoned. At last, the Uitoe station (external slope of the barrier reef, west of New Caledonia) was equipped since 1992 with a Seacat SBE16 from SEA-BIRD Electronics Inc., which samples temperature (accuracy 0.01°C, resolution 0.001°C) but also conductivity.
With the birth of ReefTEMPS in 2010 and its associated requirements, as well as the technological developments that occurred in oceanographic instrumentation, the compact loggers fleet has evolved towards models with longer autonomy and greater accuracy while measuring additional parameters. The GOPS has led a major effort to rejuvenate and homogenize the instrumental fleet. Depending on monitoring sites and scientific objectives (e.g additional observations of level and salinity),

the choice fell on a new generation of robust devices that allows long-term deployments (from 6 month up to 2 years) with minimum battery costs while being strongly reliable. Since 2010, SBE56 temperature sensors were moored (SEA-BIRD Electronics Inc.; https://www.seabird.com/sbe-56-temperature-sensor/product?id=54627897760, last access: 5 September 2024). These SBE56 loggers allow recording fast (1min sampling rate), highly accurate temperature measurements (accuracy of 0.002°C, +- 0.002°C drift/year), and provide enough battery and storage autonomy to remain deployed underwater for up to 2 years. For monitoring stations where water level dynamics is of interest, the sensors used in ReefTEMPS are now two models from RBR Ltd. namely, RBRduo T.D and RBRduet T.D (https: //rbr-global.com/, last access: 5 September 2024). These RBR loggers are used to record not only temperature (initial accuracy of 0.002°C, +- 0.002°C drift/year) but also pressure that provides information about sea-level dynamics. Finally, on stations impacted by massive freshwater inflows, temperature is monitored using the Infinity-ACTW loggers from JFE Advantech Co., Ltd. (https://www.jfe-advantech.co.jp/eng/assets/img/products/ocean-infinity/INFINITY-CTW(E)_201704.pdf, last access: 5 September 2024) which reliably samples temperature (accuracy +- 0.01°C, resolution 0.001°C) and conductivity (salinity).

3.3 Multi-parameter buoys

In French Polynesia, RESOLAG, a program dedicated to the long-term monitoring of pearl farming atolls, started in 2018 (Liao et al., 2023). The aims of the deployed sampling strategy were initially double: first to acquire multiple parameters (temperature, salinity, fluorescence, turbidity, dissolved oxygen) to understand the link between environment variability and performance of pearl farming activities (e.g spat collecting, pearl quality). The second objective was to provide pearl farmers and stakeholders with a real-time view of the lagoon's state, particularly temperature data, to make their spat collection seasons more efficient by improving their understanding of precise interseasonal periods. For this purpose two kinds of real-time multi-parameters buoys by NKE (Smatch and Sambat models; https://nke-instrumentation.com/; last access: 16 May 2024) were deployed in 7 different lagoons, sampling parameters around 3m at 1 hour frequency. Concerning the thermistors, the manufacturer's manual for the thermistors indicates for both buoys an accuracy of 0.05°C and a maximal resolution of 0.003°C. In 2023, due to some problems with live transmission and sensor maintenance, the RESOLAG strategy shifted to the use of moored loggers and, to be consistent with the ReefTEMPS logger strategy, choice fell on SBE56 and RBR Duet instrument (see section 3.2 above).

4. Processing and quality control

4.1 Overall strategy

Figure 3 presents the global data life cycle of the ReefTEMPS temperature time series. Data processing and quality control have been conducted in a standardised manner since 2010 to ensure both consistency of observed time series and diffusion using international oceanic data standards. Since 2010, maintenance and recalibration of instruments have been conducted at recommended intervals by or in accordance with the manufacturers (every 5 years for Seabird loggers, every 2-3 years for JFE Advantech and RBR loggers) to ensure reliability and quality of values observed. Recently, an intercomparison procedure for sensors compared with a reference SBE56 sensor was implemented to ensure that the sensors do not differ by more than 0.005°C from the reference sensor. Prior to 2010, the reliability and accuracy of the devices used were lower (see Section 3) and maintenance frequency was not really fixed and fluctuated according to available funds.

Early 2025, a major overhaul of the entire database, quality flags and processing states, has been carried out. Each temperature measurement of each time series now has an associated quality code (QC, see Table A5). Based on the knowledge on sensors and sampling devices accuracy, quality flags have been attributed to each measurement according to instrument type and family. Globally, buckets, Onset and NKE sensors have been flagged to "Probably good data" (this mainly concerns data prior to 2010). RBR and Seabird sensors have been flagged to good data since, in our opinion and with our expertise, they provide more reliable temperature data. A python graphical tool has been used for inspecting all temperature time series and modifying quality flags. This tool lets you zoom in to perform visual check of all time steps, display satellite temperatures (e.g OISST, OSTIA), perform basic statistical tasks (e.g remove eventual duplicate data, tests values over/below threshold) and finally assign a different quality code to desired measurement. This qualification stage will now be fully integrated in the data life cycle (see Figure 3) for future data integration in the temperature database.

Finally, a dedicated nomenclature for files based on international standards (either raw or processed) was also implemented (see tables A2, A3, A4 for information on stations, instrument types and processing states and Fiat et al. 2024). Dataset file names read as follows: ConventionFormat_CodeSite_Startime_ParameterType_ProcessingState_InstrumentType_Depth. For example, filename 'OS_POINDI01_199710_TEMP_2B_TR_125.nc' indicates that this time series is formatted following OceanSITES conventions (OS ; https://repository.oceanbestpractices.org/handle/11329/874.2; last access: 5 September 2024), taken at POINDI01 monitoring station (Poindimié station on NC east coast), beginning in October 1997, processed up to "Quality controlled data" (2B) processing state (See Appendix A Table 3), with instruments belonging to Thermistor class (See Appendix A Table 2), moored at a 12.5 meter-depth and provided in NetCDF (.nc). To avoid decimal numbers in the filenames we have chosen to indicate depths in decimeters. The global data life cycle (including processing and quality steps) is described hereafter and depicted in Figure 3 diagram. The files generated at each stage are stored on secure drives.

1. Instruments are replaced (or moored if this is a first deployment for a new station) by scuba diving at frequencies that depend on their characteristics (from 3 months up to 2 years in water). Each replacement is referred to in the database as a "measurement cycle".
2. Upon replacement raw files are retrieved using dedicated manufacturer's software and first converted in ASCII format and named following nomenclature rules.
3. Time series from each measurement cycle are then carefully visually inspected using specific softwares (ferret or matlab routines) to ensure removal of obviously "bad data" (e.g out of water observations), converted into NetCDF

cycles, and checked to ensure measurement cycles are properly connected. At this stage the corresponding processing state of the time series remains level 1A (see Appendix A3).

4. Measurement cycles are then imported into the DB Oceano database (PostgreSQL)
5. Datasets from each retrieval are then exported into NetCDF OceanSITES format (https://repository.oceanbestpractices.org/handle/11329/874.2; last access: 5 September 2024), with metadata following the Climate and Forecast metadata conventions (CF : https://cfconventions.org/; last access: 5 September 2024), and finally.
6. Using a python graphical tool, a qualification check (see above) is performed on the new cycle of observations and if necessary, modifications are performed on corresponding QC in the database. This qualification check, performed by a scientific expert in tropical coastal temperature dynamics, enables re-updating database and affecting processing state 2B to these temperature time series (see Appendix A3).
7. Fully processed NetCDF files are then exported into the ReefTEMPS Information System (IS) which allows delivering datasets in different formats and/or using different web services based on specific and standardised protocols (see 5.1).

On April 15, 2025, the global archive of temperature time series contains 132 quality-controlled temperature files: 125 files are at processing states level 2B and 7 files at 3B. The seven 3B files come from Temperature/Pressure sensors deployed at very high frequency (1Hz or 2Hz) to compute wave parameters. Temperature for these stations is therefore resampled to 30 minutes.

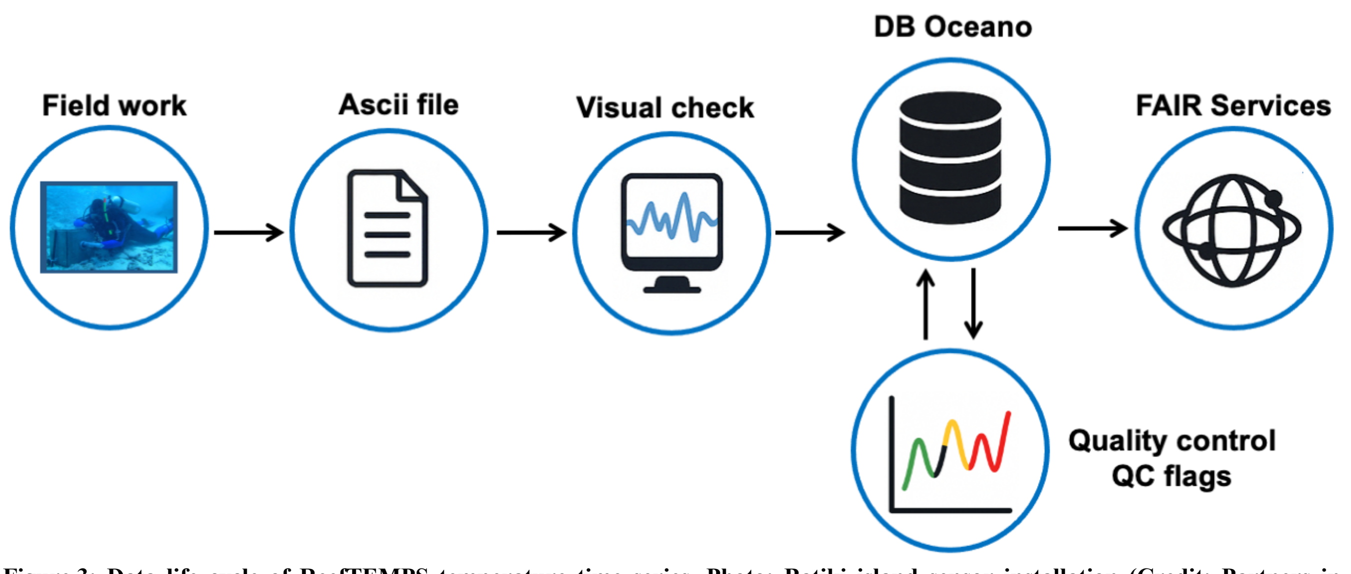


Figure 3: Data life cycle of ReefTEMPS temperature time series. Photo: Batiki island sensor installation (Credit: Partners in Community Development, Fiji).

4.2 Long-term monthly homogenised files

The instrument precision and targets of ReefTEMPS have evolved over time, starting with studies of daily-to-seasonal variability, then moving to longer term variability. Observations acquired before 2010 using oceanographic bucket or Hobo sensors suffered from a lack of precision or potential drifts. However, studies of the effects of climate change on coastal temperature require access to long homogeneous time series with sufficient precision as temperature trends detected since 1950 globally do not exceed a few tenth of degrees/decade (Cavarero et al., 2012; IPCC, 2023). Hence to avoid misinterpretation in long-term trends due to sensor turnover, displacement or change in the sensor environment, an homogenization procedure was applied to the two historical time series at Anse Vata and Phare Amédée stations in New Caledonia. That allowed providing daily homogenised time series for the longest records with which to look at climate trends. The procedure applied for building homogenised monthly long-term time series is described in depth in Guyennon (2010). During the first decades of observations (1958-1997), measurements using buckets targeted a sampling at 7 a.m. local time every day although some measurements were taken between 5 and 10 a.m. Depending on the month of the year, this sampling time difference can lead to temperature differences of up to 0.4°C. Thus, the first part of the procedure was devoted to readjust these data to be consistent. For that purpose, the HOBO sensor period (1998-2010) was used for each station to compute average daily temperature variations for each month and then perform adjustment of bucket data to represent only the 7 a.m. temperature regardless of sampling time. The second step of the homogenization procedure aimed to correct bucket data to be representative of the daily mean for each day. Common measurement periods between sensors and buckets (80 months for Anse Vata and approx 30 months for Phare Amédée) were used to quantify, for each month, the differences between bucket values and daily sensor averages. These differences were then applied to the bucket period to provide data series representative of the daily mean temperatures. Monthly mean temperature time series were computed for each station. Finally, detection and correction of artificial shifts were performed using the PRODIGE software from Météo-France (theoretical basis presented in Caussinus et Mestre, 2004) for the 1958-2010 period. After 2010, SBE56 sensor data (deemed much more accurate) were averaged monthly and concatenated to finally obtain two monthly long-term series for Anse Vata (1958 - 2023) and Phare Amédée (1967-2023). Homogeneity assessment tests were carried out using RHTest V4 (Wang et al, 2010) and revealed no significant breakpoints. The figure B4 in appendix B displays the monthly homogenized data versus raw ones.

5. Data management and dissemination - Open access

Prior to ReefTEMPS, the data was centralised on a database referred to as “DB-Oceano” (PostgresSQL database management system), which was developed by IRD in the early 2000s for managing data from marine sensors. The database framework was inspired by the one initially built by the multi-partners Coriolis Project (https://www.coriolis.eu.org/). The first version of the ReefTEMPS Information System (IS) was then put into production in 2011-2012 (Hocdé & Fiat, 2013). Then, several updates of the information system took into account technological changes and offered new functionalities to both data managers and users (Brissebrat et al., 2017). Now the ReefTEMPS IS uses DB-Oceano with a workflow manager (Apache Airflow, implemented in 2023) around which web servers are deployed to distribute/share data. The infrastructure is designed around the concept of micro-services and is fully containerized using docker technology, ensuring good system portability and the possibility of upgrading to distributed servers for better load balancing. The workflow manager automates the integration of new data by establishing a set of management rules according to the results of previous tasks (Appendix B Fig B.3).

Overall, the architecture of the ReefTEMPS IS is designed to ensure data longevity, optimise accessibility, enable widespread dissemination and ensure interoperability with other systems (Fiat, 2015, Fiat et al., 2021). These concepts are in line with the FAIR principles: Findable, Accessible, Interoperable and Reusable (Wilkinson et al., 2016). The ReefTEMPS database is provided as an open resource under a Creative Commons Attribution-ShareAlike 4.0 International license (CC BY-SA). The core of the datasets diffusion engine used on the website (https://www.reeftemps.science/) consists of interactive map showing the location of monitoring stations via Web Map Service (WMS-OGC) and Web Feature Service (WFS-OGC) geographic services. Once a station has been selected by the user, datasets can be downloaded in multiple formats (NetCDF using OceanSITES format, Ascii file, or Comma Separated Value files) via different sharing protocols/servers (Thredds server and OpenDAP protocol, Sensor Observation Service (SOS-OGC)). A dedicated visualisation service is also available to explore time series on the website, using ad hoc python web routines. Finally, the whole ReefTEMPS data archive is also accessible through Digital Object Identifiers (Varillon et al., 2025: DOI:10.17882/55128 and Liao et al., 2025: DOI:10.17882/82291) and is updated every six months on the Seanoe data repository. Each release of the semestrial whole dataset is identified by a specific and additional key (i.e https://doi.org/10.17882/55128#107183 for the 2024-01 release, https://doi.org/10.17882/55128#103428 for the 2023-07 release, etc). Nevertheless, the ReefTEMPS archive DOI is unique and common to all archive releases, which allows it to better track data usage statistics. The ReefTEMPS Data Management Plan describes the life cycle of ReefTEMPS data from their acquisition to their dissemination, including the steps of processing, archiving, etc. (Ilico, 2023). Figure 4 presents an overview of the data portal page and the associated services.

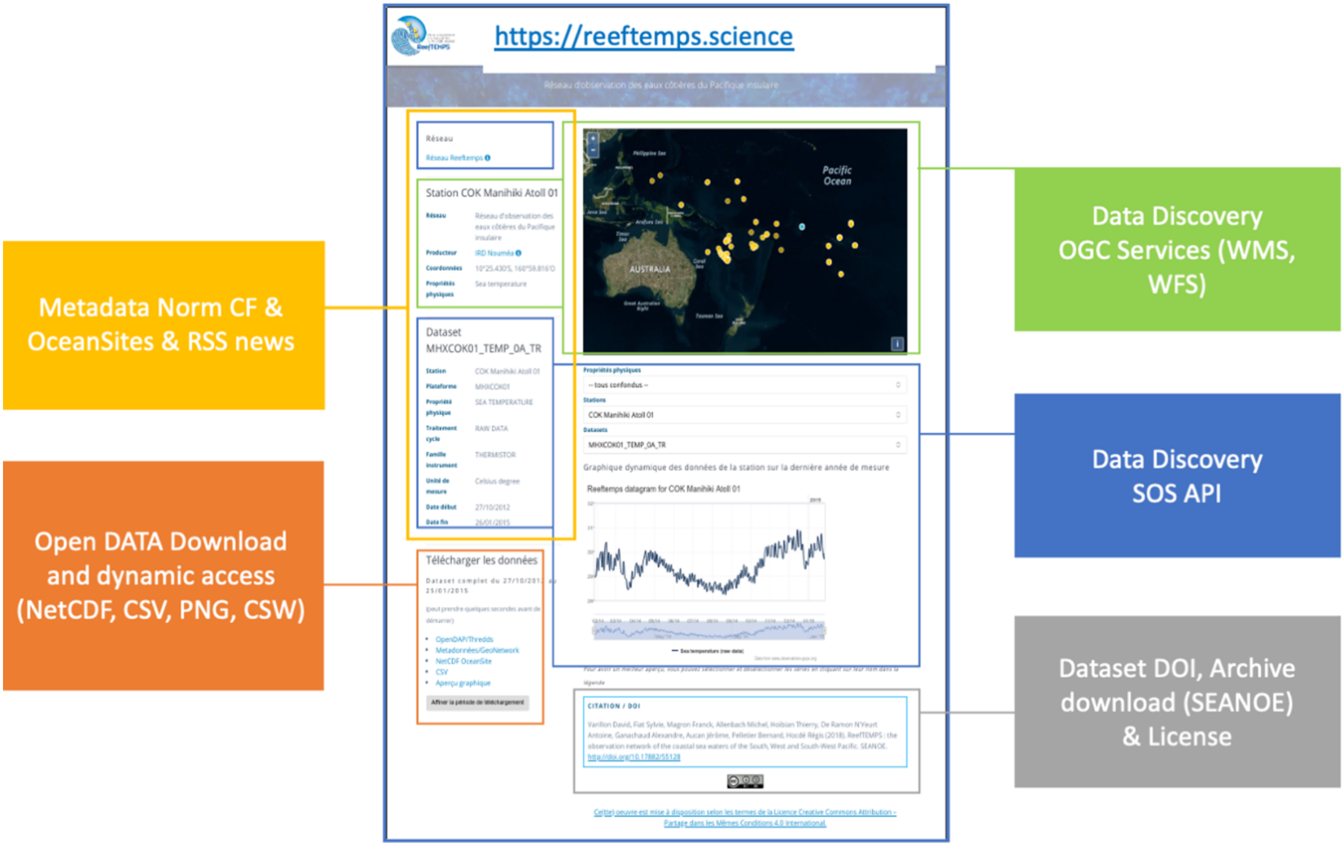


Figure 4: Data access portal page and associated services

6. Some examples of key applications

6.1 Capture and document extreme events

With the increasing frequency, intensity and duration of Marine Heatwaves (Oliver et al., 2018), in situ temperature observations are crucial for understanding the impact of true thermal variability on coral ecosystems. Figure 5 shows extracts from 3 chosen time series during austral summers 2016 (for Fiji and New Caledonia) and 2024 (for French Polynesia) where elevated temperature negatively impacted the health of ecosystems and wildlife (Holbrook et al., 2022; Dutheil et al., 2024). For the sake of illustrating the benefits of in situ observations, widely used daily L4 SST products are also displayed on each subplots for the nearest points to the ReefTEMPS stations. The two selected products are respectively OISST V2 (https://psl.noaa.gov/data/gridded/data.noaa.oisst.v2.highres.html ; last access: 5 September 2024) depicting SST at 1/4° and OSTIA SST (https://data.marine.copernicus.eu/product/SST_GLO_SST_L4_REP_OBSERVATIONS_010_011/description ; last access: 5 September 2024) at 0.05° resolution. First, Viti Levu 03 station in Fiji, moored at 12m depth on the oceanic side of the Votua lagoon, showed a sharp increase in temperature from January 15, peaking at nearly 31.25 °C on Monday 8th February 2016. On the same day, thousands of dead fish and invertebrates were found on the beaches near the village of Votua (Holbrook et al., 2022). Then category 5 tropical cyclone WINSTON re-entering the area on February 20th, induced a strong cooling by more than 5°C, participating in the demise of that massive marine heat wave (Dutheil et al., 2024). At the same time the Anse Vata station in New Caledonia, located more than 1250 km from Viti Levu and moored inside the south-west lagoon at 2m depth, showed the same tendencies of rising temperature prior to March 2016. There, temperatures began to rise rapidly from mid-January onwards and also peaked at 30.7 °C on Monday 8th February 2016. Daily maximum temperatures exceeded 30°C for about twenty days, which is between 2.5 and 3°C above the climatology computed for the 1997-2023 using Hobday et al. (2016) (see Figure 5.b). It had strong consequences on corals: the first documented massive coral bleaching event in New Caledonia's lagoons occurred during that February 2016, while that lagoon had been relatively unscathed until then (Payri et al., 2018). The third major event illustrated here occurred in 2024 in Reao atoll lagoon (orange line) in French Polynesia where the important population of giant clams (*Tridacna maxima*) provides significant incomes and food to inhabitants through fishing and aquaculture practices (IUCN, 2021). In 2024, daily maximum temperatures frequently reached or exceeded 31.5°C for about a month from the end of February onwards (even reaching max values of 31.8°C at the end of March), and always remained above 29.9°C during 40 consecutive days. The consequences of these prolonged high temperatures highly affected giant clams, with 57% of exploitable giant clams totally bleached, and 43% partially bleached, as estimated on April 1st 2024 in the area around the location of this thermistor.

These three iconic examples associated with heat waves demonstrate the crucial importance of such in situ observations for a better understanding of thermal tolerance, physiological damages and resilience of tropical marine organisms towards heat stress. Indeed, while satellites tend to capture roughly the same low frequency temperature dynamics, large biases (more than 2°C) are present and may prevent the study of ecosystem vulnerability. Moreover, these time series (Fiji versus New Caledonia) also illustrate the potential of such a geographically extensive network for studying spatial variability of coastal temperatures across regions which can be very useful to study the regional heterogeneity of coastal thermal responses to climatic modes such as ENSO. Finally, at local scales, a high density of sensors inside the same lagoon for example can also provide valuable information for understanding smaller scale spatial variability which are not captured by state-of-art current satellite measurements such as MUR (Van Wynsberge et al., 2020).

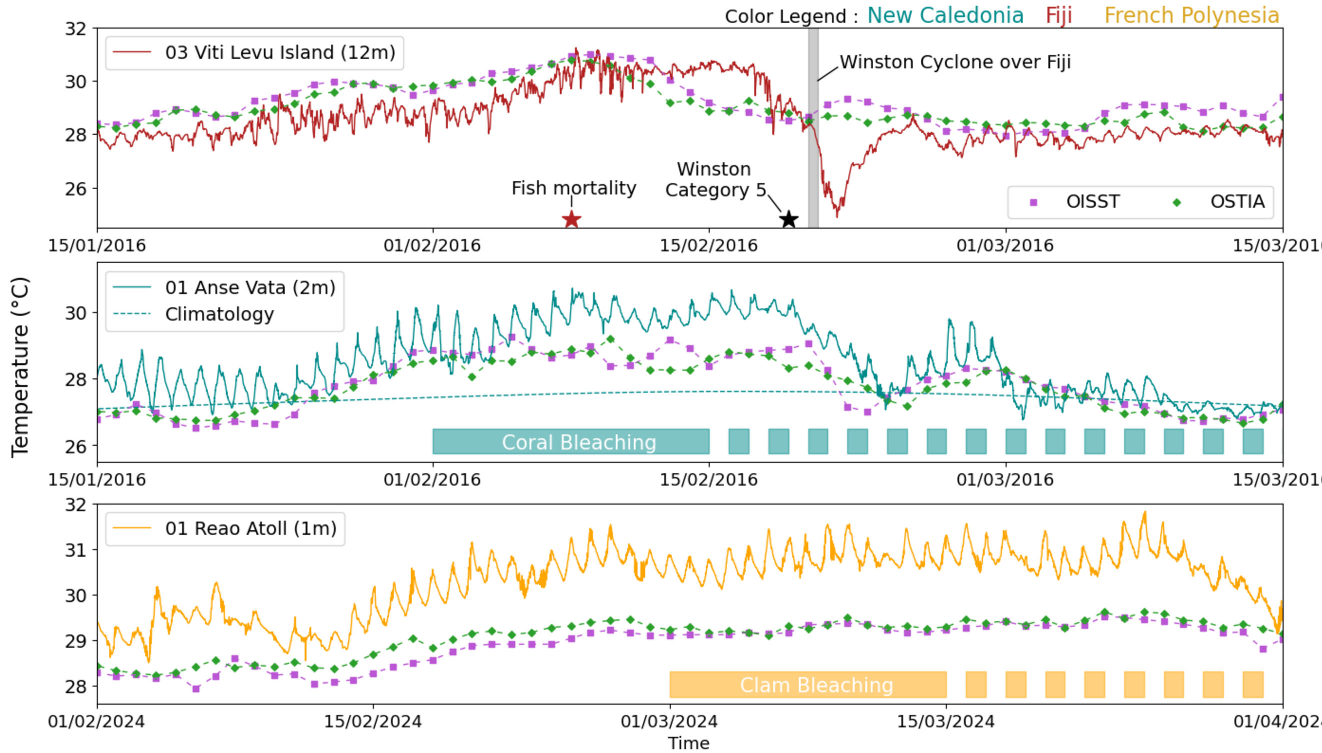


Figure 5 – a. Temperature time series during austral summer 2016 at Viti Levu Island 03 station (Fiji, 12m, red line) b. Temperature time series during austral summer 2016 at Anse Vata station (New Caledonia, depth 2m, dark cyan line) c. Temperature time series at Reao 01 station (Reao atoll lagoon, French Polynesia, depth 1m, orange line). Daily Sea Surface Temperature from Satellite products are plotted in purple for OISST V2 and green for OSTIA. Dates of the triggered ecosystem impacts are displayed on each subplot (red star for fish mortality in Fiji, dark cyan bar for coral bleaching in New Caledonia and orange bar for clam bleaching in French Polynesia). Dotted lines indicate that impacts on coral and clams have continued over time (with no precise end date to give).

6.2 Characterise physical processes at various timescales

The temperature records from the ReefTEMPS network demonstrate the importance of capturing physical processes operating across multiple temporal scales. These measurements enable the differentiation of high-frequency variability, such as tidal or diurnal fluctuations, from lower frequency signals associated with seasonal or interannual dynamics, thereby providing a comprehensive understanding of coastal oceanographic processes. Figure 6 shows examples of physical processes affecting temperature at different timescales as captured by the ReefTEMPS network. Here again, to highlight the crucial importance of in situ observation for temperature dynamics understanding, SST from OISST V2 and OSTIA satellites products are plotted on each time series. Fig. 6a shows a five-day temperature subset at Uitoe05 station (green curve), moored at 50m depth on the external slope of the South West lagoon barrier reef in New Caledonia, and the tidal elevation on the same period recomposed from FES2012 global tide solution (black curve). Temperature drops (by sometimes more than 2°C) are regularly observed at the M2 tidal wave frequency which suggests the influence of internal tides of high amplitude around New Caledonia

(Bendinger et al., 2023). As expected, the in situ data shows that the satellite data at low and high resolution are neither able to capture the amplitude observed nor the time scale linked to internal waves illustrating the strong asset of the in situ observations. At a similar frequency, the ReefTEMPS time series can also be used to characterise the diurnal temperature cycle, as depicted in Fig. 6b that displays a two-week temperature series using data from a sensor moored in the Reao atoll lagoon in 2022. With an offset of more than 1.5°C, the satellite data are not able to capture the level observed in the in-situ signal. In addition to their primary interest in understanding the physical processes controlling daily and infra-daily temperature variability, documenting this range of variations may prove useful for benthic species such as coral reefs which can benefit of some relief during stressing thermal conditions (Wyatt et al., 2020 ; Oliver and Palumbi, 2011). Naturally, daily satellite products are not able to inform about infra-daily variability but Fig. 6a and 6b also illustrate mean biases introduced when using such SST products at the coastal scale in coral reef lagoons especially when calculating coral vulnerability indices such as bleaching indices (Van Wynsberge et al., 2017).

Another key process that can induce significant cooling on the outer slopes of barrier reefs is upwelling. One example is provided in Fig. 6d where prolonged strong southeasterly trade winds flowing parallel to the coast triggered a wind-driven coastal upwelling episode in 2021 at station Fausse Passe de Uitoe 05 in New Caledonia, leading to an approx. 4°C decrease in a few days. This important upwelling feature off the south-west lagoon of New Caledonia can strongly shape biogeochemical properties of the ocean in the direct vicinity of the lagoon (Alory et al., 2006; Ganachaud et al., 2010). Here again, in situ observation proves to be essential as satellite SST products fail to reflect the drops of temperature. Finally, Fig. 6d, which represents a 5-year subset of the temperature time series observed in Fiji (Beqa Island 01 station), highlights the usefulness of long-term data for understanding seasonal to interannual variability.

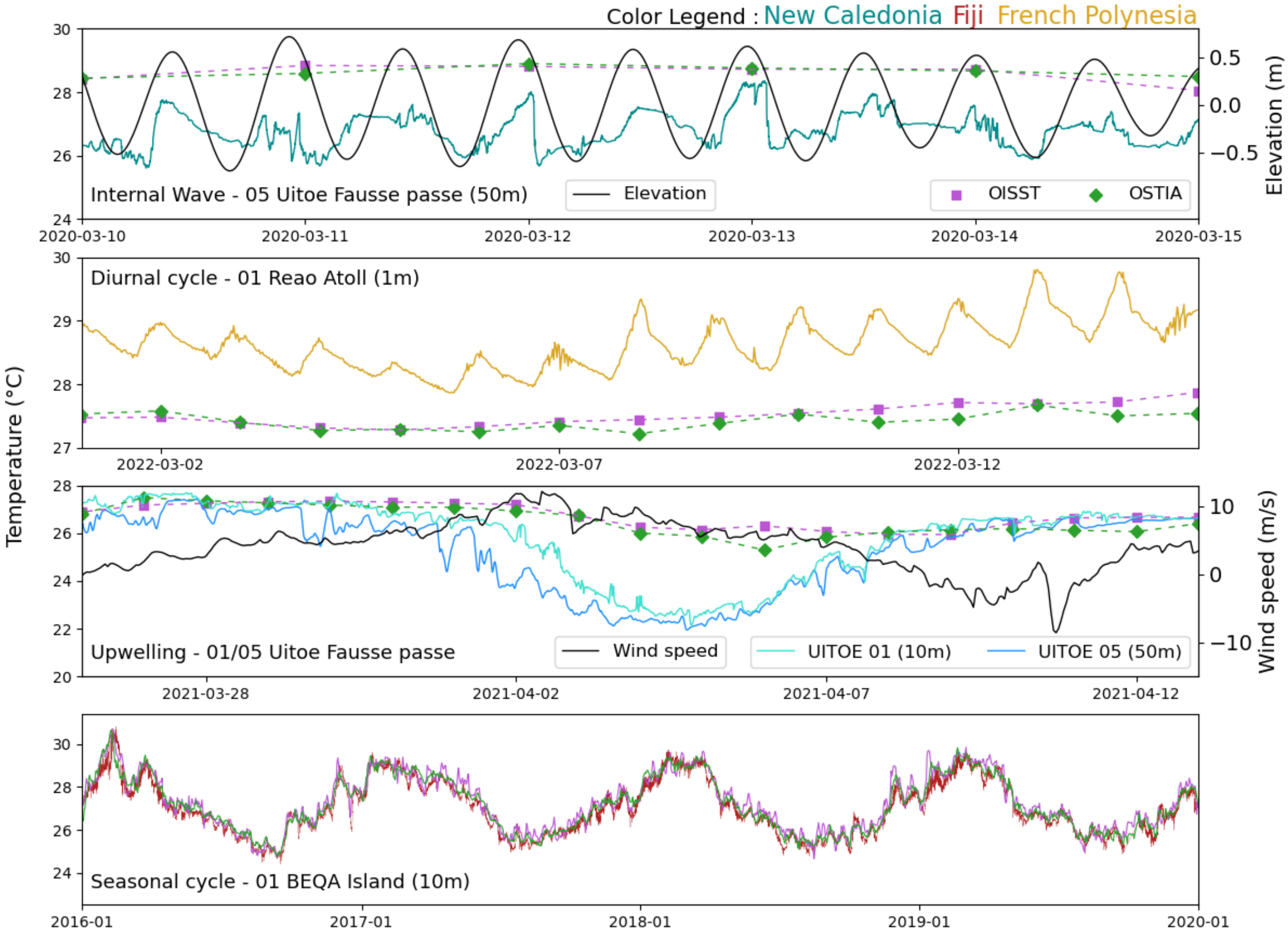
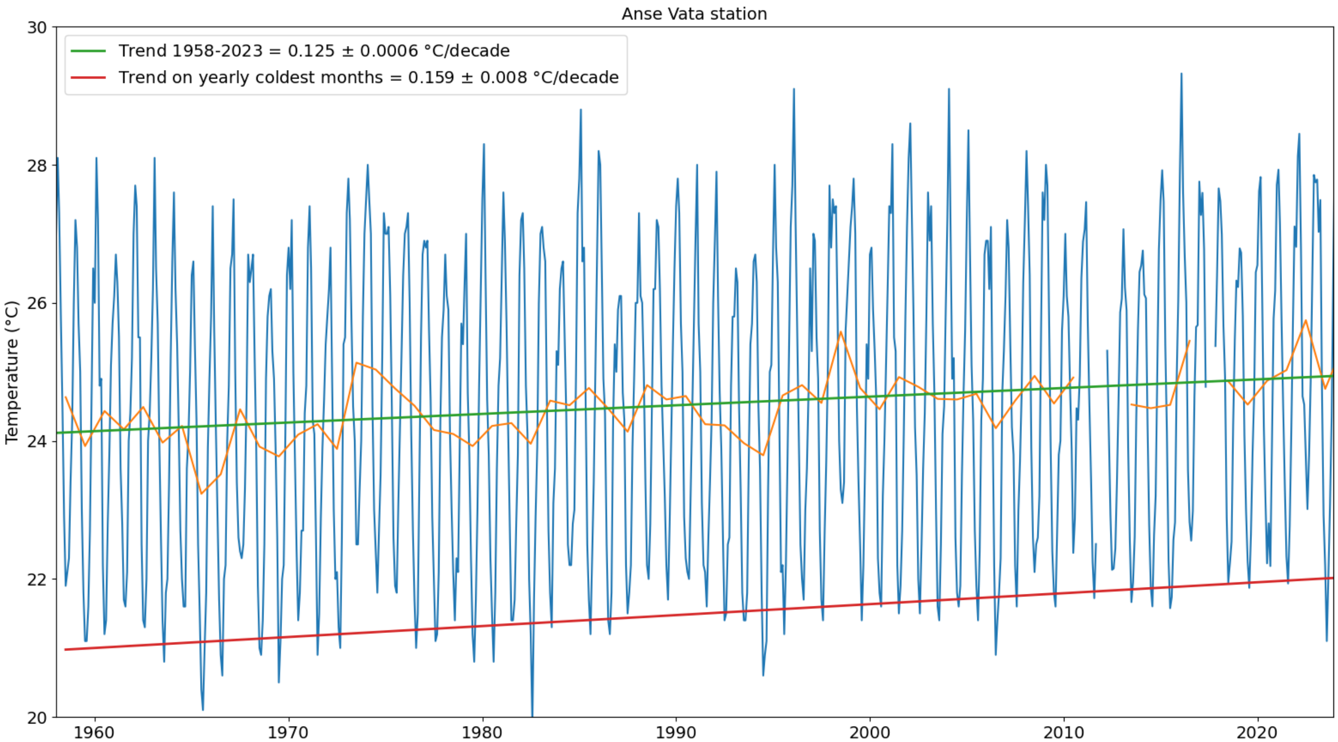


Figure 6: Illustrations of several typical thermal signatures characterised in situ and using L4 daily satellite products (OISST V2 and OSTIA, resp. purple and green points). a. temperature drops due to internal tides at the false passage of Uitoe 05 in New Caledonia (dark cyan curve) and tidal elevation (black curve) recomposed from FES2012 tidal solution at the same station. b. Diurnal cycle at Reao Atoll 01 (yellow curve) in French Polynesia c. upwelling episode at Fausse passe de Uitoe 01 and Uitoe 05 stations (resp. 10m and 50m depth). ERA5 wind speed projected along the northeast-southwest main axis of New Caledonia (Figure 2) is plotted in a plain curve to illustrate the upwelling event as the wind accelerates on 02/04/2021. d. seasonal and interannual variability of temperature at Beqa island 01 station in Fiji.

6.3 Long-term trends

Some of the historical stations from the ReefTEMPS network date back several decades. These are invaluable observations to assess the warming trends. Two of these long-term monthly homogenised time series (see 4.2) and associated trends are presented in Figure 7a and 7b respectively. Both stations, at Anse Vata and Phare Amédée, are located inside the New Caledonia South-west lagoon but Anse Vata station is very close to the shore whereas Phare Amédée is next to the ocean (see 2.1). Decadal trend computations were performed using Mann-Kendall tests combined with Theil-Sen estimate of linear trend with the pyMannKendall Python package (Hussain and Mahmud, 2019). The original Mann-Kendall test was used to compute trends on coldest months and warmer months and the Seasonal Mann-Kendall test on the monthly time series. Considering the entire observation periods, both stations exhibit increasing trends of 0.125°C / decade and 0.127°C / decade for Anse Vata and Phare Amédée respectively (p <10e-10 for both tests). Trends calculated using the warmest month of each year do not show any significant trend for any of the two stations. Conversely, trends on coldest months highlight a significant warming over the periods with a warming slightly higher next to the ocean (Phare Amédée: 0.185°C / decade) than close to the coast (Anse Vata : 0.159°C / decade). Finally, it is important to point out that Seager et al. (2022) found, over 5 datasets of global open-ocean SSTs analysed over 1958-2018, a mean SST trend of ~ 0.1°/decade around New Caledonia (see their Figure 2), which is weaker than our in-situ trends at Anse Vata and Phare Amédée.



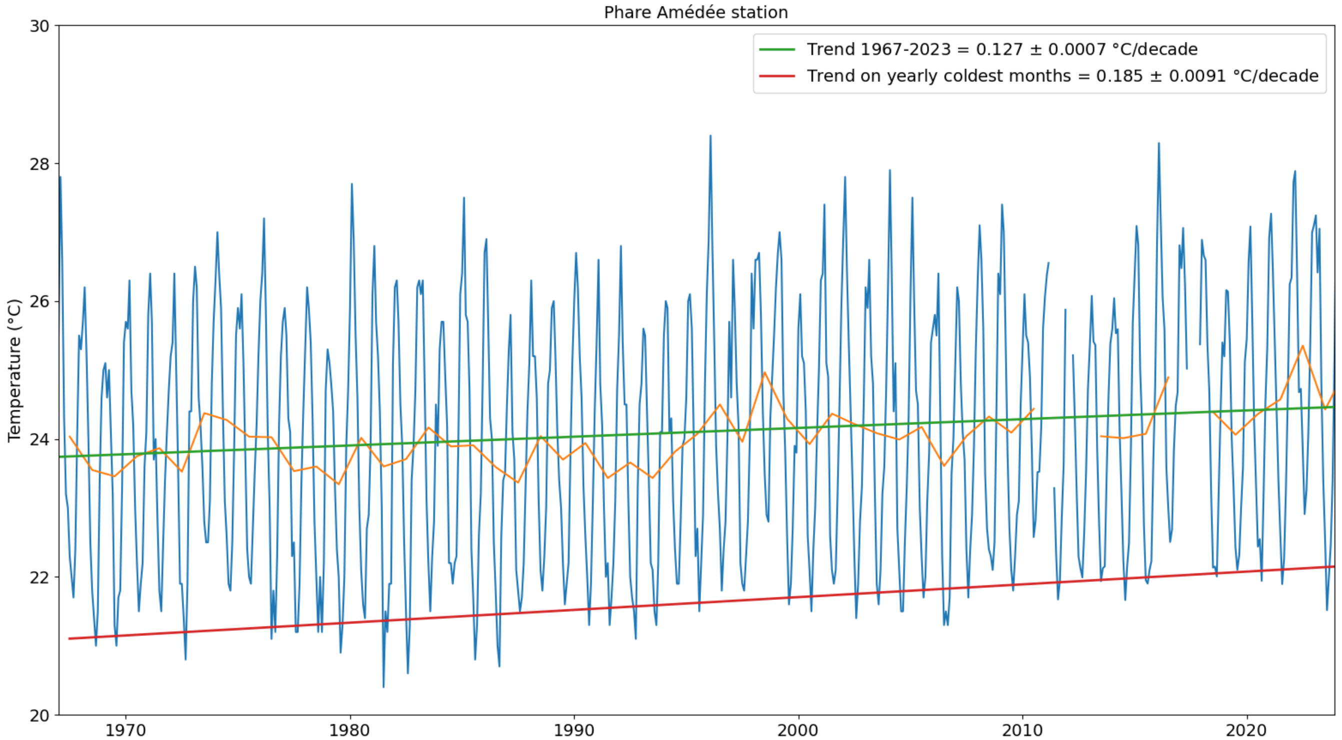


Figure 7 – Monthly temperature time series and trends at a. Anse Vata station (1958-2023) b. Phare Amédée station (1967-2023). Orange lines are the annual mean time series, green lines trends computed over the whole period, red lines the trend computed on the yearly coldest months over the whole period.

7. Ongoing developments and perspectives

Technical developments. As technologies and scientific needs are constantly evolving, the ReefTEMPS consortium develops new functionalities and methods to ensure data robustness, longevity of historical monitoring stations, improved way of disseminating information as well as establishment of new stations.
Concerning the IS and web portal, major evolutions have been underway since 2023 (see section 5) but new developments are still in progress. The next one will concern the data exchange process for which the deployment of OGC SensorThings API will replace the Sensor Observation Service former protocol (see Appendix B). Concerning the workflow manager decision have been made to shift to a workflow manager based on Apache Airflow open-source solution. Using a flow manager has the advantage of being able to adapt easily to the integration of new types of data such as real-time data.
With the increasing threats posed by marine heatwaves on coral reefs, efforts are being put into implementing access to real-time SST observation, which allows informing decision makers on the risks of incoming marine heatwaves. Such systems have already been implemented at Ilot Maître station (see Appendix C). For the first station deployed in New Caledonia at Maitre Island, it consists of an RBR Duet fixed underwater to a pile of one of the bungalows of the Hilton hotel and connected by an electronic cable to a Raspberry-type nanocomputer equipped with a LoRa transmission antenna. The measurements are

recorded on a memory card on the Raspberry and sent in packets every 15 minutes by LoraWan transmission. A Lora receiver within radio range of the station recovers the data and transmits it over the internet. It is then recovered by the ReefTEMPS information system and processed into the database. Two strategies are envisioned for the future deployment of such real-time array:

1- A low-cost strategy whenever possible using Internet of Things (IoT) communication technology (Mattern and Floerkemeier, 2010): a new station with such technology will be implemented at Phare Amédée during 2024.

2- A regular strategy with 4G or Iridium transmission for stations where IOT cannot be implemented.

Figure 8 presents the beta version of live data at Ilot Maitre available on the ReefTEMPS data portal web page. New developments are underway to display visualisation of real-time indicators such as Degree Heating Week index (DHW) used in many instances to indicate a risk for coral bleaching (ref) or Marine Heatwave real-time information. These potential applications of real-time SST data can be crucial for public bodies and researchers to access information crucial for lagoon ecosystems vulnerability in terms of preparedness and management.

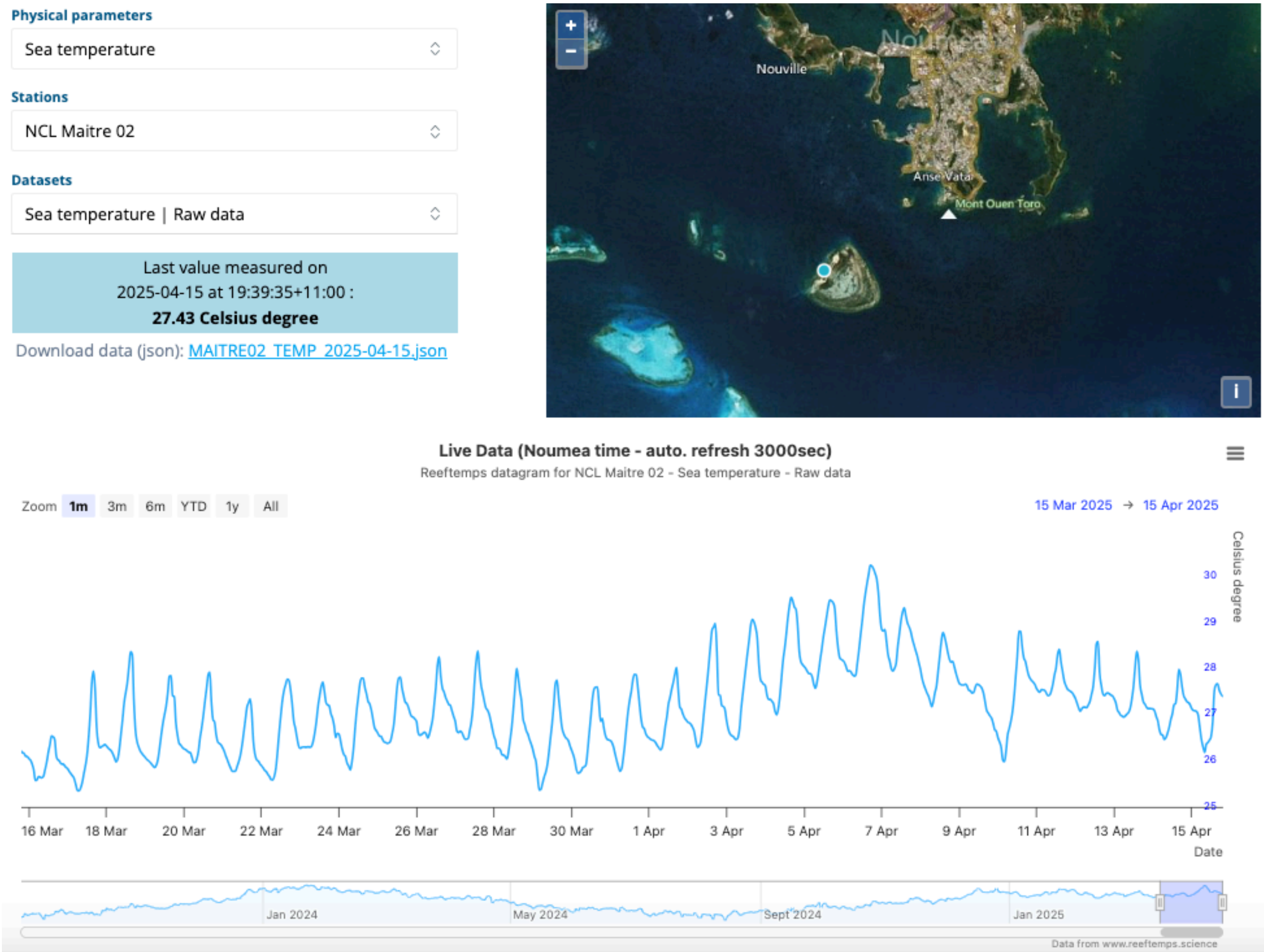


Figure 8 – Beta version of the live data webpage available on the ReefTEMPS. The temperature time series is plotted at the blue point (Ilot Maitre live station) on the map (https://www.reeftemps.science/en/live/).

Quality perspectives. To ensure more rapid and robust controls of accuracy of observations given the remote locations of the Pacific Countries to the instrument manufacturers, two new strategies have been introduced. First, a local SBE56 intercomparison protocol has been developed recently (Detandt and Varillon, 2024). The principle is that all SBE56 sensors are inter-compared in a temperature-controlled tank (from 20 to 32°C) with a reference sensor that has recently returned from calibration at the manufacturer (Seabird). The measured differences to the reference sensor must not exceed +/- 0.005°C from the calibrated sensor or that sensor is sent to the manufacturer for calibration. For stations in front of Nouméa, a second strategy that will enable a robust data quality control as well as a characterisation of the water column is a monthly visit of several stations to perform profiles over the water column with a calibrated SBE19PlusV2 CTD. Concerning long-term time series, a work has recently begun to convert raw data into daily (so far monthly) homogenised data to ensure a perfect reliability for computing trends and climate induced warming. Finally, the Python tool developed for the qualification will need to be continued, to provide a fully integrated tool that works directly on the DB-Oceano database and provides more statistical functionalities.

Future strategies for site selection. In all monitored PICTs, future strategy will first focus on maintaining historical long-term stations to provide a spatial view of the warming trends. In New Caledonia, the choice of new station locations will be guided to deeper investigate the signal deformation between open ocean temperature and lagoon temperature. In Fiji, efforts will be made to maintain unbroken time-series for the longest-established sites, such as Suva Reef and Rotuma, while expanding to new sites in the Lau Group and Vanua Levu. A major challenge has been the closing of some sites such as Batiki, Coral Coast and Yasawa, due to the loss of local partners. Another issue is the damage or loss of monitoring platforms (Beqa, Batiki) due to seasonal tropical cyclones. Furthermore, the ReefTEMPS working group also plans to deploy more vertical arrays on the external barrier reefs slopes for a more thorough understanding of the processes leading to cooling (e.g internal waves, upwelling). Future observation sites in French Polynesia will mainly be dedicated to important pearl farming atolls. In Fiji, such a pilot vertical array to 200m depth had already been deployed on a mooring off the Coral Coast of Viti Levu Island, as part of the VERTEMP Project under the IRD JEAI COPRA between May to November 2018, and January 2019 to January 2020, sampling at 30 second intervals with an array of ten SBE56 sensors (N'Yeurt et al., in prep.). Finally, the coastal monitoring sites on Wallis and Futuna will also be re-instrumented in the near future.

Diversifying observations and ocean in ReefTEMPS.

At present, ReefTEMPS is mostly based on an array of temperature sensors but the increasing challenge of long-term coastal observations is to couple these measurements with other key measurements such as salinity, pressure sensors for coastal vulnerability issues and biogeochemistry (e.g pH, fluorescence, turbidity, nutrients phytoplankton pigments, etc…) to monitor water quality and ecosystems. In our studies of the coral reef environment and bleaching surveillance, we perform regular in situ campaigns crossing ReefTEMPS stations with suites of physical and biological punctual measurements. The long-term plan for our coastal observing system is to systematically add to the automated temperature array, other automated sensors to provide a more complete monitoring of the environment facing climate change. Along these lines, a long-term, reliable funding system has to be secured, a key challenge that will require strong involvement of the government agencies for which these measurements are performed and that are lacking at present. Nevertheless, even if this paper targeted temperature observations, ReefTEMPS is also labelled by SNO (see 2.1) for other observables such conductivity and pressure. Therefore, in addition to temperature, conductivity and pressure time series are also available on many stations through the ReefTEMPS open database. Some other key in situ time series have also started in New Caledonia: pH continuous observations using in situ sensors for example at Fausse Passe de Uitoé or waves using spotter buoys. In Fiji, an experimental autonomous spectrophotometry-based pH sensor had been deployed on several occasions at the VELEVU02 site near Suva in collaboration with the National Oceanography Centre (NOC) of the United Kingdom, and preliminary datasets uploaded on the IOC-UNESCO SDG 14.3.1

data portal (https://oa.iode.org/, last access: 5 September 2024). It is hoped to continue such observations of in situ pH at this and other ReefTEMPS sites in Fiji. Finally, ReefTEMPS environment, quality observation and practices are now extended to the Indian Ocean in La Réunion Island as a first step with the will to continue that collaborative effort with other Indian Ocean Countries.

8. Data availability

All station time series are available individually, either in ASCII or NetCDF formats, on the ReefTEMPS web portal: https://www.reeftemps.science/. The whole ReefTEMPS dataset is freely available in NetCDF format on the dedicated SEANOE repositories (Varillon et al., 2025: https://doi.org/10.17882/55128 ; Liao et al., 2025: https://doi.org/10.17882/82291) and updated every semester. Filenames, variable names, dimensions, and attributes, as well as quality flagging, follow international standards, in particular the OceanSITES and NERC Vocabulary Server conventions (see Section 5 and Appendix A).

9. Conclusion

The ReefTEMPS network presented in this paper represents a unique source of knowledge for understanding coastal temperature, salinity and pressure dynamics in the South Pacific Ocean and for monitoring coral reef ecosystem thermal variability. The most striking feature that makes this network unique and extremely valuable is undoubtedly its geographical coverage (16 PICTS covered, 115 stations monitored) of temperature sensors and the duration of observations for some of its oldest monitoring stations (since 1958 for Anse Vata in New Caledonia). The network ensures open access and quality controlled in situ data that can be visualised and downloaded through the internet in ASCII and NetCDF formats according to the FAIR principles. Usefulness of these data is considerable as they can be used to investigate coastal and lagoon processes on different time scales such as waves dynamics, upwelling, extreme marine heatwave events, tropical cyclone impacts, long term interannual to decadal variabilities and climate warming trends. The basin-scale distribution of the ReefTEMPS network is also crucial for accurately capturing the spatially heterogeneous impacts of large-scale climate phenomena such as the El Niño–Southern Oscillation or the Pacific Decadal Oscillation. Finally, this in-situ network is a key asset for validating the development of remotely-sensed observations, which, at present, cannot represent the fine-scale, high temporal resolution depicted by the ReefTEMPS network and these data can be used for ocean model tuning and evaluations. In addition to highlighting the scientific value of the ReefTEMPS dataset, this paper aimed at bringing the ReefTEMPS network to the attention of as many researchers as possible and inviting interested partners from the Pacific Island Countries and Territories to join the initiative.

Author contributions

RLG, ALS, CM, SC, SF and RH prepared the paper and designed the figures with contributions from all co-authors. All the co-authors have been strongly involved in the ReefTEMPS network at some points in its life (in situ operations, web portal, organisation, processing and checking of data) or helped to raise funds to support it.

Competing interests

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

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Appendix A

Table A1. Countries and Territories codes

Country	Code	Country	Code
Cook Islands	COK	Niue	NIU
Micronesia	FSM	Palau	PLW
Fiji	FJI	Papua New Guinea	PNG
French Polynesia	PYF	Samoa	WSM
Kiribati	KIR	Tokelau	TKL
Marshall Islands	MHL	Tuvalu	TUV
Nauru	NRU	Vanuatu	VUT
New Caledonia	NCL	Wallis and Futuna	WLF

Table A2. Instrument types (Fiat et al. 2024) derived from NERC L05 (https://vocab.nerc.ac.uk/collection/L05/current/)

Code	Label	Description
TR	THERMISTOR	THERMISTOR OR THERMISTOR CHAIN
CT	CTD	CONDUCTIVITY TEMPERATURE DEPTH (CTD) PROBE
TS	TSG	THERMOSALINOGRAPH
MG	TIDEGAUGE	TIDEGAUGE
SM	BUCKET	METEOROLOGICAL BUCKET
MP	MULTIPARAMETER PROBE	MULTIPARAMETER PROBE
PH	PHMETER	PH METER

Table A3. Processing states (Fiat et al. 2024) derived from NERC Vocabulary Server (NVS) R06 (https://vocab.nerc.ac.uk/collection/R06/current/)

Processing level	ReefTEMPS Description
0A	RAW DATA
1A	GEOPHYSICAL UNCHECKED DATA
2B	QUALITY-CONTROLLED DATA
2C	HIGHEST QUALITY REFERENCED DATA
3A	UNCHECKED TIME RESAMPLED DATA
3B	QUALITY CONTROLLED TIME RESAMPLED DATA
3C	PEER-REVIEWED TIME RESAMPLED REFERENCED DATA

Table A4. ReefTEMPS stations informations: Names, positions, sensor type, depths, start and end dates, total duration (days)

Station Name	Station Code	Longitude	Latitude	Sensor Type	Depth	Active	Start	End	Duration (days)
NCL Fausse passe de Uitoe 01	UITOE01	166.1832	-22.2859	TS	10.0	True	1992-05-22	2024-07-30	11757
NCL Récif du Prony 01	RECPRO01	166.3325	-22.2673	TR	10.5	True	1996-01-12	2024-01-10	10426
NCL Anse Vata 01	ANSEVA01	166.4433	-22.3038	TR	2	True	1997-04-15	2024-08-26	9995
NCL Phare Amedee 01	PHARAM01	166.466	-22.4757	TR	4.5	True	1997-06-01	2024-01-15	9933
NCL Chesterfield 01	CHESTE01	158.3076	-19.8747	TR	17	True	1997-09-24	2024-11-01	9899
NCL Surprises 01	SURPRI01	163.0781	-18.4853	TR	14	True	1997-09-28	2024-03-17	9667
NCL Goro 01	GORO01	167.1072	-22.2725	TR	11	True	1997-04-03	2023-06-18	9572
NCL Poe Beach 01	BOURAI01	165.3388	-21.6123	TR	4	True	1999-08-12	2024-02-25	8963
NCL Poindimié 01	POINDI01	165.4850	-20.8918	TR	12.5	True	1997-10-22	2023-10-29	5851
NCL Koumac 01	KOUMAC01	164.1901	-20.6636	TR	14	True	2011-01-28	2024-11-07	5032
NCL Canard 01	CANARD01	166.4339	-22.3122	TR	5	True	2011-01-19	2024-08-26	4968
NCL Ouano 02	UARAI01	165.7238	-21.8616	TR	12	True	2011-11-30	2024-11-08	4727
NCL Maitre 01	MAITRE01	166.4030	-22.3417	TS	3.5	True	2012-04-26	2024-07-29	4476
NCL Ouano 01	CHAMBE01	165.7861	-21.8170	TR	9	True	2011-11-30	2024-01-09	4423
FJI Viti Levu Island 01	VELEVU01	178.5140	-17.5220	TR	12	True	2012-11-30	2023-12-13	4030

FJI Viti Levu Island 02	VELEVU02	178.3999	-18.1597	TR	12	True	2012-12-21	2023-11-17	3983
NCL Poindimié 01	POINDI01	165.4850	-20.8918	MG	12.5	True	2013-10-31	2024-08-18	3944
NCL Poindimié 02	POINDI02	165.3220	-20.9288	MG	1.7	True	2013-09-17	2024-03-03	3820
FJI Rotuma Island 01	ROTUMA01	177.0432	-12.5199	TR	12	True	2014-09-18	2024-11-13	3709
NCL Ile des pins 01	IDPINS01	167.4352	-22.5287	TR	14	True	2015-09-30	2024-08-21	3248
NCL Ile des pins 02	IDPINS02	167.3509	-22.6490	TR	13	True	2015-10-05	2024-08-22	3243
NCL Baie des citrons 01	LEMONB01	166.4353	-22.2958	TS	3.0	True	2016-02-26	2024-07-29	3076
NCL Fausse Passe de Uitoe 04	UITOE04	166.1930	-22.2859	MG	20	True	2016-06-23	2024-07-30	2958
NCL Ilot Laregnere 01	LAREGN01	166.3198	-22.3311	MG	8	True	2016-06-23	2024-07-17	2946
NCL Ilot Mbe-Kouen 01	MBEKOU01	166.2213	-22.2677	MG	6.5	True	2016-06-23	2024-07-17	2946
FJI Vatu-i-Ra Passage 01	VATUIR01	178.5930	-17.3315	TR	9.5	True	2016-12-04	2024-02-20	2634
WLF Alofi island 01	ALOFI01	-178.074	-14.3371	TR	11	True	2012-10-18	2019-10-30	2567
FJI BEQA Island 01	BEQA01	178.1675	-18.4137	TR	10	True	2014-05-28	2020-11-06	2354
NCL Récif de Basse Kaui 01	BAKAUI01	166.3159	-22.2466	CT	8	True	2013-08-13	2019-05-19	2104
PYF Mangareva Atoll 01	MANGAR01	-135.0048	-23.0902	MP	3.5	True	2018-05-24	2023-12-13	2029
FJI BEQA Island 02	BEQA02	178.1956	-18.3769	TR	12	True	2014-05-28	2019-09-26	1947
NCL Ilot Redika 01	REDIKA01	166.6104	-22.5191	MG	11.5	True	2018-10-05	2024-01-30	1943
NCL Fausse passe de Uitoe 05	UITOE05	166.1832	-22.2859	TR	50	True	2019-07-25	2024-08-05	1838
PYF Takapoto Atoll 01	TAKAPO01	-145.2456	-14.7037	TR	3	True	2020-08-08	2023-11-15	1194
PYF Arutua Atoll 01	ARUTUA01	-146.6167	-15.2646	MP	3.5	True	2018-06-15	2021-07-23	1134
NCL Hienghene 01	HIENGE01	164.9839	-20.6449	TS	3	True	2022-01-01	2024-12-18	1082
PYF Reao Atoll 01	REAO01	-136.4248	-18.4830	TR	1	True	2021-06-21	2024-04-01	1015
NCL Recif Snark 01	SNARK01	166.4263	-22.4437	TR	3	True	2022-01-31	2024-08-28	940
NCL Passe Boulari 02	BOULAR02	166.4304	-22.4842	TR	3	True	2022-02-01	2024-08-28	939
NCL Passe Boulari 03	BOULAR03	166.4320	-22.4907	TR	6.5	True	2022-01-31	2024-08-28	939
NCL Koumac 01	KOUMAC01	164.1901	-20.6636	TS	14	True	2008-07-22	2010-08-29	768
PYF Tahaa Atoll 01	TAHAA01	-151.5562	-16.5954	TR	3.5	True	2021-06-18	2023-07-21	763
PYF Takaroa Atoll 04	TAKARO04	-144.9595	-14.4597	MP	4	True	2019-01-30	2021-02-24	756

NCL Chesterfield 02	CHESTE02	158.6062	-19.2143	TR	5,5	True	2022-10-13	2024-11-05	754
PYF Arutua Atoll 01	ARUTUA01	-146.6167	-15.2646	TR	3.5	True	2021-12-01	2023-11-07	706
NCL Touho 02	TOUHO02	165.2439	-20.7700	TR	1	True	2022-12-01	2024-09-05	644
FJI Vanuabalavu Island 01	BALAVU01	179.0630	-17.1450	TR	10	True	2022-08-07	2024-03-18	589
NCL Atoll de Huon 01	HUON01	162.8285	-18.0708	TR	4	True	2022-10-14	2024-03-15	517
NCL Fausse passe de Uitoe 01	UITOE01	166.1832	-22.2859	PH	11	True	2022-09-02	2024-01-10	495
NCL Lifou Island 01	LIFOU01	167.12108	-20.78875	TR	5.5	True	2023-07-18	2024-11-22	492
NCL Récif de Basse Kaui 01	BAKAUI01	166.3159	-22.2466	TR	8	True	2023-04-24	2024-07-29	461
FJI ONO-I-LAU Island 01	ONOILO01	-178.7512	-20.6220	TR	12	True	2021-12-06	2023-02-22	443
PYF Tahaa Atoll 01	TAHAA01	-151.5562	-16.5954	MP	3.5	True	2018-10-17	2019-11-03	382
NCL Chesterfield 03	CHESTE03	158.4580	-19.9505	TR	4,5	True	2023-10-28	2024-10-30	368
FJI Vulaga Island 01	VULAGA01	-178.5569	-19.1396	TR	8.2	True	2022-08-20	2023-08-17	362
PYF Takapoto Atoll 01	TAKAPO01	-145.2456	-14.7037	MP	3	True	2020-02-06	2020-10-31	267
PYF AHE Atoll 01	AHE01	-146.3791	-14.5263	MP	2	True	2022-03-23	2022-09-18	178
FJI Vulaga Island 02	VULAGA02	-178.5400	-19.1213	TR	12.4	True	2022-08-20	2022-12-20	122
NCL Hienghene 01	HIENGE02	165.0035	-20.5626	TR	5	True	2022-11-29	2023-03-27	118
NCL Hienghene 01	HIENGE02	165.0035	-20.5626	TR	27	True	2022-11-29	2023-03-27	118
PYF Vairao 01	VAIRAO01	-149.2933	-17.8064	TR	3	True	2023-05-19	2023-08-04	77
NCL Anse Vata 01	ANSEVA01	166.4433	-22.3038	SM	0.5	False	1958-07-18	2005-06-28	17747
NCL Phare Amedee 01	PHARAM01	166.4660	-22.4757	SM	0.5	False	1967-02-28	2000-09-29	12266
NCL Passe Boulari 01	BOULAR01	166.4317	-22.4917	TR	14	False	1996-01-11	2024-08-28	10457
PYF Tahiti 01	TAHITI01	-149.5679	-17.5213	SM	0.5	False	1979-01-04	1989-05-30	7667
NCL Fausse passe de Uitoe 03	UITOE03	166.1832	-22.2859	TR	60.0	False	2001-07-23	2021-10-29	7403
PYF Marquises 01	NUKUHI01	-140.0944	-8.9342	TR	10	False	1997-09-19	2010-11-21	4811
NCL Fausse passe de Uitoe 01	UITOE01	166.1832	-22.2859	TR	11	False	1999-09-20	2010-06-20	3925
VUT Wusi 01	WUSI01	166.5681	-15.3702	MG	11	False	1999-11-19	2010-05-29	3844
VUT Sabine 01	SABINE01	166.1362	-15.9467	MG	11	False	1999-11-18	2010-05-26	3842
NCL Fausse passe de Uitoe 02	UITOE02	166.1832	-22.2859	TR	30.0	False	2001-07-23	2010-06-20	3254

WLF Wallis 02	WALLIS02	-176.2767	-13.3091	TR	10	False	2006-10-17	2015-08-27	3235
FSM Pohnpei 02	POHNPE02	158.1119	6.8001	TR	13	False	2010-10-01	2018-10-15	2936
FSM Pohnpei 01	POHNPE01	158.2969	7.0093	TR	13	False	2010-10-01	2018-09-28	2919
NCL Belep 01	BELEP01	163.6450	-19.7156	SM	0.5	False	1978-06-09	1986-05-30	2912
FJI Batiki Island 01	BATIKI01	179.1799	-17.7775	TR	10	False	2012-11-28	2019-01-25	2249
MHL Majuro 03	MAJURO03	171.0542	7.1924	TR	9	False	2012-08-25	2018-07-31	2166
PYF Vairao 01	VAIRAO01	-149.2933	-17.8064	MP	3	False	2018-03-03	2023-05-19	1903
NCL Ouvéa 02	OUVEA02	166.4882	-20.6533	MG	8	False	2013-09-23	2018-08-28	1800
WLF Wallis 01	WALLIS01	-176.2516	-13.2222	TS	11	False	1998-08-21	2003-03-16	1667
FJI Viti Levu Island 03	VELEVU03	177.6732	-18.2100	TR	11.9	False	2013-04-05	2017-09-23	1632
FJI Batiki Island 02	BATIKI02	179.1390	-17.7855	TR	10	False	2012-11-29	2017-03-16	1568
VUT Sabine 01	SABINE01	166.1362	-15.9467	TR	11	False	1999-11-18	2004-02-29	1564
VUT Santo Island 01	SANTO01	167.2798	-15.5480	TR	8	False	2012-06-25	2016-05-15	1420
NCL Passe de Dumbea 01	DUMBEA01	166.1887	-22.2957	TR	9	False	1996-01-10	1999-09-19	1348
NCL Passe de Dumbea 02	DUMBEA02	166.2688	-22.3705	TR	11	False	1996-01-10	1999-09-19	1348
NCL Nouville 01	NOUVIL01	166.4182	-22.2782	TR	11	False	1996-01-12	1999-09-20	1346
FJI Tawewa Island 01	TAWEWA01	177.3675	-16.9221	TR	10	False	2012-12-08	2016-05-15	1254
PYF Hapou 01	HAPOU01	-140.0468	-9.3571	SM	0.5	False	1986-01-31	1989-06-14	1230
PYF Takaroa Atoll 01	TAKARO01	-145.0161	-14.5026	TR	4	False	2012-11-29	2016-03-20	1207
FJI Tawewa Island 02	TAWEWA02	177.3379	-16.8806	TR	16.2	False	2012-12-08	2016-02-09	1158
VUT Efate Island 01	EFATE01	168.2632	-17.7696	TR	8	False	2012-06-20	2015-08-20	1156
PYF Takaroa Atoll 03	TAKARO03	-145.0524	-14.5076	TR	2	False	2012-11-29	2016-01-27	1154
NCL Le Cap Goulvain 02	LECAP02	165.2461	-21.5668	TR	20.5	False	2012-08-16	2015-08-06	1085
NCL Le Cap Goulvain 03	LECAP03	165.2397	-21.5359	TR	18	False	2012-08-15	2015-08-05	1085
NCL Le Cap Goulvain 04	LECAP04	165.2413	-21.5250	TR	1.8	False	2012-08-15	2015-08-05	1085
NIU Niue Island 01	NIUE01	-169.9192	-19.0449	TR	15	False	2016-09-29	2019-08-22	1057
PNG Manus 02	MANUS02	147.0964	-1.9318	TR	12	False	2011-07-31	2014-05-11	1014
PNG Manus 01	MANUS01	147.0965	-1.9450	TR	10	False	2011-07-31	2014-05-07	1010

PYF Rapa 01	RAPA01	-144.3323	-27.618	SM	0.5	False	1986-05-09	1989-01-29	996
VUT Wusi 02	WUSI02	166.6602	-15.355	MG	11	False	2007-10-14	2010-05-30	958
PYF Tatakoto Atoll 01	TATAKO01	-138.4353	-17.3488	TR	1	False	2012-11-07	2015-06-14	949
PYF Tatakoto Atoll 02	TATAKO02	-138.3513	-17.3334	TR	2.2	False	2012-11-09	2015-06-15	947
WSM Upolu 01	UPOLU01	-172.1281	-13.8455	TR	10	False	2012-08-31	2015-03-30	941
NCL Saint Vincent 01	STVINC01	166.0814	-21.9271	TS	0.5	False	2021-12-21	2024-07-11	933
WLF Wallis 01	WALLIS01	-176.2516	-13.2222	TR	10	False	2003-03-16	2005-09-14	912
COK Manihiki Atoll 01	MHXCOK01	-160.9969	-10.4238	TR	5.0	False	2012-10-27	2015-01-25	820
COK Manihiki Atoll 02	MHXCOK02	-160.9969	-10.4238	TR	20.0	False	2012-10-27	2015-01-25	820
NCL Le Cap Goulvain 01	LECAP01	165.2378	-21.5529	TR	10.0	False	1997-03-09	1999-05-27	809
TKL Nukunonu 01	NUKUNN01	-171.8522	-9.2007	TR	8	False	2012-05-04	2014-05-22	747
PYF Tatakoto Atoll 03	TATAKO03	-138.4099	-17.3508	MG	1.9	False	2012-11-13	2014-10-24	709
NCL Ouvéa 01	OUVEA01	166.5610	-20.5489	MG	2	False	2013-09-23	2015-08-19	691
FSM YAP 01	YAP01	138.1411	9.5030	TR	9	False	2012-12-14	2014-09-21	646
TUV Funafuti 01	FUNAFU01	179.0601	-8.4850	TR	11	False	2011-08-01	2013-04-19	627
TUV Funafuti 02	FUNAFU02	179.1328	-8.5638	TR	4	False	2011-08-15	2013-04-24	618
PYF Tubuai Island 03	TUBUAI03	-149.4141	-23.4044	MG	1.5	False	2013-04-27	2014-12-02	584
NCL Sainte Marie 01	SMARIE01	166.4813	-22.3037	TR	4.4	False	2012-02-03	2013-04-22	444
TKL Nukunonu 02	NUKUNN02	-171.8475	-9.2007	TR	12	False	2012-05-05	2013-07-09	429
COK Manihiki Atoll 03	MHXCOK03	-160.9969	-10.4238	MG	15.0	False	2012-10-29	2013-12-21	417
VUT Vanua Lava Island 01	VANULA01	167.5648	-13.8673	TR	5	False	2012-06-27	2013-07-11	378
NRU Nauru 01	NAURU01	166.9537	-0.5300	TR	9.5	False	2012-06-18	2013-06-23	370
NCL Mato 01	MATO01	166.7896	-22.5597	TR	10	False	2004-12-09	2005-12-08	363
NCL Récif Ngedembi 01	NGEDEM01	167.0373	-22.9688	TR	14	False	2004-12-10	2005-12-07	361
NCL Ilot NDA 01	ILONDA01	166.8764	-22.8497	MG	11	False	2019-09-21	2020-08-12	326
PYF Takaroa Atoll 02	TAKARO02	-145.0295	-14.4740	MG	4	False	2012-11-29	2013-09-28	303
KIR Abemama 02	ABEMAM02	173.7539	0.3922	TR	9	False	2011-11-01	2012-07-07	249
PLW Palau 01	PALAU01	134.4944	7.3261	TR	10	False	2012-03-23	2012-11-27	248

PYF Raivavae Island 01	RAIVAV01	-147.6889	-23.8825	MP	4	False	2020-03-11	2020-10-04	207
KIR Abemama 01	ABEMAM01	173.8346	0.3764	TR	9	False	2011-11-01	2012-04-03	154
MHL Majuro 02	MAJURO02	171.0451	7.1986	TR	20	False	2011-05-31	2011-10-31	152
MHL Majuro 01	MAJURO01	171.0543	7.1925	TR	4	False	2011-05-31	2011-10-20	142
PYF Vairao 01	VAIRAO01	-149.2933	-17.8064	MG	3	False	2023-12-28	2024-05-16	139

Table A5. ReefTEMPS quality flags, derived from NERC Vocabulary Server (NVS) RD2 (https://vocab.nerc.ac.uk/collection/RD2/current)

Class	Quality	Description
Flag 0	No QC done	No quality control has been assigned to this element.
Flag 1	Good data	The element appears to be correct.
Flag 2	« Probably » good data	The element appears to be probably good. Flag 2 data are good data in which some features (probably real) are present but these are unconfirmed.
Flag 3	« Probably » bad data	The element appears doubtful.
Flag 4	Bad data	The element appears erroneous.

Appendix B

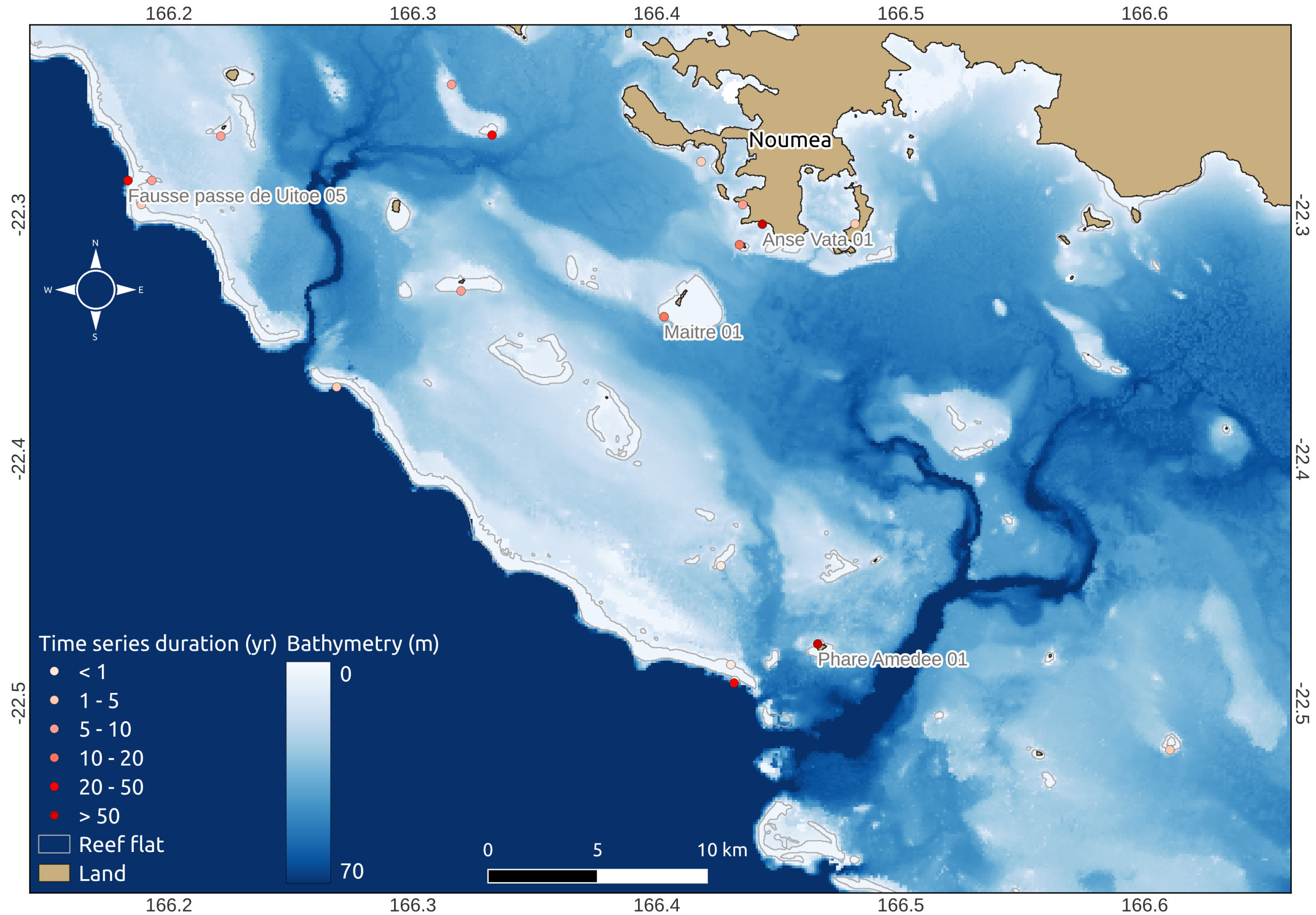

Figure B1. ReefTEMPS stations in the South-West lagoon of New Caledonia

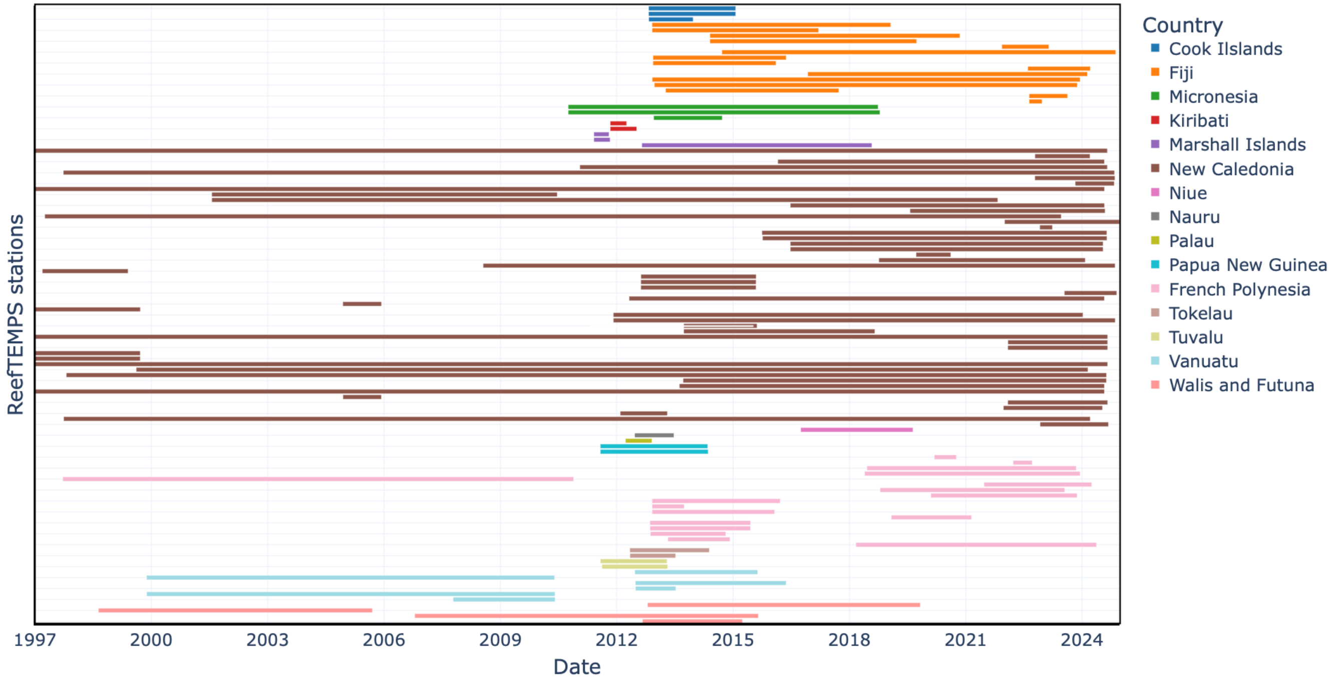

Figure B2. ReefTEMPS Stations activity timeline

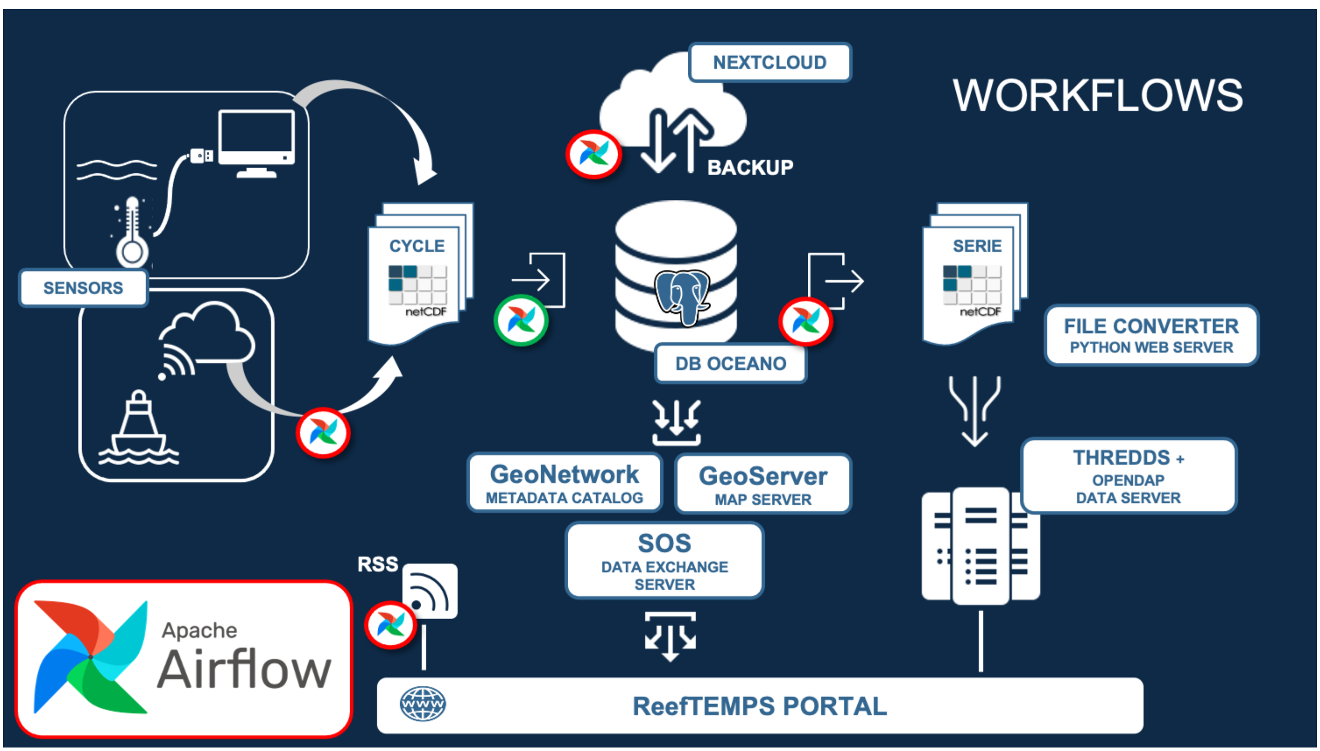

Figure B3. ReefTEMPS data workflow

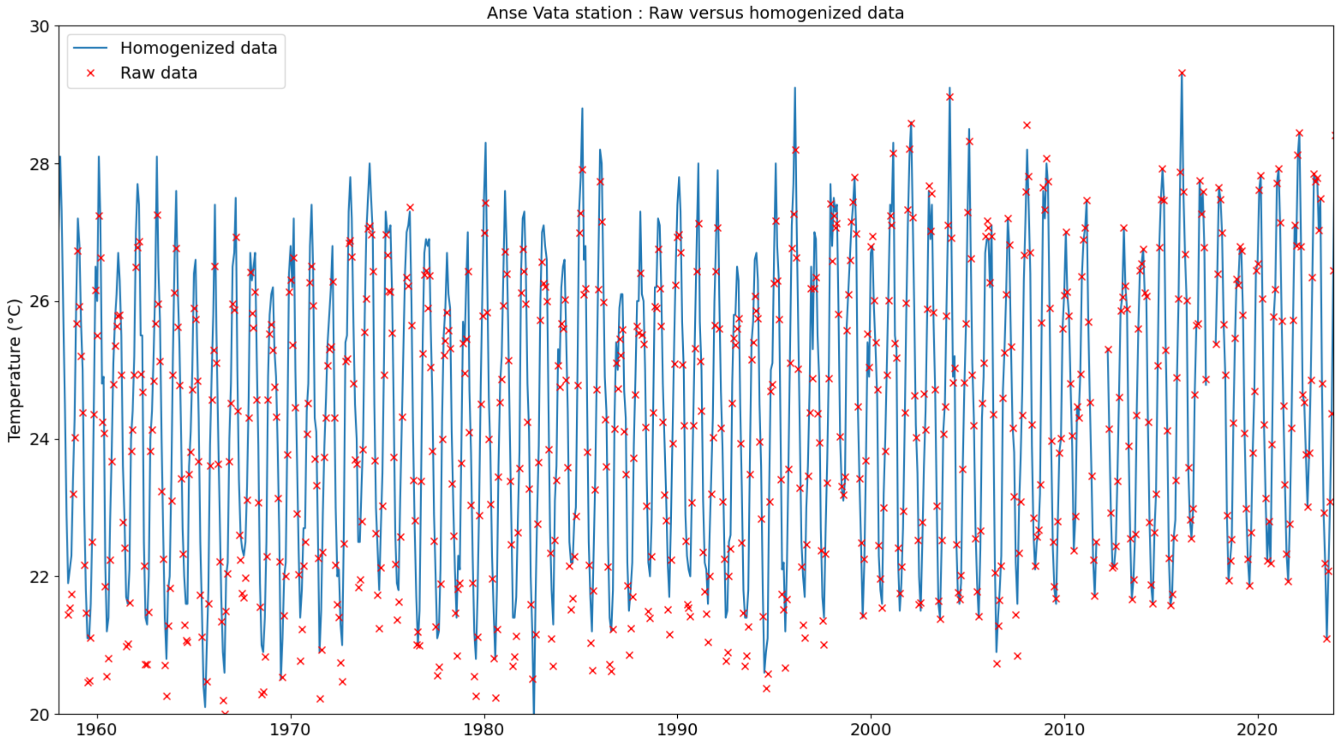

Figure B4. Raw versus homogenized monthly temperature time series at Anse Vata station.